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Environmental Determinates of Distribution for Dragonfly Nymphs (Odonata: Anisoptera) in Urban and Non-Urban East Texas Streams, USA

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Abstract: We collected environmental and habitat data for nymphs of 12 dragonfly species (Odonata: Anisoptera) from 91 stream sites throughout eastern Texas, including urban and non-urban locations. Understanding the relationship of dragonflies to habitat structure and other environmental variables is crucial for the purpose of conserving these insects and better using them as predictive tools for water quality assessments, and refining tolerance values. The objectives of this study were to determine the key environmental variables influencing the diversity and distribution of dragonflies in eastern Texas streams, and further determine if differences in those factors could be observed between urban and nonurban sites. We collected samples separately from benthic habitats and woody snag habitats. Significantly fewer sites were observed to have dragonfly species on snag habitat (mean = 1.25) compared to benthic samples (mean = 14.67) (*t*-test, $p = 0.001$). The number of dragonfly species collected among non-urban streams (mean = 9.83) was not significantly different than urban streams (mean = 6.08; *t*-test, $p = 0.07$). Detrended correspondence analysis of benthic and snag habitat data collected from non-urban and urban locations showed that most of the species are oriented most closely to benthic habitats in non-urban streams. Snag habitat was shown to be poorly ordinated for all of the species. A canonical correspondence analysis of 29 water quality and habitat variables as environmental determinants of dragonfly diversity and distribution showed that distributional relationships among species are complex and often described by multiple environmental factors.

Keywords: Anisoptera; stream habitat; insect diversity; urban streams

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1. Introduction

Dragonflies (Odonata: Anisoptera) are a relatively large, diverse group that exhibits a broad range of reactions to environmental stressors, thus making them useful indicators of water quality [1–10]. Although stream-dwelling dragonfly nymphs are often used in general community-based assessment indices because they demonstrate a wide variety of tolerances to disturbance and pollution [2,5,8,10], they have received relatively little specific attention for this purpose in the United States. Development and use of regionally focused tools for assessing aquatic condition is particularly important for the state of Texas where there is a vast diversity of aquatic ecosystems [11,12]. To develop such assessment tools, it is imperative to understand the environmental and habitat drivers that dictate the distributions of the targeted species.

Dragonfly nymphs potentially can be influenced by a broad array of environmental variables both biotic and abiotic [13], thus emphasizing a need to better understand such influences. Although abiotic conditions of the local environment are key in determining whether organisms can successfully inhabit or persist in a given habitat, they are often inadequately described. Moreover, differences observed among biotic assemblages are

often best explained by understanding the habitat structure and physicochemical tolerances of the inhabitants of those systems [14].

Landscape scale disturbances, including development (i.e., urbanization) in the flood plain and other land-use modifications, can disrupt ecological equilibrium by reducing habitat complexity [15]. Among the potential habitat modifications, destruction of riparian vegetation—increased siltation through bank instability, and loss of woody debris [16,17]—has long been known to negatively impact stream dragonfly diversity [4,18–24]. Previous studies have shown that many dragonfly species are vulnerable to stressors associated with urbanization and landscape-level disturbance, which may result in marked decreases in the occurrence and abundance of sensitive or intolerant species [2,3,7,23,25–32].

To gain a better understanding of the consequences urbanization has on streams, it is important to assess how environmental determinants influence aquatic invertebrate communities, including dragonflies. Previous studies have addressed the effects of urbanization on Texas streams [12,33,34], but assessments of such conditions for stream-dwelling odonates are quite limited in this state. For example, some studies have focused on habitat condition of odonates associated with urbanized playa lakes in western Texas [35–37], and Phillips [38] evaluated habitat preferences for aquatic invertebrates in an east Texas stream, including odonates. However, no previous studies have assessed specific influences on dragonfly diversity or community structure in streams across eastern Texas. In this study, our objectives were to determine the key environmental variables influencing the diversity and distribution of dragonfly nymphs in eastern Texas streams and determine if differences in those factors could be observed between urban and nonurban sites. We anticipated that urban streams would be less favorable for dragonflies than for non-urban streams and that an analysis of the correlated environmental variables would aid in understanding dragonfly distributions in eastern Texas.

