DESCRIPTIONS, CLASSIFICATIONS, AND EXPLANATIONS OF PROCESSES AND PATTERNS STRUCTURING AND MAINTAINING INLAND FISH COMMUNITIES

by

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ABSTRACT

Factors influencing fish community structure are numerous, complex, and interdependent. Structuring mechanisms of aquatic communities fall within four broad classes (i.e., zoogeography and deep-evolution, local abiotic and biotic phenomena, autecology of individual species, and biotic interactions among fishes) and explain why fishes are found in local and regional communities. The common theme among chapters is identification of patterns that aid in understanding contributions of the four broad classes in regulating fish community structure. A unique contribution of my work is the application of theoretical community ecology framework across multiple scales, from individuals to ecoregions, using descriptive and manipulative field and laboratory experiments. Chapter 1 provides updated drainage checklist and keys for Texas inland fishes, which provides accurate identification of study organisms. Chapter 2 establishes standardized and adaptable framework for assessing and reporting fish-environment associations. The framework was then applied to 11 habitat variables and 146 inland fishes of Texas. Remaining chapters focus on identification of mechanisms that maintain fish community structure, including water quantity and water quality within spring complexes (Chapter 3--San Antonio historical and current fish community, Chapter 4--Testing expectations of an understudied spring fish community using models and historical data) and biotic factors (Chapter 5--Temperature-mediated feeding between spring-associated and riverine-associated congeners, with implications for community segregation).

I. DRAINAGE BASIN CHECKLISTS AND DICHOTOMOUS KEYS FOR INLAND FISHES OF TEXAS

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Abstract

Species checklists and dichotomous keys are valuable tools that provide many services for ecological studies and management through tracking native and non-native species through time. We developed nine drainage basin checklists and dichotomous keys for 196 inland fishes of Texas, consisting of 171 native fishes and 25 non-native fishes. Our checklists were updated from previous checklists and revised using reports of new established native and non-native fishes in Texas, reports of new fish occurrences among drainages, and changes in species taxonomic nomenclature. We provided the first dichotomous keys for major drainage basins in Texas. Among the 171 native inland fishes, 6 species are considered extinct or extirpated, 13 species are listed as threatened or endangered by U.S. Fish and Wildlife Service, and 59 species are listed as Species of Greatest Conservation Need (SGCN) by the state of Texas. Red River drainage basin was the most speciose with 120 fishes. Rio Grande & Pecos drainage basin had the greatest number of threatened or endangered fishes (N = 7), and the greatest number of SGCN fishes (N = 28). We revised drainage basin occurrences for 77 species. Drainage basin checklists and dichotomous keys provide finer resolution of species distributions within the geopolitical boundaries of Texas and can reduce probability of errors in fish identification errors by removing species not occurring within a natural boundary.

Introduction

Species checklists consolidate biodiversity records using standardized taxonomic nomenclature and updated species occurrences within pre-defined boundaries (Fleishman et al. 2006; Martellos and Nimis 2015). Benefits of checklists include use in ecological studies and natural resources management, such as assessments of global patterns in species richness (Gaston 2000), identification of biodiversity hotspots (Kent et al. 2002), occurrences for species distribution models (Caicco et al. 1995), and expansion and contraction of native and non-native species (Lee et al. 2008; Magurran et al. 2010). Often coupled with checklists, dichotomous keys facilitate species identification using a series of distinguishing characteristics (Griffing 2011). Dichotomous keys usually are created for taxa within geopolitical boundaries (e.g., Hubbs et al. 2008); however, geopolitical boundaries often are arbitrary to species distributions (Forman 2014). Recent development and use of dichotomous keys along natural boundaries, such as drainage basin (Worsham et al. 2016), provide finer resolution on species distributions and reduce probability of identification errors by removing species not occurring within a natural boundary.

Within Texas, Evermann and Kendall (1894) published the first checklist of freshwater fishes. A revised checklist was published by Baughman (1950a, 1950b), using standardized taxonomic nomenclature provided by Jordan et al. (1930). Jurgens and Hubbs (1953) were the first to publish a checklist using standardized taxonomic nomenclature provided by American Fisheries Society Committee on Names of Fishes (Chute et al. 1948). This checklist was periodically revised by Hubbs (i.e., Hubbs 1957, 1958, 1961, 1972, 1976, 1982). Knapp (1953) published a checklist and the first dichotomous key for freshwater fishes of Texas. Texas drainage basin checklists were published for western Gulf Slope drainage basins (Conner and Suttkus 1986), Mississippi River drainage basins (Cross et al. 1986), and Rio Grande drainage basin (Smith and Miller 1986). Statewide checklist and dichotomous key were revised by Hubbs et al. (1991) and Hubbs et al. (2008).

Revisions of checklists for freshwater fishes of Texas were necessary through time to accommodate additions of previously unreported species, multiple species described from a single species, and non-native species introductions (Hanks and McCoid 1988; Eisenhour 2004; Gallaway et al. 2008) and to accommodate removal of introduced fishes that did not establish populations (Howells 2001). In addition, species distributions were updated to document range expansions (e.g., *Percina carbonaria*, Hubbs et al. 2008), range contractions (e.g., *Ictalurus lupus*, Kelsch and Hendricks 1990), and name changes (e.g., *Micropterus treculi* to *Micropterus treculii*) using standardized taxonomic nomenclature (e.g., Nelson et al. 2004). Since Hubbs et al. (2008), American Fisheries Society and American Society of Ichthyologists and Herpetologists (AFS-ASIH) Committee of Names of Fishes published a revised common and scientific names list (Page et al. 2013), new native species were reported within Texas (e.g., Craig et al. 2015), a fish name was synonymized (Echelle et al. 2013), introduced species became established (e.g., Cohen et al. 2014), and species ranges expanded (e.g., Dautreuil et al. 2016) and contracted (e.g., Craig et al. 2017).

Purposes of this paper were to develop drainage basin checklists and dichotomous keys for Texas freshwater fishes. As with previous revisions, we updated the statewide checklist and dichotomous key with new species, removal of species, and range changes.

However, our checklists and dichotomous keys differ markedly from previous revisions. We identified fishes as inland, rather than freshwater, and divided the geopolitical boundary into natural boundaries using major drainage basins. Texas is particularly well suited for drainage basin checklists and keys because majority of the drainage basins became independent of one another during the early Holocene (i.e., river termini in Gulf of Mexico bays), generally restricting freshwater fish movement among drainage basins. As such, fishes are rarely homogenously distributed among all drainage basins, with 41% of fishes restricted to one or two drainage basins (Conner and Suttkus 1986; Hubbs et al. 2008).

Methods

Development of a freshwater fish checklist is a challenge within natural or geopolitical boundaries having fresh and marine environments (Ross 2001; Moyle 2002). Inclusions of marine fishes on a freshwater fish checklist are subjective (Ross 2001). Knapp (1953) included marine fishes if observed in waters with salinities < 2 ppt. Hubbs et al. (1991) included marine fishes if found in "low salinity habitats". Using salinity as an objective measure is limiting. Several fishes found in upper reaches of the Canadian River, Red River, Brazos River, Colorado River, and Pecos River inhabit saline waters with salinities exceeding 50 ppt at times (Echelle et al. 1972), so excluding fishes based on salinity tolerances would exclude several species not known to inhabit marine or estuarine environments. Avoiding salinity as a measure, we used the term "inland" instead of "freshwater" to represent fishes found in Texas rivers generally upstream from transitory freshwater-saltwater boundaries. We accepted fishes as inland if they hatch, feed, and reproduce within inland waters (i.e., all water bodies upstream of river termini). We also accepted two forms of marine fishes as inland fishes: diadromous fishes (i.e., *Anguilla rostrata, Agonostomus monticola,* and *Trinectes maculatus*) and fishes with reported self-sustaining populations within inland waters (e.g., *Syngnathus scovelli,* Martin et al. 2013). Our acceptance of fishes as inland oversimplifies the complex and dynamic relationship of fish communities within estuarine systems of the Gulf of Mexico (Gelwick et al. 2001); therefore, our inland fish checklists underestimate the number of fishes encountered in estuarine systems.

Drainage basins were defined as major independent rivers that flow directly into the Gulf of Mexico (i.e., Sabine & Neches, Trinity & San Jacinto, Brazos, Colorado & Lavaca, Guadalupe & San Antonio, Nueces, and Rio Grande & Pecos) or beyond Texas borders (i.e., Canadian and Red) (Figure 1.1). Drainage basin checklists were developed using specific (Conner and Suttkus 1986; Cross et al. 1986; Smith and Miller 1986) and generalized (Hubbs et al. 2008) drainage basin checklists. Checklists were consolidated and updated based on drainage basin distribution records for each species using Texas Natural History Collections database (Hendrickson and Cohen 2015), published consolidated species accounts (e.g., Lee et al. 1980), and published individual species range accounts (e.g., Wilde and Bonner 2000). We only included species from previous checklists if species were recognized by Page et al. (2013) to minimize taxonomic inflation (Isaac et al. 2004). New species were added to checklists and keys based on published accounts of self-sustaining populations (*Ameiurus nebulosus*; Craig et al. 2015). A species was designated as native if it occurs within at least one Texas drainage basin without human aid. Transient border species (i.e., *Pimephales notatus,* Lee and

Shute 1980; *Hiodon tergisus,* Gilbert 1980; *Cyprinella panarcys,* Pinion et al. 2018) with occurrences in boundary waters of Texas were excluded because of uncertainty in self-sustaining populations. At least 80 non-native fishes have been introduced into Texas drainage basins; however, the majority did not establish self-sustaining populations (Howells 2001). Non-native fishes were included in drainage basin checklists if we had evidence (i.e., publications, personal communications) of self-sustaining populations or regular stocking (e.g., *Ctenopharyngodon idella*). Fishes considered extinct (IUCN 2018) were included in the checklist but excluded from keys because of low likelihood of encounter.

Each drainage basin dichotomous key consists of family and species keys. We developed novel distinguishing characteristics for family and species keys along with modifying and using characteristics from original species descriptions (e.g., Eisenhour 2004) and existing keys (e.g., Robison and Buchanan 1988; Sublette et al. 1990; Boschung and Mayden 2004; Thomas et al. 2007; Hubbs et al. 2008). Distinguishing characteristics were comprised of external and internal morphologies, meristics, and color patterns of adult fishes. Each couplet lists the most pronounced distinguishing characteristic first, followed by additional, generally less pronounced, distinguishing characteristics.

Results and Discussion

The composite drainage basin checklist included 196 inland fishes, representing 79 genera and 30 families (Table 1.1). Dichotomous keys were developed for nine drainage basins (Appendix 1.1). The number of inland fishes, based on our definition herein, reported in previous checklists ranged from 93 (Evermann and Kendall 1894) to 191 (Hubbs et al. 2008). Hubbs et al. (2008) and our composite drainage basin checklist were the most similar but with differences. Our checklist included three fishes reported in Texas after 2008: native *Ameiurus nebulosus* (Craig et al. 2015), non-native *Xiphophorus variatus* (Cohen et al. 2014), and non-native *Hypophthalmichthys nobilis* (T. Bister, Texas Parks and Wildlife Inland Fisheries, personal communication 10 March 2019). Fishes included by Hubbs et al. (2008) and excluded from our checklist were *Cyprinella* sp., *Cycleptus* sp., and *Ictalurus* sp., because Page et al. (2013) did not recognize these three putative species. Also based on Page et al. (2013), fish names were changed for three species: *Herichthys cyanoguttatus*, *Erimyzon claviformis*, and *Menidia audens*. One species (i.e., *Gambusia clarkhubbsi*) was included by Hubbs et al. (2008) and Page et al. (2013) but excluded from our checklist, because *G. clarkhubbsi* was later determined to be a junior synonym for *Gambusia krumholzi* (Echelle et al. 2013). *Gambusia krumholzi* replaced *G. clarkhubbsi* in our checklist. We excluded 8 non-native fishes reported by Hubbs et al. (2008), each lacking evidence of self-sustaining populations: *Scardinius erythrophthalmus*, *Agamyxis pectinifrons, Platydoras armatulus*, *Pterygoplichthys multiradiatus, Esox lucius, Perca flavescens, Sander canadensis,* and *Tilapia zillii*. Our checklist includes updated distributions of several fishes from previous checklists. Our checklist has 77 fishes with different drainage basin distributions compared to the drainage basin checklists of Conner and Suttkus (1986), Cross et al. (1986), and Smith and Miller (1986). Although interpreted from generalized descriptions, we determined our checklist has different drainage basin distributions of at least 46 fishes compared to Hubbs et al. (2008). Differences in distributions of fishes are largely due to the generalized nature of Hubbs et al. (2008) descriptions, but also include range expansions and contractions.

Our composite drainage basin checklist has 171 native and 25 non-native inland fishes. Among native species, three fishes (i.e., *Notropis orca*, *Gambusia amistadensis*, and *Gambusia georgei*) are considered extinct, and three fishes (i.e., *Notropis simus*, *Oncorhynchus clarkii*, and *Gambusia senilis*) are considered extirpated (Hubbs et al. 2008). Thirteen fishes are listed as threatened and endangered by U.S. Fish and Wildlife Service (USFWS), and 59 fishes are listed as Species of Greatest Conservation Need (SGCN, Texas Parks and Wildlife 2012). Number of native fishes by drainage basin ranged from 32 in the Canadian to 111 in the Red. Rio Grande & Pecos had the greatest number of USFWS threatened and endangered fishes (N = 7) and SGCN fishes (N = 28). Number of non-native fishes by drainage basin ranged from five in the Canadian to 20 in the Guadalupe & San Antonio. Origins of non-native fishes are from marine waters of Texas and from inland waters of North America and other continents (Table 1.2). Based on published accounts, non-native fishes were introduced for human consumption and sport (Nico and Fuller 1999), bait bucket releases (Howells 2001), vegetation control (Guillory and Gasaway 1978), accidental aquaculture releases (Howells 2001), and aquarium releases (Cohen et al. 2014).

A limitation of the drainage basin checklist and dichotomous keys is that documentation of species by drainage is incomplete. As such, our drainage basin checklists and dichotomous keys should be viewed as living documents and will need periodic updates. While using a drainage basin key, we caution users that the key only includes species known to occur within a basin, and the drainage basin might include more species. If an unknown specimen does not seem to key to a species, we recommend using a key from an adjacent drainage basin. Periodic updates of checklists for Texas inland fishes will come from previously unreported species, non-native species introductions, extirpations of introduced and native fishes, and multiple species described from a single species through genetic analyses. Sources of this information will be dependent on publications and ichthyological records, such as Texas Natural History Collections (Hendrickson and Cohen 2015). In addition to publications and ichthyological records, an emerging tool for documenting species occurrences is the use of citizen science through web-based applications (e.g., iNaturalist, www.inaturalist.org). We plan to publish revised checklists and keys following the next release of revised common and scientific names list by the AFS-ASIH Committee of Names of Fishes.

Table 1.1. Fishes in Texas inland waters. Presence is denoted by "X". All scientific and common names were from Page et al. (2013). Asterisk next to scientific name denotes species that were not included in the dichotomous keys due to low likelihood of encounter. "Native" denotes species is native to any Texas drainage basin. "Ext/exp" denotes species is extinct or extirpated from Texas. "USFWS" denotes species that are federally listed as Threatened or Endangered Species by United States Fish and Wildlife Service. "SGCN" denotes species that are state listed as Species of Greatest Conservation Need.

	Family	Species	Common Name	Native	Ext/exp	USFWS	SGCN	Canadian	Red	Sabine & Neches	Trinity & San Jacinto	Brazos	Colorado & Lavaca	Guadalupe & San Antonio	Nueces	Rio Grande & Pecos
1	Petromyzontidae	*Ichthyomyzon castaneus*	Chestnut Lamprey	X					X	X						
2		*Ichthyomyzon gagei*	Southern Brook Lamprey	X					X	X	X					
3	Acipenseridae	*Scaphirhynchus platorynchus*	Shovelnose Sturgeon	X			X		X							
4	Polyodontidae	*Polyodon spathula*	Paddlefish	X			X		X	X	X					
5	Lepisosteidae	*Atractosteus spatula*	Alligator Gar	X			X		X	X	X	X	X	X	X	X
6		*Lepisosteus oculatus*	Spotted Gar	X					X	X	X	X	X	X	X	X
7		*Lepisosteus osseus*	Longnose Gar	X					X	X	X	X	X	X	X	X
8		*Lepisosteus platostomus*	Shortnose Gar	X					X							
9	Amiidae	*Amia calva*	Bowfin	X					X	X	X	X	X			
10	Hiodontidae	*Hiodon alosoides*	Goldeye	X			X		X							
11	Anguillidae	*Anguilla rostrata*	American Eel	X			X		X	X	X	X	X	X	X	X
12	Clupeidae	*Dorosoma cepedianum*	Gizzard Shad	X				X	X	X	X	X	X	X	X	X
13		*Dorosoma petenense*	Threadfin Shad	X				X	X	X	X	X	X	X	X	X
14	Cyprinidae	*Campostoma anomalum*	Central Stoneroller	X				X	X		X	X	X	X	X	X
15		*Campostoma ornatum*	Mexican Stoneroller	X			X									X
16		*Carassius auratus*	Goldfish						X	X	X	X	X	X	X	X
17		*Ctenopharyngodon idella*	Grass Carp					X	X	X	X	X	X	X	X	X
18		*Cyprinella lepida*	Plateau Shiner	X			X							X	X	
19		*Cyprinella lutrensis*	Red Shiner	X				X	X	X	X	X	X	X	X	X
20		*Cyprinella proserpina*	Proserpine Shiner	X			X									X
21		*Cyprinella venusta*	Blacktail Shiner	X					X	X	X	X	X	X	X	X
22		*Cyprinus carpio*	Common carp					X	X	X	X	X	X	X	X	X
23		*Dionda argentosa*	Manantial Roundnose Minnow	X			X									X
24		*Dionda diaboli*	Devils River Minnow	X		X	X									X

25	*Dionda episcopa*	Roundnose Minnow	X			X									X
26	*Dionda nigrotaeniata*	Guadalupe Roundnose Minnow	X			X						X	X		
27	*Dionda serena*	Nueces Roundnose Minnow	X			X								X	
28	*Gila pandora*	Rio Grande Chub	X			X									X
29	*Hybognathus amarus*	Rio Grande Silvery Minnow	X		X	X									X
30	*Hybognathus hayi*	Cypress Minnow	X					X	X						
31	*Hybognathus nuchalis*	Mississippi Silvery Minnow	X					X	X	X	X				
32	*Hybognathus placitus*	Plains Minnow	X				X	X			X	X			
33	*Hybopsis amnis*	Pallid Shiner	X						X	X	X	X	X		
34	*Hypophthalmichthys nobilis*	Bighead Carp						X							
35	*Luxilus chrysocephalus*	Striped Shiner	X					X							
36	*Lythrurus fumeus*	Ribbon Shiner	X					X	X	X	X	X	X		
37	*Lythrurus umbratilis*	Redfin Shiner	X					X	X	X					
38	*Macrhybopsis aestivalis*	Speckled Chub	X			X									X
39	*Macrhybopsis australis*	Prairie Chub	X			X		X							
40	*Macrhybopsis hyostoma*	Shoal Chub	X					X	X	X	X	X			
41	*Macrhybopsis marconis*	Burrhead Chub	X									X	X		
42	*Macrhybopsis storeriana*	Silver Chub	X			X		X			X				
43	*Macrhybopsis tetranema*	Peppered Chub	X			X	X								
44	*Notemigonus crysoleucas*	Golden Shiner	X				X	X	X	X	X	X	X	X	X
45	*Notropis amabilis*	Texas Shiner	X			X						X	X	X	X
46	*Notropis atherinoides*	Emerald Shiner	X				X	X	X	X					
47	*Notropis atrocaudalis*	Blackspot Shiner	X			X		X	X	X	X				
48	*Notropis bairdi*	Red River Shiner	X			X		X							
49	*Notropis blennius*	River Shiner	X				X	X							
50	*Notropis braytoni*	Tamaulipas Shiner	X			X									X
51	*Notropis buccula*	Smalleye Shiner	X		X	X					X	X			
52	*Notropis buchanani*	Ghost Shiner	X					X	X	X	X	X	X	X	X
53	*Notropis chalybaeus*	Ironcolor Shiner	X			X		X	X	X			X		
54	*Notropis chihuahua*	Chihuahua Shiner	X			X									X
55	*Notropis girardi*	Arkansas River Shiner	X		X	X	X								
56	*Notropis jemezanus*	Rio Grande Shiner	X			X									X
57	*Notropis maculatus*	Taillight Shiner	X			X		X							
58	*Notropis orca**	Phantom Shiner	X	X											X
59	*Notropis oxyrhynchus*	Sharpnose Shiner	X		X	X					X	X			
60	*Notropis potteri*	Chub Shiner	X			X		X		X	X				
61	*Notropis sabinae*	Sabine Shiner	X			X			X	X					
62	*Notropis shumardi*	Silverband Shiner	X			X		X	X	X	X	X			

63		*Notropis simus*	Bluntnose Shiner	X	X	X	X									X
64		*Notropis stramineus*	Sand Shiner	X				X	X		X	X	X	X	X	X
65		*Notropis texanus*	Weed Shiner	X					X	X	X	X	X	X	X	
66		*Notropis volucellus*	Mimic Shiner	X					X	X	X	X	X	X	X	
67		*Opsopoeodus emiliae*	Pugnose Minnow	X					X	X	X	X	X	X	X	
68		*Phenacobius mirabilis*	Suckermouth Minnow	X				X	X	X	X		X			
69		*Pimephales promelas*	Fathead Minnow	X				X	X	X	X	X	X	X	X	X
70		*Pimephales vigilax*	Bullhead Minnow	X				X	X	X	X	X	X	X	X	X
71		*Platygobio gracilis*	Flathead Chub	X				X								
72		*Pteronotropis hubbsi*	Bluehead Shiner	X			X		X							
73		*Rhinichthys cataractae*	Longnose Dace	X			X									X
74		*Semotilus atromaculatus*	Creek Chub	X					X	X	X	X				
75	Catostomidae	*Carpiodes carpio*	River Carpsucker	X				X	X	X	X	X	X	X	X	X
76		*Cycleptus elongatus*	Blue Sucker	X			X		X	X	X	X	X	X	X	X
77		*Erimyzon claviformis*	Western Creek Chubsucker	X			X		X	X	X	X				
78		*Erimyzon sucetta*	Lake Chubsucker	X					X	X	X	X		X		
79		*Ictiobus bubalus*	Smallmouth Buffalo	X					X	X	X	X	X	X	X	X
80		*Ictiobus cyprinellus*	Bigmouth Buffalo	X					X	X						
81		*Ictiobus niger*	Black Buffalo	X					X	X		X	X			X
82		*Minytrema melanops*	Spotted Sucker	X					X	X	X	X	X			
83		*Moxostoma austrinum*	Mexican Redhorse	X			X									X
84		*Moxostoma congestum*	Gray Redhorse	X								X	X	X	X	X
85		*Moxostoma erythrurum*	Golden Redhorse	X					X							
86		*Moxostoma poecilurum*	Blacktail Redhorse	X						X	X					
87	Characidae	*Astyanax mexicanus*	Mexican Tetra	X					X		X	X	X	X	X	X
88	Ictaluridae	*Ameiurus melas*	Black Bullhead	X				X	X	X	X	X	X	X	X	X
89		*Ameiurus natalis*	Yellow Bullhead	X				X	X	X	X	X	X	X	X	X
90		*Ameiurus nebulosus*	Brown Bullhead	X					X							
91		*Ictalurus furcatus*	Blue Catfish	X					X	X	X	X	X	X	X	X
92		*Ictalurus lupus*	Headwater Catfish	X			X						X	X	X	X
93		*Ictalurus punctatus*	Channel Catfish	X				X	X	X	X	X	X	X	X	X
94		*Noturus gyrinus*	Tadpole Madtom	X					X	X	X	X	X	X	X	X
95		*Noturus nocturnus*	Freckled Madtom	X					X	X	X	X				
96		*Pylodictis olivaris*	Flathead Catfish	X				X	X	X	X	X	X	X	X	X
97		*Satan eurystomus*	Widemouth Blindcat	X			X							X		
98		*Trogloglanis pattersoni*	Toothless Blindcat	X			X							X		
99	Loricariidae	*Hypostomus plecostomus*	Suckermouth Catfish											X		X
100		*Pterygoplichthys anisitsi*	Southern Sailfin Catfish								X			X		

101		*Pterygoplichthys disjunctivus*	Vermiculated Sailfin Catfish									X			X		X
102	Salmonidae	*Oncorhynchus clarkii*	Cutthroat Trout	X	X		X										X
103		*Oncorhynchus mykiss*	Rainbow Trout						X	X	X	X	X	X	X	X	X
104	Esocidae	*Esox americanus*	Redfin Pickerel	X						X	X	X	X				
105		*Esox niger*	Chain Pickerel	X						X	X						
106	Aphredoderidae	*Aphredoderus sayanus*	Pirate Perch	X						X	X	X	X	X			
107	Mugilidae	*Mugil cephalus*	Striped Mullet	X						X	X	X	X	X	X	X	X
108		*Agonostomus monticola*	Mountain Mullet	X							X	X	X	X	X	X	X
109	Atherinopsidae	*Labidesthes sicculus*	Brook Silverside	X						X	X	X	X				
110		*Membras martinica*	Rough Silverside									X			X		X
111		*Menidia audens*	Mississippi Silverside	X					X	X	X	X	X	X	X	X	X
112	Fundulidae	*Fundulus blairae*	Western Starhead Topminnow	X						X	X	X	X				
113		*Fundulus chrysotus*	Golden Topminnow	X						X	X	X	X	X	X		
114		*Fundulus grandis*	Gulf Killifish							X			X	X			X
115		*Fundulus kansae*	Northern Plains Killifish	X					X								
116		*Fundulus notatus*	Blackstripe Topminnow	X						X	X	X	X	X	X	X	
117		*Fundulus olivaceus*	Blackspotted Topminnow	X						X	X	X	X				
118		*Fundulus zebrinus*	Plains Killifish	X						X		X	X	X			X
119		*Lucania goodei*	Bluefin Killifish												X		
120		*Lucania parva*	Rainwater Killifish	X										X	X		X
121	Cyprinodontidae	*Cyprinodon bovinus*	Leon Springs Pupfish	X		X	X										X
122		*Cyprinodon elegans*	Comanche Springs Pupfish	X		X	X										X
123		*Cyprinodon eximius*	Conchos Pupfish	X			X										X
124		*Cyprinodon pecosensis*	Pecos Pupfish	X			X										X
125		*Cyprinodon rubrofluviatilis*	Red River Pupfish	X			X		X	X			X	X			
126		*Cyprinodon variegatus*	Sheepshead Minnow									X	X	X	X		X
127	Poeciliidae	*Gambusia affinis*	Western Mosquitofish	X					X	X	X	X	X	X	X	X	X
128		*Gambusia amistadensis**	Amistad Gambusia	X	X												X
129		*Gambusia gaigei*	Big Bend Gambusia	X		X	X										X
130		*Gambusia geiseri*	Largespring Gambusia	X										X	X		X
131		*Gambusia georgei**	San Marcos Gambusia	X	X	X									X		
132		*Gambusia heterochir*	Clear Creek Gambusia	X		X	X							X			
133		*Gambusia krumholzi*	Spotfin Gambusia	X													X
134		*Gambusia nobilis*	Pecos Gambusia	X		X	X										X
135		*Gambusia senilis*	Blotched Gambusia	X	X		X										X
136		*Gambusia speciosa*	Tex-Mex Gambusia	X													X
137		*Heterandria formosa*	Least Killifish	X							X						
138		*Poecilia formosa*	Amazon Molly												X	X	X

139		*Poecilia latipinna*	Sailfin Molly						X	X	X	X	X	X	X
140		*Poecilia reticulata*	Guppy										X		
141		*Xiphophorus hellerii*	Green Swordtail										X		
142		*Xiphophorus variatus*	Variable Platyfish									X			
143	Syngnathidae	*Syngnathus scovelli*	Gulf Pipefish	X									X		
144	Moronidae	*Morone chrysops*	White Bass	X			X	X	X	X	X	X	X	X	X
145		*Morone mississippiensis*	Yellow Bass	X				X	X	X	X				
146		*Morone saxatilis*	Striped Bass					X	X	X	X	X	X	X	X
147	Centrarchidae	*Ambloplites rupestris*	Rock Bass										X		
148		*Centrarchus macropterus*	Flier	X				X	X	X					
149		*Lepomis auritus*	Redbreast Sunfish					X	X	X	X	X	X	X	X
150		*Lepomis cyanellus*	Green Sunfish	X			X	X	X	X	X	X	X	X	X
151		*Lepomis gulosus*	Warmouth	X				X	X	X	X	X	X	X	X
152		*Lepomis humilis*	Orangespotted Sunfish	X			X	X	X	X	X	X	X	X	
153		*Lepomis macrochirus*	Bluegill	X			X	X	X	X	X	X	X	X	X
154		*Lepomis marginatus*	Dollar Sunfish	X				X	X	X	X				
155		*Lepomis megalotis*	Longear Sunfish	X			X	X	X	X	X	X	X	X	X
156		*Lepomis microlophus*	Redear Sunfish	X			X	X	X	X	X	X	X	X	X
157		*Lepomis miniatus*	Redspotted Sunfish	X				X	X	X	X	X	X	X	X
158		*Lepomis symmetricus*	Bantam Sunfish	X				X	X	X	X	X			
159		*Micropterus dolomieu*	Smallmouth Bass				X	X			X	X	X	X	X
160		*Micropterus punctulatus*	Spotted Bass	X				X	X	X	X	X	X		
161		*Micropterus salmoides*	Largemouth Bass	X			X	X	X	X	X	X	X	X	X
162		*Micropterus treculii*	Guadalupe Bass	X		X					X	X	X	X	
163		*Pomoxis annularis*	White Crappie	X			X	X	X	X	X	X	X	X	X
164		*Pomoxis nigromaculatus*	Black Crappie	X				X	X	X	X	X	X	X	X
165	Percidae	*Ammocrypta clara*	Western Sand Darter	X		X		X	X						
166		*Ammocrypta vivax*	Scaly Sand Darter	X				X	X	X					
167		*Etheostoma artesiae*	Redspot Darter	X				X	X						
168		*Etheostoma asprigene*	Mud Darter	X				X	X						
169		*Etheostoma chlorosoma*	Bluntnose Darter	X				X	X	X	X	X	X		
170		*Etheostoma fonticola*	Fountain Darter	X	X	X							X		
171		*Etheostoma fusiforme*	Swamp Darter	X				X	X						
172		*Etheostoma gracile*	Slough Darter	X				X	X	X	X	X	X	X	X
173		*Etheostoma grahami*	Rio Grande Darter	X		X									X
174		*Etheostoma histrio*	Harlequin Darter	X				X	X						
175		*Etheostoma lepidum*	Greenthroat Darter	X								X	X	X	
176		*Etheostoma parvipinne*	Goldstripe Darter	X				X	X	X	X	X			

177		*Etheostoma proeliare*	Cypress Darter	X					X	X	X		X			
178		*Etheostoma radiosum*	Orangebelly Darter	X			X		X							
179		*Etheostoma spectabile*	Orangethroat Darter	X					X		X	X	X	X		
180		*Percina apristis*	Guadalupe Darter	X			X							X		
181		*Percina caprodes*	Logperch	X					X							
182		*Percina carbonaria*	Texas Logperch	X							X	X	X	X	X	
183		*Percina macrolepida*	Bigscale Logperch	X					X	X	X	X	X	X		X
184		*Percina maculata*	Blackside Darter	X			X		X	X	X					
185		*Percina phoxocephala*	Slenderhead Darter	X					X							
186		*Percina sciera*	Dusky Darter	X					X	X	X	X	X			
187		*Percina shumardi*	River Darter	X					X	X				X		
188		*Sander vitreus*	Walleye					X								X
189	Sciaenidae	*Aplodinotus grunniens*	Freshwater Drum	X					X	X	X	X	X	X	X	X
190	Elassomatidae	*Elassoma zonatum*	Banded Pygmy Sunfish	X					X	X	X	X				
191	Cichlidae	*Herichthys cyanoguttatus*	Rio Grande Cichlid	X							X	X	X	X	X	X
192		*Oreochromis aureus*	Blue Tilapia								X	X	X	X	X	X
193		*Oreochromis mossambicus*	Mozambique Tilapia											X	X	X
194	Gobiidae	*Awaous banana*	River Goby	X												X
195		*Gobiosoma bosc*	Naked Goby										X			X
196	Achiridae	*Trinectes maculatus*	Hogchoker	X						X	X	X	X	X	X	
			Total	171	6	13	59	37	120	101	102	96	94	94	66	95

Table 1.2. Non-native fishes established in Texas and their continent of origin with respective citation. Presence denoted by “X”.

Family	Species	Common Name	Marine	North America	Asia	Africa	South America	Europe	Citation
Cyprinidae	*Carassius auratus*	Goldfish			X				Hubbs et al. 2008
	Ctenopharyngodon idella	Grass Carp			X				Guillory and Gasaway 1978
	Cyprinus carpio	Common carp						X	Allen 1980
	Hypophthalmichthys nobilis	Bighead Carp			X				Kolar et al. 2007
Loricariidae	*Hypostomus plecostomus*	Suckermouth Catfish					X		Hubbs et al. 2008
	Pterygoplichthys anisitsi	Southern Sailfin Catfish					X		Nico and Martin 2001
	Pterygoplichthys disjunctivus	Vermiculated Sailfin Catfish					X		Nico and Martin 2001
Salmonidae	*Oncorhynchus mykiss*	Rainbow Trout		X					Hubbs et al. 1991
Atherinopsidae	*Membras martinica*	Rough Silverside	X						Hubbs et al. 1991
Fundulidae	*Fundulus grandis*	Gulf Killifish	X						Hubbs et al. 1991
	Lucania goodei	Bluefin Killifish		X					Gallaway et al. 2008
Cyprinodontidae	*Cyprinodon variegatus*	Sheepshead Minnow	X						Hubbs et al. 1991
Poeciliidae	*Poecilia formosa*	Amazon Molly	X						Hubbs et al. 1991
	Poecilia latipinna	Sailfin Molly	X						Hubbs et al. 1991
	Poecilia reticulata	Guppy					X		Hubbs et al. 2008
	Xiphophorus hellerii	Green Swordtail		X					Hubbs et al. 2008
	Xiphophorus variatus	Variable Platyfish		X					Cohen et al. 2014
Moronidae	*Morone saxatilis*	Striped Bass	X						Hubbs et al. 1991
Centrarchidae	*Ambloplites rupestris*	Rock Bass		X					Hubbs et al. 1991

	Lepomis auritus	Redbreast Sunfish		X		Hubbs et al. 1991
	Micropterus dolomieu	Smallmouth Bass		X		Hubbs et al. 1991
Percidae	*Sander vitreus*	Walleye		X		Hubbs et al. 1991
Cichlidae	*Oreochromis aureus*	Blue Tilapia			X	Hubbs et al. 2008
	Oreochromis mossambicus	Mozambique Tilapia			X	Hubbs et al. 2008
Gobiidae	*Gobiosoma bosc*	Naked Goby	X			T. Bonner, unpublished data

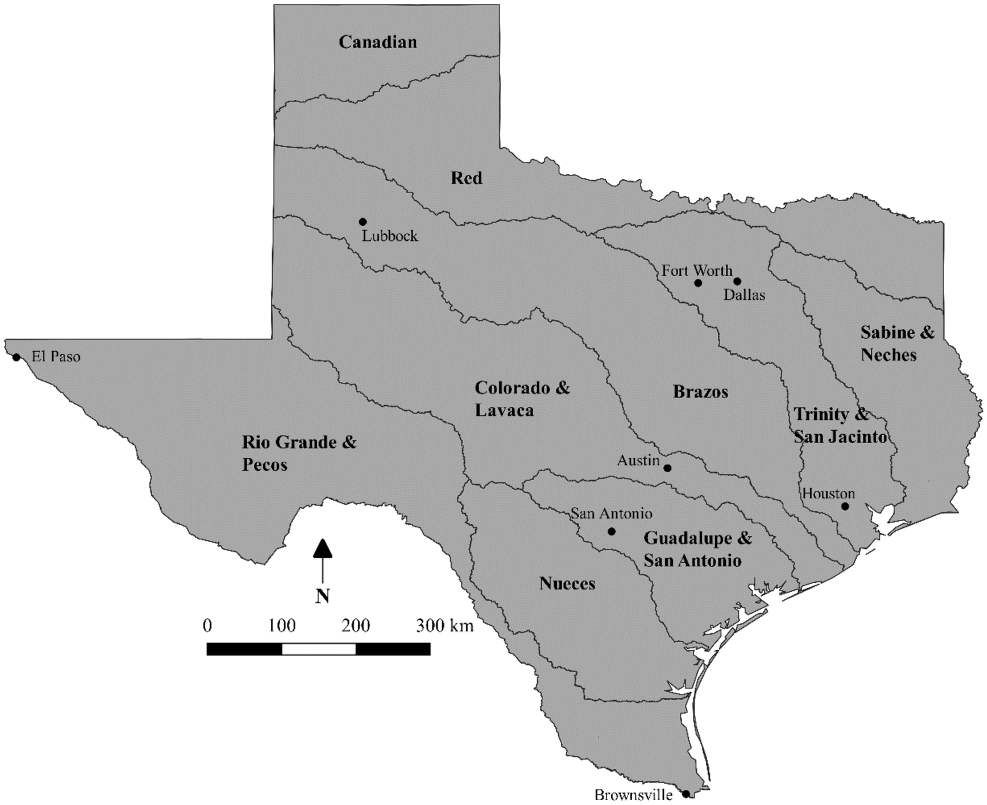


Figure 1.1. Map of Texas with major drainage basins outlined and labeled. Also included are major cities to serve as reference points.

II. A PROPOSED FRAMEWORK AND APPLICATION FOR ASSESSING AND REPORTING FISH-ENVIRONMENTAL ASSOCIATIONS

Abstract

Diversity of inland fishes is correlated with many different types of habitat variables. However, there is much variation in how species-environment relationships are reported which reduces the ability to compare data. In this study we propose a framework that resolves three major issues in reporting species-environment relationships: data resolution, terminology, and coverage. To show its utility we then applied the framework on species-environment data that was taken over 15 years by academia, government agencies, and private consulting. The result was environmental associations across 36 categories within 11 habitat variables for 146 inland fish species. Using common terminology, data resolution, and coverage, our standardized and adaptable framework will facilitate communication benefiting research, conservation, and management.

