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Technical Article

The Effects of Isolation and Acid Mine Drainage on Fish and Macroinvertebrate Communities of Monday Creek, Ohio, USA

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Abstract. Isolated headwater streams in mined watersheds may have good water quality and fish habitat, yet be disconnected from immigration sources by stream segments impaired by acid mine drainage (AMD). Studies of fish and macroinvertebrate communities, habitat, and a number of hydrochemical parameters in Monday Creek, Ohio, show that AMD eliminates fish communities and severely limits macroinvertebrate communities in directly affected tributaries. Isolated headwaters in the heavily mined Monday Creek watershed have relatively good water quality and habitat, but poor fish communities. Comparison of isolated Monday Creek headwaters with non-isolated reaches in unmined watersheds indicates that differences in fish communities are attributable to isolation. Fish communities in isolated headwaters have lower Indices of Biotic Integrity (IBI) than comparable non-isolated communities, reduced species numbers, and lower numbers of individuals, despite suitable habitat as measured by the Qualitative Habitat Evaluation Index (QHEI). Comparison of macroinvertebrate communities shows higher Invertebrate Community Indices (ICI), and no apparent species loss, which can be attributed to the obligate flight stage in the life cycle of many macroinvertebrates, which enables them to overcome aquatic barriers. The implication of this research is that there is an opportunity for recovery of depleted fish communities in large AMD-isolated areas with good water quality, suitable habitat, and intact macroinvertebrate communities, by downstream treatment or source control of AMD to create aquatic corridors for fish immigration.

Key words: acid mine drainage, isolation, fish, macroinvertebrates, habitat, diversity

Introduction

Acid mine drainage (AMD) from abandoned coal mines and waste piles has damaged over 8000 km of streams in the northern Appalachian coal province, which consists of parts of Maryland, Ohio, Pennsylvania, Virginia, and West Virginia (USEPA 1995). Half of these streams support no fish. While damage is extensive, water in mined areas is not uniformly degraded, and some headwaters and tributaries exhibit good water quality and suitable habitat. Aspects of physical habitat such as cover, channel morphology, riparian quality, gradient and pool/riffle quality may be good in underground-mined watersheds, possibly due to lack of agricultural and urban pressures. Prioritizing tributaries for restoration to 'fishable' conditions should be based on whether or not habitable conditions and regionally appropriate faunal communities can be achieved (Stoertz and Burling 1996). The existence of both habitable and potentially habitable tributaries upstream from AMD impacts is encouraging for restoration of heavily mined watersheds. Upstream areas may have been isolated from downstream sources of immigration of species for many years. The integrity of such isolated biotic communities is expected to be less than that of communities not isolated from downstream sources of re-colonization. If that proves to be true, then in cases where AMD isolates parts of a watershed, there is an opportunity for recovery of depleted fish communities in large isolated areas by downstream treatment or source control of AMD. Treatment might include addition of alkalinity by lime dosing (e.g., Zurbuch et al. 1996), diversion wells, limestone or steel slag leach beds, limestone rock channels, or passive treatment systems such as anoxic limestone drains (e.g., Skousen and Ziemkiewicz 1995) or SAPS (Successive Alkalinity-Producing Systems, Kepler and McCleary 1994). Source control might include inundation of mines or wastes, mine sealing (e.g., Stoertz et al. 2001), or stream diversion away from sinkholes or around waste piles (e.g., Pereira 2001).

Isolation of aquatic communities has been studied mainly in the context of river damming (Dynesius and Nilsson 1994; Linfield 1985; Winston et al. 1991), with relatively few studies involving isolation by contamination from sewage, agrichemicals or acid rain (Colquhoun et al. 1984; Schofield and Driscoll 1987; Zwick 1992). Even fewer address isolation by mining contamination (Zwick 1992). Interruption in any river continuum fragments the hierarchical stream network, disconnecting upper sections of the catchment and turning them into separate island-like systems (Zwick 1992). Reduced diversity on islands and the dependence of immigration and emigration on the distance from other suitable habitats are well known (MacArthur and Wilson 1967). The dangers of isolation are far greater for aquatic species without a flight stage because upstream migration is the only source of re-colonization for such species. The regular dispersal of adult aquatic insects in a characteristic colonization cycle has been well studied. The direction of this dispersal to upstream areas and neighboring streams is vital to the persistence of these species (Zwick 1992).

