



Scuds (Gammaridae) and Darters (Percidae) Dominate Aquatic Communities in a Stream Exhibiting Levels of Specific Conductance Exceeding 4,000 $\mu\text{S}/\text{cm}$

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Abstract: Surface and underground extraction of coal has degraded many landscapes throughout the Appalachian region of the United States. The deleterious effects on stream biota of untreated acidic drainages high in heavy metals from active and abandoned sites have been well-documented. Mitigation strategies frequently include the addition of strong neutralizing agents in order to elevate pH and precipitate toxic metals. The resulting effluents exhibit high concentrations of sulfates, chlorides, carbonates, and other ions which can markedly raise the specific conductance of receiving streams. However, the impacts of such inputs on stream ecosystems are not well-studied. This study documents one such case, Whiteley Creek, a Monongahela River tributary in southwestern Pennsylvania, which receives treated effluents producing in-stream conductivity values in excess of 4,000 $\mu\text{S}/\text{cm}$. Fish and macroinvertebrate communities were sampled at ten sites from its headwaters to its Monongahela River confluence exhibiting conductivity values ranging from 2,400 – 5,400 $\mu\text{S}/\text{cm}$. Specific conductance showed no relationship to taxonomic richness of either community; however fish abundance declined with increasing conductivity, while macroinvertebrates increased. Extant communities dominated by tolerant taxa resulted in low macroinvertebrate and fish Indices of Biotic Integrity scores indicative of community stress. This study underscores the importance of biomonitoring and bioassessment of streams receiving effluents of chemically-treated acid mine drainages.

Keywords: Macroinvertebrates, Fish, Specific Conductance

1. Introduction

Discharges from the extraction of anthracite and bituminous coal deposits have impacted 4,022 km of streams in the Commonwealth of Pennsylvania, constituting its single largest non-point source of pollution [1]. Bituminous coal-mining operations such as those occurring in southwestern Pennsylvania can produce acidic or alkaline discharges containing elevated concentrations of suspended solids, metals, and sulfates [2]. Both acid mine drainage (AMD) or net alkaline mine drainage (NAMD) may be produced during surface and underground mining operations depending on local geologic conditions [3]. Acid mine drainage is characterized by depressed levels of pH, total alkalinity/total acidity <1 and high levels of dissolved metals such as iron,

aluminum, and manganese which can decimate aquatic life in receiving streams. By contrast, NAMD discharges feature circumneutral pH levels, total alkalinity/total acidity >1, and metals in suspension or sediment which create the familiar orange colored “yellow-boy” of receiving streams. The two also differ in their effects on aquatic life with AMD producing toxic physiological conditions often resulting in the absence of fish and macroinvertebrate communities; while NAMD results in ferric hydroxide ($\text{Fe}(\text{OH})_3$) precipitates which cover benthic habitats – a physical constraint to aquatic life [4, 5].

While AMD often produces sterile streams, those impacted by NAMD may harbor extant fish and macroinvertebrate communities frequently depauperate in taxonomic richness and density [6-8]. Acid mine drainage may transform into

NAMD effects in a receiving stream when encountering oxygen and limestone strata which elevates pH and precipitates metals. The federal Surface Mining Control and Reclamation Act of 1977 (P. L. 95-87) has resulted in improved mining practices and remediation of increasing numbers of abandoned mine sites. However, the long history of coal extraction in Pennsylvania has left a legacy of more than 4,000 km of streams with absent or depauperate aquatic communities [1].

Treated drainages from active mining and preparation facilities along with brines from oil and gas well development [9, 10] can also impair lotic ecosystems by elevating ambient concentrations of total dissolved solids (TDS) and salinity. Much of the current focus of the impacts of wastewater from energy extraction has centered on fracking of natural gas from shale deposits. Such wastewater is high in brines which can produce extremely high levels of specific conductance. Contamination of Dunkard Creek, a Monongahela River tributary in Pennsylvania, resulted in stream conductivity of 5,000 to 50,000 $\mu\text{S}/\text{cm}$ [11]. This triggered a bloom of golden algae and its toxic metabolites which decimated fish, amphibians, and macroinvertebrates along 68 km of stream [11]. In order to protect aquatic life, the US Environmental Protection Agency (USEPA) has recommended a 300 $\mu\text{S}/\text{cm}$ benchmark for impairment of receiving waters below discharges of elevated conductivity in the Central Appalachian Region of the United States [12].

