Effects of a natural precipitation gradient on fish and macroinvertebrate assemblages in coastal streams

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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 approach 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 conductivity. Macroinvertebrate diversity peaked within the middle of the gradient. Semi-arid fish and invertebrate communities were dominated by euryhaline and live-bearing taxa. Sub-humid communities contained environmentally sensitive trichopterans and ephemeropterans as well as a variety of predatory fish which may impose top-down controls on primary consumers. These results warn that aridification coincides with the loss of competitive and environmentally sensitive taxa which could yield less desirable community states.

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18 **Abstract:**
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34 and environmentally sensitive taxa which could yield less desirable community states.

35
36 **Introduction:**
37   A warming climate warrants a better understanding of the processes that link
38 biological communities to long-term trends in temperature and precipitation (Wrona *et*
39 *al.* 2006; Miranda *et al.* 2020). The direct ecological effects of changes in temperature
40 have received greater attention in the literature, but rising temperatures are also
41 expected to alter patterns of precipitation and evaporation. A warmer, more energetic
42 atmosphere intensifies the hydrological cycle (patterns of precipitation and evaporation),
43 causing wet regions to become wetter and dry regions become drier (Allen and Ingram
44 2002), as well as increasing the frequency and intensity of extreme weather events
45 (Held and Soden 2006). In general, this raises concern for freshwater ecosystems

46 which are highly sensitive to changes in water availability and contain many species
47 with limited dispersal capabilities (Woodward *et al.* 2010).
48   Stream ecosystems are shaped by flow regimes which regulate the physical
49 extent of aquatic habitats, water quality, sourcing and exchange rates of material, and
50 habitat connectivity (Rolls *et al.* 2012). Aridification increases the prevalence of
51 droughts and flash floods which disturb local communities by imposing intolerable
52 conditions or physically displacing individuals. Lengthening dry periods cause changes
53 in macroinvertebrate communities where drought sensitive taxa (Ephemeroptera,
54 Plecoptera, and Trichoptera) are replaced by drought tolerant species (Storey 2016). In
55 contrast, humid precipitation regimes have low interannual variability and frequent bank
56 flooding that promotes hydrological connectivity and resource exchange between
57 aquatic and terrestrial systems. Fish communities become increasingly diverse with
58 precipitation and temperature along continental climate gradients (Griffiths *et al.* 2014).
59 The expansion of semi-arid regions (Huang *et al.* 2015) warrants an improved
60 understanding of the mechanistic links between precipitation, flow regime, and aquatic
61 biota to manage for the increasing societal demands for freshwater resources.
62   Hierarchical community assembly models can help us organize our hypotheses
63 regarding impacts of climate change on stream communities (Poff 1997). Assuming
64 organisms can disperse to a habitat, they must be able to survive in the local
65 environment (abiotic filters) and successfully reproduce in the presence of other
66 organisms exerting pressures (biotic interactions) such as competition and predation
67 (Patrick and Swan 2011). Species have physiological tolerances (temperature, toxin
68 concentrations, and salinity, etc.) which limit their distribution across environmental
69 gradients (Whittaker *et al.* 2001). If climate change alters those gradients, we can
70 expect concordant changes in species distributions. However, understanding how the
71 environment affects biotic interactions is more challenging due to the complex sets of
72 interactions that govern these processes (Seabra *et al.* 2015).
73   Observational surveys of existing communities spatially distributed along
74 environmental gradients can be used in a space-for-time substitution to infer how
75 communities will change through time as environmental conditions shift. The approach
76 allows for links to be drawn between climate drivers, local environmental conditions, and
77 organism abundances. Species co-occurrence patterns along environmental gradients
78 can also shed light on possible shifts in biotic interactions (D'Amen *et al.* 2018).
79 However, the space-for-time approach assumes that observed ecological differences
80 along the spatial gradient are the sole product of corresponding changes in climate.
81 This assumption may be unfair given that biogeographical studies have revealed that
82 dispersal limitation, habitat heterogeneity, and local evolution can also contribute to
83 current spatial patterns in community composition (Jacob *et al.* 2015). These studies
84 are typically large in scale, covering vast distances (thousands of km) to capture climate
85 gradients. These large scales make the precise mechanisms for observed biological
86 changes difficult to ascertain due to covarying environmental variables (e.g., elevation,
87 geology, human impacts). Thus, while current literature demonstrates that biome shifts
88 occur across temperature and latitudinal gradients (De Frenne *et al.* 2013), the value of
89 these observational studies for forecasting community responses to climate change is
90 hindered by the many confounding variables. The power of using the space-for-time
91 approach to delineate the intricacies of hydrologic cycle-ecosystem relationships is