Introduction

"Where there is water, there is fish" – C. L. Hubbs (Matthews, 1998). Organisms are directly and fundamentally linked to their environments (Kearney, 2006). Inland fishes evolved morphologically, physiologically, and behaviorally to occupy almost every aquatic habitat and tend to segregate among available habitats (Hynes, 1970; Keast and Webb, 1966; Lowe-McConnell, 1987; Matthews, 1998). Aquatic environments for fishes include water quality habitat variables, such as temperature, dissolved oxygen, conductivity, and pH (Cech et al., 1990; Craig et al., 2019; Fischer and Paukert, 2008; Winemiller et al., 2008), physical habitat variables, including geomorphic units,

substrates, vegetation, woody debris, cover, depths, and current velocities (Bond and Lake, 2003; Boys and Thoms, 2006; Hayes et al., 1989; Johnson and Jennings, 2004; Leavy and Bonner, 2009; Mueller and Pyron, 2010; Vadas, 1992). Since fishes are related and constrained by their environments, quantifying species-environment relationships are fundamental goals of fish research, conservation, and management (Rosenfeld, 2003). Research linking species-environment patterns to ecological, behavioral, and evolutionary processes (e.g., Armstrong et al., 2013; Schluter and Conte, 2009; Winemiller and Rose, 1992) utilizes species-environment relationships. Conservation of listed threatened and endangered species at the state and federal level requires description, protection, and restorations of aquatic habitats (Bender et al. 2005; Smith et al., 2018). Management of game fishes rely on fish-environment relationships to enhance fisheries (e.g., Swales, 1989). Therefore, fish research, conservation, and management depend on the resolution and accuracy of species-environment relationships. Standardizing how species-environment relationships are quantified and communicated among various studies will facilitate comparability across fish research, conservation, and management.

Quantification of species-environment relationships vary in time, effort, and inference. Studies range from intensive manipulative laboratory studies to rapid field based environmental measures of where individuals were captured (Rosenfeld, 2003). Environmental associations are often reported in species and community studies because of the speed and ease of quantification (Barbour et al., 2003). Several approaches of measuring and reporting environmental associations are available, depending on study objectives (Fisher et al., 2012). Limitations of environmental association studies are not the data themselves but the lack of comparability with other studies due to data resolution, terminology, and coverage. Firstly, data resolution differs, ranging from qualitative low-resolution environmental association statements that are common in books with compiled species profiles (e.g., Thomas et al. 2007), to semi-quantitative large-scale approaches (e.g., Frimpong and Angermeier, 2009), and quantitative high resolution environmental associations often limited in geographic scope (e.g., Kollaus and Bonner 2012). Second, terminology differs when describing habitats and fish-environment associations. Standardized habitat terminology exists for some variables (e.g., substrate; Blair and McPherson, 1999) but is lacking for others such as depth (e.g., shallow vs. deep). Terminology for fish-environment associations (e.g., riffle specialists; Martin-Smith, 1998) can be expressed using defined categories or guilds that group fishes based on similar use of a resource (Frimpong and Angermeier, 2010). An issue is that category and guild assignments are often made from low resolution, often qualitative data, and rarely are at fine-scale quantification (summary in Austen et al., 1994). When quantitative approaches are used, they often have low power (e.g., low sample size) forfor accurate and precise inference of a species. Third, coverage (i.e., how representative the sample is of the population) differs, ranging in sample size and scale spatially and temporally. Sample size improves inferences of environmental associations (e.g., Hernandez et al., 2006; Soetaert and Heip, 1990). Also, greater spatial and temporal coverage improves inferences of environmental associations (Aguirre, 2009, Cureton and Broughton, 2014). Assessing and reporting of fish-environment associations under a standardized framework that addresses limitations would improve comparability among fish-environment association estimates.

In this paper we propose a standardized and adaptable framework for assessing and reporting fish-environment associations. The framework is designed to address limitations of data resolution, terminology, and coverage in fish-environment association studies. Data resolution limitation is addressed by providing both quantitative and qualitative (i.e., quantitatively defined) descriptions for fish-environment associations, developing and using consistent terminology for habitat variable categories and fish associations, while compiling data from multiple sources to improve coverage. Herein, we described the individual steps within the framework, that consist of data compilation, categorizing habitat variables, quantifying (i.e., descriptive statistics), and qualifying (i.e., terminologies), fish-environment associations per habitat variable and categories (Figure 2.1). We demonstrated the application of the framework with a database consisting of habitat variables for 146 inland fishes taken from 10 drainages from inland water of Texas and Louisiana collected over 15 years from university, government, and private consulting studies.

Fish-environment association framework

Data compilation

Data compilation consists of delineating the area of interest, searching and obtaining data, concatenating of data into a single database, and selecting habitat variables. Area of interest could include a single drainage, multiple drainages, or drainages within a state jurisdiction boundary. Geographically larger areas of interest are recommended over geographically smaller areas of interest in order to increase coverage. Available fish-environment association data are searchable and may be obtained from publicly available sources, including published peer-reviewed studies, dissertations, theses, and government and non-government reports. Fish-environmental association data (hereafter “raw data”) typically includes occurrence or abundance estimates per species and per habitat sampled (Doledec and Chessel, 1994); however, studies often summarize the information tables and figures. Raw data are becoming more readily available via requirements to make raw data publicly accessible in most academic journals (e.g., PLOS ONE) and via online open-access databases (e.g., EPA National Aquatic Resource Surveys). If not readily available, access and permission to use raw data from corresponding author can be obtained. Coalescing raw data into a single database requires inspection of the data to ensure compatibility among raw data sets, since species-environment relationships are scale dependent (Chittaro, 2004). Habitats can be delineated and measured from the microhabitat (fine-scale quantitative examination of hydraulic, bottom-topographic variables at multiple locations within mesohabitat units; (Vadas and Orth, 2000) to continental scales (Fisher et al., 2012; Logez et al., 2013). A common scale for fish-environment associations is the geomorphic unit level 3 (e.g., riffle, run pool), which is defined in Hawkins et al., (1993), while using a range of sampling gear (e.g., seining, electrofishing, visual surveys). Therefore, compatibility of data sets is improved if taken at the same scale (e.g., geomorphic unit), although data obtained from smaller scales could be integrated to larger scales. Segregation of samples should be by the habitat, where each geomorphic unit sampled is a row within the raw data, and measured environmental variables and species are the columns. Each row of raw data should contain measurements of habitat variables and counts of individuals by species within that geomorphic unit sample. A database will be formed from the concatenated raw data, which should be sorted by species for easy calculation. After the database is created, habitat variables should be considered for inclusion if measured in the majority of studies within study area. Habitat variables do not need to be common across all raw data sets but should be common to most of the raw data sets.

Categorizing habitat variables

Habitat variables consist of three types: binomial, proportional, and continuous. Binomial and proportional habitat variable categories are defined before the collection of raw data, using dummy variables (e.g., 0, 1 to denote level 3 geomorphic units; Hawkins et al. 1993), a single category (e.g., percent cover; (Allouche, 2002), or multiple categories with standardized criteria (e.g., substrates; Blair and McPherson 1999). Continuous habitat variables can be categorized after compiling the database by using literature-supported definitions (e.g., specific conductance; Oertli, 1964) or, in the absence of literature-supported definitions for habitat variables like current velocity and water depth, quantile methodologies (Austen et al. 1994). Quantile methodologies use the breadth of the continuous habitat variable and enables the categorization (i.e., number of quantiles) to be determined based on ecologically relevant breaks. For example, three categories of water depth (i.e., shallow, moderate, and deep) might be deemed ecologically relevant and logical per the breadth of water depths measured in the habitat database. Terciles would be used to quantitatively create the three categories: shallow water depth (0 to 33rd percentile of all reported depth measurements), moderate water depths (34th to 66th percentiles), and deep water depths (67th to 100th percentiles).

Quantify and Qualify fish-environment associations per habitat variable and categories.

Steps in the quantification process differ among habitat variables, depending on if the habitat variables are binomial, proportional, or continuous. For binomial habitat variables (e.g., geomorphic unit categories: run, riffle, pools), occurrences of individuals within each category are divided by the total number of occurrences for that species and multiplied by 100. For proportional habitat variables, the central tendency (e.g., mean) is calculated for each habitat variable (e.g., percent cover) or for each habitat variable category (e.g., percent silt). For continuous habitat variables, summary statistics (i.e., mean, standard deviation, minimum, and maximum) are calculated for each habitat variable. To calculate percentages of fish in each continuous habitat variable category, the number of individuals within each habitat variable category are divided by the total number of individuals for that species and multiplied by 100. Mean and standard deviation can be calculated as either weighted (i.e., considering each individual as an independent unit) or unweighted (i.e., each observation or row is an independent unit and individuals of the same species are considered as one). Weighted means and standard deviation use abundances, whereas unweighted means and standard deviations use occurrences to express the fish-environment association. Both can be calculated, and therefore available, depending on the desire to express the fish-environment association based on occurrence or as abundance. Qualification of the quantified habitat variable categories uses a modified version of the ACFOR scale (Stiers et al., 2011, for application see Craig et al., 2017; Faucheux et al., 2019). The acronym ACFOR represents abundance, common, frequent, occasional, and rare, which are qualitative terms often used to express fish-environment associations. Qualitative terms were assigned to percentages among habitat variable categories: abundance (>75%), common (50 to 74.9%), frequent (25 to 49.9%), occasional (5 to 24.9%), and rare (> 0 to 4.9%).

Application: fish-environment associations of Texas inland fishes

Data compilation

Our area of interest was the inland waters of Texas and western Louisiana (see Craig and Bonner, 2019 for definitions of inland waters and fishes). Raw data were compiled from published literature, agency reports, and unpublished data within 10 river basins of Texas and Louisiana: Canadian, Red, Calcasieu, Sabine/Neches, Trinity, Brazos, Colorado, Guadalupe/San Antonio, Nueces, and Rio Grande/Pecos. Sources of the raw data were obtained from published studies (Bean et al., 2007, Bonner and Wilde 2000, Bonner et al., 2005, Dautreuil et al., 2016, Heard et al., 2012, Kollaus and Bonner 2012), theses and dissertations (Behen 2013, Curtis 2012, Labay 2010, Pfaff 2019, Ruppel 2019, Scanes 2016, and Watson 2006), private consultants (Bio-West, INC.), agency reports (Texas Parks and Wildlife in River Studies 1-27 reports (accessed via https://tpwd.texas.gov), and unpublished sampling collections (C. Craig and T. Bonner, unpublished data). Studies were designed primarily to collect juvenile and adult fish from lotic systems across seasons. Raw data also were taken at the geomorphic unit scale, enabling the concatenating of raw data unto a single database, although geomorphic units were sampled using different gear (i.e., seining, backpack electroshocking, boat electroshocking, and SCUBA surveys). We retained all fishes as reported within each study. The majority (85%) of fishes observed had large sample sizes (N > 20; Simonson et al., 1994). Few species had single digit counts, such as the Rio Grande Shiner *Notropis* *jemezanus* (N = 5), which is ranked low in redundancy, resiliency, and representation in my study area (Faucheux et al., 2019). My rationale for retaining species with low sample sizes is the paucity of environment information available for these species and their status as species of conservation concern. We also retained all habitat information as reported, except for turbidity estimates since turbidity was measured in <50% of the studies. Not all geomorphic units sampled within the database had a full complement of habitat variables available. Missing data remained as blanks in the database.

Categorizing habitat variables

Eleven habitat variables were retained in the database (Table 2.3). Binomial data were used for geomorphic units. Proportional data were used for percent substrates, percent cover, percent vegetation, and percent woody debris. Continuous data were used for dissolved oxygen (mg/l), conductivity (µS/cm), pH, current velocity (m/s), depth (m), and temperature (°C). Binomial and proportional habitat variables did not require categorization, since categorization was done in the raw data (Table 2.1). Among continuous habitat variables, we used literature-supported categories for dissolved oxygen, conductivity, and pH measurements. We followed U.S. Environmental Protection Agency (EPA) one-day minimum dissolved oxygen threshold (3.0 mg/L; EPA 1996) to develop two dissolved oxygen categories: hypoxic (< 3.0 mg/l) and oxic (≥ 3.0 mg/l). We followed Oertli (1964) nomenclature to develop four conductivity categories: oligohaline (< 8,959 µS/cm), mesohaline (8,959 – 29,158 µS/cm), polyhaline (29,158 – 46,248 µS/cm) and euhaline (> 46,248 µS/cm). We followed EPA standards (EPA 1996) to develop three pH categories: acidic (pH < 5), neutral (pH range: 5 to 9), and basic (pH > 9).

Quantile methodologies were used to develop categories for depth, temperature, and current velocity. Three categories (tercile) for depth and temperature and four categories (quartiles) for current velocity were deemed ecologically relevant and justified per the breadth of each habitat variable (Figure 2.2). Three categories for depth were shallow (≤0.3 m), moderate (>0.3 to 0.7 m), and deep (>0.7 m). Three categories for temperature were cold (<21.5°C), cool (21.5 – 25.7°C), and warm (>25.7°C). Four categories for current velocity were slack (0 to 0.05 m/s), slow (0.05 – 0.2 m/s), moderate (>0.2 – 0.46 m/s), and swift (>0.46 m/s).

Quantify and qualify fish-environment associations per habitat variable and categories

The concatenated database consisted of 723,505 individuals that represent 24 families and 146 species over 10 drainage taken from 23,787 geomorphic units (Table 2.2). The most abundant family was Cyprinidae (N= 537,291), followed by Poeciliidae (N = 60,891), and Centrarchidae (N= 46,902). The most abundant species was *Cyprinella lutrensis* (N= 263,964) followed by *Pimephales vigilax* (N = 83,195) (Appendix 2.1). We quantified weighted mean, ±1 standard deviation, minimum value, and maximum value per species for six continuous habitat variables (i.e., dissolved oxygen, conductivity, pH, depth, water temperature, and current velocity) and weighted mean for four proportional habitat variables (i.e., percent substrates, consisting of 10 categories, percent cover, percent vegetation, and percent woody debris) (Appendix 2.2 - Appendix 2.10). Example of qualification of the quantified habitat variables are provided in Appendix 2.11.

Discussion

This framework addresses data resolution limitation by providing both quantitative and qualitative descriptions for fish-environment associations, using consistent terminology for habitat variable categories (e.g., slack, swift) and qualitative fish-environment associations (e.g., rare, abundant), while improving coverage by compiling raw data from multiple sources. We then demonstrated the use of this framework for 146 species (>700,000 individuals) of fishes in 10 drainages in Texas and Louisiana. This framework improved fish-environment associations for many species. An example of improved fish-environment associations by addressing limitations in data resolution and terminology is with the widespread River Darter *Percina shumardi*. The River Darter appears to occupy similar habitats throughout its range (Gulf Slope drainages; Gilbert, 1980). However, data resolution and terminology differ among sources. Based on qualitative fish-current velocity association, the River Darter is “primarily found in fair” (Scott and Crossman, 1974), “characteristically found in moderate” (Ross et al., 2003), “most frequently in rather swift” (Trautman, 1981), “predilection for fast” (Robison and Miller, 2004), and “typically associated with swift” (Bonner, 2014) current velocities. Based on semi-quantitative fish-current velocity association, the River Darter ordinal rank is “swiftest” among four categories by Poff and Allan (1995). Based on quantitative fish-current velocity association, mean current velocity for River Darter is 0.44 m/s (Edwards, 1997). In contrast, the framework has each environmental variable, categories within variables, and associations within categories quantitatively and qualitatively defined, in addition to descriptive statistics which unifies terminology and data resolution. Based on our current velocity associations, the River Darter (N = 314; 2

drainages) is found between 0.0 – 1.4 m/s with weighted mean of 0.88 m/s (± 0.27) and abundant (93% occurrence) in swift (>0.46 m/s) current velocities.

An example of improved fish-environment associations by addressing limitation in coverage (i.e., sample size and spatially) is with a Texas endemic: Texas Shiner *Notropis amabilis*. The Texas Shiner's range is comprised of four drainages (Craig and Bonner, 2019), however published quantitative analysis is limited to two tributaries within two drainages with a sample size of 1,283 individuals (Bean et al., 2007; Kollaus and Bonner, 2012). Craig et al. (2017) qualitatively summarized the two quantitative studies by stating "Texas Shiner associates with clear water, pool habitats, and moderate current velocities (0.1 m/s), and sand, gravel, cobble, and bedrock substrates". In contrast, the framework allows for comparability of the two quantitative studies in addition to other studies, which increased coverage and improved breadth of the fish-environmental association. Our fish-environment associations for the Texas Shiner were calculated from 28,528 individuals to summarize that the fish was common in run (60%) and occasional in pool (26%) habitats, frequent in slack (32%) and slow (35%) current velocities, and is frequent in gravel substrates (26%).

Given that our application included unpublished raw data, a secondary benefit is the quantification of fish-environment associations for species with limited information. An example of this is the Nueces Roundnose Minnow *Dionda serena*, which is globally imperiled and a Species of Greatest Conservation Need (SGCN) by the state of Texas (NatureServe, 2019; Texas Parks and Wildlife, 2012). Previous environment associations are limited to general descriptions (i.e., rocky pools, sometimes runs; often found among filamentous algae; Page and Burr, 1991). Based on our application, Nueces Roundnose

Minnow (N = 2,297) is abundant in runs (78%), common in vegetation (54%), frequent in shallow (41%) and deep (45%) water, common in slack (54%) and slow (42%) water. Nueces Roundnose Minnow is common in cool water (54%), and abundant in oxic, oligohaline, and neutral pH waters.

Limitations of data and framework

Limitations of the raw data and framework are similar to data limitations that exist for studies that measure and report species-environment associations. Specifically, studies measuring environmental associations are constrained by 1) selection of habitat variables, 2) measurement errors, and 3) the assumption that species-environment associations are meaningful (Mitchell, 2005). Inherent biases exist when researchers choose habitat variables to quantify or exclude. Habitat variables are excluded because they are not thought to affect a species or are difficult to measure (Mitchell 2005). In the framework, we were limited to habitat variables that the studies measured. However, the framework allows for an unlimited number of habitat variables and can be easily updated as more habitat variables are included in the raw data such as riverscape variables (e.g., discharge, turbidity; Gradall and Swenson, 1982; Stefferud et al., 2011) and landscape variables (e.g., canopy cover and land use; Bojsen and Barriga, 2002; Roth et al., 1996). Measurements errors in the raw data, and therefore our quantitative and qualitative summary statistics, are in two forms: measuring the habitat variables and measuring populations. Error in measuring habitat variables comes from converting habitat variable, which are inherently continuous, into lower resolution scales. For example, geomorphic unit was used the unit of measure in the raw data, but fishes could be associating with certain microhabitats within geomorphic units (Grossman and Freeman, 1987; Yeiser and Richter 2015). Error in measuring populations comes from low spatial and temporal coverage, as well as, low sample sizes within a population. In this study, 15% of fish species had low sample sizes (< 20; Simonson et al., 1994), yet we decided not to exclude those species because our results provide preliminary environment association data and highlight the need for future study of these species. I assumed that fish-environment associations are meaningful and can be assessed (e.g., Leavy and Bonner, 2009) but requires more effort and time (e.g., conducting experiments to assess fish preferences and requirements; Rosenfeld, 2003). Although preferences and requirements might be unknown, quantifying the fish-environment associations demonstrate that fishes are not homogeneously distributed among aquatic habitats; therefore, fish-environment associations establish hypotheses for future preference and requirement research.

Future uses and directions

Future uses and directions of our standardized and adaptable framework will be benefited by the quality and quantity of fish-environment associations. Future uses of the framework and application include providing the foundation for numerous ecological, evolution, and conservation studies and applications. For example, fish-environment associations with greater quality and quantity of associations will improve upon grouping species into ecologically relevant categories (e.g., Winemiller and Rose, 1992). Likewise, ecological models, such as habitat suitability (e.g., Zorn et al., 2012), and climate change (e.g., Guse et al., 2015), are reliant on high quality and large quantity of fish-environment associations. The framework also identifies gaps in fish-environment associations. In our area of interest, our concatenated database provided fish-environment associations for 146 species, which is 75% of the inland fishes found in Texas (N=196; Craig and Bonner 2019). Future directions could include prioritizing funding and research for SGCN species in need of fish-environment association quantification. Among 59 SGCN in Texas (Bender et al. 2005), we quantified fish-environment associations for 64% (N = 38) of SGCN; however, 12% (N = 7) of SGCN were among the fishes with low sample sizes. Future uses and directions could also include expanding the framework to other aquatic organisms beyond fish. For example, benthic current velocity would be added as a habitat variable and categories calculated, which would be ecological relevant for benthic aquatic insects, mussels, and salamanders. Further modifications to environmental variables measured could be made to apply to terrestrial organisms. Regardless of lineage, habitats, and area of interests, quantification and qualification of species-environment associations using common terminology would facilitate communication (Hawkins et al. 1993) benefiting research, conservation, and management.

Table 2.1. Habitat variables and categories used in application of framework. Citation describes categories within each parameter

Category types	Habitat variables	Habitat variable categories	Category definitions	Citation
Established	Dissolved oxygen	Hypoxic	<3.0mg/L	U.S. Environmental Protection Agency 1996, Vaquer-Sunyer and Duarte 2008
		Oxic	>3.0mg/L	U.S. Environmental Protection Agency 1996, Vaquer-Sunyer and Duarte 2008
	Conductivity	Oligohaline	< 8,959 µS/cm	Oertli, 1964
		Mesohaline	8,959 – 29,158 µS/cm	Oertli, 1964
		Polyhaline	29,158 – 46,248 µS/cm	Oertli, 1964
		Euhaline	> 46,248 µS/cm	Oertli, 1964
	pH	Acidic	<5 pH	U.S. Environmental Protection Agency 1996
		Near neutral	5-9 pH	U.S. Environmental Protection Agency 1996
		Basic	>9 pH	U.S. Environmental Protection Agency 1996
	Substrate	Clay	<0.004 mm	Blair and McPherson 1999
		Silt	0.004 - 0.063 mm	Blair and McPherson 1999
		Sand	0.064 - 2mm	Blair and McPherson 1999
		Pebble	2.1 - 64 mm	Blair and McPherson 1999
		Cobble	64.1 - 256 mm	Blair and McPherson 1999
		Boulder	256.1 - 4096 mm	Blair and McPherson 1999
		Bedrock	>4096 mm	Blair and McPherson 1999
		Marl		
		Cement		
		Detritus		Bowen 1983
	Geomorphic unit	Run	See Hawkins et al. 1993	Hawkins et al. 1993
		Riffle	See Hawkins et al. 1993	Hawkins et al. 1993
		Pool	See Hawkins et al. 1993	Hawkins et al. 1993
		Backwater	See Hawkins et al. 1993	Hawkins et al. 1993
	Independent	Woody debris	>10 cm diameter	Enrong et al. 2006
		Cover	See Allouche 2002	Allouche 2002
		Vegetation	See Oyedeji and Abowei 2012	Oyedeji and Abowei 2012
Created	Depth	Shallow	Minimum - 0.3m	
		Moderate	>0.3 – 0.7m	
		Deep	0.7 - maximum	
	Temperature	Cold	Minimum – 21.5 ºC	
		Cool	>21.5 – 25.7 ºC	
		Warm	> 25.7 ºC - maximum	
	Current velocity	Slack	0 – 0.05 m/s	
		Slow	>0.05 – 0.2 m/s	
		Moderate	>0.2 – 0.46 m/s	
		Swift	>0.46 - maximum	

Table 2.2. Number of habitats sampled and fishes caught by basin.

Basin	**N of habitats sampled**	**N of individuals**
Canadian	2,491	6,496
Red	1,071	41,094
Sabine & Neches	705	15,610
Trinity	3,012	61,121
Brazos	4,263	265,664
Colorado	1,023	67,686
Guadalupe & San Antonio	6,774	197,075
Nueces	727	13,981
Rio Grande	3,721	54,778
Total	23,787	723,505

Table 2.3. Summary of habitat variables with minimum, maximum, arithmetic mean, and (±1) standard deviation reported. For geomorphic unit and substrate, the least and most common type was provided.

Variable	Minimum	Maximum	Mean	SD (±)
pH	3.2	10.8	8.1	0.54
Conductivity (µs/cm^2)	64	49,968	910	4230.8
Dissolved oxygen (mg/L)	0.1	15.4	8.0	2.04
Temperature (°C)	0.1	37.6	23.0	6.80
Depth (m)	0.02	6.4	0.5	0.63
Current Velocity (m/s)	0	1.7	0.2	0.31
Area (m^2)	0.9	21,332	15	519.6
Cover	0	100	2.3	10.54
Vegetation	0	100	9.4	24.7
woody debris	0	100	5.7	16.7

	least common	most common
Geomorphic unit	riffles (11%)	runs (53%)
Substrate	bedrock (5.1%)	sand (20.3%)

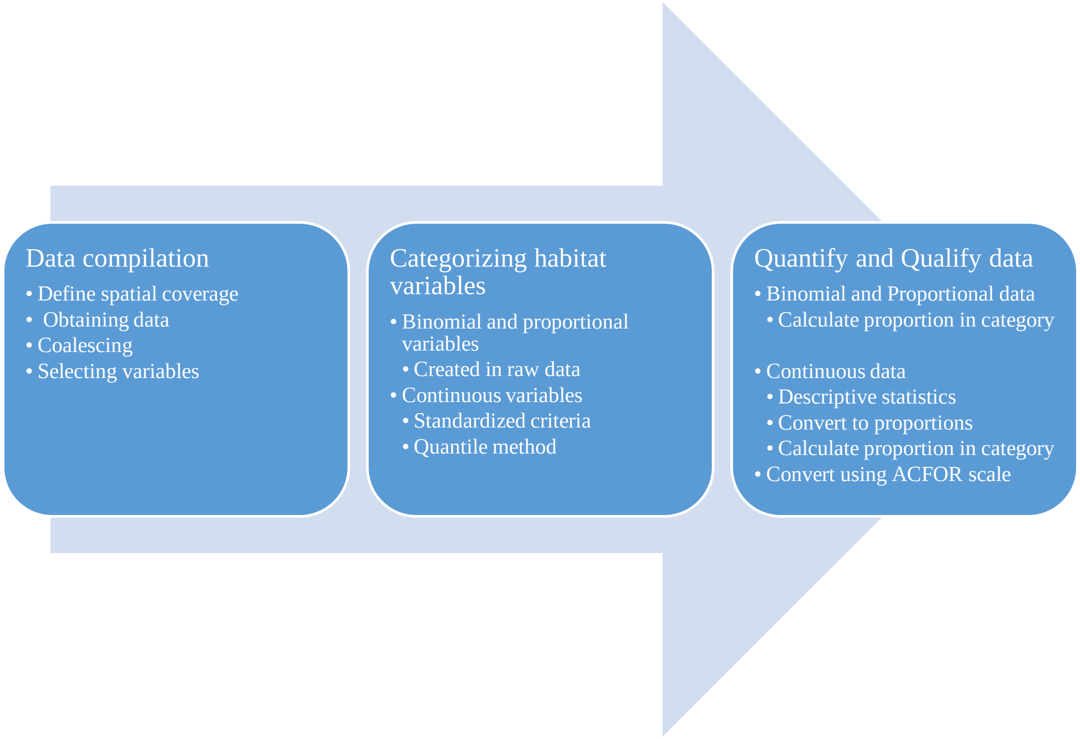


Figure 2.1. Flowchart representing the steps in the proposed framework.

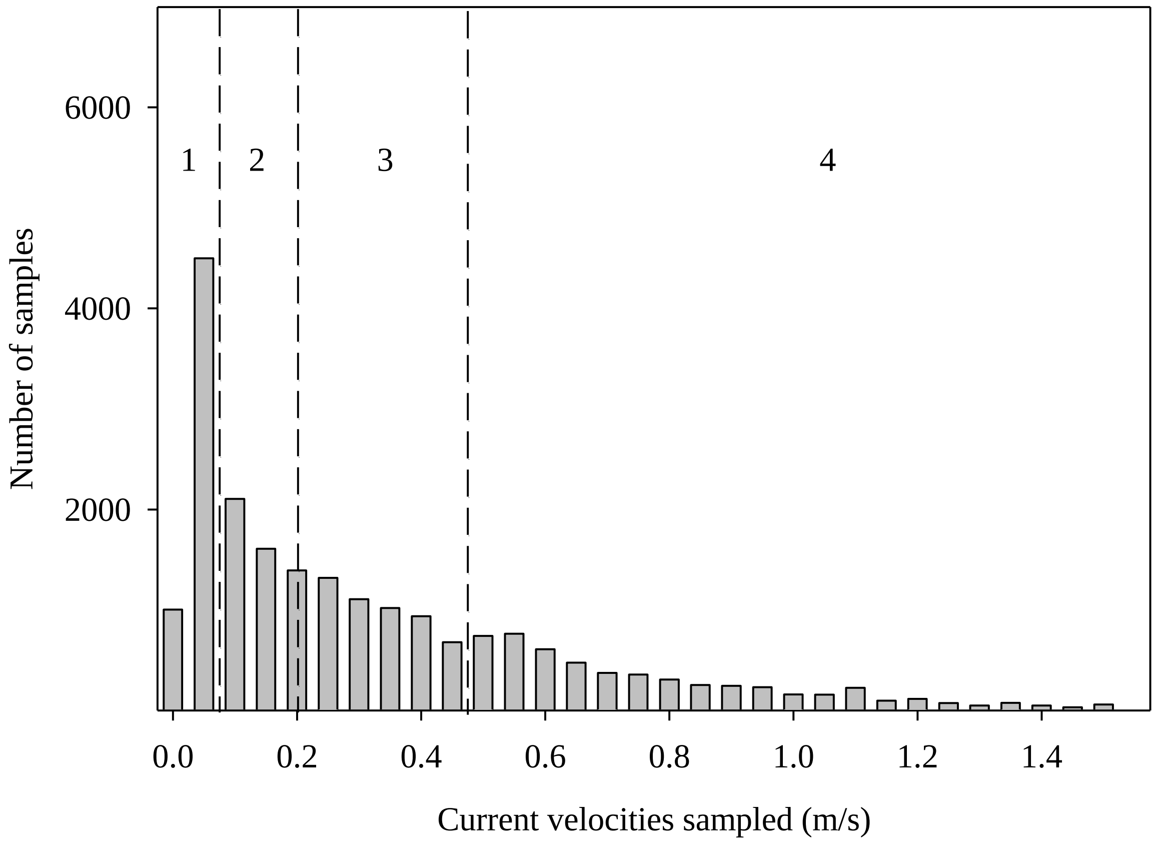


Figure 2.2. Demonstration of how quantile categories were created. X-axis represents all current velocities sampled across all raw data. Y-axis is the number of samples taken at each current velocity. Areas within dashed lines represent quartiles: 1=Slack, 2=Slow, 3=Moderate, 4=Swift.

III. SPRING FLOW LOST: A HISTORICAL AND CONTEMPORARY PERSPECTIVE OF AN URBAN FISH COMMUNITY

Abstract

Water quality and quantity within the upper San Antonio River (Bexar County, Texas) were dominated historically from spring flows of the Edwards Aquifer. Since the 1700s, water quality, quantity, physical aquatic habitats, and presumably fish communities have been altered in the upper San Antonio River, including loss of spring flow and replacement of base flow by treated waste water. The upper San Antonio river fish community provides a unique opportunity to fill gaps in knowledge on spring-associated fish responses to spring flow loss. The purpose of our study was to describe temporal changes in the upper San Antonio River fish community from reported fish collections and infer from reference conditions. Comparisons with reference conditions were necessary since anthropogenic alterations occurred before the first fish collections within the basins. We found the upper San Antonio River fish community changed through time with increases in native and introduced fishes and decreases in spring-associated fish richness and relative abundances. Decreases in spring-associated fish richness and relative abundances were attributed to decreases in spring flow and to changes in water quality; however, specific mechanisms linking loss of spring flow to declines of spring-associated fishes are unknown at this time. Quantifying historical fish community changes through time in systems with a long history of urbanization is difficult, but our assessment provides a greater understanding of the effects of urbanization on spring complexes.

Introduction

Freshwater spring and spring run environments (i.e., spring complexes) are hotspots for biodiversity and endemism (Scarsbrook et al. 2007; Cantonati et al. 2012; Davis et al. 2013), and provide evolutionary refugia for aquatic biota survival and diversification during cycles of glacial and interglacial periods (Tzedakis et al. 2002; Davis et al. 2013). Spring complexes of the karst Edwards Plateau of south central USA are historically and contemporarily habitats for endemic and cosmopolitan flora and fauna (Bowles and Arsuffi 1999). Among fishes, many of the endemic forms are thought to have radiated within the Edwards Plateau (Conner and Suttkus 1986), and some (i.e., spring-associated fishes) have a strong association with water quality (e.g., water temperature) of spring complexes that varies less than the water quality outside of spring complexes (Slade et al. 1986; Hubbs 1995; López-fernández and Winemiller 2005; Kollaus and Bonner 2012). As such, spring-associated fishes have greater relative abundances and densities within spring complexes compared to outside of spring complexes. Within spring complexes, species richness, relative abundance, and densities of spring-associated fishes are positively related to magnitude of spring flow (Craig et al. 2016).

Spring complexes of the Edwards Plateau differ along a gradient of anthropogenic alterations. Non-urbanized and minimally-disturbed spring complexes have intact fish communities, dominated by spring-associated fishes (Watson 2006; Kollaus and Bonner 2012). Urbanized spring complexes have minor changes in fish communities (e.g., increases in introduced fish richness) when spring flows are maintained (Garrett et al. 1992; Kollaus et al. 2015; Scanes 2016). When spring flows are not maintained and the spring complex is dewatered, the fish community is extirpated (e.g., Winemiller and

Anderson 1997). A gap in our understanding of anthropogenic alterations is how spring-associated fishes respond to loss of spring flows without dewatering of the spring complex.

The upper San Antonio River (Bexar County, Texas) is an example of an Edwards Plateau spring complex that, through time, has lost spring flow but has not been dewatered. The Upper San Antonio River forms from springs, which at one time were considered as one of the largest spring complexes within the Edwards Plateau with flows exceeding 4.5 m^3/s (G. Eckhardt, San Antonio Water System, San Antonio, TX, 2016 pers. comm.). Since the 1700s, the watershed surrounding the springs and upper San Antonio River has become urbanized. Anthropogenic alterations consisted of changes to stream morphology, water quality, and groundwater supply (Arneson 1921; Brune 1981; Glennon 2004). Median flow was reduced gradually to 0.36 m^3/s (USGS gaging station 08178000; 2013 – 2014) with primary source of base flow shifting from spring water to treated waste water from San Antonio Zoo (0.13 m^3/s; Miertschin 2006) and City of San Antonio (G. Eckhardt, pers. comm.). Reported changes in the fish community consist of increased occurrences and abundances of introduced species (Barron 1964; Hubbs et al. 1978). Edwards (2001) reported that introduced fishes accounted for 61% of fish species and 62% of the fish biomass. However, the response of the native fish community, including spring-associated fishes, to reduced spring flows is unknown.

Assessment of historical fish collections and comparison of existing fish community to reference conditions are two common methods used to quantify changes in fish communities related to anthropogenic alterations (e.g., Trautman 1981; Karr et al. 1985; Hughes and Noss 1992). Historical fish collections, however, can lack completeness and breadth (Davis and Simon 1994; Labay et al. 2011) and consist of fishes taken with a variety of gear and effort (Davis and Simon 1994; McManamay and Utz 2014), which compromises compatibility among collections. In the upper San Antonio River, an additional challenge is that fish collections in the 1800s were taken after documented anthropogenic alterations. In streams with incomplete historical fish collections or, like in the San Antonio River, collections taken after stream degradation, reference conditions can be used to provide expectations of historical conditions and enable assessment of community changes associated with anthropogenic alterations (Davis and Simon 1994). Craig et al. (2016) developed predictive models to estimate species richness, relative abundance, and density of spring-associated fishes within Edwards Plateau spring complex based on spring flow magnitude that range from 0.06 to 4.5 m^3/s. Predictions of Craig et al. (2016) as reference conditions, combined with quantification of fishes reported in the river, can provide a more comprehensive assessment of fish community changes in the upper San Antonio River.

The purposes of this study were to describe the temporal changes in the upper San Antonio River fish community based on reported fish collections and inferences made from predicted communities. Objectives were to 1) quantify contemporary fish community species richness and relative abundance and spring-associated fish density among four sites in 2013 and 2014, 2) compare fish community species richness, diversity, evenness, and relative abundance between contemporary collections and published and unpublished fish collections taken from 1853 through 2015, and 3) compare spring-associated fish richness, relative abundance, and density from Objective 1 and Objective 2 to reference conditions. Using reference conditions, we estimated that upper San Antonio River fish community was dominated by spring-associated fishes (i.e., 7 species, 77% in relative abundance, and 1.8 fish/m^2) before anthropogenic alterations and at earliest spring flow estimate of 4.5 m^3/s. We predicted that observed spring-associated fish richness, relative abundance, and density taken from 1853 through 2015 are less than expected by reference conditions given the history of anthropogenic alterations within the upper San Antonio River. If supported, then the information would provide insight into spring-associated fish responses to reductions of spring flow. We also estimated that the contemporary fish community should be dominated by spring-associated fishes (i.e., 5 species, 57% in relative abundance, and 0.3 fish/m^2) despite flows being reduced to 0.36 m^3/s. If observed spring-associated fish richness, relative abundance, and density are less than estimated, then the information would provide insight into effects of anthropogenic alterations (e.g., spring flow loss and replacement with treated waste water) independent of water quantity.

