3rd State of Stream Report: Aquatic Communities and Habitats in the Tributaries to French Creek, Pennsylvania

2009

Pennsylvania Natural Heritage Program
Western Pennsylvania Conservancy

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Cover Photo: South Branch French Creek, taken by Tamara Smith, PNHP/WPC

3rd State of the Stream Report on the Health of French Creek:

Aquatic Communities and Habitats in the Tributaries to French Creek, Pennsylvania

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French Creek Watershed Aquatic Biodiversity

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EXECUTIVE SUMMARY

The French Creek watershed contains a high degree of aquatic biodiversity and is one of the last remaining high quality watersheds in the Ohio River basin. This project was designed to assess, on a sub-basin by sub-basin level, the physical stream and riparian conditions, and aquatic community health of the major French Creek tributaries as recommended by the French Creek Watershed Conservation Plan (Western Pennsylvania Conservancy and French Creek Project 2002). Recommendations from this project are designed to enable targeted implementation of conservation efforts in the watershed.

Sites on the ten major tributaries of French Creek were surveyed for mussels, fish and macroinvertebrates. A total of 22 mussel species were found in the tributary surveys; 29 species have been recorded from the watershed. Mean species richness and catch per unit effort (CPUE) were significantly lower than on mainstem French Creek survey sites. Mussel species richness and CPUE were generally high at survey sites on LeBoeuf Creek. No mussels were found at survey sites on Sugar Creek or Little Sugar Creek. Fish species richness was highest on Little Sugar Creek. Host fish were detected for most mussel species at the same survey site or in the same tributary. Macroinvertebrates were sampled as indicators of water quality. Macroinvertebrate metrics indicated some sites with water quality problems, including sites on Conneaut Outlet and West Branch French Creek.

In-stream habitat mapping identified riffle-run habitats that are important to many of the mussel and fish species found in French Creek. The highest percent riffle-run habitat was found on Sugar Creek and the highest percent of pool habitat was found on Cussewago Creek. Riparian zone assessments along the length of mapped stream sections provide information about the intactness of the riparian buffer, which has a direct impact on stream ecosystem health. Riparian assessments scores rated the highest on Little Sugar Creek, while West Branch French Creek had the lowest scores. Land use analysis examined relationships between aquatic communities and land cover types. Significant relationships were found between land use and macroinvertebrate communities, indicating a degradation of water quality due to agricultural pollutants.

Conservation efforts in the watershed should include increased use of agricultural best management practices, protection and restoration of riparian buffers, preventing the spread of invasive species and protecting forested areas and wetlands. Implementing agricultural best management practices, and protecting and restoring riparian buffers is a priority throughout the French Creek watershed, because of the high percent of agricultural land use. In particular efforts to reduce the impact of agriculture should focus on LeBoeuf Creek, Conneauttee Creek and West Branch French Creek.

Although a relatively low percent of developed land is present in the watershed, for tributaries that flow through population centers reducing urban run-off should be a priority. In particular this issue should be addressed along Conneaut Outlet and Conneauttee Creek by minimizing impervious surfaces and restoring and maintaining riparian buffers.

The progress of these efforts should be monitored with regular biological and water quality assessments. Additional survey effort is needed to assess mussel population health and species distribution in tributaries where rare species and rich communities occur, including LeBoeuf Creek, Conneauttee Creek and West Branch French Creek. Community attributes and management recommendations are summarized by tributary watershed in Table 1.

Table 1. Summary of sub-basin attributes and conservation recommendations

Tributary Watershed	Notable Community Attributes	Threats and Stresses	Recommendations
Conneaut Outlet	Rare mussel and fish species present, high mussel species richness and abundance	High percent development, invasive species	Protection and restoration of riparian buffers, preventing spread of invasive species
Conneauttee Creek	Rare mussel and fish species present, high mussel abundance at some sites, high fish species richness	High percent agriculture and development, invasive species	Further characterization of mussel community, protection and restoration of riparian buffers, increased use of agricultural BMPs, preventing spread of invasive species
Cussewago Creek	Rare mussel species present (recorded near confluence with French Creek)	Impoundment, moderate percent agriculture and development	Mitigation for or possible removal of dam, protection and restoration of riparian buffers
LeBoeuf Creek	Rare mussel and fish species present, high mussel and fish species richness, high mussel abundance	High percent agriculture, poor macroinvertebrate metric scoring at some sites	Further characterization of mussel community, protection and restoration of riparian buffers, increased use of agricultural BMPs
Little Sugar Creek	High fish species richness present, high scoring riparian assessments, moderate to high scoring macroinvertebrate metrics	High percent agricultural land use	Increased use of agricultural BMPs, protection of riparian buffers
Muddy Creek	Rare mussel and fish species present, high mussel and fish species richness, high mussel abundance	Poor scoring macroinvertebrate metrics at some sites, upper reaches designated as impaired by DEP for road runoff and siltation	Further investigation of water quality issues, mitigation of road runoff including restoration and protection of riparian buffers
South Branch	Rare fish species present, moderate to high scoring macroinvertebrate metrics	Moderate percent agriculture and development	Protection of riparian buffers
Sugar Creek	Rare fish species present, high percent forest land cover, high scoring macroinvertebrate metrics	Potential land use changes	Protection of forest land cover and riparian buffers
West Branch	Rare mussel and fish species present, high fish species richness	Low scoring habitat assessments, high percent agriculture in portions of riparian zone, poor macroinvertebrate metric scoring at some sites	Further characterization of mussel community, protection and restoration of riparian buffers
Woodcock Creek	Rare mussel and fish species present	Impoundment, moderate percent agriculture	Mitigation for dam, protection and restoration of riparian buffers

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INTRODUCTION

The French Creek watershed, located at the headwaters of the Ohio River drainage, is nationally recognized for its high aquatic species diversity because it contains more species of fish and freshwater mussels (Unionidae: Bivalvia) than any other similar sized stream in the northeast United States (Bier 1994, Ortmann 1919, Western Pennsylvania Conservancy and French Creek Project 2002). Twenty-nine native freshwater mussel species have been recorded in the watershed (Western Pennsylvania Conservancy and French Creek Project 2002), including two that are presently listed as Endangered under the U.S. Endangered Species Act and the PA Fish Code, *Epioblasma torulosa rangiana* (l. Lea, 1838) (northern riffleshell) and *Pleurobema clava* (Lamarck, 1819) (clubshell). *Quadrula cylindrica* (Say, 1817) (rabbitsfoot) is listed as endangered in Pennsylvania and is a candidate for federal listing. *Villosa fabalis* (l. Lea, 1831) (rayed bean) is a candidate for federal listing (U. S. Fish and Wildlife Service 1991). *Epioblasma triquetra* (Rafinesque, 1820) (snuffbox) is listed as endangered in Pennsylvania. Thirteen other mussel species documented in the French Creek watershed are considered rare, threatened, endangered or possibly extirpated in Pennsylvania (NatureServe 2008, Appendix A). Over 80 species of fish have been recorded in the French Creek Watershed. Threatened or endangered fish include several madtom and lamprey species, as well as eight of the 15 species of darters found in the French Creek watershed (NatureServe 2008, Appendix A).

Freshwater mussels have an important ecological value and are a vital link in the food chain as food items for many animals including muskrats, raccoons and otters. These filter feeders improve water quality by straining out suspended particles and pollutants from the water. In addition, mussels serve as good indicators of ecosystem health. Freshwater mussels are long lived, typically remain in one place for most of their life and require good water quality, sediment types, and physical habitat. Freshwater mussels are used as biological indicators of past and present water and sediment quality in lakes and streams. Gradual mussel die-offs or sudden mussel kills are signs of water pollution problems and other environmental health concerns. Stable, diverse mussel populations typically indicate clean water and a healthy aquatic system (*e.g.* Elder and Collins 1991, Green *et al.* 1989, Metcalfe and Charlton 1990, Naimo 1995).

Macroinvertebrate communities are key indicators of water quality, and can reflect longer trends than snapshot water testing. Stream macroinvertebrates can serve as natural continuous water quality monitors because they generally live for at least one year, are less mobile than fish and many are sensitive to long-term, low-level stress and/or pulsed, highly concentrated discharges of water pollutants (Davis *et al.* 2001). Many environmental monitoring agencies employ macroinvertebrates to assess biotic integrity of stream ecosystems (Barbour *et al.* 1999).

The viability of freshwater mussel populations is tied closely to other aquatic organisms, particularly fish. Mussel larvae, called glochidia, are parasitic and need a host fish or amphibian to attach onto and develop, before falling off as a juvenile mussel. This essential life stage is not known to cause any harm for the host fish, but is critical for upstream dispersal of mussels. Some mussel species require a specific fish to act as a host, so if that fish species is absent, the mussel cannot successfully reproduce (McMahon 1991, Parmalee and Bogan 1998, Strayer and Jirka 1997).

Threats to the fish and mussels in the French Creek watershed include development, mineral extraction, water extraction, wastewater treatment plants, pollution and siltation due to improper agriculture and timbering practices (see review in Western Pennsylvania Conservancy and French Creek Project 2002), dams and stream channel alteration (see review in Watters 2000), and invasive species such as *Dreissena polymorpha* (Pallas, 1771) (zebra mussel) (Biggins *et al.* 1995, Ricciardi *et al.* 1998, Strayer and Malcom 2007).

The objectives of this study were to enable targeted conservation efforts by documenting freshwater mussel, fish, and benthic macroinvertebrate communities in the sub-basins of the French Creek watershed. The project was modeled after a previous study of aquatic communities in mainstem of French Creek as recommended in the French Creek Conservation Plan (Western Pennsylvania Conservancy and French Creek Project 2002). In addition, our study aimed to document available habitat for rare freshwater mussels and threats to aquatic communities. Results of this project will facilitate the implementation of cooperative actions such as Best Management Practice implementation, streambank and riparian restoration, and further aquatic community characterization.

METHODS

Study location

The French Creek watershed, covering an area of approximately 3,200 km^2, is part of the Allegheny River watershed and the greater Ohio River drainage. French Creek originates in Chautauqua County in New York State, where headwater streams comprise about 7% of the watershed area. Approximately 93% of the watershed is within Pennsylvania's Erie, Crawford, Mercer, and Venango counties. French Creek joins the Allegheny River at Franklin, Pennsylvania. The ten major tributaries to French Creek, named from the northernmost to the southernmost, include West Branch French Creek, South Branch French Creek, LeBoeuf Creek, Muddy Creek, Conneauttee Creek, Woodcock Creek, Cussewago Creek, Conneaut Outlet, Little Sugar Creek, and Sugar Creek (Figure 1). Forest, agriculture and wetlands dominate the landscape in the tributary watersheds (Table 1). The tributary streams range from relatively high gradient, fast cold waters to slow, low gradient streams meandering through wetlands (Table 1).

In-stream Habitat Mapping

The 10 major tributaries of French Creek were mapped using a Trimble GeoExplorer GPS unit as the surveyors canoed or sometimes walked the stream during low flow conditions. Stream reaches were measured and categorized into one of three flow regimes: pool, run, riffle, or a combination of these regimes. Gravel-sized substrate in riffles and runs comprise what is believed to be essential habitat to many freshwater mussels and fish of special concern in this watershed.

Mapped lengths of tributaries ranged from 4.6 to 16.6 river per tributary (Table 1). Observers stopped at approximate 0.5-1.0 mile intervals to perform detailed habitat assessments (Barbour et al. 1999, Schnier 2003). At each interval, in-stream and riparian habitat were assessed using visual estimation of the following: epifaunal substrate, embeddedness, velocity/depth regime, sediment deposition, channel flow, channel alteration, frequency of riffles, channel sinuosity, bank stability, bank vegetation protection and riparian vegetative zone width.

Site Selection for Biological Sampling

One to five sites were randomly selected from the mapped portions of each tributary. Since our main goal was to map mussel communities, site selection favored optimal habitat types for rare species and high mussel species diversity (riffle-run). Gravel-sized substrate in riffles and runs are believed to be essential habitat to many freshwater fish (Etnier and Starnes 1993, Jenkins and Burkhead 1994) and mussels (Butler 2003 and 2006, Parmalee and Bogan 1998, Ortmann 1919, U. S. Fish and Wildlife Service 1994) of special concern in the French Creek Watershed. Pool habitat was surveyed if no riffle-run habitat was documented within a tributary. Between June and October, 14 sites were surveyed for mussels in 2006 and 11 sites were surveyed in 2007. Sites selected for mussel sampling were also sampled for fish and macroinvertebrates.

The goal was to survey at least three sites per major tributary; however some tributaries fell short of that number. Mussel and fish surveys in most of Muddy Creek were conducted very recently (Mohler *et al*. 2006), so we felt that additional surveys in those areas were not necessary and may even cause stress to the mussels (Haag and Commons-Carson 2008). We did survey one site on Muddy Creek that was upstream of other sites. However we did compliment those studies with detailed habitat mapping and macroinvertebrate sampling. Cussewago Creek and Conneaut Outlet are primarily deep muddy pools which were difficult to survey with our available gear and less likely to be inhabited by the rare mussel species in this watershed (Butler 2003 and 2006, Parmalee and Bogan 1998, Ortmann 1919, U. S. Fish and Wildlife Service 1994). We surveyed the only riffle/run habitat mapped in Conneaut Outlet.

Freshwater Mussel Sampling Techniques

Using the in-stream mapping, we were able to focus mussel sampling efforts in the significant riffle/run habitats, with the assumption that these would be the best available habitats for rare mussels. The goal of the timed mussel surveys was to characterize mussel species richness and abundance as catch per unit effort (CPUE) in French Creek tributaries.

Snorkelers/SCUBA divers collected as many unionid individuals as possible with a standardized search rate of time per area. Starting at the downstream end of the study section, observers zigzagged upstream in equally sized transects (cells), covering the entire stream width. Observers used a combination of tactile and visual methods to search the surface for mussels. While most mussels detected were visible at the surface, observers occasionally brushed away sediment, flipped over non-embedded rocks and did some light substrate excavation. A target search rate of $0.5m^2$/minute was assumed, and an effective sampling fraction of 0.06 was used as a means of comparison between timed searches (Smith *et al.* 2001). Search time was calculated by:

Total Search Time = (Effective sampling fraction * Survey Area)/Target search rate.

Live mussels were kept submerged in mesh bags until each survey was completed. Mussels were identified, counted, and returned to the cell in which they were found. Each live mussel was measured in total shell length to the nearest millimeter. Representatives of each species found were photographed for most sites (Appendix E). Catch per unit effort (CPUE) was calculated as number of live unionids collected divided by survey person-hours (p-h). Species richness was defined as the number of unionid species living at each site. Species diversity was calculated using the Shannon diversity index:

$$H' = -\sum p_i \ln(p_i)$$

where p_i is the proportion of individuals in the i^{th} species and ln is the natural logarithm.

All staff on the project were experienced mussel surveyors. At least one Pennsylvania Qualified Mussel Surveyor with substantive experience with Ohio Basin mussel taxonomy oversaw all identifications and was present during all surveys. All taxonomy followed Turgeon *et al.* (1998).

Fish Sampling Techniques

To characterize the fish community present at the mussel survey locations, electro-fishing surveys were conducted using a battery powered backpack electro-fishing unit, with a three to five person crew, each carrying dip nets with 3-mm diameter mesh. A minimum of 50 minutes was spent sampling at each site, sampling various microhabitats over the entire area where the mussel survey took place. Since we were mostly interested in species presence/ absence, we did not employ population estimation techniques (e.g. three–pass depletion surveys). Fish surveys were conducted at 23 of the 25 mussel sampling locations. A fish survey was not conducted at the Cussewago Creek site because our equipment was not adequate to survey the deep water at that location. A fish survey was also not conducted at the Muddy Creek site.

Macroinvertebrate Sampling Techniques

Macroinvertebrate community structure was determined by sampling at 23 of the mussel sampling sites in the French Creek tributaries, as well as three additional sites on Muddy Creek. The macroinvertebrate community was sampled and evaluated using metrics and procedures modified from the U.S. Environmental Protection Agency's Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers (Barbour *et al*. 1999). Sampling was standardized to 1-minute kicks with a standard D-frame net for three sub-samples within each site, which were pooled together for site totals. Different habitat types were sampled in approximate proportion to their surface area in the study reach. Collected macroinvertebrates were placed in 95% ethanol for transport to the lab where they were transferred to 70% ethanol. Macroinvertebrates were identified to genus or the lowest possible taxa in the laboratory. Several metrics for evaluating benthic macroinvertebrate data were utilized in this study; including taxa richness, taxa composition and tolerance indices. Family-level biotic index (FBI) was used as the tolerance index (Hilsenhoff 1988). FBI scores range from 0 – 10 based on organic pollution tolerance values assigned to each taxa. FBI is calculated as the number of organisms in each macroinvertebrate family multiplied by the tolerance value. The products are summed and divided by the total number of macroinvertebrates in the sample. Low FBI scores indicate that the taxa are intolerant to pollution and prefer good water quality, while higher scores indicate taxa that are tolerant of poor water quality. Taxa richness tends to increase with higher water quality. Composition indices used included percent Chironomidae and percent Ephemeroptera, Plecoptera, and Trichoptera (EPT). A high percentage of Chironomidae indicates 'poor' water quality and a high percentage of EPT indicates 'good' water quality. These indices and their predicted responses to changes in water quality are further described in Barbour *et al.* (1999). Means were calculated across all sites, and comparisons were made at the $p = 0.05$ significance level.

