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A generalized watershed disturbance-invertebrate relation applicable in a range of environmental settings across the continental United States

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Abstract It is widely recognized that urbanization can affect ecological conditions in aquatic systems; numerous studies have identified impervious surface cover as an indicator of urban intensity and as an index of development at the watershed, regional, and national scale. Watershed percent imperviousness, a commonly understood urban metric was used as the basis for a generalized watershed disturbance metric that, when applied in conjunction with weighted percent agriculture and percent grassland, predicted stream biotic conditions based on Ephemeroptera, Plecoptera, and Trichoptera (EPT) richness across a wide range of environmental settings. Data were collected in streams that encompassed a wide range of watershed area (4.4–1,714 km^2), precipitation (38–204 cm/yr), and elevation (31–2,024 m) conditions. Nevertheless the simple 3-landcover disturbance metric accounted for 58% of the variability in EPT richness based on the 261 nationwide sites. On the metropolitan area scale, relationship r^2 ranged from 0.04 to 0.74. At disturbance values <15 the EPT rate of decrease was ~10 times greater than at disturbance values >15. Future work may incorporate watershed management practices within the disturbance metric, further increasing the management applicability of the relation. Such relations developed on a regional or metropolitan area scale are likely to be stronger than geographically generalized models; as found in these EPT richness relations. However, broad spatial models are able to provide much needed understanding in unmonitored areas and provide initial guidance for stream potential.

Keywords Urbanization · Agriculture · Disturbance · Macroinvertebrates · EPT richness

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Introduction

It is widely recognized that urbanization can affect ecological conditions in aquatic systems (Paul and Meyer 2001). Numerous studies have identified impervious surface cover as an indicator of urban intensity and as an index of development at the watershed, regional, and national scale (Bressler et al. 2008; Schueler et al. 2009). As processors of nutrients and organic energy macroinvertebrates have been used as a monitor of overall instream health (Gore et al. 2001). Studies have also documented the decline of benthic community, including Ephemeroptera, Plecoptera, and Trichoptera (EPT) richness with increased urbanization for specific geographic regions such as Rocky Mountain streams (Maxted 2000), Anchorage, Alaska (Ourso and Frenzel 2003), North Central Georgia (Roy et al. 2003), and Melbourne, Australia (Walsh et al. 2005).

Watershed imperviousness is an easily measureable, commonly used, well understood land-use metric that integrates cumulative water resource impacts (Arnold and Gibbons 1996). Direct connection of imperviousness to the stream has been identified as important to stream ecological condition (Walsh et al. 2005). Schueler et al. (2009) noted "impervious cover has unique properties as a watershed metric in that it can be measured, tracked, forecasted, managed, priced, regulated, mitigated, and in some cases, even traded. IC is a common currency that is understood and applied by watershed planners, storm-water engineers, water quality regulators, economists, and stream ecologists alike." The objective of this study was to determine whether watershed percent imperviousness when applied in conjunction with percent agriculture and percent grassland improved association with stream biotic conditions based on EPT richness on a national scale. This effort may be one of the first to develop a relation between a generalized land disturbance metric and a common stream biologic metric (EPT richness) applicable across the continental United States.

Methods

This study examined landcover and stream ecological conditions in nine metropolitan areas across the continental United States (Fig. 1) that represent wide physiographic and climatic settings (Table 1). In each metropolitan area, 28–30 similarly-sized watersheds, typically drained by 2nd to 3rd order streams (generally less than 50 km^2) were selected to maintain relatively homogeneous natural environmental features (e.g., ecoregion, climate, elevation, stream size) and encompassed basins with little or no urban development to basins with maximum development (Falcone et al. 2007). The amount of imperviousness within a basin and upstream of the sampling point, ranged from 0 to 55 percent (Supplemental Table 1).

Invertebrate community data were collected within each of the nine metropolitan areas in up to 30 stream reaches (n=261). Sampling reaches in each metropolitan area were selected from watersheds along gradients of increasing urbanization and were sampled during an index period appropriate for each geographic area between 1999 and 2004. Index periods were chosen to represent the optimal time to collect biological data and were based on multiple factors, such as life history attributes of the organisms to be sampled and predictable hydrologic conditions that allowed safe and effective sampling (Cuffney et al. 1993). Invertebrate data were collected from these reaches using standard U. S. Geological Survey program data-collection methods (Moulton et al. 2002) in which one semi-quantitative sample was collected from either rock or woody debris and a separate

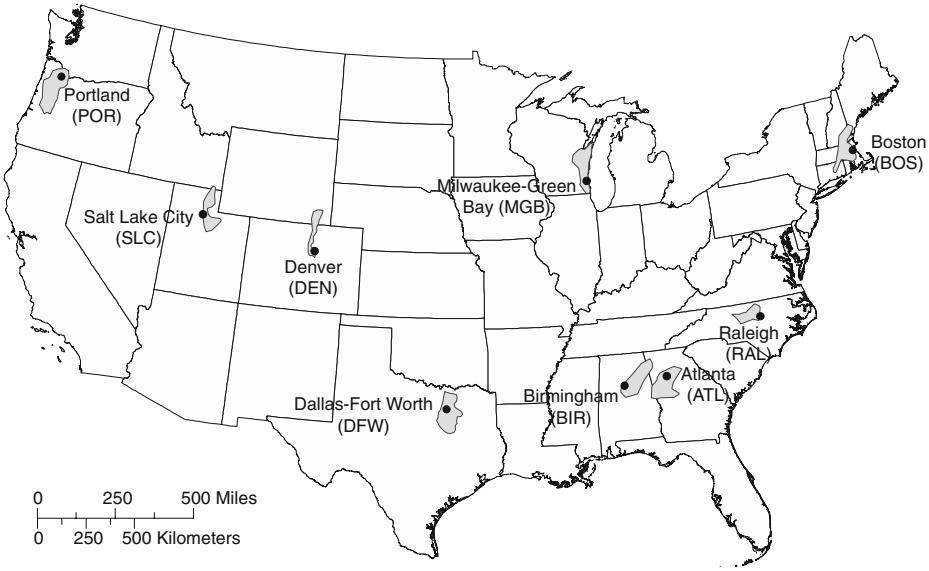

Fig. 1 Location of nine metropolitan areas in the United States sampled as part of the U.S. Geological Survey National Water-Quality Assessment Program study on the effects of urbanization on stream ecosystems, 1999–2004

qualitative sample was collected from all available habitats at each site. The two collections were combined to determine Ephemeroptera, Plecoptera, and Trichoptera (EPT) richness. EPT were selected as the endpoint metric as collectively these groups are pollution intolerant, good indicators of stream condition, sensitive to changes in stream conditions related to impervious cover, provide a critical link to the fish community and are commonly used by various State and national assessment programs (Gore et al. 2001; Fore et al. 1996)

Information on landcover, based on 30-m resolution satellite imagery, was obtained from National Land Cover Data 2001 (NLCD01) dataset classification scheme and protocols (U. S. Geological Survey 2005) and was compiled using geographic information system (GIS) software. Impervious cover, estimated from each 30-m pixel, was ground-truthed from 60 random samples digitized from high-resolution (0.3-m) orthoimagery in each of six metropolitan areas.