This paper summarizes the results of dragonfly nymphs collected from streams located in three eastern Texas ecoregions in relation to water quality, habitat, and environmental stressors with particular attention to urban versus non-urban streams.

2. Materials and Methods

2.1. Sampling Sites

We sampled 91 wadeable, second through fourth order [39], stream sites in eastern Texas from May through October during 1998–2000 using a probability-based approach [34] (Figure 1). The specific criteria for selecting sampling sites are described in Kleinsasser et al. [34]. Among the streams sampled, 34 were in urban areas while 57 were in non-urban areas. Urban streams were defined as those within corporate city limits (e.g., areas of greater human populations with assumed accompanying development). Sites were sampled over a stream reach 40 times the mean wetted width as measured at the midpoint. We collected water quality and habitat data in support of biological community sampling at each site (Table 1; see Kleinsasser et al. [34] for methodologies used).

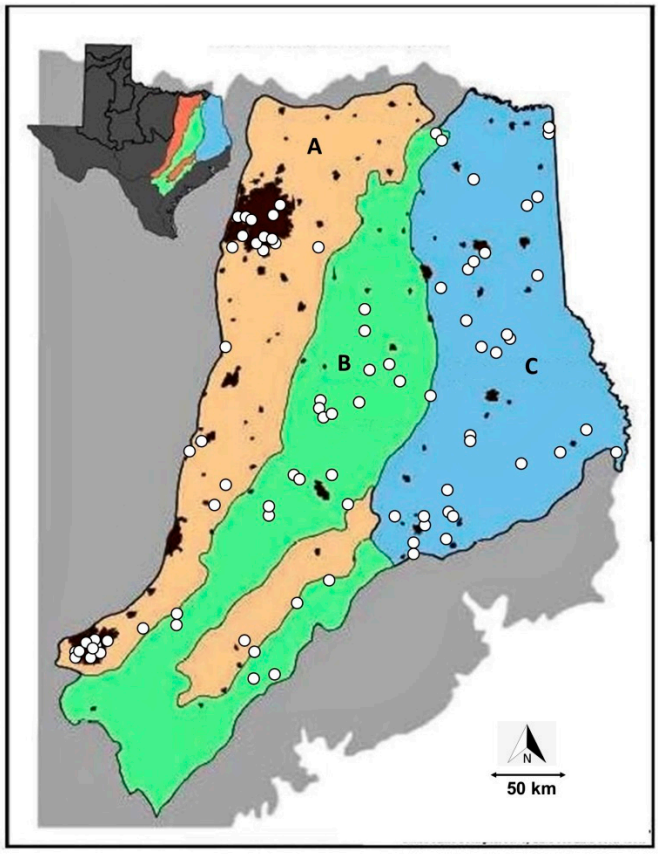

Figure 1. Approximate locations of sampled streams (circles). (**A**) Texas Blackland Prairies (orange), (**B**) East Central Texas Plains (green), (**C**) South Central Plains (blue). Map from Omernik [40] and Bowles et al. [12]. Black shading indicates urban areas.

2.2. Sample Collections

Following the methods of Klemm and Lazorchak [41], we collected benthic invertebrate samples from downstream to upstream at 9 of 11 habitat transects—excluding the ones on either end of the reach. A single benthic sample was collected from each transect, with the order of samples alternating from left, middle, and right side of the stream channel. Benthic samples were collected using a rectangular kicknet (0.5 m wide by 0.3 m high; 600-µm mesh) by disturbing an area of approximately 1 m in front of the net for 20 s and allowing the water current to carry substrate inhabitants and debris into the net. This resulted in a sampling area of approximately 0.5 m^2. For samples in pools with minimal or no current velocity, the net was dragged though the sampling area while kicking the substrate. This also resulted in a sampling area of approximately 0.5 m^2. Samples were rinsed in a wash bucket (500-µm mesh) to remove sediments, placed into labeled individual containers, and preserved with 95% isopropyl alcohol. We collected snag samples by gathering a variety of aged woody debris along the entire study reach with all habitat types being represented to the extent possible. The woody material was placed into a 4-L plastic container until it was full or nearly full and preserved with 95% isopropyl alcohol. In the laboratory, collected materials were rinsed through a 500-µm mesh sieve to remove fine sediments and sand, and then entirely sorted under 10× magnification with specimens being stored in labeled vials with 70% isopropyl alcohol. Snag material was handpicked under 10× magnification to remove attached invertebrates.

