AN ASSESSMENT OF SELECTED RARE MUSSEL POPULATIONS IN WESTERN NORTH CAROLINA FOLLOWING EXTRAORDINARY FLOODS OF SEPTEMBER 2004

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SUMMARY

High flows, particularly catastrophic floods, are known to affect distribution and abundance of mussels, especially in higher gradient streams. In September 2004, the remnants of hurricanes Frances, Ivan, and Jeanne struck western North Carolina. A number of rare mussel species, including the federal and state endangered Appalachian elktoe (*Alasmidonta raveneliana*) and the federal species of concern and state endangered Brook floater (*A. varicosa*), occur in the French Broad and upper Catawba river basins where flooding was severe. In 2005, 42 sites were surveyed in these river basins to assess the post-flood distribution and abundance of mussel populations. Twenty three of these sites were surveyed recently prior to the 2004 floods and results (catch per unit effort=CPUE) are compared. No mussel species was completely eliminated from any stream, but we failed to detect Appalachian elktoe in the Cane and South Toe rivers (French Broad basin), and Brook floater in the Johns River (Catawba basin), at sites that represented the upstream limit of their distribution prior to flooding. Greatest negative impact was observed on the Linville River (total CPUE decreased by 31 mussels/p-hr, Brook floater decreased 32 mussels/p-hr or 89%). The greatest change in abundance of Appalachian elktoe occurred in the South Toe River (total CPUE decreased by 14 mussels/p-hr or 50%). Overall, sites in the upper French Broad (Mills, South Fork Mills, and Little rivers) and Pigeon sub-basins showed the least change in mussel densities. Impacts appeared to be greatest in stream reaches with high gradient and narrow or lacking floodplains. Results suggest that management actions may be required for Linville River and other small, isolated populations. Conservation and restoration of habitat attributes that facilitate mussel survival during floods is important for the long-term conservation of these populations.

I. Introduction

Freshwater mussels have limited mobility and could be described as part of the bedload in lotic systems. Mussels can be dislodged, redistributed, and/or buried during severe hydraulic disturbance (Vannote and Minshall 1982, Hastie et al 2001). High flows, particularly catastrophic floods, are known to affect distribution and abundance of mussels, especially in higher gradient streams (DiMaio and Corkum 1995, Hastie et al 2001, Howard and Cuffy 2003).

In September 2004, the remnants of hurricanes Frances, Ivan, and Jeanne struck western North Carolina. Heavy rainfall resulted in severe flooding of streams on each side of the Eastern Continental Divide in the Blue Ridge and Piedmont ecoregions (per Griffith et al. 2002). The French Broad (Interior Basin) and Catawba River (Atlantic Slope) watersheds were among the hardest hit. Floods of 50-500 year recurrence caused extensive damage to streams and property. Substantial bedload mobilization is expected during such events and evidence of such was observed after flood waters subsided.

Within the French Broad River basin, portions of the Pigeon, Little, Mills, Nolichucky, Toe, North Toe, South Toe, and Cane rivers support the Appalachian elktoe (*Alasmidonta raveneliana*), a federal endangered mussel species. Other state listed species (Slippershell, *A. viridis*; Wavy-rayed lampmussel, *Lampsilis fasciola*; Creeper, *Strophitus undulatus*, and Long-solid, *Fusconaia subrotunda*) also occur in some of these rivers. Within the Catawba River basin, the Johns River, Upper Creek (Warrior Fork system), and Linville River support the most diverse mussel fauna remaining in the upper Catawba River Basin, including Brook floater (*A. varicosa*), a state endangered and federal species of concern, and two other state listed species (Notched rainbow, *Villosa constricta*, and Eastern creekshell, *V. delumbis*). These populations are relatively small, sparse, and occur at higher elevations and in higher gradient streams than any others in the southeastern United States. Most populations in both the French Broad and Catawba basins are constrained by the natural upstream limits of mussel distributions in Blue Ridge streams (believed to be related to water temperature, hardness, stream gradient, and host fish availability) and unfavorable habitat conditions found a relatively short distance downstream (primarily due to impoundments or water and/or habitat quality).

In many of these streams, surveys were conducted relatively recently prior to the 2004 floods (1997-2004). Flooding may have significantly affected the distribution and abundance of mussels, warranting a reassessment of these populations. Evaluating flood impacts on these populations is necessary to accurately determine status of rare species, make management decisions, and assess potential recovery efforts. The objectives of this study were to: 1) assess distribution and abundance of mussels following extraordinary flooding, and 2) compare pre- and post-flood survey data to assess potential impacts that flooding may have had on these mussel populations. Habitat conditions and other relevant observations are also reported.

II. Flood Magnitude

The remnants of Hurricane Frances passed through western North Carolina during September 6-9, Ivan during September 16-19, and Jeanne during September 26-29, 2004. Rainfall exceeded 16 inches (40cm) in some places during the Frances storm (see Appendix 1, Figures A1-1-3). While Frances generally produced the heaviest rainfall, streamflow was nearly as high after Ivan (even higher in Pigeon River), primarily due to ground saturation following Frances that resulted in more relative runoff (see Appendix 1, Figures A1-4-10). The peak flow recorded (or estimated) at USGS gages following either Ivan or Frances was the highest on record for the Pigeon, Johns, and Linville rivers (Table 1).

Table 1. Streamflow information from USGS gages nearest to sample sites. All flow data in cubic feet per second. Fifty year reference flows are adjusted for Nolichucky (30,000 & 50,000) and Mills (3000 & 5000). All data obtained from USGS National Water Information System (http://nwis.waterdata.usgs.gov/nc/nwis/nwis).

Gage	2004 max. (month/day)	Recorded historical max. (year)	Mean September streamflow (over period of record)	Times flow exceeded in past 50 years	
				10,000 (or other)	20,000 (or other)
South Toe R. @ Celo	28,000 (9/8)	32,800 (1977)	127	9	1
Nolichucky R. @ Embreeville, TN	64,100 (9/8)	110,000 (1978)	816	13 (30k)	3 (50k)
French Broad R. @ Blantyre	20,600 (9/8)	30,000 (1965)	722	12	2
Mills R. @ Mills R.	7,270 (9/8)	13,400 (1940)	123	16 (3k)	4(5k)
Pigeon R. @ Canton	51,000 (9/17)	51,000 (2004)	237	5	0
Johns R. @ Arney's Store	39,000 (9/8)	39,000 (2004)*	321*	5*	2*
Linville R. @ Nebo	42,400 (9/8)	42,400 (2004)	128	6	0

*Johns River data were available only to 1986.

III. Methods

A. Study Area

Survey sites were chosen based on locations with recent pre-flood survey data where rare mussel species were present. Where possible, sites were chosen at or near the known limits of upstream mussel distribution and at representative sites within the known range of rare species. In 2003 and 2004, extensive surveys were performed to assess Appalachian elktoe status in the French Broad River basin. In 2005, sixteen of those sites were revisited for this study (see Figure 1). Sites were surveyed in the Nolichucky sub-basin (Cane, Toe, North Toe, and South Toe rivers), the upper French Broad sub-basin (Little and Mills rivers), and the Pigeon River. Seventeen additional sites were also surveyed and reported here that did not have sufficient pre-flood data available for comparison. Data from these additional sites contributed to the overall assessment of post-flood mussel distribution and established a baseline for future assessments. In the Catawba River basin, five sites were surveyed in the Johns River and Warrior Fork systems (Johns River, Wilson Creek, and Upper Creek) that were last surveyed in 2003 or 2004 (see Figure 2). Two sites on the Linville River were surveyed that were last surveyed in 1997 and 1998. One additional site each on Johns River and Upper Creek were surveyed for which no pre-flood data were available.

The French Broad River basin in North Carolina is entirely within the Blue Ridge ecoregion (Griffith et al 2002). Within the Nolichucky subbasin, the Cane and South Toe river watersheds include the highest elevations in the eastern United States [western slopes of the Black Mountains, max. elevation: Mt. Mitchell, 6,684ft (2,038m)]. While stream gradient was not measured in the field at or across survey sites, general observations and estimates of reach-scale gradient obtained from topographic maps indicate that stream gradient is generally steepest in the Nolichucky sub-basin.

Figure 1. Sites surveyed in French Broad basin
Changes in total catch per unit effort (CPUE) relative to pre-flood data are indicated.