A univariate EPT richness scatterplot was initially constructed with percent imperviousness in the watershed as the independent variable and a fitted logarithmic regression model; 0.1% was added to the independent variable for logarithmic transformation (Data Desk, version 6.1; Data Description, Inc., Ithaca, New York[1]). Subsequently, percent agriculture in the watershed was added as part of the independent variable and iteratively weighted to maximize the coefficient of determination (r^2) of the logarithmic model; ~0.15 was the optimal coefficient. The procedure was repeated with percent grassland added to the independent variable $(\text{imperviousness}(\%) + 0.15^{*}\text{agriculture}(\%))$; ~0.15 was also the optimal coefficient for grassland (%).

[1] Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U. S. Government.

Table 1 Physiographic region, precipitation occurrence, noteworthy conditions during sampling, and summary statistics for select physical variables for the nine studied metropolitan areas in the United States

Metropolitan area (abbreviation)	Physiographic provinces (Fenneman and Johnson 1946)	Precipitation occurrence (Falcone et al. 2007)	Noteworthy conditions during hydrologic data collection	Reach water surface gradient (%) [mean (min-max)]	Mean annual precipitation for period 1980–1997 (cm) [mean (min-max)]	Drainage area (km^2) [mean (min-max)]	Mean elevation (m) [mean (min-max)]	Number of basins in metropolitan area
Portland (POR)	Pacific Mountain, Pacific Border, Cascade-Sierra Mountains	Snowmelt in spring, rainfall October-April	None	0.60 (0.11–1.7)	154 (116–204)	49.2 (17.1–103.8)	222 (53–621)	28
Salt Lake City (SLC)	Rocky Mountain System, Middle Rocky Mountains; Intermontane Plateaus, Basin and Range	Snowmelt in winter/spring major runoff source, scattered light thunderstorms in summer	Flow affected by reservoirs, interbasin transfers, and diversions	1.1 (0.46–2.6)	65 (60–73)	364.5 (8.8–1714.4)	1,435 (1,370–1,504)	30
Denver (DEN)	Interior Plains, Great Plains; Rocky Mountain System, Southern Rocky Mountains	Snowmelt in spring, rainfall April–September	Flow affected by reservoirs, interbasin transfers, and diversions	not measured	43 (38–46)	89.8 (4.4–558.6)	1,713 (1,535–2,024)	28
Dallas (DFW)	Atlantic Plain, Coastal Plain	Rainfall spring and summer	None	0.19 (0.008–0.98)	104 (96–111)	85.3 (26.8–291.4)	170 (124–220)	28
Milwaukee-Green Bay (MGB)	Interior Plains, Central Lowland	Snowmelt March–May, rainfall May–September	None	0.31 (0.02–0.63)	86 (81–91)	45.5 (16.3–100.3)	237 (202–270)	30
Birmingham (BIR)	Appalachian Highlands; Valley and Ridge, Plateaus, Piedmont	Rainfall—frontal systems in winter, thunderstorms in summer/fall	Severe drought	0.38 (0.14–0.66)	146 (141–152)	31.8 (4.7–66.1)	233 (162–324)	28
Atlanta (ATL)	Appalachian Highlands, Piedmont	Rainfall—frontal systems in winter, thunderstorms in summer/fall	Wet year	0.19 (0.04–0.59)	134 (124–140)	89.9 (43.2–146.3)	286 (193–350)	30
Raleigh (RAL)	Appalachian Highlands, Piedmont	Rainfall distributed throughout the year	Wet year	0.63 (0.26–1.3)	120 (115–125)	22.3 (4.9–82.5)	184 (89–284)	29
Boston (BOS)	Appalachian Highlands, New England	Snowmelt March–May, rainfall May–September	None	0.64 (0.12–1.6)	123 (115–136)	75.7 (45.9–124.6)	113 (31–236)	30

Results and discussion

Overall, EPT richness declined with increasing watershed imperviousness (Fig. 2a) albeit with a wedge shape commonly observed with ecological data across large spatial scales. Such data are frequently defined by an upper limit, action due to multiple factors or rural areas dominated by agriculture (Thomson et al. 1996; Carter and Fend, 2005; Wang et al. 2001). A similar wedge-shaped invertebrate response to urbanization was recently observed in three regions across the United States (Paul et al. 2008). Variability of stream quality uncertainty has been found greatest for impervious cover less than 10%; a range in which other watershed metrics such as forest cover, road density, and cropping practices may also be important (Schueler et al. 2009; Wang et al. 2001). Similarly, the greatest variability in EPT richness in this study was between 0 and ~12% imperviousness (Fig. 2a). Many of the sites with low EPT richness and low imperviousness, which plotted in the lower left scatterplot region, had substantial agriculture and grassland landcover (Supplemental Table 1).

The weighted addition of agriculture and grassland (0.15 the weight of imperviousness) to imperviousness substantially strengthened the relation between watershed disturbance and EPT richness, increasing the adjusted r^2 from 0.36 to 0.58 (Fig. 2b). Approximately two thirds of the EPT taxa were lost (~30 to ~10) in the first quarter of the generalized disturbance range. Sites with highest EPT richness were located in watersheds draining predominantly forest and wetland landcover (Supplemental Table 1). The following examples illustrate the utility of this index. Lost Creek in the Portland metropolitan area is predominantly forest and wetland (88%) which resulted in a low disturbance value of 0.7 and relatively high EPT richness (26 taxa). Conversely, the Kewaunee tributary watershed in Milwaukee-Green Bay is predominantly agriculture (86%), a disturbance value of 14.2, and reduced EPT richness (7 taxa). Similarly, Fivemile Creek in Birmingham has little agriculture or grassland (~1.5%) but 15% imperviousness, a disturbance value of 15.4 and comparatively reduced EPT richness (6 taxa).

Figure 3(a-i) illustrates the effect of including agriculture and grassland to the disturbance axis within individual metropolitan areas. In effect, data located in the left corner of the wedge scatter plot (imperviousness only; Fig. 2a) were translated proximate to the logarithmic trendline when agriculture and grassland are included as part of the disturbance axis. Substantial shifts between imperviousness only (small symbols) and the three landcover disturbance metric (large symbols) are clearly observed in the predominantly agriculture (Milwaukee-Green Bay, Dallas) and grassland (Denver) areas (Fig. 3b, e, and g respectively). Sites within Milwaukee-Green Bay that were predominantly agriculture (small symbols with x axis values ~0 and large symbols ~12) had wide variability in EPT richness (Fig. 3b, Supplemental Table 1).

