Urbanization and Aquatic Invertebrates in Central Texas

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Abstract

Central Texas has a high degree of endemic and spring-adapted species, and is experiencing large urban growth compared to the national average, which is encroaching on these unique species and their habitat. Therefore, the development of an urban intensity index (UII) for the Central Texas area would provide a threat ranking system to aid in conservation and understanding of these unique environments in relation to urbanization. Two UII models were created using land use, infrastructure and population dynamics. These models were examined with aquatic invertebrate data taken from sites across the Central Texas area. Each model showed basic trends with aquatic invertebrate metrics and provided a baseline for the effects urbanization on aquatic invertebrates within Central Texas. These UII models quantify urbanization in this unique area and provide a monitoring tool that can be replicated over time.

Introduction

Located within the Edwards Plateau in Central Texas (Figure 1), the Texas Hill Country and surrounding areas have a high degree of endemism in aquatic taxa (Bowles and Arsuffi 1993, Lugo-Ortiz and McCafferty 1995). Some of these taxa include plethodontid salamanders (Chippendale et al. 2000), blind dryopidae beetles (Gibson et al. 2008), mayflies (*Pseudocentroptiloides morihari*, *Baetodes bibrachius*), Texas Wild rice (Bowles and Arsuffi 1993), and numerous other endemic and federally listed taxa. Many of these taxa are not found anywhere else on the earth. These ecologically important areas are also experiencing rapid human population growth and urban sprawl, when compared to other areas nationally (Texas State Data Center 2008). This shift in land use has been common throughout the continental USA, and as a result, large tracts of undeveloped or agricultural lands, which historically sustained this biologically and geologically diverse landscape, have been converted to residential or other developed urban land types (Hansen et al. 2005). Urban expansion has particularly increased in the rural areas surrounding the metropolitan areas of Austin and San Antonio. These areas have experienced 47.7% and 21.6% population growth, respectively, between 1990 and 2000 (US Census Bureau 2006).

Due to differences in hydrology and geology, aquatic systems vary in magnitude and types of urbanization impacts that degrade water quality and aquatic habitat (Cuffney and Falcone 2009). Many studies have examined urbanization and its effects on aquatic communities (Tate et al. 2005; Cuffney et al. 2011; King et al. 2011). Recently, King et al. (2011) have shown that aquatic invertebrate communities and their species diversity are not protected from perturbation at generally accepted levels of impervious cover (<10%), and are adversely impacted at much lower levels of impervious cover (<2%). However, most studies of urbanization effects on aquatic communities have been mainly conducted in eastern states (e.g., Brown and Vivas 2005; Coles et al. 2010; King and Baker 2011; King et al. 2011). Currently, no comprehensive regional index exists, which would allow one to examine, quantify, and rank sites in respect to urbanization within the Central Texas region.

To examine the effects of changing land-use patterns and urbanization on aquatic habitats within the Central Texas region, a multi-metric index may be an appropriate method to rank the inherent complex interaction of ecological processes and anthropogenic effects, which alters water chemistry and modifies available stream habitat. The use of an urban intensity index (UII) allows examination of many potential variables in order to create a model for a specific region or area. The UII is measured using information on anthropogenic influences within an aquatic system. Information used in these types of models can include land cover, infrastructure, population, and socioeconomic characteristics (McMahon and Cuffney 2000). These models of anthropogenic influence can be recreated over time as new data becomes available for land use, population trends, human infrastructure, and population dynamics. By using a multi-metric model researchers and planners will be able to determine the degree of degradation a stream reach or system may be in, while tracking changes in the land use over time.

Site prioritization can be established based upon a particular UII score for an aquatic site and its particular species assemblage, in order to create a threat ranked analysis of landscape characteristics and species. This type of model can be used to aid in conservation, such as establishing a comprehensive monitoring program, critical habitat buffers, prioritize development, and the purchasing of land for preserves. Using the UII model, we hypothesize that calculated UII numbers, at different levels of ecological relevance, may coincide with shifts in aquatic community composition and reduced biodiversity across Central Texas in respect to the UII score.

Methods

Data Sources

Twelve-Digit Hydraulic Unit Water Boundaries (HUC-12 subwatersheds) were downloaded from the Natural Resource Conservation Service's Geospatial Data Gateway of the United States Department of Agriculture (USDA-NRCS 2010). A HUC-12 is a hydrologic unit code and the size of a HUC-12 ranges from 24-99 km^2. A total of 64 sub-watersheds (Figure 1; HUC-12) were used to create the multi-metric index. At least two sites were selected from each county within the study area. These sites were selected based upon access and degree or urbanization. Texas counties were downloaded from the ESRI ArcGIS website (ESRI 2012). To account for natural geological variation, most sites are within the Edwards Plateau, an ecoregion level III as delineated by the Environmental Protection Agency (Omernik 1987). Sites not located in this ecoregion are located within the fringe (<30 miles) of this delineation and account for 21 of the 64 total site. The sites outside the ecoregions were the only accessible and available sites within the counties. Land and impervious cover data were retrieved from the Multi-resolution Land Characteristics Consortium's National Land Cover Database (MRLC 2006). The Environmental Protection Agency's Toxic Release Inventory Program (TRI; EPA 2009) was the source of Toxic Release Sites data. Dam locations were accessed from the National Dam Inventory provided by the U.S. Army Corps of Engineers (USACE 2011). Census demographics and roads (derived from the census Topologically Integrated Geographic Encoding and Referencing (TIGER) files) were downloaded from the Texas State Data Center (TSDC 2010).

