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ASSESSING RELATIONSHIPS BETWEEN HUMAN LAND USES AND THE DECLINE OF NATIVE MUSSELS, FISH, AND MACROINVERTEBRATES IN THE CLINCH AND POWELL RIVER WATERSHED, USA

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Abstract—The free-flowing Clinch and Powell watershed in Virginia, USA, harbors a high number of endemic mussel and fish species but they are declining or going extinct at an alarming rate. To prioritize resource management strategies with respect to these fauna, a geographical information system was developed and various statistical approaches were used to relate human land uses with available fish, macroinvertebrate, and native mussel assemblage data. Both the Ephemeroptera, Plecoptera, Trichoptera (EPT) family-level index, and the fish index of biotic integrity (IBI) were lowest in a subwatershed with the greatest coal mining activity (analysis of variance [ANOVA], $p < 0.05$). Limited analyses in two other subwatersheds suggested that urban and agricultural land uses within a specified riparian corridor were more related to mussel species richness and fish IBI than land uses in entire catchments. Based on land uses within a riparian corridor of 200 m × 2 km for each biological site in the watershed, fish IBI was inversely related to percent cropland and urban area and positively related to pasture area (stepwise multiple regression, $R^2 = 0.55$, $p < 0.05$). Sites less than 2 km downstream of urban areas, major highways, or coal mine activities had a significantly lower mean IBI value than those more than 2 km away (ANOVA, $p < .05$). Land use effects included poorer instream cover and higher substrate embeddedness (t test, $p < 0.05$). Weaker land use relationships were observed for EPT and mussel species richness. Episodic spills of toxic materials, originating from transportation corridors, mines, and industrial facilities, also have resulted in local extirpations of native species, particularly mussels. The number of co-occurring human activities was directly related to stream elevation in the Clinch River, with more human land uses in headwater areas. Approximately 60% of known U.S. Fish and Wildlife mussel concentration sites in the watershed are located within 2 km of at least two land use sources identified as potentially stressful in our analyses. Our results indicate that a number of land uses and stressors are probably responsible for the decline in native species. However, protection of naturally vegetated riparian corridors may help mitigate some of these effects.

Keywords—Watershed Mining Land use Geographical information system Endangered species

INTRODUCTION

Protection of valued ecological resources requires knowledge of the autecological factors affecting their abundance and distribution as well as their sensitivity and resilience to potential stressors. Interest has been increasing on the part of resource managers and the public to evaluate protection of resources in watersheds, or even larger spatial scales, in part because effects of habitat fragmentation and other stressors can be underestimated at smaller spatial scales [1,2]. Furthermore, use of a watershed approach often is necessary to address effects of nonpoint sources because traditional regulatory approaches do not adequately address this issue [3].

Assessing relationships between human land use activities and ecological resources is especially complex in a watershed and larger spatial scales in which multiple land uses, and interactions among those uses, are likely to be present. The Clinch and Powell rivers watershed in southwestern Virginia, USA, was selected by the U.S. Environmental Protection Agency as one of five watersheds to demonstrate the use of the ecological risk assessment paradigm in identifying major causes of declines in valued ecological resources. This watershed was selected because it harbors a higher number of

federally threatened and endangered aquatic species (mostly mussels and fish) than almost any other watershed in the United States; the fauna are susceptible to multiple physical, chemical, and biological stressors that could be present in this watershed; and local resource managers and researchers were actively interested in further analyzing the extensive body of information that had been collected cooperatively in this watershed over many years.

The upper Clinch and Powell rivers in Virginia represent some of the last free-flowing sections of the expansive Tennessee River system. This watershed supports more native mussel and fish species than any other basin in Virginia and most streams in North America [4,5]. However, it is well established that most of the historic (pre-1910) mussel beds in the watershed have declined dramatically or been eliminated (Fig. 1) [6]. Similar extirpations have been documented for several endemic fish species as well [7,8]. Analyses of historic data for certain sites in the watershed indicate that declines in the number of mussel species have been somewhat continuous over the past 70 to 80 years, despite implementation of recovery plans and reforestation over the last century [8,9]. Recent mussel sampling in Copper Creek, a subwatershed of the Clinch-Powell river basin also has indicated continued, unexplained declines in mussel fauna (S. Ahlstedt, U.S. Geological Survey, unpublished report). The loss of native mussel and fish species in the Clinch-Powell watershed and in North America as a whole is extensive [5], indicating that the problem is widespread.

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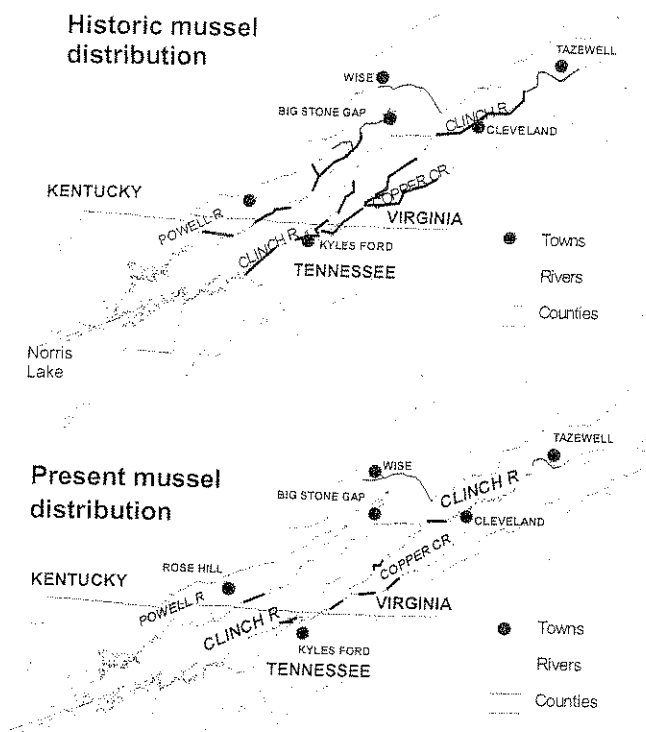