The nine individual metropolitan areas had relations consistent with the overall national relation; all but one were significant at $p<0.05$ (Fig. 3a-i). Denver's relation, which occurred over the most limited range of the disturbance index (14–48) and in the flat portion of the logarithmic curve, was not significant ($p=.3101$). In general, relations were weakest in areas in which the non-urban watersheds were predominantly agriculture or grassland. Kashuba et al. (2009) utilized a hierarchical modeling analysis for the same metropolitan areas and concluded regional mean precipitation, air temperature and antecedent agricultural could be used to determine the slope of regional basin development-stream biology relations.

A piecewise regression ("broken-stick") model (Brenden et al. 2008; Toms and Lesperance 2003) which utilized the 3-landcover disturbance metric (inclusion of

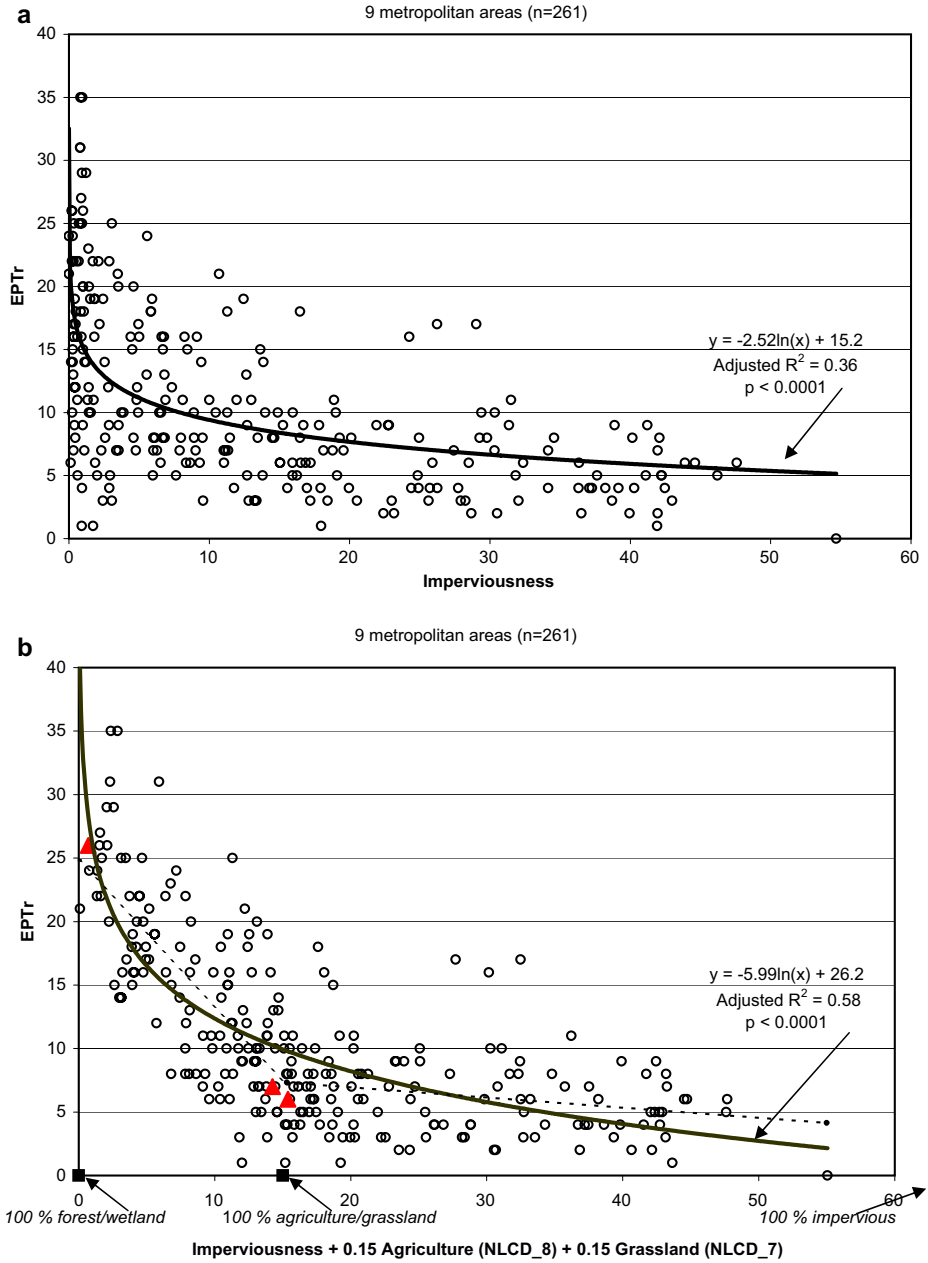

Fig. 2 Scatter plots of the invertebrate richness metric, EPTr, against imperviousness only (**a**) and the three landcover (imperviousness% +0.15 agriculture% +0.15grassland%) disturbance metric (**b**) for the combined 9 metropolitan area data set with logarithmic regression models. *Triangle symbols* identify selected sites discussed in text. *Dotted lines* are linear regressions for disturbance index < and >15

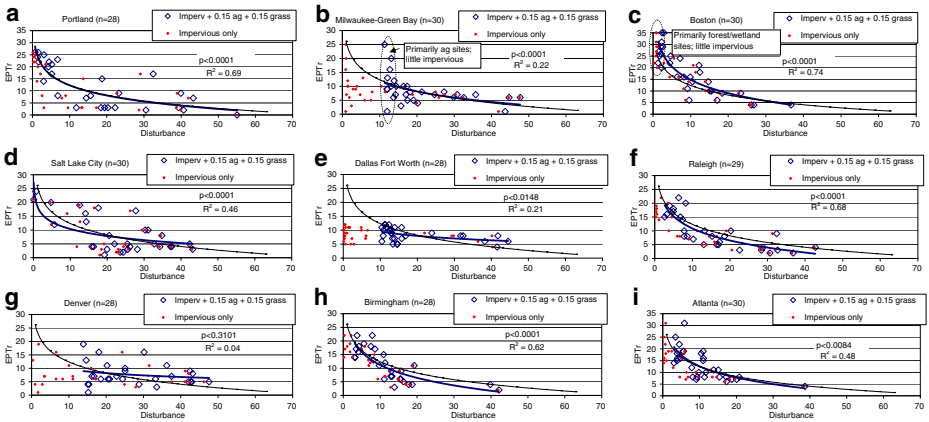

Fig. 3 Scatter plots for individual metropolitan areas of the invertebrate richness metric, EPTr, against two disturbance metrics; imperviousness only (small symbols) and the three landcover (imperviousness% +0.15agriculture% +0.15grassland%) metric. Logarithmic regression and *p* values for the three landcover metric are depicted (heavy curve). The combined nine metropolitan area data set logarithmic model (light curve) is included to enhance comparison

agriculture and grassland) identified the slope breakpoint at a disturbance value of ~15 (Fig. 2b). Linear regression in the disturbance region <15 had a slope of −1.1 ($p<0.001$); slightly more than one EPT taxa was lost with each unit increase of disturbance. For disturbance values >15 the EPT reduction was much more gradual—it required a >10 disturbance unit change for an EPT richness reduction of 1 taxa (slope = −0.08; $p=0.011$).