Aquatic Invertebrates

Sampling of aquatic invertebrates was done using a 1-ft^2 surber sampler (500µm mesh) with each site being visited once from May 30th to June 28th of 2012. Two samples per site were collected from optimal habitat as described by the Texas Center for Environmental Quality

(TCEQ) Surface Water Quality Monitoring Procedures Vol II (2007). All samples were taken from riffles, then taken back to the lab and sorted. Using the appropriate keys (Wiggins 1996; Merritt and Cummins 2008, and Weiderholm 1983) identification of aquatic invertebrates was to genus. The samples were then combined into a composite sample for each site. Metrics and analyses were completed using the composite samples.

Data Processing and Statistical Analysis

Dams and toxic release sites were spatially joined with the selected HUC-12 watersheds, with the total count of results for both layers summed for each watershed (MRLC 2006, EPA 2009, USACE 2011). Land cover and impervious cover raster data sets were clipped by individual sub-watershed, and the resulting pixel counts were summarized by each attribute (MRLC 2006). Roads were clipped by sub-watershed and then road lengths were calculated and summarized for each watershed (TSDC 2010). Census data were related to TIGER census blocks by the "GEOID" for each county, then merged together and clipped by sub-watershed (TSDC 2010). Housing and population totals were summed for each sub-watershed (TSDC 2010). All area data were then calculated in square kilometers for each sub-watershed.

Percent developed land was defined as the proportion of a HUC-12 watershed with greater than 30% of man-made structures (MRLC 2006). For this analysis, percent developed land was grouped from four categorizes (open, low, medium, and high) into one grouping, developed (Cuffney and Falcone 2009). Percent forest consisted of the combined total for evergreen, deciduous, and shrub/scrub (Cuffney and Falcone 2009). Dams and TRI densities were used as continuous variables by dividing the total numbers for dam or TRI sites by the area of the sub-watershed to provide the ratio used in the UII model (MRLC 2006, EPA 2009, USACE 2011). To calculate road density, the length of roads in kilometers was divided by the area of the sub-watershed (MRLC 2006, TSDC 2010). An urban sprawl index (USI) was created by using the total developed land area divided by the 2010 population data multiplied by 10,000 (McMahon and Cuffney 2000). Within the MRLC dataset, a range of development intensity is produced for the impervious cover layer based upon the type of impervious cover present, and ranged from 0 to 100. To account for this range of intensity, impervious cover data were calculated using weighted averages for the MRLC dataset to determine the average impervious cover for a sub-watershed.

This allowed for the intensity of the impervious cover to be taken into account and followed the procedure of McMahon and Cuffney (2000).

Two models were created using variables from the clipped data (mentioned above). No models were created using the impervious cover data, to allow for comparison of UII models with impervious cover in later analyses. The first model (Central Texas urban intensity index; CT-UII) followed the five-step process created by McMahon and Cuffney (2000). The data were examined using Pearson's Correlation Coefficient in respect to population density. All variables that were significantly correlated (±0.50) were used to create the CT-UII. Development of the second model (Common Urban Intensity Index; C-UII), was based methods established by Cuffney and Falcone (2009) and includes road density, housing density and developed land totals for each sub-watershed.

To determine relationships between calculated UII scores and urbanization, linear regressions were examined using impervious cover data for each specific sub-watershed. McMahon and Cuffney (2000) conducted the same analysis with predicted UII scores of <28 in the pre-effect zone and 28-66 for the effect zone, when compared to impervious cover. The pre-effect zone is a range of adverse effects on the aquatic community when levels of impervious cover reach around 10% (Booth and Jackson 1997; McMahon and Cuffney 2000), causing impairment in terms of species loss and shifts in the community structure. The effect zone occurs when adverse ecological conditions have extreme detrimental effects on the aquatic community at impervious cover levels of 25% (McMahon and Cuffney 2000). These impervious cover levels are not thresholds, and loss of specialized species may be seen before these levels of impervious cover (King et al 2011). Using the linear regression equations produced from the impervious cover analysis, sites were given a score based upon ecologically relevant levels of impervious cover that are tailored for the Central Texas area. For this analysis, impervious cover values of 5, 10 and 25% were selected based on the linear regression of impervious cover and calculated UIIs.

In order to examine the association of invertebrate communities with land use, canonical correspondence analysis (CCA) with software package "vegan" in R was conducted (Oksanen et al. 2011). Due to the large invertebrate community (n = 158 unique taxa) represented within the data set compared to the sample size (n = 51 sites), only aquatic invertebrates with relative abundance percentages over 1% were used in the CCA analysis (n = 17 unique taxa). The number of sites changed from 64 to 51 due to conditions at the sites (e.g. dry or no riffles present). To analyze the aquatic invertebrate community as a whole and in relation to the response variables (CT-UII, C-UII, and impervious cover), metrics were created according to the TCEQ manual (2007) guidance for surber samples and other metrics. These metrics included total taxa, Diptera taxa, Ephemeroptera taxa, intolerant taxa, percent EPT (Ephemeroptera, Trichoptera, and Plecoptera) taxa, percent Chironomidae, percent tolerant taxa, percent grazers, percent gatherers, percent filterers, percent dominance (top three taxa), ratio of intolerant to tolerant taxa, percent Hydropsychidae, Hilsenhoff biotic index (HBI), and a final ranking called the aquatic life use score. The aquatic life use score (ALU) is the sum of the various metrics used to rank a specific stream or waterway.

