Status of Native Freshwater Mussels in Copper Creek, Virginia

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Abstract - Previous freshwater mussel surveys conducted in Copper Creek showed a decline in the fauna from 1980 to 1998. In 2004 and 2005, we sampled 47 sites acquiring relative abundance estimates (measured in catch-per-unit-effort) to assess the current status of the mussel fauna relative to previous surveys. We also obtained absolute density estimates for 4 select sites for comparison with future and past surveys. Of the 25 mussel species reported from this and previous surveys, 16 were represented by living specimens, 5 are extant but may soon be extirpated, and 8 are likely extirpated from the creek. Presence-absence analysis showed a significant decline in species per site since 1980. Absolute density estimates (at Copper Creek river km 3.1) decreased significantly from 4.07 mussels/m^2 in 1981 to 0.63 mussels/m^2 in 2005. The cause of this faunal decline is likely due to several factors, including, most notably, the loss of riparian buffers. Nearly half of the stream banks in Copper Creek have inadequate riparian vegetation to provide even minimal sediment control. Precipitous declines of the Clinch River fauna (a likely source population for several species) may be another significant factor influencing the faunal decline in Copper Creek. Despite these declines, populations of several species may be in a state of recovery. Based on 18 comparable sites, average catch-per-unit-effort in 2005 was 25.16 mussels/hr, significantly higher than the 1998 survey (12.92 mussels/hr).

Introduction

Ahlstedt (1981, 1986) conducted the first comprehensive freshwater mussel survey in Copper Creek in 1980, documenting 19 living species, including 5 federally protected species (Table 1). Like many southwestern Virginia streams, Copper Creek has been severely impacted by sedimentation mainly, from stream-side livestock activity, and the elimination of riparian vegetation. As a result, mussels have undergone a dramatic decline in species richness and abundance. A 1998 survey documented only 11 species, including 2 of the 5 previously reported federally listed species (Fraley and Ahlstedt 2000).

Because of the important mussel diversity, low level of development, and lack of mining activity in the Copper Creek watershed, resource managers increasingly recognize the importance of the creek as an area on which

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to focus aquatic conservation efforts. Initial efforts to augment mussel populations and restore riparian habitat within the watershed are currently underway. A quantitative assessment of the stream's mussel fauna and habitat conditions is needed to identify and prioritize conservation actions and to provide a baseline for detection of future changes in the fauna.

We assess the current status of mussel populations in Copper Creek and compare the results with previous mussel surveys to evaluate changes in the fauna over the last 25 years. In addition, we present density estimates of 4 selected sites to provide baseline data for future assessments of the fauna, and we compare data from one of these sites with absolute estimates reported by Barr et al. (1993–1994), survey work that was conducted in 1981. We also conducted an inventory of forested riparian habitat to assess watershed condition and quantify stream-side impacts.

Study Area

Copper Creek is located in the Ridge and Valley physiographic province of southwestern Virginia (Fig. 1). The creek's confluence with the Clinch

Table 1. Living specimens recorded (X) for Copper Creek in 1980, 1998, and 2005. Fresh dead (FD), relic specimen (R), and federal protection (*) are indicated.

	1980	1998	2005
Actinonaias ligamentina Lamarck (Mucket)		R	
Actinonaias pectorosa Conrad (Pheasantshell)	X	R	X
Alasmidonta viridis Rafinesque (Slippershell)	X		X
Amblema plicata plicata Say (Three Ridge)	X	R	R
Elliptio dilatata Rafinesque (Spike)	X	X	X
Epioblasma brevidens Lea (Cumberland Combshell)			R
Epioblasma capsaeformis Lea (Oyster Mussel)*	X		
Fusconaia barnesiana Lea (Tennessee Pigtoe)	X	X	X
Fusconaia cor Conrad (Shiny Pigtoe)*	X	FD	X
Fusconaia cuneolus Lea (Fine-rayed Pigtoe)*	X	X	X
Fusconaia subrotunda Lea (Long-solid)		R	
Lampsilis fasciola Rafinesque (Wavy-rayed Lampmussel)	X	X	X
Lampsilis ovata Say (Pocketbook)	X		R
Lasmigona costata Rafinesque (Fluted-shell)	X		X
Lasmigona holstonia Lea (Tennessee Heelsplitter)		R	FD
Ligumia recta Lamarck (Black Sandshell)			R
Medionidus conradicus Lea (Cumberland Moccasinshell)	X	X	X
Pegius fabula Lea (Little-wing Pearlymussel)*			R
Pleurobema oviforme Conrad (Tennessee Clubshell)	X	X	X
Ptychobranchus fasciolaris Rafinesque (Kidneyshell)	X		X
Ptychobranchus subtentum Say (Fluted Kidneyshell)*	X	X	X
Quadrula cylindrica strigillata Say (Rough Rabbitsfoot)*	X	R	X
Villosa iris Lea (Rainbow)	X	X	X
Villosa perpurpurea Lea (Purple Bean)*	X	X	X
Villosa vanuxemensis Lea (Mountain Creekshell)	X	X	X
Total**	19	11	16

**While this study's (2005) data does not assume fresh dead specimens represent an extant population, the total number of extant species for 1998 has been figured in a manner consistent with the original sources of the data (Fraley and Ahlsedt 2000) and includes the fresh dead *F. cor*.