The low-pH conditions associated with AMD have the potential to create a chemical barrier to aquatic fauna due to interference with normal physiological function, especially respiration (Hellawell 1986). AMD is generated after sulfide minerals associated with high-sulfur coal seams are exposed to air, water, and chemosynthetic bacteria (Nordstrom and Southam 1997). Formation of acid begins with the oxidation and hydrolysis of FeS_2 (pyrite) producing soluble hydrous iron sulfates and acid. AMD is characterized by low pH, which leaches trace metals from the substrate (Henrot and Weider 1990; Spotts and Dollhopf 1992), by low alkalinity, and by elevated levels of dissolved iron, sulfate, and total dissolved solids (FWPCA 1968; Pfaff et al. 1981; Westover and Eberle 1987). Typical chemical indicators of the presence of AMD include the following: pH <6, alkalinity <20 mg/l, iron >0.5 mg/l, manganese >0.5 mg/l, sulfate >75 mg/l, aluminum >0.3 mg/l, specific conductance >800µS/cm, and zinc >5 mg/l (FWPCA 1968; USEPA 1986). AMD has been shown to decrease the number of species and organisms found in affected areas due both to reduced pH and the toxicity of dissolved metals (Brocksen et al. 1992; Hellawell 1986). Dissolved aluminum and zinc are acutely toxic (Boult et al. 1993; Exley et al. 1991; Hill et al. 1997). The combined effects of the acidity and metals can make metals more toxic in the stream environment (Katz 1969; Nichols and Bulow 1973). However, there is no clear chemical threshold for AMD indicators above which AMD is harmful, because tolerance thresholds have not been established for all AMD parameters and all species.

The three counties of the Monday Creek watershed were once among the major sources of coal in southeastern Ohio, yielding more than half a billion tons from 1816 to the present (Crowell 1995). Extensive mining operations have left portions of the watershed damaged by AMD for a century or more. Monday Creek, located in the Hocking River drainage basin (Figure 1), is undermined by about 60 km^2 of abandoned underground coal mines, amounting to 20% of the watershed's 300 km^2 drainage area (OU Cartographic Center 1985). Strip mines cover another 4%. Where mine openings and refuse piles discharge acidic water laden with heavy metals and sulfates, stream pH drops as low as 2.3. Some tributaries have poor water quality and high acidity loading; others have pH values above 6 or 7 but are isolated from the Hocking River by contamination of the lower reaches of Monday Creek. We hypothesized that a reduction in both numbers and diversity of freshwater species has occurred in headwater streams of Monday Creek isolated by downstream AMD. To test this, we assessed chemical and biological conditions in a severely AMD-polluted tributary, two isolated tributaries, and two nearby non-isolated tributaries of the same size.

Materials and methods

The effects of AMD in Monday Creek were determined by comparing faunal communities and water chemistry in affected headwater reaches with headwater reaches in unaffected drainages. Affected reaches included those with a direct AMD impact as well as those isolated by AMD. In selecting reaches for comparison, differences in stream size and habitat were minimized because such differences produce variation in species makeup. Reaches were selected in watersheds of comparable size with respect to area and discharge, but of differing order (Hughes and Omernik 1983). The Qualitative Habitat Evaluation Index (Rankin 1989; USEPA 1989) was used to assess comparability of the sites. The QHEI incorporates those physical habitat factors that have been correlated to fish (and to some extent, invertebrate) communities. The six interrelated metrics that form the QHEI are substrate, in-stream cover, channel morphology, riparian and bank condition, pool and riffle quality, and gradient.

The three sites selected based on comparable drainage area within the Monday Creek watershed were in Sycamore Hollow, Sand Run, and Brush Fork (Figure 1). Respective drainage areas for the sampling sites are 2.71 km^2, 3.39 km^2, and 3.46 km^2. The first two are 2nd-order streams that exhibit little direct effect of AMD, while Brush Fork is a severely impacted 4th order stream, almost completely undermined and with obvious mine drainage. These Monday Creek reaches were compared to two 3rd order reaches: Sharps Run (3.67 km^2) and Miller Run (3.41 km^2), 35 km to the southeast. These tributaries are neither affected nor isolated by AMD. Low stream pH correlates strongly