Spearman rank correlation was used to examine relationships among the response variables (CT-UII, C-UII and impervious cover) and the above metrics. The data for each analysis was not pooled. In addition, Spearman rank correlation was used to examine the relationship between the calculated multi-metric indices and impervious cover.

Results

Pearson correlation values that showed a strong correlation (positive and negative) with population density were percent developed land, TRI, percent forested land, road density, and housing density (Table 1). Therefore, these variables were used in the creation of the CT-UII. To create the C-UII model, road density, housing density, and percent developed land were used (Table 1; Cuffney and Falcone 2009). The San Pedro Creek site in Bandera County had the highest UII score for both models, while the Spicewood site in Travis County had the second highest values (Table 2). In addition, the levels of impervious cover for these two sites were also the highest (Table 2). In general, the CT-UII has the overall highest UII scores, and the C-UII has lower UII scores. The overall trend is an increase in developed land across an east to west gradient and north and south along the I-35 corridor.

Linear regression between the two calculated models (CT-UII, and C-UII) and impervious cover taken from the MRLC (2006) showed significant relationships ($p < 0.05$, Figure 2). The slopes of the lines between the CT-UII and the C-UII showed similar rates of response to urbanization (2.40 and 2.32 respectively). Using impervious cover values of 5, 10 and 25%, the 64 HUC-12 watersheds were ranked as either pre-effect or effect zones (Table 3). For impervious cover values of 5, 10 and 25%, corresponding CT-UII and C-UII scores were of 22, 34 and 70; and

14, 26 and 60, respectively. For this analysis, the pre-effect zone was <34 and <26 for CT-UII and C-UII scores, respectively. The effect zone was between 34-70 and 26-60 for the CT-UII and C-UII respectively.

For the remaining analyses with aquatic invertebrates and spatial variation, only 51 sites were used due to dry conditions and the lack of riffles at specific sites. The CCA explained 41% of the variation between the aquatic invertebrates and land use (Figure 3). Canonical axis I shows an environmental gradient of developed land (-0.601), TRI (-0.583), and impervious cover (-0.569) to agriculture land (0.452), forested land (0.423), and grasslands (0.229). The CA I has a land gradient from metropolitan areas to rural and suburban areas. Canonical axis II has a gradient of TRI (-0.499), impervious cover (-0.345), and developed land (-0.339) to open water areas (0.383), forested land (0.307), and grasslands (0.231).

Invertebrates that accounted for at least 1% of the total sample were used for the analysis, the resulting aquatic invertebrate community accounted for 83% of the total invertebrates enumerated. The caddisfly, *Hydroptila sp.* and the non-biting midge, *Rheocricotopus sp.* were strongly associated with developed land. While the caddisfly, *Cheumatopsyche sp.*, the damselfly, *Argia sp.*, and the non-biting midge subfamily, Tanypodinae were all associated with developed land. The black fly, *Simulium sp.*, was associated with agricultural land, while the crustacean, *Hyalella sp.*, was associated with open water habitats. Riffle beetles, *Hexacylloepus ferrugineus* and *Neolemis caesa,* were associated with non-developed land. The mayflies (*Camelobaetidius variabilis* and *Fallceon quilleri*) and the caddisfly, *Chimarra sp*., were associated with the center of the CCA plot, showing their ubiquitous distribution within the sampled watersheds.

The aquatic invertebrate metrics and the aquatic life use scores for each site are presented in Table S1. Only one site came back with a limited ALU score (Spicewood site in Travis County). The remaining 50 sites broke down into seven intermediate, 23 high, and 20 exceptional sites based on ALU scores. The CT-UII and the C-UII had negative trends with ALU scores, total taxa, the tolerance ratio, intolerant taxa, percent Ephemeroptera, Plecoptera and Trichoptera (% EPT), the ratio of intolerant to tolerant taxa, and Ephemeroptera taxa. Positive relationships between the CT-UII and the C-UII were found for dominance, percent Chironomidae, percent Hydropsyche, and the HBI. Examples of these relationships are presented in Figure 4.

Metrics that were significantly correlated using Spearman rank correlation with the CT-UII and the C-UII were the HBI, dominance, Ephemeroptera, and the tolerance ratio. The dominance and HBI metrics were positively correlated with the CT-UII and C-UII, while the Ephemeroptera and the tolerance ration were negatively correlated. Metrics that were correlated with impervious cover were the HBI, total taxa, intolerant taxa, dominance, Ephemeroptera, and the ratio of intolerant to tolerant taxa (Table 4). The dominance and HBI metrics were positively correlated with impervious cover, while total taxa, intolerant taxa, Ephemeroptera, and the tolerance ratio were negatively correlated. Spearman rank correlation showed a strong association between the calculated indices and impervious cover (Table 5). The C-UII had the strongest correlation with impervious cover (0.947), although the CT-UII still had a very strong correlation (0.886).

