City of Austin
WATERSHED PROTECTION

A Review of a Study on the Effects of Artificial Light on Stream Macroinvertebrate Drift in Central Texas Streams

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Abstract

A Master's Thesis project by Monika Henn explored the effect of artificial lighting on behavioral drift by stream macroinvertebrates within Central Texas streams. The Environmental Scientists at the City of Austin Watershed Protection Department provided input regarding site selection and taxonomic identification. In her study, no differences in taxonomic diversity or richness of drifting macroinvertebrates were observed between two treatments (ambient lighting versus artificial lighting), but the average abundance of drifting insect larvae was less in streams with artificial lighting. Notable decreases in abundance were reported for the insect families Simuliidae, Baetidae and Coenagrionidae. There was an unanticipated difference on drift from streams of different catchment area, flow regime, and degree of urbanization. The results of this study may be of interest to the City of Austin and other urbanizing areas in Central Texas in efforts to understand and reduce the effects of development on stream ecology. Although this study does concur with the literature which indicates that artificial lighting has negative effects on drift, the results from this study suggest that the experimental design needs to be repeated with a larger sample size to assess whether differing light regimes within small urban watersheds show significant, detectable effects.

Introduction

Macroinvertebrate drift refers to the movement of macroinvertebrates downstream in a creek or river. There are several established distinctions in causes for macroinvertebrate drift which include catastrophic drift, constant drift, and behavioral drift (Waters 1972). Catastrophic drift refers to the movement of macroinvertebrates after a physical disturbance to the bottom fauna. Constant drift refers to the movement of all species downstream in very low numbers. Finally, behavioral drift refers to the movement of certain species during certain periods of the day resulting from a behavioral pattern. Regardless of the form of drift, these macroinvertebrates become an important food source for downstream fish communities and other consumer populations (Elliot 1973). The species that take part in behavioral drift are distinct because catastrophic drift happens only after a scouring event and is not highly predictable and the abundance of macroinvertebrates in constant drift seems to be low (Waters 1965).

Behavioral drift is not fully understood but plausible environmental cues that might trigger species to move downstream include a lack of feeding opportunity and high abundance of predators. The movement involves the invertebrate leaving the protection of the bottom surface and floating or swimming in the open water. This leaves the invertebrate prone to predators. Thus, certain species prefer to drift under the cover of darkness shown by the increase in drift abundance from sunset to sunrise (Mueller 1963, Tanaka 1960, Waters 1961). Light seems to be the main trigger for such behavioral drift as it has been shown that artificial lighting can disrupt or stop macroinvertebrate drift (Chaston 1968, Mueller 1965). The species that experience altered behavioral drift patterns due to artificial light have been documented for temperate/northern regions.

Urban areas are large sources of light pollution during the night. Night time light sources can be much higher than the light intensity of moonlight during a full moon, which has been shown to disrupt behavioral drift in some species (Anderson 1966). Artificial light pollution could be degrading ecosystem function in urban creeks by creating a separation between macroinvertebrate communities in the headwaters and the larger channels downstream and disrupting the natural nutrient cycling of the aquatic systems. Exactly how artificial light "might influence stream and riparian ecosystems is a relatively unexplored topic… [and] carefully designed experiments are needed to determine the exact effects of artificial light on ecosystems and over what spatial and temporal scales they act" (Perkin *et al*. 2011).

Monika Henn, a graduate student at Texas State University, conducted field work for a thesis project in 2012 to investigate if artificial lights reduce macroinvertebrate drift in urbanized stream systems in semi-arid streams of Central Texas. In addition, the project also sought to determine which aquatic insect families, if any, are experiencing artificial light-disrupted drift patterns. During the experimental design phase of the project, Environmental Scientists at the City of Austin Watershed Protection Department (WPD) were consulted on site location for streams within City jurisdiction including Onion, Bull and Barton creeks. Although the City did not participate in the field work or provide financial support, WPD scientists provided advice and taxonomic support toward a mutual interest of better understanding the ecological effects of urbanization. Benthic macroinvertebrate data collected for the project from Onion, Bull and Barton are retained in the field sample database of WPD.

Methods

Sites (Table 1) were chosen for sampling because they were known to maintain high integrity macroinvertebrate communities and would facilitate a study of local taxa whose drift may be altered by artificial light. These sites are riffle/run habitats with moderate (Comal and San Marcos rivers) to low (Barton, Bull, and Onion creeks) stream discharge and watershed size. During the

November/December field effort, drift nets were set up for two hours at each site beginning at sundown to capture the macroinvertebrates that behaviorally drift when ambient light levels dropped. This was done once under ambient conditions and once under an artificial light source at each site. Nets placed on the same waterbody were located to ensure the independence of the drift sample between the nets. After the two-hour collection period, macroinvertebrates were stored in 95% ethanol and transported to Texas State University for identification and enumeration. Additional information on the experimental design can be found in the thesis (Henn 2013) or related journal article (Henn et al. 2014).

Table 1: Site list.

