Biological Assessment of Columbia Dam Alternatives, Duck River, Tennessee

River Basin Operations
Tennessee Valley Authority
October 1988

BIOLOGICAL ASSESSMENT OF COLUMBIA DAM ALTERNATIVES, DUCK RIVER, TENNESSEE

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

In July 1987, TVA proposed to reinitiate consultation with the U.S. Fish and Wildlife Service (FWS) to discuss updated status of the endangered species that persist in the Duck River and possible alternative pool levels lower than the elevation 630 full-pool option. FWS agreed to reinitiate consultation but requested that TVA prepare a comprehensive biological assessment on project alternatives before any formal discussions occur. This document is intended to comply with that request.

The assessment has two purposes. In the Biological Status Section, it presents new information on the status of the endangered mussel species and reviews research that has been conducted on these species since the last FWS Biological Opinion was issued in 1979. Both of the endangered species (birdwing pearly mussel, Conradilla caelata, and Cumberland monkeyface pearly mussel, Quadrula intermedia) covered by the 1979 Biological Opinion still persist in the Duck River. In addition, during a 1988 survey of the project area, TVA biologists discovered one specimen of the tan riffle shell, Epioblasma walkeri. This endangered species was excluded from the 1979 Biological Opinion because it was thought to have been extirpated from the Duck River.

The Project Alternatives Section describes the impacts of six permanent and four interim Columbia Dam alternatives on the endangered freshwater mussel species. Impacts described generally are caused by

the conversion of stream habitats to those that occur in lakes, with the resultant loss of stream-dwelling species like the endangered mussels. The most substantial impacts occur from alternatives that would modify the longest river reaches.

The scope of this assessment is limited to endangered species issues. From the TVA perspective, the value of this assessment will be realized if it promotes wide-ranging discussions between the affected agencies on mutually acceptable solutions.

INTRODUCTION

Early History

During the mid-1960s, residents in Maury, Marshall, Bedford, and Coffee Counties in central Tennessee requested that the Tennessee Valley Authority (TVA) study the feasibility of building a series of water supply, flood relief, and recreational reservoirs in the Duck River watershed. Continued local interest resulted in the formulation of the TVA Duck River Project which consisted of two reservoirs: a 3,230-acre impoundment in the headwaters at Normandy, Duck River Mile (DRM) 248, and a 12,600-acre impoundment in the middle reach of the river at Columbia, DRM 136. Normandy Reservoir was to be built first and it was completed in 1976. Work on Columbia Reservoir was started in 1973 but all construction on the dam was halted in October 1980. At that time, the concrete portion was about 92 percent complete and the earthfill section was about 60 percent complete. Ancillary work on roads and bridges, which would be useful even if the project were not completed, continued until September 1983, at which time all construction was halted.

From a relatively early time, this river had been known to support an extremely diverse aquatic fauna, including 65 species or forms of freshwater mussels (Ortmann, 1924). Opponents of the project argued that conversion of 17 miles of the headwaters and 54 miles of the middle of the Duck River to impoundments would have a substantial

impact on the native fauna, much of which existed only in riffle areas (shoals). In the case of freshwater mussels, this situation was aggravated by two additional factors: there had been a substantial decline in all mussel stocks in the upper Duck River between 1965 and 1972--the cause of which has never been determined (van der Schalie, 1973)--and a large number of the species were known to occur only in the upper 150 miles of the river--the reach in which both impoundments were to be built.

Endangered Species Activities

Following the passage of the Endangered Species Act in 1973, the U.S. Fish and Wildlife Service (FWS) began listing species determined to be either endangered or threatened throughout all or a significant portion of their ranges. In 1976 and 1977, the FWS added a number of freshwater mussels to their list of endangered species, including five species that had been known to occur in the Duck River. Consultation between TVA and FWS resulted in a February 1977 FWS Biological Opinion which indicated that the completion of the Columbia Dam Project would jeopardize the continued existence of the birdwing pearly mussel, Conradilla caelata, and the Cumberland monkeyface pearly mussel, Quadrula intermedia. Available information indicated the other three species no longer existed in the river.

In 1978, the Office of Management and Budget asked TVA to examine alternatives to completing Columbia Reservoir as originally

proposed that would provide project benefits but would not jeopardize the endangered species. The report on that study (TVA 1979) found the two alternatives evaluated (a river development option and a low pool option at elevation 600 ft) to be unacceptable but, in its description of the project as planned (at elevation 630 ft), outlined a conservation program that could be implemented to benefit the endangered species and other endemic mollusks.

In a September 1979 revision of the Biological Opinion, the FWS accepted the conservation program concept and made it part of a reasonable and prudent alternative that would allow completion of a full-pool Columbia Reservoir. A significant constraint associated with this alternative was that the conservation program for the two endangered species had to be proven successful before the reservoir could be filled. Another reasonable and prudent alternative included in the 1979 Biological Opinion was construction of a self-regulating reservoir at elevation 571 ft, accompanied by some mussel conservation measures.

By the time the revised Biological Opinion was issued, TVA biologists and engineers were beginning to implement the first activities in their Cumberlandian Mollusk Conservation Program (CMCP). After discussions with the FWS staff, TVA began full CMCP implementation in 1980. As designed, the CMCP consisted of two time-separated phases, each including a number of related activities. The first, or research phase of the program, was intended to accumulate information on the present distribution, life history, and

ecologic requirements of the freshwater mussel fauna. This phase also included gathering ecological information on a number of sites which either were inhabited by the two endangered species or appeared suitable to receive endangered mussel transplants. The second, or conservation phase of the program, was intended to use research phase information to enhance mussel populations wherever they occurred in the Tennessee River system.

Planning and progress of the CMCP was reviewed by the Columbia Dam Coordinating Committee (CDCC). This committee was established by the FWS Regional Director to track CMCP progress and to foster staff-level communication between TVA, FWS, and the affected States. Membership was offered to TVA, FWS, the U.S. Environmental Protection Agency, and fish and wildlife agencies in Alabama, Tennessee, and Virginia. FWS and TVA staff members served as co-chairmen. Meetings were held quarterly during most of the CMCP research phase, then on an as-needed basis once the active field work had been completed.

As the program progressed, the CDCC also was requested to recommend criteria by which success of the CMCP would be judged. Lists of "likely success" and "proven success" criteria were prepared in May 1982 and a revised list of success criteria was prepared in October 1985. The FWS transmitted each of these sets of criteria to TVA "to further implement the September 1979 Biological Opinion".

During the summer of 1982, TVA prepared draft reports on research phase activities that were pertinent to transplantation and

proposed to transplant the birdwing pearly mussel from the Columbia Dam impoundment area to four sites on the upper Duck, Buffalo, Nolichucky, and North Fork Holston Rivers. This proposal was approved by the CDCC, an endangered species permit was received from the FWS, and 1000 animals were transplanted to each site in October 1982. Monitoring of the transplants occurred on a semiannual basis through 1987, when it was reduced to an annual cycle. By that time, all four populations were still in existence; however, estimates indicated only approximately 200 individuals persisted in each area.

Results of each of the nine research phase activities were documented in TVA reports that were finalized in 1986. To date, conservation phase activities have been limited to the transplantation effort. Periodic status reports on this activity have been made to FWS but no comprehensive report has yet been prepared because the monitoring program is still under way.

Current Status

The "likely success" criteria had been written by the CDCC with the assumption that they would be applied one year after TVA transplanted specimens of the birdwing pearly mussel. By the spring of 1984, when TVA documented that several of these criteria had not been met, the FWS acknowledged that "likely success" had not been met and asked about future plans. TVA responded that sufficient funds were not available to continue most conservation activities except for monitoring of the transplants.

In 1986, TVA complied with a request from the Office of Management and Budget and submitted a revised benefit-cost analysis for Columbia Dam (TVA, 1986). That report indicates the project is holding at 45 percent complete. Major activities remaining include: purchase of 14,600 acres of land; relocation of about 30 families, 22 miles of roads, several utility services, and 16 cemeteries; completion of the dam; preparation of the reservoir pool area; construction of recreation and wildlife facilities; archaeological and cultural activities; and remaining mussel conservation activities. In recent years, Federal appropriations for TVA have not included any funds to continue constructing this project.

This Assessment

In July 1987, TVA proposed to reinitiate consultation with the FWS to discuss updated status of the endangered species and possible alternative pool levels lower than the elevation 630 full-pool option. FWS agreed to reinitiate consultation but requested that TVA prepare a comprehensive biological assessment on project alternatives before any formal discussions occur. This document is intended to comply with that request.

This assessment has two purposes. In the Biological Status Section, it presents new information on the status of the endangered mussel species and reviews research that has been conducted on these species since 1979. The Project Alternatives Section describes the

impacts of several interim or permanent Columbia Dam alternatives on the endangered freshwater mussel species. The scope of this assessment is limited to endangered species issues. From the TVA perspective, the value of this assessment will be realized if it promotes wide-ranging discussions between the affected agencies on mutually acceptable solutions.

BIOLOGICAL STATUS

Nine years have passed since the last Biological Opinion on this project was written. During that time, the FWS, the U.S. Army Corps of Engineers, TVA, and many other Federal and State agencies have conducted or funded much biological work on North American endangered mussel species. Important advances have been made in determining the distribution and abundance of most species, identifying fish hosts, exploring artificial culture, recognizing potential impacts, and planning recovery activities. Also during this time unexplained mussel dieoffs have occurred, river and stream habitats have been destroyed, and other types of mussel losses have been reported in various parts of the nation. Prior to examining the impacts of various Columbia Dam alternatives, it is important to recognize the changes that have occurred in the mussel resources that would be affected by this project.

Duck River Fauna

In 1979, prior to completion of the Biological Opinion, TVA biologists conducted a float survey of mussel resources in the Duck River from Lillard Mill dam (DRM 179) downstream to Columbia (DRM 132). That survey was used by FWS as the basis for the list of species likely to be impacted by the project, their distribution in the river, and their abundance throughout the project area. Results of the 1979 Duck River survey were presented in a compilation of all CMCP mussel surveys (Ahlstedt, 1986).

In 1988, as part of preparations for this assessment, TVA biologists repeated the Duck River float survey. Results of the survey (Appendix A) indicate the mussel fauna has changed very little in composition and, generally, is more abundant now than it was in 1979. The part of the river where most species and individual mussels were found in 1979 (DRM 170 - 179) has stayed much the same while a 20-mile reach further downstream (DRM 145 - 165) now supports more species and greater numbers than it did nine years ago.

Habitat conditions along the river have remained unchanged or have improved from what they were in 1979. TVA retains ownership of 13,000 acres of land in the lower half of the proposed project area, a declining percentage of which is being leased for row crops, hay, or pasture. Bankside vegetation, which had been cleared from at least 15 miles of the Duck River just upstream from the dam construction site in 1978, has regrown and appears to have stabilized most of the

disturbed shoreline and island areas. Farming in the remainder of the area has continued or declined slightly, following the national pattern.

Conradilla caelata

Since 1979, the birdwing pearly mussel has been the subject of considerable research interest, primarily by TVA. Distribution, ecological, life history, and transplantation studies all have been conducted focusing on this species. Recent information gathered about C. caelata is summarized in the following paragraphs. Much of this information also has been used in the FWS recovery plan for the species (Ahlstedt, 1984a).

Duck River Population--During the 1979 Duck River survey, the birdwing pearly mussel was found downstream from the (old) Columbia Dam (DRM 132) and at 27 collection sites between DRM 147.9 and 179.0 (Ahlstedt, 1986). Quantitative sampling in 1979 produced 42 C. caelata specimens from 10 sites, for an average of 0.33 specimens per square meter ($0.33/m^2$) in good mussel habitat.

The 1988 survey (Appendix A) indicated the distribution and abundance of C. caelata in the Duck River had changed very little. In 1988, this species was found in virtually the same river reach upstream from the (old) Columbia Dam, between DRM 147.4 and 179.2. Abundance information from 1988 indicated a higher average per square meter ($0.62/m^2$), but this value was not significantly different from

the average obtained in 1979 ($0.33/m^2$). Comparison of average numbers within 5-mile reaches indicated that good mussel habitat throughout most of the river supports approximately 0.14 C. caelata per square meter, while good habitat in the reach between DRM 175 and 179 supports approximately $1.21/m^2$. Length information on 70 specimens found during the 1988 survey (Appendix A) included a variety of size classes and suggested a typical bell-shaped size distribution pattern.

Populations Elsewhere--When the 1979 Biological Opinion was written, the birdwing pearly mussel was known to persist only in the Duck, Powell, and Clinch Rivers. In 1980, TVA biologists found fresh-dead C. caelata at two sites 10 miles apart on the lower Elk River (Ahlstedt, 1986). This population has not been reevaluated since 1980; however, comparable quantitative sampling has been conducted in both the Powell and Clinch Rivers as recently as 1988.

The 1979 survey of the Powell River yielded live or fresh-dead C. caelata from 5 sites between PRM 94.8 and 136.1 (Ahlstedt, 1986). None of the animals were found in any of the quantitative samples. Similarly, this species was not found when the quantitative sampling sites were revisited in 1983 and 1988 (Appendix B). While these resurveys of Powell River quantitative sampling sites provide no direct information on the status of C. caelata, the substantial decline of all mussels including most of the abundant species indicates the birdwing population also might have declined.

In the Clinch River, the 1979-1983 survey included C. caelata records from 12 sites between CRM 183.5 and 253.0 (Ahlstedt, 1986). Only one quantitative sample in the 1979 data set included the species (CRM 189.6), leading to an overall average abundance of $0.01/m^2$. During the 1988 reassessment of quantitative sites (Appendix C), C. caelata was found in samples from two sites (CRM 189.6 and 219.1) and the resulting full-river abundance estimate was $0.02/m^2$. Not surprisingly, comparison of these data sets did not indicate significant differences between the abundance of C. caelata in the two surveys. Like the Powell River, overall declines in the Clinch River mussel assemblage could be used to imply a decline in the C. caelata population as well.

Other Information--In addition to distribution and abundance surveys, TVA biologists have identified a fish host for C. caelata and have transplanted this mussel species to other parts of its historic range. Bankside laboratory infection studies identified the banded darter, Etheostoma zonale, as a fish host for C. caelata (Hill, 1986). This fish occurs throughout a large portion of the Mississippi River system. The research also has provided observational data on the reproductive cycle of the mussel species.

The C. caelata transplantation effort undertaken by TVA has been a pioneering study, from which many agencies have learned a great deal. An extensive search and comparison effort was conducted to select sites within the historic range which would be suitable for the survival and reproduction of this endangered species (Jenkinson and

Heuer, 1986). During the fall of 1982, four thousand birdwing pearly mussels from the Duck River were moved to sites on the upper Duck, Buffalo, Nolichucky, and North Fork Holston Rivers. At each site, the animals were placed in a regular pattern that would facilitate later monitoring. Semiannual evaluations of the sites during the next five years documented short- and long-term survival rates, and demonstrated problems associated with sampling the increasingly-dispersed transplants. Attempts to find evidence of successful reproduction have led through a series of tests of juvenile mussel sampling devices and procedures that may not yet be complete. After five years, each transplanted population persists, but only approximately 20 percent of the original stock can be found. Normal reproductive activity has been observed in the females each year but no juveniles have been located.

Epioblasma walkeri

The tan riffle shell, Epioblasma walkeri, was one of three endangered mussel species discussed in the 1979 FWS Biological Opinion that were not considered jeopardized by the Columbia Dam project because they appeared to have been extirpated from the project area. The species is included here because it was rediscovered in the Duck River during the 1988 survey.

Duck River Population--As indicated in Appendix A, a single fresh-dead specimen of E. walkeri was found at DRM 151.6 in April 1988

when the site was being inspected as a possible boat access point. The three-year-old female shell still had tissue clinging to one muscle scar when it was found on a gravel bar. The identification of this specimen has been substantiated by David H. Stansbery, Ohio State University Museum of Zoology, and the specimen has been deposited in that collection. Considerable searching at the site and all along the length of the Duck River during the 1988 survey failed to produce any other specimens. The condition and age of this specimen leave little doubt that a remnant population of E. walkeri persists in the Duck River.

Populations Elsewhere--The recovery plan for this species (Neves, 1984), indicates the only known population persists in a short reach of the Middle Fork Holston River in Virginia. More recent information suggests that a small population also persists in the upper Clinch River (Stansbery, personal communication) and a population of what may be this species occurs in the Big South Fork Cumberland River (Bakaletz, personal communication). None of these populations appears to include many specimens and none occupies a long reach in the stream.

Quadrula intermedia

The Cumberland monkeyface pearly mussel, Quadrula intermedia, also has been studied intensively since 1979. This work has increased our knowledge of the species and provided new field and laboratory

techniques. Information gathered during the early years of this study were incorporated into the FWS recovery plan for this species (Ahlstedt, 1984b).

Duck River Population--During the 1979 survey, Q. intermedia was found at three sites between DRM 162.8 and 173.2 (Ahlstedt, 1986). None of the animals was found in a quantitative sample. In 1980 and 1981, three specimens of the species were found near DRM 179.0 while collecting C. caelata for fish host identification tests (Charles Gooch, personal communication). In 1988, three specimens of the species were found at DRM 176.8, one of which occured in a quantitative sample (Appendix A). The animals seen in 1988 were estimated to be 12, 13, and 15 years old.

Given such small numbers, the only conclusion to be drawn is that the species persists in the Duck River, perhaps as far downstream as DRM 162. The ages of the specimens seen in 1988 suggests reproduction occurred at least as recently as the mid-1970s.

Populations Elsewhere--In 1979, Q. intermedia was known to persist only in the Duck and Powell Rivers. However, like C. caelata, this species was found when TVA biologists surveyed the Elk River in 1980 (Ahlstedt, 1986). Specimens of Q. intermedia were found at five Elk River sites between ERM 70.5 and 109.6. No quantitative samples were taken during the Elk River survey.

In the Powell River, the 1979 survey yielded records of Q. intermedia from sites between PRM 94.8 and 126.4 (Ahlstedt, 1986). The species occurred in quantitative samples from two of these sites,

for a overall abundance estimate of $0.03/m^2$. Both the 1983 and 1988 reassessments of the Powell River quantitative sites included records for Q. intermedia (Appendix B). In 1983, the Cumberland monkeyface was found at two sites ($0.02/m^2$ overall) and, in 1988, the species was found at one site ($0.03/m^2$ overall). Statistically, these overall abundance estimates are not significantly different from each other (at the 95 percent confidence level).

Other Information--Working in cooperation with Richard J. Neves, Virginia Cooperative Fisheries Unit, TVA biologists perfected techniques for handling mussels that could abort glochidia, then proceeded to determine that two minnows (streamline chub, Hybopsis dissimilis, and blotched chub, Hybopsis insignis) were fish hosts for Q. intermedia (Hill, 1986). In the process, considerable information was accumulated on the reproductive cycle and behavior of Q. intermedia, Q. cylindrica, and other species.

PROJECT ALTERNATIVES

As indicated previously, one purpose of this assessment is to describe the probable impacts of alternatives to the full-pool Columbia Reservoir that would occur to endangered freshwater mussel species in the Duck River. Many of these alternatives have been mentioned in various planning documents or proposals. Others are included to encourage wide-ranging discussions between TVA and FWS during the consultation sessions. In the following section, complete

projects are listed first, followed by interim measures anticipated to lead to the full-pool reservoir. The treatment for each alternative consists of a brief description of the project, comments on any unusual features, and the anticipated impacts on the endangered mussel species.

No mitigation measures are described as part of any alternative because a variety of mussel conservation activities and other measures could be associated with most options to minimize endangered species impacts. The determination of appropriate mitigation measures should be one of the topics discussed during the consultation sessions.

Complete Projects

1. Reservoir at Elevation 630.

   Description--This is the project as it was originally planned, the one that the Tennessee Upper Duck River Development Agency recommends, and the one Congress has directed TVA to complete. It is thoroughly described in the alternatives study report (TVA, 1979). This alternative would use the dam at DRM 136.9 to create a 12,600 acre impoundment at maximum pool elevation 630 ft. At full pool, the impoundment would extend upstream 54 miles on the Duck River to approximately DRM 191. Benefits expected from this project include flood control, water supply, recreation, and land enhancement.

Endangered Species Impacts--Construction of this reservoir would cause substantial changes in the physical, chemical, and biological character of the impounded river reach. Reduced current velocities in the reservoir would allow fine sediments to accumulate on gravel substrates that are routinely washed free of such deposits in a flowing stream. Changes in flow rates, water depth, temperature, and dissolved oxygen patterns would alter the composition and distribution of the fish fauna. Both of these major changes would lead to extirpations of endangered and other mussel species. All three endangered species (Conradilla caelata, Epioblasma walkeri, and Quadrula intermedia) occur primarily in clean-swept gravel substrates, generally in relatively shallow water. The fish hosts for two of these species (C. caelata and Q. intermedia) are now known to be stream-dwelling darters or minnows that occur on gravel shoals or in adjacent pools.

Impoundment of the Duck River between DRM 137 and 191 would eliminate all of the known habitat for the three endangered mussel species that persist in this reach of the stream. Extripation of the C. caelata population in the Duck River would reduce the species by as much as 95 percent of the current known numbers and would eliminate one of four remaining natural populations. Extripations of E. walkeri and Q. intermedia from the Duck River would not be as substantial in terms of numbers of individuals but, in each case, would eliminate one of three or four populations of these nearly-extinct species.