Table 1. Environmental variables used in the canonical correspondence analysis and their abbreviations. Adapted from Bowles et al. [12].

Variable	Abbreviation
24-h mean dissolved oxygen (mg/L)	DO
Mean temperature (Celsius)	Temp
pH	pH
Specific conductance (µm/cm)	Conductivity
Turbidity (NTU)	Turbidity
Total suspended solids (mg/L)	TSS
Chlorophyll a (mg/L)	CHL-a
Chloride (mg/L)	Chloride
Ammonia (mg/L)	NH_3
Total phosphorus (mg/L)	Phosphorus
Leaf litter (%)	Leaf litter
Filamentous algae (%)	Algae
Aquatic plants (%)	Macrophytes
Canopy, mid-channel (%)	Canopy
Substrate embeddedness (%)	Embeddedness
Large woody debris (%)	Wood
Brush (%)	Brush
Non-agricultural riparian zone (%)	Non-ag riparian
Agricultural riparian zone (%)	Ag riparian
Substrate, fines (%)	Fines
Substrate, sand (%)	Sand
Substrate $\leq$ sand/fine gravel (%)	Sand and fine gravel
Substrate, $\geq$large gravel (%)	Large gravel
Substrate, hardpan clay (%)	Hardpan
Bedrock substrate (%)	Bedrock
Channel sinuosity	Sinuosity
Glide habitat (%)	Glide
Riffle habitat (%)	Riffle
Pool habitat (%)	Pool

Because snag and benthic sample collection methods differed, we did not attempt to statistically compare the densities of specimens collected. Instead, only raw numbers of specimens collected are compared. Our groupings represent the dominant habitat in a sample (i.e., riffle, pool, glide), recognizing that vegetation or root mats may have been in the substrate and that woody debris in the snag samples may have contacted mineral substrates.

2.3. Specimen Identification

Identification was made using Needham et al. [42]. Some taxa were not identified to species because of taxonomic uncertainty, damage, or they were early instars and could only be identified to the genus level. Species collected from fewer than three sites were not included in the analyses. They include *Aphylla angustifolia* Garrison, *Orthemis ferruginea* (Fabricius), *Platythemis lydia* (Drury), *Nasiaeschna pentacantha* (Rambur), and *Somatochlora linearis* (Hagen). In summary, analyses presented in this study only includes 12 species that could be reliably identified and occurred at a sufficient number of sampling sites (Table 2).

2.4. Tolerance Values

Tolerance values for odonates and other aquatic invertebrates are crucial for calculating various biotic indices and other pollution indicators [10], and they vary considerably among different regions as do the methods for assigning those values (Table 3). Tolerance values range from 0 to 10 with values nearer 0 being less tolerant of pollution and values nearer 10 being more tolerant [43,44]. Tolerance values referenced in this study (Table 3) are derived from previously published sources. In some cases where species specific tolerance values are not known, they are presented for the genus level.

Table 2. Number of collection sites where dragonfly (Odonata) species were collected from snag and benthic substrates and from non-urban and urban streams.

Taxon	Acronym	Non-Urban	Urban	Benthic	Snag
Boyeria vinosa (Say)	BOVI	8	7	10	5
Brechmorhoga mendax (Hagen)	BRME	3	7	8	2
Didymops transversa (Say)	DITR	6	2	7	1
Erpetogomphus designatus Hagen in Selys	ERDE	6	9	14	1
Erythemis simplicicollis (Say)	ERYT	8	11	17	2
Hagenius brevistylus Selys	HABR	5	0	5	0
Macromia illinoensis Walsh	MAIL	31	10	41	0
Pachydiplax longipennis (Burmeister)	PALO	3	5	7	1
Perithemis tenera (Say)	PETE	4	5	9	0
Phyllogomphoides stigmatus (Say)	PHST	25	5	29	1
Progomphus obscurus (Rambur)	PROB	17	8	24	1
Sympetrum corruptum (Hagen)	SYCO	1	2	2	1
Mean	–	9.83	6.08	14.67	1.25

