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Resaca ecosystem development: colonization and succession of the macroinvertebrate community

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A Thesis Presented to the Graduate Faculty of the College of Science, Mathematics and Technology in Partial Fulfillment of the Requirements for the Degree of

Master of Science In the field of Biology

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Abstract

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Freshwater wetlands in the Lower Rio Grande Valley of Texas are locally known as resacas. Resacas are remnants of the Rio Grande River channel that were cut off by sedimentation and erosion of river banks. Many are maintained as permanent wetlands through intermittent water pumping from the river; and provide valuable habitat for fish, invertebrates, migratory birds and a diverse floral community in the semi-arid environment of South Texas. Three resacas in different stages of ecosystem development were studied, including one from day zero after re-flooding. The objectives were to document the colonization process of the re-flooded resaca and the macroinvertebrate community of all three sites to differentiate successional stages of the studied resacas. Two invertebrate collection methods were used, benthic corer and sweep net, in order to gather a representative sample from the entire community. Results indicated that environmental factors (i.e. water, sediment) varied little between resacas, but there were significant differences in the benthic and water column invertebrate communities among the sites studied. The most developed site exhibited the lowest diversity and richness, and the highest dominance. The intermediate site exhibited the greatest diversity and richness, and a low level of dominance. The new site fell between the other two, but was most similar to the intermediate site. Composition of the functional feeding groups did not follow expected trends within this community, but is still a useful metric for differentiating the study sites, particularly the predator and scraper taxa. The invertebrate community in the studied resacas did not follow successional trends that were expected based on other studies and the community was strongly influenced by the presence of an invasive gastropod. Based on the results of this baseline study, the invertebrate community may be useful in discriminating between successional stages of resacas.

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Chapter One

Background

Macroinvertebrates in Wetland Communities

Invertebrate communities are a vital component of wetland ecosystems. They provide an important food resource for many fish, birds and other vertebrates (Batzer and Wissinger, 1996); and as such are a crucial link between primary producers and higher trophic levels (Batzer and Wissinger, 1996). Macroinvertebrates are also involved in many ecosystem processes. They assist in the process of decomposition by breaking down leaf litter into smaller particles and consuming fine particulate organic matter to return nutrients to the trophic pathways (Reice and Wohlenberg, 1993). Due to invertebrates' central role in the flow of energy through aquatic ecosystems (Butkas et al., 2010), their community composition can be a useful tool to help understand wetland ecosystems.

Ecological Succession

Succession, the change in species composition over time, is a key concept in ecology (Walker et al., 2007). The general model of succession is that an early community of pioneer species quickly occupies a new opening in an ecosystem and eventually transitions to a relatively stable community of species with longer life cycles. This pioneer community typically consists of species that are able to easily disperse, reproduce rapidly and have low habitat requirements (Horn, 1974). Over time, the pioneer community is replaced by a more stable community that contains longer lived species that are efficient competitors and have more specific habitat requirements (Horn, 1974). This late successional community is also less diverse than previous communities, as some intermediate stage will contain a mix of both early and late successional species (Horn, 1974)

Most studies testing the theories of succession have focused on plant communities (Clements, 1936; Matthews and Spyreas, 2010), but many of the concepts can be applied to the aquatic invertebrate community of wetlands (Milner et al., 2008; Ruhí et al., 2013). Successional processes in wetlands are expected to progress in a predictable pattern (Barnes, 1983). In studies of ponds and wetlands, the sequence of colonization is primarily determined by the dispersal abilities of invertebrates, with active dispersers, mainly insects, being the first to arrive (Barnes, 1983; Canedo-Arguelles and Rieradevall, 2011; Gee et al., 1997; Hassall et al., 2012; Ruhí et al., 2012; Ruhí et al., 2013; Stewart and Downing, 2008). Hemiptera, Coleoptera and Chironomidae are all active dispersers and have been noted to be early colonizers (Barnes, 1983; Canedo-Arguelles and Rieradevall, 2011).

The rate of colonization and the composition of pioneer species is also affected by the proximity of existing wetlands that act as potential source pools (Canedo-Arguelles and Rieradevall, 2011). This initial colonization process occurs rapidly within the first two years (Bloechl et al., 2010; Ruhí et al., 2009; Voshell Jr and Simmons Jr, 1984), with later colonization being dependent on habitat characteristics (Barnes, 1983; Canedo-Arguelles and Rieradevall, 2011; Gee et al., 1997). In an age-series study of created ponds, Barnes (1983) found that the number of taxon present increased rapidly over the first two years but decreased to a rate of less than one new taxon per year in subsequent years. After these initial colonization years, studies have shown that there is no relationship between the age of the pond and invertebrate richness (Bloechl et al., 2010; Gee et al., 1997). However, the taxonomic structure of the invertebrate community does change over time (Ruhí et al., 2012).

As succession continues, the structure of the macroinvertebrate community changes and new species arrive to take advantage of the expanded resource pool. As inputs of detritus increase with time and succession, so does the contribution of detritivores to the invertebrate community composition (Barnes, 1983; Bloechl et al., 2010). The variety of predatory species should expand to take advantage of the stable prey populations (Bloechl et al., 2010; Canedo-Arguelles and Rieradevall, 2011), and taxa that rely on macrophytes for habitat arrive later, when vegetation has been able to establish (Barnes, 1983; Canedo-Arguelles and Rieradevall, 2011; Stewart and Downing, 2008). In a study comparing aquatic beetle assemblages in ponds of various ages (Bloechl et al., 2010), it was found that carnivorous beetles were dependent upon an established prey population and did not colonize ponds in the early successional stages, despite being active dispersers.

As the system becomes more stable, there is an increased number of taxa with late maturity and longer life spans (Ruhí et al., 2012; Townsend and Hildrew, 1994). A mature aquatic system would be expected to contain taxa with poor dispersal abilities, but also those with specialized habitat requirements (Barnes, 1983; Ruhí et al., 2009) Passive dispersers are reliant on chance events to invade new wetlands (Barnes, 1983), and their colonization is expected to be slower. In a long term study of a man-made freshwater wetland in Sweden (Ruhí et al., 2012), passive dispersers, such as oligochaetes, were more common at later stages, and taxa with specific habitat requirements did not colonize the wetland for several years regardless of dispersal ability.

Biological Assessment

Many monitoring agencies rely on chemical water quality analysis to assess the health of a water body (Beck and Hatch, 2009). However, this type of analysis does not fully represent the biological processes that occur, and may not reflect short term disturbances (Gibson et al., 2000; Karr, 1991). Aquatic biological communities, on the other hand, are responsive to changes in water chemistry and other disturbances making them useful indicators of environmental conditions (Lunde and Resh, 2012; MPCA, 2014; Rader et al., 2001). Aquatic macroinvertebrates, in particular, are abundant and widespread in wetland ecosystems, and have been proven to be useful tools in diagnosing the health of wetlands (Awal and Svozil, 2010; Kashian and Burton, 2000; Lunde and Resh, 2012; Rader et al., 2001; Tall et al., 2008).

Previous research in other aquatic systems has shown that macroinvertebrate community composition can be a powerful tool in assessing the health and stability of the ecosystem (Kashian and Burton, 2000; Stewart and Downing, 2008; Tall et al., 2008). Invertebrates tend to remain in their original habitat and have short life spans, making them a useful indicator of environmental conditions (US EPA, 2002). Invertebrates are taxonomically diverse, respond to different physical and chemical properties in the environment, and integrate changing conditions over time. Tolerance to environmental stressors varies by invertebrate species and the response to environmental stress is often determined by the dispersal abilities and lifespan of the invertebrate species (Rader et al., 2001). In addition, macroinvertebrates may be useful indicators for successional differences between wetlands as they respond to changes in the physical habitat in addition to environmental conditions (Rosenberg and Resh, 1993).

There are two main types of ecological indicators: structural and functional. Structural indicators are measures of a community (e.g. abundance, presence/absence of certain taxa, diversity), whereas functional indicators reflect a process (e.g. energy and matter flows, decomposition, ecosystem metabolism). Composition of the macroinvertebrate community is a structural indicator, however, assessing functional characteristics of the members of the community may provide some insight into how an ecosystem is functioning (Cummins and Merritt, 2001; Cummins et al., 2005). A functional feeding group approach for invertebrate analysis focuses on the function of a particular invertebrate and should more closely reflect ecosystem attributes and food resources than the taxonomy alone (Merritt et al., 2002).

Resacas

Wetlands are commonly recognized as being among the most productive ecosystems on Earth. They support fish and wildlife, provide floodwater storage, and improve water quality (US EPA, 2002). In addition to their ecological value they are also among the most economically important ecosystems. The economic value of the services provided by freshwater wetlands is greater than that of rivers, lakes, forests, and is second only to coastal estuaries (Costanza et al., 1997).

Historically, the Rio Grande was a meandering river subject to periodic flood events, creating a series of secondary channels and oxbow lakes. Today, the river acts as an international border and the flow is highly managed by a series of dams. Resacas, as they are locally known, are remnants of the river channel that formed naturally throughout the Lower Rio Grande Valley before damming of the river (figure 1a). During flood events water would overflow the river banks and fill the resacas, acting as ephemeral ponds and providing a vital source of freshwater. The resacas that were monitored in this study are oxbow lakes, former river bends that naturally silted in and no longer have a natural hydrological connection with the river. Currently, many resacas are maintained as reservoirs and are permanently filled with water through a series of irrigation canals and pumping of river water (Robinson, 2010). Resacas provide valuable aquatic habitat in the semi-arid environment of South Texas. These freshwater resources support a variety of terrestrial and aquatic organisms; providing refuge for wildlife including many migratory bird species. Despite the importance of the resaca habitat, little is known about how this ecosystem functions.

Rationale for Methodology

There is minimal knowledge of the macroinvertebrate community that inhabits resacas around Cameron County; this study will provide baseline information. Due to the lack of previous research, the best method for collecting a representative sample of invertebrates is speculative at best. There are a variety of sampling techniques available and comparisons between invertebrate sampling techniques have indicated that each technique has its own bias and the species composition and abundance collected vary depending on sampler used and type of habitat (de Klerk and Wepener, 2011; Meyer et al., 2011; Muzaffar and Colbo, 2002; Turner and Trexler, 1997). Two comparison studies of vegetated wetlands had conflicting results. One study identified the sweep net as being most effective in terms of consistency between samples and number of species captured (Turner and Trexler, 1997); while the other identified a corer-type device as obtaining the most consistent results (Meyer et al., 2011). It is clear that a combination of sampling techniques must be employed to collect a representative sample of the invertebrate community.

Two of the most popular collection techniques are core devices and sweep nets. The combination of a sweep-net and benthic corer has been identified as being effective to collect a whole community sample (Batzer et al., 2001). Benthic corers are a quantitative method to compare species composition, richness, distribution of individuals, and population densities among the species (Kashian and Burton, 2000; Tall et al., 2008). Sweep nets have also been successfully utilized in wetland and pond studies for the collection of macroinvertebrates (Canedo-Arguelles and Rieradevall, 2011; Merritt et al., 2002; Smith et al., 2003; Tarr et al., 2005). One of the objectives of this study is to provide guidance on the best method of sampling invertebrates in resacas for future bioassessments.

Purpose

Minimal research has been conducted into how the resaca ecosystem functions. The recent re-flooding of one of the resacas studied here provides the unique opportunity to monitor ecosystem development from day zero. I propose to monitor this development through the study of the macroinvertebrate community. Additionally, the macroinvertebrate community will be used to assess the successional state of the three resacas included in this study, as affected by various environmental conditions.

Hypotheses

1) Colonization of resacas will be fast and primarily composed of macroinvertebrates with active dispersal abilities.

2) Resacas in early stages of development have a different macroinvertebrate community composition than resacas in later stages of development.

3) Macroinvertebrate communities can be used as an indicator of the successional status of restored resacas.

Specific Objectives

1) Evaluate if macroinvertebrate colonization of the resaca follows a pattern linked to dispersal abilities of invertebrates; and if the greatest shift in the community occurs within the first year of re-flooding.

2) Determine if the composition of the macroinvertebrate community in resacas reflects the stage of ecosystem development.

3) Assess if functional feeding groups of invertebrates reflect differences in ecosystem development status of resacas.

4) Determine which macroinvertebrate community-derived metrics are the best site discriminators.

Chapter Two

Methodology

Site Description

Three resacas located in Cameron County, TX (figure 1b; table 1) were monitored throughout the course of this study. This study takes an age-series approach and each resaca has been permanently inundated for differing amounts of time. Two of the resacas are within the Sabal Palm Sanctuary. The Sabal Palm Sanctuary is 557 acres and comprises an old growth sabal palm forest. The sanctuary is located between the Rio Grande and agricultural fields. The property is managed as a natural area and is undergoing efforts to restore the sabal palm forest and a resaca. The third resaca is located 6.1 km northeast and is surrounded by citrus orchards; but is bordered by natural riparian vegetation dominated by sabal palm stands. All three resacas were formed as oxbow lakes and are maintained flooded via irrigation channels with water pumped from the Rio Grande about ten times a year. Depth is variable throughout the year, but all three have a maximum depth of less than 2 m.

The new resaca located within the Sabal Palm Sanctuary was re-flooded in February, 2013. The site is approximately 7,590 m^2 in size. This resaca was previously dry for many years and grown in with vegetation. Prior to re-flooding the majority of vegetation was cleared from the area, leaving only a few islands of vegetation. The litter layer of soil was removed during the clearing of vegetation, in an effort to ensure better initial water quality.

The second resaca in Sabal Palm Sanctuary had been continuously flooded for about three years prior to the commencement of this study and is considered the intermediate resaca. It is approximately 7,930 m^2 in size. This site is located downstream from the new resaca and receives overflow water from the new resaca. Prior to re-flooding of the new resaca with water from irrigation canals, the intermediate resaca was maintained with water pumped directly from the adjacent Rio Grande. These two resacas are continuously maintained with water for the purpose of creating wildlife habitat.

The third resaca has been continuously flooded for at least fifteen years and is considered the old resaca for this study. This site is approximately 4, 970 m^2 in size. This location has no direct hydrological connection to the Sabal Palm Sanctuary resacas, but all three resacas share the common water source of Rio Grande water delivered through irrigation channels. The old resaca is maintained flooded to provide water for irrigation, it is periodically drained and filled but does not completely dry.

Macroinvertebrate Sampling

Experimental Design and Sample Station Selection

Macroinvertebrates were collected on a monthly basis between March 2013 and February 2014, for a total of 12 months Macroinvertebrates were collected from both the benthic and water column communities at the same station. Satellite images (Google, INEGI, 2014) were used to produce a 10 by 10 m or 7 by 7 m grid overlay, and sample stations were located at intersecting points giving each resaca 80 to 90 potential sampling stations. A simple random sampling design was used. Collection sites were randomly selected for each sample trip by numbering intersection points and using a random number generator for selection. Five stations within each resaca were sampled every month, with three sites chosen as back-up stations in the event that primary stations were inaccessible. All sites were selected prior to sampling and located with the use of a hand-held GPS unit (Garmin etrex 20). A ten foot aluminum boat was used to access sampling stations. Three subsamples were collected at each station, one from each side and front of the boat, and combined into one replicate sample. A total of 60 stations within each resaca were sampled at the conclusion of this study, with no duplication of sample stations.

Water Column Community

Water column community samples were collected with the use of a D-frame sweep net with 243 µm mesh (Wildco). Samples in every station were collected using a standardized effort of three 0.8 m sweeps from the sediment surface up the water column. Standardization of this sampling method allowed the area sampled to be quantified (Muzaffar and Colbo, 2002), and represented a sampling effort of 0.09 m^3 of water per sample. The three samples were collected and homogenized into one sample for each of the five sample stations. Water column samples were sieved through a 250 µm mesh bucket sieve to remove as much fine sediment as possible. Samples were preserved in the field with a 90% ethanol solution for a final concentration of approximately 70%. Samples were stained with Rose Bengal biological stain to facilitate sorting (Mason and Yevich, 1967), and transported to the laboratory for processing. All invertebrate samples were sorted to the lowest taxonomic level possible and assigned to the appropriate functional feeding group for further analysis. Identifications were made with the use of taxonomic guides (Robertson et al., 2012; Thompson, 2004; Thorp and Covich, 2010; VCSU).

Benthic Community

Benthic macroinvertebrates were collected with the use of a modified PVC-constructed sediment corer (8 cm diameter). Three core subsamples, at least 15 cm deep (Kashian and Burton, 2000), were collected and homogenized into one sample from each of the five sample stations. This quantitative method represented a sampling effort of 150 cm^2 per sampling station. Core samples were sieved through a 250 µm mesh bucket sieve to remove as much fine sediment as possible. Samples were preserved in the field with a 90% ethanol solution for a final concentration of approximately 70%. Samples were stained with Rose Bengal biological stain to facilitate sorting (Mason and Yevich, 1967), and transported to the laboratory for processing. All invertebrate samples were sorted to the lowest taxonomic level possible and assigned to appropriate functional feeding group for further analysis. Identifications were made with the use of taxonomic guides (Robertson et al., 2012; Thompson, 2004; Thorp and Covich, 2010; VCSU).

River Community

On a quarterly basis, macroinvertebrates were also collected from three locations on the north bank of the Rio Grande, using the same methods, in an attempt to identify the invertebrate species that may be colonizing the resacas directly from the irrigation canals. These three sample locations were located by the river shore of the Sabal Palm Sanctuary (25°51’00.23” N; 97°24’51.77” W).

Functional Group Assignments

All invertebrate taxa were assigned to functional feeding groups as defined by (Merritt et al., 2002) and (Barbour et al., 1999). Functional feeding groups used were: shredders, scrapers, filterers, gatherers, and predators. Shredders feed on coarse particulate organic matter (CPOM), scrapers feed on periphyton and organic material from substrate, filterers collect fine particulate organic matter (FPOM) from the water column, gatherers feed on FPOM from sediments and predators capture live prey.

Assignment of dispersal abilities

Macroinvertebrates were identified as being active or passive dispersers at the family level from taxonomic guides (Thorp and Covich, 2010). No distinctions were made between strong and weak dispersers. The primary requirement of an active disperser was the ability to fly. Classifications were based on traits listed in taxonomic guides when there was no indication of dispersal ability.

Water Parameters

Several physical, chemical and biological water parameters were measured on a monthly basis between March 2013 and February 2014 to characterize each resaca. A multi-parameter sonde (Hach HQ40d) was employed at each sample station to measure in-situ dissolved oxygen, pH, temperature, and conductivity. Sonde measurements were taken at mid-water depth, usually around 50 cm deep. Secchi disk measurements were used to estimate water clarity at each sample station. Water parameters were collected at roughly the same time of day for each resaca. Water depth was also measured at each sample station. To the extent possible, these measurements were taken prior to disturbing the bottom sediments in order to limit re-suspension of sediments into the water column. Due to equipment failure, dissolved oxygen was not measured in June and pH was not measured in February.

Two 500 mL composite water samples were collected 15 cm below the water surface from each of the resacas. Samples were stored in the dark on ice until transported to the lab. Water samples were frozen until analyzed for nutrients. All water samples were analyzed using standard protocols according to Hach (2003): Nitrate (method 8192), Ammonia (method 8038), Nitrite (method 8507), and total phosphorus (method 8190). All water samples were analyzed for nutrients with a Hach DREL/2400 Complete Water Quality Laboratory and Spectrophotometer.

An additional 1 L composite water sample was collected in an amber bottle for chlorophyll-a analysis. In-vivo chlorophyll-a concentrations were monitored monthly with the use of a handheld fluorometer (Turner Designs 8000-010). Three readings were taken from each of the sample stations and averaged for the relative concentration. Beginning in October, in-vivo measurements were taken from the composite water sample and were averaged for the concentration reading. These readings were complemented with in-vitro determination from the composite water samples collected during monthly monitoring to develop a correlation. For this, the water sample from each resaca was filtered through a Whatman 0.45 micron nitrocellulose filter to concentrate algal cells, and chlorophyll-a concentration was measured with a Cary win-uv 50 spectrophotometer after acetone extraction (Wisconsin State Lab of Hygiene, 1991).

