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Stream Fish Community Responses to a Gradient of Specific Conductance

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Abstract We assessed the impacts of a specific conductance gradient attributable to treated coal-mining discharges on the fish communities of a southwestern Pennsylvania stream. Total dissolved solids concentrations were determined from specific conductance values. A total of 10,940 fish representing seven families and 42 species/hybrids were collected from 17 stations over the entire survey. Species richness, density, and the coefficient of community loss (*I*) showed marked impairment at the two stations directly below the discharges and the downstream recovery was interrupted at one station by untreated discharges from a mine refuse pile. Species richness declined from 28 at the reference site to 7 at the station directly below the treated effluents. This study suggests that the threshold for in-stream conductivity impairment to fish communities in this region is in the range of 3,000–3,500 μS/cm and 2,000–2,300 mg/l of total dissolved solids, respectively.

Keywords Total dissolved solids · Fish community · Specific conductance · Pennsylvania

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1 Introduction

Specific conductance (μS/cm) is defined as the ability of water to conduct an electric current and increases with increasing concentrations of total dissolved solids (TDS; Lind 1979). The composition of ions which make up TDS vary with underlying geology and precipitation/evaporation ratios. Common ions in freshwater include bicarbonate, sulfate, calcium, sodium, and silica (Weber-Scannell and Duffey (2007)). Changes in TDS levels and individual ions and anions can occur from a variety of anthropogenic sources including industry and resource extraction such as mining and gas well development (Fillo et al. 1992).

The geology of southwestern Pennsylvania's Appalachian Plateau Province harbors significant reserves of coal which were first mined in the late eighteenth century (Puglio 1983). Deep and surface mining operations here and across the state have exposed pyritic materials to oxidation and dissolution which can produce toxic acidic discharges high in metals and sulfates (Anderson et al. 2000; Kimmel 1983). In areas where coal deposits are associated with limestone, discharges may be net alkaline (alkalinity exceeds acidity) and exhibit circumneutral pH levels (Scott and Hays 1975) along with elevated concentrations of sulfates and metals (Rose and Cravotta 1998). Acid mine drainage (AMD) or net alkaline mine drainage (NAMD) may be consequences of coal extraction depending upon the underlying geology.

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Historically, in Pennsylvania, over 4,000 km of surface streams and their biota have been negatively impacted by mining activity (Kimmel 1983), a threat which continues today (Anderson et al. 2000). The Clean Water Act of 1972 and the Surface Mining Control and Reclamation Act of 1977 have resulted in improved mining practices and remediation of increasing numbers of abandoned mine sites. Remediation strategies include active and passive treatment systems designed according to the chemistry of the discharge along with recontouring and revegetating affected landscapes.

Bituminous coal-mining operations such as those in southwestern Pennsylvania can produce acidic or alkaline discharges containing elevated concentrations of suspended solids, metals, and sulfates (Scott and Hays 1975). Treated discharges from active mining and preparation facilities along with brines from oil and gas well development (Knuth et al. 2005; Short et al. 1991) can also impair lotic ecosystems by elevating ambient concentrations of salinity and TDS. Natural groundwater quality here is dependent on the underlying stratigraphy expressed as either undifferentiated sedimentary rock or carbonate-rock aquifers (Trapp and Horn 1997). The former yields about 230 mg/l of TDS while the latter 180 mg/l (Trapp and Horn 1997). Therefore, under base-flow conditions, TDS of surface streams would be expected to fall within this range. The chemical additives utilized in pH modification, metal precipitation, and sulfur oxidation may produce treated effluents high in TDS. As a result of discharges from industries, wastewater treatment facilities, and resource extraction operations, many of southwestern Pennsylvania's streams are characterized by elevated TDS and associated specific conductance.

