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The importance of space in understanding the risk of multiple stressors on the biological integrity of receiving waters

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Abstract

The relationship of water chemistry and habitat stressors with selected biological metrics and indices was determined in a watershed using two different river segmentation scales. Results show that the scale used for data aggregation affects the correlation between stressors and the biology. This study showed that habitat appears to be a more important factor than chemistry when large stream segments are used to aggregate data.

Keywords: Space; Multiple stressors; Biological integrity; Habitat

1. Introduction

The presence, abundance, diversity and distribution of aquatic species (i.e. ecological structure) in surface waters are dependent upon a myriad of physical and chemical stressors, such as temperature, suspended solids, instream and riparian habitats, pH, nutrients, and chemicals from agricultural, consumer and industrial uses. The structural responses of macroinvertebrate and fish communities to these environmental stressors may be used to characterize the biotic integrity of receiving water systems [1]. Several biotic integrity indices (e.g. Invertebrate Community Index, Index of Biotic Integrity (fish)) have been developed and have been used for this purpose.

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Recently, we conducted an analysis of fish and macroinvertebrate index and metric information collected from the Little Miami River (LMR), located in southwest Ohio. The purpose was to understand the relationships of this information to chemical and habitat stressors [2]. In conducting the analysis, we became aware that the spatial aspects of data formatting and integration play a significant role in discovering the causative factors responsible for biotic integrity. Although this finding is not new, we were unaware of any study that compared an analysis using short stream segments and one using long stream segments (segmentation scale). Therefore, the purpose of this study was to investigate the importance of segmentation scale in identifying and understanding the factors responsible for the variation of instream biology in the LMR watershed. To accomplish this goal, data for fish, invertebrate, habitat and water chemistry were obtained from Ohio Environmental Protection Agency (EPA) and US EPA and were brought together via a geographical information system (GIS) using two different unique river segmentation methodologies. Our analysis shows that the scale (segmentation) in which data are aggregated directly impacts the ability to discern chemical vs. habitat stressor responses.

2. Methods

The Little Miami River is a national and state scenic river located in southwest Ohio, adjacent to the greater metropolitan Cincinnati and Dayton areas. The LMR drains an area of 4546 km^2 and has a main stem length of 170 km (OEPA, 1994). Ninety-nine percent of the discharge volume to the LMR is from municipal waste water treatment plants (WWTPs), with the remainder from industrial sources (OEPA, 1994).

A digital map of the watershed was obtained from US EPA's RF3 file. Water chemistry data for the LMR were obtained from the US EPA database—STORET [3]. Median and 90th percentile concentrations for each water chemistry parameter per station were determined via database extracts for years 1992–1996. Location and flow information for 41 WWTP and industrial sources were determined from three data bases: US EPA Permit Compliance System, 1988 US EPA Needs Survey and Ohio EPA's Liquid Effluent Analysis Processing System. Instream habitat, fish and macroinvertebrate information collected during an intensive 1993 LMR survey were provided by Ohio EPA. Table 1 includes selected metrics used for analysis. A description of the habitat metrics and their use in deriving the qualitative habitat evaluation index (QHEI) for Ohio is provided by Rankin [4]. Fishery information used to derive the index of biotic integrity (IBI) were collected using electroshocking methods [5]. Data from Hester-Dendy samplers generated the invertebrate community index (ICI) and associated metrics [6].

Biological, chemical and habitat monitoring sites rarely occurred at the exact same latitude and longitude, therefore data were aggregated by river segment. To assess the importance of spatial aggregation in determining chemical and habitat factors linked to instream biological responses, two different segmentation schemes were used: small segment (SS) and large segment (LS). Segmentation was conducted via the geographical information system (GIS) ARC/INFO v 7.0.4, (Environmental Systems Research

Table 1
List of water chemistry, habitat and biological parameters obtained from US EPA's STORET database and Ohio EPA

Water chemistry	Units	Habitat	Scale
Alkalinity, total (ALKTOMED)	mg/l as $CaCO_3$	* Substrate (SUBSTRAT)	0–20
Aluminum, total (ALTOTMED)	ug/l as Al	* Instream cover (COVER)	0–20
Cadmium, total (CDTOTMED)	ug/l as Cd	* Channel quality (CHANNEL)	0–20
* Carbon, total organic (TOC32MED)	mg/l as C	* Riparian/erosion (RIPARIAN)	0–10
* CBOD, 5 day, 20°C (CBODMED)	mg/l	* Pool (POOL)	0–20
Copper, total (CUTOTMED)	ug/l as Cu	* Riffle (RIFFLE)	0–20
Dissolved oxygen (DOMED)	mg O_2 /l	* Gradient (GRADNT V)	0–10
Flow, stream mean daily	cu. ft^3/s	* Qualitative habitat evaluative index (QHEI)	0–100
* Hardness, total (HARDMED)	mg/l as $CaCO_3$	* Drainage area (DRNAREA)	$mile^2$
Lead, total (PBTOTMED)	ug/l as Pb		
* Manganese, total (MNTOTMED)	ug/l as Mn		
Nickel, total (NITOTMED)	ug/l as Ni		
* Nitrogen, ammonia, (NH3TOMED)	total (mg/l) as N	Biological	
* pH (PH32MED)	standard units	No. of invertebrate taxa (NUMTAXA)	
* Phosphorus, total (PHOSMED)	mg/l as P	No. mayfly taxa (NUMMAY)	
* Residue, total nonfilterable (TSS30MED)	mg/l	No. caddisfly taxa (NUMCAD)	
Selenium, total (SETOTMED)	ug/l as Se	Invertebrate community index (ICI)	
Silver, total (AGTOTMED)	ug/l as Ag	No. fish per sample (RELNO)	
* Total Kjeldahl Nitrogen (TOTKJMED)	mg/l as N	No. fish species (SPECIES)	
* Total organic carbon (TOC32MED)	mg/l as C	Percent omnivores (OMNIVOR)	
* WWTP effluent flow	cu. ft^3/s	Index of biotic integrity (IBI)	
* Zinc, total (ZNTOTMED)	ug/l as Zn		
* Toxic units (TOXUNMED, TOXUN90)			

Water chemistry and habitat parameters used to regress against biological metrics and indices are indicated by asterisk (*).