The impacts of treated mine drainages on receiving streams has been less well-documented. The treatment of mine drainages, depending on type, has been undertaken by a variety of remediation strategies broadly categorized into “active” and “passive” treatments with the former employing the direct addition of neutralizing chemicals including strong alkaline agents (e.g., NaOH, CaO, Ca (OH)₂) to neutralize

acidity and precipitate metals [13, 14]; and the latter directing the inputs into limestone beds and/or constructed wetlands to precipitate metals [1, 15, 16]. The chemical additives utilized in pH modification, metal precipitation, and sulfur oxidation may produce alkaline effluents high in TDS resulting in elevations of specific conductance in receiving streams well above the USEPA 300 $\mu\text{S}/\text{cm}$ benchmark [17, 18]. Research into the effects of treated mine drainages high in specific conductance and total dissolved solids (TDS) on aquatic communities have been limited and somewhat equivocal. Metrics such as species richness and diversity were not reliable indicators of macroinvertebrate community stress resulting from elevated TDS and specific conductance [19]. Pond et al. [20] determined adverse effects on aquatic communities at levels in excess of 500 $\mu\text{S}/\text{cm}$. However, chemical and biological assessments of a major Monongahela River tributary in Pennsylvania, the South Fork of Tenmile Creek, documented extant fish and macroinvertebrate communities at levels of specific conductance exceeding 1,000 $\mu\text{S}/\text{cm}$ [17, 18].

The objective of this study was to assess the status of fish and macroinvertebrate communities in a stream impacted by extremely high levels of specific conductance, pH, and total alkalinity as a result of active treatment of AMD in its headwaters by strong alkaline agents.

2. Methods

2.1. Description of Study Area

Whiteley Creek, a 3rd order tributary of the Monongahela River located in Greene County southwestern Pennsylvania, is designated as a Warm-Water Fishery (WWF) by the Pennsylvania Department of Environmental Protection [21] (Figure 1).

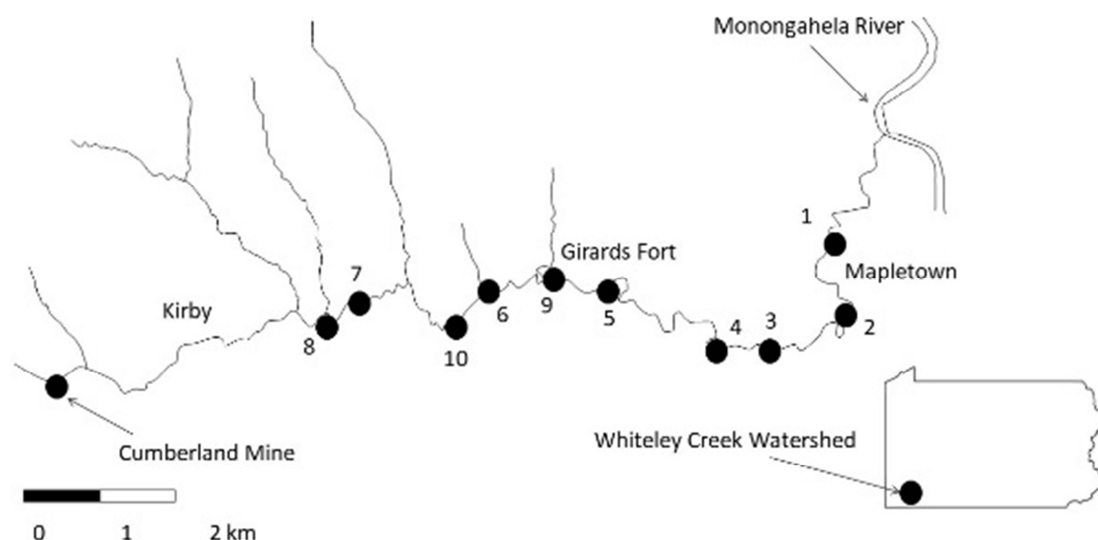


Figure 1. Sampling stations along Whiteley Creek.

Land use within the 140 km² watershed includes agriculture, small rural communities, and coal extraction. The largest influence here is the Cumberland coal

processing and treatment facility which encompasses approximately 40 ha of its headwaters. The mine drainage treatment process here relies on the addition of caustic

alkaline agent (s) to elevate pH and precipitate metals with the resulting effluents discharged directly into Whiteley Creek.

