SEASONAL AND LONGITUDINAL INVESTIGATION ON THE IMPACTS OF RECREATIONAL ACTIVITIES ON THE AQUATIC MACROINVERTEBRATE COMMUNITY WITHIN THE SAN MARCOS RIVER

by

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DEDICATION

I dedicate this paper to my late dad, Mr. A. J. Agare, my late sister Mrs. Yemisi Agare Aiyenuyo. Both of them were instrumental to my studying at Texas State University and their impact on my life was astronomic without mincing words. To the both of you I know we will meet again someday and I hope I have been able to make you happy wherever you are by completing this study. I also dedicate this paper to my late brother Mr. Femi Agare, you all continue to rest God's bosom. I wish you were here to witness this.

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TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

Figure **Page**

ABSTRACT

In the San Marcos River, recreational activities are most pronounced between April and October. Given the continued urbanization and increasing population in San Marcos there is need for a quantitative study on the possible effect of elevated recreational activities on the aquatic macroinvertebrates within the river. Furthermore, currently, there has been no study which quantified patterns in macroinvertebrate drift and benthic community structure simultaneously in the San Marcos River. Information on drift patterns and benthic macroinvertebrate habitat relationships is necessary to understand mechanisms for species persistence within the San Marcos River. In this study, I examined the seasonal and longitudinal patterns of benthic macroinvertebrate community composition at three different sites within the San Marcos River. I also examined the seasonal and longitudinal response of the drifting aquatic macroinvertebrates to changes in their habitat as a result of recreational activities in the San Marcos River. Tubing and swimming accounted for most of the recreation activity (>90%). Across all seasons, the upstream most study site had the highest drift densities compared to two downstream study sites. Canonical Correspondence Analysis (CCA) results explained 15.3% of the variability in the San Marcos River benthic macroinvertebrate community among vegetated habitats and 23.9% among open substrate habitats. Study results indicated that drift is related to benthic abundance. Macroinvertebrate drift densities followed the typical circadian pattern observed in other river systems and results indicated no increase in macroinvertebrate drift density during the peak recreation period. Conclusively, study results indicated that macroinvertebrates at the two upstream sites were not impacted by recreation and turbidity. However, the lower most study site, based on the CCA results indicate that substrate and turbidity are factors influencing the macroinvertebrate community.

I. SEASONAL AND LONGITUDINAL INVESTIGATION OF THE IMPACTS OF RECREATIONAL ACTIVITIES ON THE AQUATIC MACROINVERTEBRATE COMMUNITY WITHIN THE SAN MARCOS RIVER

INTRODUCTION

Aquatic macroinvertebrates are a key component of secondary production in aquatic habitats as they serve as food for other aquatic animals higher in the food chain. Aquatic macroinvertebrates are the most widely used organisms in river biomonitoring and are good bioindicators of stream health (Kenney et al. 2009) due to a variety of reasons such as: (i) their richness, which responds to environmental stressors (ii) their limited mobility, which aids spatial analysis of pollution effects (iii) the ability of certain species to drift, which may indicate the presence of a pollutant (iv) their availability, which can be used to trace pollution effects over longer periods (v) their abundance which can be assessed with inexpensive sampling protocols and (vi) their sensitivities, which have been established for different types of pollution (Metcalfe, 1989; Barbour *et al*. 1999; Bonada *et al.* 2006).

Macroinvertebrates are known to impact nutrient cycles, primary productivity, and material translocation (Wallace and Webster, 1996). One major factor that can affect macroinvertebrates is the pollution of their environment. Pollution of macroinvertebrate habitat can arise from human activities such as agriculture, urbanization, and recreation. Apparent effects of pollution on stream invertebrates can include altered assemblage composition, reduced richness, reduction in the density of sensitive species, and an overall reduction in functional diversity (Larsen and Ormerod 2010). Waters (1972), reported that pollution of a river could result in a catastrophic drift of macroinvertebrates. The persistent disturbance of a river substrate leading to resuspension of sediment, the release of biological organisms such as algae, and leachates from plants into the river's water column are major concerns for the macroinvertebrate community as these disturbances can cause an increase in river turbidity. Prolonged persistent increases in the turbidity of a river can cause increased macroinvertebrate drift, degradation of the food quality, and shifts in habitat use. It may also affect gill functions of aquatic animals (Rosenberg and Wiens, 1978; Culp et al., 1985; Suren and Jowett, 2001; Conner and Lake, 1994). Furthermore, persistent substrate disturbance may also result in the introduction of phosphorous into the water column. Phosphorous is often a limiting nutrient that influences algal blooms in aquatic ecosystems. Algal blooms are known to cause a reduction in photo-synthetically available radiation (PAR) which can affect the abundance of submerged aquatic plant biomass (Blinn and Cole, 1991; Davies-Colley et al., 1992; Holopainen and Huttunen, 1992; Blinn et al., 1992; Lenhart et al 2009; Bishop and Hynes 1969; Forrester 1994). The reduction in abundance of these submerged aquatic plants may affect the abundance of benthic macroinvertebrates as they rely on these plants for feeding and habitat.

Moore and Palmer (2005), found that the composition and distribution of benthic macroinvertebrates can be influenced by their habitat and environmental gradients associated with their habitat. Other factors that can also influence macroinvertebrates distribution and composition are food resources, stream velocity, and substrate type (Palmer et al. 2000). Statzner, Dejoux, and Elourad (1984) indicated that benthic macroinvertebrate density is the main biotic factor that influences drift. Furthermore, Waters (1972) stated that a ‘drift fauna’ does not necessary exist, as most drifting insects originate from the benthic assemblage.

Drift in a river system is the passive or impassive movements of macroinvertebrates within the water column. Most studies on stream drift have focused on the underlying biotic and abiotic processes involved in drift leading to suggestions that drift studies should also be used as a standard component of bioassessments because it compliments information obtained from traditional benthic macroinvertebrate sampling. Drift also provides insights into the macroinvertebrate dynamics within a river system, and it is a useful method of assessing benthic macroinvertebrate composition (Pringle and Ramirez 1998). Drift studies have shown that macroinvertebrates display distinct circadian patterns (Ramirez et al. 2001; Bishop 1969). Various reasons given for this pattern are that (i) macroinvertebrates tend to avoid benthic predators (Peckarsky, 1980), (ii) sedimentation (Culp et al. 1986), and (iii) flow dynamics (Poff and Ward, 1991).
In the San Marcos River, recreational activities are highest between April and October with peaks during the summer months. Earl et al. (2002) found that elevated concentrations of suspended sediments during the peak summer recreation periods have the potential to negatively impact the aquatic macroinvertebrate community. Preliminary data on turbidity and seasonal recreation use show a strong relationship between recreation intensity and suspended sediment concentrations in the San Marcos River (EARIP 2010). Several studies (e.g. Ward et al. 1982; Ormerod et al. 2010; Sheyla et al. 2011) have documented the effects of suspended sediments on stream ecosystems. Additionally, studies found a correlation between physical disturbances of the bottom substrate, sedimentation, or pollution and catastrophic drift (e.g. Waters 1972; Matthaei

et al. 1997). Although, in the San Marcos River, recreational motor boating is not allowed, studies looking at the effects of recreation on stream ecosystems (e.g. Hilton and Phillips 1982; Mosisch et al. 1998; Nedohin et al. (1997); Garad and Hey 1987; Anthony and John 2003) linked recreational motor boating activities to macroinvertebrate drift which occurred as a result of substrate disturbances from motorboat vibrations.

For the San Marcos River, there has been no known quantitative study on the direct or indirect impact of recreation based suspension of fine sediment on macroinvertebrates (EARIP 2010). Given the continued urbanization and increasing potential for water borne population in the San Marcos River and the problems associated with suspended sediment described above, there is need for a quantitative study on the possible effect of elevated recreational activities on the aquatic macroinvertebrates within the river. The purpose of this study was to examine aspects of the macroinvertebrate community within the San Marcos River and to see if patterns of drift and benthic composition are affected by seasonal recreational activities in the river.

Currently, no study has quantified both patterns in macroinvertebrate drift and benthic community structure simultaneously in the San Marcos River. Furthermore, studies looking at the effect of recreation on stream systems have mainly focused on mechanized recreational activities (e.g. motor boat) and angling. There seems to be a dearth of studies looking at contact recreation activities such as swimming, tubing, and kayaking, and their influences on macroinvertebrate community within a river system. Information on drift patterns and benthic macroinvertebrate habitat relationships is necessary to understand mechanisms for species persistence within the San Marcos River.

In this study, I examined the seasonal and longitudinal patterns of benthic macroinvertebrate community composition at three different sites within the San Marcos River. I also examined the seasonal and longitudinal response of the drifting aquatic macroinvertebrates to changes in their habitat as a result of high recreational activities in the San Marcos River. My hypothesis is that turbidity caused by human induced suspended sediments from recreational activities will negatively affect the diversity and abundance of aquatic macroinvertebrates seasonally and longitudinally in the San Marcos River. I also hypothesized that there would be seasonal and longitudinal variation in macroinvertebrate composition within the San Marcos River. Inferences drawn from these investigations will be important in determining possible implications of recreation based suspended sediments on the macroinvertebrates community within the San Marcos River. Information from this study may be very useful in making informed management policies that will aid in maintaining and keeping the San Marcos River healthy. Also, there will be useful information to update the database of known macroinvertebrate species in the San Marcos River.

MATERIALS AND METHODS

Site description

The San Marcos River originates from artesian springs and is the second largest spring system in Texas. It has high water quality in its headwaters but becomes more turbid as it flows downstream (Groeger et al 1997). River width ranges from 5m to 15 m (Lemke, 1989). Water temperature is relatively consistent at around 22°C (Hannan and Dorris, 1970). The San Marcos River provides habitat for two federally listed endangered species which are (Fountain Darter – *Etheostoma fonticola* and Texas Wild-rice – *Zizania texana and* the threatened San Marcos salamander – *Eurycea nana*;). The San Marcos River has a diverse macroinvertebrate community (Diaz et al 2012) that has been attributed to the Edwards Aquifer which is one of the most productive, and biologically diverse karst spring systems in Texas (Marshall 1946, and Odum 1957). The upper San Marcos River is about 7.5 km long and is aesthetically important and provides a large number of tourism and recreational benefits to residents and visitors. According to Earl et. al (2002), the San Marcos River had about 500,000 visitors engaged in water related recreational activities. Heavy recreational activities, land use, septic tank discharge, storm water run-off, non-source point pollution, bank erosion, and the spread of invasive species are the major concerns facing the river.

This study was conducted at three locations on the upper San Marcos River: Site 1- Upper Sewell Park, Site 2- City Park and Site 3- Ramon Lucio Pak (Figure 1). Study sites represent a longitudinal gradient of increasing turbidity associated with recreational activities within the San Marcos River.

Drift Sampling

Drift samples were conducted once per season (See Table 7) over a 24h period at each study site. Drift nets (0.45 x 0.25 m, 500 µm) were placed across a horizontal transect at each site on spots that were equidistant from each other. Nets were held in place by two metal rods on each side of the nets. Nets were serviced every 2 hours (Neale et al. 2008) or sooner whenever debris buildup affected sampling efficiency. Drift nets were placed in locations of similar stream velocity to minimize the effect of stream velocity on drift density (Shearer et al 2002; Neale et al. 2008). Drift nets were placed above the substratum, to prevent crawling animals from entering nets (Brewin et al. 1994). Water quality parameters such as temperature (°C), dissolved oxygen (DO; mg /l^{-1}), and specific conductivity (µS / cm-1) were measured using YSI-Model 85, and pH was measured using the pH meter before each drift and benthic sampling event at each site. Current velocity (m/s) was measured with a March-McBirney FLOW-MATE™ model 2000 flow meter and depth was measured with the flow meter rod. After each sampling period, collected macroinvertebrates were preserved in 95% ethanol.