Site #	**Site Name**	**Watershed**
48	Barton Creek @ HWY 71 d/s Little Barton	Barton Creek
255	Onion Creek @ McKinney Lower Falls	Onion Creek
348	Bull Creek in St. Edwards Park	Bull Creek
5738	Macroinvertebrate Drift on San Marcos River	San Marcos River
5740	Macroinvertebrate Drift on Comal River	Comal River

Results and Discussion

The 10 samples contained a combined total of 3,190 individuals, however, only 10% of those individuals were collected at the smaller Austin streams (Barton, Bull, and Onion). This study found evidence to partially support the hypothesis that artificial lighting disrupts behavioral macroinvertebrate drift in Central Texas streams, particularly for the families Baetidae, Chironomidae, Coenagrionidae, Leptohyphidae, and Simuliidae, however; there was an unanticipated difference in streams of differing watershed size, surrounding urbanization, and flow regime. Mean differences were observed between treatments (light addition vs. ambient light) for the total amount of larvae and among the orders Diptera and Ephemeroptera in all streams combined and in large streams treated separately (Henn et al. 2014). However, small streams treated separately did not reflect the same difference in means (Henn et al. 2014). Average biomass of drifting insects did not differ between treatments for the three most abundant families (Baetidae, Chironomidae, and Leptohyphidae), however; total biomass differed among all streams combined for the family Chironomidae, and within large streams for the families Baetidae and Chironomidae (Henn et al. 2014).

The low number of individuals collected from small streams (Barton, Bull, and Onion), and the inconclusive results obtained for those streams, suggests that the sampling methods used for this project would need to be modified to conduct any future investigations into the impact that artificial lighting has on invertebrate communities within Austin's smaller creeks. Additional details on the results of the study can be found in the related journal article (Henn et al. 2014) included as an appendix to this report.

Recommendations

The QAPP for Project 553 provides suggestions for future studies that may build on the findings of the report to include: an investigation of the effects of artificial light intensity on macroinvertebrate drift in streams with riparian zones of different 1) quality, 2) density, and 3) width. For example, a future study could provide better understanding of urban riparian zone effect by determining the light intensity in creeks that have sparse or low quality riparian zone compared to the light intensity in a creek surrounded by a dense and high quality riparian zone.

While this project found evidence that artificial light disrupts aquatic insect dispersal in Central Texas Streams, the results were inconclusive due to the low numbers of individuals collected in smaller streams. If an additional study of similar nature were to be implemented in the future, the methodology should be revised to obtain a sample size that would be sufficient to assess the effects caused not only artificial light, but by urbanization, flow regime, and watershed size. Additionally, future investigations could incorporate a sampling method (Surbers, kick nets, etc.) that can identify which taxa are present at a site prior to collecting drift net samples to supplement conclusions regarding which taxa are dispersing through behavioral drift. For a more robust data set, the sample period could include multiple seasons, since small streams may be affected more by seasonal temperature changes (compared to larger streams) and since behavioral drift may be variable through the course of a year. Due to the low number of individuals collected in smaller streams (Barton, Bull, and Onion), it may also be necessary to extend the collecting time over more than two hours in order to achieve a sample size that is sufficient for analysis.

Acknowledgments

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Appendix A

Journal of Freshwater Ecology, 2014: Effect of artificial light on the drift of aquatic insects in urban central Texas streams

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Effect of artificial light on the drift of aquatic insects in urban central Texas streams

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Light pollution can reduce night time drift of larval aquatic insects in urban streams by disrupting their circadian rhythms. Previous studies on larval insect drift show that disruption in drift leads to changes in reproduction as well as intraspecific and interspecific interactions. The purpose of this study was to conduct a preliminary investigation into the effects of extreme artificial light on insect drift in urbanized, high clarity spring systems of the karst Edwards Plateau, TX. We quantified taxa richness, diversity, and abundance in aquatic insect night time drift under two treatments (ambient night time light and artificial light addition) and among five streams using a paired design. Richness and diversity of drifting aquatic insects were similar between treatments but abundance was 37% less in the light addition treatment than that of the control. Effects of light addition on mean abundance was more notable in large streams with a 58% decrease in Simuliidae (compared to that of the control) and 51% decrease in Baetidae. Reduced drift from light addition suggests the potential of artificial lighting disrupting insect drift and consequently community structure. Results of this experiment support a growing body of knowledge on how urbanized systems influence stream communities.

Keywords: light pollution; stream ecology; urban ecology; drift; abiotic factors; Baetidae; Chironomidae

Introduction

Urbanization has the potential to cause numerous negative consequences for the physical and biological functioning of an aquatic ecosystem and looks to be a continuing ecological issue as the world's population migrates toward urban centers (Feminella & Walsh 2005). Physical processes of aquatic systems, including water quantity, stream morphology, and photoperiod, are susceptible to urbanization effects (Feminella & Walsh 2005). Photoperiod of aquatic systems can be disrupted by the presence of artificial night lights (i.e., street lights, safety lights, commercial lights) within and around the environment (Longcore & Rich 2004). Consequences of light pollution, through the increase in artificial lighting, are one frequently overlooked aspect of urbanization (Longcore & Rich 2004). In North America and Europe, 99% of the population is exposed to brighter than normal night skies with over 80% of the population experiencing skies brighter than that of a full moon (Navara & Nelson 2007).

