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Community concordance between fishes and benthic macroinvertebrates among adventitious and ordinate tributaries of a major river system

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ABSTRACT

We examined patterns of concordance between macroinvertebrate and fish communities among adventitious and ordinate tributaries of the Monongahela River in southwestern Pennsylvania in order to determine their efficacy as mutual surrogates for the assessment of ecosystem integrity. Fish, macroinvertebrates, and 19 water quality parameters were sampled from 20 streams. Collected data were analyzed by principal components analysis, redundancy analysis, and Ward's distance clustering matrices to determine degrees of community concordance and similarity. Fish and macroinvertebrate communities were assessed utilizing Indices of Biotic Integrity (IBI) in order to compare stream ecosystem health as expressed by each index. Adventitious and ordinate macroinvertebrate communities largely clustered in like groups with adventitious tributaries dominated by the crustacean *Gammarus* sp. and ordinate streams dominated by the trichopteran, *Hydropsyche* sp. Adventitious communities were strongly influenced by elevated total alkalinity and total suspended solids; ordinate communities by contrast to elevated total organic carbon and specific conductance. Fish communities showed no significant relationship to water quality parameters among either tributary type, but often grouped with their nearest geographic neighbor. The respective indices revealed a discord between the two communities suggesting that neither community serves as a surrogate for the other as an indicator of stream health in this basin. Both communities appeared to be driven by differences in local environmental conditions.

1. Introduction

The River Continuum Concept (RCC) describes the spatial relationships in aquatic community structure from headwater low-order tributaries as they merge in increasing order to form the network of a river system (Vannote et al., 1980). Spatial scales can best be described for fishes using a hierarchical analysis of watersheds which tend to be nested and integrated through their connectivity (Frissell et al., 1986; Schlosser, 1991; Osborne and Wiley, 1992; Imhol et al., 1996; Poff, 1997). These relationships often reflect changes in temperature from coldwater to warmwater, surficial geology (Hughes et al., 1987) and habitat types (riffle versus pool) throughout the continuum.

Major river system networks include a combination of adventitious (A) and ordered (O) tributaries. Adventitious streams have been described by various authors (Minshall et al., 1985; Gorman, 1986; Schaefer and Kerfoot, 2004) as usually 1st-3rd order courses that join a mainstream at least three orders greater in magnitude. By contrast, O tributaries follow the hierarchical network described by Strahler (1952). It has been hypothesized that the large change in stream order among adventitious streams can result in abrupt community differences at the interface point and an overall break in the ordered pattern of the RCC network geometry.

An alternative landscape perspective calls for viewing streams as connected networks within a definable "network geometry" (Benda et al., 2004), instead of the linear hierarchy most commonly represented by stream order (Vannote et al., 1980). Connectivity provides linkages facilitating movement of fishes (Amoros and Bornette, 2002; Argent and Kimmel, 2009, 2014; Hitt and Angermeier, 2011; McKay et al., 2013) for the purposes of feeding, reproduction, and colonization as well as separation of life history stages. While connectivity provides a basis for movement and geographic range, anthropogenic factors continue to play increasing roles as determinants of fish distribution patterns (Roth et al., 1996; Wang et al., 2000, 2001; Allan, 2004; Argent and Carline,

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2004) by isolating populations through the elimination of connectivity corridors. Dam construction, channelization, and pollution as well as the purposeful or accidental introduction of exotic species have markedly altered historical distribution patterns (Argent et al., 2007).

Argent and Kimmel (2009) analyzed patterns of fish community connectivity exhibited by tributaries to the Monongahela River (MR) in Pennsylvania. They examined mainstem and tributary confluence connectivity as expressed by species richness and taxonomic composition among A and O tributaries. The ichthyofaunal complements of A tributaries proved to be more distinct and isolated from the mainstem than those of O streams. Adventitious tributaries shared 82% of their species complement with that of O streams, and only 29% with the mainstem; while 70% of the O ichthyofauna was common to the mainstem.

In contrast to fish which are mobile, macroinvertebrate communities by virtue of their relative immobility are often more limited in their ability to overcome interruptions of connectivity. It is this characteristic which renders macroinvertebrate communities as valuable temporal ecological indicators of water quality. Behavioral downstream drift in response to population pressure is the primary means by which many macroinvertebrate taxa disperse and colonize (Brittain and Eikeland, 1988; Mackay, 1992). This movement is compensated in many insect species by the flight of egg-laying females to re-populate upstream stream reaches. Environmental perturbation events, such as episodes of pollution (Brittain and Eikeland, 1988) or increased river discharge (Gibbins et al., 2007) can create catastrophic drift which can eliminate benthic communities in impacted reaches. Thus, mechanisms of dispersion between the two communities, fish and macroinvertebrates are altered in different ways by interruptions of connectivity.