Benthic Sampling

Benthic samples were collected once per season (See table 7) at each study site within the San Marcos River. Twenty samples were collected from each study site proportionally allocated by habitat availability. Sampling was conducted using a proportional sampling method based on the three most abundant vegetation types and open substrate present during each sampling season. This method involved collecting a greater number of samples from the habitat type with the highest percentage area in each study site. Locations within specific habitat types were derived by random selection of points within either substrate and/or vegetation types. A minimum of three replicates were collected from each selected vegetation type available in each of the study sites. Vegetation maps (See Figure 2) which served as a basis to select replicates of each available vegetation types within the different study sites were produced in the week prior to each sampling event. Benthic sampling was accomplished by placing 0.25m^2 quadrats in the selected locations within the river (Diaz et al 2012). A 0.25 m x 0.25 m drift net (500-µm mesh) was then placed at the downstream side of the quadrat for collection of macroinvertebrates. Substrate or aquatic vegetation in each quadrat was agitated for approximately 30 seconds to dislodge macroinvertebrates. For each site, dominant substrate particles (silt, sand, cobble, detritus, and gravel) were visually estimated according to Wentworth grain-size classification (Wentworth, 1922). Macroinvertebrates were preserved in 95% ethanol. Macroinvertebrate identification was made to the lowest practical taxonomic level, which varied by family based on Cummings et al. (1985, 2008), Pete Diaz (2013), and TCEQ (2014). Sorted samples were archived in glass vials with polyseal caps and 95% ethanol. Macroinvertebrates were categorized by functional feeding groups (FFG): scrapers, collector-gatherers, filtering collectors, predators, and shredders based Cummins et. al (1985, 2008) and TCEQ (2014).

Recreation Counts

Plot-Watcher Pro game cameras were placed at three locations on the upper San Marcos River identified as high recreational areas. Areas were identified as prime recreation areas based on river accessibility as well as known entry/pull out points for tubers and kayakers. Cameras were placed facing the river allowing for the widest view possible. Two cameras were placed in Sewell Park on Texas State University Property, one at City Park, and one at Rio Vista Park. Each camera was programmed to capture images once an hour for nine hours a day (dusk to dawn) and images were downloaded once per month. Each picture was reviewed and only individuals in contact with the river were counted. Individuals along the bank were not included in the counts. Recreation was divided into categories: tubing, vessel (kayaking, canoeing, etc.), swimming, anglers, and dogs. Camera images at the City Park location from September 2013 – June 2014 were used to assess recreation because it was the most complete period of record. Images were collected through 2015 but due to several unforeseen factors, (e.g., freezing temperatures, flooding, sun glare, camera and battery malfunction, insect nest building on camera lens) images were not captured sufficiently to document recreation activities.

Statistical Analysis

Relative abundance of both benthic and drifting macroinvertebrates were calculated for each site and for each season. Taxa richness was calculated for benthic and drifting macroinvertebrates for all sites and seasons. The Shannon- Weiner index, which is a measure of the macroinvertebrate diversity within each site, was also calculated for all sites and seasons. Drift density was calculated for all sites and seasons. Renkonen similarity index was calculated to assess differences in the benthic macroinvertebrate community among sites. Principal component analysis (PCA; Canoco 4.5, Microcomputer Power 2002) was used to examine variation in habitat characteristics within and among sites. Environmental data were *z*-score transformed for PCA and qualitative data (i.e., site and season) were denoted as dummy variables in CCA. Quantitative data were *z*-transformed whereas qualitative data were denoted as dummy variables. Water quality parameters such as temperature, conductivity, turbidity, and pH were excluded from PCA analysis to improve discrimination between vegetation and substrate given that the range in values was relatively among all sites and for all seasons. The resulting PCA loadings were plotted to assess habitat variability among and within sites. Canonical Correspondence Analysis was used to assess environmental gradients and their relation to the benthic macroinvertebrates community. Two separate CCA analyses were performed for vegetation and substrate samples to identify the unique contributions of vegetation separate from the substrate. Care was taken to minimize substrate disturbance when sampling vegetation in an effort to reduce 'mixed' sampling in vegetation versus substrate. Relative abundance of functional feeding group (FFG) was calculated among drift and benthic samples for all sites and seasons. Spearman's rank correlation coefficient was calculated with R core team (2013) statistical software to access the relationship between benthic and drift macroinvertebrates across all three sites for all seasons.

Drift density was calculated with the following equation (Hauer and Lamberti 2011):

Drift density = $[(N)(100)]/[(t)(W)(H)(V)(3600\text{s/h})] = N/100^3\text{m}$

Where N = number of macroinvertebrates per sample; t = time; W = width of net (m); H = net height (m); and V = water velocity at the net opening (m/s).

RESULTS

Macroinvertebrate community

Drift

A total of 135,902 macroinvertebrates representing 73 taxa were collected as drift from 480 samples (Table 1). Across all seasons, amphipods 51.85%, stout crawler mayflies 28.03%, and small minnow mayflies 9.58% were the most abundant in the drift. The winter season experienced the lowest amount of drifting individuals with an overall total of 5828 individuals (Table 1) whereas, the fall season recorded the highest number of drifting individuals 56,966 (Table 1). Relative abundance of drifting *Baetidae* increased from spring through winter. The spring season was 7%, increased to 8% in the summer, 11% in the fall, and then 15% in the winter. With a relative abundance of 34%, the spring season had the highest amount of *Leptohyphidae* whereas, the summer, fall, and, winter season had relative abundances of 18%, 31%, and 32% respectively (Table 1). The summer period had the highest amount of *Hyalellidae* with 63%, with the spring, fall, and winter having 49%, 47%, and 24% respectively. Shannon-Weiner diversity (H') for the drift across all seasons varied between 1.27 – 2.03. Winter had the highest diversity (2.03) whereas (1.27) had the lowest diversity (Table 1). Overall, the Shannon-Weiner drift diversity was 1.44 (Table 1). Site 1 had the highest number of drifting macroinvertebrates (77,792), followed by Site 2 (31,723), and Site 3 (24,973) (Table 2). Among season, *Hyalellidae* had the greatest relative abundance at 52% followed by *Leptohyphidae* (28%), *Beatidae* (10%), *Chironomidae* (4%), and *Petrophila* (1%). *Hyalellidae* was most abundant taxa at Site 1 with a relative abundance of 69% but decreased in abundance downstream with a relative abundance of 41% at Site 2 and 13% at Site 3. *Leptohyphidae* increased in relative abundance downstream with an abundance of 17% at Site 1, 31% at Site 2 and 59% at Site 3. The greatest relative abundance (16%) of *Baetidae* was at Site 2 with abundances of 6% at Site 1 and 12% at Site 3. *Hyalellidae* was most abundant during the summer with a relative abundance of 64% with relative abundances of 49%, 48% and 25% for spring, fall and winter respectively. *Leptohyphidae* relative abundance was highest in the spring at 34% with relative abundances of 18%, 31% and 32% for summer, fall and winter, respectively. *Baetidae* had the highest relative abundance in winter at 16% with relative abundances of 7%, 8% and 11% for spring, summer and fall, respectively. *Chrironomidae* showed an increase in relative abundance in winter (12%) with the lowest in spring at 2%. Across all seasons, Site 1 had the highest drift densities compared to Site 2 and Site 3 (Figure 3). Highest drift densities occurred at Site 1 during the summer and fall between 2000 and 2300 hours. Drift densities at Sites 2 and 3 were relatively low compared to Site 1. Among all sites, drift rates were higher during hours of darkness and lowest during mid-day hours. Winter drift densities was lowest among seasons at all sites.

Benthic

Across all sites and seasons, a total of 39,371 macroinvertebrates representing 62 taxa were obtained from 240 benthic samples. *Hyalella azteca* 46%, *Baetidae* 20%, and *Leptohyphidae* 11%, and *Chironomidae* (7%) accounted for the macroinvertebrates with the highest relative abundance. The fall season had the highest number of individuals 16,070. In contrast, the winter season had the lowest amount of benthic macroinvertebrates collected with 4,002 individuals (Table 3). Taxa richness was highest at Site 1 (55) followed by Site 2 (50), and then Site 3 (49) (Table 4). Shannon-Weiner diversity was highest at Site 3 (2.38) and lowest at Site 1 (1.50). Renkonen similarity index for the three sites ranged between 0.53 – 0.78 with the greatest similarity between Site 1 and Site 2 (0.78) whereas it was lowest between Site 1 and Site 3 (0.53). Results of Spearman Rank correlation analysis showed a positive correlation between benthic and drift macroinvertebrates. Correlation results ranged from 0.8 to 1.0 across all sites and for all seasons (Table 6). Principal component analysis results are shown in Figure 5. Principal components axis 1 and 2 explained 28.17% of the variation in habitat measurements taken among 240 benthic samples.

Habitat and season effects

CCA axes 1 and 2 explained 15.3% of the variability in the San Marcos River benthic macroinvertebrate community among vegetation habitats (Figure 6). Physical parameters and season strongly associated with CCA axis 1 were Fall (0.81), Texas wild-rice (TWR) (-0.50), gravel (-0.49), Hydrocotyle. (0.47), and current velocity (-0.43). Physical parameters strongly associated with CCA axis 2 were gravel (0.57), current velocity (0.51) Hydrocotyle. (0.44), sand (-0.39), and Hygrophila (-0.34). Among macroinvertebrate species associated with CCA axes 1 and 2, *Ostracods, Nectopsyche*, and *Petrophila* were more abundant in fall among several vegetation types (Hydrocotyle, Potamogeton, and Sagittaria) over cobble substrate. *Hirudinea, Decapoda, Crambidae, Hydroptila*, Shrimp, *Hydrachnidae*, and *Zygoptera* were most abundant at Site 2 in *Hygrophila* over fine substrates. *Helicopsychidae, Thiaridae, Simulidae*, and *Limnocoris* were found most often in vegetation over gravel substrates in higher current velocities. *Hyalella spp., Chironomidae, Leptohyphidae*, and *Baetidae* were common among all available habitats. Other species such as *Baetodes, Glossosomatidae, Hemerodromia, Hydropsychidae* were more abundant in spring and summer within TWR over gravel substrates. Species more common at Site 1 in areas of greater depth within *Potamogeton* were *Philopotamidae, Platyhelmenthes, Mesogastropoda, Elmidae, Anisoptera spp.*, and *Cladocera.*

Invertebrate – Benthic Substrate Association

CCA axes 1 and 2 (Figure 7) explained 23.9% of the variability in the San Marcos River benthic macroinvertebrate community among open substrate habitats. Physical parameters, water quality, and site strongly associated with CCA axis 1 were Site 3 (0.71), turbidity (0.62), Site 1 (-0.52), current velocity (0.34), and silt (-0.29). Physical parameters and season strongly associated with CCA axis 2 were Spring (0.72), current velocity (-0.51), cobble (-0.44), Fall (-0.42), and sand (0.28). Among macroinvertebrate species associated with CCA 1 and 2, *Limnocoris, Ambrysus, Leptophlebiidae, Hydropsychidae, Philopotamidae, Nectopsyche, Glossosomatidae,* and *Elmidae* were more abundant during fall and winter in areas of higher current velocities over cobble substrates. *Helicopsychidae* and *Hirudinea* were more abundant in spring over gravel substrates. *Petrophila, Zygoptera, Anisoptera, Baetidae, Oxyethira,* and *Hemerodromia* were more common at Site 2 during fall over cobble substrates. *Corbicula, Thiaridae*, and *Mesogastropoda, Simulidae,* and *Bivalvia* were most abundant during spring. *Chironomidae, Annelids, Hyalella spp.*, *Platyhelmenthe*s, and *Leptohyphidae* were common among all available habitats and seasons.