River is at Clinch River kilometer 340.5, near Speers Ferry, Scott County. The stream is roughly 97 km long and flows in a southwesterly direction through Russell and Scott counties, draining the valley between Copper Ridge and Moccasin Ridge, ≈345 km^2. Hubbard (2001) showed the entire watershed to be underlain by karst topography, formed on soluble limestone bedrock and characterized by sinkholes, sinking streams, caves, and large springs where water returns to the surface. According to 1996 classified Landsat Thematic Maper imagery, land use within the watershed in 1996 consisted primarily of pasture (40.9%) and highly fragmented forest (57.7%) (USEPA 2002).

Methods

Timed searches

We surveyed 47 sites along 93 km of Copper Creek between February 2004 and April 2005 (Fig. 1, Table 2). For simplification, we refer to this study as the 2005 survey. We sampled 29 sites sampled by previous surveys (Ahlstedt 1986, Fraley and Ahlstedt 2000) as well as 18 new sites. We determined the distance from the mouth of Copper Creek to each site and numbered sites accordingly in an upstream direction (Table 2, Appendix 1).

We conducted timed searches using snorkeling and view-buckets. Survey efforts were timed searches and were expressed as catch-per-unit-effort (CPUE) in person-hours. Catch-per-unit-effort values were calculated as the total number of living mussels observed divided by the total effort in

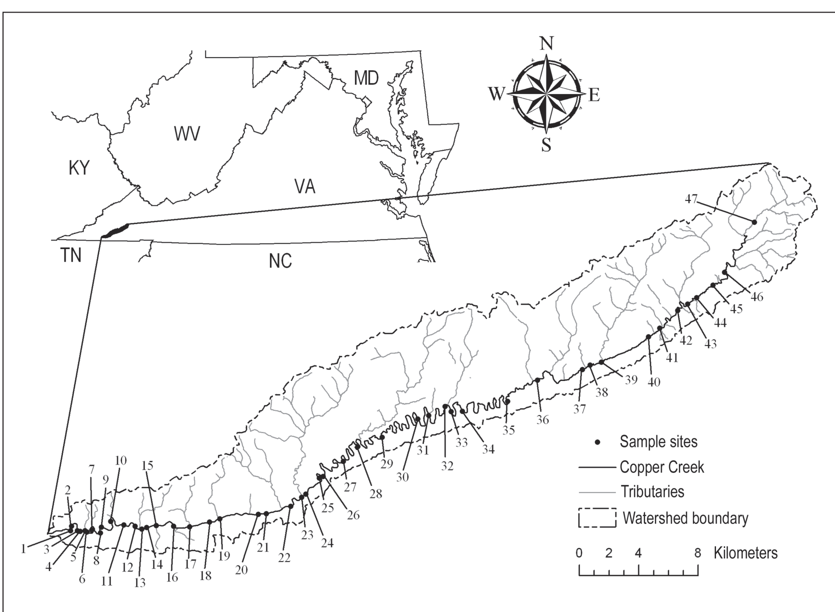

Figure 1. Sites surveyed for freshwater mussels in 2005 (solid circles) in Copper Creek, Russell and Scott counties, VA.

hours. A variety of habitats including gravel and cobble riffles and runs, gravel bars, and shallow pools are favored by species previously collected

Table 2. Sites surveyed for mussels in 2005 (Rkm = river kilometers, * = sites quantitatively sampled in 2005, X = denotes whether the site was surveyed in 1980 and/or 1998).

			Survey year	
Site	Rkm	Location	1980	1998
1	1.6	First major bend in creek adjacent to VA 627	X	
2	1.9	West side of big bend in Copper Creek	X	X
3	2.9	Below VA 627 bridge crossing		
4	3.1	Above VA 627 bridge*	X	X
5	3.4	At unnamed tributary	X	
6	3.5	Below Jennings Ford, VA 627	X	
7	4.2	Above Jennings Ford, VA 627	X	X
8	5.3	Adjacent to VA 627		
9	5.8	Below Spivey Ford	X	
10	7.1	Below junction of VA 627 and VA 644	X	X
11	8.2	Below small unnamed tributary		
12	9.5	Above swinging bridge and ford	X	X
13	10.1	Below ford and swinging foot bridge	X	
14	10.5	Above ford and swinging bridge		
15	11.1	At unnamed tributary		
16	12.6	Below Spivey Mill Dam	X	X
17	13.7	At Blackoak Branch	X	
18	15.1	Between two unnamed tributaries		
19	15.8	Above Lark Creek		X
20	18.5	Adjacent to VA 627		
21	19.0	Adjacent to VA 627	X	X
22	20.8	Above Plank Camp Creek	X	
23	22.2	Below VA 72 bridge		
24	22.5	Above VA 72 bridge	X	X
25	24.3	Below bend in Copper Creek*		
26	25.1	Above bend in Copper Creek		X
27	29.4	At island*		
28	34.0	At swinging bridge	X	X
29	38.5	At VA 671 bridge	X	X
30	47.0	At VA 674 bridge	X	X
31	49.6	Above unnamed tributary		
32	52.8	above 2nd VA 670 bridge crossing	X	
33	53.6	above first VA 670 bridge crossing		X
34	56.0	Above VA 71 bridge crossing	X	X
35	64.4	Below VA 682 bridge	X	X
36	67.8	Above VA 612 bridge	X	X
37	72.1	Below Drake Branch		
38	72.7	Above Drake Branch		
39	73.7	Below Moll Creek		
40	77.7	Below low head bridge off 678	X	
41	78.7	0.8 kilometers above low head bridge		
42	81.1	At VA 679 ford		X
43	82.9	Above bridge crossing		
44	83.8	Above bend in Copper Creek*		
45	85.3	Below island and unnamed tributary	X	
46	87.2	Wooded area adjacent to VA 678		
47	93.0	Above bridge crossing		

in Copper Creek (Fraley and Ahlstedt 2000) and were intensively searched. Beyond timed searches, stream margins were checked for shell remains and muskrat middens. Species and number of individuals were recorded to evaluate species richness and relative abundance. Each observed specimen was recorded as living, fresh dead, or relic. The presence of tissue remains, or lustrous nacre were used to define specimens as fresh dead; all other shells were considered relic. Mussels were removed from the substrate, identified, and returned to the exact location of collection.

