Fate of Freshwater Mussels Transplanted to Formerly Polluted Reaches of the Clinch and North Fork Holston Rivers, Virginia

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ABSTRACT

Adult freshwater mussels (Unionidae) were translocated to reaches of the Clinch and North Fork Holston rivers in southwestern Virginia, where mussels had previously been eliminated by water pollution. A total of 3,872 adult mussels of seven species were translocated and monitored for up to four years. Annual declines of some species were roughly 10%, whereas other species appeared to decline much more rapidly. Losses were attributed largely to the high natural mortality of the older mussels that were translocated, as little active or passive movement of mussels from the sites was detected. Some mortality of mussels moved to the Clinch River may have been related to continuing perturbations in water quality. Site selection and the use of both young and adult cohorts appear to be key factors in the successful translocation of mussels.

INTRODUCTION

The Clinch River (CL) in southwestern Virginia and eastern Tennessee contains roughly 45 species of freshwater mussels (Unionidae). However, environmental contaminants and toxic spills have eradicated mussels from a section of the river where the fauna was once diverse and abundant (Ortmann 1918). The fauna in the river section below Carbo, Russell County, Virginia, has suffered from two toxic spills from a coal-fired, steam-electric generating plant at Clinch River Mile (CLRM) 266.1. A fly-ash pond collapsed in 1967, releasing alkaline water into the river that killed fish downstream as far as 38 km beyond the Tennessee border. Mussels and snails were eliminated for roughly 20 km below Carbo (Cairns et al. 1971). The effects of a second spill (sulfuric acid) from the plant in 1970 were more restricted, but the river ecosystem was nonetheless damaged for 21.6 km downstream (Cairns et al. 1971).

Ahlstedt (1984) reported a total of 16 mussel species at three sites immediately above Carbo, but he was able to find only three Proptera alata at three sites downstream (CLRM 260.0 to 264.2). This exceptionally low diversity and reduced abundance of mussels appeared to extend more than 16 km downstream from the power plant. In a more recent survey, 145 specimens of 21 species of mussels were found downstream from the plant, but all were within 0.64 km and on the side of the river opposite the plant and its effluents (Stansbery et al. 1986). Although the last major toxic spill occurred about 15 years ago, mussels have largely failed to recolonize much of the CL below Carbo.

Freshwater mussels have also been virtually eliminated from a considerable portion of the North Fork Holston River (NF) in southwestern Virginia due to chronic water quality perturbations. Historically, more

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than 30 mussel species, including four that are now endangered, were collected below Saltville, Smyth County, Virginia (Ortmann 1918). In recent times, however, only one species was found in about 120 km of river below Saltville (Hill et al. 1975). The NF has been subjected to inorganic pollutants for decades from a chlor-alkali plant at Saltville (NFHRM 80.3) that began operation in 1893. The plant ceased operation in 1972, but had discharged about 2000 tons of salt ($CaCl_2$ and NaCl) and other wastes during each day of operation over an extended period (TVA 1983). Perhaps the most persistent legacy of the plant is the discarded mercury (Hg) that has contaminated more than 185 km of the river (Carter 1977). Before a massive clean-up effort, Hg persisted at high concentrations in fish and sediments from NFHRM 36 to 77, and no overall trends in Hg content were apparent in a three-year study (Turner 1982). In 1982, the river was diverted at Saltville, 300 m of river bottom just below the plant were dredged, and the mercury-laden sediments were removed. River conditions were then considered suitable for recolonization of all faunal groups.

Transplants of mussels have been attempted previously, but the establishment of reproducing populations has been largely unsuccessful or inadequately assessed (Ahlstedt 1979). We monitored the fate and dispersal of mussels translocated to impacted reaches of the CL and NF to determine whether these habitats had recovered sufficiently to support adult mussels. Mussel nomenclature is according to Turgeon et al. (1988).