Sediment Analysis

Sediment core samples were collected from each resaca in October 2013 to characterize the benthic habitat. Resacas were stratified into relatively homogeneous sections, and three to five sediment cores (6 cm x 15 cm) were collected and combined for each section. Sediments were analyzed for particle size distribution and total organic matter content. Particle size analysis was performed using an adapted wet sieve technique (Chesapeake Biological Laboratory, 2011; USEPA, 2001). Sediments were rinsed with a 0.5% Sodium Hexametaphosphate (SHMP) solution and decanted into a container until the supernatant was clear. The fines fraction was subsampled for drying and weighing. Remaining sediments were wet sieved into the following particle size classes: coarse sand, medium sand, fine sand and very fine sand. Sediments captured on each sieve were placed in pre-weighed aluminum trays. Trays were placed in a drying oven for at least 24 hours at 105°C, and then weighed with an analytical balance. For determination of organic matter content, sediment subsamples were incinerated in a muffle furnace at 500°C for one hour and weighed to obtain the ash-free dry mass (USEPA, 2001).

Percentages for each size fraction were calculated as follows (Chesapeake Biological Laboratory, 2011):

$$Coarse\ Sand\ (\%) = \frac{Dry\ weight\ of\ coarse\ sand}{Dry\ weight\ of\ total\ sediment} * 100$$

Percentage of clay and silt fraction was calculated as follows:

$$Dry\ weight = \left(Mean\ subsample\ conc.\left(\frac{dry\ weight}{subsample\ vol}\right) * Total\ volume\ of\ fines\right) - mass\ of\ SHMP\ used$$

$$Clay + Silt\ (\%) = \left(\frac{dry\ weight\ of\ clay + silt\ fraction}{Dry\ weight\ of\ total\ sediment}\right) * 100$$

Organic matter content was calculated as follows:

$$OM\ content = total\ sediment\ dry\ weight - total\ sediment\ ash\ free\ dry\ weight$$

Data Analysis

Data from the benthic and water column macroinvertebrate communities were analyzed separately. Species abundances from the five samples were pooled to provide a total monthly abundance for each resaca. A principal component analysis (PCA) ordination was used to investigate if physiochemical environmental factors were driving any community differences between the three study sites. Environmental metrics and species abundance patterns were compared using the BEST procedure in PRIMER v6 to ascertain which environmental variables explain changes in the macroinvertebrate community (Clarke, 1993).

A one-way analysis of variance (ANOVA) was used to determine if there were significant differences between sites for the calculated richness and diversity indices, Tukey's post hoc test was used to test pairwise comparisons. All indices met the assumptions of normality and homoscedasticity. Univariate statistics were performed using SPSS v22.

Differences in community structure between the study sites were analyzed using PRIMER v6(Clark and Gorley, 2006). The following richness and diversity indices were calculated using the DIVERSE routine: species richness (total number of species, S), Margalef's index ($d=(S-1)/\log_e N$), Shannon-Wiener diversity ($H' = - \Sigma$ pi log (Pi)), and Pielou's evenness ($J'=H'/\log_e S$)(Clark and Gorley, 2006). A dominance ratio was calculated as the percent dominance of the most abundant taxa relative to the total abundance of all taxa in each resaca. Multidimensional scaling (MDS) analyses were used to visually assess if there were differences between the invertebrate communities by configuring samples based upon their similarities. The MDS analysis was supported with a one-way analysis of similarity (ANOSIM) to identify differences in the macroinvertebrate community among sites and for each sampling episode. ANOSIM compares abundance resemblance matrices and is similar to ANOVA but does not require assumptions of normality and homoscedasticity (Clarke, 1993). Similarity percentages (SIMPER) analysis was then used to detect which species were driving similarities within sites and dissimilarities between sites (Clark and Gorley, 2006). All multivariate analyses were based upon Bray-Curtis similarity matrices. Macroinvertebrate abundance data were fourth-root transformed to decrease the influence of abundant taxa to the similarity index.

Chlorophyll-a concentrations were used to assign a trophic state index value to each resaca following Carlson's Trophic State Index (TSI; (Carlson, 1977).

$$TSI(Chla) = 10(6 - \frac{2.04 - 0.68\ln(chla)}{\ln(2)})$$

Chapter Three

Results

Sediment Analysis

Sediments at all three study sites were composed primarily of silt and clay. The new resaca bed had the highest amount of silt and clay at 93%, followed by the intermediate site with 81% and the old site with 77% (figure 2). The remaining proportion of the sediments ranged from very fine sand to very fine gravel. Mean organic content was higher in the intermediate resaca (11%) than in the new and old resacas (7%) (figure 3).

Water Quality Variables

Water temperature ranged from 12.3°C in winter to 34.9°C in summer with an average annual temperature of 25.4 °C for all three study sites (table 2). Conductivity ranged from 809.2 to 1903.6 (µs/cm) with a mean annual conductivity of 1,264 µs/cm (table 2). Mean annual pH for all three study sites was between 7.9 and 8.3 (table 2). Dissolved oxygen varied greatly over the course of the year and ranged from 2.14 to 12.8 mg/L (table 2). Mean annual dissolved oxygen was similar for the new and old sites at 7.2 and 6.6 mg/L but was higher at the intermediate site (9.4 mg/L) (table 1). Mean annual chlorophyll-a concentrations were similar for all three study sites and ranged from 40.4-48.2 µg $10cm^{-1}$ (table 3). All three sites were classified as being eutrophic based on Carlson's trophic state index (U.S. Environmental Protection Agency, 2002).

The Principal Component Analysis ordination revealed that no subset of physiochemical parameters were strong drivers for differences among the three resacas in terms of the environment (see appendix C). Five principal components were required to account for 75% of the cumulative variation (table 4a) and no single variable had a strong contribution (table 4b). PC1 accounted for 26.3% of the variation with Secchi depth, pH, dissolved oxygen, nitrate, ammonia, and organic matter content being the greatest contributors. These same variables had high contributions to PC2 with the addition of conductivity. PC 3 accounted for 14.7% of the variation with chlorophyll-a, temperature, and organic matter content being the greatest contributors.

Comparison with River

A smaller subset of environmental variables was recorded during quarterly river sampling. Only electrical conductivity, pH, dissolved oxygen, temperature and Secchi depth measurements were recorded for the four months that the river was sampled. The river was also classified as eutrophic based on fluorometer readings (table 3). Mean water parameter values from quarterly river samples were comparable to the mean annual values for the resacas (table 2).

Benthic Community

A total of forty-four taxa, within thirty-one families, were found in the three study sites (see appendix A). The groups with the greatest abundances included: Chironomidae, Thiaridae, Naididae and Ceratopogonidae. Richness and diversity measures of the benthic macroinvertebrate community varied among the three study sites based on monthly abundances. Over the course of the year, the intermediate resaca generally exhibited higher taxa richness (Margalef's index and total number of taxa, S), and diversity (Shannon, H'($\log_e$)) (figure 4). The old resaca exhibited the lowest taxa richness, evenness and diversity over the course of the study based on total monthly abundances. Comparisons of group metrics were all significant (ANOVA: $p \leq 0.05$), with significantly different pairwise comparisons between the intermediate and old site for Margalef's index (p=0.04), Pielou's evenness (p=0.009), and Shannon diversity (p=0.012). Significant differences were also found between the new and old sites for Pielou's index (p=<0.001), and Shannon diversity (p=0.049). There were no significant differences for these metrics between the new and intermediate study sites.

When samples were pooled for all twelve sampling months, the old resaca showed the highest level of dominance with 59% of the community dominated by the gastropod *Melanoides tuberculata* (figure 5), an invasive species. The new and intermediate resaca had low levels of dominance with 26% and 24% of the community composed of the chironomid *Tanypus* sp (figure 5). The new and intermediate resacas both had high levels of evenness with 80% of the community composed of four taxa in the new resaca, and five taxa in the intermediate resaca (figure 5). The old resaca had seven taxa unique to the site, twelve taxa were unique to the intermediate resaca and four taxa were found only in the new resaca (table 5).

The composition of functional feeding groups was different among all three resacas based on total annual abundances, with the new and intermediate sites being most similar. All feeding groups were present in all three resacas, but were represented by different numbers of taxa. Gatherers represented half of the benthic community in the new and intermediate resacas, with the remaining half dominated by predators. In contrast, the benthic community of the old resaca was composed mainly of scrapers, followed by gatherers with less than ten percent consisting of predators (table 6; figure 6). Scrapers were represented by the gastropods whose populations varied from 58.7 % of the community in the old resaca, 11.1% of the community in the intermediate resaca, to 1.7% in the new resaca (table 6, figure 6). Shredders and filterers were represented by only one or two taxa in all three resacas. Only two taxa made up the scraper community in the new and old resaca, and six taxa were present in the intermediate resaca. Gatherers consisted of seven taxa in the new and old resaca and six in the intermediate resaca. Predators represented the most number of taxa with twelve in the new, fourteen in the intermediate and seven in the old site (Table 6).

For all multivariate community analyses, macroinvertebrate abundances were fourth-root transformed to decrease the influence of abundant taxa on Bray-Curtis similarity values. There were small but significant differences between the macroinvertebrate communities in the three sampling sites (ANOSIM: $R=0.369$; $p=0.001$). Additionally, all pairwise comparisons between communities were significantly different ($p \leq 0.05$). These results were further supported visually with a multi-dimensional scaling (MDS) plot. The MDS ordination showed that monthly invertebrate samples were grouping together based on site, but that there was some overlap of groupings (figure 7). There was no correlation between the pattern of separation in the benthic invertebrate community and the measured environmental variables (BEST: $\rho=0.304$; $p=0.1$).

SIMPER analysis of the benthic invertebrate community identified the chironomids and tubificid worms as being responsible for similarity of the new resaca across months, with the tubificid worms being consistently good characterizing taxa. A similar community accounted for the similarity among the intermediate resaca samples, but the chironomids were the typifying taxa. *M. tuberculata* was responsible for most of the similarity among samples from the old site and may be a good characterizing species (table 7). There was no subset of the community that was responsible for differences between sites.

A total of thirty-one families of invertebrates were found in the benthic community of the three resacas. Of the nineteen families found in the new resaca, only four were unique to that resaca (table 5) and nine had some form of active dispersal ability (figure 8). The most abundant passive dispersers in the new resaca were also found in the quarterly river samples (table 8). Eleven of the families were present within the first three months of flooding and fifteen had shown up by the sixth month (figure 8). Six new families colonized the intermediate resaca, and six new families were collected in the old resaca (table 8).

Comparison with River

A total of ten invertebrate taxa were identified in the quarterly benthic samples from the Rio Grande, only one of which was unique to the river (table 5). The groups with the greatest contributions to the total abundance were the tubificid worms and chironomids. Six of the taxa found in the river were also present in all three resacas (see appendix).

Water Column Community

A total of 58 taxa within 38 families were identified in all three study sites (see appendix B). The groups with the highest contributions to total abundances were: Chironomidae, Mysidae, Baetidae and Hyalellidae. Measures of the macroinvertebrate community varied among the three study sites. The intermediate resaca generally exhibited higher taxa richness (Margalef's index (d) and total number of taxa, S), and diversity (Shannon, H'($\log_e$)) over the course of this study (Figure 9). The old resaca exhibited the lowest taxa richness and diversity over the course of the study based on total monthly abundances. Taxa richness (d) and Shannon Diversity (H') were significantly different for all three study sites (ANOVA: F=15.426; p=<0.001 and F=13.659; p<0.001) and all pairwise comparisons ($p < 0.05$) (figure 9).

When samples were pooled for all twelve sampling months, the old resaca exhibited a high level of dominance with mysid shrimp accounting for 73% of the community, this same taxa accounted for 54% of the community in the new resaca (figure 10). The intermediate resaca had low dominance with the most abundant taxa, tanypodinae, accounting for only 24% of the community (figure 10). There were five taxa unique to the new resaca, 17 taxa unique to the intermediate resaca, and four unique to the old resaca (table 9).

There were differences in the composition of functional feeding groups among the three resacas. The water column invertebrate community in the old resaca was dominated by filter feeders, primarily mysid shrimp. Half of the community in the intermediate resaca was composed of gatherers followed by predators making up 43% of the community. The new resaca was also dominated by filter feeders at 54% with gatherers and predators being the next greatest contributors (table 10, figure 11). All feeding groups were present in all three resacas, but were represented by different numbers of taxa. Filter feeders were represented by only two taxa in all three resacas. Gatherers consisted of nine taxa in the new resaca, seven in the intermediate resaca and six taxa in the old resaca. Predators represented the most number of taxa with 22 in the new, 30 in the intermediate and 12 in the old site (Table 10).

For all multivariate community analyses, macroinvertebrate abundances were fourth-root transformed to decrease the contribution of abundant taxa to Bray-Curtis similarity values. There were differences between the macroinvertebrate communities in the three sampling sites (ANOSIM: $R=0.428$; $p=0.001$). Additionally, all pairwise comparisons between communities were significantly different ($p < 0.05$). These results were further supported visually with a multi-dimensional scaling (MDS) plot. The MDS ordination showed that samples from the same sites were grouping together, but that there was some overlap of groupings (figure 12).

The pattern of separation among the water column invertebrate community was slightly correlated with the pattern of environmental variables (BEST: $\rho=0.324$; $p=.004$). The best fit solution consisted of the variables: Secchi depth, dissolved oxygen, temperature, nitrate concentration and sediment organic matter content. The correlation between these variables and the water column community differences was confirmed with the RELATE routine ($\rho=0.324$; $p=0.001$). However, due to the high number of variables required and the low correlation value it is unlikely that this relationship is ecologically significant.

SIMPER analysis of the water column invertebrate community identified the mysid shrimp as being primarily responsible for similarity of the new resaca across months. The chironominae accounted for the similarity among the intermediate resaca samples, and were also the typifying taxa. Mysid shrimp were also responsible for most of the similarity among samples from the old site (table 11). There was no subset of the community that was responsible for differences between sites.

Thirty-eight total families of invertebrates were found in the water column community of the three resacas. Of the twenty-five families found in the new resaca, only three were unique to that the resaca (table 12), seventeen possessed some level of active dispersal ability (figure 13). The most abundant passive dispersers were also found in the quarterly river samples (table 12). Fourteen of the families were present within the first three months of flooding and twenty-two showed up by the sixth month (figure 13). Nine new families colonized the intermediate resaca, and four unique families were collected in the old resaca (table 12).

Comparison with River

A total of twenty-two invertebrate taxa were identified in the quarterly water column samples from the Rio Grande, none of which were unique to the river. The groups with the greatest contributions to the total abundance were Ceratopogonidae and Mysidae (table 14). Eleven of the taxa found in the river were also present in all three resacas (see appendix B).

Chapter Four

Discussion

Macroinvertebrate colonization and dispersal ability

In several studies, the colonization of newly created wetlands occurred rapidly with the greatest shift in community composition occurring within the first two years (Bloechl et al., 2010; Ruhí et al., 2009; Voshell Jr and Simmons Jr, 1984). Over time, the rate of species gain decreases as competitive pressure increases, and the greatest amount of change occurs early in succession (Anderson, 2007). This has been confirmed with studies in newly restored wetlands which found that the majority of species present in later successional stages appeared within the first year of flooding (Ruhí et al., 2009). In this study, more than half of the families that were collected in the intermediate and old resacas were also found in the newly flooded resaca for both the benthic and water column communities. The main invertebrate community structure formed during the first year for both the benthic and water column community, which supports the results of past studies.

The two primary modes of dispersal among aquatic invertebrates are active and passive dispersal. Active dispersers are capable of moving on their own mainly through flight, while passive dispersers rely on the movement of another organism or an event like flooding (Bilton et al., 2001). Sequence of wetland colonization has been shown to be strongly linked to the dispersal abilities of invertebrates and active dispersers are expected to be early colonists (Barnes, 1983; Canedo-Arguelles and Rieradevall, 2011; Gee et al., 1997; Hassall et al., 2012; Ruhí et al., 2012; Ruhí et al., 2013; Stewart and

Downing, 2008). Passive dispersers are reliant upon chance to arrive in the wetland at a time when the habitat can support them (Barnes, 1983) and would be expected to arrive in later successional stages. The proximity of propagule sources is also a determining factor in the arrival rate and composition of colonists (Canedo-Arguelles and Rieradevall, 2011). Diptera were expected to be among the earliest colonizers due to their ability to fly (Bilton et al., 2001) and relatively short life cycles (Barnes, 1983; Canedo-Arguelles and Rieradevall, 2011). In this study, early colonizers were a mix of active and passive dispersers. Chironomidae and Ceratopogonidae were among the earliest colonists, as were Corixidae and ephemeroptera, all insects capable of flight. However, oligochaetes, gastropods, and mysid shrimp are all passive dispersers and were also early colonizers.

Vector-mediated dispersal is a significant method for movement of passive dispersers. Waterfowl and other aquatic invertebrates play an important role as vectors (Bilton et al., 2001), and due to the proximity of the resacas to the river these are likely vectors. In addition, the water source for all three resacas is the Rio Grande and water-mediated dispersal may play an important role in the colonization of resacas. The composition of the macroinvertebrate community is also affected by the proximity of existing wetlands that act as propagule sources (Biggs et al., 2005; Canedo-Arguelles and Rieradevall, 2011). A similar successional trajectory is expected for the three resacas in this study based on similar propagule sources from the Rio Grande and their proximity to each other.

Composition of the macroinvertebrate community and ecosystem development

Overall, there were differences in structural measures for the macroinvertebrate communities among the three resacas. These differences were not strongly correlated with the environmental variables as measured in this study. Invertebrate community responses to environmental variables are mixed, with some studies showing significant interactions between biotic factors and structural community measures (Spieles and Horn, 2009; Stewart and Downing, 2008) and some showing very weak relationships with environmental variables (Culler et al., 2014). The lack of a strong relationship with environmental variables in this study is likely due to the fact that the variables measured did not vary significantly among the study sites. Due to this lack of variation, the three sites were considered comparable in terms of environmental conditions.

Since the environmental factors were relatively even at each study site, differences in ecosystem development stage is the most likely explanation for the observed differences in the invertebrate community. There have been few long-term studies that monitored wetland ecosystem development for more than a few years, and as a result, have focused on the pioneer communities (Bloechl et al., 2010). Information on how the macroinvertebrate community changes over time is the result of age-series studies which suggest that changes occur in a predictable pattern (Barnes, 1983; Bloechl et al., 2010; Ruhí et al., 2012). Results of this study indicate that although there were differences among communities in the three ecosystem age classifications, these differences were not all as expected or as reported from previous studies.

According to the successional theory, the climax community should be less diverse than some previous intermediate stage that contains a mix of early and late successional species (Horn, 1974). The results of this study followed the expected trends for diversity with the mature site exhibiting the lowest levels of diversity for both the benthic and water column invertebrate communities, and the highest levels of diversity observed in the intermediate site. Diversity should increase over time as more taxonomically diverse species inhabit the wetland (Ruhí et al., 2012) until high densities and biomass lead to increased competition for resources (Guo, 2003). It is likely that the decrease in richness, evenness and diversity from the new resaca to the old resaca is due to competitive exclusion from which the community becomes dominated by a competitively superior species (Huston, 1979). The benthic and water column communities of the old resaca both exhibit high levels of dominance with 59% of the benthic community composed of the gastropod *M. tuberculata* and 73% of the water column community dominated by mysid shrimp.

Predatory species' relative contribution to the invertebrate community composition were expected to increase over time in response to more stable and abundant prey populations (Batzer and Wissinger, 1996; Bloechl et al., 2010; Ruhí et al., 2012). In this study, the contribution of the predator species to the total number of individuals was lowest in the most developed resaca. The water column predator community showed the expected trend between the new and intermediate resacas, but decreased from 43% of the total community in the intermediate site to only 7% of the community in the old site. The benthic predator community had a gradual decrease from 40% of the community in the new site to 9% in the old site. In both the water column and benthic communities, the number of predatory taxa was high in relation to the total number of taxa indicating the possibility of considerable redundancies within the predator taxa, despite the decrease in relative abundance. This decrease may be due to a lack of suitable prey species, or the abundance of vertebrate predators which was not measured in this study.

Prior studies have indicated that filter-feeder abundances have mixed responses over time. Taxa with this feeding strategy would be expected to take advantage of phytoplankton as one of the few food resources in a newly flooded environment (Voshell Jr and Simmons Jr, 1984), with their relative abundance decreasing as the resource pool expands. However, other studies have indicated that filter feeders may remain abundant into late successional stages in highly productive systems (Ruhí et al., 2012). Filter feeders had a small contribution to the benthic community assemblages, but accounted for 54% and 73% of the water column community composition in the new and old resaca respectively. Although filterers were the dominant feeding group in the new and old resaca they were only represented by two taxa. Filter feeders only made up 3.5% of the water column community composition in the intermediate site despite all three resacas having similar water column chlorophyll-a concentrations and trophic state classifications, and thus a similar primary productivity.