2. Reservoir at Elevation 600.

Description--This alternative also was described in the alternatives study report (TVA, 1979). As a complete project, this alternative would use the dam at DRM 136.9 in a modified state and would create a 3,700 acre impoundment at maximum elevation 600 ft. The reservoir would extend 35 miles upstream on the Duck River to DRM 172. This alternative could be managed in conjunction with Normandy Reservoir to provide water supply and some recreational benefits, but would have no detention capacity for flood control.

Other Considerations--The dam at DRM 136.9 was designed for use with a full-pool reservoir and would have to be modified, perhaps substantially, to be operated permanently at this level. Given the relatively shallow nature of this reservoir, plankton blooms in the impoundment are likely to cause more taste and odor problems than would be created by the full-pool alternative.

Endangered Species Impacts--The physical, chemical, and biological changes within a reservoir described under Alternative 1 also would occur in the impoundment pool proposed here. The chief difference in biological impact between this proposal and Alternative 1 is that this impoundment would not include the reach between DRM 172 and 191.

With regard to the endangered species, this proposal would avoid direct impacts to the reach most densely inhabited by C. caelata (DRM 175 - 179). However, virtually all of the rest of

the C. caelata habitat in the river (between DRM 147 and 172) would be destroyed. Determining the percentage of the population that would be destroyed requires some calculation. Average estimates of C. caelata abundance in good mussel habitat were presented in the Biological Status section ($0.14/m^2$ for DRM 150 - 175 and $1.21/m^2$ for DRM 175 - 179). Assuming that a roughly comparable amount of good mussel habitat (X square meters) occurs in each mile length of the river, the 25 mile reach that would be lost (all at $0.14/m^2$) would include 3.50X C. caelata. Similarly, the 7 mile reach that would remain (3 miles at $0.14/m^2$ and 4 miles at $1.21/m^2$) would include 5.26X C. caelata. Using these numbers, approximately 40 percent of the Duck River C. caelata population occurs in the reach that would be impounded under this alternative. All of the remaining 60 percent of the population would be located within 7 miles of the head of impoundment. Even conservative estimates of the amount of good mussel habitat in this river reach would lead to a remaining population estimate higher than 500 individuals, the level the FWS considers necessary to maintain a viable population (Ahlstedt, 1984a).

Impacts to the other endangered species must be determined using only occurrence information. If E. walkeri persists only in a short reach adjacent to where it was found (DRM 151), this population would be extirpated by construction of this alternative. Similarly, if Q. intermedia persists throughout the reach in which it was found in 1979 and 1988 (DRM 162.8 - 179.0), roughly half of that population would be destroyed.

In the 1979 FWS Biological Opinion discussion of this alternative, considerable attention was given to possible reservoir effects on fish and mussels in the adjacent upstream river reach. Isom and Yokley (1968a) reported both additions and deletions in a stream mussel fauna they believed were caused by fish movements from a downstream reservoir. This could be a possible impact to remaining populations of Duck River endangered species if this alternative was implemented; however, the likelihood of this impact has not been determined.

3. Reservoir at Elevation 585.

Description--This alternative has been included specifically to encourage discussion of pool levels between elevation 600 and 571. It would use a substantially modified dam at DRM 136.9 to create a 1,800-acre reservoir. The full-pool impoundment would extend 28 miles upstream on the Duck River, to DRM 165. While this alternative has not been evaluated in much detail, its intended benefits would be water supply and recreation. Flood control benefits probably would not be possible.

Other Considerations--This alternative would share the structural problems and taste and odor concerns mentioned under Alternative 2.

Endangered Species Impacts--Within the 28-mile long impoundment, the impacts listed under Alternative 1 would occur. Upstream from DRM 165, mussel populations would not be subject to slackwater effects.

With regard to C. caelata, this alternative would inundate 18 miles of lower density habitat but would avoid direct effects to the remaining inhabited reach, including the four miles of higher density habitat between DRM 175 and 179. Using the percentage of impact calculation technique introduced under Alternative 2, this proposal could be expected to eliminate roughly 29 percent of the C. caelata population in the Duck River. A population far in excess of 500 individuals would remain.

Impacts on one of the other endangered species also would be somewhat different from Alternative 2. All of the river reach apparently inhabited by Q. intermedia (DRM 162.8 - 179.0) would be upstream from this impoundment. However, the reach where E. walkeri was found (DRM 151) would still be well within the reservoir and the population would be extirpated if it persisted only in that area.

The comments included under Alternative 2 concerning possible reservoir effects in the adjacent upstream river reach also would apply to this proposal. Since there would be 14 miles of river habitat between the head of impoundment and the dense mussel area at Lillard Mill dam, it seems reasonable to expect that any reservoir effects would be less noticeable under this alternative.

4. Reservoir at Elevation 571.

Description--The 1979 FWS Biological Opinion recognized a self-regulating dam at elevation 571 as a reasonable and prudent

alternative to the full-pool project. In its present form, this alternative would consist of stabilizing the earthfill and diking system as it now exists at DRM 136.9 and placing a concrete overflow section in the diversion channel with several outlets to control discharge at low flows. The resulting impoundment would cover 500 acres of land and would extend 18 miles up the Duck River to DRM 155. The purpose of this project would be to serve as a focal point for regional recreation development on TVA lands already purchased for the project. Water supply and flood control benefits would be minimal.

Other Considerations--This updated alternative is accompanied by a recreational development component that would promote river use activities upstream as far as DRM 164. Proponents of the full-pool alternative consider this alternative unacceptable because significant water storage is not included.

Endangered Species Impacts--Impoundment effects would occur in this small reservoir; however, their impacts probably would be slight near the head of the fluctuating pool. Approximately eight miles of lower density C. caelata habitat would be affected (DRM 147 - 155), suggesting that roughly 13 percent of the population could be extirpated. The location where E. walkeri was found also would be inundated by this proposal. Known habitat for Q. intermedia is seven or more miles upstream from the proposed head of this impoundment.

Reservoir effects on the upstream river reach would be much less than for the other impoundment alternatives. The small size of this impoundment pool would be unlikely to encourage development of predator populations suggested to invade adjacent river reaches.

5. River Development.

Description--Three levels of river development were described in the 1979 alternatives study report (TVA, 1979). Each of these levels would include removing part or all of the partially-finished dam at DRM 136.9, accompanied by varied amounts of recreational development along the Duck River between Columbia and Henry Horton State Park (DRM 191). Recreation would be the sole benefit of such a project.

Other Considerations--This alternative has been rejected by full-pool reservoir proponents because it does not include any water supply component.

Endangered Species Impacts--Few adverse impacts to the endangered species would occur if some form of this alternative was implemented. Stabilization and maintenance of this section of the Duck River as a warm-water stream would preserve and, probably, enhance most resident mussel populations. Establishment and maintenance of some sort of protected corridor along the river would minimize shoreline disturbance and encourage stream habitat stability. Unregulated recreational activity along the river

could lead to local habitat destruction; however, such activity would be unlikely to affect endangered species populations throughout the entire river section.

6. Other Alternatives.

Description--Several additional complete projects have been mentioned as potential alternatives to the full-pool reservoir. This open-ended alternative has been included specifically to encourage wide-ranging discussions of other possibilities. Other alternatives that have been mentioned to TVA staff include:

-construction of a water supply reservoir on a Duck river tributary.

-operational modifications at Normandy Dam to augment river flow.

-installation of tertiary waste treatment at one or more municipalities on the Duck River.

-augmentation of water supplies from other sources.

Endangered Species Impacts--Impacts of various other alternatives on Duck River endangered species would have to be determined once each idea was described in detail. More than likely, sufficient information already exists to make these determinations if they are required during the consultation sessions.

Interim Projects

Each of these alternatives incorporates the assumption that completion of the full-pool alternative (# 1 above) would occur once any required mussel conservation activities had been finished.

7. Interim Reservoir at Elevation 600.

   Description--As listed for Alternative 2, above, except that the dam would not be modified for permanent use at this level.

   Other Considerations--Proponents of Columbia Reservoir see this as the only appropriate alternative to completing the full-pool impoundment as soon as possible.

   Endangered Species Impacts--Interim impacts would be as described under Alternative 2. Final impacts would be as described under Alternative 1.

8. Interim Reservoir at Elevation 585.

   Description--As listed for Alternative 3, above, except that the dam would not be modified for permanent use at this level.

   Endangered Species Impacts--Interim impacts would be as described under Alternative 3. Final impacts would be as described under Alternative 1.

9. Interim Reservoir at Elevation 571.

   Description--This alternative would be built as described in the 1979 alternatives study report (TVA, 1979) and operated as

described in the 1979 FWS Biological Opinion. The Duck River would be diverted through the dam structure at DRM 136.9 while the earthfill portion of the full-pool dam was completed. Closure of the dam could occur at any time after the earthfill section was completed.

Endangered Species Impacts--Interim impacts would be as described under Alternative 4. Final impacts would be as described under Alternative 1.

10. Other Alternatives.

Description--This open-ended range of alternatives is intended to be similar in nature to Alternative 6 except that each of these possibilities eventually would lead to, or be complimented by completion of the full-pool reservoir. Each of the possibilities listed under Alternative 6 might be considered here, perhaps accompanied by several others.

Endangered Species Impacts--The comments about potential impacts presented under Alternative 6 apply here. Final impacts would be as described under Alternative 1.

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APPENDIX A

RESURVEY OF FRESHWATER MUSSEL STOCKS IN THE DUCK RIVER, TENNESSEE

TENNESSEE VALLEY AUTHORITY

River Basin Operations
Water Resources

RESURVEY OF FRESHWATER MUSSEL STOCKS IN THE DUCK RIVER, TENNESSEE

October 1988

TENNESSEE VALLEY AUTHORITY

River Basin Operations
Water Resources

RESURVEY OF FRESHWATER MUSSEL STOCKS IN THE DUCK RIVER, TENNESSEE

Prepared by

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Knoxville, Tennessee
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TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION

Early in 1979, the Tennessee Valley Authority (TVA) realized definitive information on the distribution and abundance of freshwater mussels in the Duck River would not be known until virtually all of the possible habitat had been examined. Acting on this realization during the summer of 1979, crews of TVA biologists floated the river between Normandy Dam [Duck River Mile (DRM) 248.6] and Columbia (DRM 133.6) to conduct an adequate search. These crews made qualitative mussel collections at each shoal or other suitable habitat site and, where warranted, quantitatively sampled the mussel fauna. Data gathered during this Duck River survey, later reported upon by Ahlstedt (1986), were used by TVA and the U.S. Fish and Wildlife Service (FWS) in reviewing possible impacts of the Columbia Dam Project, then under construction. These data were used in forming the jeopardy Biological Opinion issued by the FWS in September 1979 and the scope of the TVA Cumberlandian Mollusk Conservation Program, first described completely in April 1980 (TVA, 1980).

In 1988, TVA asked the FWS to reinitiate consultation on the Columbia Dam Project. The FWS requested that TVA provide a biological assessment of alternatives to be considered, including information on the current status of endangered species that persist in the Duck River. TVA decided to meet part of this request by repeating the 1979 float survey. This report describes the 1988 survey, presents its results, and compares those results with data collected in 1979.

METHODS

Because the data from this survey were intended to be compared with a previous study, considerable effort was expended to insure that field procedures were similar. A description of the procedures used in 1979 is included in the report on that work prepared by Ahlstedt (1986).

The 1988 survey of the middle reach Duck River was conducted by two 3-man crews, each led by a biologist competent in field identification of freshwater mussels. These crews floated the river, making qualitative collections wherever suitable mussel habitat was encountered. During each timed qualitative search, crew members used a variety of techniques to find live and fresh-dead (shiny-nacre) mussels. Search techniques included looking for shells along the banks, hand raking in gravel and cobble substrates, and feeling for shells in fine substrates. Snorkel and, rarely, scuba equipment were used to facilitate scans of all suitable mussel habitat at each site.

All live and fresh-dead mussels encountered during the qualitative search were sorted to species by the crew leader, counted, and most live specimens were returned to suitable habitat at the site. Fresh-dead shells and selected old-dead (dull-nacre) shells were labeled and retained as voucher specimens. Location information, search times, and counts of each species were recorded on prepared field sheets.

Quantitative sampling was conducted if live specimens of endangered species were found or if dense mussel concentrations were present. When warranted, quantitative sampling consisted of searching

for mussels within $0.25m^2$ metal quadrat frames. The number of quadrat samples taken depended upon the crew leader's estimate of good mussel habitat at the site. A guide table, developed in 1979 (Ahlstedt, 1986), attempted to standardize the quantitative search at four percent of the suitable habitat.

The appropriate number of quadrat samples were taken scattered throughout the suitable habitat. In taking these samples, snorkel-assisted biologists disturbed the substrate within each quadrat to a depth of 5-10 cm and placed all mussels found in collection bags. The crew leader sorted the mussels from each quadrat to species, counted them, and recorded the data on a field sheet. Most of these animals also were returned to suitable habitat at the site.

Specimens of endangered species encountered during either the qualitative or quantitative sampling were measured in three dimensions (length, height, and thickness) and aged before being returned to suitable habitat.

Data collected from the sampling sites were summarized in tables and analyzed using various Statistical Analysis System (SAS) routines. Comparisons with data from the 1979 survey also were made using SAS programs. All decisions based on statistical tests were made at the 95 percent confidence level. Probability values between 0.05 and 0.1 are supplied in some tables for information purposes only.

RESULTS

This survey was conducted between May 16 and May 25, 1988. During the period, the river was at or below summer low-flow levels and

water temperatures were near 70°F. One day of rain near the end of the period reduced underwater visibility from approximately 50 cm to 20 cm but did not substantially affect flow.

The two crews floated the entire length of the Duck River from Lillard Mill Dam (DRM 179.6) downstream to the (old) Columbia Dam (DRM 133.6). Three sites downstream from the dam in Columbia (DRM 132.5, 133.3, and 133.5) were visited from access points.

Qualitative sampling was conducted at 62 sites along this 50-mile reach (table 1). No collections were made between DRM 133.5 (old Columbia Dam) and 141.3 because this reach is ponded by the dam and contains no obvious mussel habitat. At the collection sites, a total of 2,606 live or fresh-dead mussels was examined (table 1). The single Epioblasma walkeri, found at DRM 151.9, is the only specimen listed in table 1 that was not actually encountered during the float survey. It was collected during a reconnaissance of access points along the river conducted in late April. In all, these animals represented 34 species.

Quantitative sampling was conducted at 14 of the qualitative sites (table 2). The 282 0.25m^2 quadrat samples that were taken yielded 658 live mussels, for an average of 9.33 mussels per square meter.

Seventy of the 77 Conradilla caelata specimens encountered during this survey were measured, as were all three Quadrula intermedia and the single Epioblasma walkeri. Length increment summaries and river reach means of these data are presented in table 3.

At all sites, many of the mussels were found completely buried in the substrate. It was not uncommon to encounter live Lampsilis fasciola, Elliptio dilatatus, and members of several other species five or more centimeters below the firm substrate surface.

DISCUSSION

The chief purpose of this report is to recognize changes that occurred in the Duck River mussel fauna between 1979 and 1988. This is accomplished by examining differences in species composition, distribution patterns, and abundance. Comments also are included about the endangered species found and other species that exhibited substantial differences between the two data sets.

Species Composition

Table 4 summarizes presence/absence data for each 5-mile reach of the Duck River from both the 1979 (data from Ahlstedt, 1986) and 1988 surveys. Comparison of these data indicates that 31 species were found during both surveys, three species [Epioblasma triquetra, Pleurobema cordatum, and Strophitus rugosus (=S. undulatus)] were found only in 1979, and four species (Anodonta grandis, Anodonta imbecillis, Epioblasma walkeri, and Truncilla donaciformis) were found only in 1988. In Duck River collections made during 1976 and 1978 (Ahlstedt, 1981), TVA found 31 species including Dysnomia (=Epioblasma) brevidens and Micromya (=Villosa) taeniata not found in either subsequent survey.

Generally, the numbers of species found in each 5-mile reach examined during the 1979 and 1988 surveys (table 4) were similar upstream from DRM 155. Downstream from that point, more species were found in each 5-mile reach in 1988 than in 1979. The exception to this

generalization was the reach between DRM 160.1 and 165.0, where 22 species were found in 1979 and 16 species were found in 1988. This reach received considerably more sampling pressure in 1979 (collections at 15 sites) than it did in 1988 (9 sites), which may account for most of the difference in species records.

Distribution Patterns

Examination of table 4 with regard to the occurrence of species in the various 5-mile reaches indicates few differences between the surveys. Twenty-nine of the 38 species were found in roughly the same number of reaches (n±2) in 1988 as in 1979. Of the nine species which exhibited substantial differences, six (Anodonta grandis, Leptodea fragilis, Potamilus alatus, Truncilla truncata, Villosa iris, and Villosa vanuxemi) were found in more reaches during 1988. The larger number of mussels examined in 1988 (3,264 versus 1,969 in 1979) may account for many of these apparent additions.

Three species were found in substantially fewer 5-mile reaches during the 1988 survey. These species were either not found at all in 1988 (Pleurobema cordatum), or were found only in one reach each (Obovaria subrotunda and Pleurobema oviforme), when they had been widely distributed in 1979.

Considered together, the occurrence data from these surveys indicate mussel distribution patterns are quite uniform throughout this 50-mile river segment. The 5-mile reach just upstream from the (old)

Columbia Dam pool (DRM 140.1 - 145.0) supports 15 species, but reaches upstream from this point typically support 24 to 27 species. In this part of the river, most species occur in virtually every 5-mile reach or, if they occur sporadically, seem to follow a random pattern.

Species that do not seem to fit this generalization fall into two groups. Some rarely-found species (Epioblasma capsaeformis, Epioblasma triquetra, and Quadrula intermedia) occurred only in the most upstream reaches. Other species (Lasmigona complanata, Quadrula quadrula, and Truncilla donaciformis) only occurred in downstream reaches, usually only downstream from the (old) Columbia Dam. A statistical evaluation of these apparent patterns is presented below based upon the quantitative data base.

Abundance

In 1979, 509 $0.25m^2$ quadrat samples were taken, all in reaches upstream from DRM 145 (Ahlstedt, 1986). During the 1988 survey, 282 $0.25m^2$ quadrat samples were taken (table 2). Twenty of these samples were taken at DRM 133.5, just downstream from the (old) Columbia Dam, while the remaining 262 samples were taken in reaches upstream from DRM 145. In 1988, no attempt was made to sample the same sites that had been evaluated in 1979 or to take the same number of quadrant samples that had been examined in the earlier survey. The aim of the 1988 survey, like the one in 1979, was to take quantitative samples at sites where many mussels occurred or where endangered species were found alive.

Table 5 presents mean numbers per square meter for each species found in each 5-mile reach during these surveys. This table also indicates the significance level of analysis of variance (ANOVA) tests for "year" or "reach" effects when the means from the two surveys were determined to be substantially different from each other ($\alpha \leq 0.10$). The two-way ANOVA tests for the full 50-mile river segment were run only using data from the 6 reaches sampled during both surveys.

With regard to overall abundance throughout the 50-mile river segment, the data presented in table 5 indicate that significantly more mussels per square meter were found in 1988 ($9.33/m^2$) than in 1979 ($3.89/m^2$). While this difference could have been affected by the smaller number of quadrat samples taken in 1988 (for example, by collecting only in the best habitats), reach by reach examination of the results indicate the number of samples was not a factor. In the individual 5-mile reaches (table 5, figure 1), the 1988 and 1979 means for total mussels per square meter were not significantly different for reaches between DRM 170 and 179. However, between DRM 145 and 165, more mussels were encountered in each reach during 1988 than had been found in 1979. Nothing can be said about abundance trends in the reaches between DRM 130 and 145, or the reach DRM 165-170 because those areas were not quantitatively sampled during one or both surveys.

Significant differences existed between the overall means for six species. Five of these species (Elliptio dilatatus, Lampsilis fasciola, Leptodea fragilis, Medionidus conradicus, and Potamilus alatus) were more abundant in 1988. Pleurobema cordatum was present in quantita-

tive samples from four reaches in 1979 but was not found in qualitative or quantitative samples from any reaches in 1988.

With regard to uniformity of abundance throughout the 50-mile river segment, the ANOVA results indicated significant differences among river reaches for the totals and 12 species. Total abundance and abundance of most species were highest in the upstream river reach, DRM 175 to 179, while a few species (Elliptio dilatatus, Lampsilis fasciola, and Medionidus conradicus) were most abundant in one or another of the downstream reaches. Inspection of the reach-by-reach data did not indicate a consistent trend in the abundance of any common or widespread species.

Species Comments

Conradilla caelata--During the 1988 survey, 77 specimens of the birdwing pearly mussel, Conradilla caelata, were found at 14 sites located between DRM 147.4 and 179.2 (tables 1 and 2). In 1979, 67 specimens of this species were found in the Duck River, including one site downstream from the (old) Columbia Dam (DRM 132) and 27 sites between DRM 147.9 and 178.7 (Ahlstedt, 1986). Except for the record downstream from the (old) Columbia Dam (which has generally been assumed to be a remnant of the transplant effort made to this site in 1975 by Yokley), these two surveys indicate the distribution of C. caelata has remained virtually unchanged over the nine year period.