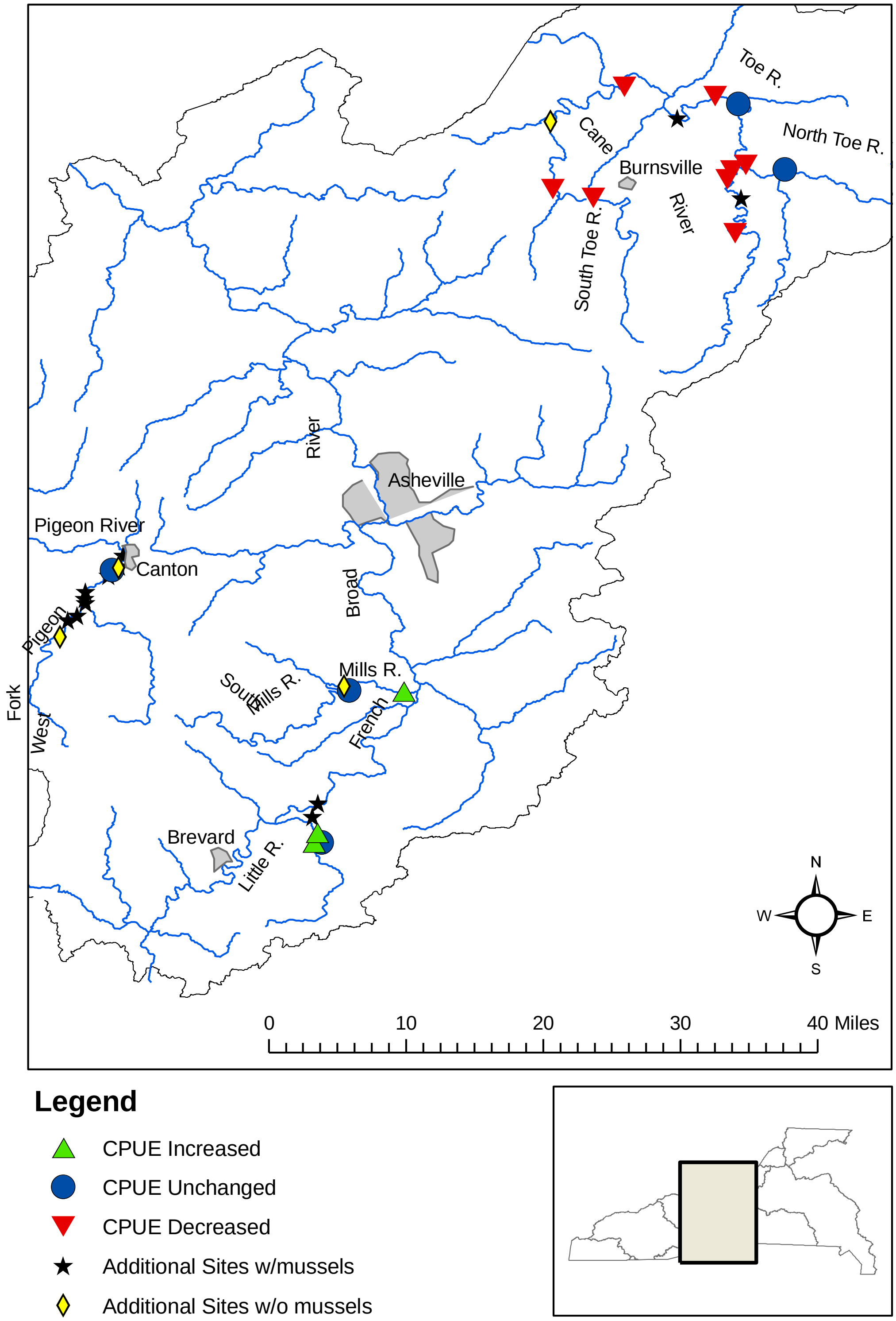
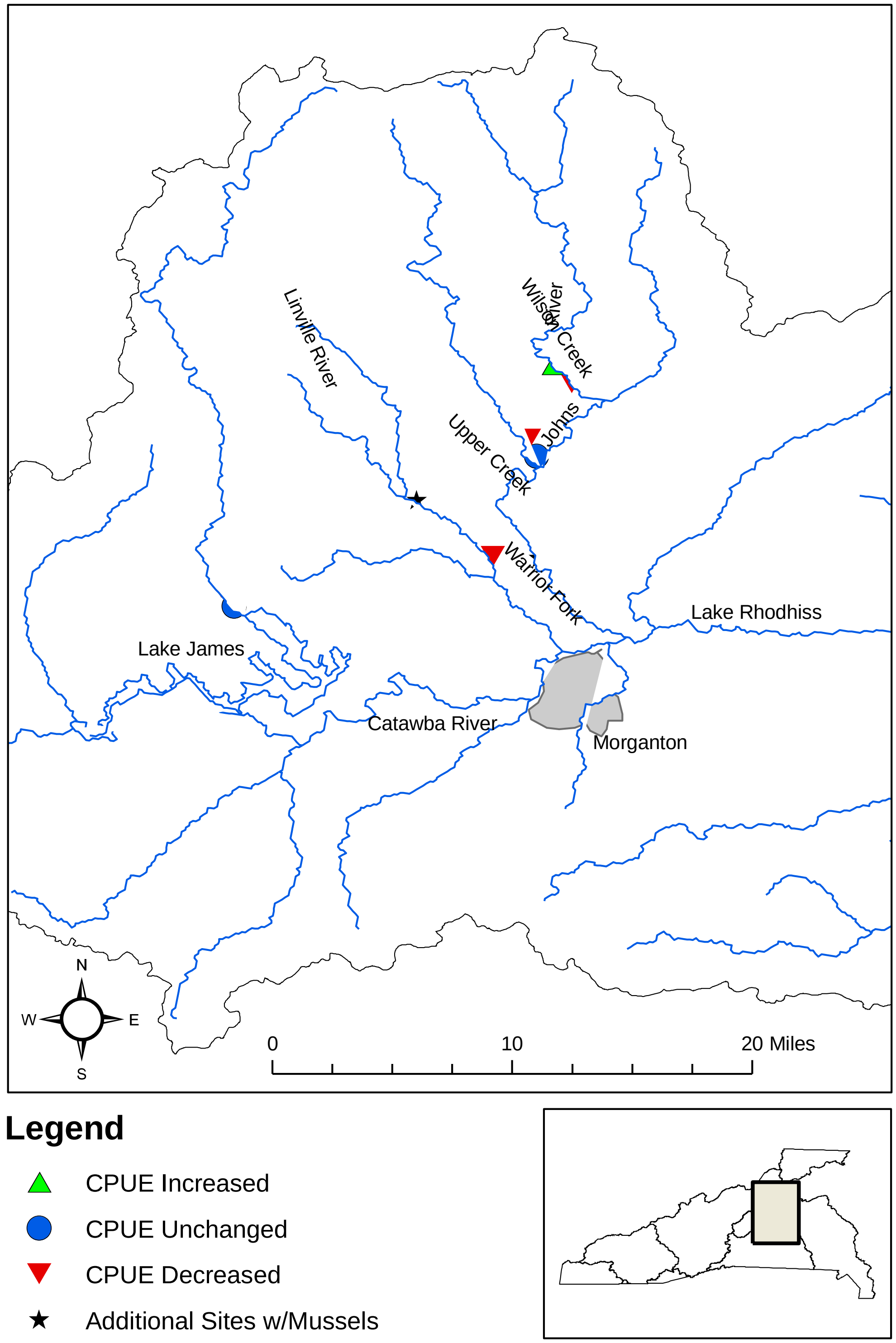


Figure 2. Sites surveyed in upper Catawba River basin.
Changes in total catch per unit effort (CPUE) relative to pre-flood data are indicated.



Throughout the Nolichucky sub-basin, flood plains are either narrow or generally lacking. Other areas surveyed in the French Broad basin are located in the relatively broad valleys of the upper French Broad and Pigeon rivers and generally are both lower gradient and have more extensive flood plains. Sites surveyed in the Catawba River basin are along the boundary of the Blue Ridge and Piedmont ecoregions. The Linville River and Wilson Creek sites are in an abrupt transition zone from high to more moderate stream gradient near the downstream end of steep, narrow gorges. Sites on Johns River are in the same general area with similar situation, although the gradient transition is spread over a longer reach.

