FISH ASSEMBLAGE CHANGES IN THREE WESTERN GULF SLOPE DRAINAGES

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Anthropogenic impacts on rivers and streams directly and indirectly affect aquatic fauna (Hughes et al. 2005). These impacts alter hierarchical-ordered abiotic and biotic factors that determine faunal distribution, composition, abundance, and life history of fishes by limiting habitat components or by modifying biotic interactions (Deacon et al. 1979; Schlosser 1991; Daniels et al. 2005). Consequently, anthropogenic impacts on fishes worldwide range from moderate to severe (Anderson et al. 1983; Rutherford et al. 1987; Warren and Burr 1994; Tallman et al. 2005a; 2005b) and likely will continue as the demand for surface waters for hydroelectricity and recreation and surface and subsurface waters for municipal use increase (Baxter and Glaude 1980; Gore and Shields 1995; Collier et al. 1996; Poff et al. 1997).

The degree of change in fish assemblage composition and abundance has often been used as a measure of anthropogenic impact (Pflieger and Grace 1987; Martinez et al. 1994; Anderson et al. 1995; Bonner and Wilde 2000; Edwards 2001; Contreras-Balderas et al. 2002). However, fish assemblages do not respond consistently across an impact gradient because of local and regional differences in lotic environments and zoogeographical influences. Nevertheless, greater understanding of the interrelationships between fish assemblage change and anthropogenic impacts is needed to assist holistic aquatic resource management as future water demands increase (Clark 1973; Schlosser 1991; 1995; Anderson et al. 1995; Quinn and Kwak 2003).

The purpose of this study was to quantify fish assemblage changes in three riverine environments in Texas (lower Brazos River, lower Sabine River, and lower San Antonio River). These rivers represent gulf slope drainages west of the Mississippi River drainage that collectively share similar geological histories and ichthyofauna (Conner and Suttkus 1987) but differ along precipitation and anthropogenic impact gradients. Additionally, we analyzed stream

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flow records in these watersheds to describe relationships among hydrologic alterations, fish assemblage changes, and specific fish population changes.

Study Areas

The Brazos River drains approximately 116,000 km^2 and is among the most impacted rivers in Texas (Anderson et al. 1983) at least in the middle reach between Possum Kingdom Reservoir and Lake Waco. The river and its tributaries compose the largest drainage basin in the state. Headwaters of the Brazos River originate near the city of Lubbock in northwest Texas. Seventeen impoundments with a total water capacity of more than 60 million m^3 impede the Brazos River and tributary flow on its southeast course through the state (Osting et al. 2004), which is approximately 1,300 river km in length. We limited the scope of our assessment to the lower Brazos River, the section of river downstream from Brazos Lake Dam to the tidal influence in the Brazos River.

The Sabine River watershed is 18,000 Km^2, originating in northeast Texas and forming the border between Louisiana and Texas beginning at the northern end of Toledo Bend Reservoir. This reservoir is the largest impediment to river flow, and its dam supports a hydropower facility. Daily river flow can fluctuate greatly for some distance downstream of the dam due to pulse releases for peak power generation; river depth may increase by one to four meters (Seidensticker 1980). Downstream from Toledo Bend Dam, the lower Sabine River passes through pine forest and agricultural land as it flows southward. Sand and compressed clay compose the substrate providing opportunity for geomorphic change (i.e. riffles and pools). The Sabine River flows for 645 km from the outfall of Lake Tawakoni to the Gulf of Mexico.

We limited the scope of our assessment to the lower Sabine River, the section of river downstream from Toledo Dam to the tidal influence in the Sabine River.

The San Antonio River watershed is 11,000 km^2 and originates in San Antonio as it emerges from the Edwards aquifer. Anthropogenic impact on the river began as early as 1718 (Fisher 1997) with the first diversions of water for municipal use. Headwaters are now channelized through the downtown portion and through an underground bypass for flood mitigation; base flow is maintained by pumping. The San Antonio River flows for approximately 615 km to its confluence with the Guadalupe River near the Gulf of Mexico. We limited the scope of our assessment to the lower San Antonio River, the section of river downstream from Loop 410 near the City of San Antonio (TX) to its confluence with the Guadalupe River.

Methods

Daily discharge records were obtained from U.S. Geological Survey gauging stations on the lower Brazos River (Waco, USGS 08096500; Richmond, USGS 08114000), lower Sabine River (Logansport LA, USGS 08022500, Burkeville TX, USGS 08026000; Ruliff TX, USGS 08030500) and lower San Antonio (Falls City, USGS 08183500; Goliad, USGS 08188500). These particular gauging stations were selected because they encompassed the greatest spatial and temporal patterns in hydrologic regime in each river. Discharge records for each site were divided into two time periods, earliest record – 1969 and 1970 – 2006, to assess temporal changes in discharge within watersheds; earlier time period generally represents river discharge before major alterations (i.e., water withdrawals and reservoir filling). Earliest record was 1900 (lower Brazos River at Waco), 1955 (lower Sabine River at Burkeville), and 1925 (lower San

Antonio River at Falls City). To extend the Burkeville station to an earlier time, discharge

records from Logansport (1907 – 1969; located 100 km upstream) were used as a surrogate to

infer changes in discharge downstream from Toledo Bend Dam at Burkeville.

Daily discharge data were analyzed with IHA (Indicators of Hydrologic Alteration, v.

7.0.3) to determine changes in number of small and large flood events and mean annual

discharge. Number of flood events and mean annual discharge are two of 33 parameters

generated by IHA to quantify hydrologic changes through time. We selected only number of

flood events and mean annual discharge to represent hydrologic changes because of their

relevancy to habitat availability and variability for fishes and to maintenance of stream

morphology (Richter et al. 1996). High flow pulses were defined as all flows that exceeded 75%

of flows for the period. Small floods were defined as high flow events with recurrence time of at

least 2 years; large floods had a recurrence time of at least 10 years. The water year was defined

as the calendar year.

Fish collection records were acquired from museum records, published and unpublished

data, and agency reports. Records were compiled by location and date within each drainage

(Appendix 1). Museum records used herein were obtained from Texas Cooperative Wildlife

Collection at Texas A&M University, Texas Natural History Collection at University of Texas,

Tulane Museum of Natural History, and University of Kansas Natural History Collection.

Unpublished data were taken from C. Williams and T. Bonner (Texas State University), G.

Wilde and T. Bonner (Texas Tech University), and J. Rosendale (U.S. Geological Survey).

References of published data and agency reports are listed in Appendix 2. Main stem and

tributary fish collection records were retained, but only main stem fish assemblages were used to

assess temporal changes. Tributary fish collection records were insufficient to assess temporal

changes; however, fish occurrences in these tributaries were recorded in Appendix 3. Native and non-native status was determined using the collection accounts of Douglas (1974), Hubbs et al. (1991), and Fuller et al. (1999).

All records were used to document fish occurrence whereas a subset of records were used to quantify fish abundance after passing through a series of filters. For occurrence and abundance records, questionable identifications (i.e., fish reported outside of their reported range) were verified or refuted if voucher specimens existed. If vouchers did not exist, questionable identifications were deleted if not within the range of published distributions or re-identified as a closely related species native to the drainage (i.e., *Notropis amabilis* changed to *Notropis atherinoides* in the lower Sabine River). Collections also were omitted from abundance calculations if they did not represent a natural fish assemblage and were taken purely for voucher purposes (i.e., one or two individuals for 15-20 taxa per collection).

For abundance records, we attempted to standardize comparisons through time by collection method. Fish were taken from the lower Brazos River by seining and electroshocking, but seining was the more common technique used among collections, and therefore we only used fish captured by seining to calculate relative abundance. Seining and electroshocking techniques were used frequently in the lower Sabine River and lower San Antonio River, thus we used fish captured by both techniques to calculate relative abundance.

Relative abundance was assessed by two methods. First, relative abundances were calculated for each collection and plotted through time by species. Rare fishes, those that occurred in <10% of the total collections within each drainage, were eliminated from further analyses and population status assessment except for taxa of conservation concern (i.e., *Notropis buccula*, *Macrhybopsis marconis*). Instead, population status of rare fishes was labeled as

indeterminable. Among the remaining taxa, we used linear least-squares regression (Neter et al. 1996) to model relative abundance of each species as a function of time. Relative abundance, the dependent variable, was $\log_{10} (n + 1)$ transformed, and time, the independent variable, was $\log_{10}$ transformed. Time was represented as the numbers of days from January 1 of the year with the earliest collection record. For example, the earliest record in the lower Brazos River was taken in 1939. Consequently, January 1, 1939 was labeled as "1", January 1, 1949 was labeled as "3,654", and so on until all collection dates were assigned a number. From the results of the linear regression, we classified populations as increasing, decreasing, or stable based on significance level of positive and negative slopes. Here, we defined increasing status as significant ($\alpha = 0.05$) increases in relative abundance through time, decreasing status as significant ($\alpha = 0.05$) decreases in relative abundance through time, stable as non-significant ($\alpha > 0.05$) slopes through time.

Second, mean relative abundance was calculated by species (sum of relative abundance in each collection / number of collections) for three periods in the lower Brazos River (Period I: 1939 – 1969; Period II: 1970 – 1994; Period III: 1995 – 2006), two periods in the lower Sabine River (Period 1: 1948 – 1969; Period II: 1970 – 2006), and two periods in the lower San Antonio River (Period I: 1950 – 1969; Period II: 1970 – 2006). As with our discharge assessment, time periods were assumed to reflect minimum (i.e., Period I) and maximum (i.e. Period II or III) anthropogenic alterations with period termination corresponding to the completion date of mainstem or large tributary reservoirs within each watershed (Texas Almanac 2006). Temporal fish collections were ample for the lower Brazos River so an additional time period was added. Taxa richness (S) and Simpson's Diversity indices ($1 - D$) were calculated for each period. Similarity matrices (Bray and Curtis 1957) were derived from mean relative

abundance and tested with analysis of similarity (ANOSIM; $\alpha = 0.05$; 9,999 permutations) within each watershed and among time periods using PRIMER 6.1.6 (Clarke 1993; Clarke and Warwick 2001); permutation analysis indicates the average rank dissimilarity within and between samples (Clarke and Gorley 2006). Data were fourth-root transformed to down-weight taxa with high relative abundance and increase the contribution of rare taxa (Clarke and Green 1988). Multi-dimension scaling (MDS) plots were generated to illustrate dissimilarity of fish assemblage among periods. Trajectory plots were created using mean values for Axes I and II from MDS in 5-year increments.

Relative abundances of trophic and reproduction guilds were calculated from the groomed subset of fish records. Species were assigned to trophic guilds using the classification scheme defined by Goldstein and Simon (1999) and to reproductive guilds using the classification scheme defined by Simon (1999). Literature sources for diet and feeding information were Moss and Mayes (1993), Goldstein and Simon (1999), Linam et al. (2002), Tamaru et al. (2001), Boschung and Mayden (2004), Hoover et al. (2004), and C. Williams, T. Bonner, and J. Perkin (Texas State University, unpublished data). Literature sources for reproductive information were Fryer and Iles (1972), Pflieger (1975), Moyle (1976), Boyer et al. (1977), Itzkowitz and Nyby (1982), Martin (1986), Sublette (1990), Heins and Machado (1993), Moss and Mayes (1993), DeWoody et al. (1998), Platania and Altenbach (1998), Marks (1999), Simon (1999), Ross (2001), and Boschung and Mayden (2004). Guild relative abundances were calculated (sum of individuals per guild in time period / total individuals in time period) across sites and time periods. Changes in guild abundances through time were assessed within each watershed and explained by changes in fish abundance among periods. Consequently, relative abundance changes in guilds and fish among periods, which provide course assessments of

temporal changes, might not correspond with increasing or decreasing populations as classified with linear regression.