We tested for overall differences across sites in the number of extant species between 1980 and 2005 and between 1998 and 2005 using a Wilcoxon Signed Rank Test ($\alpha = 0.05$) (e.g., Pilarczyk et al. 2006). We also tested for differences in overall and per species CPUE across sites between 1998 and 2005 using the Wilcoxon Signed Rank Test ($\alpha = 0.05$).

Estimation of mussel density

We estimated total mussel density (densities of all species combined) at 4 sites (Table 2). We chose sites with the highest mussel abundance and species richness, as identified in timed searches. We used a random experimental sampling design (Strayer and Smith 2003) and followed methods similar to those reported by Henley et al. (1999). Survey flags were placed along both stream banks to partition transect lanes across the stream. The number of transects and distance between transects varied among survey sites to accommodate mussel aggregations. Four to six transects were placed 20 m apart except at rkm 24.3, where an additional transect was sampled at 10 m. Ten 0.25-m^2 quadrats, made of 12-mm rebar, were randomly assigned along each transect line using a random numbers table. We estimated a requisite number of quadrats to sample each site for population density (mean mussels/m^2) using the following formula (Downing and Downing 1992):

$$n = 1 \text{ x } (P / [10{,}000 / A])^{-0.5} \text{ x } D^{-2},$$

where P = provisional estimate of mussel density (per m^2), A = area (cm^2) covered by each replicate sample (0.25-m^2 quadrat = 2500 cm^2), and D = the desired degree of precision of density estimates. Based on provisional densities obtained from 20 initial quadrat samples at each site, we calculated requisite sample numbers based on a 20% degree of precision.

Using mask and snorkel gear, we visually searched each quadrat for mussels by fanning and excavated the substrate down to the hardened and embedded layer, typically 10–20 cm in depth. Species, shell length, and estimated age were recorded for each specimen found. Age was estimated by counting external growth arrests. Shell length was measured using calipers. Mussels and substratum were returned to their original location once data were collected. Density estimates at the site located at rkm 3.1 were compared with those documented by Barr et al. (1993–1994). We note that density estimates for Copper Creek reported in Barr et al. (1993–1994) appear to be densities estimates within 0.25-m^2 quadrat units and not per m^2 as presented. Density data used in our comparison were obtained from quadrat data presented in the Appendices, Figure A-15, p. 202 of Barr et. al (1993–1994).

Riparian buffer analysis

Fraley and Ahlstedt (2000) identified livestock activity and loss of riparian vegetation as major contributors to the destabilization and siltation of Copper Creek. We conducted an inventory of riparian buffer width on the main stem of Copper Creek to provide a quantitative measure of the extent of this problem. Using ArcGIS (ESRI®ArcMap™ 9.1), we visually examined 2002 aerial imagery (Commonwealth of Virginia 2002) and quantified riparian coverage for left and right ascending stream banks along the main channel, using 4 categories of riparian buffer width. Categories of the buffer width are as follows: 1) no riparian vegetation, 2) a single row of trees, 3) wider than a single row of trees up to10 m, and 4) >10 m. These categories were chosen to define the absolute minimum in riparian benefits that have been quantified in the literature (Wenger 1999).

Results

Timed searches

Sixteen native mussel species were observed alive, and 6 additional species were represented by relic shells among all sites (Table 1). Overall, 111.5 person-hours of effort resulted in 4106 living mussels collected, with an overall CPUE of 36.8 living mussels/hour. The mussel assemblage was dominated by *Villosa iris*, representing 71.5% of the fauna. With the exception of the furthest upstream site surveyed, living *V. iris* were present at all sites. *Pleurobema oviforme*, *Medionidus conradicus*, and *Fusconaia barnesiana* were relatively abundant, composing 12.5%, 7. 9%, and 3.5% of the fauna occurring at 38, 25, and 23 sites, respectively. *Lampsilis fasciola*, *Ptychobranchus subtentum*, and *Elliptio dilatata* were uncommon, representing 0.9%, 1.6%, and 1.2% of the fauna and occurring at 15, 6, and 9 sites, respectively. Of the federally listed species, *Villosa perpurpurea* was encountered most frequently, occurring at 7 sites and constituting 0.4% of the fauna. The other federally listed species, *Fusconaia cuneolus*, *Fusconaia cor*, and *Quadrula cylindrica strigillata,* were very rare—present only at 3, 1, and 1 sites, respectively. *Actinonaias pectorosa*, *Ptychobranchus fasciolaris*, *Villosa vanuxemensis, Alasmidonta viridis*, *Lasmigona costata* were also rare, occurring at 1–4 sites. *Amblema plicata plicata*, *Epioblasma brevidens*, *Lampsilis ovata*, *Lasmigona holstonia*, *Ligumia recta*, and *Pegius fabula* were represented by relic shells in this survey.