Toxicity of TDS to aquatic life depends upon the combinations and concentrations of the ions in solution which may have additive or synergistic properties and is not predictable from TDS concentrations alone (Chapman et al. 2000). Black (1977) recommended a maximum of 400 mg/l for diverse fish populations. The effects of elevated TDS on freshwater aquatic biota derived largely from acute toxicity bioassays are summarized by Weber-Scannell and Duffey (2007) and vary by species, life stage, and mixtures and concentrations of specific ions. Much of the research on the effects of mine drainages on aquatic ecosystems has focused on untreated acidic discharges high in metals and sulfates. Less is known regarding the effects of treated mine discharges which may contain high concentrations of TDS due to the addition of treatment chemicals for the oxidation of sulfur, metal precipitation, and pH adjustment. Kennedy et al. (2003) documented the toxicity of elevated TDS from coal-mining discharges on selected aquatic macroinvertebrates in waters of varying total hardness. The effects of such treated discharges on stream fish communities of receiving waters are poorly documented. The objective of this study was to assess the effects of a longitudinal gradient of specific conductance on the fish communities of the South Fork of Tenmile Creek.

2 Materials and Methods

2.1 Description of Study Area

The Tenmile Creek drainage encompasses 875 km^2 and receives 70 named and unnamed tributaries. The mainstem and its South Fork traverses approximately 90 km. It is a low-gradient, warm-water alkaline stream impacted to varying degrees along its course by urbanization, agriculture, and resource (e.g., coal and natural gas) extraction. However, riparian buffers are largely intact and reaches consist of short riffles interspersed among long runs or pools. The substrate is a combination of silt, gravel, and cobble in most areas. The study reach is designated by the Pennsylvania Department of Environmental Protection as a "Warm Water Fishery" (PADEP 2001). While the South Fork of Tenmile Creek Basin has a long history of resource extraction, preliminary surveys by the authors have documented a diverse and abundant ichthyofauna (Argent and Kimmel 2008). However, discharges from the Emerald Mine Complex (EMC) and its treatment facility mark an upstream endpoint to over 35 km of point and non-point-source discharges within the basin (J. Folman, Pennsylvania Department of Environmental Protection, personal communication).

2.2 Sampling

A total of 16 approximately equidistant sampling stations were established on a 26 km reach of the South Fork of Tenmile Creek. An additional station (Fig. 1), unimpacted by mine drainage, located on