Fig. 1. Map of the Clinch-Powell watershed (VA, USA) showing the comparison between historic (pre-1910) and present locations of native mussel concentrations. Bold river lines indicate observed native mussel concentrations.

Although several hypotheses have been advanced to explain the decline in native mussel and fish species in this and other watersheds, definitive answers have been lacking. Resource managers recognized that a comprehensive examination of the available data for the watershed as a whole was needed to evaluate the relative effects of different human activities on native mussels and fish. This study attempted to define current human land use factors that may be associated with native species decline and to identify beneficial resource management strategies that might further protect remaining productive areas.

MATERIALS AND METHODS

Study area

The Clinch and Powell rivers flow into the upper reaches of the Tennessee River at Norris Lake in northeastern Tennessee, USA (Fig. 1). This region was unglaciated in recent geologic time and has been isolated from other nearby river systems by the mountainous terrain, thus favoring the evolution of a diverse, endemic assemblage of fish and freshwater mussel species in this watershed [9,10]. The upper regions of the Clinch and Powell rivers drain approximately 7,542 and 2,429 km², respectively [11]. A significant reduction in aquatic native species diversity is associated with impoundments in this watershed [6,8,12]. Therefore, this assessment treated Norris Lake in northeastern Tennessee (the furthest upstream impoundment on the Tennessee River system) as the terminal boundary of the study.

The economy in the Clinch-Powell region is driven pri-

marily by coal mining and agriculture. More than 40% of Virginia's coal production lies within the five counties in the basin, where the Cumberland Plateau is composed of Pennsylvanian sandstone and shale. Most of the watershed was intensively logged for agricultural production in the late 18th and early 19th centuries and the forest industry has largely declined through the 19th and 20th centuries. Beef cattle and burley tobacco are the primary agricultural products in the watershed [11]. Topographic constraints limit most of these agricultural activities to the floodplain, where livestock and row crop production is most feasible and productive.

Data sources

Several biological and habitat measures were available with which to examine relationships with human land uses. The majority of these data were collected by the Tennessee Valley Authority (TVA) as part of regular monitoring programs. The Clinch-Powell River Action Team Survey (CPRATS) included habitat quality measures (12 metrics, each scored categorically from excellent to poor [1-4], as well as a composite habitat score [13]), a fish index of biotic integrity (IBI as formulated by Karr et al. [14]), and macroinvertebrate Ephemeroptera, Plecoptera, Trichoptera (EPT) family-level index data collected between 1995 and 1998. Component metric values comprising the fish IBI scores were unavailable for analysis. The CPRATS is a fixed-station monitoring network with 155 sampling sites located throughout the watershed on both low- and high-order streams. Although land use and other landscape information was available for all CPRATS sites, biological and habitat data were not collected at all sites. A second source of biological data was the Cumberlandian Mollusc Conservation Program, which includes native mussel abundance and species richness data collected at 60 sites between 1981 and 1986. The Cumberlandian Mollusc Conservation Program has sites located mostly in larger mainstem areas.

Mussel reproduction depends on successful parasitization of fish hosts by mussel larvae or glochidia [5] and fish species distribution is related, at least in part, to aquatic insect abundance and distribution. Thus, a relationship between fish, macroinvertebrates, and mussel distribution is expected [5,8,10]. Although none of the IBI or EPT sites coincided with mussel sites in our data sets, some fish and mussel sites were near to one another, allowing for qualitative assessment of fish-mussel relationships. This was advantageous because mussel data were not as widely distributed as either fish IBI or EPT data. Because of the temporal variation between IBI, EPT, and mussel data, definitive relationships between these biological assemblages could not be determined. Therefore, data for these fauna are presented separately, although it is likely that interactions among them also are related to native species decline.

Other data used in our analyses included land cover (derived from Landsat Thematic Mapper imagery, Earth Resources Observation Systems, Sioux Falls, SD, USA), elevation and slope data obtained from a mosaic of 30-m resolution U.S. Geological Survey digital elevation models, stream drainages (U.S. Geological Survey Stream Reach File 3), road density, and locations of point source dischargers and mines (U.S. Environmental Protection Agency's Permit Compliance System). In addition, peer-reviewed biological studies obtained from other institutions, as well as historic data (pre-1920), were used to help interpret results.