Although there are inherent sources of variability and error in both landcover and biologic variables, a strong disturbance-invertebrate relation was evident across the continental United States. For example, impervious surface estimation from satellite-acquired data resulted in a general underestimation of impervious surfaces in the Atlanta, Raleigh, and Dallas datasets as compared to the Denver, Portland, and Milwaukee-Green Bay datasets (Falcone and Pearson 2006). Additionally, the large-scale effort required biologic sampling be conducted on a single occasion at one stream reach, over a 5-year period, and in streams that encompassed a wide range of watershed area (4.4–1,714 km^2), precipitation (38-204 cm/yr), and elevation (31–2,204 m) conditions (Table 1). Nevertheless the simple 3-landcover disturbance metric accounted for 58% of the variability in EPT richness across the 261 nationwide sites.

Watersheds with disturbance values <~15 that undergo modest mitigation or improvement actions may experience large gains in EPT scores and presumable overall ecosystem health. For example, a stream in a predominantly agricultural and forest/wetland watershed may gain one additional EPT taxa with each 6.7% increment of agriculture land converted to forest or wetland. Likewise for urban and forest/wetland watersheds, one additional EPT taxa may be associated with each 1% increment of imperviousness converted to forest or wetland. This is consistent with a Maryland study in which predominantly agricultural streams had significantly more EPT taxa than urban streams (Moore and Palmer 2005). In contrast, watersheds scoring >30 may require substantial investment in mitigation actions to yield improvement because they are on the segment of the curve with the lowest slope. In general, it appears that forest and wetland cover are important for higher EPT scores. This may be especially important in stream's riparian zone with the accompanying canopy, organic matter, and wood debris (Moore and Palmer 2005).

Agreement between the nine metropolitan area relations and the national scale relation (Fig. 3(a-i)) is an indication the multi-region relation may be useful as one approximation of general EPT richness expectation throughout the continental United States. For unmonitored sites the relation provides one estimate of expected EPT richness. Alternatively, monitored sites with values substantially below the relation (Fig. 2b) may be examined for possible point source input or local habitat degradation. This study also confirms previous findings that single-event biologic sampling can be an effective, economical approach (Lammert and Allan 1999). From a purely scientific standpoint however, increased temporal sampling may improve model error.

Inclusion of management practices or detailed stressors within the disturbance metric will likely strengthen the relation and make it more management oriented. For example, points beneath the curve (lower than expected EPT richness) may have increased road density, impervious surface area concentrated near or connected to the stream, or treated with substances that affect stream biology (Wang et al. 2001; Mahler et al. 2005; U. S. Environmental Protection Agency 2008). Alternatively, agriculture in these watersheds may have higher than normal pesticide, nutrient or sediment input potentially reducing EPT (Allan 2004). Sites in the upper envelope (better than expected EPT richness) may have in place best management practices to mitigate the effects of imperviousness (i.e. raingardens, grass swales, disconnected imperviousness) or agriculture (buffer strips, no till practice, appropriate chemical treatment). Prior research has suggested the importance of riparian buffers in agricultural watersheds in supporting high macroinvertebrate diversity (Watzin and McIntosh 1999). Incorporation of such factors within the disturbance metric will shift data points on the independent axis and potentially strengthen the relation.

There is some indication that management practices may have greater EPT improvement potential in highly agricultural watersheds as compared to those that contain a high percentage of impervious surfaces. Wider EPT variance is observed at disturbance values of ~10 to 15 (often highly agricultural sites) as compared to sites with disturbance values >40 (Fig. 2b). This is especially noticeable at the scale of individual metropolitan areas. The low impervious but high agricultural Milwaukee-Green Bay sites (Fig. 3b) had a wider EPT range (1–25) than did the low impervious, high forest/wetland Boston sites (20–35).

Summary

Watershed percent imperviousness, a commonly understood urban metric was used as the basis for a generalized watershed disturbance metric that, when applied in conjunction with weighted percent agriculture and percent grassland, predicted stream biotic conditions based on Ephemeroptera, Plecoptera, and Trichoptera (EPT) richness. The relation was formulated over, and applicable to, both wet and dry periods and a range of physiographic settings. A threshold was identified (disturbance values <15) that defined a region of increased EPT richness change. The relation has the potential of being a strong management tool should future work include watershed management practices within the disturbance metric. Such relations developed on a regional or metropolitan area scale are likely to be stronger than geographically generalized models; as found in these EPT richness relations. However, broad spatial models provide much needed understanding in unmonitored areas and an initial guidance for stream potential.

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Supplemental table 1. Geographic information system derived landcover characteristics (% of watershed area) for 261 sites located in 9 metropolitan areas across the continental United States.