Functional Feeding Groups (FFG)

Collector gatherers accounted for most of the composition of the FFG for all sites and seasons except for Site 3 in the spring season which was dominated by scrapers (Figure 4). In contrast, filtering collectors which were rare overall across all sites and seasons and it had the lowest relative abundance of all FFG. Benthic predators were relatively abundant compared to drifting predators overall especially during the fall and winter season. For example, benthic predators for Site 3 of the fall season had a relative abundance of 20% whereas drift predators had a relative abundance of 10% (Figure 4). Relative abundance of scrapers was highest in the benthos in the spring season (55%). Relative abundance for shredders decreased from upstream to downstream across all seasons (Figure 4). Drifting collector-gatherers collected amounted to 61% of the relative abundance, shredders were 26%, scrapers 8%, predators 3%, and filterer feeders the least with 0.5%. Relative abundance for benthic collector-gatherers was lower compared to drifting collector gatherers with 50%, benthic shredders at 23% was also lower than drifting shredders. In contrast, benthic scrapers, predators, and filterer feeders were all higher than their drifting counterparts with 17%, 6%, and 1.6% respectively.

Recreation counts

Figure 8 illustrates the total number of individuals per recreation type among the four seasons: Fall (Sept 2013), Winter (December 2013), Spring (April 2014), and Summer (June 2014). Across all seasons, tubing and swimming accounted for most of the recreation activity. In summer (June 2014), swimming and tubing individuals were estimated at 5,810 and fall was second highest with 1,284 individuals followed close by spring with 1,109 individuals. Figure 9 illustrates the average number of recreationist per weekday among seasons. Among all weekdays, recreation numbers were highest in summer (June 2014) with spikes in the number of people observed during Saturday and Sunday. Weekday recreation numbers were similar for fall and spring and very little recreation activity was observed during winter.

General habitat characteristics

Sites 1and 2 are characterized by a large proportion of the endangered Texas wild-rice (TWR) (*Zizania texana*), cobbles, sand, gravels and submerged aquatic macrophytes with some of the most abundant vegetation types varying with season. Site 3 is mainly cobbles, gravels, silt, and sand. Aquatic vegetation for Site 3 is low compared to Sites 1 and 2. Recreational activities like tubing, swimming, snorkeling, diving and kayaking are common to all sites during the recreation season of April to October, however, variation exist in recreation intensity among sites. The mean and range of measured physical parameters for each site are noted in Table 5. Water quality parameters were consistent among sites, except for turbidity, which was slightly higher at Site 3 (0.71 NTU) than Site 2 (0.29) or Site 1 (0.11). Measured depth and current velocities were similar among all sites with slightly higher current velocities at Site 1 and Site 3. Principal component axis 1 explained 16.53% whereas principal component axis 2 explained 11.64%. Strongest loadings on PC 1 were velocity (0.65), vegetation cover (-0.63), gravel (0.62), Hygrophila (-0.54), and silt (-0.54). Strongest loadings on PC 2 were cobble (0.63), vegetation cover (0.62), TWR (0.54), silt (-0.39), and Potamogeton (0.32).

DISCUSSION

The objectives of this study were to assess the seasonal and longitudinal dynamics of benthic composition and macroinvertebrate drift within the San Marcos River and to determine whether they are impacted by recreational activities. When it comes to the effect that recreational activities have on river systems, studies (e.g. Hilton and Philips (1982); Garad and Hey (1987) have mainly focused on motorized recreational activities (e.g. Motor boating) and angling. There seems to be no quantitative study focused on contact recreation activities (e.g. swimming, tubing) and their influences on stream turbidity and how anthropogenic induced turbidity from contact recreation can influence macroinvertebrate drift. Previous studies (e.g. Waters, (1972); and Statzner, Dejoux, and Elourad (1984) that have looked at macroinvertebrate benthic-drift trend within a river system had indicated a correlation between benthic and drift macroinvertebrate. The findings from these studies suggest that macroinvertebrate drift fauna primarily originates from the benthic assemblage and that benthic macroinvertebrate density is the major biotic factor that influences drift. Results of the macroinvertebrate benthic-drift trend for this study showed that drift may is related to benthic abundance as indicated by Waters (1972), and Statzner, Dejoux, and Elourad (1984). This trend was also visible in the result of the Functional Feeding Groups which showed a strong positive correlation between benthic and drifting macroinvertebrates.

Seasonal, Temporal and Longitudinal Variation

Macroinvertebrate drift densities followed the typical circadian pattern observed in other river systems and result indicated no increase in macroinvertebrate drift density during the day when recreation is occurring. According to Lancaster et al. (1996), drifting macroinvertebrates travel a distance of about 2 to 10 m during low flows. In addition, Townsend and Hildrew (1976) reported that even when substrate was disturbed, macroinvertebrates did not drift for long distance. Drift distance may therefore be a reason why there was no increase in the drift density during the day as sample collection points were ~ 100m downstream of recreation access points where bed disturbance occurs. Other factors could be that bed disturbance is localized primarily at these specific spatial locations such as at a tube rental vendor location and City of San Marcos-managed river access points. These areas are quickly denuded of aquatic vegetation early in the recreation season and remain so until aquatic vegetation recovery occurs during the fall and winter when river access dramatically drops (EAHCP biological monitoring data between 2000 and 2015). This may also reflect that drift had settled out upstream of our study sites. Other forms of contact recreation, such as kayaking and tubing do not typically disturb the river bed outside of direct access areas unless in shallow stream margins or low flows. During this study, the San Marcos River remained much higher than the long-term median flow (~ 7cms compared to ~ 5cms). Measured turbidity levels appear to be low enough as to initiate a drifting response and may in part be related to the small grain size suspended sediment (silt like) that remains entrained in the water column at relatively low velocities. Depositional areas are typically associated with lateral stream margins or in backwater areas upstream of low head dams in the system.

Overall, drift abundance was higher in the summer and fall season when recreational activities are usually high and intense in the San Marcos River. This might be related to stream productivity, high temperature and macroinvertebrate reproduction during summer and fall seasons. Drift densities in winter were lowest among all sites and is attributed to either seasonal emergence patterns and/or influenced by a large flood/scouring event that occurred only six weeks prior to the sampling event.

Functional Feeding Groups

Functional feeding groups in the drift reflect macroinvertebrates available in the benthos over all sampling periods and study sites. Overall community composition in terms of functional feeding groups was similar to results reported by Fries and Bowles (2002) for the San Marcos River collected ~ 2 km below our lowest sampling station at Ramon Lucio Park. Longitudinal analysis of functional feeding groups depicted changes in the relative abundance of some groups and not in others. According to Owen (1996), the headwater of the San Marcos River is autotrophic and mostly dominated by collector-gatherers and scrapers whereas the downstream section is more heterotrophic and dominated by collector-gatherers and filtering-collectors. This was also reflected in the result of this study. Seasonal changes in the shredder community was not evident. Shredder communities in the San Marcos River was dominated by *Hyalella azteca*

H. azteca as the dominant shredder taxa in the headwaters of the San Marcos River (i.e. Site 1) may be misleading because most of them appear to be transported into the river from Spring Lake following aquatic vegetation harvesting operations. Owens (1996) also indicated an overestimation of the shredder community in the headwaters of the San Marcos River. Relative abundance of scrapers shows a dominant benthic scraper community in the spring season especially in Site 3 which is farther away from the headwaters, however, their abundance was reduced during the other 3 seasons. The increase in anthropogenic activities on and around the river may have contributed to the decreasing population of the scraper communities in the headwaters since scrapers are sensitive to urban influences. Collector gatherers, mostly contributed by *H. azteca* were the most dominant macroinvertebrate for all sites and season and comprised 45% to 70% of the relative abundance. The longitudinal pattern in the drift showed that the relative abundance of collector- gatherers increased away from the headwaters except in the winter season where the reverse was the case. This may be an indication that collector-gatherers downstream depend mostly on the downstream transport of fine particulate organic matter (FPOM) for their food (Cummins and Klug 1979). Filtering-collectors were very low in all sites and across seasons in both the benthic and drift macroinvertebrates. *Simulidae* was the dominant filterer across all sites. Predators had a higher benthic assemblage in Site 3 for all seasons than in Site 1 which is closest to the headwaters of the San Marcos River. The reason for the higher abundance downstream may be attributed to changes in habitat characteristics. This pattern was not evident in the relative abundance of predator drift.

Taxonomic diversity, habitat diversity and similarity patterns

Comparison of the benthic composition for all three sites showed that taxonomic diversity ranged from 1.50 to 2.38 and taxonomic richness ranged from 49 to 55 taxa. Whereas Site 1 had more taxa richness, results of the Shannon-Weiner diversity indicated that Site 3 with a lesser taxa richness compared to Site 1, was the most diverse of the three sites across all seasons. This may be attributed to the relative abundance of a few taxa (e.g. *H. azteca*) that were very dominant in Site 1 and less so at Site 3. Overall taxonomic richness of the drift composition ranged from 60 to 65 taxa with Site 3 having the most richness and Site 2 with a lower taxa richness while being the most diverse. Study results indicate that the macroinvertebrate benthos and drift at Site 1 are not impacted by recreation or turbidity as would be expected given its location immediately below Spring Lake Dam and associated with a protected designation as a State Scientific Area that limits direct contact recreation. This was reflected in the results of measured turbidity and recreation counts. Site 2 appears to show very little impact associated with recreation induced turbidities on a seasonal basis and maintains a robust aquatic vegetation community that supports the aquatic macroinvertebrates both in the benthos and drift. However, Site 3, based on the CCA results indicate that substrate and turbidity are factors influencing the macroinvertebrate community. This area lies downstream of the Rio Vista Dam (kayak park) that was constructed in 2006. Vegetation and substrate monitoring during the period from 2000 to the present (Bio-West 2016) in this reach of the San Marcos River has documented both channel changes (depth decreases) and the aquatic vegetation in this reach has dramatically declined from pre-dam construction periods. Loss of aquatic vegetation obviously has a direct impact to the macroinvertebrates.

Although, there was variation in the abundance of drifting macroinvertebrate with the fall and summer seasons recording the highest drift density abundances, this study did not find any correlation between recreation induced turbidity and macroinvertebrate drift during high periods of recreation activities. Habitat associations of macroinvertebrates were similar to what was previously observed by Diaz et al. (2015) and Fries and Bowles (2002). In addition, functional feeding groups in the drift reflect macroinvertebrates available in the benthos over all sampling periods and study sites. Overall community composition in terms of functional feeding groups was similar to results reported by Fries and Bowles (2002) for the San Marcos River ~ 2 km below the lowest sampling station at Ramon Lucio. Study results documented a diverse and dense macroinvertebrate community in both the benthos for a variety of aquatic vegetation types and previously undocumented characteristics within Texas wild-rice stands. This is important given that the EAHCP is targeting non-native vegetation removal and planting of native aquatic vegetation specifically to meet target densities of the endangered fountain darter (*Etheostoma fonticola*) derived from species specific vegetation-darter densities. The aquatic vegetation restoration effort is also targeting increased areas of Texas wild-rice. We had previously documented Texas-wild rice use by the endangered fountain darter and the results of this study documents the presence of key macroinvertebrate species (e.g. *Hyalellidae*) that are important components of the fountain darter diet.