2.2. Sampling and Data Analyses

Ten sampling stations were located approximately 2.0 km apart spanning nearly the entire 26 km watercourse from headwaters to its confluence with the Monongahela River. During the summer of 2016, measurements of temperature ($^{\circ}\text{C}$), pH, and specific conductance ($\mu\text{S}/\text{cm}$) were performed in the field at each sampling station using a pH Testr3+ (Oakton Instruments) and a YSI (Yellow Springs Instruments) Model 33 S-C-T meter. A separate sample was returned to the laboratory at California University of Pennsylvania (CalU) for analysis of total alkalinity (mg/l as CaCO_3) by standard titration with N/50 sulfuric acid.

Fish were collected by one-pass back-pack electrofishing over a 100-m reach at each site, and identified, enumerated, and released in the field. Due to the very high levels of specific conductance, adjustment of voltage and amplitude of the electrofisher were necessitated at each station to ensure comparable sampling efficiency. The collection and handling of fish complied with the California University of Pennsylvania's Institutional Animal Care and Use Committee guidelines. Macroinvertebrates were sampled using a one- m^2 kick-net according to protocols established by the Pennsylvania DEP [22]. Three samples at each site were pooled to form a station composite, preserved in 70% isopropyl alcohol, and returned to the laboratory at CalU for identification to the lowest practicable taxonomic level and enumeration. Simple linear regression analysis was performed to examine the relationships among specific conductance and fish/macroinvertebrate abundance and taxonomic richness. Relationships were considered significant if the p-value < 0.05.

In order to assess biotic communities over the entire sampling reach, data from all stations were pooled for tallies of species richness, abundance, and computation of fish and macroinvertebrate Indices of Biotic Integrity (IBI). Indices of Biotic Integrity for fish and macroinvertebrate communities were those developed by Kimmel and Argent [7] and "Pennsylvania's wadeable, freestone, riffle-run streams" [22], respectively. Both employ analyses of multiple metrics to arrive at numerical total scores indicative of community health. The Fish IBI is comprised of 10 metrics and scores range from 2 ("very poor") to 48-50 ("excellent"). The Pennsylvania DEP IBI [22] integrates seven individual metrics into a scoring range from ≤ 43 ("impaired") to ≥ 43 ("attaining").

3. Results

Water quality parameters are summarized by station in Table 1. Temperatures at time of sampling ranged from 19.7 to 23.4 $^{\circ}\text{C}$, pH 8.3 to 8.6, specific conductance 2,440 to 5,400

$\mu\text{S}/\text{cm}$, and total alkalinity, 444 to 634 mg/l as CaCO_3 .

A total of 514 fishes representing six families and 16 species were documented overall (Table 2). Two percids, the Rainbow (*Etheostoma caeruleum*) and Fantail (*E. flabellare*) darters were overall dominants representing 63% of the ichthyofaunal complement, with the Rainbow Darter present at all stations and the Fantail Darter at all but one. Addition of the Greenside Darter (*E. blennioides*) brings the total dominance of these percids to 70% (Table 2). The two Rainbow Trout (*Oncorhynchus mykiss*) and one Brown Trout (*Salmo trutta*) of hatchery origin were excluded from the IBI calculation. Scuds (*Gammarus* sp.) were the macroinvertebrate dominant representing 70% of the 803 individual macroinvertebrates representing 18 taxa collected from the entire sampling reach (Table 3). No significant relationship exists between fish and macroinvertebrate taxonomic richness and specific conductance (Figure 2, p-value >0.05). Fish abundance declined with increasing specific conductance ($R^2 = 0.47$; $p < 0.05$), while macroinvertebrate communities responded positively ($R^2 = 0.44$; $p < 0.05$) (Figures. 3 and 4). Both fish and macroinvertebrate communities exhibited low IBI scores – 20 ("poor") and 41 ("impaired") respectively.