Gatherers, consumers of particulate organic matter, were expected to increase in relative abundance over time as inputs of detritus from decaying plant material increased (Batzer and Wissinger, 1996; Ruhí et al., 2012). However, in this study the contribution of gatherers to total benthic invertebrate abundance decreased over the course of resaca development. This may be explained by the dominance of an exotic gastropod in the old resaca community. In contrast, the water column community did not show an obvious trend in gatherer contribution to the invertebrate community. Their relative contribution was greater in the intermediate resaca, but was similar between the new and old resaca. This may have been due to the observed lack of aquatic macrophytes in the old resaca.

The herbivore community, including scrapers, was expected to decrease over time as their relative abundance would be minimized by the establishment of other feeding groups (Ruhí et al., 2012). The scrapers in particular increased in abundance with successional stage and were the dominant benthic taxa in the old resaca. Three families of gastropods were present in the intermediate site but were not observed in the old site, likely due to competitive exclusion considering the high abundance of *M. tuberculata*.

Macroinvertebrate functional groups and ecosystem development

Trophic metrics are a reflection of ecosystem processes such as trophic dynamics and food source availability (Barbour et al., 1999). Specific taxonomic structure might be different between wetlands, but the structure of the functional community should be the same as it reflects ecosystem processes. Functional feeding group composition of the invertebrate community should reflect food resource availability more closely than taxonomy alone (Merritt et al., 2002). The functional feeding groups assessed in this study were: predators, gatherers, shredders, filterers, and scrapers. These groups were expected to reflect the availability of food resources in the resaca.

All functional feeding groups were present in the three resacas, but observed trends differed from other studies of succession. Predator species abundance relative to total invertebrate abundance was expected to increase in response to a more stable and abundant prey population (Batzer and Wissinger, 1996; Bloechl et al., 2010; Ruhí et al., 2012). However, in this study relative abundance and number of taxa decreased over time. Gatherers were predicted to increase in relative abundance as a response to the expected increase of detritus from decaying plant material (Batzer and Wissinger, 1996; Ruhí et al., 2012). In this study their contribution to the community decreased from the new to the old resaca. Filter feeders were expected to have a high relative abundance early on due to phytoplankton being one of the few available resources (Voshell Jr and Simmons Jr, 1984), and remain high due to the resacas being eutrophic systems (Ruhí et al., 2012). However, filter feeder relative abundance was low only in the intermediate site in this study despite all three have the same trophic state.

In terms of specific richness of feeding groups, the invertebrate trophic levels trend toward simplification and diminished redundancy in this study. This is a trend that has also been seen in plant communities (Anderson, 2007), and a long-term study of a stream macroinvertebrate community (Milner et al., 2008). This was especially marked in the predators group, but also noticeable for the scrapers, gatherers and shredders, which had fewer species in the old site.

Functional feeding group composition of the macroinvertebrate community in resacas did not change as expected based on previous studies of wetlands (Batzer and Wissinger, 1996; Bloechl et al., 2010; Ruhí et al., 2012; Voshell Jr and Simmons Jr, 1984). The changes in wetland ecosystem functions that determine food resource availability during the process of succession may not be occurring as expected based on previous studies. Another possibility is that the functional feeding groups may not be an accurate reflection of these functional processes.

Metrics for discriminating between sites

The three resacas included in this study are comparable in size and environmental factors that were measured. The primary difference between sites is the length of time they have been flooded. Many studies that use invertebrates to assess the health of aquatic ecosystems have recognized the presence of indicator taxa, or the abundance of select groups of invertebrates as being useful metrics for reflecting the health of an ecosystem (Kashian and Burton, 2000; Lunde and Resh, 2012; Mereta et al., 2013). For the resacas studied, the most useful metrics for discriminating between sites of different ages were measures of diversity and the trophic structure of the community. As expected based on successional theory (Horn, 1974), Shannon diversity index increased from the new to the intermediate site followed by an overall decrease in the old site. A study of constructed wetlands also identified the Shannon-Wiener diversity index as being a reliable measure of wetland ecosystem integrity (Awal and Svozil, 2010).

The trophic structure of the benthic macroinvertebrate community in this study was useful for discriminating between sites. The groups with the most distinct differences between the three sites were predators and scrapers. The contribution of predators to the total invertebrate community structure had a gradual decrease from the new site to the old site. The ratio of scraper abundance to total community abundance increased to being the dominant feeding group in the old resaca. Differences were less defined within the water column community. Although measures of water column trophic structure have proven to be useful in discriminating between sites in other studies (Kashian and Burton, 2000), it may not be useful as an indicator metric for resaca water column communities.

The presence and abundance of *M. tuberculata* may also serve as an indicator of resaca ecosystem age. Abundance of this gastropod varied greatly between the three sites, and was the dominant species in the old resaca. In addition, a large number of empty shells were observed in benthic samples from the old resaca. The number and physical condition of the empty shells may provide an indication of how long *M. tuberculata* has been present in the resaca, which, due to the prevalence of the snail in the area, may potentially serve as an indicator of how long the resaca has been flooded.

Influence of exotic gastropod

Melanoides tuberculata, native to the Middle East, Southeast Asia and eastern Africa, was introduced and spread in Texas through the aquarium trade (Karatayev et al., 2009). The aquarium trade began importing *M. tuberculata* as early as 1930 (Benson and Neilson, 2014) and aquatic ecosystems likely experienced repeated introductions through release of unwanted aquarium snails. *M. tuberculata* is known to outcompete native gastropods (Karatayev et al., 2009) and has even been used as a form of biological control to displace a gastropod that was a vector for human parasites (Pointier and Augustin, 1999).

Three families of gastropods, Planorbidae, Lymnaeidae, and Physidae, were present in the intermediate resaca but were absent from the old resaca, suggesting that they may have been displaced by the high abundance of *M. tuberculata*. The dominance of a single gastropod species in combination with low diversity in the old resaca may indicate that *M. tuberculata* is a strong competitor and is responsible for the displacement of other species through competitive exclusion (Huston, 1979). *M. tuberculata* reproduces rapidly, grows quickly, and has been shown to reach and maintain very high population densities (Pointier et al., 1992; Rader et al., 2003; Work and Mills, 2013). There was a high density of empty shells collected in the benthic core samples during this study and it is likely that in addition to competing with the snails for food resources, benthic organisms are also competing for habitat space with the abundant empty shells, which may be a case of habitat modification.

Comparison of Sampling Methods

Two different sampling methods were utilized during this study. The benthic corer sampled invertebrates from the benthic community, while the sweep net sampled invertebrates from the water column community. Both sampling methods had their advantages and disadvantages (table 13), but produced similar results (table 14). The primary advantage of the sweep net method was the ease of sample sorting due to the low volume of sediment in the sample. The major drawback of the core device is the amount of time required to separate invertebrates from the large amount of sediment collected.

The sweep net collected a greater abundance of invertebrates for all sites representing more taxa, but resulted in similar diversity trends as the benthic corer method (table 13). The sweep net collected a greater number of insects than the benthic corer (see appendices) which may be important if using the invertebrate community to assess the health of resacas. However, trends in trophic structure were more evident in core samples than in sweep net samples, and if these trends are found in future studies the benthic core device may produce results that are reflective of differences between sites. Overall, due to the nature of resacas the benthic core device was more appropriate in that it can be used in very shallow water and in the woody vegetation that is present along the shoreline.

Conclusions

This study provides the first documented assessment of the macroinvertebrate community in resacas associated with the Rio Grande. Resacas are warm water wetlands that are eutrophic year-round. They host a diverse community of invertebrates with 51 families found within the water column and benthic communities combined. Chironomidae, Mysidae, Ceratopogonidae, Baetidae, and Thiaridae were among the families with the most abundant taxa. With the exception of one gastropod, all taxa that were found in the river were also present in the resacas.

Resacas in early stages of development hosted a more diverse community than the more developed resaca. They trend towards a simplification of the macroinvertebrate community as the system becomes established, and competitive exclusion appears to be a strong driver for the community composition in late successional stages. The more developed resaca in this study exhibited strong dominance of only a few species with the water column community being characterized by mysid shrimp and the benthic community by the exotic gastropod *M. tuberculata*. Changes in the trophic structure did not proceed as expected based on previous age-series studies, but the results of this study indicate that the composition of the macroinvertebrate community of a resaca can reflect the stage of ecosystem development. The baseline data collected during this study may be useful in future studies to gauge the successional stage of restored resacas. To better characterize resaca ecosystems these results should be supported by further studies that monitor the invertebrate community and also include a direct measure of functional processes.

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Tables

Table 1. Geographic coordinates of sample sites in Cameron County, TX. Coordinates are located at middle point of resaca.

Site	Latitude	Longitude
New	25°51’00.08” N	97°25’09.48” W
Intermediate	25°51’11.37” N	97°25’22.57” W
Old	25°53’40.31” N	97°22’49.69” W

Table 2. Average annual water parameters (± standard error) based on monthly sampling from three resacas and quarterly samples from the river from March 2013 to February 2014. Dissolved oxygen (DO), Total phosphorous (TP). (-) indicates that this parameter was not measured.

Site	Secchi (cm)	pH	Conduct (µs/cm)	DO (mg/L)	Temp (°C)	TP (mg/L PO_4^{3-})	Nitrite (mg/L NO_2^--N)	Nitrate (mg/L NO_3^--N)	Ammonia (mg/L NH_3-N)
New	21.6 ±1.4	8.1 ±0.1	1216.0 ±72.4	7.2 ±0.7	25.4 ±1.4	0.656	0.007	0.020	0.299
Intermediate	41.1 ±3.6	8.3 ±0.2	1314.6 ±71.4	9.4 ±1.0	26.3 ±1.7	1.058	0.005	0.010	0.254
Old	26.1 ±2.1	7.9 ±0.2	1263.0 ±47.3	6.6 ±0.6	24.1 ±1.7	0.550	0.005	0.013	0.264
River	24.9 ±2.9	7.8 ±0.1	1304.7 ±169	7.4 ±0.4	26.1 ±1.4	-	-	-	-

Table 3. Mean annual chlorophyll-a concentrations from monthly sampling of three resacas. Carlson's Trophic State index was derived from chlorophyll-a concentrations. River chlorophyll concentrations were calculated from fluorometer values using linear regression formula (see appendix D). Samples collected between March 2013 and February 2014, Cameron County, TX.

Site	Chlorophyll-a (ug/L)	Carlson's TSI	Trophic Classification
New	43.0 ±5.5	66.2	Eutrophic
Intermediate	48.2 ±10.0	66.5	Eutrophic
Old	40.4 ±3.6	66.5	Eutrophic
River	67.3 ±19	70.9	Eutrophic

Table 4. Summary of Principal Component Analysis results of monthly water parameters collected between March 2013 and February 2014. Expressed as (a) Eigenvalues and (b) Eigenvectors. Principal Component (PC); Cumulative percent variation (C % Var); Dissolved oxygen (DO mg/L); Organic matter (OM %); Conductivity (Cond µs/cm); Water temperature (WT °C); Chlorophyll-a (ug/L); Secchi depth (cm). Samples collected between March 2013 and February 2014, Cameron County, TX.

(a)

PC	Eigenvalues	%Variation	C %Var
1	2.89	26.3	26.3
2	1.65	15.0	41.2
3	1.62	14.7	55.9
4	1.26	11.4	67.4
5	1.09	9.9	77.3

(b)

Variable	PC1	PC2	PC3	PC4	PC5
Secchi	0.399	0.230	0.260	0.099	0.310
pH	0.386	-0.316	-0.295	0.010	0.284
Chlorophyll-a	-0.298	-0.121	0.470	0.288	0.144
Cond	0.191	-0.429	0.048	-0.055	-0.598
DO	0.344	-0.497	-0.068	0.072	0.044
WT	-0.181	-0.097	0.530	-0.212	-0.185
TP	0.225	0.041	0.169	0.497	-0.483
Nitrite	-0.047	0.169	-0.202	0.736	0.001
Nitrate	-0.323	-0.408	-0.126	0.074	0.102
Ammonia	-0.345	-0.421	0.041	0.240	0.275
OM	0.373	-0.131	0.500	0.052	0.299

Table 5. Benthic invertebrate taxa unique to each site. Samples collected between March 2013 and February 2014, Cameron County, TX.

New	Intermediate	Old	River
Enchytraeidae			
Gomphidae			
Chrysomelidae			
Ectoprocta			
	Hyalellidae		
	Baetidae		
	Planorbidae (sp.1)		
	Planorbidae (sp.2)		
	Ceratopogonidae (sp.3)		
	Planorbidae (sp.3)		
	Corixidae (sp.2)		
	Planorbidae (sp.4)		
	Haliplidae		
	Palaemonidae		
	Culicidae		
	Corixidae (sp.3)		
		Sphaeriidae	
		Erpobdellidae	
		Phryganeidae	
		Curculionidae	
		Ancylidae	
		Poduridae	
		Lumbriculidae	
			Hydrobiidae

Table 6. Trophic structure of the benthic community based on total annual abundance of individuals. Samples collected between March 2013 and February 2014, Cameron County, TX.

Metric	New	# of Taxa	Intermediate	# of Taxa	Old	# of Taxa
Total taxa	24	-	29	-	21	-
Family Richness	19	-	19	-	16	-
% Predators	40.0	12	38.2	14	8.6	7
% Gatherers	54.7	7	50.4	6	30.9	7
% Filterers	3.5	2	0.1	1	1.6	2
% Scrapers	1.7	2	11.1	6	58.7	2
% Shredders	0.2	1	0.3	2	0.2	2

Table 7. Similarity percentages (SIMPER) of benthic macroinvertebrate taxa abundances ($\sqrt[4]{}$transformed) between three resacas. Bold indicates suggested characterizing taxa (similarity/SD >2.00) for each successional category. Samples collected between March 2013 and February 2014, Cameron County, TX.

Taxa	New	Intermediate	Old
Average Similarity (%)	49.48	50.45	48.49
Tanypodinae	26.2	**17.09**	8.74
Tubificinae	**25.69**		20.27
Chironomidae	15.23	20.11	
Chironominae	14.54	**20.81**	
Probezzia		12.87	
M. tuberculata			**48.62**

Table 8. Total abundance of benthic macroinvertebrates expressed as number of individuals by family in the three resacas and the Rio Grande. * denotes family with active dispersal abilities. Samples collected between March 2013 and February 2014, Cameron County, TX.

Family	New	Intermediate	Old	River
***Chironomidae**	341	750	238	195
Naididae	141	239	162	406
***Ceratopogonidae**	39	149	17	2
Mysidae	20	0	16	55
***Chaoboridae**	18	1	1	0
***Corixidae**	13	13	0	0
Physidae	9	5	0	0
Lumbriculidae	6	0	13	0
Glossiphonidae	4	3	9	1
***Caenidae**	3	1	0	0
Nematoda	2	1	27	0
Enchytraeidae	2	0	0	0
Thiaridae	1	119	699	0
Gordiidae	1	10	0	0
***Coenagrionidae**	1	9	1	0
***Corduliidae**	1	2	0	0
***Chrysomelidae**	1	0	0	0
***Gomphidae**	1	0	0	0
Ectoprocta	1	0	0	0
Hyalellidae	0	68	0	6
Planorbidae	0	34	0	0
***Baetidae**	0	18	0	0
Palaemonidae	0	2	0	0
***Haliplidae**	0	2	0	0
***Culicidae**	0	1	0	0
Sphaeriidae	0	0	3	0
Erpobdellidae	0	0	2	0
Ancylidae	0	0	1	0
***Phryganeidae**	0	0	1	0
Poduridae	0	0	1	0
***Curculionidae**	0	0	1	0
Hydrobiidae	0	0	0	1

Table 9. Water column taxa unique to each site. Samples collected between March 2013 and February 2014, Cameron County, TX.

New	Intermediate	Old
Dytiscidae (sp.1)		
Elmidae		
Sminthuridae		
Stratiomyidae		
Dytiscidae (sp.2)		
	Planorbidae (sp.1)	
	Notonectidae (sp.3)	
	Hydrachnidae (sp.1)	
	Hydrachnidae (sp.2)	
	Corduliidae	
	hydrophilidae Berosus	
	Hydrachnidae (sp.3)	
	Planorbidae (sp.2)	
	Dytiscidae (sp.3)	
	Chaoboridae Chaoborus	
	Lymnaeidae	
	Aeshnidae	
	Calamoceratidae	
	Caenidae	
	Notonectidae (sp.4)	
	Hydrophilidae (sp.3)	
	Haliplidae	
		Thiaridae *Melanoides Tuberculata*
		Asellidae
		Glossiphoniidae
		Argulidae Argulus

Table 10. Trophic strucuture of the water column invertebrate community based on total annual abundance. Samples collected between March 2013 and February 2014, Cameron County, TX.

Metric	New	# of taxa	Intermediate	# of taxa	Old	# of taxa
Total taxa	37	-	48	-	22	-
Family Richness	25	-	31	-	18	-
% Predators	18.5	22	43.3	30	7.2	12
% Gatherers	19.3	9	50.7	7	12.8	6
% Filterers	54.6	2	3.5	2	73.3	2
% Scrapers	1.6	1	1.2	4	5.7	1
% Shredders	6.0	3	1.3	5	1.0	1

Table 11. Similarity percentages (SIMPER) of water column macroinvertebrate taxa abundances ($\sqrt[4]{}$transformed) between three resacas. Bold indicates good characterizing taxa (similarity/SD >2.00) Samples collected between March 2013 and February 2014, Cameron County, TX.

		Site	
Taxa	**New**	**Intermediate**	**Old**
Average Similarity (%)	30.84	45.04	32.34
Mysidae	33.05		66.5
Tubificinae	16.05	10.73	
Baetidae	11.08	6.65	
Tanypodinae	7.16	4.92	
Chironominae	6.67	**13.9**	
Chironominae		**13.31**	
Corixidae		11.31	
Corixidae		10.56	
Palaemonidae			11.5

Table 12. Total abundance of water column macroinvertebrates expressed as number of individuals by family. * denotes family with active dispersal abilities. Samples collected between March 2013 and February 2014, Cameron County, TX.

Family	New	Intermediate	Old	River
Mysidae	928	88	985	601
***Chironomidae**	217	1212	117	30
***Baetidae**	147	525	2	1
Palaemonidae	99	35	13	1
***Corixidae**	95	159	6	6
***Coenagrionidae**	75	97	0	0
Naididae	28	184	105	61
Physidae	27	11	0	1
***Libellulidae**	16	11	0	0
***Notonectidae**	15	20	3	4
***Culicidae**	14	21	1	0
***Gerridae**	13	4	21	2
Pleidae	12	66	0	0
Hydra	8	1	5	0
***Dytiscidae**	6	2	0	0
***Veliidae**	5	4	1	0
***Ceratopogonidae**	4	83	2	0
***Belostomatidae**	4	10	0	0
***Phryganeidae**	3	2	0	0
***Hydrophilidae**	2	8	1	0
***Tipulidae**	2	1	0	0
***Elmidae**	2	0	0	0
Hyalellidae	1	516	1	20
Sminthuridae	1	0	0	0
***Stratiomyidae**	1	0	0	0
Hydrachnidae	0	28	0	0
Planorbidae	0	26	0	0
***Corduliidae**	0	5	0	0
Lymnaeidae	0	1	0	0
***Chaoboridae**	0	1	0	0
***Calamoceratidae**	0	1	0	0
***Caenidae**	0	1	0	0
***Aeshnidae**	0	1	0	0
***Haliplidae**	0	1	0	0
Thiariidae	0	0	77	0
Glossiphoniidae	0	0	1	1
Argulidae	0	0	1	0
Asellidae	0	0	3	3

Table 13. Comparison of metrics calculated based on total annual abundances for two sampling techniques. Samples collected between March 2013 and February 2014, Cameron County, TX.

	New		Intermediate		Old	
Metric	**Core**	**Net**	**Core**	**Net**	**Core**	**Net**
Total Taxa	24	37	29	48	21	22
Margalef's Richness (d)	1.52	1.97	1.89	2.96	1.23	1.22
Pielou's Evenness (J)	0.76	0.67	0.66	0.73	0.48	0.64
Shannon Diversity (H)	1.35	1.36	1.47	1.94	0.86	0.81
% Predators	40.0	18.5	38.2	43.3	8.6	7.2
% Scrapers	1.7	1.6	11.1	1.2	58.7	5.7
% Gatherers	54.7	19.3	50.4	50.7	30.9	12.8
% Filterers	3.5	54.6	0.1	3.5	1.6	73.3

Table 14. Comparison of advantages and disadvantages to using a benthic core device versus a sweep net for the collection of macroinvertebrate samples.