The river reaches within the study area are unregulated by flood control dams. Run of river dams are located on the Little River and West Fork Pigeon River, relatively short distances upstream from the uppermost survey sites. The affects of these on the magnitude and duration of floods on these rivers was apparently negligible.

B. Field Surveys

Surveys were conducted using timed semi-quantitative searches while snorkeling, with limited use of bathyscopes (“view buckets”). Mussels were identified to species or species complex, counted, total length was measured (nearest millimeter), checked for gravidity, and returned to the substrate. Many of the Atlantic Slope *Elliptio* species are not well understood taxonomically and were identified only to putative species complexes. Survey effort (survey duration x number of personnel= total effort in person-hours) and latitude and longitude (using hand-held GPS unit) were recorded for each site. Effort ranged from 4 to 6 person-hours (6 at most sites) at each site and linear distance surveyed ranged from approximately 50-200m. Observations of habitat conditions, especially any visible changes since previous surveys, were also recorded in field notes. Additional sites on the Pigeon and West Fork Pigeon rivers (see Appendix 2, Tables A2-9 & 10) were surveyed as part of Natural Resources Conservation Service's Emergency Watershed Protection (EWP) repair projects. Data from those sites were reported by Tom Dickinson and Tim Savidge (The Catena Group, Hillsborough, NC) and collected using similar techniques.

C. Data Reporting and Analysis

Survey data were converted to catch per unit effort (CPUE) by dividing the number of individual mussels collected per species by the total effort expended at that site. These were compared arithmetically to pre-flood data (post flood CPUE subtracted from pre-flood CPUE). Differences that were less than two mussels per person hour were arbitrarily deemed unchanged. Difficulties in interpreting CPUE mussel data are discussed in Section V. Habitat observations from field notes and site photographs were reviewed and major impressions were summarized.

IV. Results

A. Mussel Distribution and Abundance

The apparent impacts of the 2004 floods on mussel populations varied among and within streams. Many sites showed a decrease in total CPUE as compared to pre-flood survey data, some increased or remained unchanged, but no species was completely eliminated from any of the streams surveyed. Overall, the Linville River showed the greatest change in CPUE (negative) for a single species (Brook floater, -30.5 at Site 1 and -32.2 total within stream), all species at a site (Site 1, -29.6), and total across all sites surveyed within a stream (-31) (Appendix 2, Table A2-1). Only two sites were surveyed on Linville River and CPUE at Site 2 for all species combined remained virtually unchanged.

Among the seven sites surveyed in the Catawba basin with pre-flood data, total CPUE decreased at four sites, remained more or less unchanged at two sites, and increased at the upper site on Johns River (see Figure 1; Appendix 2, Tables A2-1 & 2). Brook floater CPUE was relatively unchanged at four sites and decreased at three sites. The increase in total CPUE at the upper Johns River site was due to increased catch of Eastern Elliptio, while we failed to detect Brook floater there. This site was the most upstream known occurrence of Brook floater in the Johns River, where one specimen was collected in 2003.

In the French Broad basin, CPUE decreased at eight sites, was relatively unchanged at five sites, and increased at three sites (see Figure 2; Appendix 2, Tables A2-3-7). All sites that showed a decrease in total CPUE were in the Nolichucky River sub-basin. Greatest change in CPUE within the basin was on the South Toe River where Appalachian elktoe is the only mussel species known to occur (Appendix 2, Table A2-5). Total CPUE within the South Toe declined by 14.2 mussels per person-hour, while CPUE decreased by 11.8 mussels per person-hour at Site 2. We failed to detect mussels at one site on the Toe River (Site 2) and the upper sites on both the South Toe and Cane rivers (Site 1) where sparse populations were found in 2003. Overall CPUE from the three sites with pre-flood data on the Little River increased 11.36 mussels per person-hour (Appendix 2, Table A2-7).

B. Habitat and Other Observations

Not surprisingly, greatest observed habitat changes were generally at sites where decrease in mussel CPUE was also greatest. Both sites on the Linville River and Site 2 on the South Toe River showed signs of massive instream disturbance. Channel morphology had changed considerably from pre-flood conditions. Bedload was redistributed such that flow patterns and location of riffles, runs, and pools were substantially rearranged. At Site 2 on South Toe River, what had been a run-riffle complex with varied depths, velocities, and relatively stable cobble-gravel substrate had changed to near uniform depth (shallower than before) with unstable substrata dominated by fine gravel and sand. The Linville River sites had extensive scour and bank erosion, as well as bedload redistribution and altered flow patterns. In the lower half of Site 1 on Linville River, the majority of flow followed a new channel cut into the left descending bank. Most of what had been the main channel prior to the floods had aggraded with newly deposited bedload (primarily cobble) and was predominately a large, shallow pool-run. Near the upper end of the site, bedrock outcroppings and very large boulders appeared to have tightly constrained flood waters, resulting in a deep pool [~15ft (4.5m)] with substrate scoured to bedrock.

While evidence of flooding was apparent to some degree at all sites (debris in bent riparian vegetation, bank erosion, deposition of fines on the floodplain, etc.) in-stream changes generally appeared to vary with gradient and extent of flood plain at sites and within reaches. Sites and groups of sites within reaches where gradient was relatively lower and flood plains were more extensive showed fewer signs of in-stream habitat changes versus those where gradient was higher and flood plains were narrow or lacking. Consequently, these were also sites where mussel CPUE did not decrease appreciably (or even increased). This was most evident among sites surveyed in the French Broad River basin. In general, the study area within the Nolichucky River subbasin (Cane, South Toe, North Toe, and Toe rivers) experienced greater apparent habitat disturbance than those in the Little and Mills rivers in the upper French Broad sub-basin. Even in the Pigeon River, where the post-Ivan flood was estimated to be a 500-year recurrence event, in-stream habitat disturbance within the reach occupied by Appalachian elktoe appeared less severe than in the Nolichucky study area, in general.

Within individual sites, areas that were apparently sheltered from the most severe hydraulic disturbances and where substrate appeared to have remained relatively stable generally yielded the majority of mussels collected. These included the margins of streams along stable banks and downstream from boulders, bedrock shelves or other structure that deflected high flows. Best examples were at the upper North Toe River site (Site 1) and the lower Linville River site (Site 2). The only Appalachian elktoe found at the upper North Toe site was in a patch of cobble-gravel along the inside of a bend in the river. This area was apparently protected from severe shear stresses and bedload mobilization as evidenced by the presence of the only remaining river weed (*Podostemum ceratophyllum*) on rock surfaces within the site. At the lower Linville River site, all but one of the total mussels collected came from a small area downstream from a stable gravel/sand bar with woody vegetation still intact. The substrate within this area was stable mixed cobble, gravel, sand, and a little silt, with periphyton on exposed rock surfaces. Substrata throughout the rest of the site were generally unconsolidated and appeared to be recently deposited, swept clean of sand, silt, and periphyton, or scoured to bedrock.

Evidence suggesting mussel mortality caused by flooding was seen at many sites. Fresh dead shells were found in substrata deposited on floodplains and in sheltered areas in streams where fines accumulated. In particular, dead shells were much more common at sites in the Nolichucky sub-basin than have been encountered during pre-flood surveys (2003-04 and prior).

V. Discussion

A. Data Comparability and Utility of Results

Ideally, quantitative data would be available for every mussel population. Unfortunately, realities of time, resources, and opportunity force compromises. Most importantly, robust quantitative data are practically impossible to collect for rare mussel populations, primarily due to their low density and patchy distribution (Green and Young 1993, Hornbach and Deneka 1996, Vaughan et al. 1997). It was fortuitous that we had semi-quantitative data available from the recent assessment of Appalachian elktoe populations in the French Broad basin and recent surveys in the Catawba basin by which we could make even these weak comparisons.

Semi-quantitative CPUE data from timed, random search surveys are difficult to compare. Variance is nearly impossible to determine with confidence and statistical tests are not applicable. The relationship between CPUE and actual mussel density may be very “noisy” with potential for high variance and low power to detect temporal changes (Strayer et al. 1997, Strayer and Smith 2003).