Watershed Landcover Analysis

Landcover classes were summarized at three scales: 1) each tributary watershed in its entirety, 2) 100m riparian buffers for all stream reaches in each tributary watershed, 3) the watershed upstream of reaches with study sampling locations. Landcover calculations were based on the National Landcover Dataset (NLCD 1992) (http://seamless.usgs.gov) for hydrologically ordered reaches and catchments in the EPA river reach dataset (Version 3.0) (http://www.epa.gov/waters/doc/techref.html) using watershed tools (Fitzhugh 2000) with ArcView® (ESRI 1982-2000), Visual Basic®, and Arc/INFO® software (ESRI 1982-2000).

We summarized landcover classes from the NLCD into agricultural, development, wetland, and forest, and other classes. Agricultural landcover is the compilation of row crops, pasture/hay, small grains, orchard and urban/recreational grasses NLCD landcover classes. Developed landcover is the sum of commercial/industrial, low intensity and high intensity development NLCD landcover classes. Forest land cover is the sum of deciduous forest and evergreen forest NLCD classes, while wetland landcover is the compilation of woody wetlands and emergent wetland NLCD landcover classes. The other landcover category is the aggregation of bare rock, sand, clay, quarries, strip mines, gravel pits, transitional, and open water classes from the NLCD.

The EPA river reach datasets delineates stream reaches bounded by their upstream and downstream confluences. Stream reaches are hydrologically ordered based on flow direction and position in the watershed. The sum of the area of landcover classes in catchments associated with each stream reach was calculated. Land cover was summed for the catchments draining to the downstream most reach in each watershed and to reaches that contained the project study sites. Then the proportion of land cover classes was calculated for tributary watersheds and riparian buffers.

A 100-m buffer was delineated on each side of stream reaches. Within the riparian buffers we calculated the proportion of land cover in developed, agricultural landcover classes, and forest/ wetland landcover types. Stream reaches having greater than 5% development landcover in the riparian buffer were considered areas where water quality could be affected by pollution related to development (e.g. road and other impervious surface runoff). Riparian buffers with greater than 25% agriculture had the highest amounts of riparian agriculture in the French Creek watershed tributaries; these reaches are locations with the greatest potential for pollution from poorly managed agriculture. The length of all reaches and those reaches meeting the riparian development landcover (>5%) or riparian agricultural landcover criteria (>25%) was summed for each tributary watershed. The percent of total reach length with high development, agricultural, forest/ wetland land cover for each tributary watershed was calculated.

Linear regressions were used to examine the relationships between landcover types and mussel CPUE and species richness, fish species richness, and macroinvertebrate FBI scores and percent EPT (Ephemeroptera, Plecoptera, Trichoptera) taxa.

RESULTS

Figure 1. Major tributaries of French Creek.

In-stream Habitat Mapping

Portions of all ten major tributaries were mapped from 2006 – 2009 (Appendix G). ArcGIS files of completed mapping accompany this report. Little Sugar Creek had the highest percent riffle having over half of the mapped habitat in riffles (Table 1). South Branch also had a high proportion of riffle habitat compared to other tributaries, while Conneauttee Creek had the highest percent run. Highest percent riffle-run series was mapped on Sugar Creek. Combined riffle, run and riffle-run series was highest on Sugar Creek (Table 1). High gradient streams such as Sugar Creek and Little Sugar Creek (Table 1) have high percentages of riffle habitat. Having greater than 99% pool habitat, the largest proportion of habitat in tributary streams was found in Cussewago Creek. Conneaut Outlet, West Branch, and LeBoeuf Creek also had pools in more than half of mapped habitat. Maps showing habitat types and locations of riparian assessments for each tributary are included in Appendix G.

Habitat Assessments

A total of 156 habitat assessments were performed from 2006 – 2009 on the 10 major tributaries of French Creek. Table 1 shows mean habitat assessment values by tributary. Raw assessment scores are given in Appendix F. Of the ten streams mapped, Little Sugar Creek had the highest habitat assessment scores in the watershed, with a mean percent of 82.6 (SEM = 1.3). The mean percent habitat assessment score for West Branch was the lowest (63.7, SEM = 1.7). Higher habitat scores indicate a stream with fewer anthropogenic alterations. Individual assessment scores ranged from 52- 98 percent across all mapped stream sections. Of the tributaries, variation of assessment scores was greatest on LeBoeuf Creek where scores ranged from 55-97 percent. Some areas of LeBoeuf Creek showed numerous signs of disturbance, while others were relatively pristine. The lowest range of scores was found on West Branch, where the scores ranged from 52-76 percent. Mapped sections of West Branch showed signs of disturbance including eroded banks and a lack of riparian buffers.

Mussel Survey Results

A total of 25 sites were sampled for freshwater mussels during the 2006 and 2007 field seasons. Of those, we sampled five sites in LeBoeuf Creek, three sites each in West Branch French Creek, South Branch French Creek, Woodcock Creek, Sugar Creek and Conneauttee Creek, two sites in Little Sugar Creek and one site each at Conneaut Outlet, Cussewago Creek, and Muddy Creek (Table 2).

A total of 588 live unionid mussels representing 22 species were detected, as well as 29 live *D. polymorpha* (Table 3). Two additional species, *Epioblasma torulosa rangiana* and *Ligumia recta* (Lamarck, 1819) (black sandshell), were found only as weathered dead. *Dreissena polymorpha* and *Corbicula fluminea* were found, but neither is included in species richness, Shannon diversity index or CPUE calculations (Table 4). *Lampsilis siliquoidea* (Barnes, 1823) (fat mucket) was the most abundant species, found at 12 sites and accounting for 18.8% of the total number of mussels found (Table 3). The second most abundant species was the *Amblema plicata* (Say, 1817) (threeridge), which was found at seven sites and made up 17.2% of the total catch. The third and fourth most abundant species were *Strophitus undulatus* (Say, 1817) (creeper) (10.9%, 13 sites) and *Actinonaias ligamentina* (Lamarck, 1819) (mucket) (8.4%, 10 sites). *Pleurobema clava* was found live at five sites on LeBoeuf Creek and as dead shells at two sites on Conneauttee Creek. The mean abundance, or the mean number of live mussels found per site, was 31.0 (*SE* = 7.23). Across all surveys, the mean CPUE was 18.1 mussels/p-h (*SE* = 4.66) and mean species richness was 6.1 (*SE* = 1.07). No live mussels were found at Sugar Creek, Little Sugar Creek and one site on South Branch French Creek. Mean abundance, CPUE, and species richness were all significantly lower than the means calculated for main-stem French Creek surveys ($p < 0.05$) (Smith and Crabtree 2005, in review). Species diversity, measured by the Shannon Index (H′), ranged from 0 to 2.3 among sites, with a mean of 1.2 (*SE* = 0.19) in the tributary watersheds. LeBoeuf Creek and

West Branch had the highest diversity values. Figure 2 illustrates mussel species richness by tributary watershed based on the results of this study as well as available recent records from the PNHP database.

We found evidence of both sexes for sexually dimorphic species and recruitment at several study sites (Table 3). For most species, we used a cut-off length of specimens less than 30 mm to indicate recent recruitment. We used a cut-off of 20 mm for two naturally smaller species, *Villosa fabalis* and *Epioblasma triquetra*. We found evidence of recent recruitment for five species: *Lampsilis siliquoidea* at West Branch sites 1 and 2, *Actinonaias ligamentina* at Conneaut Outlet site 1, *Ptychobranchus fasciolaris* (Rafinesque, 1820) (kidneyshell) at Woodcock Creek site 2 and *Pleurobema clava* and *Alasmidonta marginata* (Say, 1818) (elktoe) at LeBoeuf Creek site 3.

Individual stream results

Conneaut Outlet

One site was surveyed on Conneaut Outlet in 2006 (Table 4). CPUE was 28.4 mussels/p-h and six live species were found, including *Ligumia nasuta* (Say, 1817) (eastern pondmussel), which was not detected in any other tributary in this study. Other species found were *Actinonaias ligamentina*, *Amblema plicata*, *Lampsilis siliquoidea*, *Pyganodon grandis* (Say, 1829) (giant floater) and *Strophitus undulatus*. One additional species, *Elliptio dilatata*, was found as only dead shells. In addition, we detected large amounts of the non-native *Corbicula fluminea* at this site, which are likely washing down from Conneaut Lake. Numbers of *C. fluminea* were so high that we did not attempt to enumerate them. *Pleurobema clava*, documented from Conneaut Outlet in 1988 (PNHP files accessed August 7, 2008), was not detected in our survey.

Conneauttee Creek

Three sites were surveyed on Conneauttee Creek (Table 4). Eleven live mussel species were found at site 1; three additional species were found only as dead shells: *Alasmidonta marginata*, *Lasmigona complanata* (Barnes, 1823) (white heelsplitter), and *Pleurobema clava*. Site 1 had the highest CPUE of any of our tributary sites: 83.5 mussels/p-h. In addition, 23 live and one weathered dead zebra mussels were found at site 1. Six live mussel species were found at site 2, and an additional five species were found as dead shells. CPUE at site 2 was 14.4 mussels/p-h. One live *Dreissena polymorpha* was found at site 2. Only one dead *Lasmigona costata* (Rafinesque, 1820) (fluted shell) and three live *D. polymorpha* were found at Conneauttee Creek site 3.

Cussewago Creek

Only one live *Pyganodon grandis,* a species typical of pool habitats, was found at the only site we surveyed in Cussewago Creek (Table 4).The entire length of this creek was mapped as deep pool habitat, so we utilized SCUBA to survey this site. The survey was aborted early because our gear quickly became clogged with silt thereby jeopardizing the safety of the divers.

LeBoeuf Creek

Three sites on LeBoeuf Creek were surveyed in 2006 and two additional sites were surveyed in 2007 (Table 4). LeBoeuf Creek had relatively high mussel species diversity and high CPUEs compared to most other tributaries surveyed in this study. Species richness ranged from 7 - 16 species per site and CPUE ranged from 17.5 to 39.6 mussels/p-h. Live *Pleurobema clava* was found at three sites and live *Villosa fabalis* was found at sites 1 and 2. Additionally, two weathered dead *E. torulosa rangiana*, one dead *Ligumia recta*, and one dead *V. fabalis* were found on site 3. Previous surveys in LeBoeuf Creek documented federally listed species below Lake LeBoeuf (see Bier 1994). LeBoeuf Creek is the only tributary where we detected *Utterbackia imbecillis* (Say, 1829) (paper pondshell).

Little Sugar Creek

Zero mussels were found at either of the two sites surveyed in Little Sugar Creek. Bier (1994) found six species at one site on Little Sugar Creek (upstream of Mud Run near Pettis Corners, roughly 9.5 km upstream of site 1), and zero mussels at another site (between hwy 428 and East Branch).

Muddy Creek

Five species were found at the site we surveyed in Muddy Creek, including *Elliptio dilatata*, *Lampsilis cardium* (Rafinesque, 1820) (plain pocketbook), *Lampsilis siliquoidea*, *Pyganodon grandis*, and *Strophitus undulatus* (Table 4). CPUE was 6.0 mussels/p-h. This encounter rate is relatively low compared to most downstream sampling stations in Muddy Creek (Mohler *et al.* 2006). No federally endangered mussels were found at this site, although *Epioblasma torulosa rangiana* and *Pleurobema clava* were both documented downstream (Mohler *et al.* 2006).

South Branch French Creek

Three sites on the South Branch of French Creek were surveyed in 2006. No live or dead mussels were found at site 1 and only live *Strophitus undulatus* was found at both sites 2 and 3 (Table 4). Dead shells of *Lampsilis ovata* (Say, 1817) (pocketbook) and *Ptychobranchus fasciolaris* were found at site 3. Previous studies in the South Branch also detected few mussel species. Bier (1994) found 124 *Elliptio dilatata* and one *Pyganodon grandis* at one site on South Branch French Creek, and seven live species at another site, including *Anodontoides ferussacianus* (l. Lea, 1834) (cylindrical papershell), *Elliptio dilatata*, *Lasmigona costata* (Rafinesque, 1820) (fluted shell), *Lampsilis fasciola* (Rafinesque, 1820) (wavy-rayed lampmussel), *Lampsilis siliquoidea*, *P. grandis,* and *S. undulatus*.

Sugar Creek

Zero mussels were found at all three sites surveyed in Sugar Creek. Previous studies in Sugar Creek also found very few mussels; only one live *Strophitus undulatus* and one relict *Pyganodon grandis* were found in four surveyed sites (Bier 1994).

West Branch French Creek

Three sites on West Branch French Creek were surveyed in 2006 (Table 4). *Lampsilis siliquoidea* was the only live species found at Site 1 on West Branch French Creek. Two additional species, *Pleurobema sintoxia* and *Strophitus undulatus,* were found only as dead shells. Four live species were found at West Branch Site 2, and it is the only site in which we found *Lasmigona compressa* (l. Lea, 1829) (creek heelsplitter). Nine species were found at West Branch site 3, which had a CPUE of 26.6 mussels/p-h. *Epioblasma triquetra* and *Ligumia recta* were found in two sites on the West Branch in previous studies (Bier 1994), but were not found in our 2006 surveys.

Woodcock Creek

Three sites were surveyed in Woodcock Creek in 2007 (Table 4). Species richness, CPUE and Shannon index of diversity all decreased going from upstream to downstream. Seventeen live mussels representing 9 species were found in the uppermost site (site 1), which had CPUE of 5.1 mussel/p-h. *Villosa fabalis* was detected at this site, but only a weathered dead shell. Twelve mussels representing five species were detected at site 2 and the CPUE was 3.0 mussels/p-h. One female *Epioblasma triquetra* was detected at this site, but only as a weathered dead shell. One earlier survey near Woodcock Lake Reservoir revealed no live or dead mussels (Bier 1994).

Fish Survey Results

Fish surveys were conducted at 23 of 25 sites that were surveyed for mussels. At least 49 fish species, including 10 species of darters were detected (Table 5). *Etheostoma blennioide*s (Rafinesque, 1819) (greenside darter) was the most ubiquitous species, found at 22 sites and accounting for 14.5% of the total number of fish found. The second most abundant species was *Etheostoma caeruleum* (Storer, 1845) (rainbow darter), which was found at 17 sites and made up 10.1% of the total number of fish found. Other commonly found species were *Semotilus atromaculatus* (Mitchill, 1818) (creek chub), *Hypentelium nigricans* (Lesueur, 1817) (northern hogsucker), and *Etheostoma zonale* (Cope, 1868) (banded darter). Species richness ranged from 8 to 23 fish species per site (Table 5). Little Sugar Creek had the highest species richness, with 22-23 species found. Conneauttee Creek (site 1 and site 3), South Branch (site 3), and West Branch (site 1) also had relatively high species richness. Surveys at sites 1 and 3 in LeBoeuf Creek had the fewest fish species.

Several notable species of special concern were found in the tributary fish surveys. *Etheostoma maculatum* (Kirtland, 1840) (spotted darter), classified as a Threatened species in Pennsylvania, occurred in Woodcock Creek (site 1) (Table 5). Fish classified as Candidate species in Pennsylvania were also found in tributary streams. *Amia calva* (Linnaeus, 1766) (bowfin) occurred in Conneaut Outlet (site 1). We found *Ichthyomyzon bdellium* (Jordan, 1885) (Ohio lamprey) in Sugar Creek (site 3). *Ichthyomyzon greeleyi* (Hubbs and Trautman, 1937) (mountain brook lamprey) was recorded in South Branch (site 2), while *Nocomis biguttatus* (Kirtland, 1841) (hornyhead chub) (S1 PC) in both South Branch (site 3) and Sugar Creek (sites 1 and 2).

Host Fish and Mussel Relationships

Each mussel species we detected in our surveys was matched with its known fish hosts out of the fish species that we detected in our surveys (Table 6) using hosts listed in the Mussel/Host Database (Cummings and Watters 2009). Most mussel species had at least one fish host detected, if known, at each site or within the same tributary (Table 7), and some species had numerous known hosts present. Hosts for *Lampsilis fasciola*, including *Micropterus dolomieu* (Lacepède, 1802) (smallmouth bass) and *Micropterus salmoides* (Lacepède, 1802) (largemouth bass) are common in the watershed, but likely inhabiting slower and deeper waters than our survey sites. Similarly, some of the confirmed hosts for *Lampsilis cardium* such as *M. salmoides*, *Lepomis macrochirus* (Rafinesque, 1819) (bluegill), *Lepomis gibbosus* (Linnaeus, 1758) (pumpkinseed), *Pomoxis annularis* (Rafinesque, 1818) (white crappie), and *Pomoxis nigromaculatus* (Lesueur, 1829) (black crappie), may not have been detected in Woodcock Creek because of the shallow riffle-run habitat sampled there. Perhaps for the same reason, fish hosts for *Lasmigona complanata,* including *Lepomis cyanellus* (Rafinesque, 1819) (green sunfish), *M. dolomieu, M. salmoides* and *Pomoxis annularis* (Rafinesque, 1818) (white crappie) were not detected in some surveys on LeBoeuf Creek. *Fundulus diaphanus* (Lesueur, 1817) (banded killifish) is another confirmed host for *L. cardium*, *L. complanata*, *Ligumia recta*, *Pyganodon grandis* and *Utterbackia imbecillis* but is not common in this watershed.