Results

Hydrologic changes

Comparative analysis of the historical (1900-1969) and current (1970-2006) periods indicated that the degree of hydrologic alterations varied among and within watersheds. In upper portions of the lower Brazos River near Waco (TX), annual frequency of small ($>1,046$ m^3/s) and large ($>2,995$ m^3/s) flood events decreased from 0.57 (40 events; 1900 – 1969) to 0.03 (1 event; 1970 – 2006), and mean annual discharge decreased from 71 to 58 m^3/s (Fig. 1). In the lower portion of the lower Brazos River near Richmond (TX), annual frequency of small (>1634 m^3/s) and large ($>2,631$ m^3/s) flood events decreased from 0.58 (28 events; 1922 – 1969) to 0.44 (16 events; 1970 – 2006) whereas the mean annual discharge increased from 204 to 222 m^3/s.

In upper portions of the lower Sabine River near Logansport (LA) and Burkeville (TX), annual frequency of small (>788 m^3/s, Logansport; >833 m^3/s, Burkeville) and large (1,154 m^3/s, Logansport; 1,332 m^3/s, Burkeville) flood events were similar (0.42, 28 events, 1903 – 1969; 0.44, 16 events, 1970 – 2006) between periods of record (Fig. 2). Mean annual discharge increased from 92 (Logansport) and 121 (Burkeville) to 166 m^3/s at Burkeville. In lower portions of the lower Sabine River, annual frequency of small ($>1,365$ m^3/s) and large ($>2,080$ m^3/s) flood events decreased from 0.37 (17 events; 1925 – 1969) to 0.27 (10 events; 1970 – 2006). Mean annual discharge increased from 230 to 240 m^3/s. Annual discharge hydrographs obscured changes in daily discharge patterns, which are notable in the lower Sabine River.

Toledo Bend Dam releases water for hydroelectric power generation, producing discharges varying up to 75 m^3/s per day or up to 100 m^3/s during a 5-day period (representative sample: July through September 2000, Burkeville).

Discharge was substantially less in the lower San Antonio River than in the lower Brazos River or lower Sabine River because of San Antonio River location in more arid regions and because of its smaller drainage basin. In upper portions of the lower San Antonio River near Falls City (TX), annual frequency of small (>254 m^3/s) and large (>436 m^3/s) flood events increased from 0.22 (10 events; 1925 – 1969) to 0.31 (11 events; 1970 – 2006), and mean annual discharge increased from 9 to 20 m^3/s (Fig. 3). In lower portions of the lower San Antonio River near Goliad (TX), frequency of small (>404 m^3/s) and large (>842 m^3/s) flood events were similar (0.27, 8 events, 1939 – 1969; 0.25, 9 events, 1970 – 2006) between periods of record whereas mean annual discharge increased from 15 to 28 m^3/s.

Fish assemblage changes

Sixty-seven species and 118 collections were taken from the lower Brazos River from 1939 through 2006 (Table 1). Cyprinidae was the most abundant family (94%), followed by Poeciliidae (2.0%), Ictaluridae (1.1%), Clupeidae (0.9%), and Centrarchidae (0.7%). Among marine-derived taxa, *Mugil curema* and *Alosa chrysochloris* were not considered significant freshwater components of the assemblage. Seven species were non-native and composed <0.1% of the total fish assemblage. Taxa richness increased among Period I ($S = 43$), Period II ($S = 55$), and Period III ($S = 60$), primarily attributed to increases in collection effort and number of individuals collected among periods. Diversity was similar between Period I (1-$D = 0.73$) and Period II (1-$D = 0.75$) but decreased by Period III (1-$D = 0.56$). Overall, fish assemblage

similarity differed (ANOSIM global R = 0.49, P <0.01) among periods; MDS trajectory indicated a shift along Axis I (Fig. 4). Bray Curtis Similarity indices were 74% between Period I and Period II, 77% between Periods II and III, and 63% between periods I and III.

Lower Brazos River fish assemblage dissimilarities among periods were attributed in part to notable changes in relative abundance for 12 species (Fig. 5). Eight species had declining population trends: *Notropis buccula*, *Notropis oxyrhynchus*, *Notropis potteri*, *Carpiodes carpio*, *Ictalurus punctatus*, *Lepomis gulosus*, *Pomoxis annularis*, and *Aplodinotus grunniens*. Collectively, these fishes represented >62% of the lower Brazos River fish assemblage in Period I and <2% in Period III. Four species had increasing population trends: *Cyprinella lutrensis*, *Notropis buchanani*, *Pimephales vigilax*, and *Gambusia affinis*. Collectively, these fishes represented <18% of the lower Brazos River fish assemblage in Period I and >86% in Period III. About 80% of the Period III fish assemblage consisted of *Cyprinella lutrensis* and *Pimephales vigilax*. Population trends for the remaining 55 species taken from the lower Brazos River were either stable ($N = 39$) or indeterminable ($N = 16$).

Ninety species and 183 collections were taken from the lower Sabine River from 1948 through 2006 (Table 2). Cyprinidae was the most abundant family (93%), followed by Centrarchidae (2.2%), Poeciliidae (1.4%), Ictaluridae (0.8%), and Percidae (0.7%). Among marine-derived taxa, nine fishes (i.e., *Elops saurus*, *Alosa chrysochloris*, *Brevoortia patronus*, *Anchoa mitchilli*, *Ariopsis felis*, *Strongylura marina*, *Mugil curema*, *Paralichthys lethostigma*, and *Trinectes maculatus*) were not considered a significant freshwater component of the assemblage. Four species were non-native and composed <0.1% of the total fish assemblage in Period I or II. Taxa richness was higher in Period I ($S = 75$) than in Period II ($S = 70$) whereas collection effort and number of individuals collected were greater in Period II than in Period I.

Diversity was higher (1-*D* = 0.84) in Period I than in Period II (1-*D* = 0.78). Fish assemblage

similarity differed (ANOSIM global R = 0.16, P <0.01) between periods; MDS trajectory

indicated a shift along Axis II (Fig. 4). Bray Curtis Similarity Index was 74% between Period I

and Period II.

Lower Sabine River fish assemblage dissimilarity between periods was attributed in part

to the large number taxa unique to either Period I (*N* = 16) or Period II (*N* = 12) and to changes

in relative abundance of 17 species (Fig. 6 and Fig. 7). Collective relative abundances of unique

taxa were <2% in Period I and <0.1% in Period II, suggesting rare natural occurrence of 28

unique taxa. Consequently, their detection in either time period was likely haphazard and not

associated with species distribution expansions or extirpations. Nine species had declining

population trends: *Cyprinella lutrensis*, *Hybognathus nuchalis*, *Macrhybopsis hyostoma*,

Notropis atherinoides, *Notropis buchanani*, *Pimephales vigilax*, *Aphredoderus sayanus*,

Gambusia affinis, and *Lepomis gulosus*. Eight species had increasing population trends:

Cyprinella venusta, Fundulus olivaceus, Menidia beryllina, Lepomis macrochirus, Lepomis

megalotis, Micropterus punctulatus, Ammocrypta vivax, and *Percina sciera.* Notable population

changes included the apparent extirpation of *Cyprinella lutrensis* by 1973, population decline in

Notropis atherinoides from a maximum relative abundance of 40% before 1969 to <1% after

1969, population decline in *Notropis buchanani* from a maximum relative abundance of 23%

before 1969 to 6% after 1969, and a population increase in *Cyprinella venusta* from a relative

abundance maximum of 54% before 1969 to 83% relative abundance in 2006. Population trends

for the remaining 73 species taken from the lower Sabine River were either stable (*N* = 23) or

indeterminable (*N* = 50).

Fifty-seven species and 73 collections were taken from the lower San Antonio River from 1950 through 2006 (Table 3). Cyprinidae was the most abundant family (62%), followed by Poeciliidae (21%), Ictaluridae (9.4%), Centrarchidae (2.7%), and Cichlidae (2.2%). Seventeen species were non-native and composed 11% of the total fish assemblage. Taxa richness was lower in Period I ($S = 23$) than in Period II ($S = 55$) as were collection effort and number of individuals collected. Diversity was lower (1-$D = 0.62$) in Period I than in Period II (1-$D = 0.80$). Overall, fish assemblage similarity was not different (ANOSIM global R = 0.12, P = 0.072; Fig. 4) between periods although Bray Curtis Similarity index was 47% between Period I and Period II. Multi-dimensional scaling trajectory indicated that little change occurred between the earliest and latest collections (Fig 4).

Failure to detect between period differences in the lower San Antonio River fish assemblage was attributed to low collection effort in Period I. Nevertheless, notable changes in occurrence and abundance were found for several fishes or groups of fishes (Fig. 7). Population of *Opsopoeodus emiliae* declined from a relative abundance of 39% in 1962 to 0% after 1964. *Gambusia affinis* population declined as well. The number of non-native taxa increased from 4 in Period I to 17 in Period II. Native taxa with increasing population trends were *Campostoma anomalum*, *Lepomis cyanellus*, and *Lepomis megalotis*. Population trends for the remaining 52 native species taken from the lower San Antonio River were either stable ($N = 18$) or indeterminable ($N = 34$).

Guild Changes

Trophic structure changed in all three drainages among periods; however, changes were not consistent among drainages or periods except for detritivores (Table 4). Detritivore

abundance decreased in the three drainages among periods. Decreases were related to population

declines in *Carpiodes carpio* in the lower Brazos River, *Hybognathus nuchalis* in the lower

Sabine River, and *Opsopoeodus emiliae* in the lower San Antonio River. Omnivore abundance

increased in the lower Brazos River, related primarily to population increase in *Pimephales*

vigilax, and in the lower San Antonio River, related to population increases in *Pimephales*

vigilax and *Poecilia latipinna*, whereas omnivore abundance decreased in the lower Sabine

River, related to population decrease in *Pimephales vigilax*. Invertivore abundance, the most

common trophic guild across drainages, decreased in the lower San Antonio River, related to

fewer *Gambusia affinis* taken in Period II, and increased in the lower Sabine River, related to the

population increase in *Cyprinella venusta*. Piscivore abundance decreased in the lower Brazos

River, related to population decreases in *Notropis potteri* and *Pomoxis annularis*, but increased

in the lower San Antonio River. However, the increase in the lower San Antonio River piscivore

abundance was not attributed to fish assemblage change, but rather to the detection of several

native piscivores (*Lepisosteus* and *Micropterus*) only during Period II. Herbivore abundance

increased in the San Antonio River, related to population increases of *Dorosoma cepedianum*

and *Campostoma anomalum*. Planktivore abundance decreased in the Sabine River, related to

population decreases in *Notropis atherinoides* and to the lack of collection of *Brevoortia*

patronus during Period II.