Methods

Groundwater of the Edwards Aquifer discharges 4.6 million m^3 of water annually (Hamilton et al. 2003) and provides surface waters in six major river basins of Texas (Rio Grande, Nueces River, San Antonio River, Guadalupe River, Colorado River, and Brazos River; Worthington 2003). Perennial portions of the upper San Antonio River historically began within the city of San Antonio at San Antonio Springs (29°28'7.73"N 98°28'2.80"W) and San Pedro Springs (29°26'49.55"N 98°30'5.86"W) (Figure 3.1). Outflows of San Pedro Springs join the San Antonio River about 10 km downstream from San Antonio Springs (Brune 1981). The upper San Antonio River (i.e., USGS

Segment 1911) continues downstream and through the City of San Antonio until merging with the Medina River approximately 30 km downstream. After the confluence, the lower San Antonio River flows into the Guadalupe River before discharging into San Antonio Bay.

Within the upper San Antonio River, largescale anthropogenic alterations began in the early 1700s with the construction of canals and aqueducts to transport water from the river to Spanish missions (Arneson 1921). By the late 1800s, water was contaminated with human waste; waterborne disease was pervasive (Brune 1981). Municipal water wells were drilled and accessed the same groundwater source as the artesian springs (Ewing 2000). As the City of San Antonio expanded rapidly from the 96th largest city in USA in 1880 to 54th by 1910, municipal water well use increased and artesian springs became intermittent by 1897 (Livingston et al. 1936). Additional water wells were drilled and diverted into the upper San Antonio River for the specific purpose of providing base flow to the river and to avoid complete dewatering of the stream channel. By 1918, artesian wells were the primary source of base flows in the river (Livingston et al. 1936). Beginning around 1930, additional artesian wells were drilled in downtown San Antonio for the purpose of single pass air conditioning systems, when after use, water was returned to upper San Antonio River and contributed to base flow (Livingston et al. 1936). Up to 1 m^3/s of well water was used and returned daily to the upper San Antonio River (Call 1953). Through time, wells were abandoned or capped, with the last remaining artesian well capped in 2004. In 2000, treated waste water was pumped into the upper reaches to supplement well water base flow. By 2004, base flows were dependent upon treated waste water discharges, although spring outflows from San

Antonio Springs and San Pedro Springs can contribute to base flows briefly following precipitation events. Currently, the upper San Antonio River drainage area (325 km^2) is highly urbanized (60% impervious cover, Kreuter et al. 2001; annual growth rate of 2.4% between 1970-2011; Zhao et al. 2016).

Earliest records of flow monitoring by USGS began in 1915 (USGS gage station 08178000) and was continuously monitored with few exceptions from 1938 to 1997. USGS gage station 08178050, located about 3 km downstream, began in 1992 and continuously monitored with few exceptions. Mean daily flow during the shared period of record (1992 – 1997) were correlated (r^2= 0.90) with gage station 8178050 having slightly greater (< 0.1 m^3/s) mean daily flow. A composite hydrograph was constructed, using mean daily flows from USGS gage station 08178000 (1915 – 1997) and mean daily flows from USGS gage station 08178050 (1997 – 2015) (Figure 3.2). Median of mean daily flows was 0.74 m^3/s from 1915 through 2015. Median of mean daily flows was 0.36 m^3/s (range: 0.01 – 5.4) during contemporary fish community collections.

To estimate contemporary community structure, we sampled four sites within the City of San Antonio four times from June 2013 to April 2014. Site 1 (29°27'32.23"N 98°28'25.75"W) was the most upstream site and located 2.5 km downstream from San Antonio Springs. Site 1 was within a forested city park, consisted of run, riffle, and pool mesohabitats, and located downstream from the San Antonio Zoo and city wastewater discharge sites. Site 2 (29°26'26.71"N 98°28'56.62"W) was located near downtown San Antonio and 2.5 km downstream from Site 1. Site 2 was artificially channelized and consisted of run mesohabitat. Site 3 (29°21'52.47"N 98°28'18.68"W) was located within another city park and located 12 km downstream from Site 2. Efforts (San Antonio River

Improvements Project, 2009 – 2012) to create mesohabitats in this area provided riffle, run, and pool habitats, riparian vegetation, and a reconfigured low head dam. Site 4 (29°16'31.55"N 98°26'5.84"W) was located 11 km downstream from Site 3. Site 4 was the least physically altered site (i.e., meandering stream, dense riparian vegetation) with run, pool, and backwater mesohabitats.

Fishes were sampled from available mesohabitats (i.e., riffles, pools, runs, and backwaters; Bain et al. 1999) within 200 to 500 m reach at each site using a combination of multiple single pass seining (3.2 mm mesh), bag seining (3.2 mm mesh), barge electrofishing (Smith-Root Model 2.5 GPP), and backpack electrofishing (Smith-Root Model 12-b POW). Seines were used at each site in slow moving, wadeable habitats, and barge and backpack electrofishing were used near woody debris, in shallow riffle habitats, or in deeper waters. Sampling techniques were standardized by area. All fishes were identified to species (Hubbs et al. 2008) and enumerated. Juvenile species of the genus *Lepomis* <15 mm in total length were grouped due to difficulty in confidently identifying morphologically distinguishing features. Fishes were released except for voucher specimens. Voucher specimens were kept, one per species, at each site and were euthanized with a lethal dose of tricaine methanesulfonate (MS-222) and fixed in a 10% formalin solution. Fishes were taken in accordance with Texas State University Animal Use and Care protocol 1207-0109-01 and Texas Parks and Wildlife Scientific Permit SPR-0601-159. Percent substrates, percent vegetation, percent woody debris, water depth, and current velocity were estimated at each site and by mesohabitat. Water temperature (°C), pH, conductivity (µS/cm), and dissolved oxygen (mg/l) were measured at each site using a YSI-85 multi-probe meter. Species richness (S), relative abundance

(%), diversity (H), and evenness (E) were calculated by combining quarterly samples by site. Diversity was calculated using the Shannon-Wiener index, and evenness was calculated using Shannon's evenness index. Species richness, Shannon-Weiner diversity index ($\log_e$), and evenness ($E = H / H_{max}$) were calculated by site.

Additional fish community data were obtained for the upper San Antonio River main stem from published and unpublished collections taken between 1853 and 2015. Collections were grouped by time periods. Fish records from 1853 through 1979 were obtained from museum records (Hendrickson and Cohen 2015), Barron (1964), and Hubbs et al. (1978). Records contained partial reporting of fish collections; therefore, we only retained and combined species occurrences to represent the earliest time period. For the 1980s (1980 – 1989), fish occurrences and counts were obtained from Twidwell (1984) and Gonzales (1988). For the 1990s (1990-1999), fish occurrences and counts were obtained from San Antonio River Authority (1996) and museum records (Hendrickson and Cohen 2015). For the 2000s (2000 – 2009), fish occurrences and counts were obtained from Edwards (2001), Hoover et al. (2004), Gonzales and Moran (2005), BIO-WEST (2012), and Texas Commission on Environmental Quality (2015). For the 2010s (2010 – 2015), fish occurrences and counts were obtained from BIO-WEST (2012), Texas Commission on Environmental Quality (2015), and this study. Species identified among published and unpublished literature were accepted as reported, except for *Pimephales notatus* and *Oreochromis niloticus* (Hoover et al. 2014) since neither species were recorded as vouchered specimens and not previously known from the drainage (Hendrickson and Cohen 2015). Fish names were revised according to Page et al. (2013). Fish occurrences and counts were summed among collections by time period to calculate relative abundances. Fish sampling, when provided, ranged from one technique (e.g., seining) to multiple techniques (e.g., seining, electrofishing, gill netting, and dip netting) and from one to multiple locations within the upper San Antonio River. Combining fish occurrences and summing collections by time period have limitations, when fishes were sampled for different purposes and by different collectors, techniques, and efforts. We acknowledge, as others (Perkin and Bonner 2011; Kollaus et al. 2015), potential limitations in compiling and interpreting fish community changes through time; however, limitations do not preclude use of these data, because these data, at the very least, are a summary of the fish community reported within the upper San Antonio River.

Fishes were categorized as native or introduced (Hubbs et al. 1978; Edwards 2001; Hubbs et al. 2008). Spring-associated fishes (i.e., *Dionda nigrotaeniata*, *Notropis amabilis*, *Astyanax mexicanus*, *Percina carbonaria*) were defined based on range-wide distributions (Craig et al. 2016). *Astyanax mexicanus* is considered introduced into San Antonio River (Brown 1953), a basin adjacent to their native range. This species was retained as a spring-associated fish, because *A. mexicanus* is native in two drainages within the Edwards Plateau reported by Craig et al. (2016) and are associated with minimally-disturbed spring systems. Other introduced fishes (e.g., *Hypostomus sp*, *Oreochromis aureus*, *Oreochromis mossambicus*) are associated with spring complexes within the Edwards Plateau. These introduced fishes were not retained as spring-associated fishes because of their certainty as introduced species within the Edwards Plateau. Species richness, relative abundance, Shannon-Weiner diversity index, and Shannon's evenness were calculated for each time period after 1979.

Reference conditions for fish community structure of the upper San Antonio River were obtained from models developed by Craig et al. (2016), which predicted spring-associated fish communities related to spring flow. Models were calculated from six independent and minimally-disturbed spring complexes within the Edwards Plateau and represent expectations of spring complex fish communities (i.e., spring-associated fish richness, relative abundance, and density) with median spring flow. Estimated historical flow (x) of the upper San Antonio River (4.5 m^3/s; maximum flow assessed in reference conditions) was used to calculate expected spring-associated fish richness ($y = 0.203 (1-e^{(-3.13x)})$). Expected spring-associated fish relative abundance and density were not calculated, because relative abundances were not available in the earliest time period (1853 – 1979) and densities were not available from additional fish collections. Observed spring-associated fish richness were taken from contemporary (2013 – 2014) and additional (1853 – 2015) fish collections. Median flow (0.36 m^3/s) was used to calculate expected spring-associated fish richness ($y = 0.203(1-e^{(-3.13x)}$), relative abundance ($y = 82.53(1-e^{(-3.35x)}$), and density ($y = 0.203 + 0.352x$). Observed spring-associated fish richness, relative abundance, and density were taken from contemporary fish collections, combined among the four sites. Differences in species richness, relative abundance, and density between expected and observed were assessed by estimating the probability of the standard residual z-score [$Z_{\text{residual}} = (y_{\text{observed}} - \hat{y}_{\text{expected}}) / SD_{\text{residual}}$] with N – 2 DF. Expected species richness was rounded to a whole number.

Results

A total of 5,806 fishes, representing 10 families and 31 species, was collected among four sites from June 2013 through April 2014 (Table 3.1). The most abundant family was Cyprinidae (55%) followed by Poeciliidae (18%), Centrarchidae (16%), and Cichlidae (8.8%). Two spring-associated fishes (*Astyanax mexicanus* and *Percina carbonaria*) were found within the upper San Antonio River. Spring-associated fishes were most abundant at Site 1 (11.3%) followed by Site 3 (1.8%) and had a combined relative abundance of 1.5% and a combined density of 0.02 fish/m^2. We caught 10 introduced species. Water temperatures ranged from 12 to 32ºC, dissolved oxygen concentrations ranged from 3 to 13 mg/L, and specific conductivities ranged from 406 to 1091 µS/cm.

A total of 34,326 fishes, representing 13 families and 52 species, was collected from 1853 through 2015 (Table 3.2). The most abundant families were Cyprinidae (range among time periods: 17 - 54%), Poeciliidae (19 - 35%), and Cichlidae (5.5 – 32%). Species richness ranged from 24 species in the 1980s to 41 species in the 2000s, diversity ranged from 1.89 in the 1980s to 2.32 in the 2000s, and evenness ranged from 0.59 in the 2010s to 0.70 in the 1990s. Diversity increased though time from 1.89 in the 1980s to 2.18 in the 2010s, whereas evenness remained similar between the 1980s and the 2010s. Spring-associated fish richness was greatest with three species in the 2000s. Introduced fish richness was greatest (S = 15) in the 2000s. Relative abundances of introduced species were 52% in the 1980s and decreased to 17% in the 2010s. Spring-associated fish relative abundances were 21% in the 1980s and decreased to 2.0% in 2010s.

The model of Craig et al. (2016) predicted a species richness of seven spring-associated fishes (95% CI = ± 2.1) at an earliest spring flow estimate of 4.5 m^3/s. Among

1853 through 2015 fish collections, observed spring-associated fish richness of four (i.e., *Dionda nigrotaeniata*, *Notropis amabilis*, *Astyanax mexicanus*, and *Percina carbonaria*) was less than expected ($P < 0.01$; Table 3.3). Models predicted a species richness of five spring-associated fishes (95% CI = ± 2.03) with a relative abundance of 57% (95% CI = ± 15.7) and a density of 0.33 fish/m^2 (95% CI = ± 0.4) at median flow of 0.36 m^3/s. Within the contemporary community, observed spring-associated fish richness of two (i.e., *Astyanax mexicanus*, and *Percina carbonaria*) was less than expected ($P < 0.01$), relative abundance of 1.5% was less than expected ($P <0.01$), and density of 0.02 fish/m^2 was not different ($P = 0.15$) from expected.

Discussion

Based on assessments of collections taken from 1853 through 2015 and comparing upper San Antonio River fish community to reference conditions, we observed differences in the fish community through time. Since the 1980s, species richness of native fishes increased, species richness of introduced species increased, and spring-associated fish relative abundance decreased. As predicted, spring-associated fish richness among 1853 through 2015 collections was less than the reference condition at historical spring flow of 4.5 m^3/s, and spring-associated fish richness and relative abundance of contemporary community (2013 – 2014) were less than reference conditions at reduced spring flow of 0.36 m^3/s.

Suburban and urban fish communities differ along a gradient of anthropogenic alteration (Wang et al. 2001; Meyer et al. 2005) ranging in extremes from fish community extirpation (Klein 1979) to less abundance in sensitive fishes (Mitner et al.

2004). Based on our assessment, the upper San Antonio River fish community has changed but maintains native fishes including sensitive fishes. The upper San Antonio River currently supports 28 native fishes including three species (i.e., *Notropis volucellus*, *Noturus gyrinus*, and *Percina carbonaria*) considered as intolerant by Linam et al. (2002) per water quality standards. Detected changes in the fish community were largely consistent with other urbanized streams (i.e., increases in introduced fishes, decreases in sensitive fishes; Walsh et al. 2005) with an exception of increases in native fishes. We found increases in native fishes, which is an uncommon finding but similar to findings of Morgan and Cushman (2005). Morgan and Cushman (2005) attribute increases in native fishes to potential changes in food web structure or habitats that allowed for invasion of opportunistic fishes. We attributed increase in native fishes within the upper San Antonio River through time to increases in sampling effort; however, fish moving into our study reach from downstream reaches is possible based on connectivity to non-urbanized reaches (Pretty et al. 2003) and could be attributed to improvements in upper San Antonio River water quality (Miertschin et al. 2006). However, most studies reviewed by Walsh et al. (2005) reported increases in introduced fishes and loss of sensitive fishes. We found increases in introduced fishes, which is associated with human activities (e.g., aquarium dumps; Marchetti et al. 2006). Likewise, we found decreases in the spring-associated fishes, which we define as the sensitive forms in spring systems.

We attributed decreases in spring-associated fish richness between expected (S = 7; reference condition) and observed (S = 4; 1853 – 2015 collections) primarily to reductions in flow from 4.5 m^3/s to 0.36 m^3/s. A caveat is our uncertainty on the species richness of spring-associated fishes within the upper San Antonio River before anthropogenic alterations. However, an estimate of seven spring-associated fishes is reasonable, given that the Guadalupe-San Antonio River drainage supports nine spring-associated fishes (Kollaus et al. 2015, Scanes 2016) and the Medina River, a spring complex tributary of the San Antonio River with a median flow of 1.4 m^3/s, supports five spring-associated fishes (Hendrickson and Cohen 2015).

We attributed the difference in spring-associated fish richness, relative abundance, and density between expected (S = 5; 57% in relative abundance; 0.33 fish/m^2 in density; reference conditions) and observed (S = 2; 1.5%; 0.02 fish/m^2; contemporary community) at 0.36 m^3/s, primarily to changes in water quality associated with loss of spring flow. Since the hydrograph record began in 1915, median flows have remained relatively unchanged among time periods (range: 0.36 – 1.95), except that spring flow gradually was reduced and then lost with capping of the last artesian well in 2004. Also, water quality has been impaired before and during the hydrograph record. More recently, the upper San Antonio River has low dissolved oxygen, acute selenium levels, acute and chronic organics levels, and high levels of *E. coli* and fecal coliform (Texas Commission on Environmental Quality 2002). The relationship between the loss of spring flow and the contemporary spring-associated fish community suggests a direct relationship. However, the exact mechanism linking spring-associated fish to spring flow is unknown at this time and more information is needed to understand specific mechanisms. Besides loss of spring flow, other factors could explain decreases in spring-associated fishes, such as legacy effects of >100 years of water quality impairment or a suite of other anthropogenic alterations. Urban systems have synergistic relationships among water quantity, water quality, and stream morphology; therefore, relating fish community response to a single or few factors is difficult (Meyer et al. 2005; Walsh et al. 2005).

Researchers struggle to quantify historical fish community changes in rivers with a long history of urbanization. Observations of the fish community changes are anecdotal (e.g., River Thames, United Kingdom; Carter and England 2004) or take place long after anthropogenic alterations occur (e.g., Seine River, France; Beslagic et al. 2013). In this study, challenges in quantifying fish community changes included fish records taken after anthropogenic alterations, incomplete records since first fish collections, inferring expected fish communities from reference conditions, and uncertainty in historical flow. Despite the challenges, our analysis of upper San Antonio River fish community can contribute to a greater understanding of urbanization effects on spring complexes. Specifically, we quantified the gap in knowledge of spring-associated fish responses to loss of spring flows without dewatering of the spring complex. With declines and loss of spring flow, spring-associated fishes decline. In contrast, spring complexes are resistant to urbanization when spring flows are maintained (Kollaus et al. 2015). Spring flow, similar to river flow (Poff et al. 1997), is likely the master variable maintaining spring complex fish communities by regulating physical, chemical, and biological processes (Whiting and Stamm 1994; Bowles and Arsuffi 1999). Our study suggests that replacement of spring flows with alternative water sources is not sufficient to maintain the spring-associated fish community because water quality in addition to quantity (Craig et al. 2016) of the spring water influences richness, relative abundance, and density of spring-associated fishes. This is in contrast with the use of treated waste water in nonspring systems, where relatively small shifts in community structure are observed (Porter and Janz 2003; Brown et al. 2011).

Table 3.1. Upper San Antonio River occurrences and abundances of fishes collected by site from 2013 through 2014. Status identified fishes as native (N) or introduced (I). Asterisk denotes spring-associated species identified by (Craig et al. 2016). Juvenile individuals of the genus *Lepomis* <15 mm in total length were grouped together and not counted towards species richness. Species within genus *Hypostomus* and *Pterygoplichthys* were counted as two species in species richness calculations. Likely each genus contains multiple species, but taxonomic status of species is uncertain (Cook-Hildreth et al. 2016). Diversity was calculated using the Shannon-Wiener index, and evenness was calculated using Shannon evenness.

	Status	**Site 1**	**Site 2**	**Site 3**	**Site 4**	**Combined**
Dorosoma cepedianum	N			<0.1	1.2	0.6
Dorosoma petenense	N				<0.1	<0.1
Campostoma anomalum	N			0.9	<0.1	0.3
Cyprinella lutrensis	N		10.4	66.0	39.3	43.4
Cyprinus carpio	I				0.2	0.1
Notropis volucellus	N	3.1	19.7	<0.1	<0.1	1.7
Pimephales promelas	N				<0.1	<0.1
Pimephales vigilax	N			2.5	17.2	9.8
*Astyanax mexicanus**	I	11.3	0.7	1.8	<0.1	1.5
Ameiurus melas	N			0.7		0.2
Ameiurus natalis	N	0.2			<0.1	<0.1
Ictalurus punctatus	N		0.5	0.6		0.2
Noturus gyrinus	N				<0.1	<0.1
Hypostomus	I	0.5				<0.1
Pterygoplichthys	I		0.5			<0.1
Menidia audens	N				<0.1	<0.1
Gambusia affinis	N	46.0	13.7	12.7	7.4	12.4
Poecilia formosa	I	0.7	0.7	0.5	0.9	0.7
Poecilia latipinna	I	1.2	1.2	0.8	7.6	4.4
Lepomis auritus	I	6.0	23.9	0.4	5.9	5.4
Lepomis cyanellus	N			0.4	0.8	0.6
Lepomis gulosus	N			<0.1	0.1	0.1
Lepomis macrochirus	N	16.6	0.9	1.8	6.9	5.4
Lepomis megalotis	N	1.2	0.7	0.9	4.4	2.7
Lepomis microlophus	N		0.2			<0.1
Lepomis		0.5	0.7	0.1	1.3	0.8
Micropterus salmoides	N	4.3	0.9	0.2	0.4	0.6
Pomoxis annularis	N			<0.1		<0.1
*Percina carbonaria**	N				<0.1	<0.1
Herichthys cyanoguttatus	I	7.5	3.3	3.4	6.1	5.1
Oreochromis aureus	I	0.7	21.8	6.3	<0.1	3.8
Tilapia zillii	I			<0.1		<0.1
Individuals collected		415	422	1,949	3,020	5,806
Species richness		13	15	21	24	31
Introduced species richness		7	7	7	7	10
Diversity (Shannon-Weiner)		1.73	1.93	1.35	1.94	2.05
Evenness		0.67	0.71	0.44	0.61	0.59

Table 3.2. Occurrences and abundances of fishes reported from contemporary (2013 – 2014) and additional (1853 – 2015) fish collections from the upper San Antonio River. Status identified fishes as native (N) or introduced (I). "X" denotes reported occurrence where quantity was not specified. Asterisk denotes spring-associated species identified by (Craig et al. 2016). Juvenile individuals of the genus *Lepomis* <15 mm in total length were grouped together and not counted towards species richness. Species within genus *Hypostomus* and *Pterygoplichthys* were counted as two species in species richness calculations. Likely each genus contains multiple species, but taxonomic status of species is uncertain (Cook-Hildreth et al. 2016). Genus *Tilapia* counted towards introduced species richness when *T. zillii* was not observed in a time period. Number of collectors represents the number of independent collections within a time period. Diversity was calculated using the Shannon-Wiener index, and evenness was calculated using Shannon evenness. Median flows were calculated from mean daily flows by time period.

	Status	**1853 - 1979**	**1980s**	**1990s**	**2000s**	**2010 - 2015**
Lepisosteus oculatus	N			<0.1	<0.1	<0.1
Lepisosteus osseus	N		<0.1			
Dorosoma cepedianum	N	X			<0.1	0.5
Dorosoma petenense	N					<0.1
Campostoma anomalum	N			0.5	4.2	2.2
Carassius auratus	I				<0.1	
Cyprinella lutrensis	N	X	28.0	15.5	32.6	41.8
Cyprinella venusta	N	X	<0.1		0.8	1.1
Cyprinus carpio	I				<0.1	<0.1
*Dionda nigrotaeniata**	N		<0.1			
Notemigonus crysoleucas	I				0.2	
*Notropis amabilis**	N	X			1.3	
Notropis buchanani	N				0.8	
Notropis stramineus	N				0.3	0.1
Notropis texanus	N	X			<0.1	<0.1
Notropis volucellus	N	X	6.1	0.1	0.1	1.6
Pimephales promelas	N		0.2	0.3		<0.1
Pimephales vigilax	N	X		0.6	5.4	7.6
Moxostoma congestum	N			0.2	0.3	0.2
*Astyanax mexicanus**	I	X	20.8	5.7	5.9	1.8
Ameiurus melas	N				<0.1	0.2
Ameiurus natalis	N	X	0.3	1.7	0.4	0.4
Ictalurus furcatus	N		0.1	0.5		
Ictalurus punctatus	N	X	0.2	4.8	0.9	0.4
Noturus gyrinus	N	X		<0.1	<0.1	0.2
Hypostomus	I	X	0.6	4.2	1.6	<0.1
Pterygoplichthys	I				0.4	<0.1
Menidia audens	N	X			<0.1	<0.1
Lucania parva	N	X				
Belonesox belizanus	I	X				<0.1
Gambusia affinis	N	X	11.7	7.9	19.2	15.0
Poecilia formosa	I	X			3.5	0.7
Poecilia latipinna	I	X	23.2	19.8	10.5	3.5
Poecilia reticulata	I	X			<0.1	
Xiphophorus helleri	I			0.5	<0.1	
Lepomis auritus	I		2.2	2.7	0.7	4.4
Lepomis cyanellus	N	X	0.5	2.6	0.5	0.5

Table 3.2. Continued.

	Status	**1853 - 1979**	**1980s**	**1990s**	**2000s**	**2010 - 2015**
Lepomis gulosus	N	X	<0.1	<0.1	<0.1	<0.1
Lepomis macrochirus	N	X	0.4	0.5	0.5	4.1
Lepomis megalotis	N	X	0.3	0.5	0.8	3.7
Lepomis microlophus	N		<0.1			<0.1
Lepomis miniatus	N	X	0.1		0.2	0.7
Lepomis			<0.1			0.6
Micropterus dolomieu	I	X				
Micropterus punctulatus	N				0.2	0.5
Micropterus salmoides	N	X	0.2	0.2	0.6	0.9
Pomoxis annularis	N					<0.1
*Percina carbonaria**	N				<0.1	0.2
Herichthys cyanoguttatus	I	X	3.7	24.8	4.4	4.2
Oreochromis aureus	I		0.3	<0.1	0.4	2.8
Oreochromis mossambicus	I	X	1.5	6.0	2.6	
Tilapia zillii	I	X			0.4	<0.1
Tilapia				0.8		
Number of collectors		15	2	2	5	4
Individuals collected		819	7,146	3,536	15,014	7,811
Species richness		29	24	26	41	39
Introduced species richness		10	7	8	15	11
Diversity (Shannon-Weiner)			1.89	2.24	2.32	2.18
Evenness			0.60	0.70	0.62	0.59
Median flows (m^3/s)		0.85	0.51	0.57	1.95	0.36

Table 3.3. Standard residual z-score ($Z_{residual}$), degrees of freedom (DF), and P-value for Craig et al. (2016) expected model parameters and observed for fish communities during two time periods in the upper San Antonio River.

Fish community	Parameter	Flow (m^3/s)	$y_{observed}$	$\hat{y}_{expected}$	SD	$Z_{residual}$	DF	P-value
1853 - 2015	species richness	4.5	4	7	1.06	-2.84	4	< 0.01
Contemporary	species richness	0.36	2	5	1.06	-2.84	4	< 0.01
	relative abundance (%)	0.36	1.5	57	11.30	-4.91	4	< 0.01
	density (fish / m^2)	0.36	0.02	0.33	0.296	-1.05	4	0.15

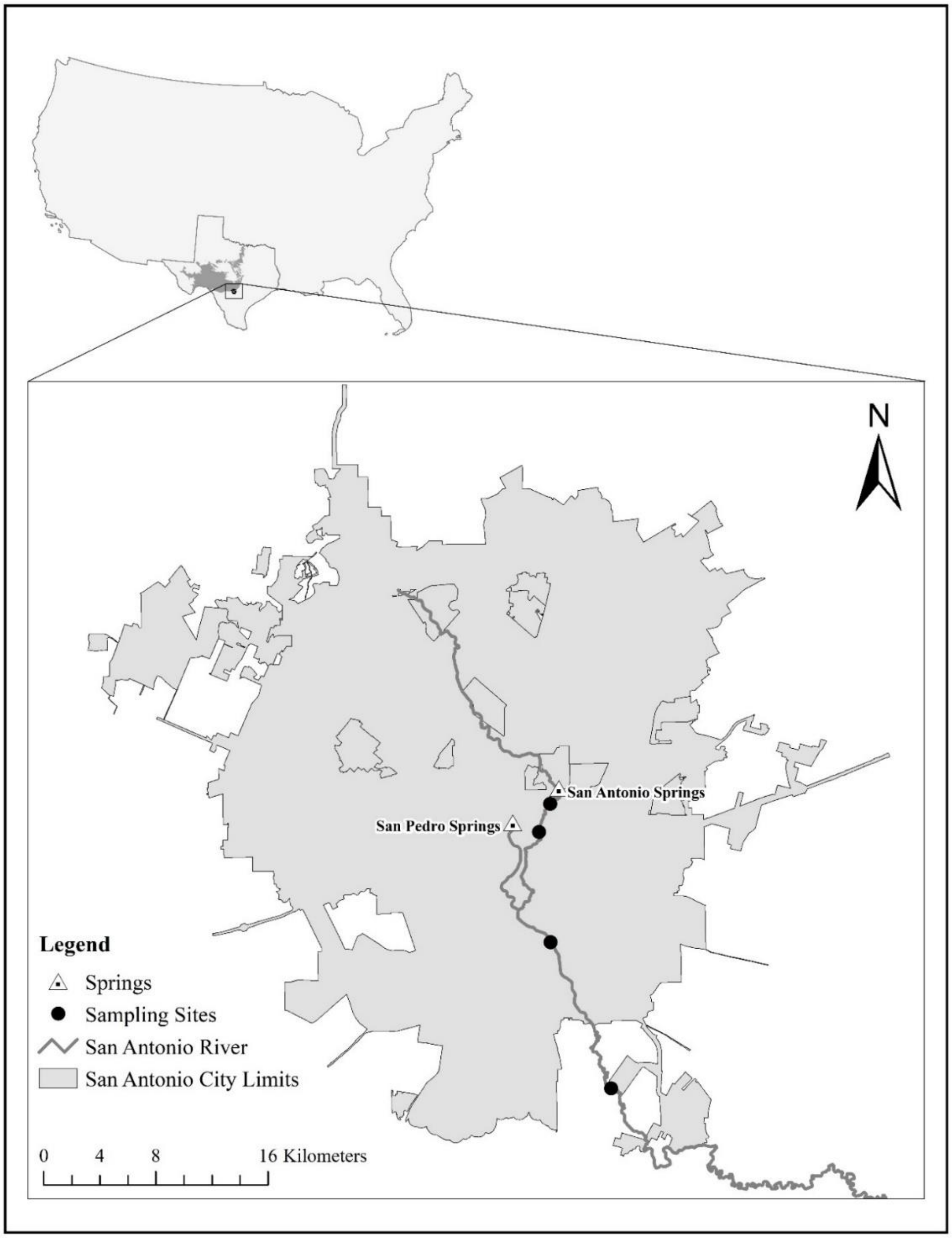


Figure 3.1. Shaded area represents the Edwards-Trinity aquifer system in Texas. Inset map illustrates the locations of the two major springs and sampling locations in the upper San Antonio River (Bexar County). Sampling locations were used to estimate contemporary fish community 2013 – 2014.

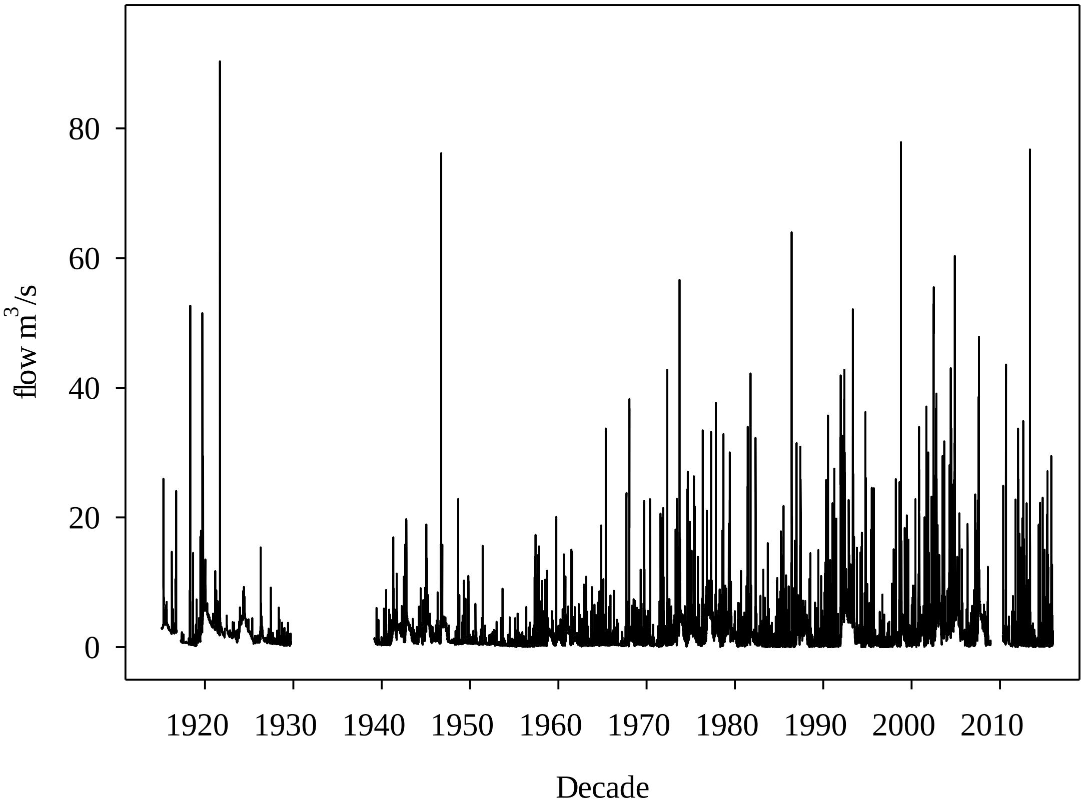


Figure 3.2. Composite hydrograph of mean daily flow for USGS gaging station 08178000 and 8178050 ($r^2 = 0.90$). Period of record from February 1915 through December 2015.

IV. TESTING EXPECTATIONS OF AN UNDERSTUDIED SPRING FISH COMMUNITY USING MODELS AND HISTORICAL DATA

Abstract

Spring complexes within the Edwards Plateau are unique headwater systems that harbor a unique and endemic spring fish communities. Upper Nueces River basin contains three spring complexes (Nueces, Frio, and Sabinal Rivers) that are understudied. Shifts in the upper Nueces River basin can be documented historically, however, since historical data is limited, models based on reference conditions of other spring complexes can supply additional predictions. The purpose of this study was to test expectations of spring fish community composition using historical data combined with models that provide predictions based on spring flow. No temporal shifts in spring fish community were detected across time periods. Contemporary sampling found species richness, relative abundance, and densities for the Nueces River basin spring complexes met model expectations. Based on the lack of historical changes and model adherence, upper Nueces River basin meets expectations of an intact spring fish community. Results bolster models, which could be used to assess other understudied or unknown spring complex fish communities

Introduction

Fish communities are regulated by a hierarchy of abiotic and biotic structuring mechanisms (Jackson et al., 2001). At a broad level, water quality and water quantity are the coarse filters for community composition (Smith and Powell, 1971). Water quality and quantity change from the headwaters to lower reaches of the river and in turn support different biotic communities. Lower reaches tend to have more stable diel temperatures as well as greater and more stable water quantity, which supports a diverse biotic community that is more permanent (Vannote et al., 1980). Conversely, headwater streams are defined by their abiotic variability, including fluctuations in temperature. Variable conditions filter the aquatic community such that headwater stream biota is represented by low species richness and transient, often seasonal, inhabitants (Whitney et al. 2016). Known distributional gradients of biota (e.g., River Continuum Concept; Vannote et al., 1980), provide sufficient replication of patterns to inform expectations for previously unstudied streams. Predictive and comparable models, such as Index of Biological Integrity (IBI; Karr, 1991), provide a standardized approach to gauging an understudied stream's health, but selection of appropriate ecological indicators can be difficult, especially in unique systems with many endemic forms (Beyeler, 2001).

Voluminous-discharge karst springs and spring complexes are unique ecosystems and provide a novel exception to headwater community structure through stenoecious abiotic conditions. Karst spring complexes are defined by stable spring discharges that are decoupled from local precipitation and climate (Davis et al., 2013). Spring complexes also offer stenoecious water quality (*e.g.*, stable water temperature, conductivity, dissolved oxygen, low turbidity, and pH). Water quantity and quality of spring complexes provide unique community of spring inhabitants, many of which are endemic to the spring complexes. Spring flow discharge is a primary structuring mechanism of spring complexes that controls secondary structuring mechanisms such as temperature (Craig et al., 2019). Because of this, spring flow discharge is a predictor of spring-associated fish ("spring fish") communities within the Edwards Plateau (Craig et al., 2016). In systems where spring flow is replaced with flow from a different source, the spring fish community richness, relative abundance, and densities are reduced (Craig and Bonner, In review). However, when spring flow is present, even in a highly urbanized river, the spring fish community remains intact (Kollaus et al., 2015). Although understudied, several spring systems exist that harbor unique and endemic biota. In Texas, at least 12 fishes are associated with spring complexes (Craig et al. 2016). Use of traditional monitoring tools poses problems to monitoring spring fish communities due to the complexity of the relationship to spring flow magnitudes, which current biomonitoring methods do not take into account (i.e., Linam et al., 2002). Therefore, predictions made about unstudied or understudied-spring complexes using traditional techniques lack resolution for assessing spring complex community health.

The Nueces river basin (43,300 km^2) is an independent river system with minimal land modification (Thomas et al., 2019) and is contained entirely within Texas. Although it is the 6th largest river by drainage area in the state, it has the least studied fish community based on number of museum occurrence records (Hendrickson and Cohen 2015; Table 4.1). Current knowledge exists in species checklists (e.g., Craig and Bonner, 2019), historical museum occurrence records (Hendrickson and Cohen, 2015), and unpublished reports within a small reach (Robertson, 2016). Lack of studies is especially surprising considering the headwaters of the three major tributaries (i.e., Nueces, Frio, and Sabinal) are spring complexes with noted ecologic and evolutionary importance (Hubbs, 1995; Lucas et al., 2009). Assessment of historical fish collections and comparison of existing fish community to reference conditions are two common methods used to quantify unknown fish communities (e.g., Hughes and Noss, 1992; Karr et al., 1985; Trautman, 1981). Historical fish collections, however, can lack completeness and breadth (Davis and Simon, 1994; Labay et al., 2011) and consist of fishes taken with a variety of gear and effort (Davis and Simon, 1994; McManamay and Utz, 2014), which compromises compatibility among collections. Although historical data are sparse, species occurrences within each tributary could be calculated, which provides insight to historical species presence. Additionally, Craig et al. (2016) predicted spring fish richness, relative abundance, and densities along a spring flow discharge gradient across 6 spring complexes of the Edwards Plateau in Texas. This model could potentially be used in addition to historical occurrence data to predict native spring fish communities based on spring discharge.