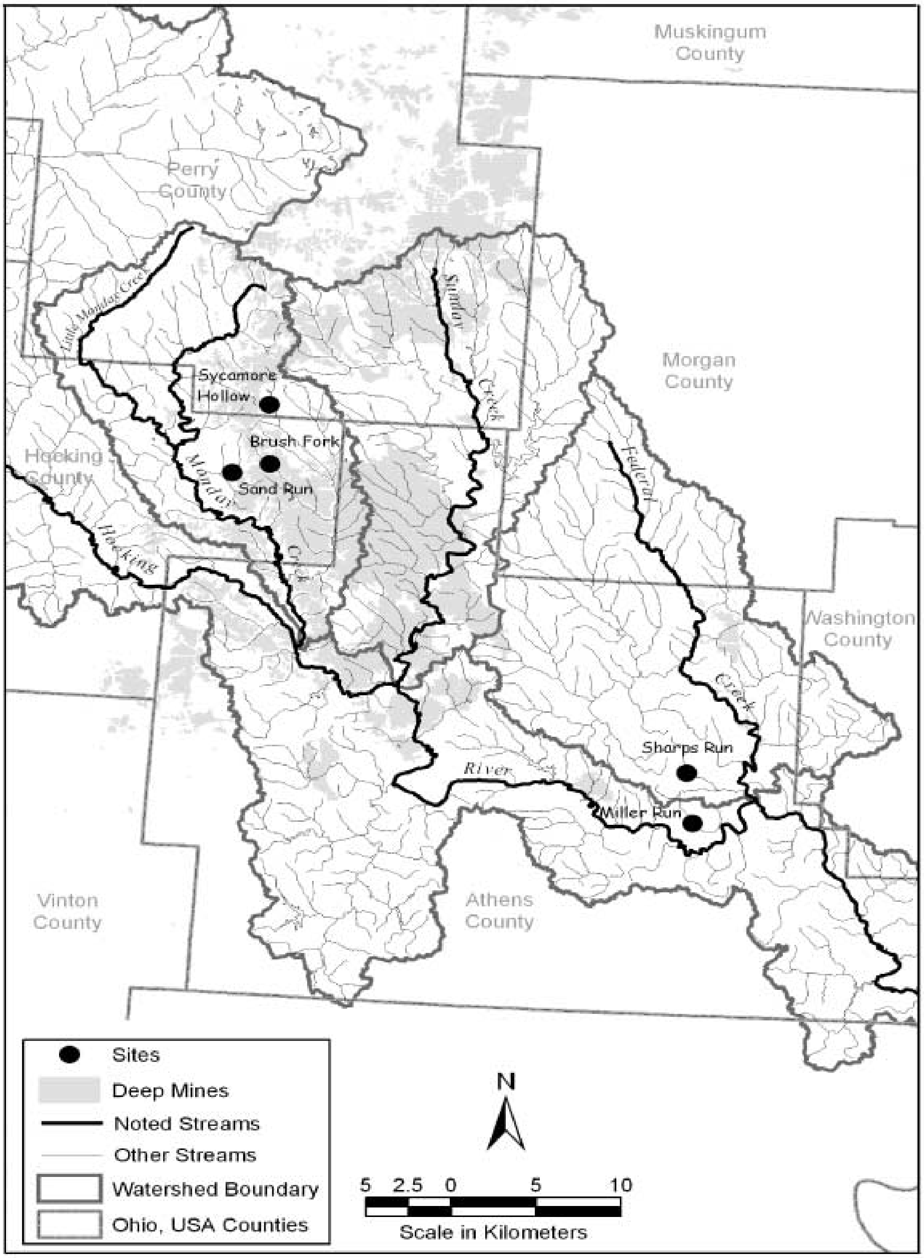

Figure 1. Map of Monday Creek, in southeastern Ohio, showing sampling site locations.

with distribution of underground mines (mines indicated by shading, Figure 1). Upper Sycamore Hollow is isolated by 15 km of pH <4.5 stream; Sand Run is isolated from the Hocking by >2 km of stream with pH <3.5, but is accessible to clean upstream tributaries. Mining affects neither Sharps nor Miller Run. The comparison between the watersheds is important because the pattern in a relatively undisturbed fauna must be known before changes due to environmental alterations can be determined (Matthews et al. 1988). Sharps and Miller Runs appear to be appropriate controls for comparison because they have IBI values similar to other similar-sized streams in this region of Ohio (OEPA 1987).

Macroinvertebrates were collected in June, September, December, and March, using a surber stream bottom sampler in riffles, and a kick net in pools. Replicate surber and kick-net samples were combined for each reach per season since intersite comparisons were of interest (Bargos et al. 1990; Peterson and VanEeckhaute 1992). This design maximized the number of taxa collected by incorporating seasonal and spatial variations (Weatherley and Ormerud 1987). Surber samples were collected from shallow areas (<25 cm depth) by stirring a 0.09-m^2 area in the riffle with a trowel to a depth of 10-15 cm. Pool samples were collected by kicking substrate materials in a 0.1 m^2 area immediately upstream from a D-frame collecting net for 30 s. At the Sycamore Hollow, Sand Run and Brush Fork sites, 3 surber samples and 3 kick net samples were collected. In Sharps and Miller Runs, 2 surber samples and 2 kick net samples were collected at each site. Fine debris and cobble were preserved in 70% ethyl alcohol and returned to the lab for further separation by the sucrose flotation method (Lind 1974). Mollusks and case-bearing larvae were separated by hand (Cummins 1962). Macroinvertebrates were classified to genus (except Chironomid midges, which were identified to tribe) since this approach has been shown to yield sufficient taxonomic resolution for identification of impacts (Cain et al. 1992). To assess the biological condition of the macroinvertebrate community, the Invertebrate Community Index (ICI; OEPA 1987) was used. This index combines 10 characteristics of the macroinvertebrate community (Table 1a).

Fish were collected at replicate sites between August and December 1995 using a 2.4-m straight minnow seine with a 3mm mesh. Each site consisted of two riffles and two pools, and was seined for 20 minutes. Fish were preserved in 10% formalin and transferred to 70% ethanol. Specimens are archived in the Ohio University Vertebrate Collection. To assess the biological condition of the fish communities, the Index of Biotic Integrity (IBI) (Angermeier and Karr 1986) was used, with a "low-end scoring" modification for headwaters sites in Ohio, appropriate when fewer than 200 individuals are recorded (OEPA 1987). This index compares 12 characteristics of a fish community with those expected under minimal human influence, allowing for natural differences in the species distribution and abundance among different water body sizes, types, and regions (Miller et al. 1988). The IBI metrics (Table 1b) relate to species composition and ecological factors, assessing the presence of intolerant species, trophic levels, and families (Karr 1981).