The number of extant species decreased from 1980–2005 across 24 comparable sites (Z = -2.255, P = 0.023; Table 3, Fig. 2). We could not compare CPUE between the 1980 and 2005 surveys because search time was not documented in 1980. Although we found 16 species in 2005 vs. 11 in 1998, there was no significant difference in the number of extant species from 1998–2005 across 18 comparable sites (Z = 1.663, P = 0.100; Table 3). However, total mussel abundance (CPUE) increased from 1998–2005 (Z = 2.847, P = 0.004; Table 3). This increase was attributed to increases in CPUE for 11 out of 14 species including *A. pectorosa*, *E. dilatata*, *F. cor*, *L. fasciola*, *M. conradicus*, *P. oviforme*, *P. fasciolaris*, *P. subtentum*, *Q. c. strigillata*, *V. iris*, and *V. perpurpurea*. Among species, only of *V. iris* had a CPUE that was significantly greater in the 2005 survey compared to the 1998 survey ($n = 18$, $Z = -2.46$, $P = 0.013$). No significant changes in abundance were evident among other species between the 1998 and 2005 surveys (P-values ranged from 0.138 to1.000).

Table 3. Comparison of 18 sites surveyed on Copper Creek, VA in 1998 (Fraley and Ahlstedt 2000) and 2005. Site number corresponds to site identifications in the 2005 survey. CPUE = catch per unit effort expressed as number of living mussels observed per person hour.

	Number of species found alive			CPUE (no/h)		
Site #	1998	2005	Difference	1998	2005	Difference
2	4	7	3	1.25	32.40	31.15
4	2	10	8	1.25	10.43	9.18
7	3	3	0	3.67	3.85	0.18
10	5	2	-3	5.00	15.00	10.00
12	1	2	1	0.50	9.33	8.83
15	0	2	2	0.00	1.52	1.52
18	2	3	1	10.50	18.00	7.50
20	3	2	-1	3.25	13.33	10.08
23	3	6	3	6.25	53.33	47.08
25	5	6	1	14.25	30.67	16.42
27	2	2	0	5.50	8.00	2.50
28	3	5	2	35.50	28.00	-7.50
29	3	4	1	21.33	17.20	-4.13
32	4	4	0	49.00	50.00	1.00
33	5	4	-1	20.25	15.11	-5.14
34	3	1	-2	29.00	35.00	6.00
35	3	4	1	21.50	67.00	45.50
41	2	4	2	4.50	44.67	40.17
Mean	2.94	3.94	1.00	12.92	25.16	12.24
± SE	± 0.32	± 0.53	± 0.56	± 3.27	± 4.41	± 4.04

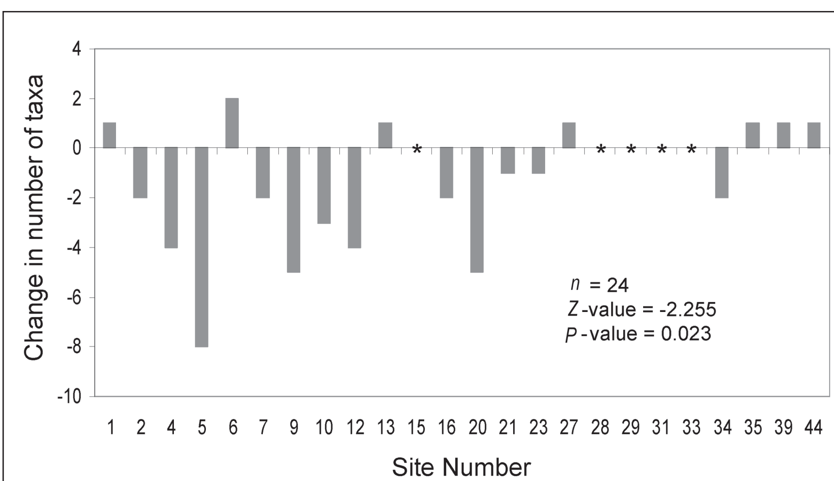

Figure 2. Change in the number of freshwater mussel species reported at 24 sites from 1980 (zero line; Ahlstedt 1986) to 2005; * = no change. Site numbers correspond to site identifications in the 2005 survey.

Estimation of mussel density

Overall, we observed a wide range of age classes, including young and mature specimens, for 6 species (Table 4). *Villosa iris* was the most abundant species and was represented by young specimens at all 4 sites. Mussel density was relatively high at the 3 sites located in the middle and upper reaches of Copper Creek, ranging from 3.10–5.95 mussels/m^2, but density was low at rkm 3.1 (Table 5). It should be noted that the coefficient of variation at the rkm 3.1 sampling site did not meet the 20% precision target. This was attributed to assumption error associated with higher mussel densities in the provisional sample set than the remaining quadrat samples. Among the 51 quadrats we sampled at rkm 3.1, we found 5 species and an overall mussel density of 0.63/m^2 (SE ± 0.21/m^2). In 1981, Barr et al. (1993–1994) reported 10 species at an overall density of 4.07/m^2 (n = 58, SE ± 1.32/m^2) at this site. Density estimates among the species found at rkm 3.1 decreased significantly (Z = -2.016, P = 0.007) from 1981 to 2005.