METHODS AND MATERIALS

We selected seven sites in the previously polluted reaches of the Clinch River (CL) and North Fork Holston River (NF) to receive adult mussels (Figure 1). Criteria for selection included historical collection records, water quality data, availability of riffle-run habitat, presence of appropriate fish-host species, and accessibility. While evaluating a number of potential sites, we also considered habitat characteristics such as substratum, water depth, and water velocity under low flow conditions. Translocation sites were selected at CLRM 264.8

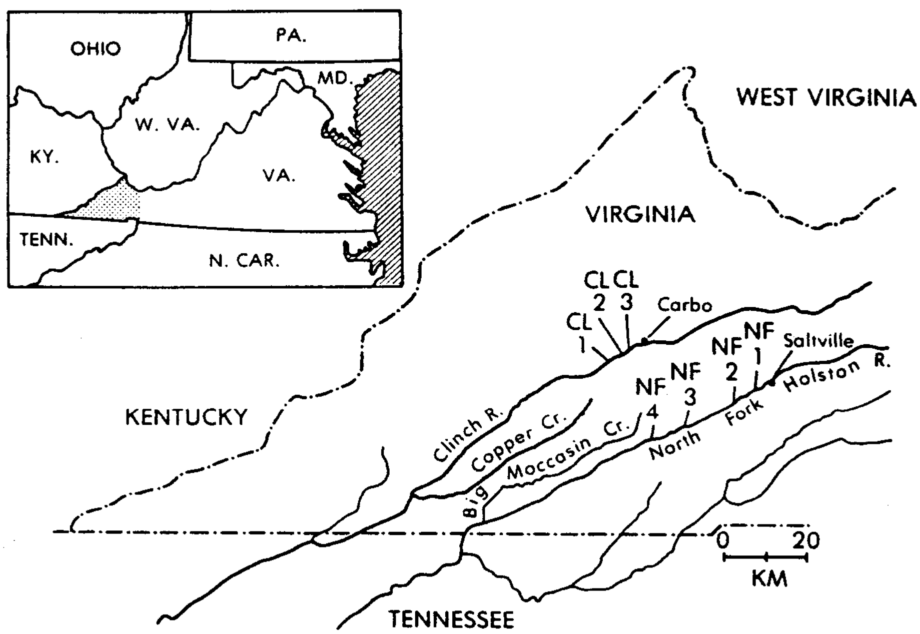

Figure 1. Locations of Clinch (CL) and North Fork Holston (NF) study sites, southwestern Virginia.

(CL1), CLRM 264.1 (CL2), CLRM 261.6 (CL3), NFHRM 79.9 (NF1), NFHRM 73.9 (NF2), NFHRM 68.6 (NF3), and NFHRM 59.5 (NF4). Water depth at the sites ranged from 30 to 45 cm, and current velocity was from 0.19 to 0.32 m/s under low-flow conditions. The most upstream site on the CL was 2.1 km below the power plant at Carbo, and the site farthest upstream on the NF was 5 km downstream from the inactive chlor-alkali plant.

The EPA STORET data base for dissolved oxygen, pH, and ammonia showed no indications of water quality perturbations in these river reaches that might threaten the success of mussel transplants other than Hg in the substratum of the NF. A sampling station where high concentrations of Hg (mean = 12.9 mg/kg) were found was at the site of the chlor-alkali plant at Saltville. The data did not preclude the possibility of sporadic degradation of water quality due to toxic spills or intermittent pollution, since samples were taken infrequently.

Four large and three small species of mussels were used in the translocations (Tables 1 and 2). All seven species are abundant in Virginia, so their use did not jeopardize existing mussel populations. The large species (104-152 mm long), Actinonaias ligamentina, A. pectorosa, Amblema plicata, and Fusconaia subrotunda, were obtained from Copper Creek, a tributary of the CL, or from reaches of the CL that are relatively free of water quality problems. The small species (28-58 mm long), Villosa nebulosa, V. vanuxemensis, and Medionidus conradicus, were obtained from Big Moccasin Creek in the NF drainage. Mussels were transported on ice in coolers for four hours or less from source sites to the translocation sites. A distinguishing mark filed on one or both valves of each mussel identified the date and locality of translocation. This technique was modified somewhat for mussels moved to NF1 so that we could later evaluate dispersal and identify species without removing the animals from the substratum. In these specimens, the shell surface adjacent to the siphons was marked with non-toxic paint, color-coded by species. The brightly colored marks also helped to locate the specimens during later evaluations.