Given the high river utilization at river access points that occurs during peak recreation weekends in the San Marcos River, we sampled downstream to avoid contact recreation conflicts and safety and this likely impacted the ability to detect proximal spatial effects. This may be one factor why recreation induced drift was not detected. Future studies should look at samples closer to recreation access points and during weekends of high recreational activities. I also recommend more drift studies to be done in other to better understand the impact that recreational activities may have on the macroinvertebrate community of the San Marcos River within these recreational access locations.

TABLES AND FIGURES

Table 1. Relative abundance by taxa (%), total N, taxa richness, and Shannon-Weiner Diversity (*H'*) for drifting macroinvertebrates collected across all seasons from the San Marcos River (April 2015 – December 2015).

Taxa	Spring	Summer	Fall	Winter	Total	Taxa	Spring	Summer	Fall	Winter	Total
Baetidae	7.00	8.02	11.51	15.77	9.58	*Petrophila*	0.78	2.38	0.85	1.24	1.31
Baetodes	0.39	0.21	0.21	0.39	0.26	*Dytiscidae*	-	0.02	<0.01	0.05	0.01
Caenidae	0.01	0.08	0.03	0.67	0.06	*Elmidae*	0.13	0.16	0.04	0.91	0.13
Heptageniidae	-	0.08	0.01	-	0.03	*Hydrophilidae*	-	0.01	0.01	0.03	0.01
Ephemeridae	0.03	0.1	-	0.03	0.04	*Haliplidae*	<0.01	<0.01	<0.01	<0.01	<0.01
Leptohyphidae	34.32	18.09	31.12	32.48	28.03	*Phanocerus*	0.17	0.07	0.19	0.55	0.16
Leptophlebiidae	0.09	0.04	0.06	0.22	0.07	*Psephenidae*	-	0.01	<0.01	0.03	<0.01
Anisoptera	0.01	0.04	0.54	0.12	0.25	*Ceratopogonidae*	<0.01	<0.01	0.02	0.02	0.01
Coenagrionidae	0.13	0.63	0.68	0.91	0.54	*Chironomidae*	2.35	3.25	3.97	12.32	3.73
Gomphidae	-	0.02	0.01	-	0.01	*Culicidae*	-	0.02	0.05	<0.01	0.03
Corduliidae	-	-	0.05	0.02	0.02	*Empididae*	-	<0.01	<0.01	0.03	<0.01
Odonata	-	-	0.03	-	0.01	*Ephrydidae*	-	0.03	0.01	<0.01	0.01
Corixidae	0.01	0.08	0	0.03	0.03	*Hemerodromia*	0.08	0.07	0.15	0.38	0.12
Zygoptera	-	-	0.14	-	0.06	*Simulidae*	0.34	0.08	0.02	0.55	0.14
Ambrysus	0.01	0.02	0.01	0.03	0.01	*Stratiomydae*	<0.01	0.1	0.07	0.29	0.07
Cryphocricos	0.01	-	0.01	-	0.01	*Tipulidae*	-	<0.01	<0.01	<0.01	<0.01
Hemiptera	-	-	0.01	-	<0.01	*Cladocera*	2.25	0.2	0.08	0.24	0.64
Limnocoris	0.04	0.01	0.04	0.07	0.03	*Decapoda*	-	0.03	0.02	0.05	0.02
Lestidae	-	-	0.01	-	<0.01	*Copepoda*	0.04	0.01	0.03	0.09	0.03
Gerridae	-	-	0.03	0.05	0.01	*Hirudinea*	0.01	0.02	-	0.45	0.03
Naucoridae Gen.	0.02	-	0.01	0.21	0.02	*Hyalellidae*	49.3	63.78	47.54	24.74	51.85
Belostomatidae	-	0.03	0.02	0.07	0.02	*Hydrachnidae*	0.19	0.05	0.23	0.24	0.17
Corylidadae	0.01	-	0.01	0.05	0.01	*Oligochaeta*	-	-	0.01	0.1	0.01
Glossosomatidae	0.39	0.11	0.26	0.29	0.25	*Ostracod*	0.01	0.02	0.03	0.43	0.04
Veliidae	-	-	0.02	0.09	0.01	*Hydropsychidae*	0.04	0.18	0.2	1	0.19
Pleidae	-	-	0.01	0.01	<0.01	*Mesogastropoda*	0.01	-	0.03	0.24	0.02
Hydroptilia	0.03	0.06	0.04	0.14	0.05	*Calopterygidae*	-	-	0.01	-	<0.01
Leptoceridae	-	-	0.02	0.02	0.01	*Hebridae*	-	-	0.01	-	<0.01
Nectopsyche	0.02	0.05	0.17	0.14	0.1	*Lepidoptera*	-	-	0.01	-	<0.01
Oecitis	-	-	0.02	0.02	0.01	*Scritidae*	-	-	-	0.05	0.01
Oxyethira	0.74	0.63	0.67	1.54	0.71	*Gyrinidae*	-	-	-	0.02	<0.01
Trianodes	0.01	0.03	-	-	0.01	*Nematoda*	-	0.01	-	-	<0.01
Helicopsychidae	0.09	-	-	0.03	0.03	*Libellulidae*	-	-	-	0.02	<0.01
Neureclipsis	0.01	-	0.01	0.02	0.01	*Limnophila*	-	-	0.02	0.02	0.01
Philopotamidae	0.19	0.1	0.15	0.75	0.17						
Polycentropodidae	-	-	0.01	0.03	0.01						
Crambidae	0.18	0.32	0.11	0.46	0.2	**Total N**	**32368**	**39326**	**56966**	**5828**	**134488**
Paraponyx	0.43	0.63	0.37	0.96	0.49	**Taxa Richness**	**55**	**60**	**67**	**56**	**73**
Petrophila	0.78	2.38	0.85	1.24	1.31	**Shannon Diversity**	**1.35**	**1.27**	**1.44**	**2.03**	**1.44**

Table 2. Relative abundance by taxa (%), total N, taxa richness, and Shannon-Weiner Diversity (*H'*) for drifting macroinvertebrates collected for all sites from the San Marcos River (April 2015 – December 2015).

Taxa	**Site 1**	**Site 2**	**Site 3**	**Total**	**Taxa**	**Site 1**	**Site 2**	**Site 3**	**Total**
Baetidae	6.09	15.99	12.21	9.56	*Trichoptera*	0.00	0.04	0.03	0.02
Baetodes	0.17	0.26	0.40	0.23	*Lepidoptera*	-	0.00	-	0.00
Caenidae	0.06	0.04	0.10	0.06	*Crambidae*	0.12	0.35	0.31	0.21
Ephemeroptera	0.01	0.01	0.04	0.02	*Paraponyx*	0.32	0.66	0.81	0.49
Ephemeridae	0.01	0.12	0.03	0.04	*Petrophila*	1.26	1.48	1.21	1.31
Heptageniidae	0.01	0.06	0.05	0.03	*Dytiscidae*	0.01	0.01	0.00	0.01
Leptohyphidae	16.75	31.10	58.51	27.89	*Elmidae*	0.15	0.05	0.16	0.13
Leptophlebiidae	0.01	0.02	0.30	0.07	*Gyrinidae*	-	-	0.00	0.00
Anisoptera	0.36	0.13	0.04	0.25	*Haliplidae*	-	-	0.00	0.00
Coenagrionidae	0.42	0.73	0.74	0.55	*Hydrophilidae*	0.01	0.00	0.01	0.01
Corduliidae	0.03	0.00	0.00	0.02	*Phanocerus*	0.07	0.15	0.46	0.16
Gomphidae	0.00	0.02	0.01	0.01	*Psephenidae*	0.01	0.01	-	0.00
Libelluloidea	0.00	-	-	0.00	*Scritidae*	-	-	0.01	0.00
Odonata	-	0.01	-	0.00	*Ceratopogonidae*	0.01	0.01	0.02	0.01
Zygoptera	0.02	0.02	0.19	0.05	*Chironomidae*	2.29	4.21	7.70	3.75
Calopterygidae	-	-	0.02	0.00	*Culicidae*	0.03	0.03	0.01	0.03
Lestidae	0.00	-	-	0.00	*Empididae*	0.00	0.07	0.02	0.02
Hemiptera	0.00	-	0.00	0.00	*Ephrydidae*	0.02	0.01	0.00	0.01
Ambrysus	0.02	0.02	-	0.01	*Hemerodromia*	0.04	0.20	0.22	0.11
Belostomatidae	0.01	0.02	0.05	0.02	*Simulidae*	0.12	0.09	0.25	0.14
Corixidae	0.01	0.05	0.06	0.03	*Stratiomydae*	0.07	0.05	0.09	0.07
Cryphocricos	0.01	-	0.03	0.01	*Tipulidae*	0.00	-	-	0.00
Gerridae	0.02	0.01	0.01	0.01	*Annelid*	0.02	0.01	0.02	0.02
Limnocoris	0.02	0.04	0.07	0.03	*Cladocera*	0.94	0.35	0.11	0.65
Pleidae	0.00	0.00	-	0.00	*Copepoda*	0.02	0.05	0.04	0.03
Hebridae	-	-	0.00	0.00	*Decapoda*	-	0.05	0.03	0.02
Veliidae	0.01	0.00	0.05	0.02	*Hirudinea*	0.03	0.02	0.04	0.03
Corydalidae	0.00	-	0.04	0.01	*Hyalellidae*	68.94	41.43	13.06	52.07
Glossosomatidae	0.12	0.29	0.61	0.25	*Hydrachnidae*	0.07	0.33	0.28	0.17
Hydroptilidae	0.02	0.08	0.09	0.05	*Oligochaete*	0.01	0.00	0.01	0.01
Leptoceridae	0.01	0.02	0.01	0.01	*Ostracod*	0.03	0.03	0.09	0.04
Nectopsyche	0.02	0.27	0.11	0.10	*Platyhelmenthes*	0.02	0.00	0.02	0.01
Oecitis	0.01	0.00	0.01	0.01	*Nematoda*	-	-	0.01	0.00
Oxyethira	0.83	0.60	0.34	0.68	*Hydropsychidae*	0.08	0.24	0.45	0.19
Trianodes	0.01	0.04	0.01	0.01					
Helicopsychidae	0.01	0.00	0.12	0.03	**Total N**	77792	31723	24973	134488
Neureclipsis	0.01	-	0.04	0.01	**Taxa richness**	64	60	65	73
Philopotamidae	0.23	0.09	0.17	0.18	**Shannon Diversity**	0.91	1.74	1.64	
Polycentropodidae	0.00	0.02	0.01	0.01					

Table 3. Relative abundance by taxa (%), total N, taxa richness, and Shannon-Weiner Diversity (*H'*) for benthic macroinvertebrates collected for all seasons from the San Marcos River (April 2015 – December 2015).