Table 4. Shell length (mm ± SE) and estimated age (years ± SE) of mussels collected within 0.25-m^2 quadrats during a quantitative survey in Copper Creek, VA. *E.d.* = *Elliptio dilatata*, *F.b.* = *Fusconaia barnesiana*, *M.*c. = *Medionidus conradicus*, *P.o.* = *Pleurobema oviforme*, *P.s.* = *Ptychobranchus subtentum*, *V.i.* = *Villosa iris*, *V.v.* = *Villosa vanuxemensis*, *n* = number of mussels collected.

Species	*n*	Mean length mm (± SE)	Range (mm)	Mean age years (± SE)	Range (years)
Overall					
E.d.	6	51.17 (4.66)	33–61	9.00 (1.15)	5–12
F.b.	18	32.11 (2.98)	10–53	5.72 (0.80)	2–13
M.c.	15	34.07 (1.36)	25–47	6.77 (0.86)	4–14
P.o.	6	44.92 (7.28)	10–61	10.67 (2.36)	2–20
P.s.	3	57.30 (20.0)	18–83	9.00 (3.51)	2–13
V.i.	113	37.69 (0.69)	17–54	5.72 (0.24)	2–18
V.v.	1	47.00	-	10.00	-
Rkm 3.1					
F.b.	1	51.00	-	13.00	-
M.c.	1	39.00	-	10.00	-
V.i.	4	37.00 (6.07)	36–48	5.75 (1.38)	3–9
V.v.	1	47.00	-	10.00	-
Rkm 24.3					
E.d.	6	51.17 (4.66)	33–61	9.00 (1.15)	5–12
F.b.	7	40.57 (3.87)	28–53	7.71(1.13)	5–13
M.c.	6	32.50 (1.89)	25–38	5.33 (0.99)	4–10
P.o.	6	44.92 (7.28)	10–61	10.67 (2.36)	2–20
P.s.	3	57.30 (20.0)	18–83	9.00 (3.51)	2–13
V.i.	35	36.46 (1.02)	17–48	5.50 (0.29)	2–10
Rkm 29.4					
F.b.	2	14.50 (4.50)	10–19	2.50 (0.50)	2–3
M.c.	5	37.00 (2.77)	30–47	10.00 (2.00)	8–14
V.i.	24	37.67 (1.69)	22–54	7.33 (0.82)	2–18
Rkm 83.8					
F.b.	8	26.75 (2.44)	19–41	3.88 (0.55)	2–7
M.c.	3	30.67 (1.45)	28–33	5.33 (0.67)	4–6
V.i.	50	38.62 (1.05)	18–54	5.10 (0.21)	2–8

Riparian buffer analysis

Approximately 48% of the length of Copper Creek had a riparian buffer >10 m, but 23% of the stream's length had no riparian vegetation. Stream banks were protected by a single row of trees along ≈22% of the creek's length, and riparian buffers wider than a single row of trees up to 10 m wide occurred along ≈7% of the stream bank.

Discussion

Current state of the fauna

In addition to the 19 species found alive in Copper Creek, 6 species represented by only relic specimens were reported in this and previous surveys, indicating that the creek supported at least 25 species during the twentieth century. Of the total species reported from Copper Creek, 8 (32%) are likely extirpated. These species include *Actinonaias ligamentina*, *A. p. plicata*, *E. brevidens*, *Epioblasma capsaeformis*, *Fusconaia subrotunda*, *L. recta*, *L. ovata*, and *P. fabula*. Although *A. viridis*, *F. cor*, *F. cuneolus*, *L. costata*, and *Q. c. strigillata* still occur in Copper Creek, they persist only as aging cohorts, and these species may soon be extirpated. Species loss has occurred most notably in the lower 24 km of the creek, where the great majority of species richness historically occurred.

Despite an overall decline in the mussel fauna since 1980, our comparison of CPUE indicates a significant increase in overall abundance since 1998. This increase in CPUE was predominantly due to a significant increase in number of *V. iris* observed. The cause of this disproportionate increase in *V. iris* is unknown but may relate to multiple factors. One suspected determinant may be inter-specific differences in sensitivity to nitrogenous wastes, as these pollutants have been prevalent in the Copper Creek watershed due to widespread livestock operations (USDA 1992). Mussels of *V. iris* may be more tolerant to certain agricultural pollutants than those species in Copper Creek that have shown the most significant declines. For example, several toxicity studies have demonstrated greater ammonia tolerance values for *V. iris* than for *E. capsaeformis*, a species now extirpated from Copper Creek

Table 5. Estimates of mean (SE) density for mussel species collected at four sites in Copper Creek, Scott and Russell counties, VA. Sample sizes (*n*) represent the number of 0.25-m^2 quadrat samples per site. nf = not found, rkm = river kilometer, CV = coefficient of variation

	Density (No. /m^2)			
Species	Rkm 3.1 (*n* = 51)	Rkm 24.3 (*n* = 60)	Rkm 29.4 (*n* = 40)	Rkm 83.8 (*n* = 41)
V. iris	0.31 (0.15)	2.47 (0.45)	2.40 (0.47)	4.98 (0.94)
M. conradicus	0.08 (0.08)	0.47 (0.19)	0.50 (0.21)	0.20 (0.14)
V. vanuxemensis	0.08 (0.08)	nf	nf	nf
F. barnesiana	0.08 (0.08)	0.53 (0.26)	0.20 (0.14)	0.78 (0.25)
P. subtentum	nf	0.13 (0.13)	nf	nf
P. oviforme	0.08 (0.08)	0.47 (0.24)	nf	nf
E. dilatata	nf	0.40 (0.18)	nf	nf
Total	0.63 (0.21)	4.47 (0.82)	3.10 (0.46)	5.95 (0.99)
CV	0.33	0.18	0.15	0.17