2.5. Statistical Analyses

Non-normal data were transformed as necessary using Log10 for water quality data and arcsine square root for proportional data to reduce skew and approach approximate multivariate normal distributions [45]. In addition, mean imputation was used to account for missing data for physiochemical variables, although they accounted for less than 0.25% of the data [46]. We used PAST statistical software version 4.06b [47] to perform all statistical analyses, including a two-tailed Student's *t*-test (alpha = 0.05) to evaluate potential significant differences in species occurrences among snag and benthic habits and from stream sites located in urban and non-urban habitats, respectively. We also used detrended correspondence analysis (DCA) with 26 segments to spatially evaluate the relationships among species richness for benthic, snag, non-urban, and urban habitats [45].

Following the recommendations of Legendre and Legendre [45] and ter Braak and Verdonschot [48] we used canonical correspondence analysis (CCA) to evaluate the relationship of odonate occurrence (response variables) to associated environmental variables (predictor variables) [47]. CCA is robust even when some species display bimodal responses, unequal ranges, or unequal maxima along environmental gradients, and it useful in identifying environmental variables that most strongly influence community composition [49,50]. We initially tested for collinear relationships among all the environmental factors using Spearman's rank order correlation coefficients (*rs*). This allowed us to reduce the total number of variables included in the model. We only retained factors with $rs > 0.5$ ($a < 0.05$) for the analyses. This process resulted in using 29 of the 43 water quality and habitat variables reported by Kleinsasser et al. [34] for use in the CCA (Table 1). A Monte Carlo permutation test ($N = 999$) was conducted on the CCA model correlation [45]. We used numbers of dragonfly species collected from among sampling sites as the response variables, with species represented at fewer than three sites not being included in the model. Vectors in the CCA triplot indicate spatial association of species with environmental variables; the value of the environmental variables increases in the direction of the vector points, and the length of the vector indicates the relative importance of that variable to the model. Vectors that lie parallel to the axis are highly correlated with that axis while vectors lying more perpendicular to an axis are poorly correlated with that axis.

Table 3. Tolerance values for dragonflies (Odonata) collected during this study. Where tolerance values are not known for species, they are presented for the genera.

	Source *										
Taxon	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Avg.**
Family Aeshnidae											
Boyeria vinosa	6.3	2	3.5	-	-	5.4	-	-	-	-	4.3
Nasiaeschna pentacantha	8	-	-	-	-	-	-	-	8	8	8.0
Family Corduliidae											
Somatochlora spp.	8.9	1	-	9	1	8.4	1	-	8.9	1	4.9
Somatochlora linearis	-	-	-	-	-	-	-	-	-	-	
Family Gomphidae											
Aphylla angustifolia	-	-	-	-	-	-	-	-	-	-	
Erpetogomphus spp.	-	-	-	4	-	-	-	-	-	1	2.5
Erpetogomphus designatus	-	-	-	-	-	-	-	-	-	-	
Hagenius brevistylus	4	1	-	-	-	-	1	-	4	-	2.0
Phyllogomphoides spp.	-	-	-	-	-	-	-	-	-	1	1
Phyllogomphoides stigmatus	-	-	-	-	-	-	-	-	-	-	
Progomphus obscurus	8.7	-	-	-	-	-	-		8.7	-	8.7
Family Libellulidae											
Brechmorhoga spp.	-	-	-	-	-	10	-	-	-	6	8.0
Brechmorhoga mendax	-	-	-	-	-	-	-	-	-	-	
Erythemis spp.	-	-	-	-	-	-	-	-	-	5	5.0
Erythemis simplicicollis	-	-	-	-	-	-	-	-	-	-	
Orthemis spp.	-	-	-	-	-	-	-	-	-	9	9.0
Orthemis ferruginea	-	-	-	-	-	-	-	-	-	-	
Pachydiplax longipennis	9.6	-	-	-	-	-	-	-	9.6	10	9.7
Perithemis spp.	10	-	-	-	4	-	10	-	-	4	7.0
Perithemis tenera (Say)	-	-	-	-	-	-	-	-	-	-	
Playthemis lydia (Drury)	-	-	-	-	-	-	-	-	-	-	
Sympetrum spp.	7.3	10	-	-	4	-	10	-	7.3	7	7.6
Sympetrum corruptum (Hagen)	-	-	-	-	-	-	-	-	-	-	-
Family Macromiidae											
Didymops spp.	-	-	-	-	-	-	-	-	-	-	-
Didymops transversa (Say)	-	-	-	-	-	-	-	-	-	-	-
Macromia spp.	6.7	2	-	-	2	4.9	2	-	6.7	3	3.9
Macromia illinoensis Walsh	-	-	-	-	-	-	-	-	-	-	-