Discussion

We observed clear differences between the two urban intensity models. For example, the UII score from the C-UII model tended to be lower compared to scores from the CT-UII model. Cuffney and Falcone (2009) showed that the more variables used for development of a UII, the more likely it is that the calculated UIIs are overestimated. This parsimony effect would explain why the simpler model (C-UII) had generally lower UII scores. When calculated UIIs are compared to scores from the published literature, in respect to pre-effect (10%) and effect zones (25%), the range of CT-UII (22 and 70) and the C-UII (26 and 60) scores are within range of other published ranges (28 and 66) (McMahon and Cuffney 2000; Tate et al. 2005; Cuffney and Falcone 2009). All calculated UIIs demonstrated a significant relationship with impervious cover. However, the slopes for the CT-UII and the C-UII were almost identical, which means that the magnitude of response projected for the Central Texas area is similar between these two models. Therefore, selection of which model to use is dependent upon the research scale and questions (e.g. local versus regional).

The CCA model depicts the gradient of land use in Central Texas area. What is interesting is the USI being associated with the forested and agriculture land on CA-I. This variable is displaying the change in land use from non-developed land to developed land across Central Texas. What can be expected is the movement and development of people and land into these rural and suburban areas over time. As this shift in land use continues within the Central Texas area, the data set should be examined for potential indicator taxa and analysis of similarity can be calculated for aquatic communities between temporal data sets.

When UII models were compared to the aquatic invertebrate community of the Central Texas region, basic trends depicting classic responses to increasing urbanization were expected.

That is, we hypothesized that certain metrics of aquatic invertebrates, such as tolerant taxa and EPT taxa, would be negatively correlated with UII scores. This was seen in the analysis, however, none of the relationships were significant. This may be a result of the site selection or the need to increase invertebrate sample size. There is a break in the data between sites that are highly impacted and the less impacted sites. The relationship between the aquatic invertebrates and the land use data may become more apparent if more sites were selected within the mid-range of development. The observed structure of the aquatic invertebrate community could be used in future analyses to determine shifts in community structure as the spread of development occurs.

The dataset that was used for this analysis shows a strong correlation between the multi-metric indices and impervious cover. While multi-metric indices are a good way to delineate sites with varying levels of degradation, these models have been criticized in past studies by King and Baker (2010), as being too simplistic for detection and interpretation of community change (King and Baker 2010). These models do provide more comprehensive interpretation of site data than a simple analysis of impervious cover. However the selection of a specific analysis needs to be constrained in relation to the level of inference made about community or species thresholds (King and Baker 2010). That being said, these models serve as a preliminary analysis of site selection or a way of dealing with management issues related to land use changes. These models are time consuming to create, and based upon the correlation results within this dataset between the models (CT-UII and C-UII) and impervious cover, the use of impervious cover as a surrogate to the UII models should be considered.

The Central Texas region is still in the early stages of urbanization compared to other metroplexes, such as Dallas-Fort Worth area. After examining the calculated UII scores from the two models, most of the 64 sites lie within either the pre-effect stage of urbanization or the early range of impairment (Table 3). Although impairment to species diversity or aquatic communities may be occurring in some of these streams, the impact appears minimal on a regional scale based upon the calculated UII scores. However, agricultural land uses prevalent in Central Texas may be shown to impact aquatic species composition. Based upon calculated UII scores, specialized taxa that have co-evolved over time may have been lost in some watersheds (King et al. 2011), and there still may be large scale ecological community changes in the future for Central Texas region. With the imminent threat of land use changes in Central Texas region, there is a need to develop plans and research strategies examining relationships between urbanization and how it affects ecosystem function and the diversity and distribution of species within Central Texas.

Table 1. Pearson correlation values between population density and Central Texas land cover data. All values ±0.50 were used to create the Central Texas Country Urban Intensity Index (CT-UII). Values with a * beside them were used in creation of the CT-UII. Values with + beside them were used in the C-UII.

Variable	Pearson Correlation Value
Dams	0.3735
Toxic Release Inventory	0.6406*
Housing Density	0.9924*+
Urban Sprawl Index	-0.281
Road Density	0.9749*+
Open Water	0.1126
Developed Land	0.9752*+
Barren Land	0.1102
Forested Land	-0.7698*
Grassland/Herbaceous	-0.3534
Agriculture	-0.0794
Wetlands	0.3250

Table 2. Calculated urban intensity index scores for the Central Texas Urban Intensity Index (CT-UII) and the Common Urban Intensity Index (C-UII) for 64 sites within Central Texas including impervious cover percentages for each site.

