**Manuscript Title**

Effects of a natural precipitation gradient on fish and macroinvertebrate assemblages

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**Abstract:**

Anthropogenic climate change is expected to increase the aridity of many regions of the world. Surface water ecosystems are particularly vulnerable to changes in the water-cycle and may suffer adverse impacts in affected regions. To enhance our understanding of how freshwater communities will respond to predicted shifts in water-cycle dynamics, we employed a space for time substitution along a natural precipitation gradient on the Texas Coastal Prairie. In the Spring of 2017, we conducted surveys of 10 USGS gauged, wadeable streams spanning a semi-arid to sub-humid rainfall gradient; we measured nutrients, water chemistry, habitat characteristics, benthic macroinvertebrates, and fish communities. Fish diversity correlated positively with precipitation and was negatively correlated with canopy cover, conductivity, and NH4+. Macroinvertebrate diversity was only significantly correlated with low-flow pulse percent, however macroinvertebrate community composition significantly changed along the gradient. Observed compositional shifts in both fish and invertebrates along the gradient are potentially indicative of both top-down and bottom-up controls on community assembly. Semi-arid sites contain salt tolerant, and rapidly proliferating taxa. Sub-humid sites contain more piscivores as well as migratory marine species which may impose top-down controls on primary consumers. These results indicate that small future changes in precipitation regime in this region may result in abrupt transitions into new community states.

**Introduction:**

A warming climate necessitates a better understanding of the processes that link biological communities to long-term trends in temperature and precipitation (Wrona, Prowse et al. 2006). The direct ecological effects of changes in temperature have received greater attention in the literature, but rising temperatures are also expected to alter patterns of precipitation and evaporation (Held and Soden 2006). A warmer, more energetic atmosphere intensifies the hydrological cycle (i.e. patterns of precipitation and evaporation), causing wet regions to become wetter and dry regions become drier (Allen and Ingram 2002), as well as increasing the frequency and intensity of extreme weather events (Held and Soden 2006). This raises concern for freshwater ecosystems which are highly sensitive to changes in water availability and contain many species with limited dispersal capabilities (Woodward, Perkins, and Brown 2010).

Streams ecosystems are shaped by flow regimes which regulate the physical extent of aquatic habitat, the water quality, sourcing and exchange rates of material, habitat connectivity and biodiversity (Rolls, Leigh et al. 2012). In addition to streamflow mechanisms, streamside vegetation mediates interactions with watershed nutrients, carbon and light inputs to streams (Schade, G. Fisher et al. 2001). Precipitation regime is one of the primary regulators of both streamflow and riparian characteristics. With predicted changes in flood and drought characteristics under global warming (Hirabayashi, Kanae et al. 2008), it is imperative to understand the mechanistic links between precipitation, streamflow, and riparian interactions with aquatic biological communities.

Hierarchical community assembly models can help us organize our hypotheses regarding impacts of climate change on stream communities (Poff 1997). Assuming organisms can disperse to a habitat, they must be able to survive in the local environment (abiotic filters) and successfully reproduce in the presence of other organisms exerting pressures (biotic interactions) such as competition and predation (Patrick and Swan 2011). Species have physiological tolerances (temperature, toxin concentrations, and salinity, etc.) which limit their distribution across environmental gradients (Whittaker, Willis et al. 2001). If climate change alters those gradients, we can expect concordant changes in species distributions. However, understanding how the environment affects biotic interactions is more challenging due to the complex sets of interactions that govern these processes (Seabra, Wethey et al. 2015). As a result, our understanding of the role of environmental filters on community assembly is disjointed due to the vastly different spatial scales of typical biogeographical and community ecology studies (Ricklefs and Jenkins 2011).