station ID	ShortName	EPT richness	NLCD_IS impervious	NLCD1_4 forest	NLCD1_5 shrubland	NLCD1_7 grassland	NLCD1_8 agriculture	NLCD1_9 wetland	impervious + 0.15 * (agriculture + grassland) disturbance metric
02335910	ATL_rot	4	38.2	11.3	0.2	0.7	1.4	0.6	38.6
02206314	ATL_jac	8	20.1	25.0	0.5	1.0	2.7	2.4	20.8
02335870	ATL_sop	7	19.6	23.0	0.3	0.5	2.0	0.8	20.1
02336635	ATL_nic	7	18.1	27.3	0.5	1.0	2.5	0.9	18.8
02336728	ATL_uto	6	16.9	35.0	0.8	0.9	1.4	0.6	17.3
02208150	ATL_alc	8	14.6	36.2	2.3	5.1	11.7	0.9	17.3
02334885	ATL_suw	8	13.5	38.0	1.5	3.3	8.8	2.5	15.4
02204230	ATL_bci	11	13.0	34.8	2.3	3.2	10.2	4.6	15.1
02344340	ATL_mor	11	12.0	39.7	1.8	2.6	9.2	5.7	13.8
02336876	ATL_pow	10	8.9	39.6	2.0	3.1	15.2	2.6	11.7
02336968	ATL_nos	8	9.5	40.8	1.0	1.7	9.7	2.3	11.3
02217471	ATL_bch	16	5.0	38.3	1.4	6.8	33.0	2.5	11.1
02204468	ATL_wal	15	6.7	37.9	2.8	5.2	22.7	3.7	11.0
02218700	ATL_apa	19	5.9	39.3	1.7	7.7	25.2	4.6	11.0
02217293	ATL_lmul	18	5.8	41.2	1.9	6.9	23.3	2.8	10.5
02344480	ATL_sho	10	6.4	46.6	2.8	4.3	17.7	3.8	9.8
02344797	ATL_who	8	6.8	48.6	2.2	3.6	12.3	5.1	9.3
02344737	ATL_whw	7	6.3	45.6	2.2	2.9	15.4	5.8	9.1
02336822	ATL_mil	8	4.6	44.8	3.8	3.8	19.0	4.3	8.1
02346358	ATL_tur	12	2.8	45.7	3.2	4.4	28.9	4.3	7.9
02338375	ATL_cen	31	0.8	55.3	4.6	5.2	28.2	1.0	5.9
02338280	ATL_whp	19	1.5	59.2	5.1	4.7	21.7	1.0	5.6
02337395	ATL_dog	19	2.4	58.0	4.1	4.7	15.6	1.3	5.6
02213450	ATL_ltob	16	0.3	58.4	3.5	6.4	22.5	3.0	4.7
02340282	ATL_hou	22	0.7	62.0	3.3	5.9	18.7	3.7	4.5
02221000	ATL_mur	16	0.4	63.0	0.8	11.1	12.5	3.9	4.0
02339480	ATL_ose	15	1.0	68.1	3.0	8.4	10.4	2.9	3.9
02344887	ATL_rdo	18	0.8	66.9	2.6	7.7	12.1	5.4	3.9
02338523	ATL_hil	25	0.4	70.4	4.3	8.7	11.3	0.5	3.5
02347748	ATL_auc	14	0.3	70.6	3.5	6.6	11.2	4.9	3.0
0209647295	RAL_dry	4	42.5	2.4	0.0	0.4	0.8	0.0	42.7
0211583580	RAL_bowen	2	36.5	1.5	0.0	0.5	1.0	0.0	36.9
0209651815	RAL_branch	3	32.0	3.2	0.5	1.1	2.6	0.0	32.7
02099480	RAL_rich	9	31.4	15.1	1.6	1.2	5.5	0.2	32.5
0208732610	RAL_pigeon	2	30.5	1.1	0.0	0.0	0.5	0.0	30.7
0209679804	RAL_lalam	4	27.7	10.4	0.8	2.1	4.3	0.1	28.8
0209517912	RAL_nbuff	3	28.3	2.5	0.0	0.0	0.2	0.0	28.4
0208726370	RAL_rschen	3	20.5	26.3	0.5	1.8	11.1	0.2	22.6
02099238	RAL_bull	10	19.0	24.2	1.2	1.2	6.2	0.1	20.2
0209647280	RAL_serv	8	16.5	17.1	3.7	2.8	10.6	0.2	18.6
02100295	RAL_hasket	6	15.9	32.9	2.5	1.3	6.8	0.4	17.2
0208725055	RAL_black	5	16.2	16.4	0.3	1.4	2.6	0.0	16.9
02081510	RAL_fondry	5	13.8	26.9	2.1	4.1	13.1	0.2	16.5
02087580	RAL_swift	8	14.5	20.5	0.6	1.3	3.1	0.7	15.3
02100634	RAL_vestal	10	11.3	46.0	2.0	1.6	11.1	0.2	13.3
0208726995	RAL_hare	5	12.7	19.7	0.3	0.6	1.0	0.6	13.0
02097355	RAL_bolin	7	9.0	45.8	1.3	2.5	5.0	0.4	10.3
0209750881	RAL_wilson	8	6.7	61.9	1.7	2.8	9.6	0.0	8.6
0209665940	RAL_rtrib	20	3.5	44.4	2.9	3.8	27.1	0.2	8.3
0208794025	RAL_camp	10	3.7	51.9	1.4	4.2	22.4	1.9	7.8
0208758440	RAL_dutch	8	6.0	45.3	1.1	3.1	8.4	2.4	7.8
0209665990	RAL_rock	14	1.1	45.2	4.4	4.3	37.1	0.1	7.4
0208500600	RAL_cates	15	4.5	60.5	4.3	4.0	10.7	0.2	6.8
0208501535	RAL_stroud	22	1.7	52.8	3.8	4.5	26.1	0.2	6.4
02085430	RAL_deep	18	0.5	60.3	4.3	5.1	23.9	1.3	5.0
02081190	RAL_tar	17	0.4	58.1	5.2	7.9	22.1	3.0	4.9
02097464	RAL_morgan	19	0.4	68.5	2.3	3.7	19.3	0.4	4.0
0209697900	RAL_poke	16	0.6	72.8	3.0	3.5	13.4	0.8	3.2