The purpose of this study was to assess if three major tributaries (Nueces, Frio, and Sabinal Rivers) of the upper Nueces basin fish communities meet expectations of intact spring complexes using historical data, statistical models, and current sampling. Historical data were compiled from museum records to assess the presence or absence and relative abundance of spring fish community through time. Model predictions from Craig et al (2016) were used to quantify divergence or conformity to other spring complexes of the Edwards Plateau and provide predictions of species richness, relative abundance, and densities based on spring flow discharge. Current fish community will be sampled along a longitudinal gradient of the three major tributaries (Nueces, Frio, and Sabinal Rivers) and were compared to historical and model predictions. Because of minimal urbanization and historically stable spring flows characteristic of Edwards Plateau spring complexes, we predict that the fish communities will have remained relatively unchanged through time and meet expectations of an intact spring fish community (i.e., the “minimally-altered” category in Craig et al 2016).

Methods

The upper Nueces River basin originates from springs from the Edwards-Trinity Aquifer and includes three main tributaries; the Nueces River, Frio River and Sabinal River that drain approximately 7,000 km^2. The three tributaries transition from the Edwards Plateau to the South Texas Plains ecoregion around US Highway 90. Once off the plateau, the Sabinal and Frio join about 17 km northwest of Frio Town, Texas (29.103448, -99.443211). The Frio and Sabinal confluence with the Nueces River is 2 km south of Three Rivers, Texas (28.437230, -98.188554), and flows southeast for 115 km where it flows into Corpus Christi Bay in the Gulf of Mexico. For this study, we delineated the upper Nueces River basin as the headwaters to the southern end of the Edwards Plateau (i.e., US highway 90). Historical median discharge is 0.65 m^3/s in the Nueces River (period of record: 2009 - 2020; USGS 0818999010), 0.28 m^3/s in the Frio River (period of record: 1991 – 2020; USGS 08195000), and 0.06 m^3/s in the Sabinal River (period of record: 2014 – 2020; 2014; USGS 08197936).

Historical fish community data was compiled from museum collections from 1851 through 2013 (Hendrickson and Cohen, 2015). The number of individuals by species were grouped by time period. Records from 1851 - 1949 were sporadic and contained partial reporting of fish collections; therefore, we combined these decades to represent the earliest time period. Historical collection reports were not specific to one site and did not provide sufficient individual count information to estimate species relative abundances until 1950s. Historical collections from 1851-1979 included some presence/absence data which were counted as one individual for analysis. Records taken from 2010 - 2013 before our study were combined with records from 2000s due to limited sampling prior to contemporary sampling.

Contemporary fish community was estimated from 13 sites (Table 4.2) in the upper Nueces River basin (Figure 4.1). Sites were sampled three times between June 2015 and April 2016. At each site, all available mesohabitats (i.e., geomorphic units level 3; Hawkins et al., 1993) were delineated and replicates of each mesohabitats were sampled when available. Within each mesohabitat, fish were taken by a combination of seining and electroshocking. In flowing water mesohabitats (i.e., riffles and shallow runs), downstream boundary of the mesohabitats were blocked with seines and an electroshocker was used, starting at the upstream boundary, to stun the fish and either float downstream into the blocking seine or captured with dip nets. In slack water mesohabitats (i.e., backwaters and pools), common sense seines (3 m x 1.8 m, mesh size = 3.2 mm) and bag seine (5 m x 1.8 m, mesh size = 3.2 mm) were employed in an upstream to downstream direction. In backwaters and pools with large boulders, electroshocker and dipnets were used to sample fish from areas inaccessible with seines. Fishes collected were retained in aerated containers by mesohabitat until after all mesohabitats were sampled. Captured fishes were identified to species (Craig and Bonner, 2019), enumerated, and released excepted for voucher species per site. Voucher specimens were anesthetized in a lethal dose (150 mg/l) of tricaine methanesulfonate (MS-222) and preserved in 10% formalin. Length and width of area sampled were measured for density estimates. Protocols and procedures followed those described in

IACUC 201473646 (issued to T. Bonner) and Texas Parks Texas Parks and Wildlife Department (TPWD) Scientific Permit 0601 – 159 (issued to T. Bonner). Contemporary collections also consisted of fishes taken from four sites on the Frio River in May 2014 with sampling methodologies reported by Robertson (2015).

Among historical and contemporary fish data, richness and relative abundances of spring fishes were calculated. Spring fishes were *Cyprinella lepida, Dionda serena*, *Notropis amabilis, Astyanax mexicanus, Ictalurus lupus, Etheostoma lepidum*, and *Percina carbonaria* as defined by Craig et al. (2016). In an effort to detect historical trends in the overall fish community, linear regressions were performed for basin-wide spring fish richness and relative abundance through time. Regressions were also performed for spring fish richness and relative abundance through time for Nueces and Frio tributaries. No regressions were performed for the Sabinal due to lack of samples from 1970 - 2014. In contemporary collections only, densities (the number of individuals taken per species per the area of a mesohabitat) of spring fishes were calculated, because area sampled were not included in historical collections. Observed richness, relative abundances, and densities of spring fishes from contemporary collections were compared to richness, relative abundance, and density model predictions of Craig et al. (2016) for intact spring fish communities per spring flow. Comparisons were made by assessing observed estimates of spring fish richness, relative abundances, and densities from contemporary collections per river with expected estimates (and 95% confidence intervals) of an intact spring fish community. Expected estimates and 95% confidence intervals were calculated for richness ($y = 0.203(1-e^{(-3.13x)})$, relative abundance ($y = 82.53(1-e^{(-3.35x)})$, and density ($y = 0.203 + 0.352x$), with x being the median flow per each river. If observed was not within 95% CI, the difference was interpreted as statistically significant. However, flows in the Sabinal River (0.06 m^3/s) were less than those reported in the predictive models. Therefore, we used expected richness, relative abundance, and density from the lowest discharge spring complex (Cypress Creek, 0.065 m^3/s) in Craig et al. (2016).

Results

The historical and contemporary fish community data within the upper Nueces River Basin consisted of 29,506 individuals, representing 12 families and 46 species, from 1851 - 2016 (Table 4.3). Historical collections (1851 – 2013) within the upper Nueces River basin consisted of 20,878 individuals, representing 12 families and 46 species. The most abundant family was Cyprinidae (66%), followed by Centrarchidae (10%), and Poeciliidae (10%). Spring fish richness was six species within the Nueces River, seven species within Frio River, and five species in the Sabinal River. Mean spring fish relative abundance was 50% in the Nueces River, 40% in the Frio River, and 20% in the Sabinal River. Contemporary collections (2014-2016) within the upper Nueces River basin consisted of 8,628 individuals, representing eight families and 26 species (Table 4.4). The most abundant family was Cyprinidae (67%), followed by Centrarchidae (13%) and Poeciliidae (13%). Spring fish species richness was five species within the Nueces River, six species within the Frio River, and four species within the Sabinal River. Mean spring fish relative abundance was 79% in the Nueces River, 45% in the Frio River, and 14% in the Sabinal River. Spring fish density was 0.69 fish/m^2 in the Nueces River, 0.18 fish/m^2 in the Frio River, and 0.35 fish/m^2 in the Sabinal River.

Across time periods, spring species richness and relative abundance of spring fishes did not differ (P>0.05; Table 5) within the entire basin, Nueces River, or the Frio River. Based on historical median spring discharge data and models adapted from Craig et al. (2016), the fish community within the Nueces River (0.65 m^3/s discharge) were predicted to have six spring species, with a relative abundance of 73% spring fish, and a spring fish density of 0.49 fish/m^2. The fish community within the Frio River (0.28 m^3/s discharge) was predicted to have 4 spring species, with a spring relative abundance of 51%, and a spring fish density of 0.22 fish/m^2. The fish community within the Sabinal River (0.06 m^3/s discharge) was predicated, based on estimates for lowest discharge (Cypress Creek, 0.065 m^3/s) in the models, to have 2 spring fishes, with a spring relative abundance of 22%, and a spring fish density of 0.07 fish/m^2. From contemporary collections, richness, relative abundances, and densities of spring fishes within the Nueces River and Frio River were within predictive models' confidence intervals (Figure 4.2). Spring fish relative abundance and density in the Sabinal River, with median flow less than those reported in the predictive models, appear to fit within the model predictions and 95% confidence intervals. Spring fish richness in the Sabinal River appear to be greater than model predications and 95% confidence intervals.

Discussion

Among contemporary collections, spring fish richness, relative abundances, and densities within the upper Nueces River basin were consistent with model predictions of intact spring fish communities (or appear to be consistent with model predictions as in the Sabinal River). In comparing contemporary spring fishes to historical collections, no differences were detected through time. However, *Percina carbonaria* were not found in contemporary collections. Only two confirmed records exist of *P. carbonaria*, both in 1970s. Occurrence in the 1970s is surprising, given that there was twice the effort (i.e., fish caught) in the 1950s. Lack of detection prior to and after 1970s could be contributed to the rare nature of *P. carbonaria*. In Faucheux et al., (2019), *P. carbonaria* was found in 6 drainages and 21 reaches within the drainages, however, it was rare (<5% occurrence) in 92% of drainages. Even with the *P. carbonaria* anomaly, upper Nueces river basin supports a diverse spring fish community, which includes two basin endemic fishes (i.e., *Dionda serena* and *Cyprinella lepida*) that occurred in all sampling periods.

Upper Nueces River basin having an intact spring fish community is not surprising given the apparent maintenance of spring flow quantity through the respective USGS gages, and quality through low levels of urbanization (Thomas et al., 2019). Spring complexes within the Edwards Plateau exist on a gradient of degradation which is driven by spring flow quantity and quality. When spring flow quantity and quality is intact, spring fish communities resist the collectively effects of urbanization, non-native introductions, and recreational use (Kollaus et al., 2015). In contrast, when spring flow quantity is altered, such as ceased flows due to excessive groundwater withdraws (Winemiller and Anderson, 1997), it decimates the spring fish community. Without surface water, spring fishes will obviously die unless species can persist in hyporheic zones or in the underground karst system. When spring flow quality is altered in acute changes (i.e., chlorination event; Garrett et al., 1992), or chronic changes (i.e., gradual replacement of spring water with wastewater effluent; Craig and Bonner, In review), spring fish richness, abundances, and densities decrease compared to those in spring complexes described as intact (Craig et al., 2016). Chronic changes in water quality are more subtle than water quantity changes (i.e., ceased flows) or acute changes (i.e., chlorination event), but can be just as lethal. Water temperature, specifically thermally stable water temperature, is thought to be the key structuring mechanism in maintaining spring fish communities (Hubbs, 1995). Thermally stable water temperature mediates spring fish feeding performance, giving spring fishes competitive advantages over fishes that are not associated with the spring complexes (i.e., riverine fishes) but do have access to them. Craig et al., (2019) provided evidence to support that a spring fish outperforms a closely-related riverine fishes in food consumption (i.e., first feeding, food amount) at spring temperatures, whereas the riverine fish outperforms the spring fish at warmer temperatures.

With changes in spring complex fish communities directly and indirectly tied to spring flow quality and quantity, we demonstrated the application of the Craig et al. (2016) models in assessing the ecological integrity of Edwards Plateau spring fish communities. Adherence with model expectations in conjunction with support of historical records, supports fish communities in the upper Nueces River, Frio River, and Sabinal River are meeting expectations of an intact spring fish community. As such, estimates of richness, abundance, and densities calculated herein can be added to the Craig et al. (2016) models, thereby increasing robustness of the models. The value to updating the Craig et al. (2016) models is that about 200 spring complexes exist in the Edwards Plateau (Brune, 1981), with the majority lacking historical or contemporary collections. Added robustness of the Craig et al. models can improve the reference conditions of Edwards Plateau spring complexes and have greater ability to assess integrity of these systems.

Table 4.1. Number of Texas Natural History Museum records by major independent drainage basin. An occurrence is defined by at least one individual of one species, taken from a location at a point in time.

Drainage	Records
Red & Canadian	5,271
Sabine & Neches	15,212
Trinity & San Jacinto	7,374
Brazos	16,600
Colorado & San Jacinto	11,689
Guadalupe & San Antonio	6,819
Nueces	2,792
Rio Grande & Pecos	18,183

Table 4.2. Sample sites within three tributaries of the upper Nueces basin with corresponding latitudes and longitudes.

Site #	Tributary	Latitude	Longitude
1	Nueces	30.023775	-100.067748
2		29.886671	-100.020384
3		29.667153	-100.028949
4		29.206561	-99.903324
5		29.722445	-100.086812
6	Frio	29.846063	-99.771701
7		29.712239	-99.758746
8		29.694270	-99.754161
9		29.495294	-99.71166
10	Sabinal	29.791774	-99.574254
11		29.744194	-99.553932
12		29.627430	-99.534462
13		29.341292	-99.48012

Table 4.3. Relative abundances (%) by time period for historical and contemporary fish collections within upper Nueces River Basin. All occurrence data (none taken after 1980) was originally counted as 1 individual. Asterisks (*) represent spring-associated fishes

	Historical							Contemporary
Species	1850-1940	1950	1960	1970	1980	1990	2000-2013	2014-2016
Lepisosteus oculatus	0.4							<0.1
Dorosoma cepedianum	77.8	<0.1		0.1	0.1			
Campostoma anomalum	0.8	6.2	0.8	1.9	7.6	3.9	3.3	2.7
*Cyprinella lepida**	0.4	5.9	10.2	1.2	4.6	6.5	13.3	1.3
Cyprinella lutrensis	4.5	8.4	8.6	40.3	11.0	1.3	16.0	
Cyprinella venusta	1.2	<0.1	12.8	16.4	24.4	14.7	15.8	15.3
Cyprinus carpio	0.4			0.2				
*Dionda serena**	0.8	9.2	9.1	6.6	5.7	11.6	15.4	27.0
Notemigonus crysoleucas	0.8							
*Notropis amabilis**	0.4	3.9	8.9	7.5	5.4	33.7	8.3	19.6
Notropis stramineus		0.4		0.7	1.2	3.2	2.1	1.1
Notropis texanus		0.9	0.3	0.6	1.9	11.2		
Notropis volucellus	0.4						<0.1	
Opsopoeodus emiliae	0.4	<0.1						
Pimephales promelas	0.4							
Pimephales vigilax		1.1	0.2	<0.1	3.1		0.4	
Moxostoma congestum	0.8	<0.1			0.1		<0.1	
*Astyanax mexicanus**	0.8	4.8	17.6	2.0	1.3	1.6	4.4	3.1
Ameiurus melas	0.4	0.3	<0.1	0.2				
Ameiurus natalis	0.4	0.6	0.3		0.6		0.2	0.1
*Ictalurus lupus**			0.6		<0.1	0.1	0.1	0.3
Ictalurus punctatus	1.2	0.5	0.6	0.1	<0.1	0.7	0.8	0.2
Pylodictis olivaris					<0.1			<0.1
Oncorhynchus mykiss							<0.1	
Fundulus notatus			<0.1					
Gambusia affinis	1.2	15.0	8.7	8.5	15.4	4.8	5.1	13.0
Poecilia latipinna		<0.1	1.6	0.1				
Lepomis sp.	0.4		0.4					

Lepomis auritus		0.4	4.9	1.8	0.8	<0.1	0.3	3.9
Lepomis cyanellus	0.8	2.0	2.4	2.9	0.5	<0.1	0.1	0.3
Lepomis gulosus	0.4	0.2	0.5	<0.1	<0.1		<0.1	<0.1
Lepomis macrochirus	1.2	1.6	1.1	0.7	0.6	<0.1	0.5	2.3
Lepomis megalotis	0.8	7.2	1.0	3.6	7.8	3.4	2.4	3.4
Lepomis microlophus		0.4	0.5	1.0	0.2		<0.1	0.3
Lepomis miniatus		0.1	2.4	<0.1				<0.1
Micropterus dolomieu					<0.1			
Micropterus salmoides	1.2	1.4	0.7	0.2	0.8	0.7	7.2	2.2
Micropterus treculii	0.4	<0.1		0.3	<0.1	0.2	<0.1	<0.1
Pomoxis annularis			<0.1	<0.1	<0.1			
Pomoxis nigromaculatus				0.2				
Etheostoma gracile	0.4							0.1
*Etheostoma lepidum**	0.4	18.0	0.6	1.2	4.5	2.0	3.5	3.1
Etheostoma spectabile						<0.1	0.2	<0.1
*Percina carbonaria**				0.4				
Oreochromis aureus					0.2	<0.1	<0.1	<0.1
Herichthys cyanoguttatus		1.1	4.8	0.9	1.9	0.3	0.2	0.4
Total species richness	28	29	28	30	30	22	28	46
Total individuals	243	5,379	1,274	2,412	2,821	4,460	4,289	8,628
Spring fish richness	5	5	6	6	6	6	6	7
Spring fish %	2.9	41.8	47.0	19.0	21.6	55.5	45.1	0.5

Table 4.4. Relative abundances (%) by river for contemporary fish collections within upper Nueces River Basin. Asterisks (*) represent spring-associated fishes

Species	Nueces	Frio	Sabinal
Lepisosteus oculatus	<0.1		
Campostoma anomalum	5.0	1.0	0.6
*Cyprinella lepida**	0.3	2.0	2.2
Cyprinella venusta	0.3	30.0	20.1
*Dionda serena**	56.6	5.5	
*Notropis amabilis**	11.1	35.6	5.4
Notropis stramineus		1.6	2.9
*Astyanax mexicanus**	3.9	0.9	6.1
Ameiurus natalis	0.1	0.1	
*Ictalurus lupus**		0.7	
Ictalurus punctatus		0.1	0.8
Pylodictis olivaris	<0.1	0.1	
Gambusia affinis	11.7	5.9	32.4
Lepomis auritus	1.0	7.0	4.4
Lepomis cyanellus		0.1	1.5
Lepomis gulosus			0.2
Lepomis macrochirus	0.2	1.3	9.8
Lepomis megalotis	1.4	4.1	7.0
Lepomis microlophus	0.1	0.4	0.3
Lepomis miniatus	0.1		
Micropterus salmoides	0.7	2.9	4.8
Micropterus treculii	<0.1	0.1	
Etheostoma gracile			
*Etheostoma lepidum**	6.9	0.3	0.6
Etheostoma spectabile			0.1
Oreochromis aureus	0.2		
Herichthys cyanoguttatus	0.2	0.5	0.8
Total species richness	20	21	18
Total individuals	3,789	3,353	1,486
Spring fish richness	5	6	4
Spring fish %	78.9	44.7	14.2

Table 4.5. Summary of spring-associated fish richness and relative abundance (%) by time period with linear regression r^2 and p-values for each regression. Regressions were not performed on Sabinal due to lack of sampling between 1970 – 2013.

		Time period								Regression	
		1850-1940	1950	1960	1970	1980	1990	2000-2013	2014-2016	r^2	p-value
Overall											
	richness	5	5	6	6	6	6	6	6	0.22	0.29
	relative abundance %	2.9	47.2	46.8	14.7	21.2	38.9	56.1	65.1	0.11	0.47
Nueces											
	richness	4	5	6	5	4	5	5	5	0.07	0.56
	relative abundance %		56.1	46.9	57.3	14.1	49.1	69.5	78.8	0.16	0.38
Frio											
	richness	1	5	6	6	6	6	6	4	0.14	0.38
	relative abundance %		32.2	45.7	12.5	24.5	60	39.1	67.7	0.12	0.45
Sabinal											
	richness	2	5	2					4	N/A	N/A
	relative abundance %		18.9						14.2	N/A	N/A

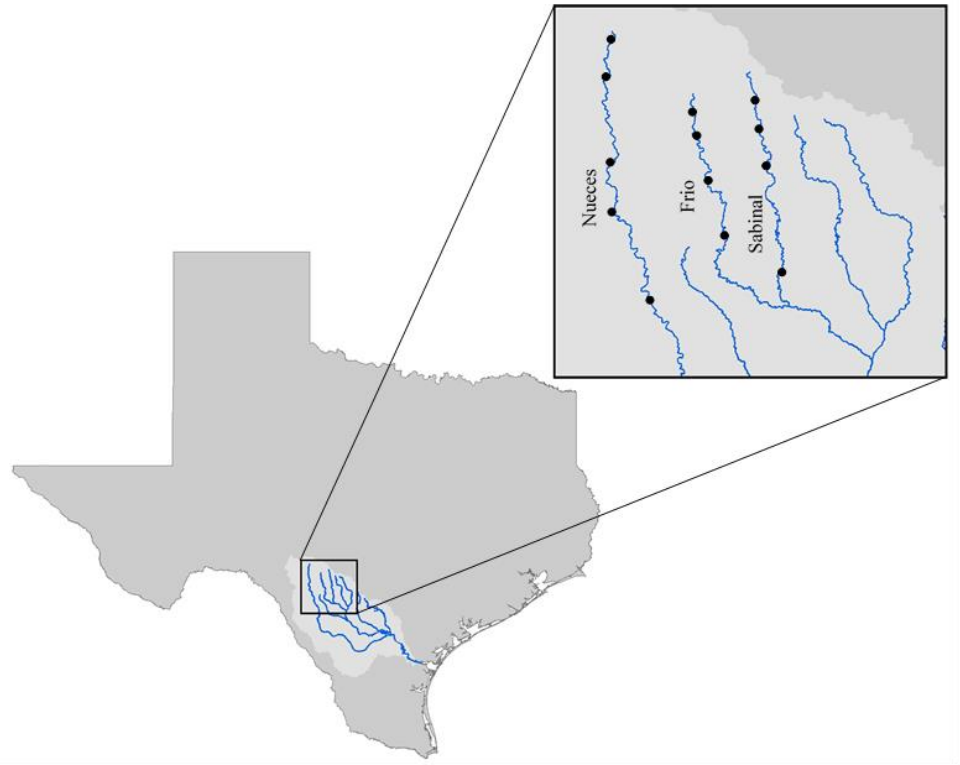
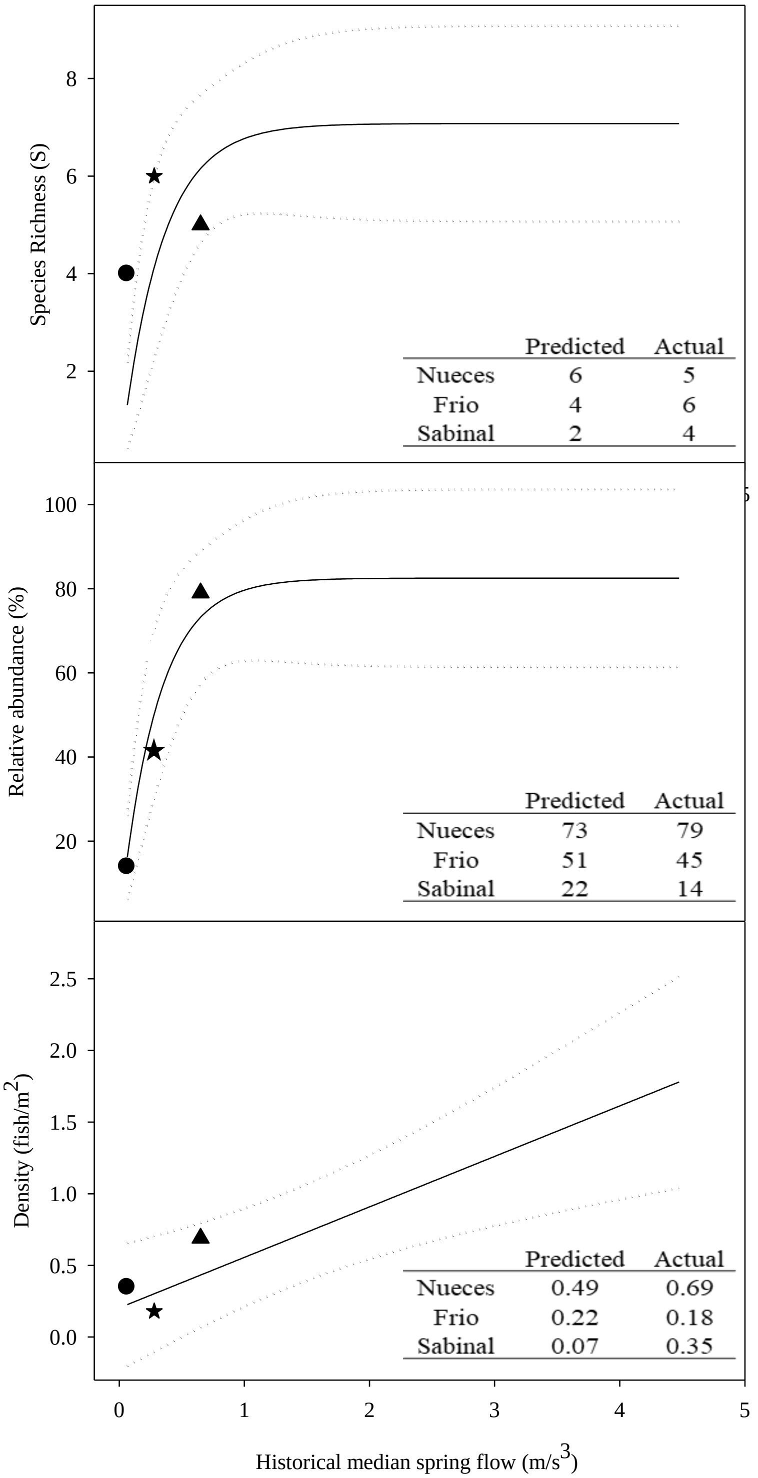


Figure 4.1. Nueces drainage within Texas. Black dots represent sampling sites among the Nueces, Frio, and Sabinal River



	Predicted	Actual
Nueces	6	5
Frio	4	6
Sabinal	2	4

	Predicted	Actual
Nueces	73	79
Frio	51	45
Sabinal	22	14

	Predicted	Actual
Nueces	0.49	0.69
Frio	0.22	0.18
Sabinal	0.07	0.35

Figure 4.2. Spring associated richness, relative abundance, and densities based on spring flow discharge per Craig et al. (2016). Triangle represents Nueces River, star represents Frio River, and circle represents Sabinal River. Solid line is predicted value. Dotted lines represent 95% confidence bands

V. TEMPERATURE-MEDIATED FEEDING BETWEEN SPRING-ASSOCIATED AND RIVERINE-ASSOCIATED CONGENERS, WITH IMPLICATIONS FOR COMMUNITY SEGREGATION

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Abstract

Freshwater fish communities segregate along water temperature gradients attributed in part to temperature-mediated physiological processes that affect species fitness. In spring complexes of southwest USA, spring complexes with narrow range of water temperatures are dominated by a community of fishes (i.e., spring-associated fishes), whereas riverine habitats with wide-range of water temperatures are dominated by a different community of fishes (i.e., riverine-associated fishes). The purpose of this study was to test a prediction of the concept that temperature-mediated species performance is a mechanism in maintaining community segregation. We predicted that a spring-associated fish (Largespring Gambusia *Gambusia geiseri*) would feed first and more often in a pairing with a riverine-associated fish (Western Mosquitofish *Gambusia affinis*) at an average spring temperature (23°C) and that the riverine-associated fish would feed first and more often in a pairing with the spring-associated fish at a warm riverine temperature (30°C). Among four trials consisting of 30 pairings at the spring complex temperature (23°C), Largespring Gambusia had a greater number of first feeds (mean ± 1 SD, 5.0 ± 0.82) than Western Mosquitofish (2.5 ± 1.73) and had greater mean number of total feeds (1.9 ± 0.31) than Western Mosquitofish (0.81 ± 0.70). At the riverine environment temperature (30°C), Western Mosquitofish had a greater number of first feeds (5.25 ± 1.71) than Largespring Gambusia (2.5 ± 1.73) and had greater mean number of total feeds (2.78 ± 1.05) than Largespring Gambusia (0.94 ± 0.68). Our findings suggest that temperature-mediated species performance could be maintaining segregation between the two fish communities. This study benefits our understanding of distributional patterns and improves threat assessments of stenothermal aquatic organisms.

Introduction

Aquatic species and communities are distributed along altitudinal, geographical, and longitudinal gradients where habitats, food resources, predation, and water quality conditions differ (Vannote et al., 1980; Taniguchi & Nakano, 2000). Among freshwater fishes, water temperature is one of several described mechanisms regulating distributional patterns (Grossman & Freeman, 1987). Temperature can influence interspecific interactions within freshwater fish communities when species temperature tolerances are overlapping (Taniguchi et al., 1998). Temperature-mediated interactions and its influence on species distributions, though difficult to quantify in nature (Gerking, 1994), are supported in laboratory experiments. Taniguchi et al. (1998) and Taniguchi & Nakano (2000) compared water temperature tolerances and behaviors among fishes distributed along an altitudinal gradient and found fish that inhabit cooler water at higher altitudes was more aggressive, consumed more food, had faster growth, and greater survival rate at cooler temperatures than lower altitude fishes. Conversely, fishes, which inhabit warmer water at lower altitudes, were more aggressive, consumed more food, and had faster growth at warmer temperatures than the higher altitude fish. Carmona-Catot, Magellan & Garcia-Berthou (2013) quantified pairwise feeding performance at three temperatures (i.e., 19, 24, and 29°C) of an introduced warm-water cyprinodont and a native cool-water cyprinodont to assess temperature-mediated interactions in non-native species range expansion and native species extirpation potential. The invasive warm-water cyprinodont had a lower food capture rate compared to the native cool-water cyprinodont at the coolest temperature. At warmer temperatures, the invasive warm-water cyprinodont had a greater food capture rate compared to native cool-water cyprinodont. Laboratory results of temperature-mediated interactions suggest water temperature regulates fish distributions.

Spring complexes within limestone formations of southwest USA are evolutionary refugia with stenoecious water quality, including thermally-constant water temperatures (i.e., stenothermal habitat; range 21.0 - 23.3°C), and distinct fish communities consisting of spring-associated fishes that have greater relative abundances and densities within spring complexes (Craig et al., 2016). As spring complexes transition downstream into riverine environments with less thermally-constant water temperatures (i.e., eurythermal habitat; range: 6 - 30°C) attributed to ambient conditions and merging with higher order streams, relative abundances and densities of spring-associated fishes are reduced and different species of fishes (i.e., riverine-associated fishes) become dominant. Similar to altitudinal gradients (Taniguchi et al., 1998; Taniguchi & Nakano, 2000), water temperature is a suggested mechanism in regulating richness, abundances, and densities of spring-associated fishes and riverine-associated fishes (Hubbs, 1995; Kollaus & Bonner, 2012) with spring-associated fishes being potentially more fit in stenothermal habitats and riverine-associated fishes being potentially more fit in eurythermal habitats.

Dissimilar to altitudinal gradients, spring-associated fishes and riverine-associated fishes do not represent previously researched cold-water and warm-water forms with overlapping tolerances, but both are warm-water forms having similar temperature tolerances (Hagen, 1964; Brandt et al., 1993). And similar reproductive tolerances (Bonner et al., 1998; McDonald et al., 2007). In marine systems, species in stenothermal habitats might select away from eurythermal enzymes and proteins (Graves & Somero, 1982) and select for proteins and enzymes that are more energy efficient within a narrow range of temperatures (Pörtner, Peck & Somero, 2007), whereas species in eurythermal habitats are suggested to conserve temperature-dependent enzymes and proteins that enable tolerance of wide-ranging water temperatures (Somero, Dahlhoff & Lin, 1996). Differences in fitness between spring-associated fishes in stenothermal habitats and riverine-associated fishes in eurythermal habitats could explain patterns in fish community segregation in spring-river systems.

The purpose of this study was to test predictions of the concept that stenothermal habitat of spring complexes is a factor in maintaining community segregation between spring-associated and riverine-associated fishes. The study objective was to quantify feeding (i.e., first feed and number of total feeds) as a measure of performance between spring-associated and riverine-associated fish pairs at two water temperatures and determine if water temperatures favored one species over the other. Water temperatures selected were 23°C, a typical water temperature in spring complexes, and 30°C, a typical summertime temperature in riverine environments. We used two congeneric species, the riverine-associated Western Mosquitofish, *Gambusia affinis* (Fig. 5.1A) and the spring-associated Largespring Gambusia, *Gambusia geiseri* (Fig. 5.1B); Hubbs, Edwards &

Garrett, 2008). Both species have similar thermal tolerances (Hagen, 1964) and mostly abutted distributions in spring-river systems (Watson, 2006; Behen, 2013). If water temperature mediates feeding and therefore potential interactions, we predict *G. geiseri* will eat first and eat more food items than *G. affinis* at 23ºC and *G. affinis* will eat first and eat more food items than *G. geiseri* at 30ºC. Ability to identify stenothermic aquatic organisms and quantify temperature-mediated segregation will benefit our understanding of distributional patterns and improve threat assessments.

Methods

Laboratory specimens were collected with a seine from the Guadalupe River drainage basin under Texas Parks and Wildlife Scientific Research Permit No. SPR-0601-159. *Gambusia geiseri* were collected from a site (29°53'22.2"N, 97°56'03.7"W) on the San Marcos River. *Gambusia affinis* were collected from a site (29°54'43.8"N, 97°53'50.3"W) on the Blanco River approximately 13 river kilometers away from the *Gambusia geiseri* collection site. Both species were collected from respective sites within the same day. Sexually-mature *Gambusia* >20 mm in total length (TL) (Stevens, 1977; Haynes & Cashner, 1995) were retained. Fishes were transported using insulated 52-L coolers to a laboratory at Texas State University Freeman Aquatic Biology Building within 30 minutes of capture. Within the laboratory, fishes were drip acclimated for 24 h to 23°C with well water from the Edwards Aquifer, which is the same water source as the San Marcos and Blanco rivers (Groeger et al., 1997) and followed approved Texas State University Institutional Animal Care and Use Committee protocol (approval number: 201658034). Fishes were separated by species and placed into 35-L glass aquaria submersed in a LS-700 Living Stream (Frigid Units, Inc.). Each aquarium was equipped with a sponge filter. The Living Stream utilized a dual feedback heating and cooling system to maintain desired temperature within ±0.5°C. Photoperiod was 14 h light:10 h dark. To maintain water quality, 50% water changes by volume were completed every 48 h. Fishes were fed high protein BioDiet Grower 1.2 mm (Bio-Oregon) daily *ad libitum*. To avoid any learned feeding behaviors, fishes were fed at varying times throughout the day and various locations of the aquaria. For 23°C feeding trials, food was withheld 24 h prior to feeding trials. For 30°C feeding trials, water temperature was adjusted 1°C per day for 7 d (Carmona-Catot, Magellan & Garcia-Berthou, 2013). Fishes remained at 30°C for 48 h before use in feeding trials, and food withheld 24 h prior to feeding trials. Fishes were kept in the laboratory for a total of three days for the 23°C trial, and ten days for the 30°C trial.

For pairwise feeding trials, one *G. geiseri* and one *G. affinis* were visually size (i.e., within 5 mm) and sex matched (Carmona-Catot, Magellan & Garcia-Berthou, 2013), placed into a 1.25-L opaque container (23 x 15 cm area), and allowed to acclimate for 1 hour. The container was immersed in the Living Stream to maintain the target temperature within ±0.5°C. Five natural prey items (Order Trichoptera, Family Hydroptilidae; Sokolov & Chvaliova, 1936) were placed into the center of the container using a plastic pipette. The species of the individual feeding (i.e., strikes that consumed all, part, or none of the prey) first was recorded and total feeds were recorded for both individuals. Each pairwise trial was limited to five minutes or until all food items were consumed. After completion, fishes were euthanized in MS-222 (Tricane-S) and preserved in 10% formalin; therefore, a fish was used only once in a feeding trial. For a no feed trial, the two individuals were given an additional 30 minutes to acclimate and tried for an additional trial. Four independent test batches were conducted at 23°C and 30°C. A test batch was defined as all successful feeding trials at a certain temperature conducted within a 4 – 6 h period. All test batches were conducted between May 2017 and July 2017. Targeted number of pairwise matches was 10 to 11 per batch, but fish jumped out of the container on four occasions, and neither fish eating after 30 minutes occurred on 16 occasions. For both instances, the pairwise trial was ended and recorded observations were discarded.

Number of first feeds and mean number of total feeds were calculated for each species by target temperature. Number of first feeds was calculated by summing the number of first feeds by species per batch. Mean number of total feeds was calculated by summing of total feeds by species in each batch and dividing by the number of pairwise trials. One tailed two sample t-tests (SAS Institute, Gary, North Carolina) were used to detect differences in first feeds and mean number of total feeds between species at 23°C and 30°C. Use of one tailed t-tests were justified by the a priori prediction that the spring-associated fish would outperform at 23°C and the riverine-associated fish would outperform at 30°C.

Results

At 23°C, 30 pairwise first feeds and 82 total feeds were observed out of 150 food items offered between *G. geiseri* and *G. affinis* pairs among four batches. Number of first feeds was greater (t = 2.61, df = 6, P = 0.02) for *G. geiseri* than *G. affinis* (Table 5.1).

Mean number of total feeds was greater (*t* = 2.82, df = 6, *P* = 0.02) for *G. geiseri* than *G. affinis*.

At 30°C, 31 pairwise first feeds and 111 total feeds were observed out of 160 food items offered between *G. geiseri* and *G. affinis* pairs among four batches. Number of first feeds was greater (*t* = 2.26, df = 6, *P* = 0.03) for *G. affinis* than *G. geiseri*. Mean number of total feeds was greater (*t* = 2.94, df = 6, *P* = 0.01) for *G. affinis* than *G. geiseri*.

Discussion

Our predictions that spring-associated *G. geiseri* has greater feeding performance than riverine-associated *G. affinis* at a temperature typical of a spring complex, and conversely, *G. affinis* has greater feeding performance than *G. geiseri* at a temperature typical of a summertime riverine environment were supported by pairwise trials. These results are similar to temperature-mediated feeding performances among families, genera, and species reported by others (De staso & Rahel, 1994; Taniguchi et al., 1998; Taniguchi & Nakano, 2000; Carmona-Catot, Magellan & Garcia-Berthou, 2013). This study, however, is novel in that it documents temperature-mediated performance between a spring-associated fish and a riverine-associated fish with similar thermal tolerances (Hagen 1964). Greater feeding performance of *G. affinis* at a water temperature of 30°C corresponds with the reported fastest growth rates and greatest natality rates of *G. affinis* at 30°C when compared to 20 and 25°C (Vondracek, Wurtsbaugh & Cech, 1988). Our results and the findings of Vondracek Wurtsbaugh & Cech (1988) suggest that a warmer water temperature increases physiological and feeding performance of *G. affinis*, which corresponds with distributions of *G. affinis* during summertime in riverine environments.