Table 1. Comparison of land cover for four subwatersheds examined in the Clinch-Powell watershed (VA, USA) risk assessment

	Upper Clinch River	Upper Powell River	Guest River	Copper Creek
Forest (%)	53.7	89.6	84.1	57.7
Cropland (%)	0.6	3.1	<0.1	1.3
Pasture (%)	44.5	2.4	10.4	40.9
Urban (%)	1.1	4.2	2.6	<0.1
Number of coal mines ^a	8	21	26	0

^aMines and coal preparation plants.

Analyses

Land use, habitat, and biological data were entered into a geographical information system (Arc/INFO, Ver 7.04, Environmental Systems Research Institute, Redlands, CA, USA) and partitioned in various ways by ACCESS (Microsoft, Redmond, WA, USA) to obtain databases that were amenable to statistical analyses (Statistica, Ver 5.0, Statsoft, Tulsa, OK, USA). Both univariate and multivariate analyses were used to identify relationships between land uses, habitat quality, and biological measures.

We performed our initial analyses with fish IBI and macroinvertebrate EPT data from four subwatersheds: Copper Creek, the Guest River, upper Clinch River, and upper Powell River (Fig. 1). The four subwatersheds comprise a range of different human land uses, particularly with respect to coal mining, pasture and crop area, and urban or developed area (Table 1). More rigorous analyses were not feasible because of unbalanced representation of biological data across subwatersheds and stream types.

Before conducting land use analyses for the watershed as a whole, we performed pilot analyses to identify the appropriate spatial scale with which to evaluate relationships between human land use and biological measures. Copper Creek subwatershed was chosen for this analysis because it was the most data-rich subwatershed and because agricultural uses were the major source of anthropogenic activity (Table 1), making the data easier to interpret. ArcView (Ver 3.0, Environmental Systems Research Institute) was used to calculate land uses in areas having several different stream riparian widths (50-, 100-, 200-, and 400-m transects across the stream) and different distances upstream (100, 200, 500, 1,000, and 2,000 m) of each of nine CPRATS sampling points. Percent agricultural land cover (pasture plus cropland) was then calculated for each different combination of riparian width and distance upstream for each site. Relationships between percent agricultural land and fish IBI, macroinvertebrate EPT, and habitat quality indices for the different combinations were determined with Spearman rank correlation ($p = 0.05$). The IBI, EPT, and habitat quality index were also analyzed in relation to riparian percent agricultural land cover for the entire subwatershed upstream of each sampling point. After the full watershed analyses (see below), a similar riparian corridor analysis was conducted, with mussel data reported by Jones et al. [15] (15 sites) from the upper Clinch River, to identify potential errors due to extrapolating fish IBI results to other fauna and to other areas of the watershed.

Results of Copper Creek pilot analyses were used to define the approach for investigating effects of human land uses for each biological sampling location in the Clinch-Powell watershed in subsequent analyses. By using ArcView Spatial

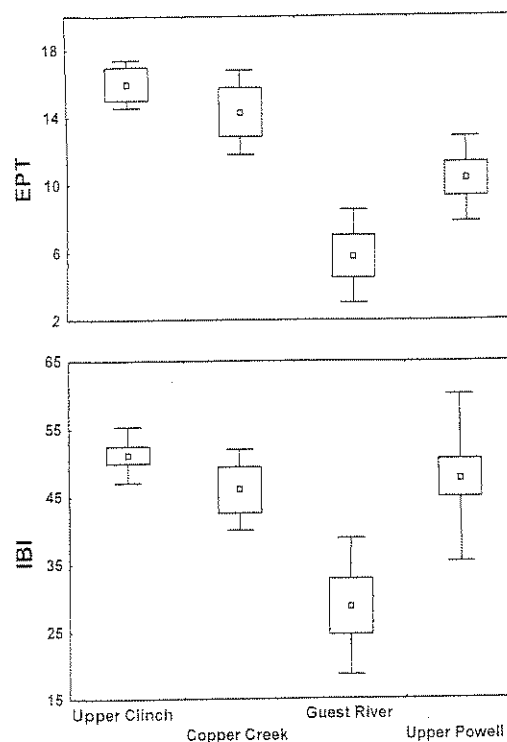


Fig. 2. Macroinvertebrate Ephemeroptera, Plecoptera, and Trichoptera (EPT) and fish index of biotic integrity (IBI) scores by subwatershed in the Clinch-Powell basin (VA, USA) based on Tennessee Valley Authority's Clinch-Powell River Action Team Survey data set. Boxes are standard errors, whisker bars are standard deviations, and the square is the mean value.

Analysis (Environmental Systems Research Institute), a 200-m \times 2-km area was created upstream of each CPRATS sampling site and land use coverages were identified at each site. Land use information included percentages (cropland, pasture, forest, and urban), and proximity to mining, urban centers, or major highways, defined categorically as either less than 1 km, 1 to 2 km, or more than 2 km upstream of the biological sampling point. Land use and biological data for each site were then aggregated into a single table and imported into Statistica for analysis.

Land use percentage data were related to fish IBI, number of mussel species, or EPT with both Pearson product moment correlation (for individual land use relationships) and forward stepwise multiple regression analyses ($p < 0.05$; for multiple land use relationships). Fish IBI, EPT, and habitat scores were also converted to categorical variables (categorized as either impaired or unimpaired based on TVA's scoring system) and then analyzed with respect to land use percentages with a one-tailed t test or one-way analysis of variance (ANOVA; $p < 0.05$). Land use proximity data (e.g., distance to nearest urban center) were related to biological data with ANOVA ($p < 0.05$).