Large species were worked into the substratum and properly oriented. To better enable us to recover the small mussel species during later site visits, we translocated them into wire-mesh baskets. The baskets were 15 cm deep by 0.5 m square, open at the top, and constructed of 1.3-cm mesh hardware cloth. They were embedded so that their tops were flush with the river bottom. Course sand and gravel were then taken from adjacent areas to provide a suitable substratum. About 50 mussels were placed in each basket. Previous laboratory trials indicated that this density could easily be sustained by these small species. The small species were translocated to CL1 and to all four sites on the NF. All translocations were made in late summer or early fall during low-flow conditions. Most translocations were conducted in 1981, but others were added in 1984 and 1985 (Table 1 and Figure 2). We returned to all translocation sites within two weeks to estimate immediate mortality and to confirm that mussels had burrowed and were siphoning. Mussels were then monitored at least annually, in late summer or early fall.

Evaluations of the success of translocations of the large mussel species in the CL were restricted to recording mortality in 1983 and 1984. Dead specimens seen through waterscopes (two man-hours per site) were counted and removed from the sites. In 1985, we quantitatively evaluated transplants to the CL. Living and dead specimens were located at the sites by snorkeling (15 man-hours per site) and marked by location with a flag in the substratum. We defined a rectangle that encompassed the area over which mussels were clustered. Substrata were removed from ten 0.5 m^2 random quadrats (10 to 35% of the total area of the defined rectangles) to a depth of 10 to 20 cm, and all living and dead specimens were counted. The number of mussels per species was then estimated from average densities in the quadrat samples. This procedure was repeated up to six times per study site in 1985, since mussels were translocated in clusters by species (and in some cases by year of translocation).

Success of the transplants of the three small species at CL1, NF2, and NF3 was evaluated quantitatively in 1983 and 1984. Mussels at NF4 were evaluated only in 1984, because an extensive growth of macrophytes, which we did not want to disturb until the study was completed, precluded sampling in 1983. We examined each basket and the surrounding substrata by water-scoping, and counted the number of live and dead mussels. Mussels found outside the baskets were left in place. One to two baskets of each species at each site were emptied of their contents (subsequently replaced), and all mussels were counted. A correction factor was developed for each species, study site, and year of evaluation to estimate total numbers of mussels actually present. This monitoring program was terminated in 1985, when we quantitatively evaluated the translocated mussels by water-scoping and removed the contents of all baskets.

We monitored the fate and dispersal of mussels translocated in 1985 to NF1 by snorkeling first at weekly intervals and then monthly. For the small species, we counted (1) live versus dead, (2) number of specimens inside the baskets, and (3) number of specimens outside, and their distance from the baskets. After about one year, all baskets were removed, and the remaining mussels were counted. We also excavated the substratum within 1 m of each basket, to a depth of about 5 cm, to locate additional mussels. Movements of the large species at the site were evaluated by measuring the distance from the 3- x 4-m area of the river bottom where they were originally translocated. All specimens of the large species were counted and removed after about one year following traslocation, and the translocation area was sampled for additional specimens by randomly excavating twelve 0.5 m^2 quadrats (50% of the translocation area). We also snorkeled for mussels immediately upstream and for about 0.5 km downstream, since significant movements of mussels would probably be in a downstream direction. The fate of mussel translocations to NF1 were of particular interest because they were subjected to near-record discharges in the fall of 1985.

RESULTS

No mortalities were seen at any of the study sites two weeks after the mussels were translocated. We observed no predation or human tampering at any time during the study. However, some habitat changes were apparent. Pondweed (*Potamogeton diversifolius*) invaded NF4 in 1982, and became abundant at the site each summer through 1985. A bridge was erected about 200 m upstream from our translocated mussels at CL2 in 1983, which probably increased suspended solids and sedimentation in the river during construction. Also, a small tributary at this site deposited a layer of silt over the specimens of *Amblema plicata* transplanted in 1981 and 1984. We saw no other adverse habitat changes at the other transplant sites.

Mussel Translocations in 1981 and 1984

Mussels translocated in 1981 declined sharply through the four years in the CL at CL2 and CL3. In 1985, no live specimens were recovered at CL2; and, only about 13% of the three species of large mussels translocated in 1981 remained at CL3. However, a much larger proportion of mussels translocated in 1984 was recovered; about 49% of the 475 specimens translocated in 1984 were still alive in 1985. We could not document the fate of most (91%) of the large mussels translocated in 1981 to CL2 and CL3. However, we accounted for (live and dead) an estimated 257 (54%) of the mussels translocated in 1984 (Table 1).

The small species translocated to CL1 just below Carbo appeared to suffer the most rapid decline (Table 2). We found only one live *Villosa nebulosa* at the site in 1985, of the 574 mussels translocated in 1981. In 1985, we could account for only 5.6% (live and dead) of the mussels of the small species translocated to CL1 in 1981.

