RESPONSES OF AQUATIC BENTHIC MACROINVERTEBRATE COMMUNITIES TO A LARGE FLOW PULSE IN THE GUADALUPE, SAN ANTONIO AND BRAZOS RIVER BASINS, TEXAS

by

Jeremy D. Maikoetter, B.S.

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Committee Members:

Timothy H. Bonner, Chair

Caitlin Gabor

Archis Grubh

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ABSTRACT

Riverine benthic macroinvertebrates (BMI) communities are regulated, in part, by the dynamic character of the river's flow regime. Purpose of this study was to assess the influence of a flow regime component (i.e., large flow pulse) on BMI riffle communities, specifically that large flow pulses shifted structure (i.e., richness and density), and therefore maintain the biotic integrity of riverine riffle BMI communities. Predictions were that BMI richness and density would decrease and recover with large flow pulses, ranging between 1 in 2 year events (340 m^3/s) to 1 in 5 year events (331 to 886 m^3/s), but that density reductions and recovery would differ among taxa categorized as swift, moderate, and slack forms. BMI communities were monitored at 11 sites located in three river basins and distributed among upper and lower reaches of major rivers and tributary streams. A total of 93,400 aquatic macroinvertebrates were identified to family and used to estimate BMI richness and BMI density among 102 riffles (61 riffles pre-flood and 41 riffles post-flood) between 2014 and 2017. Physical and chemical aspects of riffle habitats were similar between pre-flood and post-flood, except that post-flood riffles had less sand and gravel than pre-flood. BMI communities were similar among river basins and were segregated along environmental gradients related to physical and chemical (16%), season (6%), and flood (2%) effects. Only a few sites differed in BMI richness and density between pre-flood and post-flood, indicating that BMI communities among seven of the 11 sites likely recovered before the post-flood sampling events. Increased densities or relative abundances were detected at four sites for swift BMI, at one site for moderate BMI, and at one site for slack BMI. Decreased densities or relative abundances were detected at one site for moderate BMI and at two sites for slack BMI. Among taxa, relative abundances of seven BMI families, which were categorized as swift or moderate, generally increased among the 11 sites, whereas relative abundances of five BMI families, which were categorized as moderate or slack, generally decreased among the 11 sites. Although increasing or decreasing trends in BMI categories and families between pre-flood and post-flood periods were not consistent among all sites, study results suggest that density and relative abundance of some BMI taxa responded positively (e.g., Baetidae, Hydropsychidae, Isonychiidae) and negatively (e.g., Elmidae, Leptophlebiidae, Chironomidae) to high flow pulses. Therefore, flow-responsive BMI taxa found in this study provide potential indicator species for environmental flow standards assessments, although the ubiquitous use of these indicator species across and within drainages is limited.

1. INTRODUCTION

Within flowing waters, aquatic organisms assemble along a longitudinal gradient from low order headwater streams to high order lowland rivers, attributed primarily to modes in nutrient processing (Vannote et al. 1980). Within a reach of a stream or river, aquatic habitats consist of a heterogeneous mix of lotic and lentic waters, which supports a diversity of aquatic organisms that acquire and partition available nutrients (Vaugn and Hakenkamp 2001; Vanni 2002; Vanni et al. 2002; Quevedo et al. 2009). The community of aquatic organisms, therefore, is a heterogeneous mix of taxa with some associating with swifter current velocity habitats, some associating with slacker current velocity habitats, and some associating with swift and slack current velocity habitats (i.e., intermediate forms) (Extence et al. 1999). Persistence in occurrence and relative abundances of lotic, lentic, and intermediate forms (i.e., biotic integrity) is thought to depend on the dynamic characters of the flow regime (Poff et al. 1997). The dynamic characters of the flow regime differ among and within streams and rivers based on suite of hydrological factors, including base flow magnitude, water permanency, flow pulse periodicity, flow pulse magnitude, and flow pulse duration (Richter et al. 1996).

Flow pulses are considered a primary factor in maintaining productivity and interactions within river systems (Junk et al. 1989). Flow pulses are defined as additions to groundwater contribution to river flow (i.e., base flow) due to runoff from precipitation events, ranging from low magnitude and high frequency events to high magnitude and low frequency events (Poff et al. 1997). Flow pulses influence physical, chemical, and biological aspects of flowing waters. Physically, flow pulses erode, transport, and deposit sediments, which defines channel morphology, available mesohabitats (i.e., runs, riffles, pools), and available benthic substrates (Scrimgeour and Winterbourn 1989; Poff et al. 1997). Chemically, flow pulses change water temperature, specific conductance, turbidity, and dissolved oxygen for a period of time until flows return to base (Junk et al. 1989; Bayley 1995; Tockner et al. 2011). Biologically, flow pulses reduce densities and richness of aquatic organism communities, including benthic macroinvertebrates (BMI) (Scrimgeour and Winterbourn 1989; Fritz and Dodds 2004; Suren and Jowett 2006); however reductions in denstities are not equal among all BMI taxa as swift water forms tend to be more resistant and resilient to higher current velocities than slack water forms (Extence et al. 1999). Aquatic communities persist temporally and spatially in flowing waters because of a differential in selection pressures of flow pulses, with organisms adapted to local flow regime showing higher resistance to flow pulses than non-native organisms not adapted to local flow regime (i.e., differential selection, Minckley and Meffre 1987). Aquatic organisms with flow-adapted traits, such as longer adult life span and multivoltine, are thought to be more fit in streams and rivers with higher flows than those without flow-adapted traits (Horrigan and Baird 2008).

Ecological services of natural flow regimes, which includes flow pulses, are central concepts in environmental flow management (Poff et al. 1997; Lytle and Poff 2004; Poff and Zimmerman 2010). However, high magnitude, low frequency flow pulses (i.e., floods) are considered as natural disasters, occurring more often and affecting more people worldwide than other types of natural disasters (e.g., droughts, earthquakes; Jonkman 2005). As such, instream dams are used to minimize or prevent large floods and the loss of property and life (Oud and Muir 1997). Anthropogenic alterations of the natural flow regime by dams mute natural flow pulses as intended, but alterations to flow, in particular high flow pulses, contribute to biodiversity homogenization and large-scale shifts within aquatic and riparian communities (Stevens et al. 1997; Bonner and Wilde 2000; Cortes et al. 2002; Poff et al. 2007; Poff and Zimmerman 2010). However, perspectives on the relationship between aquatic communities and flow pulses are developed from case studies where rivers were already modified by dams or where flows in a reach were restored to mimic natural flows (Minckley and Meffre 1987; Cortes et al. 2002; Robinson et al. 2003; Propst and Gido 2004). Relationships between aquatic communities and flow pulses in unregulated or less regulated (e.g., not immediately downstream of a dam) portions of rivers is less known and can inform environmental flow management.

Purpose of this study was to assess BMI community responses to a large flood event among 11 unregulated or less regulated stream sites and three river basins within western gulf slope drainages of Texas to determine if aquatic biota are influenced by flow pulses and the potential use of BMI as indicators of water quantity management. This study is part of a larger environmental flow study in which the sites were selected and monitored for one year prior to and after a large flow event. Sampling after large flow event ranged between 14 months and 22 months, depending on when sites returned to or near base flow conditions. Objectives of this study were 1) to describe riffle habitats across basin, site, season, and flood event, 2) to quantify BMI communities across three river basins, and their relationship to physical-chemical parameters, basin, season, and flood event, and 3) to assess flood effects on BMI flow association guilds and individual families. I predicted that BMI richness and density would decrease at all sites following a flood (Angradi 1997; Fritz and Dodds 2004; Scrimgeour and Winterbourn 1989), but decreases will not be equal across flow association BMI guilds. Densities of swift and moderate BMI guild families (Extence et al. 1999; Armanini et al. 2011) will be greater proportionally in the community relative to slack water BMI guild families, if differential selection is occurring among taxa within the BMI community. However, BMI communities recover (i.e., post-flood community obtaining similar richness and densities as those of the pre-flood community) 42 days to 22 months after flood events (Angradi 1997, Mundahl and Hunt 2011). As such, BMI richness or densities might be similar pre-flood to post-flood, but swift and moderate BMI guilds and families will be proportionally greater than those of slack BMI guild and families.

2. METHODS

Study Area

The study area was within two major river basins of Texas (i.e., Brazos River basin and Guadalupe-San Antonio rivers basin; Figure 1), which flow independently into the Gulf of Mexico. Study sites (N = 11) were selected based on reaches with established environmental flow recommendations by BBEST (Brazos and Guadalupe-San Antonio Basin and Bay Expert Science Team) and USGS gaging stations (Vaugh et al. 2011; Gooch et al. 2012). Among all sites with environmental flow recommendations, sites for this study were selected to represent and replicate the diversity of river reaches within a river network, consisting of upper reaches, lower reaches, and adventitious tributaries. Sites are arranged and described by basin, system, river, and median base flow (Table 1). Sites were also selected to represent the more unregulated reaches of river within each basin. Here, unregulated reaches are defined as reaches that are not substantially altered physically or hydrologically by an immediate upstream reservoir but flows at all sites are reduced at some level by anthropogenic alterations of flow by instream or watershed dams. All sites consisted of a heterogeneous mix of swiftwater (e.g., riffle and run) and slackwater (e.g., pool and backwater) mesohabitats with silt through cobble substrates.

The Brazos River basin consists of at least two dendritic river systems (i.e., Little River system and Brazos River system). Origin of the Little River system is within the Cross Timbers ecoregion (Griffith et al. 2007), and origin of the Brazos River system is within the Rolling Plains ecoregion. Both systems flow southeasterly through the Blackland Prairie ecoregion, merge in the Post Oak Savanna ecoregion, bisect another section of Blackland Prairie ecoregion, Gulf Coast Prairie ecoregion, and then discharges into the Gulf of Mexico. Within the Little River system, sites were in the Leon River (Gatesville), Lampasas River (Kempner), and Little River (Little River – Academy; LRA). In the Brazos River system, sites were in the upper Navasota River (Easterly). The study also initially included two mainstem Brazos sites (i.e., Hempstead and Rosharon); however, riffle habitats in braided, sand-bed rivers like the lower Brazos River with small gravels interspersed within sand substrates are more susceptible to burial from silt and sand than riffle habitats elsewhere in the study area. Riffle habitats were not found or sampled within lower Brazos River sites following the flood. Therefore, the two lower Brazos River sites were excluded from the study.

The Guadalupe-San Antonio (GSA) rivers basin consist of two dendritic river systems (i.e., Guadalupe system and San Antonio system). Both systems share a confluence about 20 km upstream before discharging into San Antonio Bay. Origins of the GSA are within the Edwards Plateau ecoregion. Streams flow southeasterly into lower gradient rivers and bisects Blackland Prairie, Post Oak Savanna, and Gulf Coast Prairie ecoregions. Within the Guadalupe system, sites were in the Guadalupe mainstem (Comfort, Gonzales, and Cuero) and the San Marcos River (Luling). Within the San Antonio system, sites were in the Medina River (Bandera), Cibolo Creek (Falls City), and lower San Antonio River (Goliad).

In 2015, an unusual wet month of May along with an intense precipitation event towards the end of May, produced up to 550 mm of rain in some areas (annual mean average = 860 mm; Blanco Texas) and caused wide spread flooding within the GSA. In 2016, another intense precipitation event producing up to 457 mm of rain in some areas (annual mean average: 1,143 mm; Brenham Texas) occurred in June and caused wide spread flooding in the Brazos River basin and GSA river basin. Collectively, both events were considered historic and catastrophic floods based on the loss of human life and property damage. Flow magnitude periodicities across all study sites were classified as 1 per 2 year or greater than 1 per 5 year events (Vaugh et al. 2011; Gooch et al. 2012; Appendix 1).

Field and Laboratory Methods

Study sites were established as long-term biomonitoring locations in September 2014 and sampled through May 2017. Biomonitoring consisted of macroinvertebrate sampling within riffle mesohabitats. During each season as designated by BBEST, flows were monitored daily using USGS gaging stations near each study site. Peak flow (largest flow magnitude in a 24-h period; m^3/s) was used to identify flow tier as defined by BBEST stakeholder reports (Vaugh et al. 2011; Gooch et al. 2012). Flow tiers were subsistence, base, 4 per season, 3 per season, 2 per season, 1 per season, 1 per year, 1 per two years, and 1 per five years high flow pulses. Sites with subsistence or base flows were sampled seasonally and sampled again after 30 days of continuous base or subsistence flows. Sites with flow events were sampled within 10 - 15 days after the flow event subsided to base flow. Sampling the aquatic community at base flow and after flow pulse subsided avoided dilution effect of sampling during a flow pulse and enabled assessment of the community after the flow pulse passed. As such, collections consisted of BMI at subsistence, base, and low flow pulses before the 2015 - 2016 high flow pulse and base and low pulses after the 2016 high flow pulse. Sites were sampled from August 2014 through May 2015, and again September 2016 through May 2017. Number of samples per site depended upon number of tier changes observed at each site and how quick flows returned to base following high flow pulses. As such, number of samples per site were not standardized across sites and ranged from 5 (Goliad and Cuero) to 13 (Little River - Academy) (Appendix B).

One to three BMI samples were collected using Wildco Hess Stream Bottom Sampler (area = 0.086 m^2). Number of BMI samples taken at a site depended on the amount of available mesohabitat during each sampling event. Small riffle mesohabitats were sampled once or twice per visit. Large riffle mesohabitats or runs were sampled three times per visit to obtain multiple representative subsamples per mesohabitat (Mundahl and Hunt 2011). Benthic substrates were agitated and overturned for 3 to 5 minutes per sample within the Hess Stream Bottom Sampler. Each sample was rinsed into a Nasco Whirlpak and stored in 90% ETOH for future identification and enumeration. Substrate composition and amount of vegetation were visually estimated, depth and current velocity were measured, and water quality (i.e., temperature, pH, specific conductance, and dissolved oxygen) were taken with a YSI-85 multiprobe meter.

In the laboratory, samples were rinsed using a 250-µm sieve and placed in a shallow pan with water. Macroinvertebrates were searched and counted for a minimum of 30 minutes. Time search was stopped after five minutes without locating BMI (Moulton II et al. 2000). Total BMI count was taken from individual samples. BMI density (BMI / 0.086 m^2) counts ranged from 0 to 1,812 across all individual samples. BMI were dispersed onto a 36-grid tray and a 10 grid subsample was taken to determine composition (Moulton II et al. 2000) and were identified to the lowest practical taxonomic level, usually family, and enumerated (Merritt et al. 1996; Birmingham et al. 2005).