Results

Water Quality and Habitat

Sycamore Hollow water-quality parameters were near or below levels indicative of AMD (Table 2). Sand Run showed evidence of AMD, attributed to mining on the watershed periphery, and Brush Fork was clearly impacted by AMD. Sharps and Miller Runs exhibited few signs of AMD. Although sulfate concentrations in Sycamore Hollow, Sharps Run and Miller Run were below levels indicative of AMD, they generally were above the ~20 mg/l level expected in average streams (FWPCA 1968). Not surprisingly, QHEI values for Brush Fork (Table 3) are consistent with heavy mining. The other four tributaries all have QHEI scores >60, indicating that they should be attaining warmwater habitat standards (Rankin 1989).

Table 1. a) Metrics used to calculate the Invertebrate Community Index (ICI: OEPA 1987) for macroinvertebrate communities. All metrics except 5 and 7 have criteria that vary with drainage size.

1. Total number of taxa
2. Total number of mayfly taxa
3. Total number of caddisfly taxa
4. Total number of dipteran taxa
5. % mayfly composition
6. % caddisfly composition
7. % Tanytarsini midge composition
8. % other Diptera and non-insect composition
9. % tolerant organisms
10. Total number of EPT taxa

b) Metrics used to calculate the Index of Biotic Integrity (IBI: OEPA 1987) for fish communities surveyed in this study. The metrics are derived for headwater streams. Asterisks indicate scoring criteria that vary with drainage area.

1. Total number of species*
2. Number of darter and sculpin species*
3. Number of headwater species
4. Number of minnow species*
5. Number of sensitive species*
6. % tolerant species
7. % pioneering species
8. % omnivores*
9. % insectivores*
10. Number of simple lithophilic species*
11. % DELT anomalies
12. Number of individuals sampled per 0.3 km of stream*

Macroinvertebrates

Fifty-seven macroinvertebrate genera were collected at all tributaries together (Table 4). As expected, community composition of the sites not directly affected by AMD was more diverse than that of Brush Fork (Table 3). Of 8 genera in Brush Fork, Chironimini accounted for 94% of the individuals collected. Samples from Sycamore Hollow and Sand Run included 45 genera, while samples from Sharps and Miller Runs included 37 genera. The Shannon-Weiner diversity index shows no significant difference in diversity between the isolated and non-isolated tributaries (Table 3).

Table 2. Water chemistry averaged over 2-3 sample sites in each tributary. Blank entry indicates no data; "n.d." indicates that the parameter is below detection limit. Bold type indicates levels associated with AMD (FWPCA 1968; USEPA 1986), but these levels do not necessarily indicate a biotic impact.

	pH	Temp (C)	Alkalinity (mg/L)	Spec. Cond. (uS/cm)	Sulfate (mg/L)	Total Al (mg/L)	Total Fe (mg/L)	Total Zn (mg/L)	Total Mn (mg/L)
Sycamore Hollow (3 sites)									
6/14/95	7.2	20.0		371	36	0.03	0.09	0.005	0.09
7/19/95	6.9	21.0	145	409	30	**0.36**	**2.37**	0.023	**1.54**
8/21/95	6.9	22.4	156	415	29	0.10	**0.96**	0.012	0.45
10/22/95	6.6	9.7	140	530	36	0.09	**1.54**	0.009	**0.59**
11/18/95	6.9	6.0	128	519	49	0.13	**1.33**	0.004	0.21
12/3/95	6.5	4.0	132	514	46	n.d.	0.05	n.d.	0.04
2/10/96	6.9	1	65	503	38	**0.46**	**1.85**	0.033	**0.56**
3/2/96		2.3	59	271	38	0.17	**0.51**	n.d.	0.08
4/12/96	7.1	18	73	454	40	**0.43**	**0.65**	0.020	0.05
5/12/96	7.1	12.5	61	218	32	**0.60**	**0.53**	0.006	0.06
Mean	6.9	11.7	107	420	37	0.24	**0.99**	0.011	0.37
Sand Run (3 sites)									
6/14/95	6.6	21.8		636	**477**	0.25	0.47	0.028	**0.96**
7/19/95	6.5	23.5	26	619	**381**	0.30	**0.56**	0.012	**0.62**
8/21/95	6.6	25.5	34	576	**438**	0.08	**0.71**	0.025	0.46
9/14/95	**5.8**	20.3	35	541	**331**	0.29	**1.01**	0.105	**1.07**
10/22/95	6.8	10	45	**1030**	**559**	0.24	0.48	0.033	**0.64**
11/18/95	6.6	6	47	**1035**	**559**	0.23	0.39	0.030	**0.74**
12/3/95	6.1	5	35	**1001**	**513**	0.11	n.d.	0.023	**1.67**
2/10/96	6.5	1	**19**	**1293**	**421**	**0.38**	**1.11**	0.074	**0.82**
3/2/96		3.5	**14**	611	**473**	**0.44**	**0.73**	0.027	**0.97**
4/12/96	6.1	18.3	**13**	552	**394**	**0.52**	0.49	0.034	**0.83**
5/12/96	6.8	15	21	538	**456**	**0.45**	**0.52**	0.026	**0.99**
Mean	6.4	16.0	37	777	**465**	0.21	**0.61**	0.037	**0.88**
Brush Fork (3 sites)									
6/14/95	**3.2**	19.3		**1601**	**741**	**11.1**	**9.4**	0.281	**4.89**
7/19/95	**2.8**	20.7	**n.d.**	**1582**	**624**	**15.3**	**9.1**	0.309	**5.60**
8/21/95	**2.8**	22.0	**n.d.**	**1462**	**776**	**15.6**	**11.0**	0.352	**6.07**
9/14/95	**2.8**	20.7	**n.d.**	**1662**	**722**	**19.4**	**15.0**	0.393	**6.48**
10/22/95	**2.8**	12.2	**n.d.**	**2017**	**790**	**17.6**	**20.6**	0.357	**6.47**
11/18/95	**3.1**	7.0	**n.d.**	**1744**	**817**	**10.9**	**14.8**	0.235	**4.76**
12/3/95	**2.8**	7.0	**n.d.**	**1889**	**817**	**8.0**	**5.3**	0.211	**3.87**
3/2/96		6.0	**n.d.**	733	**537**	**7.1**	**9.8**	0.143	**2.82**
4/12/96	**3.7**	18.0	**n.d.**	**900**	**559**	**9.3**	**9.9**	0.250	**4.01**
5/12/96	**4.8**	15.5	**4**	515	**489**	**4.0**	**3.2**	0.150	**2.44**
Mean	**3.2**	14.0	**0.4**	**1416**	**679**	**12.4**	**12.6**	0.279	**4.92**
Sharps Run (2 sites)									
8/3/95	7.0	22.5	215	**805**	22	0.17	0.21	0.003	0.065
9/21/95	6.8	17.0	216	797	22	n.d.	0.19	0.008	0.100
12/2/95	6.9	5.5	196	**881**	36	0.17	0.29	0.018	0.040
3/3/96		2.0	158	494	29	n.d.	n.d.	n.d.	n.d.
Mean	6.9	11.8	196	744	27	0.09	0.17	0.007	0.051
Miller Run (2 sites)									
8/3/95	6.9	21.5	97	584	15	0.13	0.22	0.004	0.17
9/21/95									
12/2/95	6.9	3.8	84	639	33	0.30	**1.06**	0.049	0.28
3/3/96		2.5	120	400	27	n.d.	n.d.	n.d.	n.d.
Mean	6.9	9.3	100	541	25	0.14	0.43	0.018	0.15