To study the effects of light pollution on the environment, Longcore and Rich (2004) coined the term ecological light pollution that refers specifically to the disruption of ecosystem functioning by artificial night lights. Since the majority of organisms operate on a specific circadian rhythm, light pollution has the potential to impact the biological

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*Corresponding author. Email: mjh101@txstate.edu community by disrupting an organism’s migratory and reproductive habits, thereby affecting biomass and population size through changes in interspecific and intraspecific interactions (Longcore & Rich 2004; Hölker 2010, Wolter, et al. 2010). Behavioral characteristics of larval aquatic insects are susceptible to ecological light pollution (Feminella & Walsh 2005). In particular, photoperiods of aquatic invertebrates are disrupted by artificial night lights located near or distant from aquatic ecosystems (Longcore & Rich 2004). Downstream drift is an essential part of dispersion among many aquatic invertebrates and is thought to assist in locating optimal living conditions (Müller 1974) or avoiding predation (Flecker 1992). As such, invertebrate drift rates peak immediately following dusk and continue through the night hours (Cloud & Stewart 1974; Ciborowski 1982; Brittain & Eikeland 1988). A number of families within orders Ephemeroptera, Diptera, Plecoptera, and Trichoptera undergo diel drift (Elliott & Minshall 1968; Pearson & Franklin 1968; Brusven 1970; Steine 1972; Cloud & Stewart 1974; Casey 1987).

Under laboratory conditions (Bishop 1969; Chaston 1969) and natural settings (Holt & Waters 1966; Perkin et al. 2011) aquatic invertebrate drift is reduced by artificial light. Disruption of night time drift from artificial lights causes insects to stop drifting over areas of suboptimum substrate or increased predation, leading to changes in recruitment for individual species and overall community composition (Blakely et al. 2006; Smith et al. 2009). Additionally, artificial light reduces the number of benthic invertebrates dispersing from the substrate, possibly increasing densities and intraspecific interactions among larvae (Palmer et al. 1996). Varying climates and ecosystem structures should be considered when studying drift to obtain a general picture of ecological significance (Brittain & Eikeland 1988) but, to date, effects of ecological light pollution are reported in streams at northern latitudes and researchers have yet to investigate the possible effects of artificial light in arid and semi-arid climates.

The purpose of this study was to conduct a preliminary assessment on the effects of additional artificial light on evening drift of larval insects in headwater streams within urbanized areas of the semi-arid Edwards Plateau region of central Texas. Urbanized streams within the Edwards Plateau provide a unique opportunity to assess the effects of artificial lights because of high water clarity (ranging from 0.1 to 10 Nephelometric Turbidity Units [NTUs]; Groeger et al. 1997), attributed to base flows predominantly from karst spring discharge (Hubbs 1995; Groeger et al. 1997; Saunders et al. 2001). With high water clarity, artificial lighting extends further into the water column. As such, we predicted that the light addition treatments would cause greater disruption of evening drift of aquatic insects than that reported at northern latitudes. The objective of this study was to quantify aspects of larval insect drift (diversity, abundance, and biomass) in urban streams under ambient night light conditions and under extreme light addition conditions.

Method

Study area

Study sites were located on two large spring runs with moderate levels of urbanization and three small spring runs with high levels of urbanization. The two large spring runs were San Marcos River (29.869395° N, −97.930194° W; Hays County, TX) and Comal River (29.710164° N, −98.129171° W; Comal County, TX). The three small spring runs were Onion Creek (30.188457° N, −97.71964° W; Travis County, TX), Bull Creek (30.40468° N, −97.789655° W; Travis County, TX), and Barton Creek (30.295928° N, −97.92642° W; Travis County, TX). Discharge at each site was near base flow conditions. Each site included moderately flowing riffle or run mesohabitats with low levels of ambient light pollution. All streams had healthy riparian zones with moderate to high levels of riparian cover.

Physical habitat characteristics and water quality parameters were similar within large streams and within small streams. Large streams (>10 m width and >1.76 m^3/s; San Marcos River and Comal River) were characterized by moderate depths (>0.5 m), swift current velocities (> 0.30 m/s), gravel to cobble substrates, and high water clarity (<10 NTUs). Smaller streams (<5 m and <0.12 m^3/s; Barton Creek, Bull Creek, and Onion Creek) exhibited shallow depths (<0.3 m), slow current velocities (<0.1 m/sec), and sand to bedrock substrates. Water temperatures were 22–23 ^{o}C in large streams and cooler (<16 ^{o}C) in small streams. Dissolved oxygen levels were relatively low across all streams except at Bull Creek (10.6 mg/L). Specific conductance ranged between 491 and 650 mS/cm across all streams. Ambient light, measured directly above the water surface, was <2 lux across all streams.