Statistical Methods

Variables were averaged among all samples taken at a site per day of collection. If only one sample was taken, the calculated response variables for one sample represented the BMI community at a site per day of collection. Likewise, percent substrates, percent vegetation, water depth, current velocity, and water quality parameters were averaged among samples taken at a site per day of collection to represent the physical and chemical parameters of the sample. Total BMI composition was calculated using the proportion of subsampled taxa multiplied by the total number of BMI in the sample. When multiple riffle samples were taken at a specific site and date, the sample compositions were averaged. Family BMI count was used to calculate taxa richness. BMI families were assigned flow guilds based on previous literature (Extence et al. 1999; Armanini et al. 2011), expert opinion, and field observations. Flow guilds did not include all taxa present (42 out of 51 families were included), therefore only taxa listed in the flow guilds were used to determine flow guild composition of BMI (Table 2). Flow guild densities were calculated by summing the family densities for each flow guild. Relative abundance of each flow guild was calculated by summing the total BMI counts for each flow guild and dividing by the total BMI count.

For Objective 1, changes in physical and chemical properties of riffle habitats were assessed with principal component analysis (PCA; Proc PCA, SAS 9.4) to assess potential changes in abiotic factors: site, season and post-flood conditions. Site differences among physical and chemical properties among factors were assessed using ANOVA and Fisher's LSD post-hoc tests. For Objective 2, BMI communities across basins and sites described using densities and relative abundances overall, pre-flood and post-flood. Relative abundances will be calculated at the order and family level. Pre-flood and post-flood differences in BMI richness and BMI density were assessed among basin and sites using ANOVA. Associations between taxa and environmental parameters were assessed with Canonical Correspondence Analysis (CCA; Canoco 4.5). For CCA, two matrices were developed. Taxa matrix consisted of BMI family taxonomy (columns), counts, and site per day of collection (rows). Environmental matrix consisted of corresponding rows of physical and chemical parameters, season, drainage, and post flood. Total variation was partitioned into pure effects of physical and chemical parameters, season, drainage, and flood (Borcard et al. 1992), and Monte Carlo tests (1,000 permutations) were used to determine the significance ($\alpha = 0.05$) of each effect. For Objective 3, BMI densities were summarized across all sites for pre-flood and post-flood samples. Differences in pre-flood and post-flood flow guild densities were assessed with ANOVA to test post-flood contrasts among basin and sites. Changes in BMI guild densities and relative abundances were assessed with paired t-tests (i.e., pre-flood and post-flood estimates paired by site) to eliminate potential sites differences in BMI communities. Six paired t-tests were assessed: three using log-transformed density as the response variable to assess changes in swift, moderate, and slack BMI taxa, and three using arcsin-transformed relative abundance as the response variable to assess changes in swift, moderate, and slack BMI taxa.

3. RESULTS

Habitats

A total of 102 riffle habitats was sampled among 11 sites. By drainage, 46 riffle habitats were sampled in the Brazos River drainage (22 pre-flood, 24 post-flood) and 56 riffle habitats were sampled in the GSA River drainage (39 pre-flood, 17 post-flood). Summaries of physical and chemical habitat parameters are provided by site in Appendix B. Generally, physical and chemical habitat parameters were similar among sites. Principal component axes I and II explained 37% of the total variation in riffle habitat parameters. PC axis I explained 19% of the total variation and described primarily a substrate and specific conductance gradient (Figure 2). Strongest loadings on PC axis I was bedrock (0.57), specific conductance (0.48), percent vegetation (0.41), and current velocity (-0.34). PC axis II explained 17% of the total variation and described a fine to coarse substrate gradient. Strongest loadings on PC axis II was sand (0.55), cobble (-0.50), and gravel (0.40). Riffle sample scores were not different among seasons for PC I (ANOVA: $F_{3, 98} = 0.74$, $P = 0.53$) and PC II (ANOVA: $F_{3, 98} = 1.72$, $P = 0.17$). Riffle sample scores differed among sites for PC I (ANOVA: $F_{10, 91} = 34.2$, $P < 0.01$) and for PC II (ANOVA: $F_{10, 91} = 9.4$, $P < 0.01$). Kempner site was different ($P < 0.05$) from other sites along PC I with greater bedrock substrates and higher specific conductance. Easterly site was different ($P < 0.05$) from other sites along PC II because of greater amounts of sand substrates and less cobble substrates. Other differences were detected among sites related primarily to proportions of fine and coarse substrates. Riffle sample scores were not different between pre-flood and post-flood for PC I (ANOVA: $F_{1, 100} = 0.99$, $P = 0.32$) and PC II (ANOVA: $F_{1, 100} = 1.89$, $P = 0.17$). Assessing pre-flood and post-flood riffle sample scores by site (t-tests), three sites (i.e., Comfort, Goliad and Cuero) had < 3 post-flood observations and were not analyzed. Riffle sample scores were not different ($P > 0.05$) between pre-flood and post-flood along PC I for the remaining eight sites. Riffle sample scores were different ($P < 0.05$) for three (i.e., Bandera, Gatesville, and Little River - Academy) between pre-flood and post-flood for PC II. At these three sites, riffle sample scores were less post-flood than pre-flood, indicating less gravel or sand and more cobble post-flood.

BMI Communities

A total of 93,432 aquatic insects was taken, identified to order and family, and used to estimate densities among the 102 riffles (Appendix C). BMI communities were similar in order richness ($N_{Brazos} = 9$, $N_{GSA} = 9$) and family richness ($N_{Brazos} = 42$, $N_{GSA} = 43$) and dominance at the order and family level between basins. Dominant orders were Ephemeroptera (39% in relative abundance overall) and Trichoptera (21%), followed by Diptera (18%) and Coleoptera (17%). Relative abundance of Diptera was greater in the Brazos River (23%) than GSA River (13%). Correspondingly, relative abundance of Coleoptera was greater in the GSA River (20%) than in the Brazos River (14%). BMI community relative abundances were also similar at the family level. The following five families were the most dominant in both basins: Baetidae (11% in Brazos, 9.4% in GSA), Chironomidae (15%, 7.9%), Elmidae (13%, 20%), Hydropsychidae (17%, 12%), and Leptophlebiidae (15%, 22%).

Multivariate Associations

Twenty-five percent ($P < 0.01$) of the BMI density variation was explained by pure effects of physical and chemical habitat parameters (16%; $P < 0.01$), season (6.0%; $P < 0.01$), flood effects (1.8%; $P > 0.02$), and basin (1.6%; $P = 0.05$) (Figure 3). The first CCA axis described primarily a season and substrate gradient. Parameters strongly associated with CCA axis I were summer season (-0.51), gravel (0.47) and sand (0.54). BMI families strongly associated with CCA axis I were Polycentropodidae (-0.85), Philopotamidae (-0.53), Coenagrionidae (-0.49), Crambidae (-0.49), Naucoridae (-0.40), Corydalidae (-0.34), Simuliidae (0.32), Perlodidae (0.44), Ceratopogonidae (0.57), Tipulidae (0.59), and Perlidae (0.61). The second CCA axis described primarily a flood effect, water chemistry, and physical habitat gradient. Parameters strongly associated with CCA axis II were flood effect (0.69), pH (0.53), percent vegetation (-0.47), and sand (-0.45). BMI families strongly associated with CCA axis II were Ceratopogonidae (-0.72), Helicopsychidae (-0.70), Hydrophilidae (-0.57), Hydroptilidae (-0.47), Psephenidae (-0.40), Naucoridae (-0.31), Glossosomatidae (0.32), Perlodidae (0.40), Philopotamidae (0.43), Perlidae (0.44), and Polycentropodidae (0.51). Families with strong associations for CCA axis I and II represented 32% of the BMI community represented in multivariate analysis.

BMI Responses to Flood

Seven of the 11 sites had similar or greater BMI densities post-flood than pre-flood, whereas four of the 11 sites had lesser BMI densities post-flood than pre-flood. Seven sites with similar or greater BMI densities were located at or towards the upper reaches of their respected basins with high flow duration of <130 days. In contrast, four sites with lesser BMI densities were located towards the lower reaches of their respected basins with high flow duration of >150 days. Plotting differences in density between pre-flood and post-flood by lag times in sampling between pre-flood and post-flood suggest that BMI communities had time to recover before post-flood samples at the seven upper reach sites but not at the four lower reach sites (Figure 4).

BMI richness decreased following the flood among Brazos River sites ($F_{1,44}$ = 6.69, P = 0.01) and GSA sites ($F_{1,54}$ = 15.20, P < 0.001) (Table 3), whereas BMI density did not change among Brazos River sites ($F_{1,44}$ = 3.68, P = 0.06) or GSA sites ($F_{1,54}$ = 1.45, P = 0.23) (Table 4). By site, a decrease in BMI richness was detected at one site in the Brazos River basin (Easterly, $F_{1,9}$ = 7.13, P = 0.03), attributed to the non-detection of six families post-flood that represented 0.6% of the Navasota BMI community pre-flood. A decrease in BMI richness was also detected at one site in the GSA basin (Gonzales, $F_{1,5}$ = 7.97, P = 0.04), attributed to the non-detection of 16 families post-flood that represented 7.8% of the Gonzales BMI community pre-flood. Three sites (i.e., Comfort, Goliad, Cuero) had insufficient post-flood sampling (n < 3 samples) and were excluded from univariate analysis. By site, no changes in BMI density were detected in the Brazos or GSA basins.

Among sites, swift BMI did not differ between pre-flood and post-flood mean densities (paired t-test, t = 1.55, df = 10, P = 0.15) or mean relative abundances (paired t-test, t = 1.63, df = 10, P = 0.13). Moderate BMI did not differ between pre-flood and post-flood mean densities (paired t-test, t = 0.37, df = 10, P = 0.71) or mean relative abundances (paired t-test, t = 0.41, df = 10, P = 0.69). Slack BMI did not differ between pre-flood and post-flood mean densities (paired t-test, t = 0.21, df = 10, P = 0.83) or mean relative abundances (paired t-test, t = 1.82, df = 10, P = 0.10).

Within sites, densities of swift BMIs increased at three of eight sites (Kempner, Gatesville, and LRA), and relative abundances of swift BMIs increased at three of eight sites (Kempner, LRA, and Luling) (Table 5). Families contributing primarily to increases in swift BMI among the four sites were Isonychiidae (N of sites: 4; percent relative abundance change between pre-flood and post flood: 1.7 – 4.6%), Simuliidae (3 sites, 5.0 – 38%), Perlidae (2 sites, 2.7 – 4.8%), and Philopotamidae (2 sites, 0.7 – 1.5%). Among sites without detectable changes in swift BMI densities or relative abundances, changes in relative abundances ranged from -4.2 to 15.7% for Isonychiidae, -11.1 to 3.7% for Simuliidae, -6.1 to 18.4% for Perlidae, and -0.1 to 16% for Philopotamidae.

Densities of moderate BMI increased at one site (Gatesville), and relative abundances of moderate BMI decrease at two sites (Kempner and Luling) (Table 6). The family primarily contributed to the increases of moderate BMI at Gatesville was Hydropsychidae (33.8%). Families contributing primarily to decreases in moderate BMI among the two sites were Elmidae (2 sites, -20.81 – -23.6%) and Leptophlebiidae (2 sites, -39.94 – -8.42%). Among sites without detectable changes in moderate BMI densities or relative abundances, changes in relative abundances ranged from -17.9 to 27.0% for Hydropsychidae, -32.4 to 6.5% for Elmidae, and -21.7 to 14.6% for Leptophlebiidae.

Densities of slack BMI increased at one site (Kempner) and decreased at one site (Gonzales), and relative abundances of slack BMI decreased at one site (Bandera) (Table 7). The family primarily contributed to an increase in slack BMI density at Kempner was Chironomidae (8.29%). The family primarily contributed to decreases in slack BMI density at Gonzales was Chironomidae (-14.65%). Families primarily contributing to decreases in slack BMI relative abundance were Chironomidae (-5.91%), Hydroptilidae (-3.82%), and Coenagrionidae (-1.95%). Among sites without detectable changes in moderate BMI densities or relative abundances, changes in relative abundances ranged from -22.7 to 22.6% for Chironomidae, -1.5 to 0.13% for Hydroptilidae, and -2.3 to 0.31% for Coenagrionidae.

Among the 47 families reported within two basins, seven families (three swift BMI families, four moderate BMI families) had a mean relative abundance increase of ≥1%, and five families (three moderate BMI families, two slack BMI families) had a mean relative abundance decrease of ≥1% between pre-flood and post-flood periods. Baetidae had the greatest mean (± 1 SE) percent abundance increase (8.1% ± 2.47) and increased at 55% of the sites, followed by Hydropsychidae (3.9% ± 1.52; 55% of sites), Simuliidae (3.0% ± 1.14; 55% of sites), Gomphidae (2.4% ± 1.11; 36% of sites), Isonychiidae (2.5% ± 0.46; 72% of sites), Philopotamidae (2.0% ± 0.49; 60% of sites), and Leptohyphidae (1.9% ± 0.87; 36% of sites). Elmidae had the greatest mean (± 1 SE) percent abundance decrease (-10.0% ± 1.68) and decreased at 82% of the sites, followed by Leptophlebiidae (-8.62% ± 1.33; 82% of sites), Chironomidae (-2.8% ± 1.11; 64% of sites), Helicopsychidae (-2.1% ± 0.83; 67% of sites), and Hydroptilidae (-1.0% ± 0.10; 91% of sites).

4. DISCUSSION

High flow pulses differentially selecting swift or moderate BMI taxa, as predicted, was not supported among all sites. However, greater densities and relative abundances of swift and moderate BMI taxa were detected at some sites and lesser densities and relative abundances of moderate and slack BMI taxa at some sites suggest that high flow pulses are influencing community structure of BMI taxa. Exact mechanisms of the differentially selection on resistance or resiliency of BMI taxa are unknown, and why flow-dependent responses of the BMI community are inconsistent among sites, but my study results support the continuation of exploring BMI communities as indicators of environmental flow standards.

In the absence of long-term BMI community data to adequately quantify recovery, BMI communities at seven of the 11 sites seemed to have recovered within 600 days post-flood with some changes in taxa occurrence and proportions. Among riffle habitats with coarse substrates (i.e., gravel, cobble, boulder, and bedrock), reductions in BMI richness are found following flow pulses as low as 2 m^3/s (Fritz and Dodds 2004) and up to 1 in 2000 year event (flow estimate not available; Mundahl and Hunt 2011). Percent reduction in BMI richness range between 30 to 70% following catastrophic flooding (Mundahl and Hunt 2011). Reductions in BMI density were detected at flow pulses of 2 m^3/s (Angradi 1997; Fritz and Dodds 2004), >10 m^3/s (Suren and Jowett 2006), and 30 m^3/s (Scrimgeour and Winterbourn 1989) and range between 70 and 95% (Angradi 1997; Mundahl and Hunt 2011). Mechanisms for reduction in BMI richness and BMI density are thought to be related to disruption and mobilization of substrates (Scrimgeour and Winterbourn 1989; Angradi 1997; Collier and Quinn 2003). However, some BMI families (Baetidae and Hydropsychiidae; Rempel et al. 1999) shift towards flow refuge to resist high flow effects. Following the flow pulses, recovery to similar pre-flood richness and densities ranged between 42 days (Angradi 1997) and up to 22 months (Mundahl and Hunt 2011). Four sites located in the lower reaches of the basins seemed to not have recovered up to 750 days post-flood. High flow pulses were generally of greater magnitude in the lower reaches, remained above base flow conditions longer than in upper reaches, and affected by subsequent flow pulses, which can slow recovery times (Robinson et al. 2004).