* 1. Southeast [10]; 2. Upper Midwest (Wisconsin) [10]; 3. Midwest (Ohio) [10]; 4. Northwest (Idaho) [10]; 5. Mid-Atlantic [10]; 6. [51]; 7. [43]; 8. [44]; 9. [52]; 10. [53].

3. Results

Dragonfly nymphs were found at 90 (99%) of the 91 sites we sampled. Among all sites and habitats, we collected six families and 21 genera of dragonflies (Suborder Anisoptera), 17 of which were identified to species (Table 3). Of those, 12 species from among 79 sampling sites are included in further analyses here with the remaining five species not being included because they were not collected from a sufficient number of sampling sites (Tables 2 and 3).

Several dragonfly species collected in this study are commonly considered lentic or pond inhabiting. They include *Phyllogomphoides stigmatus* (Say) and *Perithemis tenera* (Say), in addition to the five previously referenced taxa not included in the analyses. Their occurrence at some of our sampling sites is not unexpected given sluggish flows and extensive pools in some systems that may approximate lentic habitats. *Macromia illinoensis* Walsh, *P. stigmatus* and *Progomphus obscurus* (Rambur) were the most commonly collected dragonflies—being found at 41, 30, and 25 sampling sites, respectively—and primarily from non-urban streams.

The number of dragonfly species collected among non-urban streams (mean = 9.83) was greater than that of urban streams (mean = 6.08), although the difference was not statistically significant (t-test $\alpha = 0.05$, $t = 1.53$, $p = 0.07$) (Table 2, Figure 2). For sites having three or fewer of the species included in the analysis, they occurred primarily at non-urban sites (Figure 2). However, as the number of species increased, they tended to be comparably represented at urban sites and non-urban sites. It is notable that one non-urban site had six species represented, while the greatest number of dragonfly species ($n = 8$) collected from

among any sites was from an urban stream (Figure 2). We recognize those findings may not obviate biological significance. Most species were collected from both urban and non-urban streams and often in similar amounts with the exception of *Hagenius brevistylus* Selys, which was collected only from non-urban streams. Additionally, *M. illinoensis*, *P. stigmatus* (Say), and *P. obscurus* (Rambur) were found predominantly in non-urban streams.