Two mussel species that we found in our surveys have no identified fish host; *Ligumia nasuta* and *Lampsilis ovata*. *Villosa fabalis* has only one known host in the watershed, *Etheostoma tippecanoe* (Jordan and Evermann, 1890) (Tippecanoe darter), which was not detected in our surveys and is apparently rare in the French Creek Watershed (Smith and Crabtree 2005). Although *Ptychobranchus fasciolaris* was found at several sites as adults and showed evidence of recruitment, it had relatively few host fish matches.

Macroinvertebrate Survey Results

Surveys for aquatic macroinvertebrates were conducted at 23 of sites that were surveyed for mussels, as well as three additional sites on Muddy Creek (Table 8). The mean FBI score amongst all sites was 4.87 (std. deviation = 0.95), mean percent EPT was 25.61% (std. deviation = 16.844), mean family richness was 15.3 (std. deviation = 5.65) and mean generic richness was 18.3 (std. deviation = 6.9).

The macroinvertebrate community was depressed in Conneaut Outlet. Conneaut Outlet site 1 had the lowest total number of macroinvertebrates of all tributary sites. This site had significantly lower generic richness, family richness, and percent Diptera than the mean of all tributary sites ($P < 0.05$), but had the second highest FBI score of all tributary sites. Additionally, no EPT taxa were found at the Conneaut Outlet site. High numbers of the introduced *C. fluminea* were present in our samples.

Macroinvertebrates indicated moderate to high quality in the Woodcock Creek watershed. All Woodcock Creek sites had significantly higher generic and family richness, and number of EPT families and genera than the mean of all sampled sites ($P < 0.05$). Percent EPT was significantly higher than the mean at sites 1 and 3. Woodcock Creek site 3 had the highest family- and generic-level richness of all tributary sites. Percent Diptera was significantly higher than the mean at sites 2 and 3 on Woodcock Creek. FBI scores for sites 2 and 3 fell within the 95% confidence interval of the mean; the FBI score for site 1 was significantly lower than the mean

Having relatively high quality macroinvertebrate community, sites on Sugar Creek had a significantly higher percentage of EPT taxa than the mean of all tributary sites ($P < 0.05$). Site 2 had the lowest FBI score of all sites. FBI scores were significantly lower than the mean at sites 2 and 3. Taxa richness was significantly higher than the mean at site 3, but significantly lower at site 1. Percent Diptera was significantly lower for Sugar Creek sites 1 and 2 than the mean of all tributary sites. Percent Chironomidae was significantly lower than the mean of all sites at sites 2 and 3.

Similar to Sugar Creek, macroinvertebrate community metrics in Little Sugar Creek suggested good water quality. Little Sugar Creek site 1 had a significantly lower FBI score than the mean of all tributary sites ($P < 0.05$). The FBI score for site 2 was not significantly lower than the mean. Family and generic-level richness fell within the 95% confidence interval of the mean at both sites 1 and 2. Both sites had a significantly higher number of EPT taxa than the mean of all tributary sites. Percent EPT was significantly higher than the mean at site 1, but significantly lower than the mean at site 2. Percent Diptera and percent Chironomidae were significantly lower than the mean of all sites at site 1, but significantly higher than the mean at site 2.

Inconsistent macroinvertebrate metrics in the West Branch French Creek watershed may reflect variable water quality or habitat conditions. Sites on West Branch French Creek had significantly lower generic richness and numbers of EPT taxa than the mean of all tributary sites ($P < 0.05$). Percent EPT taxa was significantly higher than the mean at site 2, but significantly lower at site 1. Percent Chironomidae and percent Diptera were significantly higher at West Branch French Creek sites 1 and 3 than the mean of all sites, and significantly lower than the mean at site 2. FBI scores were significantly higher than the mean at site 1 and site 3, but significantly lower at West Branch site 2.

Good water quality conditions were indicated by the macroinvertebrate community in the South Branch French Creek. At survey site 2 all metrics fell within the 95% confidence interval of the mean of all tributary sites. At site 1 family-level richness and percent Diptera were significantly lower than the mean of all sampled sites ($P < 0.05$). For site 3 on South Branch French the FBI score, percent Diptera, and percent Chironomidae were significantly lower than the mean of all sites. Generic-level richness, number of EPT taxa, and percent EPT were significantly higher than the mean.

Some stress on the macroinvertebrate community was apparent in LeBoeuf Creek sites. On LeBoeuf Creek site 1 had significantly lower generic richness than the mean of all survey sites ($P < 0.05$).

Site 2 had a significantly lower FBI score and family- and generic-level richness than the mean. Sites 1-4 had a significantly lower percent Diptera than the mean; site 5 had a significantly higher percent Diptera. The number of EPT taxa was significantly higher at sites 4 and 5 than the mean of all tributary sites. At sites 1, 2 and 3 the number of EPT taxa was significantly lower than the mean. LeBoeuf Creek site 5 had a high percentage of Chironomidae. Site 2 had the highest FBI score of all tributary sites. FBI scores were also high at sites 3 and 5 on LeBoeuf Creek. Percent EPT taxa was high at site 1, but low at sites 2 and 3 on LeBoeuf Creek.

A range of high and low quality conditions on Conneauttee Creek were suggested by the macroinvertebrate community. Sites on Conneauttee Creek had a significantly higher percent Chironomidae and a significantly lower percent EPT than the mean of all tributary sites ($P < 0.05$). Taxa richness and number of EPT taxa were significantly higher than the mean at Conneauttee Creek site 3. Both sites 1 and 2 had significantly lower numbers of EPT taxa than the mean. At site 1 the FBI score and generic-level richness was significantly lower than the mean of all tributary sites; site 2 had significantly lower family-level richness than the mean.

Macroinvertebrate community metrics from sampled sites on Muddy Creek indicated varying water quality conditions. Muddy Creek site 2 had significantly higher taxa richness and number of EPT taxa than the mean of all tributary sites ($P < 0.05$). Taxa richness and number of EPT taxa were significantly lower than the mean at sites 3 and 4. Percent EPT was significantly lower than the mean at sites 3 and 4. Percent Chironomidae and Diptera were significantly lower than the mean at site 2. At sites 3 and 4 percent Chironomidae was significantly higher than the mean of all tributary sites.

Relationships between Fish, Mussels, and Macroinvertebrates

An analysis using Pearson's correlation coefficient indicates no statistically significant linear relationships between fish species richness and mussel species richness (r = -0.1319476, t= 10.6514, *d.f.* = 21, P = 0.5484), mussel species richness and macroinvertebrate genus richness (r = -0.1935538, t= 9.9995, *d.f.* = 21, P = 0.3762), and fish species richness and macroinvertebrate genus richness (r = 0.1539617, t= 4.1447, *d.f.* = 21, P = 0.4831). Figure 3 illustrates fish, mussel and macroinvertebrate richness for each site.

Riparian Assessment scores and Fish, Mussels, and Macroinvertebrates

In regression analyses, no significant relationships were found between riparian assessment scores and fish species richness, mussel species richness and CPUE, or macroinvertebrate family-level biotic index (FBI) scores and percent EPT (Ephemeroptera, Plecoptera, Trichoptera) taxa.

Surrounding Land Use Relationships with Fish, Mussels, and Macroinvertebrates

Land cover data for the watershed upstream of each survey sites was variable between tributary streams (Table 10). Percent agriculture and percent development were highest upstream of sites on Conneauttee Creek. LeBoeuf Creek had the second highest percent agriculture. Sugar Creek had the lowest percent agriculture and the highest percent forest. Little Sugar and Sugar Creek had the lowest percent development. Percent development was relatively low throughout the survey area, while percent agriculture was relatively high.

Watershed land cover types upstream of survey sites were related to biological data. Significant relationships were found between macroinvertebrate metrics and percent land use in regression analysis at all scales of land use analysis. Macroinvertebrate FBI scores were significantly negatively related to percent forested landcover and percent EPT (Ephemeroptera, Plecoptera, Trichoptera) taxa were significantly positively related to percent forested landcover within the survey site reach riparian zone and catchment, as well as at the upstream watershed scale (Figure 4a - f). Percent agricultural land use in the riparian zone or catchment was not significantly related to macroinvertebrate metrics at the reach level.

However at the watershed scale, FBI score was significantly positively related to percent agricultural land use and percent EPT taxa was significantly negatively related to agricultural land use (Figure 4g and 3h).

At the watershed scale, mussel catch per unit effort (CPUE) and mussel species richness were significantly negatively associated with percent forested landcover (Figure 5a and b). Mussel species richness was significantly positively associated with percent agricultural land use (Figure 5c). The relationship between mussel CPUE and percent agriculture was not significant. At the reach catchment scale, mussel species richness was also significantly negatively related to percent forested land use (Figure 5d). Mussel CPUE was not significantly related to percent forested land use, and mussel CPUE and richness was not significantly related to percent agriculture at the reach catchment scale. Additionally relationships of mussel CPUE and richness to land cover in the reach riparian zone were not significant.

Regression analysis of fish species richness and land use found no significant relationships to percent agricultural or forested land use in the riparian zone, the reach catchment or at the watershed scale.

Table 1. Total mapped stream miles, percent flow regimes and habitat assessment scores by tributary.

Stream	Stream kilometers mapped	Percent riffle	Percent run	Percent riffle-run series	Combined percent riffle, run and riffle-run series	Percent pool	Mean habitat assessment score	Minimum habitat assessment score	Maximum habitat assessment score
West Branch	16.4	15.4	12.0	1.9	29.4	70.6	63.7	52	76
South Branch	16.8	45.3	18.5	11.5	75.3	24.7	75.8	63	85
LeBoeuf Creek	17.1	5.7	23.4	0.0	29.1	70.9	79.0	55	97
Woodcock Creek	26.7	28.3	21.0	3.7	53	47.0	75.9	66	94
Muddy Creek	20.2	0.6	10.9	13.5	25	75.0	79.8	70	87
Conneauttee Creek	13.3	4.2	52.2	0.0	56.4	43.6	72.2	61	85
Cussewago Creek	9.7	0.0	0.7	0.0	0.7	99.3	68.7	55	82
Conneaut Outlet	9.6	4.9	2.6	0.0	7.5	92.4	75.6	65	98
Little Sugar Creek	7.4	59.2	3.9	18.5	81.6	18.4	82.6	78	88
Sugar Creek	12.9	23.1	9.9	53.8	86.8	13.3	75.0	61	98

Table 2. Sites and survey dates for French Creek tributary surveys. Exact locations are not given to protect sensitive species.

Site Code	Site Name	County	Mussel Survey Date	Fish Survey Date	Macroinvertebrate Survey Date
CO01	Conneaut Outlet Site 1	Crawford	25-Jul-06	10-Oct-06	10-Oct-06
CT01	Conneauttee Creek Site 1	Crawford	8-Sep-06	25-Oct-07	25-Oct-07
CT02	Conneauttee Creek Site 2	Crawford	8-Sep-06	25-Oct-07	25-Oct-07
CT03	Conneauttee Creek Site 3	Crawford	13-Sep-07	12-Oct-07	12-Oct-07
CU01	Cussewago Creek Site 1	Crawford	22-Jun-07	NA	NA
LB01	LeBoeuf Creek Site 1	Erie	6-Jun-06	2-Sep-06	26-Sep-07
LB02	LeBoeuf Creek Site 2	Erie	30-Jun-06	2-Sep-06	26-Sep-07
LB03	LeBoeuf Creek Site 3	Erie	30-Jun-06	26-Sep-06	26-Sep-07
LB04	LeBoeuf Creek Site 4	Erie	2-Jul-07	17-Oct-07	17-Oct-07
LB05	LeBoeuf Creek Site 5	Erie	2-Jul-07	17-Oct-07	17-Oct-07
LS01	Little Sugar Creek Site 1	Crawford	16-Aug-07	15-Oct-07	15-Oct-07
LS02	Little Sugar Creek Site 2	Crawford	16-Aug-07	15-Oct-07	15-Oct-07
MD01	Muddy Creek site 1	Crawford	4-Oct-07	NA	NA
MD02	Muddy Creek Site 2	Crawford	NA	NA	10-Oct-07
MD03	Muddy Creek Site 3	Crawford	NA	NA	5-Oct-07
MD04	Muddy Creek Site 4	Crawford	NA	NA	1-Oct-07
SB01	South Branch Site 1	Erie	24-Jul-06	31-Aug-06	25-Sep-06
SB02	South Branch Site 2	Erie	24-Jul-06	26-Oct-07	5-Sep-06
SB03	South Branch Site 3	Erie	25-Jul-06	18-Oct-07	22-Sep-06
SC01	Sugar Creek Site 1	Venango	7-Aug-06	19-Oct-07	22-Sep-06
SC02	Sugar Creek Site 2	Venango	7-Aug-06	19-Oct-07	22-Sep-06
SC03	Sugar Creek Site 3	Venango	6-Sep-07	26-Oct-07	19-Oct-07
WB01	West Branch Site 1	Erie	22-Jun-06	7-Sep-06	27-Sep-06
WB02	West Branch Site 2	Erie	22-Jun-06	2-Oct-06	27-Sep-06
WB03	West Branch Site 3	Erie	7-Jul-06	18-Oct-07	18-Oct-07
WK01	Woodcock Creek Site 1	Crawford	1-Aug-07	16-Oct-07	16-Oct-07
WK02	Woodcock Creek Site 2	Crawford	1-Aug-07	16-Oct-07	16-Oct-07
WK03	Woodcock Creek Site 3	Crawford	6-Sep-07	24-Oct-07	24-Oct-07

Table 3. Total numbers, percent relative abundance, minimum length, maximum length, mean length, standard error (*SE*) mean length, number of recruits, number of sites where each species was found, number of sites with recruits of each species, number of male, number of female, number of unreported sex, and female to male ratio for each species for timed searches.

	Total numbers	Percent relative abundance	Minimum length (mm)	Maximum length (mm)	Mean length (mm)	*SE* mean length (mm)	Number of recruits	Number of sites	Number of sites with recruits	Number of females	Number of males	Unreported sex	F:M ratio
Actinonaias ligamentina	52	8.43	27.0	140.0	109.1	3.33	1	10	1			52	
Alasmidonta marginata	4	0.65	29.0	76.0	59.5	10.43	1	5	1			4	
Amblema plicata	106	17.18	38.0	139.0	89.6	2.41		7	0			106	
Dreissena polymorpha	29	4.70	14.0	27.0	20.6	0.59	NA	3				29	
Elliptio dilatata	40	6.48	36.0	109.0	75.8	2.93		7				40	
*Epioblasma torulosa rangiana**	0	0.00										0	
Epioblasma triquetra	4	0.65	32.0	58.0	47.3	5.47		2		1	3	0	0.33
Lampsilis cardium	3	0.49	77.0	104.0	94.7	8.84		3		1	2	0	0.50
Lampsilis fasciola	6	0.97	50.0	80.0	63.5	5.63		4		3	2	1	1.50
Lampsilis ovata	17	2.76	67.0	137.0	102.9	4.65		5		6	8	3	0.75
Lampsilis siliquoidea	116	18.80	16.0	150.0	84.2	2.34	3	12	2	36	74	6	0.49
Lasmigona complanata	3	0.49	98.0	141.0	117.3	12.60		3				3	
Lasmigona compressa	7	1.13	48.0	68.0	57.0	3.21		1				7	
Lasmigona costata	29	4.70	52.0	127.0	98.0	3.42		9				29	
Ligumia nasuta	15	2.43	84.0	108.0	95.9	2.11		1				15	
*Ligumia recta**	0	0.00										0	
Pleurobema clava	29	4.70	22.0	84.0	57.2	2.96	1	5	1			29	
Pleurobema sintoxia	12	1.94	43.0	100.0	64.3	5.61		5				12	
Ptychobranchus fasciolaris	44	7.13	19.0	113.0	74.7	4.17	1	8	1			44	
Pyganodon grandis	21	3.40	40.0	121.0	86.5	3.94		10				21	
Quadrula cylindrica	5	0.81	82.0	119.0	95.8	6.60		3				5	
Strophitus undulatus	67	10.86	31.0	100.0	62.6	1.61		13				67	
Utterbackia imbecillis	2	0.32	60.0	71.0	65.5	5.50		2				2	
Villosa fabalis	6	0.97	21.0	40.0	30.7	2.91		2		2	4	0	0.50
Total	617												

*Species found only as dead shells.