Lack of consistency in detecting densities and proportions of swift, moderate, and slack BMI taxa could be attributed to several factors. One factor is that patterns in BMI communities tend to be highly variable spatially and temporally (Bêche et al. 2006; Leunda et al. 2009) and attributing community changes to a single independent variable (e.g., flow pulse) can be challenging. Another factor is that reported flow guilds (Extence et al. 1999), even with regional modifications using expert opinion, might not be relevant for the study area. Flow-positive taxa (i.e., taxa that increased in density or relative abundance at majority of sites) included taxa categorized as swift and moderate BMI taxa, and flow-negative taxa included taxa categorized as moderate and slack BMI taxa. Results of this study could be used in the future to help better identify flow-positive and flow-negative taxa for future studies. However, flow guilds were largely based on habitat associations (e.g., preferred current velocity). Preference for a higher current velocity does not necessarily translate into greater resistance or resilience to flood events, which might explain why some swift or slack BMI were responsive to high flow pulses. Although variable response among individual families was not consistent with the flow guilds, family-level responses support for differential selection on BMI communities following a large flood event. Trends in certain BMI taxa indicated some families were flood sensitive, therefore these families might be reliable indicators for water quantity management.

My results provide mixed implications for the role of floods in maintaining BMI communities and for the use of BMI as indicators for water quantity management. Flood effects were detected and positively associated with a few swift and moderate BMI (Baetidae, Hydropsychidae, Simuliidae, Isonychiidae, and Leptohyphidae) and negatively associated with a few moderate and slack BMI (Elmidae, Leptophlebiidae, Chironomidae, Helicopsychidae, and Hydroptilidae), but flood effects described less of BMI community variation than habitat and season, which is similar to the influence of floods reported by Angradi (1997). Furthermore, shifts among swift, moderate, and slack BMIs were not detected following a flood. While trends in BMI families were observed within this study the value of BMI communities as indicators for water quantity is unknown, however the use of BMI for water quality management is established and used globally (Metcalfe 1989; Resh et al. 1995). Before contemplating study implications, this study has a number of caveats. Long-term data sets, including biota and environmental parameters, are lacking at the 11 sites and would be beneficial in detecting and understanding more of the BMI community variation related to habitat, season, basin, and flow (Monk et al. 2006; Armanini et al. 2011). This study had a limited temporal perspective, which was a dry year followed by a very high flow wet year. Long-term data sets by would provide more site-level replication of low and high flow events. Site-level replication at low flow might be the most informative, given that low flow (e.g., subsistence flows) might be the primary factor of a dynamic flow regime in regulating swift, moderate, and slack BMIs (Fritz and Dodds 2004). With these caveats, it is apparent that more research is needed to address the value of flow pulses and floods in maintaining riverine BMI communities and the value of using BMI for water quantity management.

Biomonitoring of water quantity standards in Texas is at the beginning stages following the implementation of environmental flow standards for surface water in the GSA basin in 2012 and in the Brazos River basin in 2013 (https://www.tceq.texas.gov). Monitoring of BMI communities might or might not prove beneficial in directly linking ecological value to subsistence, base, and high flow pulse standards, but BMI communities are only part of a multidisciplinary approach, which also includes fish, riparian, and estuarine communities, to detect ecological value of water quantity standards in Texas and elsewhere (Monk et al. 2006). While floods are not recommended in water quantity management standards, value in monitoring floods and other flow pulses can provide insight into riverine biota relationship with dynamic characters of flows, which is described by the moniker “Natural Flow Paradigm” (Poff et al. 1997) and serves as the basis for water quantity standards in Texas (Vaugh et al. 2011; Gooch et al. 2012). Developing sound biomonitoring indicator species and protocols and taking the time necessary to understand biota relationship to flow are logical next steps following implementation of water quantity standards. Estimated surface water use is 4.2% of the naturalized runoff in North America (up to 30% in western North America; Haddeland et al. 2006). However, surface water demands (increase by 17% in Texas, 2020 – 2070; 2017 State Water Plan, http://www.twdb.texas.gov) and global climate change (Seager et al. 2013) will further restrict the quantity of water flowing through small creeks to large rivers in Texas and western North America. Ability to understand, protect, and manage water quantity needs now will benefit aquatic biota into the future.

Table 1. Study sites arranged and described by basin, system, river, and median base flow along with geographic location.

Basin	System	River or Creek	USGS Gauge Site	Ecoregion	Latitude	Longitude	Median flow (m^3/s)
Brazos	Little River	Lampasas	Kempner	Cross Timbers	31.079869	-98.016412	2.2
		Leon	Gatesville	Cross Timbers	31.424617	-97.749522	3.9
		Little River	Little River Academy	Cross Timbers	30.961320	-97.340860	22.9
	Brazos	Navasota	Easterly	Post Oak Savanna	31.254709	-96.330631	1.0
GSA	Guadalupe	Guadalupe	Comfort	Edwards Plateau	29.964438	-98.897769	4.1
		San Marcos	Luling	Post Oak Savanna	29.667002	-97.698840	7.8
		Guadalupe	Gonzales	Post Oak Savanna	29.484333	-97.448162	24.8
		Guadalupe	Cuero	Blackland Prairie	29.092864	-97.331378	39.1
	San Antonio	Medina	Bandera	Edwards Plateau	29.733283	-99.114473	2.0
		Cibolo	Falls City	Post Oak Savanna	29.022762	-97.919760	1.0
		San Antonio	Goliad	Blackland Prairie	28.661736	-97.389558	12.6

Table 2. Families present within this study that are classified within BMI flow guilds.

BMI Flow Guilds		
Swift	**Moderate**	**Slack**
Corydalidae	Baetidae	Athericidae
Heptageniidae	Calopterygidae	Caenidae
Isonychidae	Ceratopogonidae	Chironomidae
Perlidae	Elmidae	Coengrionidae
Perlodidae	Ephemerellidae	Cordulidae
Philoptamidae	Gomphidae	Corixidae
Psephenidae	Helicopsychidae	Empididae
Simulidae	Hydropsychidae	Gerridae
	Leptoceridae	Gyrinidae
	Leptohyphidae	Hydrophilidae
	Leptophlebidae	Hydroptilidae
	Polycentropodidae	Lestidae
	Psychomyiidae	Libellulidae
		Naurcoridae
		Neophemeridae
		Pleidae
		Polymitarcyidae
		Sciomyzidae
		Tabanidae
		Tipulidae
		Veliidae

Table 3. Pre-flood and post-flood BMI family richness across sites with sample size and t-test P-values. Dagger (†) indicates insufficient post-flood replication for univariate analysis.

		BMI Richness							
		Pre-flood			Post-flood			Post-flood Change	
		N	Richness	SE	N	Richness	SE	Change	P-value
Brazos	Kempner	6	20.33	1.41	6	17.17	1.38	–	0.14
	Gatesville	5	14.00	2.92	5	13.40	1.69	–	0.86
	LRA	6	18.33	0.95	7	13.86	1.90	–	0.07
	Easterly	5	15.20	1.50	6	10.83	0.83	Decrease	0.03
GSA	Bandera	7	15.86	2.21	3	10.67	0.67	–	0.17
	Comfort	6	17.33	1.69	2	18.50	0.50	†	†
	Luling	8	16.38	1.55	4	13.50	2.18	–	0.31
	Falls City	6	15.50	0.62	3	15.33	1.45	–	0.90
	Gonzales	4	15.40	1.75	3	7.00	1.00	Decrease	0.04
	Goliad	4	15.25	1.11	1	3.00	0.00	†	†
	Cuero	4	16.75	0.75	1	1.00	0.00	†	†

Table 4. Pre-flood and post-flood BMI density across sites with sample size and t-test P-values. Dagger (†) indicates insufficient post-flood replication for univariate analysis.

		BMI Density							
		Pre-flood			Post-flood			Post-flood Change	
		N	Density	SE	N	Density	SE	Change	P-value
Brazos	Kempner	6	333.5	73.64	6	432.5	76.19	–	0.37
	Gatesville	5	218.6	34.73	5	511.8	147.10	–	0.09
	LRA	6	277.2	84.55	7	371.9	136.07	–	0.58
	Easterly	5	185.9	57.83	6	253.4	65.14	–	0.46
GSA	Bandera	7	131.1	26.89	3	114.0	48.08	–	0.74
	Comfort	6	290.9	75.14	2	386.1	137.33	†	†
	Luling	8	344.7	120.06	4	134.1	57.20	–	0.26
	Falls City	6	131.0	49.85	3	155.0	89.25	–	0.21
	Gonzales	4	214.5	51.70	3	7.8	0.83	–	0.06
	Goliad	4	118.9	42.29	1	16.0	0.00	†	†
	Cuero	4	350.7	89.39	1	5.0	0.00	†	†

Table 5. Pre-flood and post-flood swift taxa density relative abundance (%) across sites with sample size and t-test P-values. Dagger (†) indicates insufficient post-flood replication for univariate analysis.

Swift									
		Pre-flood			Post-flood			Post-flood Change	
Density		N	Density	SE	N	Density	SE	Change	P-value
Brazos	Kempner	6	13.9	5.58	6	52.7	15.98	Increase	0.02
	Gatesville	5	20.1	8.27	5	112.3	32.40	Increase	0.02
	LRA	6	11.5	2.36	7	192.8	99.91	Increase	0.03
	Easterly	5	24.8	8.92	6	16.5	6.52	—	0.32
GSA	Bandera	7	17.3	4.23	3	40.6	13.81	—	0.11
	Comfort	6	99.6	31.26	2	114.0	50.30	—	†
	Luling	8	11.1	4.03	4	27.8	6.42	—	0.07
	Falls City	6	11.4	1.43	3	24.7	13.23	—	0.19
	Gonzales	4	21.0	4.65	3	23.5	22.51	—	0.31
	Goliad	4	36.0	10.09	1	3.2	—	—	†
	Cuero	4	27.4	10.48	1	0.0	—	—	†
		Pre-flood			Post-flood			Post-flood Change	
Relative Abundance		N	RA	SE	N	RA	SE	Change	P-value
Brazos	Kempner	6	3.7	1.39	6	8.6	1.83	Increase	0.04
	Gatesville	5	8.6	3.15	5	16.6	2.96	—	0.10
	LRA	6	4.3	1.08	7	37.3	7.88	Increase	0.01
	Easterly	5	14.0	4.71	6	5.7	2.15	—	0.11
GSA	Bandera	7	15.1	2.51	3	28.6	7.17	—	0.17
	Comfort	6	31.2	5.74	2	31.4	5.22	—	†
	Luling	8	3.0	0.78	4	19.0	5.94	Increase	0.03
	Falls City	6	8.2	1.67	3	9.6	1.31	—	0.43
	Gonzales	4	8.3	2.62	3	16.5	8.27	—	0.76
	Goliad	4	24.0	4.44	1	20.0	—	—	†
	Cuero	4	8.0	2.28	1	0.0	—	—	†

Table 6. Pre-flood and post-flood moderate taxa density relative abundance (%) across sites with sample size and t-test P-values. Dagger (†) indicates insufficient post-flood replication for univariate analysis.

		Moderate							
		Pre-flood			Post-flood			Post-flood Change	
Density		N	Density	SE	N	Density	SE	Change	P-value
Brazos	Kempner	6	297.3	43.47	6	424.4	81.23	—	0.18
	Gatesville	5	159.5	31.34	5	419.7	76.30	Increase	0.02
	LRA	6	207.4	35.89	7	155.4	45.72	—	0.23
	Easterly	5	100.8	31.02	6	146.1	27.50	—	0.28
GSA	Bandera	7	80.6	20.22	3	85.9	2.29	—	0.56
	Comfort	6	180.7	29.75	2	204.4	44.68	—	†
	Luling	8	299.2	114.26	4	114.9	30.65	—	0.49
	Falls City	6	124.6	24.31	3	191.2	79.63	—	0.42
	Gonzales	4	200.0	38.44	3	66.0	60.80	—	0.07
	Goliad	4	101.6	22.01	1	12.8	—	—	†
	Cuero	4	253.3	68.50	1	4.0	—	—	†
		Pre-flood			Post-flood			Post-flood Change	
Relative Abundance		N	RA	SE	N	RA	SE	Change	P-value
Brazos	Kempner	6	83.7	2.28	6	74.1	2.60	Decrease	0.02
	Gatesville	5	76.1	10.83	5	65.7	8.70	—	0.41
	LRA	6	75.0	10.56	7	55.6	7.24	—	0.13
	Easterly	5	53.9	10.17	6	56.1	6.92	—	0.88
GSA	Bandera	7	65.3	6.59	3	67.2	8.68	—	0.89
	Comfort	6	57.8	4.05	2	60.6	5.08	—	†
	Luling	8	81.0	4.73	4	59.4	4.61	Decrease	0.01
	Falls City	6	75.9	5.43	3	80.7	4.76	—	0.55
	Gonzales	4	73.3	10.20	3	73.7	3.36	—	0.92
	Goliad	4	67.1	7.91	1	80.0	—	—	†
	Cuero	4	81.0	7.79	1	100.0	—	—	†

Table 7. Pre-flood and post-flood slack taxa density and relative abundance (%) across sites with sample size and t-test P-values. Dagger (†) indicates insufficient post-flood replication for univariate analysis.