(Augspurger et al. 2003; Wang et al. 2007a, b). Similarly, the ammonia sensitivity level reported for *M. conradicus*, a species maintaining population abundance in Copper Creek, is similar to that reported for *V. iris* (Augspurger et al. 2003). Perhaps other species that have been extirpated or had significant reductions in abundance in Copper Creek have higher sensitivities to agricultural pollutants such as ammonia. The emerging discipline of ecotoxicology and mussels is still in its infancy (Farris and Van Hassel 2007), but chemical toxicity and the variety of exposure routes for contaminants to affect mussels may help to explain both the chronic and acute decline of populations throughout many river systems.

Another factor that may explain the recent increase in *V. iris* is its pre-decline population size. This pattern of persistence was documented in the Little South Fork Cumberland River, where 65% of the mussel fauna was seemingly extirpated due to surface mining and oil extraction (Warren and Haag 2005). If Copper Creek is entering into some state of recovery, then species populations with the highest abundance such as *V. iris, F. barnesiana*, *P. oviforme*, and *M. conradicus* will likely have the highest probability of survival over time. These species are also widespread throughout the mainstem and likely occur in larger tributaries of Copper Creek, enabling greater success in reestablishing populations if losses occur in the mainstem population. Recovery of less widespread species are presumably compromised by their limited distribution, particularly species occupying only the lower mainstem reach of the creek.

Although our data show an increase in mussel abundance from 1998 to 2005, statistical analysis did not support a significant increase in the number of species per site. Presence-absence sampling designs typically have a low to moderate statistical power to detect modest and uniform changes (<20–50%) in a population (Strayer 1999). Therefore, a change in the fauna was not discernible. Although we observed 5 additional species that were not reported in the 1998 survey, these species were represented by older specimens during our survey and were most likely present, but simply undetected during the 1998 survey. This possibility is logical given the lower level of survey effort conducted in the 1998 survey.

Causes of decline

There are likely multiple factors that have contributed to the faunal decline in Copper Creek, particularly in the lower reaches of the creek. Exactly when this decline began and what the historic status of fauna in Copper Creek was prior to 1980 is clouded by lack of data.

Declining populations in the lower reaches of Copper Creek may be "sink" populations and may depend on the Clinch River "source" populations; the lower reaches of the creek may merely represent a habitat interface between species adapted to smaller and larger streams. Lower Copper Creek may represent marginal habitat for much of the declining fauna, especially for those species that were never reported in any abundance in Copper Creek. Although data collected on overall mussel densities at Speers Ferry have been relatively consistent since 1979, the composition of the fauna has changed (Ahlstedt et al. 2005). Prior to 1979, there are no population data from Speers Ferry to evaluate changes in density. However, Ortmann (1918) reported 25 species from Speers Ferry, 15 species more than what was detected in the most recent survey conducted in 2004, indicating a substantial decline in species richness. While some species populations could likely persist in isolation of the Clinch River, others species such as *A. p. plicata*, *A. ligamentina*, *E. brevidens*, *E. capsaeformis*, *F. cor*, *F. cuneolus*, *F. subrotunda*, and *Q. c. strigillata*, may represent declining sink populations that have subsequently followed population declines in the Clinch River.

Another factor that would impede dispersal of mussels upstream from source populations is the presence of the Spivey Mill dam. This low-head dam is located in Copper Creek 20 rkm from the confluence with the Clinch River. While the dam certainly limits upstream expansion of mussel populations, 20 km of the creek below the dam has suffered the greatest loss in species richness, indicating other factors are also contributing to the decline.

In 1992, Copper Creek ranked number one for the most significant agricultural water quality and erosion problems in the Clinch River basin (USDA 1992). Primary problems were siltation and pathogens related to poor agricultural and silvicultural practices. Soil loss in the watershed was estimated to be 130,329 metric tons/year. High levels of nitrogenous wastes may have also contributed to the decline in mussel fauna. Nitrogen and phosphorus production from livestock and other forms of agriculture was estimated to be 927,918 kg/yr or 27 kg/ha/yr. By comparison, estimates for the Guest River and Swords/Lewis Creek watersheds, adjacent hydrologic units of comparable size, were 1.96 and 8.27 kg/ha/yr, respectively.

Given that several species including *E. brevidens*, *L. recta, A. ligamentina, F. subrotunda*, and *P. fabula* were only reported as relics and were not reported alive during the initial survey (Ahlstedt 1981, 1986), it is possible that the mussel fauna in Copper Creek was more diverse prior to 1980. In fact, some level of faunal decline may have been linked to land-use legacies initiated during the early 20th century, when most of the region's forest was harvested and the watershed was converted to row cropping and pasture land (Pederson 1925).

However, forest cover has increased in Scott and Russell counties, VA, from 42.2% of land area in 1940 to 66.6% in 2002 (Lotti and Evans 1942, Miles 2007). A similar rate of increase has occurred in the Copper Creek watershed, which occupies 13.5% of the area in the combined counties. Forest cover in the Copper Creek watershed apparently increased from 38.9% in 1992 (USDA 1992) to 57.7% in 2002 (USEPA 2002). Perhaps impacts from the larger landscape level are beginning to lessen and may, in part, influence recovery of the Copper Creek fauna.