Fish

Four species of fish were collected in Sycamore Hollow and Sand Run (Table 5). *Semotilus atromaculatus* constituted 50% of the fish collected in Sycamore Hollow and 42% in Sand Run. The most abundant of the 12 species in Sharps and Miller Runs were *P. erythrogaster*, *S. atromaculatus, R. atratulus*, and *Campostoma anomalum*. IBI values indicate that Sharps and Miller Runs have 'good' fish community condition, and Sycamore Hollow and Sand Run have 'poor' conditions (OEPA 1987) relative to reference sites in Ohio. Sharps and Miller Runs attain modified warmwater habitat standards (IBI=24-43) for reference streams in the Western Allegheny Plateau ecoregion (OEPA 1989a). Streams of similar drainage size in this region have similar numbers of fish species (8.5) (Clifford and Snavely 1954). Sycamore Hollow and Sand Run barely attain these standards. Brush Fork is considered a limited-resource water (OEPA 1987), due to its extremely low IBI score.

Discussion

The impact of coal mining on the Monday Creek watershed varies depending on whether tributaries directly receive AMD or are indirectly affected through isolation by polluted reaches. Brush Fork is directly and severely impacted by AMD, having poor water quality and supporting no fish community and a low-diversity macroinvertebrate community. Sand Run and Sycamore Hollow are isolated by AMD, showing little or no direct AMD impact. These isolated tributaries have good water quality and good habitat, and support a diverse macroinvertebrate community. Fish communities, however, have lower diversity than comparable non-isolated tributaries. A barrier of poor water quality in lower Monday Creek causes isolation, cutting off downstream sources for re-establishment of fish. Fish sampling by the Ohio EPA in the lower Monday Creek mainstem yielded 15 individuals of 4 species, an inconsequential number compared to the 1200 individuals of 30 species expected in similar-sized healthy drainages in the area (Ohio ECOS database, OEPA). Moreover, these few fish are believed to have strayed from tributaries, and are surviving in narrow stream margins where hyporheic flows create tolerable conditions (C. Boucher 2002, OEPA, pers comm).

Tolerance to AMD

Numerous macroinvertebrate taxa collected in Sycamore Hollow and Sand Run have previously been designated as intolerant to low pH (Bell 1971; Hellawell 1986; Warner 1971). The large number of species found in Sycamore Hollow and Sand Run (30 and 41) is consistent with other streams in Ohio considered of high quality, such as the upper Cuyahoga, which has 24-63 species (Olive et al. 1988). The presence of intolerant taxa (*Gyrinus, Gerris*) in Brush Fork suggests that there may be tolerant macroinvertebrate species within otherwise intolerant genera.