Slack									
		Pre-flood			Post-flood			Post-flood Change	
Density		N	Density	SE	N	Density	SE	Change	P-value
Brazos	Kempner	6	42.4	6.25	6	86.1	13.26	Increase	0.02
	Gatesville	5	36.6	21.01	5	100.2	33.28	—	0.27
	LRA	6	88.1	66.76	7	15.6	6.54	—	0.30
	Easterly	5	71.6	38.61	6	105.2	34.86	—	0.33
GSA	Bandera	7	20.5	5.34	3	6.1	3.06	—	0.06
	Comfort	6	35.6	9.78	2	27.3	7.65	—	†
	Luling	8	24.6	6.53	4	57.1	32.75	—	0.60
	Falls City	6	22.3	4.74	3	18.6	6.48	—	0.57
	Gonzales	4	56.3	35.34	3	4.1	3.35	Decrease	0.03
	Goliad	4	16.6	10.33	1	0.0	—	—	†
	Cuero	4	36.3	22.17	1	0.0	—	—	†
		Pre-flood			Post-flood			Post-flood Change	
Relative Abundance		N	RA	SE	N	RA	SE	Change	P-value
Brazos	Kempner	6	12.7	2.23	6	17.3	3.77	—	0.37
	Gatesville	5	15.3	8.40	5	17.7	7.95	—	0.77
	LRA	6	20.7	11.25	7	7.1	2.04	—	0.34
	Easterly	5	32.0	10.23	6	38.2	8.46	—	0.65
GSA	Bandera	7	19.6	5.21	3	4.2	1.73	Decrease	0.02
	Comfort	6	11.0	2.21	2	7.9	0.15	—	†
	Luling	8	16.0	4.70	4	21.6	9.33	—	0.56
	Falls City	6	15.9	4.42	3	9.7	4.46	—	0.36
	Gonzales	4	18.4	9.42	3	9.8	4.92	—	0.46
	Goliad	4	8.9	4.78	1	0.0	—	—	†
	Cuero	4	11.1	5.65	1	0.0	—	—	†

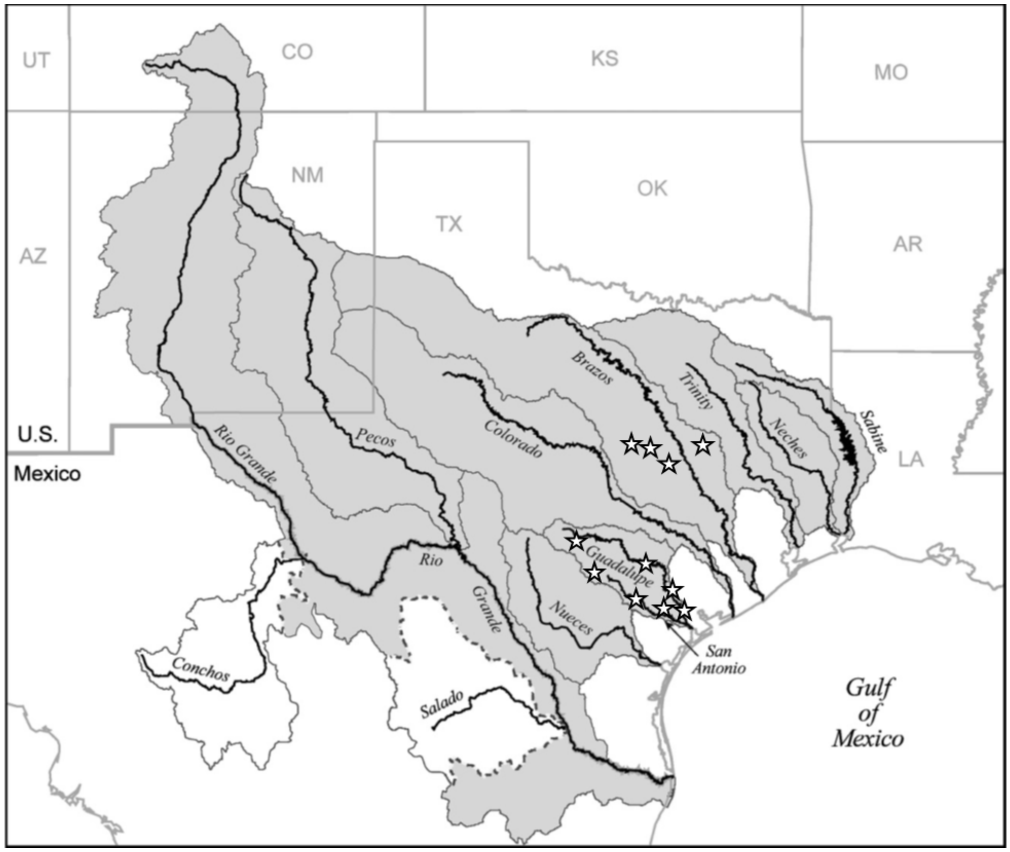


Figure 1. Gulf Coast rivers of the southwestern United States. Study sites are denoted with a star and were located within tributaries and rivers of the Brazos, Guadalupe and San Antonio River basins.

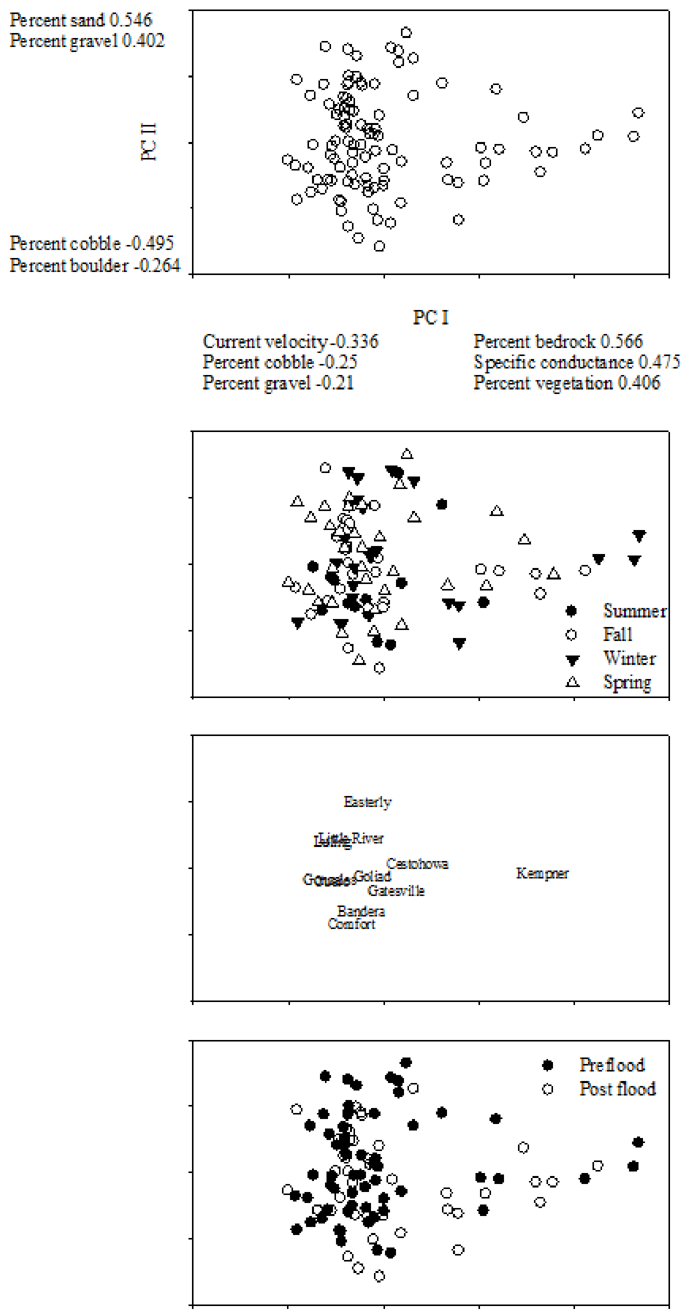


Figure 2. PCA explaining quantitative and qualitative habitat parameters on principal component axes 1 and 2 for samples, seasons, sites and post-flood.

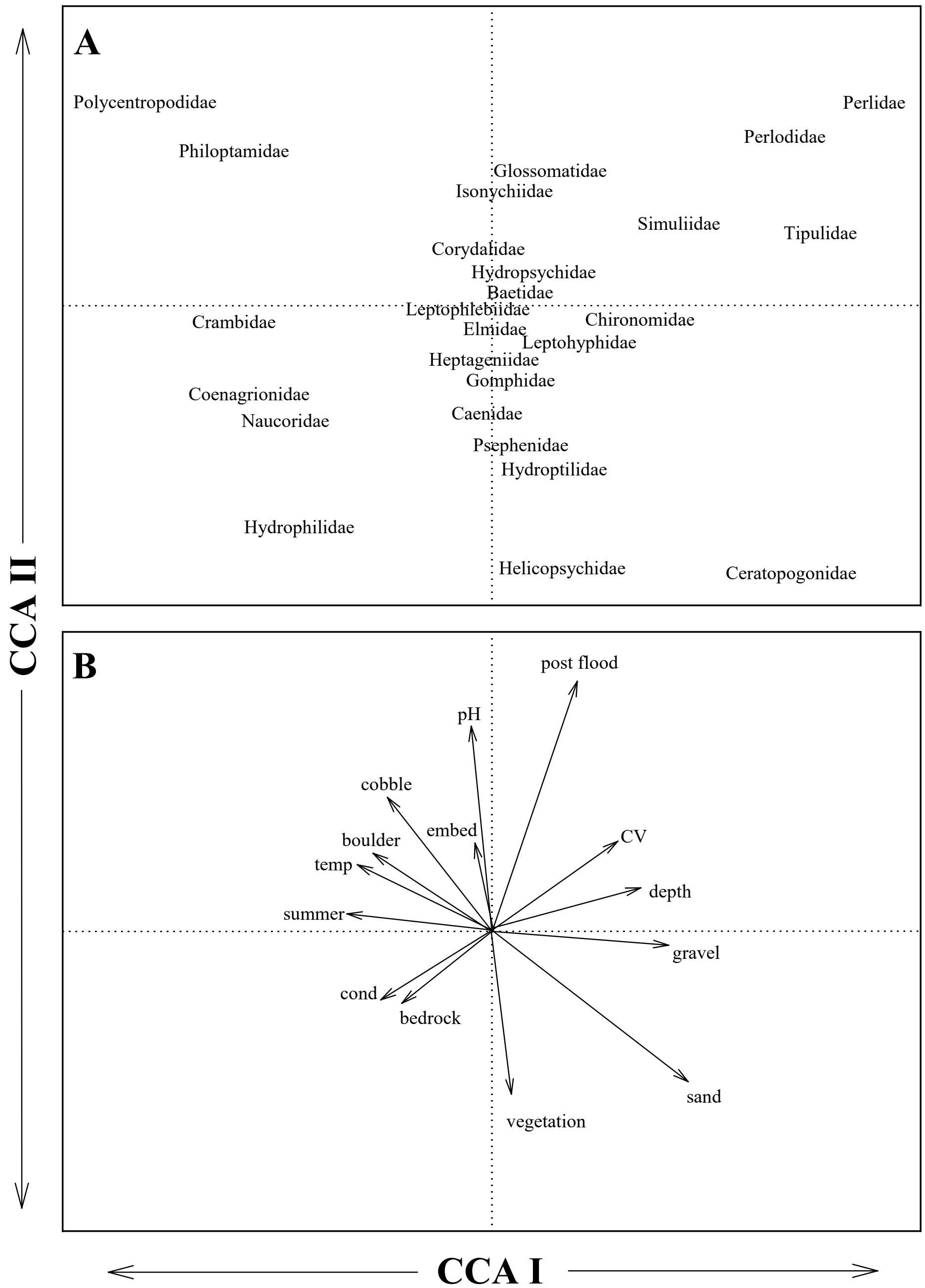


Figure 3. Canonical Correspondence Analysis (CCA) with BMI families and physical-chemical sample factors.

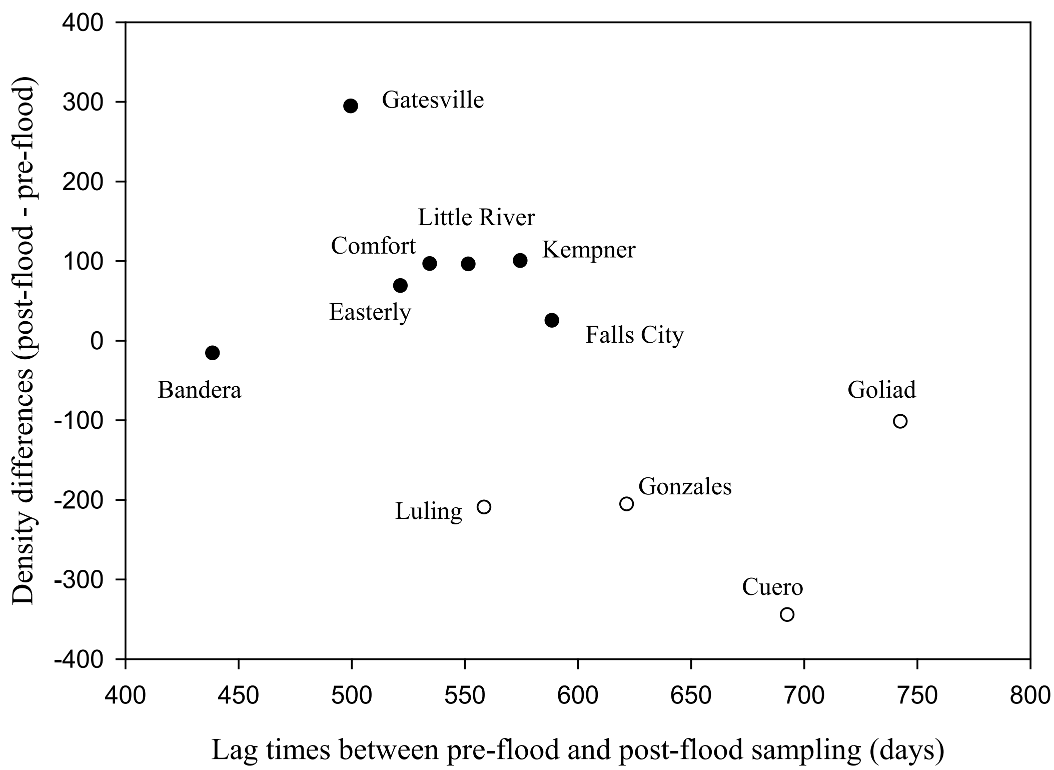
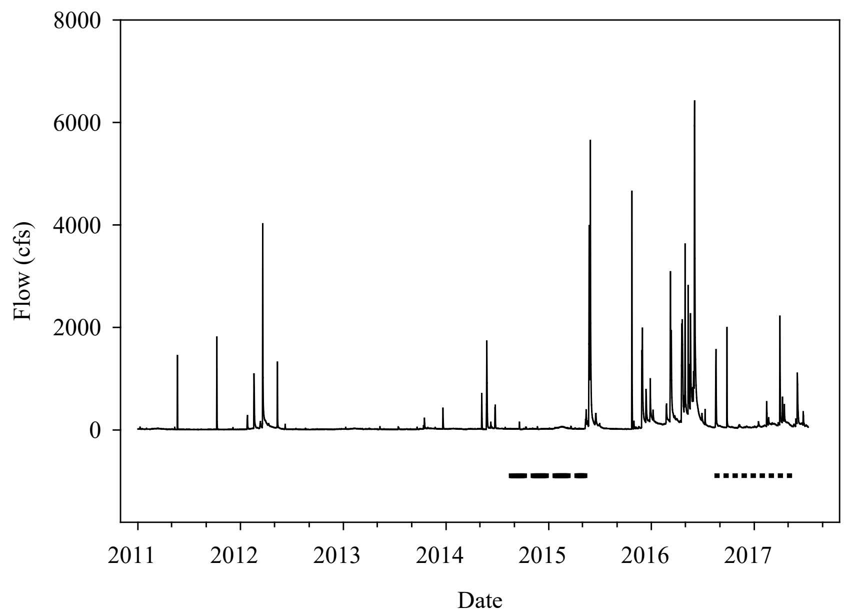


Figure 4. Plot of density differences between pre-flood and post-flood samples based on the number of days in between the last pre-flood sample and the first post-flood sample. Closed circles denote upper reach sites with flood durations less than 130 days. Open circles denote lower reach sites with flood durations greater than 150 days.