station ID	ShortName	EPT richness	NLCD_IS impervious	NLCD1_4 forest	NLCD1_5 shrubland	NLCD1_7 grassland	NLCD1_8 agriculture	NLCD1_9 wetland	impervious + 0.15 * (agriculture + grassland) disturbance metric
0209695780	RAL_brooks	15	0.3	75.8	5.3	6.5	8.6	0.2	2.6
40421811152	SLC_m300	3	43.0	0.3	0.6	0.0	0.5	1.7	43.2
40392711152	SLC_lcmu	5	42.2	0.6	1.8	0.0	0.3	0.3	42.4
40375511151	SLC_lcwh	4	37.3	1.4	3.8	0.0	0.6	0.7	37.5
40400011151	SLC_bc900	4	37.1	2.2	5.3	0.1	0.1	0.4	37.2
10167800	SLC_	8	34.6	1.9	5.2	0.0	0.9	1.0	34.8
40394511150	SLC_bcmal	4	34.1	4.1	9.6	0.3	0.1	0.7	34.3
40414011148	SLC_m3060	5	31.8	4.6	8.6	0.0	5.4	13.7	32.7
40144211140	SLC_p800	10	30.4	5.9	14.3	0.7	3.6	3.2	31.1
40414311150	SLC_m2000	10	29.4	3.5	6.4	0.0	5.2	19.6	30.3
41034211157	SLC_kayl	3	25.6	0.6	3.3	0.1	16.2	11.7	28.2
41425811150	SLC_log	17	26.2	2.7	4.1	0.1	9.1	8.8	27.7
41023111156	SLC_holm	4	24.4	0.4	1.5	0.0	11.2	19.5	26.2
41045311157	SLC_k1000	3	23.0	0.8	4.1	0.1	16.1	16.0	25.5
40431711150	SLC_parl	5	24.9	8.7	17.8	2.5	0.9	4.6	25.5
40434911151	SLC_ewmin	2	23.2	9.2	12.8	0.3	6.8	3.1	24.3
41050111155	SLC_sfk	2	22.4	1.3	5.8	0.3	6.6	16.4	23.6
41025011157	SLC_nkho	5	19.1	1.3	6.6	0.0	18.5	13.9	22.0
41140711158	SLC_owas	8	19.3	8.1	17.1	0.0	7.8	9.3	20.6
40443011149	SLC_e1300	3	18.4	12.8	17.8	0.5	9.1	3.2	20.0
41004111158	SLC_bafr	1	18.0	3.3	5.7	0.2	7.8	6.3	19.3
40165311140	SLC_p3700	18	16.5	16.7	28.7	0.8	6.1	4.5	17.6
40095911136	SLC_hcen	4	11.8	10.0	14.2	4.0	25.6	6.5	16.3
40585411153	SLC_farm	4	15.6	26.9	17.5	0.2	1.1	3.7	15.9
41141311156	SLC_ohar	13	12.7	11.7	24.7	0.0	10.5	13.1	14.3
40092711135	SLC_h800	16	9.1	11.0	15.7	4.4	28.3	7.2	14.1
40370711146	SLC_bcwtp	19	12.4	22.2	29.6	0.0	0.0	0.0	12.5
41141311155	SLC_oval	12	4.9	21.5	46.8	0.0	5.0	0.0	5.7
40185011139	SLC_p189	20	4.6	34.3	43.3	0.0	0.3	1.5	4.8
41014811153	SLC_ba1800	24	0.0	21.6	35.1	0.0	4.5	38.7	0.8
41052211154	SLC_fern	21	0.0	87.4	12.4	0.0	0.0	0.1	0.1
02461200	BIR_valle	2	42.0	3.5	0.2	0.1	0.5	0.0	42.1
02423590	BIR_utsha	4	39.2	10.3	0.7	0.7	3.0	0.1	39.8
02423515	BIR_patto	11	18.9	15.1	0.1	0.2	1.1	0.0	19.2
02400675	BIR_utrwil	4	17.9	45.9	0.6	1.2	3.0	0.0	18.7
02458150	BIR_villa	4	17.0	16.2	0.2	0.3	4.1	0.0	17.7
02423581	BIR_shasam	5	15.9	38.0	0.5	0.6	1.2	0.2	16.3
02423576	BIR_shade	9	15.3	43.2	0.6	0.8	1.2	0.3	15.6
02403380	BIR_snow	6	15.0	43.9	0.6	1.7	1.0	0.0	15.5
02456900	BIR_fivfi	6	15.1	20.7	0.6	0.5	1.1	0.3	15.4
02398001	BIR_town	3	12.8	31.7	4.0	0.2	6.1	0.1	13.9
02406930	BIR_shirt	7	11.2	37.9	1.8	4.3	8.6	1.0	13.2
02456980	BIR_filaw	9	12.7	27.0	0.8	0.6	1.2	0.3	13.1
02401749	BIR_willi	7	11.4	48.0	2.3	1.3	8.2	0.0	12.9
0242339580	BIR_lcabr	12	7.3	39.0	3.7	5.3	20.3	2.3	11.3
02423536	BIR_buck	6	9.3	42.2	4.8	6.9	4.3	0.4	11.1
02423397	BIR_lcale	15	8.5	41.4	2.7	4.6	11.4	1.1	10.9
02461670	BIR_fivne	11	6.9	39.8	3.0	2.2	16.3	1.9	9.8
02423729	BIR_dry	17	5.0	44.6	4.6	8.0	15.4	0.2	8.6
0242354750	BIR_cvc	13	6.8	58.5	0.7	1.5	6.9	0.4	8.2
0242372950	BIR_sprin	22	2.1	43.1	2.0	2.9	34.7	4.0	7.9
0242354650	BIR_cvci	18	5.9	54.7	0.7	1.5	8.6	0.4	7.5
02400800	BIR_lwill	19	1.8	62.1	3.6	2.1	22.6	0.0	5.6
02401355	BIR_utrbc	18	1.1	64.1	2.3	2.4	18.1	0.1	4.2
02401760	BIR_ltal	16	1.8	73.4	1.3	6.3	8.4	0.3	4.1
02397939	BIR_chapp	22	0.3	70.7	2.2	3.4	19.2	0.1	3.8
02400725	BIR_mush	17	0.5	70.0	5.1	2.1	17.5	0.0	3.5
02401350	BIR_bigca	14	0.2	73.8	2.9	2.7	16.5	0.5	3.1
02423620	BIR_lshad	14	2.6	63.0	3.6	1.5	1.6	3.1	3.1