Abundance information on this species from both surveys (table 5) indicates more specimens were found per square meter during the

1988 survey ($0.62/m^2$) than in 1979 ($0.33/m^2$); however, this difference between years is not statistically significant ($p>F=0.96$). Similarly, there were no statistical differences in C. caelata abundance between the survey results for any of the 5-mile reaches. In the case of DRM 175-179 this lack of a significant difference is an interesting result. In 1982, 4,000 C. caelata were removed from this reach to reintroduce the species to four other river segments. The absence of these 4,000 specimens was not sufficient to yield a significant difference.

The combined data did indicate that C. caelata was not uniformly abundant in all of the 5-mile reaches ($p>F=0.0001$). In both years the highest abundance occurred in the river reach between DRM 175 and 179, followed by DRM 160-165. Results of a Duncan's Multiple Range test ($\alpha=0.05$) indicated the mean for the upstream reach, DRM 175 - 179, was different from each of the five other means, but none of the five downstream means were different from each other. Apparently, the C. caelata population in the Duck River is relatively dense in the 4-mile reach just downstream from Lillard Mill Dam (average $1.21/m^2$) and is uniformly less dense ($0.14/m^2$) from DRM 175 downstream to approximately DRM 147.

Epioblasma walkeri - The single specimen of the tan riffle shell was found at DRM 151.9 on April 26, 1988, when the site was being inspected as a possible boat launch point. The specimen was picked up from the shore with a small amount of adductor muscle tissue still

attached to one valve. Shell characteristics indicate this animal was a female, approximately 3 years old. As indicated in table 3, the shell was 40mm long. This was the only specimen of the species observed during the survey, in spite of all attempts to locate others and the considerable effort spent at this site when it was sampled (table 1).

This species was not encountered during the 1979 survey, nor was it found during TVA surveys in 1976 and 1978 (Ahlstedt, 1981). The tan riffle shell apparently was last collected in the Duck River by Stansbery in 1964 (Neves, 1984).

Pleurobema cordatum - As indicated previously, the Ohio River pigtoe was found at seven Duck River sites in 1979 but was not encountered at all during the 1988 survey. The range of this pigtoe includes medium to large rivers throughout much of the Mississippi River drainage basin. The species was once abundant enough that it made up a substantial part of the commercial mussel harvest. Populations of P. cordatum in larger rivers declined as the rivers were impounded (Yokley, 1972) but the species typically persists in most of its historic range at some low level (Gooch, et al, 1979; Ahlstedt, 1986). The fact that no specimens of the species were found during the 1988 survey could indicate that it has been extripated from the Duck River. However, in the absence of any other substantial declines, a more plausible explanation might be that the small population simply was not sampled in 1988.

Quadrula intermedia - During the 1988 survey, three live specimens of the Cumberland monkeyface pearly mussel, Quadrula intermedia, were found at DRM 176.8. Two of these animals were found

during the qualitative search (table 1) and the third was found in one of 21 quadrat samples (table 2). These animals were estimated to be 12, 13, and 15 years old. All three were very similar in size (lengths 49.1, 50.3, and 51.9mm) with an average length of 50.43mm (table 3).

During the 1979 survey, 6 specimens of this species were found at three sites: DRM 162.8 (2 specimens), DRM 171.2 (1 specimen), and DRM 173.2 (3 specimens). No member of the species was found in quadrat samples during the 1979 survey (Ahlstedt, 1986).

The very low numbers of this species found in either year virtually preclude drawing any generalizations about distribution patterns or abundance. About the most that can be said from the 1988 data is that Q. intermedia persists as a rare inhabitant of this section of the Duck River, certainly so in the reach between DRM 175 and 179. The fact that the species was not found downstream from DRM 175 during the 1988 survey should not be taken to indicate it no longer occurs there. Because Q. intermedia is rare in this river, the likelihood of finding any specimen of the species is determined strictly by chance and, from the 1988 survey data, that likelihood is approximately one in 1,000 (3 of 3,264 mussels counted in 1988).

SUMMARY

The 1988 survey of the middle reach Duck River included qualitative mussel collections at 62 sites between DRM 132.5 and 179.2. Quantitative collections were made at 14 of these sites. The qualitative collections yielded 2,606 live or fresh-dead mussels representing 34 species. The 282 0.25m^2 quadrat samples yielded 658 live mussels, or 9.33 mussels per square meter.

Comparisons with data from the 1979 survey of this same river reach indicated that 31 species were found during both surveys, three species [Epioblasma triquetra, Pleurobema cordatum, and Strophitus rugosus (=S. undulatus)] were found only in 1979, and four species (Anodonta grandis, Anodonta imbecillis, Epioblasma walkeri, and Truncilla donaciformis) were found only in 1988. Distribution patterns of most species remained virtually unchanged over the nine year period but three species (Obovaria subrotunda, Pleurobema cordatum, and Pleurobema oviforme) were found in substantially fewer areas in 1988 than they had occupied in 1979.

Quantitative sampling indicated that significantly more mussels were found in 1988 (overall average 9.33/m^2) than were there in 1979 (3.89/m^2). Along the length of the river, mussel density had not changed in the most upstream nine miles examined (DRM 170 - 179) but was significantly higher throughout a 20-mile area near the downstream end of the survey (DRM 145 - 165). Abundance of 23 species was statistically unchanged between the surveys. Five species (Elliptio dilatatus,

Lampsilis fasciola, Leptodea fragilis, Medionidus conradicus, and Potamilus alatus) were more abundant in 1988 while one species (Pleurobema cordatum) showed a significant quantitative decline.

Overall, the 1988 survey indicated the mussel fauna in this river reach was about as diverse and more abundant than it had been in 1979. The area with the densest and most species-rich mussel assemblage (DRM 175 - 179) had changed very little while a 20-mile reach further downstream (DRM 145 - 165) was inhabited by more species and more mussels per square meter in 1988.

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Table 1. Number of mussels collected during timed random searches in the Duck River, May 1988

River Mile	132.5	133.3	133.5	141.3	142.7	143.6	144.1	145.0	145.9	146.3	147.0	147.3	147.4	148.1	148.5
Actinonaias carinata	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–
Actinonaias pectorosa *	–	–	–	–	–	–	–	–	–	–	–	–	2	–	–
Amblema plicata	22	65	44	–	4	1	3	1	47	–	–	–	1	–	–
Anodonta grandis	–	3	–	–	6	–	–	–	–	–	–	–	–	–	–
Anodonta imbecilis	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Conradilla caelata *+	–	–	–	–	–	–	–	–	–	–	–	–	1	1	–
Cyclonaias tuberculata	17	49	6	–	1	–	23	12	25	3	2	33	5	7	2
Elliptio dilatatus	–	–	–	–	–	–	2	2	2	3	3	6	1	1	3
Epioblasma walkeri *+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Fusconaia barnesiana *	–	1	–	–	–	–	–	–	–	–	–	1	–	–	–
Lampsilis fasciola	2	–	2	–	–	1	–	3	2	–	1	3	3	–	14
Lampsilis ovata	–	3	4	–	–	–	–	–	2	–	1	1	–	–	1
Lasmigona complanata	1	2	–	–	–	–	–	–	–	–	–	–	–	–	–
Lasmigona costata	1	1	1	–	–	–	–	–	–	1	–	2	–	–	–
Leptodea fragilis	–	4	5	–	–	–	1	–	–	1	–	–	–	–	–
Lexingtonia dolabelloides *	–	1	1	–	1	–	–	–	7	1	–	1	–	–	–
Medionidus conradicus *	–	–	–	–	–	–	–	–	–	–	5	–	5	3	23
Megalonaias gigantea	3	2	3	–	18	–	12	12	1	2	3	21	–	1	–
Obliquaria reflexa	6	11	28	1	5	–	–	1	–	–	–	–	1	–	–
Obovaria subrotunda	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–
Pleurobema oviforme *	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pleurobema rubrum	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–
Potamilus alatus	2	6	15	–	6	2	3	1	–	–	–	2	1	–	–
Ptychobranchus fasciolaris	1	2	–	–	–	–	–	–	–	–	–	–	1	–	–
Quadrula cylindrica	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–
Quadrula intermedia *+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Quadrula pustulosa	12	34	3	1	1	2	6	10	14	2	2	5	–	3	–
Quadrula quadrula	12	6	10	–	–	–	–	–	–	–	–	1	–	–	–
Toxolasma lividus *	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Tritogonia verrucosa	12	13	22	–	–	–	2	–	–	–	–	–	–	–	–
Truncilla donaciformis	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Truncilla truncata	1	2	5	2	–	–	–	1	–	–	–	–	–	–	1
Villosa iris	–	–	–	–	–	–	–	–	–	–	–	–	3	1	1
Villosa vanuxemi *	–	–	–	1	–	–	–	–	–	–	–	1	1	–	–
Total specimens	93	206	149	5	42	6	52	43	103	13	17	77	25	17	45
Species included	14	18	14	4	8	4	8	9	11	7	7	12	12	7	7
Collection time (man/min.)	150	120	120	15	30	90	60	75	60	60	75	100	75	60	60
Specimens per minute	0.62	1.72	1.24	0.33	1.40	0.07	0.87	0.57	1.72	0.22	0.23	0.77	0.33	0.28	0.75

* Cumberlandian species (10)
\+ Endangered species (3)

Table 1. (Continued)

River Mile	149.7	149.9	151.2	151.6	151.9	153.2	154.2	154.6	155.1	155.3	155.7	156.1	156.2	156.3	157.6
Actinonaias carinata	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Actinonaias pectorosa *	–	–	–	–	1	–	–	–	–	1	–	–	–	1	–
Amblema plicata	–	–	–	–	4	4	1	1	3	–	3	3	1	–	–
Anodonta grandis	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–
Anodonta imbecilis	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–
Conradilla caelata *+	–	1	–	4	2	2	8	–	–	–	–	1	–	–	–
Cyclonaias tuberculata	1	2	18	2	28	14	25	6	13	17	10	22	9	13	–
Elliptio dilatatus	16	5	9	4	28	12	13	4	2	6	1	–	–	3	–
Epioblasma walkeri *+	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–
Fusconaia barnesiana *	–	–	–	–	1	–	1	–	1	–	1	–	–	–	–
Lampsilis fasciola	5	13	1	5	14	9	11	3	3	7	1	5	1	3	–
Lampsilis ovata	1	2	–	–	4	5	5	3	2	3	–	–	–	–	–
Lasmigona complanata	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lasmigona costata	–	1	2	1	1	1	–	2	–	3	1	4	1	2	–
Leptodea fragilis	–	2	–	–	–	–	1	–	–	–	–	1	–	–	–
Lexingtonia dolabelloides *	1	–	2	–	3	4	10	–	5	1	–	–	–	1	–
Medionidus conradicus *	–	6	1	16	19	36	–	2	1	3	–	–	–	–	1
Megalonaias gigantea	–	–	11	–	24	4	6	–	5	–	3	15	6	3	–
Obliquaria reflexa	–	–	1	–	–	–	2	–	–	–	–	–	–	–	–
Obovaria subrotunda	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pleurobema oviforme *	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pleurobema rubrum	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Potamilus alatus	1	–	–	–	2	1	4	1	–	–	1	1	1	–	–
Ptychobranchus fasciolaris	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–
Quadrula cylindrica	–	–	–	1	2	–	2	1	–	–	–	1	–	–	–
Quadrula intermedia *+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Quadrula pustulosa	–	1	1	–	2	3	13	2	–	–	5	3	2	2	–
Quadrula quadrula	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Toxolasma lividus *	–	–	–	–	2	1	1	–	–	–	–	–	–	–	–
Tritogonia verrucosa	–	–	–	–	–	–	2	–	–	–	–	–	–	–	–
Truncilla donaciformis	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Truncilla truncata	1	–	2	–	1	2	2	–	–	–	–	–	–	–	–
Villosa iris	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–
Villosa vanuxemi *	1	4	–	1	–	4	–	–	–	–	1	–	–	–	–
Total specimens	27	37	49	36	138	103	107	25	35	41	27	56	21	29	1
Species included	8	10	11	10	17	16	17	10	9	8	10	10	7	9	1
Collection time (man/min.)	60	60	60	20	480	120	160	120	80	80	60	100	60	90	60
Specimens per minute	0.45	0.62	0.82	1.80	0.29	0.86	0.67	0.21	0.44	0.51	0.45	0.56	0.35	0.32	0.02

Table 1. (Continued)

River Mile	157.8	158.3	158.7	159.4	160.1	161.0	161.6	161.8	162.5	162.9	163.1	164.3	164.5	166.1	167.5
Actinonaias carinata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Actinonaias pectorosa *	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Amblema plicata	-	-	-	1	-	-	-	-	1	-	1	-	-	-	2
Anodonta grandis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Anodonta imbecilis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Conradilla caelata *+	-	-	-	-	-	-	-	-	-	1	-	1	-	-	-
Cyclonaias tuberculata	10	1	1	-	2	8	13	-	8	3	21	6	7	5	8
Elliptio dilatatus	-	-	-	-	-	2	1	-	-	-	7	3	-	-	2
Epioblasma walkeri *+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fusconaia barnesiana *	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
Lampsilis fasciola	-	2	2	5	-	3	1	-	2	-	1	7	-	1	1
Lampsilis ovata	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Lasmigona complanata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lasmigona costata	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
Leptodea fragilis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lexingtonia dolabelloides *	-	-	-	-	-	-	1	-	-	-	2	1	-	1	-
Medionidus conradicus *	3	3	7	7	-	-	-	-	2	-	1	17	-	-	-
Megalonaias gigantea	57	4	6	-	35	2	15	1	5	1	12	-	10	-	71
Obliquaria reflexa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Obovaria subrotunda	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pleurobema oviforme *	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pleurobema rubrum	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Potamilus alatus	-	-	-	-	-	1	1	-	-	-	2	-	1	-	1
Ptychobranchus fasciolaris	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Quadrula cylindrica	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-
Quadrula intermedia *+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Quadrula pustulosa	1	-	-	-	-	4	1	-	-	-	5	-	1	-	-
Quadrula quadrula	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Toxolasma lividus *	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tritogonia verrucosa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Truncilla donaciformis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Truncilla truncata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Villosa iris	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-
Villosa vanuxemi *	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total specimens	71	10	16	13	37	20	33	1	18	5	54	38	20	9	85
Species included	4	4	4	3	2	6	7	1	5	3	11	8	5	4	6
Collection time (man/min.)	60	75	60	60	60	60	60	60	90	60	90	60	75	60	60
Specimens per minute	1.18	0.13	0.27	0.22	0.62	0.33	0.55	0.02	0.20	0.08	0.60	0.63	0.27	0.15	1.42

Table 1. (Continued)

River Mile	168.5	168.6	169.1	170.5	170.6	171.6	171.7	172.8	173.1	173.8	173.9	175.0	176.8	177.2	177.8
Actinonaias carinata	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Actinonaias pectorosa *	–	–	–	–	–	1	–	–	–	–	–	–	1	–	–
Amblema plicata	–	–	–	–	1	1	–	–	–	1	–	2	3	–	4
Anodonta grandis	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Anodonta imbecilis	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–
Conradilla caelata *+	1	1	–	–	–	–	–	–	–	–	–	–	–	–	2
Cyclonaias tuberculata	2	2	5	1	–	1	2	–	–	12	7	8	19	–	30
Elliptio dilatatus	1	1	5	1	–	2	–	–	–	4	–	–	3	–	–
Epioblasma walkeri *+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Fusconaia barnesiana *	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lampsilis fasciola	4	2	4	1	1	–	–	–	1	7	–	4	6	3	–
Lampsilis ovata	–	–	–	–	–	–	–	–	–	1	3	–	–	–	–
Lasmigona complanata	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lasmigona costata	–	–	–	1	–	–	–	–	–	–	–	2	–	–	6
Leptodea fragilis	–	1	–	–	–	–	–	–	–	–	–	–	1	–	–
Lexingtonia dolabelloides *	2	1	4	1	2	–	–	–	1	6	–	–	5	–	–
Medionidus conradicus *	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Megalonaias gigantea	–	4	5	40	5	1	3	1	3	4	3	8	–	–	22
Obliquaria reflexa	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Obovaria subrotunda	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pleurobema oviforme *	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–
Pleurobema rubrum	–	–	–	–	–	–	–	–	–	–	–	–	2	–	–
Potamilus alatus	–	–	1	1	2	–	–	–	–	1	1	2	–	–	2
Ptychobranchus fasciolaris	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Quadrula cylindrica	–	–	1	–	1	–	–	–	–	–	2	1	1	–	–
Quadrula intermedia *+	–	–	–	–	–	–	–	–	–	–	–	–	2	–	–
Quadrula pustulosa	1	2	1	–	–	1	–	2	–	–	–	–	8	1	3
Quadrula quadrula	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Toxolasma lividus *	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–
Tritogonia verrucosa	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–
Truncilla donaciformis	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Truncilla truncata	–	–	1	–	–	–	–	–	–	1	–	1	3	–	–
Villosa iris	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Villosa vanuxemi *	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–
Total specimens	11	15	27	46	13	7	5	4	5	38	16	28	55	4	69
Species included	6	9	9	7	7	6	2	3	3	10	5	8	13	2	7
Collection time (man/min.)	60	60	60	90	60	60	50	60	60	60	60	60	60	60	60
Specimens per minute	0.18	0.25	0.45	0.51	0.22	0.12	0.10	0.07	0.08	0.63	0.27	0.47	0.92	0.07	1.15

Table 1. (Continued)

River Mile	178.4	179.2	Totals	No. Sites
Actinonaias carinata	-	-	1	1
Actinonaias pectorosa *	-	-	7	6
Amblema plicata	11	54	290	29
Anodonta grandis	-	-	10	3
Anodonta imbecilis	-	-	2	2
Conradilla caelata *+	-	7	33	14
Cyclonaias tuberculata	7	57	611	53
Elliptio dilatatus	1	1	160	35
Epioblasma walkeri *+	-	-	1	1
Fusconaia barnesiana *	-	-	7	7
Lampsilis fasciola	-	4	174	44
Lampsilis ovata	-	2	44	18
Lasmigona complanata	-	-	3	2
Lasmigona costata	1	3	39	22
Leptodea fragilis	-	1	18	10
Lexingtonia dolabelloides *	-	5	71	27
Medionidus conradicus *	-	-	161	20
Megalonaias gigantea	7	3	483	46
Obliquaria reflexa	-	1	57	10
Obovaria subrotunda	-	-	1	1
Pleurobema oviforme *	-	-	1	1
Pleurobema rubrum	-	-	4	3
Potamilus alatus	-	3	69	30
Ptychobranchus fasciolaris	-	-	5	4
Quadrula cylindrica	-	2	18	13
Quadrula intermedia *+	-	-	2	1
Quadrula pustulosa	-	14	174	37
Quadrula quadrula	-	-	29	4
Toxolasma lividus *	-	-	5	4
Tritogonia verrucosa	-	6	58	7
Truncilla donaciformis	-	-	1	1
Truncilla truncata	6	12	44	17
Villosa iris	-	-	8	5
Villosa vanuxemi *	-	-	15	9
Total specimens	33	175	2,606	
Species included	6	16	34	
Collection time (man/min.)	60	80	4,810	
Specimens per minute	0.55	2.19	0.54	

Table 2. Quantitative sampling results from the Duck River, May 1988, presented as numbers per square meter