Taxa	Spring	Summer	Fall	Winter	Total	Taxa	Spring	Summer	Fall	Winter	Total
Baetidae	16.49	22.13	21.16	16.34	20.28	*Philopotamidae*		0.05	0.07	0.65	0.11
Baetodes	0.02	0.05	0.01	0.62	0.09	*Polycentropodidae*	-	-	0.02	-	0.01
Caenidae	-	-	0.01	0.02	0.01	*Crambidae*	0.12	0.06	0.03	0.12	0.06
Heptageniidae	0.03	-	-	0.02	0.01	*Paraponyx*	0.15	0.19	0.12	0.22	0.16
Hexagenia	0.02	-	-	-	0	*Petrophila*	0.05	0.08	0.06	0.07	0.07
Ephemeridae	0.02	0.01	0.01	0.05	0.01	*Berosus*	0.02	-	0.01	-	0.01
Leptohyphidae	13.85	11.54	9.12	12.52	11.01	*Elmidae*	1.01	0.54	0.26	1	0.55
Leptophlebiidae	0.03	0.02	0.63	0.72	0.34	*Phanocerus*	0.07	0.12	0.07	0.3	0.11
Anisoptera	-	0.03	0.07	0.22	0.06	*Psephenidae*	0.02	0.02	-	0.02	0.01
Coenagrionidae	0.43	0.55	0.63	0.4	0.55	*Ceratopogonidae*	0.02	-	0.01	-	0.01
Gomphidae	0.02	0.01	0.01	-	0.01	*Chironomidae*	4.21	3.79	10.41	10.09	7.2
Libelluloidea	0.02	-	-	-	0	*Ephrydidae*	-	-	0.01	-	-
Corduliidae	-	0.02	0.01	-	0.01	*Hemerodromia*	0.33	0.08	0.29	0.3	0.23
Zygoptera	-	0.02	-	0.12	0.02	*Simulidae*	2.15	1.76	0.11	2.35	1.21
Ambrysus	0.07	0.2	0.04	1.1	0.21	*Bivalvia*	0.12	0.06	-	-	0.04
Cryphocricos	0.05	0.03	0.03	0.12	0.04	*Stratiomydae*	-	0.02	0.01	0.07	0.02
Limnocoris	1.91	0.9	0.89	0.9	1.05	*Cladocera*	0.1	0.05	-	0.02	0.04
Gerridae	-	-	0.01	-	0.01	*Decapoda*	0.38	0.1	0.01	0.1	0.11
Naucoridae Gen.	0.12	0.12	-	0.05	0.06	*Copepoda*	0.05	0.01	-	-	0.01
Belostomatidae	-	-	0.01	-	0	*Hirudinea*	3.2	0.01	0.04	0.2	0.53
Veliidae	-	0.02	0.01	-	0.01	*Hyalellidae*	27.33	53.93	47.3	43.78	46.1
Corylidadae	-	0.02	-	-	0.01	*Hydrachnidae*	0.83	0.03	0.74	0.85	0.53
Glossosomatidae	13.24	0.81	3.49	2.47	3.99	*Oligochaeta*	1.24	0.2	0.07	0.22	0.31
Hydroptilia	0.1	0.21	0.09	0.2	0.14	*Ostracod*	1.01	0.6	2.53	0.25	1.42
Leptoceridae	0.02	-	0.01	0.12	0.02	*Hydropsychidae*	0.1	0.12	0.26	1.25	0.29
Nectopsyche	0.46	0.16	0.85	0.52	0.52	*Mesogastropoda*	2.97	0.32	0.08	0.65	0.67
Oecitis	0.05	-	0.02	0.02	0.02	*Limnophila*	0.92	0.03	0.01	-	0.16
Oxyethira	0.73	0.45	0.22	0.2	0.37	*Thiaridae*	3.12	0.07	0.01	-	0.51
Trianodes	0.02	-	0.01	0.02	0.01	*Corbiculidae*	0.2	0.01	-	-	0.03
Helicopsychidae	2.59	0.35	0.05	0.52	0.59	*Palaemonidae*	0.03	0.08	0.09	0.02	0.07
Hydrobiosidae	0.03	-	-	0.02	0.01	**Total N**	**6059**	**14157**	**16070**	**4002**	**40,288**
Neureclipsis	-	0.02	-	-	0.01	**Taxa Rich**	**49**	**48**	**49**	**44**	**62**
						Shannon-Weiner	**2.37**	**1.5**	**1.68**	**1.97**	**1.85**

Table 4. Relative abundance by taxa (%), total N, taxa richness, and Shannon Diversity (*H'*) for benthic macroinvertebrates collected across all sites from the San Marcos River (April 2015 – December 2015).

Taxa	Site 1	Site 2	Site 3	Total	Species	Site 1	Site 2	Site 3	Total
Baetidae	13.45	27.00	21.23	19.99	*Paraponyx*	0.13	0.10	0.30	0.16
Baetodes	0.01	0.04	0.06	0.03	*Petrophila*	0.08	0.04	0.09	0.07
Caenidae	0.01	0.01	-	<0.01	*Berosus*	0.01	-	-	<0.01
Ephemeridae	-	0.01	0.04	0.01	*Elmidae Gen.*	0.70	0.22	0.72	0.54
Heptageniidae	0.01	-	0.02	0.01	*Phanocerus*	0.11	0.05	0.18	0.11
Hexagenia	-	0.01	-	<0.01	*Psephenidae*	0.02	-	-	0.01
Leptohyphidae	7.03	9.74	18.75	10.75	*Ceratopogonidae*	0.01	-	-	<0.01
Leptophlebiidae	0.08	0.04	1.16	0.32	*Chironomidae*	3.73	5.95	14.41	7.03
Zygoptera	0.49	0.33	0.99	0.56	*Ephrydidae*	0.01	-	-	<0.01
Anisoptera	0.07	0.04	0.13	0.07	*Hemerodromia*	0.14	0.35	0.19	0.22
Ambrysus	0.14	0.21	0.15	0.16	*Simulidae*	1.05	0.55	2.31	1.18
Belostomatidae	-	0.01	-	<0.01	*Stratiomyidae*	0.02	0.01	0.01	0.02
Cryphocricos	0.02	0.05	0.06	0.04	*Annelid*	1.01	1.03	1.09	1.03
Gerridae	0.01	-	0.02	0.01	*Bivalvia*	-	0.06	0.07	0.04
Limnocoris	0.28	1.26	2.13	1.06	*Cladocera*	0.04	0.01	0.05	0.03
Veliidae	0.01	-	0.01	<0.01	*Copepoda*	0.01	0.01	0.04	0.01
Corydalidae	-	-	0.01	<0.01	*Decapoda*	0.01	0.04	0.34	0.10
Sialidae	0.01	0.01	-	<0.01	*Hirudinea*	0.05	0.05	2.04	0.52
Glossosomatidae	2.76	3.91	5.74	3.86	*Hyalellidae*	62.82	44.92	18.24	46.04
Hydroptilia	0.04	0.23	0.16	0.13	*Hydrachnidae*	0.13	0.40	1.39	0.52
Leptoceridae	0.01	0.01	0.03	0.02	*Oligochaete*	0.36	0.32	0.19	0.31
Nectopsyche	0.40	0.53	0.69	0.51	*Ostracod*	1.89	1.01	1.03	1.39
Oecitis	0.02	0.02	0.02	0.02	*Platyhelmenthes*	0.53	0.20	0.45	0.40
Oxyethira	0.52	0.32	0.17	0.36	*Mesogastropoda*	0.88	0.34	0.59	0.62
Trianodes	0.01	0.00	0.02	0.01	*Corbiculidae*	0.01	0.01	0.11	0.03
Helicopsychidae	0.13	0.04	2.10	0.57	*Hydropsychidae*	0.29	0.24	0.36	0.29
Hydrobiosidae	0.02	-	-	0.01	*Limnophila*	0.11	0.01	0.03	0.05
Neureclipsis	0.01	-	0.01	<0.01	*Thiaridae*	0.09	0.11	1.77	0.49
Philopotamidae	0.16	0.03	0.13	0.11	*Palaemonidae*	0.04	0.11	0.10	0.08
Polycentuopodidae	0.02	-	-	0.01	**Total N**	**16,782**	**13,939**	**9,567**	**40,288**
Crambidae	0.05	0.04	0.05	0.05	**Taxa richness**	**55**	**49**	**50**	**60**
					Shannon Diversity	**1.50**	**1.70**	**2.38**	

Table 5. Mean (range) of physical parameters observed at each site on the San Marcos River April 2015 – December 2015. Parameters are displayed as Mean (Min – Max)

	Site 1			Site 2			Site 3		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Conductivity (µS)	606.06	594.00	614.00	605.51	596.00	616.00	605.27	594.00	616.00
Depth (m)	2.20	1.20	3.70	2.69	1.30	3.70	2.26	0.80	4.50
D.O. (mg/l)	8.09	7.37	8.45	8.18	7.37	8.32	8.25	7.98	8.75
pH	7.71	7.43	8.16	7.66	7.52	7.88	7.77	7.62	8.04
Vegetation Cover (%)	40.30	0.00	99.00	49.45	0.00	100.00	0.40	0.00	1.00
Velocity (m/s^2)	0.42	0.01	0.97	0.38	0.01	0.77	0.37	0.01	0.95
Temperature (°C)	21.97	21.70	22.37	22.25	21.70	23.20	21.74	21.20	22.24
Turbidity (FTU)	0.11	0.05	0.24	0.29	0.12	0.48	0.71	0.39	0.90

Table 6. Spearman's correlation coefficient for FFG in the drift and benthic samples for all sites and seasons in the San Marcos River (April 2015 – Dec 2015).

	Site 1		**Site 2**		**Site 3**	
FFG	Benthic	Drift	Benthic	Drift	Benthic	Drift
Spring						
Scrappers	724	1,387	579	792	1,109	502
Collector Gatherers	1,145	10,188	821	4,037	793	6,556
Filtering Collector	29	116	48	11	71	58
Predator	108	289	125	118	118	141
Shredder	658	7,122	239	655	264	395
Spearman Coefficient	**0.9**		**1**		**0.9**	
Summer						
Scrappers	505	1,593	1,153	936	286	611
Collector Gatherers	3,018	13,678	3,103	6,327	950	2,809
Filtering Collector	72	54	28	87	159	47
Predator	142	581	293	409	109	165
Shredder	2,057	9,058	1,394	3,518	195	730
Spearman Coefficient	**1**		**1**		**0.8**	
Fall						
Scrappers	497	1,478	792	1,937	942	1,251
Collector Gatherers	3,240	17,334	2,513	10,081	2,681	9,421
Filtering Collector	40	109	13	69	19	76
Predator	203	730	348	678	955	981
Shredder	2,093	10,503	1,353	2,891	488	700
Spearman Coefficient	**1**		**1**		**0.9**	
Winter						
Scrappers	497	1,478	792	1,937	942	1,251
Collector Gatherers	3,240	17,334	2,513	10,081	2,681	9,421
Filtering Collector	40	109	13	69	19	76
Predator	203	730	348	678	955	981
Shredder	2,093	10,503	1,353	2,891	488	700
Spearman Coefficient	**1**		**1**		**0.9**	

Table 7. Sampling dates for drift and benthic macroinvertebrate collections for all sites and seasons in the San Marcos River (April 2015 – Dec 2015).