Table 4. Catch per unit effort (CPUE, #/p-h) of live individuals of each mussel species found at each French Creek tributary site. Total number of live individuals, Shannon Index (H´), and number of sites in which freshwater mussels species were found is also given. Zeros for species CPUE indicate species found as only dead shells at a particular site. No live unionid mussels or shells were found at LS01, LS02, SB01, SC01, SC02 and SC03 and those sites are not included in this table.

Species/Site	CT01	CT02	CT03	CO01	CU01	LB01	LB02	LB03	LB04	LB05	MD01	SB02	SB03	WB01	WB02	WB03	WK01	WK02	WK03	No. Sites
Actinonaias ligamentina	3.95	1.52		0.55			11.37	2.57	2.57	3.43						1.59	0.30	0.25		12
Alasmidonta marginata	0	0.76					0.39	0.86							0		0.30			7
Amblema plicata	60.00	6.08		3.27		5.85	1.96			1.71							0.30			13
Dreissena polymorpha	18.16	2.28	3.16																	10
Elliptio dilatata	3.95	4.56		0		0	0.39		13.71	4.29	1.21					2.12		0		8
Epioblasma t. rangiana								0												7
Epioblasma triquetra							1.18	0	0								0.30	0		5
Lampsilis cardium	0.79										0.40						0.30			9
Lampsilis fasciola	0.79								0.86								0.90	0.25		10
Lampsilis ovata	7.89	1.52					1.18	0.86	0	0			0		0	0.53				5
Lampsilis siliquoidea	2.37	0		6.00		3.66	7.84	0.86	13.71	3.43	1.21			11.36	9.35	2.12				1
Lasmigona complanata	0					0.73	0.39	0.86												3
Lasmigona compressa															2.73					5
Lasmigona costata	1.58	0	0			0.73	0.39	3.43	3.43	0.86					1.56	5.84			0.45	1
Ligumia nasuta				8.18																4
Ligumia recta								0												2
Pleurobema clava	0	0				2.93	5.10	7.71	0.86	1.71										3
Pleurobema sintoxia		0				0	0.78	1.71	0.86	0.86				0		3.19				5
Ptychobranchus fasciolaris				9.27			1.96	1.71	6.00	0.86				0	0	1.59	1.81	0.76		2
Pyganodon grandis					0.43	2.20	1.96	2.57	0.86	0.00	0.81					1.59	0.30	0.25	0.45	2
Quadrula cylindrica	0.01						0.39	2.57												2
Strophitus undulatus	0.03			1.09			2.75	2.57	3.43	2.57	2.42	0.32	1.06	0	5.45	7.96	0.60	1.52		3
Utterbackia imbecillis							0.39	0.86												0
Villosa fabalis						1.46	1.57	0									0			0
Survey area (m^2)	635	657	478	920	1165	685	1276	582	1016	385	1244	1570	940	1102	1282	940	1528	1828	1106	
Search time (min.)	76	79	57	110	140	82	153	70	122	46	149	188	113	132	154	113	199	237	132	
CPUE (#/p-h)*	83.5	14.4	0	28.4	0.4	17.5	40.0	29.1	26.6	30	6	0.3	1.1	11.3	19.1	26.6	5.1	3	0.9	
Total no. mussels (live)*	106	19	0	52	1	24	102	34	54	23	15	1	2	25	49	50	17	12	2	**588**
Total no. species (live)*	10	5	0	6	1	7	17	13	10	9	5	1	1	1	4	9	9	5	2	
Total no. species (incl.dead)*	13	10	1	7	1	9	17	17	12	11	5	1	3	3	7	9	10	7	2	
Shannon Index (H')*	1.13	1.35	0.00	1.50	0.00	1.72	2.25	2.31	1.83	2.04	1.46	0.00	0.00	0.00	1.19	1.94	1.93	1.31	0.69	

* Total CPUE, abundance, species richness, and Shannon indices do not include *Dreissena polymorpha*.

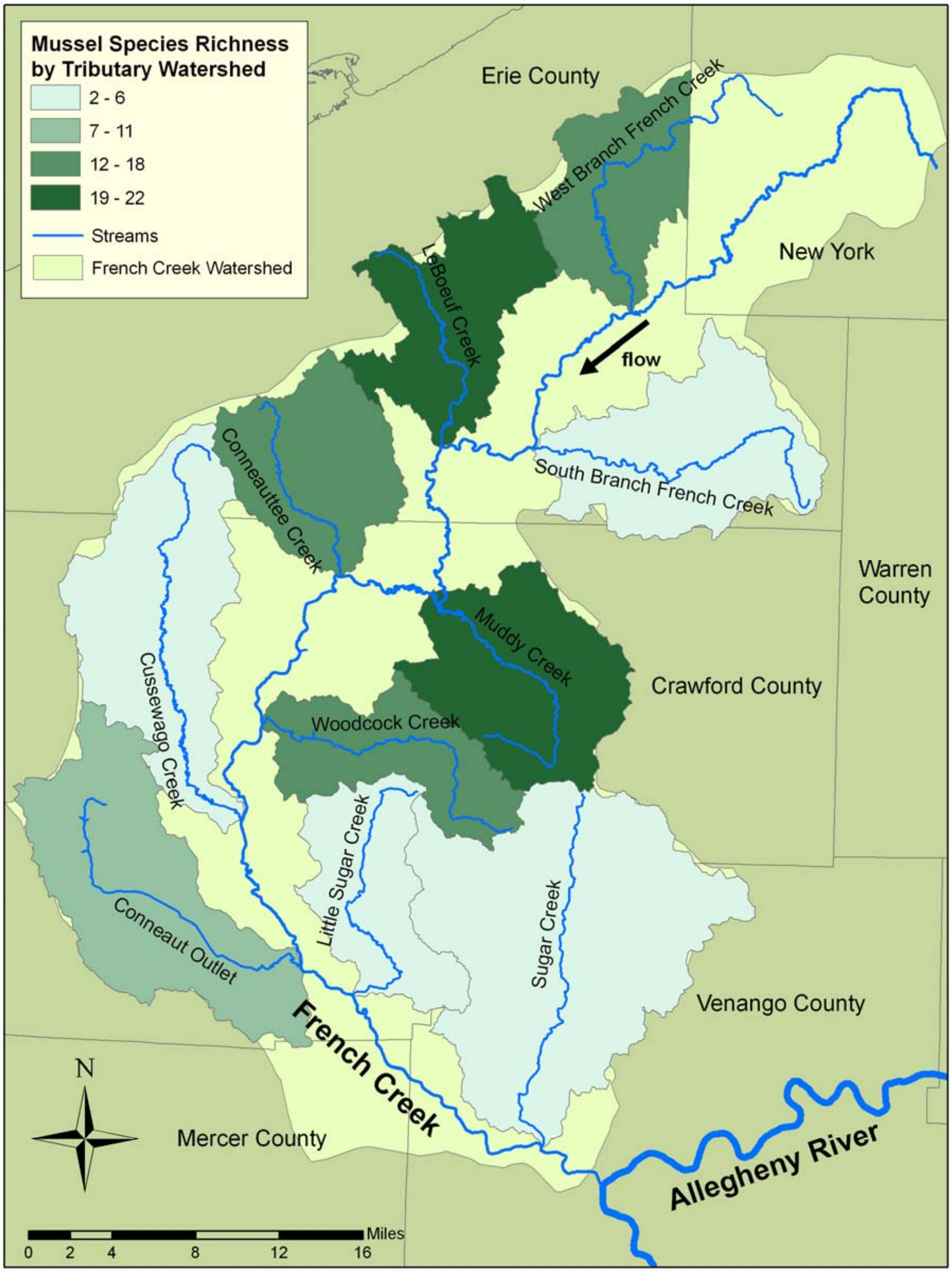

Figure 2. Mussel species richness by tributary watershed based on this project and additional available data recorded since 1990.

Table 5. Total number, percent total catch, and number of sites in which freshwater fish species were found in the French Creek tributary sites.

Species	CT01	CT02	CT03	CO01	LB01	LB02	LB03	LB04	LB05	LS01	LS02	SB01	SB02	SB03	SC01	SC02	SC03	WB01	WB02	WB03	WK01	WK02	WK03	Total	% Total	No. Sites
Ambloplites rupestris				5							3		1	1			1	1	1	2				15	0.5	8
Ameiurus natalis				4		1				1	3													9	0.3	4
Ameiurus nebulosus				2																				2	0.1	1
Amia calva				6																				6	0.2	1
Campostoma anomalum	7				12			42		1	3			4	7	3			3		2	7	1	92	3.0	12
Catostomus commersoni	11	2	4		2	1			2	2	2					9		3			1		1	40	1.3	12
Cottus bairdi										34	51	48	1	18	124	3	1						21	301	9.7	9
Erimystax dissimilis	2	1	2							3	35				9									52	1.7	6
Esox a. verrmiculatus	1																			1				2	0.1	2
Etheostoma blennioides	25	5	84		3	2	1	59	8	8	23	32	11	29	40	42	11	16	7	3	5	17	12	443	14.3	22
Etheostoma caeruleum	3	2	50		3			5		8	18	32	6	5	30	81	6		3		8	20	10	290	9.4	17
Etheostoma flabellare										1	1	1		2	4	36		1			11	16	9	82	2.6	10
Etheostoma maculatum																					1			1	0.0	1
Etheostoma nigrum	46	25	12			1			1									8	2	10		15		120	3.9	9
Etheostoma variatum		1								11	18	45	24	7	5	13	24	11	5	2	2	6		174	5.6	14
Etheostoma zonale	1		8		4	2		11	2	1	5	16	7			16	7	4	1		7	9	8	109	3.5	17
Fundulus diaphanus				1																				1	0.0	1
Hybopsis amblops								21	3															24	0.8	2
Hypentelium nigricans	20	7	64		1	3		10	12	10	13		4	36	3	6	4	27	1	10	11	3	15	260	8.4	20
Ichthyomyzon bdellium																	1							1	0.0	1
Ichthyomyzon greeleyi													1											1	0.0	1
Lepomis cyanellus				1						1														2	0.1	2
Lepomis gibbosus				3		1	2																	6	0.2	3
Lepomis macrochirus				32	1	1	6		3				1	1			1							46	1.5	8
Luxilus chrysocephalus	3							1	1	5	5			8				7	11	3	1	11		56	1.8	11
Luxilus cornutus							1																	1	0.0	1
Micropterus dolomieu	3		5					2	4	3	10		4	13	13	5	4	1		3	5	2	5	82	2.6	16
Micropterus salmoides				3			1	1	1															6	0.2	4
Moxostoma anisurum										1														1	0.0	1
Moxostoma sp.			3								1							2						6	0.2	3
Moxostoma macrolepidotum	24	20	15					12	5				1		1	2	1	2		4		1		88	2.8	12

Table 5. Continued.

Species	CT01	CT02	CT03	CO01	LB01	LB02	LB03	LB04	LB05	LS01	LS02	SB01	SB02	SB03	SC01	SC02	SC03	WB01	WB02	WB03	WK01	WK02	WK03	Total	% Total	No. Sites
Nocomis biguttatus														2	8	2								12	0.4	3
Nocomis micropogon										10	2			3										15	0.5	3
Notropis atherinoides			3			1	1			12	15	2		2	5				4		6	1	4	59	1.9	13
Notropis buccatus			4																					4	0.1	1
Notropis ludibundus	1							39	4	1		7			1					3		10		66	2.1	8
Notropis photogenis	7	1	4					18	5	3	12	3		6	2			12	17	6	1		5	102	3.3	15
Notropis sp.	16	4				3	3										1							27	0.9	5
Notropis volucellus	1					2	1	17	2									10				2		35	1.1	7
Noturus flavus																1		1					1	3	0.1	3
Oncorhynchus mykiss														1									3	4	0.1	2
Perca flavescens								1	5															6	0.2	2
Percina caprodes			1					3	1		7	1	1	1		1	1			1	4			22	0.7	11
Percina macrocephala	1					3	2		3		8		2	2			2	2						27	0.9	10
Percina maculata	1	2	1										1				1	9		3				20	0.6	8
Pimephales notatus	9	3						9						5	3			27						56	1.8	6
Pomoxis annularis				1																				1	0	1
Pomoxis nigromaculatus				5																				5	0.2	1
Rhinichthys atratulus	7	2	45							5	1	2	1								1	2		66	2.1	9
Rhinichthys cataractae	2		4							5	4				5									20	0.6	5
Semotilus atromaculatus	13	6	26	1	1	12	11	2		22	15	4			3	2		18	4	2	5	13		160	5.2	18
Unidentified						3													6					10	0.3	3
TOTAL	204	81	335	64	27	36	29	253	62	148	255	193	66	146	263	222	66	162	65	53	71	135	95	3033		
No. Species (Richness)	22	14	18	12	8	14	10	17	17	22	23	12	15	19	17	15	15	19	13	14	16	16	13			
Area Surveyed	635	657	478	920	685	1276	582	1016	385	1248	1268	1001	1570	940	1000	1003	1447	1102	1282	940	1528	1828	1106			
Time Surveyed (min)	36	60	120	60	50	50	50	55	33	60	60	75	40	65	45	45	40	60	50	38	40	59	60			

Table 6. Mussel species detected in our surveys and known fish hosts out of the fish species that we detected in our French Creek tributary surveys.

	Fish Host Species																																				
Mussel Species	*A. rupestris*	*A. natalis*	*A. nebulosus*	*A. calva*	*C. anomalum*	*C. commersoni*	*C. bairdi*	*E. caeruleum*	*E. dissimilis*	*E. flabellare*	*E. nigrum*	*E. zonale*	*F. diaphanus*	*H. nigricans*	*L. cyanellus*	*L. gibbosus*	*L. macrochirus*	*L. chrysocephalus*	*L. cornutus*	*M. dolomieu*	*M. salmoides*	*M. carinatum*	*M. macrolepidotum*	*N. micropogon*	*N. atherinoides*	*N. ludibundus*	*N. volucellus*	*P. flavescens*	*P. caprodes*	*P. maculata*	*P. notatus*	*P. annularis*	*P. nigromaculatus*	*R. atratulus*	*R. cataractae*	*S. atromaculatus*	*Number of known fish host species present*
A. ligamentina	x				x								x		x		x			x	x							x				x	x				**10**
A. marginata	x					x								x									x														**4**
A. plicata	x								x					x	x	x	x				x				x			x	x			x	x				**12**
E. dilatata																												x				x	x				**3**
E. t. rangiana							x					x																									**2**
E. triquetra							x																						x	x							**3**
L. cardium															x	x	x			x	x							x				x	x				**8**
L. fasciola																				x	x																**2**
L. ovata																																					**0**
L. siliquoidea	x					x									x	x	x	x	x	x	x					x		x			x	x	x				**15**
L. complanata													x		x						x	x										x					**5**
L. compressa															x		x								x		x	x					x		x	x	**8**
L. costata	x		x	x	x			x		x		x		x	x	x	x				x	x						x							x	x	**16**
L. nasuta																																					**0**
L. recta	x				x								x		x	x	x				x							x				x	x				**10**
P. clava					x													x											x	x							**4**
P. sintoxia					x												x														x						**3**
P. fasciolaris								x		x																											**2**
P. grandis	x	x			x	x		x			x		x		x	x	x	x	x		x							x			x	x	x	x		x	**20**
Q. cylindrica								x										x																			**2**
S. undulatus	x	x			x			x		x	x	x			x	x	x		x		x			x				x	x	x	x	x	x	x	x	x	**22**
U. imbecillis	x												x		x	x	x				x							x					x			x	**9**
V. fabalis																																					**0**

Table 7. Number of host fish matches to each mussel species at each tributary site. Zeros indicate mussel presence, but no fish host matches. Dead indicates mussel presence as dead shells only. The letter u indicates mussel presence but no host fish has been identified for that mussel species.

Species/Site	CT01	CT02	CT03	CO01	LB01	LB02	LB03	LB04	LB05	SB03	WB01	WB02	WB03	WK01	WK02	WK03
A. ligamentina	2	0		8		1	2	4	4				3	2	2	
A. marginata	3	3				2	0					2 dead		2		
A. plicata	2	2		7	2	4			5					3		
E. dilatata	0	0		2 dead	dead			1 dead	1 dead				0		0 dead	
E. t. rangiana							0 dead									
E. triquetra						0	0 dead	1 dead						1	0 dead	
L. cardium	1													1		
L. fasciola	1							2						1	1	
L. ovata	u	u				u	u						u			
L. siliquoidea	4	1 dead		6	1	2	4	6	6		3	1	3			
L. complanata	0 dead				0	0	1									
L. compressa												2				
L. costata	6	3 dead	5 dead		6	5	4	7	5			6	3			5
L. nasuta				u												
L. recta							3 dead									
P. clava	3 dead	1 dead			1	0	0	3	2							
P. sintoxia		1 dead			2 dead	1	1	2	1		1 dead		1			
P. fasciolaris				0		0	0	1	0	2		1	0	2	2	
P. grandis					5	6	5	3	8 dead				3	7	7	4
Q. cylindrica							0									
S. undulatus	8			10		6	5	7	6	6	6	6	4	6	6	
U. imbecillis						3	4									
V. fabalis					0	0	0 dead							0 dead		

Table 8. Macroinvertebrate community metrics for 26 sites on the tributaries of French Creek.