92 enhanced in study systems with limited confounding environmental variables
93 (temperature, elevation, distance, and underlying geology).
94   The Texas Coastal Prairie (TCP) within the Western Gulf coastal grasslands is
95 an ideal system for evaluating the effect of hydrologic climate change on ecological
96 communities. It is located within the Western Gulf coastal grasslands which are a
97 subtropical ecotone that spans Louisiana, Texas, and northern Mexico's coastal areas.
98 The system encompasses the sharpest non-montane precipitation gradient in the
99 continental United States. The climate becomes more arid as you move west, with
100 gradual change for much of the coast and a region of rapid change located in southern
101 Texas. In this region the annual rainfall changes from 55cm•yr-1 (semi-arid) to 135
102 cm•yr-1 (sub-humid) over a 300 km gradient, but there are minimal changes in
103 elevation, air temperature, underlying geology, and human land use. The region is
104 characterized by gently rolling landscapes (slopes < 5%), afisol soils, streams with
105 forested riparian zones, and a widespread conversion of grasslands to the agricultural
106 production of cattle, cotton, corn, and soy products (Chapman 2018). As conditions
107 become wetter, there is an observable ecological shift from mesquite groves in the
108 semi-arid West to live oak and pecan forests towards the East. The TCP is an ideal
109 study region for isolating precipitation influences on natural ecosystem processes
110 because of the minimal impact of covarying predictors that typify climate gradient
111 research.
112   Despite the intrinsic value of this region as a candidate for climate gradient
113 research, there is limited prior biological sampling by governmental agencies of running
114 waters in the TCP. To address this need, we conducted the first dedicated survey of
115 streams across the climate gradient. We applied rapid bioassessment protocols to 10
116 USGS-gauged (U.S. Geological Survey), wadeable streams for characterization of fish,
117 benthic macroinvertebrates, and quantification of environmental variables. Our
118 objectives were to: 1) Isolate and clarify the effects of annual precipitation on patterns in
119 the diversity and composition of fish and macroinvertebrates communities, and 2)
120 Specify the hydrologic and water quality predictors that mediate the effects of
121 precipitation on community assembly. We expected that annual precipitation would be
122 positively correlated with community diversity because humid precipitation regimes are
123 expected to create more stable environmental conditions by creating predictable flow
124 regimes which promote the development of greater biodiversity (Boulton *et al.* 1992;
125 Bunn and Arthington 2002). We further expected that evapotranspiration by riparian
126 vegetation would increase solute concentrations in semi-arid streams, particularly
127 during base flows (Tabacchi *et al.* 2000; Lupon *et al.* 2016), creating environmental
128 filters that limit recruitment of sensitive fish and macroinvertebrates (hereafter referred
129 to as invertebrates).
130
131 **Methods**
132 *Study Region***:** The Texas Coastal Prairie contains grassland prairie with forested areas
133 occurring primarily along riverine systems. During March and April of 2017, we sampled
134 ten, wadeable, perennial streams which span 12 counties from Kleberg County to
135 Montgomery in South-Central Texas, USA (Fig. 1). Each study site was located within
136 100 meters of a USGS stream gauge which continuously monitor streamflow and
137 climate data year-round. Study sites were chosen to maximize differences in

138   precipitation with minimal changes in underlying geology and elevation. The annual
139   precipitation ranges from 61-121 cm within the study region which spans a linear
140   distance from end to end of 378 km (Falcone 2011). The surface geology is
141   characterized by fine clays, quaternary and sedimentary sand. The streams have similar
142   elevations (14-62 m), substrates (quaternary), and average air temperatures (19.8-
143   22.1℃) (Falcone 2011). Sampling was conducted by students and faculty at Texas A&M
144   (Corpus Christi) under permit SPR-0716-170, granted by Texas Parks and Wildlife
145   Department.
146
147   *Biological Sampling***:** Fish communities were sampled using a Smith-Root LR-24
148   Backpack in a single pass survey (Lamberti 2017). Each reach length was 25 times the
149   average stream width, in accordance with EPA rapid bioassessment protocols (US EPA
150   2019). Low variability in stream withs (4.9 ± .6 m) resulted in comparable catch effort
151   across sites, so fish abundances were reported in terms of catch per sample event. Fish
152   species were field identified to species using a field guide (Thomas *et al.* 2007) and
153   photographed. Several specimens of each species were euthanized using tricaine
154   mesylate (MS-222) and stored in >70% denatured ethanol as voucher specimens for lab
155   confirmation of species identification. Fish Voucher specimens were identified using the
156   Texas Academy of Science dichotomous key (Hubbs, Edwards, and Garrett 2008) and
157   cross referenced with field identifications. Vertebrate sampling was permitted by the
158   Institutional Animal Care and Use Committee, Texas A&M University Corpus Christi
159   (AUP# 05-17).
160   Invertebrates were collected using a 0.305m wide D-frame net equipped with
161   500-μm mesh. Twenty 0.093 m^2 samples were collected via a combination of kick and
162   sweep (15 s duration) sampling from a representative distribution of best available
163   habitat (riffles, large woody debris, overhanging vegetation) (Southerland *et al.* 2007).
164   Samples were pooled in a 500-μm sieve bucket where larger sticks and leaves were
165   rinsed and removed. The captured invertebrates and remaining debris were preserved
166   in 95% EtOH for transport to the lab. In the lab, samples were spread across a gridded
167   sampling tray and randomly selected grid cells were picked to completion until the total
168   count was > 300 individuals (USEPA 2015). Samples containing less than 300
169   individuals were picked to completion. Invertebrates were identified to lowest taxonomic
170   resolution (typically genus) using taxonomic keys cross referenced with species
171   observations recorded by the TCEQ's (Texas Commission on Environmental Quality)
172   Surface Water Quality Monitoring Program (Wiggins 2015; Cummins and Merritt 1996).
173   The sum of individuals in each taxon were multiplied by the fraction of unpicked sample
174   and reported as abundance of individuals per square meter.
175
176   *Environmental Data:* For each stream, we averaged values for each of the following
177   habitat measurements that were taken at 4 cross-sections spaced 25m apart. A Rosgen
178   Index value was calculated by dividing the bank-full width by the maximum depth
179   (Rosgen 2001). Bank height was recorded as vertical difference between water level
180   and the height of the first bench. We estimated sediment grain size within each cross-
181   section using Wentworth size categories to calculate a median grain-size (d50)
182   (Wentworth 1922). Oxygen, temperature (T$_{water}$), conductivity, turbidity, and pH were
183   measured at each point using a YSI ProDSS multiparameter probe. Two 60 mL water