Temporal differences in CPUE may be due to actual changes in mussel densities, but can also be influenced by behavior of the mussels, skill of the surveyors, or site conditions that result in unequal likelihood of detection between surveys. Mussels burrow into the substrate and may be partially exposed or completely buried. Such vertical migration can occur over various time scales (e.g. daily, seasonally, or relative to the age of the mussel) and is known to affect catch rates (Villella et al. 2004). Visual searches conducted without excavating substrate can only estimate the abundance of mussels visible at the substrate surface. The ability of survey personnel to see partially buried mussels and their knowledge of habitat associations (i.e. knowing what to look for and where) can profoundly influence survey results. Turbidity, depth, aquatic vegetation, water temperature, and weather can all influence the ability of surveyors with equal skills to collect mussels at equal rates during timed visual searches.

We sought to minimize the potential sources of bias, and within broad limits, we believe we were successful enough to allow some meaningful, but cautious, use of CPUE comparisons. The survey crews who conducted these surveys were at least as effective (in some cases, probably a little more effective) at finding mussels as personnel involved in previous surveys. Thus, we believe that at most sites, surveyor bias was minimal or tended toward collecting more of the detectable mussels available at a site in 2005. Minimizing bias from the proportion of the population that is buried and undetectable is more difficult. An attempt at that is to conduct surveys near the same time of year as previous surveys at a site. We were able to do that in a few cases, but many of the available pre-flood surveys were conducted in spring and early summer. The study area experienced a relatively wet spring and early summer in 2005, with stream conditions unsuitable for effective mussel surveys during much of that time. Consequently, minimizing bias from site condition took precedence over seasonal variability in detection potential, and many sites that were previously surveyed in spring were re-surveyed in late summer or fall when conditions were more favorable.

Presence-absence is a more reliable result of the survey methods used in this study, especially given the relatively high survey effort expended at each site (see Metcalfe-Smith et al. 2000, Strayer and Smith 2003). The primary utility of this study is documentation of the distribution of rare mussel species in the study area following the floods of 2004. The federal and state endangered Appalachian elktoe is presently under a 5-year review by the U.S. Fish and Wildlife Service "to ensure that the classification of the species as…endangered…is accurate" (Federal Register Vol. 70, No. 181 September 20, 2005). The status of state listed species (Brook floater, Creeper, Eastern creekshell, Long-solid, Notched rainbow, Slippershell, Wavy-rayed lampmussel) is also under a periodic review for state listing classification by the North Carolina Wildlife Resources Commission. This study provides timely information for these reviews.

B. Effects of Floods on Mussel Populations

Despite the potential pitfalls of comparing CPUE data, it was relatively clear that changes occurred in mussel distribution and abundance in both the French Broad and Catawba river basins. The total linear reaches occupied by mussels did not appear to change much, if at all, in any stream. While we failed to detect Appalachian elktoe at the upper-most sites in the South Toe and Cane rivers, and Brook floater at the uppermost Johns River sites, only one individual had been found at each site in 2003 surveys. This may represent a loss of occupied range; however, it is possible that they are still present but were undetected. Regardless, it appeared that distribution and relative abundance changed within and among sites in most streams in the study area. Some proportion of mussels at sites where CPUE decreased were likely lost to flood related mortality, while others may have survived displacement and deposition outside the surveyed reach. Changes in channel form (e.g. cross section elevations, riffle-pool sequence), patterns of substrate size distribution and flow velocity, and other habitat variables affected by the 2004 floods may be a major influence on the long-term spatial distribution of mussels throughout the study area.

Published studies of the impacts of floods on mussel populations are rare. Miller and Payne (1998) found little affect on unionid populations in the large, relatively low gradient upper Mississippi River following the extensive flood of 1993. However, in the only other known study that describes direct observations of flood impacts, Hastie et al. (2001) reported high mortality in a population of the endangered freshwater pearl mussel (*Margaritifera margaritifera*) in Scotland. They reported four apparent causes of mussel mortality: "1) desiccation of mussels stranded when the river level fell; 2) damage by mobile coarse substrata; 3) mussels crushed by large deposits of substrata on the river bed; and 4) mussels washed out to sea." We observed evidence of each of these causes of mortality (or analogous events) at many sites throughout the study area, but especially in the streams with declines in CPUE. During reconnaissance of several streams in the weeks following the floods, mussel shells with desiccated body tissue still attached were commonly found in flood plain sediment deposits. Although not directly observed, there was ample evidence that mussels may have been buried under instream bedload deposits. During another study in the Little Tennessee River in October 2004 where excavated quadrat samples were taken, dead mussels were found buried *in situ* under ~8in (20cm) of recently deposited cobble and gravel (NCWRC, unpublished data). While no substrate excavation was done during this study, channel form and elevation changed substantially at many sites, including aggradations in areas where mussels were known to have inhabited prior to the floods.

Not all mussels that were dislodged during floods were deposited on the flood plain. Obviously, washing out to sea is not probable in our study area; but mussels were surely washed downstream into other unsuitable habitats. For example, mussels from the Linville River likely washed into Lake James along with the substantial volume of bedload that was evidently deposited in the impoundment. Additionally, the downstream distribution of Appalachian elktoe in the Pigeon River ends abruptly at Canton where habitat becomes unsuitable due to a small impoundment and physico-chemical impacts from point and non-point sources. Mussels may also have been deposited in suitable habitats and become reestablished. Strayer (1999) suggested that it is unlikely that mussels passively accumulate in flow refuges during spates; however, Hastie et al. (2001) documented the appearance of mussel beds at new locations following a major flood and presumed that they consisted of dislodged mussels that had survived transport and deposition. This may explain the increase in CPUE at some sites. For example, Slippershells at the Mills River site and Eastern Elliptios at the upper Johns River site were found in areas that appeared to be dominated by recently deposited substrata.

The importance of flow refuges to the persistence of mussel populations during these floods was obvious. After a much lower intensity event (5-6 year interval) in two southeastern New York streams, Strayer (1999) found that mussels (including Brook floater) were 5-15 times more likely to occur within flow refuges than outside them. Spatial distribution of mussels was also strongly correlated with areas of low velocity and shear stress during high flows in a California stream with similar physical characteristics to streams in our study area (Howard and Cuffey 2003). Flow refuges have been associated with boulder fields and other structure that resist and deflect high flows and contribute to substrate stability (Vannote and Minshall 1982, Strayer 1999). Our observation of areas where mussels persisted at sites where substrate disturbance was otherwise severe was clearly consistent with these observations. In addition to the examples cited from the North Toe and Linville rivers, differences in post-flood mussel abundance between South Toe sites 2 (greatly reduced) and 3 (virtually unchanged) were clearly related to the presence of more effective refuge from the degree of high flows experienced during these events that was available at site 3. In the 2003 surveys, we found mussels at site 2 on both the Toe and North Toe rivers almost exclusively within areas that appeared to offer refuge from high flows, at least during the relatively low intensity events that had been experienced during the life span of those mussels up to that point. Our failure to detect mussels in 2005 at both these sites may have been due to ineffectiveness of apparent velocity refuges at the exceptionally high flows experienced during the long-interval recurrence events of 2004.

Hydrologic variability of streams and interactions among substrate size, channel form, slope, and patterns of flow velocity during high flows appear to be major factors in species composition and spatial distribution of mussel populations. A comparison of two streams in the Great Lakes/St. Lawrence basin correlated differences in hydrologic regime to differences in mussel species composition and distribution (DiMaio and Corkum 1995). Slope and percentage of substrate mobilization during spates were implicated as contributing factors. Howard and Cuffey (2003) also found highest densities of Western pearlshell (*Margaritifera falcata*) in two areas of lowest average gradient within their study area. The apparent difference in flood impacts between streams in the French Broad basin with different reach-scale gradient and flood plain width is consistent with these observations. These factors may also help explain the presence of more species in the Little and Mills rivers (Creeper, Slippershell, and Long-solid) and greater abundance of Wavy-rayed lampmussel in the Pigeon than are seen in the Nolichucky sub-basin.

Flow-conditional complex hydraulic variables (i.e. higher shear stresses during high flows) have been negatively correlated with mussel densities (Layzer and Madison 1995, Hardison and Layzer 2001). These studies suggested that shear stresses at times of glochidia (mussel larvae) release and excystment of juveniles from their fish hosts is a primary factor in determining the suitability of a location for juvenile settlement and may be a significant limiting factor on recruitment. Changes in channel form, substrate size distribution, and flow velocity patterns may also affect patterns of habitat use by host fishes. Given the substantial changes in habitat throughout many of the streams in the study area, it's likely that the spatial patterns of mussel distribution will also change as new recruitment occurs and mussel populations recover.