Site	System	Impervious Cover %	CT-UII	C-UII
1	Bandera Co. - Medina River	0.94	10.86	5.61
2	Bandera Co. - Sabinal River	0.16	5.66	1.11
3	Bell Co. - Moon Branch-Salado Creek	0.19	24.08	5.21
4	Bell Co. - Salado Creek	0.91	23.72	7.13
5	Bexar Co. - Beitel Creek-Salado Creek	36.54	89.07	75.58
6	Bexar Co. - Dietz Creek-Cibolo Creek	12.33	55.12	25.54
7	Bexar Co. - Lewis Creek-Salado Creek	7.28	34.65	24.36
8	Bexar Co. - Middle Leon Creek	29.23	95.22	66.60
9	Bexar Co. - Olmos Creek-San Antonio River	36.45	87.53	83.57
10	Bexar Co. - Salado Creek-San Antonio River	28.13	88.69	67.44
11	Bexar Co. - San Pedro Creek	42.62	100.00	100.00
12	Blanco Co. - Flat Creek-Blanco River	0.88	9.19	5.51
13	Blanco Co. - Miller Creek	0.39	4.57	1.16
14	Blanco Co. - North Grape Creek	0.04	4.45	0.35
15	Burnet Co. - Hamilton Creek	0.34	10.43	2.48
16	Burnet Co. - Honey Creek	2.20	20.29	5.58
17	Burnet Co. - Rocky Creek	0.18	11.67	3.80
18	Comal Co. - Comal River	6.35	30.76	18.37
19	Comal Co. - Elm Creek-Guadalupe River	1.94	13.71	10.75
20	Comal Co. - Guadalupe River	0.22	3.09	0.31
21	Comal Co. - Spring Branch-Guadalupe River	1.25	13.51	9.08
22	Edwards Co. - Hackberry Creek	0.20	0.83	0.47
23	Edwards Co. - South Llano River	0.27	1.81	1.88
24	Gillespie Co. - Pedernales River	0.70	11.71	4.45
25	Gillespie Co. - Threadgill Creek	0.05	3.23	0.78
26	Hays Co. - Blanco River	2.51	25.94	11.57
27	Hays Co. - Headwaters Barton Creek	0.71	9.76	6.87
28	Hays Co. - Headwaters Onion Creek	0.97	8.71	4.64
29	Hays Co. - Jacobs Well	1.21	16.88	10.08
30	Hays Co. - Mustang Branch-Onion Creek	2.47	24.06	9.34
31	Hays Co. - San Marcos River	5.07	23.30	17.97
32	Hays Co. - Wilson Creek-Blanco River	1.35	12.94	8.86
33	Kendall Co. - Cibolo Creek	2.16	10.23	6.64
34	Kendall Co. Guadalupe River	0.94	12.22	5.78
35	Kerr Co. - Guadalupe River	4.34	19.03	14.21
36	Kerr Co. - South Fork Guadalupe River	0.15	1.44	1.42
37	Kimble Co. - Llano River east	0.10	4.34	1.87
38	Kimble Co. - Llano River west	0.32	1.73	1.63

Site	System	Impervious Cover %	CT-UII	C-UII
39	Llano Co. - Llano River in Llano	1.24	11.26	4.91
40	Llano Co. - Sandy Creek	0.10	3.65	1.15
41	Llano Co.- Crabapple Creek	0.05	4.49	0.79
42	Mason Co. - James River	0.03	1.67	0.00
43	Mason Co. - Llano River east	0.11	5.38	1.98
44	Mason Co. - Llano River west	0.05	1.71	0.31
45	Medina Co. - Chacon Creek	1.77	16.56	5.99
46	Medina Co. - Medina River	0.97	19.71	6.99
47	Menard Co. - San Saba downstream of Menard	0.23	5.59	2.57
48	Menard Co. - San Saba upstream of Menard	0.13	1.90	1.51
49	Real Co. - East Frio River	0.15	1.41	0.03
50	Real Co. - Frio River	0.61	6.32	3.40
51	Travis Co. - Barton Creek	11.60	42.79	41.49
52	Travis Co. - Bear Creek	1.59	14.60	9.46
53	Travis Co. – Bull Creek	12.04	38.99	37.51
54	Travis Co. - Carson Creek-Colorado River	8.66	38.51	16.41
55	Travis Co. - Little Barton Creek-Barton Creek	2.28	8.86	5.31
56	Travis Co. - Slaughter Creek-Onion Creek	8.50	33.74	30.00
57	Travis Co. – Spicewood Creek	34.30	95.93	94.78
58	Travis Co. - Williamson Creek-Onion Creek	20.34	73.98	58.00
59	Uvalde Co. - Frio River	0.19	2.51	0.88
60	Uvalde Co. - Sabinal River	0.39	13.24	3.26
61	Val Verde Co. - Devils River	0.07	0.00	0.16
62	Val Verde Co. - Dolan Creek	0.17	0.36	1.10
63	Williamson Co. - North San Gabriel	2.42	22.67	13.87
64	Williamson Co. - Twin Creek Preserve	0.76	17.45	9.33

Table 3. This table shows the distribution of sites for the Central Texas Urban Intensity Index (CT-UII) and the Common Urban Intensity Index (C-UII) in respect to levels of urbanization. Calculated values were created using linear regression equations with impervious cover from each subwatershed. The CT-UII values are <34 and between 34-70 for pre-effect and effect zone respectively. The C-UII values are <26 and between 26-60 for pre-effect and effect zone respectively. The calculated UII scores for the two models are also compared to previous work by Cuffney and Falcone (2009). The MA-UII is the metropolitan model specifically designed for the Dallas-Fort Worth area, and the N-UII is the national model (Cuffney and Falcone 2009).

Model	Pre-Effect Zone	Effect Zone	High Effect Zone
CT-UII	50	7	7
Cuffney and Falcone (2009) MA-UII DFW	55	2	7
C-UII	54	4	6
Cuffney and Falcone (2009) N-UII	54	4	6

Table 4. The significant results of the Spearman rank correlation tests for aquatic invertebrate metrics, urban intensity index, and impervious cover. Correlation coefficients are displayed.

	Hilsenhoff biotic index	Total Taxa	Intolerant Taxa	Dominance	Ephemeroptera	Intolerant to tolerant ratio
CT-UII	0.404	--	--	0.353	-0.307	-0.405
C-UII	0.401	--	--	0.334	-0.341	-0.370
Impervious Cover	0.371	-0.288	-0.299	0.287	-0.351	-0.358

Table 5. This table shows the relationship between the CT-UII, C-UII and impervious cover. Correlation coefficients are displayed.