Observational surveys of existing communities spatially distributed along environmental gradients can be used in a space-for-time substitution to infer how communities will change through time as environmental conditions shift (Ricklefs and Jenkins 2011). The approach allows for links to be drawn between climate drivers, local environmental conditions, and organism abundances. Species co-occurrence patterns along environmental gradients can also shed light on possible shifts in biotic interactions (D'Amen, Mod et al. 2018). However, the space-for-time substitution approach assumes that observed ecological differences along the spatial gradient are the sole product of corresponding changes in climate. This assumption may be unfair given that biogeographical studies have revealed that dispersal limitation, habitat heterogeneity, and local evolution can also contribute to current spatial patterns in community composition (Jacob et al. 2015). These studies are typically large in scale, covering vast distances (thousands of km) to capture climate gradients. These large scales make the precise mechanisms for observed biological changes difficult to ascertain due to covarying environmental variables (e.g., elevation, geology, human impacts). Thus, while current literature demonstrates that biome shifts occur across temperature and latitudinal gradients (De Frenne, Graae et al. 2013), the value of these observational studies for forecasting community responses to climate change is hindered by the many confounding variables. The power of using the space-for-time approach to delineate the intricacies of hydrologic cycle-ecosystem relationships is enhanced in study systems with limited confounding environmental variables (temperature, elevation, distance, and underlying geology).

Fortunately, the Texas Coastal Prairie (TCP) within the Western Gulf coastal grasslands is an ideal system for evaluating the effect of hydrologic climate change on ecological communities. It is located within the Western Gulf coastal grasslands which are a subtropical ecotone that spans Louisiana, Texas, and northern Mexico’s coastal areas. The system encompasses the sharpest non-montane precipitation gradient in the continental United States. The climate becomes more arid as you move west, with gradual change for much of the coast and a region of rapid change located in southern Texas. In this region the annual rainfall changes from 55cm•yr-1 (semi-arid) to 135 cm•yr-1 (sub-humid) over a 300 km gradient, but there are minimal changes in elevation, air temperature, underlying geology, and human land use (Table 1). The region is characterized by gently rolling landscapes (slopes < 5%), afisol soils, streams with forested riparian zones, and a widespread conversion of grasslands to the agricultural production of cattle, cotton, corn, and soy products (Chapman 2018). As conditions become wetter, there is an observable ecological shift from Thornwood groves in the semi-arid West to Live oak forests towards the East. The TCP is an ideal study region for isolating precipitation influences on natural ecosystem processes because of the minimal impact of covarying predictors that typify climate gradient research.

Despite the intrinsic value of this region as a candidate for climate gradient research, there is limited prior biological sampling by governmental agencies of running waters in the TCP. To address this need, we conducted the first dedicated survey of streams across the climate gradient. We applied bioassessment protocols to 10 USGS-gauged, wadeable streams for quantification of fish, benthic macroinvertebrates, and environmental variables. Our objectives were to: 1) Identify patterns in the diversity and composition of fish and macroinvertebrates communities that correspond to changes in precipitation, and 2) identify environmental predictors that mediate the effects of climate on community processes. We expected that annual precipitation would be positively correlated with community diversity because humid precipitation regimes are expected to create more stable environmental conditions by creating habitat heterogeneity and predictable flow regimes which promote the development of greater biodiversity (Boulton et al. 1992; Bunn and Arthington 2002). We further expected that evapotranspiration by riparian vegetation would increase solute concentrations in semi-arid streams, particularly during base flows (Tabacchi, Lambs et al. 2000, Lupon, Bernal et al. 2016), creating environmental filters that limit recruitment of sensitive fish and macroinvertebrates (hereafter referred to as invertebrates).

**Methods**

*Study Region***:** The Texas Coastal Prairie contains grassland prairie with forested areas occurring primarily along riverine systems. During March and April of 2017, we sampled ten, wadeable, perennial streams which span 12 counties from Kleberg County to Montgomery in South-Central Texas, USA (Fig. 1). Each study site was located within 100 meters of a USGS stream gauge which continuously monitor streamflow and climate data year-round. Study sites were chosen to maximize differences in precipitation with minimal changes in underlying geology and elevation. The annual precipitation ranges from 61-121 cm within the study region which spans a linear distance from end to end of 378 km (Falcone 2011). The surface geology is characterized by fine clays, quaternary and sedimentary sand. The streams have similar elevations (14-62 m), substrates (quaternary), and average air temperatures (19.8-22.1℃) (Supplemental Data S1). Sampling was conducted by students and faculty at Texas A&M (Corpus Christi) under permit SPR-0716-170, granted by Texas Parks and Wildlife Department.