As with trophic guilds, shifts in reproductive guilds were not consistent among drainages

(Table 4). Reproductive guilds with greatest shifts in relative abundance were speleophils, both

brood hiders and nest spawners, and open substrate pelagophils. Speleophil abundance increased

in the lower Brazos River, lower Sabine River, and lower San Antonio River, related to

population increases of *Cyprinella lutrensis* (brood hider) and *Pimephales vigilax* (nest spawner)

in the lower Brazos River, *Cyprinella venusta* (brood hider) in the lower Sabine River, catfishes (native and exotic; nests spawner) in the lower San Antonio River. Pelagophil abundance decreased in the lower Brazos River, related to population declines in *Notropis buccula*, *Notropis oxyrhynchus*, *Notropis potteri*, *Carpiodes carpio*, and *Aplodinotus grunniens*. Additional shifts in reproductive guild abundance were found (i.e., decrease in viviparous fishes due to decline of *Gambusia affinis* in the lower San Antonio River), but not all of these were attributed to population declines. Instead, they were attributed to abundance differences through time among stable populations.

Discussion

Fish occurrence (i.e., taxa richness), assemblage structure (i.e., relative proportions by families) and function (i.e., measured here as trophic guild) remained fairly intact within all drainages, despite changes in some populations through time. Taxa richness generally increased, but increases generally were associated with capture of native taxa with greater sampling efforts in recent periods rather than associated with non-native fish introductions. Cyprinidae historically and currently was the most abundant family in the lower Brazos River (94%), lower Sabine River (93%) and lower San Antonio River (62%). Consequently, trophic structure historically and currently was dominated by invertivores. Other families of fishes and trophic guilds persisted with few exceptions (i.e., detritivores declined) through time. Although our study reaches represented a small portion of the western gulf slope drainages, these three study reaches encompassed fairly broad ranges in geography, precipitation, and anthropogenic impacts, and yet they collectively indicated and inferred a prevalence of relatively intact fish assemblages at least in lower reaches of gulf slope watersheds. This is in contrast to other watersheds and

rivers throughout the USA, where an estimated 81% of water bodies are negatively affected by anthropogenic modifications (Judy et al. 1984), >70% of wadeable streams and non-wadeable rivers are in sub-optimal condition in eastern Atlantic slope drainages (USEPA 2003, Hughes et al. 2005), and non-indigenous fishes and cosmopolitan sportfishes introductions are contributing to large-scale fish assemblage homogenizations (Rahel 2002). Nevertheless, apparent extirpations were found our three river reaches: two obligate riverine fishes (*Notropis buccula* and *Hybognathus placitus*) in the lower Brazos River, five marine fishes and perhaps *Cyprinella lutrensis* in the lower Sabine River, and *Opsopoeodus emiliae* in the lower San Antonio River. Among these, the apparent extirpation of *N. buccula* in the lower Brazos River is significant from a species conservation perspective. *Notropis buccula* is a Brazos River endemic and now restricted to the upper reaches of the Brazos River in west Texas. Currently, it is a candidate for listing under the Endangered Species Act (USFWS 2006).

Statistically significant shifts in fish assemblages were attributed primarily to changes in species abundance through time. Among all drainages and excluding extirpated fishes, 17 historically abundant fishes became rare whereas 14 historically rare fishes became common to abundant. Abundance declines in Brazos River endemic *Notropis oxyrhynchus,* another candidate for listing under the Endangered Species Act, and *Notropis potteri*, endemic to the Brazos River and Red River, are significant from a species conservation perspective. These fishes along with *Notropis buccula*, *Hybognathus placitus*, *Carpiodes carpio*, and *Aplodinotus grunniens* in the lower Brazos River and *Notropis atherinoides* and *Notropis buchanan*i in the lower Sabine River comprised 64% of the extirpated or declining taxa and are pelagophilic or lithopelagophilic open substrate spawners. However, one population of pelagophilic spawners (*Notropis buchanani* in the lower Brazos River) increased in abundance through time. Others

with large abundance increases included *Cyprinella lutrensis* and *Pimephales vigilax* in the lower Brazos River and *Cyprinella venusta* in the lower Sabine River, which all are speleophils, although C*yprinella lutrensis* apparently was extirpated in the lower Sabine River.

Linkages among hydrologic alterations, species extirpations or population declines, and reproductive strategy of open substrate spawning are well established for prairie streams and large rivers in the central USA. Stream fishes such as most *Notropis*, *Macrhybopsis*, and *Hybognathus* broadcast spawn semi-buoyant eggs that disperse downstream (Moore 1944; Lehtinen and Layzer 1988; Bestgen et al. 1989; Taylor and Miller 1990; Platania and Altenbach 1998). After drifting for several days, larvae move out of the currents, seeking refuge in off-channel, slack water, or backwater habitats (Platania and Altenbach 1998; Porter and Massong 2004). Eventually, these fishes migrate upstream for spawning (Cross et al. 1985). Duration and distance of upstream migration likely are species specific, with one species of *Macrhybopsis* traveling a shorter distance than a species of *Notropis* (Bonner 2000). The broadcast spawning strategy is an adaptation to variable riverine environments with fluctuating stream flows and substantial sediment deposition, which reduces success of eggs spawned in nests or crevices (i.e., speleophils) (Platania and Altenbach 1998). Dams, channel dewatering, and associated hydrological changes disrupt this reproductive cycle and upstream migration on multiple levels. Dams block potamodromous migration routes and downstream dispersal (Cross et al. 1985; Wilde and Ostrand 1999; Bonner 2000) and alter stream flows needed for successful rearing of larvae (Durham and Wilde 2006). Likewise, altered stream flows (i.e., fewer small and large flood events, timing and duration of floods) affect physical (i.e., geomorphology, turbidity) and chemical conditions of the riverine environment (Baxter 1977; Stanford and Ward 1979; Bonner and Wilde 2002). Consequently, numerous broadcast spawning fishes and other obligate riverine

fishes have declined in abundance or have been extirpated (Cross et al. 1985; Cross and Moss 1987; Larson et al. 1991; Limbird 1993; Bonner and Wilde 2000), whereas speleophils, such as *Cyprinella lutrensis*, have increased in abundance because of less variable flows that benefit their reproduction and that minimize downstream displacement of individuals (Minckley and Meffe 1987; Cross and Moss 1987; Larson 1991; Bonner and Wilde 2000).

Abundance changes in this study are consistent with species declines and replacements in prairie streams and large rivers of central USA. Pelagophilic or lithopelagophilic open substrate spawners have decreased in abundance or have been extirpated likely due to dams and changes in flow regime that fragment riverine habitats (i.e., source-sink relationships; Dunning et al. 1992), alter available habitats (i.e., turbidity), impact reproductive success, or facilitate speleophil abundance, which in turn affects biotic interactions with open substrate spawners (Pflieger and Grace 1987, Scott and Helfman 2001). Not all open substrate spawners are affected, as with *Macrhybopsis*, likely because of species-specific adaptations in life history patterns. Apparent extirpations of speleophils C*yprinella lutrensis* in the lower Sabine River and *Opsopoeodus emiliae* in the lower San Antonio River was surprising given that these fishes are rarely reported as declining in abundance. *Cyprinella lutrensis* extirpation in the lower Sabine River might be caused by fragmentation effects of Toledo Bend dam, eliminating upstream sources of downstream dispersants, or associated with flow alterations related to hydroelectric generation where flows fluctuate up to 100 m^3/s within a few days. Extirpation of *Opsopoeodus emiliae* in the lower San Antonio River is possibly due to changes in habitat and distance of the San Antonio River from the species geographic center (Gilbert 1980). In northern U.S. rivers where *Opsopoeodus emiliae* exists on the periphery of its range (i.e., Ohio and Michigan) it is listed as endangered due to changes in geomorphology and aquatic vegetation (Smith et al. 1973;

Anonymous 2005). The lower San Antonio River is near the western range extent of

Opsopoeodus emiliae and has sustained habitat changes similar to those reported in Ohio and

Michigan. Unknown interaction with non-indigenous fishes is another plausible threat.

Non-indigenous fishes represented only a minor component of the lower Brazos River

and lower Sabine River fish assemblages in taxa richness and relative abundance, but a larger

component in the lower San Antonio River where 17 species (31% of taxa) composed 13% of the

relative abundance in recent collections. Edwards (2001) reported occurrence of nine of these

non-indigenous species (*Astyanax mexicanus*, *Hypostomus sp.*, *Poecilia latipinna*, *P. formosa*,

Xiphophorus helleri, *Cichlasoma cyanoguttatum*, *Oreochromis mossambicus*, *O. aureus*, and

Tilapia zillii) in the upper San Antonio River. In contrast, Hubbs et al. (1978) reported only six

non-indigenous species in the upper reach. Established populations of non-indigenous fishes in

the upper portion of the San Antonio River likely will spread downstream with unknown

ecological consequences; however, dispersion downstream beyond the influence of spring

discharges was impeded in the winter of 2007 by cold temperatures that caused a major fish kill

of tropical and semi-tropical non-indigenous fishes. Therefore, abundance and distribution of

non-indigenous fishes might be regulated by natural means.

It is interesting to note that assemblage composition and structure differed among

drainages although our study streams and western gulf slope watersheds in general share a

common geological history with numerous interconnections and physicochemical characteristics

(Conner and Suttkus 1986). Taxa richness, number of basin endemics, pervasiveness of

cyprinids (>90%), and differences therein are shaped historically by factors such as proximity to

adjacent species pools (i.e., Mississippi River drainage), precipitation and temperature gradients,

drainage basin size, and flow rates. These collectively or independently regulate fish dispersion

and extinctions, facilitate rates of endemism, and develop evolutionary relationships between fish and habitat. Consequently, our assessment indicated that anthropogenic impacts can have varying effects on the resident fish assemblages depending on the type and uniqueness of the assemblage. For example, we consider lower Brazos River fish assemblage imperiled because of the number of endemic and semi-endemic forms that are decreasing in abundance. Yet, if we exclude consideration of these taxa (or they never existed), the lower Brazos River fish assemblage would appear exceptional because majority of the fish assemblage is intact. Likewise the San Antonio River is the most anthropologically impacted system in our study yet the fish assemblage showed the least change because its relatively small drainage size and distance from Mississippian-type fishes precluded endemic taxa instead selecting a more generalist fish assemblage that are more adept to withstand flow alterations and water quality problems associated with highly urbanized watersheds.

Twenty-eight percent of fishes in the southern U.S. (Warren et al. 2000) and 38% of Texas freshwater fishes considered imperiled, thus greater understanding of relationships between discharge and species, and assemblage sustainability is critical for proper management of water resources and native fishes. Anthropogenic impacts, on both local (i.e., dam) and watershed (i.e., urbanization, introduced taxa) scales, have altered the natural fish assemblage of the studied drainages; however, the ecological and biodiversity consequence of the impact depends on the fish assemblage and degree of endemism. Assemblage changes appear predictable and therefore likely avoidable with adequate planning and management. For example, several stream segments in Texas support a large number of diverse fish assemblages containing many of the Texas imperiled fishes such as Big Bend reach of the Rio Grande (Edwards et al. 2002), San Marcos River (Kelsey 1997), Independence Creek (Bonner et al

2005), upper Brazos River (Hubbs et al. 1991), upper Red River (Hubbs et al. 1991), and

Canadian River (Bonner and Wilde 2000). These streams have all been impacted at some level;

however, future anthropogenic modifications should be minimized to maintain the high

biodiversity each sustains. Alternatively, biologically unique assemblages that are already

stressed (i.e., lower Brazos River) can be maintained and even restored by a suite of techniques

that were developed, designed, and tested to balance water needs between humans and the

riverine community (Richter et al. 2003). The science of river ecology is slowly moving past

basic research and understanding towards sustainable use management and riverine restoration,

which imparts an optimistic future for water resource management.