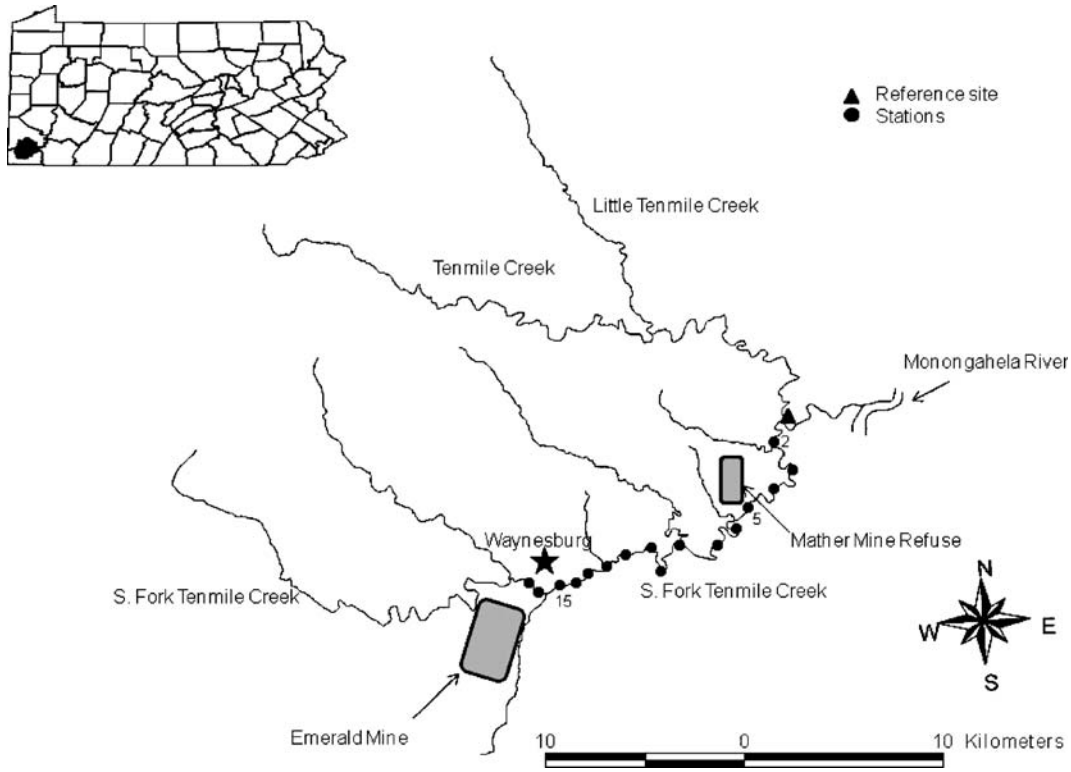

Fig. 1 Locations of sampling stations within the Tenmile Creek basin

Tenmile Creek approximately 500-m upstream of its confluence with the South Fork and harboring a diverse ichthyofauna (Kimmel and Argent 2005) served as a reference site (Ref). Stations 2–15 were located along the conductivity gradient below the major treated discharges from the EMC; while Stations 16 and 17 were established above the EMC (Fig. 1).

We sampled fish along a 200-m reach at each georeferenced station on the mainstem which included at least one riffle/run/pool sequence during the summers of 2007 and 2008. We estimated our area (m^2) sampled by multiplying station length by mean width. Fish were collected with backpack and/or towboat electrofishers using a standard two-pass sampling protocol developed by the authors (Kimmel and Argent 2006b). All electrofishing was conducted at approximately 200–400 V and 3–4 A in an upstream manner from the nearest natural break to the 200-m endpoint. Blocking nets, ineffective in improving catch rates (Paller 1995) or species richness estimates (Simonson and Lyons 1995) were not utilized. Upon completion of both passes, large specimens (>250 mm TL) and gamefish were identified in the field and released. All others were fixed in 10% formalin and returned to the laboratory for identification and enumeration.

Measurements of temperature (°C), pH, and specific conductance (μS/cm) were taken in the field using a standard thermometer, pH Testr3+ (Oakton Instruments), and YSI Model 33 S-C-T meter (Yellow Springs Instruments), respectively. A 500-ml water sample was collected at each site, stored on ice, and returned to the laboratory for analysis of total alkalinity (mg/l as $CaCO_3$) by standard titration. We calculated TDS from conductivity measurements using the multiplier (0.65) as described by Rainwater and Thatcher (1960).

2.3 Data Analysis

We determined species richness and density (number of fish/m^2); and utilized the Shannon-Weaver function (Krebs 1989) to calculate fish community diversity ($\bar{d}$) at each station. We calculated the *I*-metric score (Argent and Kimmel 2006) to evaluate the fish community in one metric along the gradient of conductivity. Streams with *I*-values of ≥0.8 are