Macroinvertebrate Sampling Periods								
	Spring		Summer		Fall		Winter	
	Drift	Benthic	Drift	Benthic	Drift	Benthic	Drift	Benthic
Site 1	April 20, 2015	April 21, 2015	July 13, 2015	July 15, 2015	September 28, 2015	September 22, 2015	December 15, 2015	December 8, 2015
Site 2	April 15, 2015	April 16, 2015	July 8, 2015	July 8, 2015	September 22, 2015	September 24, 2015	December 9, 2015	December 10, 2015
Site 3	April 14, 2015	April 14, 2015	July 6, 2015	July 6, 2015	September 21, 2015	September 21, 2015	December 7, 2015	December 7, 2015

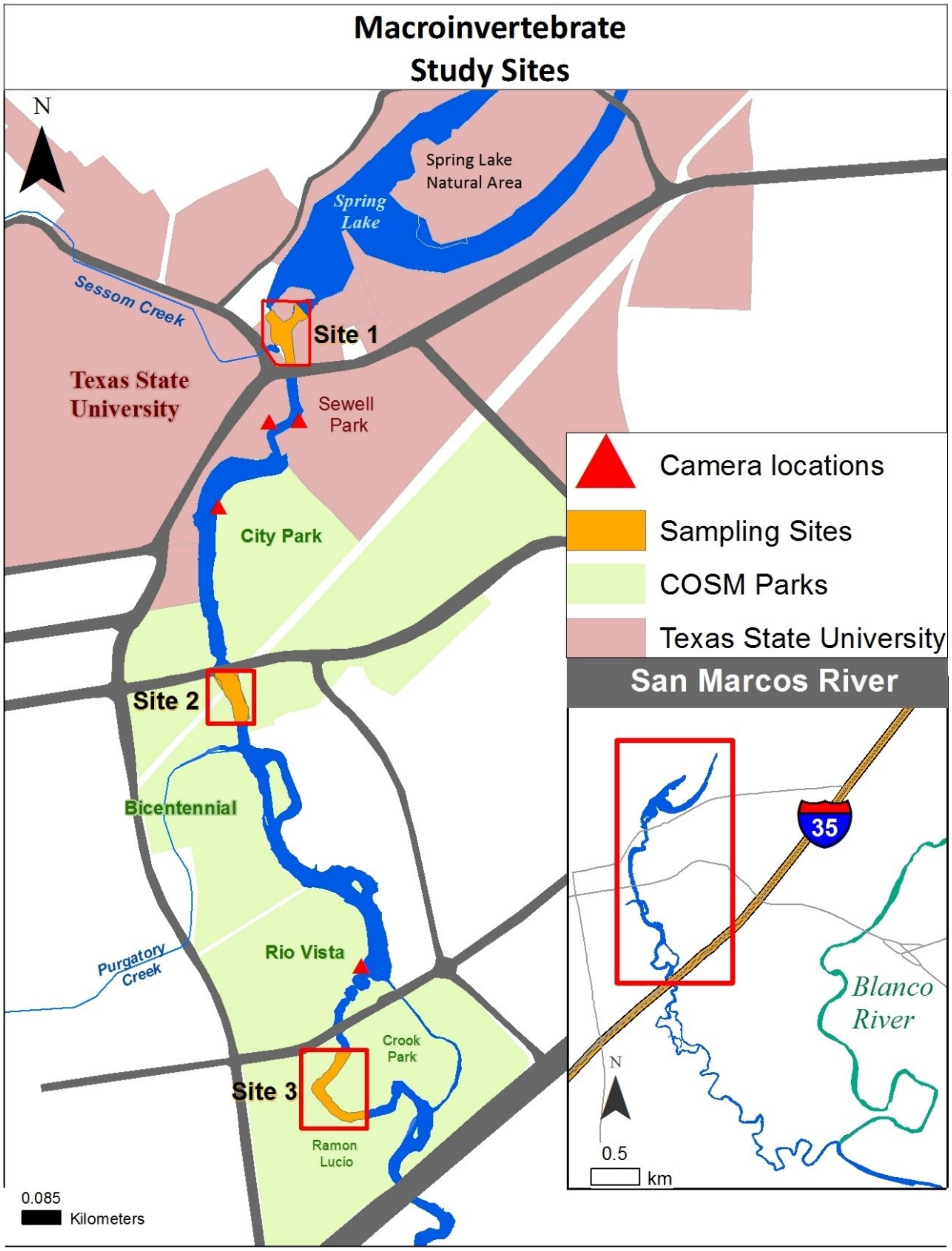


Figure 1. Macroinvertebrate site map and camera locations on the San Marcos River.

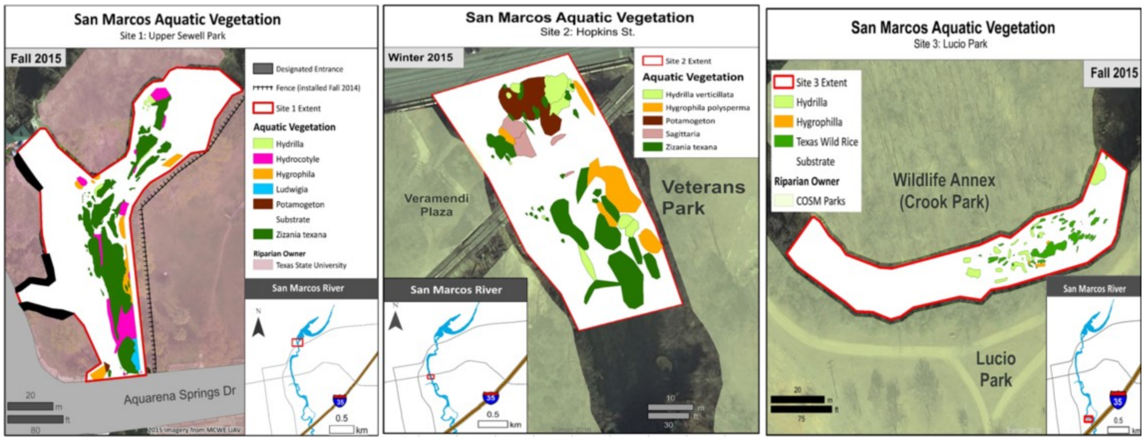


Figure 2. Example of substrate and vegetation maps at each study site utilized to select random locations for benthic samples.

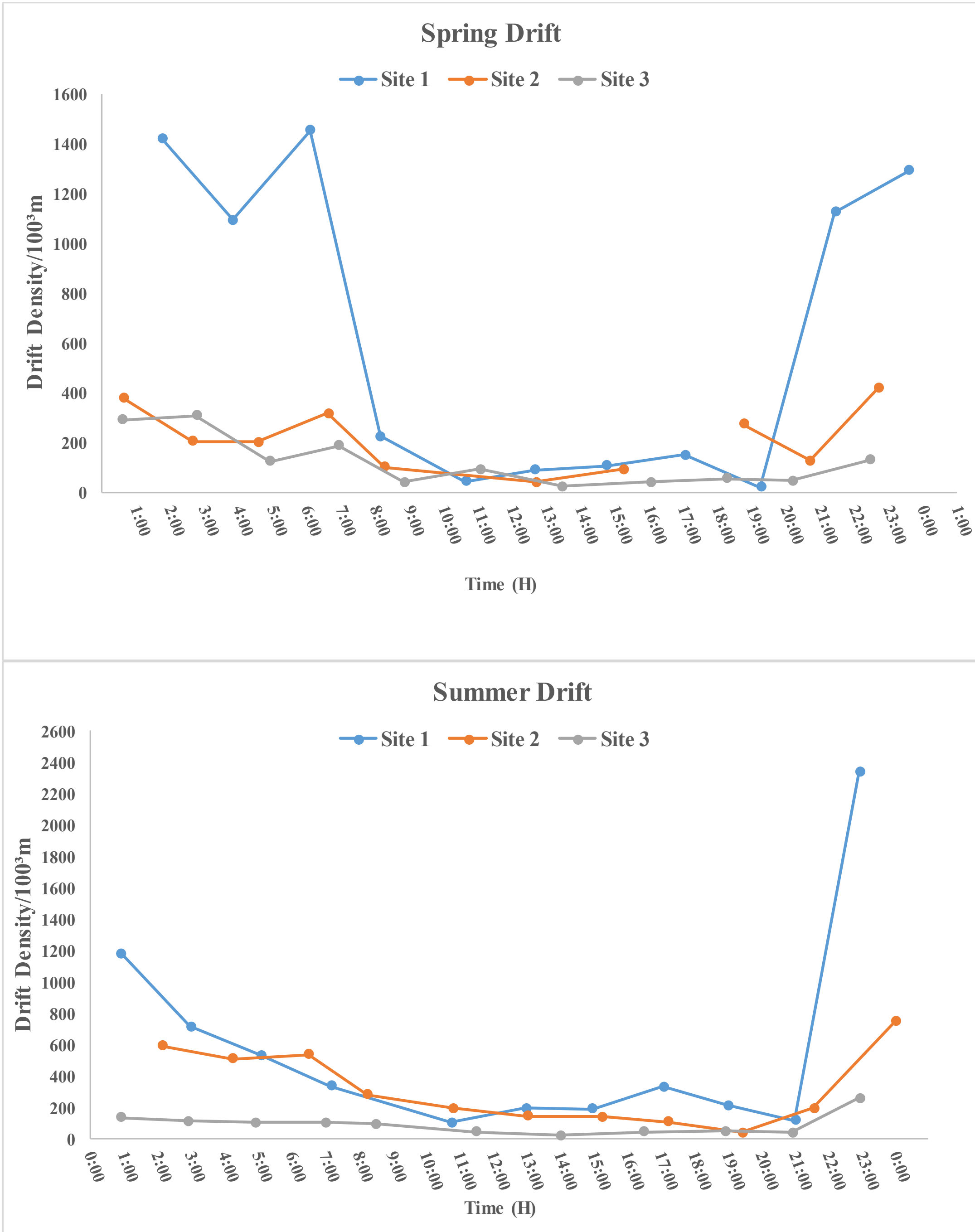
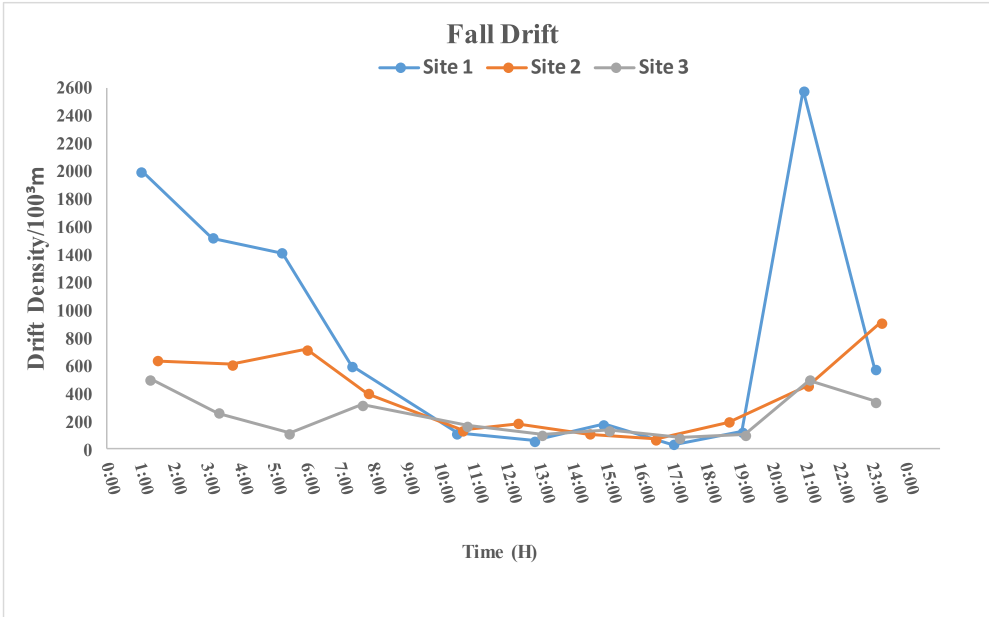


Figure 3. Drift densities/100^{3}m for Sites 1-3 on the San Marcos River among seasons (April 2015 – Dec 2015).