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Table 1. Relative abundance, population status, and reproduction and trophic guilds of fishes in the lower Brazos River, Texas. Status refers to native (N), non-indigenous (I), or present (X) during period but in an unused collection. Mean relative abundance is presented for Period I (1939-1969), Period II (1970-1994), and Period III (1995-2006). Population trend is indicated as increasing (↑), decreasing (↓), stable (S), or indeterminable (-). Reproductive guilds follow Simon (1999) classification scheme. Trophic guilds are detritivore (DT), herbivore (H), invertivore (IF), omnivore (O), piscivore (P), and planktivore (PL).

Species	Status	Period I	Period II	Period III	Population Trend	Primary Reproductive Guild	Secondary Reproductive Guild	Trophic Guild
Atractosteus spatula[*]	N			<0.01	-	Open Substrate	Phytophil	P
Lepisosteus oculatus	N	0.55	0.51	0.02	↓	Open Substrate	Phytophil	P
Lepisosteus osseus	N	0.03	0.28	0.36	S	Open Substrate	Phytolithophil	P
Amia calva	N		0.03	<0.01	S	Nest Spawner	Phytophil	P
Anguilla rostrata[*†]	N	X			-	Catadromous	Catadromous	P
Alosa chrysochloris	N			0.02	-	Open Substrate	Phytolithophil	PL
Dorosoma cepedianum	N	0.97	4	1	S	Open Substrate	Lithopelagophil	H
Dorosoma petenense	N	0.12	0.97	0.36	S	Open Substrate	Phytophil	PL
Campostoma anomalum[*]	N			<0.01	-	Brood Hider	Lithophil	H
Cyprinella lutrensis	N	15	35	58	↑	Brood Hider	Speleophil	IF
Cyprinella venusta	N	0.04	0.14	0.58	S	Brood Hider	Speleophil	IF
Cyprinus carpio	I	<0.01	0.20	<0.01	S	Open Substrate	Phytolithophil	O
Hybognathus nuchalis	N	0.17	0.25	0.08	S	Open Substrate	Lithopelagophil	DT
Hybognathus placitus	N	0.02	0.24		-	Open Substrate	Pelagophil	H
Hybopsis amnis	N	0.01	0.07	<0.01	S	Open Substrate	Lithophil	IF
Lythrurus fumeus	N		0.02	0.02	S			IF
Macrhybopsis hyostoma	N	1	2	3	S	Open Substrate	Pelagophil	IF
Macrhybopsis storeriana	N	0.21	0.39	0.18	S	Open Substrate	Lithopelagophil	IF
Notemigonus crysoleucas	N		0.05	<0.01	S	Open Substrate	Phytophil	IF
Notropis buccula	N	3	0.43		↓	Open Substrate	Pelagophil	IF
Notropis buchanani	N	1	0.90	5	↑	Open Substrate	Pelagophil	IF
Notropis oxyrhynchus	N	22	4	0.04	↓	Open Substrate	Pelagophil	IF

Species	Status	Period I	Period II	Period III	Population Status	Primary Reproductive Guild	Secondary Reproductive Guild	Trophic Guild
Notropis potteri	N	11	4	0.05	↓	Open Substrate	Pelagophil	P
Notropis shumardi	N	6	11	3	S	Open Substrate	Pelagophil	IF
Notropis volucellus	N		0.03	0.02	S	Open Substrate	Phytophil	O
Opsopoeodus emiliae	N	0.02	0.14	0.01	S	Nest Spawner	Speleophil	DT
Pimephales promelas	I	X	<0.01	<0.01	S	Nest Spawner	Speleophil	O
Pimephales vigilax	N	1	12	21	↑	Nest Spawner	Speleophil	O
Carpiodes carpio	N	4	6	0.57	↓	Open Substrate	Lithopelagophil	DT
Ictiobus bubalus	N	0.02	0.17	0.03	S	Open Substrate	Lithopelagophil	O
Moxostoma congestum	N			<0.01	-	Open Substrate	Lithophil	IF
Ameiurus melas	N			<0.01	-	Nest Spawner	Speleophil	IF
Ameiurus natalis[*†]	N	X			-	Nest Spawner	Speleophil	IF
Ictalurus furcatus	N	1	0.91	0.92	S	Nest Spawner	Speleophil	P
Ictalurus punctatus	N	17	6	0.62	↓	Nest Spawner	Speleophil	O
Noturus gyrinus	N	0.04	0.03	0.10	S	Nest Spawner	Speleophil	IF
Pylodictis olivaris	N	0.01	0.25	0.01	S	Nest Spawner	Speleophil	IF
Aphredoderus sayanus	N	0.29	0.04	0.02	S	Bearer	Mouth brooder	IF
Fundulus notatus	N	0.04	<0.01	0.01	S	Open Substrate	Phytophil	H
Fundulus olivaceus[*]	I	4			-	Open Substrate	Phytophil	IF
Cyprinodon variegatus[*]	N		0.12		-	Nest Spawner	Polyphil	O
Gambusia affinis	N	0.24	5	3	↑	Bearer	Viviparous	IF
Poecilia latipinna	N			0.11	-	Bearer	Viviparous	O
Labidesthes sicculus	I		0.06	0.07	S	Open Substrate	Phytolithophil	IF
Menidia beryllina	N		0.05	0.15	S	Open Substrate	Phytophil	IF
Morone chrysops	I		<0.01	0.06	S	Open Substrate	Phytolithophil	P
Lepomis cyanellus	N	0.05	0.35	0.10	-	Nest Spawner	Polyphil	IF
Lepomis gulosus	N	0.55	0.23	0.04	↓	Nest Spawner	Lithophil	IF

Species	Status	Period I	Period II	Period III	Population Status	Primary Reproductive Guild	Secondary Reproductive Guild	Trophic Guild
Lepomis humilis	N	0.13	0.88	0.14	S	Nest Spawner	Lithophil	IF
Lepomis macrochirus	N	0.30	0.50	0.12	S	Nest Spawner	Polyphil	IF
Lepomis marginatus	N			<0.01	-	Nest Spawner	Polyphil	IF
Lepomis megalotis	N	0.19	0.69	0.15	S	Nest Spawner	Polyphil	IF
Lepomis microlophus	N	<0.01	0.01	0.07	S	Nest Spawner	Polyphil	IF
Lepomis miniatus	N	2	0.27	0.02	-	Nest Spawner	Polyphil	IF
Lepomis symmetricus	N	0.53		<0.01	S	Nest Spawner	Polyphil	IF
Micropterus punctulatus	N		0.05	0.06	S	Nest Spawner	Polyphil	IF
Micropterus salmoides	N	0.02	0.05	0.04	S	Nest Spawner	Polyphil	P
Pomoxis annularis	N	3	1	0.11	↓	Nest Spawner	Phytophil	P
Pomoxis nigromaculatus	N		<0.01	0.02	S	Nest Spawner	Phytophil	IF
Etheostoma chlorosomum	N	0.76	X	<0.01	S	Substratum Chooser	Phytophil	IF
Etheostoma gracile	N	0.17	0.07	0.02	S	Substratum Chooser	Phytophil	IF
Percina caprodes	I		X	<0.01	-	Brood Hider	Lithophil	IF
Percina sciera	N		0.12	0.03	S	Brood Hider	Lithophil	IF
Aplodinotus grunniens	N	2	1	0.04	↓	Open Substrate	Pelagophil	IF
Oreochromis aureus	I		0.01	<0.01	S	Bearer	Mouth Brooder	O
Agonostomus monticola*	N		<0.01		-	Catadromous		O
Mugil cephalus	N	0.01	0.15	1	S	Catadromous		DT
Mugil curema	N		<0.01	<0.01	S	Catadromous		O
Collections During Period:		18	36	64				
Individuals Collected:		7,259	28,807	257,782				
Taxa Richness:		43	55	60				
Diversity:		0.73	0.75	0.56				

* Species represented by one collection.

† Species not used for richness and diversity.

Table 2. Relative abundance, population status, and reproduction and trophic guilds of fishes in the lower Sabine River, Texas. Mean relative abundance is presented for Period I (1948-1969) and Period II (1970-2006). Abbreviations are presented in Table 1.

Species	Status	Period I	Period II	Population Trend	Primary Reproductive Guild	Secondary Reproductive Guild	Trophic Guild
Ichthyomyzon castaneus	N	0.08	<0.01	S	Brood Hider	Lithophil	Parasitic
Ichthyomyzon gagei[*†]	N		X	-	Brood Hider	Lithophil	PL
Atractosteus spatula[*†]	N	X		-	Open Substrate	Phytophil	P
Lepisosteus oculatus	N	<0.01	0.17	S	Open Substrate	Phytophil	P
Lepisosteus osseus	N	0.02	<0.01	S	Open Substrate	Phytolithophil	P
Amia calva	N		0.13	S	Nest Spawner	Phytophil	P
Elops saurus[*]	N		<0.01	-	Anadromous	Anadromous	
Alosa chrysochloris[*]	N	<0.01		-	Anadromous	Anadromous	PL
Brevoortia patronus	N	0.40		-	Catadromous	Catadromous	PL
Dorosoma cepedianum	N	0.20	0.37	S	Open Substrate	Lithopelagophil	H
Dorosoma petenense	N	0.19	0.60	S	Open Substrate	Phytophil	PL
Anchoa mitchilli	N	1		-	Anadromous	Anadromous	
Cyprinella lutrensis	N	20	19	↓	Brood Hider	Speleophil	IF
Cyprinella venusta	N	15	41	↑	Brood Hider	Speleophil	IF
Cyprinus carpio	I		0.03	-	Open Substrate	Phytolithophil	O
Hybognathus hayi[*]	N		<0.01	-			
Hybognathus nuchalis	N	10	4	↓	Open Substrate	Lithopelagophil	DT
Hybopsis amnis	N	0.83	0.27	S	Open Substrate	Lithophil	IF
Lythrurus fumeus	N	0.08	0.10	S			
Lythrurus umbratilis	N	0.02		-	Open Substrate	Lithophil	IF
Macrhybopsis hyostoma	N	0.79	0.09	↓	Open Substrate	Pelagophil	IF
Notemigonus crysoleucas	N	0.25	0.01	-	Open Substrate	Phytophil	IF
Notropis atherinoides	N	3	0.01	↓	Open Substrate	Pelagophil	PL
Notropis atrocaudalis	N	0.03		-			
Notropis blennius	I	0.41		-	Open Substrate	Pelagophil	IF
Notropis buchanani	N	2	0.28	↓	Open Substrate	Pelagophil	IF