Sampling Method	Advantages	Disadvantages
Benthic Corer	• Easily quantified • Less potential for variability due to person collecting sample	• Separating specimens from sediment was time consuming (1-3 hours per sample) • Generally had lower abundance and species richness than sweep net
D-frame Sweep Net	• Lack of sediment made picking out specimens less time consuming (< 1 hour) • Greater species richness than benthic corer	• Cannot be used in very shallow water • Difficult to use in areas with woody vegetation

Figures

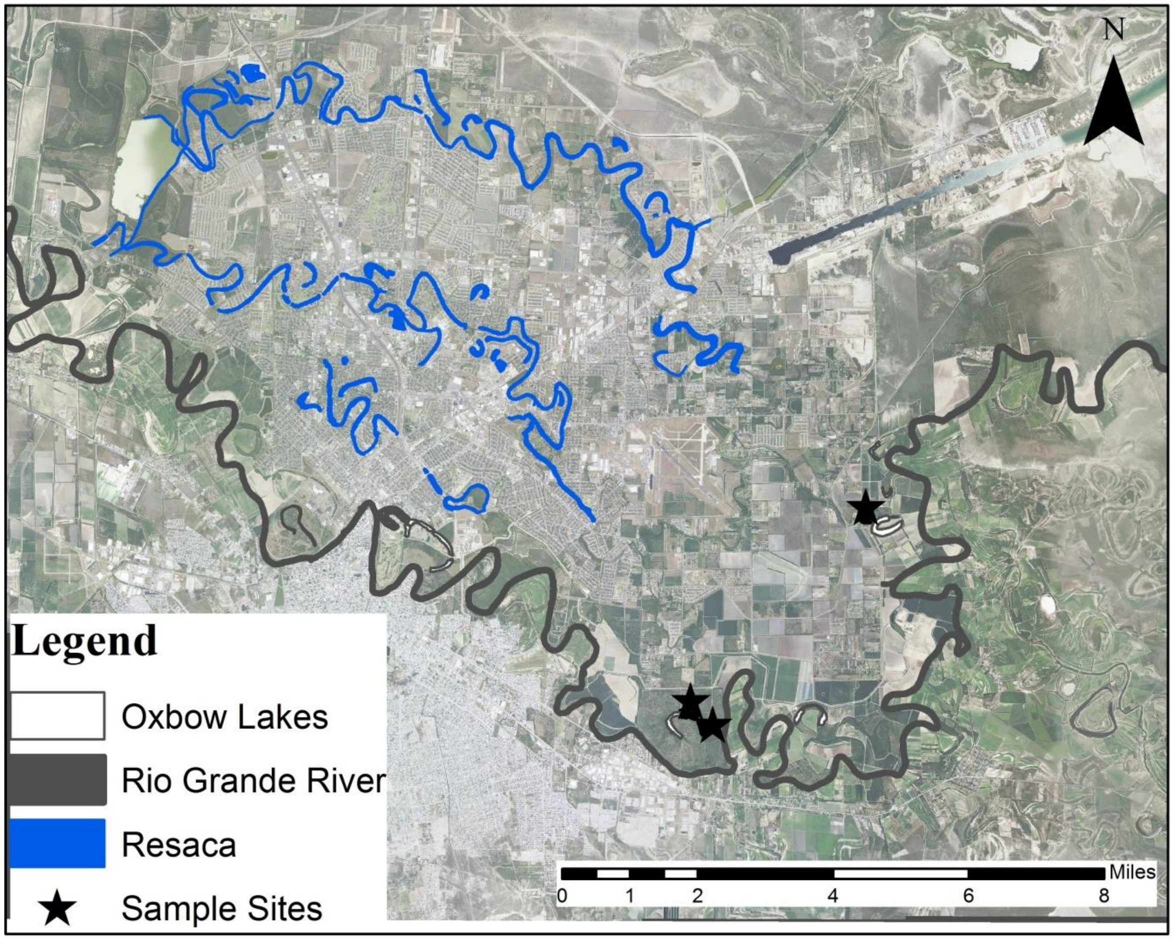


Figure 1a. Secondary channels and oxbow lakes formed by the Rio Grande, locally known as resacas. Located in Brownsville, TX.

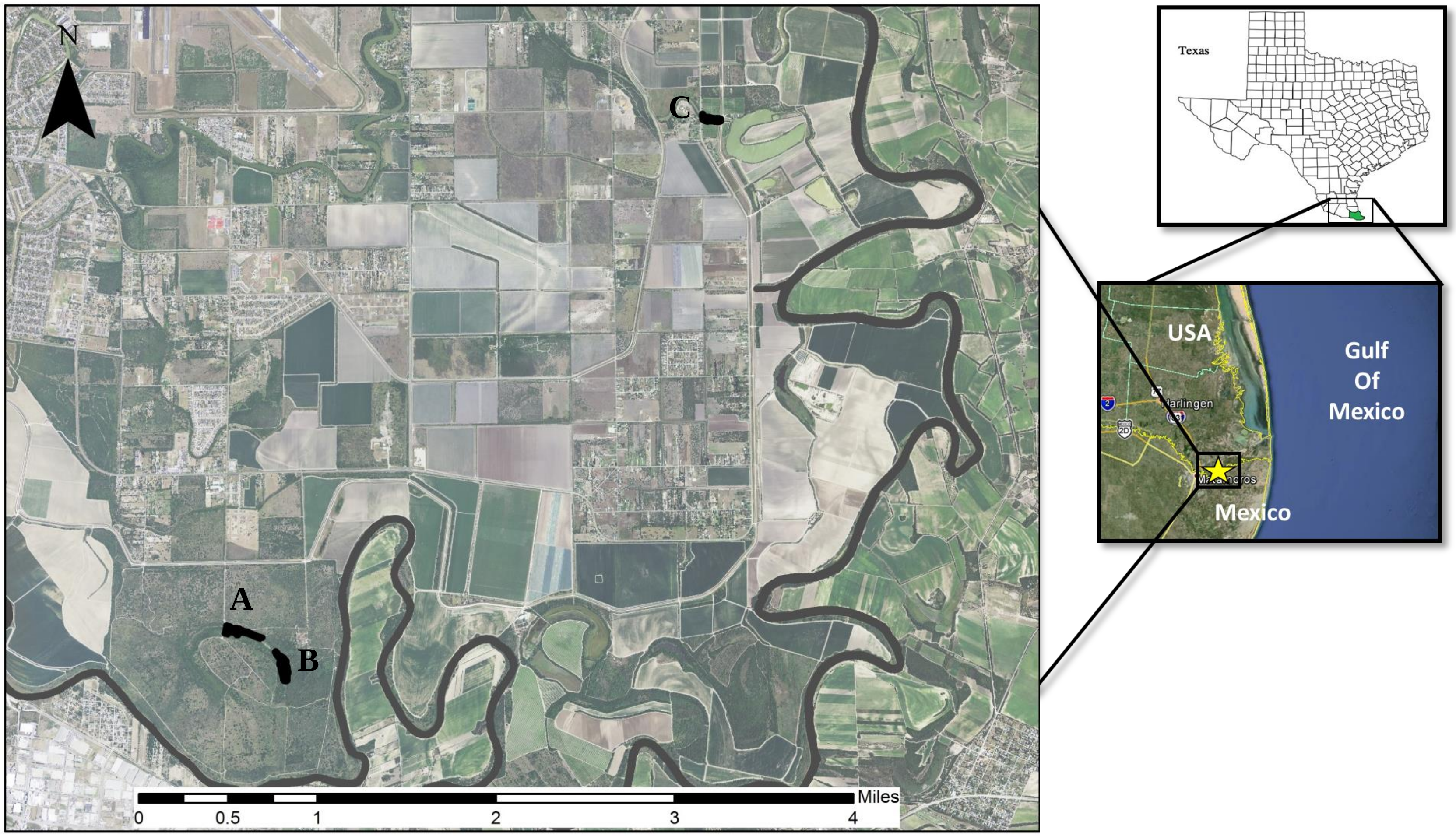


Figure 1b. Locations of study sites in Cameron County, TX. A = New site; B= Intermediate site; C= Old site

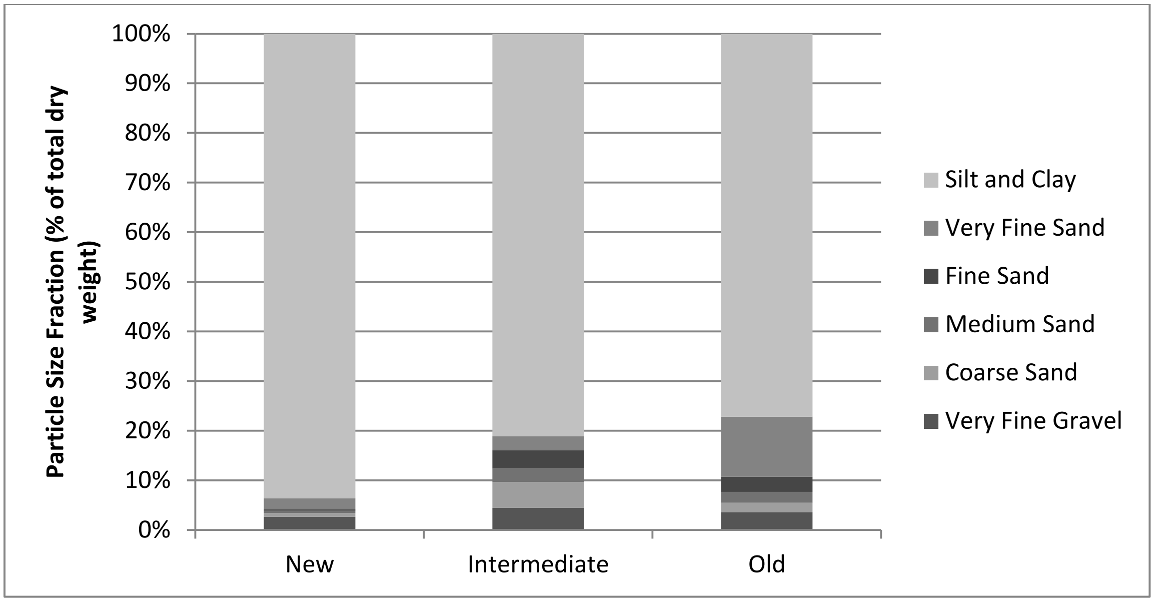


Figure 2. Mean sediments particle size (% of dry weight) distribution from stratified sampling of three resacas. n=3 for all sites. Samples collected in October 2013, Cameron County, TX.

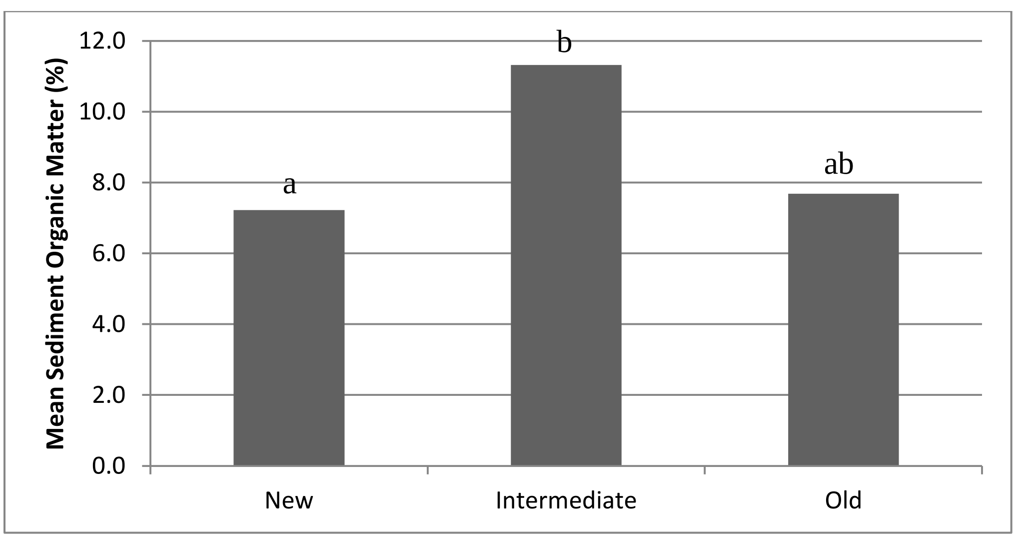


Figure 3. Mean sediment organic matter content from stratified samples of three resacas. n=3 for all sites. Samples collected in October 2013, Cameron County, TX. Different letters indicate significant differences ($p<0.05$) among sites.

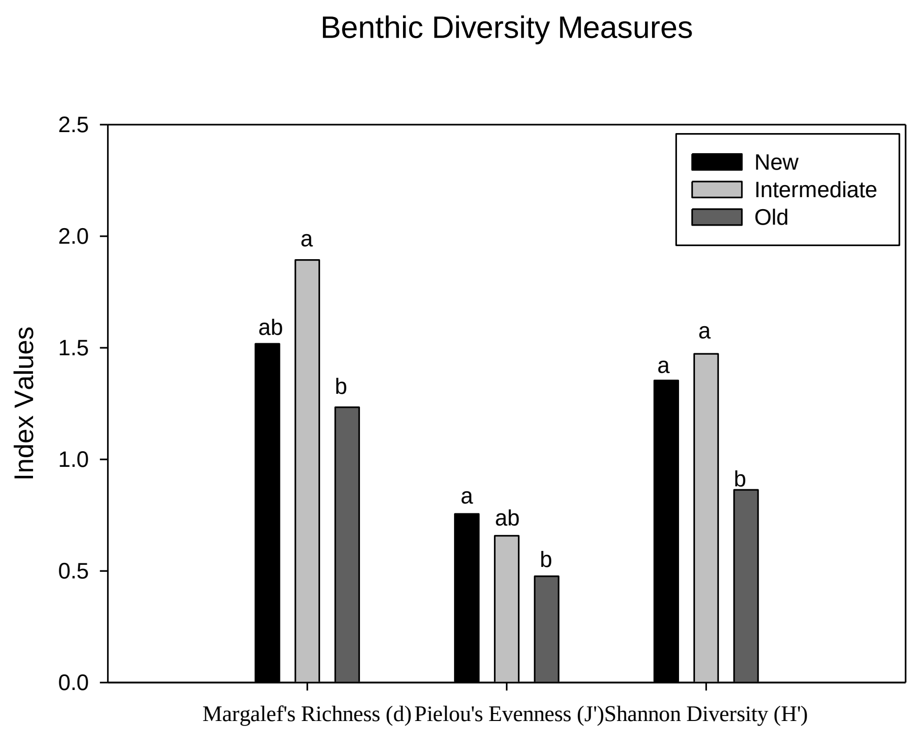


Figure 4. Mean annual diversity indices for benthic community based on monthly samples from three resacas. n=12 for all sites. Different letters indicate significant difference ($p<0.05$) among sites based on ANOVA and Tukey post hoc test. Samples collected between March 2013 and February 2014, Cameron County, TX.

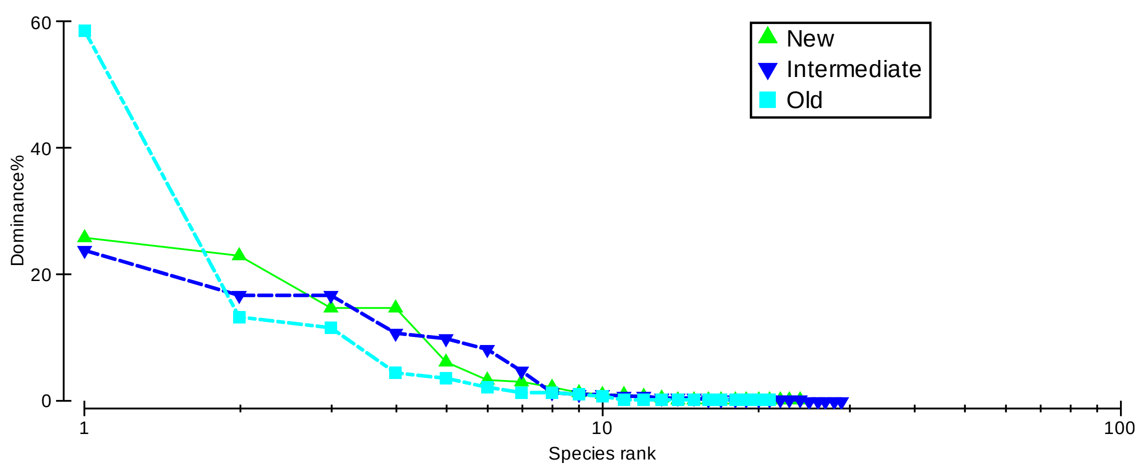


Figure 5. Dominance plot based on total annual abundance of the benthic community. Species rank represents the percent contribution of a single taxa. Samples collected between March 2013 and February 2014, Cameron County, TX.

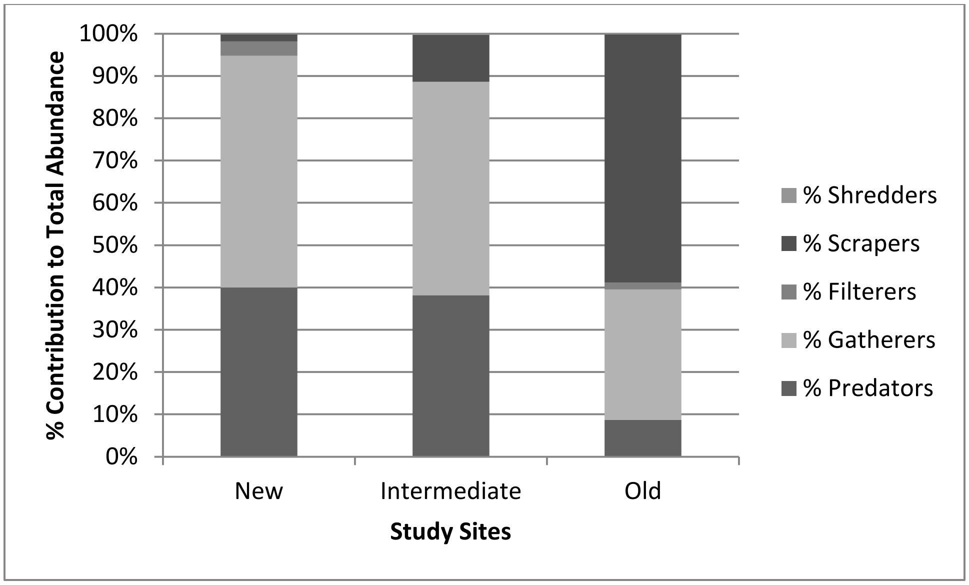


Figure 6. Relative contribution of functional feeding groups to the total abundance of benthic macroinvertebrates in three study sites. Samples collected between March 2013 and February 2014, Cameron County, TX.

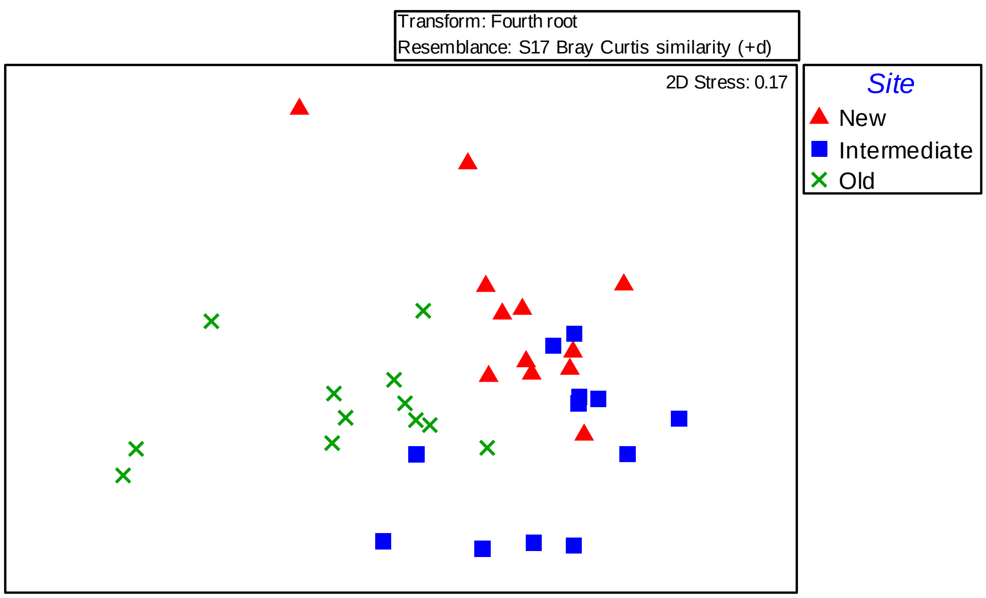


Figure 7. Multi-dimensional scaling (MDS) ordination of monthly invertebrate taxa abundances ($^4\sqrt{}$transformed) from benthic community of three resacas. Samples collected between March 2013 and February 2014, Cameron County, TX.