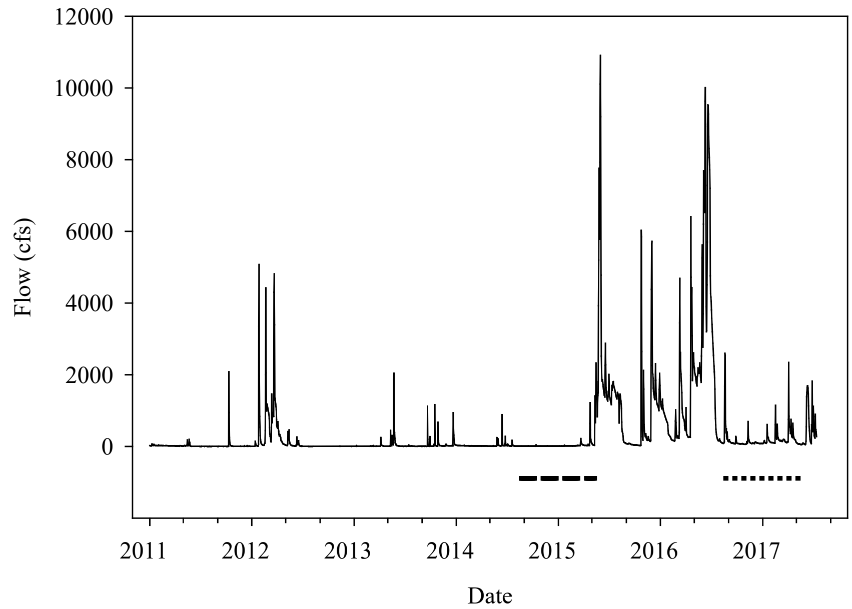
APPENDIX SECTION

Appendix A. USGS hydrographs from Brazos, Guadalupe and San Antonio River basin sites, January 2011 through July 2017. Dashed black line represents first year of the study (2014 – 2015, pre-flood) and dotted black line represents second year of the study (2016 – 2017, post-flood).

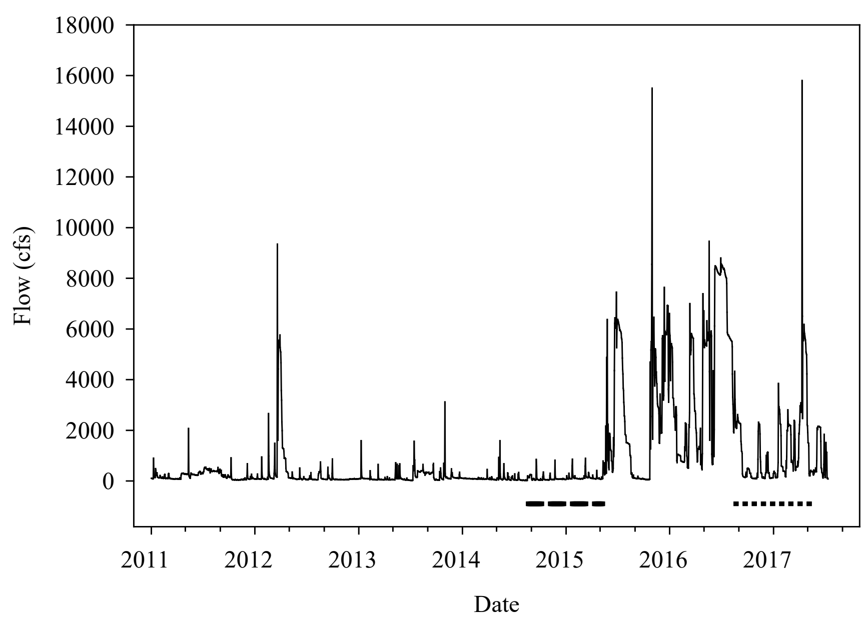
Lampasas River – Kempner USGS 08103800



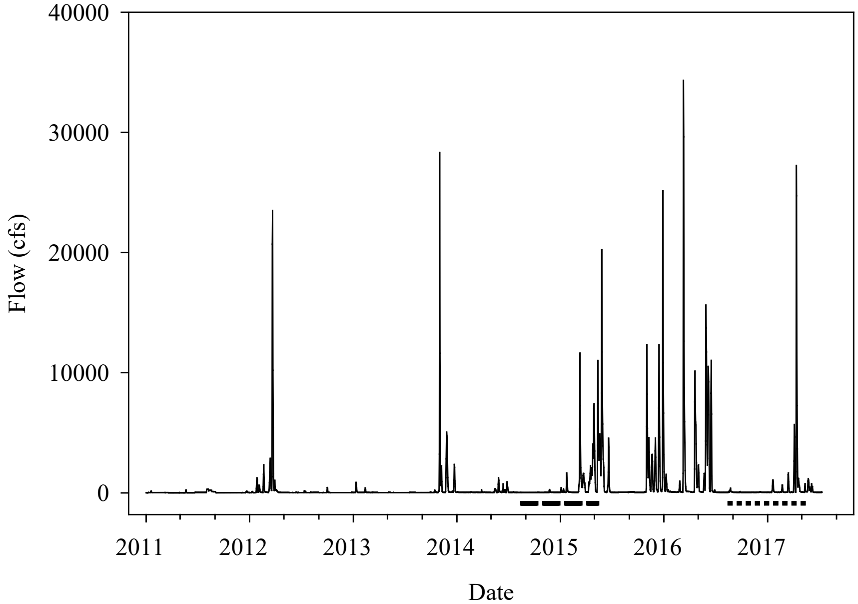
Leon River – Gatesville USGS 08100500



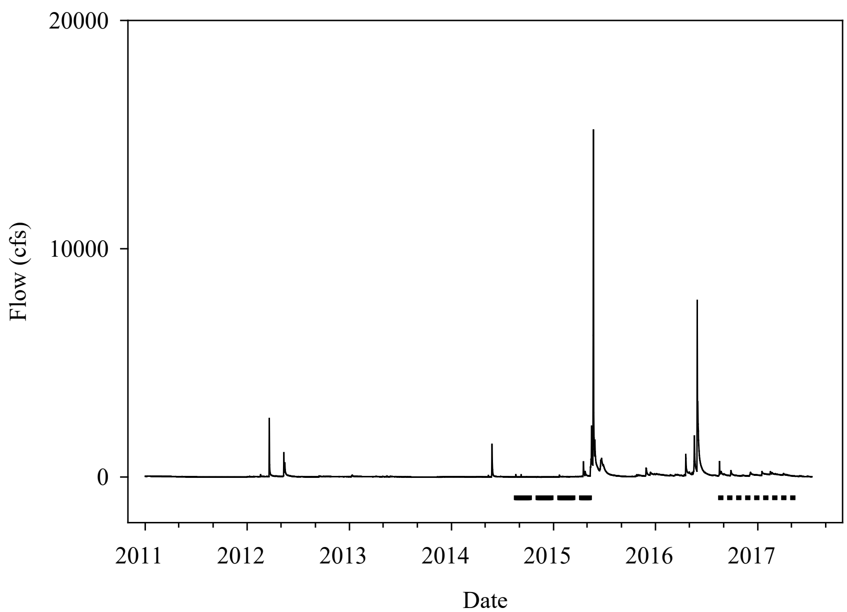
Little River – Little River - Academy USGS 08104500



