Status of the Mussel Resource in Little South Fork Cumberland River

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Final Report for Project

**Mussel-Fish Host Relationships in
Little South Fork Cumberland River, Kentucky**

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Introduction

As recently as the 1980s, the Little South Fork Cumberland River of southeastern Kentucky supported a diverse freshwater mussel fauna (Starnes and Bogan 1982; Appendix A). The Little South Fork represented one of the last rivers to support a high number of mussel species in the Cumberland River drainage of Kentucky and Tennessee. The river was first surveyed comprehensively in 1981 by Starnes and Bogan (1982) who found 25 species (19 alive) and reported mussel densities as high as 7 individuals m^{-2} in the lower reaches of the river. The Little South Fork also supported two federally endangered mussel species (little-wing pearlymussel, *Pegias fabula*, and Cumberland bean, *Villosa trabalis*); four species considered threatened or endangered by the Kentucky State Nature Preserves Commission (KSNPC) (KSNPC 1996); and five other species considered of special concern by the American Fisheries Society (Williams et al. 1993) (Appendix A).

Acting on information about possible declines (G. Schuster in Millican Associates, Inc. 1982, Ahlstedt 1986, Ahlstedt and Saylor 1995-1996), the U.S. Fish and Wildlife Service initiated a resurvey of the mussel fauna of Little South Fork in 1987 (Anderson et al. 1991, Layzer and Anderson 1992). The results indicated an apparent die-off of mussels in the lower one third of the river (downstream of the mouth of Kennedy Creek). Densities of mussels ranged from 0 to 1.1 m^{-2} at the same sites at which Starnes and Bogan (1982) had found 2.9 to 7.2 individuals m^{-2}. The die-off appeared to be correlated with surface-mining activities in the lower one third of the watershed which increased in extent from 1981 through 1987. Although mining had all but eliminated the mussel fauna in the lower river, Anderson et al. (1991) concluded that the middle and upper sections remained unimpacted and were considered important refugia for the fauna.

In their 1987 survey, Anderson et al. (1991) reported more species alive in the upstream sections than had been recorded by Starnes and Bogan (1982). However, for the section of river from the State Route 167 bridge to Kennedy Creek, Starnes and Bogan (1982) presented data from Harker et al. (1979, 1980) in which no distinction was made between live and relict specimens. Nevertheless, in the 1987 resurvey most species in the river upstream of Kennedy Creek were represented by more than one live individual (Anderson et al. 1991).

The original objectives for this investigation were focused on: 1) examining the relationships of mussel species and their fish-hosts and 2) analyzing the spatial interrelationships of mussels, fish-hosts, and habitat along the entire river. These objectives were premised on the occurrence in the river of federally listed mussel and fish species (palezone shiner, *Notropis albizonatus*) and the role of the river as a refugia for a significant number of mussel species that have declined elsewhere in the Cumberland River system. Further, mussels in the upper reaches of the Little South Fork might have served as source populations for recovery of populations in the lower third of the river if the habitat and fish-host populations were intact. Our initial field work made it apparent however that the mussel community in the river had declined precipitously. It was not possible to locate gravid female mussels from the river for most targeted species, and inadequate numbers of mussel species previously known from the river precluded examination of spatial interrelationships of mussels, host fishes, or habitat. We were able to conduct only one laboratory trial to attempt to determine fish hosts for the painted creekshell (*Villosa taeniata*) (Appendix B.1). Given the circumstances, we focused on a resurvey of the river to determine the magnitude and spatial extent of the freshwater mussel decline.

We report here on a resurvey of the freshwater mussels of the Little South Fork. In July 1997, we surveyed a segment of the river extending from Green Ford to about 2-km downstream of the mouth of Kennedy Creek. We began our resurvey in this section because Anderson et al. (1991) and Anderson and Layzer (1992) reported live individuals of 13 mussel species and some of the highest species richness values in the river at that time. In August 1998, we surveyed the uppermost section of the stream from the State Route 167 bridge to Green Ford and the lowermost section of the river from the State Route 92 bridge to Freedom Church Ford. We also report results of laboratory trials to identify host species for the painted creekshell and summarize known host information for species formerly of regular occurrence in the river (Appendix B).

Methods

We surveyed sites at historical collections sites and in areas not previously surveyed. Historical sites surveyed included those of Starnes and Bogan (1982), Millican Associates, Inc. (1982), Anderson et al. (1991), Layzer and Anderson (1992), and Ahlstedt and Saylor (1995-1996). We sampled previously unsurveyed reaches by locating our mussel sites at or near those that had been randomly selected for fish surveys (Poly 1997, Henry et al. 1998; and field notes) (Table 1). The study area or various collection sites in the river were described in detail by several previous workers (Harker et al. 1979, 1980, Millican Associates, Inc. 1982, Starnes and Bogan 1982, Anderson et al. 1991, Layzer and Anderson 1992, Poly 1997).

We sampled mussels at most sites using randomly placed 5-m x 0.7-m transects (3.5-m^2 total area) (Tables 2 and 3). We placed transects by laying a tape marked at 1-m intervals parallel to a riffle or run and, using a random numbers table, randomly selecting the longitudinal (upstream to downstream) and transverse (right, left, or middle of channel) positions of transects. Transect positions were marked using 5-m lines placed at a slight upstream or downstream diagonal to the shore and anchored on each end by a metal stake. An observer, using a mask and snorkel or a glass-bottomed view bucket, visually examined the substrate and then disturbed the substrate to a depth of about 10 cm along the entire transect in 0.5-m^2 sections, and identified, measured, and replaced any live freshwater mussels encountered. Measurements were of total shell length (nearest 1.0 mm) and were summarized to provide information on recent recruitment (Table 4). Sampled sites were all < 0.75 m deep. The bottom was clearly visible to observers on all sampling dates. At each site, we sampled two to five transects (7.0 - 17.5 m^2) allocated among one or more habitat units (Tables 1 and 2). Generally, if two or three transects revealed no or few live mussels, we discontinued sampling at that habitat unit. For small specimens, we counted shell growth rings to estimate the minimum age of the animal.

At six sites, we deviated from the quadrat excavation methods in the interests of time and to extend areal coverge. We conducted visual searches (Site H334-H344, SR 167 bridge), timed visual searches (Site H-432-433 downstream Langham bridge, Site H-518 wooden bridge #2, Site H-564-571, Lonesome Creek, Site Kennedy Creek, Site PB-212-213 Bakers Branch), and timed visual searches with disturbance of the substrate (Site PB-140-142 Bell Hill) (Table 1). Person-minutes searched included only the time observers spent with a view bucket or mask and snorkel in the water. The results of these visual searches are included or footnoted in the tables (Tables 1 and 2).

To compare the historical and present-day mussel fauna, we made relict shell collections, many of which represented old, washed-out shell middens deposited by muskrats (Tables 5 - 8). We retained all relict shells from selected reaches in an effort to document relative abundance of each species (Tables 5 and 7). We identified shells in the laboratory, and only relict (i.e., weathered dry) shells were included. Very few freshly dead shells were found (< 5 per site). To avoid inflating abundance estimates, we paired as many single valves as possible, then counted each pair of valves and each remaining unpaired valve as one individual. We combined relict collections from sites PB-59 and PB-60, PB-150 and PB-153, and PB-172 and PB-173 to represent the historical fauna over these extended reaches (Table 7). We further compared relict and live collections using our data and those reported by Layzer and Anderson (1992) (Table 8). Common and scientific names follow Williams et al. (1993) except we use creeper as the common name for *Strophitus undulatus*.

Results

We sampled 29 sites located along about 47 river kilometers of the Little South Fork (i.e., SR 167 bridge to Freedom Church Ford) (Tables 1 and 2). We sampled 23 sites using transects, resulting in a total area sampled of 273 m^2, and six sites using timed searches. For summary purposes, we grouped sites into four river segments (listed upstream to downstream): Segment I, SR 167 bridge to upstream of Green Ford; Segment II, Green Ford to mouth of Kennedy Creek (Baldy Road bridge); Segment III, downstream of Kennedy Creek to SR 92 bridge; and Segment IV, downstream of SR 92 bridge to downstream of Freedom Church Ford. We present our survey results by summarizing the data among the four river segments. Detailed results for each segment are presented in Appendix C.

We found a very sparse mussel community remaining in Little South Fork. We located a total of 236 living mussels with a mean density of 0.7 individuals m^{-2} over the entire river. However, there was high variation in density among sites (Table 2). At 16 of the transect sites, (70%) we found 5 or fewer living mussels and mean densities at most of these sites were < 0.2 (range = 0 - 0.5 individuals m^{-2}) . At eight transect sites (35%), we found either one or no living mussels. The highest density we recorded was 2.9 individuals m^{-2} and only 3 sites (13%) had mussel densities > 2 individuals m^{-2}. Mean densities among river segments showed a progressive decline from upstream to downstream, but even the highest mean segment density, in the most upstream segment, was < 0.90 individuals m^{-2} (Table 3). In the two most downstream segments only 33 live individuals were encountered, and mean densities were < 0.30 individuals m^{-2}.

Species richness also was low in the Little South Fork. We found a total of nine living species in the entire Little South Fork in 1997-1998 compared to 12 in 1987 (Anderson et al. 1991) and 19 in 1981 (Starnes and Bogan 1982). Of the total known mussel fauna of the river (26 species), species richness has declined by 64% (Tables 2 and 3). Painted creekshells (*Villosa taeniata*) and fluted kidneyshells (*Ptychobranchus subtentum*) comprised 72% of all live individuals encountered. Wavy-rayed lampmussels (*Lampsilis fasciola)*, Cumberland moccasinshells (*Medionidus conradicus)*, and rainbows (*Villosa iris)* comprised 13%, 8%, and 5% of all living individuals, respectively. Fluted kidneyshells and wavy-rayed lampmussels were the only species found alive in all four segments of the river (Table 3). The Tennessee clubshell (*Pleurobema oviforme*) was represented by a single live individual and the pheasantshell (*Actinonaias pectorosa),* kidneyshell (*Ptychobranchus fasciolaris)*, and the pink heelsplitter (*Potamilus alatus),* by two live individuals each. Freshly dead shells were encountered rarely and included only representatives of the nine species found alive.

Lengths of the five most numerous live species showed low variability (CV < 21%), and no juveniles (< 30 mm) were found for any species (Table 4). Variation in length was highest for fluted kidneyshells and wavy-rayed lampmussels and lowest for Cumberland moccasinshells. Growth lines on the the smallest fluted kidneyshells (38 mm) indicated an age of 9+ years old. Lengths and estimated ages from growth lines on other individuals of this species were: 43-mm, 12 + years old; 48 mm 13+ years old; 60 mm, 13+ years old; and 76 mm, 15+ years old. For wavy-rayed lampmussels, a 52-mm male showed an age of 6+ years, and a 49-mm female was estimated as 11+ years old. Estimated ages for painted creekshells (n=4) ranged from 8+ years old (56-mm male) to 12+ years (42-mm and 47-mm females). In another Cumberland River tributary, most painted creekshells with shell lengths of 46 to 74 mm were between 11 and 40 years old as determined by examining thin-sections of shells (Houslet 1996). The only rainbow aged was 12+ years old at 39-mm in length.

Richness of relict shells collected in our survey was high, and the total numbers of species present was similar to that reported for the Little South Fork in previous surveys (Tables 5 - 7). As relict shells, we found a total of 22 species (including the nine species also found alive). Only four species encountered by previous surveys were not found by us as relict shells: purple warty-back (*Cyclonaias tuberculata)*, giant floater (*Pyganodon grandis*), creeper (*Strophitus undulatus*), and paper pondshell (*Utterbackia imbecillis*). We discovered a single, paired specimen of black sandshell (*Ligumia recta)* in the relict collections, a species previously unreported from the Little South Fork.

Relict species richness was high and distribution was relatively even across all four stream segments. Mean relict species richness ranged from 11 species in Segment I (most upstream) to 17 species in Segment IV (most downstream) (Table 5). Downstream succession of the fauna is apparent in the collections (e.g., slippershells, *Alasmidonta viridis,* in the headwaters and fragile papershells, *Leptodea fragilis,* in downriver segments); however, 13 of 22 species

(59%) represented as relicts were found in all four river segments (Table 5). Twelve of these occurred as relict shells in nearly every collection within every segment.

Species relative abundances in the relict collections indicate that most species historically were present in comparable numbers. Few species showed relative abundance values > 33% (Table 5). The relict collections were dominated (relative abundance > 10% in most collections) by wavy-rayed lampmussels , fluted kidneyshells , painted creekshells, and to a lesser extent, kidneyshells (*Ptychobranchus fasciolaris*), all of which were found alive in our survey (Table 5). However, relative abundances of these species in relict shell collections were usually less than 33%. Several formerly widespread species showed consistent values in relict relative abundances of < 10%: plain pocketbooks (*Lampsilis cardium*), round hickorynuts (*Obovaria subrotunda*), purple lilliputs (*Toxolasma lividus*), rainbows (*Villosa iris*), Cumberland beans (*Villosa trabilis*), and little-wing pearlymussels. None of these species, except the rainbow, was found alive in our survey. The relict collections further highlight the severe decreases in species numbers throughout the entire length of Little South Fork. Estimated species losses were 73%, 60%, 75%, and 75% for river segments I through IV, respectively. Eleven of fifteen collections showed within segment species losses of > 74% (Table 5).

Mean numbers of relict shells per meter searched were highest in the two upstream-most gradient sections; numbers declined steeply downstream (Table 6). The decrease in numbers of relict shells is first noticeable upstream of Kennedy Creek but becomes increasingly apparent from Kennedy Creek downstream to Freedom Church Ford.

Discussion

Our survey represents the most extensive and intensive survey for freshwater mussels ever conducted in the Little South Fork Cumberland River. Starnes and Bogan (1982), Anderson et al. (1991), and Layzer and Anderson (1992) provided valuable quantitative data for comparison of composition and abundance of the mussel fauna over time. In fact, the quantitative sampling conducted by Starnes and Bogan (1982), which was a near precedent-setting sampling method at the time, allowed Anderson et al. (1991) to demonstrate dramatic freshwater mussel declines in the lower third of the Little South Fork. However, these previous workers concentrated quantitative efforts primarily on Segments IV and to a lesser extent on Segments II and III. We quantitatively sampled over 19 times the area sampled by previous surveyors in Segment II, four times the area in Segment III, and two times the area in Segment IV. Unfortunately, the reaches from SR 167 bridge to Steele Hollow bridge (all of Segment I and most of Segment II) had never been sampled quantitatively before our survey. The lack of historical quantitative samples (i.e., timed searches or transect sampling) in the upper segments of the river hampered assessment of faunal changes over time despite the availability of two previous surveys. We consider this a pointed lesson for conducting freshwater mussel surveys in the future. Presence/absence sampling, even of live individuals, is of limited value in monitoring freshwater mussel communities over time and lacks the sensitivity to detect declines in the fauna until losses have accumulated to the point of effective extirpation of entire populations. We strongly recommend that any future surveys supported by state, federal, or other institutions minimally require timed searches for surveys of freshwater mussel communities.

The potential for demise of freshwater mussels in Little South Fork has been noted repeatedly for over two decades. In 1977, Starnes and Starnes (1980) discovered a large, reproducing population of the federally endangered little-wing pearly mussel in Little South Fork. They stated the Little South Fork "is perhaps the most pristine stream remaining within the entire known range of *Pegias* in the Cumberland and Tennessee River drainages." They further noted that if the river, "which is designated a Kentucky Wild River, continues to enjoy protection from surface mining and other perturbations," its mussel fauna "should be afforded continued preservation." Evidence of freshwater mussel decline in Little South Fork was first noted three years later at Ritner Ford by G. Schuster (in Millican Associates, Inc., 1982). Based on observations in 1980, Schuster reported that the mussel fauna at Ritner Ford consisted almost entirely of relict shells in contrast to the abundance of live individuals and active muskrat shell middens he observed upstream at the Baker Branch and Jones School sites. As unintended foreshadowing, Starnes and Bogan (1982) closed their paper with the statement, "Survival of the river's unionid fauna possibly will be directly related to compliance with and enforcement of ... " the Surface Mining Control and Reclamation Act. In 1984-85, Ahlstedt and Saylor (1995-1996) noted that "large numbers of mussels" were freshly dead in the lower third of the river. They regarded Little South Fork as essential habitat for the federally endangered the little-wing pearly mussel, but stated that the river "may be impacted by activities associated with coal mining ..." and that mining or oil and gas exploration "could cause major changes" in the watershed. In 1987-88, Anderson et al. (1991) and Layzer and Anderson (1992) documented an almost complete kill of mussels from upstream of SR 92 bridge to Freedom Church Ford. They concluded that expansion of surface mines coincided with mussel declines and attributed the die-off in the lower third of the river to surface mine runoff. Layzer and Anderson (1992) recommended a total moratorium be placed on mining in Cumberland River watersheds harboring federally listed mussel species or "extinction of these animals is inevitable."