The small species translocated to NF2, NF3, and NF4 in 1981 also declined markedly in later years (Table 2). Of the 1,692 translocated

Table 1. Recovery of mussels from 1981 and 1984 translocations of three large species to the Clinch River (CL). Transplants were evaluated in October 1985.

Year of Transplant, Site, and Species	Number translocated	Number recovered live	Abundance estimate [a]	Number recovered dead	Percent of transplanted mussels recovered	
					Estimated live	Dead
1981						
CL2						
Actinonaias ligamentina	111	0	0	9	0	8
Actinonaias pectorosa	159	0	0	0	0	0
Amblema plicata	117	0	0	1	0	1
CL3						
Actinonaias ligamentina	981	1	0	10	10	10
Actinonaias pectorosa	198	0	0	6	0	3
Amblema plicata	98	1	10	22	10	22
1984						
CL1						
Actinonaias spp.	125	3	24	4	19	3
Amblema plicata	25	1	8	2	32	8
Fusconaia subrotunda	25	1	9	0	36	0
CL2						
Actinonaias spp.	100	16	104	8	104	8
Amblema plicata	15	1	7	2	47	13
Fusconaia subrotunda	35	4	26	3	74	9
CL3						
Actinonaias spp.	110	14	40	4	36	4
Amblema plicata	20	1	3	0	15	0
Fusconaia subrotunda	20	4	12	1	60	5

[a] Mussel abundance estimates derived from mean densities from quantitative quadrat samples taken within measured areas of river bottom.

Table 2. Annual evaluations of transplants of small species of mussels at Clinch River (CL) site CL1 and North Fork Holston River (NF) study sites in 1981. Data were collected by water-scoping in 1983-1984 and by emptying baskets in 1985. Mussels were not evaluated in 1983 at site NF4.

Site	Species	Number translocated	Number recovered live (%)			Total recovered dead 1981-85	Total number accounted for in 1985
			1983	1984	1985		
CL1	*Villosa nebulosa*	104	5 (24)	2 (1)	1 (1)	2 (2)	3 (3)
	V. vanuxemensis	264	12 (12)	0 (0)	0 (0)	2 (1)	2 (1)
	Medionidus conradicus	206	0 (0)	0 (0)	0 (0)	27 (13)	27 (13)
NF2	*Villosa nebulosa*	95	18 (18.9)	6 (6.3)	7 (7.4)	7 (7.4)	14 (14.7)
	V. vanuxemensis	301	52 (17.3)	29 (9.6)	22 (7.4)	14 (4.7)	36 (12.0)
	Medionidus conradicus	210	54 (25.7)	19 (9.0)	23 (11.0)	6 (2.9)	29 (13.8)
NF3	*Villosa nebulosa*	243	37 (15.2)	3 (1.2)	3 (1.2)	10 (4.1)	13 (5.3)
	V. vanuxemensis	230	58 (25.2)	20 (8.7)	4 (1.7)	14 (6.1)	18 (7.8)
	Medionidus conradicus	310	128 (41.3)	4 (1.3)	11 (3.5)	61(19.7)	72 (23.2)
NF4	*Villosa nebulosa*	99	---------	12 (12.1)	6 (6.1)	0 (0.0)	6 (6.1)
	V. vanuxemensis	100	---------	26 (26.0)	2 (2.0)	0 (0.0)	2 (2.0)
	Medionidus conradicus	104	---------	2 (1.9)	6 (5.8)	1 (1.0)	7 (6.7)

specimens, we found 84 (5%) live and 84 dead in 1985, and we accounted for only 10% of the mussels that were translocated to the NF in 1981. There were no large differences among our relative recovery rates for the three small species, but recovery of live mussels after four years did vary among sites. The greatest declines were at NF3, where only 18 of 783 (about 2%) translocated mussels were recovered live. Mussels at NF4 survived only slightly better; 14 of 303 (4.6%) were recovered live in 1985. Our relative recovery rate was highest at NF2, where 52 live specimens (8.6%) were collected after four years.