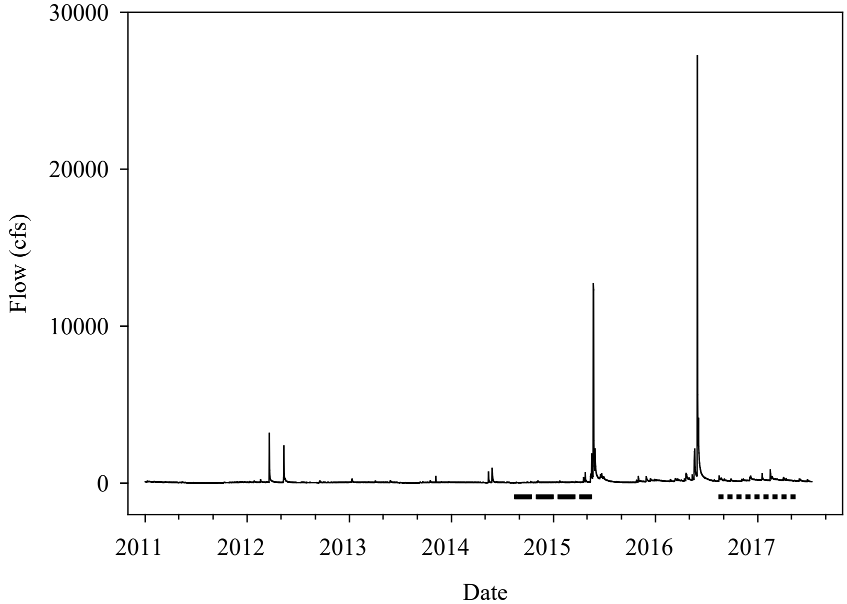
Navasota River – Easterly USGS 08110500



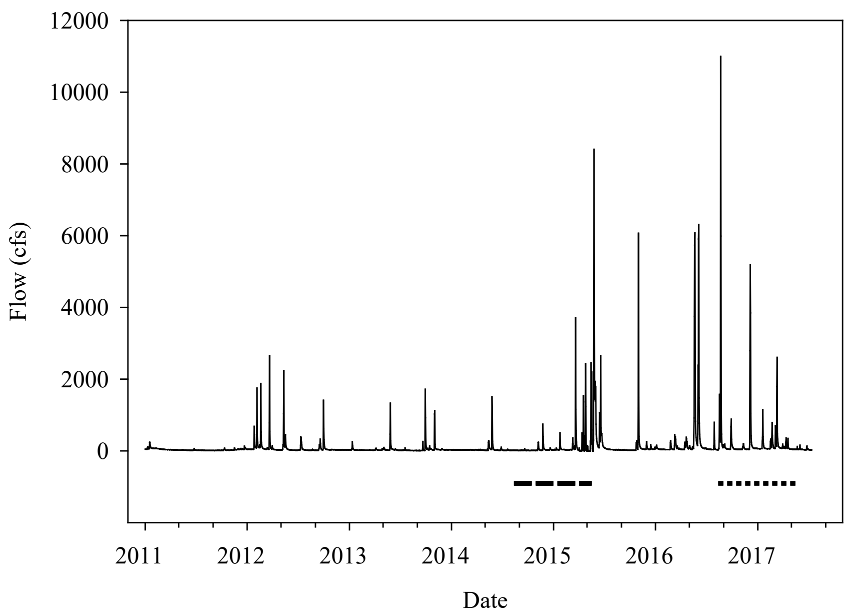
Medina River – Bandera USGS 08178880



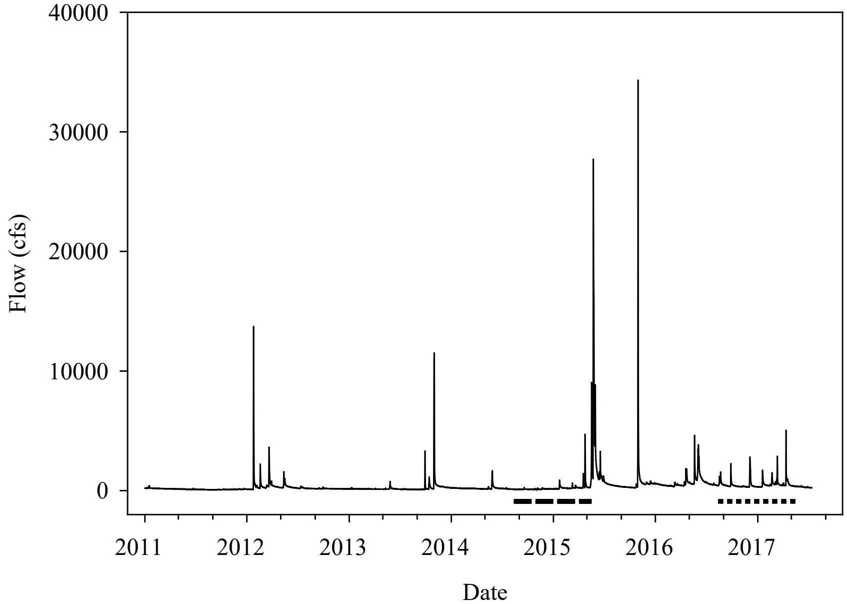
Guadalupe River - Comfort USGS 08167000



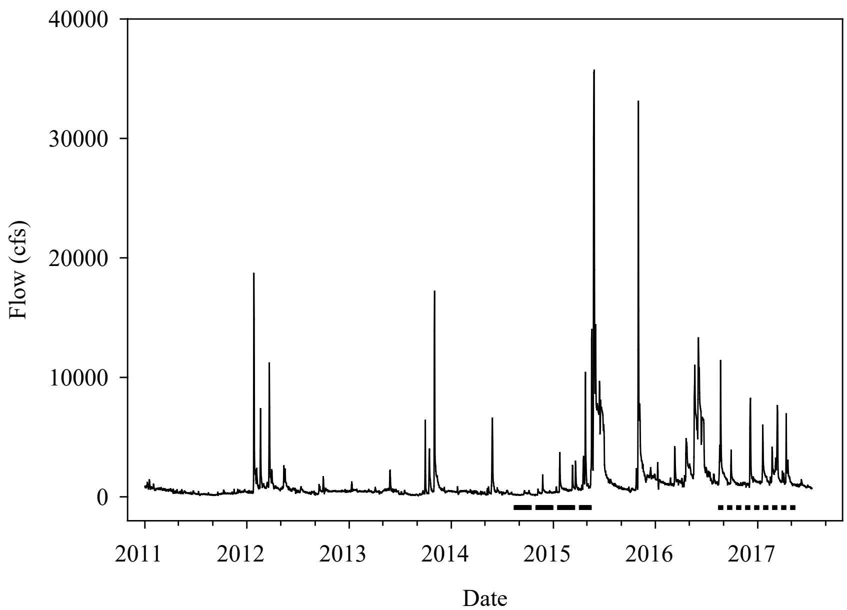
Cibolo Creek – Falls City USGS 08186000



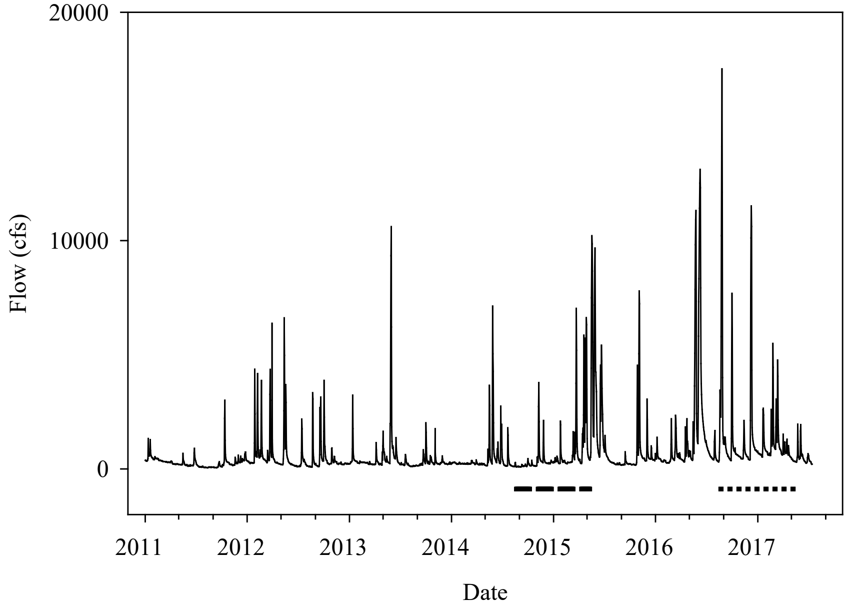
San Marcos River – Luling USGS 08172000



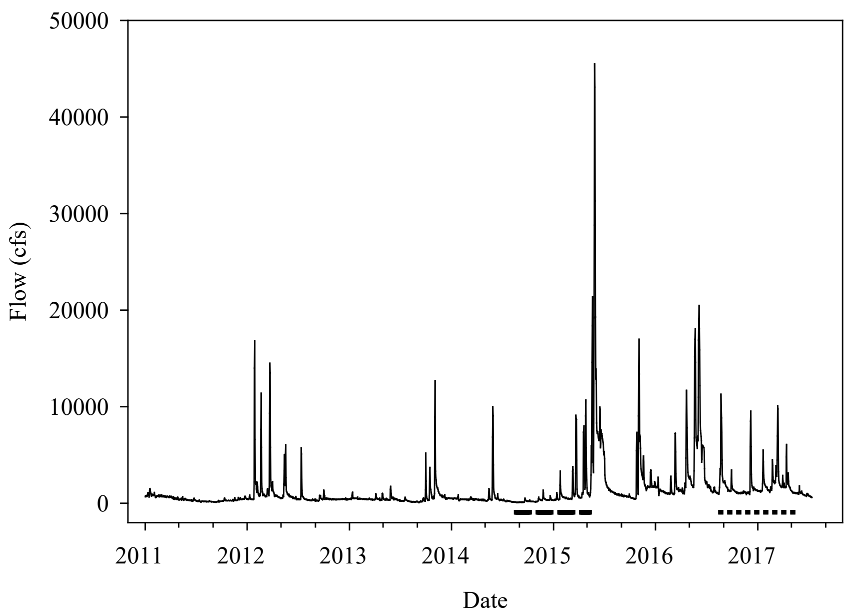
Guadalupe River – Gonzales USGS 08173900



San Antonio River – Goliad USGS 08188500



Guadalupe River – Cuero USGS 08175800



Appendix B. Samples, seasons and physical-chemical observations for all study sites.

Table B-1. Lampasas River at Kempner (USGS 08103800) sample and abiotic summaries with mean, standard deviation, minimum and maximum observed quantitiative abiotic values from 2014 - 2017.

Kempner

	N	Mean	SD	Min	Max
Samples	12				
Season					
Summer	1				
Fall	5				
Winter	3				
Spring	3				
Water Temperature (°C)		19.48	6.54	7.77	32.34
Dissolved Oxygen (mg/l)		10.62	2.64	6.63	15.24
Specific Conductance (µS/cm)		1208.16	495.42	581.00	1881.00
pH				7.16	9.37
Current Velocity (m/s)		0.47	0.18	0.22	0.75
Depth (m)		0.25	0.07	0.17	0.39
Vegetation (%)		35.42	27.06	0.00	70.00
Substrate					
Silt (%)		0.49	1.12	0.00	3.33
Sand (%)		5.93	7.00	0.00	23.33
Gravel (%)		34.94	15.45	15.00	61.67
Cobble (%)		2.39	3.32	0.00	8.33
Boulder (%)		5.14	9.49	0.00	28.33
Bedrock (%)		51.11	24.28	5.00	80.00

Table B-2. Leon River at Gatesville (USGS 08100500) sample and abiotic summaries with mean, standard deviation, minimum and maximum observed quantitiative abiotic values from 2014 - 2017.

Gatesville

	N	Mean	SD	Min	Max
Samples	10				
Season					
Summer	1				
Fall	3				
Winter	3				
Spring	3				
Water Temperature (°C)		19.38	7.55	7.76	31.16
Dissolved Oxygen (mg/l)		9.40	1.65	6.61	12.18
Specific Conductance (µS/cm)		635.41	119.72	429.00	795.00
pH				7.59	9.37
Current Velocity (m/s)		0.44	0.21	0.12	0.79
Depth (m)		0.17	0.10	0.06	0.34
Vegetation (%)		2.33	4.46	0.00	14.00
Substrate					
Silt (%)		0.20	0.63	0.00	2.00
Sand (%)		10.88	5.76	3.33	20.00
Gravel (%)		38.11	13.66	16.67	58.33
Cobble (%)		37.07	12.18	13.33	55.00
Boulder (%)		10.08	14.32	0.00	46.67
Bedrock (%)		3.67	8.67	0.00	26.67

Table B-3. Little River at Little River-Academy (USGS 08104500) sample and abiotic summaries with mean, standard deviation, minimum and maximum observed quantitiative abiotic values from 2014 - 2017.

Little River Academy

	N	Mean	SD	Min	Max
Samples	13				
Season					
Summer	1				
Fall	5				
Winter	4				
Spring	3				
Water Temperature (°C)		19.66	5.74	9.56	30.31
Dissolved Oxygen (mg/l)		9.23	2.11	6.67	12.20
Specific Conductance (µS/cm)		566.02	62.54	400.30	639.00
pH				7.00	9.05
Current Velocity (m/s)		0.73	0.15	0.29	0.88
Depth (m)		0.28	0.08	0.18	0.48
Vegetation (%)		13.33	22.29	0.00	66.67
Substrate					
Silt (%)		0.38	1.00	0.00	3.33
Sand (%)		15.77	8.41	0.00	30.00
Gravel (%)		66.54	12.83	35.00	85.00
Cobble (%)		17.31	12.72	3.33	43.33
Boulder (%)		0.00	0.00	0.00	0.00
Bedrock (%)		0.00	0.00	0.00	0.00

Table B-4. Navasota River near Easterly (USGS 08110500) sample and abiotic summaries with mean, standard deviation, minimum and maximum observed quantitiative abiotic values from 2014 - 2017.

Easterly

	N	Mean	SD	Min	Max
Samples	11				
Season					
Summer	1				
Fall	3				
Winter	4				
Spring	3				
Water Temperature (°C)		19.54	6.52	8.59	30.35
Dissolved Oxygen (mg/l)		8.66	2.51	5.16	13.05
Specific Conductance (µS/cm)		290.72	44.72	233.00	358.00
pH				6.98	8.27
Current Velocity (m/s)		0.45	0.15	0.30	0.82
Depth (m)		0.19	0.05	0.09	0.25
Vegetation (%)		13.03	22.92	0.00	66.67
Substrate					
Silt (%)		7.73	9.26	0.00	26.67
Sand (%)		27.16	9.82	13.33	46.67
Gravel (%)		50.08	12.52	33.33	70.00
Cobble (%)		11.78	8.79	3.33	30.00
Boulder (%)		3.26	4.16	0.00	15.00
Bedrock (%)		0.00	0.00	0.00	0.00

Table B-5. Medina River near Bandera (USGS 08178880) sample and abiotic summaries with mean, standard deviation, minimum and maximum observed quantitiative abiotic values from 2014 - 2017.

Bandera

	N	Mean	SD	Min	Max
Samples	10				
Season					
Summer	3				
Fall	2				
Winter	2				
Spring	3				
Water Temperature (°C)		21.12	5.96	12.15	28.81
Dissolved Oxygen (mg/l)		8.75	1.58	6.94	11.20
Specific Conductance (µS/cm)		637.80	58.79	521.00	717.00
pH				6.90	9.20
Current Velocity (m/s)		0.65	0.26	0.30	1.20
Depth (m)		0.24	0.09	0.09	0.33
Vegetation (%)		4.03	5.03	0.00	11.67
Substrate					
Silt (%)		0.00	0.00	0.00	0.00
Sand (%)		4.31	3.70	0.00	10.83
Gravel (%)		36.09	15.97	18.75	60.00
Cobble (%)		50.35	15.89	30.00	76.67
Boulder (%)		9.25	14.46	0.00	36.67
Bedrock (%)		0.00	0.00	0.00	0.00

Table B-6. Guadalupe River near Comfort (USGS 08167000) sample and abiotic summaries with mean, standard deviation, minimum and maximum observed quantitiative abiotic values from 2014 - 2017.

Comfort

	N	Mean	SD	Min	Max
Samples	8				
Season					
Summer	2				
Fall	1				
Winter	2				
Spring	3				
Water Temperature (°C)		19.83	6.26	10.89	28.18
Dissolved Oxygen (mg/l)		9.28	2.65	6.00	13.10
Specific Conductance (µS/cm)		528.88	21.66	501.00	567.00
pH				7.08	9.12
Current Velocity (m/s)		0.79	0.27	0.40	1.27
Depth (m)		0.23	0.06	0.15	0.29
Vegetation (%)		13.96	10.61	0.00	30.00
Substrate					
Silt (%)		0.42	0.77	0.00	1.67
Sand (%)		3.23	3.41	0.00	10.00
Gravel (%)		26.09	10.49	8.33	41.67
Cobble (%)		66.56	15.11	46.67	90.00
Boulder (%)		3.70	6.48	0.00	16.25
Bedrock (%)		0.00	0.00	0.00	0.00

Table B-7. San Marcos River near Luling (USGS 08172000) sample and abiotic summaries with mean, standard deviation, minimum and maximum observed quantitiative abiotic values from 2014 - 2017.

Luling	N	Mean	SD	Min	Max
Samples	12				
Season					
Summer	1				
Fall	4				
Winter	2				
Spring	5				
Water Temperature (°C)		21.47	6.24	11.45	30.04
Dissolved Oxygen (mg/l)		8.29	2.41	4.80	13.76
Specific Conductance (µS/cm)		516.90	43.68	407.00	567.00
pH				7.10	8.76
Current Velocity (m/s)		0.79	0.19	0.51	1.22
Depth (m)		0.36	0.11	0.19	0.56
Vegetation (%)		8.27	9.06	0.00	27.50
Substrate					
Silt (%)		0.42	1.04	0.00	3.33
Sand (%)		16.74	10.20	2.50	32.50
Gravel (%)		64.03	13.25	30.00	77.50
Cobble (%)		18.40	18.57	0.00	61.67
Boulder (%)		0.42	1.44	0.00	5.00
Bedrock (%)		0.00	0.00	0.00	0.00

Table B-8. Cibolo Creek near Falls City (USGS 08186000) sample and abiotic summaries with mean, standard deviation, minimum and maximum observed quantitiative abiotic values from 2014 - 2017.

Falls City

	N	Mean	SD	Min	Max
Samples	9				
Season					
Summer	1				
Fall	2				
Winter	3				
Spring	3				
Water Temperature (°C)		18.31	6.50	10.83	31.05
Dissolved Oxygen (mg/l)		10.11	2.85	7.05	15.91
Specific Conductance (µS/cm)		866.56	224.60	613.00	1171.00
pH				7.28	8.98
Current Velocity (m/s)		0.57	0.12	0.36	0.72
Depth (m)		0.28	0.09	0.15	0.43
Vegetation (%)		19.81	27.77	0.00	80.00
Substrate					
Silt (%)		2.59	7.78	0.00	23.33
Sand (%)		15.52	9.87	0.00	31.67
Gravel (%)		39.16	20.01	10.00	80.00
Cobble (%)		28.52	24.39	0.00	72.50
Boulder (%)		1.59	3.34	0.00	10.00
Bedrock (%)		12.62	20.37	0.00	61.25

Table B-9. Guadalupe River near Gonzales (USGS 08173900) sample and abiotic summaries with mean, standard deviation, minimum and maximum observed quantitiative abiotic values from 2014 - 2017.

Gonzales

	N	Mean	SD	Min	Max
Samples	7				
Season					
Summer	1				
Fall	2				
Winter	1				
Spring	3				
Water Temperature (°C)		20.11	7.27	10.24	32.28
Dissolved Oxygen (mg/l)		9.04	2.05	7.41	13.18
Specific Conductance (µS/cm)		520.80	35.88	455.00	562.00
pH				7.93	9.35
Current Velocity (m/s)		0.82	0.15	0.64	1.04
Depth (m)		0.39	0.15	0.15	0.64
Vegetation (%)		1.71	4.54	0.00	12.00
Substrate					
Silt (%)		1.52	2.14	0.00	5.00
Sand (%)		8.57	8.23	1.67	21.00
Gravel (%)		56.50	16.12	37.67	80.00
Cobble (%)		32.93	22.92	0.00	59.00
Boulder (%)		0.48	1.26	0.00	3.33
Bedrock (%)		0.00	0.00	0.00	0.00

Table B-10. San Antonio River near Goliad (USGS 08173900) sample and abiotic summaries with mean, standard deviation, minimum and maximum observed quantitiative abiotic values from 2014 - 2017.