Field collection

Five sites in Central Texas were sampled twice at night between November and December 2012 under two treatments: under ambient lighting (control) and with artificial light addition. Each night of sampling utilized one drift net (0.45 × 0.25 m, 500 mm mesh) and tested randomly one of the two treatments. Drift nets for each treatment were placed on separate evenings to ensure that the light addition treatment did not influence the results of the ambient light treatment. Additionally, only one location in each stream was tested at a time to minimize changes caused by environmental heterogeneity in large streams and due to minimal stream width and low water flow in small streams. Nets were set 30 minutes before sampling and captured drifting invertebrates for two-hour time periods starting within an hour after local sunset, because drift is highest during the first few hours after sunset (Cloud & Stewart 1974). Both ambient and light addition treatments were conducted within a week at each site to limit environmental differences between treatments.

Drift nets were placed in stream sections with the highest current velocities, typically downstream from a riffle, and supported by two metal fence posts. Nets were placed in the water column at least 5 cm above the substrate to minimize the likelihood of benthic insects crawling into the net. In large streams with a depth greater than the height of the net, the net was placed immediately below the water surface, since drift has been shown to be greatest in the surface current layer (Furukawa-Tanaka 1992). For the light addition treatment, two metal fence posts were set 1 m apart and supported a 1.2-m wooden plank with four portable work lights attached. Each portable work light held a 300-watt incandescent light bulb and was placed about 0.6 m above the stream surface. Lights were powered by a portable gas-powered generator. Artificial lights [mean ¼ 1482 lx; standard error (SE) ¼ 533] intensely illuminated a 1 × 4 m area and were placed 1 m upstream of the drift net. In large stream segments, the ambient light treatment included an additional two metal fence posts to simulate the setup of the light array. This addition was intended to control for the possibility of vegetation from the streams with high current velocity attaching to the metal posts and disrupting insect drift. After each sampling period, all contents collected from the drift nets were stored in 95% ethanol.

Laboratory analysis

Larval insects were separated from the rest of sample debris and placed in 95% ethanol for each sample site and treatment designation. Insects were identified to family level and counted for abundance, richness, and diversity at each site and for each treatment. Biomass was estimated for the three most abundant taxa across all five streams. Lengths were measured for all individuals taken from small streams and for a subsample (::;30%) of individuals taken from large streams (Allan 1982; McIntosh & Townsend 1996). Average biomass was estimated from average length using taxon-specific length–mass regressions (Table 2; Benke et al. 1999). Regression coefficients were unavailable for Leptohyphidae; therefore, coefficients for Ephemerellidae, a member of the same subfamily, were used instead. Total biomass was calculated by multiplying the mean family biomass per treatment by total number of individuals.

Data analysis

The experimental design was initially developed to accommodate a paired t-test in order to block differences in insect communities among streams. Drift densities of all taxa among five streams did not differ ($p > 0.05$) between treatments; however, trends in the data suggested an unanticipated stream size effect. The number of drifting taxa was more abundant and differences between treatments were more apparent in larger streams (San Marcos River and Comal River) than in smaller streams (Bull, Barton, and Onion Creeks). With low power (n ¼ 2) to detect differences with parameter statistics for large or small streams, we calculated mean differences and 1 SE for dependent variables (density, richness, and total number) between the ambient light treatment and light addition treatment for all streams, and we visually estimated distributional differences among all orders and among most abundant families (n 2: 82 individuals). We considered treatment effects informative and detectable if mean differences and 1 SE were much less than zero (i.e., taxa $\text{richness}_{\text{light addition}} << \text{taxa richness}_{\text{ambient light}}$). Differences in biomass were tested with a paired t-test comparing results across all streams and within large streams.

Results

Among 10 collections, we captured 3190 individuals representing six insect orders [Ephemeroptera (53%), Diptera (24%), Coleoptera (11%), Odonata (6.6%), Trichoptera (4.7%), and Lepidoptera (1.3%)] and 36 families (Table 1). Abundant families were Leptohypidae (33%), Baetidae (19%), Chironomidae (14%), Simuliidae (8.3%), Elmidae (6.8%), and Coenagrionidae (5.7%). The number of individuals per site was related to stream size with 90% of the insects captured from larger rivers (San Marcos River: 62%; Comal River: 28%). Overall, the number of drifting insects among all ambient light treatments (n ¼ 1979) was greater than all light addition treatments (1212).

Mean differences (light addition − ambient light) plus 1 SE were <<0 for total number of larvae in all streams and large streams and for richness in large streams (Figure 1). Mean differences (light addition − ambient light) plus 1 SE among orders were <<0 for Diptera and Ephemeroptera in all streams and in large streams (Figure 2). Mean differences (light addition − ambient light) plus 1 SE among families were <<0 for Baetidae, Chironomidae, and Simuliidae among all streams and for Baetidae, Chironomidae, Coenagrionidae, Leptohyphidae, and Simuliidae among large streams (Figure 2).

Average biomass (mg) of drifting insects did not differ ($p > 0.05$) between treatments among the three most abundant families (Baetidae, Chironomidae, and Leptohyphidae) among all streams, large streams, or small streams (Table 2). However, total biomass, calculated by multiplying estimated average biomass by the total number of captured

Table 1. Total number of individuals (N), family richness (S), and Shannon–Weiner diversity (H’) during the light addition and ambient light treatments at each of the five sampling sites.