*Biological Sampling***:** Fish communities were sampled using a Smith-Root LR-24 Backpack in a single pass survey of a 100-meter reach (Lamberti 2007). The reach length was approximately 25 times the average stream width (4.1m), in accordance with EPA rapid bioassessment protocols (Barbour, Gerritsen et al. 1999). Study sites were characterized by low variation in geomorphology and overall habitat heterogeneity resulting in high success in assessing community composition over a shorter distance. Fish species were field identified to species using a field guide (Thomas C 2007) and photographed. Several specimens of each species were euthanized using tricaine mesylate (MS-222) and stored in >70% denatured ethanol as voucher specimens for lab confirmation of species identification. Fish Voucher specimens were identified using the Texas Academy of Science dichotomous key (Hubbs 2008) and cross referenced with field identifications. Vertebrate sampling was permitted by the Institutional Animal Care and Use Committee, Texas A&M University Corpus Christi (AUP# 05-17).

Invertebrates were collected using a 0.305m wide D-frame net equipped with 500-µm mesh. Twenty 0.093 m2 samples were collected via a combination of kick and sweep sampling from a representative distribution of best available habitat (riffles, large woody debris, overhanging vegetation). Samples were pooled in a 500-µm sieve bucket where larger sticks and leaves were rinsed and removed. The captured invertebrates and remaining debris were preserved in 95% EtOH for transport to the lab. In the lab, samples were spread across a gridded sampling tray and randomly selected grid cells were picked to completion until the total count was > 300 individuals. Samples containing less than 300 individuals were picked to completion. Invertebrates were identified to lowest taxonomic resolution (typically genus) using taxonomic keys cross referenced with species observations recorded by the TCEQ’s (Texas Commission on Environmental Quality) Surface Water Quality Monitoring Program (Wiggins 2015, Merritt, Cummins et al. 2019). The sum of individuals in each taxon were multiplied by the fraction of unpicked sample and reported as abundance of individuals per square meter.

*Environmental Data:* For each stream, we averaged values for each of the following habitat measurements that were taken at 4 cross-sections spaced 25m apart. Canopy cover was measured using a spherical densiometer. A Rosgen Index value was calculated by dividing the bank-full width by the maximum depth (DL 2001). Bank height was recorded as vertical difference between water level and the height of the first bench. We estimated Sediment grain size within each cross-section using Wentworth size categories to calculate a median grain-size (d50) (Wentworth 1922). Oxygen, temperature (Twater), conductivity, turbidity, and pH were measured at each point using a YSI ProDSS multiparameter probe. Two 60 mL water samples were collected and filtered through a pre-combusted (500℃ for 4 hours) glass fiber filter (Whatman GF/F) into acid washed amber bottles, transferred to the lab in a cooler on ice, and stored frozen (-20℃) until analysis for nutrients (NH4+, NO3-, and PO4-). Water samples were run using colorimetric methods on a latchet autoanalyzer by the Oklahoma University Soil Water and Forage Laboratory.

In addition to the habitat metrics measured in the field, we mined climate and watershed data, from the US Geologic Surveyors Geospatial Attributes of Gages for Evaluating Streamflow, version II dataset (Falcone 2011). A twenty-year continuous daily flow record was downloaded for each site (except Tranquitas Creek which only had 4 years of available data) from the USGS water services (Falcone 2011).

*Analyses*: Due to a small number of sample sites and replicates, the statistical analyses relating environmental drivers to organismal responses are restricted to seven *a priori* environmental predictors. Annual precipitation is evaluated to identify gradient effects. The Rosgen index characterizes the channel shape which is a product of flow regime, slope, substrate, and bank stability. Canopy coverage is determined by the type of vegetation which visibly shift across the study region with implications for stream insolation and basal resources. We include conductivity and NH4+ to evaluate water quality. Since the selected streams were deliberately chosen to be wadeable at base flow, we calculated two flow metrics to approximate the typical flow regime of each site in the context of seasonal droughts and floods, as well as overall variation in flow: Flash Index (cumulative changes in day to day daily flow / cumulative flow) and the Low-Flow Pulse Percent (LFPP = times where daily discharge drops below the 25th percentile) (Olden and Poff 2003, Patrick and Yuan 2017).