Site	Total Number Identified	Richness - Family	FBI	Richness - Genus	% Ephemeroptera	% Plecoptera	% Trichoptera	% Diptera	% Chironomidae	% EPT	No. Ephemeroptera Taxa - Genus	No. Plecoptera Taxa - Genus	No. Trichoptera Taxa - Genus	No. EPT Taxa - Genus	No. Ephemeroptera Taxa - Family	No. Plecoptera Taxa - Family	No. Trichoptera Taxa - Family	No. EPT Taxa - Family
CO 01	32	9	6.34	9	0	0	0	9.38	3.13	0	0	0	0	0	0	0	0	0
CT 01	321	13	5.36	15	0.31	0	1.56	71.34	68.85	1.87	1	0	4	5	1	0	4	5
CT 02	294	12	4.75	16	0	0	0.34	39.12	37.07	0.34	0	0	1	1	0	0	1	1
CT 03	632	19	5.04	24	0.63	0.47	16.77	53.32	48.58	17.88	2	1	7	10	2	1	6	9
LB 01	63	14	4.81	15	1.59	0	50.79	17.46	14.29	52.38	1	0	3	4	1	0	2	3
LB 02	66	11	6.89	11	0	0	12.12	4.55	1.52	12.12	0	0	2	2	0	0	2	2
LB 03	122	18	5.84	18	2.46	0	7.38	22.95	22.13	9.84	2	0	2	4	2	0	2	4
LB 04	629	26	4.49	32	10.49	10.49	10.65	15.74	13.2	31.64	3	3	7	13	3	3	5	11
LB 05	549	15	5.68	19	13.66	0.36	1.82	51.18	51.00	15.85	3	1	6	10	3	1	4	8
LS 01	62	15	3.97	19	11.29	1.61	16.13	14.52	12.9	33.87	6	1	4	11	4	1	3	8
LS 02	118	13	4.89	19	5.93	3.39	7.63	54.24	48.31	16.95	5	1	4	10	3	1	3	7
MD 02	147	21	4.58	24	15.65	1.36	6.12	12.93	4.08	23.13	5	1	5	11	4	1	5	10
MD 03	35	7	4.83	9	8.57	8.57	0	20.00	20.00	14.29	1	1	0	2	1	1	0	2
MD 04	43	11	5.63	11	2.33	6.98	2.33	72.09	69.77	11.63	1	2	1	4	1	2	1	4
SB 01	113	12	4.52	16	11.5	0	19.47	2.65	2.65	30.97	3	0	4	7	3	0	2	5
SB 02	54	14	5.26	18	9.26	0	12.96	35.19	31.48	22.22	3	0	3	6	3	0	2	5
SB 03	101	17	3.82	22	34.65	0	5.94	9.90	4.95	40.59	9	0	3	12	6	0	3	9
SC 01	62	11	4.89	14	37.10	0	1.61	22.58	22.58	38.71	6	0	1	7	4	0	1	5
SC 02	204	15	2.04	19	42.16	0.49	15.2	12.25	11.27	57.84	6	1	4	11	5	1	2	8
SC 03	542	24	3.49	30	25.28	1.48	23.43	35.61	13.28	50.18	7	3	8	18	5	3	5	13
WB 01	45	14	5.73	14	6.67	0	4.44	66.67	42.22	11.11	2	0	1	3	2	0	1	3
WB 02	33	7	4.33	10	45.45	0	6.06	12.12	12.12	51.52	3	0	1	4	2	0	1	3
WB 03	58	8	5.5	8	13.79	5.17	1.72	65.52	65.52	20.69	2	1	1	4	2	1	1	4
WK 01	356	23	4.35	28	12.08	1.12	28.09	38.2	16.29	41.29	3	3	8	14	2	3	6	11
WK 02	220	21	4.62	25	20.45	11.36	8.64	44.55	35.91	20.45	3	1	6	10	3	1	5	9
WK 03	304	27	4.92	30	17.11	0.66	20.72	51.32	43.09	38.49	5	1	6	12	3	1	5	9
Mean	200.2	15.3	4.87	18.3	13.4	2.06	10.84	32.90	27.55	25.61	3.2	0.8	3.5	7.5	2.5	0.8	2.8	6.1
Standard Deviation	194.90	5.65	0.95	6.9	13.41	3.455	11.320	22.162	21.430	16.844	2.34	0.98	2.49	4.62	1.58	0.98	1.86	3.46
Lower 95% CI	118.05	12.96	4.48	15.4	7.9	0.65	6.22	23.84	18.79	18.73	2.2	0.4	2.5	5.6	1.9	0.4	2.0	4.7
Upper 95% CI	282.34	17.58	5.26	21.1	18.9	3.47	15.47	41.96	36.30	32.49	4.1	1.2	4.6	9.4	3.2	1.2	3.5	7.5

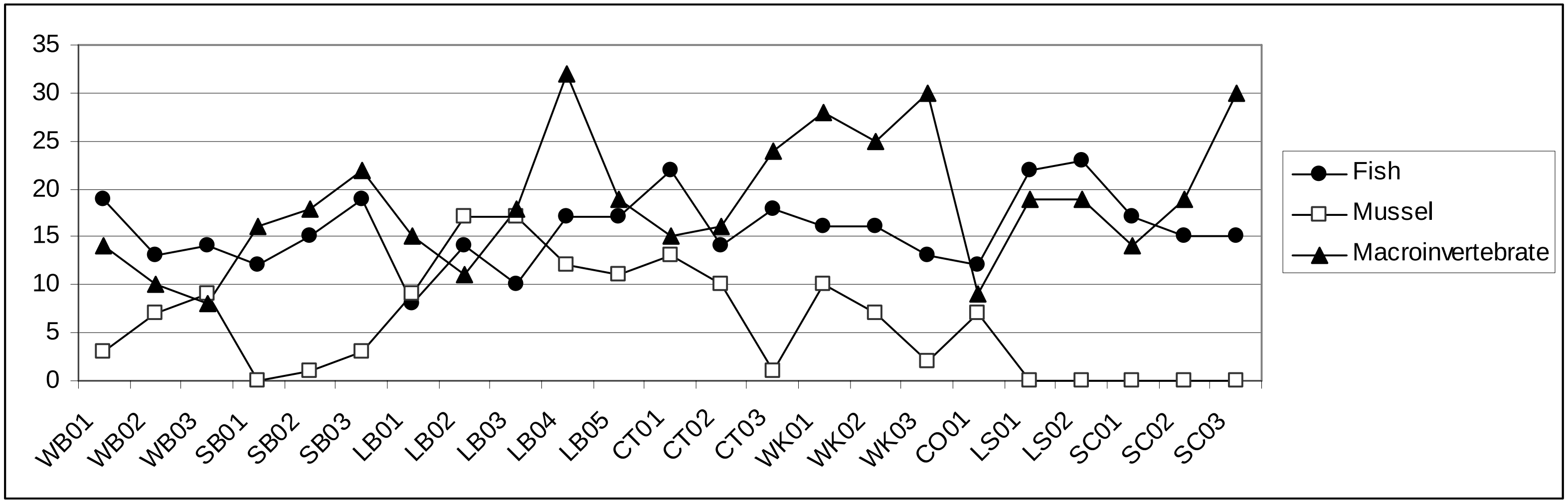

Figure 3. Fish species, mussel species, and macroinvertebrate genus richness for tributary sites. Sites are listed from the northernmost to the southernmost tributary. Only sites where all 3 taxa were sampled are shown.

Table 9. Percent major watershed landcover types for the ten major tributaries of French Creek and for the entire watershed (calculated from the National Landcover Data 1992).

	Percent watershed land cover type					
Watershed	% Developed	% Agriculture	% Natural (Wetland, forest & shrubland)	% Wetlands	% Forest and shrubland	% Other landcover
Conneaut Outlet	2.9	37.3	59.6	10.2	46.6	0.2
Conneauttee Creek	3.9	47.4	48.6	0.9	46.3	0.0
Cussewago Creek	2.3	38.9	58.8	8.4	49.8	0.0
French Creek	1.4	38.6	59.9	3.7	55.6	0.1
LeBoeuf Creek	1.3	44.6	53.8	7.5	45.9	0.3
Little Sugar Creek	0.2	44.1	55.6	2.8	51.4	0.0
Muddy Creek	0.3	38.6	61.0	5.3	55.7	0.0
South Branch	1.4	39.9	58.4	4.3	54.0	0.4
Sugar Creek	0.3	27.4	72.2	1.3	70.7	0.1
West Branch	0.8	35.6	63.4	4.5	57.8	0.1
Woodcock Creek	0.8	39.2	59.9	2.0	57.1	0.1

Table 10. Upstream watershed percent agriculture, forest and developed land cover for each survey site.

Site	% Agriculture	% Forest	% Developed
CO01	35.2	51.5	4.5
CT01	46.8	45.8	4.6
CT02	46.8	45.8	4.6
CT03	46.2	46.4	4.8
CU01	38.9	49.8	2.3
LB01	44.6	45.9	1.3
LB02	44.6	45.9	1.3
LB03	44.6	45.9	1.3
LB04	43.6	46.4	0.9
LB05	43.6	46.4	0.9
LS01	43.3	52.2	0.1
LS02	44.1	51.4	0.2
MD01	42.3	55.9	0.3
MD02	39.1	59.2	0.3
MD03	38.9	58.3	0.4
MD04	38.6	55.7	0.3
SB01	38.8	54.8	1.5
SB02	39.9	54.0	1.4
SB03	37.1	56.2	1.3
SC01	27.4	70.7	0.3
SC02	27.5	70.7	0.3
SC03	27.2	70.9	0.3
WB01	35.6	57.8	0.8
WB02	35.6	57.8	0.8
WB03	34.8	58.6	0.9
WK01	38.8	57.5	0.7
WK02	38.8	57.5	0.7
WK03	38.5	57.7	0.7

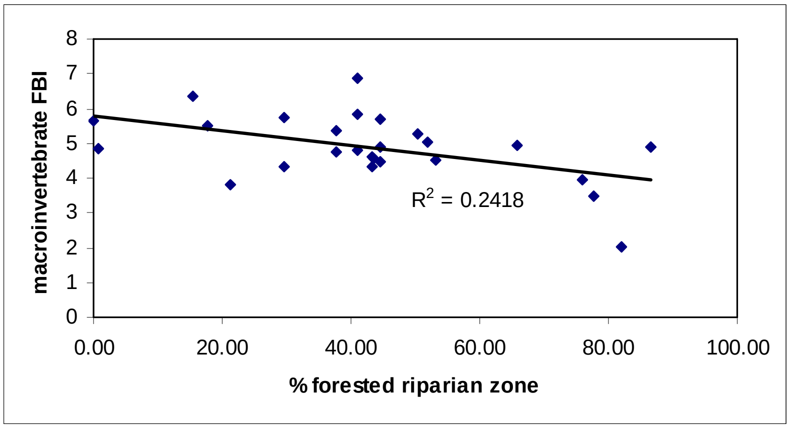

Figure 4a. Regression of macroinvertebrate FBI scores by percent forest landcover in the riparian zone (p = 0.01).

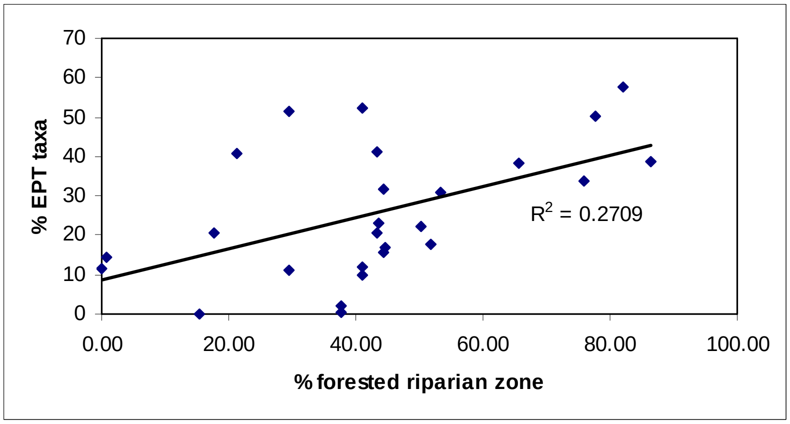

Figure 4b. Regression of macroinvertebrate percent EPT taxa by percent forested landcover in the riparian zone (p = 0.006).

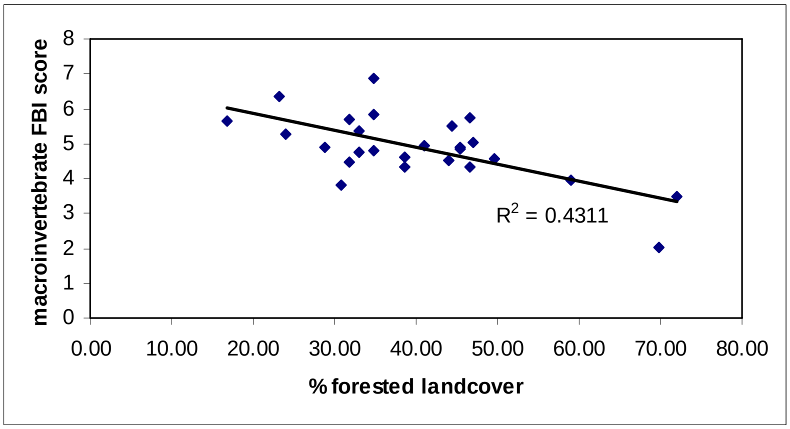

Figure 4c. Regression of macroinvertebrate FBI scores by percent forested landcover in the reach catchment (p = 0.0003).

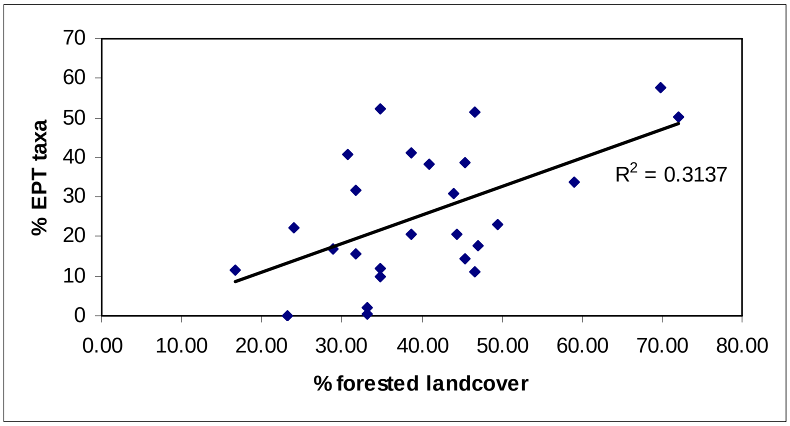

Figure 4d. Regression of macroinvertebrate %EPT taxa by percent forested landcover in the reach catchment (p = 0.003).

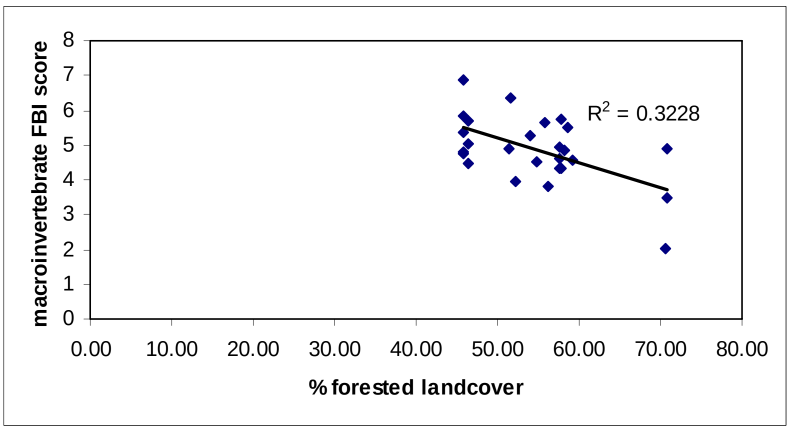

Figure 4e. Regression of macroinvertebrate FBI scores by percent forested landcover in the watershed (p = 0.002).