The presence of fish in isolated reaches suggests that these sites may never have been so damaged as to have completely lost their fauna. It is not surprising that the tolerant and abundant cyprinids are the predominant species in these headwaters. The absence of less tolerant species (e.g., *Etheostoma spp*., OEPA 1989b) indicates that there may have been conditions that only the most tolerant species could survive. The fish faunal variation between Sharps and Miller Runs was higher than that observed between Sycamore Hollow and Sand Run. This finding is consistent with the observation that healthy streams will display wider variation in species makeup than polluted streams, due to regular stochastic processes (Reash and Berra 1987). Polluted streams are able to support a small number of pollution-tolerant species that are regulated by environmental stress rather than biological interactions.

R. atratulus cannot survive sustained levels of dissolved Al above 0.11 mg/l (Simonin and Kretser 1993). Total Al levels reached 0.60 and 0.52 mg/l for Sycamore Hollow and Sand Run respectively.

Aluminum is much less toxic at the near-neutral pH measured during the occurrences of high total Al levels (Brocksen et al. 1992), and is likely to form complexes at these pH levels (Stumm and Morgan 1996). When such high total Al concentrations were detected in Sycamore Hollow, *Rhinichthys* was not found. This species was never found in Sand Run, which had higher average aluminum levels. Iron concentrations in Sycamore Hollow and Sand Run

Table 3. QHEI, IBI, ICI, and Shannon-Weiner macroinvertebrate diversity values averaged over samples in each tributary

Tributary	QHEI	IBI	ICI	Diversity
Monday Creek				
Sycamore Hollow	70.5	28	42	0.69
Sand Run	62.5	23	50	0.85
Brush Fork	49.0	12	2	0.14
Eastern tributaries				
Miller Run	69.0	45	34	0.79
Sharps Run	73.5	44	42	0.67

Table 4. Occurrence of macroinvertebrate taxa collected from Hocking River tributaries, Athens, Hocking, and Perry Counties, Ohio, 1995-1996. Table continues on next page. Asterisks (*) indicate taxa reported as intolerant to low pH (Bell 1971; Hellawell 1986; Warner 1971).

Taxa	Sycamore Hollow	Sand Run	Brush Fork	Miller Run	Sharps Run
Coleoptera					
Carabidae			1		
*Dubiraphia**		5		3	3
Eubrianax	1			6	
Gyrinus			5		
Hydactus			13		
Hydrobus				1	
Macronychus	26	2			
Neoelmis					2
Rhizelmis	2	2		101	27
Sperchopsis	1				
*Stenelmis**	5	3		5	1
Stenopelmus		1			
Diptera					
Chironomidae			16	3	
Chironomini	5	29	825	259	59
Chrysops		3			
Hexatoma	40	27		2	12
Molophilus			1		
Orthocladiinae	3	2			
Pseudolimnophila	3	20		3	
Psychoda					3
Stratiomys					4
*Simulium**		6			
Tabanus	7	35		16	5
Tanypodinae		24		44	21
Tipula	10	10		3	6
Ephemeroptera					
Ameletus	9	6		3	
*Caenis**	2	106		36	74
Ephemera	13	3		31	24
Ephemerella	14	2			
Eurylophella	86	30		63	3
Leptophlebia	7	24			
Neoephemera		2			
*Stenonema**	40	25		58	137
Hemiptera					
Gerris	3		1		1
Micracanthia				1	
Microvelia		1			
Megaloptera					
Neohermes		17		3	1
Sialis		13	14	30	6
Odonata					
Calopteryx	3	8		1	
Cordulegaster	10	35			2
*Gomphus**		6			
Plecoptera					
Allocapnia	1005	121		90	337
Beloneuria	4	4			
Capnia	167	13			136
Isoperla	38	26		26	60
Leuctra	73	6			12
*Perlesta**	14	12			
Taeniopteryx	14			1	17

Taxa	Sycamore Hollow	Sand Run	Brush Fork	Miller Run	Sharps Run
Trichoptera					
Cheumatopsyche		16		2	
Hydropsyche		55		1	
Macrostemum		4			
*Neureclipsis**		15			
Phryganea		1			
Pyncnopsyche	10	16			1
Amphipoda					
Gammarus				15	8
Decapoda					
Orconectes	6	14		7	13
Isopoda					
Asellus				294	4
Number of taxa	30	41	8	29	28
Individuals	1621	750	876	1984	962

Table 5. Summary of species, tolerances, feeding guilds and number of individuals of fishes sampled in Monday Creek and Federal Creek tributaries.