We used linear regression and Pearson correlation coefficients to identify potential confounding relationships between precipitation and each environmental predictor (Table 2). We then, used singular value decomposition of the centered and scaled data matrix in a principal component analysis with all seven environmental predictors (Figure 3, Table 3).

For each community (fish and invertebrate) we calculated Shannon diversity and rarified taxonomic richness (Hurlbert 1971).Diversity and richness measures were calculated using the Vegan Library (Oksanen, Blanchet et al. 2019) in the statistical program R (R Core Team 2019). While rarified richness is reported in supplemental appendices, further analyses and discussion regarding diversity utilize the Shannon-Weiner index which incorporates species evenness in addition to richness. We used linear regression to evaluate community diversity relationships with the precipitation gradient and each environmental predictor (Figures: 4 & 5, Tables: 4 & 7). To create a predictive model of community diversity, we used multiple regression with an additive global model utilizing all seven environmental predictors and ranked them using Aikake’s information criterion corrected for small sample sizes (AICc). All the results were compared to the best overall model by calculating the difference in AICc values (ΔAICc). Models with ΔAICc < 10 are reported (Tables: 6 & 8) and models with ΔAICc < 2 were considered to have substantial support (Burnham and Anderson 2002).

To discern compositional shifts in fish and invertebrates across the precipitation gradient, we used Redundancy Analysis (RDA), constrained by precipitation, on Hellinger-transformed community data for each group (Pierre Legendre and Gallagher 2001; P. Legendre and Legendre 2012). We then fit the species and environmental variables to each ordination using the ‘envfit’ function in the vegan library in the statistical program R (Oksanen, Blanchet et al. 2019). This function fits environmental vectors onto the ordination by calculating the maximum correlation with the projection of points (sites in this case). The direction of each arrow is determined by the average directional cosines and the distance to the origin is scaled by each variable’s correlation coefficient, so that “weak” predictors have shorter arrows than “strong” predictors (Tables: 5 & 9).

**Results**

*Site Overview:*

The Principal Component Analysis of the study sites displays patterns of variation among environmental predictors along the gradient (Figure 2). The first two principal component axes, PC1 and PC2, contain 43.2% and 19.9% of the variation within the environmental predictors among the sites (Table 2). It is visually apparent that the sample sites, colored by precipitation, stratify concordantly with annual rainfall along Principal Component Axis 1 (PC1). Predictor variable vectors with similar directionality (parallel axes) can be inferred to covary. The PCA indicates that conductivity negatively covaries with precipitation and low-flow pulse % negatively covaries with flash index. A pairs regression analysis of the seven environmental variables reveals two significant (*p*-value < 0.05) correlations (Table 3). Conductivity negatively correlates with precipitation. NH4+ positively correlates with canopy coverage.

*Fish Community*: Eighteen fish species were identified among the surveyed sites. Proceeding from semi-arid to sub-humid sites, fish Shannon index increases from 0.64 - 1.81, richness increases from 2 - 7 species, and rarified richness increases from 2.09 - 5.48 species (Supplemental Data S2). Regression analysis indicates that fish Shannon diversity is positively correlated with precipitation and negatively correlated with canopy coverage, conductivity, and NH4+ (Figure 3 a-d, Table 4). The most plausible multivariate regression model of fish Shannon diversity includes precipitation and Low-Flow Pulse Percent (LFPP) and is 2.5 times more likely than the next-best model (Table 5). The second-best model contains a single predictor, precipitation. Across models, precipitation positively relates to Shannon diversity while LFPP is negatively related.

The Redundancy Analysis (RDA) of fish communities constrained to precipitation captures 23.6% of the overall variation in the horizontal axis (RDA1) and 25.4% in the vertical axis (PC1) (Figure 4 e-f). Sites are stratified in ordination space horizontally according to annual rainfall; the fitted precipitation vector has a significant correlation within the ordination and is closely aligned with RDA1 (Table 6). Five statistically significant, fitted species vectors indicate that species compositions shift from small, elongate live-bearer taxa (*Poecilia latipinna*, and *Gambusia affinis*) in the most arid sites to deep-bodied, nesting centrarchids (*Lepomis megalotis* and *Lepomis macrochirus)* in the more humid sites. The remaining fitted species vector indicates that some mesic and humid stream communities are distinguished by the presence of *Cyprinella lutrensis*, a small, invasive habitat-generalist. Species found in small numbers or at singular sites fail to produce significant vectors in the RDA. Unique species found in sites on the humid side of the climate gradient include hogchoker(*Trinectes maculatus*), black bullhead catfish (*Ameirus melas*), and blacktail shiner (*Cyprinella venusta*).