The mussel fauna of the Little South Fork has been reduced from 26 to 9 species, but even a loss of 65% of the mussel fauna understates the situation. The abundance of nearly all the extant species in the river is so low that their long-term viability is questionable. Densities in 1997-98 for the lower third of the river suggest no recovery has occurred since the 1987 surveys. Sites at the SR 92 bridge (Segment III), Jones School (Segment IV), and Freedom Church Ford (Segment IV) showed lower densities than recorded by Anderson et al. (1991). In 1987-88, densities upstream of surface mining impacts ranged from about 3 to 5.5 individuals m^{-2} (Segment II); our surveys revealed that mean densities for Segment II were < 1.0 individuals m^{-2} and at individual sites ranged from 0 to 2.9 individuals m^{-2}.

Further, recruitment of mussels throughout Little South Fork in the past decade or longer has been low to nonexistent. The lengths, low coefficients of variation, and counts of growth rings indicated most specimens within a species originated from only a few successive cohorts that originated ten or more years ago. The fluted kidneyshell and wavy-rayed lampmussel may have reproduced in the last decade, and we found gravid or recently spent specimens of painted creekshell. However, we found no juveniles of any species despite efforts to do so. We are confident the lack of juveniles is not a sampling artifact. Our experience with the transect sampling method indicates it is quite sensitive to detection of juveniles (Warren and Haag, unpublished). The lengths, minimum ages, and lack of juveniles are strong evidence that most living individual mussels in the river are simply surviving while edging toward senescence or premature death.

Numbers of relict shells at sites showed a counterintuitive decline from upstream to downstream in the Little South Fork. Expectations in a viable mussel community would be for relict shell numbers to increase downstream or at least be coequal across reaches with the possible exception of less productive or small headwaters. We did not analyze this data statistically, but the trend is apparent. The progressive paucity of relict shells from upstream to downstream was also obvious in the field. The low relict shell numbers in downstream segments support previous observations that the decline of the mussel fauna began in the lower reaches of the river (Anderson et al. 1991) and support our conclusion that no recovery has occurred.

Importantly, the relict shell data also provide strong evidence that the decline of the mussel fauna has continued upstream over time and now encompasses the entire river. The fauna upstream of the kill zone documented by Anderson et al. (1991) was apparently already in decline at the time of their survey. At their most diverse sites in Segments I, II, and III (i.e., upstream of surface-mining runoff) from 36% to 69% of the mussel fauna was represented only as relicts in 1987, despite their sampling goal of locating as many live species as possible (R. Anderson, personal communication). Our collections at these same sites showed a further increase in species losses ranging from 69% to 85%. In addition, most species represented by live individuals in their survey of upstream segments were restricted in distribution to one or two sites, but the same species had widespread relict shell distributions. From this and other lines of evidence from our survey, it is clear that the mussel community upstream of the previously documented kill zone has also undergone catastrophic declines.

The relict shell and extant mussel fauna suggest the factor(s) causing the mussel decline operated by eliminating species in proportion to their abundance. Our extensive and near comprehensive relict shell collections indicated the mussel community that formerly occurred in Little South Fork was not only diverse, but was widespread and showed relatively consistent abundances among species. We recognize that relative abundance estimates made from relict shell collections may be conservative for thin, less weather resistant shells such as the little-wing pearlymussel. Nevertheless, the general pattern in the data indicate that species showing the highest relative abundances in the relict shell collections are the primary species surviving in the river today. Hence, whether the cause of the decline is related to periodic events or is chronic in nature, it has eliminated with few exceptions all but the most formerly abundant species from the system.

The specific cause or causes of the mussel decline in the river are not clear even after over a decade of observed mussel species extirpations and population declines. From our experience with freshwater mussel habitat, there appeared to be an abundance of clean, shallow, gravel-bottomed riffle and run habitats throughout the length of the river. Few obvious physical problems were observed by us or D. Henry and W. Poly (personal communication and field notes) with the exception of degradation of riparian areas and the stream channel by cattle and seepage of oil and sulphur-laden waters (see following paragraphs). Eroding banks, sediment accumulation in pools, trampled substrate, and severely eroding, incised trails were characteristics of areas used by cattle. However, cattle access to the river was site-specific and confined to relatively short reaches of the river. We believe it unlikely that cattle impacts alone could have contributed to the extensive decline of mussels. We feel however that land-owners in the watershed should be informed of the ecological and water quality benefits of keeping cattle out of the river and of restoring riparian areas. If possible, a land owner contact program with incentives to rehabilitate stream banks should be initiated in the watershed.

A compelling case has been made previously that toxic run off and increased sediment from surface mining eliminated mussels in the lower third of the Little South Fork (Anderson et al. 1991, Layzer and Anderson 1992). This does not explain the decline upstream of surface-mining activities, and to our knowledge, no new surface mining has occurred upstream of the Kennedy Creek watershed. Hence, the upstream decline may be unrelated to the downstream decline and two (or more) factors have acted to devastate the mussel fauna of the entire river.

Besides cattle impacts, we believe two other potential causes for the decline need investigation in both upstream and downstream segments of the Little South Fork: water quality, particularly ground water quality, and the presence of pathogens. Given the condition of the physical habitat, the Little South Fork could serve as a viable system for the re-introduction of native mussels. Before this option is entertained, the problems in the river need to be identified and if possible corrected or mitigated.

Ground water flow is conspicuous along the entire length of the Little South Fork. Springs enter as tributaries, through small caves, or upwell from the channel bottom (personal observations and field notes of D. Henry and W. Poly). Abandoned and active oil wells are numerous in the upper watershed, and oil extraction in the upper segments of the river may have modified ground water quality. As far upstream as the SR 167 bridge, high levels of dissolved solids, such as sodium, chloride, sulfates, iron, and zinc as well as a persistent petrolic slick and sulphurous odor have been noted repeatedly (Harker et al. 1979, 1980, Layzer and Anderson 1992). Harker et al. (1980) stated that oil wells or possibly naturally occurring sulphur springs might be the source of the high dissolved solids, and added "steps should be taken to determine the exact causes, duration, and intensity" of these unusual water quality conditions. We were apprised of the location of one spring (located 420 m downstream of SR 167 bridge) by D. Henry (personal communication) that discharges a milky white, sulphurous precipitant into the river. Vegetation was killed and the ground blackened around the spring head when we observed the area. About 1.6 km downstream of the SR 167 bridge D. Henry (personal communication and field notes) observed abandoned, broken pipes in the stream with exposed rocks and the bottom covered with oil. An oil slick covered the surface and bottom substrates were oil laden for several hundred meters downstream. Further, local residents indicated to us that former freshwater springs had "gone sulfur" in recent years. Adverse changes to water quality may be particularly manifest during periods of storm run-off, when both surface and ground water discharge increases in the Little South Fork. Relying only on base flow sampling may be of little value in diagnosing the water quality problems and determining the cumulative effects on the aquatic fauna of Little South Fork.

During their 1987-88 surveys, Layzer and Anderson (1992) took mussel tissue and sediment samples for analysis from 10 localities along Little South Fork from the SR 167 bridge to Freedom Church Ford. The final report on the tissue and sediment analyses including concentrations of polycyclic aromatic hydrocarbons and aliphatic hydrocarbons was not released until December of 1996 (Robison 1996). For reference, we append a copy of that report and codes for interpretation of sediment and tissue sample locations (Appendix D). Notably, none of the 23 organochlorines (pesticides) analyzed were detected in either sediment or tissue samples (Layzer and Anderson 1992) and of the 24 polycyclic aromatic hydrocarbons analyzed nine were detected only in *Corbicula fluminea*. A number of metals and aliphatic hydrocarbons were recorded in both sediments and mussel tissues along the entire length of the river. Robison (1996) concluded that effects of the aliphatic hydrocarbons found in the mussel samples was uncertain and that some heavy metals may be impacting mussel populations in the Little South Fork. He did not comment on the effects or possible source of the aliphatic hydrocarbons that occurred in sediment samples throughout the river. The aliphatic hydrocarbons found in the Little South Fork sediments are typical constituents of both crude and refined petroleum (Anne Keller, personal communication). Given the normal volatility of these compounds, it is not likely they would persist in the river sediments for long periods unless there was periodic or ongoing release. A comprehensive review and interpretation of these data are beyond the scope of this report, but the data do provide a valuable starting point for determining the source of water quality problems in Little South Fork.

The loss of the mussel fauna upstream of mining activity also could be the result of an unidentified epidemic affecting mussels. At present, we have no evidence for the presence of a pathogen. We note, however, that the pattern of the decline suggests an upstream progression, and one plausible mode of upstream movement of the die-off would be a pathogen transmitted from fishes or other mobile aquatic organisms to freshwater mussels.

We cannot rule out the possibility that toxic substances were dumped into the upper Little South Fork, resulting in a one-time massive kill of freshwater mussels. We believe, however, that three lines of evidence cast doubt on that possibility. First, the extent of the decline would require that a toxic spill would kill mussels over a reach of 25 or more river kilometers. Second, we would expect some evidence of recovery in extant species in the upper river if the decline were related to a single event, and we found no evidence of recovery. Finally, we present evidence that declines in the upper river began before 1987 and have continued to the present. A single toxic spill is not likely to continue to eliminate mussel species over a several year period.

We believe the loss of freshwater mussels in the Little South Fork is the result of exposure to one or more insults over an extended period of time.

The mussel fauna of the Little South Fork has been decimated. Once viable populations of two mussel species protected under the federal Endangered Species Act have been extirpated from the system within the past 10 years. The palezone shiner is also protected under the Endangered Species Act, and one of two remaining populations persists in Little South Fork. The lower 16.7 river kilometers of the Little South Fork are designated under state law as a Kentucky Wild River. One headwater tributary to Little South Fork, Flint Fork, originates in the Pickett State Forest which is managed by the state of Tennessee. In addition, the river forms the western proclamation boundary of the Daniel Boone National Forest with actual federal ownership confined primarily to the ridgetops that define the eastern divide of the watershed. Under requirements of the federal Clean Water Act, the Kentucky Division of Water categorized the aquatic life use support as "Threatened" for the lowermost Little South Fork (KDOW 1998). Surface mining in the watershed is regulated under the federal Surface Mining Control and Reclamation Act administered by the Kentucky Department of Surface Mining and Reclamation. Clearly, an array of state and federal agencies have statutory and regulatory authority over the river and the organisms it supports. The biological integrity of the Little South Fork has been severely compromised despite the river's remoteness, predominately forested watershed, and ostensible protective blanket of state and federal statutes, regulations, and management agencies.

Summary and Recommendations

Our survey data indicate a more severe and spatially extended decline in the mussel fauna of Little South Fork than reported in the 1987-88 survey. The die-off documented for the lower third of the river (Anderson et al. 1991, Layzer and Anderson 1992) and attributed to surface-mining now extends well upstream of Kennedy Creek and known surface-mining activity. We found no living individuals of the little-wing pearly mussel or the cumberland bean and regard these federally listed species as extirpated from the system along with 10 other species of state or national conservation concern. Our analysis of the relict shells indicates species losses in the upper segments of the river likely began prior to the mid-1980s. Losses apparently have continued to the present to reduce overall species richness in the river by two thirds and to reduce numbers of individuals to the point of questionable long-term viability. Recruitment is low or nonexistent for surviving individuals of the nine species persisting in the river.

The Little South Fork, despite the near total loss of the mussel fauna, could serve as a viable re-introduction site for freshwater mussels in the future. The use of the river for re-introductions of native mussels is contingent upon assessing current conditions in the river, identifying problems, and as possible correcting factors that contributed to the observed mussel declines. In concluding, we present a list of recommendations concerning future management actions in the Little South Fork.

- We recommend that the tissue and sediment data of Robison (1996) be re-examined, re-interpreted, and perhaps repeated to identify water quality problems occurring in Little South Fork.

- We recommend that state and federal agencies charter an interdisciplinary scientific team to develop and implement a study to investigate potential sources of toxic substances in surface and ground waters within the watershed and examine mussel specimens for incidence of stress and disease. Based on the findings, the team could evaluate the potential of the river as a re-introduction site for native mussels.
- We recommend that appropriate federal and state agencies coordinate a land-owner contact program within the watershed to educate land owners about the ecological and water quality benefits that can be derived from implementing best management practices in riparian areas. If possible, incentives should be provided to landowners to fence cattle out of the river and to revegetate and restore damaged riparian areas.
- We recommend the recovery plans of *Pegias fabula* and *Villosa trabilis* be re-examined and as necessary revised to reflect the loss of populations in the Little South Fork. The loss of the Little South Fork populations increases the urgency of providing full protection to and accelerating recovery of remaining populations.
- We recommend an interagency task force be implemented to investigate establishment of a fund to mitigate the extirpation of federally listed mussels in Little South Fork. Initiation of a Natural Resource Damage Assessment should be considered. The funds could be used to rehabilitate the mussel fauna of Little South Fork or other priority watersheds in the Cumberland River.
- We recommend any future inventories or status surveys of freshwater mussels conducted under the auspices of state or federal agencies be required to include quantitative sampling techniques (e.g., timed searches or quadrat excavation). Qualitative inventories provide only limited information on the status of the fauna at one point in time and limit assessment of long-term changes in populations.

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Table 1. Collection localities for freshwater mussels in the Little South Fork Cumberland River. Site numbers with a prefix of "PB" or "H" reference habitat unit numbers of Poly (1997; and field notes) and Henry et al. (1998; and field notes), respectively, and indicate mussel sample sites (in bold) of this survey in 1997-98. Sites followed by asterisks denote samples by Anderson et al. (1991) or Layzer and Anderson (1992) and Starnes and Bogan (1982). The Anderson et al. (1991) site number is shown first and as appropriate followed by a slash and the site number of Starnes and Bogan (1982) and Anderson et al. (1991). The " Landmark" column indicates the proximity of each site to bridges, fords, creek mouths, or other named places and is included to facilitate comparison of this and previous mussel surveys of the river. Habitat classification (riffle, run, or pool) and lengths are from Poly (1997; and field notes) and Henry et al. (1998; and field notes).