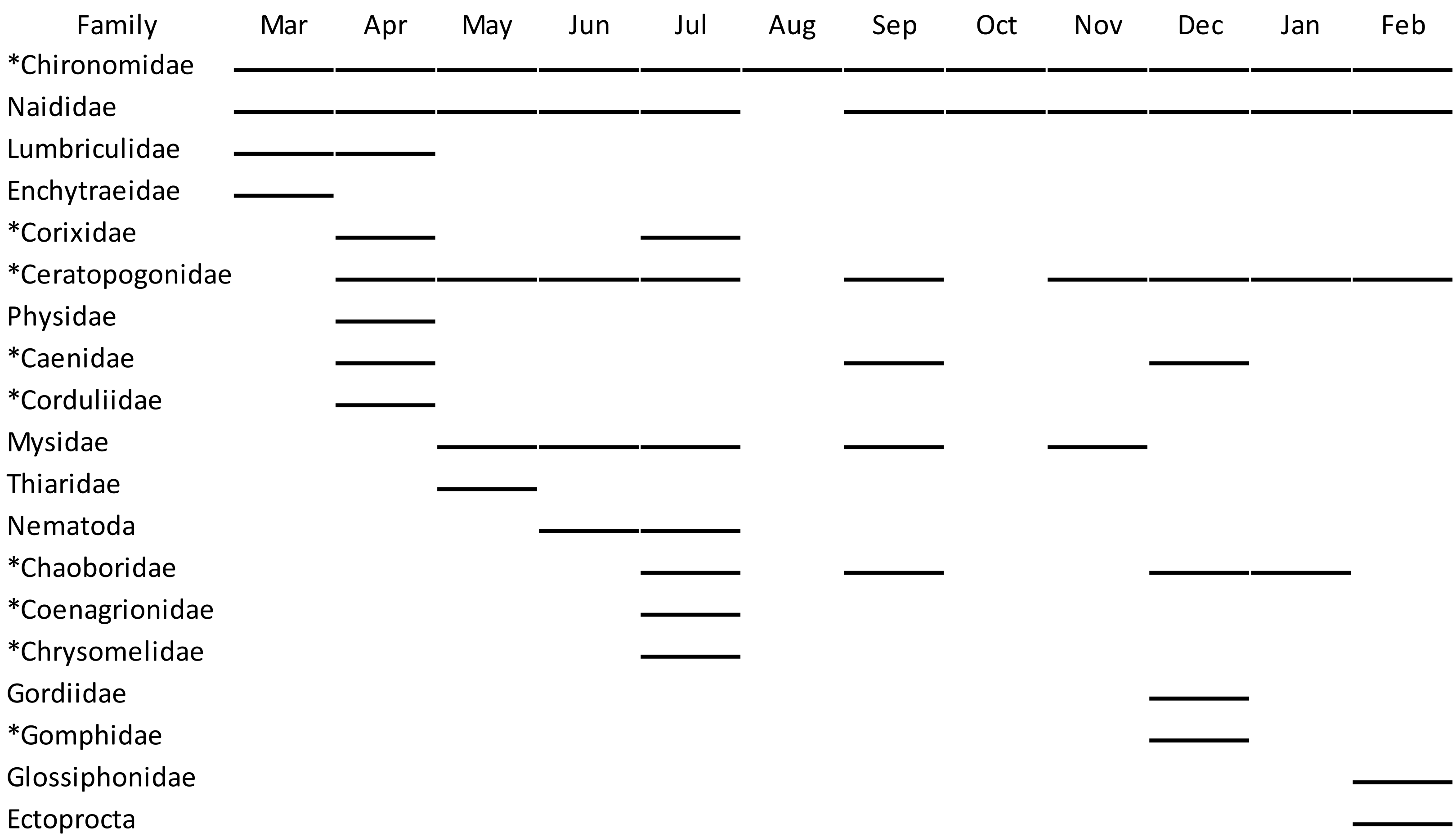


Figure 8. Colonization pattern of benthic macroinvertebrates in the new resaca based on the first time of an individual of that family was found in a sample. * indicates a family with active dispersal ability. Samples collected between March 2013 and February 2014, Cameron County, TX.

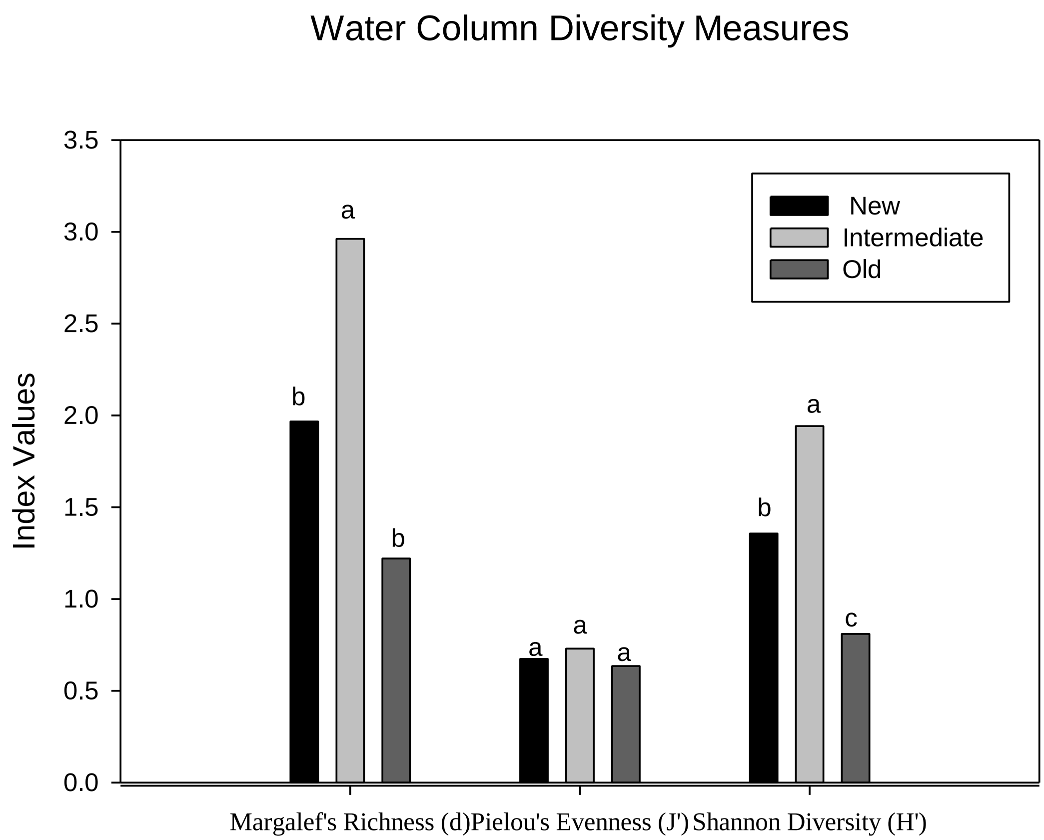


Figure 9. Mean annual diversity measures based on monthly taxa abundances of water column community. n=12 for all sites. Different letter indicates significant difference (p<0.05) among sites based on ANOVA and Tukey post hoc test. Samples collected between March 2013 and February 2014, Cameron County, TX.

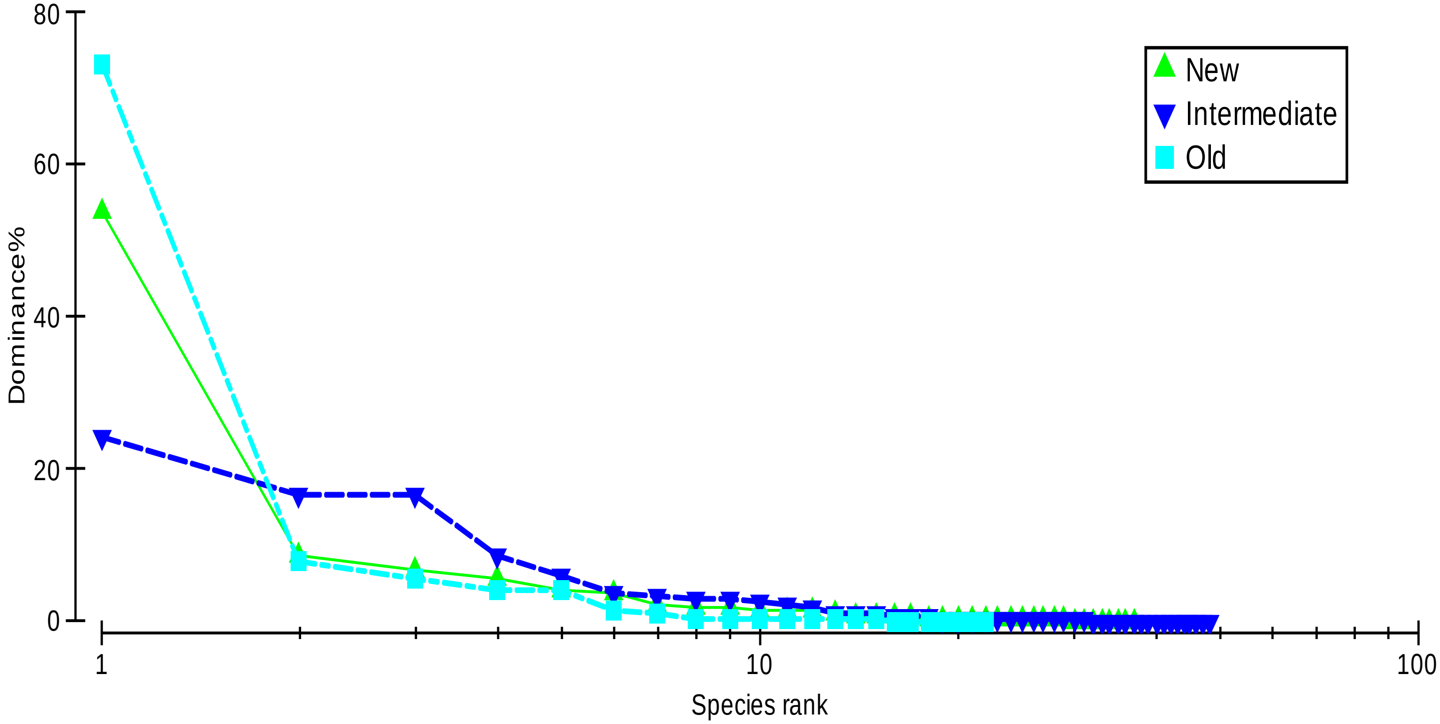


Figure 10. Dominance plot based on total annual abundance of water column community. Species rank represents the percent contribution of a single taxa. Samples collected between March 2013 and February 2014, Cameron County, TX.

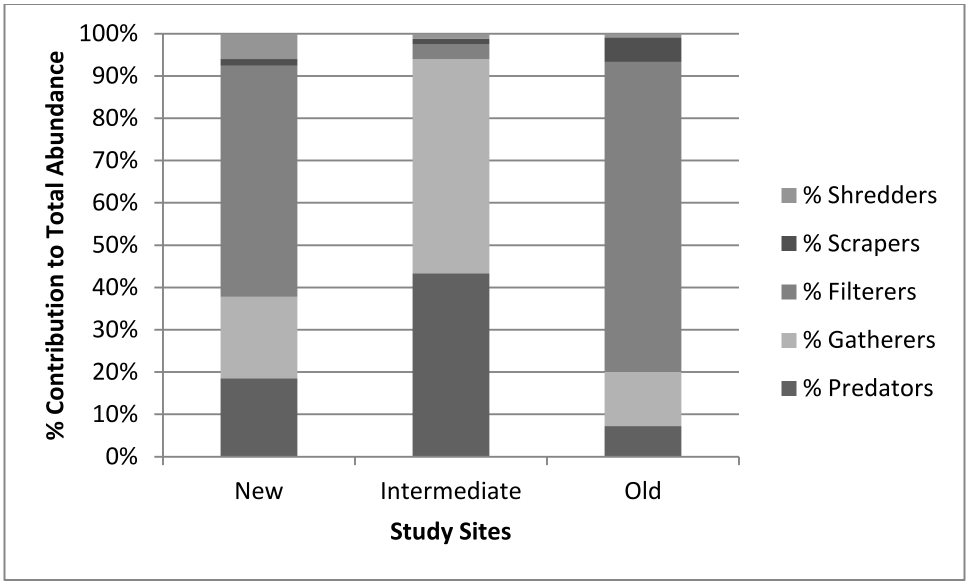


Figure 11. Relative contribution of functional feeding groups to the total abundance of water column macroinvertebrates in three study sites. Samples collected between March 2013 and February 2014, Cameron County, TX.

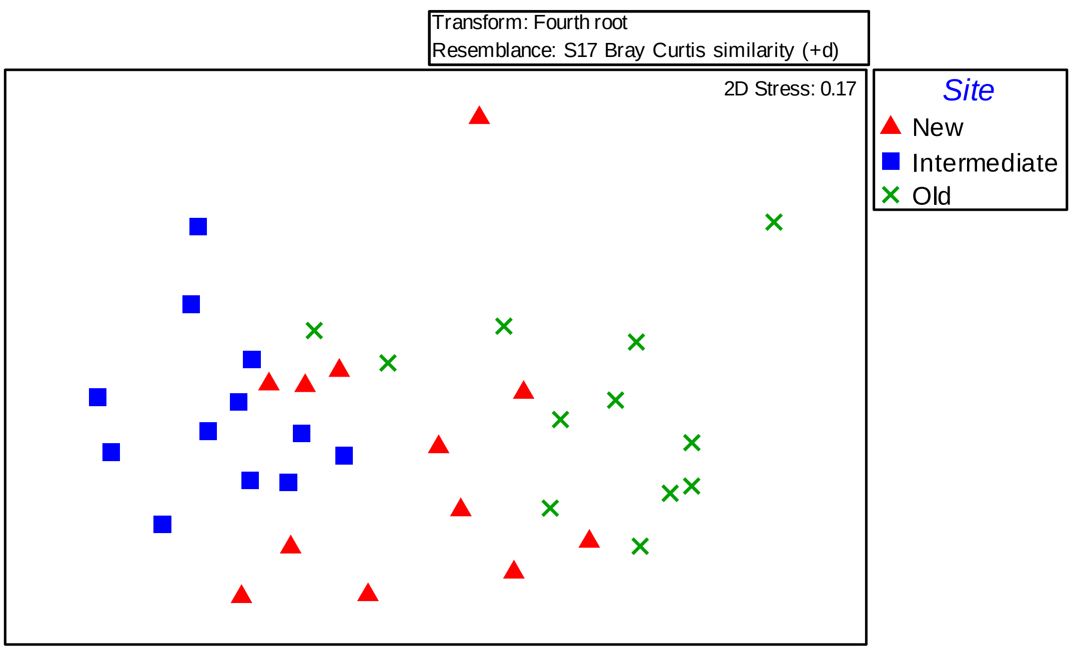


Figure 12. Multi-dimensional scaling (MDS) ordination of monthly taxa abundances ($^4\sqrt{}$transformed) from water column community of three resacas. Samples collected between March 2013 and February 2014, Cameron County, TX.

Figure 13. Colonization pattern of water column macroinvertebrates in the new resaca based on first time an individual of that family was found in samples. * indicates a family with active dispersal ability. Samples collected between March 2013 and February 2014, Cameron County, TX

Appendices

Appendix A: Taxonomic identifications of all benthic invertebrates

Table 15. Taxonomic identifications of all benthic macroinvertebrates collected with core device with assigned functional feeding group (FFG). GC = Gatherer collector; PR = Predator; SH = Shredder; FC = Filterer Collector; SC = Scraper. Samples collected between March 2013 and February 2014 in Cameron County, TX

ID #	Phylum	Class	Order	Family	Subfamily	Genus	Species	FFG
N72	Annelida	Clitella		Enchytraeidae				GC
N88	Annelida	Clitella		Naididae				GC
N84	Annelida	Clitella	Arhynchobdellida	Erpobdellidae				PR
N73	Annelida	Clitella	Lumbriculida	Lumbriculidae			*Sp. 1*	GC
N81	Annelida	Clitella	Lumbriculida	Lumbriculidae			*Sp. 2*	GC
N83	Annelida	Clitella	Rhynchobdellida	Glossiphoniidae				PR
N20	Annelida	Clitella	Tubificidae	Naididae	Tubificinae			GC
N97	Arthropoda	Collembola	Poduromorpha	Poduridae				GC
N95	Arthropoda	Insecta	Coleoptera	Chrysomelidae				SH
N106	Arthropoda	Insecta	Coleoptera	Haliplidae				SH
N107	Arthropoda	Insecta	Coleoptera	Curculionidae				SH
N76	Arthropoda	Insecta	Diptera	Chironomidae	tanypodinae	*tanypus*	*Sp. 4*	PR
N79	Arthropoda	Insecta	Diptera	Chironomidae			*Sp. 3*	GC
N2	Arthropoda	Insecta	Diptera	Chironomidae	Chironominae		*Sp. 1*	GC
N23	Arthropoda	Insecta	Diptera	Ceratopogonidae		*Probezzia*	*Sp. 1*	PR
N82	Arthropoda	Insecta	Diptera	Chaoboridae		*Chaoborus*		PR
N66	Arthropoda	Insecta	Diptera	Chironomidae	tanypodinae		*Sp. 2*	PR

N93	Arthropoda	Insecta	Diptera	Ceratopogonidae		*Sp. 2*	PR
N104	Arthropoda	Insecta	Diptera	Ceratopogonidae	*Bezzia*	*Sp. 3*	PR
N57	Arthropoda	Insecta	Diptera	Culicidae			FC
N100	Arthropoda	Insecta	Ephemeroptera	Caenidae			GC
N90	Arthropoda	Insecta	Ephemeroptera	Baetidae			GC
N17	Arthropoda	Insecta	Hemiptera	Corixidae		*Sp. 1*	PR
C13	Arthropoda	Insecta	Hemiptera	Corixidae		*Sp. 3*	PR
N27	Arthropoda	Insecta	Hemiptera	Corixidae		*Sp. 2*	PR
N92	Arthropoda	Insecta	Odonata	Coenagrionidae		*Sp. 2*	PR
N98	Arthropoda	Insecta	Odonata	Corduliidae			PR
N102	Arthropoda	Insecta	Odonata	Gomphidae	*Aphylla*		PR
N85	Arthropoda	Insecta	Trichoptera	Phryganeidae			SH
N89	Arthropoda	Malacostraca	Amphipoda	Hyalellidae	*Hyalella*		GC
N7	Arthropoda	Malacostraca	Decapoda	Palaemonidae			SH/OM
N8	Arthropoda	Malacostraca	Mysida	Mysidae	*Taphromysis*		FC
N105	Bryozoa	phylactolaemata		Fredericellidae			FC
C2	Mollusca	Bivalvia	Veneroida	Sphaeriidae			FC
N77	Mollusca	Gastropoda		Physidae			SC
N40	Mollusca	Gastropoda		Thiaridae	*Melanoides*	*tuberculata*	SC
N96	Mollusca	Gastropoda		Planorbidae		*Sp. 1*	SC
N99	Mollusca	Gastropoda		Planorbidae		*Sp. 2*	SC
N91	Mollusca	Gastropoda		Planorbidae		*Sp. 3*	SC
N101	Mollusca	Gastropoda		Planorbidae		*Sp. 4*	SC
N78	Mollusca	Gastropoda		Hydrobiidae			SC
N80	Mollusca	Gastropoda	Basommatophora	Ancylidae	*Hebetancylus*		SC
N75	Nematoda			Nematoda			PR
N87	Nematomorpha		Gordioidea	Gordiidae	*Gordius*		PR

Table 16. Total abundances of benthic macroinvertebrate in new resaca collected with benthic corer. Samples collected between March 2013 and February 2014 in Cameron County, TX