C. Conservation and Management Implications

A major threat to the conservation of rare species with limited distribution is mortality and habitat disturbance from stochastic events. While our results show substantial impacts at many sites, the persistence of these species following such severe disturbance shows their resiliency and adaptation to life in these habitats. Nonetheless, these species came to inhabit these rivers and adapt to the vagaries of life there long before the environmental manipulations that European humans have wrought on the region over the past 200 years. These populations have surely endured and recovered from floods of this size (and larger) over the centuries, but many may not have experienced a similar event since their range and overall population levels have been reduced due to human activity. Historically, populations in the upper French Broad and Catawba were likely contiguous throughout the larger tributaries and mainstem. Mussel populations in the region today are greatly reduced in range, fragmented, and many are isolated from one another, with no natural route for recolonization or opportunity to interbreed.

Based on the results of surveys prior to the 2004 floods, Appalachian elktoe populations in the Nolichucky sub-basin were found to be increasing in abundance (as indicated by CPUE) and expanding their range. It appears that the floods of 2004 have set that recovery back to some degree; however, their persistence throughout most of the occupied range known in 2003 also shows the resiliency of the species to periodic hydraulic disturbance, especially in a system that is more prone to habitat disturbance from floods. The Nolichucky population appears to be a relatively large (at least in terms of spatial distribution) metapopulation that is more or less contiguous, with at least the opportunity for some level of gene flow throughout the sub-basin. Other Appalachian elktoe populations in the French Broad basin are smaller, more restricted in range, and potential for gene flow among populations is either nil (Pigeon) or unknown (Mills & Little). The long-term survival of these populations is potentially more vulnerable to habitat disturbance events or other sources of mortality that reduce the effective population size. Fortunately, our results from the Pigeon, Little, and Mills river suggest that they weren't affected as badly by the 2004 floods.

In the Upper Catawba River basin, Brook floater, Notched rainbow, and Eastern creekshell populations in the Linville River, Warrior Fork and Johns River systems are relatively small and are apparently isolated from one another, with little potential for gene flow. While the degree of reproductive isolation between the Warrior Fork and Johns River is unknown (but likely complete), the Linville River is completely isolated from the others. Our results suggest that the already small Linville River populations were substantially reduced by impacts from the 2004 floods. The long-term survival of rare mussel populations in the Linville River may be in jeopardy. Management actions, such as determining effective population size and levels of genetic diversity within and among all Catawba basin populations to inform population augmentation and/or reintroduction efforts, should be carefully considered and pursued.

Our observations and those from the literature emphasize the importance of conserving habitat attributes that facilitate the survival of mussels during floods. Habitat heterogeneity, in-stream flow refuges, flood plain connection and function, and stream sinuosity appear to be very important to the long-term survival of mussels in high gradient systems. Unfortunately, some actions taken during EWP and other repair and restoration efforts in the region following the 2004 floods actually removed and/or degraded these attributes (authors' personal observations; D. McHenry and R. Brown, NCWRC, and M. Cantrell, USFWS, personal communications). Incorporation of natural stream channel design concepts and further refinements of stream restoration techniques will help insure that flood-related impacts on mussel populations end when flood waters subside and the ability to endure future events is not compromised (perhaps even enhanced).

VI. Acknowledgements

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Appendix 1. Rainfall and Streamflow, September 2004

Figure A1-1. Precipitation associated with Hurricane Frances September 6-9, 2004.

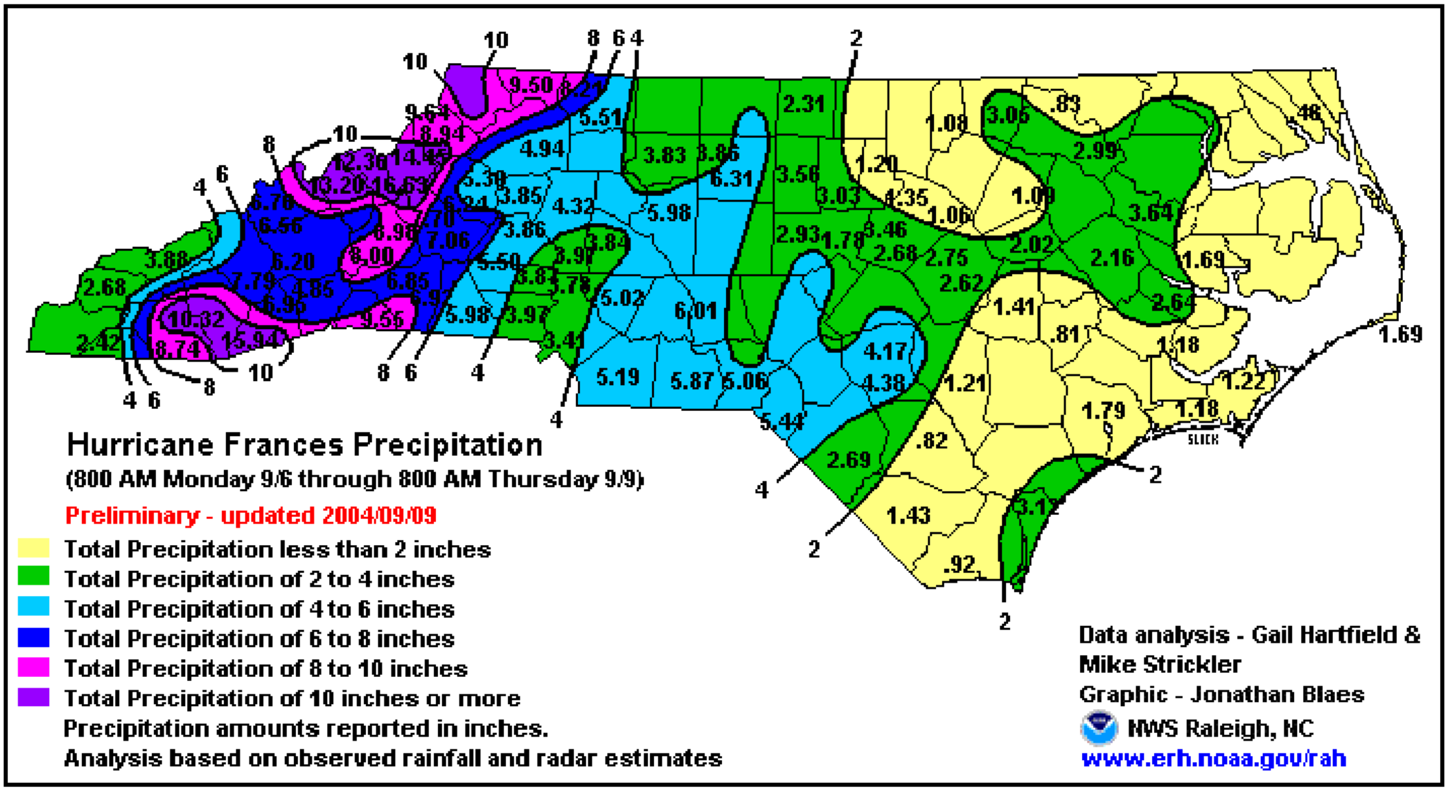


Figure A1-2. Precipitation associated with Hurricane Ivan September 16-19, 2004.