	CT-UII	C-UII	Impervious Cover
CT-UII	--	0.944	0.886
C-UII	0.944	--	0.947
Impervious Cover	0.886	0.947	--

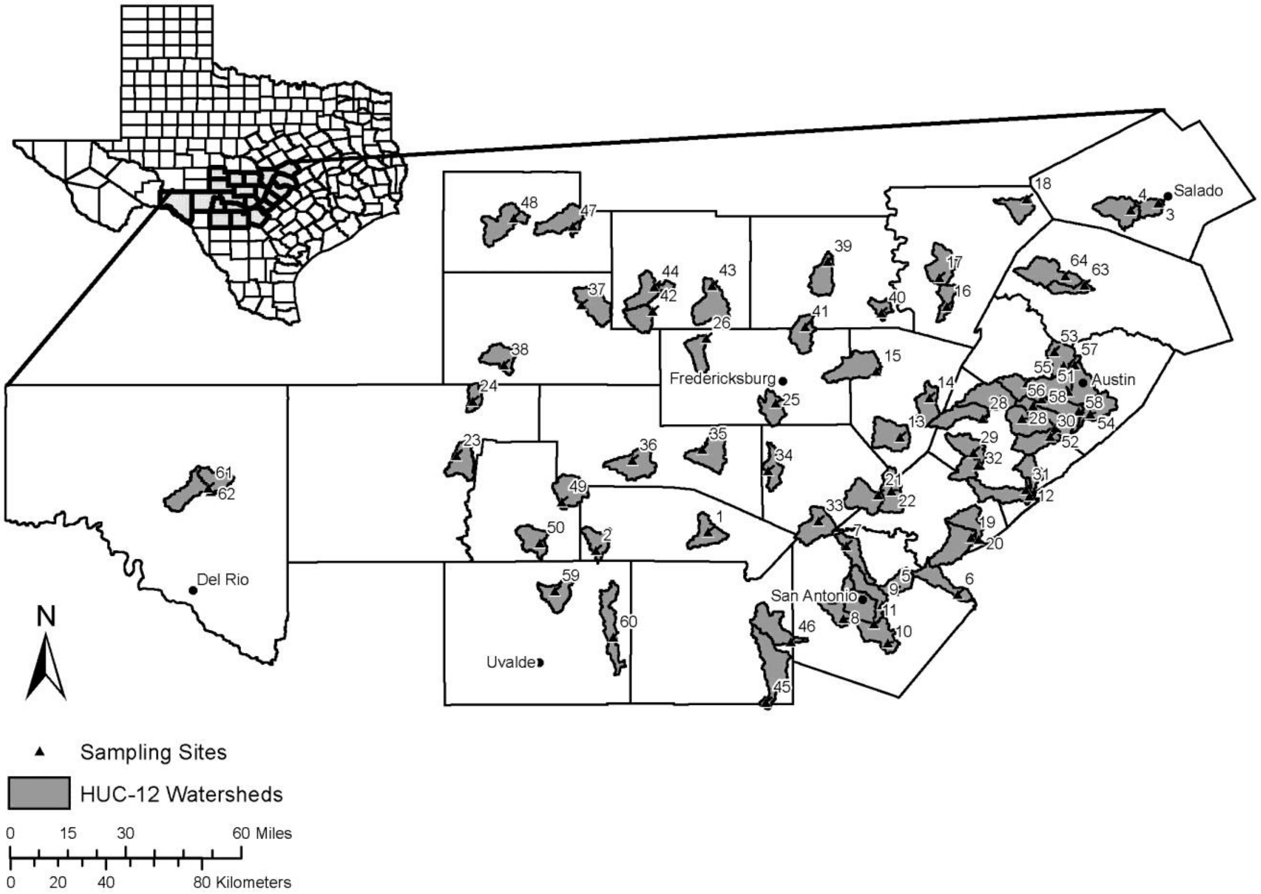

Figure 1. The 64 sites sampled in the Central Texas region for the development of the urban intensity index. This map shows HUC-12's where data the data was collected from and county lines.