Site No.	Landmark	Location	Habitat (length)
00/1*	Mt. Pisgah	Mt. Pisgah, Wayne Co., Kentucky (Site 1 of Starnes and Bogan 1982).	Not reported
H-334-344	**SR 167 bridge**	**State Route 167 bridge, Wayne Co. Kentucky. Visual search and relict collection only. Segment I, Relict Collection 1**	**Riffle-Run-Pool Complex (275 m)**
65/2*	SR 167 bridge	"Route 167 bridge", Wayne Co., Kentucky (Site 65 of Layzer and Anderson, 1992, and Site 2 of Starnes and Bogan, 1982).	Not reported
66/3*	Langham bridge (wooden bridge #1)	"At ford, about 0.4 km downstream of Burnett Branch", Wayne Co., Kentucky. (Site 66 of Layzer and Anderson, 1992, and Site 3 of Starnes and Bogan, 1982).[the reference to "Burnett Branch" may actually refer to Langham Branch given mapped locations in Starnes and Bogan 1982 and Anderson et al. 1991].	Not reported
H-427	**Langham bridge (wooden bridge #1)**	**ca. 3,300 m downstream of SR 167 crossing (50 m upstream of Langham Bridge and 1,000 stream meters downstream of mouth of Burnett Branch), Wayne Co., Kentucky. Quantitative samples (3, 3.5-m² transects).**	**Run (130 m)**
H-432-433	**Downstream Langham bridge**	**ca. 3,790 m downstream of SR 167 crossing (360 m downstream of wooden bridge #1, Langham Bridge, and 1,360 m downstream of mouth of Burnett Branch), Wayne Co., Kentucky. Quantitative samples (3, 3.5-m² transects) and timed search (10 person minutes).**	**Riffle (3 m) Run (12 m)**
67/4*	Downstream Langham bridge	"Above farm ford, about 1.6 km downstream of Burnett Branch", Wayne Co., Kentucky. (Site 67 of Layzer and Anderson, 1992, and Site 4 of Starnes and Bogan, 1982),[the reference to "Burnett Branch" may actually refer to Langham Branch given mapped locations in Starnes and Bogan 1982 and Anderson et al. 1991].	Not reported
H-495-498	**Parmleysville**	**ca. 7,753 m downstream of SR 167 crossing (at Parmleysville, ca. 4,403 m downstream of wooden bridge #1, Langham Bridge, and ca. 635 m upstream of wooden bridge #2), Wayne Co., Kentucky. Quantitative samples (6, 3.5-m² transects) and relict collection. Segment I, Relict Collection 2.**	**Run (15 m) Riffle (10 m) Pool-run complex (18 m) Riffle (24 m)**
H-518	**Wooden bridge #2**	**8,682 m downstream of SR 167 crossing (ca. 294 m downstream of wooden bridge #2 and 928 m downstream of ford at Parmleysville), Wayne Co., Kentucky. Quantitative samples (5, 3.5-m² transects), timed visual search (25 person minutes) and relict collection. Segment I, Relict Collection 3.**	**Run (51 m)**
68*	Wooden bridge #2 ?	"Lonesome Road Ford", Wayne Co., Kentucky	Not reported
H-564-571	**Lonesome Cr.**	**ca. 1,960 m upstream of Green Ford at mouth of Lonesome Creek, Wayne Co., Kentucky. Timed visual search (178 person minutes) and relict collection.**	**Pool (213 m) Riffle-Run complex (104 m)**
69/5*	Green Ford	"Green Church Ford", Wayne Co., Kentucky. (Site 69 of Layer and Anderson, 1992, and Site 5 of Starnes and Bogan, 1982).	Not reported
PB-7	**downstream Stillhouse Hollow**	**ca. 1,050 m downstream of Green Ford, Wayne Co., Kentucky. Quantitative samples (2, 3.5-m² transects).**	**Run (58 m)**
PB-8	**downstream Stillhouse Hollow**	**ca. 1,208 m downstream of Green Ford, Wayne Co., Kentucky. Quantitative samples (2, 3.5-m² transects).**	**Riffle (64 m)**
PB-11-12	**downstream Stillhouse Hollow**	**ca. 1,272 m and 1,285 m downstream of Green Ford, Wayne Co., Kentucky. Quantitative samples (5, 3.5-m² transects).**	**Run (13 m)**
PB-26-27	**upstream Steele Hollow bridge**	**ca. 2,134 m and 2,163 m downstream of Green Ford, Wayne Co., Kentucky. Quantitative samples (5, 3.5-m² transects).**	**Riffle (29 m) Run (186 m)**
70*	upstream Steele Hollow bridge	"Upstream of bridge at Griffin", Wayne Co., Kentucky. (Site 70 of Layzer and Anderson, 1992). Griffin is Steele Hollow Road bridge of Poly (1997).	Not reported
PB-59	**downstream Steele Hollow bridge**	**ca. 600 m downstream of Steele Hollow Road bridge, Wayne Co., Kentucky. Quantitative samples (5, 3.5-m² transects) and relict collection. Segment II, Relict Collection 1.**	**Riffle (86 m)**

PB-59	**downstream Steele Hollow bridge**	**ca. 600 m downstream of Steele Hollow Road bridge, Wayne Co., Kentucky. Quantitative samples (5, 3.5-m^2 transects) and relict collection. Segment II, Relict Collection 1.**	**Riffle (86 m)**
PB-60	**downstream Steele Hollow bridge**	**ca. 686 m downstream of Steele Hollow Road bridge, Wayne Co., Kentucky. Quantitative samples (2, 3.5-m^2 transects) and relict collection. Segment II, Relict Collection 1.**	**Run (30 m)**
PB-79	**upstream Dobbs Hollow**	**ca. 3,380 m downstream of Steele Hollow Road bridge, Wayne Co., Kentucky. Quantitative samples (4, 3.5-m^2 transects) and relict collection. Segment II, Relict Collection 2.**	**Run (99 m)**
PB-85	**upstream Dobbs Hollow**	**ca. 4,183 m downstream of Steele Hollow Road bridge, Wayne Co., Kentucky. Quantitative samples (2, 3.5-m^2 transects) and relict collection. Segment II, Relict Collection 3.**	**Run (41 m)**
71*	Bell Hill	"Bell Hill, about 1.6 km upstream of Kennedy Creek", Wayne Co., Kentucky. (Site 71 of Layzer and Anderson 1992).	Not reported
PB-140-142	**Bell Hill**	**ca. 1,680 m upstream of Baldy Road bridge, Wayne Co. Kentucky. Baldy Road bridge is a few meters downstream of the mouth of Kennedy Creek (Poly 1997). Timed search (183 person minutes) with substrate disturbance and relict collection. Segment II, Relict Collection 4.**	**Run (17 m) Riffle (43 m) Run (57 m)**
PB-150	**upstream Kennedy Cr.**	**ca. 786 m upstream of Baldy Road bridge, Wayne Co. Kentucky. Baldy Road bridge is a few meters downstream of the mouth of Kennedy Creek (Poly 1997). Quantitative samples (2, 3.5-m^2 transects) and relict collection. Segment II, Relict Collection 5.**	**Run (180 m)**
PB-153	**upstream Kennedy Cr.**	**ca. 580 m m upstream of Baldy Road bridge, Wayne Co. Kentucky. Baldy Road bridge is a few meters downstream of the mouth of Kennedy Creek (Poly 1997).Quantitative samples (2, 3.5-m^2 transects) and relict collection. Segment II, Relict Collection 5.**	**Riffle (91 m)**
72/6*	Kennedy Cr.	"Kennedy Creek...near confluence with Little South Fork...", Wayne Co., Kentucky. (Site 72 of Layzer and Anderson 1992 and Site 6 of Starnes and Bogan 1982).	Not reported
Kennedy Creek	**Kennedy Cr.**	**Kennedy Creek from mouth to ca. 300 m upstream, Wayne Co., Kentucky. Timed search (40 person minutes) and relict collection.**	**Not recorded**
73/7*	downstream Kennedy Cr.	"Downstream of confluence with Kennedy Creek", Wayne Co., Kentucky. (Site 73 of Layzer and Anderson 1992 and Site 7 of Starnes and Bogan 1982).	Not reported
PB-172	**Burkes Cr.**	**ca. 2,089 m downstream of Baldy Road bridge, Wayne Co., Kentucky. Baldy Road bridge is a few meters downstream of the mouth of Kennedy Creek (Poly 1997). Quantitative samples (4, 3.5-m^2 transects) and relict collection. Segment III, Relict Collection 1.**	**Run (124 m)**
PB-173	**Burkes Cr.**	**ca. 2,222 m downstream of Baldy Road bridge, Wayne Co., Kentucky. Baldy Road bridge is a few meters downstream of the mouth of Kennedy Creek (Poly 1997). Quantitative samples (4, 3.5-m^2 transects) and relict collection. Segment III, Relict Collection 1.**	**Riffle (79 m)**
74*	Kidds Br.	"First riffle upstream of Kidds Branch", Wayne and McCreary counties., Kentucky. (Site 74 of Layzer and Anderson, 1992).	Riffle
75*	Kidds Br.	"First riffle downstream of Kidds Branch", Wayne and McCreary counties., Kentucky. (Site 75 of Layzer and Anderson, 1992).	Riffle
PB-190	**downstream Kidds Br.**	**ca. 1,137 m upstream of SR 92 bridge, Wayne and McCreary counties, Kentucky. Quantitative samples (3, 3.5-m^2 transects) and relict collection. Segment III, Relict Collection 2.**	**Riffle (27 m)**
PB-203-204	**SR 92 bridge**	**ca. 129 m upstream of SR 92 bridge, Wayne and McCreary counties, Kentucky. Quantitative samples (3, 3.5-m^2 transects) and relict collection Segment III, Relict Collection 2.**	**Riffle (43 m)**
76/8*	SR 92 bridge	"Route 92 bridge", Wayne and McCreary counties, Kentucky. (Site 76 of Layzer and Anderson, 1992, and Site 8 of Starnes and Bogan, 1982).	Not reported
77/9*	downstream SR 92 bridge	"LSFkm 21.3", Wayne and McCreary counties, Kentucky. (Site 77 of Layzer and Anderson, 1992, and Site 9 of Starnes and Bogan, 1982).	Not reported
78/10*	downstream SR 92 bridge	"LSFkm 20.5", Wayne and McCreary counties, Kentucky. (Site 78 of Layzer and Anderson, 1992, and Site 10 of Starnes and Bogan, 1982).	Not reported
79/11*	Bakers Br.	"LSFkm 19.6", at mouth Bakers Branch, Wayne and McCreary counties, Kentucky. (Site 79 of Layzer and Anderson, 1992, and Site 11 of Starnes and Bogan, 1982).	Not reported

80/12*	upstream Jones School	"LSFkm 17.8", Wayne and McCreary counties, Kentucky. (Site 80 of Layzer and Anderson, 1992, and Site 12 of Starnes and Bogan, 1982).	Not reported
81/13*	Jones School	"Kidd Crossing Ford (LSFkm 16.8)", Wayne and McCreary counties, Kentucky. (Site 81 of Layzer and Anderson, 1992, and Site 13 of Starnes and Bogan, 1982).	Not reported
PB-237-238	**Jones School**	**ca. 6,100 m downstream of SR 92 bridge, Wayne and McCreary counties, Kentucky. Quantitative samples (3, 3.5-m^2 transects) and relict collection. Segment IV, Relict Collection 2.**	**Riffle (20 m) Run (47)**
PB-242-244	**Jones School**	**ca. 6,256 m downstream of SR 92 bridge, Wayne and McCreary counties, Kentucky. Quantitative samples (3, 3.5-m^2 transects) and relict collection. Segment IV, Relict Collection 2.**	**Run (19 m) Riffle (20 m) Run (13 m)**
82/14*	Ritner Ford	"Ritner Ford LSFkm 13.2", Wayne and McCreary counties, Kentucky. (Site 82 of Layzer and Anderson, 1992, and Site 14 of Starnes and Bogan, 1982).	Not reported
PB-292	**Ritner Ford**	**First riffle upstream of Ritner Ford, Wayne and McCreary counties, Kentucky. Quantitative samples (4, 3.5-m^2 transects) and relict collection. Segment IV, Relict Collection 3.**	**Riffle (49 m)**
83/15*	Roberts Hollow	"Roberts Hollow LSFkm 10.6", Wayne and McCreary counties, Kentucky. (Site 83 of Layzer and Anderson, 1992, and Site 15 of Starnes and Bogan, 1982).	Not reported
84/16*	Freedom Church Ford	"Freedom Church Ford LSFkm 8.5" Wayne and McCreary counties, Kentucky. (Site 84 of Layzer and Anderson, 1992, and Site 16 of Starnes and Bogan, 1982).	Not reported
Freedom Church Ford	**Freedom Church Ford**	**ca. 300 meters downstream of Freedom Church Ford (second riffle downstream of ford), Wayne and McCreary counties, Kentucky. Quantitative samples (3, 3.5-m^2 transects), timed visual search (15 person minutes) and relict collection. Segment IV, Relict Collection 4.**	**Riffle**

Table 2. Results of freshwater mussel survey from Little South Fork Cumberland River, Wayne and McCreary Co., KY. Only observations of live individuals are included. All sites were sampled quantitatively (two or more 3.5-m^2 transects) unless otherwise noted. Complete localities referenced by site numbers are given in Table 1.

Segment I: State Route 167 bridge to upstream of Green Ford

Species	Site					
	SR167 bridge H-334-344*	Langham bridge H-427	downstrm Langham bridge H-432-433	Parmleysville H-495-498	bridge #2 H-518	Lonesome Cr. H-564-571**
Lampsilis fasciola wavy-rayed lampmussel	0	1	1	1	1	2
Ptychobranchus subtentum fluted kidneyshell	0	0	0	0	2	1
Villosa iris rainbow	0	0	0	0	2	0
V. taeniata painted creekshell	1*	7	22	2	2	5
Total individuals	1	8	23	3	7	8
Area sampled (m^2)	NA*	10.5	10.5	21	17.5	NA**
Mussel density (no./m^2)	NA*	0.8	2.2	0.1	0.4	NA**

*Visual search

**Timed Visual Search (178 person minutes)

Table 2. cont.

Segment II: Green Ford to mouth of Kennedy Creek (Baldy Road bridge)

Species	Site				
	downstm Stillhouse Hollow PB-7	downstm Stillhouse Hollow PB-11&12		upstm Steele Hollow PB-26&27	downstm Steele Hollow PB-59
Lampsilis fasciola wavy-rayed lampmussel	0	10		0	2
Medionidus conradicus Cumberland moccasinshell	0	0 (1)*	2	0	3
Pleurobema oviforme Tennessee clubshell	0	0	0	0 (1)*	0
Ptychobranchus fasciolaris kidneyshell	0	0	0	0	0 (1)*
Ptychobranchus subtentum fluted kidneyshell	0	0	23	1	6
Villosa iris rainbow	0	1	1	0	0 (1)*
V. taeniata painted creekshell	1	0 (2)*	14	4	24
Total individuals	1	1	50	5	35
Area sampled (m^2)	7.0	7.0	17.5	17.5	17.5
Mussel density (no./m^2)	0.1	0.1	2.9	0.3	2.0

*live individual(s) observed outside transects.

Segment II: Green Ford to mouth of Kennedy Creek (Baldy Road bridge) cont.

Species	Site						
	downstm Steele Hollow PB-60	upstm Dobbs Hollow PB-79	upstm Dobbs Hollow PB-85	Bell Hill PB-140-142**	upstm Kennedy Cr. PB-150	upstm Kennedy Cr. PB-153	Kennedy Cr.***
Lampsilis fasciola wavy-rayed lampmussel	0 (1)*	0	0	2	0	0	0
Medionidus conradicus Cumberland moccasinshell	0	0	0	12	0	0	0
Ptychobranchus subtentum fluted kidneyshell	1	0	0	5	0	0	0
Villosa iris rainbow	0	0	0	7	0	0	0
V. taeniata painted creekshell	5	0	0 (1)*	5	1	0	0
Total individuals	6	0	0	31	1	0	0
Area sampled (m^2)	7.0	14.0	7.0	NA**	7.0	7.0	NA***
Mussel density (no./m^2)	0.9	0	0	NA*	0.1	0	NA**

* Live individual(s) observed outside transects;**timed visual and substrate disturbance search (183 person minutes); *** timed visual search (40 person minutes).

T le 2. cont.
  ment III: Downstream of Kennedy Creek (Baldy Road bridge) to State Route 92 bridge

Species	Site			
	Burkes Cr. PB-172	Burkes Cr. PB-173	downstm Kidds Br. PB-190	SR 92 bridge PB-203-204
Lampsilis fasciola wavy-rayed lampmussel	0	1	0	0
Medionidus conradicus Cumberland moccasinshell	0	1	0	0
Ptychobranchus subtentum fluted kidneyshell	1	10	0	0
Villosa taeniata painted creekshell	1	1	0	0
Total individuals	2	13	0	0
Area sampled (m^2)	14.0	14.0	10.5	10.5
Mussel density (no./m^2)	0.1	0.9	0	0

T-ble 2. cont.