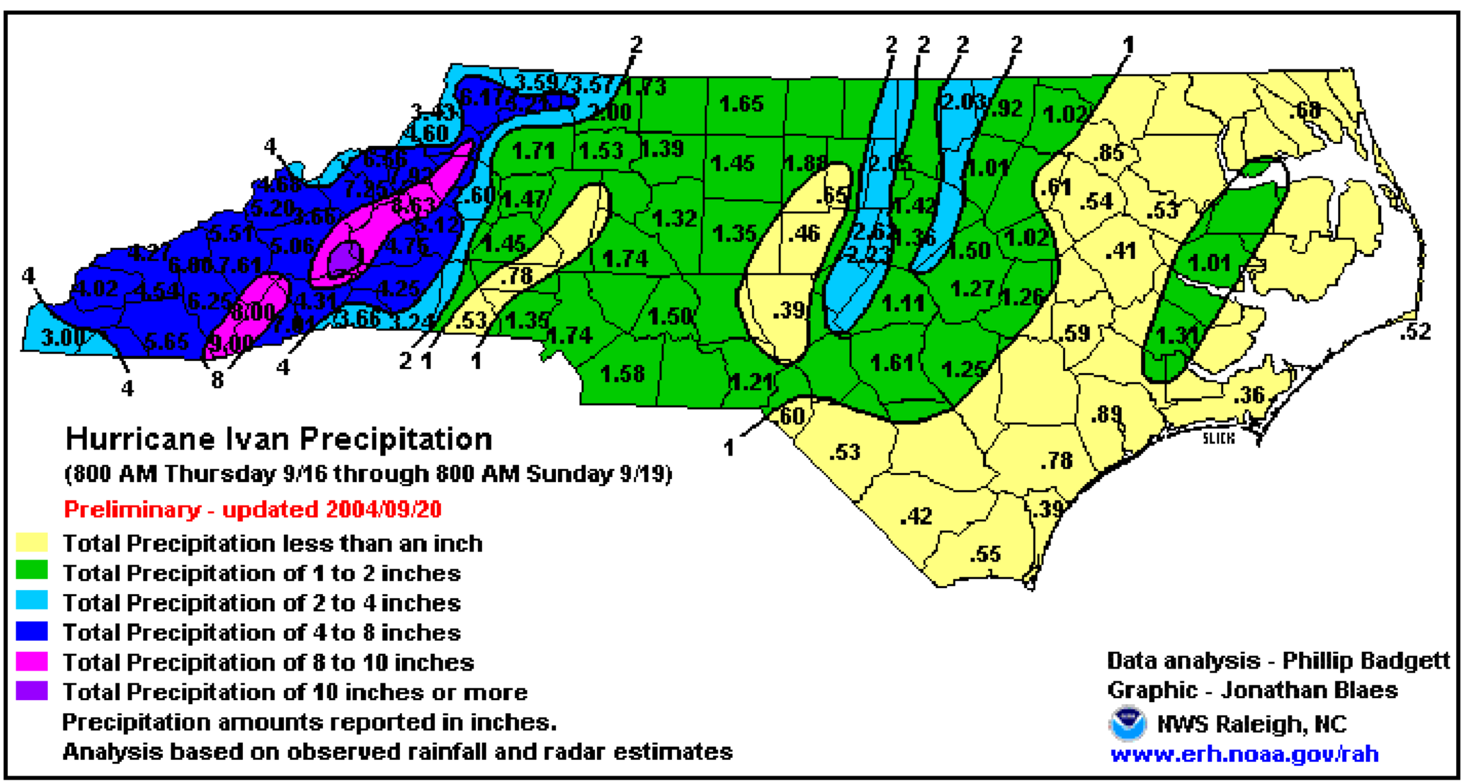
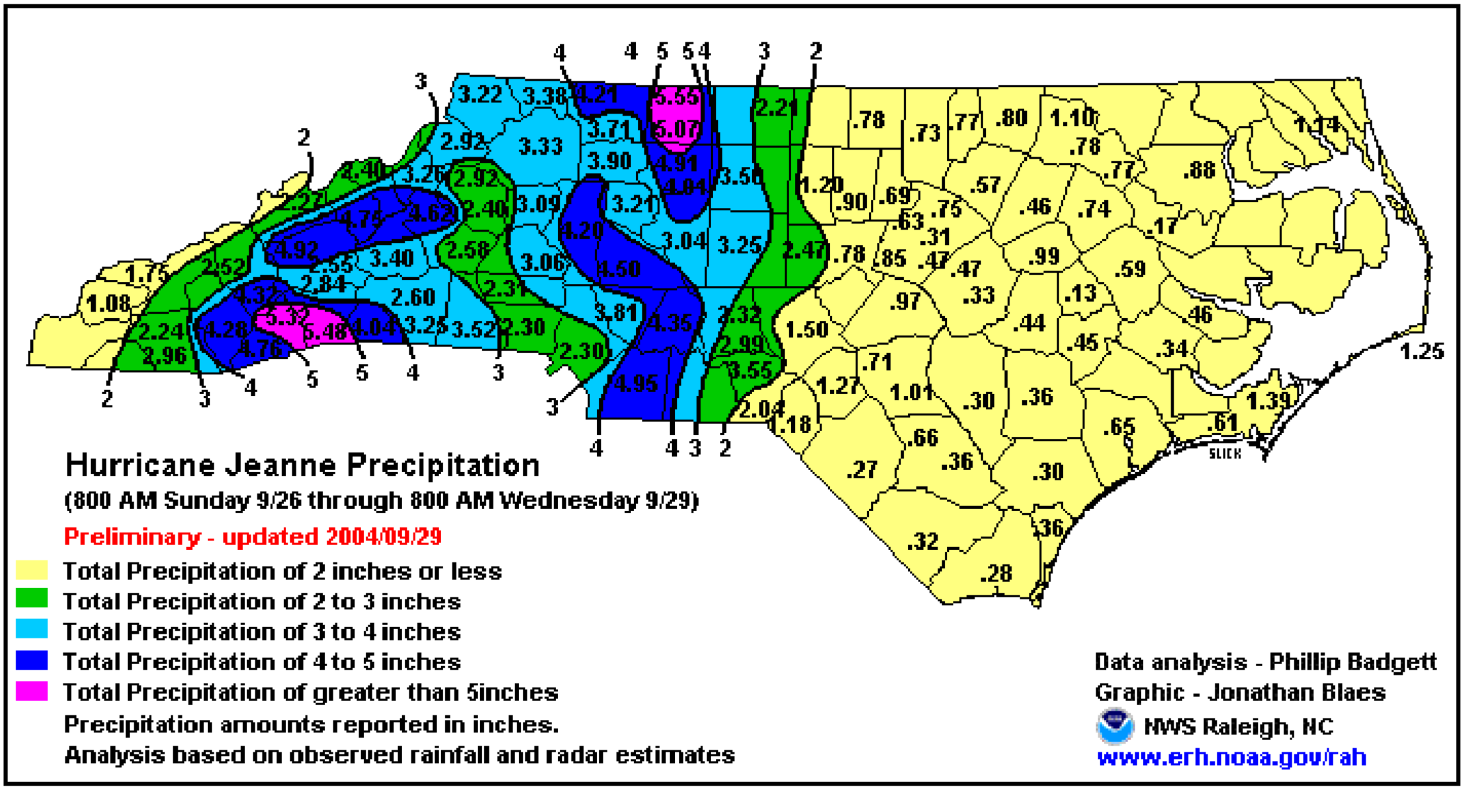
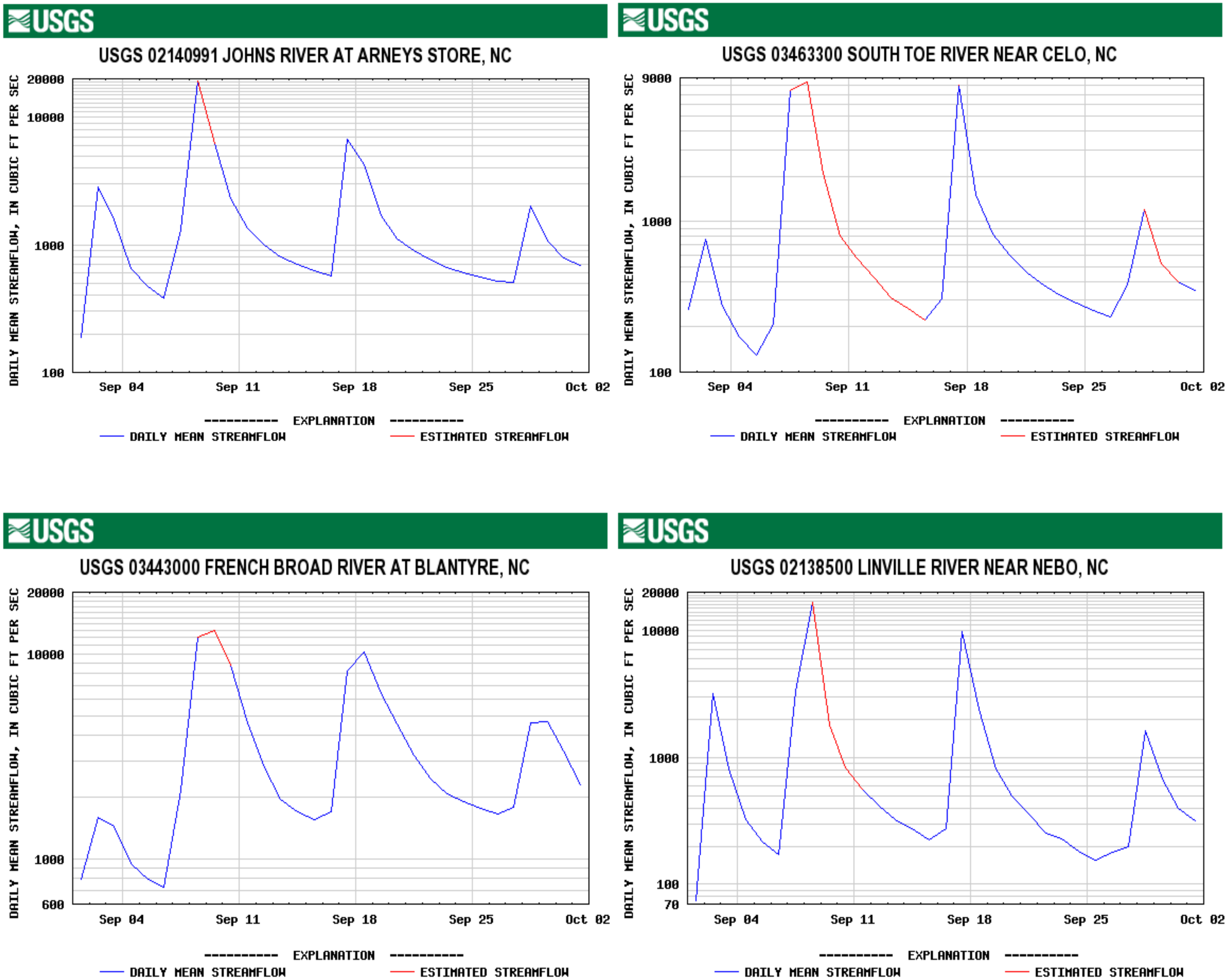