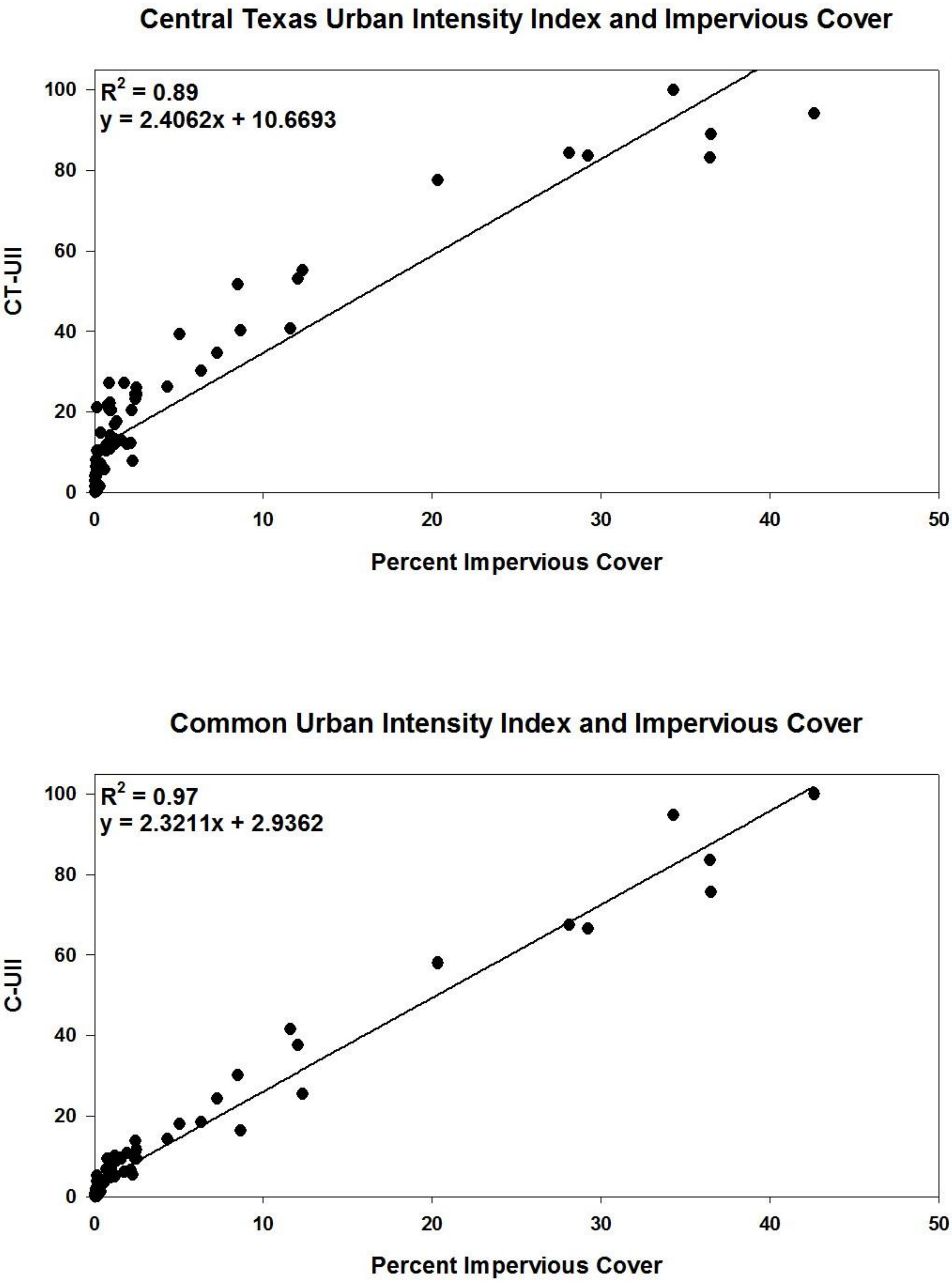

Figure 2. The relationship between impervious cover and the two urban intesity index models, the Central Texas Urban Intensity Index (CT-UII) and Common Urban Intensity Index (C-UII). Impervious cover data were not included in the calculation for the UIIs, in order to examine its relationship to the two UII models.