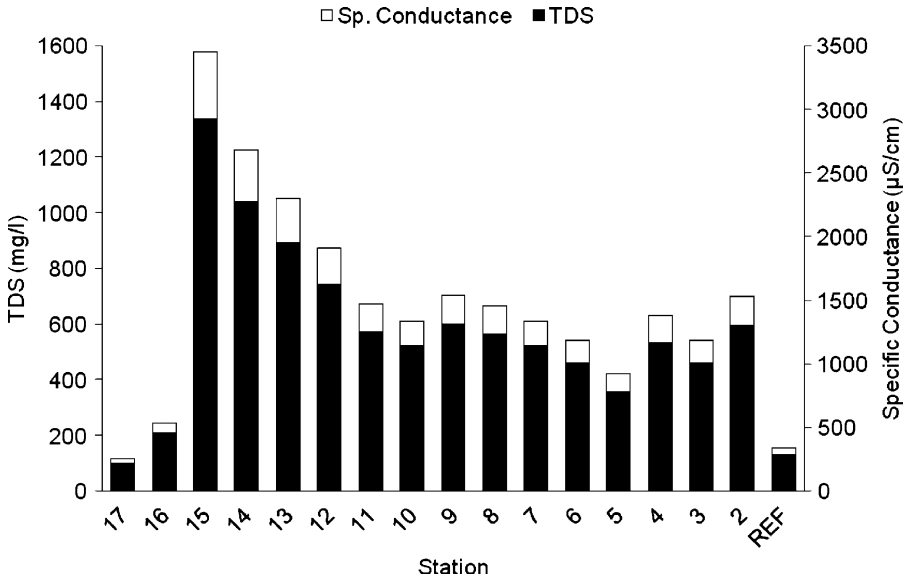

Fig. 2 Specific conductance and TDS values of South Fork and Tenmile sampling stations

indicative of organic and/or toxic stressors, while values <0.8 indicate pristine or enriched conditions (Courtemanch and Davies 1987).

3 Results and Discussion

A gradient of elevated specific conductance was observed on the South Fork extending from its confluence with the Tenmile Creek mainstem to the town of Waynesburg, PA (Figs. 1 and 2). The gradient declined from a high of 4,500 µS/cm below the EMC effluents to a low of 440 µS/cm at the reference station. Values upstream of the mine discharges mirrored those of the reference station (Fig. 2). All stations along the gradient exceeded TDS values of the reference station (Fig. 2) and those that would be expected from local geology (Trapp and Horn 1997). All stations were alkaline and exhibited pH values well above neutral (Table 1).

Table 1 South Fork and Tenmile station dimensions and selected physico-chemical parameters

Station	Mean area sampled (m^2)	Temperature (°C)	pH	Total alkalinity (mg/l)
Reference	3,296	13	8.0	170
2	4,356	22	8.5	196
3	2,416	22	8.2	172
4	4,420	24	8.4	184
5	2,772	20	8.0	154
6	3,232	21	8.1	182
7	3,152	22	8.3	186
8	2,780	17	8.4	218
9	3,752	16	8.3	266
10	2,828	18	8.2	194
11	3,816	20	8.2	194
12	3,652	21	8.2	264
13	3,492	22	8.2	310
14	3,712	22	8.2	362
15	3,688	22.5	8.4	488
16	2,820	22	8.1	152
17	4,020	24	8.0	120

Table 2 Summary of fishes collected from sampling stations along the South Fork gradient of conductivity compared with reference site

			Station															
Common name	Scientific name	Ref	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Central stoneroller	*Campostoma anomalum*	x		x	x	x	x	x		x	x	x	x	x	x			x
Spotfin shiner	*Cyprinella spiloptera*	x	x	x	x	x	x	x	x	x	x	x	x		x		x	x
Common carp	*Cyprinus carpio*		x	x			x	x					x	x	x		x	x
Silverjaw minnow	*Ericymba buccata*																x	
Common shiner	*Luxilus cornutus*	x	x	x	x		x						x	x	x		x	x
River chub	*Nocomis micropogon*	x	x	x	x		x											
Emerald shiner	*Notropis atherinoides*	x		x	x		x				x		x					
Sand shiner	*Notropis ludibundus*	x		x	x	x	x	x		x	x	x	x	x				x
Rosyface shiner	*Notropis rubellus*	x		x	x		x	x		x	x	x	x	x			x	x
Mimic shiner	*Notropis volucellus*	x	x	x	x		x	x		x	x	x	x	x		x	x	x
Channel shiner	*Notropis wickliffi*	x					x	x			x		x	x			x	x
Bluntnose minnow	*Pimephales notatus*	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x
Blacknose dace	*Rhinichthys atratulus*	x											x					
Creek chub	*Semotilus atromaculatus*	x		x	x	x	x	x			x			x			x	x
Quillback	*Carpiodes cyprinus*										x	x						
White sucker	*Catostomus commersoni*	x				x	x	x	x	x	x	x	x	x	x		x	x
Northern hogsucker	*Hypentelium nigricans*	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Silver redhorse	*Moxostoma anisurum*	x	x						x		x	x				x	x	x
Black redhorse	*Moxostoma duquesnei*	x	x						x									x
Golden redhorse	*Moxostoma erythrurum*	x	x					x	x	x	x	x	x	x	x	x	x	x
Shorthead redhorse	*Moxostoma macrolepidotum*								x									
Shorthead redhorse	*Moxostoma macrolepidotum*								x									
Yellow bullhead	*Ictalurus natalis*	x	x				x	x	x	x	x	x	x	x				
Channel catfish	*Ictalurus punctatus*		x															
Stonecat	*Noturus flavus*	x		x	x	x	x	x		x	x		x	x				
Hybrid striped bass	*Morone* hybrid		x															
Rock bass	*Ambloplites rupestris*	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Green sunfish	*Lepomis cyanellus*	x	x	x			x		x	x	x	x	x		x	x	x	
Pumpkinseed	*Lepomis gibbosus*	x			x			x				x					x	x
Bluegill	*Lepomis macrochirus*			x					x		x	x	x				x	x
Hybrid sunfish	*Lepomis hybrid*				x	x			x	x	x		x	x	x	x	x	
Smallmouth bass	*Micropterus dolomieui*	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Largemouth bass	*Micropterus salmoides*	x	x		x							x		x			x	x
Greenside darter	*Etheostoma blennioides*	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x
Rainbow darter	*Etheostoma caeruleum*	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x
Fantail darter	*Etheostoma flabellare*	x					x	x				x						
Johnny darter	*Etheostoma nigrum*																x	x
Logperch	*Percina caprodes*	x				x	x	x	x	x	x	x	x		x		x	x
Blackside darter	*Percina maculata*																	x
Sauger	*Sander canadensis*		x	x													x	
Saugeye	*Sander* hybrid		x						x		x	x		x			x	x
Walleye	*Sander vitreum*		x															
Freshwater drum	*Aplodinotus grunniens*					x		x	x			x	x	x	x		x	