*Invertebrate Community:* In total, 94 invertebrate genera were identified within the surveyed sites. Invertebrate richness ranges 7–29 genera with the highest values occurring at three sites in the middle of the precipitation gradient (Figure 5a, Supplemental Data S3). Regression analysis indicates that invertebrate Shannon diversity does not significantly correlate with precipitation. However, invertebrate diversity has a significant negative correlation with LFPP (Figure 5 a-b & Table 7). The most plausible multivariate regression model of fish Shannon diversity includes only Low-Flow Pulse Percent (LFPP) and is 1.6 times more likely than the next-best model (Table 5). The second-best model contains a fixed random effect, and the third-best model contains LFPP and NH4+ as predictors. Across models, LFPP is a negatively related to invertebrate diversity, and NH4+ is positively related to invertebrate diversity.

The Redundancy Analysis (RDA) of invertebrate communities constrained to precipitation captures 15.4% of the overall variation in the horizontal axis (RDA1) and 16.5% in the vertical axis (PC1) (Figure 5 c-d). Like fish, invertebrate communities are stratified in ordination space horizontally concordantly with annual precipitation; the fitted precipitation and conductivity vectors have significant correlations within the ordination and are closely aligned with RDA1 (Table 9). Eight statistically significant, fitted species vectors indicate that species compositions shift along the precipitation gradient. The most arid sites are strongly correlated with an non-native burrowing gastropod (*Melanoides tuberculata*). Mesic invertebrate communities are strongly correlated with an air-breathing gastropod (*Physa*) and an amphibious Coleopteran (*Hydraena*). Mesic and humid sites separate along the vertical axis of the RDA plot and appear to both weakly correlate with the species vectors of several Ephemeroptera (*Caenis* and *Plauditus*). Humid sites correlate with a mixture of fully aquatic taxa including Crustacea (*Palaemonetes*), Amphipoda (*Hyalella*), and Trichoptera (*Cheumatopsyche*).

**Discussion**

Using the Texas Coastal Prairie (TCP) as a model system, our goal was to quantify patterns in the diversity and composition of stream communities along an extreme precipitation gradient to better understanding how streams might respond to future changes in mean annual rainfall. Our observational study identified strong compositional shifts in both fish and invertebrate communities along the precipitation gradient. We also observed a positive relationship between fish diversity and mean annual rainfall, matching expectations, however, invertebrate diversity did not exhibit the expected relationships with rainfall. Environmental data collected at each site suggest several mechanistic drivers of these changes operating through water solute concentrations and flow regimes. Below, we discuss these results, place them in the context of other literature, and make suggestions for future work.

The paucity of covarying relationships between precipitation and other environmental variables exceed our expectations, confirming that the TCP is an exemplary region to conduct space for time substitutions to make useful ecological predictions regarding climate change. We expected precipitation to covary with flow regime, water quality, canopy coverage, and stream geomorphology. However, while study sites separated horizontally in ordination space according to their annual precipitation, relatively few predictors in our analysis covaried with precipitation save for a negative relationship with water conductance (Fig. 2, Table 4). We attribute the increasing conductivity with aridity to the inherently larger water shed area that is a necessary consequence in order to maintain similar flow conditions across the gradient which results in more water contact with soils before reaching the stream. We also suspect surface evaporation drives solute concentrations higher in these semi-arid freshwater systems (Williams 1999).