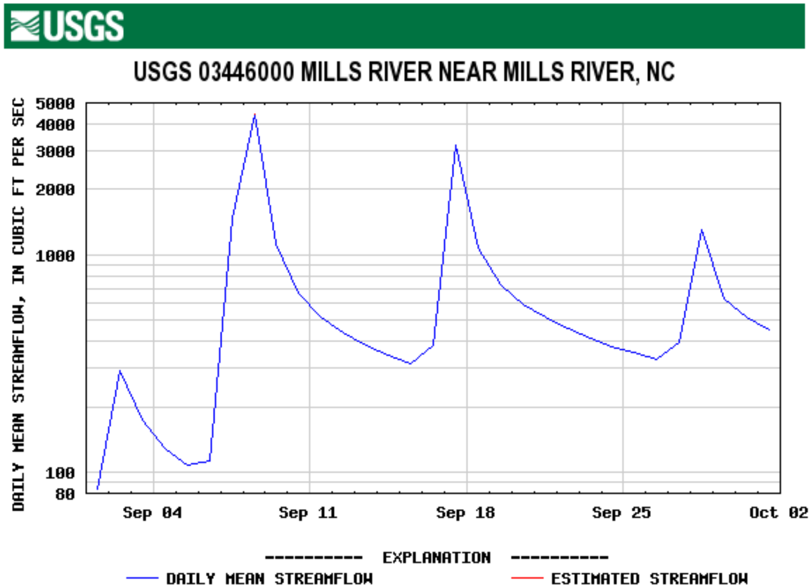
Figure A1-3. Precipitation associated with Hurricane Jeanne September 26-29, 2004.

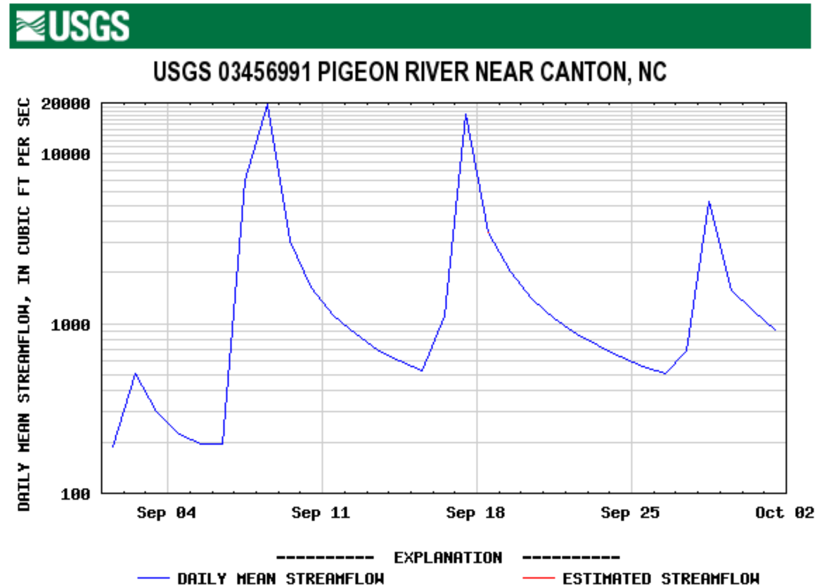


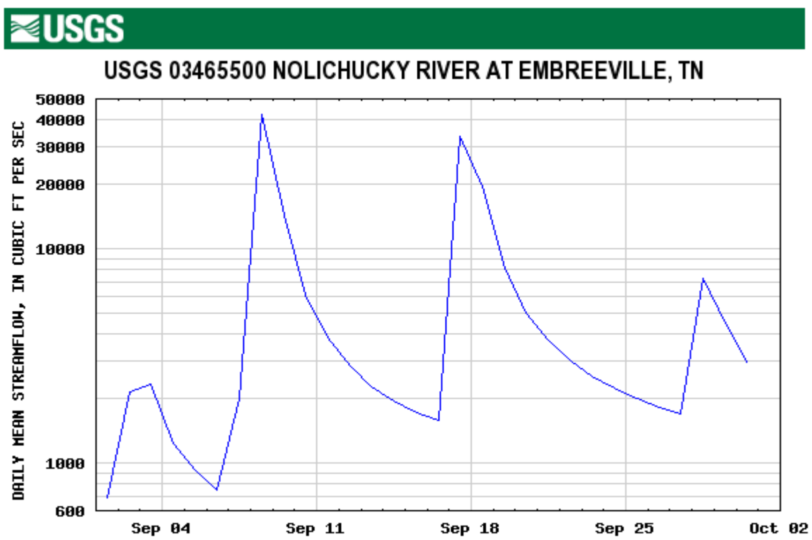
Figures A2-4-7. USGS streamflow data from gauges nearest study areas.



Figures A2-8-10. USGS streamflow data from gauges nearest study areas (cont.).







Appendix 2. Site CPUE Data Tables

Tables A2-1 & 2. Catawba River basin CPUE data summary for sites with comparable pre-flood survey data.

Table A2-1. Linville River and Upper Creek

Species		Stream	Linville River							Upper Creek		
		Site	**1** - Mtns to Sea trail x-ing Burke Co.			**2** - NC 126 Burke Co.			Total Change w/in Stream	Henderson Mill Rd Burke Co.		
		Date	Jul 1998	Oct 2005	Change	Jul 1997	Mar 2005	Change		Oct 2003	Aug 2005	Change
Brook floater	*Alasmidonta varicosa*		31.5	1	-30.5	4.7	3	-1.7	-32.2	8.7	4.8	-3.9
Eastern Elliptio complex	*Elliptio sp. cf. complanata*		0.5	1.7	1.2	0	0	0	1.2	1.1	1	-0.1
Variable spike complex	*E. sp. cf. icterina*			1.7	1.7				1.7	*	(10.8)	*
Carolina lance complex	*E. sp. cf. angustata/producta*									*	(1.3)	*
Notched rainbow	*Villosa constricta*									0.9	0.3	-0.6
Eastern creekshell	*V. delumbis*		2	0	-2	0	0.25	0.25	-1.75	0.7	1.7	1
		Total	34	4.4	-29.6	4.7	3.25	-1.45	-31.05	11.4	7.8	-3.6

***Not all Elliptio spp. were counted during 2003 Upper Creek survey.**

Table A2-2. Wilson Creek and Johns River.