Goliad	N	Mean	SD	Min	Max
Samples	5				
Season					
Summer	1				
Fall	0				
Winter	1				
Spring	3				
Water Temperature (°C)		21.83	6.22	12.78	28.62
Dissolved Oxygen (mg/l)		8.18	2.50	5.50	12.10
Specific Conductance (µS/cm)		1034.20	153.80	844.00	1212.00
pH				7.64	9.20
Current Velocity (m/s)		0.77	0.11	0.62	0.91
Depth (m)		0.37	0.09	0.29	0.53
Vegetation (%)		8.00	17.89	0.00	40.00
Substrate					
Silt (%)		7.67	17.14	0.00	38.33
Sand (%)		10.00	7.82	1.67	18.33
Gravel (%)		46.33	20.80	16.67	71.67
Cobble (%)		36.00	31.50	8.33	78.33
Boulder (%)		0.00	0.00	0.00	0.00
Bedrock (%)		0.00	0.00	0.00	0.00

Table B-11. Guadalupe River near Cuero (USGS 08175800) sample and abiotic summaries with mean, standard deviation, minimum and maximum observed quantitiative abiotic values from 2014 - 2017.

Cuero	N	Mean	SD	Min	Max
Samples	5				
Season					
Summer	1				
Fall	1				
Winter	0				
Spring	3				
Water Temperature (°C)		20.77	8.24	12.02	31.68
Dissolved Oxygen (mg/l)		9.11	2.37	6.40	12.26
Specific Conductance (µS/cm)		519.75	16.35	501.00	536.00
pH				7.70	8.88
Current Velocity (m/s)		0.90	0.28	0.59	1.31
Depth (m)		0.34	0.14	0.23	0.57
Vegetation (%)		11.25	17.05	0.00	40.00
Substrate					
Silt (%)		0.33	0.75	0.00	1.67
Sand (%)		12.25	4.48	6.25	16.67
Gravel (%)		45.08	20.42	16.67	65.00
Cobble (%)		42.33	20.67	20.00	66.67
Boulder (%)		0.00	0.00	0.00	0.00
Bedrock (%)		0.00	0.00	0.00	0.00

Appendix C. Community data for all samples during the study, including density and relative abundance.

Table C-1. Relative abundance and total N for BMI quantified across the Brazos basin, including pre-flood, post-flood, and total relative abundance across all sites.

Brazos						
	Pre		**Post**		**Total**	
Order	N	RA	N	RA	N	RA
Diptera	1102.0	19.38	2627.5	25.74	3729.5	24.92
Odonata	192.5	3.39	101.5	0.99	294.1	1.97
Ephemeroptera	2003.4	35.23	3305.9	32.39	5309.4	35.48
Coleoptera	1408.3	24.77	663.7	6.50	2072.0	13.85
Plecopotera	18.0	0.32	162.9	1.60	180.8	1.21
Megaloptera	8.1	0.14	15.9	0.16	24.0	0.16
Trichoptera	873.5	15.36	2348.3	23.01	3221.9	21.53
Hemiptera	67.7	1.19	14.3	0.14	81.9	0.55
Lepidoptera	12.9	0.23	37.7	0.37	50.7	0.34
Family						
Sciomyzidae	0.0	0.00	1.8	0.02	1.8	0.01
Ceratopogonidae	14.6	0.26	3.9	0.04	18.5	0.12
Tanyderidae	0.0	0.00	1.1	0.01	1.1	0.01
Chironomidae	925.7	16.28	1313.1	12.86	2238.8	14.96
Athericidae	3.1	0.05	0.8	0.01	4.0	0.03
Tabanidae	11.3	0.20	5.4	0.05	16.7	0.11
Empididae	0.0	0.00	2.8	0.03	2.8	0.02
Simuliidae	108.2	1.90	1291.6	12.65	1399.8	9.35
Tipulidae	0.3	0.01	1.6	0.02	1.9	0.01
Gomphidae	75.5	1.33	43.7	0.43	119.2	0.80
Lestidae	0.0	0.00	0.0	0.00	0.0	0.00
Cordulidae	6.1	0.11	3.3	0.03	9.4	0.06
Libellulidae	3.7	0.07	11.8	0.12	15.5	0.10
Coenagrionidae	95.1	1.67	42.0	0.41	137.2	0.92
Calopterygidae	0.0	0.00	0.9	0.01	0.9	0.01
Caenidae	17.3	0.30	37.8	0.37	55.1	0.37
Baetidae	504.7	8.88	1162.1	11.38	1666.8	11.14
Isonychiidae	50.2	0.88	332.0	3.25	382.2	2.55
Neoephemeridae	0.0	0.00	4.7	0.05	4.7	0.03
Heptageniidae	87.2	1.53	108.1	1.06	195.3	1.31
Ephemerellidae	1.9	0.03	1.5	0.01	3.4	0.02
Leptohyphidae	311.5	5.48	514.3	5.04	825.8	5.52
Polymitarcyidae	0.0	0.00	0.0	0.00	0.0	0.00
Leptophlebiidae	1056.2	18.57	1141.0	11.18	2197.2	14.68
Carabidae	21.8	0.38	0.0	0.00	21.8	0.15
Hydrophilidae	26.2	0.46	20.4	0.20	46.6	0.31
Gyrinidae	0.0	0.00	0.0	0.00	0.0	0.00
Elmidae	1356.7	23.86	648.3	6.35	2005.0	13.40
Psephenidae	19.7	0.35	1.1	0.01	20.9	0.14
Perlidae	13.9	0.25	145.8	1.43	159.7	1.07
Perlodidae	3.5	0.06	8.6	0.08	12.0	0.08
Corydalidae	8.2	0.14	16.1	0.16	24.3	0.16
Helicopsychidae	144.8	2.55	23.2	0.23	168.1	1.12
Hydropsychidae	548.2	9.64	1939.0	19.00	2487.2	16.62
Glossosomatidae	12.6	0.22	72.4	0.71	85.0	0.57
Philopotamidae	65.1	1.14	225.1	2.20	290.1	1.94
Hydroptilidae	90.8	1.60	60.8	0.60	151.6	1.01
Leptoceridae	2.3	0.04	6.4	0.06	8.7	0.06
Polycentropodidae	17.6	0.31	19.3	0.19	36.9	0.25
Odontoceridae	0.3	0.01	0.0	0.00	0.3	0.00
Psychomyiidae	0.5	0.01	13.4	0.13	13.8	0.09
Naucoridae	68.4	1.20	13.8	0.14	82.2	0.55
Corixidae	0.0	0.00	0.0	0.00	0.0	0.00
Veliidae	0.0	0.00	0.0	0.00	0.0	0.00
Gerridae	0.0	0.00	0.0	0.00	0.0	0.00
Pleidae	0.0	0.00	0.6	0.01	0.6	0.00
Crambidae	13.1	0.23	38.1	0.37	51.2	0.34
Total	5686		10207		14964	

Table C-2. Relative abundance and total N for BMI quantified across the Guadalupe – San Antonio basin, including pre-flood, post-flood, and total relative abundance across all sites.

GSA						
	Pre		Post		Total	
Order	N	RA	N	RA	N	RA
Diptera	1064.3	11.97	433.2	15.86	1497.5	12.88
Odonata	224.1	2.52	56.9	2.08	281.1	2.42
Ephemeroptera	3726.4	41.92	1052.3	38.52	4778.8	41.12
Coleoptera	1973.1	22.19	258.6	9.46	2231.7	19.20
Plecopotera	102.6	1.15	110.7	4.05	213.3	1.84
Megaloptera	86.5	0.97	35.5	1.30	122.0	1.05
Trichoptera	1604.2	18.04	768.9	28.14	2373.2	20.42
Hemiptera	86.6	0.97	13.3	0.49	99.8	0.86
Lepidoptera	22.4	0.25	2.7	0.10	25.1	0.22
Family						
Sciomyzidae	0.0	0.00	0.0	0.00	0.0	0.00
Ceratopogonidae	27.7	0.31	0.0	0.00	27.7	0.24
Tanyderidae	0.0	0.00	0.0	0.00	0.0	0.00
Chironomidae	689.0	7.75	226.5	8.29	915.5	7.88
Athericidae	12.4	0.14	6.5	0.24	19.0	0.16
Tabanidae	3.4	0.04	1.2	0.04	4.6	0.04
Empididae	1.7	0.02	12.4	0.45	14.1	0.12
Simuliidae	234.1	2.63	128.3	4.70	362.4	3.12
Tipulidae	15.7	0.18	26.8	0.98	42.6	0.37
Gomphidae	125.5	1.41	25.9	0.95	151.4	1.30
Lestidae	1.4	0.02	0.0	0.00	1.4	0.01
Cordulidae	8.5	0.10	3.8	0.14	12.4	0.11
Libellulidae	1.3	0.01	8.0	0.29	9.3	0.08
Coenagrionidae	92.8	1.04	19.0	0.70	111.8	0.96
Calopterygidae	1.8	0.02	0.0	0.00	1.8	0.02
Caenidae	16.7	0.19	3.7	0.13	20.4	0.18
Baetidae	827.0	9.30	261.4	9.57	1088.4	9.36
Isonychiidae	191.1	2.15	59.3	2.17	250.4	2.15
Neoephemeridae	0.8	0.01	0.0	0.00	0.8	0.01
Heptageniidae	68.2	0.77	8.6	0.32	76.8	0.66
Ephemerellidae	0.3	0.00	4.0	0.14	4.2	0.04
Leptohyphidae	522.6	5.88	314.0	11.49	836.6	7.20
Polymitarcyidae	0.8	0.01	0.0	0.00	0.8	0.01
Leptophlebiidae	2167.2	24.38	401.2	14.68	2568.3	22.10
Carabidae	0.0	0.00	0.2	0.01	0.2	0.00
Hydrophilidae	18.4	0.21	0.0	0.00	18.4	0.16
Gyrinidae	0.4	0.00	0.0	0.00	0.4	0.00
Elmidae	2042.8	22.98	272.0	9.96	2314.8	19.92
Psephenidae	13.9	0.16	2.5	0.09	16.4	0.14
Perlidae	100.8	1.13	95.4	3.49	196.2	1.69
Perlodidae	5.7	0.06	9.5	0.35	15.3	0.13
Corydalidae	90.5	1.02	36.7	1.34	127.2	1.09
Helicopsychidae	15.0	0.17	2.4	0.09	17.4	0.15
Hydropsychidae	913.4	10.27	486.1	17.79	1399.6	12.04
Glossosomatidae	23.8	0.27	24.6	0.90	48.4	0.42
Philopotamidae	410.6	4.62	238.2	8.72	648.7	5.58
Hydroptilidae	128.2	1.44	7.6	0.28	135.8	1.17
Leptoceridae	0.7	0.01	0.0	0.00	0.7	0.01
Polycentropodida	14.7	0.16	28.3	1.04	42.9	0.37
Odontoceridae	0.0	0.00	0.0	0.00	0.0	0.00
Psychomyiidae	4.9	0.05	1.0	0.04	5.8	0.05
Naucoridae	71.6	0.81	13.0	0.47	84.6	0.73
Corixidae	0.4	0.00	0.0	0.00	0.4	0.00
Veliidae	0.7	0.01	1.2	0.04	1.9	0.02
Gerridae	0.4	0.00	0.0	0.00	0.4	0.00
Pleidae	0.0	0.00	0.0	0.00	0.0	0.00
Crambidae	23.6	0.27	2.9	0.11	26.5	0.23
Total	8890		2732		11622	

Table C-3. Relative abundance and total N for BMI quantified across the Brazos basin, including pre-flood, post-flood, and total relative abundance by site.

Brazos Relative Abundance (%)

	Easterly			Gatesville			Kempner			LRA		
Order	**Pre**	**Post**	**All**	**Pre**	**Post**	**All**	**Pre**	**Post**	**All**	**Pre**	**Post**	**All**
Diptera	40.73	37.93	38.99	14.66	23.47	20.83	4.17	13.00	9.16	28.85	42.75	37.33
Odonata	3.27	1.27	2.03	3.06	0.20	1.06	5.30	2.35	3.63	1.36	0.62	0.91
Ephemeroptera	35.72	30.67	32.59	22.95	16.50	18.43	46.33	59.47	53.75	29.68	33.58	32.06
Coleoptera	8.72	15.29	12.80	29.57	7.35	14.00	28.89	4.92	15.36	25.61	4.43	12.69
Plecopotera	0.77	0.31	0.48	0.09	0.06	0.07	0.02	0.44	0.26	0.57	5.57	3.62
Megaloptera	0.36	0.40	0.38	0.07	0.04	0.05	0.11	0.19	0.16	0.11	0.15	0.13
Trichoptera	9.60	14.02	12.34	27.34	51.86	44.52	12.91	18.30	15.95	13.66	12.80	13.14
Hemiptera	0.76	0.11	0.36	2.13	0.00	0.64	1.76	0.38	0.98	0.12	0.11	0.11
Lepidoptera	0.07	0.00	0.03	0.12	0.52	0.40	0.52	0.95	0.76	0.03	0.00	0.01
Total N	**929**	**1520**	**2450**	**1093**	**2559**	**3652**	**2001**	**2595**	**4596**	**1663**	**2603**	**4266**
Family												
Sciomyzidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.01	0.00	0.04	0.03
Ceratopogonidae	0.71	0.21	0.40	0.00	0.00	0.00	0.24	0.03	0.12	0.20	0.00	0.08
Tanyderidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.03
Chironomidae	33.40	36.65	35.41	10.89	14.51	13.43	2.89	11.18	7.57	26.37	3.63	12.49
Athericidae	0.00	0.00	0.00	0.03	0.00	0.01	0.14	0.03	0.08	0.00	0.00	0.00
Tabanidae	0.00	0.00	0.00	0.10	0.00	0.03	0.31	0.17	0.23	0.24	0.04	0.12
Empididae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.07
Simuliidae	4.86	1.43	2.73	3.22	8.73	7.08	0.48	1.27	0.92	1.10	38.94	24.19
Tipulidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.01	0.02	0.04	0.03
Gomphidae	3.09	0.79	1.66	0.70	0.10	0.28	1.24	0.91	1.05	0.86	0.22	0.47
Cordulidae	0.03	0.00	0.01	0.02	0.00	0.01	0.19	0.05	0.11	0.11	0.08	0.09
Libellulidae	0.06	0.00	0.02	0.00	0.04	0.03	0.14	0.20	0.18	0.02	0.21	0.14
Coenagrionidae	0.19	0.50	0.39	2.36	0.06	0.75	3.04	1.22	2.01	0.40	0.05	0.19
Calopterygidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.02
Caenidae	0.95	1.21	1.11	0.18	0.00	0.05	0.33	0.71	0.54	0.00	0.03	0.02
Baetidae	11.65	7.50	9.08	7.29	5.10	5.76	10.72	23.49	17.93	6.14	11.82	9.61
Isonychiidae	1.37	1.42	1.40	2.03	4.90	4.04	0.42	2.10	1.37	0.41	5.01	3.22
Neoephemeridae	0.00	0.31	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Heptageniidae	5.17	1.28	2.75	1.98	1.48	1.63	0.40	1.60	1.08	0.58	0.36	0.44
Ephemerellidae	0.00	0.04	0.03	0.00	0.00	0.00	0.09	0.03	0.06	0.00	0.00	0.00
Leptohyphidae	6.83	11.32	9.61	2.55	0.83	1.35	5.80	11.19	8.84	6.26	1.17	3.16
Leptophlebiidae	10.86	6.93	8.42	9.04	4.25	5.68	28.98	20.56	24.23	16.63	15.11	15.70
Carabidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.31	0.00	0.51
Hydrophilidae	0.00	0.00	0.00	1.14	0.67	0.81	0.54	0.13	0.31	0.17	0.00	0.07
Gyrinidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Elmidae	8.99	15.51	13.04	28.31	6.71	13.18	28.44	4.87	15.13	23.72	4.39	11.93
Psephenidae	0.00	0.00	0.00	0.32	0.00	0.10	0.16	0.00	0.07	0.78	0.04	0.33
Perlidae	0.46	0.15	0.27	0.03	0.04	0.04	0.00	0.08	0.04	0.56	5.39	3.51
Perlodidae	0.27	0.00	0.10	0.06	0.02	0.03	0.00	0.12	0.07	0.02	0.19	0.12
Corydalidae	0.37	0.40	0.39	0.07	0.04	0.05	0.11	0.20	0.16	0.11	0.15	0.14
Helicopsychidae	0.00	0.00	0.00	12.21	0.00	3.65	0.29	0.90	0.63	0.34	0.00	0.13
Hydropsychidae	8.73	12.04	10.78	13.37	47.20	37.07	6.01	11.93	9.35	12.07	9.17	10.30
Glossosomatidae	0.08	0.05	0.06	0.16	1.13	0.84	0.43	0.33	0.37	0.09	1.31	0.83
Philopotamidae	0.07	1.46	0.93	1.52	2.17	1.97	2.28	3.81	3.15	0.13	1.86	1.18
Hydroptilidae	0.86	0.61	0.71	0.14	0.27	0.23	3.18	1.36	2.15	1.06	0.36	0.63
Leptoceridae	0.00	0.00	0.00	0.00	0.12	0.08	0.00	0.07	0.04	0.14	0.06	0.09
Polycentropodidae	0.13	0.00	0.05	0.00	0.76	0.53	0.81	0.00	0.35	0.01	0.00	0.01
Odontoceridae	0.03	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Psychomyiidae	0.00	0.05	0.03	0.00	0.36	0.25	0.02	0.09	0.06	0.00	0.04	0.02
Naucoridae	0.78	0.12	0.37	2.15	0.00	0.64	1.78	0.36	0.98	0.12	0.11	0.11
Pleidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.00	0.00	0.00
Crambidae	0.08	0.00	0.03	0.12	0.52	0.40	0.53	0.96	0.77	0.03	0.00	0.01
Total N	**929**	**1520**	**2450**	**1093**	**2559**	**3652**	**2001**	**2595**	**4596**	**1663**	**2603**	**4266**