Table 3 Fish community species richness, density, and diversity of South Fork and Tenmile sampling stations

Station	Species richness	Density (No./m^2)	$\bar{d}$
Reference	28	0.725	3.18
2	22	0.057	3.11
3	20	0.287	3.27
4	19	0.098	2.97
5	15	0.073	2.51
6	22	0.581	3.02
7	22	0.223	3.03
8	19	0.063	2.77
9	18	0.100	3.06
10	25	0.357	3.15
11	24	0.097	3.68
12	25	0.288	3.57
13	22	0.141	3.22
14	13	0.016	2.90
15	7	0.005	2.49
16	27	0.111	3.87
17	26	0.133	3.78

A total of 10,940 fish representing seven families and 42 species/hybrids were collected over the entire survey. The faunal complement was typical for a warm-water stream in this area dominated by cyprinids, catastomids, centrarchids, and percids (Table 2). Species richness declined precipitously at Station 5 below the Mather dump and at Stations 14 and 15 directly downstream of the EMC discharges where densities also reached their lowest levels before recovering at Stations 16 and 17 (Table 3). Community diversity ($\bar{d}$), however, was equivocal (Table 3) possibly because of uniformity of relative abundance among the species present at the impacted sties. A total of 77 individuals were collected from Stations 14 and 15 combined, 59 and 18, respectively. By contrast, the reference site yielded a total of 2,389 individuals and the other stations ranged from 174 to 1,877. Common species such as the bluntnose minnow (*Pimephales notatus*), greenside (*Etheostoma blennoides*), rainbow (*Etheostoma caeruleum*), and logperch (*Percina caprodes*) darters were absent from Stations 14 and 15 (Table 2).

Fish community metrics declined precipitously at Stations 5, 14, and 15 when compared with the reference site (Table 3, Fig. 3). Stations 14 and 15 had the highest conductivity and TDS levels, but values at Station 5 were, by comparison, only about double those of the reference site (Fig. 2). Since runoff from the Mather coal refuse site is untreated, it may contain toxic substances in concentrations high enough to affect fish populations. In addition, this site