Segment IV: Downstream of State Route 92 bridge to downstream of Freedom Church Ford

Species	Site				
	Bakers Br. PB-212-213	Jones School PB-237-238	Jones School PB-242-244	Ritner Ford PB-292	Freedom Church Ford
Actinonaias pectorosa pheasantshell	0	0	1	0	0
Lampsilis fasciola wavy-rayed lampsmussel	0	2	0	0	0 (2)*
Potamilus alatus pink heelsplitter	0 (2)*	0	0	0	0
Ptychobranchus subtentum fluted kidneyshell	0	3	4	0	0
Ptychobranchus fasciolaris kidneyshell	0 (1)*				0 (1)*
Total individuals	0	5	5	0	0
Area sampled (m^2)	10.5	10.5	10.5	14	10.5
Mussel density (no./m^2)	0	0.5	0.5	0	0

*Live individual(s) observed outside transects.

Table 3. Summary of numbers of individuals, density, and percent abundance of freshwater mussels in 1997-98 in four segments of the Little South Fork Cumberland River, Wayne and McCreary counties, Kentucky. Tabled entries include the number of individuals taken in transect sampling and in parentheses the number of individuals found in visual searches followed by the numbers observed outside of transects. Mean densities were calculated from site specific densities in that respective segment; "n" is the number of sites sampled, and "SE", the standard error of the mean. Percent abundance is calculated from all individuals encountered. Segment numbers correspond to: I - SR 167 bridge to upstream of Green Ford; II - Green Ford to mouth of Kennedy Cr.; III - downstream of Kennedy Cr. to SR 92 bridge; and IV - downstream of SR 92 bridge to Freedom Church Ford.

Species	Segment				Total	Percent
	I	II	III	IV		Abundance
Actinonaias pectorosa	-	-	-	1	2	<1
pheasantshell				(0,1)		
Lampsilis fasciola	4	12	1	2	30	13
wavy-rayed lampmussel	(2,4)	(2,0)	(0,0)	(2,1)		
Pleurobema oviforme	-	0	-	-	1	<1
Tennessee clubshell		(0,1)				
Potamilus alatus	-	-	-	0	2	<1
pink heelsplitter				(0,2)		
Ptychobranchus subtentum	3	31	11	6	58	25
fluted kidneyshell	(0,1)	(5,0)	(0,0)	(1,0)		
Ptychobranchus fasciolaris	-	-	-	0	2	<1
kidneyshell				(1,1)		
Medionidus conradicus	-	5	1	-	18	8
Cumberland moccasinshell		(12,0)	(0,0)			
Villosa iris	2	2	-	-	12	5
rainbow	(0,1)	(6,0)				
Villosa taeniata	33	49	2	-	111	47
painted creekshell	(8,11)	(5,3)	(0,0)			
Total	42	99	15	9	236	
	(10,17)	(30,3)	(0,0)	(4,5)		
Mean Density (no. m^{-2})	0.88	0.64	0.25	0.20		
(SE)	(0.464)	(0.320)	(0.218)	(0.123)		
n	4	10	4	5		

Table 4. Mean lengths (mm) and length variation of live freshwater mussels in 1997-98 in Little South Fork Cumberland River, Wayne and McCreary counties, Kentucky. Table entries include sample size (N), minimum length (Min.), maximum length (Max.), mean length, standard deviation (SD), standard error of the mean (SE), and coefficient of variation (CV).

Species	N	Min.	Max.	Mean	SD	SE	CV
Actinonaias pectorosa **pheasantshell**	2	100	104	102.0	nd	nd	n
Lampsilis fasciola **wavy-rayed lampmussel**	30	45	90	62.0	12.551	2.29	20.3
Potamilus alatus **pink heelsplitter**	2	127	146	136.5	nd	nd	nd
Ptychobranchus subtentum **fluted kidneyshell**	58	38	89	54.7	11.512	1.51	21.1
Ptychobranchus fasciolaris **kidneyshell**	2	89	101	95.0	nd	nd	nd
Medionidus conradicus **Cumberland moccasinshell**	18	31	41	36.6	3.342	0.79	9.1
Villosa iris **rainbow**	12	34	55	43.2	6.555	1.89	15.2
Villosa taeniata **painted creekshell**	111	38	78	52.8	7.327	0.70	13.9

Table stribution and percent relative abundance of relict freshwater mussels collected in 1997 .n Little South Fork Cumberland River. Relict shell collection sites are presented in an ups: to downstream sequence. Segment numbers (Roman numerals) reference: I - SR 167 bridge to upstream of Green Ford; II - Green Ford to mouth of Kennedy Cr.; III - downstream of Kennedy Cr. to SR 92 bridge; and IV - SR 92 bridge to Freedom Church Ford. Complete locality information for relict collections is given in Table 1. Species are listed by the collection of first occurrence. "L" indicates one or more live individuals were found in 1997-98 surveys. Species loss is estimated as the number of relict only species divided by the total species richness (x 100).

Species / Segment No.	I-1	I-2	I-3	I-4	II-1	II-2	II-3	II-4	II-5	III-1	III-2	IV-1	IV-2	IV-3	IV-4
Alasmidonta viridis	40	<1	<1	-	-	<1	-	1	<1	-	-	-	-	-	-
Lasmigona costata	7	<1	2	1	<1	3	<1	3	1	14	9	7	4	6	4
Medionidus conradicus	7	1	3	4	3 L	1	<1	25 L	2	7 L	3	4	2	-	-
Villosa taeniata	46 L	54 L	34 L	38 L	33 L	31	25	17 L	21 L	5 L	22	11	6	20	9
Lampsilis cardium		<1	3	<1	2	4	6	1	-	-	3	6	2	3	1
Lampsilis fasciola		13 L	25 L	16 L	19 L	22	21	6 L	11	5 L	16	8	18 L	15	7 L
Obovaria subrotunda		3	3	2	3	10	9	3	5	5	4	7	9	9	6
Pleurobema oviforme		1	3	1	2 L	3	2	6	12	7	2	3	2	-	1
Ptychobranchus fasciolaris		<1	2	7	11 L	4	5	3	20	38	13	11 L	13	6	8 L
Ptychobranchus subtentum		4	6 L	17 L	17 L	9	11	13 L	12	12 L	9	9	14 L	17	19
Toxolasma lividus		5	2	1	<1	2	2	3	4	2	3	1	4	3	2
Villosa iris		6	8 L	7	4 L	3	1	3 L	3	-	1	2	3	3	10
Villosa trabilis		8	10	4	3	3	10	4	6	-	2	2	2	3	6
Actinonaias pectorosa				<1	-	-	-	-	-	-	-	-	1 L	-	-
Elliptio dilatata				<1	-	1	<1	1	-	-	1	4	5	12	13
Pegias fabula					2	<1	-	10	<1	-	<1	2	1	-	2
Potamilus alatus						5	3	1	<1	5	11	24 L	12	3	8
Ligumia recta								1	-	-	-	-	-	-	-
Leptodea fragilis											<1	<1	<1	-	1
Actinonaias ligmentina												<1	1	-	-
Alasmidonta marginata												<1	<1	-	1
Villosa lienosa												<1	-	-	1
Total Species	4	13	13	14	13	16	14	17	14	10	16	19	19	12	17
Species Loss (%)	75%	85%	69%	79%	46%	100%	100%	71%	93%	60%	100%	89%	89%	100%	88%

Table 6. Number of relict shells collected in upstream to downstream gradient sections of the Little South Fork Cumberland River, Wayne and McCreary counties, Kentucky. Actual numbers collected have been adjusted to reflect number of shells per meter of the river searched. Gradient section refers to the location of relict shell collecting sites relative to stream gradient as indicated by 20-ft contour intervals of 1:24000 topographic maps.

Collection Locations	Gradient Section	Total Shells (meters searched)	Relict shells m^{-1}	
Parmleysville	1	238 (67)	3.5522	
Wooden Bridge # 2	2	268 (294)	0.9116	**Mean (Section 1 and 2) = 2.2 shells m^{-1} (SE = 0.57)**
Lonesome Cr.	2	170 (104)	1.6346	
Downstream Steele Hollow bridge	2	296 (116)	2.5517	
upstream Dobbs Hollow	3	196 (99)	1.9797	
upstream Dobbs Hollow	3	391 (41)	9.5366	**Mean (Section 3) = 4.1 shells m^{-1} (SE = 2.72)**
Bell Hill	3	104 (117)	0.8889	
upstream Kennedy Cr.	4	206 (271)	0.7601	
mouth Burkes Cr.	4	42 (203)	0.2069	**Mean (Section 4) = 1.7 shells m^{-1} (SE = 1.19)**
downstream Kidds Br. to SR 92 bridge	4	429 (1008)	0.4256	
mouth Bakers Br.	4	325 (62)	5.24	
Jones School	5	192 (208)	0.9231	
Ritner Ford	6	34 (49)	0.6939	**Mean (Section 5-7) = 0.6 shells m^{-1} (SE = 0.18)**
Freedom Church Ford	7	90 (300)	0.3000	

Table 7. Comparisons of percent relative abundances of live freshwater mussels and relict shells of freshwater mussels in Little South Fork Cumberland River, Kentucky. Sites are presented in an upstream to downstream sequence. Unless otherwise noted, only live individuals from quantitative samples (2 or more 3.5-m^2 transects/site) are included in percent abundance estimates. Percent relative abundances less than 1 percent are indicated by "tr". Complete localities referenced by site number are given in Table 1.

Segment I: State Route 167 bridge to upstream of Green Ford

Species	I-1 SR 167 bridge H-334-344		I-2 Langham Bridge to Parmleysville H-427, H-432-433 and H-495 thru H-498		I-3 Bridge #2 H-518		I-4 Lonesome Cr. H-564 thru H-571	
	LIVE	RELICT	LIVE	RELICT**	LIVE	RELICT	LIVE	RELICT
Alasmidonta viridis	0	40	0	tr	0	tr	0	0
Actinonaias pectorosa	0	0	0	0	0	-	0	tr
Elliptio dilatata	0	0	0	0	0	-	0	tr
Lampsilis cardium	0	0	0	tr	0	3	0	tr
Lampsilis fasciola	0	0	9	13	13*	25	25	16
Lasmigona costata	0	7	0	tr	0	2	0	1
Medionidus conradicus	0	7	0	1	0	3	0	4
Obovaria subrotunda	0	0	0	3	0	3	0	2
Pegias fabula	0	0	0	0	0		0	0
Pleurobema oviforme	0	0	0	1	0	3	0	1
Potamilus alatus	0	0	0	0	0		0	0
Ptychobranchus fasciolaris	0	0	0	tr	0	2	0	7
Ptychobranchus subtentum	0	0	0	4	29	6	13*	17
Toxolasma lividus	0	0	0	5	0	2	0	1
Villosa iris	0	0	0	6	29	8	0	7
Villosa taeniata	100*	46	91	54	29	34	62	38
Villosa trabilis	0	0	0	8	0	10	0	4
Total Species	1	4	2	13	4	13	3	14

*only one live individual found.
**relict collection from Parmleysville only.

Table 7. cont.

Segment II: Green Ford to mouth of Kennedy Creek (Baldy Road bridge)

Species	II-1 downstrm Steele Hollow PB-59 & PB-60		II-2 upstrm Dobbs Hollow PB-79		II-3 upstm Dobbs Hollow PB-85		II-4 Bell Hill PB-140 thru PB-142		II-5 upstm Kennedy Cr. PB-150 & PB-153		Kennedy Cr.	
	LIVE	RELICT	LIVE	RELICT	LIVE	RELICT	LIVE	RELICT	LIVE	RELICT	LIVE	RELICT
Alasmidonta viridis	0	0	0	tr	0	-	0	1	0	tr	0	0
Elliptio dilatata	0	0	0	1	0	tr	0	1	0	0	0	0
Lampsilis cardium	0	2	0	4	0	6	0	1	0	0	0	0
Lampsilis fasciola	5	19	0	22	0	21	6	6	0	11	0	2
Lasmigona costata	0	tr	0	3	0	tr	0	3	0	1	0	0
Ligumia recta	0	0	0	0	0	0	0	1	0	0	0	0
Medionidus conradicus	7	3	0	1	0	tr	39	25	0	2	0	36
Obovaria subrotunda	0	3	0	10	0	10	0	3	0	5	0	0
Pegias fabula	0	2	0	tr	0	0	0	10	0	tr	0	2
Pleurobema oviforme	0	2	0	3	0	2	0	6	0	12	0	0
Potamilus alatus	0	0	0	5	0	3	0	1	0	tr	0	0
Ptychobranchus fasciolaris	0	11	0	4	0	5	0	3	0	20	0	0
Ptychobranchus subtentum	17	17	0	9	0	11	16	13	0	12	0	7
Toxolasma lividus	0	tr	0	2	0	2	0	3	0	4	0	0
Villosa iris	0	4	0	3	0	1	23	3	0	3	0	12
Villosa taeniata	71	33	0	31	0	25	16	17	100*	21	0	31
Villosa trabilis	0	3	0	3	0	10	0	4	0	6	0	10
Total Species	4	13	0	16	0	14	5	17	1	14	0	7

*only one live individual found in quantitative samples.

Table 7. cont.

Segment III: Downstream of Kennedy Creek (Baldy Road bridge) to State Route 92 bridge

Species	III-1 Burkes Cr. PB-172 & PB-173		III-2 downstm Kidds Br. to SR92 bridge PB-190 & PB-203-304	
	LIVE	RELICT	LIVE	RELICT
Alasmidonta viridis	0	0	0	0
Elliptio dilatata	0	0	0	1
Lampsilis cardium	0	0	0	3
Lampsilis fasciola	7*	5	0	16
Lasmigona costata	0	14	0	9
Leptodea fragilis	0	0	0	tr
Medionidus conradicus	7*	7	0	3
Obovaria subrotunda	0	5	0	4
Pegias fabula	0	0	0	tr
Pleurobema oviforme	0	7	0	2
Potamilus alatus	0	5	0	11
Ptychobranchus fasciolaris	0	38	0	13
Ptychobranchus subtentum	73	12	0	9
Toxolasma lividus	0	2	0	3
Villosa iris	0	0	0	1
Villosa taeniata	13	5	0	22
Villosa trabilis	0	0	0	2
Total Species	4	10	0	16

*only one live individual found in quantitative samples
**individuals observed outside transects

Table 7. cont.

Segment IV: Downstream of State Route 92 bridge to downstream of Freedom Church Ford

Species	IV- 1 Bakers Br. PB-212 & PB-213		IV-2 Jones School PB-237 & PB-238, PB-242 thru 244		IV-3 Ritner Ford PB-292		IV-4 Freedom Church Ford	
	LIVE	RELICT	LIVE	RELICT	LIVE	RELICT	LIVE	RELICT
Actinonaias ligamentina	0	tr	0	1	0	0		1
Actinonaias pectorosa	0	0	10*	1	0	0	0	0
Alasmidonta marginata	0	tr	0	tr	0	0		1
Alasmidonta viridis	0	0	0	0	0	0	0	0
Elliptio dilatata	0	4	0	5	0	12	0	13
Lampsilis cardium	0	6	0	2	0	3	0	1
Lampsilis fasciola	0	8	20	18	0	15	0**	7
Lasmigona costata	0	7	0	4	0	6	0	4
Leptodea fragilis	0	tr	0	tr	0	0		1
Medionidus conradicus	0	4	0	2	0	0	0	6
Obovaria subrotunda	0	7	0	9	0	9	0	2
Pegias fabula	0	2	0	1	0	0	0	0
Pleurobema oviforme	0	3	0	2	0	0	0	1
Potamilus alatus	0**	24	0	12	0	3	0	8
Ptychobranchus fasciolaris	0**	11	0	13	0	6	0**	8
Ptychobranchus subtentum	0	9	70	14	0	17	0	19
Toxolasma lividus	0	1	0	4	0	3	0	2
Villosa iris	0	2	0	3	0	3	0	10
Villosa lienosa	0	tr	0		0	0	0	1
Villosa taeniata	0	11	0	6	0	20	0	9
Villosa trabilis	0	2	0	2	0	3	0	6
Total Species	2	19	3	19	0	12	2	18

*only one live individual found in quantitative samples, **live individual(s) observed outside transects

Table 8. Comparison of the presence of live individuals (L) and relict shells (R) of freshwater mussel species collected in 1997-98 (shown as bold) with live and relict shells collected in 1987-88 by Layzer and Anderson (1992) in Little South Fork Cumberland River, Kentucky. Collection sites are arranged in an upstream to downstream sequence. Complete localities referenced by site number are given in Table 1.