Mussel Translocations in 1985

Declines of the small species translocated to NF1 in 1985 followed a pattern similar to that observed for these species at the other sites. Despite more intensive monitoring, we were again unable to account for 45% of the specimens of the three small species in August 1986, when the study was terminated after 328 days. Of the 150 translocated specimens, 9 (6%) were recovered dead and 73 (49%) were alive at the site. However, the large species translocated to NF1 in 1985 declined little over 355 days (Figure 2). We were able to account for about 94% of the 200 mussels of the large species in August 1986, and only 10 (5%) of these were recovered dead.

There was considerable localized and lateral movement of mussels, but little evidence of net upstream or downstream movement. Small species readily escaped from the wire mesh baskets, but all specimens settled within 1 m of the baskets, except for one M. conradicus found about 15 m downstream. We found only 7 mussels of the large species

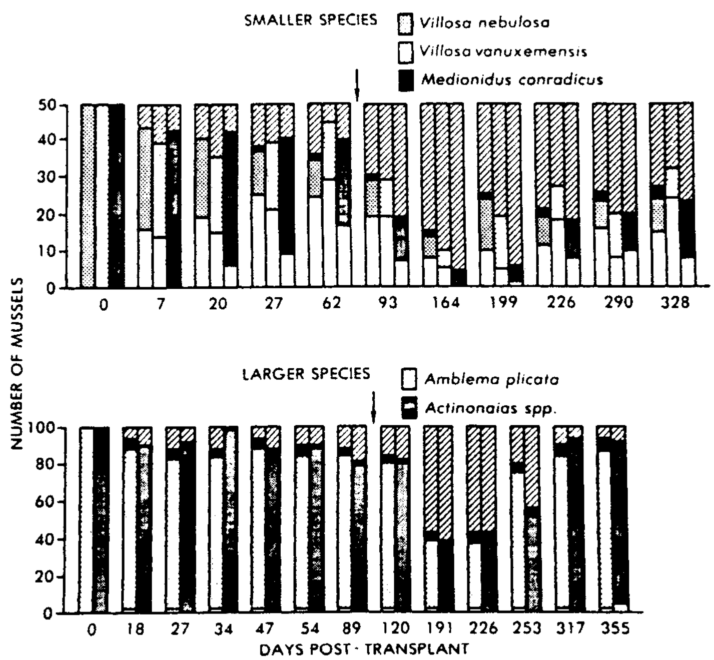

Figure 2. Abundance of smaller species (50 of each translocated 16 August 1985) and larger species (100 of each translocated 18 July 1985) of mussels at NF1 over time. Blackened portions of histograms indicate dead mussels; unshaded areas represent mussels that moved out of the 0.5 m^2 transplant baskets or out of the 3- x 4-m translocation area for the smaller and larger species, respectively; stippled areas indicate mussels found in transplant baskets or the initial translocation area for the larger species; and cross-hatched areas represent mussels not accounted for during a sampling trip. Arrows indicate a major flood (near 100-year flood levels) in October 1985.

outside of the 3- x 4-m translocation area after 355 days; four were within 2 m of the rectangle, and the other three were 20-30 m downstream.

Discharges of the NF and CL in spring 1984 approached the record 100-year flood level of 1977 (TVA 1978). Impacts of these floods were not immediately evaluated, so their effects on the translocated mussels are unknown. However, we monitored the effects of near-record discharges in fall 1985 on mussels translocated to NF1. There was a substantial, but temporary, reduction in the number of mussels of the small species observed in November (93 days post-translocation) following the fall spate (Figure 2). Our sampling efficiency, however, was probably diminished by high discharge, ice cover, overcast skies, and lush growth of epilithic algae. Our ability to find each of the five species by snorkeling at NF1 appeared to be a function of mussel size (Table 3). The small species were more difficult to locate in the substratum than the larger ones. Reduced visibility probably resulted in an underestimate of the number of small mussels present after the flood waters. Another confounding factor affecting our efficiency in locating mussels was water temperature, which appeared to influence vertical movements of mussels in the substratum. The number of mussels observed at NF1 decreased as water temperatures declined through fall and winter and then increased during spring and summer.