RESULTS

Subwatershed characterization

Both EPT and IBI were lowest in the Guest River subwatershed (ANOVA, $p < 0.05$; Fig. 2), which has had intense coal mining activity (Table 1), acid mine drainage for many years [16], and few other potential land use stressors such as urban or pasture influences. Ephemeroptera, Plecoptera, Trichoptera was also lower in the upper Powell than either Copper Creek

Table 2. Summary of Spearman rank correlation coefficients between percent agricultural area and fish index of biotic integrity (IBI) as a function of different combinations of riparian corridor width and distance upstream. The IBI values were obtained from Tennessee Valley Authority's Clinch Powell River Action Team Survey. Coefficients marked with italics were significant at $p < 0.05$

Riparian width (m)	Upstream riparian length (m)				
	100	200	500	1,000	2,000
50	0.09	0.14	0.10	0.06	-0.04
100	0.19	0.24	0.26	0.09	-0.11
200	0.14	0.18	<i>0.30</i>	<i>0.34</i>	-0.11
400	0.09	0.14	-0.18	-0.20	-0.19

or the upper Clinch River subwatershed (ANOVA, $p < 0.05$; Fig. 2). Index of biotic integrity was not significantly different among these three subwatersheds ($p > 0.10$). The upper Powell subwatershed also has substantial coal mining activity (Table 1), although it has slightly more urban area and cropland than in the Guest River subwatershed (Table 1). These data indicate that coal mining is the human land use most associated with insect and fish distribution in the watershed as a whole.

Subwatershed pilot analyses

Fish IBI showed a weak negative relationship with total catchment agricultural area ($r = -0.30$, $p = 0.08$), whereas EPT seemed to be unrelated to upstream agricultural area ($r = 0.23$, $p > 0.20$). The TVA's habitat quality index also seemed to be unrelated to catchment agricultural land use upstream ($r = -0.14$, $p = 0.21$). Thus, given the constraints of this analysis ($n = 9$), total catchment agricultural area seemed to have little relationship with biological or habitat measures examined. More significant trends between percent agricultural land and fish IBI were evident in intermediate-sized riparian areas (200-m buffer width and 500–1,000 m upstream) as opposed to either larger (i.e., greater riparian width, greater distance upstream, or both) or smaller (i.e., narrower riparian widths, shorter distances upstream, or both) riparian areas (Table 2). Habitat quality and EPT did not exhibit significant relationships with percent agricultural land in any of the riparian corridor dimensions examined ($r < 0.10$, $p > 0.20$).

Similar analyses performed with mussel data in a small portion of the upper Clinch River [15] indicated that the correlation between riparian urban land use and mussel species richness was highest in 2-km-long corridors as opposed to longer or shorter corridors, similar to the Copper Creek results with fish IBI (Table 3). Agricultural land exhibited significant correlation with mussel species richness in longer (5-km) riparian corridors (Table 3). Mussel richness was positively associated with percent forest in all corridor lengths examined (1–10 km) but not in the drainage as a whole (Table 3). Mussel abundance was uncorrelated with land uses in any of the riparian dimensions examined. These additional pilot analyses suggested that mussel species richness is more sensitive to human land uses than is abundance. Furthermore, 2-km-long riparian corridors, as suggested by analysis of the Copper Creek data, may underestimate agricultural effects on mussels at some sites in the watershed.

Too few sites were available in which mussels, fish, and EPT were simultaneously sampled in Copper Creek, and in the watershed as a whole, for us to compare statistically responses of these fauna to the same land use patterns. By using fish species data collected by Masnik [12] and Cumberlandian

Table 3. Correlation (Pearson product moment R values) between mussel data and land use percentages in whole drainage and different sized riparian corridors. Mussel data were obtained from Jones et al. [15]. Italicized values are significant at $p < 0.10$

Riparian corridor	Land use	Mussel richness	Mussel abundance
100 m × 1 km	Forest	0.62	0.11
	Urban	-0.42	-0.05
	Agriculture	-0.33	-0.07
100 m × 2 km	Forest	<i>0.68</i>	-0.19
	Urban	-0.49	-0.06
	Agriculture	-0.39	0.25
100 m × 5 km	Forest	0.77	-0.07
	Urban	-0.40	-0.13
	Agriculture	-0.59	0.18
100 m × 10 km	Forest	<i>0.65</i>	0.07
	Urban	-0.08	-0.14
	Agriculture	0.15	-0.22
200 m × 1 km	Forest	<i>0.62</i>	0.11
	Urban	-0.43	-0.04
	Agriculture	-0.39	-0.08
200 m × 2 km	Forest	<i>0.69</i>	-0.16
	Urban	-0.46	-0.01
	Agriculture	-0.43	0.21
200 m × 5 km	Forest	<i>0.62</i>	-0.16
	Urban	-0.28	-0.05
	Agriculture	-0.47	0.19
200 m × 10 km	Forest	<i>0.62</i>	0.05
	Urban	0.01	-0.08
	Agriculture	0.19	-0.21
Whole drainage	Forest	0.12	-0.20
	Urban	0.35	-0.037
	Agriculture	-0.20	0.20

Mollusc Conservation Program mussel data collected six years later in Copper Creek, we observed a similar spatial pattern between fish and mussel species richness with river mile (Fig. 3; Wilcoxon matched pairs test, $p < 0.05$). EPT exhibited relatively little variability with stream location in Copper Creek (total range of EPT values was 13–19) and appeared to be unrelated to either fish IBI or mussel species richness ($r < 0.12$; $p > 0.10$).