184   samples were collected and filtered through a pre-combusted (500℃ for 4 hours) glass
185   fiber filter (Whatman GF/F) into acid washed amber bottles, transferred to the lab in a
186   cooler on ice, and stored frozen (-20℃) until analysis for nutrients (NH_4^+, NO_3^-, and PO_4^-
187   ). Water samples were run using colorimetric methods on a latchet autoanalyzer by the
188   Oklahoma University Soil Water and Forage Laboratory.
189   In addition to the habitat metrics measured in the field, we gathered climate and
190   watershed data, from the US Geologic Surveyors Geospatial Attributes of Gages for
191   Evaluating Streamflow, version II dataset (Falcone 2011). A twenty-year continuous
192   daily flow record was downloaded for each site (except Tranquitas Creek which only
193   had 4 years of available data) from the USGS Water Services
194   (https://waterservices.usgs.gov).
195
196   *Analyses*: Due to a small number of sample sites and replicates, the statistical
197   analyses relating environmental drivers to organismal responses were restricted to six *a*
198   *priori* environmental predictors. Annual precipitation was evaluated to identify gradient
199   effects. Channel shape is a product of flow regime, slope, substrate, and bank stability
200   and was summarized by the Rosgen index. We included conductivity and NH_4^+ to
201   evaluate water quality. Since the selected streams were deliberately chosen to be
202   wadeable at base flow, we calculated two flow metrics to approximate the typical flow
203   regime of each site in the context of seasonal droughts and floods, as well as overall
204   variation in flow: Flash Index (cumulative changes in day to day daily flow / cumulative
205   flow) and the Low-Flow Pulse Percent (LFPP = times where daily discharge drops
206   below the 25th percentile) (Olden and Poff 2003; Patrick and Yuan 2017).
207   We used linear regression and Pearson correlation coefficients to identify
208   potential confounding relationships between precipitation and each environmental
209   predictor. We then, used singular value decomposition of the centered and scaled data
210   matrix in a principal component analysis with all six environmental predictors. The
211   environmental PCA and associated exploratory results are described in the
212   supplemental data.
213   For each community (fish and invertebrate) we estimated coverage and Hill
214   diversity metrics (Roswell *et al.* 2021). We used coverage-based estimates of species
215   richness, Shannon entropy and Gini-simpson index (Chao *et al.* 2014). While richness
216   and Gini-Simpson index values are reported in supplemental materials, further analyses
217   and discussion regarding diversity utilize the Shannon Entropy because it is not overly
218   sensitive to either rare or common species. We used univariate regression to evaluate
219   community diversity relationships with the precipitation gradient and each environmental
220   predictor. We also performed exhaustive multiple regression with an additive global
221   model utilizing all six environmental predictors and ranked them using Aikake's
222   information criterion corrected for small sample sizes (AIC_c). All the results were
223   compared to the best overall model by calculating the difference in AIC_c values (ΔAIC_c).
224   Models with $\Delta AIC_c < 2$ were considered to have substantial support (Burnham and
225   Anderson 2002). Diversity Hill metrics were calculated using the iNEXT package (Hsieh
226   *et al.* 2020) in R (R Core Team 2018).
227   To discern compositional shifts in fish and invertebrates across the precipitation
228   gradient, we used Redundancy Analysis (RDA) on Hellinger-transformed community
229   data, constrained to the six environmental variables in Table 1 (Legendre and Gallagher