Institute, Redlands, CA) and aggregation within segments with Microsoft Access® and Excel® (Redmond, WA, USA). For the SS analysis, the head of each segment was based on the following criteria: (1) WWTP discharge point, (2) confluence of a significant tributary (generally > 1st order), and (3) the confluence of every other small tributary (typically 1st order). In addition, a 30-m error tolerance was allowed, i.e., any segments less than 30-m long were combined with an adjacent segment. This scheme resulted in 420 segments ranging from 0.03–19.0 km in length (average of 3.0 km). LS segment boundaries were defined by: (1) WWTP discharge points, and (2) significant tributary confluences. This method yielded 134 segments ranging from 0.08–38.5 km (average of 9.5 km).

In addition to the suite of water chemistry parameters presented in Table 1, two calculated parameters were included in the analysis for each segment scheme. The first, cumulative percent WWTP effluent, was included as a crude indicator of persistent wastewater contributions to receiving water quality. The second parameter, toxic units, pertained to the total toxic load of contaminants at each sampling site and was based on the concept of effects addition. Effects thresholds for each chemical considered were based on established US water quality criteria. Only metals and ammonia contributed to the mixture evaluation since too few organic contaminant data were available from STORET to allow for their contribution in the derivation of toxic units for segments in the LMR.

Forward stepwise multiple regression was used to determine the causal habitat and chemical factors responsible for biotic integrity within the LMR [7]. All analyses were conducted using SAS® version 6.11 (1989, Cary, NC). Prior to conducting multiple regressions, univariate correlations of habitat and water chemistry data vs. biotic metrics were determined and corresponding scatter plots were created for each spatially relevant pair. These investigations indicated that several of the water chemistry parameters were dominated by detection limit data. These parameters were deleted from the regression analysis. Parameters used in the regressions are indicated in Table 1.

3. Results and discussion

Twenty-nine river segments contained the full complement of water chemistry, habitat and biological information for multivariate analysis. Three invertebrate metrics (NUMTAXA, NUMMAY, NUMCAD) and the ICI were regressed against habitat and chemical variables aggregated by long (LS) and short (SS) river segment lengths (Table 2). Contrasting results were observed between significant regressions identified in LS vs. SS data files. For NUMTAXA, no significant trends were observed for the LS data set yet water chemistry variables were identified as the causative factors in the SS set. For the other metrics and ICI, habitat variables appeared to be most significant followed by chemical variables, such as hardness, pH, percent cumulative effluent, and toxic units. Contrasting results were also observed in the fish data set. Habitat variables appeared to be the principal factors related with RELNO and SPECIES metrics, followed by chemical variables for both LS and SS data sets. However, strong contrasts were observed between the two data sets for OMNIVOR and IBI. For instance, in the LS set DRNAREA and PCTEFLUM corresponded to the first two forward selection steps, respectively, for OMNIVOR. In contrast, only the water chemistry parameter TSS30MED was significantly related to OMNIVOR metric data. Identifying chemical factors as the primary stressors appeared to be segmentation scale dependent as also seen with the IBI scores. In this case, IBI was primarily related to CHANNEL scores and secondarily by PCTEFLUM in the long segment data set. Contrastingly, PCTEFLUM was the primary factor followed by habitat variables in the SS set.

These results indicate that the ability to determine stressor–response relationships may be segmentation scale dependent. Our results show that habitat variables become increasingly important as causative stressors when the scale of data aggregation in-

Table 2
Forward stepwise regression results from large segment (LS) and small segment (SS) analysis

Dependent variable	Segment size	Forward selection step				
		1	2	3	4	R^2
NUMTAXA	LS	NONE				
	SS	PCTEFLUM	TOXUN90	TOC32MED		0.37
NUMMAY	LS	POOL	DRNAREA			0.48
	SS	CHANNEL	DRNAREA	PCTEFLUM		0.65
NUMCAD	LS	DRNAREA	HARDMED	PH32MED		0.68
	SS	DRNAREA	HARDMED			0.36
ICI	LS	DRNAREA	PH32MED	TOXUNUMED		0.48
	SS	POOL	PCTEFLUM			0.33
RELNO	LS	DRNAREA	RIPARIAN	SUBSTRAT	TOXUNMED	0.65
	SS	DRNAREA	ZNTOTMED	PHOSMED		0.48
SPECIES	LS	QHEI	PCTEFLUM	COVER		0.53
	SS	COVER	PCTEFLUM			0.60
OMNIVOR	LS	DRNAREA	PCTEFLUM			0.53
	SS	TSS30MED				0.42
IBI	LS	CHANNEL	PCTEFLUM			0.56
	SS	PCTEFLUM	COVER	RIPARIAN		0.58

creases. This has important ramifications for watershed vs. subwatershed or limited sampling assessments. Further, it may indicate that chemical factors that are associated with WWTPs may become 'diluted' via large segment data aggregation. Therefore, where point sources are the primary focus—small segment sizes are recommended. On the other hand, our analysis may indicate that habitat may be the most important factor for the diversity, distribution and abundance of biota in the LMR.

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