Invertebrate Identification	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Annual Total
N76 = Chironomidae *Tanypus* (sp. 4)	0	6	6	9	31	2	49	3	8	32	6	4	**156**
N20 = Naididae Tubificinae	15	9	8	6	6	0	21	1	12	18	25	19	**140**
N79 = Chironomidae (sp. 3)	0	0	2	20	10	0	14	3	22	10	2	7	**90**
N2 = Chironomidae Chironominae (sp. 1)	52	16	10	2	2	0	2	1	1	2	0	1	**89**
N23 = Ceratopogonidae *Probezzia*	0	9	5	2	3	0	3	0	4	4	6	1	**37**
N8 = Mysidae *Taphromysis*	0	0	13	4	1	0	1	0	1	0	0	0	**20**
N82 = Chaoboridae *Chaoborus*	0	0	0	0	6	0	9	0	0	2	1	0	**18**
N17 = Corixidae (sp. 1)	0	12	0	0	1	0	0	0	0	0	0	0	**13**
N77 = Physidae	0	9	0	0	0	0	0	0	0	0	0	0	**9**
N66 = Chironomidae Tanypodinae (sp. 2)	0	2	0	0	3	0	1	0	0	0	0	0	**6**
N73 = Lumbriculidae	2	4	0	0	0	0	0	0	0	0	0	0	**6**
N83 = Glossiphoniidae	0	0	0	0	0	0	0	0	0	0	0	4	**4**
N100 = Caenidae	0	1	0	0	0	0	1	0	0	1	0	0	**3**
N93 = Ceratopoginidae (sp. 2)	0	0	0	0	0	0	0	0	0	0	0	2	**2**
N75 = Nematode	0	0	0	1	1	0	0	0	0	0	0	0	**2**
N72 = Enchytraeidae	2	0	0	0	0	0	0	0	0	0	0	0	**2**
N40 = Thiaridae *Melanoides tuberculata*	0	0	1	0	0	0	0	0	0	0	0	0	**1**
N87 = Gordiidae *Gordius*	0	0	0	0	0	0	0	0	0	1	0	0	**1**
N92 = Coenagrionidae	0	0	0	0	1	0	0	0	0	0	0	0	**1**
N98 =Corduliidae	0	1	0	0	0	0	0	0	0	0	0	0	**1**

N88 = Naididae (sp. 2)	0	0	0	0	0	0	0	0	0	0	0	1	**1**
N95 = Chrysomelidae	0	0	0	0	1	0	0	0	0	0	0	0	**1**
N105 = Ectoprocta Fredericellidae	0	0	0	0	0	0	0	0	0	0	0	1	**1**
N102 = Gomphidae *Aphylla*	0	0	0	0	0	0	0	0	0	1	0	0	**1**
Monthly Totals	**71**	**69**	**45**	**44**	**66**	**2**	**101**	**8**	**48**	**71**	**40**	**40**	**605**

Table 17. Total abundances of benthic macroinvertebrate in intermediate resaca collected with benthic corer. Samples collected between March 2013 and February 2014 in Cameron County, TX

Invertebrate Identification	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Annual Total
N76 = Chironomidae *Tanypus* (sp. 4)	133	163	2	1	3	1	9	1	11	1	7	8	**340**
N20 = Naididae Tubificinae (sp. 1)	2	126	3	2	3	0	3	0	2	1	41	56	**239**
N79 = Chironomidae (sp. 3)	0	3	16	49	60	18	9	4	31	26	16	6	**238**
N2 = Chironomidae Chironominae (sp. 1)	7	6	2	5	33	10	7	3	32	2	18	30	**155**
N23 = Ceratopogonidae *Probezzia* (sp. 1)	2	4	0	1	2	5	4	0	45	10	25	42	**140**
N40 = Thiaridae *Melanoides tuberculata*	35	10	18	2	0	0	0	54	0	0	0	0	**119**
N89 = Hyalellidae *Hyalella*	0	35	23	9	0	0	0	0	0	0	1	0	**68**
N90 = Baetidae	0	8	4	3	0	0	0	0	0	0	3	0	**18**
N66 = Chironomidae Tanypodinae (sp. 2)	0	0	2	8	1	0	6	0	0	0	0	0	**17**
N96 = Planorbidae (sp. 1)	0	6	0	0	1	1	1	2	2	0	2	0	**15**
N99 = Planorbidae (sp. 2)	0	10	0	0	0	1	0	0	0	0	0	0	**11**
N87 = Gordiidae *Gordius*	0	0	0	0	0	0	0	0	1	0	3	6	**10**
N17 = Corixidae (sp. 1)	2	4	0	0	0	0	0	1	0	0	2	0	**9**
N92 = Coenagrionidae (sp. 2)	0	0	0	5	1	0	1	0	1	0	1	0	**9**
N104 = Ceratopogonidae *Bezzia* (sp. 3)	0	0	0	0	0	0	0	0	0	0	6	0	**6**
N77 = Physidae	0	1	2	0	0	0	0	0	0	1	0	1	**5**
N91 = Planorbidae (sp. 3)	0	0	1	1	0	3	0	0	0	0	0	0	**5**
N83 = Glossiphoniidae	0	0	1	2	0	0	0	0	0	0	0	0	**3**
N93 = Ceratopogonidae (sp. 2)	0	0	0	3	0	0	0	0	0	0	0	0	**3**

C13 = Corixidae (sp. 3)	0	3	0	0	0	0	0	0	0	0	0	0	**3**
N101 = Planorbidae (sp. 4)	0	0	0	0	0	0	0	3	0	0	0	0	**3**
N98 =Corduliidae	0	0	0	0	0	2	0	0	0	0	0	0	**2**
N106 = Haliplidae	0	0	0	2	0	0	0	0	0	0	0	0	**2**
N7 = Palaemonidae	0	0	0	1	0	1	0	0	0	0	0	0	**2**
N82 = Chaoboridae *Chaoborus*	0	0	0	0	1	0	0	0	0	0	0	0	**1**
N100 = Caenidae	0	0	0	0	0	0	1	0	0	0	0	0	**1**
N75 = Nematode	0	0	0	0	0	0	0	0	0	0	1	0	**1**
N27 = Corixidae (sp. 2)	1	0	0	0	0	0	0	0	0	0	0	0	**1**
N57 = Culicidae	0	0	1	0	0	0	0	0	0	0	0	0	**1**
Monthly Totals	**182**	**379**	**75**	**94**	**105**	**42**	**41**	**68**	**125**	**41**	**126**	**149**	**1427**

Table 18. Total abundances of benthic macroinvertebrate in old resaca collected with benthic corer. Samples collected between March 2013 and February 2014 in Cameron County, TX

Invertebrate Identification	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Annual Total
N40 = Thiaridae *Melanoides tuberculata*	132	71	120	98	31	70	54	41	38	38	4	2	**699**
N20 = Naididae Tubificinae	10	5	32	32	6	2	3	0	0	6	41	23	**160**
N2 = Chironomidae Chironominae (sp. 1)	10	0	16	89	12	2	0	0	0	7	0	1	**137**
N79 = Chironomidae (sp. 3)	0	0	1	47	0	0	6	0	0	0	0	1	**55**
N76 = Chironomidae *Tanypus* (sp. 4)	6	1	3	22	2	6	2	0	0	2	0	0	**44**
N75 = Nematode	26	0	0	1	0	0	0	0	0	0	0	0	**27**
N23 = Ceratopogonidae *Probezzia* (sp. 1)	1	1	1	9	2	0	0	0	0	1	0	2	**17**
N8 = Mysidae *Taphromysis*	1	0	13	0	0	2	0	0	0	0	0	0	**16**
N73 = Lumbriculidae	0	0	0	3	6	0	1	0	0	1	0	1	**12**
N83 = Glossiphoniidae	0	0	1	2	1	1	4	0	0	0	0	0	**9**
C2 = Sphaeriidae	0	0	0	0	0	1	0	1	0	0	1	0	**3**
N66 = Chironomidae Tanypodinae (sp. 2)	0	0	0	2	0	0	0	0	0	0	0	0	**2**
N88 = Naididae	0	0	0	0	0	0	0	0	0	1	1	0	**2**
N84 = Erpobdellidae	0	0	1	0	0	0	0	1	0	0	0	0	**2**
N82 = Chaoboridae *Chaoborus*	0	0	0	0	0	0	0	1	0	0	0	0	**1**
N92 = Coenagrionidae	0	0	0	0	1	0	0	0	0	0	0	0	**1**
N80 = Ancylidae *Hebetancylus*	0	0	0	1	0	0	0	0	0	0	0	0	**1**
N107 = Curculionidae	0	0	0	0	0	0	0	0	0	0	0	1	**1**
N81 = Lumbriculidae	0	0	0	0	0	1	0	0	0	0	0	0	**1**
N85 = Phryganeidae	0	0	1	0	0	0	0	0	0	0	0	0	**1**
N97 = Poduridae	0	0	0	0	1	0	0	0	0	0	0	0	**1**
Monthly Totals	**186**	**78**	**189**	**306**	**62**	**85**	**70**	**44**	**38**	**56**	**47**	**31**	**1192**

Table 19. Total abundances of benthic macroinvertebrate in Rio Grande collected with benthic corer. Samples collected between March 2013 and February 2014 in Cameron County, TX

Invertebrate Identification	Feb	May	Aug	Nov	Annual Total
N20 = Naididae Tubificinae	69	162	50	124	**405**
N79 = Chironomidae (sp. 3)	29	0	5	83	**117**
N2 = Chironomidae Chironominae (sp. 1)	39	23	2	11	**75**
N8 = Mysidae *Taphromysis*	54	1	0	0	**55**
N89 = Hyalellidae Hyalella	6	0	0	0	**6**
N76 = Chironomidae *Tanypus* (sp. 4)	0	2	0	1	**3**
N23 = Ceratopogonidae *Probezzia* (sp. 1)	1	1	0	0	**2**
N83 = Glossiphoniidae	1	0	0	0	**1**
N88 = Naididae	0	0	1	0	**1**
N78 = Hydrobiidae	0	1	0	0	**1**
Monthly Totals	**199**	**190**	**58**	**219**	**666**

Appendix B: Taxonomic identifications of all water column invertebrates

Table 20. Taxonomic identifications of all water column macroinvertebrates collected with sweep net with assigned functional feeding group (FFG). GC = Gatherer collector; PR = Predator; SH = Shredder; FC = Filterer Collector; SC = Scraper. Samples collected between March 2013 and February 2014 in Cameron County, TX

ID #	Phylum	Class	Order	Family	Subfamily	Genus	Species	FFG
N83	Annelida	Clitella	Rhynchobdellida	Glossiphoniidae				PR
N20	Annelida	Clitella	Tubificidae	Naididae	Tubificinae		*Sp. 1*	GC
N122	Arthropoda	Collembola		Sminthuridae				GC
N10	Arthropoda	Insecta	Coleoptera	Belostomatidae				PR
N30	Arthropoda	Insecta	Coleoptera	Dytiscidae			*Sp. 1*	PR
N112	Arthropoda	Insecta	Coleoptera	Dytiscidae			*Sp. 2*	PR
N61	Arthropoda	Insecta	Coleoptera	Dytiscidae			*Sp. 3*	PR
N114	Arthropoda	Insecta	Coleoptera	Elmidae				GC
N106	Arthropoda	Insecta	Coleoptera	Haliplidae				SH
N44	Arthropoda	Insecta	Coleoptera	Hydrophilidae			*Sp. 1*	PR
N6	Arthropoda	Insecta	Coleoptera	Hydrophilidae		*Berosus*	*Sp. 2*	PR/PI
N120	Arthropoda	Insecta	Coleoptera	Hydrophilidae			*Sp. 3*	PR
N23	Arthropoda	Insecta	Diptera	Ceratopogonidae		*Probezzia*	*Sp. 1*	PR
N93	Arthropoda	Insecta	Diptera	Ceratopogonidae			*Sp. 2*	PR
N104	Arthropoda	Insecta	Diptera	Ceratopogonidae		*Bezzia*	*Sp. 3*	GC/PR
N68	Arthropoda	Insecta	Diptera	Ceratopogonidae			*Sp.4*	PR
N82	Arthropoda	Insecta	Diptera	Chaoboridae		*Chaoborus*		PR

N2	Arthropoda	Insecta	Diptera	Chironomidae	Chironominae		*Sp. 1*	GC
N66	Arthropoda	Insecta	Diptera	Chironomidae	Tanypodinae		*Sp.2*	PR
N79	Arthropoda	Insecta	Diptera	Chironomidae			*Sp. 3*	GC
N76	Arthropoda	Insecta	Diptera	Chironomidae	Tanypodinae	*tanypus*	*Sp. 4*	PR
N57	Arthropoda	Insecta	Diptera	Culicidae		*Culex*		FC
N64	Arthropoda	Insecta	Diptera	Stratiomyidae				GC
N9	Arthropoda	Insecta	Diptera	Tipulidae				SH
N90	Arthropoda	Insecta	Ephemeroptera	Baetidae				GC
N100	Arthropoda	Insecta	Ephemeroptera	Caenidae				GC
N17	Arthropoda	Insecta	Hemiptera	Corixidae			*Sp. 1*	PR
N27	Arthropoda	Insecta	Hemiptera	Corixidae			*Sp. 2*	PR
60	Arthropoda	Insecta	Hemiptera	Gerridae			*Sp. 1*	PR
51	Arthropoda	Insecta	Hemiptera	Gerridae			*Sp. 2*	PR
116	Arthropoda	Insecta	Hemiptera	Gerridae			*Sp. 3*	PR
N70	Arthropoda	Insecta	Hemiptera	Notonectidae		*Buenoa*	*Sp. 1*	PR
N117	Arthropoda	Insecta	Hemiptera	Notonectidae		*Anisops*	*Sp.2*	PR
N47	Arthropoda	Insecta	Hemiptera	Notonectidae			*Sp. 3*	PR
N59	Arthropoda	Insecta	Hemiptera	Notonectidae			*Sp. 4*	PR
N25	Arthropoda	Insecta	Hemiptera	Pleidae				PR
N115	Arthropoda	Insecta	Odonata	Aeshnidae				PR
N113	Arthropoda	Insecta	Odonata	Coenagrionidae			*Sp. 1*	PR
N92	Arthropoda	Insecta	Odonata	Coenagrionidae			*Sp. 2*	PR
N98	Arthropoda	Insecta	Odonata	Corduliidae				PR
N111	Arthropoda	Insecta	Odonata	Libellulidae				PR
N119	Arthropoda	Insecta	Trichoptera	Calamoceratidae				SH
N85	Arthropoda	Insecta	Trichoptera	Phryganeidae				SH
N56	Arthropoda	Insecta		veliidae				PR

N89	Arthropoda	Malacostraca	Amphipoda	Hyalellidae		*Hyalella*		GC
N7	Arthropoda	Malacostraca	Decapoda	Palaemonidae				SH/OM
N109	Arthropoda	Malacostraca	Isopoda	*Asellidae*				GC
N8	Arthropoda	Malacostraca	Mysida	Mysidae		*Taphromysis*		FC
N108	Arthropoda	Maxillopoda	Arguloida	Argulidae	Argulus			PR
N52	Cnidaria	Hydrozoa	Anthomedusae	Hydridae	Hydra			PR
N121	Mollusca	Gastropoda		Lymnaeidae				SC
N77	Mollusca	Gastropoda		Physidae				SC
N96	Mollusca	Gastropoda		Planorbidae			*Sp. 1*	SC
N99	Mollusca	Gastropoda		Planorbidae			*Sp. 2*	SC
N40	Mollusca	Gastropoda		Thiaridae		*Melanoides*	*tuberculata*	SC
67	Arthropoda	Arachnida	Trombidiformes	Hydrachnidae			*Sp. 1*	PR
58	Arthropoda	Arachnida	Trombidiformes	Hydrachnidae			*Sp. 2*	PR
110	Arthropoda	Arachnida	Trombidiformes	Hydrachnidae			*Sp. 3*	PR

Table 21. Total abundances of water column macroinvertebrate in new resaca collected with sweep net. Samples collected between March 2013 and February 2014 in Cameron County, TX

Invertebrate Identification	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Annual Total
N8 = Mysidae *Taphromysis*	27	69	731	52	6	0	1	8	13	15	3	3	**928**
N90 = Baetidae	79	10	8	40	5	0	0	1	1	3	0	0	**147**
N2 = Chironomidae Chironominae (sp. 1)	103	7	0	0	5	0	1	2	0	0	0	0	**118**
N7 = Palaemonidae	0	0	0	1	16	0	80	2	0	0	0	0	**99**
N113 = Coenagrionidae (sp. 1)	0	0	2	54	14	0	1	0	1	0	0	0	**72**
N17 = Corixidae (sp. 1)	18	31	10	0	0	1	0	0	0	2	0	0	**62**
N66 = Chironimidae tanypodinae (sp. 2)	0	0	0	7	31	0	0	0	0	0	0	0	**38**
N79 = Chironomidae Chironominae (sp. 3)	2	1	5	11	12	0	1	0	0	0	2	0	**34**
N27 = Corixidae (sp. 2)	3	3	23	2	0	0	0	0	0	1	1	0	**33**
N20 = Naididae Tubificinae (sp. 1)	2	2	7	5	0	0	1	0	1	1	8	1	**28**
N76 = Chironomidae *Tanypus* (sp. 4)	3	5	8	6	1	3	1	0	0	0	0	0	**27**
N77 = Physidae	5	21	0	0	0	0	0	0	0	1	0	0	**27**
N111 = Libellulidae	0	0	0	0	16	0	0	0	0	0	0	0	**16**
N57 = Culicidae	0	0	0	4	10	0	0	0	0	0	0	0	**14**
N70 = Notonectidae *Buenoa* (sp. 1)	0	0	0	0	0	0	0	1	12	0	0	0	**13**
N25 = Pleidae	1	0	0	0	9	0	0	2	0	0	0	0	**12**
N60 = Gerridae	0	0	0	0	9	0	0	0	0	0	0	0	**9**
N52 = Hydra	0	0	8	0	0	0	0	0	0	0	0	0	**8**
N30 = Dytiscidae (sp. 1)	5	0	0	0	0	0	0	0	0	0	0	0	**5**
N56 = Veliidae	0	0	1	2	0	1	0	1	0	0	0	0	**5**

N10 = Belostomatidae	0	0	0	1	2	0	1	0	0	0	0	0	**4**
N92 = Coenagrionidae (sp. 2)	0	0	0	2	0	1	0	0	0	0	0	0	**3**
N85 = Phryganeidae	1	0	0	2	0	0	0	0	0	0	0	0	**3**
N114 = Elmidae	0	0	0	0	2	0	0	0	0	0	0	0	**2**
N44 = Hydrophilidae (sp. 1)	0	2	0	0	0	0	0	0	0	0	0	0	**2**
N9 = Tipulidae	0	0	0	1	0	0	1	0	0	0	0	0	**2**
N51 = Gerridae (sp. 2)	0	0	1	0	0	0	0	1	0	0	0	0	**2**
N116 = Gerridae (sp. 3)	0	0	0	0	0	0	0	0	2	0	0	0	**2**
N117 = Notonectidae *Anisops* (sp. 2)	0	0	0	0	0	0	2	0	0	0	0	0	**2**
N122 = Sminthuridae	0	0	0	0	0	0	0	0	0	0	1	0	**1**
N112 = Dytiscidae (sp. 2)	0	0	0	0	1	0	0	0	0	0	0	0	**1**
N23 = Ceratopogonidae *Probezzia* (sp. 1)	0	0	1	0	0	0	0	0	0	0	0	0	**1**
N93 = Ceratopoginidae (sp. 2)	1	0	0	0	0	0	0	0	0	0	0	0	**1**
N104 = Ceratopogonidae *Bezzia* (sp. 3)	0	0	0	0	0	0	1	0	0	0	0	0	**1**
N68 = Ceratopogonidae (sp. 4)	0	1	0	0	0	0	0	0	0	0	0	0	**1**
N64 = Stratiomyidae	0	0	0	1	0	0	0	0	0	0	0	0	**1**
N89 = Hyalellidae *Hyalella*	0	0	0	0	0	0	0	0	0	0	0	1	**1**
Monthly Totals	**250**	**152**	**805**	**191**	**139**	**6**	**91**	**18**	**30**	**23**	**15**	**5**	**1725**

Table 22. Total abundances of water column macroinvertebrate in intermediate resaca collected with sweep net. Samples collected between March 2013 and February 2014 in Cameron County, TX