Table 3. Sampling efficiency for mussels by snorkeling at NF1. Water clarity was excellent and water depth was 0.4 m at time of sampling

Species	Mean length (mm)	Total number present	Number observed snorkeling	Sampling efficiency (% observed)
Small species				
Villosa nebulosa	43.7	24	19	79
Villosa vanuxemensis	47.1	26	32	81
Medionidus conradicus	43.1	17	9	53
Large species				
Actinonaias spp.	116.9	89	85	96
Amblema plicata	115.9	88	88	100

DISCUSSION

We were unable to document the fate of the majority of translocated specimens at most of our sites. Low recapture rates of marked mussels in previous studies have been attributed to emigration from study areas (Negus 1966). Golightly (1982) concluded that passive movements of mussels from study sites in the Little Brazos River, Texas, were linked to large-scale disturbances such as floods. However, we documented little active or passive dispersal of mussels from translocation sites. All five species translocated to NF1 in 1985 showed little net movement upstream or downstream, even though these mussels were exposed to a near-record flood. We rarely found mussels more than a few meters from their original location.

The decline in the number of small mussels observed at NF1 after high fall discharges was partly due to reduced visibility, and this trend continued until river conditions improved in the spring. Perhaps the best indication that spates did not affect the distribution of translocated mussels was that the proportions of mussels found inside baskets or inside the translocation area did not decrease for any of the species after the flood. Imlay (1982) also concluded that mussels are probably not transported downstream by floods to any great extent. We attribute the limited movements of mussels from our study sites to firm, stable substrata composed of coarse particle sizes (pebble to cobble) that would impede active and passive movements of live mussels. Passive dispersal of mussels reported in the Little Brazos River, Texas, probably occurs because the bottom is soft and unstable, and consists of particles less than 2 mm (Golightly 1982).

The seasonal difference in our ability to locate mussels by snorkeling at NF1 was probably due to mussels being more deeply burrowed during winter. However, problems associated with winter sampling, such as seasonal increases in epilithic algae, ice cover, and the effects of low water temperatures on the divers undoubtedly reduced the efficiency of sampling.

Ahlstedt (1979), who translocated 16 mussel species to four sites on the NF between 1975 and 1978, found a high degree of variability in the success of his mussel translocations during later evaluations. Some of his translocated mussels were completely washed out and lost to floods in 1977, whereas some specimens from other translocations persisted for more than five years. Nelson 1982, who checked mussels in the Upper Mississippi River one year after translocation, reported the following recovery percentages: Megalonaias nervosa, 60; Amblema plicata, 20; Lampsilis higginsi, 100; and Cumberlandia monodonta, 69.

Variable and low recovery rates of translocated mussels are common. Only 33% of the mussels marked by Golightly (1982) on the Little Brazos River persisted at study sites for one year. Sparks and Blodgett (1983), who marked and placed 26 specimens of Proptera alata and 10 Quadrula quadrula in the Mississippi River, were able to find a total of only four specimens after one year. Isely (1914) recovered 85% of marked Quadrula spp. and 46% of Anodonta grandis after one year at sites in Oklahoma streams. He noted that the recovery rate for A. grandis was surprisingly high, since this species was believed to be highly mobile. Recovery rates for our transplant specimens in 1984 and 1985 were similar to those of Isley (1914) and Nelson (1982) and somewhat better than those reported by Negus (1966), Golightly (1982), and Sparks and Blodgett (1983). Our recovery rate in 1985 of live specimens, for all species and sites, in the CL translocations of 1984 was about 49%. We recovered an average of about 49% of the small species and 89% of the large species translocated to NF1 in 1985.

On the basis of field observations and indirect evidence, we conclude that mortality was the probable cause for the observed declines in the numbers of mussels translocated. We found no evidence that significant numbers of live mussels had dispersed from the translocation sites. Although live mussels did not disperse widely from translocation sites, dead specimens were probably more susceptible to hydraulic downstream displacement and burial. Also, most of our efforts were directed at locating live, siphoning mussels; embedded valves would probably go undetected.

We identified three major factors that apparently influenced survival of translocated mussels: 1) changes in habitat, 2) water quality, and 3) natural mortality. Habitat changes seemed to reduce survival at two of the seven study sites. Siltation from bridge construction during 1983 and sedimentation from a tributary apparently smothered mussels translocated to CL2 in 1981. We recovered no live specimens from the 1981 transplants at CL2, but transplants to this site in 1984 survived better than those at other CL sites. The overgrowth of aquatic vegetation at NF4 also appeared to affect survival of translocated mussels. The dense growth of macrophytes reduced current velocities, promoted siltation and, therefore, altered what previously appeared to be suitable habitat for these species.

Little information is available on population dynamics of freshwater mussels, but observed declines of the small species in the NF may not