Segment I: State Route 167 bridge to upstream of Green Ford

	Site Numbers and Dates							
Species	SR 167 bridge 65/2 1987-88	**SR 167 bridge H-334-344 1997-98**	Langham bridge 66/3 1987-88	downstm Langham bridge 67/4 1987-88	**Langham bridge to Parmleysville H-427, H-432-433 to H-495-498 1997-98**	Bridge #2? 68 1987-88	**Bridge #2 H-518 1997-98**	**Lonesome Cr. H-564-571 1997-98**
Actinonaias pectorosa	-	-	-	-	-	-	-	**R**
Alasmidonta viridis	R	**R**	-	-	**R**	-	**R**	-
Elliptio dilatata	-	-	-	-	-	-	-	**R**
Lampsilis cardium	-	-	-	R	**R**	-	**R**	**R**
Lampsilis fasciola	-	-	-	L	**L**	-	**L**	**L**
Lasmigona costata	-	**R**	-	-	**R**	-	**R**	**R**
Medionidus conradicus	-	**R**	-	R	**R**	-	**R**	**R**
Obovaria subrotunda	-	-	-	R	**R**	-	**R**	**R**
Pegias fabula	-	-	-	-	-	-	-	-
Pleurobema oviforme	-	-	-	R	**R**	-	**R**	**R**
Potamilus alatus	-	-	-	L	-	-	-	-
Ptychobranchus fasciolaris	-	-	-	L	**R**	-	**R**	**R**
Ptychobranchus subtentum	-	-	-	L	**R**	-	**L**	**L**
Toxolasma lividus	-	-	-	-	**R**	R	**R**	**R**
Villosa iris	-	-	-	L	**R**	-	**L**	**R**
Villosa taeniata	R	**L**	R	L	**L**	L	**L**	**L**
Villosa trabilis	-	-	-	L	**R**	R	**R**	**R**
Total Live Species	0	**1**	0	7	**2**	1	**4**	**3**
Total Relict Species	2	**3**	1	4	**11**	2	**9**	**11**
Percent species loss	100%	**75%**	100%	36%	**85%**	66%	**69%**	**79%**

Table 8. cont. **Segment II: Green Ford to mouth of Kennedy Creek (Baldy Road bridge)**

Species	Green Ford 69/5 1987-88	**downstm Stillhouse Hollow to upstm Steele Hollow bridge PB-7,8,11,12,26,27 1997-98**	upstm Steele Hollow bridge 70 1987-88	**downstm Steele Hollow bridge to upstrm Dobbs Hollow PB-59,60,79,85 1997-98**
Alasmidonta viridis	-	-	R	**R**
Elliptio dilatata	-	-	-	**R**
Lampsilis cardium	-	-	L	**R**
Lampsilis fasciola	R	**L**	L	**L**
Lasmigona costata	L	-	R	**R**
Medionidus conradicus	-	**L**	R	**L**
Obovaria subrotunda	-	-	L	**R**
Pegias fabula	-	-	L	**R**
Pleurobema oviforme	-	**L***	R	**R**
Potamilus alatus	-	-	R	**R**
Ptychobranchus fasciolaris	-	-	L	**L**
Ptychobranchus subtentum	-	**L**	L	**L**
Strophitus undulatus	-	-	R	-
Toxolasma lividus	-	-	-	**R**
Villosa iris	R	**L**	L	**R**
Villosa taeniata	-	**L**	L	**L**
Villosa trabilis	L	-	R	**R**
Utterbackia imbecillus	-	-	-	-
Total Live Species	2	**6**	8	**5**
Total Relict Species	2	**nd**	7	**11**
Percent species loss	50%	**nd**	47%	**69%**

*one live individual found outside transects

Table 8. cont. **Segment II cont.: Green Ford to mouth of Kennedy Creek (Baldy Road bridge)**

Species	Bell Hill 71 1987-88	**Bell Hill PB-140-142 1997-98**	**upstm Kennedy Cr. PB-150,153 1997-98**	Kennedy Cr. 72/6 1987-88	**Kennedy Cr. 1997-98**
Alasmidonta viridis	-	**R**	**R**	R	-
Elliptio dilatata	-	**R**	-	-	-
Lampsilis cardium	-	**R**	-	R	-
Lampsilis fasciola	L	**L**	**R**	L	**R**
Lasmigona costata	-	**R**	**R**	-	-
Medionidus conradicus	L	**L**	**R**	R	**R**
Obovaria subrotunda	R	**R**	**R**	-	-
Pegias fabula	L	**R**	**R**	-	**R**
Pleurobema oviforme	L	**R**	**R**	R	-
Potamilus alatus	-	**R**	**R**	-	-
Ptychobranchus fasciolaris	R	**R**	**R**	-	-
Ptychobranchus subtentum	L	**L**	**R**	R	**R**
Toxolasma lividus	R	**R**	**R**	L	-
Villosa iris	L	**L**	**R**	L	**R**
Villosa taeniata	L	**L**	**L**	L	**R**
Villosa trabilis	R	**R**	**R**	R	**R**
Utterbackia imbecillus	R	-	-	-	-
Total Live Species	7	**5**	**1**	4	**0**
Total Relict Species	5	**11**	**13**	6	**7**
Percent species loss	42%	**69%**	**93%**	60%	**100%**

Table 8. cont. **Segment III: Downstream of Kennedy Creek (Baldy Road bridge) to State Route 92 bridge**

Species	downstm Kennedy Cr. 73/7 1987-88	**Burkes Cr. PB-172,173 1997-98**	Kidds Br. 74 & 75 1987-88	**downstm Kidds Br. & SR 92 bridge PB-190,203,204 1997-98**	SR 92 bridge 76\8 1987-88
Alasmidonta marginata	-	-	-	-	R
Alasmidonta viridis	-	-	-	-	R
Elliptio dilatata	-	-	-	**R**	R
Lampsilis cardium	-	-	L	**R**	R
Lampsilis fasciola	R	**L**	R	**R**	R
Lasmigona costata	-	**R**	R	**R**	L
Leptodea fragilis	-	-	R	**R**	R
Medionidus conradicus	-	**L**	R	**R**	R
Obovaria subrotunda	-	**R**	R	**R**	R
Pegias fabula	-	-	R	**R**	R
Pleurobema oviforme	R	**R**	R	**R**	R
Potamilus alatus	-	**R**	R	**R**	R
Ptychobranchus fasciolaris	-	**R**	L	-	L
Ptychobranchus subtentum	R	**L**	L	**R**	L
Strophitus undulatus	-	-	-	-	R
Toxolasma lividus	-	**R**	R	**R**	R
Villosa iris	R	-	L	**R**	L
Villosa lienosa	-		-	-	R
Villosa taeniata	R	**L**	L	**R**	R
Villosa trabilis	R	-	R	**R**	R
Total Live Species	0	**4**	5	**0**	4
Total Relict Species	6	**6**	10	**9**	16
Percent species loss	100%	**60%**	66%	**100%**	75%

*live individuals found outside transects

Table 8. cont. **Segment IV: Downstream of State Route 92 bridge to downstream of Freedom Church Ford**

Species	downstm SR 92 77/9 & 78/10 1987-88	Bakers Br. 79/11 1987-88	**Bakers Br. PB-212-213 1997-98**	upstm Jones School 80/12 1987-88	Jones School 81/13 1987-88	**Jones School PB-237-238 & 242-244 1997-98**
Actinonaias ligamentina	-	R	**R**	-	R	**R**
Actinonaias pectorosa	-	-	-	R	L	**L**
Alasmidonta marginata	-	-	**R**	-	R	-
Alasmidonta viridis	-	-	-	R	-	**L**
Elliptio dilatata	R	L	**R**	-	L	**R**
Lampsilis cardium	R	R	**R**	R	R	**R**
Lampsilis fasciola	R	R	**R**	R	L	**L**
Lasmigona costata	R	R	**R**	-	L	**R**
Leptodea fragilis	-	-	**R**	-	R	**R**
Medionidus conradicus	R	L	**R**	R	L	**R**
Obovaria subrotunda	R	R	**R**	R	R	**R**
Pegias fabula	R	R	**R**	R	R	**R**
Pleurobema oviforme	R	R	**R**	-	R	**R**
Potamilus alatus	R	R	**L***	-	R	**R**
Ptychobranchus fasciolaris	R	L	**L***	R	L	**R**
Ptychobranchus subtentum	R	L	**R**	L	L	**L**
Toxolasma lividus	R	R	**R**	R	R	**R**
Villosa iris	R	R	**R**	R	L	**R**
Villosa lienosa	-	-	**R**	-	R	-
Villosa taeniata	R	L	**R**	R	L	**R**
Villosa trabilis	-	-	**R**	R	R	**R**
Total Live Species	0	5	**2**	1	9	**3**
Total Relict Species	14	10	**17**	12	11	**16**
Percent species loss	100%	66%	**89%**	92%	55%	**84%**

*live individuals found outside transects

Table 8. cont. **Segment IV cont.: Downstream of State Route 92 bridge to downstream of Freedom Church Ford**

Species	Ritner Ford 82/14 1987-1988	**Ritner Ford PB-292 1987-1988**	Roberts Hollow 83/15 1987-1988	**Freedom Church Ford 1997-1998**
Actinonaias ligamentina	-	-	-	**R**
Alasmidonta marginata	R	-	-	**R**
Elliptio dilatata	R	**R**	R	**R**
Lampsilis cardium	R	**R**	-	**R**
Lampsilis fasciola	L	**R**	-	**L***
Lasmigona costata	R	**R**	-	**R**
Leptodea fragilis	-	-	-	**R**
Medionidus conradicus	R	-	R	**R**
Obovaria subrotunda	R	**R**	R	**R**
Pegias fabula	R	-	R	-
Pleurobema oviforme	R	-	-	**R**
Potamilus alatus	R	**R**	R	**R**
Ptychobranchus fasciolaris	-	**R**	R	**L***
Ptychobranchus subtentum	R	**R**	R	**R**
Strophitus undulatus	R	-	-	-
Toxolasma lividus	R	**R**	-	**R**
Villosa iris	R	**R**	R	**R**
Villosa lienosa	R	-	-	**R**
Villosa taeniata	R	**R**	R	**R**
Villosa trabilis	R	**R**	-	**R**
Total Live Species	1	**0**	0	**2**
Total Relict Species	16	**12**	9	**15**
Percent species loss	94%	**100%**	100%	**88%**

Appendix A. Scientific and common names and conservation status for freshwater mussels known to have occurred in the Little South Fork Cumberland River, Wayne and McCreary counties, Kentucky. Conservation status designations are: Fed - federal listing; AFS - Williams et al. (1993); KSNPC - KSNPC (1996).

Scientific Name	Common Name	Conservation Status
Actinonaias ligamentina	Mucket	none
Actinonaias pectorosa	Pheasantshell	AFS - Special conern
Alasmidonta marginata	Elktoe	AFS- Special concern, KSNPC - Threatened
Alasmidonta viridis	Slippershell	AFS - Special conern
Cyclonaiais tuberculata	Purple wartyback	AFS - Special concern
Elliptio dilatata	Spike	none
Lampsilis cardium	Plain pocketbook	AFS - Special concern
Lampsilis fasciola	Wavy-rayed lampmussel	none
Lasmigona costata	Fluted shell	none
Leptodea fragilis	Fragile papershell	none
Ligumia recta	Black sandshell	AFS - Special concern
Medionidus conradicus	Cumberland moccasinshell	AFS-Special concern
Obovaria subrotunda	Round hickorynut	AFS-Special concern
Pegias fabula	Little-wing pearlymussel	Fed-Endangered, AFS-Endangered, KSNPC - Endangered
Pleurobema oviforme	Tennessee clubshell	AFS-Special concern, KSNPC - Endangered
Potamilus alatus	Pink heelsplitter	none
Ptychobranchus fasciolaris	Kidneyshell	none
Ptychobranchus subtentum	Fluted kidneyshell	AFS - Special concern; KSNPC - Threatened
Pyganodon grandis	Giant floater	none
Strophitus undulatus	Creeper	none
Toxolasma lividus	Purple lilliput	AFS - Special concern; KSNPC - Endangered
Utterbackia imbecillis	Paper pondshell	none
Villosa iris	Rainbow	none
Villosa lienosa	Little spectaclecase	KSNPC - Special concern
Villosa taeniata	Painted creekshell	none
Villosa trabilis	Cumberland bean	Fed - Endangered, AFS - Endangered, KSPNC - Endangered

Appendix B.1
Host-fish Mussel Relationships

We compiled all available host information for species in the Little South Fork drainage (Appendix B.2) and began to fill in knowledge gaps by initiating host studies with *Villosa taeniata*, one of the most common remaining species in the Little South Fork. Host trials conducted for this species failed to identify host fishes, even though a wide variety of potential hosts were used, and our laboratory has been successful in identifying host fishes for a number of freshwater mussel species (Haag and Warren 1997). Glochidia were rejected from all but one species tested in less than two weeks, and none of these species produced juvenile mussels. One individual of *Fundulus chrysotus* carried a low level of glochidial infestation for approximately 30 days but produced no juvenile mussels.

Fishes in host trials for *Villosa taeniata* from the Little South Fork Cumberland River, KY. None of these fishes produced juvenile mussels, and all but one, *Fundulus chrysotus*, rejected glochidia in less than two weeks.

<u>Fish species tested</u>

Campostoma oligolepis
Lythrurus ardens
Ictalurus punctatus
Noturus miurus
Cottus carolinae
Fundulus chrysotus
F. olivaceus
Gambusia affinis
Lepomis cyanellus
L. gulosus
L. macrochirus
L. megalotis
Micropterus punctulatus
Etheostoma blenniodes
E. lynceum
E. ruflineatum
Percina caprodes
P. evides
P. sciera

Appendix B.2. Two published studies have reported results of extensive mussel surveys conducted in 1977-1981 (Starnes and Bogan 1982) and 1987-88 (Anderson et al. 1991) and include data from several reports (Harker et al. 1979, 1980; Ahlstedt 1986; Layzer and Anderson 1992) and unpublished sources (Eastern Kentucky University collections). These studies provide mussel community composition data for 19 sites in the mainstem of the Little South Fork. Twenty-one species were of regular occurrence in the mainstem of the Little South Fork (see below) and five species (*Cyclonaias tuberculata*, *Ligumia recta*, *Pyganodon grandis*, *Villosa lienosa*, and *Utterbackia imbecillis*) are of sporadic occurrence.

Mussel species of regular occurrence in the Little South Fork Cumberland River and subfamily affiliations.

Subfamily	Species
Anodontinae	
	Alasmidonta viridis[5]
	A. marginata[4,5]
	Lasmigona costata
	Pegias fabula[1,2]
	Strophitus undulatus
Ambleminae	
	Elliptio dilatata
	Pleurobema oviforme[1,3,5]
Ambleminae "lampsiline clade" sensu Lydeard et al. 1996	
	Actinonaias ligamentina
	A. pectorosa[1,5]
	Lampsilis cardium[5]
	L. fasciola
	Leptodea fragilis
	Medionidus conradicus[1,5]
	Obovaria subrotunda[5]
	Potamilus alatus
	Ptychobranchus fasciolaris
	P. subtentum[1,4,5]
	Toxolasma lividus[3,5]
	Villosa iris
	V. taeniata[1]
	V. trabalis[1,2]

[1] Cumberlandian species; [2] Federally endangered species; [3] Species considered endangered by KSNPC (1996); [4] Species considered threatened by KSNPC (1996); [5] Species considered of special concern by the American Fisheries Society (Williams et al. 1993).