4. Discussion

Values of temperature, pH, and total alkalinity fall within acceptable levels according to PA DEP WWF criteria for these parameters [21]. However, background levels of pH and total alkalinity for a nearby unimpacted reach of Tenmile Creek were 8.0 and 170 mg/l as CaCO_3 respectively. While no regulatory criterion has been developed for specific conductance relative to aquatic life in Pennsylvania, Black [23] recommended a maximum of 400 mg/l of TDS for sustaining diverse fish populations. Conversion of specific conductance values to TDS values utilizing the 0.65 multiplier [24] for all stations sampled in this study well exceed this maximum. In addition, all stations far exceed the USEPA recommended benchmark of 300 $\mu\text{S}/\text{cm}$. In two recent studies of aquatic communities in Tenmile Creek and its South Fork, Kimmel and Argent [17, 18] describe extant fish and macroinvertebrate communities at levels of specific conductance exceeding 1,000 $\mu\text{S}/\text{cm}$. These values were attributed to treated mine effluents which elevated stream levels far above the 400 $\mu\text{S}/\text{cm}$ background and for the Basin [18] as well as the USEPA benchmark.

The range of specific conductance values recorded in the present study far exceed those encountered in the Tenmile Creek Basin and have negatively impacted aquatic communities here as reflected by the IBI scores. Both fish and macroinvertebrate communities are dominated by taxa tolerant or moderately tolerant to non-specific stressors [25]. Only four individuals representing two of the EPT taxonomic metric of the IBI - (Ephemeroptera and Plecoptera) were collected; and the two Trichoptera taxa, *Hydropsyche* sp. and *Chimarra* sp. are listed as having "intermediate" pollution tolerance by the Pennsylvania DEP

[22]. The fish community was dominated by “tolerant” and “intolerant” taxon present. “intermediate” fishes, with the Greenside Darter the only

Table 1. Water quality parameters measured from Whiteley Creek sampling stations.

Site No.	Temp. (°C)	pH	Sp. Cond. (µS/cm)	Alkalinity (mg/l as CaCO ₃)
1	20.2	8.5	2400	444
2	20.6	8.5	3868	446
3	21.1	8.6	3961	456
4	21.6	8.6	4393	470
5	19.7	8.4	3810	488
6	20.7	8.4	4218	492
7	19.7	8.3	5150	598
8	20.5	8.3	5400	634
9	22.7	8.4	4020	458
10	23.4	8.4	4825	578

Table 2. Taxonomic distribution and abundances of the ichthyofauna among Whiteley Creek sampling stations. Salmonids have been excluded from species richness enumeration.

Common Name	Scientific Name	1	2	3	4	5	6	7	8	9	10
Central Stoneroller	<i>Camptostoma anomalum</i>	8	5	12	1	4			2		6
Bluntnose Minnow	<i>Pimephales notatus</i>							1			
Creek Chub	<i>Semotilus atromaculatus</i>				1		1	1		1	
White Sucker	<i>Catostomus commersonii</i>	2	4	1				2	6	3	
Northern Hog Sucker	<i>Hypentelium nigricans</i>			6	2	3			1	1	
Yellow Bullhead	<i>Ameiurus natalis</i>		1				1	3	4		3
Rock Bass	<i>Ambloplites rupestris</i>	1			1		1			2	
Green Sunfish	<i>Lepomis cyanellus</i>	5	6	2	7	1	3	17	8	3	
Pumpkinseed	<i>Lepomis gibbosus</i>							1			
Bluegill	<i>Lepomis macrochirus</i>					1			2		
Smallmouth Bass	<i>Micropterus dolomieu</i>	1			1						
Rainbow Trout	<i>Oncorhynchus mykiss</i>			2							
Brown Trout	<i>Salmo trutta</i>										1
Greenside Darter	<i>Etheostoma blennioides</i>	2	5	3	9	7	5			4	1
Rainbow Darter	<i>Etheostoma caeruleum</i>	36	33	33	29	12	29	8	7	18	31
Fantail Darter	<i>Etheostoma flabellare</i>	23	12	24	9	14	1	4		2	1
Total Abundance		78	66	83	60	42	41	37	30	34	43
Species Richness		8	7	6	9	7	7	8	7	8	5

Table 3. Taxonomic distribution and abundances of macroinvertebrates among Whiteley Creek sampling stations.