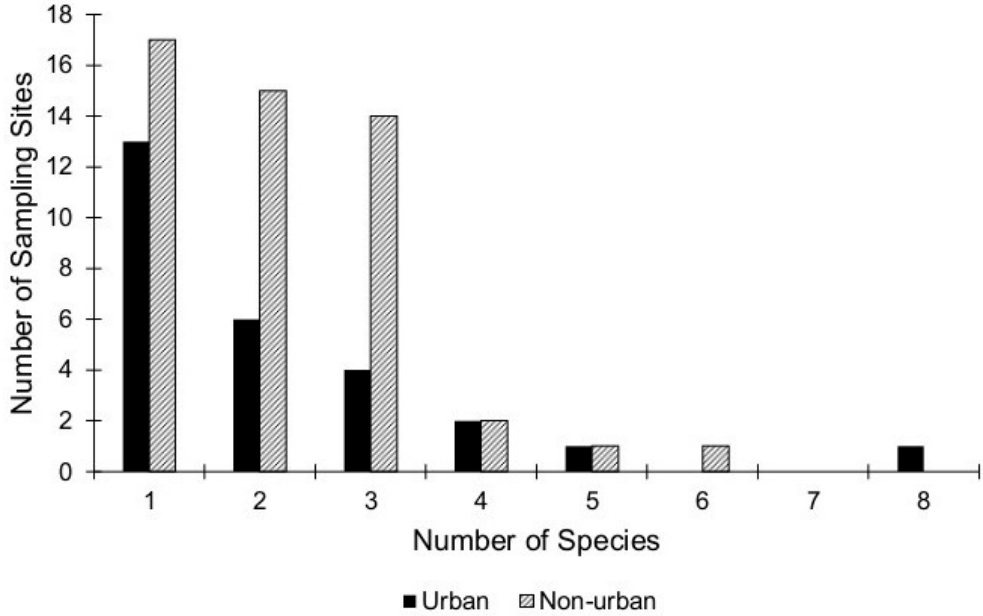

Figure 2. Number of dragonfly (Odonata) species collected from urban and non-urban sites in eastern Texas.

We found significantly fewer species on snag habitats (mean = 1.25) compared to benthic samples among sites (mean = 14.46) (*t*-test $\alpha = 0.05$, $t = 3.88$, $p = 0.001$) (Table 2). No taxa were found exclusively on snags, but some were found exclusively in benthic samples and never on snag habitat (e.g., *H. brevistylus*, *M. illinoensis*, and *P. tenera*). All other species were found in both benthic and snag samples.

Tolerance values previously reported for the taxa in this study ranged from 1.0 (*Phyllogomphoides* sp.) to 9.7 (*Pachydiplax longipennis*), with a mean across all taxa of 5.83 ($n = 14$), which indicates that dragonflies, as a group, are moderately tolerant (Table 3). Tolerance values have not been published for several of the taxa we collected. In cases where no tolerance values have been published for the species, we included the tolerance value for the genus as a substitute with an assumption that most species in that genus would have similar tolerance values.

Detrended correspondence analysis demonstrated distinct relationships among occurrences of dragonfly species in non-urban, urban, benthic, and snag habitats, respectively, although in several instances these species were represented at only a few sampling sites (Figure 3). The ordination space shows that most of the species are oriented most closely to benthic habitats in non-urban streams and less so to urban streams. Snag habitat was shown to be poorly ordinated with the dragonfly species included in the analysis.

The CCA corroborated the results of the DCA. The first two CCA axes accounted for 40.16% of the total inertia while the first three axes accounted for 54.62% (Figure 4). Monte Carlo simulations indicated the first three axes were significant (999 permutations, $p = 0.001$, $\alpha = 0.05$). The Eigenvalues for axis one and two (0.57 and 0.51, respectively) are relatively high and indicate strong unimodality [48]. The total inertia for the CCA model was 3.25. The CCA demonstrated that several species were strongly correlated with pool habitat, bedrock substrate, aquatic plants, and non-agricultural riparian disturbance. They include *D. transversa*, *E. simplicicollis*, *P. tenera*, and *P. longipennis*, *Sympetrum corruptum* was strongly correlated with chloride, conductivity, pH, and temperature, but because

this species was collected only at three sites, those findings may not be solidly predictive. *Phyllogomphoides stigmatus* was weakly associated with the previous variables, but this species was collected from 30 sampling sites of which most were non-urban. *Boyeria vinosa*, and *M. illinoensis* were associated primarily with high substrate embeddedness, sand and fine gravel substrates, brush, accumulated leaf litter, and turbidity. *Progomphus obscurus* and *H. brevistylus* were strongly correlated with sand substrate, sinuosity, canopy, and bedrock. Two species typically associated with clear-flowing streams, *B. mendax* and *E. designatus*, were most strongly correlated with riffle habitat having large gravel substrate. Although generally not considered an eastern Texas species, all of our collections of *B. mendax* (n = 10) were from the western edge of the study area where streams generally have a more typical riffle-pool structure compared to streams farther east. Interestingly, none of the species in this study strongly correlated with glide habitat, fine sediments, or macrophytes.