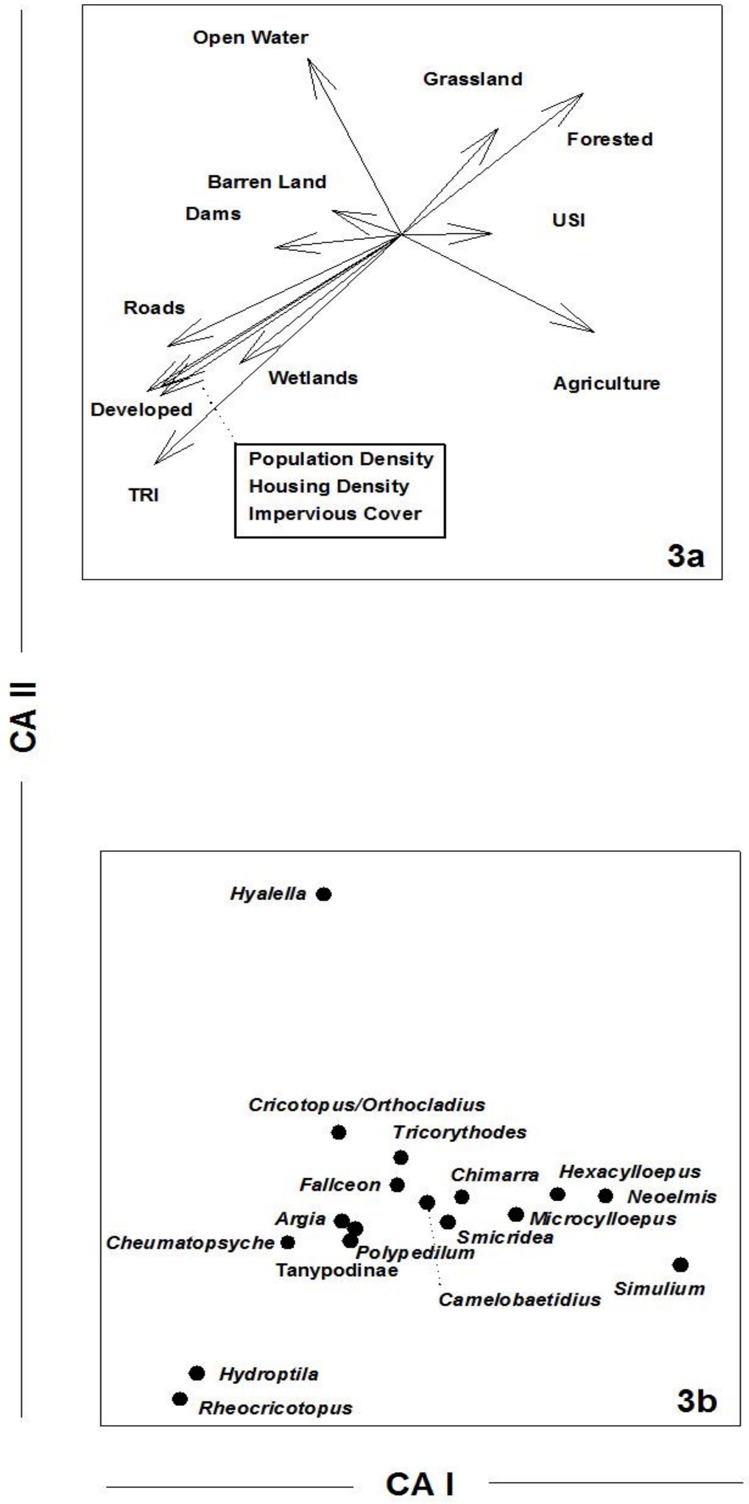

Figure 3. Canonical correspondence analysis between land use and the aquatic invertebrate community data from Central Texas. Figure 3a shows physical characteristics of the land use data. Figure 3b is the species biplot for the analysis.

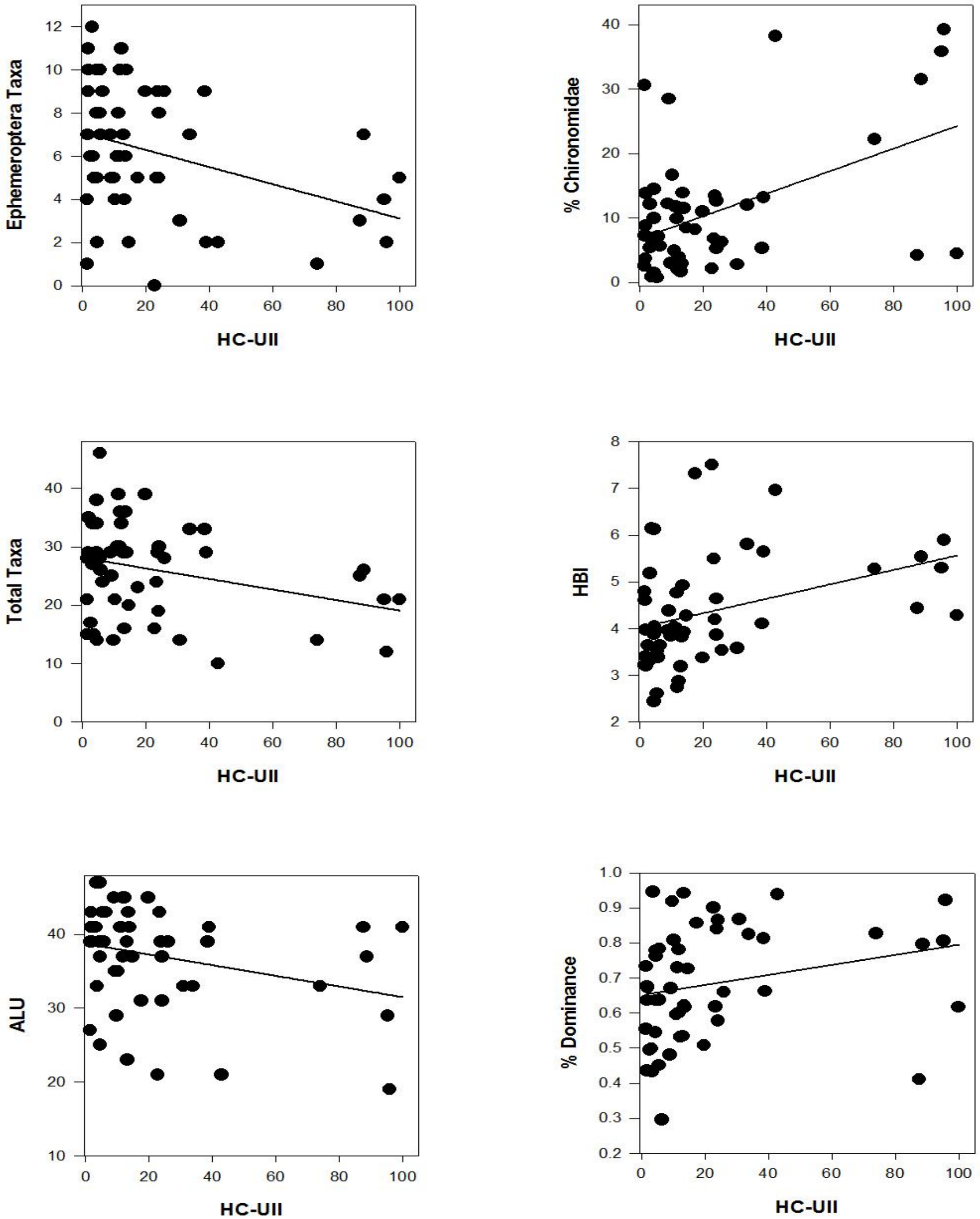

Figure 4. Linear relationships between the Central Texas Urban Intensity Index and calculated metrics from aquatic invertebrates enumerated from the Central Texas area. Negative relationships were seen with Ephemeroptera taxa, total taxa, and aquatic life use score (ALU). Postive relationships were seen with percent Chironomidae, Hilsenhoff Biotic Index (HBI), and percent dominant taxa.

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