River Mile	133.5	145.9	151.6	154.2	157.8	164.3	170.5	171.6	176.8	177.2	177.8	178.4	179.2	179.4	Overall Average	Number of Specimens
Species																
Actinonaias carinata	-	0.33	-	-	-	-	-	-	-	-	-	-	-	-	0.01	1
Actinonaias pectorosa *	-	-	-	-	-	-	-	-	-	-	0.67	-	0.10	-	0.04	3
Amblema plicata	0.60	-	-	0.40	-	-	-	-	-	-	0.33	-	4.30	0.20	0.72	51
Conradilla caelata *+	-	-	0.40	-	-	0.67	-	-	0.57	-	0.33	-	1.70	1.85	0.62	44
Cyclonaias tuberculata	0.20	1.00	0.20	2.20	0.50	0.33	0.17	-	2.10	-	2.33	1.33	7.10	3.32	2.09	147
Elliptio dilatatus	-	-	3.00	1.40	-	3.33	-	-	1.52	0.40	0.33	0.67	2.00	0.20	0.95	67
Epioblasma capsaeformis *	-	-	-	-	-	-	-	-	-	-	0.67	-	-	-	0.03	2
Fusconaia barnesiana *	-	-	-	0.40	-	-	0.17	-	-	-	-	-	0.10	0.10	0.07	5
Lampsilis fasciola	0.40	-	0.80	0.80	0.25	1.33	0.17	0.33	1.33	0.60	0.33	0.33	0.60	0.49	0.57	40
Lampsilis ovata	-	0.33	-	-	-	-	-	-	-	-	-	-	-	0.20	0.04	3
Lasmigona costata	-	-	-	-	-	-	0.33	-	0.19	-	-	-	0.60	0.20	0.16	11
Leptodea fragilis	-	-	-	0.20	-	0.33	0.17	-	-	-	0.33	0.33	0.50	0.10	0.16	11
Lexingtonia dolabelloides *	-	-	-	0.60	-	-	0.17	-	0.57	-	-	-	1.20	0.59	0.35	25
Medionidus conradicus *	-	-	6.00	-	0.25	2.33	-	-	-	-	-	-	-	-	0.54	38
Megalonaias gigantea	-	-	-	-	0.75	-	0.67	-	0.19	-	0.33	0.33	1.00	-	0.28	20
Obliquaria reflexa	1.40	0.33	-	0.40	-	-	-	-	-	-	0.67	0.33	0.30	-	0.23	16
Pleurobema rubrum	-	-	-	-	-	-	-	-	-	-	-	-	-	0.10	0.01	1
Potamilus alatus	0.40	0.33	-	-	-	1.00	-	-	-	-	-	-	0.20	0.29	0.16	11
Quadrula cylindrica	-	-	-	0.20	-	-	-	-	0.19	-	-	-	-	-	0.03	2
Quadrula intermedia *+	-	-	-	-	-	-	-	-	0.19	-	-	-	-	-	0.01	1
Quadrula pustulosa	-	0.67	-	1.60	0.25	-	-	-	0.76	-	2.00	0.33	3.20	0.88	0.89	63
Tritogonia verrucosa	0.60	-	-	-	-	-	-	-	-	0.20	-	0.33	0.50	0.20	0.17	12
Truncilla truncata	-	-	0.20	0.20	-	-	0.17	-	0.19	-	1.33	3.33	3.40	2.83	1.15	81
Villosa iris	-	-	-	-	-	-	-	-	-	-	-	-	-	0.10	0.01	1
Villosa vanuxemi *	-	-	-	-	-	-	-	-	-	-	-	0.33	-	0.10	0.03	2
Total per square meter	3.60	3.00	10.60	8.40	2.00	9.33	2.00	0.33	7.81	1.20	9.67	7.67	26.80	11.71	9.33	
Number of samples	20	12	20	20	16	12	24	12	21	20	12	12	40	41	282	
Specimens found	18	9	53	42	8	28	12	1	41	6	29	23	268	120		658
Species included	6	6	6	11	5	7	8	1	11	3	12	10	16	17		25

* Cumberlandian species (8)
\+ Endangered species (2)

Table 3. Lengths of Federally-listed endangered species encountered during the 1988 survey of the Duck River

Duck River Reach	Length Increments (mm) 20	30	40	50	Totals	Mean	Comments
Conradilla caelata							
145.1 - 150.0		1			1	34.50	
150.1 - 155.0	2	7	5		14	38.11	
155.1 - 160.0					0		
160.1 - 165.0	1	3			4	33.17	
165.1 - 170.0		1	1		2	42.65	
170.0 - 175.0					0		
175.1 - 179.2	3	26	13	7	49	39.63	
Totals	6	38	19	7	70	38.97	
Epioblasma walkeri							
150.1 - 155.0			1		1	40	3 year old female
Quadrula intermedia							
175.0 - 179.2			1	2	3	50.43	12, 13, and 15 years old

Table 4. Occurrence of live or fresh-dead specimens of mussel species found in each 5-mile reach of the Duck River during the 1979 (X) and 1988 (O) surveys. Both qualitative and quantitative data were used to indicate occurrence within a given river reach.

Species	Duck River Reaches (river miles) 130.1 -135.0	135.1 -140.0	140.1 -145.0	145.1 -150.0	150.1 -155.0	155.1 -160.0	160.1 -165.0	165.1 -170.0	170.1 -175.0	175.1 -179.2	Occurrences 1979	1988
Actinonaias carinata	O			O		X	X				2	2
Actinonaias pectorosa				O	O	O	X		X,O	X,O	3	5
Amblema plicata	X,O		X,O	X,O	X,O	X,O	X,O	X,O	X,O	X,O	9	9
Anodonta grandis	O		O			O					0	3
Anodonta imbecillis					O				O		0	2
✓Conradilla caelata	X			X,O	X,O	X,O	X,O	X,O	X	X,O	8	6
Cyclonaias tuberculata	O		X,O	X,O	X,O	X,O	X,O	X,O	X,O	X,O	8	9
Elliptio dilatatus			O	X,O	X,O	X,O	X,O	X,O	X,O	X,O	7	8
✓Epioblasma capsaeformis										X,O	1	1
Epioblasma triquetra									X		1	0
✓Epioblasma walkeri					O						0	1
Fusconaia barnesiana	O			O	X,O	X,O	X,O		X,O	X,O	5	7
Lampsilis fasciola	O		O	X,O	X,O	X,O	X,O	X,O	X,O	X,O	7	9
Lampsilis ovata	X,O			X,O	X,O	X,O	O		O	X,O	5	7
Lasmigona complanata	X,O										1	1
Lasmigona costata	O			X,O	X,O	O	X,O		X,O	X,O	5	7
Leptodea fragilis	X,O		O	O	O	O	O	O	O	X,O	2	9
✓Lexingtonia dolabelloides	O		X,O	X,O	X,O	X,O	X,O	X,O	X,O	X,O	8	9
Medionidus conradicus				X,O	X,O	X,O	X,O			X	5	4
Megalonaias gigantea	X,O		X,O	X,O	X,O	X,O	X,O	X,O	X,O	X,O	9	9
Obliquaria reflexa	X,O		X,O	O	O	X	X		X	X,O	6	5
Obovaria subrotunda				O	X		X	X	X		4	1

Table 4. (Continued)

Species	Duck River Reaches (river miles) 130.1 -135.0	135.1 -140.0	140.1 -145.0	145.1 -150.0	150.1 -155.0	155.1 -160.0	160.1 -165.0	165.1 -170.0	170.1 -175.0	175.1 -179.2	Occurrences 1979	1988
Pleurobema cordatum				X		X	X	X	X	X	6	0
✓Pleurobema oviforme			X	X	X	X	X	X	X	0	7	1
✓Pleurobema rubrum				0			0			X,0	1	3
Potamilus alatus	X,0		0	X,0	X,0	0	X,0	X,0	0	X,0	6	9
Ptychobranchus fasciolaris	X,0			X,0	0				X		3	3
Quadrula cylindrica				0	X,0	X,0	X	0	X,0	0	4	6
✓Quadrula intermedia							X		X	0	2	1
Quadrula pustulosa	X,0		X,0	X,0	X,0	X,0	X,0	X,0	X,0	X,0	9	9
Quadrula quadrula	X,0			0							1	2
Strophitus rugosus						X					1	0
Toxolasma lividus					0		X	0			1	2
Tritogonia verrucosa	X,0		X,0		0		X		0	X,0	4	5
Truncilla donaciformis	0										0	1
Truncilla truncata	X,0		0	0	0			0	0	X,0	2	7
Villosa iris				0	0	X	0			0	1	4
Villosa vanuxemi			0	0	0	0			0	X,0	1	6
Totals												
Species Present - 1979	13	0	8	15	16	18	22	12	19	22	34	
- 1988	20	0	14	25	25	18	16	13	18	24		35
Sites Visited - 1979	1	0	1	5	6	11	15	4	9	10	62	
- 1988	3	0	5	9	6	11	9	5	9	6		63

Table 5. Comparison of Duck River quantitative sampling results, 1979 and 1988. Abundance values for 1979 and 1988 are numbers per square meter. Year and Reach values are significance levels of ANOVA tests.

Species	130.1 - 135.0		145.1 - 150.0			150.1 - 155.0			155.1 - 160.0		
	1979	1988	1979	1988	Year	1979	1988	Year	1979	1988	Year
Actinonaias carinata	-	-	-	0.33		-	-		-	-	
Actinonaias pectorosa	-	-	-	-		-	-		-	-	
Amblema plicata	-	0.06	-	-		0.08	0.20		-	-	
Conradilla caelata	-	-	-	-		-	0.20		0.13	-	
Cyclonaias tuberculata	-	0.20	-	1.00	0.07	0.69	1.20		0.13	0.50	
Elliptio dilatatus	-	-	-	-		0.08	2.20	0.0001	-	-	
Epioblasma capsaeformis	-	-	-	-		-	-		-	-	
Fusconaia barnesiana	-	-	-	-		0.08	0.20		-	-	
Lampsilis fasciola	-	0.40	-	-		0.08	8.00	0.03	-	0.25	0.04
Lampsilis ovata	-	-	-	0.33		0.08	-		0.06	-	
Lasmigona costata	-	-	-	-		0.08	-		-	-	
Leptodea fragilis	-	-	-	-		-	0.10		-	-	
Lexingtonia dolabelloides	-	-	0.33	-		0.08	0.30		0.25	-	
Medionidus conradicus	-	-	-	-		0.15	3.00	0.0003	-	0.25	0.04
Megalonaias gigantea	-	-	-	-		-	-		-	0.75	0.0003
Obliquaria reflexa	-	1.40	-	0.33		-	0.20		-	-	
Obovaria subrotunda	-	-	-	-		0.08	-		-	-	
Pleurobema cordatum	-	-	0.33	-		-	-		-	-	
Pleurobema oviforme	-	-	-	-		-	-		0.06	-	
Pleurobema rubrum	-	-	-	-		-	-		-	-	
Potamilus alatus	-	0.40	-	0.33		-	-		-	-	
Quadrula cylindrica	-	-	-	-		-	0.10		-	-	
Quadrula intermedia	-	-	-	-		-	-		-	-	
Quadrula pustulosa	-	-	-	0.67		0.38	0.80		0.06	0.25	
Strophitus rugosus	-	-	-	-		-	-		0.06	-	
Toxolasma lividus	-	-	-	-		-	-		-	-	
Tritogonia verrucosa	-	0.60	-	-		-	-		-	-	
Truncilla truncata	-	-	-	-		-	0.20		-	-	
Villosa iris	-	-	-	-		-	-		-	-	
Villosa vanuxemi	-	-	-	-		-	-		-	-	
Totals		3.60	0.67	3.00	0.03	1.85	9.50	0.0001	0.75	2.00	0.03
Quadrats Examined	0	20	12	12		52	40		64	16	
Mussels Encountered	0	18	2	9		24	95		12	8	

Table 5. (Continued)

Species	160.1 - 165.0			165.1 - 170.0		170.1 - 175.0			175.1 - 179.2		
	1979	1988	Year	1979	1988	1979	1988	Year	1979	1988	Year
Actinonaias carinata	0.06	-		-	-	-	-		-	-	
Actinonaias pectorosa	0.02	-		-	-	-	-		-	0.08	
Amblema plicata	0.12	-		-	-	0.15	-		1.32	1.26	
Conradilla caelata	0.25	0.67		-	-	0.10	-		1.42	1.10	
Cyclonaias tuberculata	1.68	0.33	0.09	0.27	-	0.44	0.11		3.01	3.48	
Elliptio dilatatus	0.29	3.33	0.0001	-	-	0.10	-		0.38	0.96	0.03
Epioblasma capsaeformis	-	-		-	-	-	-		0.22	0.05	0.08
Fusconaia barnesiana	0.02	-		-	-	0.05	0.11		0.22	0.05	0.08
Lampsilis fasciola	0.06	1.33	0.0001	-	-	-	0.22	0.03	0.05	0.63	0.004
Lampsilis ovata	-	-		-	-	-	-		0.11	0.05	
Lasmigona costata	0.04	-		-	-	-	0.22	0.03	0.33	0.25	
Leptodea fragilis	-	0.33	0.0001	-	-	-	0.11		0.05	0.22	
Lexingtonia dolabelloides	0.41	-		0.13	-	-	0.11		0.55	0.58	
Medionidus conradicus	0.23	2.33	0.0001	-	-	-	-		0.05	-	
Megalonaias gigantea	0.66	-		-	-	0.20	0.44		0.11	0.36	
Obliquaria reflexa	-	-		-	-	-	-		0.11	0.16	
Obovaria subrotunda	0.10	-		-	-	-	-		-	-	
Pleurobema cordatum	0.06	-		0.13	-	0.10	-		0.05	-	
Pleurobema oviforme	0.04	-		0.13	-	0.05	-		-	-	
Pleurobema rubrum	-	-		-	-	-	-		-	0.03	
Potamilus alatus	0.02	1.00	0.0001	-	-	-	-		0.11	0.14	
Quadrula cylindrica	-	-		-	-	0.05	-		-	0.03	
Quadrula intermedia	-	-		-	-	-	-		-	0.03	
Quadrula pustulosa	0.43	-		0.40	-	0.30	-	0.1	1.64	1.42	
Strophitus rugosus	-	-		-	-	-	-		-	-	
Toxolasma lividus	0.02	-		-	-	-	-		-	-	
Tritogonia verrucosa	-	-		-	-	-	-		0.11	0.25	
Truncilla truncata	-	-		-	-	-	0.11		0.49	2.14	0.001
Villosa iris	-	-		-	-	-	-		-	0.03	
Villosa vanuxemi	-	-		-	-	-	-		-	0.05	
Totals	4.47	9.33	0.001	1.07		1.98	1.44		10.36	13.34	
Quadrats Examined	195	12		30	0	81	36		73	146	
Mussels Encountered	220	28		8	0	40	13		189	487	

Table 5. (Continued)

Species	Composite Means 1979	Composite Means 1988	ANOVA Results Year	ANOVA Results Reach
Actinonaias carinata	0.02	0.01		
Actinonaias pectorosa	0.01	0.04		
Amblema plicata	0.27	0.72		0.0001
Conradilla caelata	0.33	0.62		0.0001
Cyclonaias tuberculata	1.25	2.09		0.0001
Elliptio dilatatus	0.19	0.95	0.0001	0.0001
Epioblasma capsaeformis	0.03	0.03		0.0004
Fusconaia barnesiana	0.06	0.07		
Lampsilis fasciola	0.04	0.57	0.0001	0.009
Lampsilis ovata	0.03	0.04		
Lasmigona costata	0.07	0.16		0.01
Leptodea fragilis	0.01	0.16	0.03	
Lexingtonia dolabelloides	0.36	0.35		
Medionidus conradicus	0.11	0.54	0.0001	0.0001
Megalonaias gigantea	0.30	0.28		
Obliquaria reflexa	0.02	0.23	0.09	
Obovaria subrotunda	0.05	-		
Pleurobema cordatum	0.06	-	0.03	
Pleurobema oviforme	0.04	-		
Pleurobema rubrum	-	0.01		
Potamilus alatus	0.02	0.16	0.001	0.0001
Quadrula cylindrica	0.01	0.03		
Quadrula intermedia		0.01		
Quadrula pustulosa	0.52	0.89		0.0001
Strophitus rugosus	0.01	-		
Toxolasma lividus	0.01	-		
Tritogonia verrucosa	0.02	0.17		0.006
Truncilla truncata	0.07	1.15		0.0001
Villosa iris	-	0.01		
Villosa vanuxemi	-	0.03		
Totals	3.89	9.33	0.003	0.0001
Quadrats Examined	509	282		
Mussels Encountered	495	658		

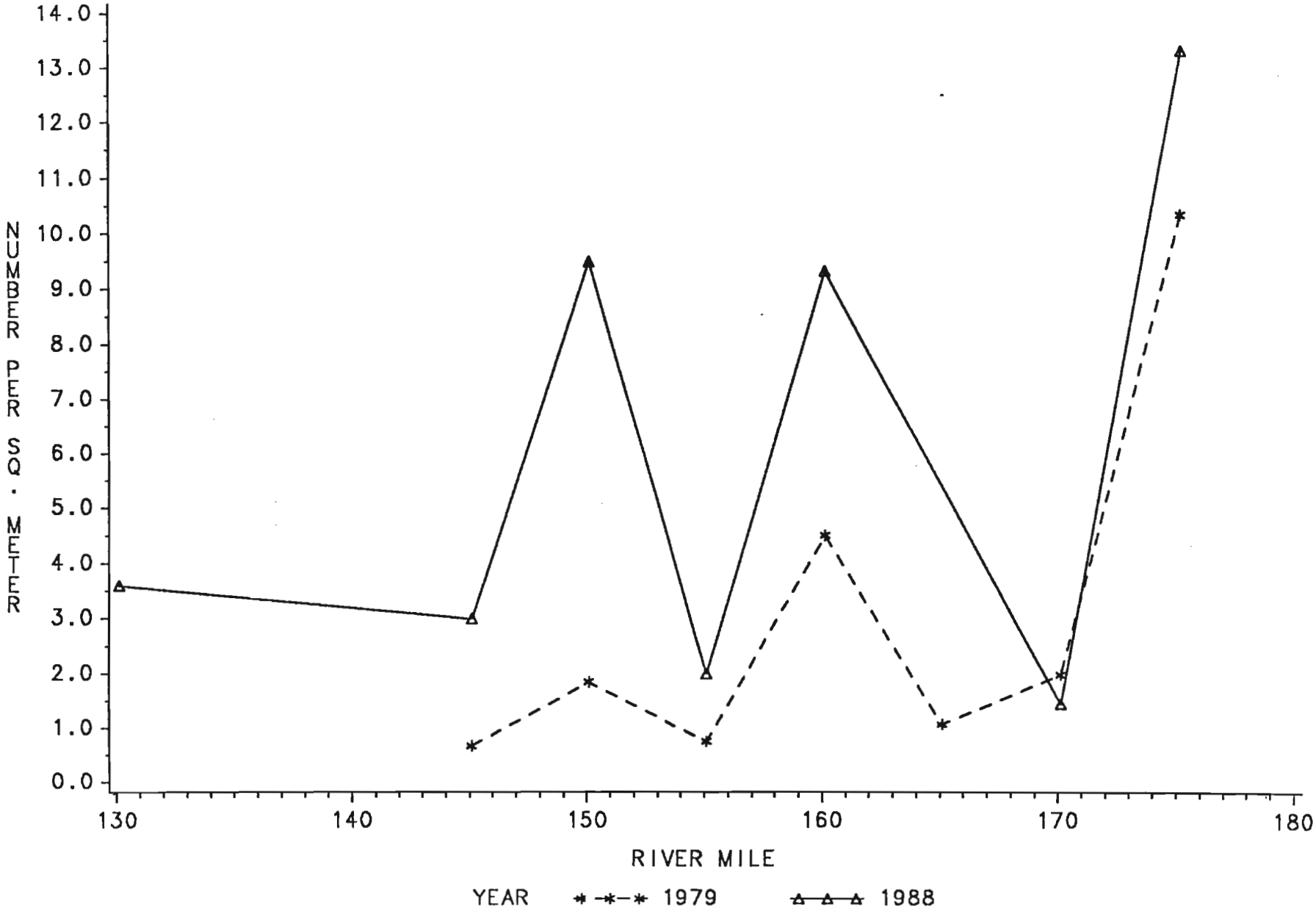

Figure 1. Mean number of freshwater mussels found in 5-mile reaches of the Duck River during 1979 (stars) and 1988 (triangles).

APPENDIX B

QUANTITATIVE REASSESSMENT OF THE FRESHWATER MUSSEL FAUNA IN THE POWELL RIVER, TENNESSEE AND VIRGINIA

TENNESSEE VALLEY AUTHORITY

River Basin Operations
Water Resources

QUANTITATIVE REASSESSMENT OF THE FRESHWATER MUSSEL FAUNA IN THE POWELL RIVER, TENNESSEE AND VIRGINIA

Prepared by

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Knoxville, Tennessee
October 1988

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

In 1979, The Tennessee Valley Authority (TVA) conducted a float survey of freshwater mussel resources in the Powell River. This river, which drains approximately 700 square miles of NE Tennessee and SW Virginia, was one of nine streams TVA surveyed primarily in 1979 and 1980 to determine the distribution and abundance of endemic freshwater mussel species. The results of all of these surveys were presented in a single Cumberlandian Mollusk Conservation Program report (Ahlstedt, 1986).

During the 1979 Powell River survey, both qualitative and quantitative data were taken. Qualitative data were gathered wherever suitable mussel habitat was encountered by the survey crews. Quantitative data were collected only at sites that yielded live specimens of Federaly-listed endangered species or where dense mussel concentrations were present. In 1979, quantitative samples were taken at 15 sites on the Powell River (table 1).

Since 1979, TVA has resampled some or all of these 15 Powell River quantitative sites on two occasions: in 1983, and again in 1988. This report describes the resampling effort, presents the results, and discusses statistical trends in the data from all three surveys over the nine year period.

METHODS

During the 1979 survey, the quantitative sampling sites had been selected because they yielded live specimens of endangered species or supported dense mussel concentrations. In both 1983 and 1988, the intention was to quantitatively resample the same sites using the same techniques that had been applied in 1979. No broad qualitative search was mounted in either year to locate better or additional sites to be included.

Quantitative sampling techniques used during the 1979 survey are presented in the report prepared by Ahlstedt (1986). On all three occasions (1979, 1983, and 1988), quantitative sampling consisted of searching for mussels within $0.25m^2$ metal quadrat frames placed at random throughout good mussel habitat. The number of quadrat samples taken in 1979 depended upon the crew leader's estimate of good mussel habitat at the site. A guide table attempted to standardize the search at four percent of the suitable habitat (Ahlstedt, 1986). In both 1983 and 1988, considerable care was taken to collect data from the same number of quadrat samples at each site that had been examined in 1979.