230   2001; Legendre and Legendre 2012). We then fit vectors to the species and
231   environmental variables where the direction of each arrow is determined by the average
232   directional cosines from the origin to site values within the ordination. Significant vectors
233   had an associated *p*-value < 0.05. Ordination and vectors were calculated using the
234   'rda' and 'envfit' functions respectively in the vegan package in R (J. Oksanen *et al.*
235   2019, Bellier *et al.* 2012). Statistics and analytical R scripts for analyses described
236   above are reported in the supplemental data.
237

238   **Results**
239   *Fish Community*: Eighteen fish species were identified. Proceeding from semi-arid to
240   sub-humid sites, Shannon entropy increased from 1.6 to 6.1 and richness increased
241   from 2 to 9 species (Fig. 2). Univariate regressions indicate that Shannon diversity is
242   positively correlated with precipitation and negatively correlated with conductivity (Table
243   1). Multiple regression indicates that precipitation alone is the strongest predictor of
244   Shannon diversity.
245   Communities along the precipitation gradient are stratified in ordination space
246   with significant vector loading on NH_4^+ (Fig. 3). The position of species and sites
247   indicate that compositions shift from small, elongate live-bearer taxa (*Poecilia latipinna*,
248   and *Gambusia affinis*) in the most arid sites to deep-bodied, nesting centrarchids
249   (*Lepomis megalotis* and *Lepomis macrochirus)* in the more humid sites. Some mesic
250   and humid stream communities are distinguished by the presence of *Cyprinella*
251   *lutrensis*, a small, invasive habitat-generalist. Species found in small numbers or at
252   singular sites fail to produce significant vectors in the RDA. Unique species found in
253   sites on the humid side of the climate gradient include hogchoker (*Trinectes maculatus*),
254   black bullhead catfish (*Ameirus melas*), and blacktail shiner (*Cyprinella venusta*).
255

256   *Invertebrate Community:* In total, 94 invertebrate genera were identified. Invertebrate
257   richness ranged 7–29 genera with the highest values occurring at three sites in the
258   middle of the precipitation gradient (Fig. 4). Regression analysis indicates that Shannon
259   entropy does not significantly correlate with precipitation. However, multiple regression
260   indicates that invertebrate diversity relates negatively with LFPP (Table 1).
261   Communities along the precipitation gradient stratify in ordination space along
262   opposite/parallel axes of precipitation and conductivity. Arid communities are strongly
263   correlated with gastropods including a non-native burrowing snail (*Melanoides*
264   *tuberculata*). Mesic invertebrate communities are strongly correlated with crawling
265   beetles (*Hydraena*) and swimming beetles (*Peltodytes*). The most humid communties
266   correlate with several Ephemeroptera (*Caenis* and *Plauditus*), Crustacea
267   (*Palaemonetes*), Amphipoda (*Hyalella*), and Trichoptera (*Cheumatopsyche*).
268

269   **Discussion**
270   Our goal was to quantify patterns in the diversity and composition of stream
271   communities along an extreme precipitation gradient to better understand how streams
272   might respond to future changes in mean annual rainfall. We identified compositional
273   shifts in both fish and invertebrate communities along the precipitation gradient. We also
274   observed a positive relationship between fish diversity and mean annual rainfall,
275   matching expectations, whereas invertebrate diversity did not exhibit the expected