Conversely, a water temperature typical of spring complexes increases feeding performance for *G. geiseri*, which corresponds with distributions of *G. geiseri* during summertime in spring complexes. Growth rates, natality rates, and other measures of physiology are not known at this time for *G. geiseri*. Additionally, influences of other abiotic differences between spring systems and riverine systems (e.g., pH, specific conductance, and turbidity; Groeger et al., 1997) have not been assessed as to their role underlying *G. geiseri* and *G. affinis* segregation.

In order to show ubiquity of temperature-mediated performance as a mechanism for segregation among species distributions, feeding comparisons in addition to quantification of other temperature-mediated performance measures (e.g., growth and swimming performance) can be assessed for several other closely related taxa with similar distributions as *G. geiseri* and *G. affinis* within spring-river systems, such as spring-associated *Etheostoma lepidum* (Hubbs, 1985) and riverine-associated *E. spectabile*, *E. fonticola* (Bonner & McDonald, 2005) and *E. proeliare, Cyprinella proserpina* (Hubbs, 1995) and *C. lutrensis*, *Dionda argentosa* (Garrett, Hubbs & Edwards, 2002) and *D. diaboli*, and *Ictalurus lupus* (Sublette, Hatch & Sublette, 1990) and *I. punctatus*. In addition, spring-associated fishes and riverine-associated fishes maintain segregation during the winter when water temperatures of riverine environments are colder than water temperatures of spring complexes (Kollaus & Bonner, 2012). Assessments of feeding performance among spring-associated fishes and riverine-associated fishes at typical winter time temperatures would complete the range of conditions in which segregation is maintained. Ultimately, quantification of genetic, physiological, and biochemical mechanisms will be necessary to describe underlying temperature-mediated performance of spring-associated and riverine-associated species (see review in Somero, Dahlhoff & Lin, 1996). At a minimum, known mechanisms for stenotherm radiation and maintenance can serve as a basis for understanding evolutionary origins and maintenance of segregation among spring-associated and riverine-associated fishes.

Ability to identify stenothermic aquatic organisms and to quantify temperature-mediated segregation will benefit our understanding of distributional patterns and improve threat assessments. Stenothermic organisms are potentially more sensitive to temperature changes related to physical habitat alterations and global climate change than eurythermic organisms because of the lack of gene product selection associated with eurythermic organisms (Somero, Dahlhoff & Lin, 1996). Physical habitat alterations include instream or riparian modifications that manipulate the energy budget or thermal capacity of the surface water (Poole & Berman, 2001), such as discharge of heated effluents (Langford, 1990; Olden & Rahel, 2008), removal of riparian vegetation (Moore, Spittlehouse & Story, 2005), stream channel modification (Nelson & Palmer, 2007), dams and diversions (Olden & Naiman, 2010), and reduction of discharge through groundwater pumping (Sinokrot & Gulliver, 2000). Groundwater sources supporting spring complexes of southwest USA are commodities (Loaiciga, 2003), and groundwater harvest is linked to the loss of spring complexes and associated biota (Craig & Bonner, unpublished data ; Winemiller & Anderson, 1997). Within the Edwards Plateau, there are eight federally listed and 12 Texas state listed fishes that are associated with spring complexes. Our manuscript supports why spring-associated fishes are found within spring complexes, which informs natural resource managers in supervising species and their habitats (e.g., minimize groundwater withdrawals during periods of natural low flow periods to maintain stenothermal habitats for the spring fishes). Continued climate change in North America is predicted to alter stream flow patterns, increasing storm events, decreased dissolved oxygen, and increases in groundwater temperatures (Poff, Brinson & Day, 2002; Ficke, Myrick & Hansen, 2007). As with physical habitat alterations, stenothermic aquatic organisms are predicted to follow isoclines of suitable habitat (Ficke, Myrick & Hansen, 2007), remain in place and wait for better times, adapt to changes, or become extinct (Clarke, 1996).

Conclusions

This study supports a prediction that temperature mediates species distribution of a spring-associated and a riverine-associated fish through laboratory trials. Novel results of this study show temperature-mediated feeding performance of two species with similar temperature tolerances that inhabit spring-river systems. Although further work is needed to test for the ubiquity among other fishes, this study suggests temperature to be a structuring mechanism for organisms in spring-river systems.

Table 5.1. Number of first feeds and mean number of total feeds by batch *for Gambusia geiseri* and *Gambusia affinis* at 23 and 30°C.

Temperature (°C)	Batch	N of pairs	Number of first feeds		Mean number of total feeds	
			G. geiseri	*G. affinis*	*G. geiseri*	*G. affinis*
23	1	7	5	2	2.29	0.29
	2	6	4	2	2.00	0.83
	3	6	5	1	1.60	0.33
	4	11	6	5	1.70	1.80
	Mean		5.00	2.50	1.90	0.81
	SD		0.82	1.73	0.31	0.70
30	1	9	3	6	1.44	2.11
	2	7	4	3	1.43	2.71
	3	7	0	7	0.00	4.29
	4	8	3	5	0.88	2.00
	Mean		2.50	5.25	0.94	2.78
	SD		1.73	1.71	0.68	1.05

Figure 5.1. *Gambusia affinis* and *Gambusia geiseri*. Example of species (A) *Gambusia affinis* female and (B) *Gambusia geiseri* male used in study. Picture from Thomas, Bonner & Whiteside (2007).

APPENDIX SECTION

Appendix 1.1 Drainage Basin keys for inland fishes of Texas.

BRAZOS RIVER BASIN

KEY TO THE FAMILIES

1a. Both eyes on one side of head; without right pectoral fin.. American Soles – Achiridae

1b. One eye on either side of head; with both pectoral fins..2

2a. (1b) Body long and slender; without pelvic fins............Freshwater Eels – Anguillidae

2b. (1b) Body truncated or elongated; with pelvic fins 3

3a. (2b) Caudal fin heterocercal or abbreviated heterocercal 4

3b. (2b) Caudal fin homocercal 5

4a. (3a) Body covered with ganoid scales; snout formed into a beak; without gular plate...Gars – Lepisosteidae

4b. (3a) Body covered with cycloid scales, snout not formed into a beak, with a gular plate...Bowfin – Amiidae

5a. (3b) Jaws duckbilled .... Pickerels – Esocidae

5b. (3b) Jaws not duckbilled 6

6a. (5b) One dorsal fin; pelvic fins without uniserial spines 7

6b. (5b) One or two dorsal fins; pelvic fins with uniserial spines 15

7a. (6a) With adipose fin...8

7b. (6a) Without adipose fin 10

8a. (7a) Without barbels...9

8b. (7a) With barbels...Bullhead Catfishes – Ictaluridae

9a. (8a) Scales large, < 50 lateral line scales; incisor teeth present.......Tetras – Characidae

9b. (8a) Scales small, > 60 lateral line scales; incisor teeth absent .... Trouts – Salmonidae

10a. (7b) Long anal fin with ≥ 17 fin rays ....Shads – Clupeidae

10b. (7b) Short anal fin with ≤ 13 rays 11

11a. (10b) Caudal fin forked or emarginated; lateral line usually present.........................12

11b. (10b) Caudal fin truncated or rounded; lateral line usually absent 13

12a. (11a) Inferior, fleshy mouth modified for sucking; > 7 pharyngeal teeth in main row, usually ≥ 10 dorsal fin rays ....Suckers – Catostomidae

12b. (11a) Mouth usually not fleshy or modified for sucking; < 7 pharyngeal teeth in main row, usually ≤ 10 dorsal fin rays...Minnows – Cyprinidae

13a. (11b) Mature males with rounded anal fin; males and females with 3rd anal fin ray branched, no gonopodium present 14

13b. (11b) Mature males with pointed anal fin forming a gonopodium; males and females with 3rd anal fin ray unbranched ....Livebearers – Poeciliidae

14a. (13a) Body robust; teeth in single row are incisor-like and tricuspid (three points on a tooth) ....Pupfishes – Cyprinodontidae

14b. (13a) Body elongate; conical (cone-shaped) pointed teeth in a single row or several rows..Killifishes – Fundulidae

15a. (6b) Anus anterior to pelvic fins; > 5 soft rays on each pelvic fin................................

.... Pirate Perch – Aphredoderidae

15b. (6b) Anus posterior to pelvic fins; 5 soft rays on pelvic fins....................................16

16a. (15b) Pelvic fin position abdominal or sub-thoracic; dorsal fins widely separated...17

16b. (15b) Pelvic fin position thoracic; dorsal fins joined or, if separate, closely adjacent to one another...18

17a. (16a) Dorsal fin with 4 thick spines; anal fin with 2-3 spines; adipose eyelids present...Mullets – Mugilidae

17b. (16a) Dorsal fin with 4 to 8 thin spines; anal fin with 1 spine; adipose eyelids absent ....Silversides – Atherinopsidae

18a. (16b) One nostril (nare) on each side of head; lateral line interrupted ....Cichlids – Cichlidae

18b. (16b) Two nostrils (nares) on each side of head; lateral line complete, incomplete, or absent 19

19a. (18b) Dorsal fin with > 23 fin rays; lateral line extends to tip of caudal fin.. Drums – Sciaenidae

19b. (18b) Dorsal fin with < 23 fin rays; lateral line, if present, does not extend to tip of caudal fin...20

20a. (19b) Anal fin with 1 to 2 spines.. Perches – Percidae

20b. (19b) Anal fin with 3 to 8 spines 21

21a. (20b) Posterior margin of operculum with a sharp spine; spiny and soft dorsal fin separate or only slightly connected; pseudobranchium present and exposed..Temperate Basses – Moronidae

21b. (20b) Posterior margin of operculum without a sharp spine; spiny and soft dorsal fins connected or with deep notch; pseudobranchium covered or absent..........................22

22a. (21b) Lateral line present or incomplete ....Sunfishes – Centrarchidae

22b. (21b) Lateral line absent ....Pygmy Sunfishes – Elassomatidae

KEY TO THE SPECIES

FAMILY LEPISOSTEIDAE—gars

1a. Large teeth in upper jaw in parallel rows on each side ....*Atractosteus spatula*

1b. Large teeth in upper jaw in one row, although another non-parallel row might be present 2

2a. (1b) Beak long and narrow, least width goes about 12 to 20 times in length; width of beak at nostrils < eye diameter; snout > ⅔ of head length...................... *Lepisosteus osseus*

2b. (1b) Beak short and blunt, least width goes about 5 to 7 times in length; width of beak at nostrils > eye diameter; snout < ⅔ of head length .... *Lepisosteus oculatus*

FAMILY AMIIDAE—bowfins

Amia calva

FAMILY ANGUILLIDAE—freshwater eels

Anguilla rostrata

FAMILY CLUPEIDAE—herrings

1a. Twenty-nine to 33 anal fin rays; mouth subterminal and below level of middle of eye; black; shoulder spot ≥ pupil of eye .... *Dorosoma cepedianum*

1b. Twenty-four to 28 anal fin rays; mouth terminal and at level of eye; black shoulder spot < pupil of eye ....*Dorosoma petenense*

FAMILY CYPRINIDAE - minnows

1a. More than 15 soft rays on dorsal fin; dorsal and anal fins each with a strong serrated spine 2

1b. Fewer than 10 soft rays on dorsal fin; dorsal and anal fins without spine 3

2a. (1a) Upper jaw with two pairs of barbels.. *Cyprinus carpio*

2b. (1a) Upper jaw without barbels.. *Carassius auratus*

3a. (1b) Anal fin near caudal fin, distance from snout to origin of anal fin is > 2.5 times the distance from origin of anal fin to base of caudal fin; pharyngeal teeth with prominent parallel grooves..*Ctenopharyngodon idella*

3b. (1b) Anal fin not noticeably near caudal fin: distance from snout to origin of anal fin is < 2.5 times the distance from origin of anal fin to base of caudal fin; pharyngeal teeth without prominent parallel grooves 4

4a. (3b) Intestine wound spirally around swim bladder; keratinous ridge on lower jaw...*Campostoma anomalum*

4b. (3b) Intestine not wound spirally around swim bladder; keratinous ridge of lower jaw hardly evident...5

5a. (4b) Abdomen behind pelvic fins with a fleshy keel lacking scales; lateral line greatly decurved, distance between anterior lateral line scale and ventral most lateral line scale is > 3 scales in height...*Notemigonus crysoleucas*

5b. (4b) Abdomen behind pelvic fin with scales; lateral line not greatly decurved, lateral line descends < 3 scales ventrally from highest point 6

6a. (5b) With maxillary barbels, might be small and not observable without opening the mouth or with magnification...7

6b. (5b) Without maxillary barbels 9

7a. (6a) Mouth terminal; distinct black spot located anteriorly on dorsal fin; pharyngeal teeth on main row 5-4 or 5-5...*Semotilus atromaculatus*

7b. (6a) Mouth subterminal or inferior; no distinct black spot on dorsal fin; pharyngeal teeth on main row 4-4 8

8a. (7b) Body silvery, without scattered black specks................. *Macrhybopsis storeriana*

8b. (7b) Body with scattered black specks......................................*Macrhybopsis hyostoma*

9a. (6b) Predorsal scales appear crowded, smaller than scales on lateral body or appear as overlapping scales; black spot in the middle, anterior portion of the dorsal fin................10

9b. (6b) Predorsal scales not crowded; without black spot in the middle, anterior portion of the dorsal fin 11

10a. (9a) Caudal spot, if distinct, continuous with mid-lateral stripe; lateral line incomplete; intestine long, more than twice the standard length……. *Pimephales promelas*

10b. (9a) Caudal spot distinct from mid-lateral stripe; lateral line complete, intestine forming a short S-shaped loop .... *Pimephales vigilax*

11a. (9b) Long intestine in a flat coil 12

11b. (9b) Short S-shaped intestine 13

12a. (11a) Head width greater than distance from tip of snout to posterior margin of orbital; internal posterior basiocciptial process is narrow and peg-like, width of internal posterior basiocciptal process fits in to head width at occipital > 7 times............................

....*Hybognathus placitus*

12b. (11a) Head width about equal to distance from tip of snout to posterior margin of orbital; internal posterior basiocciptial process is wide and flat, width of internal posterior basioccipital process fits in to head width at occipital < 7 times.......*Hybognathus nuchalis*

13a. (11b) Moderately decurved lateral line; diamond-shaped scales; dark shoulder patch present; melanophores concentrated between rays of dorsal and anal fins 14

13b. (11b) Lateral line incomplete, complete-straight, or complete-slightly decurved; scales not noticeably diamond-shaped; without dark shoulder patch; melanophores concentrated along rays of dorsal and anal fins 15

14a. (13a) Caudal fin base with a large black spot, about size of eye .... *Cyprinella venusta*

14b. (13a) Caudal fin base without a large black spot..........................*Cyprinella lutrensis*

15a. (13b) Distinct and separate black dash at base of dorsal fin; apparent when viewed from above; pharyngeal teeth count usually 0,4-4,0..16

15b. (13b) No distinct and separate black dash at base of dorsal fin; pharyngeal teeth count usually 1,4-4,1 or 2,4-4,2 19

16a. (15a) Lateral line scales markedly elevated (taller than wide) anteriorly, elevated scale height 2 to 5 times scale width..17

16b. (15a) Lateral line scales not markedly elevated anteriorly, scale height 1 to 2 times scale width 18

17a. (16a) Dorsal and lateral body with melanophores outlining scales; with pronounced black lateral stripe; dorsal fin height goes 2.1 or more times in pre-dorsal length; infraorbital canal complete .... *Notropis volucellus*

17b. (16a) Dorsal and lateral body with sparse melanophores; scales outlined with melanophores are rare; pre-dorsal black spot is prominent and distinct from mid-dorsal stripe; dorsal fin height goes 2.0 or fewer times in pre-dorsal length; infraorbital canal incomplete..*Notropis buchanani*

18a. (16b) Eye large, eye diameter is > snout length...........................*Notropis stramineus*

18b. (16b) Eye small, eye diameter is < snout length ....*Notropis buccula*

19a. (15b) Depressed dorsal fin longer than head......................................*Hybopsis amnis*

19b. (15b) Depressed dorsal fin shorter than head 20

20a. (19b) Mouth is sub-terminal; pharyngeal teeth are 0,4-4,0........ *Notropis atrocaudalis*

20b. (19b) Mouth is terminal; pharyngeal teeth are 1,4-4,1 or 2,4-4,2 or 5-5 21

21a. (20b) Dorsal fin origin opposite or anterior to pelvic fin origin 22

21b. (20b) Dorsal fin origin posterior to pelvic fin origin 25

22a. (21a) Prominent mid-lateral stripe; extending through eye 23

22b. (21a) No prominent mid-lateral stripe present..24

23a. (22a) Pharyngeal teeth 5-5; mouth small and almost vertical.....*Opsopoeodus emiliae*

23b. (22a) Pharyngeal teeth are 1,4-4,1 or 2,4-4,2; mouth large and oblique ....
.... *Notropis texanus*

24a. (22b) Usually 8 anal fin rays; head is narrow, depth at occiput more than width at occiput .... *Notropis shumardi*

24b. (22b) Usually 7 anal fin rays; head is wide, depth at occiput less than or equal to width at occiput..*Notropis potteri*

25a. (21b) Small scales, ≥ 41 lateral line scales, > 25 predorsal scales.... *Lythrurus fumeus*

25b. (21b) Moderate-sized scales, ≤ 40 lateral line scales, < 24 predorsal scales.. *Notropis oxyrhynchus*

FAMILY CATOSTOMIDAE—suckers

1a. Dorsal fin long, base > than ⅓ of standard length; 22 to 30 dorsal fin rays 2

1b. Dorsal fin short, base < than ¼ of standard length; 4 to 18 dorsal fin rays 5

2a. (1a) Small scales, lateral line scales > 50; eye closer to back of head than to tip of snout; head abruptly more slender than body; papillose lips................ *Cycleptus elongatus*

2b. (1a) Large scales, lateral line scales < 45; eye closer to tip of snout than back of head; plicate lips 3

3a. (2b) Subopercle triangular, broadest toward base; knob present at tip of lower lip; blunt snout, forming level with eye .... *Carpiodes carpio*

3b. (2b) Subopercle semicircular, broadest towards middle; knob absent at tip of lower lip; rounded snout, forming below level of eye 4

4a. (3b) Body elongate and slender, greatest body depth goes 2.6 to 3.3 times in standard length, and height of anterior rays in dorsal and anal fins often less than 2/3 head length in individuals >300 mm; small eye, eye diameter goes ≥ 2 times in snout length of individuals <300 mm .... *Ictiobus niger*

4b. (3b) Body deep and narrow, greatest body depth goes 2.2 to 2.8 times in standard length, and height of anterior dorsal and anal fin rays often greater than 2/3 head length in individuals >300 mm; large eye, eye diameter goes ≤ 2 times in snout length of individuals <300 mm ....*Ictiobus bubalus*

5a. (1b) Lateral line complete and well developed; air bladder with 3 chambers ....*Moxostoma congestum*

5b. (1b) Lateral line incomplete or absent; air bladder with 2 chambers 6

6a. (5b) Lateral line incomplete; rows of spots...................................*Minytrema melanops*

6b. (5b) Lateral line absent 7

7a. (6b) Scales larger, lateral scale count 34 to 37; eye larger, eye length ½ of snout length; dorsal fin rays 11 or 12; back with crescentic scale marks............*Erimyzon sucetta*

7b. (6b) Scales smaller, lateral scale count 39 to 43; eye smaller, eye length < ½ of snout length; dorsal fin rays 9 or 10; back without crescentic scale marks.. *Erimyzon claviformis*

FAMILY CHARACIDAE—characins

Astyanax mexicanus

FAMILY ICTALURIDAE—bullhead catfishes

1a. Adipose fin joined to the caudal fin or separated by a shallow notch............................2

1b. Adipose fin free at tip, not joined to caudal fin 3

2a. (1a) Mouth terminal; pectoral fin spine not serrated; lower lip and chin not heavily speckled with black pigment...*Noturus gyrinus*

2b. (1a) Mouth sub-terminal; pectoral spine serrated; lower lip and chin heavily speckled with black pigment..*Noturus nocturnus*

3a. (1b) Head dorso-ventrally compressed; mouth terminal to superior . *Pylodictis olivaris*

3b. (1b) Head rounded; mouth subterminal 4

4a. (3b) Caudal fin rounded or shallowly emarginate...5

4b. (3b) Caudal fin deeply forked 6

5a. (4a) Chin barbels completely or partially black; anal fin rays 17 to 24; anal fin broadly rounded ....*Ameiurus melas*

5b. (4a) Chin barbels white or yellow; anal fin rays 24 to 27; margin of anal fin generally straight... *Ameiurus natalis*

6a. (4b) Anal fin rays 30 to 36; anal fin free margin is straight; medial keel-like ridge anterior to dorsal fin forms humped back appearance ....*Ictalurus furcatus*

6b. (4b) Anal fin rays 22 to 29; anal fin free margin is rounded; no humped back appearance...*Ictalurus punctatus*

FAMILY SALMONIDAE—salmons

Oncorhynchus mykiss

FAMILY ESOCIDAE—pikes and pickerels

Esox americanus

FAMILY APHREDODERIDAE—pirate perch

Aphredoderus sayanus

FAMILY MUGILIDAE—mullets

1a. Lower jaw rounded, without a symphyseal knob; lower limb of 1st gill arch with 17 to 20 gill rakers; no adipose eyelid; scales ctenoid............................*Agonostomus monticola*

1b. Lower jaw angular, with a prominent symphyseal knob; lower limb of 1st gill arch with 25 to 60 gill rakers; adipose eyelid well developed in adults; scales cycloid in young, ctenoid in adults..*Mugil cephalus*

FAMILY ATHERINOPSIDAE—New World silversides

1a. Scales small, > 60 scales in lateral series, jaws produced into a short beak; snout length > eye length; > 20 anal fin rays..*Labidesthes sicculus*

1b. Scales large, < 50 scales in lateral series; jaws not produced into a beak; snout length ≤ eye length; < 20 anal fin rays...*Menidia audens*

FAMILY FUNDULIDAE—topminnows

1a. More than 40 longitudinal scale rows; dark vertical barring; gill slit not extending dorsal to uppermost pectoral fin ray ....*Fundulus zebrinus*

1b. Fewer than 40 longitudinal scale rows; gill slit extending dorsal to uppermost pectoral fin ray..2

2a. (1b) Body with a distinct black lateral band 3

2b. (1b) Body without a distinct black lateral band..4

3a. (2a) Distinct black spots on anterior dorso-lateral region are as pronounced as lateral stripe; distinct black spots throughout dorsal and caudal fins .... *Fundulus olivaceus*

3b. (2a) Faint black spots on anterior dorso-lateral region are not as pronounced as lateral stripe; distinct black spots near base of dorsal and caudal fins.................*Fundulus notatus*

4a. (2b) Dorsal fin originating anterior to anal fin origin; more than 15 scale rows from pelvic fin origin to isthmus predorsal stripe absent or not reaching occiput ....

.... *Fundulus grandis*

4b. (2b) Dorsal fin originating posterior to anal fin origin 5

5a. (4b) Red to dark spots in multiple rows longitudinally along lateral sides; usually with dark subocular bar..*Fundulus blairae*

5b. (4b) Body mottled, barred or irregularly spotted; no dark subocular bar ....

.... *Fundulus chrysotus*

FAMILY CYPRINODONTIDAE—pupfishes

1a. Abdomen with scales anterior to pelvic fins; distance from origin of dorsal fin to end of hypural plate > distance from origin of dorsal to anterior nostril.....................................

....*Cyprinodon variegatus*

1b. Abdomen without scales anterior to pelvic fins; distance from origin of dorsal fin to end of hypural plate < the distance from origin of dorsal to anterior nostril ....

.... *Cyprinodon rubrofluviatilis*

FAMILY POECILIIDAE—livebearers

1a. Origin of dorsal fin anterior to anal fin origin; intestinal canal long with many convolutions..*Poecilia latipinna*

1b. Origin of dorsal fin posterior to anal fin origin; intestinal canal short with few convolutions... *Gambusia affinis*

FAMILY MORONIDAE—temperate basses

1a. Body depth goes < 3 times in standard length; teeth in single patch on back of tongue..*Morone chrysops*

2b. Body depth goes > 3 times in standard length; teeth in 2 parallel patches on back of tongue ....*Morone saxatilis*

FAMILY CENTRARCHIDAE—sunfishes

1a. Five to 8 anal spines...2

1b. Three anal spines...3

2a. (1a) Dorsal fin set back on body, length of dorsal fin base < distance from its origin to posterior margin of eye; lateral body with wide to narrow dorsal black bands; ≤ 6 dorsal spines.. *Pomoxis annularis*

2b. (1a) Dorsal fin set forward on body, length of dorsal fin base equal to or greater than distance from its origin to posterior margin of eye; lateral body with checkerboard black and light pattern; ≥7 dorsal spines ....*Pomoxis nigromaculatus*

3a. (1b) Body slender, body depth contained > 3 times into standard length......................4

3b. (1b) Body deep, body depth contained < 3 times into standard length..........................7

4a. (3a) Dorsal fins narrowly joined at base, forming a deep notch; upper jaw extends past posterior margin of eye in adults; mid-lateral stripe generally complete, rows of spots ventral to mid-lateral stripe faint and incomplete ....*Micropterus salmoides*

4b. (3a) Dorsal fins broadly joined at base forming a shallow notch; upper jaw does not reach past posterior portion of eye; bases of soft dorsal and anal fins scaled 5

5a. (4b) No tooth patch on tongue; lower lateral region scales without black spots forming horizontal rows...*Micropterus dolomieu*

5b. (4b) Tooth patch on tongue; lower lateral region scales with black spots forming horizontal rows..6

6a. (5b) Mid-lateral stripe often appears interrupted anteriorly, rows of spots ventral to mid-lateral stripe distinct and complete...*Micropterus punctulatus*

6b. (5b) Dark wide midlateral stripe present and disconnected anteriorly into a narrow midlateral stripe posteriorly, forming vertical bars.............................. *Micropterus treculii*

7a. (3b) Teeth on tongue; head and opercle with 3 to 5 distinct dark and light longitudinal stripes; red spot on posterior margin of opercle flap in fresh specimens....*Lepomis gulosus*

7b. (3b) No teeth on tongue; head and opercle lacking distinct dark and light longitudinal stripe...8

8a. (7b) Pectoral fins long and pointed, reach anterior portion of eye or beyond when bent forward...9

8b. (7b) Pectoral fins short and rounded, do not reach past eye when bent forward.........11

9a. (8a) Opercle flap stiff to its margin, posterior margin either red or orange in live specimens..*Lepomis microlophus*

9b. (8a) Opercle flap flexible, posterior margin not red or orange in live specimens 10

10a. (9b) Opercle flap black to the margin; black spot on posterior base of soft dorsal fin ....*Lepomis macrochirus*

10b. (9b) Opercle flap outlined with thick white band; lacking black spot on posterior base of soft dorsal fin.. *Lepomis humilis*

11a. (8b) Black opercle flap stiff near the posterior margin with bone supporting all or majority of the flap...12

11b. (8b) Black opercle flap flexible near the posterior margin without bone supporting majority of the flap...14

12a. (11a) Lateral line incomplete; smaller individuals with black spot surrounded by white margin on posterior base of soft dorsal fin ....*Lepomis symmetricus*

12b. (11a) Lateral line complete; black spot, if present, on posterior base of soft dorsal fin without white margin 13

13a. (12b) Body elongated with black spot on posterior base of soft dorsal fin....................
....*Lepomis cyanellus*

13b. (12b) Body rounded without black spot on posterior base of soft dorsal fin; lateral body with alternating stripes formed from black and red spots............... *Lepomis miniatus*

14a. (11b) Opercle flap black to the posterior margin; opercle flap is thin near the opercle bone with the narrowest width of the flexible portion of the flap about the same diameter of the eye pupil...*Lepomis auritus*

14b. (11b) Opercle flap black and surrounded by white on the posterior margin; opercle flap is wide with narrowest width of the flexible flap is about two times the diameter of the eye pupil 15

15a. (14b) Twelve pectoral fin rays, 3 to 5 cheek scales; opercle flap often with white pigment form speckles, distinct red spots (white in preserved specimens) along lateral line..*Lepomis marginatus*

15b. (14b) Thirteen to 15 pectoral fin rays, 5 to 7 cheek scales; opercle flaps with red or white margin; 13 to 15 pectoral fin rays .... *Lepomis megalotis*

FAMILY PERCIDAE—perches

1a. Snout conical, extends beyond upper lip; body with ≥ 14 black vertical bars..............2

1b. Snout less conical, does not extend beyond upper lip; body with < 14 black vertical bars or with a pattern other than vertical bars...3

2a. (1a) Body with thick vertical bars, bars alternate in length from long to short; 9 to 10 long bars...*Percina carbonaria*

2b. (1a) Body with 14 to 16 thin vertical bars of similar length..........*Percina macrolepida*

3a. (1b) Sides of body with large black blotches; midline of abdomen naked or with enlarged scales ....*Percina sciera*

3b. (1b) Sides of body without large black blotches; scales on abdomen normal..............4

4a. (3b) Lateral line arched upward .... *Etheostoma gracile*

4b. (3b) Lateral line straight...5

5a. (4b) Lateral body with distinct series of M-shaped pigments; snout rounded and blunt ....*Etheostoma chlorosoma*

5b. (4b) Lateral body without distinct series of M-shaped pigments; snout not noticeably rounded and blunt 6

6a. (5b) Lateral region with mottling bisected by a light colored lateral stripe.....................

.... *Etheostoma parvipinne*

6b. (5b) Anterior portion of lateral region with black horizontal dashes and posterior portion of lateral region with 8 to 11 vertical bars; throat of live males orange...................

.... *Etheostoma spectabile*

FAMILY SCIAENIDAE—drums

Aplodinotus grunniens

FAMILY ELASSOMATIDAE—pygmy sunfishes

Elassoma zonatum

FAMILY CICHLIDAE—cichlids

1a. Anal fin spines 5 to 6 ....*Herichthys cyanoguttatus*

1b. Anal fin spines < 5 (usually 3).. *Oreochromis aureus*

FAMILY ACHIRIDAE—American soles

Trinectes maculatus

CANADIAN RIVER BASIN

KEY TO THE FAMILIES

1a. With adipose fin 2

1b. Without adipose fin 3

2a. (1a) Without barbels.. Trouts – Salmonidae

2b. (1a) With barbels... Bullhead Catfishes – Ictaluridae

3a. (1b) One dorsal fin; pelvic fins without uniserial spines 4

3b. (1b) One or two dorsal fins; pelvic fins with uniserial spines 9

4a. (3a) Long anal fin with ≥ 17 fin rays ....Shads – Clupiedae

4b. (3a) Short anal fin with ≤ 13 rays 5

5a. (4b) Caudal fin forked or emarginated; lateral line usually present..............................6

5b. (4b) Caudal fin truncated or rounded; lateral line usually absent.................................7

6a. (5a) Inferior, fleshy mouth modified for sucking; > 7 pharyngeal teeth in main row, usually ≥ 10 dorsal fin rays... Suckers – Catostomidae

6b. (5a) Mouth usually not fleshy or modified for sucking; < 7 pharyngeal teeth in main row, usually ≤ 10 dorsal fin rays.....................................Carps and Minnows – Cyprinidae

7a. (5b) Mature males with rounded anal fin; males and females with 3rd anal fin ray branched, no gonopodium present 8

7b. (5b) Mature males with pointed anal fin forming a gonopodium; males and females with 3rd anal fin ray unbranched .... Livebearers – Poeciliidae

8a. (7a) Body robust; teeth in single row are incisor-like and tricuspid (three points on a tooth)... Pupfishes – Cyprinodontidae

8b. (7a) Body elongate; conical (cone-shaped) pointed teeth in a single row or several rows.. Killifishes – Fundulidae

9a. (3b) Pelvic fin position abdominal or sub-thoracic; dorsal fins widely separated ....Silversides – Atherinopsidae

9b. (3b) Pelvic fin position thoracic; dorsal fins joined or, if separate, closely adjacent to one another..10

10a. (9b) Anal fin with 1 to 2 spines.. Perches – Percidae

10b. (9b) Anal fin with 3 to 8 spines 11

11a. (10b) Posterior margin of operculum with a sharp spine; spiny and soft dorsal fin separate or only slightly connected; pseudobranchium present and exposed........................

....Temparate Basses – Moronidae

11b. (10b) Posterior margin of operculum without a sharp spine; spiny and soft dorsal fins connected or with deep notch; pseudobranchium covered or absent..............................

....Sunfishes – Centrarchidae

KEY TO THE SPECIES

FAMILY CLUPEIDAE—herrings

1a. Twenty-nine to 33 anal fin rays; mouth subterminal and below level of middle of eye; black shoulder spot ≥ pupil of eye .... *Dorosoma cepedianum*

1b. Twenty-four to 28 anal fin rays; mouth terminal and at level of eye; black shoulder spot < pupil of eye ....*Dorosoma petenense*

FAMILY CYPRINIDAE - minnows

1a. More than 15 soft rays on dorsal fin; dorsal and anal fins each with a strong serrated spine .... *Cyprinus carpio*

1b. Fewer than 10 soft rays on dorsal fin; dorsal and anal fins without spine 2

2a. (1b) Anal fin near caudal fin, distance from snout to origin of anal fin is > 2.5 times the distance from origin of anal fin to base of caudal fin; pharyngeal teeth with prominent parallel grooves..*Ctenopharyngodon idella*

2b. (1b) Anal fin not noticeably near caudal fin: distance from snout to origin of anal fin is < 2.5 times the distance from origin of anal fin to base of caudal fin; pharyngeal teeth without prominent parallel grooves 3

3a. (2b) Intestine wound spirally around swim bladder; keratinous ridge on lower jaw...*Campostoma anomalum*

3b. (2b) Intestine not wound spirally around swim bladder; keratinous ridge of lower jaw hardly evident..4

4a. (3b) Abdomen behind pelvic fins with a fleshy keel lacking scales; lateral line greatly decurved, distance between anterior lateral line scale and ventral most lateral line scale is > 3 scales in height...*Notemigonus crysoleucas*

4b. (3b) Abdomen behind pelvic fin with scales; lateral line not greatly decurved, lateral line descends < 3 scales ventrally from highest point 5

5a. (4b) With maxillary barbels, might be small and not observable without opening the mouth or with magnification...6

5b. (4b) Without maxillary barbels 7

6a. (5a) Body with scattered black specks ....*Macrhybopsis tetranema*

6b. (5a) Body silvery, without scattered black specks............................*Platygobio gracilis*

7a. (5b) Thick lower lip at corners, mouth noticeably ventral; black spot at base of caudal fin .... *Phenacobius mirabilis*

7b. (5b) Lower lip thin or not noticeably thick; with or without black spot at base of caudal fin..8

8a. (7b) Predorsal scales appear crowded, smaller than scales on lateral body or appear as overlapping scales; black spot in the middle, anterior portion of the dorsal fin..................9

8b. (7b) Predorsal scales not crowded; without black spot in the middle, anterior portion of the dorsal fin 10

9a. (8a) Caudal spot, if distinct, continuous with mid-lateral stripe; lateral line incomplete; intestine long, more than twice the standard length........*Pimephales promelas*

9b. (8a) Caudal spot distinct from mid-lateral stripe; lateral line complete, intestine forming a short S-shaped loop ....*Pimephales vigilax*

10a. (8b) Long intestine in a flat coil...*Hybognathus placitus*

10b. (8b) Short S-shaped intestine..11

11a. (10b) Moderately decurved lateral line; diamond-shaped scales; dark shoulder patch present; melanophores concentrated between rays of dorsal and anal fins ....
....*Cyprinella lutrensis*

11b. (10b) Lateral line incomplete, complete-straight, or complete-slightly decurved; scales not noticeably diamond-shaped; without dark shoulder patch; melanophores concentrated along rays of dorsal and anal fins..12

12a. (11b) No distinct and separate black dash at base of dorsal fin; pharyngeal teeth count usually 1,4-4,1 or 2,4-4,2 13

12b. (11b) Distinct and separate black dash at base of dorsal fin; apparent when viewed from above; pharyngeal teeth count usually 0,4-4,0...14

13a. (12a) Dorsal fin origin opposite to pelvic fin origin ....*Notropis blennius*

13b. (12a) Dorsal fin origin posterior to pelvic fin origin ....*Notropis atherinoides*

14a. (12b) Eye large, eye diameter is > snout length .... *Notropis stramineus*

14b. (12b) Eye small, eye diameter is < snout length................................ *Notropis girardi*

FAMILY CATOSTOMIDAE—suckers

Carpiodes carpio

FAMILY ICTALURIDAE—bullhead catfishes

1a. Head dorso-ventrally compressed; mouth terminal to superior .... *Pylodictis olivaris*

1b. Head rounded; mouth subterminal...2

2a. (1b) Caudal fin rounded or shallowly emarginate...3

2b. (1b) Caudal fin deeply forked...*Ictalurus punctatus*

3a. (2a) Chin barbels completely or partially black; anal fin rays 17 to 24; anal fin broadly rounded ....*Ameiurus melas*

3b. (2a) Chin barbels white or yellow; anal fin rays 24 to 27; margin of anal fin generally straight.. *Ameiurus natalis*

FAMILY SALMONIDAE—salmons

Oncorhynchus mykiss

FAMILY ATHERINOPSIDAE—New World silversides

Menidia audens

FAMILY FUNDULIDAE—topminnows

Fundulus kansae

FAMILY POECILIIDAE—livebearers

Gambusia affinis

FAMILY CYPRINODONTIDAE— pupfishes

Cyprinodon rubrofluviatilis

FAMILY MORONIDAE—temperate basses

Morone chrysops

FAMILY CENTRARCHIDAE—sunfishes

1a. Five to 8 anal spines.. *Pomoxis annularis*

1b. Three anal spines...2

2a. (1b) Body slender, body depth contained > 3 times into standard length......................3

2b. (1b) Body deep, body depth contained < 3 times into standard length..........................4

3a. (2a) Dorsal fins narrowly joined at base forming a deep notch; upper jaw extends past posterior margin of eye in adults; mid-lateral stripe generally complete, rows of spots ventral to mid-lateral stripe faint and incomplete ....*Micropterus salmoides*

3b. (2a) Dorsal fins broadly joined at base forming a shallow notch; upper jaw does not reach past posterior portion of eye; bases of soft dorsal and anal fins scaled ....*Micropterus dolomieu*

4a. (2b) Pectoral fins long and pointed, reach anterior portion of eye or beyond when bent forward...5

4b. (2b) Pectoral fins short and rounded, do not reach past eye when bent forward..........7

5a. (4a) Opercle flap stiff to its margin, posterior margin either red or orange in live specimens..*Lepomis microlophus*

5b. (4a) Opercle flap flexible, posterior margin not red or orange in live specimens 6

6a. (5b) Opercle flap black to the margin; black spot on posterior base of soft dorsal fin ....*Lepomis macrochirus*

6b. (5b) Opercle flap outlined with thick white band; lacking black spot on posterior base of soft dorsal fin .... *Lepomis humilis*

7a. (4b) Black opercle flap stiff near the posterior margin with bone supporting all or majority of the flap...*Lepomis cyanellus*

7b. (4b) Black opercle flap flexible near the posterior margin without bone supporting majority of the flap.. *Lepomis megalotis*

FAMILY PERCIDAE—perches

Sander vitreus

COLORADO AND LAVACA RIVER BASINS

KEY TO THE FAMILIES

1a. Both eyes on one side of head; without right pectoral fin.. American Soles – Achiridae

1b. One eye on either side of head; with both pectoral fins...2

2a. (1b) Caudal fin heterocercal or abbreviated heterocercal 3

2b. (1b) Caudal fin homocercal 4

3a. (2a) Body with ganoid scales; snout formed into a beak; without gular plate ....Gars – Lepiososteidae

3b. (2a) Body covered with cycloid scales, snout not formed into a beak, with a gular plate...Bowfin – Amiidae

4a. (2b) One dorsal fin; pelvic fins without uniserial spines 5

4b. (2b) One or two dorsal fins; pelvic fins with uniserial spines 13

5a. (4a) With adipose fin..6

5b. (4a) Without adipose fin 8

6a. (5a) Without barbels..7

6b. (5a) With barbels...Bullhead Catfishes – Ictaluridae

7a. (6a) Scales large, < 50 lateral line scales; incisor teeth present ....Tetras – Characidae

7b. (6a) Scales small, > 60 lateral line scales; incisor teeth absent ..... Trouts – Salmonidae

8a. (5b) Long anal fin with ≥ 17 fin rays ....Shads – Clupiedae

8b. (5b) Short anal fin with ≤ 13 rays 9

9a. (8b) Caudal fin forked or emarginated; lateral line usually present............................10

9b. (8b) Caudal fin truncated or rounded; lateral line usually absent...............................11

10a. (9a) Inferior, fleshy mouth modified for sucking; > 7 pharyngeal teeth in main row, usually ≥ 10 dorsal fin rays .... Suckers – Catostomidae

10b. (9a) Mouth usually not fleshy or modified for sucking; < 7 pharyngeal teeth in main row, usually ≤ 10 dorsal fin rays .... Carps and Minnows – Cyprinidae

11a. (9b) Mature males with rounded anal fin; males and females with 3rd anal fin ray branched, no gonopodium present 12

11b. (9b) Mature males with pointed anal fin forming a gonopodium; males and females with 3rd anal fin ray unbranched .... Livebearers – Poeciliidae

12a. (11a) Body robust; teeth in single row are incisor-like and tricuspid (three points on a tooth). .... Pupfishes – Cyprinodontidae

12b. (11a) Body elongate; conical (cone-shaped) pointed teeth in a single row or several rows .... Killifishes – Fundulidae

13a. (4b) Anus anterior to pelvic fins; > 5 soft rays on each pelvic fin ....