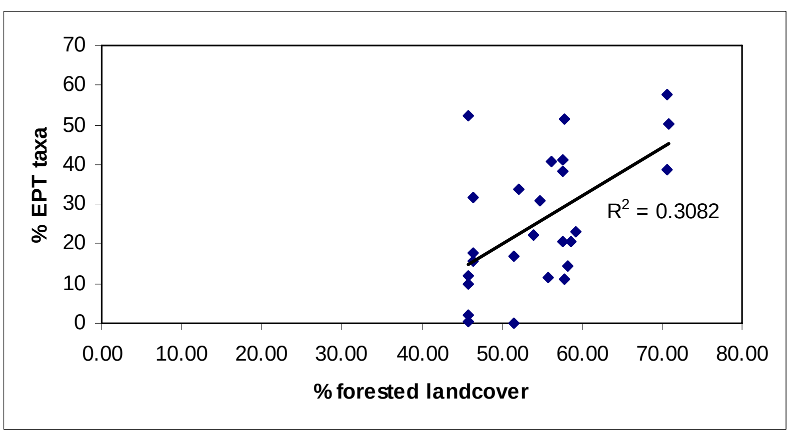

Figure 4f. Regression of %EPT taxa by percent forested landcover in the watershed (p = 0.003).

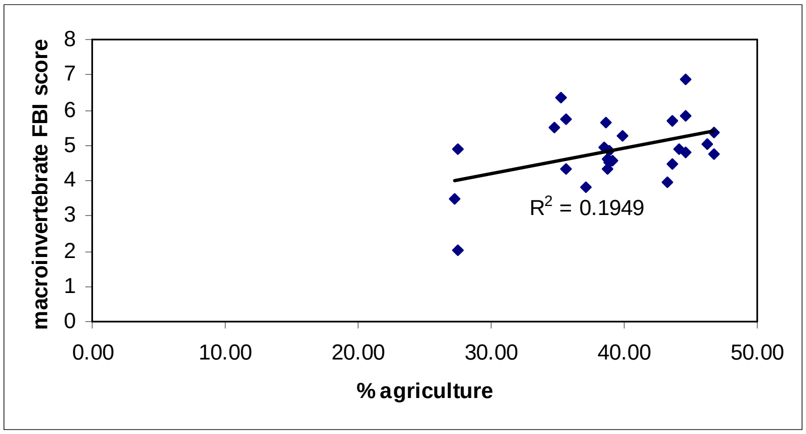

Figure 4g. Regression of FBI score by percent agricultural landcover in the watershed (p = 0.02).

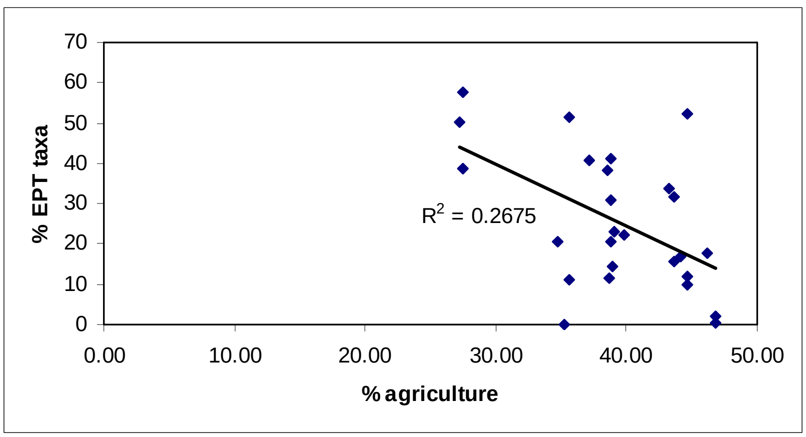

Figure 4h. Regression of percent EPT taxa by percent agricultural landcover in the watershed (p = 0.007).

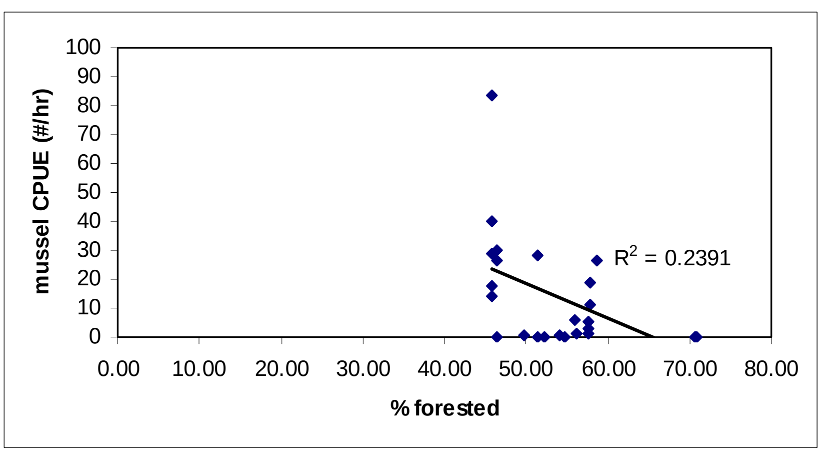

Figure 5a. Regression of mussel catch per unit effort (CPUE) by percent forested landcover in the watershed (p = 0.01).

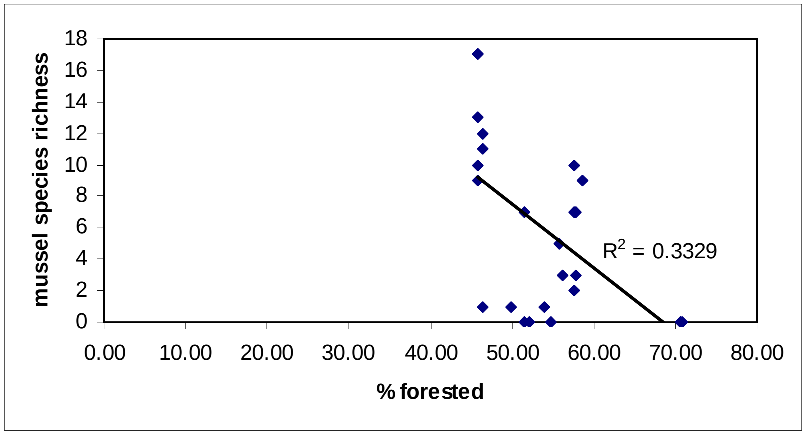

Figure 5b. Regression of species richness by percent forested landcover in the watershed (p = 0.003).

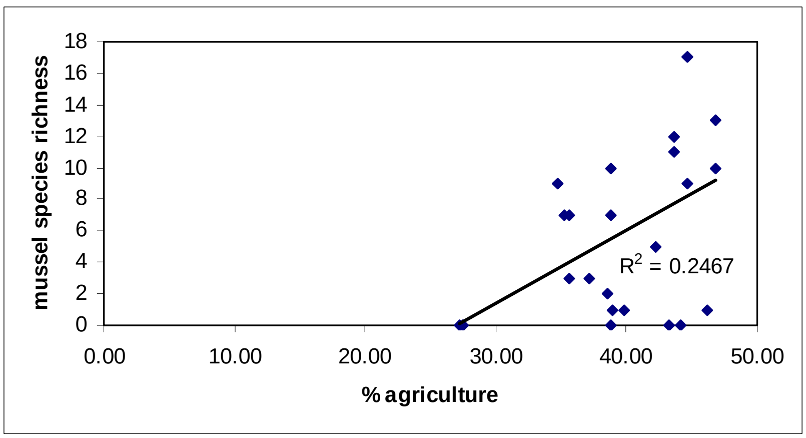

Figure 5c. Regression of mussel species richness by percent agricultural landcover in the watershed (p = 0.01).

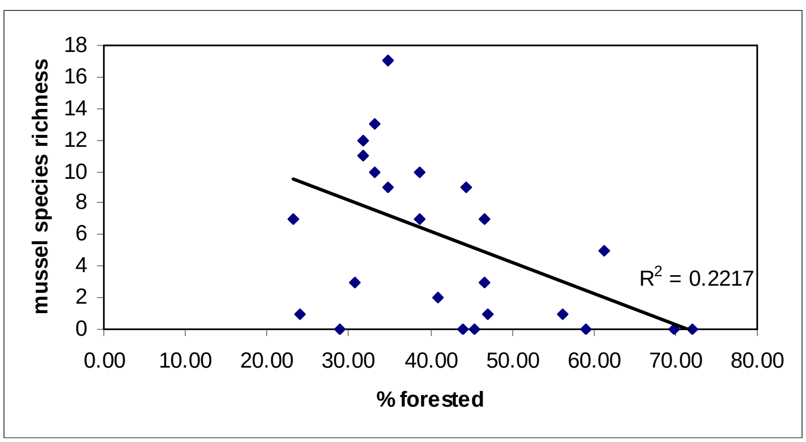

Figure 5d. Regression of mussel species richness by percent forested landcover in the reach catchment (p = 0.02).

DISCUSSION

The French Creek watershed currently contains 27 species of native freshwater mussels, more than any other watershed in Pennsylvania or anywhere in the northeastern United States. Of these 27 species, two are federally and state endangered: *Pleurobema clava* and *Epioblasma torulosa rangiana*; *Quadrula cylindrica* is a federal candidate and state endangered and *Epioblasma triquetra* is state endangered. The Pennsylvania Biological Survey lists fourteen other unionid species, found in French Creek, as proposed threatened or endangered in Pennsylvania. Aquatic mollusks, including bivalves and gastropods, are a critically imperiled group across the globe (Bogan 1993, Williams *et al.* 1993, Riccardi and Rasmussen 1999). This fact makes WPC's research extremely valuable and places particular importance on the conservation of places like French Creek. To further emphasize the value of this project, *P. clava* and *E. torulosa rangiana* have been lost from over 95% of their historic world ranges (U. S. Fish and Wildlife Service 1994), yet both maintain relatively healthy populations in the French Creek watershed (Crabtree and Smith in review, Mohler *et al*. 2006, Smith and Crabtree in review, Zanatta and Murphy 2007). This project benefits conservation efforts of these important aquatic species.

In our tributary surveys we detected 23 of the 29 unionid species historically recorded in the French Creek Watershed. *Cyclonaias tuberculata* (Rafinesque, 1820) (purple wartyback) and *Toxolasma parvus* (Barnes, 1823) (lilliput) were documented in Ortmann's early surveys of French Creek (1919); however neither species were documented in a basin wide survey in 1993 (Bier 1994), nor in later surveys on the main stem of French Creek (Environmental Science 2002a, 2002b, Smith and Crabtree 2005, in review). *Cyclonaias tuberculata* is now considered extirpated from Pennsylvania. *Simpsonaias ambigua* (Say, 1825) (salamander mussel), also collected by Ortmann (1919) in French Creek, has only been found recently as two dead shells; one collected in 1985 and another in 1995 (PNHP files accessed August 8, 2008). No further evidence of the salamander mussel has been found since the discovery of those two shells (Bier 1994, EnviroScience 2002a, 2002b, Mohler *et al*. 2006, Smith and Crabtree 2005, in review). Two additional species documented from recent surveys but not detected in our tributary studies include *Anodontoides ferussacianus* (l. Lea, 1834) (cylindrical papershell) and *Villosa iris* (l. Lea, 1829) (rainbow mussel), which are generally only found in low numbers in this watershed (Bier 1994, EnviroScience 2002a, 2002b, Mohler *et al*. 2006, Smith and Crabtree 2005, in review).

No live *Epioblasma torulosa rangiana* were found in our tributary surveys, and only one dead shell was detected in lower LeBoeuf Creek. It is not known if this shell indicates a population within the tributary, or if it is a remnant of the relatively large population in the main stem of the river. Other studies in the French Creek watershed show that *Pleurobema clava* is found in very low numbers, has a limited range and has little evidence of recent recruitment (Bier 1994, Smith and Crabtree in review). Live *P. clava* is only found in the upper portion of the watershed (Bier 1994, Smith and Crabtree 2005, in review), but results from Mohler *et al.* (2006) and this study indicate that Muddy Creek and LeBoeuf Creek may hold significant numbers of *P. clava*. *Pleurobema clava* has also been reported from Conneaut Outlet (PNHP files accessed August 8, 2008), although we did not detect it in our survey. The discovery of dead *P. clava* shells in Conneauttee Creek necessitates further investigation to determine if there are live individuals present and how the presence of *Dreissena polymorpha* may be affecting native mussels in this tributary.

Exotic species, such as *Dreissena polymorpha*, threaten the native biota in aquatic ecosystems where they have invaded (Biggins *et al.* 1995, Ricciardi *et al.* 1998, Strayer and Malcom 2007) and are a threat to the French Creek watershed (Western Pennsylvania Conservancy and French Creek Project 2002). Live zebra mussels were found at two sites on Conneauttee Creek, downstream of Edinboro Lake, the location of the first reported zebra mussels in the watershed (DEP 2000 news release). The relative large size and low numbers of zebra mussels detected at these sites indicates that the individuals we found were likely washed down from the lake, rather than actively reproducing (Parendes pers. comm). *Dreissena polymorpha* have been documented in the main stem of French Creek downstream of Conneauttee Creek (Smith and Crabtree in review). Close monitoring of zebra mussels in Conneauttee Creek and the main stem of French Creek is recommended to determine whether actively reproducing populations will establish in these streams. High numbers of the introduced *Corbicula fluminea* were present at the Conneaut Outlet site, which likely washed down from Conneaut Lake (Western Pennsylvania Conservancy and French Creek Project 2002). Ammonia toxicity and dissolved oxygen reductions caused *C. fluminea* die-offs has been shown to be harmful to native unionids (Cherry *et al*. 2005, Cooper *et al*. 2005). We did not document *C. fluminea* in other tributaries.

The threats to freshwater mussels posed by hydrologic and stream channel alterations are well documented (see review in Watters 2000), however the specific threats to aquatic life in the French Creek tributaries need further assessment. Only two U.S. Army Corps of Engineers dams exist in the watershed; one on the main stem French Creek near Union City, and the other on Woodcock Creek, but there are several small dams throughout the watershed (Western Pennsylvania Conservancy and French Creek Project 2002). Dams alter aquatic habitats, affecting water temperature, current velocity and sedimentation, as well as acting as barriers to fish hosts (Watters 2000). Many of the mussel species in the French Creek watershed prefer riffle/run habitat (Butler 2003 and 2006, Parmalee and Bogan 1998, Ortmann 1919, U. S. Fish and Wildlife Service 1994) making the availability of this flow regime important to continued population viability.

Results from Environmental Protection Agency (EPA) water quality studies placed several streams in the watershed on the section 303(d) Clean Water Act impaired stream list. Most of these streams are in the northern portion of the watershed and include portions of Conneauttee Creek LeBoeuf Creek, Muddy Creek and South Branch French Creek, tributaries to Conneauttee Creek: Torry Run and Little Conneauttee Creek and tributaries to French Creek: Boles Run, and Gravel Run; Also on the list are Bentley Run, below Union City Reservoir, and Darrows Creek. The major sources of impairment of these streams include high levels of siltation, organic enrichment, and nutrients which are often attributed to improper agricultural practices (Environmental Protection Agency 2008, Henley *et al*. 2000, Waters 1995). Siltation can cause reduced feeding and growth rates, clog gills, disrupt metabolic processes, limit burrowing activity and smother freshwater mussels; thereby reducing freshwater mussel assemblages (Brim Box and Mossa 1999, Vannote and Minshall 1982, Waters 1995). Water withdrawals for municipal, industrial and agricultural needs may also cause decreases in flow velocities and dissolved oxygen levels (Johnson *et al*. 2001). Ammonia, a common pollutant from pesticide and fertilizers (Augspurger *et al*. 2003, Newton 2003), has been shown to be lethal to freshwater mussels (Havlik and Marking 1987).

In general, results of the macroinvertebrate analyses indicate good to fair water quality at the survey sites on the French Creek tributaries. Agriculture and urban development are likely the major cause of impacted water quality for many sites, particularly those sites located near or just downstream of population centers (Environmental Protection Agency 2008). Indices of water quality varied not only between streams, but also between survey sites. Our results indicated that water quality was consistently good at sampling sites on Sugar Creek, Little Sugar Creek, and Woodcock Creek. These sites had relatively low FBI scores and high taxa richness. Indices showed water quality varied between sites on LeBoeuf Creek, Muddy Creek, West Branch, and South Branch French Creek. Sites on Conneauttee Creek showed fair water quality with a high percentage of Chironomidae and median FBI scores at all sites.

Our surveys indicate that the water quality at the Conneaut Outlet site may be the poorest of the sampled sites, with low numbers of macroinvertebrates, a high FBI score, and no EPT taxa. Most of Conneaut Outlet consists of pool habitat, although the area sampled was a shallow run a short distance downstream of Conneaut Lake. Generally, fewer macroinvertebrates are found in pool habitats and many macroinvertebrates require well oxygenated (*e.g* riffle-run) water, which is especially true of EPT taxa (Barbour *et al.* 1999). Additionally, the large number of *Corbicula fluminea* present at the site may compete for food with other aquatic life (Devick 1991).

Not only do freshwater mussels have to contend with invasive species, pollutants and stream alterations, but they also depend on other species to complete their life cycle. Fish play an essential role in freshwater mussel reproduction; most unionids have a parasitic larval stage (glochidia), where they depend on a vertebrate host, usually a fish. Fish hosts are often found to be the limiting factor in freshwater mussel distribution (Haag and Warren 1998), so we examined each of the mussel sites for fish species presence. Over 80 species of fish have been documented in the French Creek watershed (Western Pennsylvania Conservancy and French Creek Project 2002), and our surveys documented 49 of those species, including many that have been documented as fish hosts. Many of our survey sites had known host fish present for several imperiled mussels.