Despite an increase in forest cover within the watershed, removal of riparian vegetation has progressively increased in the last 30 years (Fraley and Ahlstedt 2000). Even while conducting our survey, we observed land owners actively removing large trees and root masses from stream banks, presumably to accommodate livestock grazing. Elimination of stream-side riparian vegetation is widespread, and cattle have unlimited access to the creek in many places (Fraley and Ahlstedt 2000). The removal of riparian vegetation has destabilized stream banks and has destroyed reaches of suitable mussel habitat.

Nearly 23% of the mainstem length has no riparian vegetation, and ≈22% of stream banks are protected only by a narrow strip of trees. Riparian widths of about 9 m are a minimum for effective sediment control (Wenger 1999). Therefore, approximately half (45%) of the stream banks in Copper Creek have inadequate riparian vegetation necessary to provide even minimal sediment control. Historically, species diversity in Copper Creek increased in a downstream direction, with the lower 24 km being the most diverse section of the creek. It is clear from our data that significant declines in species richness and abundance have occurred in the downstream section, particularly in the lower 32 km of the creek. Mussel populations in the upper reaches, although not excluded from impacts, seem to have remained relatively intact. Stressors impacting the lower reaches may be more intense, given the culmination of hydrologic impacts associated with widespread riparian degradation and loss of forest cover. Therefore, a resultant increase in siltation and stream-bed destabilization will impact mussel habitat, particularly in the lower reaches.

Implications

In summary, there are several factors that are likely contributing to the current faunal structure of Copper Creek. These factors include: 1) agricultural and land conversion stressors and the inter-specific tolerances to those stressors among species, 2) pre-decline population densities and distribution, 3) population source-sink relationships with the Clinch River, and 4) a barrier (Spivey Mill Dam) to upstream dispersal. What exact weight each factor has in determining the current and future fauna of Copper Creek is unclear. Faunal decline in the Clinch River and agricultural and land conversion stressors may be the most significant factors in driving the decline.

Copper Creek was one of the most diverse lotic systems of its size in North America, and is of national importance as a refugium for rare and endangered mussel species. Unlike many tributaries of the Upper Tennessee River system, it has escaped large-scale impacts from urban, railroad, and highway development, as well as mining and point-source discharges. Gradual reforestation of the watershed may be providing some relief to the system at a larger landscape level. However, this reforestation is occurring more in upland areas and may be less important than the riparian corridor in influencing suitable habitat for mussels (USEPA 2002). Although the mussel fauna has shown some initial signs of recovery, streamside livestock activity and loss of forested riparian vegetation may be pivotal in contributing to the faunal decline. Currently there are no state laws or county ordinances to mandate livestock exclusion from streams or riparian protection in the watershed. Government-sponsored incentive programs such as the Conservation Reserve Enhancement Program, Landowner Incentive Program, and Partners for Fish and Wildlife Program have succeeded in introducing best management practices (BMPs) into the watershed. However voluntary cost-share programs such as these may not be enough to correct perturbations within the time frame necessary to prevent the extirpation of additional species.

A higher level of resources and focus must be dedicated to establishing conservation easements, purchasing lands for permanent protection, educating the public, and assisting land owners in implementing BMPs. Although installation of a fish-passage structure or removal of the Spivey Mill dam will reestablish connectivity to the middle and upper reaches of Copper Creek, further investigation on sediment transport and changes in hydraulics will need to be conducted to estimate the impact to mussel populations below the dam. Further monitoring of the mussel populations will be necessary periodically to evaluate trends in populations over time. Specifically, comprehensive surveys need to be conducted in the near future to determine whether mussel populations are truly rebounding or continuing in a state of decline.

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Appendix 1. Mussel data for 47 survey sites in Copper Creek, Scott and Russell counties, VA collected in 2004 and 2005. Data represent living individuals observed. R = relic specimen. * = federally listed endangered or candidate species.

	Site number												
	1	2	3	4	5	6	7	8	9	10	11	12	13
River kilometer	1.6	1.9	2.9	3.1	3.4	3.5	4.2	5.3	5.8	7.1	8.2	9.5	10.1
Person hours	3.75	2.5	2	4.6	2	2	1.3	2	1.5	2	2	0.75	1
Actinonaias pectorosa		2		1	1	1							
Alasmidonta viridis													
Amblema plicata plicata		R											
Elliptio dilatata		3		3	1	1	R					R	
*Epioblasma brevidens**													
Fusconaia barnesiana				1		1						1	
*Fusconaia cor**				1								R	
*Fusconaia cuneolus**				1	1		R					R	
Lampsilis fasciola	1	5	1		1								
Lampsilis ovata									R				
Lasmigona costata						1							
Lasmigona holstonia													
Ligumia recta				R									
Medionidus conradicus		4		1		1	1		R				
*Pegias fabula**											R		
Pleurobema oviforme		3		8	1	2	1	2	1	3	2		10
Ptychobranchus fasciolaris	1	1				1	R						
*Ptychobranchus subtentum**	1												
*Quadrula c.strigillata**				2		R						R	
Villosa iris	8	63	10	28	31	54	3	2	19	27	2	6	15
*Villosa perpurpurea**				2		1					R	R	1
Villosa vanuxemensis						1			1				
Total living mussels	11	81	11	48	36	64	5	4	21	30	4	7	26
Living mussels CPUE	2.93	32.40	5.50	10.43	18.00	32.00	3.85	2.00	14.00	15.00	2.00	9.33	26.00
Total living species	4	7	2	10	6	10	3	2	3	2	2	2	3