276 relationships with rainfall. Changes in water solute concentrations and flow regime
277 appear to be additional important drivers of community responses.
278   The fish communities displayed increasing diversity moving from the drier to
279 wetter sides of the survey region. Fish diversity increased with precipitation but was
280 negatively related to conductivity, NH_4^+, and canopy coverage. Elevated conductivity
281 and NH_4^+ in semi-arid streams exhibited levels similar to urbanized streams (Hatt *et al.*
282 2004), creating stressful osmotic and toxic conditions for fish (J. M. Redding and
283 Schreck 1983; Lock and Wendelaar Bonga 1991). Elevated NH_4^+ has been shown to be
284 directly toxic to many fish (Randall and Tsui 2002) and has also fueled cytotoxic algal
285 growth (Fetscher *et al.* 2015). Elevated solute concentrations were likely driven by
286 evaporation, the watershed area/discharge ratio, and the greater influence of
287 wastewater effluent on low discharge streams that typify semi-arid streams (Williams
288 1999; Dehedin *et al.* 2013). We interpreted these patterns to mean that as conditions
289 become drier, water quality imposes abiotic filters on fish assembly which reduce overall
290 community diversity and selects for taxa with specialized adaptations for the harsh
291 conditions. The negative relationship between fish diversity and canopy coverage was
292 attributed to incomplete leaf-emergence in deciduous canopies prior to May.
293   Communities in semi-arid streams were composed of small, live-bearing,
294 omnivores able to tolerate high salinities including Sailfin Molly (*Poecilia latipinna*, 95
295 psu) and Western Mosquitofish (*Gambusia affinis*, 58.5 psu) (Page and Burr, B.M.
296 1991). The strongest compositional shift observed were increases in the abundance of
297 centrarchids (sunfish) with increases in annual rainfall. Centrarchid species have 3-7
298 year lifespans, breed annually, build nests, and are omnivores (Cooke and Philipp
299 2009). Additional increases in diversity towards the wetter side of the climate gradient
300 included the addition of black bullhead catfish (a demersal, nesting omnivore), and
301 several shiner species (small broadcast spawning minnows). These organisms require
302 conditions that are stable across years as well as suitable substrate for rearing young,
303 suggesting that conditions in semi-arid sites were excluding these taxa through
304 environmental filtering. Additionally, some of the sub-humid and mesic sites also had
305 seasonally migrating taxa including Rio Grande Cichlid (*Hericthys cyanogutattus)*,
306 Hogchoker (*Trinectes maculatus),* and American Eel (*Anguilla rostrate*) (Rehage *et al.*
307 2016; Koski 1978; Wenner 1978). These were absent from semi-arid sites. Given the
308 similar proximity to nearby reservoirs and estuaries, migratory taxa may have been
309 excluded from streams with habitat fragmentation, approximated here by low flow pulse
310 %, that typify semi-arid streams (De Jong *et al.* 2015).
311   Contrary to expectations, Red shiners (*Cyprinella lutrensis*) were absent from
312 semi-arid sites and were only present in four mesic and sub-humid sites. In ordination
313 space, two sites with the highest abundances of red shiner (Aransas and Placedo)
314 separated perpendicularly from the rainfall-gradient effects and coextended with stream
315 morphology and hydrologic flashiness indices. High abundances of red shiner were
316 associated with shallow riffle habitats with gravel substrates which occurred at three
317 sites throughout the gradient. This was peculiar since red shiner are considered to be a
318 habitat generalist and rugged invasive throughout the United States (Marsh-Matthews
319 and Matthews 2000; Matthews and Marsh-Matthews 2007). We suspected their
320 apparent habitat preference was driven by competition and predation by centrarchids in
321 nearby pool and run habitats. Although red shiners tolerate high temperatures and low

322 oxygen, conductivity was likely excluding red shiner (salinity tolerance < 10 psu) from
323 the arid sites (Matthews and Hill 1977). In this light, we considered hydrologic flashiness
324 a spurious influence on red shiner distributions beyond its capacity to influence channel
325 geomorphology.

326   LFPP approximated drought prevalence and was the sole significant predictor of
327 invertebrate community diversity. In addition to LFPP, the top-ranked multiple
328 regression models also implicated NH_4^+ was an effective predictor of invertebrate
329 diversity. These results corroborate expectations for the ramping disturbance conditions
330 typical of droughts in which water availability and quality diminish over time. Compared
331 to fish, invertebrates have restricted in-stream mobility and traditionally seek refuge in
332 the hyporheic zone, interstitial spaces, and in some cases utilize desiccation-resistant
333 life-stages (Boulton *et al.* 1992; Boulton 2003). Here, Semi-arid community
334 compositions included a higher proportion of gastropods which are well adapted to the
335 stresses that characterize increased LFPP. For example, *M. tuberculata* were the most
336 abundant primary consumers in the semi-arid streams and can resist the osmotic stress
337 imposed by drought conditions with a broad range of salinity tolerance (0-23 PSU). This
338 species is also well-adapted to survive and reproduce throughout periodic dewatering
339 due to its rapid maturation (21-62 days), asexual reproduction, and internal offspring
340 gestation (Farani *et al.* 2015).
341   Despite relating with LFPP, invertebrate diversity did not correlate linearly with
342 precipitation. Instead, invertebrate diversity peaked in the middle of the rainfall gradient.
343 The lack of a linear correlation between invertebrate diversity and precipitation may
344 have been caused by the inherently larger species pool for invertebrates which included
345 more taxa with biological adaptations to drought compared to fish (Eriksson 1993). The
346 peak likely represented the transition zone where taxa common on each side of the
347 gradient were able to co-occur. Alternatively, the driest site (Tranquitas Creek)
348 displayed uncharacteristically low diversity compared to other semi-arid sites and may
349 constitute an outlier. When removed, invertebrate diversity correlated negatively with
350 precipitation (R^2 = 0.43, *p*-value = 0.06). Regardless, the relation between precipitation
351 and invertebrate diversity remains unclear.
352   Invertebrate community compositional shifts with rising precipitation invite
353 continued assessment on the following speculative premises within the region: 1) The
354 observed shift in primary consumers from short-lived, euryhaline dipterans and
355 gastropods to ephemeropterans and trichopterans, environmentally sensitive species
356 with longer lifespans, pointed towards improved water quality conditions and hydrologic
357 stability (Rosenberg and Resh 1993; Jackson and Sweeney 1995). Taken further, this
358 pattern alludes towards the evolutionary trade-off between aridity tolerance and
359 competitive specialization (Fréjaville *et al.* 2018). 2) The increased prevalence of
360 shredder-crustaceans (amphipods and crayfish) at wetter sites pointed towards a
361 possible shift in available basal resources; precipitation-mediated shifts in riparian
362 vegetation from evergreen, xeric mesquite trees to deciduous hardwoods could bring
363 about increased allochthonous inputs to support more shredder taxa (Giling, Reich, and
364 Thompson 2009). 3) The decreased abundance of odonate and hempiteran predators
365 may have been due to competition with and predation by insectivorous centrarchids
366 (Dahl and Greenberg 1998). In this way, top-down trophic interactions at sub-humid
367 sites could have restricted invertebrate communities to species with anti-predator