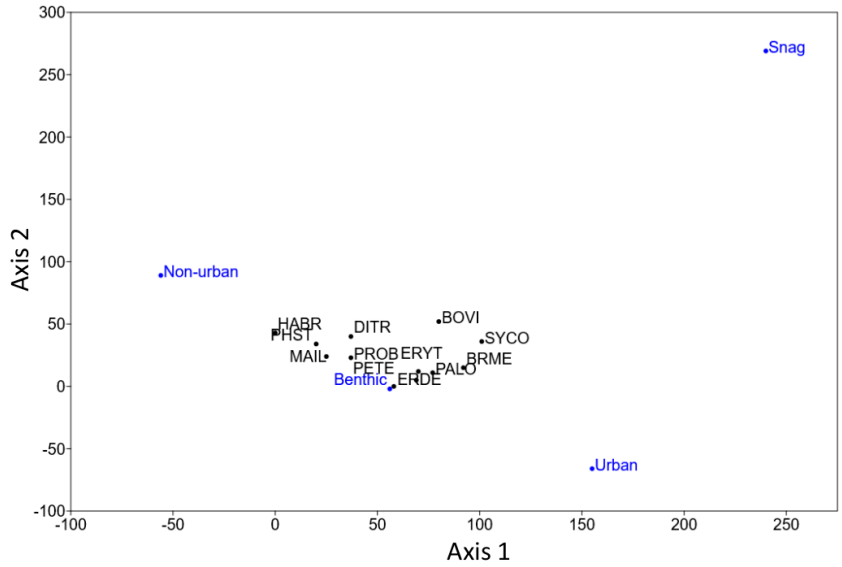

Figure 3. Detrended correspondence analysis biplot of dragonfly (Odonata) diversity in east Texas streams based on benthic, snag, non-urban, and urban distributions. See Table 2 for taxa abbreviations. Eigenvalues were 0.14 for Axis 1, 0.07 for Axis 2.

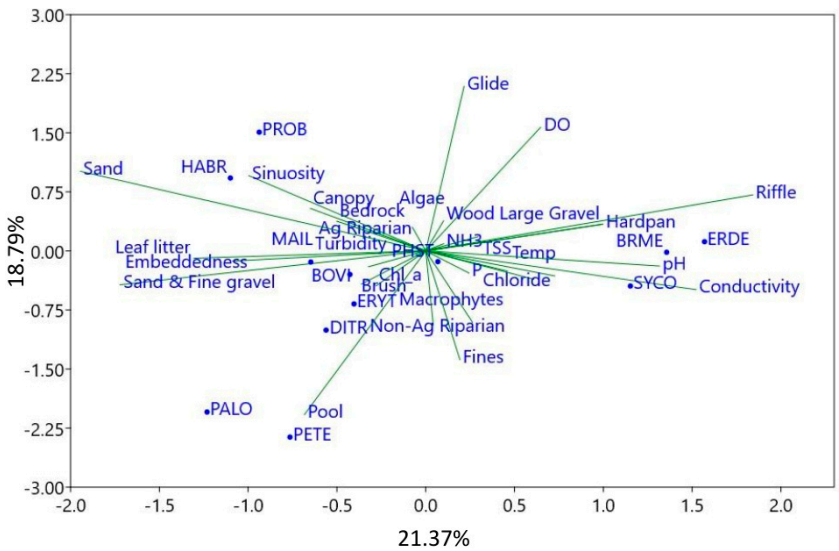

Figure 4. Canonical correspondence analysis triplot of dragonfly (Odonata) associations with environmental variables in east Texas streams based on benthic, snag, non-urban, and urban distributions. See Table 1 for a description of the variables and Table 2 for a description of the Odonata taxa.

4. Discussion

The most important finding of this study was that the number of dragonfly species occurring in urbanized streams was not significantly different than that of non-urban streams, although non-urban streams collectively had a numerically greater representation of total species. With the exception of *Hagenius brevistylus*, all other species were collected in both stream types. Some taxa were found about equally in both stream types suggesting that dragonfly. We recognize that the degree of impairment in urban streams is related to the observed nymphs are generally tolerant of conditions in urban streams. In contrast, other dragonfly taxa were less frequently represented in urban streams suggesting intolerance for disturbed systems. Our finding echoes that reported in other studies [30,54]. In contrast, other studies have found that dragonflies were more significantly underrepresented in urban streams [2,3,27] biodiversity with more severely impaired streams having fewer species.