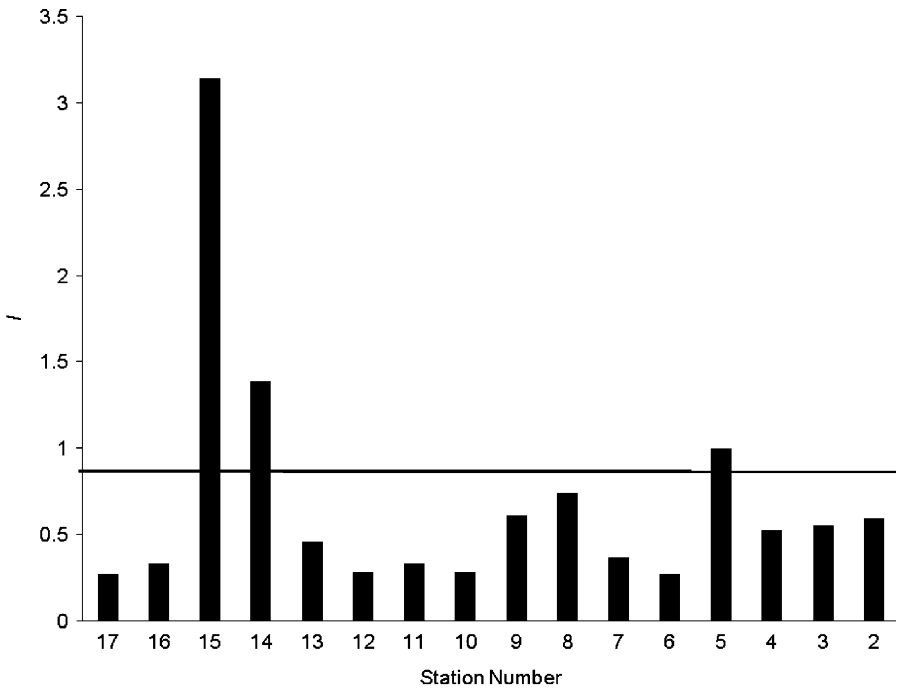

Fig. 3 Values of *I* along the South Fork of Tenmile Creek conductivity gradient compared with the reference site. Threshold of community impairment, 0.8, is indicated by the *horizontal line* and the reference is by definition *0*

is impacted by discharges of untreated sewage. Only three species, the central stoneroller (*Campostoma anomalum*), and greenside and rainbow darters comprised 80% of the total catch at Station 5 and all are considered intermediate in their tolerance to stress (Barbour et al. 1999). However, the authors have collected rainbow darters from a number of Monongahela River tributaries impacted by a variety of stressors including untreated sewage and NAMD (Kimmel and Argent 2006a) indicating that this species may be more tolerant than its assigned designation (Barbour et al. 1999).

The impacts of treated mine drainages high in specific conductance and TDS on aquatic macroinvertebrates have been investigated by Kennedy et al. (2003) through field and laboratory bioassay conditions. They found that field assessments of traditional benthic community metrics such as species richness and diversity were not sensitive to elevated levels of TDS. Laboratory bioassays indicated that toxicity was due to sodium/sulfate dominated TDS with potential chronic toxicities ranging from about 2,100–3,200 µS/cm (1,523–2,342 mg/l TDS) depending upon total hardness. Conductivity and TDS values at Stations 14 and 15 of our study (Fig. 2) were well above this chronic toxicity range; and fish species richness here, unlike the macroinvertebrate communities of Kennedy et al. (2003), exhibited marked sensitivity to this form of water quality degradation (Table 3, Fig. 3). The darter assemblage may provide a useful metric for the assessment of biotic impacts of elevated conductivity as it is relatively immobile and reliant on benthic macroinvertebrates which may also be sensitive to this type of perturbation (Kennedy et al. 2003).

4 Conclusion

The recovery of the fish community at Station 13 (Table 2, Fig. 3) suggests that the threshold for in-stream conductivity/TDS impairment to fish communities in this region is in the range of 3,000–3,500 µS/cm and 2,000–2,300 mg/l TDS, respectively. The potential harm to stream biota from point-source discharges high in specific conductance/TDS should be taken into consideration in the design of treatment facilities which utilize reagents to achieve effluent-specific water quality criteria.

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