Watershed analyses

A 200-m × 20-km riparian corridor was applied to all biological sites in the watershed based on results of Copper

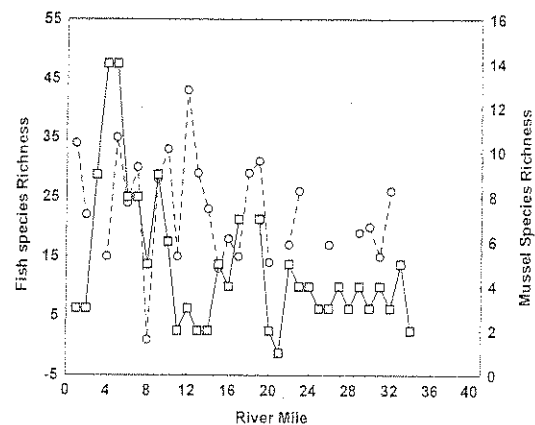


Fig. 3. Fish and mussel species richness by river mile in Copper Creek (VA, USA). Fish data are based on U.S. Soil Conservation Service data [11]; mussel data are based on Tennessee Valley Authority's 1981 Cumberlandian Mussel Conservation Program data. ○ = fish; □ = mussels.

Table 4. Summary of stepwise multiple regression and analysis of variance (ANOVA) analyses of fish index of biotic integrity (IBI) values in relation to human land uses in the Clinch-Powell watershed (VA, USA). Data were obtained from the Tennessee Valley Authority's Clinch-Powell River Action Team Survey data set

<i>n</i>	<i>R</i> ²	Land use factors	Association	Partial <i>R</i> ²	<i>p</i> value	Mean IBI <2 km	Mean IBI >2 km
38	0.55	Percent pasture area	+	0.15	0.019		
		Percent cropland	-	0.06	0.15		
		Percent urban	-	0.04	0.23		
ANOVA		Highway proximity	-	<i>F</i> = 3.01	0.05	34.2	39.5
ANOVA		Mining proximity	-	<i>F</i> = 17.27	0.01	31.7	41.6

Creek analysis. Agricultural land was split into two categories for these analyses (cropland and pasture land), because both of these uses occur in the watershed as a whole. We observed a significant relationship between elevation and either fish IBI or EPT for the watershed as a whole (Pearson correlation coefficient [*r*] = 0.54, *p* < 0.01, and *r* = -0.19, *p* = 0.05, respectively, *n* = 137). Because many of the CPRATS sites that had concurrent habitat and biological information were located between 350 and 450 m elevation (*n* = 52 out of 80 sites), and no correlation was found between elevation and either IBI or EPT within this range (*r* < 0.2, *p* > 0.10), subsequent watershed analyses concentrated on sites within 350 and 450 m elevation. A broader elevation range resulted in significant elevation effects in multiple regression analyses (*p* < 0.05). Approximately 5 and 30% of the sites were less than 350 m or more than 450 m in elevation, respectively.

Index of biotic integrity

Fish IBI was inversely related to percent cropland and urban land use and positively related to percent pasture land (forward stepwise multiple regression, *n* = 52; Table 4). Sites more than 2 km downstream of mining or major transportation routes had a significantly higher mean IBI value than sites less than 2 km downstream (ANOVA; Table 4). Mean riparian urban area was significantly higher at sites in which fish IBI was categorized as impaired (based on TVA's IBI scoring: urban area = 5.6 and 12.2% for unimpaired and impaired IBI sites, respectively; *t* test, *n* = 52, *p* < 0.05).

Effects of urban and cropland uses on IBI were due, at least in part, to poorer instream cover and higher substrate embeddedness, as evidenced by analyses of categorical IBI data (mean instream cover values = 2.9 and 3.9 and mean stream embeddedness values = 2.7 and 3.2 for impaired and unimpaired IBI condition, respectively, *t* tests, *p* < 0.05, *n* = 52).

Ephemeroptera, Plecoptera, and Trichoptera

Forward stepwise multiple regression analyses indicated that EPT was negatively related to percent urban area and positively related to percent pasture, but the overall *R*² was much lower than that for IBI (*R*² = 0.29; Table 5). Percent

urban area showed the clearest association with EPT with categorical EPT data (mean riparian urban area = 25.2 and 7.4% for impaired and unimpaired EPT condition respectively, *t* tests, *p* < 0.05). The ANOVA indicated that proximity to mining and major roads were also factors associated with EPT (Table 5).

Mussels

Stepwise multiple regression analysis indicated a significant negative association between mussel species richness and urban and cropland land use (Table 6). However, like EPT, less than a third of the variance in mussel species richness was explained by riparian human land uses in our analysis. Given the results of pilot analyses in the upper Clinch River noted earlier, the relationship with agricultural uses possibly was underestimated in this analysis.