Current status of host information for mussel species in Little South Fork Cumberland River.

No host information	Incomplete host information	Complete host information
Actinonaias pectorosa	*Actinonaias ligamentina*	*Alasmidonta viridis*
Obovaria subrotunda	*Alasmidonta marginata*	*Lampsilis fasciola*
Ptychobranchus fasciolaris	*Elliptio dilatata*	*Medionidus conradicus*
P. subtentum	*Lampsilis cardium*	*Pegias fabula*
Villosa taeniata	*Lasmigona costata*	*Pleurobema oviforme*
	Leptodea fragilis	*Strophitus undulatus*
	Potamilus alatus	*Toxolasma lividus*
		Villosa iris
		V. trabalis

Host information for mussel species of regular occurrence in the Little South Fork Cumberland River.

Actinonaias ligamentina (mucket) - Host information is limited to early studies, however, successful transformation of glochidia was documented for at least eight species of fishes: white bass (*Morone chrysops*), white crappie (*Pomoxis annularis),* black Crappie (*P. nigromaculatus),* rock bass (*Ambloplites rupestris),* largemouth bass (*Micropeterus salmoides),* green sunfish (*Lepomis cyanellus*), sauger (*Stizostedion canadense),* and yellow perch (*Perca flavescens)* (Coker et al. 1921). It is likely that some of these species may serve as hosts in the LSF. However, the implied host relationships should be validated using modern techniques and other fish species common in the LSF should be tested for suitability as hosts.

Actinonaias pectorosa (pheasantshell) - There is no host information available for this species. It is likely that hosts for this species are similar to those used by *A. ligamentina.* Thus, if the available host information for *A. ligamentina* is valid, it is likely that hosts for *A. pectorosa* are basses, sunfishes, and other large, predaceous fishes

Alasmidonta marginata (elktoe) - Host information is limited to early studies and no species have been confirmed as hosts. Five species in three families are implied as hosts (northern hog sucker. *Hypentelium nigricans*; shorthead redhorse, *Moxostoma macrolepidotum*; white sucker, *Catostomus commersoni*; warmouth, *Lepomis gulosus*; and rock bass, *Ambloplites rupetris*) (Howard and Anson 1923, in Hoggarth 1992 and Watters 1994). Based on these preliminary results and the widepread distribution of the elktoe, this species may be a generalist that is able to use a wide variety of fish species as hosts. However, these and other host relationships need to be tested.

Alasmidonta viridis (slippershell) - The banded sculpin (*Cottus carolinae*) has been identified as host for this species (Zale and Neves 1982a). A wide variety of other fishes were found unsuitable, suggesting that this species may be a host specialist.

Elliptio dilatata (spike) - Host information is limited to early studies and no species have been confirmed as hosts. The following species have been implied as hosts: gizzard shad (*Dorosoma cepedianum*), flathead catfish (*Pylodictis olivaris*), white crappie (*Pomoxis annularis*), black crappie (*P. nigromaculatus*), and sauger (*Stizostedion canadense*)(Howard 1914 in Hoggarth 1992 and Watters 1994).

Lampsilis cardium (plain pocketbook) - Host information is limited to early studies, however, successful transformation of glochidia was documented for at least five species of fishes: white crappie (*Pomoxis annularis*), largemouth bass (*Micropterus salmoides*), smallmouth bass (*M. dolomieu*), bluegill (*Lepomis macrochirus*), yellow perch (*Perca flavescens*) (Coker et al. 1921). The sauger (Stizostedion canadense) was implied as a host but transformation was not reported (Coker et al. 1921). In the LSF, basses (*Micropterus* spp.) are probably the most important hosts for the plain pocketbook.

Lampsilis fasciola (wavy-rayed lampmussel) - Smallmouth bass (*Micropterus dolomieu*) has been confirmed as host for this species (Zale and Neves 1982b). It is likely that other species of *Micropterus* can also serve as hosts.

Lasmigona costata (fluted shell) - Six species of fishes in four families (Amiidae, Esocidae, Centrarchidae, and Percidae) have been identified as hosts (Hove et al. 1994), suggesting that this species is a host-generalist. A congener, *L. compressa*, uses fishes in at least two additional families (Cyprinidae, Cottidae) as well as centrarchids and percids (Hove et al. 1995). In the LSF, it is likely that *L. costata* uses a taxonomically wide variety of fishes.

Leptodea fragilis (fragile papershell) - The freshwater drum (*Aplodinotus grunniens*) has been implied as host based on the occurrence of its glochidia on wild fish (Howard and Anson 1923 in Watters 1994; Cummings and Mayer 1993) however, transformation of glochidia has not been documented.

Medionidus conradicus (Cumberland moccasinshell) - The redline darter (*Etheostoma ruflineatum*) and fantail darter (*E. flabellare*) have been confirmed as hosts (Zale and Neves 1982b). However, this study revealed that not all darter species served as hosts. Non-host darter species were the Tennessee snubnose darter (*E. simoterum*) and the greenside darter (*E. blenniodes*). A congener, *M. acutissimus*, used 4 species of darters, including the logperch (*Percina caprodes*)(Haag and Warren 1997), suggesting that this species may also serve as host for *M. conradicus* in the LSF.

Obovaria subrotunda (round hickorynut) - There are no known hosts for this species and no information for congeneric species that suggests potential hosts. The only information for a congener is the apparent mussel/host fish relationship between *O. olivaria* and the shovelnose sturgeon (*Scaphirhynchus platorynchus*) (Coker et al. 1921). However, the shovelnose sturgeon does not occur in the LSF nor in many other streams inhabited by *O. subrotunda.*

Pegias fabula (little-wing pearlymussel) - The emerald darter (*Etheostoma baileyi*) and greenside darter (*E. blennioides*) have been identified as hosts (Layzer and Anderson 1992). This species may be a specialist on darters, although it is likely that other darter species also serve as hosts.

Pleurobema oviforme (Tennessee clubshell)- The whitetail shiner (*Cyprinella galactura*), striped shiner (*Luxilus chrysocephalus*), river chub (*Nocomis micropogon*), central stoneroller (*Campostoma anomalum*), and fantail darter (*Etheostoma flabellare*) have been identified as hosts (Weaver et al. 1991). With exception of *E. flabellare*, this species is probably a specialist on cyprinids. Most known hosts for other species of *Pleurobema* are cyrinids (Yokely 1972, Hove and Neves 1994, Hove et al. 1997, Haag and Warren 1997). However, not all cyprinids can serve as hosts: non-hosts cyprinids reported by Weaver et al. (1991) include *Pimephales notatus* and *Luxilus coccogenis*; non hosts cyprinids for other *Pleurobema* include *Notemigonus chrysoleucas* (Hove and Neves 1994), *Lythrurus bellus, Notropis asperifrons, Notropis stilbius* (Haag and Warren 1997).

Potamilus alatus (pink heelsplitter) - The freshwater drum (*Aplodinotus grunniens*) has been implied as host based on the occurrence of its glochidia on wild fish (Howard and Anson 1923 in Watters 1994; Cummings and Mayer 1993) however, transformation of glochidia has not been documented.

Ptychobranchus fasciolare (kidneyshell) - No host information is available for this species. However, a number of darter species (*Etheostoma* spp. and *Percina* spp.) serve as hosts for two congeners, *P. occidentalis* (Barnhart and Roberts 1997) and *P. greeni* (Haag and Warren 1997). It is likely that darters serve as hosts for *P. fasciolare*, as well.

Ptychobranchus subtentum (fluted kidneyshell) - No host information is available for this species. However, a number of darter species (*Etheostoma* spp. and *Percina* spp.) serve as hosts for two congeners, *P. occidentalis* (Barnhart and Roberts 1997) and *P. greeni* (Haag and Warren 1997). It is likely that darters serve as hosts for *P. subtentum*, as well.

Strophitus undulatus (creeper) - Eight fish species in four families (Cyprinidae, Ictaluridae, Centrarchidae, and Percidae) have been identified as hosts (Hove et al. 1997), suggesting that this species is a host-generalist. Similarly, hosts for a congener, *S. subvexus*, are a taxonomically diverse group of fishes representing five families (Haag and Warren 1997). In the LSF, *S. undulatus* probably uses a wide variety of fishes as hosts.

Toxolasma lividus (purple lilliput) - The green sunfish (*Lepomis cyanellus*) and longear sunfish (*L. megalotis*) have been identified as hosts (Gooch 1986). Two additional species of sunfish (*L. gulosus* and *L. macrochirus*) have been identified as hosts for a congener, *T. texasensis* (Stern and Felder 1978), suggesting that other species of *Lepomis* and possibly basses (*Micropterus*) may serve as hosts for *T. lividus*.

Villosa iris (rainbow) - Largemouth bass (*Micropterus salmoides*), smallmouth bass (*M. dolomieu*), spotted bass (*M. punctulatus*), Suwanee bass (*M. notius*), rock bass (*Ambloplites rupestris*), and mosquitofish (*Gambusia affinis*)(Zale and Neves 1982b, Neves et al. 1985) have been identified as hosts.

Villosa taeniata (painted creekmussel) - There is no host information available for this species. The majority of other species of *Villosa* for which hosts are known use basses (*V. iris*, Zale and Neves 1982b; *V. nebulosa*, Haag and Warren 1997; *V. vibex*, Haag and Warren unpublished data).

Appendix C. Detailed results of mussels in Segments I - IV of Little South Fork

Mussel Survey - Section I: SR 167 bridge to upstream of Green Ford

In August 1998, we sampled six sites (4 via transects) in Section I (SR 167 bridge to 1.9-km upstream of Green Ford) (about 11.3 river kilometers). This section of the Little South Fork includes five sites sampled qualitatively by Harker et al. (1979, 1980), Starnes and Bogan (1982), Anderson et al. (1991), or Layzer and Anderson (1992) (Table 1). We resampled at least four of the sites surveyed by previous workers (Table 3). We excavated a total of 59.5 m^2 (10.5 - 21.0 m^2/site) in a section of the river that had never before been quantitatively surveyed for freshwater mussels (Tables 2 and 3).

Both species richness and densities of freshwater mussels were low at most surveyed sites (Tables 2 and 3). We found only four species of live freshwater mussels in the transects with a range of 1 to 4 live species/site; visual searches failed to add additional live species. Across sites, the most persistent species were painted creekshells (*Villosa taeniata)* and wavy-rayed lampmussels (*Lampsilis fasciola)*. Rainbows *(Villosa iris*) were represented by only two individuals over all sites. The highest density was recorded at sites H-432-433 (downstream Langham bridge) (2.7 individuals m^{-2}). The other three sites yielded densities of 0.1 to 0.8 individuals m^{-2}.

Comparison of the present-day living mussel fauna with our relict shell collections indicates a dramatic decline in diversity and evenness of the freshwater mussel community in this section of the river (Tables 7). Diversity of the relict collections abruptly increases from 4 species at the SR 167 bridge to 13 and 14 species at the three downstream sites and totaled 15 species for the segment. The relict fauna at most sites was dominated (>10% relative abundance) by painted creekshells and wavy-rayed lampsmussels. Both species also were represented by live individuals. Aside from these dominants, most other species in the relict collections showed relative abundances of <10%, but 13 of 15 relict species were recovered from at least three of four sites surveyed. Notably, Cumberland beans (*Villosa trabilis)* comprised from 4% to 10% of the relict fauna in this segment, but no live or fresh dead shells of this species were encountered. The only relict species restricted in distribution in this segment were pheasantshells (*Actinonaias pectorosa)* and spikes (*Elliptio dilatata*). Both species historically occurred most frequently in lower reaches of Little South Fork (Starnes and Bogan 1982, Anderson et al. 1992).

Historical collections further document an extensive and relatively rapid loss of species even in this upstream segment of Little South Fork (Table 8). In 1987-88, seven live and nine relict species were observed in this segment (Layzer and Anderson 1992). Their data suggest about 56% of the historical mussel fauna in this reach was rare or extirpated at that time. Our data yielded overall species losses of 69% to 85% relative to the historical fauna documented in this segment. Further declines from seven to four live species have occurred since 1987-1988.

Mussel Survey- Segment II: Green Ford to mouth of Kennedy Creek

In July 1997 and August 1998, we sampled 12 sites in Segment II (from 1-km downstream of Green Ford to Baldy Road bridge = mouth of Kennedy Creek)(about 14.5 river kilometers). This segment of the Little South Fork includes four sites sampled for mussels by Harker et al. (1980, 1981; also reported by Starnes and Bogan 1982), Anderson et al. (1991), or Layzer and Anderson

(1992) (Table 1). Layzer and Anderson (1992) reported results from two quantitative samples totaling 2.8 m^{-2} each at Site 70 (upstream Steele Hollow bridge) and Site 71 (Bell Hill). We sampled a total of 108.5 m^2 (7.0 -17.5 m^2 per site). For comparison, this represents over 19 times the area quantitatively sampled in previous surveys.

We found low species richness and low densities of freshwater mussels in this segment (Tables 2 and 3); however, species richness and densities were the highest observed for the entire river. Total species richness for the segment was seven, and site richness ranged from 1 to 6 species. We found only five species of live freshwater mussels in the transects. We observed two other species, the kidneyshell (*Ptychobranchus fasciolaris)* and Tennessee clubshell (*Pleurobema oviforme*), alive outside the transects. These specimens represented the only live individual of the Tennessee clubshell observed in the entire river, and for kidneyshells, one of only two live individuals observed. Across sites, the most persistent species were painted creekshells (*Villosa taeniata)*,wavy-rayed lampmussels (*Lampsilis fasciola)*, and fluted kidneyshells (*Ptychobranchus subtentum),* but none of the live species occurred at all sites. Four of the 12 sites failed to yield any living mussels. The highest densities were recorded at sites PB-11&12 (downstream Stillhouse Hollow) (2.9 individuals m^{-2}) and PB-59 (downstream Steele Hollow) (2.0 individuals m^{-2}). Site PB-26&27 (upstream Steele Hollow bridge) had a density of 0.30 individuals m^{-2}; Layzer and Anderson (1992) reported a density 3.0 individuals m^{-2} at or near this site. Other sites yielded densities of 0 to 0.9 individuals m^{-2}. Density and species richness dropped to zero at sites from PB-79 (upstream Dobbs Hollow) downstream to Kennedy Creek with the exception of PB-140-142 (Bell Hill). A timed visual search with substrate disturbance at the Bell Hill site revealed 12 live Cumberland moccasinshells (*Medionidus conradicus*), the largest concentration of this species observed, as well as individuals of four other species. In 1987-88, Layzer and Anderson (1992) reported a density at this site of about 5.8 individuals/m^{-2}. A timed visual search of Kennedy Creek from the mouth to about 300 m upstream failed to reveal any live mussels.

Comparison of the present-day living mussel fauna with the our relict shell collections indicates a dramatic decline in species richness, evenness, and distributional extent of all freshwater mussels in this segment of the river (Table 7). Our relict collections in this segment yielded 17 species. Species richness at mainstem sites ranged from 13 to 17 relict species; Kennedy Creek yielded 7 relict species. The relict fauna at most sites was dominated (>10% relative abundance) by painted creekshells, wavy-rayed lampmussels, and fluted kidneyshells; all three species persist in this segment of the river. Aside from these dominants, most of the remaining 14 species in the relict collections showed relative abundances of <10% across sites; however, distributions were extensive. Fully 13 of 17 relict species occurred at all five relict shell collection sites in the mainstem of Little South Fork (i.e., except Kennedy Creek). The only species with restricted distributions and consistently low relative abundances in the relict fauna was the slippershell (*Alasmidonta viridis)* and the black sandshell (*Ligumia recta*). We found one relict black sandshell which is to our knowledge the first report of this species from the Little South Fork. Notably relict shells of little-wing pearlymussels (*Pegias fabula)* and Cumberland beans (*Villosa trabilis)* occurred throughout this river segment with relative abundances of up to 10%.