Invertebrate Identification	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Annual Total
N76 = Chironomidae *Tanypus* (sp. 4)	675	36	1	12	0	2	7	1	19	0	0	0	**753**
N90 = Baetidae	1	9	456	30	0	0	2	11	2	5	9	0	**525**
N89 = Hyalellidae Hyalella	5	16	454	40	0	0	0	0	0	0	0	1	**516**
N79 = Chironomidae Chironominae (sp. 3)	1	3	89	97	1	22	18	8	17	5	1	6	**268**
N20 = Naididae Tubificinae (sp 1)	31	77	0	13	0	6	3	1	3	6	6	38	**184**
N66 = Chironimidae tanypodinae (sp. 2)	0	0	62	12	0	0	7	30	0	0	0	0	**111**
N17 = Corixidae Larvae (sp. 1)	17	43	1	2	4	5	8	1	0	3	15	8	**107**
N113 = Coenagrionidae (sp. 1)	0	0	72	11	0	0	0	0	1	3	3	1	**91**
N8 = Mysidae *Taphromysis*	0	15	38	0	0	1	16	0	0	3	14	1	**88**
N2 = Chironomidae Chironominae (sp. 1)	32	5	5	4	3	6	12	3	1	2	2	5	**80**
N25 = Pleidae	0	1	24	14	17	2	6	2	0	0	0	0	**66**
N27 = Corixidae (sp. 2)	8	7	1	4	5	10	9	3	2	0	1	2	**52**
N23 = Ceratopogonidae *Probezzia* (sp. 1)	10	8	2	1	0	0	4	0	4	1	0	6	**36**
N7 = Palaemonidae	0	1	21	8	1	0	1	0	3	0	0	0	**35**
N93 = Ceratopoginidae (sp. 2)	0	0	0	15	0	0	6	8	0	0	0	0	**29**
N96 = Planorbidae (sp. 1)	0	1	4	1	0	1	2	12	0	1	0	0	**22**
N57 = Culicidae	0	0	15	6	0	0	0	0	0	0	0	0	**21**
N47 = Notonectidae (sp. 3)	0	9	0	0	0	0	7	1	0	0	0	0	**17**
N67 = Hydrachnidae (sp. 1)	0	1	0	2	1	0	0	10	0	0	0	0	**14**
N104 = Ceratopogonidae *Bezzia* (sp. 3)	0	0	0	1	0	0	9	0	0	0	1	0	**11**
N111 = Libellulidae	0	0	1	0	0	0	3	6	0	1	0	0	**11**
N77 = Physidae	0	4	5	1	0	0	0	0	0	1	0	0	**11**
N10 = Belostomatidae	0	0	7	2	0	0	0	0	1	0	0	0	**10**

N58 = Hydrachnidae (sp. 2)	0	0	1	2	5	2	0	0	0	0	0	0	**10**
N68 = Ceratopogonidae (sp. 4)	0	0	0	5	0	0	1	1	0	0	0	0	**7**
N92 = Coenagrionidae (sp. 2)	0	0	0	6	0	0	0	0	0	0	0	0	**6**
N6 = Hydrophilidae *Berosus* (sp. 2)	5	0	0	0	0	0	0	0	0	0	0	0	**5**
N98 = Corduliidae	0	0	0	1	4	0	0	0	0	0	0	0	**5**
N56 = Veliidae	0	0	4	0	0	0	0	0	0	0	0	0	**4**
N99 = Planorbidae (sp. 2)	0	1	0	0	0	1	0	0	0	2	0	0	**4**
N110 = Hydrachnidae (sp. 3)	0	0	0	0	1	0	0	3	0	0	0	0	**4**
N61 = Dytiscidae (sp. 3)	0	0	2	0	0	0	0	0	0	0	0	0	**2**
N44 = Hydrophilidae (sp. 1)	1	0	0	1	0	0	0	0	0	0	0	0	**2**
N60 = Gerridae (sp. 1)	0	0	2	0	0	0	0	0	0	0	0	0	**2**
N117 = Notonectidae *Anisops* (sp. 2)	0	0	0	0	0	0	2	0	0	0	0	0	**2**
N85 = Phryganeidae	0	0	0	1	0	1	0	0	0	0	0	0	**2**
N106 = Haliplidae	0	0	0	1	0	0	0	0	0	0	0	0	**1**
N120 = Hydrophilidae (sp. 3)	0	0	0	0	0	0	0	1	0	0	0	0	**1**
N82 = Chaoboridae *Chaoborus*	0	0	0	0	0	0	1	0	0	0	0	0	**1**
N9 = Tipulidae	0	0	0	0	0	0	0	1	0	0	0	0	**1**
N100 = Caenidae	0	0	0	1	0	0	0	0	0	0	0	0	**1**
N51 = Gerridae (sp. 2)	0	0	1	0	0	0	0	0	0	0	0	0	**1**
N116 = Gerridae (sp. 3)	0	0	0	0	0	0	1	0	0	0	0	0	**1**
N59 = Notonectidae (sp. 4)	0	0	1	0	0	0	0	0	0	0	0	0	**1**
N115 = Aeshnidae	0	0	0	1	0	0	0	0	0	0	0	0	**1**
N119 = Calamoceratidae	0	0	0	0	0	0	0	1	0	0	0	0	**1**
N52 = Hydra	0	0	0	0	0	0	0	0	0	1	0	0	**1**
N121 = Lymnaeidae	0	0	0	0	0	0	0	0	0	1	0	0	**1**
Monthly Totals	**786**	**237**	**1269**	**295**	**42**	**59**	**125**	**104**	**53**	**35**	**52**	**68**	**3125**

Table 23. Total abundances of water column macroinvertebrate in old resaca collected with sweep net. Samples collected between March 2013 and February 2014 in Cameron County, TX

Invertebrate Identification	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Annual Total
N8 = Mysidae Taphromysis	242	21	572	42	0	8	13	1	76	7	2	1	**985**
N20 = Naididae Tubificinae	95	5	5	0	0	0	0	0	0	0	0	0	**105**
N40 = Thiaridae *Melanoides tuberculata*	77	0	0	0	0	0	0	0	0	0	0	0	**77**
N76 = Chironomidae *Tanypus* (sp. 4)	50	0	1	4	0	0	1	0	0	0	0	0	**56**
N79 = Chironomidae Chironominae (sp. 3)	50	0	2	1	0	0	0	0	2	0	0	0	**55**
N51 = Gerridae (sp. 2)	0	0	11	3	1	0	1	1	1	0	0	0	**18**
N7 = Palaemonidae	6	2	0	0	0	2	1	0	1	0	0	1	**13**
N2 = Chironomidae Chironominae (sp. 1)	5	0	1	0	0	0	0	0	0	0	0	0	**6**
N17 = Corixidae (sp. 1)	2	0	4	0	0	0	0	0	0	0	0	0	**6**
N52 = Hydra	0	0	5	0	0	0	0	0	0	0	0	0	**5**
N70 = Notonectidae *Buenoa*	0	0	0	0	0	1	2	0	0	0	0	0	**3**
N109 = Trichoniscidae	0	0	0	0	1	0	1	0	0	1	0	0	**3**
N23 = Ceratopogonidae *Probezzia* (sp. 1)	2	0	0	0	0	0	0	0	0	0	0	0	**2**
N90 = Baetidae	0	0	1	0	0	0	0	1	0	0	0	0	**2**
N60 = Gerridae (sp. 1)	0	0	0	0	0	2	0	0	0	0	0	0	**2**
N83 = Glossiphoniidae	0	1	0	0	0	0	0	0	0	0	0	0	**1**
N44 = Hydrophilidae (sp. 1)	0	0	0	1	0	0	0	0	0	0	0	0	**1**
N57 = Culicidae	0	0	0	0	1	0	0	0	0	0	0	0	**1**
N116 = Gerridae (sp. 3)	0	0	1	0	0	0	0	0	0	0	0	0	**1**
N56 = Veliidae	0	0	0	0	0	0	0	1	0	0	0	0	**1**
N89 = Hyalellidae *Hyalella*	0	0	0	1	0	0	0	0	0	0	0	0	**1**
N108 = Argulidae *Argulus*	0	0	0	0	1	0	0	0	0	0	0	0	**1**
Monthly Totals	**529**	**29**	**603**	**52**	**4**	**13**	**19**	**4**	**80**	**8**	**2**	**2**	**1345**

Table 24. Total abundances of water column macroinvertebrate in Rio Grande collected with sweep net. Samples collected between March 2013 and February 2014 in Cameron County, TX

Invertebrate Identification	**May**	**Aug**	**Nov**	**Feb**	**Annual Total**
N8 = Mysidae *Taphromysis*	3	6	166	426	**601**
N20 = Naididae Tubificinae (sp. 1)	0	10	3	48	**61**
N79 = Chironomidae Chironominae (sp. 3)	1	2	14	3	**20**
N89 = Hyalellidae *Hyalella*	0	0	0	20	**20**
N2 = Chironomidae Chironominae (sp. 1)	1	7	0	2	**10**
N27 = Corixidae (sp. 2)	0	0	0	6	**6**
N70 = Notonectidae *Buenoa* (sp. 1)	0	2	0	2	**4**
N109 = Asellidae	**0**	**0**	**3**	**0**	**3**
N51 = Gerridae (sp. 2)	0	0	1	1	**2**
N77 = Physidae	0	0	0	1	**1**
N7 = Palaemonidae	0	0	1	0	**1**
N90 = Baetidae	0	0	1	0	**1**
Monthly Totals	5	27	189	509	**730**

Appendix C: Supplemental Tables and Figures

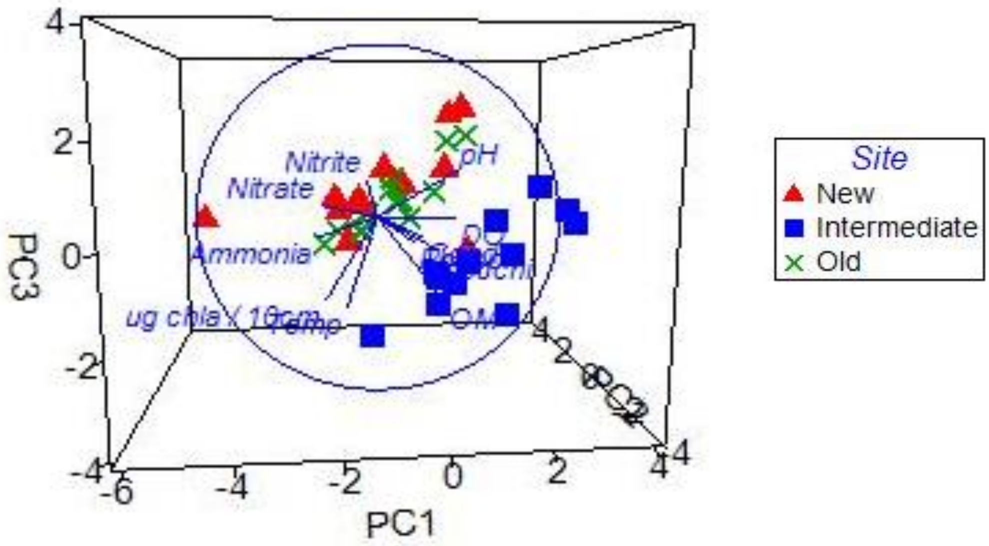


Figure 14. Principal component ordination of monthly environmental variables. Five principal components were required to account for 75% of the variation among sites. PC2 is located on the z-axis. Samples collected between March 2013 and February 2014, Cameron County, TX.

Table 25. Results of analysis of similarity (ANOSIM) global and pairwise test based on benthic community monthly abundances ($\sqrt[4]{}$transformed) between three resacas and quarterly abundances of Rio Grande samples. Samples collected between March 2013 and February 2014, Cameron County, TX.

Global Test
Sample statistic (Global R): 0.231
Significance level of sample statistic: 0.6%

Groups	R Statistic	Significance %
New, Intermediate	0.083	20
New, Old	0.156	17.1
New River	0.125	22.9
Intermediate, Old	0.438	5.7
Intermediate, River	0.385	2.9
Old, River	0.427	2.9

Table 26. Similarity percentages (SIMPER) of benthic macroinvertebrate taxa monthly abundances ($^{4}\sqrt{}$transformed) between three resacas and quarterly abundances from Rio Grande. Bold indicates good characterizing taxa (similarity/SD >2.00) Samples collected between March 2013 and February 2014, Cameron County, TX.

	Site		
Taxa	New & River	Inter & River	Old & River
Average Dissimilarity (%)	54.02	54.69	65.83
Contribution to dissimilarity (%)			
Tubificidae	22.25	14.34	16.49
Chironomidae	14.38	7.59	12.75
Chironominae	13.06		
Ceratopogonidae		11.42	
Tanypodinae		7.07	
M. tuberculata			**20.81**

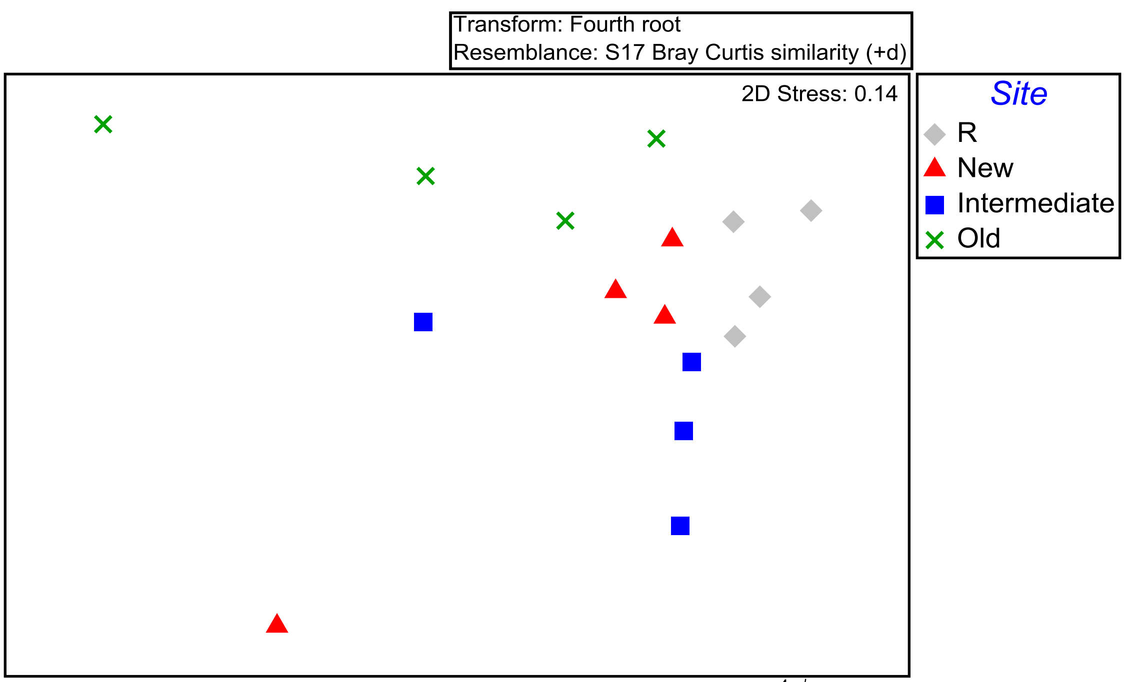


Figure 15. Multi-dimensional scaling (MDS) ordination of ($^{4}\sqrt{}$transformed) quarterly invertebrate taxa abundances from benthic community of three resacas and Rio Grande. Samples collected between March 2013 and February 2014, Cameron County, TX.

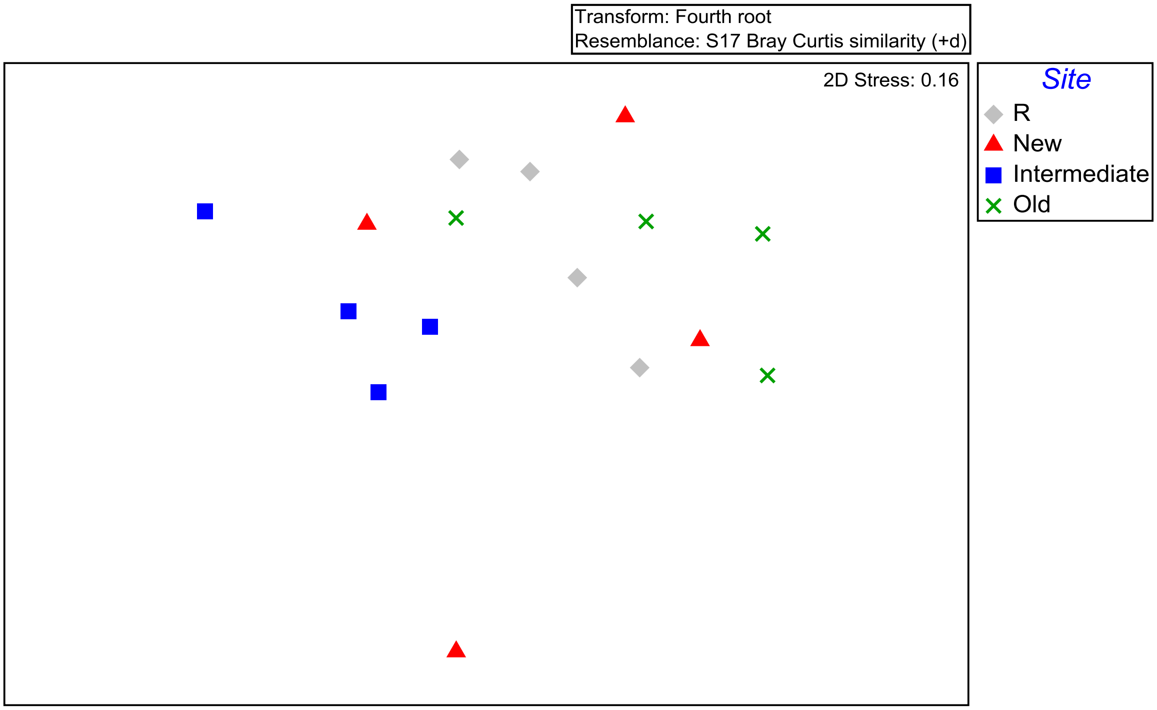


Figure 16. Multi-dimensional scaling (MDS) ordination of monthly abundances ($\sqrt[4]{}$transformed) from water column community of three resacas and quarterly abundances from Rio Grande. Samples collected between March 2013 and February 2014, Cameron County, TX.

Appendix D: Correlation of fluorometer chlorophyll-a readings

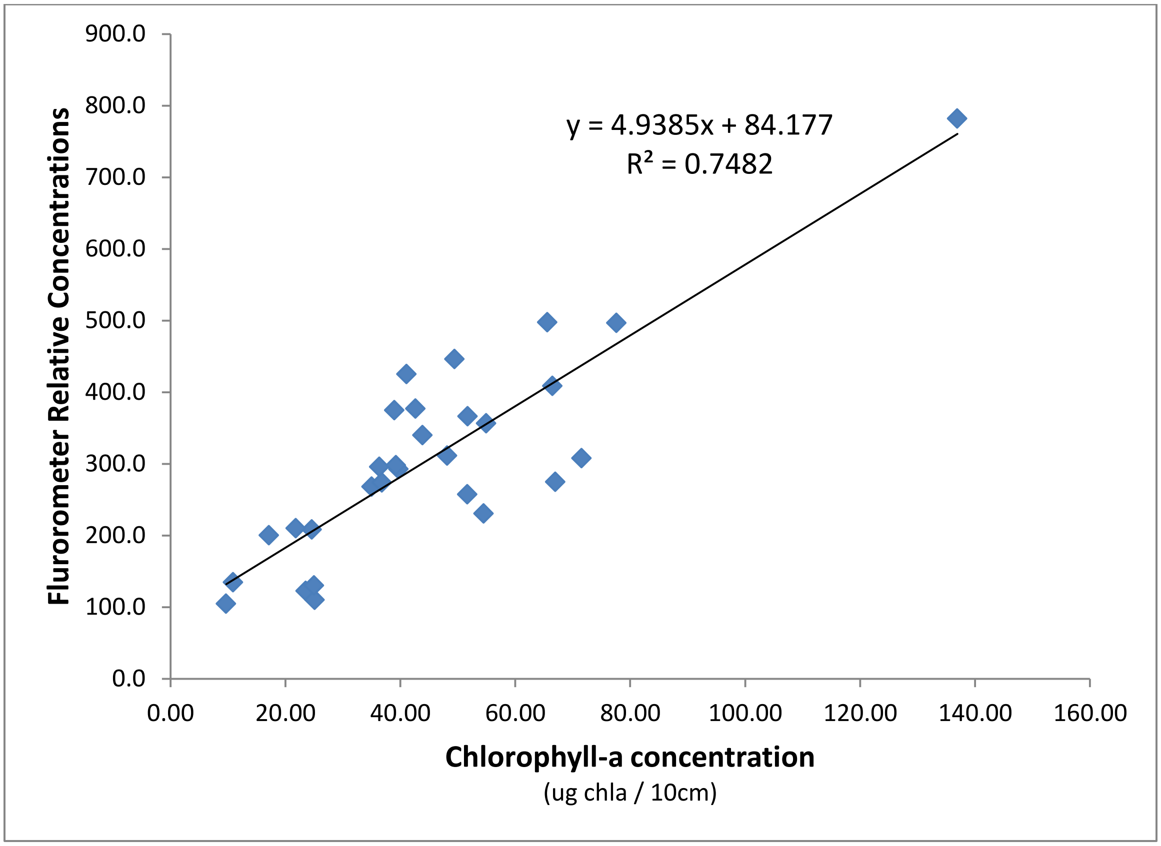


Figure 17. Correlation of relative chlorophyll-a readings from handheld fluorometer *in-vivo* readings with *in-vitro* determinations of chlorophyll-a concentrations. Chlorophyll-a concentrations were measured with a Cary win-UV 50 spectrophotometer after acetone extraction. Samples collected between May 2013 and February 2014 from three resacas located in Cameron County, TX.