Our fish surveys had their limitations; more intensive fish survey effort, surveys in other habitats and in different seasons may reveal additional species. These surveys were a one-time snapshot of species presence focusing on relatively small riffle-run habitats. Fish are highly mobile and may utilize several habitat types to derive essential ecological requirements, including spawning, rearing (juveniles), and feeding. In addition, our surveys did not incorporate containment techniques such as block nets, thereby allowing the escape of highly mobile species. In addition to fish hosts, we encountered *Necturus maculosus* (Rafinesque, 1818) (mudpuppy) at a few study sites, a confirmed host for *Simpsonaias ambigua* (Roe 2003).

Absence of glochidial hosts would be a limiting factor of freshwater mussel populations. However, we found evidence of fish hosts associated with each mussel species within its tributary watershed with the exception of *Ligumia nasuta* and *Lampsilis ovata*. There are no known hosts for *L. nasuta* and *L. ovata*. Both species were found in moderate abundances in at least one tributary stream. Although no recruits were found for either species, glochidial host fish could in the watershed. Hosts are not known for all mussels species and many mussels may be able to use additional fish species that have not been documented. Glochidia-host relationships continue to be studied and new hosts continue to be discovered. *Villosa fabalis* is quite common in French Creek (Smith and Crabtree 2005, in review), but has only one known and fairly uncommon host in the watershed (Smith and Crabtree 2005) indicating perhaps there are other unidentified hosts present in this watershed. Freshwater mussels depend on the conservation and protection of their fish and amphibian hosts.

Although we documented the presence of small individuals of several species, for most mussel species in the tributaries, no evidence of recruitment was found. In the mainstem of French Creek, most mussel species are known to be successfully reproducing. Ninteen of 25 species had evidence of recruitment (Smith and Crabtree 2005). More intensive, quadrat based surveys similar to those conducted on the mainstem of French Creek would be necessary to determine whether significant recruitment is occurring in tributary streams (Hornbach and Deneka 1996, Smith and Crabtree in press, Smith *et al*. 2001, Vaughn *et al*. 1997). Evidence of both sexes and recent recruitment are important measures of mussel viability, and should be further examined at these sites. In addition to providing a better representation of sex ratios within each site, quadrat sampling (*e.g.* using methods described in Smith *et al.* 2001) would result in accurate population density estimates, which would be useful for monitoring population trends.

Our results find varying fish and mussel and macroinvertebrate populations between tributaries. LeBoeuf Creek stands out as a particularly important tributary, hosting live populations of *Pleurobema clava* and *Villosa fabalis*, with evidence of the federally endangered *Epioblasma torulosa rangiana*. Conneauttee Creek, Muddy Creek and Woodcock Creek also exhibit relatively high species diversity and harbor several mussel species of special concern. These tributary populations may be important contributors to main stem populations. Past studies on Sugar Creek and Little Sugar Creek resulted in few mussels (Bier 1994), and we found no live specimens on these streams. Sugar Creek and Little Sugar Creek had long sections of riffle-run habitat, high riparian assessment scores, high percent forested landcover, and low percent agriculture and developed landcover. An array of fish and macroinvertebrate species are present in these relatively large streams, but the water may be simply too cold to sustain mussel populations.

Land use and its potential impacts on water quality can play a major role in the distribution of mussels and their host fish. Macroinvertebrates can serve as an indicator of the impacts that land use has on water quality. In the French Creek watershed the major land use of concern for water quality is agriculture. Although development and associated pollution is cause for some concern, the percent development land cover in the watershed was generally low and regression analyses did not reveal significant relationships between biological resources and development.

Improper agricultural practices can lead to high levels of silt and nutrient inputs to which aquatic organisms are sensitive. In the tributaries agricultural land use ranged from 27 – 47 percent of the sub-watersheds (Table 10). The results of this study indicate high quality macroinvertebrate communities were found at sites with the highest percent forested landcover and the lowest percent agricultural landcover, both within in the riparian zone and in the larger watershed. Interestingly, mussel species richness and CPUE decreased with higher percent forested land cover in the watershed. Mussel species richness also increased with higher percent agricultural land use in the watershed. There are several possible explanations for this trend. Mussel species distribution in the watershed may be related to other factors that correlate with low percent forest and high percent agriculture such as relatively level land with lower gradient streams and soil rich in nutrients. For example, Sugar Creek and Little Sugar Creek are high quality watersheds, but no mussels were found there in our surveys, possibly due to high gradients or cold water. However, regression analyses with these sites removed still showed similar trends. Ideally, to examine the effects of agriculture on mussels one would compare modern and pre-agriculture mussel data for the same streams. However, there is no known appropriate information to which we could compare the current state of French Creek tributaries.

Although eutrophication and siltation from agriculture can be problematic for mussels the relationship is not necessarily a linear one. A certain increase in nutrients provides more food for the mussels. However, too large nutrient inputs can cause blooms of algae and other aquatic vegetation leading to problems with dissolved oxygen (Richter et al. 1997). Large amounts of silt can smother mussels (Brim Box and Mossa 1999). The analysis was not able to detect an effect of land use on fish species richness, possibly because of the mobile nature of fish or due to the presence/absence sampling technique.

Conservation Values and Management Recommendations

Protecting water quality throughout the watershed should be a priority for the continued health of the important aquatic communities that occur in French Creek. High percentages of agricultural land use in the watershed make implementing agricultural best management practices (BMPs) throughout the watershed a priority. The relationships between macroinvertebrate metrics and agricultural land use found in our study demonstrate the connection between agriculture and water quality. Riparian buffer zones are commonly recommended to remediate agricultural run-off and stream bank erosion. Although there is a relatively low level of development in the watershed some of these tributaries flow through the center of towns. Minimizing impervious surfaces, stormwater management, maintaining and creating riparian buffer zones, and avoiding stream channelization are all things that can help minimize the impact of development on water quality and should be considered in community planning.

Any watershed protection and restoration efforts should be coupled with biological assessments to monitor the effectiveness of the efforts. Additional surveys in tributaries containing relatively rich mussel communities and rare mussel species could provide more detailed information about mussel abundance, species distributions, and population health. In particular, future survey efforts should include LeBoeuf Creek, Conneauttee Creek, and West Branch French Creek because of the rare species in these streams and the threats in these watersheds.

French Creek tributary watersheds are compared for their relative water quality, watershed land cover (Table 9), macroinvertebrate communities, habitat assessments, and fish and mussel resources. Categories of ‘Good’, ‘Moderate’, or ‘Poor’ were assigned to each of the watershed attributes (Table 11, Table 12). If any rare fish species, any rare mussel species, or the invasive zebra mussel are known to occur in stream, they are designated as ‘present.’ Some considerations for protection, conservation, and restoration of each watershed are outlined here.

Table 11. Ranking of quality indicator metrics by tributary watershed.

	Watershed									
	Conneaut Outlet	Conneauttee Creek	Cussewago Creek	LeBoeuf Creek	Little Sugar Creek	Muddy Creek	South Branch	Sugar Creek	West Branch	Woodcock Creek
<u>Land cover</u>										
% Agriculture in watershed	Moderate	Poor	Moderate	Poor	Poor	Moderate	Moderate	Good	Moderate	Moderate
% Natural land cover in watershed	Moderate	Poor	Moderate	Moderate	Moderate	Moderate	Moderate	Good	Moderate	Moderate
% Development in watershed	Poor	Poor	Moderate	Moderate	Good	Good	Moderate	Good	Good	Good
<u>Habitat assessment</u>										
% Total score	Moderate	Moderate	Moderate	Moderate	Good	Moderate	Moderate	Moderate	Poor	Moderate
<u>Macroinvertebrate</u>										
Richness - genus taxa	Poor	Moderate to Good	------	Poor to Good	Moderate	Poor to good	Moderate	Moderate to Good	Poor to Moderate	Good
% EPT	Poor	Poor to Moderate	------	Poor to Good	Moderate	Poor to Moderate	Moderate to Good	Good	Poor to Good	Moderate to Good
FBI	Poor	Moderate	------	Poor to Moderate	Moderate to Good	Poor to Moderate	Moderate to Good	Moderate to Good	Poor to Moderate	Moderate to Good
<u>Biodiversity and rare species</u>										
Rare* (S1, S2, PE, PT) mussels	Present	Present	Present	Present		Present			Present	Present
Rare* (S1, S2, PE, PT) fish	Present		------	Present		Present	Present	Present	Present	Present
Mussel Abundance (CPUE)	Good	Low to Good	Low	Moderate to Good	Low	Good	Low to Moderate	Low	Moderate	Low to Moderate
Mussel Richness	Good	Low to Moderate	Low	Moderate to Good	Low	Good	Low to Moderate	Low	Moderate	Low to Moderate
Fish Richness	Moderate	Moderate to Good	------	Poor to Good	Good	Good	Good	Moderate	Moderate to Good	Moderate
<u>Other threats:</u>										
Zebra mussels		Present								

* S1 - Critically Imperiled, S2 - Imperiled, PE - Pennsylvania Endangered, PT - Pennsylvania Threatened

Table 12. Indicator metric scoring used for ranking.

	Ranking category			
	Good	Moderate	Poor	Other category
Land cover				
% Agriculture in watershed	<30%	30-49%	>40%	
% Natural land cover in watershed	>70%	50-69%	<50%	
% Development in watershed	<2.5%	2.5-4%	>4%	
Habitat Assessment				
% Total score	≥ 81.0%	68.0-81.0%	≤ 68.0%	
Water quality				
Richness - genus taxa	≤ 4.51	5.51-4.5	≥ 6.5	
% EPT	≥ 38.5%	13.8 - 38.4%	≤ 13.7%	
FBI	≥ 22.5	22.4-13.25	≤ 13.25	
Watershed Land Cover				
% Agriculture in watershed	<30%	30-49%	>40%	
% Natural land cover in watershed	>70%	50-69%	<50%	
% Development in watershed	<2.5%	2.5-4%	>4%	
Biodiversity and rare species				
Rare* (S1, S2, PE, or PT) mussel species				Present
Rare* (S1, S2, PE, or PT) fish				Present
Relative abundance of mussels (CPUE)	≥ 28.4	1.1 - 28.3	≤ 1.0	
Mussel Richness	≥ 11	3-10	≤ 2	
Fish Richness	≥ 18	13-17	≤12	
Zebra mussels				Present

Table 13. The percent of the total reach length in each tributary watershed of reaches having greater than 75% forest and wetland land cover, greater than 25% agriculture, or greater than 5% development in the riparian buffer.

Stream Name	% Length of reaches of total watershed reach length		
	>% 75 Riparian Forest/Wetland	> 25% Riparian Agriculture	> 5% Riparian Development
Conneaut Outlet	46.6	41.4	16.0
Conneauttee Creek	21.5	67.2	13.0
Cussewago Creek	68.2	20.6	0.1
LeBoeuf Creek	44.9	49.3	2.6
Little Sugar Creek	23.9	74.4	1.7
Muddy Creek	58.0	40.8	0.0
South Branch Creek	47.9	45.9	39.4
Sugar Creek	69.9	35.6	0.8
West Branch French Creek	87.5	12.5	0.0
Woodcock Creek	39.4	58.3	33.9

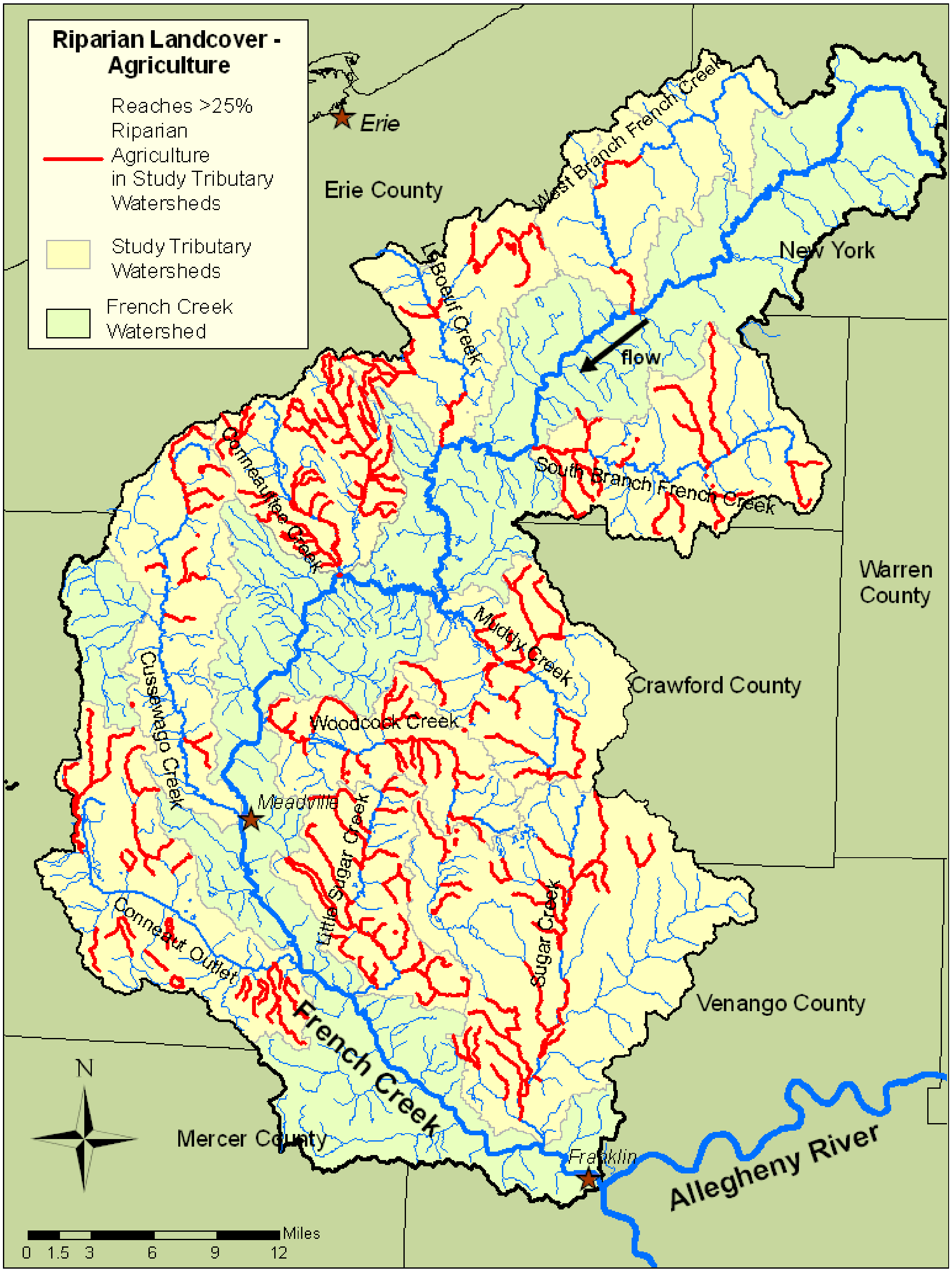

Figure 6. Stream reaches with the highest percentages of agriculture within the riparian buffer in study tributary watersheds.