Contrary to our predictions, flash index and low-flow pulse percent did not covary with annual rainfall. Hydrologic flashiness exhibited weak, negative relationships with drainage area and mean daily discharge. It is common to observe increased flashiness in smaller drainage areas due to hydrograph mixing accompanying flood routing through stream networks and other scale-dependent runoff factors (Baker et al. 2004). Increasing watershed size with declining annual precipitation was intentional and necessary to maintain wadeable, perennial stream habitats throughout the gradient. Unlike flashiness, Low-flow pulse percent showed a weak, negative relationship with the proportion of forested riparian zone which could have exacerbated low-flows during dry seasons by up-taking groundwater and evapotranspiration (Connor et al. 2013). Average daily discharge and the proportion of forested riparian zone represent drivers of hydrologic variation that act at the watershed scale, outside of precipitation gradient effects.

The fish communities displayed a pattern of increasing diversity moving from the drier to wetter sides of the survey region (Fig. 4. Fish Shannon diversity correlates positively with precipitation, but negatively with conductivity and NH4+, canopy coverage and Low-Flow Pulse Percent (LFPP) (Table 5, Table 6). Water quality was similar to polluted streams in the semi-arid streams; Conductivity and NH4+ were higher in semi-arid streams and exhibited levels similar to urbanized stream are high (Figure 4). High solute concentrations and biological waste products could limit diversity by permitting only species with specialized osmoregulatory adaptations (East et al. 2017). We also noted but did not quantify higher concentrations of silt in the semi-arid streams with prohibitive implications for nesting species. These results suggest that as conditions become drier, water quality imposes abiotic filters on fish assembly which reduce overall community diversity.

In addition to diversity, fish community composition also correlated with annual precipitation. Communities in semi-arid streams (<75 cm annual precipitation) were composed of small, live-bearing, omnivores able to tolerate high salinities including Sailfin Molly (*Poecilia latipinna*, 95 psu) and Western Mosquitofish (*Gambusia affinis*, 58.5 psu) (Page and Burr, B.M. 1991). The strongest compositional shift observed were increases in the abundance of centrarchids (sunfish) with increases in annual rainfall. Centrarchid species have 3-7 year lifespans, breed annually, build nests, and are omnivores (Cooke and Philipp 2009). Additional increases in diversity towards the wetter side of the climate gradient include the addition of black bullhead catfish (a demersal, nesting omnivore), and several shiner species (small broadcast spawning minnows). These organisms require conditions that are stable across years as well as suitable substrate for rearing young, suggesting that conditions in semi-arid sites are excluding these taxa through environmental filtering. Additionally, some of the sub-humid and mesic sites also had seasonally migrating taxa including Rio Grande Cichlid (*Hericthys cyanogutattus)*, Hogchoker (*Trinectes maculatus),* and American Eel (*Anguilla rostrate*)(Rehage et al. 2016; Koski 1978; Wenner, C.A. 1978). These were absent from semi-arid sites. Given the similar proximity to nearby reservoirs and estuaries, migratory taxa may have been excluded from streams with habitat fragmentation, indicated here by low flow pulse %, that typify semi-arid streams (Williams 1999; De Jong et al. 2015).

Red shiners (*Cyprinella lutrensis*) were curiously absent from semi-arid sites and were only present in four mesic and sub-humid sites. In ordination space, two sites with the highest abundances of red shiner (Aransas and Placedo) separated perpendicularly from the rainfall-gradient effects and coextended with Rosgen (stream morphology) and hydrologic flashiness indices (Fig.4). High abundances of red shiner were associated with shallow riffle habitats with gravel substrates which occurred at three sites throughout the gradient. This was peculiar since red shiner are considered to be a habitat generalist and rugged invasive throughout the United States (Marsh-Matthews and Matthews 2000; Matthews and Marsh‐Matthews 2007). So, we suspect their apparent habitat preference to be driven by competition and predation by centrarchids in nearby pool and run habitats. Although red shiners tolerate high temperatures and low oxygen, conductivity is likely excluding red shiner (salinity tolerance < 10 psu) from the arid sites (Matthews and Hill 1977). In this light, we considered hydrologic flashiness a spurious influence on red shiner distributions beyond its capacity to influence channel geomorphology.