Taxa		1	2	3	4	5	6	7	8	9	10
Tubificidae		1		1							
Physidae		6		4			1	8		2	
Gammaridae	Gammarus	9	5	10	23	89	19	179	112	66	51
Cambaridae	Cambarus	1									
Baetidae				1	1						
Leuctridae	Leuctra								1		
Perlidae	Acroneuria		1								
Hydropsychidae	Hydropsyche	11	12	5	3	3		15	34		3
Philopotamidae	Chimarra		2	4	2	2	1			3	14
Gyrinidae	Gyrinus	3	6	1	4	5	1	2	20	1	4
Psephenidae	Psephenus					2					
Sialidae	Sialis			4		1	1	1			
Corydalidae	Corydalus		2	1	1	4	3	2	3	2	1
	Nigronia	1									
Athericidae	Atherix		2	2	3	2	1			1	1
Simuliidae			1					1			
Tipulidae			1								
TAXA		7	9	9	7	8	7	7	6	7	6
INDIVIDUALS		32	32	33	37	108	27	208	170	75	74

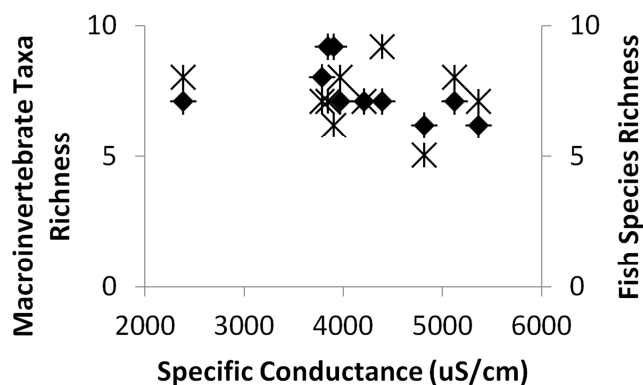


Figure 2. Responses of Whiteley Creek fish and macroinvertebrate taxonomic richness to elevated levels of specific conductance. Asterisks and diamonds denote fish and macroinvertebrates respectively.

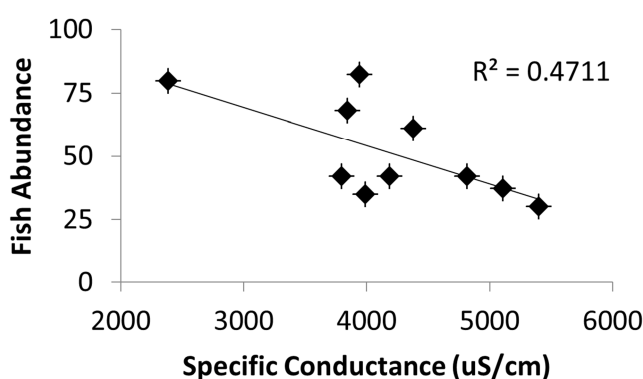


Figure 3. Responses of Whiteley Creek fish abundance to elevated levels of specific conductance.

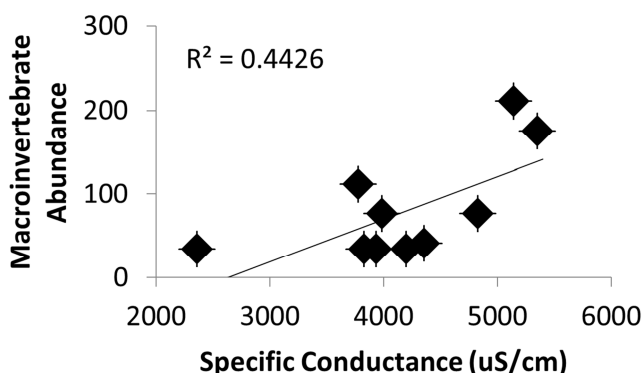


Figure 4. Responses of Whiteley macroinvertebrate abundance to elevated levels of specific conductance.

Elevated specific conductance which increases with increasing TDS can exert osmoregulatory stress on aquatic biota [26, 27, 28] as well as toxicity from the ionic constituents' present. Toxicity of the mixtures of TDS to aquatic life depends upon the combinations and concentrations of the ions in solution which may produce additive or synergistic effects and is not predictable from TDS or specific conductance [29]. Weber-Scannell and Duffy [30], in a summary of TDS effects on aquatic life from bioassays, report varying responses by species and life stages to mixtures and concentrations of specific ions. The effects of discharges of treated mine effluents on the biota of receiving

streams depends on its volume and ionic constituents as well as the assimilative capacity of the receiving water.

5. Conclusion

Here we describe the structures of resident fish and macroinvertebrate communities of a stream exhibiting elevated levels of specific conductance resulting from treated AMD effluent. Both communities exhibited low bioassessment metric scores and suggest the importance of biomonitoring and bioassessment of streams receiving effluents from active treatment of AMD.

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