	Barton Creek		Bull Creek		Onion Creek		Comal River		San Marcos River	
	Light	No light	Light	No light	Light	No light	Light	No light	Light	No light
Coleoptera										
Elmidae	6	3	0	0	0	0	12	12	71	112
Dropidae	0	0	0	0	1	0	0	0	0	0
Dystiscidae	0	0	0	0	0	2	1	0	0	0
Gyrinidae	0	0	0	0	0	0	0	0	0	1
Hydrophilidae	0	0	2	1	1	3	0	0	0	0
Lampyridae	0	0	0	0	0	0	0	4	0	0
Scirtidae	0	0	1	0	26	48	1	2	17	10
Tipulidae	0	0	0	0	0	1	0	0	0	0
Diptera										
Ceratopogonidae	0	0	0	0	0	0	0	1	0	2
Chironomidae	11	1	5	12	7	22	73	134	78	115
Culicidae	0	0	0	0	1	0	0	0	0	0
Empididae	0	0	0	0	0	0	1	5	2	0
Ephydridae	0	0	0	0	0	1	0	0	0	0
Simuliidae	0	0	1	2	1	7	75	171	0	8
Stratiomyidae	0	0	2	1	0	1	0	1	6	3
Tipulidae	0	0	0	0	0	0	0	1	0	1
Ephemeroptera										
Baetidae	4	3	12	15	7	6	54	139	132	237
Caenidae	2	0	0	0	2	2	0	2	3	1
Ephemeridae	0	0	0	0	0	0	0	0	5	3
Heptageniidae	2	0	3	1	0	0	0	0	0	0
Leptohyphidae	22	0	9	7	0	0	41	68	377	512
Leptophlebiidae	1	0	1	0	0	0	4	0	5	18
Lepidoptera										
Crambidae	0	0	0	0	0	2	7	12	9	12
Odonata										
Aeshnidae	0	0	0	0	0	0	0	2	2	3
Calopterygidae	0	0	0	0	0	0	0	5	3	9
Coenagrionidae	9	0	11	12	0	0	6	20	44	80
Cordulidae	0	0	0	0	0	0	0	0	0	2
Libellulidae	0	0	0	0	0	0	0	0	1	0
Protoneuridae	0	0	0	0	0	0	0	0	0	1
Trichoptera										
Brachycentridae	0	0	0	0	0	0	1	1	2	7
Hydrobiosidae	0	0	0	0	0	0	0	0	1	2
Helicopsychidae	0	0	0	0	0	0	0	1	0	0
Hydropsychidae	0	0	1	3	0	2	2	10	2	1
Hydroptilidae	0	0	1	3	0	0	5	4	1	5
Philopotamidae	0	0	0	2	0	1	3	6	26	44
Polycentropodidae	0	0	0	0	0	0	0	0	6	7
Total	57	7	49	59	46	98	286	601	791	1196
Shannon diversity	1.706	1.004	2.053	1.988	1.365	1.656	1.89	1.918	1.769	1.842
Family-level Richness	8	3	11	11	5	9	15	21	21	25