368   adaptations including small size, passive foraging strategies, camouflage, and armoring
369   (Straile and Halbich 2000).
370   While this survey only consisted of 10 streams, it is the first published rapid
371   bioassessment of systems along the rainfall gradient on the Texas Coastal Prairie. The
372   results largely conform to *a priori* hypotheses indicating that the region represents a
373   promising study region for climate research. In addition to its capacity for a space for
374   time substitution, the TCP is poised to provide real-time data on the effects of climate
375   change on ecosystems. Future research in this region would benefit from higher
376   frequency sampling over a longer time period and quantification of invertebrate and fish
377   functional traits. An in-depth time series study would allow for evaluation of how these
378   communities change across seasons, how they respond to periodic droughts and
379   floods, and how stable the communities are through time. More detailed quantification of
380   the fish communities through depletion surveys and invertebrate communities via
381   biomass cores would allow for greater characterization of the relative abundance of
382   different taxa through time, and these could be linked to functional traits to explore the
383   mechanisms behind some of the patterns that we observed here. A continuation of this
384   sampling program with thorough methods will augment the analytical power, precision,
385   and depth of this natural experiment.
386   Despite this study's limitations, our results highlight the breadth and far-reaching
387   ecological consequences associated with small changes in precipitation. They warn that
388   regions expected to become more arid, like Central and Western Texas (Jiang and
389   Yang 2012), could expect a loss of competitive taxa with low environmental tolerances
390   as observed here with centrarchids, ephemeropterans, and trichopterans. And that in
391   their absence, rugged and euryhaline taxa (like livebearers, burrowing gastropods and
392   predatory invertebrates) flourish. Furthermore, this study warrants investigation to clarify
393   the causal relationships between the ecological constraints imposed by aridity and
394   these observed community shifts.
395

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401
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Figure 1

Map of South-Central Texas, where 10 USGS gaged Streams were sampled in the Spring of 2017.

An annual precipitation overlay indicates that the sample sites span a gradient from 61 cm/yr in the Southwest to 134 cm/yr in the Northeast.