Species	Status	Period I	Period II	Population Status	Primary Reproductive Guild	Secondary Reproductive Guild	Trophic Guild
Notropis sabinae	N	7	8	S	Open Substrate	Pelagophil	O
Notropis shumardi[*]	N	0.13		-	Open Substrate	Pelagophil	IF
Notropis texanus	N	4	3	S			DT
Notropis volucellus	N	4	3	S	Open Substrate	Phytophil	O
Opsopoeodus emiliae	N	0.34	0.31	S	Nest Spawner	Speleophil	DT
Phenacobius mirabilis	N	0.03	0.02	S			
Pimephales vigilax	N	15	9	↓	Nest Spawner	Speleophil	O
Semotilus atromaculatus[*†]	N	X		-	Brood Hider	Lithophil	P
Carpiodes carpio	N	0.26	0.32	S	Open Substrate	Lithopelagophil	DT
Cycleptus elongatus[*†]	N		X	-			
Erimyzon oblongus	N	0.07	<0.01	-	Open Substrate	Lithopelagophil	IF
Erimyzon sucetta[*†]	N		X	-	Open Substrate	Phytolithophil	IF
Ictiobus bubalus[*]	N	<0.01		-	Open Substrate	Lithopelagophil	O
Minytrema melanops	N	0.01	0.05	S	Open Substrate	Lithopelagophil	IF
Moxostoma poecilurum	N	0.02	0.11	-	Open Substrate	Lithophil	IF
Ameiurus melas[*]	N	0.04		-	Nest Spawner	Speleophil	IF
Ameiurus natalis	N	0.16	<0.01	-	Nest Spawner	Speleophil	IF
Ictalurus furcatus	N	<0.01	<0.01	-	Nest Spawner	Speleophil	P
Ictalurus punctatus	N	2	0.60	-	Nest Spawner	Speleophil	O
Noturus gyrinus[*]	N		<0.01	-	Nest Spawner	Speleophil	IF
Noturus nocturnus	N	0.02	0.03	-	Nest Spawner	Speleophil	IF
Pylodictis olivaris	N	<0.01	<0.01	-	Nest Spawner	Speleophil	IF
Ariopsis felis[*]	N	0.12		-	Bearer	Mouth Brooder	O
Esox americanus	N	0.05	<0.01	-	Open Substrate	Phytophil	P
Aphredoderus sayanus	N	0.11	<0.01	↓	Bearer	Mouth Brooder	IF
Strongylura marina	N	<0.01	0.02	-	Open Substrate	Phytolithophil	P
Fundulus chrysotus	N	0.35	<0.01	-	Open Substrate	Phytophil	IF
Fundulus notatus	N	0.60	0.29	S	Open Substrate	Phytophil	H

Species	Status	Period I	Period II	Population Status	Primary Reproductive Guild	Secondary Reproductive Guild	Trophic Guild
Fundulus olivaceus	N	0.02	0.23	↑	Open Substrate	Phytophil	IF
Gambusia affinis	N	4	1	↓	Bearer	Viviparous	IF
Labidesthes sicculus	N	0.34	0.31	S	Open Substrate	Phytolithophil	IF
Menidia beryllina	N	0.01	0.77	↑	Open Substrate	Phytophil	IF
Morone mississippiensis	N		0.03	-	Open Substrate	Phytolithophil	IF
Centrarchus macropterus	N	0.36	<0.01	-	Nest Spawner	Lithophil	IF
Lepomis cyanellus	N	0.02	<0.01	-	Nest Spawner	Polyphil	IF
Lepomis gulosus	N	0.11	0.06	↓	Nest Spawner	Lithophil	IF
Lepomis humilis	N	0.03	<0.01	-	Nest Spawner	Lithophil	IF
Lepomis macrochirus	N	0.27	2	↑	Nest Spawner	Polyphil	IF
Lepomis marginatus	N		0.02	-	Nest Spawner	Polyphil	IF
Lepomis megalotis	N	0.43	0.50	↑	Nest Spawner	Polyphil	IF
Lepomis microlophus	N	0.74	0.54	S	Nest Spawner	Polyphil	IF
Lepomis miniatus	N	<0.01	0.04	-	Nest Spawner	Polyphil	IF
Lepomis symmetricus	N	0.63		-	Nest Spawner	Polyphil	IF
Micropterus punctulatus	N	0.34	2	↑	Nest Spawner	Polyphil	IF
Micropterus salmoides	N	0.32	0.43	S	Nest Spawner	Polyphil	P
Pomoxis annularis	N	0.96	0.07	-	Nest Spawner	Phytophil	P
Pomoxis nigromaculatus	I	0.24	0.14	-	Nest Spawner	Phytophil	IF
Elassoma zonatum	N	0.32		-	Substratum Chooser	Phytophil	IF
Ammocrypta clara	N	0.02	0.03	-	Open Substrate	Psammophil	IF
Ammocrypta vivax	N	0.46	0.49	↑	Open Substrate	Psammophil	IF
Etheostoma asprigene	N		0.05	-	Substratum Chooser	Phytophil	IF
Etheostoma chlorosoma	N	0.06	0.09	S	Substratum Chooser	Phytophil	IF
Etheostoma gracile	N	0.47	0.02	-	Substratum Chooser	Phytophil	IF
Etheostoma histrio	N	<0.01	<0.01	-	Substratum Chooser	Phytophil	IF
Etheostoma proeliare	N	0.02	<0.01	-	Substratum Chooser	Phytophil	IF
Etheostoma artesiae[†]	N	X	X	-	Substratum Chooser	Phytophil	IF

Species	Status	Period I	Period II	Population Status	Primary Reproductive Guild	Secondary Reproductive Guild	Trophic Guild
Percina caprodes[*]	I	<0.01		-	Brood Hider	Lithophil	IF
Percina macrolepida	N	<0.01	<0.01	S	Brood Hider	Lithophil	IF
Percina sciera	N	0.11	0.15	↑	Brood Hider	Lithophil	IF
Percina shumardi	N	<0.01	<0.01	-	Brood Hider	Lithophil	IF
Mugil cephalus	N	0.13	0.54	S	Catadromous		DT
Mugil curema[*]	N	<0.01		-	Catadromous		O
Paralichthys lethostigma[*]	N		<0.01	-	Marine		
Trinectes maculatus	N	0.06	<0.01	S	Anadromous		IF

Collections During Period:		59	124				
Individuals Collected:		57,442	111,693				
Taxa Richness:		75	70				
Diversity:		0.84	0.78				

* Species represented by one collection.

† Species not used for richness and diversity.

Table 3. Relative abundance, population status, and reproduction and trophic guilds of fishes in the lower San Antonio River, Texas. Mean relative abundance is presented for Period I (1950-1969) and Period II (1970-2006). Abbreviations are presented in Table 1.

Species	Status	Period I	Period II	Population Trend	Primary Reproductive Guild	Secondary Reproductive Guild	Trophic Guild
Atractosteus spatula[*]	N		<0.01	-	Open Substrate	Phytophil	P
Lepisosteus oculatus	N		0.97	-	Open Substrate	Phytophil	P
Lepisosteus osseus	N		1	-	Open Substrate	Phytolithophil	P
Dorosoma cepedianum	N	0.35	3	S	Open Substrate	Lithopelagophil	H
Dorosoma petenense	N		0.02	-	Open Substrate	Phytophil	PL
Campostoma anomalum	N		2	↑	Brood Hider	Lithophil	H
Cyprinella lutrensis	N	45	29	S	Brood Hider	Speleophil	IF
Cyprinella venusta	N		0.63	-	Brood Hider	Speleophil	IF
Cyprinus carpio	I		2	S	Open Substrate	Phytolithophil	O
Macrhybopsis marconis	N	0.01	0.13	S	Open Substrate	Pelagophil	IF
Notropis amabilis	N		0.02	-	Open Substrate	Pelagophil	IF
Notropis buchanani	N	X	0.33	-	Open Substrate	Pelagophil	IF
Notropis stramineus	N		0.02	-	Open Substrate	Lithophil	IF
Notropis volucellus	N		0.36	S	Open Substrate	Phytophil	O
Opsopoeodus emiliae	N	8		↓	Nest Spawner	Speleophil	DT
Pimephales promelas	I	0.02	0.02	S	Nest Spawner	Speleophil	O
Pimephales vigilax	N	5	10	S	Nest Spawner	Speleophil	O
Carpiodes carpio[*]	N		<0.01	-	Open Substrate	Lithopelagophil	DT
Ictiobus bubalus	N	0.01	2	S	Open Substrate	Lithopelagophil	O
Ictiobus niger[*]	N		<0.01	-	Open Substrate	Lithopelagophil	O
Moxostoma congestum	N		0.21	S	Open Substrate	Lithophil	IF
Astyanax mexicanus	I	0.13	2	S	Open Substrate	Pelagophil	IF
Ameiurus melas	N	0.05	<0.01	-	Nest Spawner	Speleophil	IF
Ameiurus natalis	N		0.32	-	Nest Spawner	Speleophil	IF
Ictalurus furcatus	N		2	-	Nest Spawner	Speleophil	P

Species	Status	Period I	Period II	Population Status	Primary Reproductive Guild	Secondary Reproductive Guild	Trophic Guild
Ictalurus punctatus	N	2	5	S	Nest Spawner	Speleophil	O
Noturus gyrinus[‡]	N	0.03	0.13	-	Nest Spawner	Speleophil	IF
Noturus nocturnus[*]	I		0.07	-	Nest Spawner	Speleophil	IF
Pylodictis olivaris	N		8	-	Nest Spawner	Speleophil	IF
Hypostomus plecostomus	I		0.37	-	Nest Spawner	Speleophil	DT
Pterygophlichthys multiradiatus	I		0.02	-	Nest Spawner	Speleophil	DT
Fundulus notatus	N	0.18		-	Open Substrate	Phytophil	H
Gambusia affinis	N	34	10	↓	Bearer	Viviparous	IF
Poecilia formosa	I	0.21	1	S	Bearer	Viviparous	IF
Poecilia latipinna	I	1	5	S	Bearer	Viviparous	O
Xiphophorus helleri[*]	I		0.15	-	Bearer	Viviparous	IF
Menidia beryllina	N	0.88	0.02	-	Open Substrate	Phytophil	IF
Lepomis auritus	I		1	S	Nest Spawner	Polyphil	IF
Lepomis cyanellus	N		2	↑	Nest Spawner	Polyphil	IF
Lepomis gulosus	N		0.20	S	Nest Spawner	Lithophil	IF
Lepomis humilis[*‡]	I		<0.01	-	Nest Spawner	Lithophil	IF
Lepomis macrochirus	N	1	2	S	Nest Spawner	Polyphil	IF
Lepomis marginatus	I		0.02	-	Nest Spawner	Polyphil	IF
Lepomis megalotis	N	0.03	2	↑	Nest Spawner	Polyphil	IF
Lepomis microlophus[*]	N		<0.01	-	Nest Spawner	Polyphil	IF
Lepomis miniatus	N		0.14	-	Nest Spawner	Polyphil	IF
Micropterus dolomieu[*]	I		0.03	-	Nest Spawner	Polyphil	P
Micropterus punctulatus	N		0.78	-	Nest Spawner	Polyphil	IF
Micropterus salmoides	N	0.27	0.72	S	Nest Spawner	Polyphil	P
Micropterus treculii[*]	N		0.06	-	Nest Spawner	Polyphil	P
Pomoxis annularis	N	0.01	0.13	-	Nest Spawner	Phytophil	P

Species	Status	Period I	Period II	Population Status	Primary Reproductive Guild	Secondary Reproductive Guild	Trophic Guild
Percina carbonaria	N		0.02	-	Brood Hider	Lithophil	IF
Cichlasoma cyanoguttatum	I	0.35	4	S	Substratum Chooser	Lithophil	IF
Oreochromis aureus	I		0.01	-	Bearer	Mouth Brooders	O
Oreochromis mossambica	I		0.49	-	Bearer	Mouth Brooders	O
Tilapia zillii	I		0.03	-	Nest Spawner	Lithophil	O
Mugil cephalus	N	0.33	<0.01	-	Catadromous		DT
Collections During Period:		10	63				
Individuals Collected:		7,639	26,652				
Taxa Richness:		23	55				
Diversity:		0.62	0.80				

* Species represented by one collection.