In both 1983 and 1988, the appropriate number of quadrat samples were taken scattered throughout the same habitat areas that had been sampled previously. Snorkel-assisted biologists disturbed the substrate within each quadrat to a depth of 5-10 cm and placed all live mussels found in collection bags. The crew leader sorted the mussels from each quadrat to species, counted them, and recorded the data on a field sheet. All of the animals were returned to suitable habitat at the site.

Data collected from the sampling sites were summarized in tables and analyzed using various Statistical Analysis System (SAS) routines. Comparisons of the data from the three surveys also were made using SAS programs. All decisions based on statistical tests were made at the 95 percent confidence level. Probability values between 0.05 and 0.1 are supplied in some tables for information purposes only.

RESULTS

As reported previously (Ahlstedt, 1986), the 1979 Powell River survey included 441 quadrat samples taken at 15 sites between Powell River Miles (PRM) 72.8 and 166.3 (table 1). At these sites, a total of 779 live mussels was found, for an overall average of 7.25 mussels per square meter. These animals represented 30 species.

The 1983 survey, conducted early in June, included 430 quadrat samples from 14 sites (table 2). One of the 1979 sites (PRM 119.3) was not accessible by land and was not sampled. A total of 523 live mussels found in these quadrat samples produced an overall average of $4.67/m^2$. These animals included representatives of 23 species.

During the 1983 survey, the TVA crew encountered dead and dying mussels at several sites. The extent and immediate magnitude of the die-off were studied by TVA and the Virginia Cooperative Fisheries Unit (Ahlstedt and Jenkinson, 1987); however, no additional quantitative samples were taken until 1988.

The 1988 survey also was conducted early in June, during a serious drought. Water levels at the collection sites were extremely low and the water was exceptionally clear. This survey included 476 quadrat samples, taken at 15 sites (table 3). Some sites sampled in prior years were no longer accessible by land and adjacent sites were sampled in their stead. Twenty-three species were included in these samples. In all, 287 live mussels were found, yielding an overall average of $2.41/m^2$.

These three quantitative surveys from the Powell River include a total of 31 freshwater mussel species. The 1979 survey included the most species (30), while both the 1983 and 1988 surveys yielded 23 species. Eighteen species were encountered in all three years. Three species (Alasmidonta marginata, Leptodea fragilis, and Villosa vanuxemi) were found only in 1979 and Fusconaia cuneolus was encountered only in 1983. Survey results from 1983 did not include five species found in both other years (Fusconaia edgariana, Pleurobema oviforme, Quadrula cylindrica, Quadrula sparsa, and Villosa iris). Similarly, the results from 1988 did not include four species found in both 1979 and 1983 (Epioblasma capsaeformis, Fusconaia barnesiana, Potamilus alatus, and Ptychobranchus subtentum).

During all three surveys, the three most abundant species were Actinonaias carinata, Actinonaias pectorosa, and Medionidus conradicus. In 1979 and 1988, Actinonaias carinata was most abundant (34.0 and 24.4 percent of the respective totals) followed by Actinonaias pectorosa (24.7 and 22.6 percent, respectively); however, the relationship between these two species was reversed in 1983 (38.2 percent for A. pectorosa and 25.2

percent for A. carinata). Medionidus conradicus was consistently third in all three surveys (6.1, 9.9, and 16.0 percent of the respective totals). In 1979, Amblema plicata and Fusconaia subrotunda were tied for fourth place (5.5 percent each), followed by Elliptio dilatatus (3.0 percent). Amblema plicata dropped far down the list in both 1983 and 1988. Fusconaia subrotunda was fourth in 1983 (6.3 percent) and fifth in 1988 (6.3 percent). Elliptio dilatatus was fifth in 1983 (5.5 percent) and fourth in 1988 (7.3 percent). Together, the five most abundant species accounted for 75.8 percent of the total in 1979, 85.3 percent of the 1983 total, and 76.7 percent of the 1988 total.

DISCUSSION

The results presented in tables 1, 2, and 3 indicate that overall average freshwater mussel abundance in the Powell River decreased from $7.25/m^2$ in 1979, through $4.87/m^2$ in 1983, to $2.41/m^2$ in 1988. These tables also include substantial variation among mussel species and the 17 sites examined one or more times during these surveys. Clearly, some additional analysis is required to determine the nature and timing of these mussel declines.

Site Analyses

The ten sites that were examined during all three surveys were used in a variety of statistical analyses to clarify what changes had

occurred. The same habitats at all but one of these sites had been sampled in virtually identical ways on each occasion. The exception in this group is the site called PRM 106.7 in table 4. Sampling occurred at this site in 1983 and 1988, but the data included here from the 1979 survey were collected 0.2 mi. upstream, at PRM 106.9. The construction and removal of a culvert bridge at 106.9 caused considerable local impact at the site sampled in 1979, but did not appear to affect mussel habitat 0.2 mi. downstream. Even though PRM 106.7 was not sampled in 1979, the close proximity of these sites suggested they might be combined for use in these analyses.

Table 4 draws together the species-by-species information from all three surveys at these ten sites. The presentation on each site includes species abundance information from each survey, occasionally followed by the probability value of a one-way analysis of variance (ANOVA) test. Probability values are presented in the table only if they were less than or equal to 0.1 (the 90 percent confidence level). As indicated in results, statistical decisions were made using a 95 percent confidence level (0.05).

Total abundance information from each survey is presented at the bottom of each site entry. These abundance values also are plotted on figure 1. In table 4, these numbers are accompanied by meaningful one-way ANOVA probability values. Where warranted, letters indicate which of the total abundance values were found to be different from each other in Duncan's Multiple Range tests.

Four of the last seven columns in table 4 present abundance information and one-way ANOVA results on the combined survey data from these ten sites. Combined abundance values for the various species and annual totals in these columns differ from overall averages in tables 1, 2, and 3 because only sites sampled during all three surveys are included in table 4. The Duncan's Multiple Range relationships presented in the final columns indicate which combined survey abundance values for the species were found to be different from each other.

The site-by-site species information presented in the body of table 4 includes considerable variability and a few exceptional abundance values (such as $10.1/m^2$ Actinonaias pectorosa found at PRM 99.2 in 1983). Less variable information occurs in the site totals and in the combined survey totals. Total mussel abundance at eight of the ten sites included statistically significant differences. At seven of these sites, the 1979 abundance value was the highest, and it usually was statistically different from the others. Also at seven of these eight sites, the 1988 abundance value was the lowest; however, it typically was not different from the abundance in 1983.

Total abundance changes over time at the various sites did not seem to follow a consistent pattern. Figure 1 illustrates this inconsistency in the way the 1983 values seem to occur at random between and, once, beyond the bounds provided by the 1979 and 1988 data.

Combined Analyses

Combining the data from each survey presents the best opportunity to identify trends that might be overlooked in the variations between sampling sites. In table 4, the combined totals clearly indicate that overall abundance was significantly different between the three surveys of these sites (ANOVA) and that each survey value was different from the others (Duncan's). Using the combined totals from the surveys, these analyses demonstrate that a distinct decline in mussel abundance has occurred in the Powell River and that this decline continued throughout the nine year period.

Surprisingly, this pattern was followed by only one of the ten species that exhibited statistically significant differences among the combined survey results. The combined data for Actinonaias carinata yielded significantly different mean values for all three surveys, with highest abundance in 1979 ($2.56/m^2$) and the lowest value in 1988 ($0.55/m^2$). Since Actinonaias carinata was the most abundant species encountered during the 1979 survey (34.0 percent of the total), substantial changes in its population level were likely to be reflected in total mussel abundance.

Along similar lines, Actinonaias pectorosa exhibited a difference among the combined survey results, but only the 1988 value was found to be different and lower than the others. More than likely, the atypically high abundance of this species found at PRM 99.2 in 1983 had a substantial effect on these apparent relationships. This species was

first or second in abundance during all three of these surveys and changes in its population level also would be reflected in the totals.

Another abundance pattern was shared by all eight remaining species that exhibited significant differences among the combined survey results. For each of these species, the 1979 abundance values were different from the others, but the values for 1983 and 1988 were not different from each other. The analysis results suggest each of these populations declined between 1979 and 1983, but sustained no statistically significant change between 1983 and 1988. Apparently, the effect of the steady or apparent recent declines in both dominant species masked the early declines of these less abundant species in the combined total analysis.

Closer examination of these eight species can be accomplished by viewing them as three groups. Two species (Amblema plicata and Lampsilis ovata) were relatively abundant in 1979 and, even though they experienced population declines, still were found during each succeeding survey. Three other species (Epioblasma capsaeformis, Fusconaia barnesiana, and Plethobasus cyphyus) were found during both the 1979 and 1983 surveys, but did not occur in the 1988 samples. The remaining three species (Fusconaia edgariana, Leptodea fragilis, and Villosa vanuxemi) were found only during the 1979 survey. These species were present in the 1979 samples from these sites at high enough abundance levels ($0.04/m^2$) for the analysis to recognize statistically significant declines to the zeros encountered during both later surveys.

Not mentioned so far are the 21 species which did not exhibit statistically significant differences in the combined totals analyses. Seven of these species (Alasmidonta marginata, Fusconaia cuneolus, Ligumia recta, Pleurobema oviforma, Quadrula cylindrica, Quadrula sparsa, and Villosa iris) were represented in the entire data set by no more than five individuals, too few to be expected to establish any statistical trend. Eight species (Cyclonaias tuberculata, Dromus dromas, Elliptio dilatatus, Epioblasma brevidens, Epioblasma triquetra, Medionidus conradicus, Ptychobranchus fasciolaris, and Quadrula intermedia) were represented in the entire data set by abundance values that differed only slightly among the surveys. These species appeared to maintain stable population levels over the nine year period. The remaining six species (Elliptio crassidens, Fusconaia subrotunda, Lampsilis fasciola, Lasmigona costata, Potamilus alatus, and Ptychobranchus subtentum) experienced population declines in both the combined and entire data sets; however, these declines were not pronounced enough to be recognized by the statistical analyses.

Endangered Species

During these three surveys of the Powell River, five species were encountered that are on the U.S. Fish and Wildlife Service list of endangered wildlife (tables 1, 2, and 3). Two of these species (Dromus dromas and Quadrula intermedia) were found in all three years, Fusconaia edgariana and Quadrula sparsa were found in 1979 and 1988, and Fusconaia

cuneolus was found only in 1983. In all the quantitative samples, Quadrula intermedia was represented by nine individuals, Dromus dromas by seven, Fusconaia edgariana by six, Quadrula sparsa by three, and Fusconaia cuneolus by two. The highest overall average abundance for any of these species was $0.05/m^2$ (Fusconaia edgariana) recorded in 1979. Fusconaia edgariana also was the only species in this group to show a significant difference in the one-way ANOVA on the combined data set (table 4). Like most other species which showed significant differences, the Duncan's test indicated that Fusconaia edgariana declined between 1979 and 1983, but sustained no statistically significant decline between 1983 and 1988.

SUMMARY

The results of three quantitative surveys conducted in the Powell River since 1979 indicate that the average numbers of mussels per square meter has declined substantially over this nine year period (from $7.25/m^2$ in 1979 to $2.41/m^2$ in 1988). Statistical differences occurred in total mussel abundance at eight of ten sites examined during all three surveys, typically with the highest number of mussels occurring in 1979 and the lowest number occurring in 1988.

Ten species were found to show statistically significant abundance differences among the three surveys. For eight of these species (Amblema plicata, Epioblasma capsaeformis, Fusconaia barnesiana, Fusconaia edgariana, Lampsilis ovata, Leptodea fragilis, Plethobasus

cyphyus, and Villosa vanuxemi), the abundance in 1979 was statistically different from the others, but the values for 1983 and 1988 were not different from each other.

The two dominant species (Actinonaias carinata and Actinonaias pectorosa) also were most abundant in 1979 and least abundant in 1988, but Actinonaias carinata was statistically intermediate in 1983 while Actinonaias pectorosa showed no statistical difference between the 1979 and 1983 levels. In the case of Actinonaias pectorosa, these statistical results may reflect the influence of an unusually high specimen count at one site during 1983.

These results suggest that most species declined between 1979 and 1983, and that those populations remained (statistically) unchanged in 1988. The decline in the dominant species (Actinonaias carinata) continued throughout the sampling period.

Six other species (Elliptio crassidens, Fusconaia subrotunda, Lampsilis fasciola, Lasmigona costata, Potamilus alatus, and Ptychobranchus subtentum) also experienced population declines; however, none of these patterns was supported by the statistical analyses. Eight species (Cyclonaias tuberculata, Dromus dromas, Elliptio dilatatus, Epioblasma brevidens, Epioblasma triquetra, Medionidus conradicus, Ptychobranchus fasciolaris, and Quadrula intermedia) appeared to have maintained stable population levels.

Five endangered species were found during these surveys. Two of them (Dromus dromas and Quadrula intermedia) were found in all three

surveys, two (Fusconaia edgariana and Quadrula sparsa) were found in 1979 and 1988, and one (Fusconaia cuneolus) was found only in 1983. Fusconaia edgariana, the only member of this group to show a significant difference among the surveys, apparently declined between 1979 and 1983, but sustained no statistically significant decline between 1983 and 1988.

ACKNOWLEDGEMENTS

We sincerely thank several TVA biologists who participated in conducting the 1983 survey. Thanks also are due to the Tennessee Wildlife Resources Agency employees and biology graduate students from Virginia Polytechnic Institute and State University who took many of the samples during the 1988 survey. Tabular summaries, statistical analyses, and interpretation assistance were provided by Thomas A. McDonough, TVA Data Services Group.

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Ahlstedt, S. A. and Jenkinson, J. J. 1987. A mussel die-off in the Powell River, Virginia and Tennessee, in 1983. pages 21 - 28 IN Neves, R. J., editor. Proceedings of the Workshop on Die-offs of Freshwater Mussels in the United States. Sponsored by the U.S. Fish and Wildlife Service and the Upper Mississippi River Conservation Committee, 166 pages.

Table 1. Quantitative sampling results from the Powell River in 1979, presented as numbers per square meter

River Mile	72.8	81.5	84.6	84.8	94.8	99.2	106.9	112.2	117.3	119.3
Actinonaias carinata	1.90	1.00	2.20	3.69	3.20	5.50	2.46	1.80	1.90	4.33
Actinonaias pectorosa *	0.70	0.80	1.80	0.46	0.10	1.60	1.03	1.60	4.86	10.00
Alasmidonta marginata	–	–	–	–	–	0.10	–	–	–	–
Amblema plicata	2.10	0.20	0.20	0.15	1.40	0.20	0.31	–	0.10	–
Cyclonaias tuberculata	0.20	–	0.60	–	0.10	0.10	–	0.20	0.10	–
Dromus dromas *+	–	–	–	–	–	–	0.10	0.20	–	–
Elliptio crassidens	–	–	–	0.15	0.10	0.20	0.21	–	–	–
Elliptio dilatatus	–	–	0.40	–	–	–	0.10	0.20	0.48	2.67
Epioblasma brevidens *	0.40	–	0.20	–	–	–	0.10	–	0.38	–
Epioblasma capsaeformis *	–	–	–	–	–	0.30	–	0.40	0.29	–
Epioblasma triquetra	0.10	–	–	–	–	–	–	–	0.10	–
Fusconaia barnesiana *	–	–	–	–	0.10	–	–	0.80	0.19	–
Fusconaia edgariana *+	–	–	–	0.31	0.10	–	0.10	0.20	–	–
Fusconaia subrotunda	0.60	–	0.20	0.15	1.10	1.00	0.10	–	0.38	–
Lampsilis fasciola	0.10	0.20	0.40	–	–	–	0.21	–	0.38	–
Lampsilis ovata	0.10	0.20	–	–	0.30	0.20	0.21	0.20	–	1.00
Lasmigona costata	0.40	–	0.40	0.92	0.10	0.20	–	–	–	0.67
Leptodea fragilis	–	–	–	0.15	0.10	–	–	–	0.19	–
Ligumia recta	–	–	–	–	–	–	–	–	–	0.33
Medionidus conradicus *	–	0.40	0.60	–	0.10	1.00	0.21	0.80	1.43	1.00
Plethobasus cyphyus	0.10	0.20	0.20	–	0.40	0.10	0.10	–	–	–
Pleurobema oviforme *	–	–	–	–	0.10	–	–	–	0.19	–
Potamilus alatus	0.20	–	–	0.15	0.10	0.30	–	–	–	0.33
Ptychobranchus fasciolaris	0.10	–	–	0.31	0.20	0.10	0.10	0.20	0.10	–
Ptychobranchus subtentum *	0.10	–	0.80	–	0.10	–	–	0.60	–	0.67
Quadrula cylindrica	–	–	–	–	–	–	0.10	–	–	–
Quadrula intermedia *+	–	–	–	–	–	–	0.21	–	0.10	–
Quadrula sparsa *+	–	–	–	–	–	–	–	–	–	–
Villosa iris	–	–	–	–	–	–	–	–	–	–
Villosa vanuxemi *	–	–	–	–	–	–	–	–	–	–
Total per square meter	7.10	3.00	8.00	6.46	7.70	10.90	5.64	7.20	11.14	21.00
Number of samples	40	20	20	26	40	40	39	20	42	12
Specimens found	71	15	40	42	77	109	55	36	117	63
Species included	14	7	12	10	17	14	16	12	16	9

*Cumberlandian species (12)
+Endangered species (4)

Table 1. (Continued)

River Mile	126.4	127.2	130.6	136.1	166.3	Overall Average	Number of Specimens
Actinonaias carinata	3.38	2.00	1.78	0.82	-	2.47	272
Actinonaias pectorosa *	4.75	-	2.22	-	-	1.79	197
Alasmidonta marginata	-	-	-	-	-	0.01	1
Amblema plicata	-	-	-	-	-	0.40	44
Cyclonaias tuberculata	-	-	-	0.12	-	0.09	10
Dromus dromas *+	-	-	-	-	-	0.02	2
Elliptio crassidens	-	-	-	-	-	0.05	6
Elliptio dilatatus	0.63	-	0.11	0.12	-	0.22	24
Epioblasma brevidens *	-	-	-	-	-	0.09	10
Epioblasma capsaeformis *	-	-	-	-	-	0.07	8
Epioblasma triquetra	-	-	-	-	-	0.02	2
Fusconaia barnesiana *	0.75	-	-	-	-	0.12	13
Fusconaia edgariana *+	-	-	-	-	-	0.05	5
Fusconaia subrotunda	-	-	0.33	0.82	-	0.40	44
Lampsilis fasciola	0.25	0.20	-	-	0.20	0.13	14
Lampsilis ovata	0.13	-	0.11	-	-	0.14	15
Lasmigona costata	-	-	0.22	0.12	-	0.18	20
Leptodea fragilis	-	-	-	-	0.20	0.05	5
Ligumia recta	-	-	-	-	-	0.01	1
Medionidus conradicus *	0.88	-	0.22	-	-	0.44	49
Plethobasus cyphyus	-	-	-	-	-	0.08	9
Pleurobema oviforme *	-	-	-	-	-	0.03	3
Potamilus alatus	-	-	-	0.12	0.40	0.10	11
Ptychobranchus fasciolaris	-	-	0.11	-	-	0.09	10
Ptychobranchus subtentum *	-	-	-	-	-	0.10	11
Quadrula cylindrica	-	-	-	-	-	0.01	1
Quadrula intermedia *+	-	-	-	-	-	0.03	3
Quadrula sparsa *+	-	-	0.11	-	-	0.01	1
Villosa iris	0.13	-	-	-	-	0.01	1
Villosa vanuxemi *	-	-	-	-	1.40	0.06	7
Total per square meter	10.88	2.20	5.22	2.12	2.20	7.25	
Number of samples	32	20	36	34	20	441	
Specimens found	87	11	47	18	11		799
Species included	8	2	9	6	4		30

Table 2. Quantitative sampling results from the Powell River, June 1983, presented as numbers per square meter