.... Pirate perch – Aphredoderidae

13b. (4b) Anus posterior to pelvic fins; 5 soft rays on pelvic fins 14

14a. (13b) Pelvic fin position abdominal or sub-thoracic; dorsal fins widely separated ... 15

14b. (13b) Pelvic fin position thoracic; dorsal fins joined or, if separate, closely adjacent to one another 16

15a. (14a) Dorsal fin with 4 thick spines; anal fin with 2-3 spines; adipose eyelids present .... Mullets – Mugilidae

15b. (14a) Dorsal fin with 4 to 8 thin spines; anal fin with 1 spine; adipose eyelids absent .... Silversides – Atherinopsidae

16a. (14b) One nostril (nare) on each side of head; lateral line interrupted ....

.... Cichlids – Cichlidae

16b. (14b) Two nostrils (nares) on each side of head; lateral line complete, incomplete, or absent 17

17a. (16b) Dorsal fin with > 23 fin rays; lateral line extends to tip of caudal fin.................. .... Drums – Sciaenidae

17b. (16b) Dorsal fin with < 23 fin rays; lateral line, if present, does not extend to tip of caudal fin..18

18a. (17b) Pelvic fins joined into a sucking disk, gill membranes broadly joined to isthmus ....Gobies – Gobiidae

18b. (17b) Pelvic fins not joined, gill membranes free or nearly free from isthmus (may be joined to each other across isthmus) 19

19a. (18b) Anal fin with 1 to 2 spines.. Perches – Percidae

19b. (18b) Anal fin with 3 to 8 spines 20

20a. (19b) Posterior margin of operculum with a sharp spine; spiny and soft dorsal fin separate or only slightly connected; pseudobranchium present and exposed........................ ....Temperate Basses – Moronidae

20b. (19b) Posterior margin of operculum without a sharp spine; spiny and soft dorsal fins connected or with deep notch; pseudobranchium covered or absent............................. ....Sunfishes – Centrarchidae

KEY TO THE SPECIES

FAMILY LEPISOSTEIDAE—gars

1a. Large teeth in upper jaw in parallel rows on each side .... *Atractosteus spatula*

1b. Large teeth in upper jaw one row, although another non-parallel row might be present 2

2a. (1b) Beak long and narrow, least width goes about 12 to 20 times in length; width of beak at nostrils < eye diameter; snout > ⅔ of head length...................... *Lepisosteus osseus*

2b. (1b) Beak short and blunt, least width goes about 5 to 7 times in length; width of beak at nostrils > eye diameter; snout < ⅔ of head length .... *Lepisosteus oculatus*

FAMILY AMIIDAE—bowfins

Amia calva

FAMILY ANGUILLIDAE—freshwater eels

Anguilla rostrata

FAMILY CLUPEIDAE—herrings

1a. Twenty-nine to 33 anal fin rays; mouth subterminal and below level of middle of eye; black shoulder spot ≥ pupil of eye .... *Dorosoma cepedianum*

1b. Twenty-four to 28 anal fin rays; mouth terminal and at level of eye; black shoulder spot < pupil of eye .... *Dorosoma petenense*

FAMILY CYPRINIDAE - minnows

1a. More than 15 soft rays on dorsal fin; dorsal and anal fins each with a strong serrated spine 2

1b. Fewer than 10 soft rays on dorsal fin; dorsal and anal fins without spine 3

2a. (1a) Upper jaw with two pairs of barbels... *Cyprinus carpio*

2b. (1a) Upper jaw without barbels... *Carassius auratus*

3a. (2b) Anal fin near caudal fin, distance from snout to origin of anal fin is > 2.5 times the distance from origin of anal fin to base of caudal fin; pharyngeal teeth with prominent parallel grooves..*Ctenopharyngodon idella*

3b. (2b) Anal fin not noticeably near caudal fin: distance from snout to origin of anal fin is < 2.5 times the distance from origin of anal fin to base of caudal fin; pharyngeal teeth without prominent parallel grooves 4

4a. (3b) Intestine wound spirally around swim bladder; keratinous ridge on lower jaw...*Campostoma anomalum*

4b. (3b) Intestine not wound spirally around swim bladder; keratinous ridge of lower jaw hardly evident...5

5a. (4b) Abdomen behind pelvic fins with a fleshy keel lacking scales; lateral line greatly decurved, distance between anterior lateral line scale and ventral most lateral line scale is > 3 scales in height...*Notemigonus crysoleucas*

5b. (4b) Abdomen behind pelvic fin with scales; lateral line not greatly decurved, lateral line descends < 3 scales ventrally from highest point 6

6a. (5b) With maxillary barbels, might be small and not observable without opening the mouth or with magnification...7

6b. (5b) Without maxillary barbels...8

7a. (6a) Prominent mid-lateral stripe reaching from opercle to caudal peduncle ....*Macrhybopsis marconis*

7b. (6a) Mid-lateral stripe incomplete or absent, more pronounced posteriorly on caudal peduncle when incomplete...*Macrhybopsis hyostoma*

8a. (6b) Thick lower lip at corners, mouth noticeably ventral; black spot at base of caudal fin .... *Phenacobius mirabilis*

8b. (6b) Lower lip thin or not noticeably thick; with or without black spot at base of caudal fin..9

9a. (8b) Predorsal scales appear crowded, smaller than scales on lateral body or appear as overlapping scales; black spot in the middle, anterior portion of the dorsal fin................10

9b. (8b) Predorsal scales not crowded; without black spot in the middle, anterior portion of the dorsal fin 11

10a. (9a) Caudal spot, if distinct, continuous with mid-lateral stripe; lateral line incomplete; intestine long, more than twice the standard length. .... *Pimephales promelas*

10b. (9a) Caudal spot distinct from mid-lateral stripe; lateral line complete, intestine forming a short S-shaped loop .... *Pimephales vigilax*

11a. (9b) Long intestine in a flat coil 12

11b. (9b) Short S-shaped intestine 13

12a. (11a) Black mid-lateral stripe extends through eye to snout; eye width greater than or equal to snout length .... *Dionda nigrotaeniata*

12b. (11a) Mid-lateral stripe, if present (sometimes appears as a broad, diffuse band of melanophores), does not extend through the eye to the snout; eye width less than snout length .... *Hybognathus placitus*

13a. (11b) Moderately decurved lateral line; diamond-shaped scales; dark shoulder patch present; melanophores concentrated between rays of dorsal and anal fins 14

13b. (11b) Lateral line incomplete, complete-straight, or complete-slightly decurved; scales not noticeably diamond-shaped; without dark shoulder patch; melanophores concentrated along rays of dorsal and anal fins 15

14a. (13a) Sub-terminal mouth; caudal fin base with a spot larger than eye ....

.... *Cyprinella venusta*

14b. (13a) Terminal mouth; no caudal spot .... *Cyprinella lutrensis*

15a. (13b) Distinct and separate black dash at base of dorsal fin; apparent when viewed from above; pharyngeal teeth count usually 0,4-4,0 16

15b. (13b) No distinct and separate black dash at base of dorsal fin; pharyngeal teeth count usually 1,4-4,1 or 2,4-4,2 19

16a. (15a) Lateral line scales markedly elevated (taller than wide) anteriorly, elevated scale height 2 to 5 times scale width 17

16b. (15a) Lateral line scales not markedly elevated anteriorly, scale height 1 to 2 times scale width 18

17a. (16a) Dorsal and lateral body with melanophores outlining scales; with pronounced black lateral stripe; dorsal fin height goes 2.1 or more times in pre-dorsal length; infraorbital canal complete .... *Notropis volucellus*

17b. (16a) Dorsal and lateral body with sparse melanophores; scales outlined with melanophores are rare; pre-dorsal black spot is prominent and distinct from mid-dorsal stripe; dorsal fin height goes 2.0 or fewer times in pre-dorsal length; infraorbital canal incomplete..*Notropis buchanani*

18a. (16b) Eye large, eye diameter is > snout length...........................*Notropis stramineus*

18b. (16b) Eye small, eye diameter is < snout length...............................*Notropis buccula*

19a. (15b) Depressed dorsal fin longer than head......................................*Hybopsis amnis*

19b. (15b) Depressed dorsal fin shorter than head 20

20a. (19b) Dorsal fin origin opposite or anterior to pelvic fin origin 21

20b. (19b) Dorsal fin origin posterior to pelvic fin origin 24

21a. (20a) Prominent mid-lateral stripe; extending through eye 22

21b. (20a) No prominent mid-lateral stripe present............................... *Notropis shumardi*

22a. (21a) Pharyngeal teeth 5-5; mouth small and almost vertical.....*Opsopoeodus emiliae*

22b. (21a) Pharyngeal teeth are 1,4-4,1 or 2,4-4,2; mouth large and oblique ....
....*Notropis texanus*

23a. (20b) Small scales, ≥ 41 lateral line scales, > 25 predorsal scales.... *Lythrurus fumeus*

23b. (20b) Moderate-sized scales, ≤ 40 lateral line scales, < 24 predorsal scales.............24

24a. (23b) Eye larger, eye diameter > snout length.................................*Notropis amabilis*

24b. (23b) Eye smaller, eye diameter < snout length .... *Notropis oxyrhynchus*

FAMILY CATOSTOMIDAE—suckers

1a. Dorsal fin long, base > than ⅓ of standard length; 22 to 30 dorsal fin rays 2

1b. Dorsal fin short, base < than ¼ of standard length; 4 to 18 dorsal fin rays 5

2a. (1a) Small scales, lateral line scales > 50; eye closer to back of head than to tip of snout; head abruptly more slender than body; papillose lips................ *Cycleptus elongatus*

2b. (1a) Large scales, lateral line scales < 45; eye closer to tip of snout than back of head; plicate lips 3

3a. (2b) Subopercle triangular, broadest toward base; knob present at tip of lower lip; blunt snout, forming level with eye .... *Carpiodes carpio*

3b. (2b) Subopercle semicircular, broadest towards middle; knob absent at tip of lower lip; rounded snout, forming below level of eye 4

4a. (3b) Body elongate and slender, greatest body depth goes 2.6 to 3.3 times in standard length, and height of anterior rays in dorsal and anal fins often less than 2/3 head length in individuals >300 mm; small eye, eye diameter goes ≥ 2 times in snout length of individuals <300 mm .... *Ictiobus niger*

4b. (3b) Body deep and narrow, greatest body depth goes 2.2 to 2.8 times in standard length, and height of anterior dorsal and anal fin rays often greater than 2/3 head length in individuals >300 mm; large eye, eye diameter goes ≤ 2 times in snout length of individuals <300 mm .... *Ictiobus bubalus*

5a. (1b) Lateral line complete and well developed; air bladder with 3 chambers; no rows of spots present .... *Moxostoma congestum*

5b. (1b) Lateral line incomplete or absent; air bladder with 2 chambers; rows of spots present.. *Minytrema melanops*

FAMILY CHARACIDAE—characins

Astyanax mexicanus

FAMILY ICTALURIDAE—bullhead catfishes

1a. Adipose fin joined to the caudal fin or separated by a shallow notch....*Noturus gyrinus*

1b. Adipose fin free at tip, not joined to caudal fin 2

2a. (1b) Head dorso-ventrally compressed; mouth terminal to superior . *Pylodictis olivaris*

2b. (1b) Head rounded; mouth subterminal 3

3a. (2b) Caudal fin rounded or shallowly emarginate...4

3b. (2b) Caudal fin deeply forked 5

4a. (3a) Chin barbels completely or partially black; anal fin rays 17 to 24; anal fin broadly rounded .... *Ameiurus melas*

4b. (3a) Chin barbels white or yellow; anal fin rays 24 to 27; margin of anal fin generally straight.. *Ameiurus natalis*

5a. (3b) Anal fin rays 30 to 36; anal fin free margin is straight; medial keel-like ridge anterior to dorsal fin forms humped back appearance .... *Ictalurus furcatus*

5b. (3b) Anal fin rays 22 to 29; anal fin free margin is rounded; no humped back appearance..6

6a. (5b) Anal fin rays 27 to 29; pectoral fin spine goes < 5 times into standard length; random scattering of few black spots may be present .... *Ictalurus punctatus*

6b. (5b) Anal fin rays 22 to 26; pectoral fin spine goes > 5 times into standard length; diffuse black spots on sides.. *Ictalurus lupus*

FAMILY SALMONIDAE—salmons

Oncorhynchus mykiss

FAMILY APHREDODERIDAE—pirate perch

Aphredoderus sayanus

FAMILY MUGILIDAE—mullets

1a. Lower jaw rounded, without a symphyseal knob; lower limb of 1st gill arch with 17 to 20 gill rakers; no adipose eyelid; scales ctenoid............................ *Agonostomus monticola*

1b. Lower jaw angular, with a prominent symphyseal knob; lower limb of 1st gill arch with 25 to 60 gill rakers; adipose eyelid well developed in adults; scales cycloid in young, ctenoid in adults. .... *Mugil cephalus*

FAMILY ATHERINOPSIDAE—New World silversides

Menidia audens

FAMILY FUNDULIDAE—topminnows

1a. Distance from origin of dorsal fin to end of hypural plate < distance from origin of dorsal fin to preopercle or occasionally about equal to that distance; more than 30 longitudinal scale rows 2

1b. Distance from origin of dorsal fin to end of hypural plate > distance from origin of dorsal fin to preopercle; 30 or fewer longitudinal scale rows........................*Lucania parva*

2a. (1a) More than 40 longitudinal scale rows; dark vertical barring; gill slit not extending dorsal to uppermost pectoral fin ray ....*Fundulus zebrinus*

2b. (1a) Fewer than 40 longitudinal scale rows; gill slit extending dorsal to uppermost pectoral fin ray...3

3a. (2b) Body with a distinct black lateral band ....*Fundulus notatus*

3b. (2b) Body without a distinct black lateral band...4

4a. (3b) Dorsal fin originating posterior to anal fin origin ....*Fundulus chrysotus*

4b. (3b) Dorsal fin originating anterior to anal fin origin; > 15 scale rows from pelvic fin origin to isthmus; predorsal stripe absent or not reaching occiput ....*Fundulus grandis*

FAMILY CYPRINODONTIDAE— pupfishes

1a. Abdomen with scales anterior to pelvic fins; distance from origin of dorsal fin to end of hypural plate > distance from origin of dorsal to anterior nostril.*Cyprinodon variegatus*

1b. Abdomen without scales anterior to pelvic fins; distance from origin of dorsal fin to end of hypural plate < the distance from origin of dorsal to anterior nostril..... *Cyprinodon rubrofluviatilis*

FAMILY POECILIIDAE—livebearers

1a. Origin of dorsal fin anterior to anal fin origin; intestinal canal long with many convolutions...2

1b. Origin of dorsal fin posterior to anal fin origin; intestinal canal short with few convolutions...3

2a. (1a) Teeth in single row; dorsal fin rays ≥ 12; parallel rows of spots usually present ....*Poecilia latipinna*

2b. (1a) Teeth in villiform bands; dorsal fin rays ≤ 12; spots, if present, are diffuse ....*Xiphophorus variatus*

3a. (1b) Spines at tip of 3rd anal fin ray of male gonopodium (first enlarged ray) 1 to 3 times longer than wide .... *Gambusia affinis*

3b. (1b) Spines at tip of 3rd anal fin ray of male gonopodium 4 to 10 times longer than wide 4

4a. (3b) Dorsal and anal fins without yellow pigmentation; dusky lateral stripe indistinct; mouth without black markings and anal spot of females not restricted to area immediately around anus; pectoral fin of males with indentation, much deeper than widest pectoral fin ray; found in Clear Creek, Menard County only .... *Gambusia heterochir*

4b. (3b) Dorsal and (in females) anal fins with yellow pigmentation (lost in preservation); males with a shallow pectoral indentation .... *Gambusia geiseri*

FAMILY MORONIDAE—temperate basses

1a. Body depth goes < 3 times in standard length; teeth in single patch on back of tongue .... *Morone chrysops*

1b. Body depth goes > 3 times in standard length; teeth in 2 parallel patches on back of tongue .... *Morone saxatilis*

FAMILY CENTRARCHIDAE—sunfishes

1a. Five to 8 anal spines 2

1b. Three anal spines 3

2a. (1a) Dorsal fin set back on body, length of dorsal fin base < distance from its origin to posterior margin of eye; lateral body with wide to narrow dorsal black bands; ≤ 6 dorsal spines .... *Pomoxis annularis*

2b. (1a) Dorsal fin set forward on body, length of dorsal fin base equal to or greater than distance from its origin to posterior margin of eye; lateral body with checkerboard black and light pattern; ≥7 dorsal spines .... *Pomoxis nigromaculatus*

3a. (1b) Body slender, body depth contained > 3 times into standard length 4

3b. (1b) Body deep, body depth contained < 3 times into standard length 7

4a. (3a) Dorsal fins narrowly joined at base forming a deep notch; upper jaw extends past posterior margin of eye in adults; mid-lateral stripe generally complete, rows of spots ventral to mid-lateral stripe faint and incomplete .... *Micropterus salmoides*

4b. (3a) Dorsal fins broadly joined at base forming a shallow notch; upper jaw does not reach past posterior portion of eye; bases of soft dorsal and anal fins scaled 5

5a. (4b) No tooth patch on tongue; lower lateral region scales without black spots forming horizontal rows...*Micropterus dolomieu*

5b. (4b) Tooth patch on tongue; lower lateral region scales with black spots forming horizontal rows..6

6a. (5b) Mid-lateral stripe often appears interrupted anteriorly, rows of spots ventral to mid-lateral stripe distinct and complete. ....*Micropterus punctulatus*

6b. (5b) Dark wide midlateral stripe present and disconnected anteriorly into a narrow midlateral stripe posteriorly, forming vertical bars..............................*Micropterus treculii*

7a. (3b) Teeth on tongue; head and opercle with 3 to 5 distinct dark and light longitudinal stripes; red spot on posterior margin of opercle flap in fresh specimens....*Lepomis gulosus*

7b. (3b) No teeth on tongue; head and opercle lacking distinct dark and light longitudinal stripes 8

8a. (7b) Pectoral fins long and pointed, reach anterior portion of eye or beyond when bent forward...9

8b. (7b) Pectoral fins short and rounded, do not reach past eye when bent forward.........11

9a. (8a) Opercle flap stiff to its margin, posterior margin either red or orange in live specimens...*Lepomis microlophus*

9b. (8a) Opercle flap flexible, posterior margin not red or orange in live specimens 10

10a. (9b) Opercle flap black to the margin; black spot on posterior base of soft dorsal fin ....*Lepomis macrochirus*

10b. (9b) Opercle flap outlined with thick white band; lacking black spot on posterior base of soft dorsal fin.. *Lepomis humilis*

11a. (8b) Black opercle flap stiff near the posterior margin with bone supporting all or majority of the flap...12

11b. (8b) Black opercle flap flexible near the posterior margin without bone supporting majority of the flap...14

12a. (11a) Lateral line incomplete; smaller individuals with black spot surrounded by white margin on posterior base of soft dorsal fin ....*Lepomis symmetricus*

12b. (11a) Lateral line complete; black spot, if present, on posterior base of soft dorsal fin without white margin 13

13a. (12b) Body elongated with black spot on posterior base of soft dorsal fin...*Lepomis cyanellus*

13b. (12b) Body rounded without black spot on posterior base of soft dorsal fin; lateral body with alternating stripes formed from black and red spots................ *Lepomis miniatus*

14a. (11b) Opercle flap black to the posterior margin; opercle flap is thin near the opercle bone with the narrowest width of the flexible portion of the flap about the same diameter of the eye pupil...*Lepomis auritus*

14b. (11b) Opercle flap black and surrounded by white on the posterior margin; opercle flap is wide with narrowest width of the flexible flap is about two times the diameter of the eye pupil... *Lepomis megalotis*

FAMILY PERCIDAE—perches

1a. Snout conical, extends beyond upper lip; body with ≥ 14 black vertical bars...............2

1b. Snout less conical, does not extend beyond upper lip; body with < 14 black vertical bars or with a pattern other than vertical bars...3

2a. (1a) Body with thick vertical bars, bars alternate in length from long to short; 9 to 10 long bars...*Percina carbonaria*

2b. (1a) Body with 14 to 16 thin vertical bars of similar length..........*Percina macrolepida*

3a. (1b) Sides of body with large black blotches; midline of abdomen naked or with enlarged scales ....*Percina sciera*

3b. (1b) Sides of body without large black blotches; scales on abdomen normal...............4

4a. (3b) Lateral line short, < 6 pored scales; single row of horizontal dashes present...*Etheostoma proeliare*

4b. (3b) Lateral line long (complete or incomplete), > 6 pored scales; if horizontal dashes present, accompanied by vertical bars 5

5a. (4b) Lateral line arched upward .... *Etheostoma gracile*

5b. (4b) Lateral line straight...6

6a. (5b) Lateral body with distinct series of M-shaped pigments; snout rounded and blunt ....*Etheostoma chlorosoma*

6b. (5b) Lateral body without distinct series of M-shaped pigments; snout not noticeably rounded and blunt 7

7a. (6b) Lateral region with mottling bisected by a light colored lateral stripe.....................

.... *Etheostoma parvipinne*

7b. (6b) Lateral region without mottling bisected by a light colored lateral stripe 8

8a. (7b) Anterior portion of lateral region with black horizontal dashes and posterior portion of lateral region with vertical bars; uninterrupted supratemporal canal; throat of live males orange; no reddish orange spots on sides .... *Etheostoma spectabile*

8b. (7b) Lateral region with vertical bars, horizontal dashes on anterior portion sometimes visible, but obscured by vertical bars; interrupted supratemporal canal; throat of live males blue or green; sides of live males scattered with reddish orange spots ....

....*Etheostoma lepidum*

FAMILY SCIAENIDAE—drums

Aplodinotus grunniens

FAMILY CICHLIDAE—cichlids

1a. Anal fin spines 5 to 6 ....*Herichthys cyanoguttatus*

1b. Anal fin spines < 5 (usually 3)...*Oreochromis aureus*

FAMILY GOBIIDAE—gobies

Gobiosoma bosc

FAMILY ACHIRIDAE—American soles

Trinectes maculatus

GUADALUPE AND SAN ANTONIO RIVER BASINS

KEY TO THE FAMILIES

1a. Both eyes on one side of head; without right pectoral fin.. American Soles – Achiridae
1b. One eye on either side of head; with both pectoral fins...2

2a. (1a) Body without pelvic fins...3
2b. (1a) Body with pelvic fins...4

3a. (2a) Dorsal fin attached to caudal fin.............................Freshwater Eels – Anguillidae
3b. (2a) Dorsal fin not attached to caudal fin............................. Pipefishes – Syngnathidae

4a. (2b) Caudal fin heterocercal or abbreviated heterocercal ....Gars – Lepiososteidae
4b. (2b) Caudal fin homocercal 5

5a. (4b) One dorsal fin; pelvic fins without uniserial spines 6
5b. (4b) One or two dorsal fins; pelvic fins with uniserial spines 15

6a. (5a) With adipose fin...7
6b. (5a) Without adipose fin 10

7a. (4a) Without barbels..8
7b. (4a) With barbels...9

8a. (6a) Scales large, < 50 lateral line scales; incisor teeth present.......Tetras – Characidae
8b. (6a) Scales small, > 60 lateral line scales; incisor teeth absent ..... Trouts – Salmonidae

9a. (7b) Body covered with bony plates; head with one pair of barbels...............................
....Armored Catfishes – Loricariidae
9b. (7b) Scales absent; head with four to eight barbels ..... Bullhead Catfishes – Ictaluridae

10a. (6b) Long anal fin with ≥ 17 fin rays ....Shads – Clupiedae

10b. (6b) Short anal fin with ≤ 13 rays 11

11a. (10b) Caudal fin forked or emarginated; lateral line usually present.........................12

11b. (10b) Caudal fin truncated or rounded; lateral line usually absent 13

12a. (11a) Inferior, fleshy mouth modified for sucking; > 7 pharyngeal teeth in main row, usually ≥ 10 dorsal fin rays ....Suckers – Catostomidae

12b. (11a) Mouth usually not fleshy or modified for sucking; < 7 pharyngeal teeth in main row, usually ≤ 10 dorsal fin rays............................Carps and Minnows – Cyprinidae

13a. (11b) Mature males with rounded anal fin; males and females with 3rd anal fin ray branched, no gonopodium present 14

13b. (11b) Mature males with pointed anal fin forming a gonopodium; males and females with 3rd anal fin ray unbranched ....Livebearers – Poeciliidae

14a. (13a) Body robust; teeth in single row are incisor-like and tricuspid (three points on a tooth) ....Pupfishes – Cyprinodontidae

14b. (13a) Body elongate; conical (cone-shaped) pointed teeth in a single row or several rows...Killifishes – Fundulidae

15a. (5b) Pelvic fin position abdominal or sub-thoracic; dorsal fins widely separated.....16

15b. (5b) Pelvic fin position thoracic; dorsal fins joined or, if separate, closely adjacent to one another...17

16a. (15a) Dorsal fin with 4 thick spines; anal fin with 2-3 spines; adipose eyelids present..Mullets – Mugilidae

16b. (15a) Dorsal fin with 4 to 8 thin spines; anal fin with 1 spine; adipose eyelids absent ....Silversides – Atherinopsidae

17a. (15b) One nostril (nare) on each side of head; lateral line interrupted ....
....Cichlids – Cichlidae

17b. (15b) Two nostrils (nares) on each side of head; lateral line complete, incomplete, or absent 18

18a. (17b) Dorsal fin with > 23 fin rays; lateral line extends to tip of caudal fin.. Drums – Sciaenidae

18b. (17b) Dorsal fin with < 23 fin rays; lateral line, if present, does not extend to tip of caudal fin...19

19a. (17b) Anal fin with 1 to 2 spines.. Perches – Percidae

19b. (17b) Anal fin with 3 to 8 spines 20

20a. (19b) Posterior margin of operculum with a sharp spine; spiny and soft dorsal fin separate or only slightly connected; pseudobranchium present and exposed..Temperate Basses – Moronidae

20b. (19b) Posterior margin of operculum without a sharp spine; spiny and soft dorsal fins connected or with deep notch; pseudobranchium covered or absent..Sunfishes – Centrarchidae

KEY TO THE SPECIES

FAMILY LEPISOSTEIDAE—gars

1a. Large teeth in upper jaw in parallel rows on each side .... *Atractosteus spatula*

1b. Large teeth in upper jaw one row, although another non-parallel row might be present 2

2a. (1b) Beak long and narrow, least width goes about 12 to 20 times in length; width of beak at nostrils < eye diameter; snout > ⅔ of head length...................... *Lepisosteus osseus*

2b. (1b) Beak short and blunt, least width goes about 5 to 7 times in length; width of beak at nostrils > eye diameter; snout < ⅔ of head length .... *Lepisosteus oculatus*

FAMILY ANGUILLIDAE—freshwater eels

Anguilla rostrata

FAMILY CLUPEIDAE—herrings

1a. Twenty-nine to 33 anal fin rays; mouth subterminal and below level of middle of eye; black shoulder spot ≥ pupil of eye .... *Dorosoma cepedianum*

1b. Twenty-four to 28 anal fin rays; mouth terminal and at level of eye; black shoulder spot < pupil of eye .... *Dorosoma petenense*

FAMILY CYPRINIDAE - minnows

1a. More than 15 soft rays on dorsal fin; dorsal and anal fins each with a strong serrated spine 2

1b. Fewer than 10 soft rays on dorsal fin; dorsal and anal fins without spine.....................3

2a. (1a) Upper jaw with two pairs of barbels... *Cyprinus carpio*

2b. (1a) Upper jaw without barbels.. *Carassius auratus*

3a. (1b) Anal fin near caudal fin, distance from snout to origin of anal fin is > 2.5 times the distance from origin of anal fin to base of caudal fin; pharyngeal teeth with prominent parallel grooves.. *Ctenopharyngodon idella*

3b. (1b) Anal fin not noticeably near caudal fin: distance from snout to origin of anal fin is < 2.5 times the distance from origin of anal fin to base of caudal fin; pharyngeal teeth without prominent parallel grooves 4

4a. (3b) Intestine wound spirally around swim bladder; keratinous ridge on lower jaw ....*Campostoma anomalum*

4b. (3b) Intestine not wound spirally around swim bladder; keratinous ridge of lower jaw hardly evident...5

5a. (4b) Abdomen behind pelvic fins with a fleshy keel lacking scales; lateral line greatly decurved, distance between anterior lateral line scale and ventral most lateral line scale is > 3 scales in height...*Notemigonus crysoleucas*

5b. (4b) Abdomen behind pelvic fin with scales; lateral line not greatly decurved, lateral line descends < 3 scales ventrally from highest point 6

6a. (5b) With maxillary barbels, might be small and not observable without opening the mouth or with magnification...*Macrhybopsis marconis*

6b. (5b) Without maxillary barbels...7

7a. (6b) Predorsal scales appear crowded, smaller than scales on lateral body or appear as overlapping scales; black spot in the middle, anterior portion of the dorsal fin..................8

7b. (6b) Predorsal scales not crowded; without black spot in the middle, anterior portion of the dorsal fin 9

8a. (7a) Caudal spot, if distinct, continuous with mid-lateral stripe; lateral line incomplete; intestine long, more than twice the standard length........*Pimephales promelas*

8b. (7a) Caudal spot distinct from mid-lateral stripe; lateral line complete, intestine forming a short S-shaped loop ....*Pimephales vigilax*

9a. (7b) Long intestine in a flat coil; black mid-lateral stripe extends through eye to snout...*Dionda nigrotaeniata*

9b. (7b) Short S-shaped intestine..10

10a. (9b) Moderately decurved lateral line; diamond-shaped scales; dark shoulder patch present; melanophores concentrated between rays of dorsal and anal fins 11

10b. (9b) Lateral line incomplete, complete-straight, or complete-slightly decurved; scales not noticeably diamond-shaped; without dark shoulder patch; melanophores concentrated along rays of dorsal and anal fins...13

11a. (10a) Terminal mouth ....*Cyprinella lutrensis*

11b. (10a) Sub-terminal mouth 12

12a. (11b) Caudal fin base with a large black spot, about size of eye .... *Cyprinella venusta*

12b. (11b) Caudal fin base without a large black spot............................ *Cyprinella lepida*

13a. (10b) Distinct and separate black dash at base of dorsal fin; apparent when viewed from above; pharyngeal teeth count usually 0,4-4,0..14

13b. (10b) No distinct and separate black dash at base of dorsal fin; pharyngeal teeth count usually 1,4-4,1 or 2,4-4,2 16

14a. (13a) Lateral line scales markedly elevated (taller than wide) anteriorly, elevated scale height 2 to 5 times scale width...15

14b. (13a) Lateral line scales not markedly elevated anteriorly, scale height 1 to 2 times scale width ....*Notropis stramineus*

15a. (14a) Dorsal and lateral body with melanophores outlining scales; with pronounced black lateral stripe; dorsal fin height goes 2.1 or more times in pre-dorsal length; infraorbital canal complete .... *Notropis volucellus*

15b. (14a) Dorsal and lateral body with sparse melanophores; scales outlined with melanophores are rare; pre-dorsal black spot is prominent and distinct from mid-dorsal stripe; dorsal fin height goes 2.0 or fewer times in pre-dorsal length; infraorbital canal incomplete...*Notropis buchanani*

16a. (13b) Depressed dorsal fin longer than head......................................*Hybopsis amnis*

16b. (13b) Depressed dorsal fin shorter than head 17

17a. (16a) Dorsal fin origin opposite or anterior to pelvic fin origin 18

17b. (16a) Dorsal fin origin posterior to pelvic fin origin 20

18a. (17a) Pharyngeal teeth 5-5; mouth small and almost vertical..... *Opsopoeodus emiliae*

18b. (17a) Pharyngeal teeth are 1,4-4,1 or 2,4-4,2; mouth large and oblique 19

19a. (18b) Usually 8 anal fin rays; inside of mouth with black melanophores; dorsal fin insertion is opposite to pelvic fin insertion..*Notropis chalybaeus*

19b. (18b) Usually 7 anal fin rays; inside of mouth without black melanophores; dorsal fin insertion is anterior to pelvic fin insertion... *Notropis texanus*

20a. (17b) 32 – 36 lateral line scales; melanophores concentrated on upper and lower jaws; predorsal scales are not crowded .... *Notropis amabilis*

20b. (17b) 41 – 45 lateral line scales; melanophores scattered on chin; crowded predorsal scales .... *Lythrurus fumeus*

FAMILY CATOSTOMIDAE—suckers

1a. Dorsal fin long, base > than ⅓ of standard length; 22 to 30 dorsal fin rays 2

1b. Dorsal fin short, base < than ¼ of standard length; 4 to 18 dorsal fin rays 4

2a. (1a) Small scales, lateral line scales > 50; eye closer to back of head than to tip of snout; head abruptly more slender than body; papillose lips .... *Cycleptus elongatus*

2b. (1a) Large scales, lateral line scales < 45; eye closer to tip of snout than back of head; plicate lips 3

3a. (2b) Subopercle triangular, broadest toward base; knob present at tip of lower lip; blunt snout, forming level with eye .... *Carpiodes carpio*

3b. (2b) Subopercle semicircular, broadest towards middle; knob absent at tip of lower lip rounded snout, forming below level of eye .... *Ictiobus bubalus*

4a. (1b) Lateral line complete and well developed; air bladder with 3 chambers .... *Moxostoma congestum*

4b. (1b) Lateral line absent in adults; air bladder with 2 chambers; color pattern (except in young with 2 dark stripes) consists of narrow vertical bars; back with crescentric scale marks... *Erimyzon sucetta*

FAMILY CHARACIDAE—characins

Astyanax mexicanus

FAMILY ICTALURIDAE—bullhead catfishes

1a. Eyes absent; skin without pigment..2

1b. Eyes present; skin pigmented..3

2a. (1a) No teeth on jaws; lips at corner of mouth thin................... *Trogloglanis pattersoni*

2b. (1a) Well developed teeth on jaws; lips at corner of mouth thick ...... *Satan eurystomus*

3a. (1b) Adipose fin joined to the caudal fin or separated by a shallow notch....................4

3b. (1b) Adipose fin free at tip, not joined to caudal fin...5

4a. (3a) Mouth terminal; pectoral fin spine not serrated; lower lip and chin not heavily speckled with black pigment..*Noturus gyrinus*

4b. (3a) Mouth sub-terminal; pectoral spine serrated; lower lip and chin heavily speckled with black pigment..*Noturus nocturnus*

5a. (3b) Head dorso-ventrally compressed; mouth terminal to superior . *Pylodictis olivaris*

5b. (3b) Head rounded; mouth subterminal 6

6a. (5b) Caudal fin rounded or shallowly emarginate...7

6b. (5b) Caudal fin deeply forked 8

7a. (6a) Chin barbels completely or partially black; anal fin rays 17 to 24; anal fin broadly rounded ....*Ameiurus melas*

7b. (6a) Chin barbels white or yellow; anal fin rays 24 to 27; margin of anal fin generally straight.. *Ameiurus natalis*

8a. (6b) Anal fin rays 30 to 36; anal fin free margin is straight; medial keel-like ridge anterior to dorsal fin forms humped back appearance ....*Ictalurus furcatus*

8b. (6b) Anal fin rays 22 to 29; anal fin free margin is rounded; no humped back appearance...9

9a. (8b) Anal fin rays 27 to 29; pectoral fin spine goes < 5 times into standard length; random scattering of few black spots may be present ....*Ictalurus punctatus*

9b. (8b) Anal fin rays 22 to 26; pectoral fin spine goes > 5 times into standard length; diffuse black spots on sides... *Ictalurus lupus*

FAMILY LORICARIIDAE—suckermouth catfishes

1a. Dorsal fin short with ≤ 9 rays...*Hypostomus plecostomus*

1b. Dorsal fin long with ≥ 10 rays 2

2a. (1b) Light spots on a dark background ....*Pterygoplichthys anisitsi*

2b. (1b) Dark spots on a light background............................. *Pterygoplichthys disjunctivus*

FAMILY SALMONIDAE—salmons

Oncorhynchus mykiss

FAMILY MUGILIDAE—mullets

1a. Lower jaw rounded, without a symphyseal knob; lower limb of 1st gill arch with 17 to 20 gill rakers; no adipose eyelid; scales ctenoid............................*Agonostomus monticola*

1b. Lower jaw angular, with a prominent symphyseal knob; lower limb of 1st gill arch with 25 to 60 gill rakers; adipose eyelid well developed in adults; scales cycloid in young, ctenoid in adults..*Mugil cephalus*

FAMILY ATHERINOPSIDAE—New World silversides

1a. Scales ctenoid, rough to the touch; double pairs of black spots on dorsum; bases of dorsal and anal fin covered with scales..*Membras martinica*

1b. Scales cycloid, smooth to the touch; dorsum with crosshatching, but not double pairs of black spots; bases of dorsal and anal fins not covered with scales; horizontal distance between spinous dorsal and anal fin origin less than 7% of standard length.........................