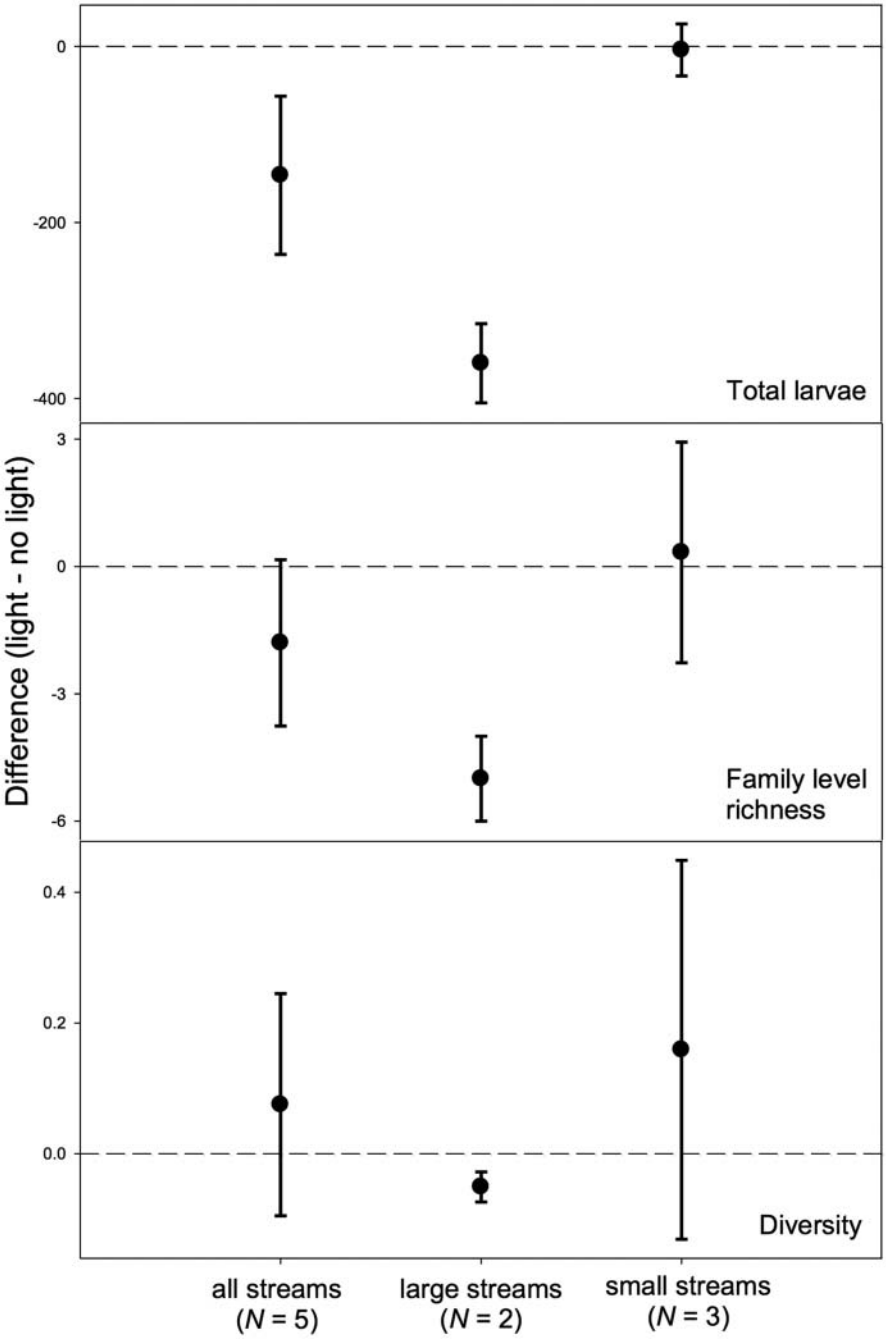

Figure 1. Mean abundance, family-level richness, and diversity ± SE across all streams and within large and small streams from November 2012 to December 2012.

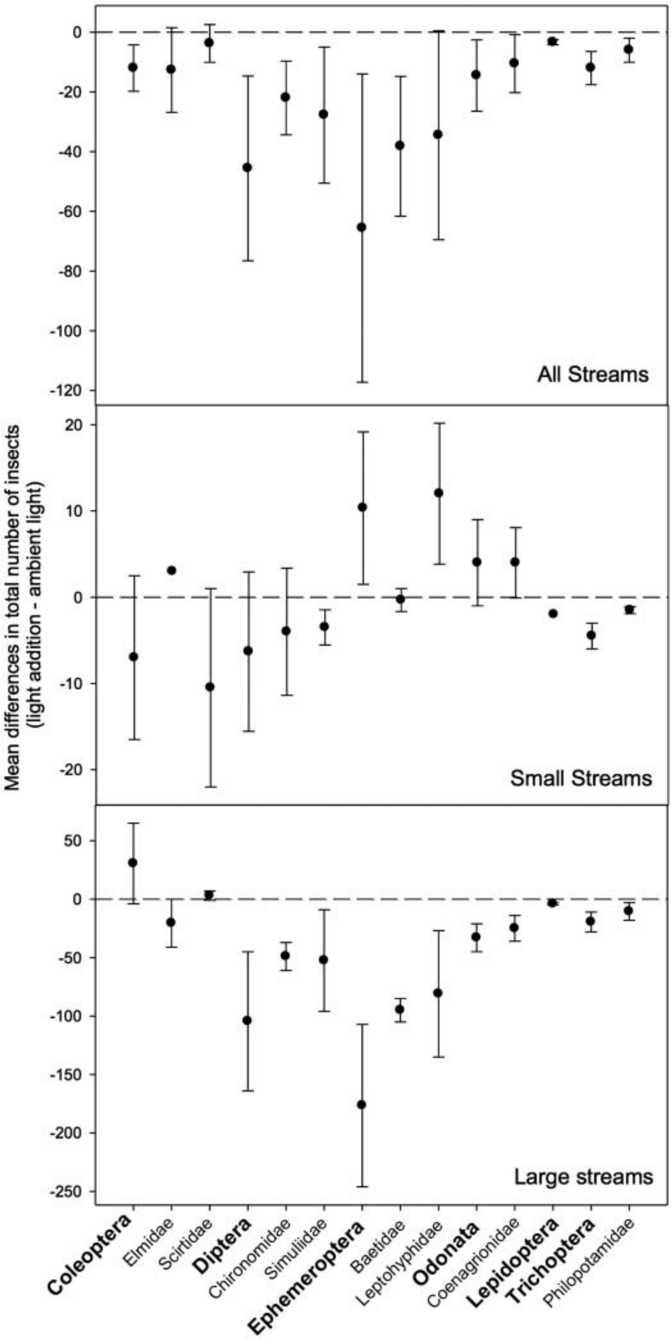

Figure 2. Mean abundance ± SE for each order and family of aquatic insects across all streams and within large and small streams from November 2012 to December 2012. Difference for Lepidoptera in small streams and Elmidae in small streams based on one number.