station ID	ShortName	EPT richness	NLCD_IS impervious	NLCD1_4 forest	NLCD1_5 shrubland	NLCD1_7 grassland	NLCD1_8 agriculture	NLCD1_9 wetland	impervious + 0.15 * (agriculture + grassland) disturbance metric
01102500	BOS_aber	4	36.3	15.8	0.4	0.1	1.9	3.2	36.7
01106468	BOS_matf	4	26.3	25.9	0.7	0.1	3.0	8.2	26.8
01102345	BOS_saug	4	25.7	19.7	0.4	0.2	1.8	9.4	26.1
01105581	BOS_mona	9	22.8	29.1	0.5	0.0	3.0	10.1	23.4
01110000	BOS_quin	9	17.8	33.1	2.3	0.4	2.5	6.3	18.4
01105500	BOS_enep	6	16.5	35.8	0.6	0.1	2.7	11.7	17.0
01101500	BOS_ipsw	10	14.9	30.8	0.3	0.4	3.2	19.8	15.5
011032058	BOS_char	10	14.0	42.5	2.6	1.1	5.5	11.9	15.1
01105000	BOS_nepo	14	13.9	40.5	0.8	0.2	4.7	13.1	14.7
01096710	BOS_assa	18	11.3	44.8	2.5	1.0	5.9	8.2	12.4
010965852	BOS_beav	21	10.7	48.5	3.1	0.1	9.2	7.5	12.2
01097476	BOS_sudb	14	9.4	49.7	1.6	0.1	6.3	13.9	10.5
01096544	BOS_ston	16	8.2	50.2	1.9	0.4	9.9	9.9	9.9
01109595	BOS_midd	6	8.7	54.3	1.2	0.1	5.6	5.9	9.6
01109000	BOS_wade	11	8.1	49.6	1.4	0.3	6.0	16.4	9.2
01097270	BOS_fort	16	6.8	52.8	1.6	0.2	8.6	16.2	8.2
01112262	BOS_mill	24	5.6	58.0	2.9	0.6	9.3	10.9	7.2
01096945	BOS_eliz	16	4.4	66.8	2.1	0.4	12.3	7.1	6.4
01072650	BOS_grea	25	3.1	65.9	3.6	0.2	9.7	10.7	4.7
01072904	BOS_bell	22	2.9	58.5	4.1	0.7	9.5	13.4	4.5
01072540	BOS_lime	35	0.9	67.9	6.8	0.5	11.6	10.5	2.9
01089743	BOS_lsun	29	1.2	73.1	4.3	0.3	7.9	3.8	2.6
01193340	BOS_blal	35	0.8	67.5	3.2	0.2	9.6	12.4	2.4
01095220	BOS_stil	31	0.8	74.4	1.4	0.2	9.1	10.0	2.3
01094005	BOS_babo	20	1.0	76.6	1.2	0.3	7.3	7.4	2.2
01073458	BOS_nort	26	1.0	79.2	3.8	0.3	6.3	6.2	2.1
01073260	BOS_lamp	29	0.9	78.6	6.4	0.6	6.3	4.9	2.1
01072845	BOS_isin	25	0.7	74.2	5.2	0.2	5.7	4.6	1.7
010734833	BOS_linh	27	0.9	78.6	4.4	0.5	3.5	6.9	1.6
01090477	BOS_blab	22	0.3	80.4	4.3	0.1	6.0	7.2	1.4
39440910502	DEN_lakew	5	46.2	1.8	0.1	8.6	0.1	0.1	47.6
39492110501	DEN_litdry	8	42.1	2.4	0.0	6.8	0.0	0.0	43.2
06713500	DEN_cherry	5	41.1	0.5	1.6	11.4	0.0	2.2	42.9
39410710502	DEN_sander	5	42.3	2.0	0.0	2.4	0.0	0.6	42.7
40303510503	DEN_mail	9	41.2	4.4	0.0	6.9	0.6	0.0	42.5
39455310507	DEN_lena	5	37.6	1.3	0.1	28.8	0.1	0.1	42.1
39355710503	DEN_dutch	7	34.2	3.5	1.2	21.9	0.0	0.1	37.5
39462910506	DEN_clear	11	31.5	2.5	0.3	30.7	0.2	0.4	36.2
39361310451	DEN_cotton	3	27.9	0.6	2.0	36.8	0.0	0.4	33.5
40335610502	DEN_spcree	6	28.5	4.4	0.0	29.6	1.1	0.1	33.2
40021710512	DEN_bould	16	24.3	6.1	1.7	32.0	6.8	0.5	30.2
40002310514	DEN_brwell	4	24.9	7.2	8.5	25.0	0.4	0.0	28.8
39394810505	DEN_breste	9	16.7	2.4	1.4	54.0	1.3	0.5	25.1
39532410503	DEN_bigdry	10	16.0	0.9	0.0	58.6	1.6	0.3	25.1
39491910507	DEN_ralst	6	17.2	3.7	0.4	45.2	1.9	0.4	24.4
40254910504	DEN_dry287	7	11.0	0.9	0.1	15.4	62.5	0.1	22.8
40092510502	DEN_spgulc	6	11.1	1.4	0.0	11.8	53.4	0.5	20.9
39555410508	DEN_rock	6	8.4	0.4	0.0	78.9	1.7	0.1	20.5
40060710509	DEN_dryniw	11	10.0	1.9	1.8	42.4	25.1	0.6	20.2
40304810504	DEN_fossil	6	6.5	1.4	0.6	65.1	14.4	0.1	18.6
39595810511	DEN_drybas	16	6.6	4.7	0.0	57.6	18.0	0.2	18.1
40085510509	DEN_dryair	7	3.5	0.7	0.1	42.0	45.4	0.3	16.7
40081010507	DEN_lhand	7	3.4	3.3	0.1	32.3	52.3	1.1	16.2
41071410448	DEN_crow	4	2.9	0.8	1.4	80.8	1.6	2.4	15.3
40330810500	DEN_boxel	1	1.7	0.4	0.3	66.2	23.0	0.3	15.2
39570710510	DEN_coal	4	0.9	2.5	0.1	91.6	2.6	0.3	15.2
41365910437	DEN_brphil	13	0.3	0.0	1.9	88.6	6.5	0.7	14.7
40000010512	DEN_sbould	19	1.9	9.4	2.4	68.4	11.1	0.9	13.9
08049490	DFW_johnsn	6	43.9	7.2	0.1	0.4	3.1	0.1	44.5
08057200	DFW_white	8	40.2	5.5	0.2	1.7	8.2	0.1	41.7