Historical collections further document an extensive and relatively rapid loss of species in the Green Ford to Kennedy Creek segment of Little South Fork. Freshwater mussel decline in this segment of the Little South Fork was apparently well-advanced in the mid-1980s with continued losses to the present day (Table 8). Layzer and Anderson (1993) observed 13 live and five relict species in the segment in 1987-88. However, eight live species were restricted to single sites among the 4 sites they surveyed. From this, we infer that about 28% of the mussel species in this segment were extirpated or nearly so and another 44% were narrowly distributed in 1987-88. A decade later, we estimate 69% to 92% of the species at sites in the segment are extirpated. Over the entire river segment, 61% of the historical mussel fauna is extirpated or functionally extirpated (i.e., below detectable limits). Most notably, living species have decreased from 13 to 7 since 1987-88.

Mussel Survey - Segment III: Downstream of Kennedy Creek to State Route 92

In July 1997 and August 1998, we sampled 4 sites located in Segment III (2-km downstream of Kennedy Creek to 129-m upstream of the State Route 92 bridge) (about 12.3 river kilometers). This segment of the Little South Fork includes three sites previously sampled for mussels by Starnes and Bogan (1983) in 1977-1981; Ahlstedt and Saylor (1995-1996) in 1984 and 1985; and Anderson et al. (1991) or Layzer and Anderson (1992) in 1987-1988 (Table 1). Starnes and Bogan (1982) quantitatively sampled at the SR 92 bridge (Site 76/8) (2.8 m^2 total), and Layzer and Anderson (1992) quantitatively resurveyed this site as well as two other sites in this segment (Site 74, upstream of Kidds Branch, and Site 75, downstream of Kidds Branch) (8.4 m^2 total). We sampled a total of 49.0 m^2 (10.5 - 14.0 m^2/site) in this segment of the river (Table 3). For perspective, we sampled over 4 times the area quantitatively sampled by previous workers.

We found low species richness and low densities of freshwater mussels in this segment (Tables 2 and 3). Only 15 live individuals representing four species were observed in the segment; site species richness ranged from 0 to 4 species. None of the live species occurred at more than two sites; two of the four sites failed to yield any living mussels. Wavy-rayed lampmussels (*Lampsilis fasciola*) and Cumberland moccasinshells (*Medionidus conradicus)* were represented by one individual each, and painted creekshells (*Villosa taeniata)* by two individuals. Densities ranged from 0 to 0.9 individuals m^{-2}. We observed no live mussels from downstream of Burkes Creek to the SR 92 bridge. In 1981, Starnes and Bogan (1982) measured a density of 7.50 individuals m^{-2} at the SR 92 bridge; they encountered eight live species in just 2.8 m^2 of sampled area. In 1987-88, Layzer and Anderson (1992) reported densities of 3.0 individuals m^{-2} above Kidds Branch, 1.5 individuals m^{-2} below Kidds Branch, and 0 individuals m^{-2} at the SR 92 bridge.

Comparison of the present-day living mussel fauna with the our relict shell collections indicates a near demise of the freshwater mussel community in this segment of the river (Table 7). Our relict collections in this segment yielded 16 species from Kidds Branch to the SR 92 bridge and 10 species at the Burkes Creek site. At the Burkes Creek site the relict fauna was dominated (>10% relative abundance) by kidneyshells (*Ptychobranchus fasciolaris*), fluted kidneyshells (*Ptychobranchus subtentum*), and fluted shells (*Lasmigona costata)*. At the two downstream sites, the relict fauna was dominated by painted creekshells, kidneyshells , wavy-rayed lampmussels, and pink heelsplitters (*Potamilus alatus).* Of these formerly dominant species, we observed only two alive in this segment of the river. Most of the other 10 species in the relict collections showed relative abundances of <10%. Ten of 16 species occurred in both relict collections indicating most were formerly widely distributed in this segment of Little South Fork.

Historical collections further document an extensive and relatively rapid loss of species from downstream of Kennedy Creek to SR 92 bridge (Table 8). Freshwater mussel decline in this section of the Little South Fork was first noted in 1984-85 (Ahlstedt and Saylor 1995-1996). Starnes and Bogan (1982) reported 11 species alive and 9 represented only by shells (not designated as relict or fresh dead) at the SR 92 bridge. In 1984-85, Ahlstedt and Saylor (1995-1996) documented 17 species from this segment, all of which were represented by fresh dead shells. By 1987-88, Layzer and Anderson (1993) could find only four live species at the SR 92 bridge site (Table 8). Of the six living species they found in this river segment, three were restricted to single sites. They collected 14 other species that were represented only by relict shells. We found no living species from downstream of the Burkes Creek site to the SR 92 bridge (Tables 5 and 8). Our data indicate living species have decreased from 6 to 4 since 1987-88, and in effect, the mussel community has been eliminated altogether from this segment.

Mussel Survey - Segment IV: Downstream of SR 92 Bridge to Freedom Church Ford

In August 1998, we sampled five sites in Segment IV (2.8 km downstream of the SR 92 bridge to about 300 m downstream of Freedom Church Ford) (about 15.0 river kilometers). This section of the Little South Fork includes eight sites sampled for mussels by Harker et al. (1980, 1981), Starnes and Bogan (1982), G. A. Schuster (in Millican Associates, Inc. 1982); and Anderson et al. (1991) or Layzer and Anderson (1992) (Table 1). In 1981, Starnes and Bogan (1982) quantitatively sampled at two stations: Site 81/13 (Jones School) and Site 84/16 (Freedom Church Ford) (5.6 m^2 total). Layzer and Anderson (1992) quantitatively resurveyed these sites in 1987-1988 (5.6 m^2 total). Ahlstedt and Saylor (1995-1996) quantitatively sampled 10 m^2 at Ritner Ford in 1985. We sampled a total of 56.0 m^2 (10.5 - 14.0 m^2/site) in this segment of the river (Table 3). For perspective, we sampled over twice the area quantitatively sampled by previous workers.

We found low species richness and low densities of freshwater mussels in this segment (Tables 2 and 3). Four of five sites yielded living mussels, but only 17 live individuals representing five species were found. Site species richness ranged from 0 to 3 species. Two species, pink heelsplitters (*Potamilus alatus*) and kidneyshells (*Ptychobranchus fasciolaris*), were observed only outside transects. The pheasantshell (*Actinonaias pectorosa*) and the kidneyshell were represented by one individual each, and the wavy-rayed lampmussel (*Lampsilis fasciola*) by two individuals. Densities ranged from 0 to 0.50 individuals m^{-2}. In 1981, Starnes and Bogan (1982) measured a density of 7.2 individuals m^{-2} at the Jones School site and 2.90 individuals m^{-2} at Freedom Church Ford; they encountered nine and three live species, respectively, in their quantitative sampling. In 1987-88, Layzer and Anderson (1992) reported densities of about 1 individual m^{-2} at the Jones School site and 0 individuals m^{-2} at Freedom Church Ford.

Comparison of the present-day living mussel fauna with the our relict shell collections indicates a dramatic decline in species richness, evenness, and distributional extent of all freshwater mussels in this segment of the river (Table 7). Our relict collections in this segment yielded 20 species. Species richness ranged from 12 to 19 relict species/site. The relict fauna was dominated (>10% relative abundance) by spikes (*Elliptio dilatata*), wavy-rayed lampmussels, pink heelsplitters, kidneyshells, fluted kidneyshells (*Ptychobranchus subtentum*), and painted creekshells (*Villosa taeniata*). Only three of these former dominant species persist in this lowermost segment of the river. Aside from these dominants, most of the remaining 14 species in the relict collections showed relative abundances of <10% across sites; however, former distributions were extensive. Fully 17 of 20 relict species occurred at all four relict shell collection sites in this segment. Notably, both the Cumberland bean (*Villosa trabilis)* and the little-wing pearlymussel (*Pegias fabula)* were distributed widely in this segment; the Cumberland bean showed relative abundance values of 2 to 6% within relict collections.

Historical collections further document an extensive and relatively rapid loss of species in Segment IV of Little South Fork. Evidence of freshwater mussel decline in this section of the Little South Fork was first noted by G. A. Schuster (in Millican Associates, Inc., 1982). Based on observations made in November 1980, Schuster reported that the mussel fauna at Ritner Ford consisted almost entirely of relict shells in contrast to the abundance of live individuals and active muskrat shell middens he observed at the Baker Branch and Jones School sites. Likewise, in 1981, Starnes and Bogan (1982) found only three live species at the Ritner site, but over the segment recorded 11 species alive and 12 others as shells (not designated as relict or fresh dead). However, ten of the live species they collected were restricted to one or two of the eight sites surveyed. In 1984-85, Ahlstedt and Saylor (1995-1996) found 3 live and 14 fresh dead species at the Ritner and Freedom Church Ford sites and noted "large numbers of mussels" were dead in the lower third of the river. By 1987-88, Layzer and Anderson (1993) were still able to find nine live species in the segment, but eight of these were restricted to one or two sites of eight sites surveyed (Table 8). They collected 13 other species represented only by relict shells. Estimated species losses for the segment at the time of their survey is 59%, and species losses at their sites range from 55% to 100%. From our data, we estimate species losses for the segment at 75% and species losses at sites ranged from 75% to 100% (Table 7). Our data indicate living species have decreased from 9 to 5 since 1987-88, and in terms of both diversity and abundance, the mussel community has been effectively eliminated from this segment.

Appendix D. Report of the U.S. Fish and Wildlife Service, Ecological Services, Cookeville, Tennessee entitled "Impacts of Coal Mining-related Contaminants on Freshwater Mussels: Little South Fork Cumberland River, Kentucky--Special Report" by W. Allen Robison.

To facilitate interpretation of the sediment samples and tissue samples, Dr. James Layzer furnished us with the following list of site numbers referenced to the sediment sample numbers and mussel tissue sample numbers used in the report. Dr. Layzer also noted that mussel tissue sample numbers M7, M9, M10, M13, M14, M15, and M16 were from *Elliptio dilatata* collected from the Rockcastle River in December 1987 and placed in cages in the substrate of the Little South Fork Cumberland River (see Layzer and Anderson 1992). Mussel tissue sample M12 consisted of 70 *Corbicula*. Other tissue samples were composite samples of varying numbers and species of unionids at the sites. If needed, Dr. Layzer has specific information on the species composition of each of the samples.

Site Number (Layzer and Anderson, 1992; and Table 1 of this report)	Sediment Sample Number in Robison (1996)	Mussel Tissue Sample Number in Robison (1996)
65	S9	---
67	S6	M3
70	S5	M4
71	S8	M11, M13, M14
74	S7	M5
76	S4	M15, M16
80	S2	M8, M12
81	S3	M1, M2, M7
82	S1	M9, M10
84	S10	---

APPENDIX D

CFO-EC-96-04 TENNESSEE

Impacts of Coal Mining-Related Contaminants on Freshwater Mussels:

Little South Fork Cumberland River, Kentucky--

Special Report

U.S. Fish and Wildlife Service
Ecological Services
446 Neal Street
Cookeville, Tennessee 38501

December 1996

U.S. FISH and WILDLIFE SERVICE / SOUTHEAST REGION / ATLANTA, GEORGIA

U.S. Fish and Wildlife Service

Southeast Region

Impacts of Coal Mining-Related Contaminants on Freshwater Mussels:

Little South Fork Cumberland River--

Special Report

by

W. Allen Robison

Ecological Services Field Office
446 Neal Street
Cookeville, Tennessee

December 1996

(Project No. 88-4-046)

INTRODUCTION

Numerous species of native freshwater mussels are exposed to contaminants related to oil/gas production and coal mining. Several of these species are federally listed as endangered or threatened. In the Southern Appalachian Ecosystem, the Little South Fork Cumberland River (LSFCR) has historically supported a diverse mussel fauna and has also been subjected to impacts from oil/gas production and coal mining. The mussel populations inhabiting the LSFCR have shown substantial declines and periodic die-offs.

To investigate impacts to mussels in the LSFCR, the Fish and Wildlife Service (Service) initiated a three-pronged investigation involving: (1) a mussel survey, (2) juvenile mussel bioassays; and (3) collection and analysis of mussel and sediment samples. This project was funded through the Asheville Field Office (North Carolina) and included participation by the Service's Cooperative Research Units at Virginia Polytechnic Institute (juvenile mussel bioassays) and Tennessee Technological University (mussel survey; mussel and sediment sample collections). The Service's Raleigh Field Office (North Carolina) and Cookeville Field Office (Tennessee) provided technical support. The results of contaminant analyses on sediment and mussel samples are briefly summarized and discussed in the following sections. This report should be used only in conjunction with the results of the other two phases of the project and was prepared primarily to ensure that the reporting requirements of the Service's contaminants program are met.

RESULTS

Ten sediment and 15 composite mussel samples were collected from the Little South Fork Cumberland River (LSFCR) in July 1988 (Table 1). Mussel samples consisted of soft tissue collected from specimens of the following species: *Ellipto dilatata, Medionidus conradicus, Villosa iris, V. taeniata, Lasmigona costata, Lampsilis fasciola, Actinonaias pectorosa, Ptychobranchus fasciolaris, and Corbicula fluminea.* Samples were analyzed for the 23 metals, 23 organochlorine compounds, 11 aliphatic hydrocarbons, and 24 polycyclic aromatic hydrocarbons (PAHs) shown in Table 2.

Organochlorines and PAHs

None of the 23 target organochlorine chemicals were detected in any of the ten sediment samples or eight mussel samples which were analyzed. Of the 24 PAHs analyzed, nine were detected at low concentrations (0.01 to 0.03 ppm, wet weight) only in mussel sample LSF-M12.

Table 1. Little South Fork Cumberland River Sediment and Mussel Sample Information.

Sample Type and No.	Sample Weight (grams)		Percent Moisture		
Sediment	Field	Lab	Organics	Metals	
LSF-S1	362	18.61	46.2	49.8	
LSF-S2	332	14.37	30.2	32.3	
LSF-S3	317	13.12	23.2	22.8	
LSF-S4	346	16.26	38.5	36.5	
LSF-S5	462	13.29	24.6	25.3	
LSF-S6	272	16.90	40.6	37.0	
LSF-S7	543	13.26	24.3	23.8	
LSF-S8	383	14.12	29.2	23.6	
LSF-S9	200	24.73	59.6	40.2	
LSF-S10	200	25.60	60.7	41.3	
Mussel Tissue	Field	Lab	Organics	Metals	Percent Lipid
LSF-M1	51.66	10.61	87.6	87.3	0.20
LSF-M2	45.62	10.00	88.7	87.5	0.14
LSF-M3	56.53	10.56	88.6	88.7	0.05
LSF-M4	62.01	10.02	90.0	86.3	0.32
LSF-M5	58.79	10.14	87.3	87.7	0.53
LSF-M8	59.29	11.59	87.0	86.9	1.16
LSF-M11	42.19	10.55	89.8	90.4	0.12
LSF-M12	28.13	5.04	88.1	88.2	2.43
LSF-M7	30.36	---	---	87.7	---
LSF-M9	38.70	---	---	89.4	---
LSF-M10	50.46	---	---	86.4	---
LSF-M13	49.13	---	---	90.7	---
LSF-M14	56.10	---	---	89.0	---
LSF-M15	64.64	---	---	89.3	---
LSF-M16	63.81	---	---	88.7	---

Table 2. Analyses Performed on Little South Fork Cumberland River Samples.