....*Menidia audens*

FAMILY FUNDULIDAE—topminnows

1a. Distance from origin of dorsal fin to end of hypural plate < distance from origin of dorsal fin to preopercle or occasionally about equal to that distance; more than 30 longitudinal scale rows 2

1b. Distance from origin of dorsal fin to end of hypural plate > distance from origin of dorsal fin to preopercle; 30 or fewer longitudinal scale rows...3

2a. (1a) Body with a distinct black lateral band..*Fundulus notatus*

2b. (1a) Body without a distinct black lateral band ....*Fundulus chrysotus*

3a. (1b) Conspicuous lateral stripe extending through eye to snout; body depth goes 4.5 to 5 times in standard length ....*Lucania goodei*

3b. (1b) No distinct lateral stripe; body depth goes 3.5 to 4 times in standard length..*Lucania parva*

FAMILY CYPRINODONTIDAE— pupfishes

Cyprinodon variegatus

FAMILY POECILIIDAE—livebearers

1a. Origin of dorsal fin anterior to anal fin origin; intestinal canal long with many convolutions..2

1b. Origin of dorsal fin posterior to anal fin origin; intestinal canal short with few convolutions..5

2a. (1a) Teeth in single row; ventral rays of caudal fin in mature males extended to form swordlike extension .... *Xiphophorus hellerii*

2b. (1a) Teeth in villiform bands; caudal fin rays symmetrical..3

3a. (2b) Dorsal fin rays < 9 ....*Poecilia reticulata*

3b. (2b) Dorsal fin rays ≥10 4

4a. (3b) Dorsal fin rays 12 to 14; dorsal fin base more than ½ predorsal length; rows of dark spots on scales obscure diamond-shaped color pattern ....*Poecilia latipinna*

4b. (3b) Dorsal fin rays 10 to 12; dorsal fin base < ½ predorsal length; dark spots on scales do not obscure diamond-shaped color pattern; only exists as females.......................

....*Poecilia formosa*

5a. (1b) Spines at tip of 3rd anal fin ray of male gonopodium (first enlarged ray) 1 to 3 times longer than wide...*Gambusia affinis*

5b. (1b) Spines at tip of 3rd anal fin ray of male gonopodium 4 to 10 times longer than wide...6

6a. (5b) Distal segments of anterior branch of 4th fin ray of gonopodium coalesced to elbow; Extinct...*Gambusia georgei*

6b. (5b) Distal segments of anterior branch of 4th fin ray of gonopodium not coalesced to elbow; postanal streak prominent (darker than markings on scale pockets); black markings on mouth; median row of spots on caudal fin; median row of spots on dorsal fin; terminal hook on 4th and 5th rays of gonopodium angular at tip ...... *Gambusia geiseri*

FAMILY SYNGNATHIDAE—pipefishes

Syngnathus scovelli

FAMILY MORONIDAE—temperate basses

1a. Body depth goes < 3 times in standard length; teeth in single patch on back of tongue..*Morone chrysops*

1b. Body depth goes > 3 times in standard length; teeth in 2 parallel patches on back of tongue..*Morone saxatilis*

FAMILY CENTRARCHIDAE—sunfishes

1a. Five to 8 anal spines..2

1b. Three anal spines..4

2a. (1a) Eleven to 13 dorsal fin spines..*Ambloplites rupestris*

2b. (1a) Six to 8 dorsal fin spines 3

2a. (1a) Dorsal fin set back on body, length of dorsal fin base < distance from its origin to posterior margin of eye; lateral body with wide to narrow dorsal black bands; ≤ 6 dorsal spines.. *Pomoxis annularis*

2b. (1a) Dorsal fin set forward on body, length of dorsal fin base equal to or greater than distance from its origin to posterior margin of eye; lateral body with checkerboard black and light pattern; ≥7 dorsal spines ....*Pomoxis nigromaculatus*

4a. (1b) Body slender, body depth contained > 3 times into standard length......................5

4b. (1b) Body deep, body depth contained < 3 times into standard length..........................8

5a. (4a) Dorsal fins narrowly joined at base forming a deep notch; upper jaw extends past posterior margin of eye in adults; mid-lateral stripe generally complete, rows of spots ventral to mid-lateral stripe faint and incomplete ....*Micropterus salmoides*

5b. (4a) Dorsal fins broadly joined at base forming a shallow notch; upper jaw does not reach past posterior portion of eye; bases of soft dorsal and anal fins scaled 6

6a. (5b) No tooth patch on tongue; lower lateral region scales without black spots forming horizontal rows..*Micropterus dolomieu*

6b. (5b) Tooth patch on tongue; lower lateral region scales with black spots forming horizontal rows..7

7a. (6b) Mid-lateral stripe often appears interrupted anteriorly, rows of spots ventral to mid-lateral stripe distinct and complete. .... *Micropterus punctulatus*

7b. (6b) Dark wide midlateral stripe present and disconnected anteriorly into a narrow midlateral stripe posteriorly, forming vertical bars.............................. *Micropterus treculii*

8a. (4b) Teeth on tongue; head and opercle with 3 to 5 distinct dark and light longitudinal stripes; red spot on posterior margin of opercle flap in fresh specimens....*Lepomis gulosus*

8b. (4b) No teeth on tongue; head and opercle lacking distinct dark and light longitudinal stripes 9

9a. (8b) Pectoral fins long and pointed, reach anterior portion of eye or beyond when bent forward 10

9b. (8b) Pectoral fins short and rounded, do not reach past eye when bent forward 12

10a. (9a) Opercle flap stiff to its margin, posterior margin either red or orange in live specimens ....*Lepomis microlophus*

10b. (9a) Opercle flap flexible, posterior margin not red or orange in live specimens 11

11a. (10b) Opercle flap black to the margin; black spot on posterior base of soft dorsal fin ....*Lepomis macrochirus*

11b. (10b) Opercle flap outlined with thick white band; lacking black spot on posterior base of soft dorsal fin .... *Lepomis humilis*

12a. (9b) Black opercle flap stiff near the posterior margin with bone supporting all or majority of the flap...13

12b. (9b) Black opercle flap flexible near the posterior margin without bone supporting majority of the flap...14

13a. (12a) Body elongated with black spot on posterior base of soft dorsal fin....................

....*Lepomis cyanellus*

13b. (12a) Body rounded without black spot on posterior base of soft dorsal fin; lateral body with alternating stripes formed from black and red spots................ *Lepomis miniatus*

14a. (12b) Opercle flap black to the posterior margin; opercle flap is thin near the opercle bone with the narrowest width of the flexible portion of the flap about the same diameter of the eye pupil..*Lepomis auritus*

14b. (12b) Opercle flap black and surrounded by white on the posterior margin; opercle flap is wide with narrowest width of the flexible flap is about two times the diameter of the eye pupil... *Lepomis megalotis*

FAMILY PERCIDAE—perches

1a. Snout conical, extends beyond upper lip; body with ≥ 14 black vertical bars...............2

1b. Snout less conical, does not extend beyond upper lip; body with < 14 black vertical bars or with a pattern other than vertical bars...3

2a. (1a) Body with thick vertical bars, bars alternate in length from long to short; 9 to 10 long bars...*Percina carbonaria*

2b. (1a) Body with 14 to 16 thin vertical bars of similar length..........*Percina macrolepida*

3a. (1b) Sides of body with large black blotches; midline of abdomen naked or with enlarged scales 4

3b. (1b) Sides of body without large black blotches; scales on abdomen normal...............5

4a. (3a) Upper lip connected to snout by a narrow frenum; blotches on sides of body are rectangle-shaped and bleed downward ....*Percina shumardi*

4b. (3a) Upper lip connected to snout by a broad frenum; blotches on sides of body do not bleed downward...*Percina apristis*

5a. (3b) Lateral line short, < 6 pored scales; single row of horizontal dashes present.. *Etheostoma fonticola*

5b. (3b) Lateral line long (complete or incomplete), > 6 pored scales; if horizontal dashes present, accompanied by vertical bars 6

6a. (5b) Lateral line arched upward .... *Etheostoma gracile*

6b. (5b) Lateral line straight...7

7a. (6b) Lateral body with distinct series of M-shaped pigments; snout rounded and blunt ....*Etheostoma chlorosoma*

7b. (6b) Lateral body without distinct series of M-shaped pigments; snout not noticeably rounded and blunt 8

8a. (7b) Anterior portion of lateral region with black horizontal dashes and posterior portion of lateral region with vertical bars; uninterrupted supratemporal canal; throat of live males orange; no reddish orange spots on sides .... *Etheostoma spectabile*

8b. (7b) Lateral region with vertical bars, horizontal dashes on anterior portion sometimes visible, but obscured by vertical bars; interrupted supratemporal canal; throat of live males blue or green; sides of live males scattered with reddish orange spots ....

....*Etheostoma lepidum*

FAMILY SCIAENIDAE—drums

Aplodinotus grunniens

FAMILY CICHLIDAE—cichlids

1a. Anal fin spines 5 to 6 ....*Herichthys cyanoguttatus*

1b. Anal fin spines < 5 (usually 3)... 2

2a. (1b) Gill rakers 14 to 20 (usually 17 to 18) on lower part of first gill arch; most teeth in outer row are unicuspid in adults; sides with 3 or 4 dark blotches or with no markings; no yellow on dorsal fin; caudal fin without distinct vertical stripes ....

....*Oreochromis mossambicus*

2b. (1b) Gill rakers 18 to 26 on lower part of 1st gill arch; outer row of teeth bicuspid in adults; caudal fin unmarked, or with vague, irregular dark markings, caudal fin often with a broad, red distal margin; young often with vertical bands on caudal fin............................

....*Oreochromis aureus*

FAMILY ACHIRIDAE—American soles

Trinectes maculatus

NUECES RIVER BASIN

KEY TO THE FAMILIES

1a. Both eyes on one side of head; without right pectoral fin.. American Soles – Achiridae
1b. One eye on either side of head; with both pectoral fins..2

1a. (1b) Body long and slender; without pelvic fins............Freshwater Eels – Anguillidae
1b. (1b) Body truncated or elongated; with pelvic fins 2

3a. (2b) Caudal fin heterocercal or abbreviated heterocercal ....Gars – Lepiososteidae
3b. (2b) Caudal fin homocercal 4

4a. (3b) One dorsal fin; pelvic fins without uniserial spines 5
4b. (3b) One or two dorsal fins; pelvic fins with uniserial spines 11

5a. (4a) With adipose fin...6
5b. (4a) Without adipose fin 8

6a. (5a) Without barbels..7
6b. (5a) With barbels..Bullhead Catfishes – Ictaluridae

7a. (6a) Scales large, < 50 lateral line scales; incisor teeth present.......Tetras – Characidae
7b. (6a) Scales small, > 60 lateral line scales; incisor teeth absent ..... Trouts – Salmonidae

8a. (5b) Long anal fin with ≥ 17 fin rays ....Shads – Clupiedae
8b. (5b) Short anal fin with ≤ 13 rays 9

9a. (8b) Caudal fin forked or emarginated; lateral line usually present............................10
9b. (8b) Caudal fin truncated or rounded; lateral line usually absent...................................
....Livebearers – Poeciliidae

10a. (9a) Inferior, fleshy mouth modified for sucking; > 7 pharyngeal teeth in main row, usually ≥ 10 dorsal fin rays .... Suckers – Catostomidae

10b. (9a) Mouth usually not fleshy or modified for sucking; < 7 pharyngeal teeth in main row, usually ≤ 10 dorsal fin rays .... Carps and Minnows – Cyprinidae

11a. (4b) Pelvic fin position abdominal or sub-thoracic; dorsal fins widely separated 12

11b. (4b) Pelvic fin position thoracic; dorsal fins joined or, if separate, closely adjacent to one another 13

12a. (11a) Dorsal fin with 4 thick spines; anal fin with 2-3 spines; adipose eyelids present .... Mullets – Mugilidae

12b. (11a) Dorsal fin with 4 to 8 thin spines; anal fin with 1 spine; adipose eyelids absent .... Silversides – Atherinopsidae

13a. (12b) One nostril (nare) on each side of head; lateral line interrupted ....

.... Cichlids – Cichlidae

13b. (12b) Two nostrils (nares) on each side of head; lateral line complete, incomplete, or absent 14

14a. (15b) Dorsal fin with > 23 fin rays; lateral line extends to tip of caudal fin.................

.... Drums – Sciaenidae

14b. (15b) Dorsal fin with < 23 fin rays; lateral line, if present, does not extend to tip of caudal fin 15

15a. (14b) Anal fin with 1 to 2 spines .... Perches – Percidae

15b. (14b) Anal fin with 3 to 8 spines 16

16a. (15b) Posterior margin of operculum with a sharp spine; spiny and soft dorsal fin separate or only slightly connected; pseudobranchium present and exposed........................

.... Temperate Basses – Moronidae

16b. (15b) Posterior margin of operculum without a sharp spine; spiny and soft dorsal fins connected or with deep notch; pseudobranchium covered or absent..............................

.... Sunfishes – Centrarchidae

KEY TO THE SPECIES

FAMILY LEPISOSTEIDAE—gars

1a. Large teeth in upper jaw in parallel rows on each side ....*Atractosteus spatula*

1b. Large teeth in upper jaw one row, although another non-parallel row might be present 2

2a. (1b) Beak long and narrow, least width goes about 12 to 20 times in length; width of beak at nostrils < eye diameter; snout > ⅔ of head length...................... *Lepisosteus osseus*

2b. (1b) Beak short and blunt, least width goes about 5 to 7 times in length; width of beak at nostrils > eye diameter; snout < ⅔ of head length .... *Lepisosteus oculatus*

FAMILY ANGUILLIDAE—freshwater eels

Anguilla rostrata

FAMILY CLUPEIDAE—herrings

1a. Twenty-nine to 33 anal fin rays; mouth subterminal and below level of middle of eye; black shoulder spot ≥ pupil of eye .... *Dorosoma cepedianum*

1b. Twenty-four to 28 anal fin rays; mouth terminal and at level of eye; black shoulder spot < pupil of eye ....*Dorosoma petenense*

FAMILY CYPRINIDAE - minnows

1a. More than 15 soft rays on dorsal fin; dorsal and anal fins each with a strong serrated spine 2

1b. Fewer than 10 soft rays on dorsal fin; dorsal and anal fins without spine.....................3

2a. (1a) Upper jaw with two pairs of barbels... *Cyprinus carpio*

2b. (1a) Upper jaw without barbels.. *Carassius auratus*

3a. (1b) Anal fin near caudal fin, distance from snout to origin of anal fin is > 2.5 times the distance from origin of anal fin to base of caudal fin; pharyngeal teeth with prominent parallel grooves..*Ctenopharyngodon idella*

3b. (1b) Anal fin not noticeably near caudal fin: distance from snout to origin of anal fin is < 2.5 times the distance from origin of anal fin to base of caudal fin; pharyngeal teeth without prominent parallel grooves 4

4a. (3b) Intestine wound spirally around swim bladder; keratinous ridge on lower jaw..*Campostoma anomalum*

4b. (3b) Intestine not wound spirally around swim bladder; keratinous ridge of lower jaw hardly evident...5

5a. (4b) Abdomen behind pelvic fins with a fleshy keel lacking scales; lateral line greatly decurved, distance between anterior lateral line scale and ventral most lateral line scale is > 3 scales in height...*Notemigonus crysoleucas*

5b. (4b) Abdomen behind pelvic fin with scales; lateral line not greatly decurved, lateral line descends < 3 scales ventrally from highest point 6

6a. (5b) Predorsal scales appear crowded, smaller than scales on lateral body or appear as overlapping scales; black spot in the middle, anterior portion of the dorsal fin..................7

6b. (5b) Predorsal scales not crowded; without black spot in the middle, anterior portion of the dorsal fin 8

7a. (6a) Caudal spot, if distinct, continuous with mid-lateral stripe; lateral line incomplete; intestine long, more than twice the standard length........*Pimephales promelas*

7b. (6a) Caudal spot distinct from mid-lateral stripe; lateral line complete, intestine forming a short S-shaped loop ....*Pimephales vigilax*

8a. (6b) Long intestine in a flat coil..*Dionda serena*

8b. (6b) Short S-shaped intestine..9

9a. (8b) Moderately decurved lateral line; diamond-shaped scales; dark shoulder patch present; melanophores concentrated between rays of dorsal and anal fins 10

9b. (8b) Lateral line incomplete, complete-straight, or complete-slightly decurved; scales not noticeably diamond-shaped; without dark shoulder patch; melanophores concentrated along rays of dorsal and anal fins 12

10a. (9a) Terminal mouth ....*Cyprinella lutrensis*

10b. (9a) Sub-terminal mouth..11

11a. (10b) Caudal fin base with a large black spot, about size of eye .... *Cyprinella venusta*

11b. (10b) Caudal fin base without a large black spot............................. *Cyprinella lepida*

12a. (9b) Distinct and separate black dash at base of dorsal fin; apparent when viewed from above; pharyngeal teeth count usually 0,4-4,0..13

12b. (9b) No distinct and separate black dash at base of dorsal fin; pharyngeal teeth count usually 1,4-4,1 or 2,4-4,2..15

13a. (12a) Lateral line scales not markedly elevated anteriorly, scale height 1 to 2 times scale width ....*Notropis stramineus*

13b. (12a) Lateral line scales markedly elevated (taller than wide) anteriorly, elevated scale height 2 to 5 times scale width..14

14a. (13b) Dorsal and lateral body with melanophores outlining scales; with pronounced black lateral stripe; dorsal fin height goes 2.1 or more times in pre-dorsal length; infraorbital canal complete .... *Notropis volucellus*

14b. (13b) Dorsal and lateral body with sparse melanophores; scales outlined with melanophores are rare; pre-dorsal black spot is prominent and distinct from mid-dorsal stripe; dorsal fin height goes 2.0 or fewer times in pre-dorsal length; infraorbital canal incomplete..*Notropis buchanani*

15a. (12b) Dorsal fin origin opposite or anterior to pelvic fin origin 16

15b. (12b) Dorsal fin origin posterior to pelvic fin origin ....*Notropis amabilis*

16a. (15a) Pharyngeal teeth 5-5; mouth small and almost vertical.....*Opsopoeodus emiliae*

16b. (15a) Pharyngeal teeth are 1,4-4,1 or 2,4-4,2; mouth large and oblique ....

.... *Notropis texanus*

FAMILY CATOSTOMIDAE—suckers

1a. Dorsal fin long, base > than ⅓ of standard length; 22 to 30 dorsal fin rays 2

1b. Dorsal fin short, base < than ¼ of standard length; 4 to 18 dorsal fin rays ....

....*Moxostoma congestum*

2a. (1a) Small scales, lateral line scales > 50; eye closer to back of head than to tip of snout; head abruptly more slender than body; papillose lips................ *Cycleptus elongatus*

2b. (1a) Large scales, lateral line scales < 45; eye closer to tip of snout than back of head; plicate lips 3

3a. (2b) Subopercle triangular, broadest toward base; knob present at tip of lower lip; blunt snout, forming level with eye .... *Carpiodes carpio*

3b. (2b) Subopercle semicircular, broadest towards middle; knob present at tip of lower lip; rounded snout, forming below level of eye ....*Ictiobus bubalus*

FAMILY CHARACIDAE—characins

Astyanax mexicanus

FAMILY ICTALURIDAE—bullhead catfishes

1a. Adipose fin joined to the caudal fin or separated by a shallow notch....*Noturus gyrinus*

1b. Adipose fin free at tip, not joined to caudal fin 2

2a. (1b) Head dorso-ventrally compressed; mouth terminal to superior . *Pylodictis olivaris*

2b. (1b) Head rounded; mouth subterminal 3

3a. (2b) Caudal fin rounded or shallowly emarginate...4

3b. (2b) Caudal fin deeply forked 5

4a. (3a) Chin barbels completely or partially black; anal fin rays 17 to 24; anal fin broadly rounded ....*Ameiurus melas*

4b. (3a) Chin barbels white or yellow; anal fin rays 24 to 27; margin of anal fin generally straight.. *Ameiurus natalis*

5a. (3b) Anal fin rays 30 to 36; anal fin free margin is straight; medial keel-like ridge anterior to dorsal fin forms humped back appearance ....*Ictalurus furcatus*

5b. (3b) Anal fin rays 22 to 29; anal fin free margin is rounded; no humped back appearance...6

6a. (5b) Anal fin rays 27 to 29; pectoral fin spine goes < 5 times into standard length; random scattering of few black spots may be present ....*Ictalurus punctatus*

6b. (5b) Anal fin rays 22 to 26; pectoral fin spine goes > 5 times into standard length; diffuse black spots on sides.. *Ictalurus lupus*

FAMILY SALMONIDAE—salmons

Oncorhynchus mykiss

FAMILY MUGILIDAE—mullets

1a. Lower jaw rounded, without a symphyseal knob; lower limb of 1st gill arch with 17 to 20 gill rakers; no adipose eyelid; scales ctenoid............................*Agonostomus monticola*

1b. Lower jaw angular, with a prominent symphyseal knob; lower limb of 1st gill arch with 25 to 60 gill rakers; adipose eyelid well developed in adults; scales cycloid in young, ctenoid in adults...*Mugil cephalus*

FAMILY ATHERINOPSIDAE—New World silversides

Menidia audens

FAMILY FUNDULIDAE—topminnows

Fundulus notatus

FAMILY POECILIIDAE—livebearers

1a. Origin of dorsal fin anterior to anal fin origin; intestinal canal long with many convolutions..2

1b. Origin of dorsal fin posterior to anal fin origin; intestinal canal short with few convolutions...*Gambusia affinis*

2a. (1a) Dorsal fin rays 12 to 14; dorsal fin base more than ½ predorsal length; rows of dark spots on scales obscure diamond-shaped color pattern ....*Poecilia latipinna*

2b. (1a) Dorsal fin rays 10 to 12; dorsal fin base < ½ predorsal length; dark spots on scales do not obscure diamond-shaped color pattern; only exists as females.......................

....*Poecilia formosa*

FAMILY MORONIDAE—temperate basses

1a. Body depth goes < 3 times in standard length; teeth in single patch on back of tongue...*Morone chrysops*

1b. Body depth goes > 3 times in standard length; teeth in 2 parallel patches on back of tongue...*Morone saxatilis*

FAMILY CENTRARCHIDAE—sunfishes

1a. Five to 8 anal spines...2

1b. Three anal spines...3

2a. (1a) Dorsal fin set back on body, length of dorsal fin base < distance from its origin to posterior margin of eye; lateral body with wide to narrow dorsal black bands; ≤ 6 dorsal spines.. *Pomoxis annularis*

2b. (1a) Dorsal fin set forward on body, length of dorsal fin base equal to or greater than distance from its origin to posterior margin of eye; lateral body with checkerboard black and light pattern; ≥7 dorsal spines ....*Pomoxis nigromaculatus*

3a. (1b) Body slender, body depth contained > 3 times into standard length......................4

3b. (1b) Body deep, body depth contained < 3 times into standard length..........................6

4a. (3a) Dorsal fins narrowly joined at base forming a deep notch; upper jaw extends past posterior margin of eye in adults; mid-lateral stripe generally complete, rows of spots ventral to mid-lateral stripe faint and incomplete ....*Micropterus salmoides*

4b. (3a) Dorsal fins broadly joined at base forming a shallow notch; upper jaw does not reach past posterior portion of eye; bases of soft dorsal and anal fins scaled 5

5a. (4b) No tooth patch on tongue; lower lateral region scales without black spots forming horizontal rows..*Micropterus dolomieu*

5b. (4b) Tooth patch on tongue; lower lateral region scales with black spots forming horizontal rows... *Micropterus treculii*

6a. (3b) Teeth on tongue; head and opercle with 3 to 5 distinct dark and light longitudinal stripes; red spot on posterior margin of opercle flap in fresh specimens....*Lepomis gulosus*

6b. (3b) No teeth on tongue; head and opercle lacking distinct dark and light longitudinal stripes 7

7a. (6b) Pectoral fins long and pointed, reach anterior portion of eye or beyond when bent forward 8

7b. (6b) Pectoral fins short and rounded, do not reach past eye when bent forward.........10

8a. (7a) Opercle flap stiff to its margin, posterior margin either red or orange in live specimens ....*Lepomis microlophus*

8b. (7a) Opercle flap flexible, posterior margin not red or orange in live specimens 9

9a. (8b) Opercle flap black to the margin; black spot on posterior base of soft dorsal fin ....*Lepomis macrochirus*

9b. (8b) Opercle flap outlined with thick white band; lacking black spot on posterior base of soft dorsal fin .... *Lepomis humilis*

10a. (7b) Black opercle flap stiff near the posterior margin with bone supporting all or majority of the flap..11

10b. (7b) Black opercle flap flexible near the posterior margin without bone supporting majority of the flap..12

11a. (10a) Body elongated with black spot on posterior base of soft dorsal fin...................

....*Lepomis cyanellus*

11b. (10a) Body rounded without black spot on posterior base of soft dorsal fin; lateral body with alternating stripes formed from black and red spots .... *Lepomis miniatus*

12a. (10b) Opercle flap black to the posterior margin; opercle flap is thin near the opercle bone with the narrowest width of the flexible portion of the flap about the same diameter of the eye pupil..*Lepomis auritus*

12b. (10b) Opercle flap black and surrounded by white on the posterior margin; opercle flap is wide with narrowest width of the flexible flap is about two times the diameter of the eye pupil .... *Lepomis megalotis*

FAMILY PERCIDAE—perches

1a. Snout conical, extends beyond upper lip; body with ≥ 14 black vertical bars; bars contain medial constrictions, giving them an hourglass shape ....*Percina carbonaria*

1b. Snout less conical, does not extend beyond upper lip; body with < 14 black vertical bars or with a pattern other than vertical bars 2

2a. (1b) Lateral line arched upward; lateral region may contain verticle 8-10 green vertical bars .... *Etheostoma gracile*

2b. (1b) Lateral line straight; lateral region with 8 to 13 vertical bars .*Etheostoma lepidum*

FAMILY SCIAENIDAE—drums

Aplodinotus grunniens

FAMILY CICHLIDAE—cichlids

1a. Anal fin spines 5 to 6 ....*Herichthys cyanoguttatus*

1b. Anal fin spines < 5 (usually 3)... 2

2a. (1b) Gill rakers 14 to 20 (usually 17 to 18) on lower part of first gill arch; most teeth in outer row are unicuspid in adults; sides with 3 or 4 dark blotches or with no markings; no yellow on dorsal fin; caudal fin without distinct vertical stripes ....

.... *Oreochromis mossambicus*

2b. (1b) Gill rakers 18 to 26 on lower part of 1st gill arch; outer row of teeth bicuspid in adults; caudal fin unmarked, or with vague, irregular dark markings, caudal fin often with a broad, red distal margin; young often with vertical bands on caudal fin ....

....*Oreochromis aureus*

FAMILY ACHIRIDAE—American soles

Trinectes maculatus

RED RIVER BASIN

KEY TO THE FAMILIES

1a. Jawless, disc-shaped mouth; without pectoral and pelvic fins; 7 pairs of external gill openings .... Lampreys – Petromyzontidae

1b. Jawed mouth; one gill opening on each side of head; with pectoral, pelvic, or both fins 2

2a. (1b) Body long and slender; without pelvic fins .... Freshwater Eels – Anguillidae

2b. (1b) Body truncated or elongated; with pelvic fins 3

3a. (2b) Caudal fin heterocercal or abbreviated heterocercal 4

3b. (2b) Caudal fin homocercal 7

4a. (3a) Caudal fin heterocercal, body with bony scutes or appears scaleless 5

4b. (3a) Caudal fin abbreviated heterocercal; body with ganoid or cycloid scales 6

5a. (4a) Long, paddle shaped snout; scaleless, except for a few ganoid scales at the base of caudal fin .... Paddlefishes – Polyodontidae

5b. (4a) Snout conical or shovel-shaped with four barbels on ventral surface; several rows of bony scutes (plates) along body .... Sturgeons – Acipenseridae

6a. (4b) Body covered with ganoid scales; snout formed into a beak; without gular plate .... Gars – Lepisosteidae

6b. (4b) Body covered with cycloid scales, snout not formed into a beak, with a gular plate .... Bowfin – Amiidae

7a. (3b) Jaws duckbilled .... Pickerels – Esocidae

7b. (3b) Jaws not duckbilled 8

8a. (7b) One dorsal fin; pelvic fins without uniserial spines 9

8b. (7b) One or two dorsal fins; pelvic fins with uniserial spines 18

9a. (8a) With adipose fin..10

9b. (8a) Without adipose fin 12

10a. (9a) Without barbels...11

10b. (9a) With barbels...Bullhead Catfishes – Ictaluridae

11a. (10a) Scales large, < 50 lateral line scales; incisor teeth present...Tetras – Characidae

11b. (10a) Scales small, > 60 lateral line scales; incisor teeth absent . Trouts – Salmonidae

12a. (9b) Long anal fin with ≥ 17 fin rays 13

12b. (9b) Short anal fin with ≤ 13 rays 14

13a. (12a) Belly with scales forming a saw-like keel ....Shads – Clupiedae

13b. (12a) Belly without scales forming a saw-like keel............. Mooneyes – Hiodontidae

14a. (12b) Caudal fin forked or emarginated; lateral line usually present.........................15

14b. (12b) Caudal fin truncated or rounded; lateral line usually absent............................16

15a. (14a) Inferior, fleshy mouth modified for sucking; > 7 pharyngeal teeth in main row, usually ≥ 10 dorsal fin rays..Suckers – Catostomidae

15b. (14a) Mouth usually not fleshy or modified for sucking; < 7 pharyngeal teeth in main row, usually ≤ 10 dorsal fin rays............................Carps and Minnows – Cyprinidae

16a. (14b) Mature males with rounded anal fin; males and females with 3rd anal fin ray branched, no gonopodium present 17

16b. (14b) Mature males with pointed anal fin forming a gonopodium; males and females with 3rd anal fin ray unbranched. ....Livebearers – Poeciliidae

17a. (16a) Body robust; teeth in single row are incisor-like and tricuspid (three points on a tooth). ....Pupfishes – Cyprinodontidae

17b. (16a) Body elongate; conical (cone-shaped) pointed teeth in a single row or several rows...Killifishes – Fundulidae

18a. (8b) Anus anterior to pelvic fins; > 5 soft rays on each pelvic fin................................ .... Pirate Perch – Aphredoderidae

18b. (8b) Anus posterior to pelvic fins; 5 soft rays on pelvic fins....................................19

19a. (18b) Pelvic fin position abdominal or sub-thoracic; dorsal fins widely separated...20

19b. (18b) Pelvic fin position thoracic; dorsal fins joined or, if separate, closely adjacent to one another...21

20a. (19a) Dorsal fin with 4 thick spines; anal fin with 2-3 spines; adipose eyelids present..Mullets – Mugilidae

20b. (19a) Dorsal fin with 4 to 8 thin spines; anal fin with 1 spine; adipose eyelids absent ....Silversides – Atherinopsidae

21a. (19b) Dorsal fin with > 23 fin rays; lateral line extends to tip of caudal fin................. .... Drums – Sciaenidae

21b. (19b) Dorsal fin with < 23 fin rays; lateral line, if present, does not extend to tip of caudal fin...22

22a. (21b) Anal fin with 1 to 2 spines.. Perches – Percidae

22b. (21b) Anal fin with 3 to 8 spines 23

23a. (22b) Posterior margin of operculum with a sharp spine; spiny and soft dorsal fin separate or only slightly connected; pseudobranchium present and exposed........................ ....Temperate Basses – Moronidae

23b. (22b) Posterior margin of operculum without a sharp spine; spiny and soft dorsal fins connected or with deep notch; pseudobranchium covered or absent..........................24

24a. (23b) Lateral line present or incomplete ....Sunfishes – Centrarchidae

24b. (23b) Lateral line absent ....Pygmy Sunfishes – Elassomatidae

KEY TO THE SPECIES

FAMILY PETROMYZONTIDAE – lampreys

1a. Disc-shaped mouth large, diameter of mouth > body width and about 140 times into total length; with rasping teeth; adults with well-developed intestine..................................

....*Ichthyomyzon castaneus*

1b. Disc-shaped mouth small, diameter of mouth ≤ body width and about 170 to 250 times into total length; without rasping teeth; adults without well-developed intestine.. *Ichthyomyzon gagei*

FAMILY ACIPENSERIDAE—sturgeons

Scaphirhynchus platorynchus

FAMILY POLYODONTIDAE—paddlefishes

Polyodon spathula

FAMILY LEPISOSTEIDAE—gars

1a. Large teeth in upper jaw in parallel rows on each side ....*Atractosteus spatula*

1b. Large teeth in upper jaw one row, although another non-parallel row might be present 2

2a. (1b) Beak long and narrow, least width goes about 12 to 20 times in length; width of beak at nostrils < eye diameter; snout > ⅔ of head length...................... *Lepisosteus osseus*

2b. (1b) Beak short and blunt, least width goes about 5 to 7 times in length; width of beak at nostrils > eye diameter; snout < ⅔ of head length 3

3a. (2b) Fifty-nine to 63 lateral line scales; 38 to 44 scale rows around body, lacking black spots on head ....*Lepisosteus platostomus*

3b. (2b) Fifty-four to 57 lateral line scales; 32 to 38 scale rows around body; with black spots on head.. *Lepisosteus oculatus*

FAMILY AMIIDAE—bowfins

Amia calva

FAMILY HIODONTIDAE—mooneyes

Hiodon alosoides

FAMILY ANGUILLIDAE—freshwater eels

Anguilla rostrata

FAMILY CLUPEIDAE—herrings

1a. Twenty-nine to 33 anal fin rays; mouth subterminal and below level of middle of eye; black shoulder spot ≥ pupil of eye .... *Dorosoma cepedianum*

1b. Twenty-four to 28 anal fin rays; mouth terminal and at level of eye; black shoulder spot < pupil of eye ....*Dorosoma petenense*

FAMILY CYPRINIDAE - minnows

1a. More than 15 soft rays on dorsal fin; dorsal and anal fins each with a strong serrated spine 2

1b. Fewer than 10 soft rays on dorsal fin; dorsal and anal fins without spine.....................3

2a. (1a) Upper jaw with two pairs of barbels.. *Cyprinus carpio*

2b. (1a) Upper jaw without barbels... *Carassius auratus*

3a. (1b) Middle of eye is noticeably low on head, ventral to head midline ....*Hypophthalmichthys nobilis*

3b. (1b) Middle of eye is not noticeably low on head, equal or dorsal to head midline......4

4a. (3b) Anal fin near caudal fin, distance from snout to origin of anal fin is > 2.5 times the distance from origin of anal fin to base of caudal fin; pharyngeal teeth with prominent parallel grooves..*Ctenopharyngodon idella*

4b. (3b) Anal fin not noticeably near caudal fin: distance from snout to origin of anal fin is < 2.5 times the distance from origin of anal fin to base of caudal fin; pharyngeal teeth without prominent parallel grooves 5

5a. (4b) Intestine wound spirally around swim bladder; keratinous ridge on lower jaw ....*Campostoma anomalum*

5b. (4b) Intestine not wound spirally around swim bladder; keratinous ridge of lower jaw hardly evident...6

6a. (5b) Abdomen behind pelvic fins with a fleshy keel lacking scales; lateral line greatly decurved, distance between anterior lateral line scale and ventral most lateral line scale is > 3 scales in height...*Notemigonus crysoleucas*

6b. (5b) Abdomen behind pelvic fin with scales; lateral line not greatly decurved, lateral line descends < 3 scales ventrally from highest point 7

7a. (6b) With maxillary barbels, might be small and not observable without opening the mouth or with magnification...8

7b. (6b) Without maxillary barbels...11

8a. (7a) Mouth terminal; distinct black spot located anteriorly on dorsal fin; pharyngeal teeth on main row 5-4 or 5-5...*Semotilus atromaculatus*

8b. (7a) Mouth subterminal or inferior; no distinct black spot on dorsal fin; pharyngeal teeth on main row 4-4 9

9a. (8b) Body silvery, without scattered black specks................. *Macrhybopsis storeriana*

9b. (8b) Body with scattered black specks...10

10a. (9b) Two pairs of barbels; posterior barbels longer than orbit length; anterior barbels usually half of orbit length...*Macrhybopsis australis*

10b. (9b) One or 2 pairs of barbels; posterior barbels less than orbit length; anterior barbels, if present, < half of posterior barbel length......................*Macrhybopsis hyostoma*

11a. (7b) Thick lower lip at corners, mouth noticeably ventral; black spot at base of caudal fin.. *Phenacobius mirabilis*

11b. (7b) Lower lip thin or not noticeably thick; with or without black spot at base of caudal fin 12

12a. (11b) Predorsal scales appear crowded, smaller than scales on lateral body or appear as overlapping scales; black spot in the middle, anterior portion of the dorsal fin............13

12b. (11b) Predorsal scales not crowded; without black spot in the middle, anterior portion of the dorsal fin...14

13a. (12a) Caudal spot, if distinct, continuous with mid-lateral stripe; lateral line incomplete; intestine long, more than twice the standard length........*Pimephales promelas*

13b. (12a) Caudal spot distinct from mid-lateral stripe; lateral line complete, intestine forming a short S-shaped loop ....*Pimephales vigilax*

14a. (12b) Long intestine in a flat coil 15

14b. (12b) Short S-shaped intestine 17

15a. (14a) Terminal mouth; scales are diamond-shaped, most noticeable dorsally.. *Hybognathus hayi*

15b. (14a) Sub-terminal mouth; scales not diamond-shaped 16

16a. (15b) Head width greater than distance from tip of snout to posterior margin of orbital; internal posterior basiocciptial process is narrow and peg-like, width of internal posterior basiocciptal process fits in to head width at occipital > 7 times............................