Appendix E: Size-Mass relationship of *M. tuberculata*

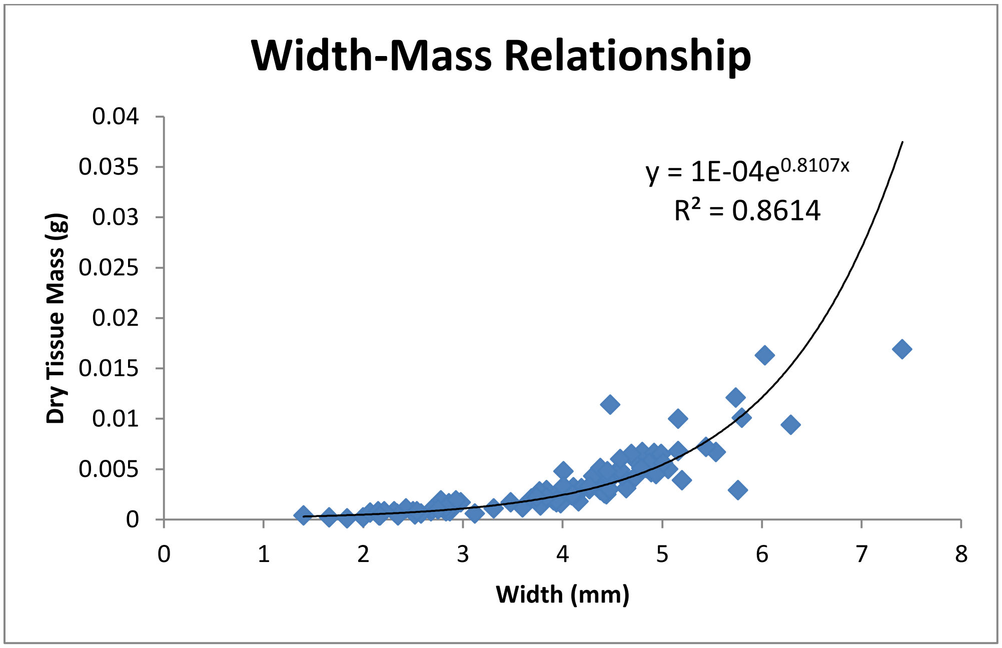


Figure 18. Width –mass relationship for *Melanoides tuberculata*. Measurement was taken at widest point across aperture. Samples represent gastropods collected in all seasons n=116. Samples collected in Cameron County, TX between March 2013 and February 2014.

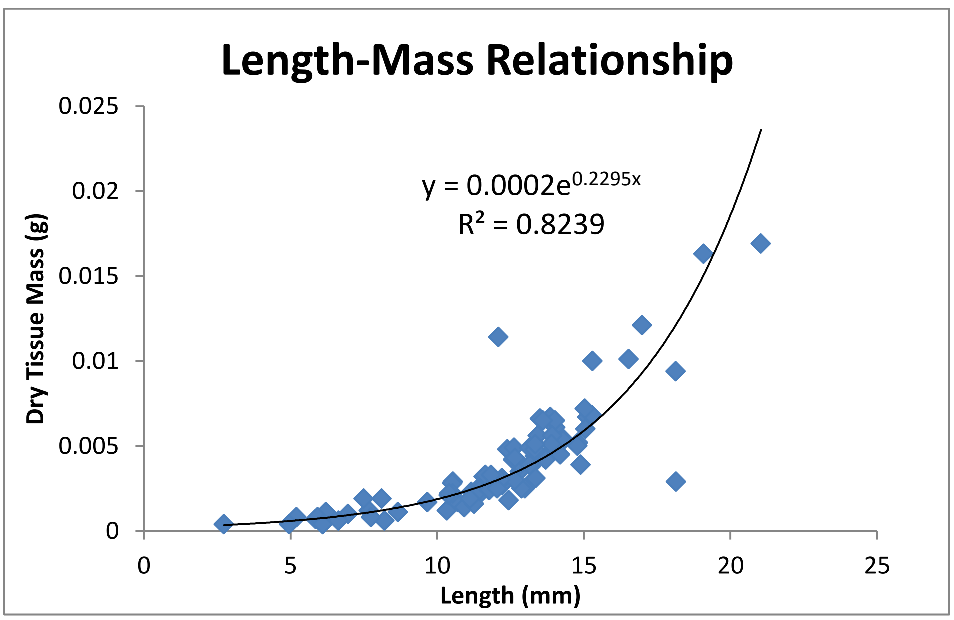
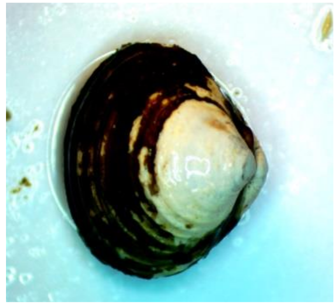


Figure 19. Length-mass relationship for *Melanoides tuberculata*. Measurement was taken at longest point from apex to basal lip. Samples represent gastropods collected in all seasons N=116. Samples collected in Cameron County, TX between March 2013 and February 2014. n=97

Appendix F: Invertebrate Pictures for Reference

Melanoides tuberculata

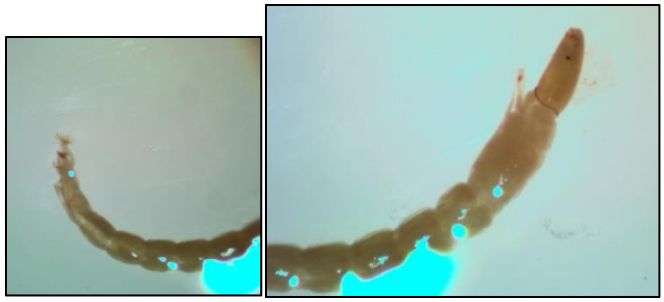


Sphaeriidae

Chironomidae sp. 1

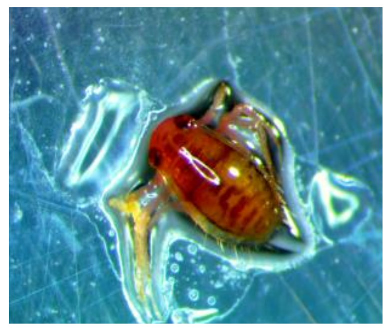
Hyalellidae *Hyalella*

Ceratopogonidae *Probezzia*



Tanypodinae Sp. 2

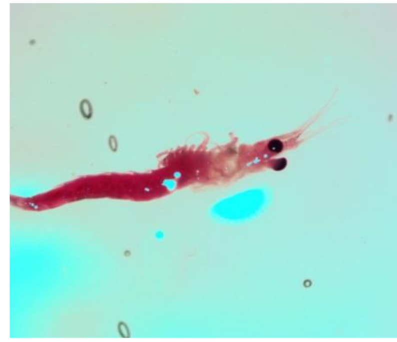
Hydrachnidae sp. 2



Corixidae Sp. 3

Hydrophilidae *Berosus*

Palaemonidae



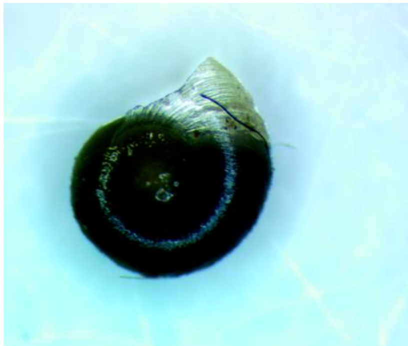
Mysidae

Tipulidae

Belostomatidae

Coenagrionidae

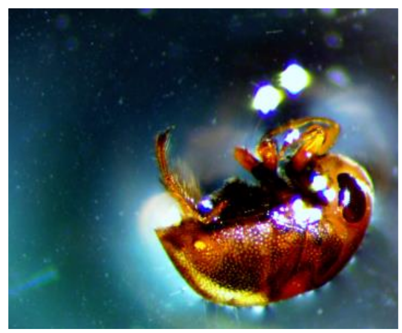
Aeshnidae



Planorbidae

Lymnaeidae

Corixidae Sp. 1



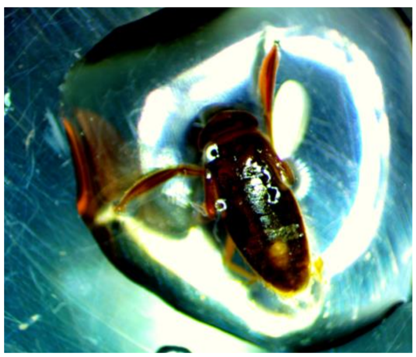
Pleidae

Baetidae

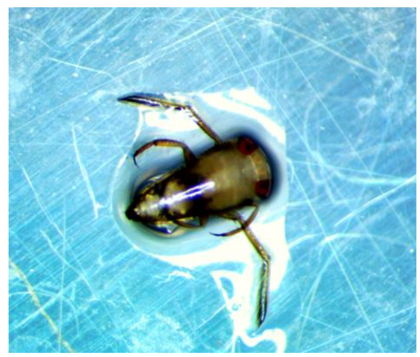
Hydrophilidae Sp. 1

Corixidae Sp. 2

Hydridae



Notonectidae Sp. 3



Notonectidae Sp. 4

Gerridae Sp. 2

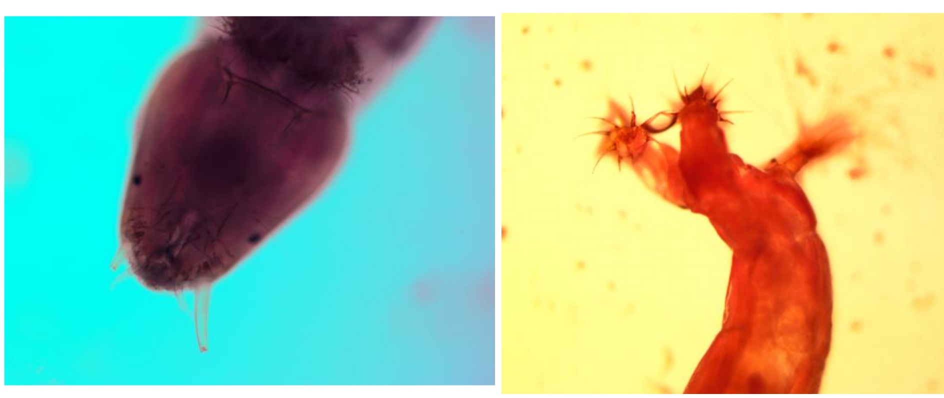
Culicidae

Gerridae Sp. 1

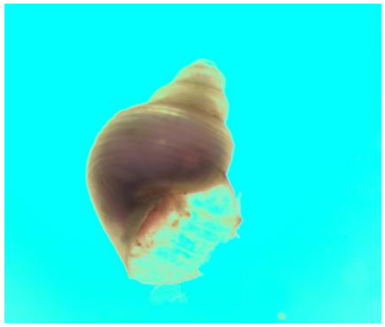
Dytiscidae Sp. 3

Stratiomyidae

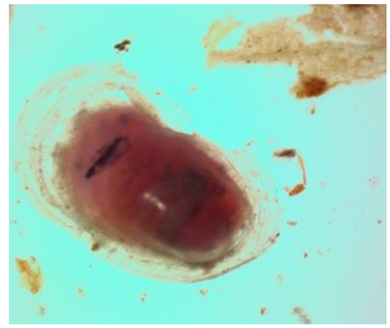
Notonectidae
Buenoa



Tanypodinae Sp. 4

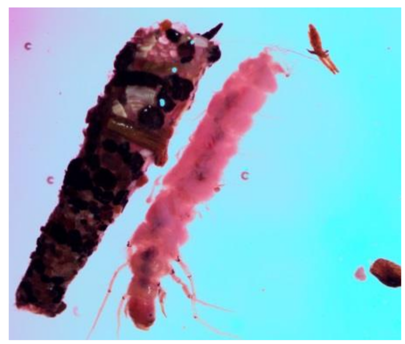


Hydrobiidae

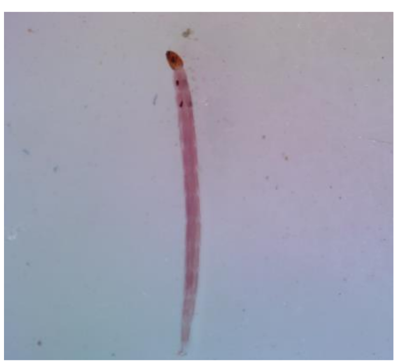


Ancylidae

Chaoboridae
Chaoborus

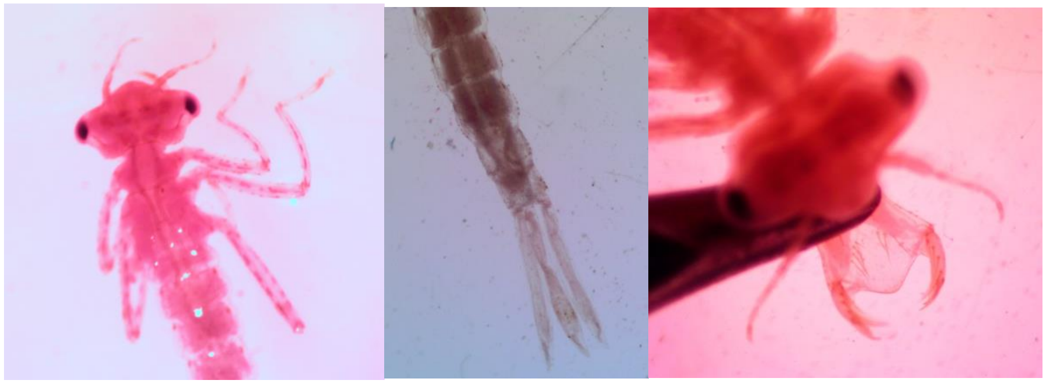


Phryganeidae



Ceratopogonidae
Sp. 2

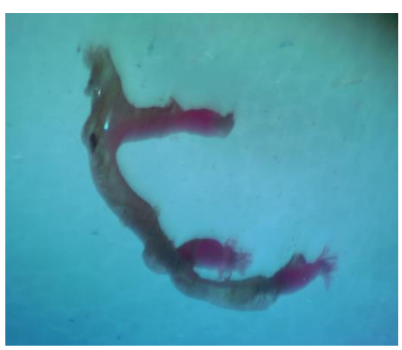
Ceratopgonidae
Sp. 3



Coenagrionidae Sp. 2

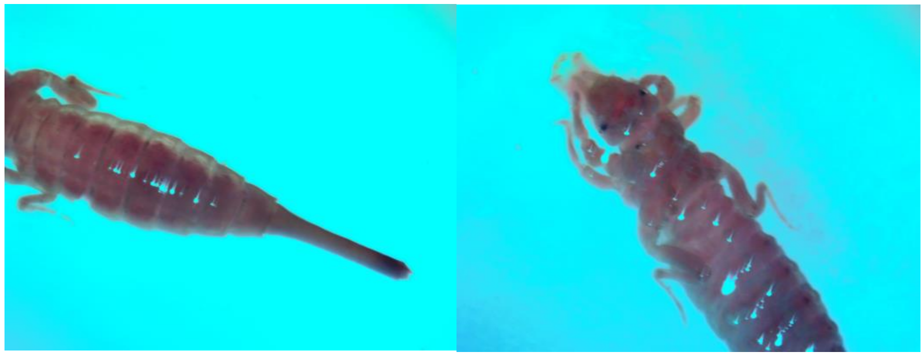
Chrysomelidae

Caenidae



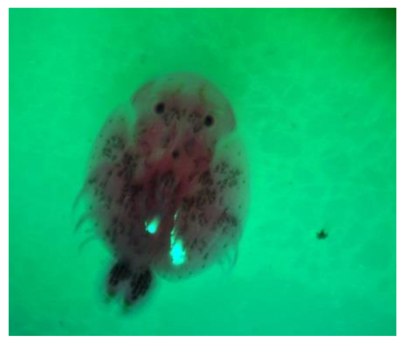
Fredericellidae

Curculionidae



Gomphidae *Aphylla*

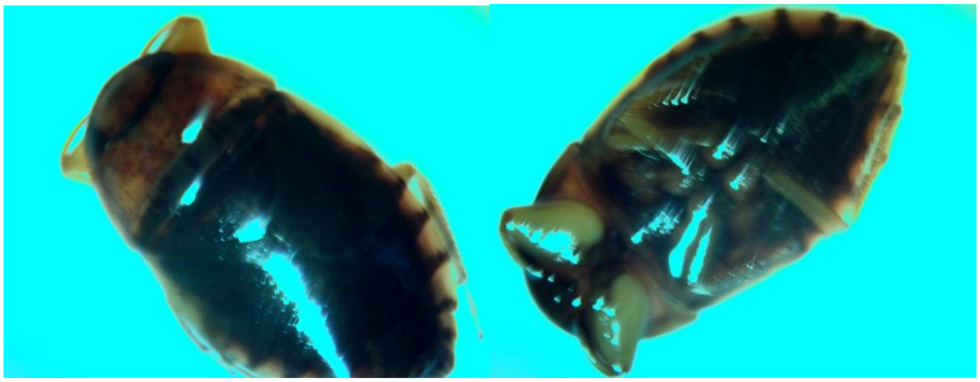
Haliplidae



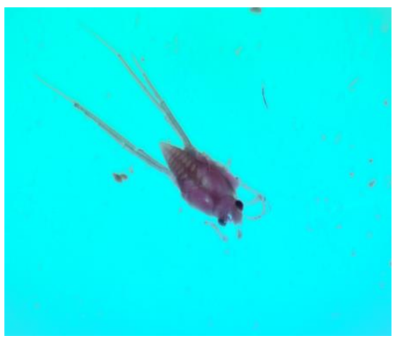
Argulidae *Argulus*

Asellidae

Calamoceratidae



Dytiscidae Sp. 1

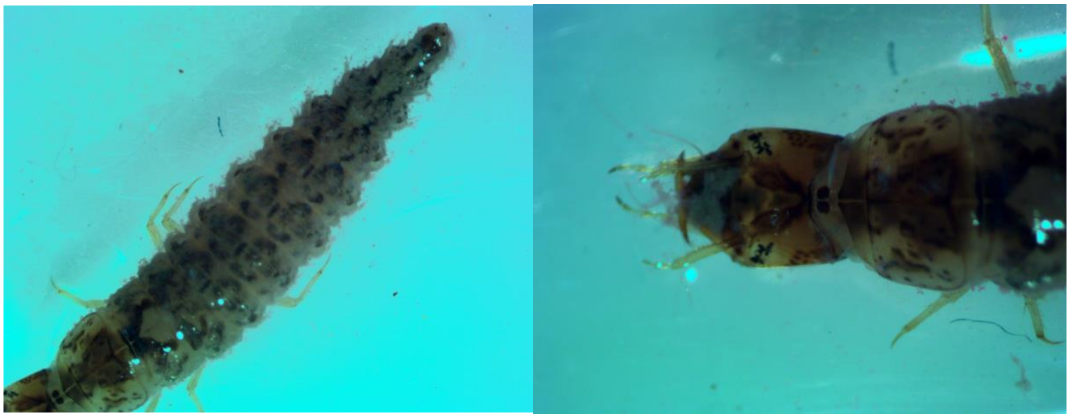


Gerridae Sp. 3

Elmidae

Notonectidae *Anisops*

Sminthuridae



Hydrophilidae Sp. 3