station ID	ShortName	EPT richness	NLCD_IS impervious	NLCD1_4 forest	NLCD1_5 shrubland	NLCD1_7 grassland	NLCD1_8 agriculture	NLCD1_9 wetland	impervious + 0.15 * (agriculture + grassland) disturbance metric
08061536	DFW_spring	4	40.3	5.5	0.4	2.7	5.1	0.1	41.6
08061740	DFW_duck	6	36.4	8.4	0.2	1.9	9.8	0.4	38.2
08061952	DFW_smesq	8	29.8	11.1	0.1	3.2	13.2	0.2	32.3
08049955	DFW_fish	8	29.3	13.3	0.4	4.0	11.6	0.2	31.7
08057431	DFW_5mile	9	21.9	24.8	0.5	3.5	9.1	0.4	23.9
08061995	DFW_muscra	8	6.1	6.3	3.2	20.4	50.4	0.5	16.9
08061780	DFW_buftri	7	6.0	15.8	1.0	14.9	49.6	0.8	15.8
08063692	DFW_musenn	11	4.8	6.4	6.2	17.8	54.3	0.4	15.7
08052740	DFW_doe	5	2.0	6.9	2.3	14.3	68.9	0.3	14.6
08059530	DFW_tickey	5	2.9	10.5	2.4	16.9	60.0	0.5	14.6
08062020	DFW_bufcra	11	1.8	6.2	5.4	20.2	59.9	0.3	13.9
08059571	DFW_wilson	7	2.3	12.9	2.8	22.1	53.8	0.5	13.8
08062525	DFW_walker	5	0.6	9.2	2.8	27.7	57.0	0.2	13.4
08063047	DFW_bynum	7	0.3	3.3	7.3	12.4	73.3	0.3	13.3
08057475	DFW_parsn	10	6.6	24.4	0.7	6.1	36.6	2.3	13.1
08049580	DFW_mount	9	1.0	9.6	5.5	22.0	57.5	0.3	13.0
08063300	DFW_pinoak	9	0.4	6.5	6.8	12.1	70.6	0.1	12.9
08062090	DFW_redoak	10	4.9	26.2	8.1	21.7	28.0	0.1	12.5
08063574	DFW_bigoni	12	0.4	4.4	12.4	23.3	55.7	0.3	12.4
08063555	DFW_sfkcha	11	0.6	17.2	4.5	17.3	56.1	0.6	11.7
08063565	DFW_mill	12	0.4	9.9	14.6	35.4	36.4	0.2	11.3
08063595	DFW_sprong	12	0.5	14.2	11.6	17.5	53.4	0.2	11.2
08062600	DFW_grays	10	0.2	15.8	9.9	25.9	44.3	0.4	10.9
08063510	DFW_lpin	8	0.5	7.8	18.4	25.2	43.0	0.1	10.8
08062805	DFW_will	6	0.1	20.0	9.6	15.4	52.5	0.0	10.4
08064695	DFW_tehuac	11	1.3	12.5	20.5	25.3	34.4	0.0	10.4
45002212301	POR_clagg	0	54.7	0.1	0.0	1.6	0.3	0.1	55.0
44555112301	POR_pring	7	41.9	2.1	0.3	2.2	5.9	0.0	43.3
14206435	POR_beave	2	39.9	11.4	1.2	2.7	1.4	0.3	40.7
45252612236	POR_kello	9	38.9	9.5	1.5	4.0	2.1	1.6	39.9
14206950	POR_fanno	3	38.7	10.1	0.9	2.6	1.1	0.9	39.4
45432112235	POR_curti	17	29.0	1.8	2.1	6.0	16.3	1.4	32.5
44025712310	POR_amazo	2	28.7	23.0	2.2	4.0	7.9	0.8	30.5
14211315	POR_tryon	9	22.7	35.0	1.4	2.7	0.0	1.4	23.3
45291212229	POR_johns	3	17.2	22.2	1.4	9.4	23.6	1.4	22.2
44502912259	POR_battl	3	13.2	18.0	1.3	7.1	39.6	0.9	20.3
14206347	POR_rocor	3	13.4	27.8	2.6	13.6	26.1	1.3	19.4
45451012242	POR_whipp	15	13.6	17.6	5.2	14.0	19.2	6.5	18.7
45233712224	POR_nfdep	3	9.6	12.2	0.8	11.0	47.5	1.2	18.4
14206750	POR_chick	8	8.9	29.3	2.9	8.7	35.6	1.4	15.7
45241412221	POR_tickl	7	7.9	34.1	3.3	9.3	33.9	0.2	14.5
45173412258	POR_cheha	3	3.1	26.5	4.8	13.5	44.3	2.1	11.8
44332612316	POR_oak	8	2.6	55.2	7.8	8.6	18.9	1.8	6.8
45223112220	POR_deep	23	1.4	53.3	6.4	5.4	29.7	0.7	6.8
45454912229	POR_salmo	21	3.5	46.5	24.2	8.3	2.4	4.3	5.2
45512212231	POR_rocwa	17	2.2	43.2	19.2	12.5	6.8	10.2	5.2
14199710	POR_nate	22	0.6	64.2	7.2	13.3	12.0	0.8	4.5
43474512304	POR_silk	20	1.4	59.9	15.5	7.8	10.6	1.5	4.3
45095512229	POR_milk	25	0.8	73.0	7.6	6.0	8.6	0.5	3.1
45454312252	POR_sscap	14	1.2	63.9	15.2	8.6	2.5	0.8	3.0
45350612312	POR_iler	22	0.2	73.0	15.6	3.7	4.9	1.0	1.6
14205400	POR_efdar	26	0.2	68.6	18.3	7.2	0.8	0.5	1.5
45214912319	POR_nyamh	24	0.3	77.7	12.5	6.1	0.4	0.3	1.4
43521212248	POR_lost	26	0.2	86.8	7.8	2.0	0.6	0.8	0.7
04087118	MGB_hony	6	47.6	0.6	0.2	0.0	0.0	0.0	47.7
040869415	MGB_linc	6	44.6	1.0	1.1	0.1	0.0	0.1	44.7
04087270	MGB_pikc	1	41.9	1.0	0.5	0.2	10.8	0.3	43.7
04084429	MGB_mudc	7	30.3	4.4	0.1	1.2	34.2	1.0	35.8
04087213	MGB_root	6	32.4	4.3	1.6	0.1	0.3	0.8	32.5
04087204	MGB_oakc	7	27.4	9.8	1.4	0.8	21.0	3.9	30.8

station ID	ShortName	EPT richness	NLCD_IS impervious	NLCD1_4 forest	NLCD1_5 shrubland	NLCD1_7 grassland	NLCD1_8 agriculture	NLCD1_9 wetland	impervious + 0.15 * (agriculture + grassland) disturbance metric
04084468	MGB_garn	6	25.9	4.5	0.2	0.1	25.4	0.6	29.8
0408703164	MGB_lily	8	24.9	4.4	0.7	0.2	14.8	1.8	27.3
04087070	MGB_ltme	7	18.8	9.5	1.0	0.6	38.2	5.9	24.7
04087258	MGB_pikr	8	11.5	4.8	0.4	0.7	64.0	2.4	21.3
040870856	MGB_undw	4	20.0	5.9	1.2	0.1	0.8	5.2	20.2
04085046	MGB_appl	5	7.6	4.7	0.1	0.9	74.5	1.9	19.1
040851235	MGB_bowr	8	8.0	6.5	0.3	0.7	66.6	1.5	18.2
040872393	MGB_hood	5	6.0	4.4	0.2	0.7	75.2	2.9	17.5
04087030	MGB_meno	10	10.5	12.0	0.5	1.1	44.4	10.8	17.4
04081897	MGB_sawy	7	4.8	2.5	0.4	1.4	79.9	1.8	17.1
05527729	MGB_kilb	10	3.9	5.6	0.0	1.1	81.8	3.9	16.4
040850683	MGB_ashw	3	2.4	4.9	0.1	0.6	87.3	1.2	15.7
040851325	MGB_bair	10	1.6	4.4	0.1	0.8	84.4	4.6	14.4
040851932	MGB_kewa	7	1.1	5.8	0.1	0.6	86.3	2.9	14.2
040854395	MGB_poin	12	1.4	5.9	0.1	0.9	81.7	6.3	13.9
04078085	MGB_blot	6	1.9	8.6	0.2	0.6	77.8	6.7	13.7
04085322	MGB_devl	20	1.0	8.8	0.2	0.7	79.3	6.8	13.1
04085455	MGB_meme	10	1.4	11.0	0.0	1.9	75.2	5.9	13.1
04085188	MGB_rioc	16	0.9	9.5	0.1	0.6	77.6	8.6	12.7
055437901	MGB_foxr	13	5.5	18.7	0.9	1.4	41.5	13.9	12.1
04086699	MGB_pign	9	3.5	21.4	0.0	1.4	54.8	6.4	12.1
040853145	MGB_blak	1	0.9	16.6	0.0	0.6	72.7	6.7	12.0
04072233	MGB_lanc	9	2.9	22.6	0.4	1.3	58.8	4.3	12.0
04085270	MGB_jamb	25	0.9	11.9	0.1	0.6	67.9	14.6	11.3