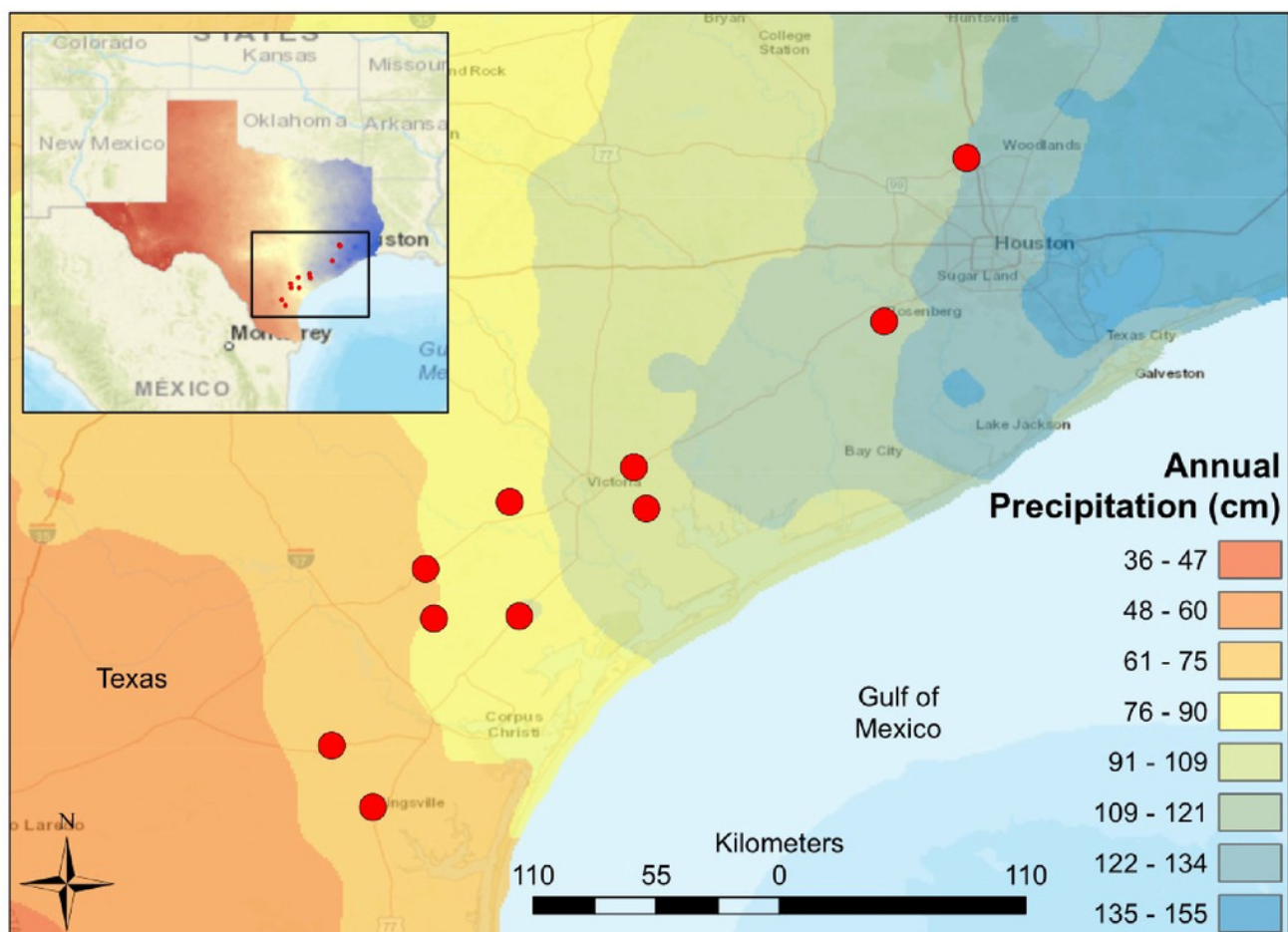



Figure 2

(A) Fish Shannon-Hill diversity plotted against annual precipitation (cm/yr) (B) Fish community ordination using Hellinger transformation and redundancy analysis. Axes labels display the proportion of the variance explained as a percentage.

Sites are represented by grey circles. Species are represented by red crosses, with species labels and reference images added to outer members. Environmental variables are shown in arrows and the significant ones are presented in red.