Fish Species	Tolerances[1]	Feeding Guild[1]	Sycamore Hollow	Sand Run	Miller Run	Sharps Run
Semotilus atromaculatus	T	G	80	48	6	18
Phoxinus erythrogaster	ND	H	60	57	76	167
Rhinichthys atratulus	T	G	18	1	9	6
Pimephales notatus	T	O			5	1
Cyprinella whippeli	M	I			2	
Ericymba buccata	ND	I			5	
Campostoma anomalum	ND	H			20	4
Catostomus commersoni	T	O			1	
Ethestoma spectabile	ND	I				3
Etheostoma flabellare	ND	I			2	7
Etheostoma nigrum	ND	I				2
Lepomis macrochirus	M	I	1		1	

[1] Pollution tolerances and feeding guilds as determined by the Ohio EPA (1989b); T-highly tolerant, M-moderately intolerant, ND-not determined; G-generalist, H-herbivore, I-specialist insectivore, O-omnivore

exceeded threshold levels associated with AMD. Unmined basins have been shown to commonly exceed EPA indicator limits of 0.5 mg/l, but seldom exceed 1.0 mg/l (Pfaff et al. 1981), whereas mined basins frequently exceed 1.0 mg/l iron. Zinc and manganese are not at levels that are considered a threat to fish in these streams (Hellawell 1986), but suggest that mining has occurred in the area. Other indicators include sulfates and specific conductance. The Ohio Administrative Code sulfate standard for protection of aquatic life is 1500 mg/L, a level that was not reached in these tributaries.

Reduced species richness, as observed in Brush Fork, is consistently associated with acidic conditions (Baker and Christensen 1991; Griffith et al. 1995). The pH has been shown to play a large role in influencing community composition and abundance. Species responses to decreased pH levels include increases in drift and lower species richness (Feldman and Connor 1992). Odonata, Ephemeroptera, and Plecoptera have been eliminated from communities exposed to constant AMD, while Trichoptera, Megaloptera, and Diptera may be represented by only a few species (Hellawell 1986). Brush Fork followed this pattern of community composition.

Habitat and community indicators

The IBI scores for Sharps Run and Miller Run rate the biological integrity of these tributaries as good to exceptional. Sycamore Hollow and Sand Run score as poor to fair. Some of the variation may be attributable to position of the sampling site in the stream network. IBI scores in the headwater portions of streams are expected to be lower than scores in similar size streams connected directly to the mainstem. At least 3 of the 12 metrics, including species richness and the number of darter and sucker species, are influenced by the location of a tributary within a drainage network

(Osborne and Wiley 1992). Even in non-fragmented stream systems, the increase in species number from small tributaries of main channels to similar-size headwaters can vary from 130 to 160% (Osborne and Wiley 1992). In comparison, the increase from Miller Run, which is near the main channel, and Sycamore Hollow and Sand Run, which are headwater tributaries, is 250-330%.

The makeup of trophic guilds can also provide information on the health of streams. Dominance of insectivores is evidence that stream habitat is good (Karr 1981). In addition, a small proportion of omnivores and a large number of darters and minnows also reflect environmental health. In polluted waters, generalized omnivores, and herbivores are dominant (Reash and Berra 1987). The Monday Creek tributaries support generalist and herbivore species (only one specimen of an insectivore species was found) while the eastern non-isolated tributaries support a more diverse fauna. Differences in fish species richness have been related to the proximity of higher order streams and increased rates of recolonization after disturbance (Osborne and Wiley 1992). The Monday Creek tributaries are isolated from a species pool for re-colonization. The species makeup of the eastern tributaries is a typical headwater fauna consisting of approximately 12 species representing a variety of trophic levels and tolerances. Twelve to 34 fish species can be expected in streams that are of the same size as the investigated tributaries (Osborne and Wiley 1992; Paller 1994; Reash and Berra 1987). Clearly, Monday Creek tributaries have fewer species than would be expected.

Effects of isolation

The IBI shows that while non-isolated Sharps and Miller Runs meet warm water standards of biological integrity, isolated Sycamore Hollow and Sand Run do not, even though water quality and habitat (as measured by QHEI) are not limiting (Figure 2). Clean-water communities are expected to consist of a small number of abundant species with a greater number of rare species (e.g., Reash and Berra 1987). Following environmental perturbation, some species may be lost, especially rare species. These populations normally are reestablished from downstream areas via dispersal. In Monday Creek, however, downstream pollution has made recolonization by these species unlikely. Sand Run potentially can be repopulated from uncontaminated upstream Monday Creek, which itself is isolated from the Hocking River (Figure 1) and shows reduced species richness (J Grow 1998, OEPA, pers comm). Isolation has been shown to delay the ability of stream fish communities to recover after a perturbation (Lonzarich et al. 1998). Three of the four most abundant species found in Sharps and Miller Runs, *P. erythrogaster, S. atromaculatus*, and *R. atratulus*, were also found in Sycamore Hollow and Sand Run. Species less abundant in Sharps and Miller Runs (*Pimephales notatus* and *Catostomus catostomus*), though tolerant to degraded environments (Table 5), have been lost. The absence of rare but tolerant species suggests that factors other than water chemistry (i.e. stochasticity due to isolation) may be contributing to community composition. Local or occasional damage to fish populations may turn into large-scale extermination in cases where distances to other appropriate reaches are greater than the average dispersal capacity. In some cases, recolonization can occur from within the affected river if the area is large enough. With isolation, missing species may not return even with an improvement in water quality.