‡ Pending voucher confirmation; probable misidentification.

Table 4. Trophic and reproduction guilds for the lower Brazos River, lower Sabine River, and lower San Antonio River by time period.

	Brazos			Sabine		San Antonio	
	Period I	Period II	Period III	Period I	Period II	Period I	Period II
Trophic Guild							
Detritivore	3	3	0.99	11	6	6	0.33
Herbivore	1	3	0.51	0.15	0.2	0.79	3
Invertivore	78	73	78	59	68	89	61
Omnivore	14	18	20	28	24	4	32
Piscivore	5	3	0.49	0.31	0.35	0.38	3
Planktivore	0.01	0.62	0.12	2	0.42		0.03
Reproductive Guild							
Non Guarders:							
Open substrate							
Pelagophil	30	19	13	11	9	0.09	2
Lithopelagophil	4	5	0.91	9	4	0.13	2
Lithophil				0.73	0.36		0.15
Phytolithophil	0.21	0.2	0.22	0.33	0.28		1
Phytophil	0.51	0.91	0.19	4	4	0.76	0.96
Psammophil				0.39	0.45		
Brood Hiders							
Lithophil		0.15	0.02	0.12	0.18		2
Speleophil	48	45	63	49	65	48	39
Guarders:							
Substrate Chooser							
Lithophil						0.37	3
Phytophil	0.28	0.01	>0.01	0.16	0.1		
Nest Spawners							
Polyphil	1	2	0.21	1	2	1	3