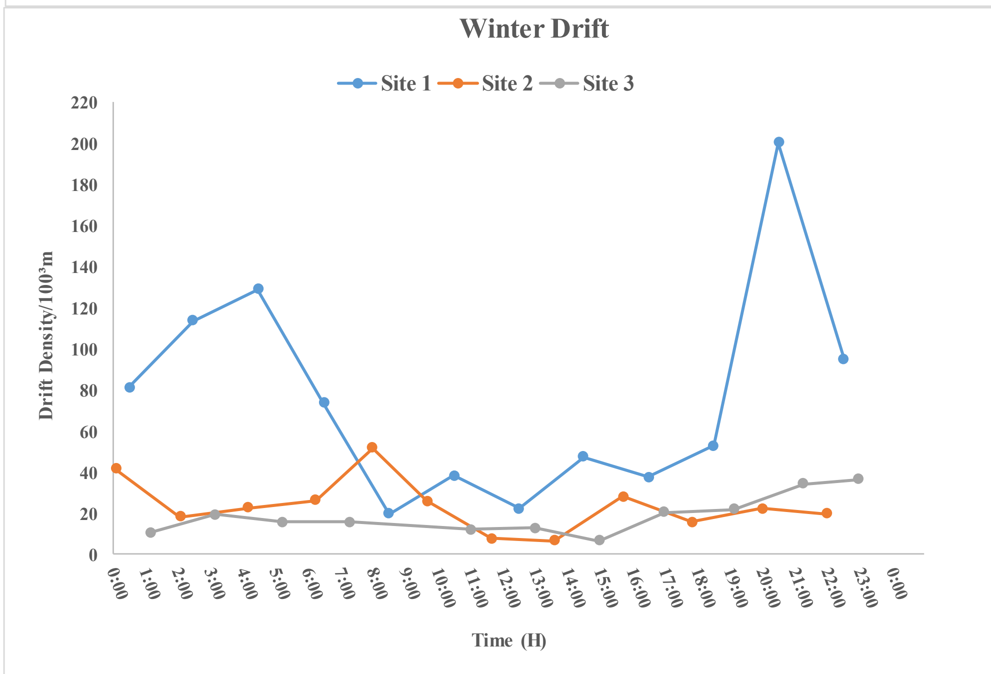


Figure 3. (Continued) Drift densities/100^{3}m for Sites 1-3 on the San Marcos River among seasons (April 2015 – Dec 2015).

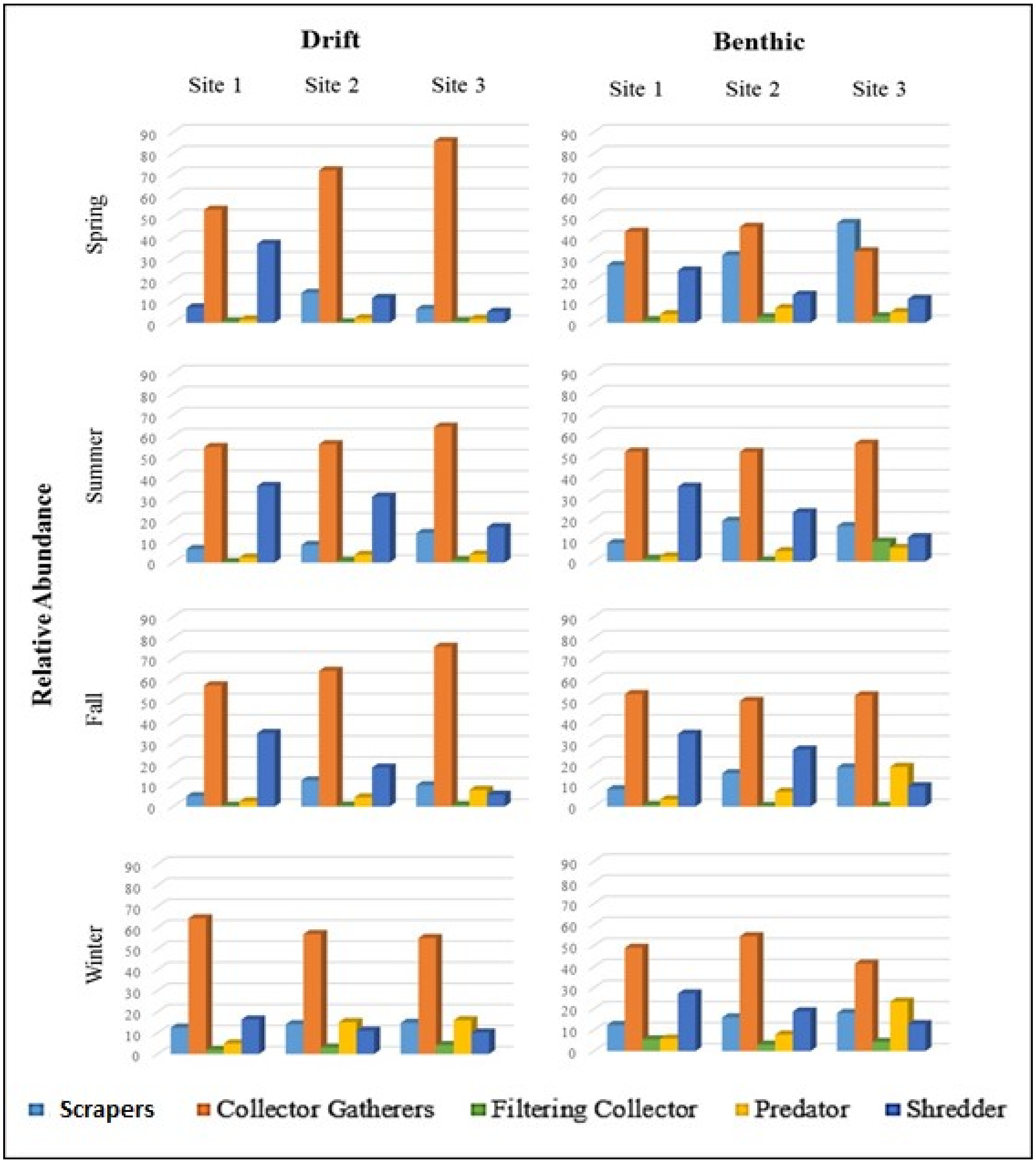


Figure 4. Relative abundance for FFG in the drift and benthic samples for all sites and seasons in the San Marcos River (April 2015 – Dec 2015).

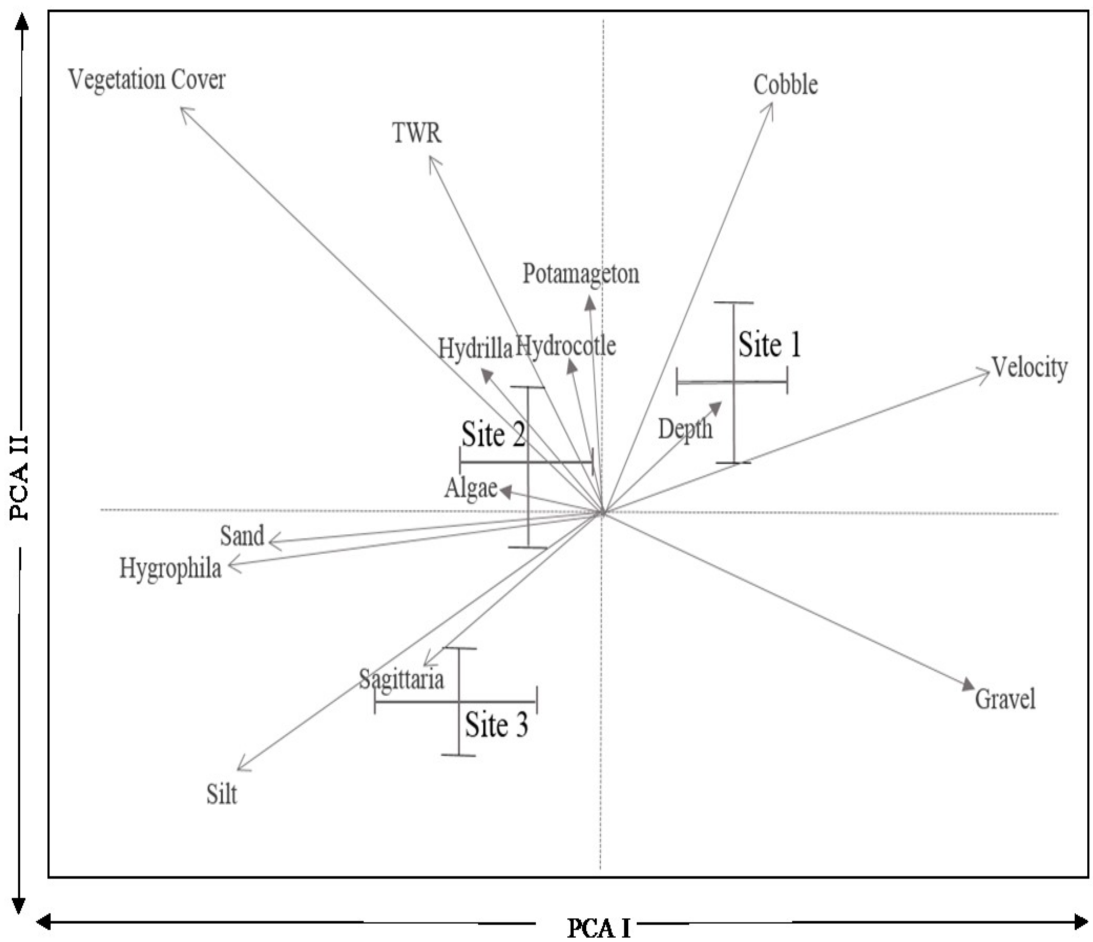


Figure 5. Principal component analysis bi-plot for measured environmental parameters and general habitat characteristics by site for habitat sampled on the San Macros River during April 2015 – December 2015.

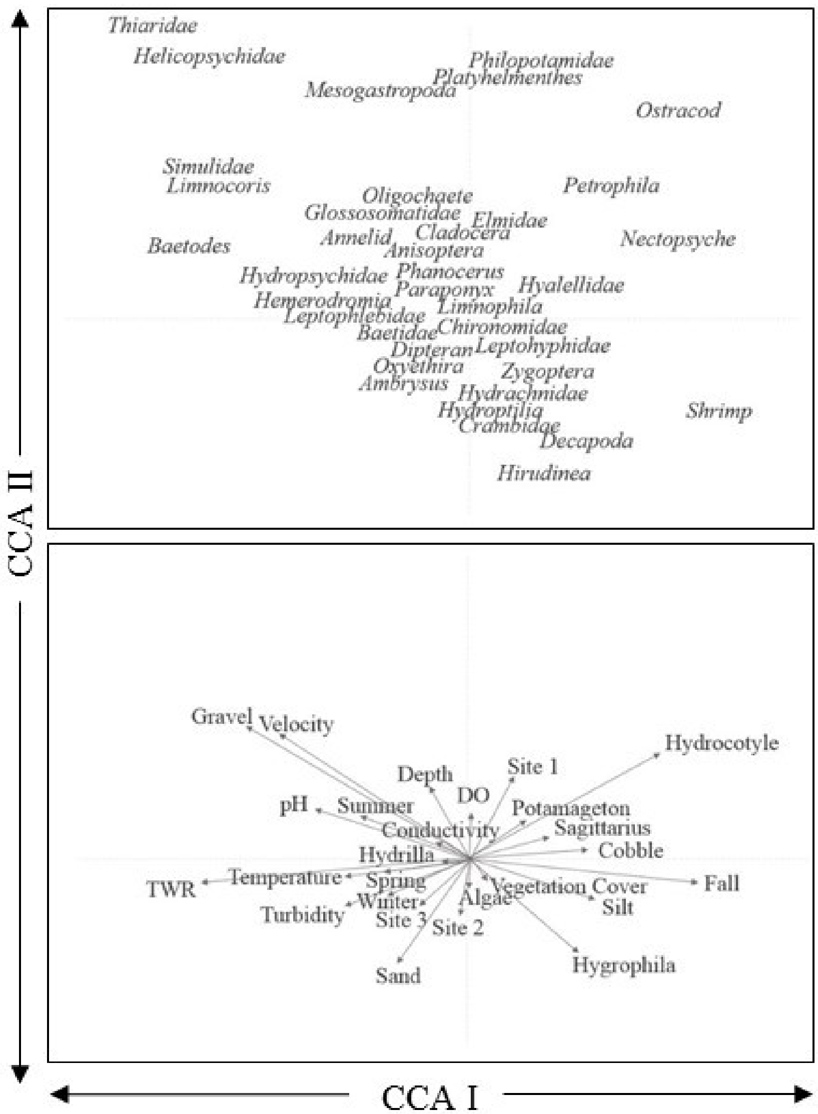


Figure 6. Canonical correspondence analysis bi-plots for macroinvertebrate species among vegetation samples (upper) and environmental parameters, site, and season from San Marcos River (April 2015 – December 2015).