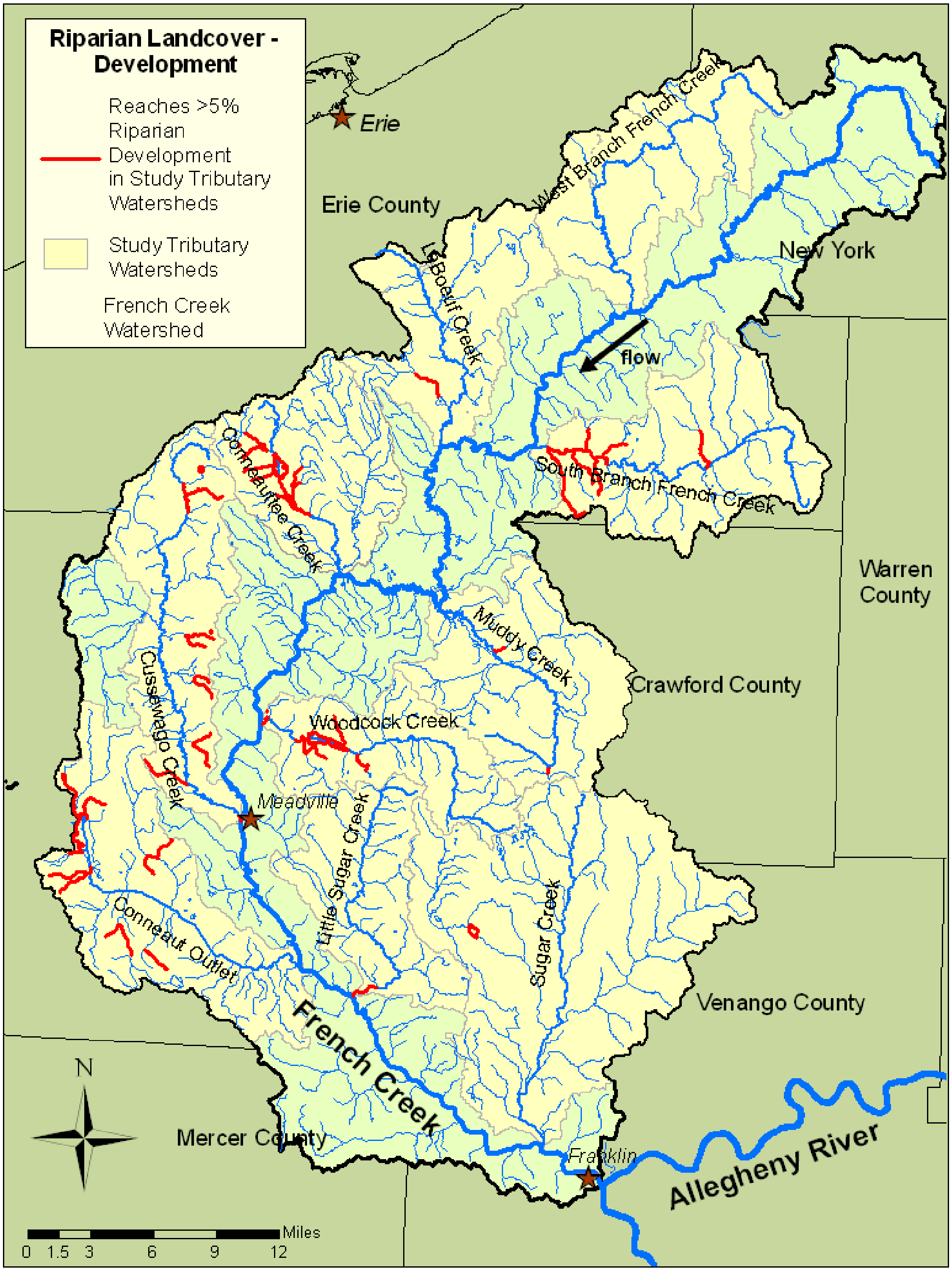

Figure 7. Stream reaches with the highest percentages of development within the riparian buffer in study tributary watersheds.

Conneauttee Creek

In this watershed, residential development and roads around Edinboro and the adjacent Edinboro Lake, as well as improperly managed agriculture, are a concern for water quality. The proportion of development and agriculture is relatively high in the Conneauttee Creek watershed compared to other tributaries of French Creek. DEP classified numerous streams as "impaired" in the Conneauttee Creek watershed from grazing-related agriculture resulting in siltation, organic enrichment and low dissolved oxygen (DEP 2008). Other streams are degraded by siltation and poor water quality due to urban runoff and storm sewers; a tributary to Edinboro Lake was classified as "impaired" because of pathogens and chlorine from a municipal point source. The creek has a large proportion of reaches where agriculture is more than 25% of land cover in the riparian zone (Table 13 and Figure 6).

The macroinvertebrate community data from this study further indicates stress on the watershed water quality. Macroinvertebrate indicators of water quality are depressed at some sites while other sites indicate moderately good water quality. An additional threat to the watershed is the presence of zebra mussels that originated from Edinboro Lake. Boater education on zebra mussels is important to minimize the spread of zebra mussels to other waterways in the area. Despite the water quality issues, there are rich fish and mussel resources that should be protected in the watershed. The presence of rare mussel species, high numbers of mussels, and rich fish communities make this watershed a priority for water quality improvement efforts. Focusing restoration efforts on reaches with poorly managed agriculture is important for health of the biological resources and the stream habitat.

Conneaut Outlet

Large numbers of mussels, including some rare species and a moderately rich fish community were recorded in this tributary. However, residential and commercial development around Conneaut Lake has led to water quality degradation. Conneaut Outlet drains Conneaut Lake, flows through the borough of Conneaut Lake and then meanders through Conneaut Marsh, eventually reaching French Creek. Some reaches surrounding Conneaut Lake have relatively large proportions of development in the riparian zone (Table 13 and Figure 7). The section of Conneaut Outlet immediately downstream of the lake and Barber Run, a tributary near the lake outlet, are both classified as "Impaired" by DEP for nutrients, urban/road runoff and siltation (DEP 2008).

Invasive species are of concern in this stream, where large amounts of Asian clams (*Corbicula fluminea*) and Eurasian watermilfoil (*Myriophyllum spicatum*) were recorded. These species were probably initially introduced to Conneaut Lake through heavy use by recreational boaters. Boater education about invasive species should be emphasized to reduce further spread.

Additionally, macroinvertebrate community data collected downstream of the lake outlet indicate poor water quality. Row crop and livestock agriculture in the watershed may also contribute to siltation or nutrient enrichment if not properly managed. The headwaters and tributaries the lower reaches of Conneaut Outlet have relatively high proportions of riparian agriculture (Table 13 and Figure 6). However, the wetlands along the stream may filter some pollutants. Therefore, maintaining Conneaut Marsh as a functioning wetland will help to improve water quality inputs from Conneaut Outlet to the mainstem of French Creek.

Cussewago Creek

This low-gradient stream flows through extensive wetlands before its confluence with French Creek. A dam located on Cussewago Creek creates a long section of pool habitat. Many of the rare mussel and fish species in the French Creek watershed prefer riffle-run habitats. A mussel survey at the lower part of the watershed did not reveal rare species occurrences or a very diverse mussel community. No fish or macroinvertebrate data was collected here due to stream depth. The watershed has moderate amounts of agriculture and development that could threaten water quality if not properly managed. However, no impaired streams are currently identified by DEP. The natural land cover along the stream including the wetlands may be protecting the watershed from impairment. Less than a quarter of stream reach length in the watershed has a high proportion of riparian agriculture, while less than 1% of stream reach length has a large proportion of riparian development (Table 13, Figures 6 and 7)

LeBoeuf Creek

A large proportion of agricultural land in this watershed is the source of some water quality problems. In the upper portions of the watershed, streams are classified as "impaired' by DEP because of flow variability, siltation, organic enrichment, and low dissolved oxygen (DEP 2008). Tributaries in the upper part of the watershed and the mainstem upstream of the confluence with French Creek have large proportions or riparian agriculture (Figures 6 and 7); almost of half of the reach length in the watershed has a high amount of riparian agriculture (Table 14). The lower section of LeBoeuf Creek is also degraded, but DEP cites unknown causes. The macroinvertebrate community metrics suggest poor water quality conditions at sampling stations LB01, LB02 and LB03, while further upstream sites support slightly improved communities. Riparian assessments indicate moderately good quality habitat in the stream. Similar to other low gradient tributaries, wetlands along LeBoeuf Creek are likely to retain some siltation and excess nutrients contributed from improperly managed farming operations. Despite some water quality degradation, a diverse fish community was found at some locations on the creek. Additionally, the creek supports a high relative abundance of mussels including rare mussel species. Mussels are tolerant of modest siltation and nutrient enrichment. Yet, poor water quality in some parts of the watershed and degraded habitats are a serious threat to the fish and mussel resources in LeBoeuf Creek. Efforts in this watershed should focus on reducing siltation and organic enrichment through implementation of agricultural best management practices.

Little Sugar Creek

Potential threats to water quality come from the large proportion of agriculture in the watershed. Most of the agriculture is pasture, with relatively little row crops. No streams in the watershed are classified "impaired" by DEP even though most of the stream reaches in the watershed have a large amount of riparian agriculture, particularly in the tributaries to Little Sugar Creek, water quality remains in relatively good condition (Table 13, Figure 6).

The creek contains moderate to high quality macroinvertebrate communities which infer that water quality is relatively good despite watershed agriculture. No mussels were found at this project survey sites on Little Sugar Creek, but they are known to occur at other locations in the watershed (Bier 1994). Some sites had diverse fish communities in Little Sugar Creek. Relatively high gradient, coldwater habitat may exclude mussels from some parts of the stream, but may be preferred by some fish species. The stream supports a number of species in the fish community and its habitat was determined to be moderately good.

Muddy Creek

The watershed has moderate amounts of agriculture and relatively little development. However, the upper reaches of Muddy Creek are classified as 'impaired' by DEP for road runoff and siltation (DEP 2008). Much of the mainstem of Muddy Creek slowly flows through a wetland at the Erie National Wildlife Refuge and State Game Land #85. Macroinvertebrate communities were variable, revealing that conditions are diverse at the sampling locations. Community metrics were rated from good to poor at the three sampling sites. However, communities in slow-flowing streams have different organisms than faster flowing streams; community metrics from low-gradient streams may be incorrectly interpreted as indicating low quality conditions when compared to rapidly flowing streams. At our survey site in the upper portion of the stream moderately high numbers of mussels and mussel species were found, but no rare species. However, the stream was extensively surveyed by U. S. Fish and Wildlife Service (Mohler et al. 2006) and several rare species of mussels were documented further downstream from our sampling site. Some protection of the stream is ensured by the public landownership. However, it is concerning that macroinvertebrate communities suggest poor water quality in some locations. Additional investigation of the water quality issues, particularly in the upper watershed, should occur.

South Branch French Creek

Threats to the water quality in the South Branch French Creek watershed originate from intermediate amounts of agriculture and development, particularly near Union City. Some tributaries to South Branch French Creek are listed as 'impaired' by DEP because of nutrient enrichment, siltation, organic enrichment, low dissolved oxygen, and road runoff (DEP 2008). Many of the stream reaches have a high proportion of riparian land cover in development or agriculture (Table 13, Figure 6 and 7). Despite some water quality issues in the tributaries, macroinvertebrate communities suggest that the mainstem had moderate to high quality conditions. While there were only a few mussels found, high numbers of fish species, including rare species inhabit the watershed. Riparian assessments indicate that intermediate quality habitats occur in South Branch French Creek. Improvements to in-stream habitats and riparian buffers in stressed sections of the watershed are suggested.

Sugar Creek

The least disturbed tributary to French Creek, Sugar Creek has the highest amount of natural land cover among the tributaries in this study. There are relatively low amounts of agriculture and development in the land cover for the watershed. A moderate proportion of stream length was found to have a relatively high level of agriculture land cover in the riparian zone (Table 13 and Figure 6). There is the potential for pollution to the stream from poorly managed agriculture, but no impaired streams have been identified by DEP in the watershed. The watershed supports high quality and intermediate quality macroinvertebrate communities. Moderately diverse fish communities occur in the watershed, but no mussels were found in this study of Sugar Creek. However, Sugar Creek had the highest gradient of all the tributaries in this study, and high gradient streams are not believed to be supportive of diverse mussel populations. Protection of this high quality watershed will ensure that the aquatic resources here and in the downstream waters of French Creek will be maintained in the long term.

West Branch French Creek

Poor water quality from development or agricultural sources is believed to be an intermediate level threat because of moderate levels of those landcover types in the watershed. Overall, relatively little disturbance of natural land cover occurs in the riparian zones. A small proportion of stream reach length has high proportion of riparian agriculture. No watershed reaches had greater than 5% development in the riparian zone (Table 13 and Figure 6). One tributary to the West Branch, Alder Brook, is 'impaired' for unknown causes (DEP 2008). Macroinvertebrate communities indicated that a range of conditions occurs among the three sampling sites. Some community metrics indicated rather high water quality while others suggested that water quality was poor. The reason for macroinvertebrate community degradation may be related to habitat. The riparian assessments were worst of the tributaries surveyed. Scores for canopy cover, bank stability, embeddedness, and bank vegetation were low. Nevertheless, a moderately high number of mussels and mussel species, including rare mussel species are present. The number of fish found at the sampling sites was moderate to high. Conservation efforts should focus on riparian buffer improvements such as stream bank fencing and riparian zone plantings, which will help to maintain healthy fish and mussel populations.

Woodcock Creek

No notable population centers occur in Woodcock Creek watershed, but moderate levels of watershed agriculture are found. Some disturbances in the watershed occur along the stream corridor, indicating that there is some potential for polluted run-off from improperly managed agriculture or development. A relatively large length of stream in the watershed has a high proportion of riparian agriculture and development (Table 13; Figures 6 and 7). Roads along the creek contribute to proportion of land cover classified as developed, despite the watershed having little development of other types. Riparian assessment scores suggest intermediate habitat conditions. Additionally, a dam impounds Woodcock Creek upstream of Saegertown, potentially disrupting the connection between upstream and downstream populations of fish and mussels. High quality macroinvertebrate communities indicate relatively good water quality. Conservation priorities for the watershed include protecting the rare fish and mussel species, as well as minimizing pollution run-off. Mitigating the impact of the dam on water quality, habitat, and fish and mussel populations should be considered.

Preserving French Creek aquatic biodiversity is among the region's topmost conservation priorities. The aquatic communities in the French Creek watershed exemplify some of the last remaining high quality natural communities found anywhere in the Ohio River basin. There are a lot of unknowns, such as population genetics and viability, which need further study to fully comprehend these aquatic communities. Threats these organisms face from improper land use, habitat degradation, pollution and invasive species need to be addressed in order to maintain or improve upon habitats and conservation efforts. With continued research, combined with public education we can hope to expand conservation efforts for these important systems.

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ADDITIONAL RESOURCES

County Conservation Districts
Directory
www.pacd.org/districts/directory.htm

MD Native Plant Society
Control of Invasive Non-Native Plants: A Guide for Gardeners and Homeowners in the Mid-Atlantic Region
www.mdflora.org/publications/invasives.htm

PA Department of Conservation and Natural Resources
Service Foresters
www.dcnr.state.pa.us/FORESTRY/serviceforesters_select.aspx

Invasive Plants
www.dcnr.state.pa.us/forestry/wildplant/invasive.aspx

PA Department of Agriculture
PA Invasive Species Council
www.invasivespeciescouncil.com

PA Department Environmental Protection
Agriculture and Runoff Areas
www.elibrary.dep.state.pa.us/dsweb/Get/Document-73556/3910-FS-DEP2597.pdf

Conservation Reserve Enhancement Program (CREP)
www.elibrary.dep.state.pa.us/dsweb/Get/Document-72107/3940-FS-DEP3156.pdf

Nutrient Management Program
www.depweb.state.pa.us/watershedmgmt/cwp/view.asp?a=1442&q=513908&watershedmgmtNav=|

Home Nitrogen Pollution Tips
www.depweb.state.pa.us/watershedmgmt/lib/watershedmgmt/nonpoint_source/factsheets/know_your_nitrogen.pdf

Common Invasive Plants in Riparian Areas
www.dep.state.pa.us/dep/deputate/watermgt/wc/subjects/streamreleaf/Docs/Invasive%20Plants.pdf

Streambank Fencing Program
www.elibrary.dep.state.pa.us/dsweb/Get/Document-73642/3910-FS-DEP1971.pdf

Stream Re-Leaf
www.elibrary.dep.state.pa.us/dsweb/Get/Document-65485/3940-FS-DEP2206.pdf

Sinkholes
www.depweb.state.pa.us/sinkholes/site/default.asp?watershedmgmtNav=|

Stormwater Best Management Practices
www.depweb.state.pa.us/watershedmgmt/cwp/view.asp?a=1437&q=529063

PA Game Commission
Private Landowner Assistance Program
www.pgc.state.pa.us/pgc/cwp/view.asp?a=513&q=168220

PA Fish and Boat Commission
PA fish, reptiles and amphibians
PA aquatic species of special concern
Aquatic Invasive Species
www.fish.state.pa.us

Landowner Incentive Program (LIP)
www.fish.state.pa.us/promo/grants/lip/00lip.htm>

PA Land Trust Association
List of conservancies
http://conserveland.org

PA Organization for Watersheds and Rivers
http://pawatersheds.org/#

PA Sea Grant
Aquatic invasive species publications
http://seagrant.psu.edu/publications/ais.htm

Penn State Agricultural Extension
http://panutrientmgmt.cas.psu.edu/

Penn State Center for Dirt and Gravel Road Studies
Road improvement
www.dirtandgravel.psu.edu/education_training/education_training.html

US Department of Agriculture
Conservation Reserve Enhancement Program (CREP)
www.nrcs.usda.gov/programs/CRP/>

Environmental Quality Incentives Program (EQUIP)
www.nrcs.usda.gov/PROGRAMS/EQIP/>

Invasive Species Resources for Pennsylvania
www.invasivespeciesinfo.gov/unitedstates/pa.shtml

Natural Resources Conservation Service
www.nrcs.usda.gov/programs/

Stream Corridor Restoration Guide
www.nrcs.usda.gov/technical/stream_restoration/newtofc.htm

Wildlife Habitat Incentive Program (WHIP)
ww.nrcs.usda.gov/Programs/whip/>

US Environmental Protection Agency
Agricultural Best Management Practices
www.epa.gov/watertrain/agmodule/

US Geological Survey
Nonindigenous Aquatic Species
nas.er.usgs.gov/

Western Pennsylvania Conservancy
www.waterlandlife.org/