Variation in the data set was insufficient to evaluate relationships between mussel assemblage characteristics and proximity to mining, urban, or major highways. However, episodic spills of a variety of contaminants from coal mines, industrial facilities, and transportation accidents clearly have contributed to declines in native mussels (and other fauna) in many locations in this watershed. For example, mussel species richness data collected over a 93-year period at two different locations, one downstream of coal mining in the Powell River [10] and one downstream of a power generation facility in the upper Clinch River [17], indicated sharp declines in native mussels after spills of toxic materials (Fig. 4).

Cumulative effects of land uses

In an effort to address cumulative effects of human activities, riparian land use sources determined to be significant in previous analyses and in other research [18] (mining, urban areas, major transportation corridors, and percentage of cropland area) were calculated and summed for each biological sampling site. Land use sources were expressed as a binary function: 0 if the particular source was not present or nearby (within 2 km upstream) and a 1 if the source was present. A cumulative stressor index was then computed for each site

Table 5. Summary of stepwise multiple regression and analysis of variance (ANOVA) analyses of macroinvertebrate Ephemeroptera, Plecoptera, Trichoptera (EPT) values in relation to human land uses in the Clinch-Powell watershed (VA, USA). The EPT values were obtained from the Tennessee Valley Authority's Clinch-Powell River Action Team Survey

<i>n</i>	<i>R</i> ²	Land use factors	Association	Partial <i>R</i> ²	<i>p</i> value	Mean EPT <2 km	Mean EPT >2 km
34	0.29	Percent urban area	-	0.14	0.033		
		Percent pasture	+	0.08	0.127		
ANOVA		Mining proximity	-	<i>F</i> = 5.01	0.02	9.8	12.5
ANOVA		Highway proximity	-	<i>F</i> = 3.70	0.03	10.4	12.3

Table 6. Summary of stepwise multiple regression analysis of native mussel species richness as a function of riparian human land use factors. Data were obtained from the Tennessee (USA) Valley Authority's Cumberlandian Mussel Conservation Program database

<i>n</i>	<i>R</i> ²	Land use factors	Association	Partial <i>R</i> ²	<i>p</i> value
33	0.26	Percent urban area	-	0.09	0.007
		Percent cropland	-	0.02	0.30

ranging between 0 and 4 (representing the four human land uses above).

Fish IBI decreased as more riparian land use sources co-occurred (ANOVA, $p < 0.01$; Table 7). Fish IBI was consistently low (rated as poor based on TVA ecoregional reference site data) at sites having all four stressors present. Approximately 66% of the sites having two of the four stressors present had IBI scores less than 35, indicating impaired fish community integrity at those sites according to TVA. In nearly all of these cases (88%), the sources present were urban areas and mining. Cropland and transportation corridors were potential sources at 12% of the sites having impaired fish community integrity.

We could not statistically analyze relationships between either mean number of mussel species or mean mussel abundance and the number of human land uses present because of low sample size in certain land use categories. However, we observed lower mussel abundance and fewer mussel species

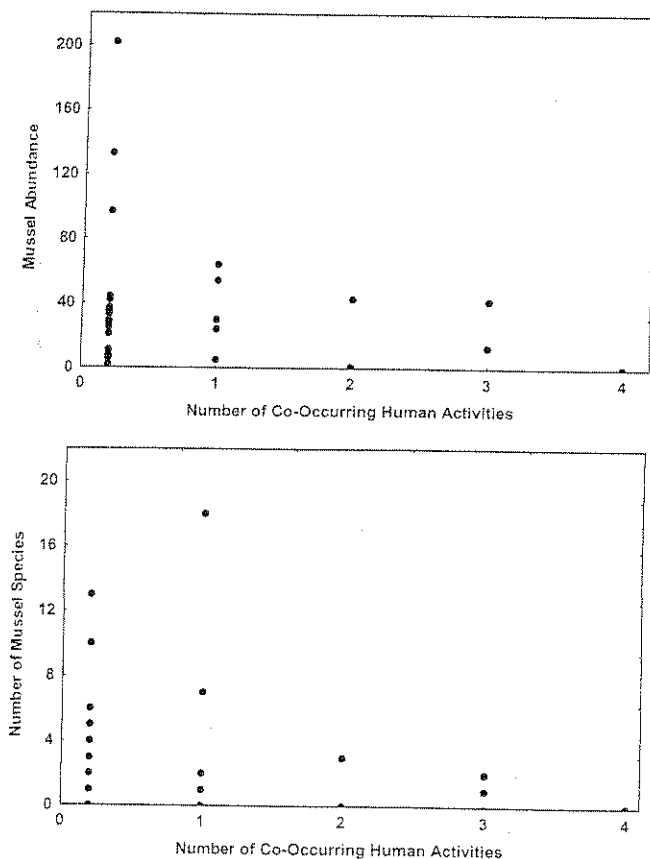


Fig. 4. Number of native mussels and number of mussel species collected as a function of the number of human land uses co-occurring. Data are taken from Tennessee Valley Authority's Cumberlandian Mollusc Conservation Program, 1986 ($n = 48$).