Table C-4. Relative abundance and total N for BMI quantified across the Guadalupe – San Antonio basin, including pre-flood, post-flood, and total relative abundance by site.

GSA Relative Abundance (%)

	Bandera			**Comfort**			**Falls City**			**Luling**		
Order	**Pre**	**Post**	**All**	**Pre**	**Post**	**All**	**Pre**	**Post**	**All**	**Pre**	**Post**	**All**
Diptera	13.39	6.46	11.51	11.51	11.39	11.47	9.97	16.86	13.40	4.22	34.17	9.09
Odonata	9.92	3.25	8.11	1.84	2.05	1.91	6.93	1.19	4.07	0.92	2.02	1.10
Ephemeroptera	37.67	37.20	37.54	23.90	40.13	28.88	43.40	34.75	39.10	56.98	42.74	54.67
Coleoptera	17.45	17.35	17.42	16.13	14.13	15.52	19.21	3.39	11.34	29.28	8.87	25.96
Plecopotera	0.07	2.21	0.65	0.15	0.73	0.33	0.09	2.25	1.17	0.44	4.05	1.02
Megaloptera	0.74	2.70	1.28	0.13	0.90	0.37	0.58	0.14	0.36	1.78	1.38	1.72
Trichoptera	19.69	30.49	22.62	44.06	29.59	39.62	19.79	41.14	30.41	4.68	6.62	5.00
Hemiptera	0.65	0.34	0.57	1.96	0.99	1.66	0.00	0.00	0.00	1.53	0.15	1.30
Lepidoptera	0.42	0.00	0.30	0.31	0.08	0.24	0.03	0.27	0.15	0.17	0.00	0.14
Total N	**918**	**342**	**1260**	**1745**	**772**	**2517**	**786**	**778**	**1564**	**2758**	**536**	**3294**
Family												
Ceratopogonidae	0.43	0.00	0.32	0.27	0.00	0.18	0.28	0.00	0.14	0.11	0.00	0.09
Chironomidae	8.45	2.54	6.85	7.13	5.15	6.52	8.64	3.63	6.15	3.71	26.31	7.39
Athericidae	0.86	1.91	1.14	0.06	0.00	0.04	0.00	0.00	0.00	0.09	0.00	0.07
Tabanidae	0.04	0.35	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.08
Empididae	0.00	0.00	0.00	0.08	0.00	0.05	0.00	0.32	0.16	0.01	1.83	0.31
Simuliidae	4.49	1.52	3.68	3.76	7.42	4.88	2.13	4.90	3.51	0.13	5.17	0.95
Tipulidae	0.04	0.00	0.03	0.00	0.00	0.00	0.28	2.76	1.52	0.11	0.99	0.25
Gomphidae	5.97	0.76	4.56	0.18	0.73	0.35	5.28	0.34	2.82	0.46	0.96	0.54
Lestidae	0.16	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cordulidae	0.16	0.00	0.11	0.00	0.00	0.00	0.35	0.49	0.42	0.16	0.00	0.13
Libellulidae	0.00	0.76	0.21	0.00	0.13	0.04	0.00	0.19	0.10	0.04	0.53	0.12
Coenagrionidae	3.79	1.84	3.26	1.45	1.32	1.41	2.24	0.24	1.24	0.29	0.13	0.26
Calopterygidae	0.00	0.00	0.00	0.10	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00
Caenidae	0.35	0.00	0.26	0.00	0.00	0.00	0.94	0.47	0.71	0.07	0.00	0.06
Baetidae	11.19	14.73	12.15	4.92	8.07	5.89	7.17	11.38	9.26	7.64	5.32	7.26
Isonychiidae	0.71	1.94	1.04	6.84	2.60	5.54	2.76	1.99	2.38	0.31	2.30	0.64
Neoephemeridae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Heptageniidae	2.13	0.00	1.55	0.04	0.13	0.07	0.59	0.55	0.57	0.55	0.62	0.56
Ephemerellidae	0.00	0.00	0.00	0.00	0.10	0.03	0.00	0.13	0.06	0.01	0.17	0.03
Leptohyphidae	7.06	2.93	5.94	5.42	5.13	5.33	15.70	7.36	11.55	4.90	29.62	8.92
Polymitarcyidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Leptophlebiidae	13.75	18.88	15.14	6.41	21.04	10.90	16.82	15.07	15.95	44.82	4.88	38.32
Carabidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydrophilidae	0.04	0.00	0.03	0.05	0.00	0.03	1.22	0.00	0.61	0.23	0.00	0.20
Gyrinidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Elmidae	18.79	17.56	18.45	16.35	15.72	16.16	19.69	3.46	11.61	29.71	8.90	26.33
Psephenidae	0.08	0.38	0.16	0.28	0.00	0.19	0.91	0.15	0.53	0.00	0.00	0.00
Perlidae	0.08	0.00	0.06	0.07	0.62	0.24	0.07	2.08	1.07	0.29	3.02	0.74
Perlodidae	0.00	0.00	0.00	0.00	0.19	0.06	0.00	0.32	0.16	0.15	1.04	0.30
Corydalidae	0.81	2.79	1.35	0.13	1.01	0.40	0.66	0.15	0.41	1.82	1.39	1.75
Helicopsychidae	0.00	0.00	0.00	0.19	0.20	0.19	0.00	0.00	0.00	0.38	0.17	0.35
Hydropsychidae	8.69	6.84	8.19	22.72	4.81	17.23	13.50	40.45	26.90	0.77	5.87	1.60
Glossosomatidae	0.04	1.39	0.41	0.01	0.00	0.01	0.00	2.47	1.23	0.03	0.13	0.05
Philopotamidae	6.02	22.53	10.50	20.22	20.87	20.42	0.03	0.00	0.02	0.04	0.00	0.03
Hydroptilidae	3.82	0.00	2.78	0.66	0.30	0.55	0.70	0.52	0.61	1.72	0.22	1.48
Leptoceridae	0.00	0.00	0.00	0.02	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Polycentropodidae	0.68	0.00	0.49	0.39	3.16	1.24	0.00	0.30	0.15	0.00	0.26	0.04
Psychomyiidae	0.43	0.00	0.32	0.02	0.13	0.05	0.00	0.00	0.00	0.00	0.00	0.00
Naucoridae	0.42	0.00	0.31	1.92	1.11	1.67	0.00	0.00	0.00	1.16	0.15	0.99
Corixidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Veliidae	0.04	0.35	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01
Gerridae	0.04	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Crambidae	0.45	0.00	0.33	0.32	0.09	0.25	0.03	0.29	0.16	0.17	0.00	0.14
Total N	**918**	**342**	**1260**	**1745**	**772**	**2517**	**786**	**778**	**1564**	**2758**	**536**	**3294**

Table C-4 Cont. Relative abundance and total N for BMI quantified across the Guadalupe – San Antonio basin, including pre-flood, post-flood, and total relative abundance by site.

GSA Relative Abundance (%) Cont.

	Gonzales			Goliad			Cuero		
Order	**Pre**	**Post**	**All**	**Pre**	**Post**	**All**	**Pre**	**Post**	**All**
Diptera	22.14	3.11	17.19	20.46	0.00	19.80	19.27	0.00	19.20
Odonata	0.46	1.23	0.66	1.68	40.00	2.92	0.67	0.00	0.66
Ephemeroptera	48.24	38.36	45.68	39.91	20.00	39.26	33.70	80.00	33.86
Coleoptera	13.11	3.45	10.60	10.32	40.00	11.29	29.82	0.00	29.72
Plecopotera	2.23	20.60	7.00	5.82	0.00	5.63	2.92	0.00	2.91
Megaloptera	0.63	3.83	1.46	0.61	0.00	0.59	1.12	0.00	1.11
Trichoptera	12.57	28.15	16.62	21.02	0.00	20.34	12.02	20.00	12.05
Hemiptera	0.30	1.28	0.55	0.18	0.00	0.17	0.07	0.00	0.07
Lepidoptera	0.32	0.00	0.24	0.00	0.00	0.00	0.40	0.00	0.40
Total N	**805**	**283**	**1088**	**476**	**16**	**492**	**1403**	**5**	**1408**
Family									
Ceratopogonidae	0.27	0.00	0.20	0.72	0.00	0.70	0.60	0.00	0.59
Chironomidae	17.75	3.11	13.95	9.24	0.00	8.94	9.26	0.00	9.23
Athericidae	0.09	0.00	0.07	0.00	0.00	0.00	0.03	0.00	0.03
Tabanidae	0.04	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00
Empididae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Simuliidae	3.18	0.00	2.36	11.08	0.00	10.72	2.04	0.00	2.04
Tipulidae	0.54	0.00	0.40	0.00	0.00	0.00	0.41	0.00	0.41
Gomphidae	0.09	1.23	0.38	1.36	40.00	2.62	0.44	0.00	0.44
Lestidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cordulidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Libellulidae	0.00	0.00	0.00	0.05	0.00	0.05	0.00	0.00	0.00
Coenagrionidae	0.37	0.00	0.28	0.35	0.00	0.34	0.18	0.00	0.18
Calopterygidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Caenidae	0.00	0.00	0.00	0.88	0.00	0.85	0.00	0.00	0.00
Baetidae	17.86	9.41	15.66	10.55	0.00	10.20	12.65	####	12.96
Isonychiidae	0.25	0.55	0.33	4.33	20.00	4.84	0.88	0.00	0.88
Neoephemeridae	0.00	0.00	0.00	0.16	0.00	0.15	0.00	0.00	0.00
Heptageniidae	0.97	0.00	0.72	0.91	0.00	0.88	1.14	0.00	1.13
Ephemerellidae	0.00	0.47	0.12	0.00	0.00	0.00	0.00	0.00	0.00
Leptohyphidae	4.36	17.07	7.66	3.26	0.00	3.15	3.86	0.00	3.84
Polymitarcyidae	0.00	0.00	0.00	0.16	0.00	0.15	0.00	0.00	0.00
Leptophlebiidae	25.21	10.86	21.48	21.68	0.00	20.98	18.16	0.00	18.10
Carabidae	0.00	0.07	0.02	0.00	0.00	0.00	0.00	0.00	0.00
Hydrophilidae	0.09	0.00	0.07	0.00	0.00	0.00	0.03	0.00	0.03
Gyrinidae	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.03
Elmidae	12.98	3.38	10.48	10.84	40.00	11.79	32.42	0.00	32.30
Psephenidae	0.15	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.00
Perlidae	2.25	20.60	7.02	6.11	0.00	5.92	3.08	0.00	3.07
Perlodidae	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.10
Corydalidae	0.64	3.83	1.47	0.64	0.00	0.62	1.22	0.00	1.21
Helicopsychidae	0.13	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00
Hydropsychidae	10.40	28.08	15.00	16.61	0.00	16.07	10.48	0.00	10.44
Glossosomatidae	0.39	0.00	0.29	0.75	0.00	0.72	1.11	0.00	1.11
Philopotamidae	0.06	0.00	0.04	0.00	0.00	0.00	0.05	0.00	0.05
Hydroptilidae	1.07	0.00	0.79	0.16	0.00	0.15	1.37	0.00	1.37
Leptoceridae	0.04	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00
Polycentropodidae	0.12	0.07	0.11	0.08	0.00	0.08	0.03	0.00	0.03
Psychomyiidae	0.07	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00
Naucoridae	0.30	1.28	0.55	0.00	0.00	0.00	0.00	0.00	0.00
Corixidae	0.00	0.00	0.00	0.08	0.00	0.08	0.00	0.00	0.00
Veliidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gerridae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Crambidae	0.33	0.00	0.24	0.00	0.00	0.00	0.44	0.00	0.44
Total N	**805**	**283**	**1088**	**476**	**16**	**492**	**1403**	**5**	**1408**

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