Isolation appears to have had less effect on macroinvertebrate communities than on fish communities. Macroinvertebrate species richness in Sycamore Hollow and Sand Run is similar to that observed in Sharps and Miller Runs. Despite similar species richness, a number of taxa are not shared among the surveyed streams (Table 4). The isolation of headwater streams may result in changes in diversity patterns, especially for those species closely tied to dispersal along the streams (e.g., Jansson et al. 2000; Zwick 1992). Furthermore, short-distance dispersers would have greater difficulty colonizing isolated reaches than species with greater flight abilities (Zwick 1992). Recolonization for most macroinvertebrates would be easier than for fish due to the obligate flight stage in the life cycles of all of the macroinvertebrates collected in the tributaries except Amphipoda, Decapoda, and Isopoda.

Importance for restoration

Macroinvertebrate diversity did not differ significantly between isolated and non-isolated streams in this study, and macroinvertebrate species numbers were in fact greater in the isolated streams. Macroinvertebrates with a flight stage have maintained populations in the isolated tributaries. Fish species numbers in the isolated streams, in contrast, are reduced greatly from numbers in comparable non-isolated streams. Water quality is high, and therefore not likely to be contributing to the reduced richness of the fish community. In streams where AMD inputs are buffered and water quality is good, metal hydroxide precipitation may nevertheless degrade habitat and result in low numbers of organisms, particularly

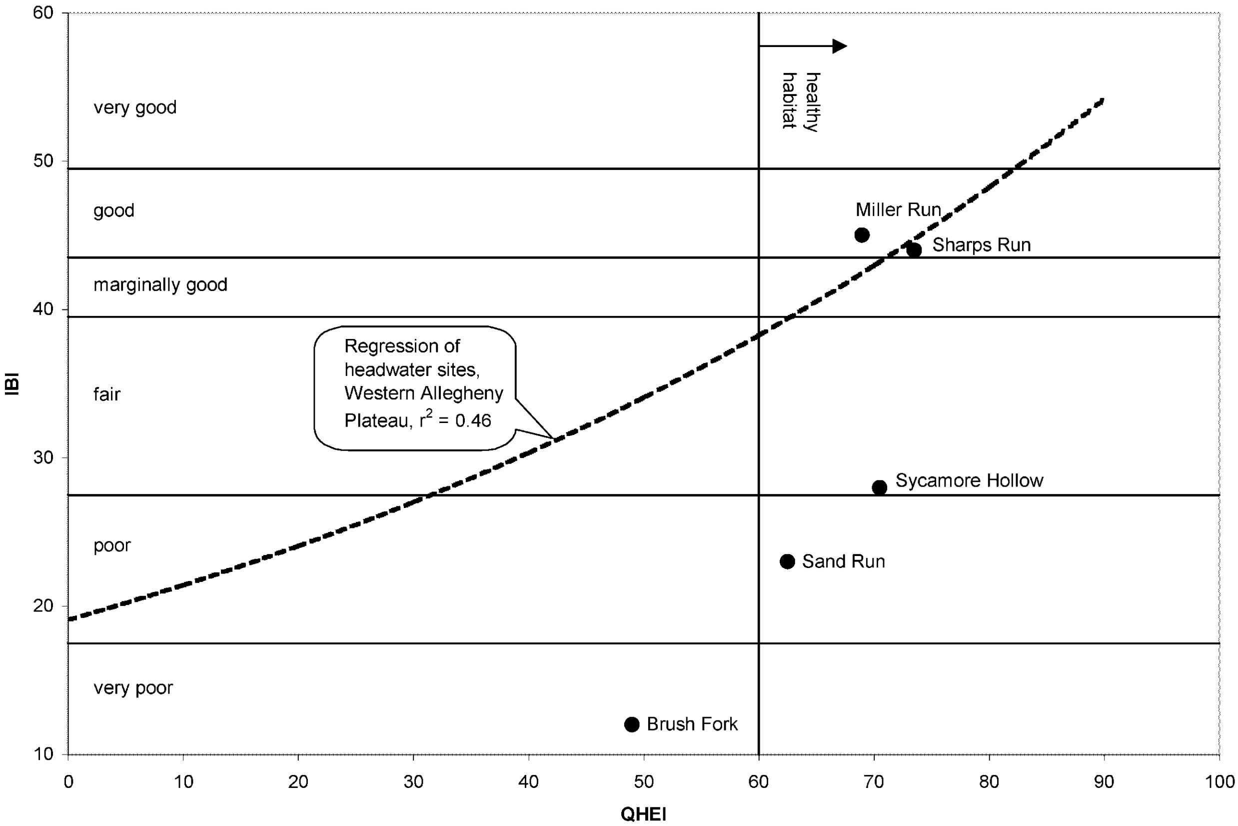

Figure 2. Correlation of biological integrity with habitat quality

benthic species (Hoehn and Sizemore 1977; Letterman and Mitsch 1978). Species are assumed to have been lost over time due to stochastic events, in which decimation (e.g., by drought) eliminated rare species. Immigration is most likely to occur from nearby streams. In Monday Creek, the recolonization of the isolated streams is expected to occur from the Hocking River or adjacent tributaries within Monday Creek. Therefore, opening a corridor for immigration by improving water quality in isolating reaches will lead to the re-establishment of regional fish fauna in high-quality headwaters.

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