The decreased representation of some dragonfly species in urban stream sites compared to non-urban ones reflects a probable greater variety and number of stressors in the former. As Kleinsasser et al. [34] noted, urban stream sites included in this study had significantly greater riparian disturbance and lower habitat quality, the latter conclusion based upon a multimetric index used by Texas state agencies. The urban streams in our study generally had less sinuosity, canopy cover, large woody debris, and natural cover compared to nonurban ones [34]. Integrity of riparian vegetation and forest cover has been demonstrated to be crucial for sustaining dragonfly diversity, and urbanization often results in clearing of riparian vegetation [4,22,23,27,29,55].

An additional important finding of this study is that dragonflies in eastern Texas streams generally prefer the benthic substrate as a habitat over woody snag. Although a broad range of species were found on snag, only *Boyeria vinosa* was found in abundance on this substrate from more than two sampling sites. Similarly, Burcher and Smock [56] showed snag habitat was the least used substrate by several odonate species in a Virginia blackwater stream, but some species—including *B. vinosa*—were commonly found in debris dams. Furthermore, our finding that several species (i.e., *D. transversa*, *E. simplicicollis*, *P. tenera*, and *P. longipennis*) showed an affinity for pool habit in east Texas streams as shown in the CCA results is not surprising, With the exception of *D. transversa*, these species often inhabit ponds or streams with sluggish flow, the latter of which characterizes some of our sampling sites. Five species were not included in the analyses because they were not collected at a sufficient number of locations (i.e., *A. angustifolia*, *O. ferruginea*, *P. lydia*, *N. pentacantha*, *S. linearis*). We do not know the specific reasons for their apparent rarity in collections, but it may have resulted from scant sampling of their preferred microhabitats, seasonality, or other unknown factors.

Our study demonstrates that alteration of physical habitat in urban eastern Texas streams may come as a detriment to some species of dragonflies that inhabit them. We acknowledge that such factors may be symptoms of a broad range of impacts that occur in urban streams that may work collectively to alter stream condition and habitat [57,58]. The various dragonflies we collected exhibited a broad range of responses to the environmental correlates that were measured. Other investigators have found similar relationships with environmental variables for some of the dragonflies reported here. In particular, broad habitat descriptors such as benthic vs. snag and riffle vs. pool habitat preferences appear to be consistent through the ranges of several species included in this study [56]. When such analyses are conducted with the notion of refining tolerance values for water quality assessments, they should be done on the local and regional scale to make them as accurate as practical. For most of the species we report, there is little specific comparative environmental information in the published literature, and that which is available shows a wide range of responses to environmental conditions that likely are due to species-specific and/or geographic factors.

The broad survey data we present informs knowledge about the species observed and follow-up studies of those individual taxa may benefit from that data. For example, the

information we present here can be used as support for continued refining of tolerance values for some taxa in eastern Texas and perhaps adjacent areas in the Gulf Coastal Plain. We recognize, however, that stream condition may matter more than where the stream is in the landscape. For example, an urban stream with clear water, sufficient vegetation and shade, and good flow may provide better habitat for some lotic dragonflies than a non-urban stream with turbid water, sluggish flows, and a disturbed shoreline. Moreover, although some species appear to be intolerant of anthropogenic stressors, others readily inhabit disturbed habitats [54]. Many of the previously published tolerance values, which indicate dragonflies are a largely tolerant as a group, are supported by our analysis. Our finding that some species were more commonly associated with urban streams suggests that the higher tolerance values presently assigned to some (e.g., *B. mendax*) are accurate with respect to Texas streams, while others may require reevaluation (e.g., *E. designatus*, *P. longipennis*). An additional consideration for future studies is to account for behavior of the species studied because perch choice, oviposition sites of adults, and substrate choice by nymphs all play important roles in where the nymphs are ultimately collected.

The ultimate goal of biotic diversity and distribution studies is to better enable resource managers to make sound, informed decisions on those resources particularly considering anthropogenic disturbance. Detailed knowledge of local and regional biodiversity patterns is crucial for making sound conservation management decisions. Moreover, understanding the relationship of dragonfly communities to habitat structure is crucial for the purpose of conserving these insects especially considering the broad scale of anthropogenic stressors faced by aquatic systems [59,60], as well as refining their use as predictive tools for water quality assessments.

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