	Site number												
	14	15	16	17	18	19	20	21	22	23	24	25	26
River kilometer	10.5	11.1	12.6	13.7	15.1	15.8	18.5	19.0	20.8	22.2	22.5	24.3	25.1
Person hours	5.5	1.5	3.3	0.75	1.5	2	2	1.5	5	4.5	3	5	3
Actinonaias pectorosa													
Alasmidonta viridis													
Amblema plicata plicata													
Elliptio dilatata	1	R		R					R	R	5	24	10
*Epioblasma brevidens**										R			
Fusconaia barnesiana	22	1		1					7	1	6	19	7
*Fusconaia cor**		R											
*Fusconaia cuneolus**	1												
Lampsilis fasciola	6	1					R		2	2	1	6	
Lampsilis ovata													
Lasmigona costata													
Lasmigona holstonia													
Ligumia recta													
Medionidus conradicus		1		1					3	4	5	88	11
*Pegias fabula**													
Pleurobema oviforme	42	2	4	R	8	5	5	4	11	10	43	11	5
Ptychobranchus fasciolaris												2	
*Ptychobranchus subtentum**				R	1	R	R		R	3	R	22	8
*Quadrula c. strigillata**						R							
Villosa iris	36	10	1	7	5	27	10	16	50	30	100	169	51
*Villosa perpurpurea**	2	R		R	5R	4	R	R	3	R	R	3	R
Villosa vanuxemensis				R					R				
Total living mussels	110	15	5	9	14	36	15	20	76	50	160	344	92
Living mussels CPUE	20.00	10.00	1.52	12.00	9.33	18.00	7.50	13.33	15.20	11.11	53.33	68.80	30.67
Total living species	7	5	2	3	3	3	2	2	6	6	6	9	6

	Site number												
	27	28	29	30	31	32	33	34	35	36	37	38	39
River kilometer	29.4	34.0	38.5	47.0	49.6	52.8	53.6	56.0	64.4	67.8	72.1	72.7	73.7
Person hours	3.5	0.75	4	5	1	0.25	1	4.5	1	1	2	1	0.75
Actinonaias pectorosa													
Alasmidonta viridis													
Amblema plicata plicata													
Elliptio dilatata	1												
*Epioblasma brevidens**													
Fusconaia barnesiana	21		11	2	1		1	3		1	13	5	
*Fusconaia cor**													
*Fusconaia cuneolus**													
Lampsilis fasciola	1		2				R						
Lampsilis ovata													
Lasmigona costata													
Lasmigona holstonia						1R							
Ligumia recta													
Medionidus conradicus	102		4	1		R	3	1		6	7	1	
*Pegias fabula**													
Pleurobema oviforme	90	1	23	5	1	1	8	4	R	10	28	20	
Ptychobranchus fasciolaris													
*Ptychobranchus subtentum**	30												
*Quadrula c. strigillata**													
Villosa iris	150	5	72	78	22	3	38	60	35	50	115	64	8
*Villosa perpurpurea**													
Villosa vanuxemensis													
Total living mussels	395	6	112	86	24	4	50	68	35	67	163	90	8
Living mussels CPUE	112.86	8.00	28.00	17.20	24.00	16.00	50.00	15.11	35.00	67.00	81.50	90.00	10.67

	Site number										No. of sites occurring alive
	40	41	42	43	44	45	46	47	Total	% of total	
River kilometer	77.7	78.7	81.1	82.9	83.8	85.3	87.2	93.0			
Person hours	3	0.75	3	4	3.5	1.5	2	2	111.45		
Actinonaias pectorosa									5	0.12%	4
Alasmidonta viridis					1	1R	3RD		1	0.02%	1
Amblema plicata plicata									0	0.00%	0
Elliptio dilatata									49	1.19%	9
*Epioblasma brevidens**									0	0.00%	0
Fusconaia barnesiana	6		2		12				145	3.53%	23
*Fusconaia cor**									1	0.02%	1
*Fusconaia cuneolus**									3	0.07%	3
Lampsilis fasciola	1		1R	2	8				40	0.97%	15
Lampsilis ovata									0	0.00%	0
Lasmigona costata									1	0.02%	1
Lasmigona holstonia				1R		1R	1R	5R	0	0.00%	0
Ligumia recta									0	0.00%	0
Medionidus conradicus	2		3	11	53	6	4		324	7.89%	25
*Pegias fabula**									0	0.00%	0
Pleurobema oviforme	11		3	41	75	9			513	12.49%	38
Ptychobranchus fasciolaris									5	0.12%	4
*Ptychobranchus subtentum**									65	1.58%	6
*Quadrula c. strigillata**									2	0.05%	1
Villosa iris	101	6	126	318	438	172	293		2934	71.46%	46
*Villosa perpurpurea**									16	0.39%	7
Villosa vanuxemensis				1R					2	0.05%	2
Total living mussels	121	6	134	372	587	187	297	0	4106	100.00%	
Living mussels CPUE	40.33	8.00	44.67	93.00	167.71	124.67	148.50	0.00	36.84		
Total living species	5	1	4	4	6	3	2	0	16		