Community concordance describes the degree of structural similarity in distribution patterns and abundances of organisms from different taxonomic groups within a spatial scale or scales (Paavola et al., 2006). High community concordance assumes similar responses of various taxonomic groups within an ecosystem to various environmental factors including stressors (Infante et al., 2009). Accordingly, expectations involving analyses of resident stream communities to anthropogenic insults would be concordant; and one taxonomic group (e.g. fish, macroinvertebrates) could serve as a predictor of the other, and perhaps, overall ecosystem integrity (Infante et al., 2009; Heino, 2010). While understanding community concordance is increasingly recognized as an important tool in assessing ecosystem integrity (Backus-Freer and Pyron 2015), few have focused on the concordance of stream macroinvertebrate and fish communities within a singular river network examining concordance patterns in terms of the RCC.

Numerous metrics have been developed for stream fish and macroinvertebrate communities as a means of assessing ecosystem health (Karr, 1981; Barbour et al., 1999; Tetra Tech, 2000; Karr and Kimberling, 2003; Klemm et al., 2003; PADEP, 2005, 2007; Botts 2009; PADEP, 2012). Studies of stream fish and macroinvertebrate concordance in response to a variety of environmental factors have been equivocal particularly at varying spatial scales (Paavola et al., 2006; Infante et al., 2009; Dolph et al., 2011; Bae et al., 2014). Infante et al. (2009) describe concordances in these communities in terms of regional and local influences with concordance greater at larger scales than smaller as differences in local conditions predominate. Bae et al. (2014) describe concordance patterns among fish and macroinvertebrate communities as being high at national and catchment scales. Pilière et al. (2014) concluded from a multi-metric study of fish and macroinvertebrate communities in Ohio that the two communities responded to different environmental factors. Fish communities were strongly tied to latitude and stream channel characteristics while macroinvertebrate communities to phosphorus concentration. Similarly, Backus-Freer and Pyron (2015) report that macroinvertebrate distribution and relative abundance were best predicted by in-stream cover and turbidity, while fish were best predicted by substrate and habitat characteristics. The consensus from the few published studies indicate that macroinvertebrate and fish communities are not useful surrogates for each other in assessments of stream ecological integrity, even when concordant, as they respond to differing environmental factors (Grenouillet et al., 2008; Infante et al., 2009; Bae et al., 2014) often at small geographic scales (Backus-Freer and Pyron, 2015). However, few studies have integrated the responses of such communities to form a more complete assessment and demonstrate concordance through these methodologies. The objectives of this study were to assess the principal of community concordance as expressed among A and O tributaries of the MR, a large regulated waterway, and to evaluate their conformity as indicators of ecosystem integrity at a basin-wide scale.

2. Methods

2.1. Description of study area

The MR arises from the confluence of the West Fork and Tygart rivers at Fairmont, West Virginia and flows 206 km north to Pittsburgh, Pennsylvania where it joins the Allegheny River to form the Ohio River (Fig. 1). The 130 km 7th order reach that lies in Pennsylvania is underlain by the Pennsylvanian geological formation consisting of sandstone, limestone, shale, clay, and coal deposits and is encompassed by large portions of the Pittsburgh Low Plateau Section of the Appalachian Plateaus Province. The 105 km mainstem reach encompassing the selected tributary network evaluated in this paper can, on a spatial scale, be described as local. Here, the river is divided into a series of impoundments by six navigational lock-and-dam structures built and maintained by the US Army Corps of Engineers. Along its course, the MR traverses varying land uses including active and abandoned coal mines, the industrialized Mid-Mon Valley, agriculture, forested patches, and small towns. Historically, the river has been severely degraded by industrial discharges and acid mine drainage to the extent that its resident ichthyofauna was nearly eliminated. One record from 1957 reports a pH of 3.8 and one fish species at Elizabeth Lock-and-Dam (Preston, 1974). Passage of the Federal Clean Water Act Amendments of 1972 (PFEB, 1972) have resulted in improved water quality in the mainstem and tributary network such that its ichthyofauna now numbers 14 families representing 64 species (Argent et al., 2007).

2.2. Sampling design and analysis

In order to evaluate the degree of concordance between fish and macroinvertebrate communities of A and O tributaries to the MR, we selected 20 of the 40 tributaries previously surveyed for fish and water quality by Kimmel and Argent (2006) – 10 from each category (A and O) – for macroinvertebrate and water quality assessment (Fig. 1). Streams were selected to reflect the greater linear extant of the Mid-Monongahela River Basin in Pennsylvania, bounded by two major tributaries over The Cheat and Youghiogheny rivers south and north respectively along with varying degrees of cultural impairment. Secondly, due to the uneven numbers of streams in each category in the original data set, we selected 10 from each in order to obtain equal sample size for analyses. Additionally any stream with obvious obstacles to connectivity were not considered for this study. These streams can best be described as warm-water, low-gradient and alkaline, with varying degrees of elevated specific conductance. Macroinvertebrate and fish communities extant in streams of high conductivity in this basin have been documented by Kimmel and Argent (2010, 2012).