River Mile	81.5	84.6	84.8	94.8	99.2	106.7	106.9	112.2	117.3	126.4
Actinonaias carinata	0.40	1.20	-	1.50	6.30	0.82	0.41	3.00	1.24	0.25
Actinonaias pectorosa *	1.00	1.00	-	1.40	10.10	0.62	0.62	0.40	4.38	0.25
Amblema plicata	-	-	-	-	-	0.21	-	-	-	-
Cyclonaias tuberculata	-	0.40	-	0.10	-	-	-	-	-	-
Dromus dromas *+	-	-	-	0.10	0.10	0.10	0.10	-	-	-
Elliptio crassidens	-	-	-	-	-	0.10	0.10	-	0.10	-
Elliptio dilatatus	-	0.60	-	0.10	-	0.10	-	-	1.33	0.50
Epioblasma brevidens *	-	-	-	0.10	-	-	-	0.20	-	0.38
Epioblasma capsaeformis *	-	-	-	-	-	-	-	-	0.19	-
Epioblasma triquetra	-	-	-	0.20	0.30	-	-	-	0.10	-
Fusconaia barnesiana *	-	-	-	-	0.10	0.10	-	-	0.10	-
Fusconaia cuneolus *+	-	-	-	-	0.10	-	-	-	-	-
Fusconaia subrotunda	-	-	-	0.20	1.40	0.10	-	0.20	0.95	-
Lampsilis fasciola	0.20	-	-	-	0.50	-	-	0.20	0.29	0.13
Lampsilis ovata	-	-	0.15	-	0.20	-	0.10	-	0.10	-
Lasmigona costata	-	-	-	-	0.10	-	-	-	0.19	0.25
Ligumia recta	-	-	-	-	0.10	-	-	-	-	-
Medionidus conradicus *	0.80	0.80	0.15	0.40	2.10	-	-	0.40	1.14	0.25
Plethobasus cyphyus	-	-	-	-	0.10	-	-	0.20	-	-
Potamilus alatus	-	-	-	-	-	-	-	-	-	0.38
Ptychobranchus fasciolaris	-	-	-	0.30	0.20	0.10	0.10	0.20	0.10	0.13
Ptychobranchus subtentum *	-	-	-	-	-	-	-	-	0.10	-
Quadrula intermedia *+	-	-	-	-	0.10	0.10	-	-	-	-
Total per square meter	2.40	4.00	0.31	4.40	21.80	2.36	1.44	4.80	10.29	2.50
Number of samples	20	20	26	40	40	39	39	20	42	32
Specimens found	12	20	2	44	218	23	14	24	108	20
Species included	4	5	2	10	15	10	6	8	14	9

* Cumberlandian species (9)
+ Endangered species (3)

Table 2. (Continued)

River Mile	127.2	130.6	136.1	166.1	Overall Average	Number of Specimens
Actinonaias carinata	-	0.44	-	-	1.23	132
Actinonaias pectorosa *	0.80	0.22	0.78	-	1.86	200
Amblema plicata	-	-	-	-	0.02	2
Cyclonaias tuberculata	-	-	-	-	0.03	3
Dromus dromas *+	-	-	-	-	0.04	4
Elliptio crassidens	-	-	-	-	0.03	3
Elliptio dilatatus	0.40	0.11	0.33	-	0.27	29
Epioblasma brevidens *	-	-	-	-	0.05	5
Epioblasma capsaeformis *	-	-	-	-	0.02	2
Epioblasma triquetra	-	-	-	-	0.06	6
Fusconaia barnesiana *	-	-	-	-	0.03	3
Fusconaia cuneolus *+	-	-	0.11	-	0.02	2
Fusconaia subrotunda	0.40	0.11	0.22	-	0.31	33
Lampsilis fasciola	-	0.33	0.11	-	0.14	15
Lampsilis ovata	-	-	-	-	0.05	5
Lasmigona costata	-	0.11	-	-	0.06	6
Ligumia recta	-	-	-	-	0.01	1
Medionidus conradicus *	-	-	0.22	-	0.48	52
Plethobasus cyphyus	-	-	-	-	0.02	2
Potamilus alatus	-	-	-	0.20	0.04	4
Ptychobranchus fasciolaris	0.20	-	-	-	0.10	11
Ptychobranchus subtentum *	-	-	-	-	0.01	1
Quadrula intermedia *+	-	-	-	-	0.02	2
Total per square meter	1.80	1.33	1.78	0.20	4.87	
Number of samples	20	36	36	20	430	
Specimens found	9	12	16	1		523
Species included	4	6	6	1		23

Table 3. Quantitative sampling results from the Powell River, June 1988, presented as numbers per square meter

River Mile	72.8	81.5	83.6	94.8	99.2	106.7	106.9	112.2	117.2	119.3
Actinonaias carinata	1.40	0.80	1.00	1.00	1.20	0.50	-	0.20	0.76	1.00
Actinonaias pectorosa *	0.50	0.20	0.40	0.30	1.00	0.10	-	0.60	2.67	1.67
Amblema plicata	0.10	-	0.30	0.10	-	0.60	-	-	0.10	-
Cyclonaias tuberculata	0.40	-	0.30	0.10	0.10	-	-	-	0.10	-
Dromus dromas *+	-	-	-	-	-	-	-	0.20	-	-
Elliptio crassidens	-	-	-	-	-	0.10	-	-	-	-
Elliptio dilatatus	0.30	0.20	0.40	0.10	-	0.50	-	0.20	0.38	-
Epioblasma brevidens *	-	-	-	-	-	0.10	-	0.20	-	-
Epioblasma triquetra	0.10	-	0.10	0.10	-	0.10	-	-	0.10	-
Fusconaia edgariana *+	0.10	-	-	-	-	-	-	-	-	-
Fusconaia subrotunda	0.10	-	0.10	0.10	0.30	0.30	-	0.60	0.38	-
Lampsilis fasciola	0.30	0.20	-	0.10	-	-	-	0.20	-	-
Lampsilis ovata	-	0.40	-	-	0.10	0.10	-	-	-	-
Lasmigona costata	-	-	-	-	-	-	-	-	-	-
Ligumia recta	0.20	-	-	-	-	-	-	-	-	-
Medionidus conradicus *	0.90	0.40	0.90	0.20	0.60	0.30	0.10	0.40	0.76	-
Plethobasus cyphyus	0.10	-	-	-	-	-	-	-	-	-
Pleurobema oviforme *	-	-	-	-	-	-	-	-	0.10	-
Ptychobranchus fasciolaris	0.10	-	-	0.20	0.20	0.10	-	-	0.10	-
Quadrula cylindrica	-	-	0.10	-	-	-	-	-	-	-
Quadrula intermedia *+	-	-	-	-	-	0.40	-	-	-	-
Quadrula sparsa *+	-	0.20	-	-	-	-	-	-	0.10	-
Villosa iris	-	-	-	-	-	0.10	-	-	-	-
Total per square meter	4.60	2.40	3.60	2.30	3.50	3.30	0.10	2.60	5.52	2.67
Number of samples	40	20	40	40	40	40	40	20	42	12
Specimens found	46	12	36	23	35	33	1	13	58	8
Species included	13	7	9	10	7	13	1	8	11	2

* Cumberlandian species (8)
+ Endangered species (4)

Table 3. (Continued)

River Mile	126.4	127.2	130.6	133.0	166.3	Overall Average	Number of Specimens
Actinonaias carinata	0.38	-	-	-	-	0.59	70
Actinonaias pectorosa *	0.25	0.20	0.11	0.12	-	0.55	65
Amblema plicata	-	-	-	-	-	0.10	12
Cyclonaias tuberculata	-	-	-	-	-	0.08	10
Dromus dromas *+	-	-	-	-	-	0.01	1
Elliptio crassidens	-	-	-	-	-	0.01	1
Elliptio dilatatus	0.13	-	-	0.12	-	0.18	21
Epioblasma brevidens *	-	-	0.11	-	-	0.03	3
Epioblasma triquetra	-	-	-	-	-	0.04	5
Fusconaia edgariana *+	-	-	-	-	-	0.01	1
Fusconaia subrotunda	0.13	-	0.11	-	-	0.15	18
Lampsilis fasciola	0.38	-	0.11	-	-	0.08	10
Lampsilis ovata	-	-	-	-	-	0.03	4
Lasmigona costata	-	-	0.11	-	-	0.01	1
Ligumia recta	-	-	-	-	-	0.02	2
Medionidus conradicus *	0.13	0.40	-	0.12	-	0.39	46
Plethobasus cyphyus	-	-	-	-	-	0.01	1
Pleurobema oviforme *	-	-	-	-	-	0.01	1
Ptychobranchus fasciolaris	-	-	-	-	-	0.06	7
Quadrula cylindrica	-	-	-	-	-	0.01	1
Quadrula intermedia *+	-	-	-	-	-	0.03	4
Quadrula sparsa *+	-	-	-	-	-	0.02	2
Villosa iris *	-	-	-	-	-	0.01	1
Total per square meter	1.38	0.60	0.56	0.35	0.00	2.41	
Number of samples	32	20	36	34	20	476	
Specimens found	11	3	5	3	0		287
Species included	6	2	5	3	0		23

Table 4. Numbers of freshwater mussels found at each Powell River site sampled in all three years (1979, 1983, and 1988). Abundance values for each year are numbers per square meter. Year values are significance levels of one-way ANOVA tests where (P>F)<0.10.

Species	81.5 1979	1983	1988	Year	94.8 1979	1983	1988	Year
Actinonaias carinata	1.00	0.40	0.80		3.20	1.50	1.00	0.001
Actinonaias pectorosa	0.80	1.00	0.20		0.10	1.40	0.30	
Alasmidonta marginata	–	–	–		–	–	–	
Amblema plicata	0.20	–	–		1.40	–	0.10	0.001
Cyclonaias tuberculata	–	–	–		0.10	0.10	0.10	
Dromus dromas	–	–	–		–	0.10	–	
Elliptio crassidens	–	–	–		0.10	–	–	
Elliptio dilatatus	–	–	0.20		–	0.10	0.10	
Epioblasma brevidens	–	–	–		–	0.10	–	
Epioblasma capsaeformis	–	–	–		–	–	–	
Epioblasma triquetra	–	–	–		–	0.20	0.10	
Fusconaia barnesiana	–	–	–		0.10	–	–	
Fusconaia cuneolus	–	–	–		–	–	–	
Fusconaia edgariana	–	–	–		0.10	–	–	
Fusconaia subrotunda	–	–	–		1.10	0.20	0.10	0.002
Lampsilis fasciola	0.20	0.20	0.20		–	–	0.10	
Lampsilis ovata	0.20	–	0.40		0.30	–	–	0.04
Lasmigona costata	–	–	–		0.10	–	–	
Leptodea fragilis	–	–	–		0.10	–	–	
Ligumia recta	–	–	–		–	–	–	
Medionidus conradicus	0.40	0.80	0.40		0.10	0.40	0.20	
Plethobasus cyphyus	0.20	–	–		0.40	–	–	0.02
Pleurobema oviforme	–	–	–		0.10	–	–	
Potamilus alatus	–	–	–		0.10	–	–	
Ptychobranchus fasciolaris	–	–	–		0.20	0.30	0.20	
Ptychobranchus subtentum	–	–	–		0.10	–	–	
Quadrula cylindrica	–	–	–		–	–	–	
Quadrula intermedia	–	–	–		–	–	–	
Quadrula sparsa	–	–	0.20		–	–	–	
Villosa iris	–	–	–		–	–	–	
Villosa vanuxemi	–	–	–		–	–	–	
Totals	3.00	2.40	2.40		7.70	4.40	2.30	0.0001
Duncan's Multiple Range Test	A*	A	A		A	B	C	

*Years with the same letter are not significantly different from each other (P > 0.05)

Table 4. (Continued)

Species	99.2 1979	1983	1988	Year	106.7 1979	1983	1988	Year
Actinonaias carinata	5.50	6.30	1.20	0.0002	2.46	0.82	0.50	0.002
Actinonaias pectorosa	1.60	10.10	1.00		1.03	0.62	0.10	0.02
Alasmidonta marginata	0.10	-	-		-	-	-	
Amblema plicata	0.20	-	-	0.1	0.31	0.21	0.60	
Cyclonaias tuberculata	0.10	-	0.10		-	-	-	
Dromus dromas	-	0.10	-		0.10	0.10	-	
Elliptio crassidens	0.20	-	-	0.1	0.21	0.10	0.10	
Elliptio dilatatus	-	-	-		0.10	0.10	0.50	0.09
Epioblasma brevidens	-	-	-		0.10	-	0.10	
Epioblasma capsaeformis	0.30	-	-	0.04	-	-	-	
Epioblasma triquetra	-	0.30	-		-	-	0.10	
Fusconaia barnesiana	-	0.10	-		-	0.10	-	
Fusconaia cuneolus	-	0.10	-		-	-	-	
Fusconaia edgariana	-	-	-		0.10	-	-	
Fusconaia subrotunda	1.00	1.40	0.30	0.08	0.10	0.10	0.30	
Lampsilis fasciola	-	0.50	-		0.21	-	-	
Lampsilis ovata	0.20	0.20	0.10		0.21	-	0.10	
Lasmigona costata	0.20	0.10	-		-	-	-	
Leptodea fragilis	-	-	-		-	-	-	
Ligumia recta	-	0.10	-		-	-	-	
Medionidus conradicus	1.00	2.10	0.60		0.21	-	0.30	
Plethobasus cyphyus	0.10	0.10	-		0.10	-	-	
Pleurobema oviforme	-	-	-		-	-	-	
Potamilus alatus	0.30	-	-	0.04	-	-	-	
Ptychobranchus fasciolaris	0.10	0.20	0.20		0.10	0.10	0.10	
Ptychobranchus subtentum	-	-	-		-	-	-	
Quadrula cylindrica	-	-	-		0.10	-	-	
Quadrula intermedia	-	0.10	-		0.21	0.10	0.40	
Quadrula sparsa	-	-	-		-	-	-	
Villosa iris	-	-	-		-	-	0.10	
Villosa vanuxemi	-	-	-		-	-	-	
Totals	10.90	21.80	3.50	0.0001	5.64	2.36	3.30	0.002
Duncan's Multiple Range Test	B	A	C		A	B	B	

Table 4. (Continued)

Species	112.2 1979	1983	1988	Year	117.3 1979	1983	1988	Year
Actinonaias carinata	1.80	3.00	0.20	0.09	1.90	1.24	0.76	0.06
Actinonaias pectorosa	1.60	0.40	0.60		4.86	4.38	2.67	0.04
Alasmidonta marginata	–	–	–		–	–	–	
Amblema plicata	–	–	–		0.10	–	0.10	
Cyclonaias tuberculata	0.20	–	–		0.10	–	0.10	
Dromus dromas	0.20	–	0.20		–	–	–	
Elliptio crassidens	–	–	–		–	0.10	–	
Elliptio dilatatus	0.20	–	0.20		0.48	1.33	0.38	
Epioblasma brevidens	–	0.20	0.20		0.38	0.00	–	0.05
Epioblasma capsaeformis	0.40	–	–	0.09	0.29	0.19	–	0.09
Epioblasma triquetra	–	–	–		0.10	0.10	0.10	
Fusconaia barnesiana	0.80	–	–	0.01	0.19	0.10	–	
Fusconaia cuneolus	–	–	–		–	–	–	
Fusconaia edgariana	0.20	–	–		–	–	–	
Fusconaia subrotunda	–	0.20	0.60	0.06	0.38	0.95	0.38	
Lampsilis fasciola	–	0.20	0.20		0.38	0.29	–	0.09
Lampsilis ovata	0.20	–	–		–	0.10	–	
Lasmigona costata	–	–	–		–	0.19	–	
Leptodea fragilis	–	–	–		0.19	–	–	0.09
Ligumia recta	–	–	–		–	–	–	
Medionidus conradicus	0.80	0.40	0.40		1.43	1.14	0.76	
Plethobasus cyphyus	–	0.20	–		–	–	–	
Pleurobema oviforme	–	–	–		0.19	–	0.10	
Potamilus alatus	–	–	–		–	–	–	
Ptychobranchus fasciolaris	0.20	0.20	–		0.10	0.10	0.10	
Ptychobranchus subtentum	0.60	–	–		–	0.10	–	
Quadrula cylindrica	–	–	–		–	–	–	
Quadrula intermedia	–	–	–		0.10	–	–	
Quadrula sparsa	–	–	–		–	–	0.10	
Villosa iris	–	–	–		–	–	–	
Villosa vanuxemi	–	–	–		–	–	–	
Totals	7.20	4.80	2.60	0.03	11.14	10.29	5.52	0.002
Duncan's Multiple Range Test	A	AB	B		A	A	B	

Table 4. (Continued)

Species	126.4 1979	1983	1988	Year	127.2 1979	1983	1988	Year
Actinonaias carinata	3.38	0.25	0.38	0.0005	2.00	-	-	0.005
Actinonaias pectorosa	4.75	0.25	0.25	0.0001	-	0.80	0.20	
Alasmidonta marginata	-	-	-		-	-	-	
Amblema plicata	-	-	-		-	-	-	
Cyclonaias tuberculata	-	-	-		-	-	-	
Dromus dromas	-	-	-		-	-	-	
Elliptio crassidens	-	-	-		-	-	-	
Elliptio dilatatus	0.63	0.50	0.13		-	0.40	-	
Epioblasma brevidens	-	0.38	-		-	-	-	
Epioblasma capsaeformis	-	-	-		-	-	-	
Epioblasma triquetra	-	-	-		-	-	-	
Fusconaia barnesiana	0.75	-	-	0.003	-	-	-	
Fusconaia cuneolus	-	-	-		-	-	-	
Fusconaia edgariana	-	-	-		-	-	-	
Fusconaia subrotunda	-	-	0.13		-	0.40	-	
Lampsilis fasciola	0.25	0.13	0.38		0.20	-	-	
Lampsilis ovata	0.13	-	-		-	-	-	
Lasmigona costata	-	0.25	-		-	-	-	
Leptodea fragilis	-	-	-		-	-	-	
Ligumia recta	-	-	-		-	-	-	
Medionidus conradicus	0.88	0.25	0.13	0.05	-	-	0.40	0.07
Plethobasus cyphyus	-	-	-		-	-	-	
Pleurobema oviforme	-	-	-		-	-	-	
Potamilus alatus	-	0.38	-		-	-	-	
Ptychobranchus fasciolaris	-	0.13	-		-	0.20	-	
Ptychobranchus subtentum	-	-	-		-	-	-	
Quadrula cylindrica	-	-	-		-	-	-	
Quadrula intermedia	-	-	-		-	-	-	
Quadrula sparsa	-	-	-		-	-	-	
Villosa iris	0.13	-	-		-	-	-	
Villosa vanuxemi	-	-	-		-	-	-	
Totals	10.88	2.50	1.38	0.0001	2.20	1.80	0.60	
Duncan's Multiple Range Test	A	B	B		A	A	A	

Table 4. (Continued)

Species	130.6 1979	1983	1988	Year	166.3 1979	1983	1988	Year
Actinonaias carinata	1.78	0.44	-	0.0001	-	-	-	
Actinonaias pectorosa	2.22	0.22	0.11	0.0001	-	-	-	
Alasmidonta marginata	-	-	-		-	-	-	
Amblema plicata	-	-	-		-	-	-	
Cyclonaias tuberculata	-	-	-		-	-	-	
Dromus dromas	-	-	-		-	-	-	
Elliptio crassidens	-	-	-		-	-	-	
Elliptio dilatatus	0.11	0.11	-		-	-	-	
Epioblasma brevidens	-	-	0.11		-	-	-	
Epioblasma capsaeformis	-	-	-		-	-	-	
Epioblasma triquetra	-	-	-		-	-	-	
Fusconaia barnesiana	-	-	-		-	-	-	
Fusconaia cuneolus	-	-	-		-	-	-	
Fusconaia edgariana	-	-	-		-	-	-	
Fusconaia subrotunda	0.33	0.11	0.11		-	-	-	
Lampsilis fasciola	-	0.33	0.11		0.20	-	-	
Lampsilis ovata	0.11	-	-		-	-	-	
Lasmigona costata	0.22	0.11	0.11		-	-	-	
Leptodea fragilis	-	-	-		0.20	-	-	
Ligumia recta	-	-	-		-	-	-	
Medionidus conradicus	0.22	-	-	0.09	-	-	-	
Plethobasus cyphyus	-	-	-		-	-	-	
Pleurobema oviforme	-	-	-		-	-	-	
Potamilus alatus	-	-	-		0.40	0.20	-	
Ptychobranchus fasciolaris	0.11	-	-		-	-	-	
Ptychobranchus subtentum	-	-	-		-	-	-	
Quadrula cylindrica	-	-	-		-	-	-	
Quadrula intermedia	-	-	-		-	-	-	
Quadrula sparsa	0.11	-	-		-	-	-	
Villosa iris	-	-	-		-	-	-	
Villosa vanuxemi	-	-	-		1.40	-	-	0.009
Totals	5.22	1.33	0.56	0.0001	2.20	0.20	0.00	0.003
Duncan's Multiple Range Test	A	B	B		A	B	B	

Table 4. (Contineud)

Species	Combined 1979	1983	1988	Year	Duncan's Multiple Range Test 1979	1983	1988
Actinonaias carinata	2.56	1.58	0.55	0.0001	A	B	C
Actinonaias pectorosa	1.92	2.36	0.64	0.0001	A	A	B
Alasmidonta marginata	0.01	-	-				
Amblema plicata	0.27	0.02	0.10	0.0006	A	B	B
Cyclonaias tuberculata	0.05	0.01	0.04				
Dromus dromas	0.02	0.04	0.01				
Elliptio crassidens	0.06	0.02	0.01				
Elliptio dilatatus	0.17	0.30	0.17				
Epioblasma brevidens	0.06	0.06	0.04				
Epioblasma capsaeformis	0.10	0.02	-	0.005	A	B	B
Epioblasma triquetra	0.01	0.08	0.04				
Fusconaia barnesiana	0.17	0.04	-	0.0001	A	B	B
Fusconaia cuneolus	-	0.01	-				
Fusconaia edgariana	0.04	-	-	0.05	A	B	B
Fusconaia subrotunda	0.38	0.40	0.21				
Lampsilis fasciola	0.14	0.18	0.09				
Lampsilis ovata	0.14	0.04	0.05	0.03	A	B	B
Lasmigona costata	0.06	0.08	0.01				
Leptodea fragilis	0.05	-	-	0.02	A	B	B
Ligumia recta	-	0.01	-				
Medionidus conradicus	0.56	0.58	0.34				
Plethobasus cyphyus	0.09	0.02	-	0.01	A	B	B
Pleurobema oviforme	0.04	-	0.01				
Potamilus alatus	0.08	0.05	-	0.06			
Ptychobranchus fasciolaris	0.09	0.13	0.08				
Ptychobranchus subtentum	0.05	0.01	-				
Quadrula cylindrica	0.01	-	-				
Quadrula intermedia	0.04	0.02	0.05				
Quadrula sparsa	0.01	-	0.02				
Villosa iris	0.01	-	0.01				
Villosa vanuxemi	0.09	-	-	0.01	A	B	B
Totals	7.31	6.10	2.49	0.0001	A	B	C
Duncan's Multiple Range Test							