Lithophil	0.54	2	0.05	0.12	0.03		0.17
Phytophil	0.48	0.35	0.09	0.34	0.14	0.01	0.06
Speleophil	14	19	20	20	14	10	32
Bearers:							
Gill brooder	0.03	0.03	0.01	0.1	<0.01		0.25
Viviparous	0.69	6	2	3	0.48	40	14
Anadromous:				0.03	<0.01		
Catadromous:	0.01	0.12	0.64	0.7	0.09	0.04	<0.01
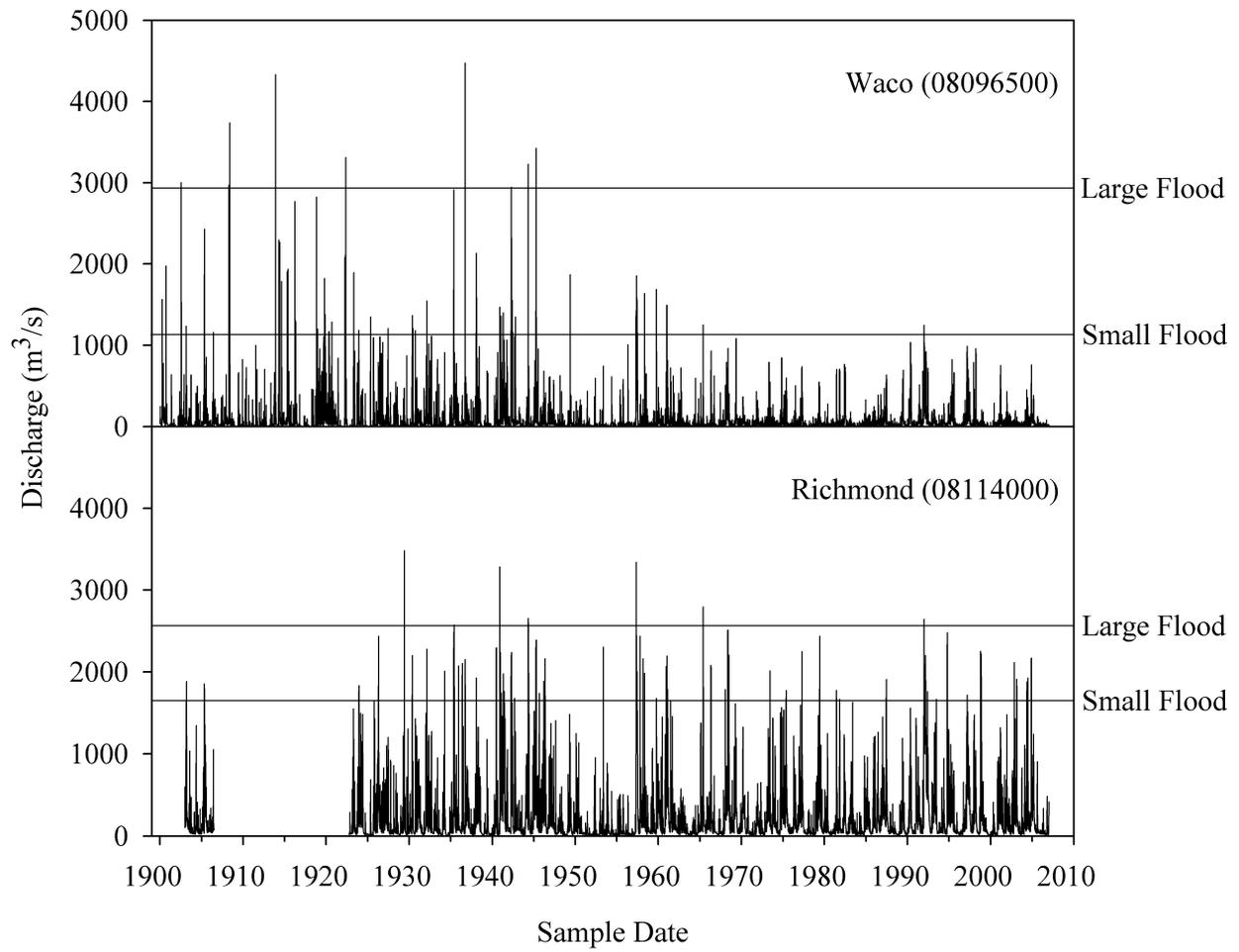
Figure 1. Hydrographs of the Brazos River at Waco and Richmond, Texas USGS gauging stations.
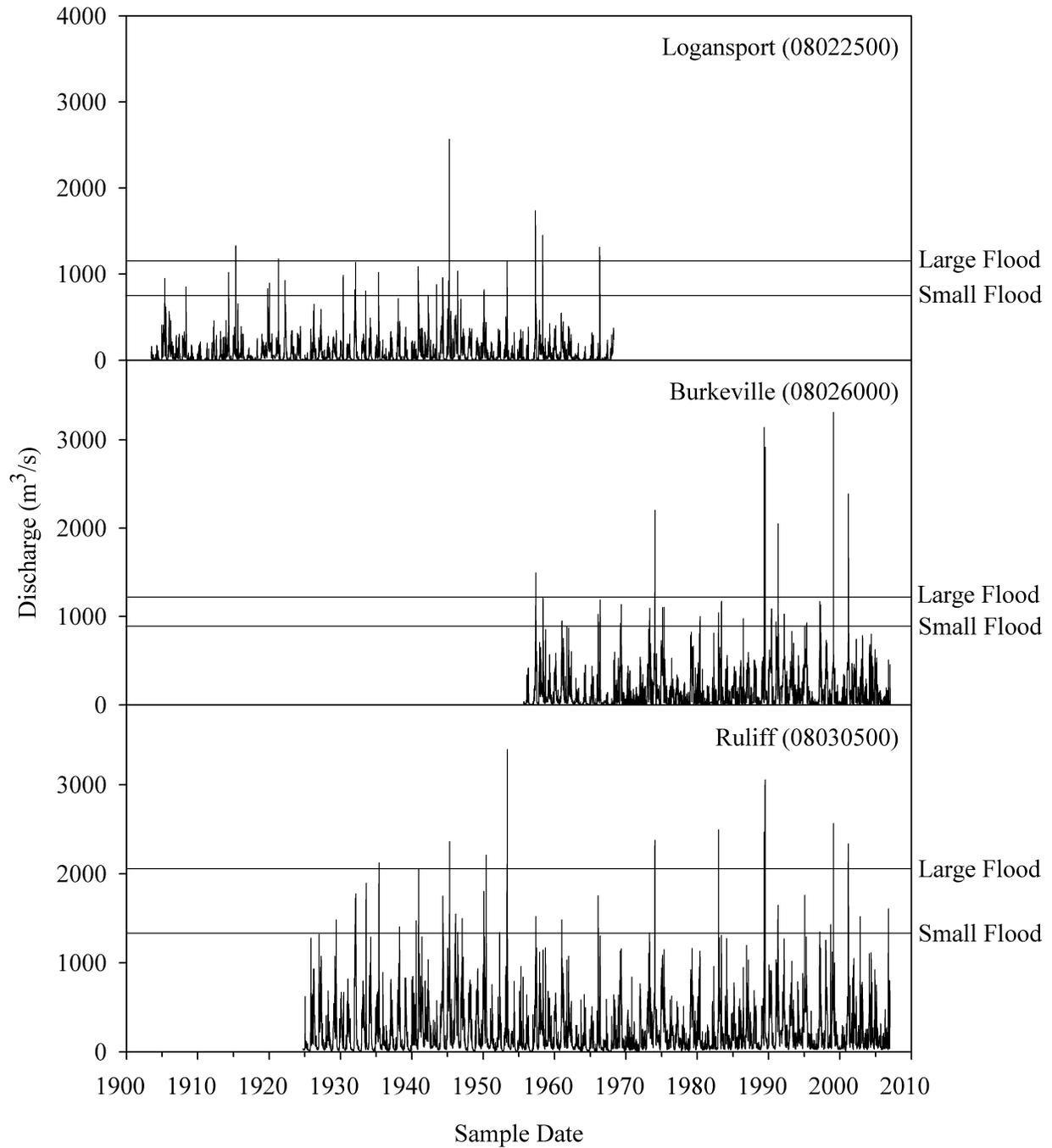
Figure 2. Hydrographs of the Sabine River at Logansport, Louisiana and Burkeville and Ruliff, Texas USGS gauging stations.
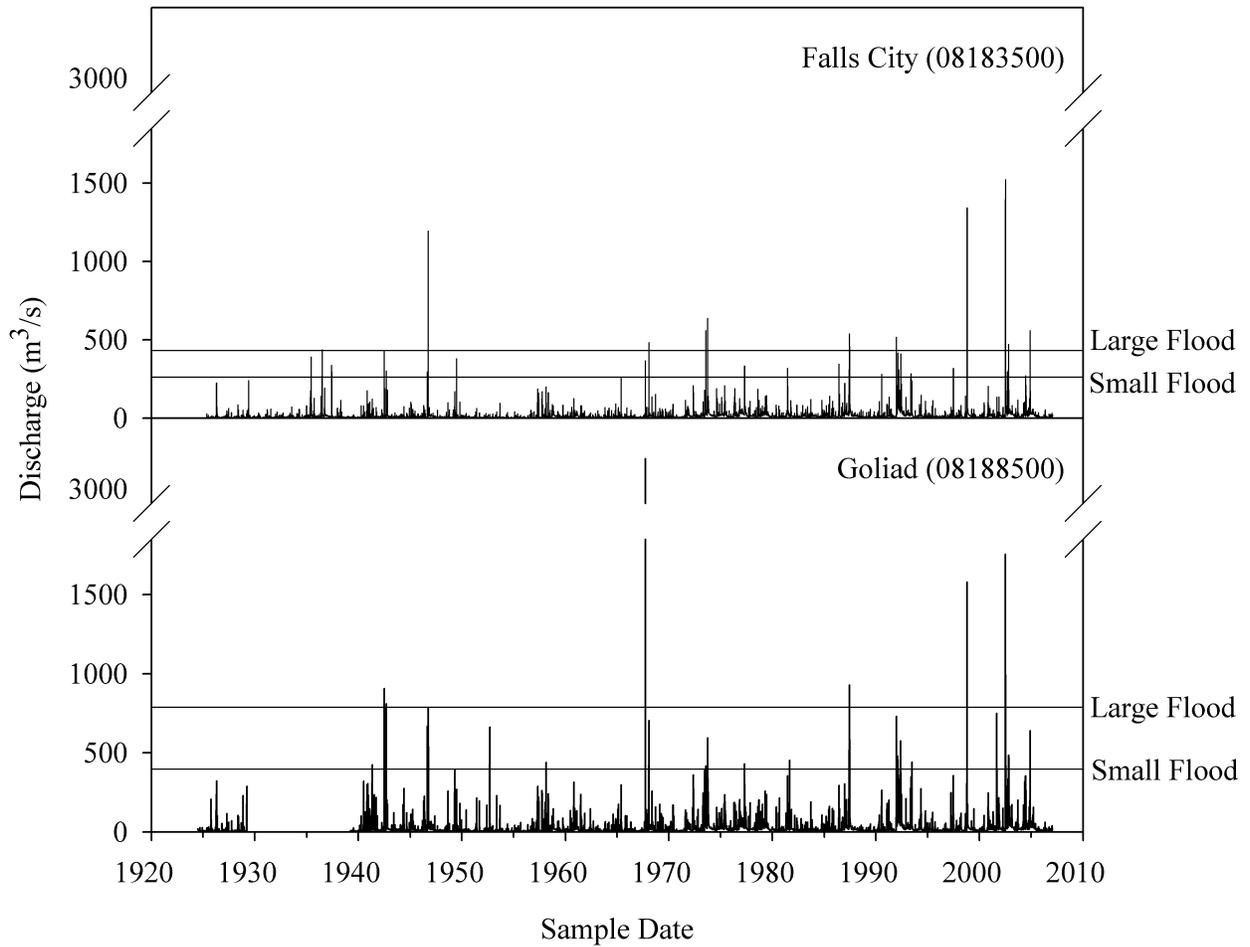
Figure 3. Hydrographs of the lower San Antonio River at Falls City and Goliad, Texas USGS gauging stations.
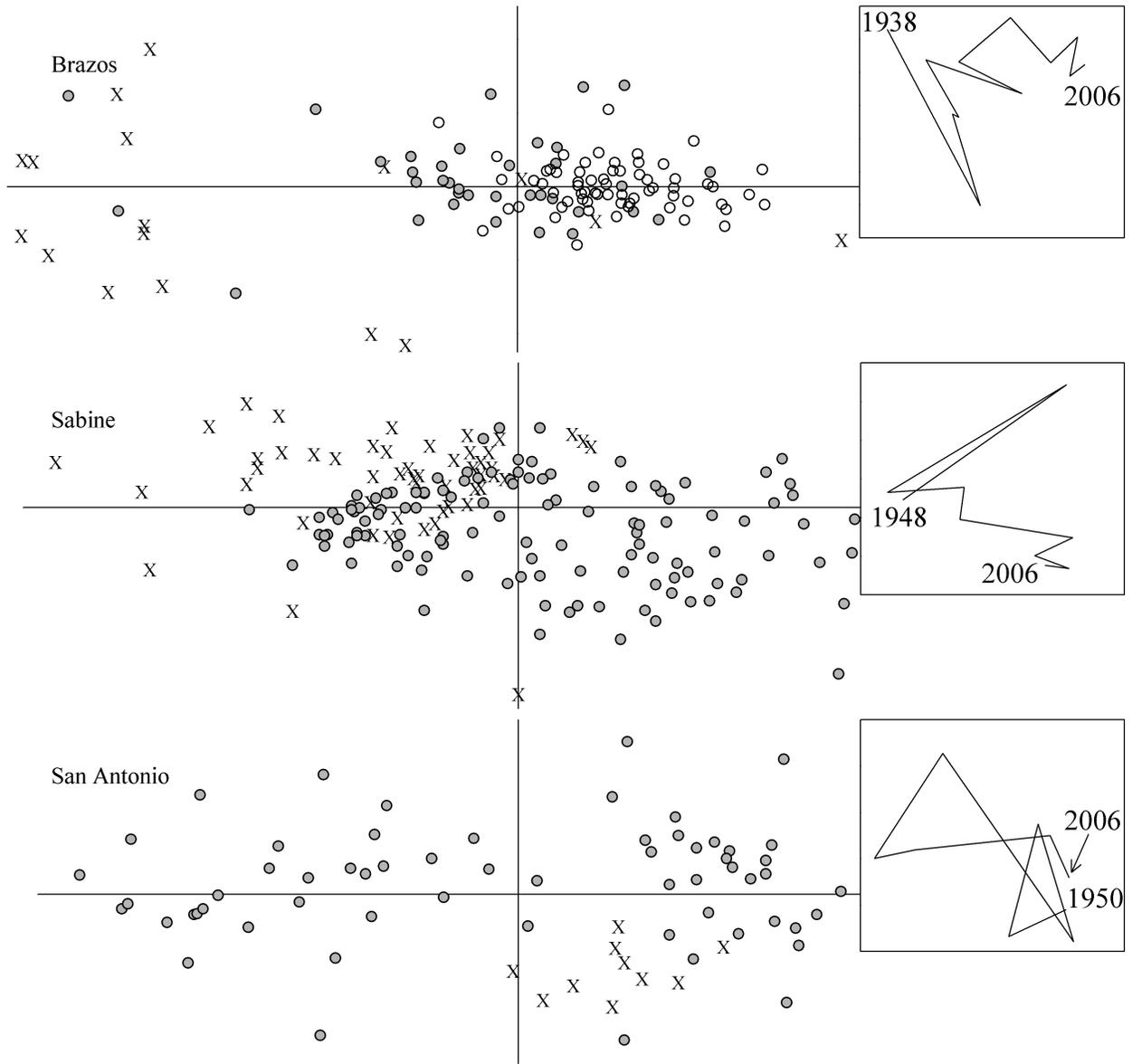
Figure 4. Multi-dimensional scaling (MDS) plots and trajectories for the lower Brazos River, lower Sabine River, and lower San Antonio River. Data was standardized by relative abundance and fourth-root transformed for similarity matrices (Bray-Curtis). X's represent Period I, shaded circles Period II, and open circles Period III. Trajectory plots were created using mean values for Axes I and II from MDS in 5-year increments.