Species		Stream	Wilson Creek							Johns River						
		Site	**1** – Adako Rd. Caldwell Co.			**2** – Playmore Beach Rd Caldwell Co.			Total Change w/in Stream	**1** – Upper Old Johns R. Rd Caldwell Co.			**2** – Lower Old Johns R. Rd Caldwell Co.			Total Change w/in Stream
		Date	Apr 2004	Sep 2005	Change	Apr 2004	Sep 2005	Change		Sep 2003	Sep 2005	Change	Sep 2003	Sep-05	Change	
Brook floater	*Alasmidonta varicosa*		2.3	0.3	-2	0.2	2	1.8	-0.2	0.2	0	-0.2	2.5	1	-1.5	-1.7
Eastern Elliptio complex	*Elliptio sp. cf. complanata*		0	0.2	0.2	0	1.5	1.5	1.7	10.3	39.5	29.2	62	35	-27	2.2
Variable spike complex	*E. sp. cf. icterina*									0.8	0.7	-0.1	1.8	1.7	-0.1	
Carolina lance complex	*E. sp. cf. angustata/producta*					0.9	0.3	-0.6	-0.6	1.7	0	-1.7	1.3	1.5	0.2	-1.5
Eastern creekshell	*V. delumbis*		1	0	-1	0.4	0.8	0.4	-0.6	1	0.2	-0.8	0.7	0.3	-0.4	-1.2
		Total	3.3	0.5	-2.8	1.5	4.6	3.1	0.3	14	40.4	26.4	68.3	39.5	-28.8	-2.4

Tables A2-3-7. French Broad River basin CPUE data summary for sites with comparable pre-flood survey data.

Table A2-3. North Toe and Pigeon rivers.

Species		Stream	North Toe River							Pigeon River		
		Site	**1** - Btwn Penland & Wing Yancey/Mitchell Co.			**2** - At S. Toe Confluence Yancey/Mitchell Co.			Total Change w/in Stream	NC 215 at Plott Farm Addition Haywood Co.		
		Date	Oct 2003	Aug 2005	Change	Oct 2003	Aug 2005	Change		Jul 2003	May 2005	Change
Appalachian elktoe	*Alasmidonta raveneliana*		0.3	0.1	-0.2	1.5	0	-1.5	-1.7	2	0.15	-1.85
Wavy-rayed lampmussel	*Lampsilis fasciola*					0.2	0	-0.2	-0.2	0.5	1	0.5
		Total	0.3	0.1	-0.2	1.7	0	-1.7	-1.9	2.5	1.15	-1.35

Table A2-4. Toe River.

Species		Stream	Toe River									
		Site	**1** - Toecane Yancey/Mitchell Co.			**2** - Btwn Toecane & Red Hill Yancey/Mitchell Co.			**3** - Huntdale Yancey/Mitchell Co.			Total Change w/in Stream
		Date	Apr 2003	Oct 2005	Change	Oct 2003	Sep 2005	Change	Feb 2003	May 2005	Change	
Appalachian elktoe	*Alasmidonta raveneliana*		2.7	3.6	0.9	1.5	0	-1.5	4	0.5	-3.5	-4.1
Wavy-rayed lampmussel	*Lampsilis fasciola*		0	0.6	0.6	0.7	0	-0.7	1	0.1	-0.9	-1
		Total	2.7	4.2	1.5	2.2	0	-2.2	5	0.6	-4.4	-5.1

Table A2-5. South Toe and Cane rivers.

		Stream	South Toe River										Cane River						
		Site	**1** - Blue Rock Rd Yancey Co.			**2** - Baccus Siding Yancey Co.			**3** - Btwn Baccus S. & N. Toe, Yancey Co.			Total Change w/in Stream	**1** - Bakers Cr. Rd Yancey Co.			**2** - 19W below Bald Cr. Yancey Co.			Total Change w/in Stream
		Date	Jun 2003	Sep 2005	Change	Oct 2003	Sep 2005	Change	Oct 2003	Sep 2005	Change		Jul 2003	Oct 2005	Change	Jul 2003	Oct 2005	Change	
Appalachian elktoe	*Alasmidonta raveneliana*		0.4	0	-0.4	13	1.2	-11.8	16	14	-2	-14.2	0.5	0	-0.5	8	1.25	-6.75	-7.25

Table A2-6. Mills and South Mills rivers.

Species		Stream	Mills River			South Fork Mills River		
		Site	Hooper Lane Henderson Co.			S. Fk Rd x-ing Henderson Co.		
		Date	Jul 2003	Sep 2005	Change	Aug 2004	Sep 2005	Change
Slippershell	*A. viridis*		73.3	85.3	12	0.44	2.2	1.76
Creeper	*Strophitus undulatus*		0	0.75	0.75			
		Total	73.3	86.05	12.75	0.44	2.2	1.76

Table A2-7. Little River.

Species		Stream	Little River									
		Site	**1** - Shipman Rd Transylvania Co.			**2** - Cascade Rd Transylvania Co.			**3** - Merrill Rd Transylvania Co.			Total Change w/in Stream
		Date	Aug 2004	Sep 2005	Change	Aug 2004	Sep 2005	Change	Aug 2004	Sep 2005	Change	
Appalachian elktoe	*Alasmidonta raveneliana*		5.6	4.7	-0.9	4.8	11.7	6.9	3	5	2	8
Longsolid	*Fusconaia subrotunda*					0.16	0.17	0.01				0.01
Creeper	*Strophitus undulatus*		1.6	0.5	-1.1	2.1	3.7	1.6	2.4	5.25	2.85	3.35
		Total	7.2	5.2	-2	7.06	15.57	8.51	5.4	10.25	4.85	11.36

Tables A2-8-11. CPUE data summary for additional sites surveyed that lacked comparable pre-flood survey data.

Table A2-8. Additional Catawba River basin sites: Upper Creek and Johns River.

		Stream	**Upper Creek**	**Johns River**
		Site	Brown Mtn Beach Rd., Burke Co.	Below Corpening Bridge, Burke Co.
Species		Date	Sept 2005	Mar 2005
Brook floater	*Alasmidonta varicosa*		1.8	0.4
Eastern Elliptio complex	*Elliptio sp. cf. complanata*			83
Variable spike complex	*E. sp. cf. icterina*		0.8	1.7
Carolina lance complex	*E. sp. cf. angustata/producta*			1.7
Notched rainbow	*Villosa constricta*			
Eastern creekshell	*V. delumbis*		1	
		Total	3.6	86.8

Table A2-9. Additional French Broad River basin sites: West Fork Pigeon River.

		Stream	**West Fork Pigeon River, Haywood Co.**			
		Site	Retreat (below SR 1118)	Retreat (at SR 1118)	Chambers property	Leatherwood property
Species		Date	Mar 2005	Mar 2005	Mar 2005	Mar 2005
Appalachian elktoe	*Alasmidonta raveneliana*		0	0	0.4	0.2
		Total	0	0	0.4	0.2

Table A2-10. Additional French Broad River basin sites: Pigeon River.

		Stream	**Pigeon River, Haywood Co.**						
		Site	At confluence of East & West forks	River mile 69	near mouth of Stamey Cove Br.	Garrison property	Upstrm. from Garden Cr. Island	River mile 65	Upstrm. from Main St. (US 19/23)
Species		Date	Mar 2005	Mar 2005	Mar 2005	Mar 2005	Mar 2005	Mar 2005	Mar 2005
Appalachian elktoe	*Alasmidonta raveneliana*		0.6	1.4	3.7	1.6	0	2	0.4
Wavy-rayed lampmussel	*Lampsilis fasciola*			2	0.9	0.4	0	1.3	0.4
		Total	0.6	3.4	4.6	2	0	3.3	0.8

Table A2-11. Additional French Broad River basin sites: Cane, Toe, South Toe, Little, upper French Broad, and Mills rivers.

	Stream	**Cane River**	**Toe River**	**South Toe R.**	**Little River**	**French Broad R.**	**Mills River**
	Site	Near mouth of Bald Mtn. Cr, Yancey Co..	Near Green Mtn., Yancey/Mitchell Co.	Btw US 19E and NC 80, Yancey Co.	Everett Rd. Transylvania Co.	Crab Creek Rd. Transylvania Co.	River Loop Rd. Henderson Co.
Species	Date	Oct 2005	Oct 2005	Sept 2005	Sept 2005	Sept 2005	Sept 2005
Appalachian elktoe	*Alasmidonta raveneliana*	0	1	0.33	13	2	0
Creeper	*Strophitus undulatus*				19	8	0
Slippershell	*A. viridis*						0
	Total	0	1	0.33	32	10	0