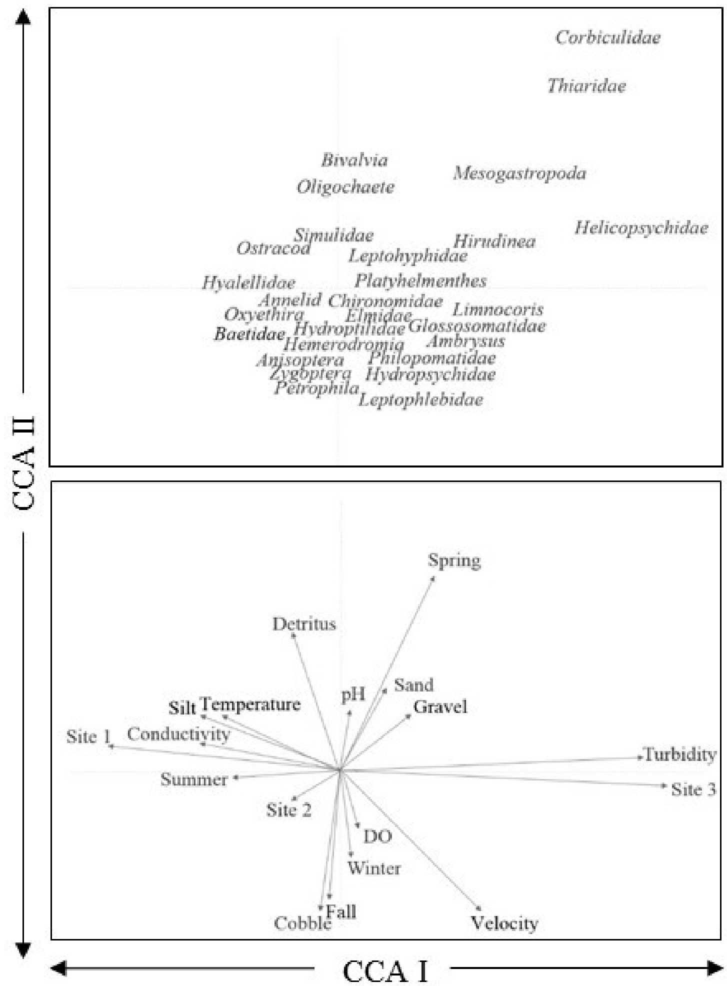


Figure 7. Canonical correspondence analysis bi-plots for macroinvertebrate species among substrate samples (upper) and environmental parameters, site, and season from San Marcos River (April 2015 – December 2015).

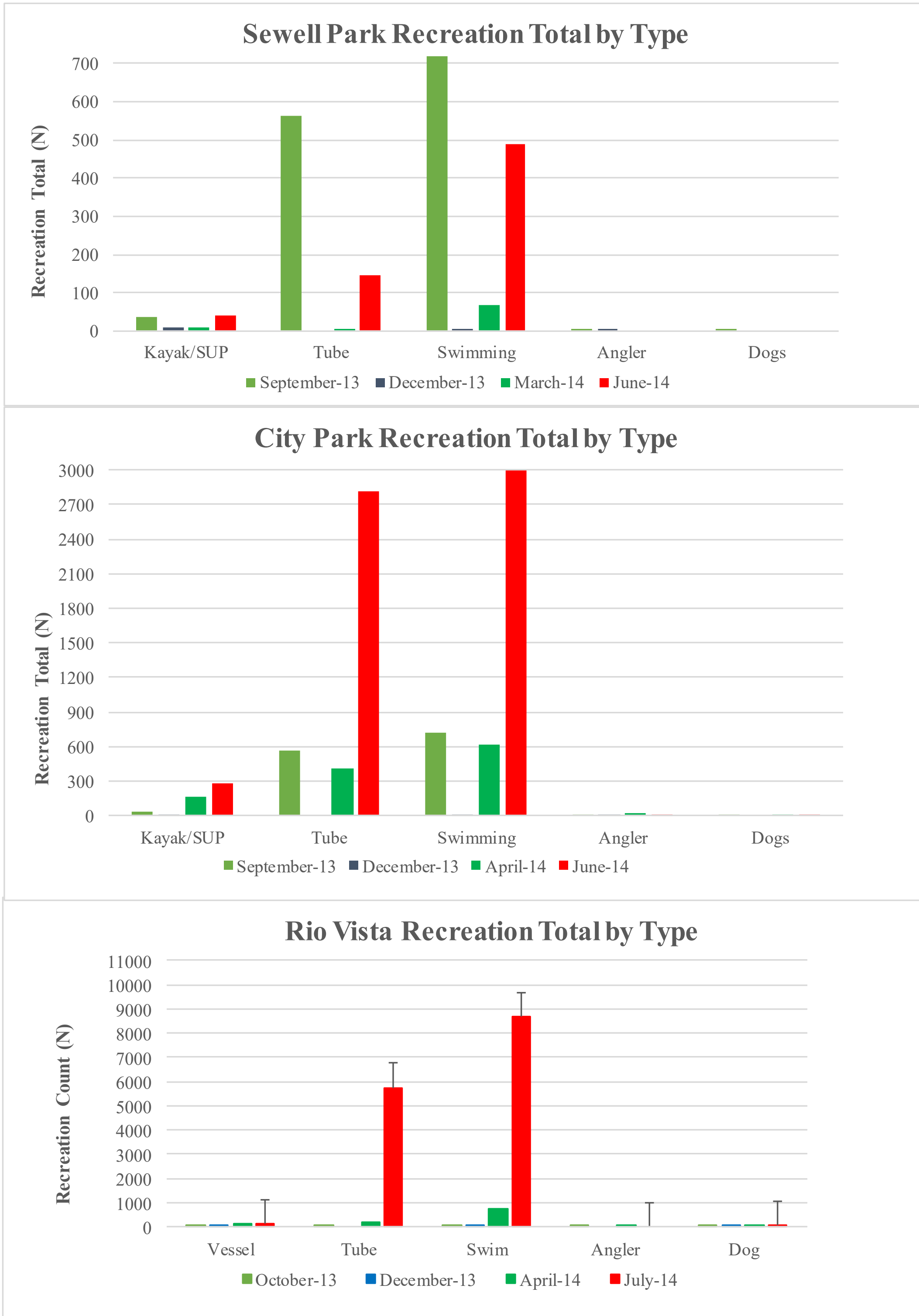


Figure 8. Total number of individuals per recreation type for each season captured by Sewell Park, City Park, and Rio Vista Park game cameras.

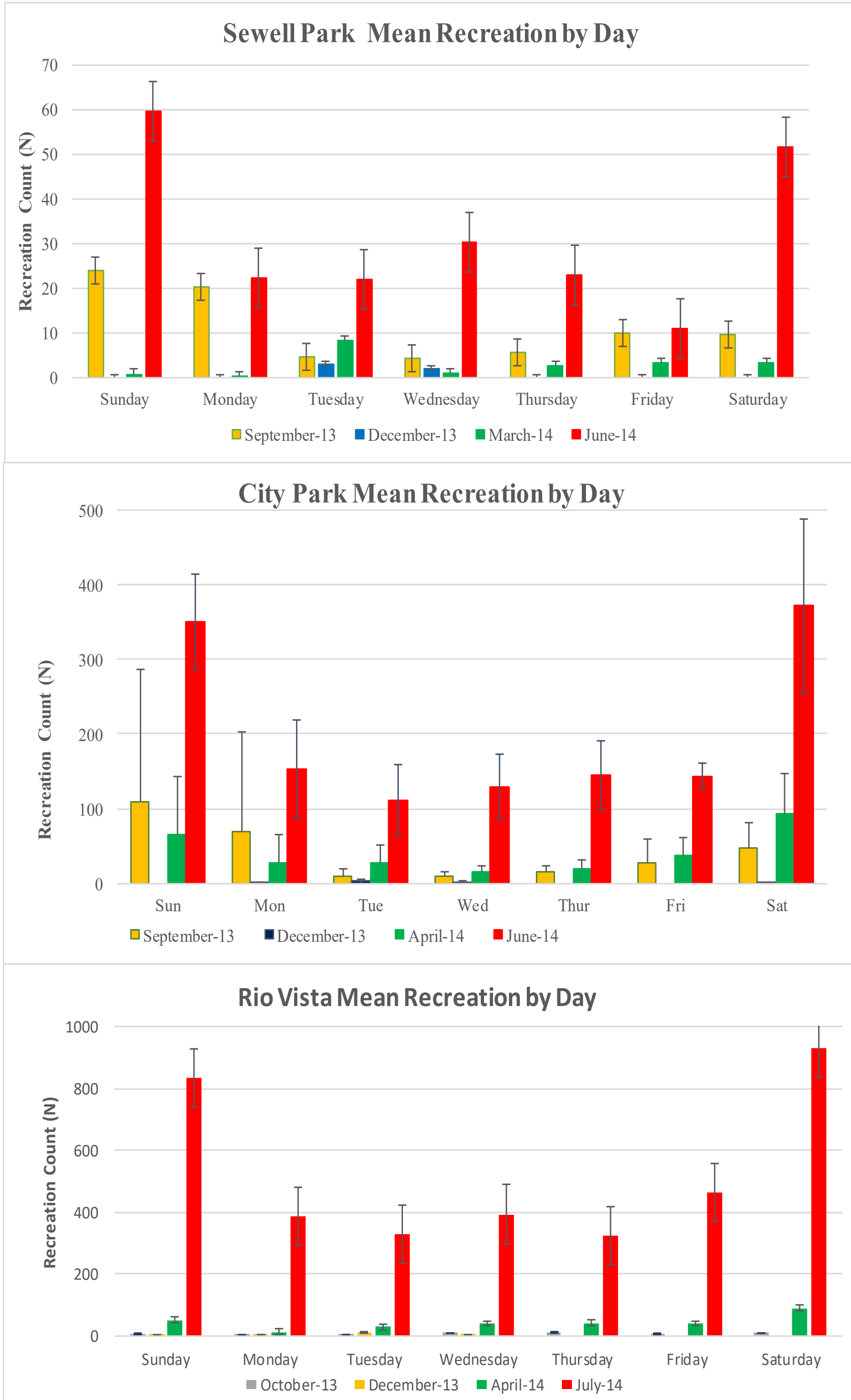


Figure 9. Average recreation per weekday for all recreation types captured by Sewell park, City park and Rio Vista park game camera (Sept 2013 – June 2014).

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