Organochlorines (23)

Aldrin	Dieldrin	Mirex
BHC (3 isomers)	Endrin	Nonachlor (2 isomers)
DDE (2 isomers)	HCB	PCBs (total)
DDD (2 isomers)	Heptachlor	Oxychlordane
DDT (2 isomers)	Heptachlor epoxide	Toxaphene
DDT (total)	Lindane	

Polycyclic Aromatic Hydrocarbons (24)

Acenapthene	Benzo(b)fluoranthene	Perylene
Acenapthylene	Benzo(k)fluoranthene	Benzo(ghi)perylene
Anthracene	Fluorene	Phenanthracene
Benzo(a)anthracene	Naphthylene	1-methyl phenanthracene
Dibenzo(a)anthracene	1-methyl naphthylene	Pyrene
Biphenyl	2-methyl naphthylene	Benzo(a)pyrene
Chrysene	2,6-dimethyl naphthylene	Benzo(e)pyrene
Fluoranthene	2,3,4-trimethyl naphthylene	Indenopyrene

Metals (23)

Aluminum (Al)	Cadmium (Cd)	Manganese (Mn)	Strontium (Sr)
Antimony (Sb)	Chromium (Cr)	Mercury (Hg)	Thallium (Th)
Arsenic (As)	Copper (Cu)	Molybdenum (Mo)	Tin (Sn)
Barium (Ba)	Iron (Fe)	Nickel (Ni)	Vanadium (V)
Beryllium (Be)	Lead (Pb)	Selenium (Se)	Zinc (Zn)
Boron (B)	Magnesium (Mg)	Silver (Ag)	

Aliphatic Hydrocarbons (11)

n-dodecane	n-hexadecane	phytane
n-tridecane	n-heptadecane	n-nonadecane
n-tetradecane	pristane	n-eicosane
n-pentadecane	n-octadecane	

These compounds were: benzo(a)anthracene (0.03 ppm), dibenzoanthracene (0.01 ppm), chrysene (0.03 ppm), benzo(b)fluoranthracene (0.02 ppm), benzo(k)fluoranthracene (0.02 ppm), perylene (0.02 ppm), benzo(a)pyrene (0.02 ppm), benzo(e)pyrene (0.02 ppm), and indenopyrene (0.01 ppm).

In sediment samples, anthracene, dibenzoanthracene, benzo(k)fluoranthracene, and indenopyrene were not detected (<0.01 ppm, wet weight). Ten compounds were detected at low concentrations (0.01-0.05 ppm) only in sediment sample LSF-S1 (Table 3). The following three PAHs were detected in all sediment sample: 2,3,4-trimethyl napthalene (0.01-0.14 ppm), phenanthracene (0.04-0.36 ppm); and 1-methyl phenanthracene (0.02-0.16 ppm). The remaining PAHs occurred sporadically (mainly in LSF-S1 and LSF-S10) and ranged from non-detect (<0.01 ppm) to 0.51 ppm (Table 3).

Aliphatic Hydrocarbons

Dodecane (C-12) was not detected (<0.01 ppm, wet weight) in any sample while tridecane (C-13) was found in only one sediment sample (LSF-S1@0.08 ppm). Concentrations of the other aliphatic hydrocarbons analyzed were detected in all or most of the sediment samples, and ranged from 0.01 ppm to a high of 0.81 ppm (pristane in LSF-S1). In each sediment sample, pristane and phytane had higher concentrations than the other aliphatic compounds (Table 4).

Heptodecane (C-17) was detected in all mussel samples at concentrations ranging from 0.03 to 0.37 ppm, wet weight (Table 5). Of the remaining aliphatic hydrocarbons analyzed, only a trace amount (0.04 ppm) of nonadecane (C-19) was found. It was detected in a replicate aliquot taken from mussel sample LSF-M12.

Metals

Of the 23 metals analyzed, 19 (83%) were detected in the sediment samples (Table 6) and 17 (74%) were found in the mussel samples (Table 7). Antimony, molybdenum, silver, and thallium were not detected in either sediments or mussels, while beryllium and boron were not found in mussels. Mercury concentration in mussels ranged from 0.412 ppm (LSF-M8) to 1.150 ppm (LSF-M9). Mercury concentrations in mussels were 10-35 times higher than sediment mercury concentrations. Lead concentrations in mussels varied from 1.80 ppm (LSF-M14) to 3.50 ppm (LSF-M3 and LSF-M16).

Quality Assurance

Replicate, spike, and blank samples were analyzed for all the target organic parameters. Results for these samples were acceptable and did not indicate any analytical quality assurance or quality control concerns.

Table 3. Polycyclic Aromatic Hydrocarbons (PAHs) Detected* in LSFCR Sediment Samples (July 1988).

Sample	Fluoranthracene	Pyrene	Benzo(a)anthracene	Chrysene	Benzo(b)fluoranthracene	Benzo(a)pyrene	Benzo(e)pyrene	Perylene	Bipheny
LSF-S1	0.04	0.04	0.03	0.06	0.03	0.02	0.05	<0.01	0.06
LSF-S2	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
LSF-S3	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01
LSF-S4	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	0.05	<0.01
LSF-S5	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
LSF-S6	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
LSF-S7	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
LSF-S8	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01
LSF-S9	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
LSF-S10	<0.01	<0.01	<0.01	0.03	<0.01	<0.01	<0.01	0.02	0.01

*ppm, wet weight

Table 3. Continued.

Sample	Benzo(ghi)perylene	Naphthalene	1-Methylnaphthalene	2-Methylnaphthalene	2,6-Dimethylnaphthalene	2,3,4-Trimethylnaphthalene
LSF-S1	0.02	0.30	0.44	0.51	0.14	0.14
LSF-S2	<0.01	0.01	<0.01	<0.01	0.01	0.04
LSF-S3	<0.01	<0.01	<0.01	<0.01	<0.01	0.06
LSF-S4	<0.01	<0.01	<0.01	<0.01	<0.01	0.05
LSF-S5	<0.01	<0.01	<0.01	<0.01	0.01	0.04
LSF-S6	<0.01	<0.01	<0.01	<0.01	<0.01	0.03
LSF-S7	<0.01	<0.01	<0.01	<0.01	<0.01	0.01
LSF-S8	<0.01	<0.01	<0.01	<0.01	<0.01	0.02
LSF-S9	<0.01	<0.01	<0.01	<0.01	<0.01	0.03
LSF-S10	<0.01	0.04	0.04	0.05	0.02	0.02

*ppm, wet weight.

Table 3. Continued.

Sample	Acenaphthalene	Acenaphthene	Fluorene	Phenanthracene	1-Methylphenanthracene
LSF-S1	0.01	0.03	0.05	0.36	0.16
LSF-S2	<0.01	<0.01	<0.01	0.07	0.04
LSF-S3	<0.01	<0.01	<0.01	0.13	0.07
LSF-S4	<0.01	<0.01	<0.01	0.08	0.04
LSF-S5	<0.01	<0.01	<0.01	0.07	0.03
LSF-S6	<0.01	<0.01	<0.01	0.06	0.03
LSF-S7	<0.01	<0.01	<0.01	0.04	0.02
LSF-S8	<0.01	<0.01	<0.01	0.05	0.03
LSF-S9	<0.01	<0.01	<0.01	0.06	0.04
LSF-S10	<0.01	<0.01	<0.01	0.06	0.03

*ppm, wet weight.

Table 4. Aliphatic Hydrocarbons Detected* in Sediment Samples From LSFCR (July 1988).

	C-13	C-14	C-15	C-16	C-17	Pristane	C-18	Phytane	C-19	C-20
LSF-1	0.08	0.14	0.25	0.19	0.33	0.81	0.11	0.41	0.09	0.09
LSF-2	<0.01	0.03	0.08	0.12	0.11	0.41	0.04	0.28	0.01	0.07
LSF-3	<0.01	0.04	0.10	0.19	0.14	0.75	0.07	0.52	0.03	0.02
LSF-4	<0.01	0.03	0.08	0.11	0.04	0.57	0.05	0.48	0.03	0.03
LSF-5	<0.01	0.03	0.07	0.11	<0.01	0.48	0.05	0.34	0.01	0.08
LSF-6	<0.01	0.02	0.05	0.11	0.02	0.38	0.04	0.29	0.02	0.08
LSF-7	<0.01	<0.01	0.03	0.06	<0.01	0.25	0.03	0.19	0.09	0.05
LSF-8	<0.01	0.02	0.06	0.10	<0.01	0.34	0.04	0.27	0.12	0.05
LSF-9	<0.01	0.01	0.04	0.08	0.01	0.26	0.04	0.25	0.10	0.03
LSF-10	<0.01	0.02	0.03	0.05	0.21	0.15	0.02	0.11	0.08	<0.01

*reported in ppm (wet weight) as normal alkane concentrations.

Table 5. Heptodecane Concentrations* in Mussel Samples from Little South Fork Cumberland River, Kentucky (July 1988).

Samples	Heptodecane (C-17)
LSF-M1	0.36
LSF-M2	0.28
LSF-M3	0.03
LSF-M4	0.10
LSF-M5	0.28
LSF-M8	0.37
LSF-M11	0.07
LSF-M12	0.32

*ppm, wet weight.

Table 6. Metals (ppm, dry wt.) and Total Volatile Sulfides (TVS-%) LSFCR Sediment Samples (July 1988).

	LSF-S1	LSF-S2	LSF-S3	LSF-S4	LSF-S5	LSF-S6	LSF-S7	LSF-S8	LSF-S9	LSF-S10
Aluminum (%)	0.95	0.69	0.335	1.22	0.26	0.65	0.44	0.47	0.74	0.95
Arsenic	26.50	6.60	10.40	13.10	5.10	6.00	4.60	5.90	16.40	14.10
Barium	64.90	27.10	18.50	58.30	12.20	24.20	19.60	21.90	56.40	60.60
Beryllium	1.20	0.89	0.32	0.79	<0.33	<0.40	<0.33	0.33	0.42	0.94
Boron	5.08	<3.69	<3.24	8.58	<3.35	5.95	<3.28	<3.27	5.85	<4.26
Cadmium	<0.50	<0.37	0.32	0.39	<0.33	1.11	<0.33	<0.33	<0.42	<0.43
Chromium	47.40	34.60	45.80	20.90	34.10	16.40	17.70	29.60	22.20	17.60
Copper	14.10	3.47	<1.62	6.77	<1.67	3.41	2.30	2.55	4.93	9.54
Iron (%)	5.02	1.61	1.74	1.67	1.45	1.02	0.98	1.16	1.83	1.72
Lead	8.47	7.83	6.93	9.13	2.54	4.76	4.13	<1.96	8.44	13.60
Magnesium	1260	739	395	2490	268	1020	604	648	1100	1700
Manganese	1580	1130	587	1010	357	221	193	287	3500	1370
Mercury	0.068	<0.037	<0.032	<0.039	0.033	<0.040	<0.033	<0.033	<0.042	0.055
Nickel	26.70	29.20	8.74	13.40	4.08	7.46	5.71	7.00	10.30	35.30
Selenium	0.400	0.300	<0.130	<0.160	0.270	<0.160	0.390	<0.130	0.330	0.340
Strontium	26.30	21.50	26.90	42.20	13.20	33.70	15.00	38.00	69.80	80.80
Tin	8.76	5.91	7.32	4.25	6.36	6.83	8.33	3.99	6.86	8.60
Vanadium	36.40	16.50	15.90	22.80	11.11	11.50	8.40	11.40	18.10	16.70
Zinc	59.00	52.30	22.10	43.90	17.10	26.40	19.00	24.10	41.00	72.70
TVS (%)	5.14	2.65	1.68	5.03	0.67	3.19	1.34	3.03	4.25	5.66

Table 7. Metals Results (ppm, dry weight) for LSFCR Mussel Samples (July 1988).

	M1	M2	M3	M4	M5	M7	M8	M9	M10	M11	M12	M13	M14	M15	M16
Al (%)	0.067	0.041	0.137	0.080	0.069	0.045	0.137	0.045	0.049	0.082	0.104	0.017	0.038	0.045	0.046
As	3.90	1.60	2.70	1.50	1.60	1.60	1.50	0.94	0.71	1.00	4.20	<1.10	0.91	<0.93	<0.88
Ba	300	354	286	313	192	1210	343	1140	1260	526	18.80	1370	955	1170	1170
Cd	2.60	2.32	2.30	1.75	2.20	2.11	1.83	1.51	2.87	2.40	2.66	3.44	3.55	2.80	1.77
Cr	4.65	5.12	9.29	4.60	3.90	6.83	7.56	6.23	7.43	5.62	5.93	7.31	6.00	5.70	6.64
Cu	11.40	13.80	16.70	12.30	17.30	5.12	13.70	6.89	6.54	13.00	85.40	4.84	7.00	6.64	6.55
Fe (%)	0.291	0.211	0.403	0.270	0.297	0.778	0.360	0.821	0.700	0.348	0.212	0.838	0.646	0.693	0.713
Mg (%)	0.168	0.184	0.202	0.172	0.159	0.189	0.192	0.181	0.181	0.250	0.138	0.189	0.162	0.187	0.185
Mn (%)	0.494	0.720	0.735	0.683	0.398	1.110	0.622	1.140	1.300	0.793	0.047	1.200	0.897	1.140	1.190
Hg	0.748	1.020	0.566	0.445	0.675	0.886	0.412	1.150	0.860	0.958	NA*	0.989	0.964	0.953	1.040
Ni	3.86	4.72	4.60	<2.92	<3.25	<3.25	4.58	5.09	3.68	<4.17	<4.84	<4.30	<3.64	<3.74	<3.54
Pb	3.10	3.20	3.50	2.20	2.40	2.40	2.30	1.90	2.20	2.10	3.40	3.20	1.80	1.90	3.50
Se	6.30	7.20	5.30	4.40	3.30	4.10	5.30	3.80	3.70	4.20	NA*	5.40	3.60	7.50	7.10
Sr	458	530	790	617	375	467	526	433	457	746	88.50	509	393	460	457
Sn	10.40	12.00	11.80	11.80	12.80	6.34	10.00	<4.72	10.40	<5.21	8.72	14.30	<4.55	10.80	8.94
V	<3.94	<4.00	4.78	3.80	<4.07	5.28	4.35	4.91	5.96	<5.21	<6.05	<5.38	<4.55	5.23	5.40
Zn	243	477	372	303	320	185	345	195	229	450	192	186	190	189	183

*NA- Not analyzed due to insufficient sample.

Blank, duplicate, and reference material samples were also analyzed for metals. Results for these quality assurance/quality control samples were generally acceptable, except for the following:

1) the amount of LSF-M12 was insufficient to complete selenium and mercury analyses;

2) the relative percent difference for the ten duplicate analyses was out of acceptable range (51%); and

3) the recovery for the barium and tin spike analyses were out of acceptable range (75% and 73%, respectively).

DISCUSSION

Overall, the concentrations of organochlorine chemicals and PAHs in these sediment and mussel samples do not appear to represent a significant threat to mussels in the LSFCR (Eisler 1987). Water samples were not analyzed in this phase of the study and the results of the juvenile mussel toxicity tests should be consulted for a more complete evaluation. Concentrations measured in mussels were similar to those found in sediment.

The effects of the aliphatic hydrocarbons found in the mussel samples is uncertain. The concentrations appear to be fairly low, and were not notably higher than those found in the sediment samples. Comparisons with the results of the mussel survey and toxicity tests may provide additional information.

Based on a comparison with Kelly and Hite (1984), total volatile sulfides were not elevated at any of these ten sampling locations. Most sediment metal concentrations were within normal ranges expected in soils of the eastern United States (Shacklette and Boerngen 1984). Several notable exceptions included: arsenic at five sites (1, 3, 4, 9 and 10); iron and copper at Site 1; nickel at Sites 1 and 2; and manganese at five sites (1, 2, 4, 9 and 10). Manganese also approached or exceeded the limit of tolerance values established for Canada (Jaagumagi 1992, Persaud et al. 1989) at these same five sites. Based on unpublished USEPA (1977) guidelines, the six sites where manganese exceeded 500 ppm (Table 6) would be considered heavily polluted.

Mercury was only detected in sediment samples from Sites 1 and 10, however, it was found in all mussel samples, except M12, at an average concentration of 0.833 ppm. Mercury concentrations exceeded 1.0 ppm in samples from Sites 1 and 9 and would be considered moderately polluted based on USEPA (1977) unpublished guidelines. On average, mercury concentrations in mussel samples were about 14 times greater than those in sediment. While it has been widely noted that mussels accumulate a variety of metals, the effects of these body burdens is not certain.

Overall, our results indicate that some heavy metals may be impacting mussel populations in LSFCR. The primary metals of greatest concern are arsenic, manganese, and mercury. The contaminant analyses obtained from this portion of the project should be used in conjunction with results from the mussel survey and the juvenile mussel toxicity tests.

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