Table 2. Average and total biomass (mg) for Baetidae, Chironomidae, and Leptohyphidae.

	ln(M) ¼ ln(a) þ b × ln(body length)	
	a	b
Baetidae	0.0053	2.875
Chironomidae	0.0018	2.617
Leptohyphidae	0.0103	2.676

	Bull Creek		Onion Creek		Comal River		San Marcos River	
	Light	No light	Light	No light	Light	No light	Light	No light
Baetidae								
Average biomass	0.14	0.11	0.17	0.32	0.15	0.19	0.35	0.27
Total biomass	1.68	1.75	1.21	1.92	8.17	27.01	47.04	64.23
Chironomidae								
Average biomass	0.03	0.05	0.12	0.07	0.06	0.06	0.05	0.06
Total biomass	0.14	0.57	0.85	1.54	4.26	7.84	3.73	6.41
Leptohyphidae								
Average biomass	0.09	0.09	NC	NC	0.18	0.21	0.18	0.20
Total biomass	0.79	0.65	NC	NC	7.43	14.55	69.25	100.0

Note: NC ¼ none collected.

individuals per treatment, differed for Chironomidae ($p < 0.01$) among all streams and Baetidae ($p < 0.01$) and Chironomidae ($p < 0.01$) within large streams (Figure 3).

Discussion

We found evidence to partially support our prediction that larval insect drift was less under additional light treatment than ambient light but only among a few taxonomic groups in larger streams. As such, insect drift within streams of high water clarity is not necessarily more susceptible to ecological light pollution but was disrupted similarly to drift reported outside of arid and semi-arid regions (Holt & Waters 1966; Perkin et al. 2011). Effects of additional artificial light were most evident for five families (Baetidae, Chironomidae, Coenagrionidae, Leptohyphidae, and Simuliidae) within larger streams. All are reported to undergo diurnal drift (Elliott & Minshall 1968; Pearson & Franklin 1968; Brusven 1970; Steine 1972; Cloud & Stewart 1974; Casey 1987), and our findings are consistent with reported decreases in drift abundance under artificial light for Baetidae and Simuliidae (Bishop 1969; Chaston 1969). Baetids decreased from 92% (number expressed as percentage of individuals drifting in that light level versus drifting in control with complete darkness) in a low light treatment (<0.2 lx) to 5.5% in the highest light intensity treatment (8.8 lx) and Simuliids decreased from 102% to 0% (Chaston 1969). Herein, we report a 48% decrease, on average, for Baetids and a 59% decrease for Simuliidae. Also, we report for the first time light effects on three of the families – Chironomidae, Coenagrionidae, and Leptohyphidae – that all experienced a decrease in drift due to the addition of artificial light.

The prediction of decreased drift due to the addition of artificial light was not supported within the smaller stream segments of this experiment. Small streams showed little difference in total abundance and richness. Each family captured in small streams on average showed no difference between the two treatments. A possible explanation for these unexpected results is that the smaller streams were part of a more urbanized