Table 7. Fish index of biotic integrity (IBI) scores in relation to the number of co-occurring land use sources present within 2 km upstream of the sampling point. Means with the same letter in common are not significantly different (Duncan multiple range test, $I < 0.05$)

Number of co-occurring land uses	Mean IBI	Minimum	Maximum	SD ^a
0	48.8 A	42	58	5.8
1	41.5 A, B	26	58	10.3
2	35.6 B, C	20	56	10.1
3	31.3 C	20	48	9.1
4	21.0 D	18	28	4.8

^a SD = standard deviation.

at sites having two or more of the four human land uses present as compared to sites with one or no human land use within the riparian corridor (Fig. 5). The maximum number of native mussel species observed in this data set (18) is comparable to some of the better mussel sites in the entire watershed, although still far less than the number of species historically reported (>35 species at many of these sites [9]).

In an attempt to examine vulnerability of native mussels to multiple land use sources of potential stress, we used the geographical information system (ArcInfo) to map significant mussel concentration sites, identified by the U.S. Fish and Wildlife Service, in relation to mines, major roadways, urban centers, and riparian agricultural areas. Mussel concentration sites typically harbor federal- as well as state-listed species of concern [10,19] and they are located in several locations within the Clinch River and some of its tributaries. No mussel concentration sites currently are known in the upper Powell and Guest rivers, consistent with the more intensive coal mining in that area. Of the 18 mussel concentration sites examined, none are reasonably isolated from major roads, mines, urban areas, or agricultural uses (Table 8). Ten of the 18 sites (55%) are within 2 km of a major transportation corridor, which, in some cases, have been sources of episodic toxic spills, as mentioned previously. Eight of the sites (44%) are vulnerable to two or more human land uses shown to be negatively associated with either fish IBI, EPT, mussel species richness, or a combination of these (Table 8).

More human sources of potential stress tended to co-occur

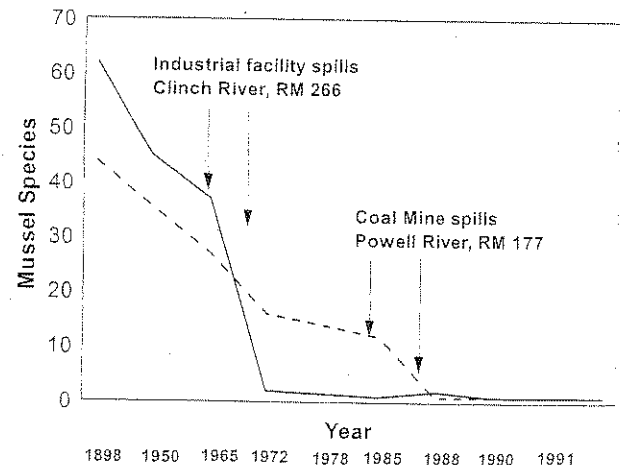


Fig. 5. Number of mussel species recorded over time at two sites in the Clinch-Powell watershed (VA, USA), each affected by large toxic spill events.

Relationships between human land uses and stream biota

Table 8. Riparian human land uses within 2 km of known mussel concentration sites identified by the U.S. Fish and Wildlife Service in the Clinch-Powell watershed (VA, USA). The plus symbol (+) denotes that source is present

Site	Mines	Urban	Agriculture	Major transportation
1	+	+		+
2	+	+		
3	+			+
4		+		+
5	+	+	+	+
6			+	+
7				+
8				+
9	+			
10	+		+	+
11				
12			+	
13				+
14			+	
15			+	
16			+	
17			+	
18			+	

in the upper Clinch River as compared to the upper Powell River (means = *t* test, and $p < 0.05$, $n = 33$, respectively). This was due to the greater frequency of urban and industrial activity and major highways in the upper Clinch River. Furthermore, the cumulative source index increased as one progressed upstream in the Clinch River ($r = 0.74$, $p < 0.05$, $n = 14$) because of the addition of more mining and urban influences in the upstream part of the river. A direct relationship between number of land use sources and river mile was not observed in the upper Powell River ($n = 19$, $r = 0.03$, $p > 0.10$), probably because of the concentration of mining activity in much of that subwatershed. Given that most mussel concentration sites presently are located in the Clinch-River drainage, the above information suggests that native mussel populations are relatively vulnerable in this watershed and that further extinctions or extirpations are likely to occur unless resource protection measures are taken.

DISCUSSION

Results of our analyses suggest that riparian human land use activities are important factors affecting native mussel, aquatic insect, and fish distribution in the Clinch-Powell watershed. Similar findings have been reported in many other watersheds [18,19]. However, our results indicate that moderate differences in the aerial extent of the riparian corridor can have large effects on the strength of observed land use-biota associations. The two subwatershed pilot analyses performed in this study indicated that agricultural land use associations with mussel species richness may have been underestimated when using a 2-km-long riparian corridor for all sites. Depending on the range of stream sizes, types of land uses, and perhaps other catchment characteristics observed across biological sampling sites, it may be necessary to calibrate appropriate riparian corridor dimensions to determine whether particular land use combinations are significantly affecting biota or their habitat.