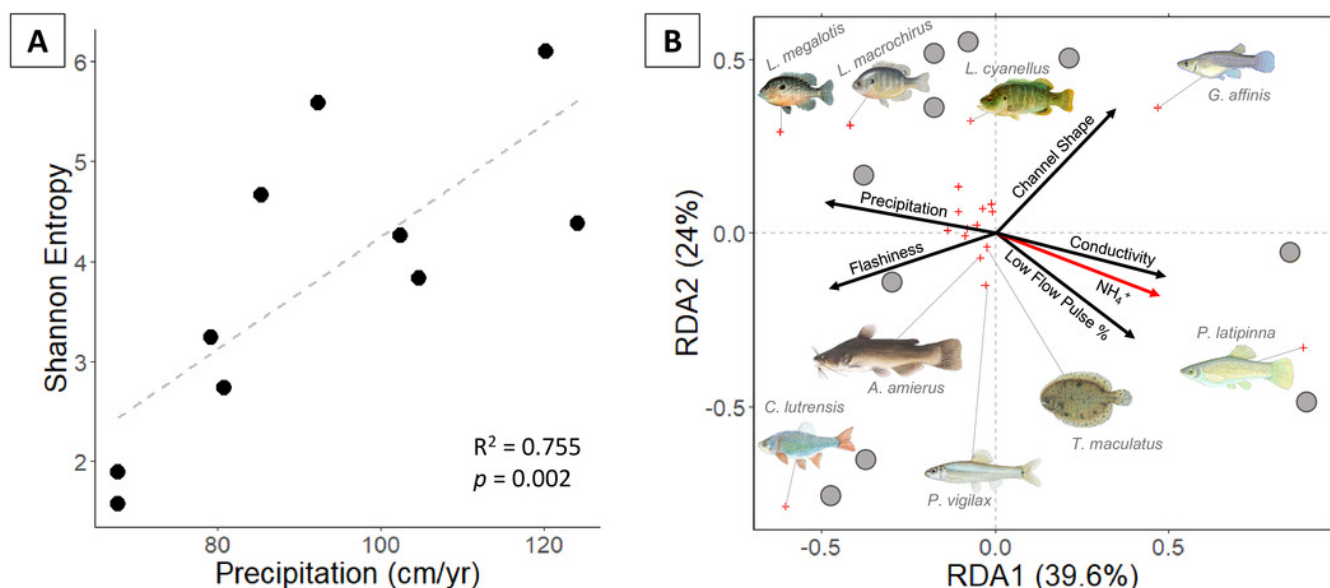
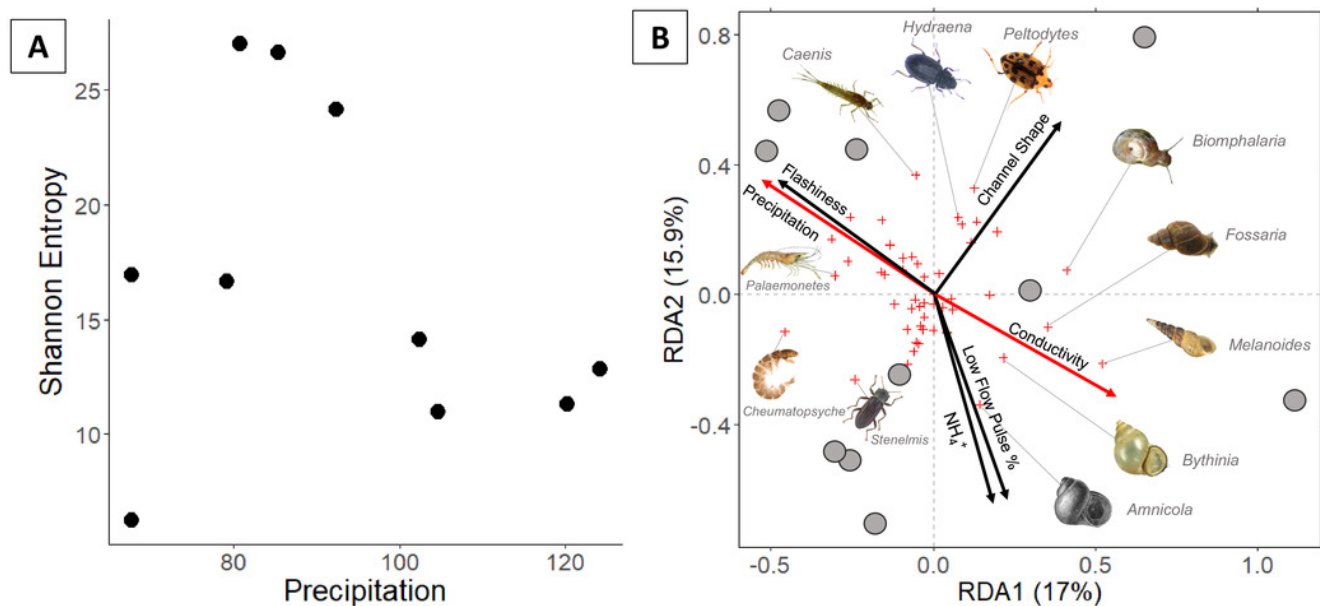



Figure 3

(A) Invertebrate diversity plotted against annual precipitation (cm/yr) (B) Invertebrate community ordination using Hellinger transformation and redundancy analysis.

Axes labels display the proportion of the variance explained as a percentage. Sites are represented by grey circles. Species are represented by red crosses, with species labels and reference images added to outer members. Environmental variables are shown in arrows and the significant ones are presented in red.

Univariate regression summary statistics and multiple regression relationships predicting fish and invertebrate Shannon entropy using environmental predictors.

* denotes a p-value < 0.05 or an Δ AICc < 2.

Response	Input	Slope	R^2	F-stat	df	p-value	Multiple Regression
Shannon$_{Fish}$	Precipitation	0.056	0.576	10.885	2	0.011*	+ *
Shannon$_{Fish}$	Flashiness	1.430	0.038	0.316	2	0.589	+
Shannon$_{Fish}$	Channel Shape	0.113	0.069	0.597	2	0.462	+
Shannon$_{Fish}$	Low Flow Pulse %	-0.083	0.222	2.281	2	0.169	-
Shannon$_{Fish}$	NH$_4^+$	-13.221	0.326	3.877	2	0.084	-
Shannon$_{Fish}$	Conductivity	-0.920	0.413	5.636	2	0.045*	-
Shannon$_{Invert}$	Flashiness	8.651	0.061	0.517	2	0.493	+
Shannon$_{Invert}$	Precipitation	-0.085	0.057	0.487	2	0.505	-
Shannon$_{Invert}$	Low Flow Pulse %	-0.489	0.336	4.056	2	0.079	- *
Shannon$_{Invert}$	NH$_4^+$	-2.519	0.001	0.004	2	0.950	-
Shannon$_{Invert}$	Conductivity	-0.884	0.017	0.135	2	0.723	-
Shannon$_{Invert}$	Channel Shape	-0.899	0.193	1.917	2	0.204	-