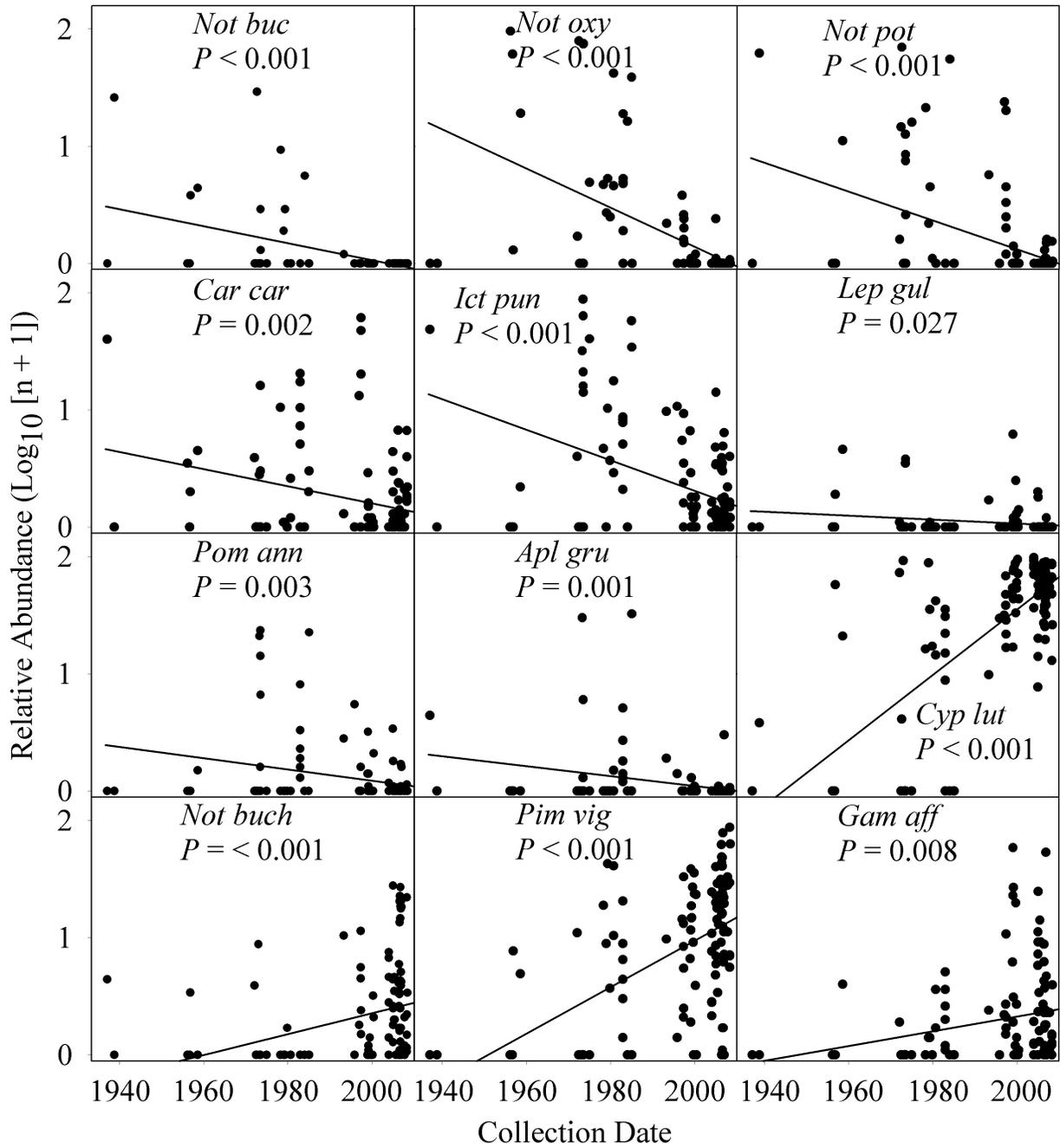
Figure 5. Relationship of $\log_{10} (n + 1)$ relative abundance through time with linear least-squares regression and associated P-value for lower Brazos River fishes.
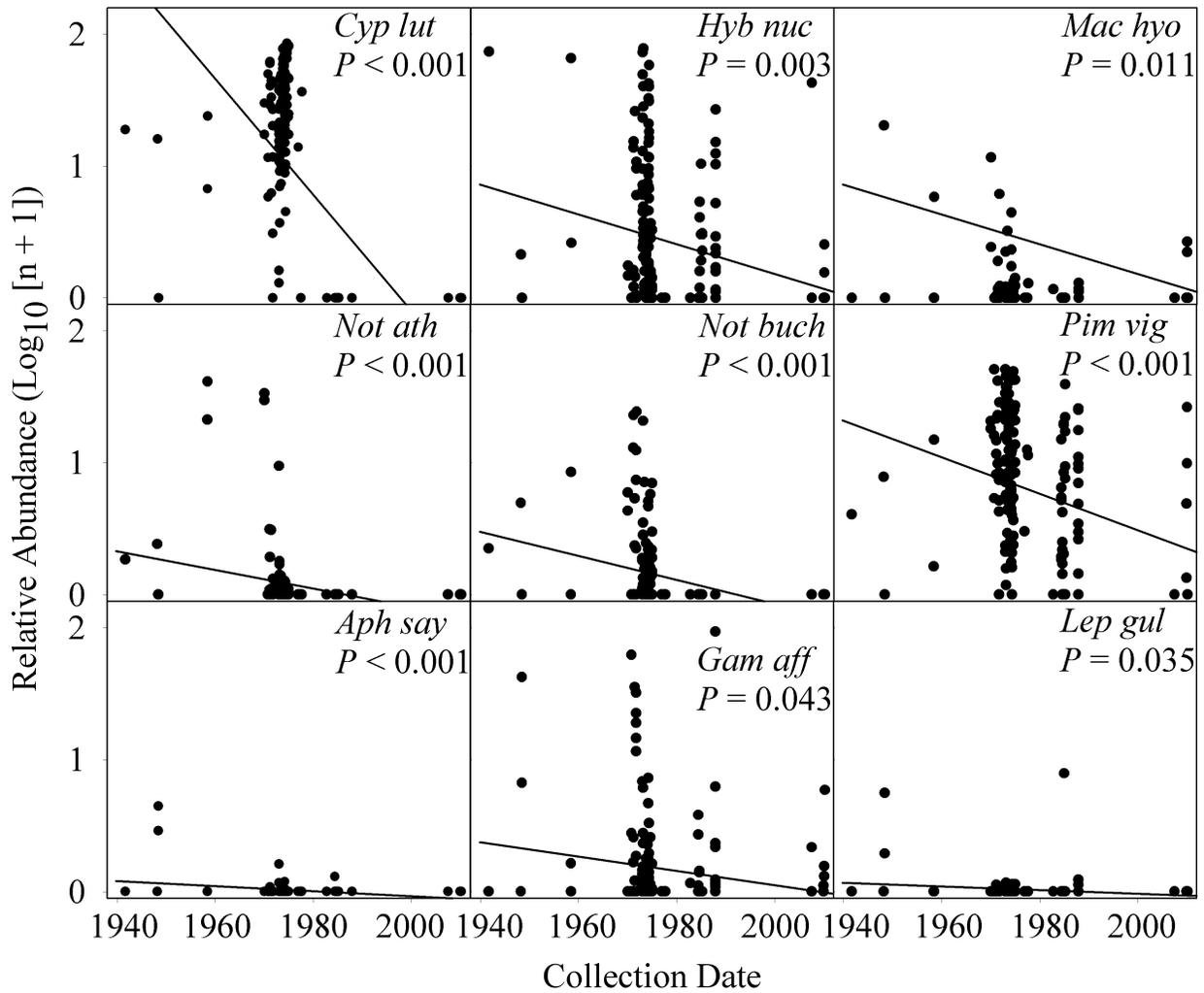
Figure 6. Relationship of $\log_{10}(n+1)$ relative abundance through time with linear least-squares regression and associated P-value for fishes with decreasing populations in the lower Sabine River.
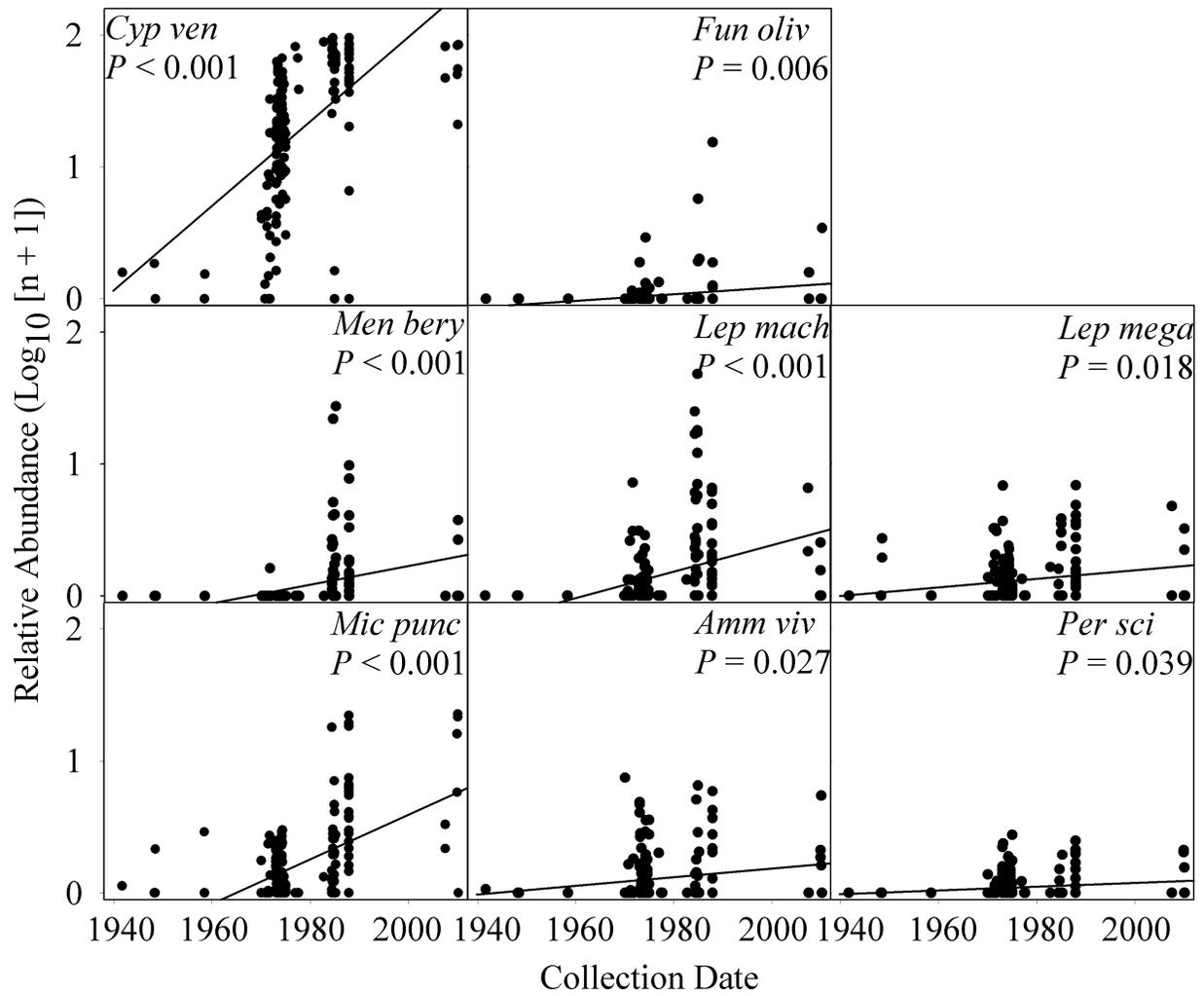
Figure 7. Relationship of $\log_{10}(n + 1)$ relative abundance through time with linear least-squares regression and associated P-value for fishes with increasing populations in the lower Sabine River.
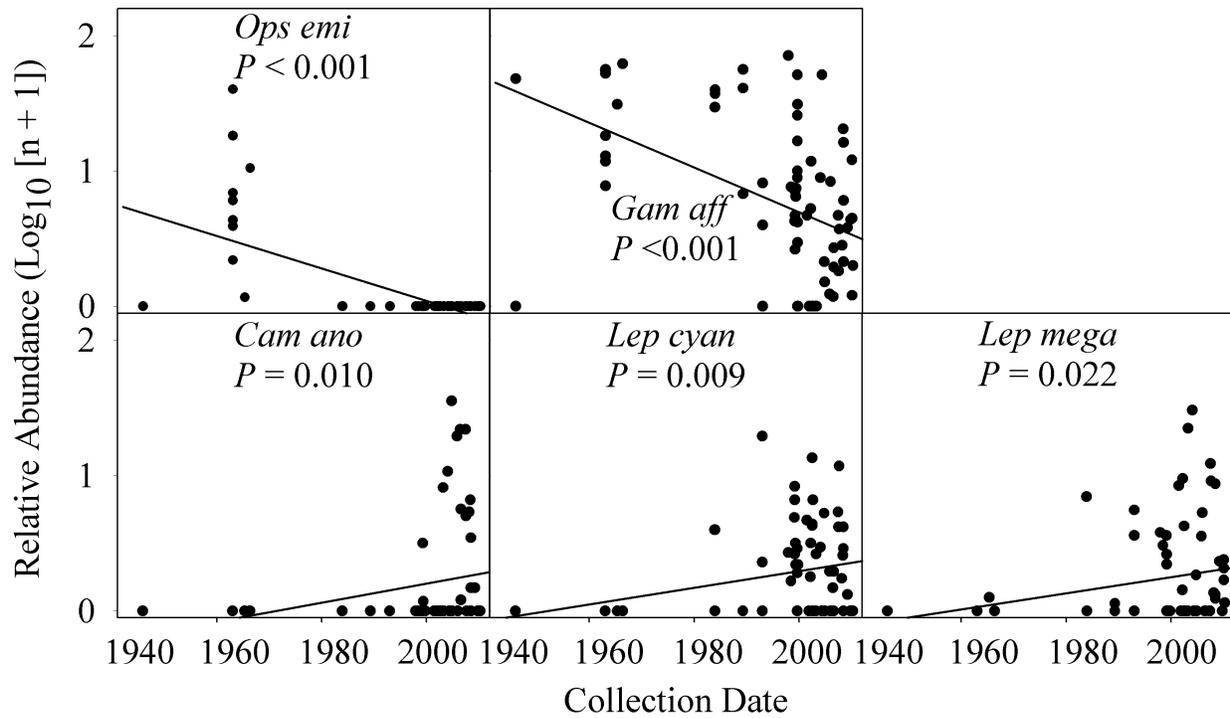
Figure 8. Relationship of $\log_{10}$ (n + 1) relative abundance through time with linear least-squares regression and associated P-value for lower San Antonio River fishes.