The fairly low R^2 values observed in multiple regression analyses in this study demonstrate the difficulties in relating land use activities to biological or habitat measures on large spatial scales. Natural ecological features such as drainage area

(corresponding to elevation in our data set) or catchment slope (which may or may not be related to elevation), for example, are expected to influence biota distribution and abundance [19], independent of land uses. In the present study, we observed more significant relationships between land uses and fish IBI when using sites from a limited elevation range. Perhaps if other natural watershed factors can be controlled in analyses, relationships with land uses may be more readily observed. However, a difficulty with limiting our analyses to sites within a prescribed elevation range is that sample size decreased accordingly. As a result, the variability in land use percentages or combinations of land uses may not have been broad enough to allow large-scale relationships to be distinguished accurately. For example, we observed that percentage of pastureland was negatively associated with fish IBI in the Copper Creek subwatershed analysis (in which pasture was the major land use other than forest). However, in the watershed analysis, pasture was positively associated with fish IBI (and EPT as well). These disparate results may have been due to truly positive effects of pasture on fish and macroinvertebrates (e.g., nutrient enrichment) as compared to effects of other land uses such as mining. Alternatively, these results may have been due to too few sites with certain land use combinations [20].

Data quantity and variability also may have been factors affecting our ability to distinguish land use relationship with mussels. Sample size was limited more for mussels as compared to either fish IBI or EPT, and most sampling locations were on the mainstem rivers where local riparian land uses may have less influence on stream fauna as compared to smaller streams [21]. However, other researchers in this watershed also have reported limited associations between mussels and land uses [10,22]. Possible reasons include episodic toxic spills that did not originate from sources in the immediate vicinity of the site (i.e., >2 km upstream) and are too infrequent to yield consistent land use associations; fish host abundance in the area varies from year to year; or site-specific habitat characteristics such as orientation of bedrock strata or stream slope (shown to be a possible factor affecting mussel communities in the upper Clinch River) are more important in defining abundance and distribution of native mussel species [23].

Available information in this watershed, and results of this study, suggest that sedimentation and other forms of habitat degradation from urban uses, mining, and agricultural areas are likely to be limiting aquatic fauna in this watershed. For example, sedimentation due to accumulation of coal fines (fine particulate coal and refuse rock material) has been reported in many areas downstream of active coal mines and coal slurry ponds in the upper Powell River drainage [22,24]. Sedimentation and substrate embeddedness are major factors affecting mussel and fish distribution and abundance in lotic systems [24]. In most of these cases, little evidence has been found of mussel recolonization or recruitment to the affected areas despite improved water quality and documented recovery of fish populations [22,25].

Point and nonpoint source contaminants from coal mine activities, agricultural uses, and urban areas are also likely to be limiting aquatic fauna distribution. Insufficient water quality data were available for analyses in this study. However, previous site-specific studies in this watershed have documented water quality problems in certain locations in the watershed [26]. Deep coal mines, the dominant form of mining in the watershed, also have discharged toxic concentrations of

hydraulic emulsion oils originating from underground coal mining equipment [27]. Non-point-source inputs of agricultural pesticides, particularly in the more fertile bottomlands and valleys, also are a potential source of toxic stress on native fish and mussels in this watershed.

Although others have observed that riparian vegetation can reduce deleterious land use effects on water quality if large enough [28,29], it is not clear that improvement of the riparian corridor alone in this watershed will result in recovery of native mussel and fish populations. Several researchers have reported significant effects of upland land uses on surface water quality depending on catchment topography and the spatial pattern of land uses in the watershed [18,30]. For example, a 1999 mussel survey of Copper Creek indicated a loss of mussel species as compared to a similar survey performed in the 1980s, apparently because of more pervasive sedimentation in the stream, even though riparian land uses have not changed appreciably (S. Ahlstedt, U.S. Geological Survey, unpublished data). If agricultural or livestock use upstream is great enough, sedimentation effects and subsequent loss of habitat may result for some distance downstream even though forested riparian areas may be present directly upstream of a given site.

In the Clinch-Powell watershed, several reports have been made of little or no recovery of threatened or endangered mussel or fish species [10,31]. Mussel introduction efforts have had very limited success in most cases [32; R. Neves, U.S. Fish and Wildlife Service, personal communication] and would not be expected to improve mussel recruitment unless no habitat limitations exist and sufficient host fish are present in the area [33]. For some threatened and endangered mussel species, glochidia may be able to parasitize only a few fish host species [5,33]. If fish host species are reduced in number or avoid an area because of certain stressors, mussels dependent on those species will also be affected.

We observed a greater number of co-occurring potential land use stressors in the upper parts of this watershed, which is particularly significant in terms of resource conservation efforts. This pattern, combined with naturally fewer mussel and fish species at higher elevations and decreased drainage area, suggests that mussels and other aquatic life are especially vulnerable in upstream reaches of the Powell and Clinch rivers and their tributaries. The vulnerability of fauna in headwater areas of this watershed has been evidenced by the fact that many current threatened and endangered mussel species were historically present in fair numbers in small tributaries and headwater areas of the Clinch-Powell watershed (Fig. 1) [8,9].

With any endemic population, a high risk exists of extirpation due to habitat fragmentation resulting in populations that are too inbred, small in size, and more susceptible to stressors [1]. Native mussels and fish in the Clinch-Powell watershed are no exception. Populations are now more widely separated than they were historically [8], which could lead to reduced recruitment success and declining populations. For this reason, it may be a higher priority to further protect those populations that appear most vulnerable due to proximity to mining, urban and agricultural areas, or transportation corridors. Protection or enhancement of the riparian corridor at these sites, as well as protection from toxic spills and sedimentation, may help to sustain endemic species in the watershed.

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