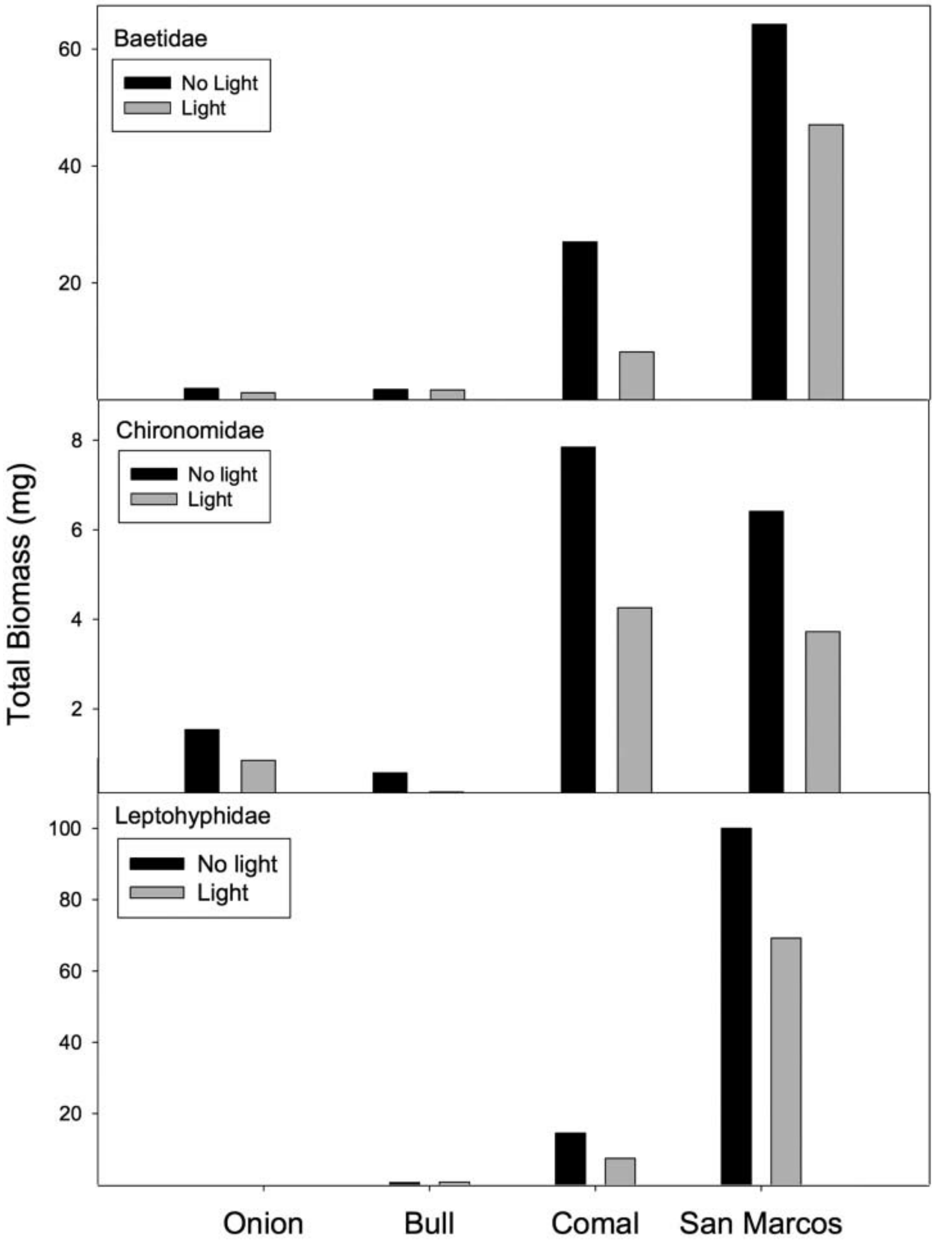

Figure 3. Total biomass (mg) for Baetidae, Chironomidae, and Leptohyphidae.

ecosystem, which can cause a simplification in the insect stream community (Morse et al. 2002; Gray 2004), potentially preselecting individuals with greater tolerance for urbanization and light tolerance. Taxa within orders Ephemeroptera, Plecoptera, and Trichoptera are considered pollution sensitive and have decreased in richness since 1996 in the lower reaches of Bull Creek (COA 2010). During this time, percentage of collectors has increased, which is often associated with streams of reduced water quality (COA 2010).

The decrease in drift shown across all streams and within larger streams has implications for community dynamics within streams and their adjacent riparian zones. Light pollution could cause insects to drop out early, disrupting drift and leading to changes in recruitment for individual species, and could simplify community composition as fewer insects make it downstream (Longcore & Rich 2004; Blakely et al. 2006; Smith et al. 2009). Since >80% of colonization movements are hypothesized to be caused by drift, any disruption due to light barriers could lead to an uneven distribution of insects within the benthic substrate (Townsend & Hildrew 1976). Urbanization, a major cause of the increase in light pollution, is also known to create subpar aquatic habitat, potentially causing drifting insects to land in areas of poor substrate (Blakely et al. 2006). Additionally, decreases in colonization due to light barriers could result in a loss of overall ecosystem productivity. Benthic invertebrates are often overlooked contributors to the aquatic ecosystem and play a key role in the aquatic trophic system (Covich et al. 1999). As stream insects are a large source of secondary productivity, an uneven distribution of drifting larval aquatic insects could result in a net loss of stream-wide productivity (Huryn & Wallace 2000).

Since many organisms operate on a circadian rhythm, ecological light pollution affects dispersal, communication, and predation among taxa, including aquatic insects, fish, terrestrial insects, bats, and migratory birds (Rydell 1992; Longcore & Rich 2004; Davies et al. 2012). Research in the area of ecological light pollution is still relatively new (Perkin et al. 2011) and there are many predictions to be tested. This experiment provides support for the hypothesis that extreme artificial light has negative effects on the abundance of drifting larval insects creating a need for conservation managers to look for ways to mitigate the effects. One possibility is the development of riparian buffer zones to decrease the amount of artificial light reaching the stream environment. Riparian buffer zones decrease the total amount and duration of light reaching a stream environment and influencing a sensitive biological process (Kiffney et al. 2004). Also, high-intensity lights have the greatest effect on insect drift (i.e., more than wavelength; Bishop 1969; Chaston 1969) and with light intensity varying by light source (Perkin et al. 2011), changes in the type of artificial lighting used (H€lker 2010, Moss, et al. 2010) could decrease the levels of light pollution. Installing low-intensity light bulbs, directing light away from the water's surface, or smart grids that turn off lights when not in use are among the possible solutions to light pollution, and already being implemented in major urban centers such as the city of Austin in central Texas. Tests on how stream communities respond to these higher efficiency lights could provide biological support to these initiatives as well as guide selection of future light efficiency measures.

This study provides specific evidence that artificial light disrupts the dispersal of larval aquatic insects in urban semi-arid streams; however, community-level implications of these changes are still to be determined. As an ideal biological indicator, benthic insects can be used to provide insight to environmental managers on the general health of an urban stream (Purcell et al. 2009). Given sufficient evidence that larval drift in urban semi-arid Texas streams decreases with light pollution, further studies could assess artificial light effects on larval insects with the addition of other urban stressors as urban streams can be difficult to restore with the numerous stressors at play (Purcell et al. 2009). However, it may be important to utilize larger and healthier stream environments in future studies, as treatment effects could be difficult to obtain within overly simplified communities of small urban streams. Future research will be necessary to determine how best to mitigate these effects and whether investments in mitigation have tangible environmental benefits.

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