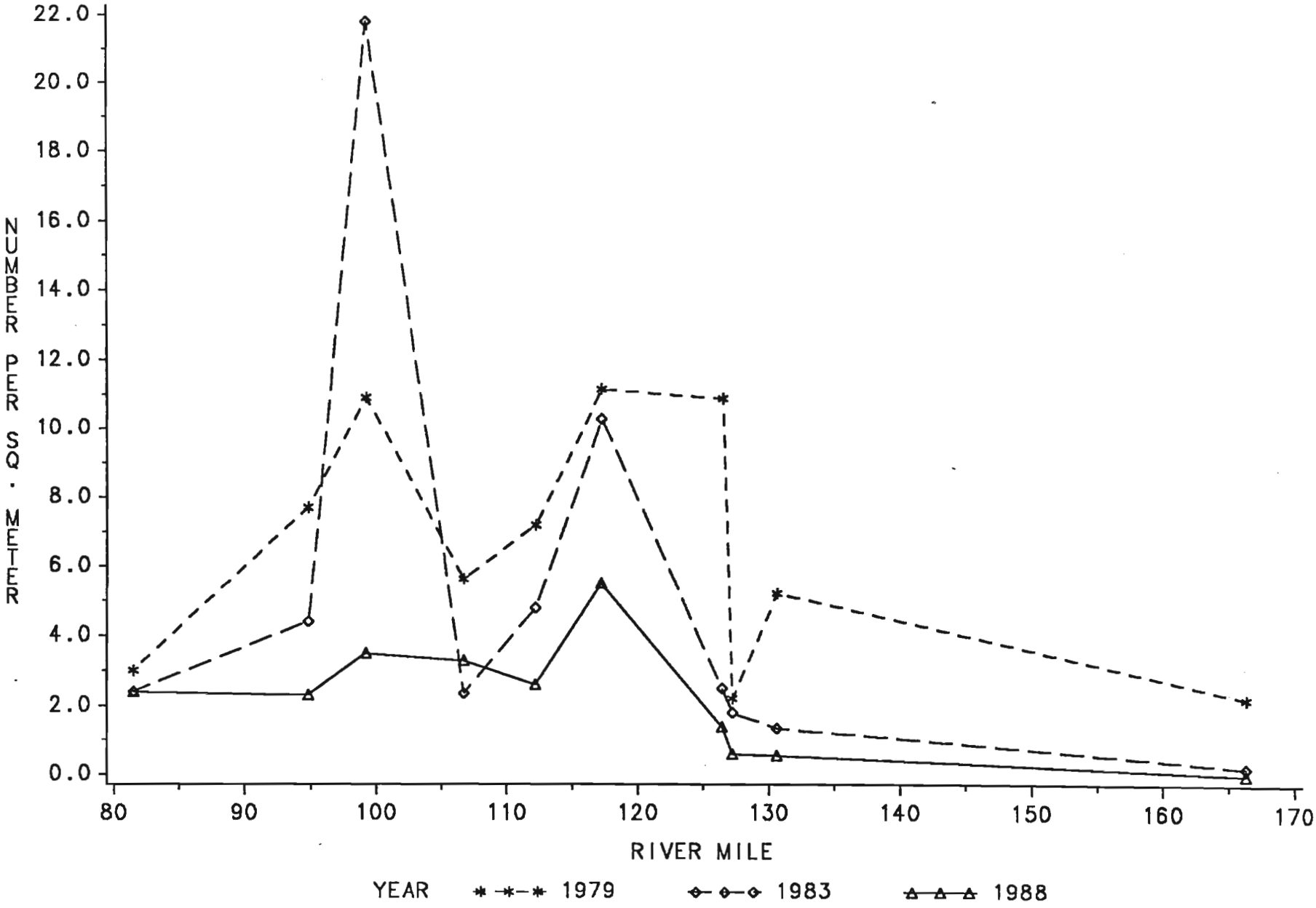

Figure 1. Numbers of freshwater mussels found at Powell River quantitative sampling sites visited in 1979 (stars), 1983 (diamonds), and 1988 (triangles).

APPENDIX C

QUANTITATIVE REASSESSMENT OF THE FRESHWATER MUSSEL FAUNA IN THE CLINCH RIVER, TENNESSEE AND VIRGINIA

TENNESSEE VALLEY AUTHORITY

River Basin Operations
Water Resources

QUANTITATIVE REASSESSMENT OF THE FRESHWATER MUSSEL FAUNA IN THE CLINCH RIVER, TENNESSEE AND VIRGINIA

Prepared by

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October 1988

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

In the fall of 1979, the Tennessee Valley Authority (TVA) conducted a float survey of freshwater mussel resources in much of the length of the Clinch River. The survey was halted by cold weather in November 1979 and the remaining reaches were not floated until spring 1983. In all, approximately 170 miles of the Clinch River mainstem were examined, from the head of Norris Reservoir in NE Tennessee upstream into SW Virginia. This part of the watershed drains an area of approximately 1,500 square miles.

The Clinch River survey was one of nine stream investigations TVA conducted primarily in 1979 and 1980 to determine the distribution and abundance of endemic freshwater mussel species in many Tennessee River tributaries. The results of all of these surveys were presented in a single Cumberlandian Mollusk Conservation Program report (Ahlstedt, 1986).

During the 1979-1983 Clinch River survey, both qualitative and quantitative data were taken. Qualitative data were gathered wherever suitable mussel habitat was encountered by the survey crews. Quantitative data were collected only at sites that yielded live specimens of Federaly-listed endangered species or where dense mussel concentrations were present. In 1979, quantitative samples were taken at 11 Clinch River sites (table 1). One additional quantitative site was sampled during 1983 (table 2).

In 1988, TVA biologists resampled eleven of these quantitative sites. This report describes the resampling effort, presents the results, and discusses statistical trends in the data over the nine year period.

METHODS

During the 1979-1983 survey, the quantitative sampling sites had been selected because they yielded live specimens of endangered species or supported dense mussel concentrations. In 1988, the intention was to quantitatively sample the same sites using the same techniques that had been applied earlier. No broad qualitative search was mounted in 1988 to locate better or additional sites to be included.

Quantitative sampling techniques used during the 1979-1983 survey are presented in the report prepared by Ahlstedt (1986). On all three occasions (1979, 1983, and 1988), quantitative sampling consisted of searching for mussels within $0.25m^2$ metal quadrat frames placed at random throughout good mussel habitat. The number of quadrat samples taken in 1979 and 1983 depended upon the crew leader's estimate of good mussel habitat at the site. A guide table attempted to standardize the search at four percent of the suitable habitat (Ahlstedt, 1986). In 1988, considerable care was taken to collect data from the same number of quadrat samples at each site that had been examined during the earlier survey.

In 1988, the appropriate number of quadrat samples were taken scattered throughout the same habitat areas that had been sampled previously. Snorkel-assisted biologists disturbed the substrate within each quadrat to a depth of 5-10 cm and placed all live mussels found in collection bags. The crew leader sorted the mussels from each quadrat to species, counted them, and recorded the data on a field sheet. All of the animals were returned to suitable habitat at the site.

Data collected from the sampling sites were summarized in tables and analyzed using various Statistical Analysis System (SAS) routines. Comparisons of the data from the 1979 and 1988 surveys also were made using SAS programs. All decisions based on statistical tests were made at the 95 percent confidence level. Probability values between 0.05 and 0.1 are supplied in some tables for information purposes only.

RESULTS

As reported previously (Ahlstedt, 1986), the 1979-1983 Clinch River survey included 385 quadrat samples taken at 12 sites. These sites were located between Clinch River Miles (CRM) 159.2 and 321.7 (tables 1 and 2). At these sites, a total of 1,121 live mussels were found, for an overall average of 11.64 mussels per square meter. These animals represented 34 different species.

The survey conducted early in June 1988 included 348 quadrat samples taken at 11 sites (table 3). One of the sites sampled in 1979 (CRM 226.3) is now a private protection reserve and was not sampled in 1988. A nearby site was sampled instead (CRM 235.1). At these sites, a total of 523 live mussels were found, yielding an overall average of $6.00/m^2$. These animals included representatives of 31 species.

This survey was conducted during a serious drought. Water levels were extremely low, particularly at the most upstream site, and the water was exceptionally clear. Most mussels, especially smaller individuals, were found completely buried in the substrate. While this is common behavior for a few species (i.e. Lastena lata) it is unusual for the remainder of the Clinch River mussel fauna. At several sites, particularly CRM 270.9, many of the mussels were small and were still attached to adjacent rocks by byssal threads.

During the survey, some mussels appeared to be showing signs of stress. Members of several species could be pried open with little effort. Some of these animals were unable to keep their shells fully closed. A few dead specimens were found with soft parts still attached to the shells.

These quantitative surveys from the Clinch River include a total of 41 freshwater mussel species. The 1979 survey included the most species (34), while the 1988 survey yielded 31 species. All 14 species found in 1983 were included in both more extensive surveys. Twenty-nine species were encountered in both 1979 and 1988. Five

species (Epioblasma triquetra, Fusconaia edgariana, Pleurobema cordatum, Quadrula cylindrica, and Truncilla truncata) were found only in 1979. Two species (Alasmidonta marginata and Lexingtonia dolabelloides) were found only in 1988.

The five most abundant species during the 1979 survey (in order: Actinonaias carinata, Actinonaias pectorosa, Elliptio dilatatus, Ptychobranchus subtentum, and Lasmigona costata) accounted for 65.5 percent of the quantitative total (table 1). Three of these species were still among the five most abundant species in 1988 (Actinonaias carinata was still first, Actinonaias pectorosa was still second, and Ptychobranchus subtentum was still fourth); however, Medionidus conradicus moved into third place (from seventh in 1979) and Fusconaia subrotunda moved into fifth place (from sixth in 1979). In 1988, the five most abundant species accounted for 73.2 percent of the total.

DISCUSSION

The results presented in tables 1 and 3 indicate that overall average freshwater mussel abundance in the Clinch River decreased from 11.64/m^2 in 1979 to 6.00/m^2 in 1988. These tables also indicate substantial differences among the mussel species and the 13 sites examined during one or both of these surveys. Clearly, some additional analysis is required to clarify the nature of this decline in abundance.

Site Analyses

The ten sites that were examined during both the 1979 and 1988 surveys were used in a variety of statistical analyses. The same habitats at all of these sites had been sampled in virtually identical ways on each occasion.

Table 4 presents the species-by-species information from both surveys at these ten sites. The presentation on each site includes species abundance information from the surveys, occasionally followed by the probability value of a one-way analysis of variance (ANOVA) test. Probability values are presented in the table only if they were less than or equal to 0.1 (the 90 percent confidence level). As indicated in results, statistical decisions were made using a 95 percent confidence level.

Annual total abundance information is presented at the bottom of each site entry, on six occasions accompanied by one-way ANOVA probability values. The annual total abundance values from these ten sites also are plotted on figure 1.

The last columns in table 4 present abundance information and one-way ANOVA results on the combined data from these ten sites. Combined abundance values for the various species during each survey and annual totals in these columns differ from the overall averages in tables 1 and 3 because only sites sampled in both years have been included in table 4.

The site-by-site species information presented in the body of table 4 includes considerable variability and a few exceptional

abundance values (such as 5.40/m^2 Actinonaias pectorosa and 1.20 Fusconaia subrotunda found at CRM 270.9 in 1988). Less variable information occurs in the site totals and in the combined survey totals.

Results of the ANOVA tests on the site total data indicate statistically significant differences at six of the ten sites (table 4). At five of these six sites, total abundance was lower in 1988 than it was in 1979. Abundance in 1988 was significantly higher only at CRM 270.9. The increase in mussel abundance at this site appears to be an indication of recent colonization along the left (descending) bank.

The five sites where abundance in 1988 was significantly lower than it had been in 1979 occurred along the length of the river from CRM 172.2 to 219.2. Two of the four sites that did not show significant differences between surveys also occurred in this reach. Both of these sites (CRM 184.5 and 211.1) yielded slightly lower abundance values in 1988 than they did in 1979.

The other two sites that did not show significant differences between surveys occurred at the extreme ends of the river reach. The downstream site (CRM 159.2) yielded a slightly higher 1988 abundance value while the upstream site (CRM 321.7) yielded a slightly lower 1988 value. The plot of all site total abundance values (figure 1) illustrates the variability between the two surveys.

Combined Analyses

Combining the data from all ten of these sites provides a way to look at trends between the survey totals and each of the species found at the sites. In table 4, the combined totals clearly indicate that overall mussel abundance was significantly different between the surveys ($p>F=0.0001$). These data indicate that significantly more mussels occurred in the Clinch River during 1979 than in 1988. The overall average values presented in tables 1 and 3 were $12.10/m^2$ in 1979 and $6.01/m^2$ in 1988.

Given the significant difference between total abundance values for the two surveys, it seems surprising to find that only seven of the 35 species included in this analysis (using a 95 percent confidence level) yielded significant differences between the data from 1979 and 1988 (table 4). While none of the 35 species increased between 1979 and 1988, no significant differences were found in the abundance values for 28 species.

One reason some species might not show statistical differences is that 13 taxa in the analysis were represented by five or fewer specimens in the entire 1979 and 1988 data sets. The expected random occurrence of these rare species would be unlikely to result in recognizable differences between the surveys. However, even excluding these rare species, significant differences only occurred in 7 of 22, or 32 percent of the more common mussel species found during these surveys.

This apparent anomaly may be clarified by examining the species which did show statistical differences. Three of these seven species (Actinonaias carinata, Elliptio dilatatus, and Lasmigona costata) were among the five most abundant mussel taxa in 1979. While Actinonaias carinata maintained its most abundant position in the 1988 survey, both of the other species dropped out of the top five list (table 1). Together these three species averaged 5.47 animals/m^2 in the full 1979 data set, but they averaged only 2.01/m^2 in the 1988 data set, a decrease of 3.46/m^2, or 63.3 percent of the 1979 value.

The other four species which showed significant differences (Epioblasma capsaeformis, Epioblasma triquetra, Fusconaia barnesiana, and Truncilla truncata) were much less abundant in 1979, with a composite average of 0.82/m^2 in the full data set. In the 1988 data set, their composite average was 0.03/m^2, a decrease of 0.79/m^2, or 96.4 percent of what it had been in 1979.

Together, these seven species averaged 6.29 animals/m^2 in 1979 and 2.05/m^2 in 1988, a decrease of 4.24/m^2. The total decrease in average mussel abundance between the 1979 and 1988 surveys was 6.09/m^2. Apparently, the population declines in these seven species account for 69.6 percent of the observed differences between the surveys. The remaining 15 mussel species which showed non-significant declines between the two surveys probably contributed to the remaining 30.4 percent of the difference (1.85 animals/m^2).

Endangered Species

During the 1979 and 1983 surveys, four species were found that are on the U.S. Fish and Wildlife Service list of endangered wildlife. All four species (Conradilla caelata, Dromus dromas, Fusconaia cuneolus, and Fusconaia edgariana) were found in 1979 but Fusconaia edgariana was not found during the 1988 survey (tables 1 and 3). Three of the four species were represented by five or fewer specimens in both surveys while Fusconaia cuneolus was represented by 20 specimens in 1979 and by 8 specimens in 1988. The one-way ANOVAs for these species in the combined data set (table 4) did not indicate significant differences between the surveys for any of them.

SUMMARY

The results of two quantitative surveys conducted in the Clinch River indicate the average number of mussels per square meter declined from $12.10/m^2$ in 1979 to $6.01/m^2$ in 1988. The total mussel abundance at six of ten sites examined during both surveys resulted in statistical differences. Five of these sites had lower abundance values in 1988. The sixth site was one where many small mussels were found in part of the habitat during 1988.

None of the 35 species included in one-way analysis of variance tests increased in abundance over the survey period but only seven species showed statistically significant declines between the surveys (at the 95 percent confidence level). These seven species

included three (Actinonaias carinata, Elliptio dilatatus, and Lasmigona costata) which were among the most abundant species encountered during the 1979 survey and four (Epioblasma capsaeformis, Epioblasma triquetra, Fusconaia barnesiana, and Truncilla truncata) which were much less abundant in 1979. Together, these seven species averaged 6.29 animals/m^2 in 1979 and 2.05/m^2 in 1988, for a decrease of 4.24/m^2. This composite decrease accounts for 69.6 percent of the difference between the survey results.

Four endangered species were found during these surveys. Three of them (Conradilla caelata, Dromus dromas, and Fusconaia cuneolus) were found in both surveys. Fusconaia edgariana was only found during 1979. Only Fusconaia cuneolus was represented by more than five specimens from both surveys. The ANOVA tests did not reveal differences between survey averages for any of these endangered species.

ACKNOWLEDGEMENTS

We sincerely thank the Tennessee Wildlife Resources Agency employees and biology graduate students from Virginia Polytechnic Institute and State University who took many of the samples during the 1988 survey. Tabular summaries, statistical analyses, and interpretation assistance were provided by Thomas A. McDonough, TVA Data Services Group.

LITERATURE CITED

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Table 1. Quantitative sampling results from the Clinch River in 1979, presented as numbers per square meter

River Mile	159.2	172.2	184.5	189.6	206.9	211.1	219.1	219.2	226.3	270.9	321.7	Overall Average	Number of Specimens
Actinonaias carinata	5.20	5.10	6.62	7.41	5.50	0.80	2.50	3.36	3.40	0.20	–	3.56	307
Actinonaias pectorosa *	0.20	0.60	0.31	6.05	2.75	1.10	0.30	0.48	3.60	–	0.11	1.58	136
Amblema plicata	–	–	0.15	0.39	–	–	0.60	0.48	0.80	0.60	–	0.29	25
Conradilla caelata *+	–	–	–	0.10	–	–	–	–	–	–	–	0.01	1
Cumberlandia monodonta	–	–	–	0.78	–	–	–	–	–	–	–	0.09	8
Cyclonaias tuberculata	0.80	–	1.08	0.39	0.50	0.20	0.30	0.32	1.10	–	–	0.41	35
Cyprogenia irrorata	–	–	–	0.10	–	0.10	0.10	–	–	–	–	0.03	3
Dromus dromas *+	–	0.10	–	–	–	–	–	–	–	–	–	0.01	1
Elliptio dilatatus	0.20	–	–	2.15	0.25	0.10	1.00	0.48	6.30	0.20	–	1.18	102
Epioblasma brevidens *	–	–	–	0.10	0.25	–	–	0.16	–	–	–	0.03	3
Epioblasma capsaeformis *	–	–	–	0.39	2.00	0.20	–	0.64	0.80	–	–	0.30	26
Epioblasma triquetra	–	0.10	0.15	0.10	0.25	–	–	–	–	–	–	0.05	4
Fusconaia barnesiana *	0.20	0.10	–	2.15	–	–	0.40	0.48	0.10	0.20	0.32	0.42	36
Fusconaia cuneolus *+	–	–	–	0.29	–	–	0.10	0.16	1.10	0.40	0.22	0.23	20
Fusconaia edgariana *+	–	–	–	0.20	–	–	–	–	0.30	–	–	0.06	5
Fusconaia subrotunda	–	0.30	0.46	0.78	0.25	0.10	1.10	1.60	1.70	–	0.43	0.67	58
Lampsilis fasciola	–	–	–	0.20	0.25	–	–	–	0.20	–	0.11	0.07	6
Lampsilis ovata	–	0.20	0.92	0.10	0.25	0.30	0.10	–	0.50	–	–	0.22	19
Lasmigona costata	0.80	0.20	–	1.27	1.00	0.20	1.10	0.48	1.30	2.20	–	0.73	63
Lastena lata	–	0.10	0.15	0.10	–	–	0.20	–	–	–	–	0.06	5
Leptodea fragilis	–	–	–	–	–	–	–	–	0.10	–	–	0.01	1
Ligumia recta	–	–	0.31	–	0.25	–	–	–	0.10	–	–	0.05	4
Medionidus conradicus *	–	0.10	–	2.44	2.50	–	–	0.16	0.20	1.40	–	0.53	46
Plethobasus cyphyus	–	–	0.15	–	–	–	–	–	–	–	–	0.01	1
Pleurobema cordatum	–	–	0.15	–	–	–	–	–	–	–	–	0.01	1
Pleurobema oviforme *	–	–	–	0.29	–	–	–	–	–	–	0.11	0.05	4
Potamilus alatus	–	–	0.31	–	–	–	0.10	–	0.10	–	–	0.05	4
Ptychobranchus fasciolaris	–	–	0.15	0.29	0.25	0.10	0.10	–	0.40	–	0.11	0.14	12
Ptychobranchus subtentum *	0.80	0.10	0.15	4.20	2.00	0.50	0.10	–	1.10	0.20	0.11	0.88	76
Quadrula cylindrica	–	–	–	0.10	0.25	–	–	–	1.30	–	–	0.17	15
Quadrula pustulosa	–	–	0.31	0.10	–	–	–	–	–	–	–	0.03	3
Truncilla truncata	–	–	–	0.10	0.25	–	–	0.32	–	–	–	0.05	4
Villosa iris	–	–	–	0.39	–	–	–	–	–	–	0.54	0.10	9
Villosa perpurpurea *	–	–	–	–	–	–	–	–	0.10	–	–	0.01	1
Total per square meter	8.20	7.00	11.38	30.93	18.75	3.70	8.10	9.12	24.60	5.40	2.05	12.10	
Number of samples	20	40	26	41	16	40	40	25	40	20	37	345	
Specimens found	41	70	74	317	75	37	81	57	246	27	19		1,044
Species included	7	11	15	27	17	11	15	13	21	8	9		34