Low flow pulse percentage (LFPP) approximated drought prevalence and was the sole significant predictor of invertebrate community diversity (Fig.5). In addition to LFPP, the top-ranked multiple regression models also implicated NH4+ was an effective predictor of invertebrate diversity. Semi-arid community compositions included a higher proportion of gastropods which are well adapted to the stresses that characterize increased LFPP (Fig 5.). For example, *M. tuberculata* were the most abundant primary consumers in the semi-arid streams and can resist the osmotic stress imposed by drought conditions with a broad range of salinity tolerance (0-23 PSU). This species is also well-adapted to survive and reproduce throughout periodic dewatering due to its rapid maturation (21-62 days), asexual reproduction, and internal offspring gestation (Farani et al. 2015). Droughts represent a ramping disturbance as water availability and quality diminish over time and most invertebrates are unable to escape due to restricted in-stream mobility compared to fish. aquatic invertebrates can access refuge in the hyporheic zone, interstitial spaces, and in some cases utilize desiccation-resistant life-stages (Boulton, Peterson et al. 1992, Boulton 2003).

Surprisingly, while invertebrate community composition shifted with rainfall, invertebrate diversity did not correlate linearly with precipitation. Instead, invertebrate diversity peaked in the middle of the rainfall gradient. The lack of a linear correlation between invertebrate diversity and precipitation may have been caused by the inherently larger species pool for invertebrates which included more taxa with biological adaptations to drought compared to fish (Eriksson 1993). The peak likely represented the transition zone where taxa common on each side of the gradient were able to co-occur. As precipitation increased, there were three points of interest: 1) The shift in primary producers and the increased prevalence of amphipods and decapods at wetter sites implied a corresponding shift in available basal resources. Specifically, precipitation-mediated shifts in riparian vegetation from evergreen, xeric mesquite trees to deciduous hardwoods likely altered the inputs of terrestrially derived detrital inputs and instream productivity to promote the inclusion of shredder taxa (Giling, Reich, and Thompson 2009). 2) The observed shift in primary consumers from short-lived, euryhaline dipterans and gastropods to ephemeropterans and trichopterans, environmentally sensitive species with longer lifespans, pointed towards improved water quality conditions and hydrologic stability (Rosenberg and Resh 1993; Jackson and Sweeney 1995). Taken further, this pattern alludes to trade-off between aridity tolerance and competitive specialization (Fréjaville et al. 2018). 3) The decreased abundance of odonates and hempiterans predators may have been due to competition with and predation by insectivorous centrarchids (Dahl and Greenberg 1998). In this way, biotic interactions at sub-humid sites presumably restricted invertebrate communities to species with anti-predator adaptations including small size, passive foraging strategies, camouflage, and armoring (Straile and Hälbich 2000). Taken together, these invertebrate (and fish) community compositional patterns suggest that small changes in precipitation regime could result in abrupt ecosystem shifts (Scheffer and Carpenter 2003).

While this survey only consisted of 10 streams, it is the first published rapid bioassessment of systems along the rainfall gradient on the Texas Coastal Prairie. The results largely conform to *a priori* hypotheses indicating that the region represents a promising study region for climate research. In addition to its capacity for a space for time substitution, the TCP makes is poised to provide real-time data on the effects of climate change on ecosystems. Future research in this region would benefit from higher frequency sampling over a longer time period and quantification of invertebrate and fish functional traits. An in-depth time series study would allow for evaluation of how these communities change across seasons, how they response to periodic droughts and floods, and how stable the communities are through time. More detailed quantification of the fish communities through depletion surveys and invertebrate communities via biomass cores would allow for greater characterization of the relative abundance of different taxa through time, and these could be linked to functional traits to explore the mechanisms behind some of the patterns we observe here. A continuation of this sampling program with thorough methods will augment the analytical power, precision, and depth of this natural experiment.

Despite this study’s limitations, our results highlight the breadth and far-reaching ecological consequences associated with small changes in precipitation. They warn that regions expected to become more arid, like Central and Western Texas (Jiang and Yang 2012), could expect a loss of competitive taxa with low environmental tolerances as observed here with centrarchids, ephemeropterans, and trichopterans. And that in their absence, rugged and euryhaline taxa (like livebearers, burrowing gastropods and predatory invertebrates) flourish. Furthermore, this study warrants investigation to clarify the causal relationships between the ecological constraints imposed by aridity and these observed community shifts.

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