*Cumberlandian species (12)
+Endangered species (4)

Table 2. Quantitative sampling results from the Clinch River, June 1983, presented as numbers per square meter

River Mile	235.1	Overall Average	Number of Specimens
Actinonaias carinata	1.90	1.90	19
Actinonaias pectorosa *	2.50	2.50	25
Amblema plicata	0.20	0.20	2
Cyclonaias tuberculata	0.20	0.20	2
Elliptio dilatatus	0.10	0.10	1
Epioblasma capsaeformis *	0.10	0.10	1
Fusconaia barnesiana *	0.10	0.10	1
Fusconaia edgariana *+	0.30	0.30	3
Fusconaia subrotunda	1.00	1.00	10
Lampsilis fasciola	0.30	0.30	3
Lampsilis ovata	0.10	0.10	1
Lasmigona costata	0.10	0.10	1
Potamilus alatus	0.10	0.10	1
Ptychobranchus fasciolaris	0.70	0.70	7
Total per square meter	7.70	7.70	
Number of samples	40	40	
Specimens found	77		77
Species included	14		14

*Cumberlandian species (4)
+Endangered species (1)

Table 3. Quantitative sampling results from the Clinch River, June 1988, presented as numbers per square meter

River Mile	159.2	172.2	184.5	189.6	206.9	211.1	219.1	219.2	235.1	270.9	321.7	Overall Average	Number of Specimens
Actinonaias carinata	-	0.60	5.85	5.66	2.25	0.50	1.10	0.48	1.00	0.20	-	1.62	141
Actinonaias pectorosa *	1.00	-	0.46	2.44	3.00	0.70	0.60	1.28	1.80	5.40	-	1.28	111
Alasmidonta marginata	-	-	-	0.10	-	-	-	-	-	-	-	0.01	1
Amblema plicata	-	0.10	-	0.29	-	0.10	0.30	-	0.10	0.40	-	0.13	11
Conradilla caelata *+	-	-	-	0.10	-	-	0.10	-	-	-	-	0.02	2
Cumberlandia monodonta	-	-	-	0.10	-	-	-	-	-	-	-	0.01	1
Cyclonaias tuberculata	-	0.10	1.08	0.29	0.25	0.10	0.20	-	0.30	-	-	0.21	18
Cyprogenia irrorata	-	-	-	0.10	-	0.10	-	-	-	-	-	0.02	2
Dromus dromas *+	-	0.10	-	-	-	-	-	-	-	-	-	0.01	1
Elliptio dilatatus	-	-	-	0.29	0.25	0.10	-	0.32	0.10	0.40	-	0.11	10
Epioblasma brevidens *	-	0.20	0.31	-	-	0.10	-	-	-	-	-	0.06	5
Epioblasma capsaeformis *	-	-	-	0.10	-	-	-	-	-	-	-	0.01	1
Fusconaia barnesiana *	-	-	-	-	-	-	-	-	-	0.40	-	0.02	2
Fusconaia cuneolus *+	-	-	-	0.39	-	0.10	0.10	-	0.20	-	-	0.09	8
Fusconaia subrotunda	-	-	0.62	0.29	-	0.10	0.80	0.16	0.70	1.20	-	0.34	30
Lampsilis fasciola	-	-	0.15	-	-	-	-	-	-	0.60	-	0.05	4
Lampsilis ovata	-	0.10	0.15	-	0.25	0.10	0.10	-	-	0.60	-	0.09	8
Lasmigona costata	0.60	0.20	0.46	0.29	-	0.20	0.20	-	0.10	1.60	-	0.28	24
Lastena lata	-	-	-	0.20	-	-	-	-	-	-	-	0.02	2
Leptodea fragilis	-	-	-	-	-	-	0.10	-	-	0.20	-	0.02	2
Lexingtonia dolabelloides *	-	-	-	-	-	-	-	-	0.10	-	-	0.01	1
Ligumia recta	-	0.10	-	-	-	-	-	-	-	-	-	0.01	1
Medionidus conradicus *	4.20	-	-	2.24	-	0.40	0.10	-	-	1.00	-	0.62	54
Plethobasus cyphyus	-	0.10	0.15	-	-	-	-	-	-	-	-	0.02	2
Pleurobema oviforme *	-	-	-	-	-	-	-	-	-	0.20	-	0.01	1
Potamilus alatus	-	-	-	-	-	-	-	-	-	0.20	-	0.01	1
Ptychobranchus fasciolaris	-	-	-	0.20	0.25	-	-	0.32	0.10	1.00	-	0.13	11
Ptychobranchus subtentum *	6.00	-	0.46	0.59	0.75	-	-	0.16	0.10	0.60	-	0.54	47
Quadrula pustulosa	-	-	-	0.29	-	-	-	-	-	-	-	0.03	3
Villosa iris	-	-	-	0.10	-	-	0.10	-	-	-	1.50	0.20	17
Villosa perpurpurea *	-	-	-	-	-	0.10	-	-	-	-	-	0.01	1
Total per square meter	11.80	1.60	9.69	14.05	7.00	2.70	3.80	2.72	4.60	14.00	1.50	6.01	
Number of samples	20	40	26	41	16	40	40	25	40	20	40	348	
Specimens found	59	16	63	144	28	27	38	17	46	70	15		523
Species included	4	9	10	19	7	13	12	6	11	15	1		31

*Cumberlandian species (12)
+Endangered species (3)

Table 4. Numbers of freshwater mussels found at Clinch River sites sampled in both 1979 and 1988. Abundance values for each year are numbers per square meter. Year values are significance levels of One-Way ANOVA tests where (P>F)<0.10.

Species	159.2 1979	159.2 1988	Year	172.2 1979	172.2 1988	Year	184.5 1979	184.5 1988	Year
Actinonaias carinata	5.20	-	0.0006	5.10	0.60	0.001	6.62	5.85	
Actinonaias pectorosa	0.20	1.00		0.60	-	0.03	0.31	0.46	
Alasmidonta marginata	-	-		-	-		-	-	
Amblema plicata	-	-		-	0.10		0.15	-	
Conradilla caelata	-	-		-	-		-	-	
Cumberlandia monodonta	-	-		-	-		-	-	
Cyclonaias tuberculata	0.80	-	0.1	-	0.10		1.08	1.08	
Cyprogenia irrorata	-	-		-	-		-	-	
Dromus dromas	-	-		0.10	0.10		-	-	
Elliptio dilatatus	0.20	-		-	-		-	-	
Epioblasma brevidens	-	-		-	0.20		-	0.31	
Epioblasma capsaeformis	-	-		-	-		-	-	
Epioblasma triquetra	-	-		0.10	-		0.15	-	
Fusconaia barnesiana	0.20	-		0.10	-		-	-	
Fusconaia cuneolus	-	-		-	-		-	-	
Fusconaia edgariana	-	-		-	-		-	-	
Fusconaia subrotunda	-	-		0.30	-	0.08	0.46	0.62	
Lampsilis fasciola	-	-		-	-		-	0.15	
Lampsilis ovata	-	-		0.20	0.10		0.92	0.15	0.08
Lasmigona costata	0.80	0.60		0.20	0.20		-	0.46	0.08
Lastena lata	-	-		0.10	-		0.15	-	
Leptodea fragilis	-	-		-	-		-	-	
Ligumia recta	-	-		-	0.10		0.31	-	
Medionidus conradicus	-	4.20	0.03	0.10	-		-	-	
Plethobasus cyphyus	-	-		-	0.10		0.15	0.15	
Pleurobema cordatum	-	-		-	-		0.15	-	
Pleurobema oviforme	-	-		-	-		-	-	
Potamilus alatus	-	-		-	-		0.31	-	
Ptychobranchus fasciolaris	-	-		-	-		0.15	-	
Ptychobranchus subtentum	0.80	6.00	0.08	0.10	-		0.15	0.46	
Quadrula cylindrica	-	-		-	-		-	-	
Quadrula pustulosa	-	-		-	-		0.31	-	
Truncilla truncata	-	-		-	-		-	-	
Villosa iris	-	-		-	-		-	-	
Villosa perpurpurea	-	-		-	-		-	-	
Totals	8.20	11.80		7.00	1.60	0.001	11.38	9.69	

Table 4. (Continued)

Species	189.6 1979	189.6 1988	Year	206.9 1979	206.9 1988	Year	211.1 1979	211.1 1988	Year
Actinonaias carinata	7.41	5.66		5.50	2.25	0.02	0.80	0.50	
Actinonaias pectorosa	6.05	2.44	0.02	2.75	3.00		1.10	0.70	
Alasmidonta marginata	–	0.10		–	–		–	–	
Amblema plicata	0.39	0.29		–	–		–	0.10	
Conradilla caelata	0.10	0.10		–	–		–	–	
Cumberlandia monodonta	0.78	0.10		–	–		–	–	
Cyclonaias tuberculata	0.39	0.29		0.50	0.25		0.20	0.10	
Cyprogenia irrorata	0.10	0.10		–	–		0.10	0.10	
Dromus dromas	–	–		–	–		–	–	
Elliptio dilatatus	2.15	0.29	0.008	0.25	0.25		0.10	0.10	
Epioblasma brevidens	0.10	–		0.25	–		–	0.10	
Epioblasma capsaeformis	0.39	0.10		2.00	–	0.01	0.20	–	
Epioblasma triquetra	0.10	–		0.25	–		–	–	
Fusconaia barnesiana	2.15	–	0.0007	–	–		–	–	
Fusconaia cuneolus	0.29	0.39		–	–		–	0.10	
Fusconaia edgariana	0.20	–		–	–		–	–	
Fusconaia subrotunda	0.78	0.29		0.25	–		0.10	0.10	
Lampsilis fasciola	0.20	–		0.25	–		–	–	
Lampsilis ovata	0.10	–		0.25	0.25		0.30	0.10	
Lasmigona costata	1.27	0.29	0.05	1.00	–	0.09	0.20	0.20	
Lastena lata	0.10	0.20		–	–		–	–	
Leptodea fragilis	–	–		–	–		–	–	
Ligumia recta	–	–		0.25	–		–	–	
Medionidus conradicus	2.44	2.24		2.50	–	0.01	–	0.40	0.04
Plethobasus cyphyus	–	–		–	–		–	–	
Pleurobema cordatum	–	–		–	–		–	–	
Pleurobema oviforme	0.29	–	0.08	–	–		–	–	
Potamilus alatus	–	–		–	–		–	–	
Ptychobranchus fasciolaris	0.29	0.20		0.25	0.25		0.10	–	
Ptychobranchus subtentum	4.20	0.59	0.0009	2.00	0.75		0.50	–	0.05
Quadrula cylindrica	0.10	–		0.25	–		–	–	
Quadrula pustulosa	0.10	0.29		–	–		–	–	
Truncilla truncata	0.10	–		0.25	–		–	–	
Villosa iris	0.39	0.10		–	–		–	–	
Villosa perpurpurea	–	–		–	–		–	0.10	
Totals	30.93	14.05	0.0003	18.75	7.00	0.0004	3.70	2.70	

Table 4. (Continued)

Species	219.1 1979	219.1 1988	Year	219.2 1979	219.2 1988	Year	270.9 1979	270.9 1988	Year
Actinonaias carinata	2.50	1.10	0.02	3.36	0.48	0.004	0.20	0.20	
Actinonaias pectorosa	0.30	0.60		0.48	1.28		-	5.40	0.0005
Alasmidonta marginata	-	-		-	-		-	-	
Amblema plicata	0.60	0.30		0.48	-	0.08	0.60	0.40	
Conradilla caelata	-	0.10		-	-		-	-	
Cumberlandia monodonta	-			-	-		-	-	
Cyclonaias tuberculata	0.30	0.20		0.32	-		-	-	
Cyprogenia irrorata	0.10	-		-	-		-	-	
Dromus dromas	-	-		-	-		-	-	
Elliptio dilatatus	1.00	-	0.005	0.48	0.32		0.20	0.40	
Epioblasma brevidens	-	-		0.16	-		-	-	
Epioblasma capsaeformis	-	-		0.64	-	0.04	-	-	
Epioblasma triquetra	-	-		-	-		-	-	
Fusconaia barnesiana	0.40	-	0.04	0.48	-	0.08	0.20	0.40	
Fusconaia cuneolus	0.10	0.10		0.16	-		0.40	-	
Fusconaia edgariana	-	-		-	-		-	-	
Fusconaia subrotunda	1.10	0.80		1.60	0.16	0.005	-	1.20	0.007
Lampsilis fasciola	-	-		-	-		-	0.60	0.08
Lampsilis ovata	0.10	0.10		-	-		-	0.60	0.08
Lasmigona costata	1.10	0.20	0.02	0.48	-	0.08	2.20	1.60	
Lastena lata	0.20	-		-	-		-	-	
Leptodea fragilis	-	0.10		-	-		-	0.20	
Ligumia recta	-	-		-	-		-	-	
Medionidus conradicus	-	0.10		0.16	-		1.40	1.00	
Plethobasus cyphyus	-	-		-	-		-	-	
Pleurobema cordatum	-	-		-	-		-	-	
Pleurobema oviforme	-	-		-	-		-	0.20	
Potamilus alatus	0.10	-		-	-		-	0.20	
Ptychobranchus fasciolaris	0.10	-		-	0.32		-	1.00	0.02
Ptychobranchus subtentum	0.10	-		-	0.16		0.20	0.60	
Quadrula cylindrica	-	-		-	-		-	-	
Quadrula pustulosa	-	-		-	-		-	-	
Truncilla truncata	-	-		0.32	-		-	-	
Villosa iris	-	0.10		-	-		-	-	
Villosa perpurpurea	-	-		-	-		-	-	
Totals	8.10	3.80	0.002	9.12	2.72	0.0001	5.40	14.00	0.002

Table 4. (Continued)

Species	321.7 1979	321.7 1988	321.7 Year	Combined 1979	Combined 1988	Combined Year
Actinonaias carinata	-	-		3.58	1.70	0.0001
Actinonaias pectorosa	0.11	-		1.31	1.21	
Alasmidonta marginata	-	-		0.01	-	
Amblema plicata	-	-		0.22	0.13	
Conradilla caelata	-	-		0.03	0.01	
Cumberlandia monodonta	-	-		0.10	0.01	
Cyclonaias tuberculata	-	-		0.31	0.19	0.1
Cyprogenia irrorata	-	-		0.04	0.02	
Dromus dromas	-	-		0.01	0.01	
Elliptio dilatatus	-	-		0.51	0.11	0.01
Epioblasma brevidens	-	-		0.06	0.04	
Epioblasma capsaeformis	-	-		0.24	0.01	0.0001
Epioblasma triquetra	-	-		0.05	-	0.03
Fusconaia barnesiana	0.32	-	0.07	0.46	0.02	0.0007
Fusconaia cuneolus	0.22	-		0.12	0.08	
Fusconaia edgariana	-	-		0.03	-	
Fusconaia subrotunda	0.43	-	0.09	0.54	0.30	
Lampsilis fasciola	0.11	-		0.05	0.05	
Lampsilis ovata	-	-		0.18	0.10	
Lasmigona costata	-	-		0.66	0.30	0.005
Lastena lata	-	-		0.06	0.03	
Leptodea fragilis	-	-		0.02	-	
Ligumia recta	-	-		0.04	0.01	0.09
Medionidus conradicus	-	-		0.70	0.58	
Plethobasus cyphyus	-	-		0.02	0.01	
Pleurobema cordatum	-	-		0.01	-	
Pleurobema oviforme	0.11	-		0.05	0.01	
Potamilus alatus	-	-		0.04	0.01	
Ptychobranchus fasciolaris	0.11	-		0.13	0.10	
Ptychobranchus subtentum	0.11	-		0.85	0.60	
Quadrula cylindrica	-	-		0.03	-	0.07
Quadrula pustulosa	-	-		0.04	0.04	
Truncilla truncata	-	-		0.05	-	0.01
Villosa iris	0.54	1.50		0.11	0.06	
Villosa perpurpurea	-	-		-	0.01	
Totals	2.05	1.50		10.46	6.89	0.0001

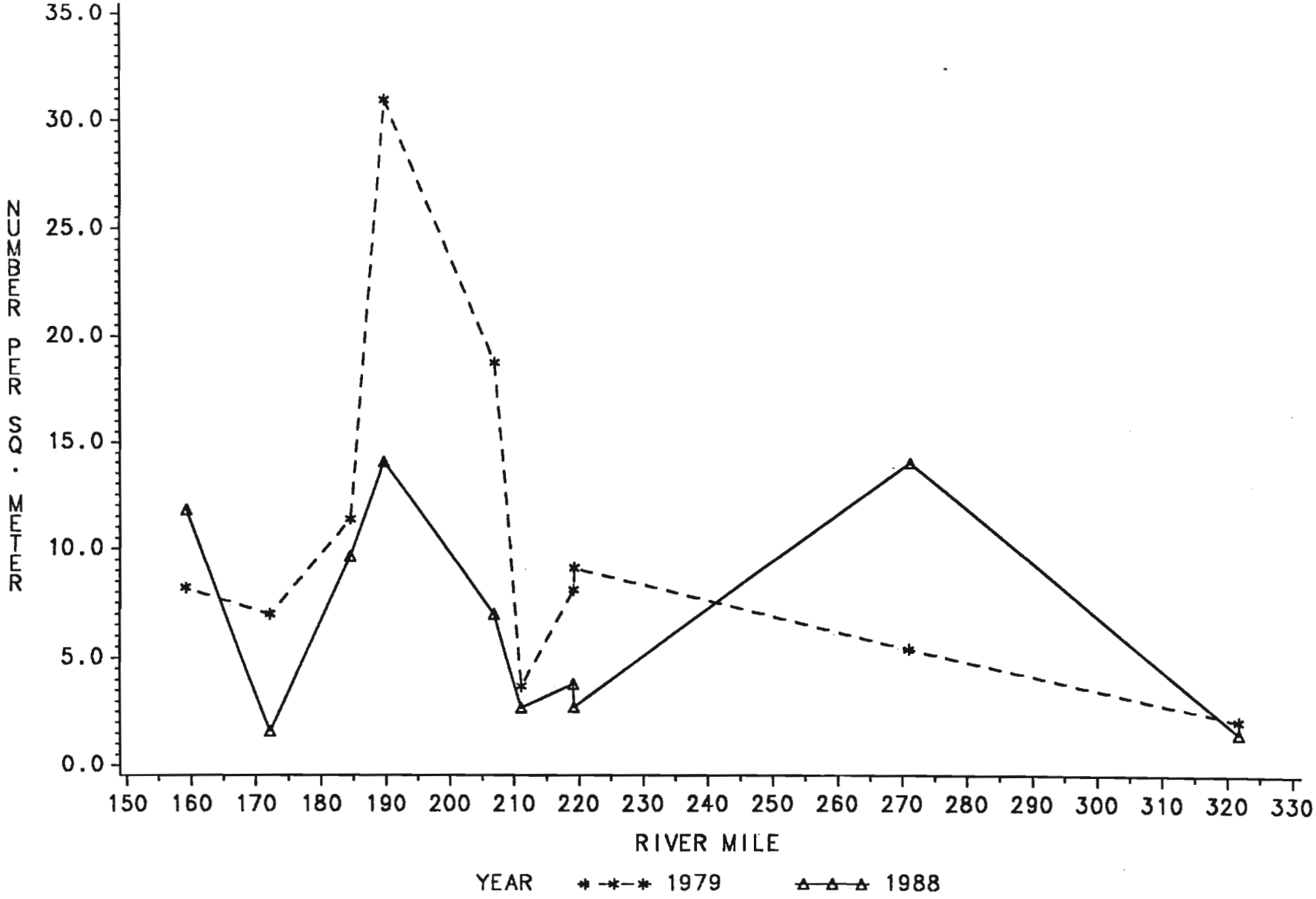

Figure 1. Numbers of freshwater mussels found at Clinch River quantitative sampling sites visited in both 1979 (stars) and 1988 (triangles).