....*Hybognathus placitus*

16b. (15b) Head width about equal to distance from tip of snout to posterior margin of orbital; internal posterior basiocciptial process is wide and flat, width of internal posterior basioccipital process fits in to head width at occipital < 7 times..

....*Hybognathus nuchalis*

17a. (14b) Moderately decurved lateral line; diamond-shaped scales; dark shoulder patch present; melanophores concentrated between rays of dorsal and anal fins 18

17b. (14b) Lateral line incomplete, complete-straight, or complete-slightly decurved; scales not noticeably diamond-shaped; without dark shoulder patch; melanophores concentrated along rays of dorsal and anal fins 19

18a. (17a) Caudal fin base with a large black spot, about size of eye ... *Cyprinella venusta*

18b. (17a) Caudal fin base without a large black spot...........................*Cyprinella lutrensis*

19a. (17b) Lateral line incomplete, < 11 pored scales 20

19b. (17b) Lateral line complete or mostly complete, > 11 pored scales 21

20a. (19a) Mouth terminal and oblique; dorsal fin origin posterior to pelvic fin origin; lacking smaller black spots above or below black spot at base of caudal fin ....

....*Pteronotropis hubbsi*

20b. (19a) Mouth sub-terminal and horizontal; dorsal fin origin in line with pelvic fin origin with smaller black spots above and below black spot at base of caudal fin................

....*Notropis maculatus*

21a. (19b) Distinct and separate black dash at base of dorsal fin; apparent when viewed from above; pharyngeal teeth count usually 0,4-4,0...22

21b. (19b) No distinct and separate black dash at base of dorsal fin; pharyngeal teeth count usually 1,4-4,1 or 2,4-4,2 25

22a. (21a) Lateral line scales markedly elevated (taller than wide) anteriorly, elevated scale height 2 to 5 times scale width...23

22b. (21a) Lateral line scales not markedly elevated anteriorly, scale height 1 to 2 times scale width 24

23a. (22a) Dorsal and lateral body with melanophores outlining scales; with pronounced black lateral stripe; dorsal fin height goes 2.1 or more times in pre-dorsal length; infraorbital canal complete .... *Notropis volucellus*

23b. (22a) Dorsal and lateral body with sparse melanophores; scales outlined with melanophores are rare; pre-dorsal black spot is prominent and distinct from mid-dorsal stripe; dorsal fin height goes 2.0 or fewer times in pre-dorsal length; infraorbital canal incomplete ....*Notropis buchanani*

24a. (22b) Eye large, eye diameter is > snout length...........................*Notropis stramineus*

24b. (22b) Eye small, eye diameter is < snout length..................................*Notropis bairdi*

25a. (21b) Exposed portions of lateral line scales greatly elevated (taller than wide), elevated scale height 2 to 5 times scale width; dorsal scales with dark marking forming longitudinal stripes..*Luxilus chrysocephalus*

25b. (21b) Lateral line scales not elevated, scale height 1 to 2 times scale width; dorsal scales to not form longitudinal stripes 26

26a. (25b) Depressed dorsal fin longer than head.......................................*Hybopsis amnis*

26b. (25b) Depressed dorsal fin shorter than head 27

27a. (26b) Mouth is sub-terminal; pharyngeal teeth are 0,4-4,0........ *Notropis atrocaudalis*

27b. (26b) Mouth is terminal; pharyngeal teeth are 1,4-4,1 or 2,4-4,2 or 5-5...................28

28a. (27b) Dorsal fin origin opposite or anterior to pelvic fin origin 29

28b. (27b) Dorsal fin origin posterior to pelvic fin origin 34

29a. (28a) Prominent mid-lateral stripe, extending through eye 30

29b. (28a) No prominent mid-lateral stripe present..32

30a. (29a) Pharyngeal teeth 5-5; mouth small and almost vertical..... *Opsopoeodus emiliae*

30b. (29a) Pharyngeal teeth are 1,4-4,1 or 2,4-4,2; mouth large and oblique 31

31a. (30b) Usually 8 anal fin rays; inside of mouth with black melanophores; dorsal fin insertion is opposite to pelvic fin insertion..*Notropis chalybaeus*

31b. (30b) Usually 7 anal fin rays; inside of mouth without black melanophores; dorsal fin insertion is anterior to pelvic fin insertion.. *Notropis texanus*

32a. (29b) Usually 8 anal fin rays; head is narrow, depth at occiput more than width at occiput .... *Notropis shumardi*

32b. (29b) Usually 7 anal fin rays; head is wide, depth at occiput less than or equal to width at occiput...33

33a. (32b) Mid-dorsal stripe about 5 chromatophores wide; snout overhanging mouth; middle portion of upper jaw narrower than ends..*Notropis potteri*

33b. (32b) Mid-dorsal stripe about 10 chromatophores wide; snout not overhanging mouth; middle portion of upper jaw is about the same width as the ends *Notropis blennius*

34a. (28b) Small scales, ≥ 41 lateral line scales, > 25 predorsal scales.............................35

34b. (28b) Moderate-sized scales, ≤ 40 lateral line scales, < 24 predorsal scales ....

....*Notropis atherinoides*

35a. (34a) Dorsal fin with black melanophores extending from mid-dorsal stripe into the anterior fin ray; edges of the anterior dorsolateral scales are outlined with black melanophores, producing chevron pattern.. *Lythrurus umbratilis*

35b. (34a) Dorsal fin with black melanophores not extending from mid-dorsal stripe into the anterior fin ray, lacks chevron pattern .... *Lythrurus fumeus*

FAMILY CATOSTOMIDAE—suckers

1a. Dorsal fin long, base > than ⅓ of standard length; 22 to 30 dorsal fin rays 2

1b. Dorsal fin short, base < than ¼ of standard length; 4 to 18 dorsal fin rays 6

2a. (1a) Small scales, lateral line scales > 50; eye closer to back of head than to tip of snout; head abruptly more slender than body; papillose lips................ *Cycleptus elongatus*

2b. (1a) Large scales, lateral line scales < 45; eye closer to tip of snout than back of head; plicate lips..3

3a. (2b) Subopercle triangular, broadest toward base; knob present at tip of lower lip; blunt snout, forming level with eye .... *Carpiodes carpio*

3b. (2b) Subopercle semicircular, broadest towards middle; knob absent at tip of lower lip; rounded snout, forming below level of eye 4

4a. (3b) Mouth large and oblique; upper jaw length is equal to snout length.......................

....*Ictiobus cyprinellus*

4b. (3b) Mouth small and nearly horizontal; upper jaw shorter than snout.........................5

5a. (4b) Body elongate and slender, greatest body depth goes 2.6 to 3.3 times in standard length, and height of anterior rays in dorsal and anal fins often less than 2/3 head length in individuals >300 mm; small eye, eye diameter goes ≥ 2 times in snout length of individuals <300 mm .... *Ictiobus niger*

5b. (4b) Body deep and narrow, greatest body depth goes 2.2 to 2.8 times in standard length, and height of anterior dorsal and anal fin rays often greater than 2/3 head length in individuals >300 mm; large eye, eye diameter goes ≤ 2 times in snout length of individuals <300 mm ....*Ictiobus bubalus*

6a. (1b) Lateral line complete and well developed; air bladder with 3 chambers ....*Moxostoma erythrurum*

6b. (1b) Lateral line incomplete or absent; air bladder with 2 chambers 7

7a. (6b) Lateral line incomplete; rows of spots...................................*Minytrema melanops*

7b. (6b) Lateral line absent 8

8a. (7b) Scales larger, lateral scale count 34 to 37; eye larger, eye length ½ of snout length; dorsal fin rays 11 or 12; back with crescentic scale marks............*Erimyzon sucetta*

8b. (7b) Scales smaller, lateral scale count 39 to 43; eye smaller, eye length < ½ of snout length); dorsal fin rays 9 or 10; back without crescentic scale marks *Erimyzon claviformis*

FAMILY CHARACIDAE—characins

Astyanax mexicanus

FAMILY ICTALURIDAE—bullhead catfishes

1a. Adipose fin joined to the caudal fin or separated by a shallow notch...........................2

1b. Adipose fin free at tip, not joined to caudal fin 3

2a. (1a) Mouth terminal; pectoral fin spine not serrated; lower lip and chin not heavily speckled with black pigment...*Noturus gyrinus*

2b. (1a) Mouth sub-terminal; pectoral spine serrated; lower lip and chin heavily speckled with black pigment..*Noturus nocturnus*

3a. (1b) Head dorso-ventrally compressed; mouth terminal to superior . *Pylodictis olivaris*

3b. (1b) Head rounded; mouth subterminal 4

4a. (3b) Caudal fin rounded or shallowly emarginate...5

4b. (3b) Caudal fin deeply forked 7

5a. (4a) Chin barbels white or yellow; anal fin rays 24 to 27; margin of anal fin generally straight.. *Ameiurus natalis*

5b. (4a) Chin barbels completely or partially black; anal fin rays 17 to 24; anal fin broadly rounded 6

6a. (5b) Posterior margin of pectoral fin spine nearly smooth; anal fin rays 17 to 23; dorsal and lateral body uniformly dark ....*Ameiurus melas*

6b. (5b) Posterior margin of pectoral fin spine with serrations; anal fin rays 21 to 24; dorsal and lateral body mottled.. *Ameiurus nebulosus*

7a. (4b) Anal fin rays 30 to 36; anal fin free margin is straight; medial keel-like ridge anterior to dorsal fin forms humped back appearance ....*Ictalurus furcatus*

7b. (4b) Anal fin rays 22 to 29; anal fin free margin is rounded; no humped back appearance...*Ictalurus punctatus*

FAMILY SALMONIDAE—salmons

Oncorhynchus mykiss

FAMILY ESOCIDAE—pikes and pickerels

1a. Snout short, distance from tip of snout to center of eye ≤ distance from center of eye to rear margin of operculum; < 115 scale rows along body .... *Esox americanus*

1b. Snout long, distance from tip of snout to center of eye > distance from center of eye to rear margin of operculum; > 120 scale rows along body .... *Esox niger*

FAMILY APHREDODERIDAE—pirate perch

Aphredoderus sayanus

FAMILY MUGILIDAE—mullets

Mugil cephalus

FAMILY ATHERINOPSIDAE—New World silversides

1a. Scales small, > 60 scales in lateral series, jaws produced into a short beak; snout length > eye length; > 20 anal fin rays...*Labidesthes sicculus*

1b. Scales large, < 50 scales in lateral series; jaws not produced into a beak; snout length ≤ eye length; < 20 anal fin rays...*Menidia audens*

FAMILY FUNDULIDAE—topminnows

1a. Lateral body with 15 to 17 prominent dark bars alternating with near equal width bands of white or yellow bars, dark bars less distinct in females; small scales, usually > 40 scales along lateral row ....*Fundulus zebrinus*

1b. Lateral body without 15 to 17 prominent dark bars, with spots or a prominent mid-lateral stripe; large scales, usually < 40 scales along lateral row..2

2a. (1b) Body with a distinct black lateral band 3

2b. (1b) Body without a distinct black lateral band..4

3a. (2a) Distinct black spots on anterior dorso-lateral region are as pronounced as lateral stripe; distinct black spots throughout dorsal and caudal fins .... *Fundulus olivaceus*

3b. (2a) Faint black spots on anterior dorso-lateral region are not as pronounced as lateral stripe; distinct black spots near base of dorsal and caudal fins.................*Fundulus notatus*

4a. (2b) Dorsal fin originating anterior to anal fin origin; more than 15 scale rows from pelvic fin origin to isthmus predorsal stripe absent or not reaching occiput ....

.... *Fundulus grandis*

4b. (2b) Dorsal fin originating posterior to anal fin origin 5

5a. (4b) Red to dark spots in multiple rows longitudinally along lateral sides; usually with dark subocular bar... *Fundulus blairae*

5b. (4b) Body mottled, barred or irregularly spotted; no dark subocular bar ....

.... *Fundulus chrysotus*

FAMILY CYPRINODONTIDAE— pupfishes

Cyprinodon rubrofluviatilis

FAMILY POECILIIDAE—livebearers

Gambusia affinis

FAMILY MORONIDAE—temperate basses

1a. Dorsal fins united at base; 2nd and 3rd anal fin spines approximately equal in length; no teeth on tongue; 9 to 10 anal fin soft rays; stripes along sides usually sharply broken and offset above front of anal fin... *Morone mississippiensis*

1b. Dorsal fins separated; 2nd anal fin spine much shorter than 3rd; base of tongue with teeth; 11 to 13 anal fin soft rays; stripes along sides usually continuous 2

2a. (1b) Body depth goes < 3 times in standard length; teeth in single patch on back of tongue... *Morone chrysops*

2b. (1b) Body depth goes > 3 times in standard length; teeth in 2 parallel patches on back of tongue .... *Morone saxatilis*

FAMILY CENTRARCHIDAE—sunfishes

1a. Five to 8 anal spines...2

1b. Three anal spines...4

2a. (1a) Eleven to 13 dorsal fin spines....................................... *Centrarchus macropterus*

2b. (1a) Six to 8 dorsal fin spines 3

3a. (2b) Dorsal fin set back on body, length of dorsal fin base < distance from its origin to posterior margin of eye; lateral body with wide to narrow dorsal black bands; ≤ 6 dorsal spines.. *Pomoxis annularis*

3b. (2b) Dorsal fin set forward on body, length of dorsal fin base equal to or greater than distance from its origin to posterior margin of eye; lateral body with checkerboard black and light pattern; ≥7 dorsal spines ....*Pomoxis nigromaculatus*

4a. (1b) Body slender, body depth contained > 3 times into standard length.....................5

4b. (1b) Body deep, body depth contained < 3 times into standard length.........................7

5a. (4a) Dorsal fins narrowly joined at base forming a deep notch; upper jaw extends past posterior margin of eye in adults; mid-lateral stripe generally complete, rows of spots ventral to mid-lateral stripe faint and incomplete ....*Micropterus salmoides*

5b. (4a) Dorsal fins broadly joined at base forming a shallow notch; upper jaw does not reach past posterior portion of eye; bases of soft dorsal and anal fins scaled 6

6a. (5b) No tooth patch on tongue; lower lateral region scales without black spots forming horizontal rows...*Micropterus dolomieu*

6b. (5b) Tooth patch on tongue; lower lateral region scales with black spots forming horizontal rows...*Micropterus punctulatus*

7a. (4b) Teeth on tongue; head and opercle with 3 to 5 distinct dark longitudinal stripes; red spot on posterior margin of opercle flap in fresh specimens...............*Lepomis gulosus*

7b. (4b) No teeth on tongue; head and opercle lacking distinct dark longitudinal stipes....8

8a. (7b) Pectoral fins long and pointed, extending past anterior portion of eye or when bent forward..9

8b. (7b) Pectoral fins short and rounded, do not extend past eye when bent forward.......11

9a. (7a) Opercle flap stiff to its margin, posterior margin either red or orange in live specimens...*Lepomis microlophus*

9b. (7a) Opercle flap flexible, posterior margin not red or orange in live specimens 10

10a. (9b) Opercle flap black to the margin; black spot on posterior base of soft dorsal fin ....*Lepomis macrochirus*

10b. (9b) Opercle flap outlined with think white band; lacking black spot on posterior base of soft dorsal fin... *Lepomis humilis*

11a. (8b) Black opercle flap stiff near the posterior margin with bone supporting all or majority of the flap..12

11b. (8b) Black opercle flap flexible near the posterior margin without bone supporting majority of the flap..14

12a. (11a) Lateral line incomplete; smaller individuals with black spot surrounded by white margin on posterior base of soft dorsal fin ....*Lepomis symmetricus*

12b. (11a) Lateral line complete; black spot, if present, on posterior base of soft dorsal fin without white margin 13

13a. (12b) Body elongated with black spot on posterior base of soft dorsal fin...................

....*Lepomis cyanellus*

13b. (12b) Body rounded without black spot on posterior base of soft dorsal fin; lateral body with alternating stripes formed from black and red spots................ *Lepomis miniatus*

14a. (11b) Opercle flap black to the posterior margin; opercle flap is thin near the opercle bone with the narrowest width of the flexible portion of the flap about the same diameter of the eye pupil..*Lepomis auritus*

14b. (11b) Opercle flap black and surrounded by white on the posterior margin; opercle flap is wide with narrowest width of the flexible flap is about two times the diameter of the eye pupil 15

15a. (14b) Twelve pectoral fin rays, 3 to 5 cheek scales; opercle flap often with white pigment form speckles, distinct red spots (white in preserved specimens) along lateral line...*Lepomis marginatus*

15b. (14b) Thirteen to 15 pectoral fin rays, 5 to 7 cheek scales; opercle flaps with red or white margin; 13 to 15 pectoral fin rays .... *Lepomis megalotis*

FAMILY PERCIDAE—perches

1a. Body depth contained in standard length more than 7 times 2

1b. Body depth contained in standard length less than 7 times 3

2a. (1a) Lateral blotches longer than deep ....*Ammocrypta clara*

2b. (1a) Lateral blotches deeper than long..*Ammocrypta vivax*

3a. (1b) Snout conical, extends beyond upper lip; body with ≥ 14 black vertical bars 4

3b. (1b) Snout less conical, does not extend beyond upper lip; body with < 14 black vertical bars or with a pattern other than vertical bars..5

4a. (3a) Body with 14 to 16 thin vertical bars of similar length ....*Percina macrolepida*

4b. (3a) Body with thick vertical bars, bars alternate in length from long to short .... *Percina caprodes*

5a. (3b) Sides of body with large black blotches; midline of abdomen naked or with enlarged scales 6

5b. (3b) Sides of body without large black blotches; scales on abdomen normal 9

6a. (5a) Upper lip connected to snout by a narrow frenum; blotches on sides of body are rectangle-shaped and bleed downward ....*Percina shumardi*

6b. (5a) Upper lip connected to snout by a broad frenum; blotches on sides of body do not bleed downward...7

7a. (6b) Nape unscaled; blotches on sides of body are rectangle shaped and might appear connected ....*Percina maculata*

7b. (6b) Nape scaled; blotches on sides of body not rectangle shaped................................8

8a. (7b) Sides of body with large, black heart-shaped blotches; preopercle with ≥ 5 serrations...*Percina sciera*

8b. (7b) Sides of body with large diamond-shaped blotches; preopercle with 0 to 3 serrations... *Percina phoxocephala*

9a. (5b) Lateral line short, < 6 pored lateral line scales; single row of horizontal dashes present...*Etheostoma proeliare*

9b. (5b) Lateral line long, > 6 pored lateral line scales; if horizontal dashes present, accompanied by vertical bars..10

10a. (9b) Pectoral fin long, pectoral fin folded forward extends past head ....*Etheostoma histrio*

10b. (9b) Pectoral fin short, pectoral fin folded forward does not extend past.................11

11a. (10b) Lateral line arched upward...12

11b. (10b) Lateral line straight...13

12a. (11a) Breast without scales; breast and abdomen without black speckles.................... .... *Etheostoma gracile*

12b. (11a) Breast with scales; breast and abdomen with black speckles............................. ....*Etheostoma fusiforme*

13a. (11b) Lateral body with distinct series of M-shaped pigments; snout rounded and blunt ....*Etheostoma chlorosoma*

13b. (11b) Lateral body without distinct series of M-shaped pigments; snout not noticeably rounded and blunt..14

14a. (13b) Lateral region with mottling bisected by a light colored lateral stripe.. *Etheostoma parvipinne*

14b. (13b) Lateral region without mottling bisected by a light colored lateral stripe 15

15a. (14b) Gill membranes widely joined across isthmus..16

15b. (14b) Gill membranes either not joined or barely joined across isthmus 17

16a. (15a) Lateral region with red or yellow spots ....*Etheostoma artesiae*

16b. (15a) Lateral region without red or yellow spots.......................*Etheostoma radiosum*

17a. (15b) Cheek not scaled; infraorbital canal incomplete; lateral body with 8 to 9 vertical bars.. *Etheostoma spectabile*

17b. (15b) Cheek scaled; infraorbital canal complete; lateral body with 6 to 8 vertical bars...*Etheostoma asprigene*

FAMILY SCIAENIDAE—drums

Aplodinotus grunniens

FAMILY ELASSOMATIDAE—pygmy sunfishes

Elassoma zonatum

RIO GRANDE AND PECOS RIVER BASINS

KEY TO THE FAMILIES

1a. Body long and slender; without pelvic fins.................... Freshwater Eels – Anguillidae
1b. Body truncated or elongated; with pelvic fins 2

2a. (1b) Caudal fin heterocercal or abbreviated heterocercal .... Gars – Lepiososteidae
2b. (1b) Caudal fin homocercal 3

3a. (2b) One dorsal fin; pelvic fins without uniserial spines 4
3b. (2b) One or two dorsal fins; pelvic fins with uniserial spines 13

4a. (3a) With adipose fin..5
4b. (3a) Without adipose fin 8

5a. (4a) Without barbels...6
5b. (4a) With barbels..7

6a. (5a) Scales large, < 50 lateral line scales; incisor teeth present ....Tetras – Characidae
6b. (5a) Scales small, > 60 lateral line scales; incisor teeth absent ..... Trouts – Salmonidae

7a. (5b) Body covered with bony plates; head with one pair of barbels...............................
....Armored Catfishes – Loricariidae
7b. (5b) Scales absent; head with four to eight barbels ..... Bullhead Catfishes – Ictaluridae

8a. (4b) Long anal fin with ≥ 17 fin rays ....Shads – Clupiedae
8b. (4b) Short anal fin with ≤ 13 rays 9

9a. (8b) Caudal fin forked or emarginated; lateral line usually present............................10
9b. (8b) Caudal fin truncated or rounded; lateral line usually absent 11

10a. (9a) Inferior, fleshy mouth modified for sucking; > 7 pharyngeal teeth in main row, usually ≥ 10 dorsal fin rays .... Suckers – Catostomidae

10b. (9a) Mouth usually not fleshy or modified for sucking; < 7 pharyngeal teeth in main row, usually ≤ 10 dorsal fin rays .... Carps and Minnows – Cyprinidae

11a. (9b) Mature males with rounded anal fin; males and females with 3rd anal fin ray branched, no gonopodium present 12

11b. (9b) Mature males with pointed anal fin forming a gonopodium; males and females with 3rd anal fin ray unbranched. .... Livebearers – Poeciliidae

12a. (11a) Body robust; teeth in single row are incisor-like and tricuspid (three points on a tooth). .... Pupfishes – Cyprinodontidae

12b. (11a) Body elongate; conical (cone-shaped) pointed teeth in a single row or several rows .... Killifishes – Fundulidae

13a. (3b) Pelvic fin position abdominal or sub-thoracic; dorsal fins widely separated 14

13b. (3b) Pelvic fin position thoracic; dorsal fins joined or, if separate, closely adjacent to one another 15

14a. (13a) Dorsal fin with 4 thick spines; anal fin with 2-3 spines; adipose eyelids present .... Mullets – Mugilidae

14b. (13a) Dorsal fin with 4 to 8 thin spines; anal fin with 1 spine; adipose eyelids absent .... Silversides – Atherinopsidae

15a. (13b) One nostril (nare) on each side of head; lateral line interrupted ....

.... Cichlids – Cichlidae

15b. (13b) Two nostrils (nares) on each side of head; lateral line complete, incomplete, or absent 16

16a. (15b) Dorsal fin with > 23 fin rays; lateral line extends to tip of caudal fin.................

.... Drums – Sciaenidae

16b. (15b) Dorsal fin with < 23 fin rays; lateral line, if present, does not extend to tip of caudal fin 17

17a. (16b) Pelvic fins joined into a sucking disk, gill membranes broadly joined to isthmus ....Gobies – Gobiidae

17b. (16b) Pelvic fins not joined, gill membranes free or nearly free from isthmus (may be joined to each other across isthmus) 18

18a. (17b) Anal fin with 1 to 2 spines.. Perches – Percidae

18b. (17b) Anal fin with 3 to 8 spines 19

19a. (18b) Posterior margin of operculum with a sharp spine; spiny and soft dorsal fin separate or only slightly connected; pseudobranchium present and exposed........................

....Temparate Basses – Moronidae

19b. (18b) Posterior margin of operculum without a sharp spine; spiny and soft dorsal fins connected or with deep notch; pseudobranchium covered or absent..............................

....Sunfishes – Centrarchidae

KEY TO THE SPECIES

FAMILY LEPISOSTEIDAE—gars

1a. Large teeth in upper jaw in parallel rows on each side ....*Atractosteus spatula*

1b. Large teeth in upper jaw one row, although another non-parallel row might be present 2

2a. (1b) Beak long and narrow, least width goes about 12 to 20 times in length; width of beak at nostrils < eye diameter; snout > ⅔ of head length...................... *Lepisosteus osseus*

2b. (1b) Beak short and blunt, least width goes about 5 to 7 times in length; width of beak at nostrils > eye diameter; snout < ⅔ of head length .... *Lepisosteus oculatus*

FAMILY ANGUILLIDAE—freshwater eels

Anguilla rostrata

FAMILY CLUPEIDAE—herrings

1a. Twenty-nine to 33 anal fin rays; mouth subterminal and below level of middle of eye; black shoulder spot ≥ pupil of eye .... *Dorosoma cepedianum*

1b. Twenty-four to 28 anal fin rays; mouth terminal and at level of eye; black shoulder spot < pupil of eye ....*Dorosoma petenense*

FAMILY CYPRINIDAE - minnows

1a. More than 15 soft rays on dorsal fin; dorsal and anal fins each with a strong serrated spine 2

1b. Fewer than 10 soft rays on dorsal fin; dorsal and anal fins without spine.....................3

2a. (1a) Upper jaw with two pairs of barbels... *Cyprinus carpio*

2b. (1a) Upper jaw without barbels.. *Carassius auratus*

3a. (1b) Anal fin near caudal fin, distance from snout to origin of anal fin is > 2.5 times the distance from origin of anal fin to base of caudal fin; pharyngeal teeth with prominent parallel grooves..*Ctenopharyngodon idella*

3b. (1b) Anal fin not noticeably near caudal fin: distance from snout to origin of anal fin is < 2.5 times the distance from origin of anal fin to base of caudal fin; pharyngeal teeth without prominent parallel grooves 4

4a. (3b) Intestine wound spirally around swim bladder; keratinous ridge on lower jaw.....5

4b. (3b) Intestine not wound spirally around swim bladder; keratinous ridge of lower jaw hardly evident...6

5a. (4a) Intestine wound completely around swim bladder, large scales, 41 to 58 lateral line scales ....*Campostoma anomalum*

5b. (4a) Intestine only partially wound around swim bladder; 58 to 77 lateral line scales; more common in the Presidio to Big Bend Reach of Rio Grande drainage ....
....*Campostoma ornatum*

6a. (4b) Upper jaw with frenum, dorsal part of premaxillary bones connected to frenum are not protractible ....*Rhinichthys cataractae*

6b. (4b) Upper jaw without frenum, premaxillary bones are protractible 7

7a. (6b) Abdomen behind pelvic fins with a fleshy keel lacking scales; lateral line greatly decurved, distance between anterior lateral line scale and ventral most lateral line scale is > 3 scales in height..*Notemigonus crysoleucas*

7b. (6b) Abdomen behind pelvic fin with scales; lateral line not greatly decurved, lateral line descends < 3 scales ventrally from highest point 8

8a. (7b) With maxillary barbels, might be small and not observable without opening the mouth or with magnification...*Macrhybopsis aestivalis*

8b. (7b) Without maxillary barbels...9

9a. (8b) Small scales, ≥ 50 lateral line scales; current Texas distribution is Little Aguja Creek in the Rio Grande drainage...*Gila pandora*

9b. (8b) Larger scales, < 45 lateral line scales...10

10a. (9b) Predorsal scales appear crowded, smaller than scales on lateral body or appear as overlapping scales; black spot in the middle, anterior portion of the dorsal fin............11

10b. (9b) Predorsal scales not crowded; without black spot in the middle, anterior portion of the dorsal fin 12

11a. (10a) Caudal spot, if distinct, continuous with mid-lateral stripe; lateral line incomplete; intestine long, more than twice the standard length........*Pimephales promelas*

11b. (10a) Caudal spot distinct from mid-lateral stripe; lateral line complete, intestine forming a short S-shaped loop .... *Pimephales vigilax*

12a. (10b) Long intestine in a flat coil 13

12b. (10b) Short S-shaped intestine 16

13a. (12a) Black mid-lateral stripe extends through eye to snout; eye width greater than or equal to snout length 14

13b. (12a) Mid-lateral stripe, if present (sometimes appears as a broad, diffuse band of melanophores), does not extend through the eye to the snout; eye width less than snout length .... *Hybognathus amarus*

14a. (13a) Scales outlined with melanophores, most noticeable dorsal of mid-lateral stripe, forming a cross-hatched appearance; more of a triangular shaped caudal spot; sympatric with.. *Dionda diaboli*

14b. (13a) Scales equally covered with melanophores; more of a rounded caudal spot ...15

15a. (14b) Located (all water bodies) downstream from I-10 in the Pecos and within and downstream from Lake Amistad in the Rio Grande .... *Dionda argentosa*

15b. (14b) Complete description pending. Based on genetic analyses, located in Trans Pecos region (all water bodies) upstream from I-10 in the Pecos River and upstream from Lake Amistad in the Rio Grande. Not sympatric with other *Dionda* .... *Dionda episcopa*

16a. (12b) Moderately decurved lateral line; diamond-shaped scales; dark shoulder patch present; melanophores concentrated between rays of dorsal and anal fins 17

16b. (12b) Lateral line incomplete, complete-straight, or complete-slightly decurved; scales not noticeably diamond-shaped; without dark shoulder patch; melanophores concentrated along rays of dorsal and anal fins 19

17a. (16a) Terminal mouth .... *Cyprinella lutrensis*

17b. (16a) Sub-terminal mouth 18

18a. (17b) A thick distinct black bar extends from lower jaw through isthmus; caudal fin base without a large black spot .... *Cyprinella proserpina*

18b. (17b) Caudal fin base with a large black spot, about size of eye.... *Cyprinella venusta*

19a. (16b) Dorsal fin origin opposite or anterior to pelvic fin origin 20

19b. (16b) Dorsal fin origin posterior to pelvic fin origin 23

20a. (19a) Lateral line scales markedly elevated (taller than wide) anteriorly, elevated scale height 2 to 5 times scale width...*Notropis buchanani*

20b. (19a) Lateral line scales not markedly elevated anteriorly, scale height 1 to 2 times scale width 21

21a. (20b) Black mid-lateral stripe; melanophores form double dashes above and below the lateral line inferior to mid-lateral stripe between pectoral and pelvic fins ....
....*Notropis braytoni*

21b. (20b) Faint or absent mid-lateral stripe..22

22a. (21b) Melanophores form double dashes above and below the entire lateral line; without scattered, black melanophores on dorsal of body....................*Notropis stramineus*

22b. (21b) If present, melanophores form double dashes above and below the anterior portion of the lateral line; with scattered, black melanophores on dorsal of body ....
....*Notropis chihuahua*

23a. (19b) Sub-terminal mouth .... *Notropis simus*

23b. (19b) Terminal mouth 24

24a. (23b) Depressed pelvic fins reach or extend past origin of anal fin; eye larger, eye diameter greater than snout length..*Notropis amabilis*

24b. (23b) Depressed pelvic fins do not reach origin of anal fin; eye smaller, eye diameter about equal to snout length ....*Notropis jemezanus*

FAMILY CATOSTOMIDAE—suckers

1a. Dorsal fin long, base > than ⅓ of standard length; 22 to 30 dorsal fin rays 2

1b. Dorsal fin short, base < than ¼ of standard length; 4 to 18 dorsal fin rays 5

2a. (1a) Small scales, lateral line scales > 50; eye closer to back of head than to tip of snout; head abruptly more slender than body; papillose lips................ *Cycleptus elongatus*

2b. (1a) Large scales, lateral line scales < 45; eye closer to tip of snout than back of head; plicate lips 3

3a. (2b) Subopercle triangular, broadest toward base; knob present at tip of lower lip; blunt snout, forming level with eye .... *Carpiodes carpio*

3b. (2b) Subopercle semicircular, broadest towards middle; knob absent at tip of lower lip; rounded snout, forming below level of eye 4

4a. (3b) Body elongate and slender, greatest body depth goes 2.6 to 3.3 times in standard length, and height of anterior rays in dorsal and anal fins often less than 2/3 head length in individuals >300 mm; small eye, eye diameter goes ≥ 2 times in snout length of individuals <300 mm .... *Ictiobus niger*

4b. (3b) Body deep and narrow, greatest body depth goes 2.2 to 2.8 times in standard length, and height of anterior dorsal and anal fin rays often greater than 2/3 head length in individuals >300 mm; large eye, eye diameter goes ≤ 2 times in snout length of individuals <300 mm ....*Ictiobus bubalus*

5a. (1b) 44 to 46 scales along the lateral line; pectoral fin length equal to head length...*Moxostoma congestum*

5b. (1b) 47 to 50 scales along the lateral line; pectoral fin length < head length ....
....*Moxostoma austrinum*

FAMILY CHARACIDAE—characins

Astyanax mexicanus

FAMILY ICTALURIDAE—bullhead catfishes

1a. Adipose fin joined to the caudal fin or separated by a shallow notch....*Noturus gyrinus*

1b. Adipose fin free at tip, not joined to caudal fin 2

2a. (1b) Head dorso-ventrally compressed; mouth terminal to superior . *Pylodictis olivaris*

2b. (1b) Head rounded; mouth subterminal 3

3a. (2b) Caudal fin rounded or shallowly emarginate..4

3b. (2b) Caudal fin deeply forked...5

4a. (3a) Chin barbels completely or partially black; anal fin rays 17 to 24; anal fin broadly rounded ....*Ameiurus melas*

4b. (3a) Chin barbels white or yellow; anal fin rays 24 to 27; margin of anal fin generally straight.. *Ameiurus natalis*

5a. (3b) Anal fin rays 30 to 36; anal fin free margin is straight; medial keel-like ridge anterior to dorsal fin forms humped back appearance .... *Ictalurus furcatus*

5b. (3b) Anal fin rays 22 to 29; anal fin free margin is rounded; no humped back appearance..6

6a. (5b) Anal fin rays 27 to 29; pectoral fin spine goes < 5 times into standard length; random scattering of few black spots may be present ....*Ictalurus punctatus*

6b. (5b) Anal fin rays 22 to 26; pectoral fin spine goes > 5 times into standard length; diffuse black spots on sides.. *Ictalurus lupus*

FAMILY LORICARIIDAE—suckermouth catfishes

1a. Dorsal fin short with ≤ 9 rays...*Hypostomus plecostomus*

1b. Dorsal fin long with ≥ 10 rays; dark spots forming extensive vermiculations on sides and ventral surface .... *Pterygoplichthys disjunctivus*

FAMILY SALMONIDAE—salmons

1a. Lateral scale rows 120 to 140; basibranchial teeth absent; paired fins with a white border; no deep red to orange slash on each side of throat along inner side of dentary bone; small spots heavily scattered along sides and caudal fin ....*Oncorhynchus mykiss*

1b. Lateral scale rows 150 to 180; basibranchial teeth usually present, but small or vestigial; paired fins uniformly brown or reddish but without a white border; deep red to orange slash on each side of throat along inner side of dentary bone; large spots concentrated on caudal peduncle in adults..*Oncorhynchus clarki*

FAMILY MUGILIDAE—mullets

1a. Lower jaw rounded, without a symphyseal knob; lower limb of 1st gill arch with 17 to 20 gill rakers; no adipose eyelid; scales ctenoid............................*Agonostomus monticola*

1b. Lower jaw angular, with a prominent symphyseal knob; lower limb of 1st gill arch with 25 to 60 gill rakers; adipose eyelid well developed in adults; scales cycloid in young, ctenoid in adults...*Mugil cephalus*

FAMILY ATHERINOPSIDAE—New World silversides

1a. Scales ctenoid, rough to the touch; double pairs of black spots on dorsum; bases of dorsal and anal fin covered with scales..*Membras martinica*

1b. Scales cycloid, smooth to the touch; dorsum with crosshatching, but not double pairs of black spots; bases of dorsal and anal fins not covered with scales; horizontal distance between spinous dorsal and anal fin origin less than 7% of standard length........................

....*Menidia audens*

FAMILY FUNDULIDAE—topminnows

1a. Distance from origin of dorsal fin to end of hypural plate < distance from origin of dorsal fin to preopercle or occasionally about equal to that distance; more than 30 longitudinal scale rows 2

1b. Distance from origin of dorsal fin to end of hypural plate > distance from origin of dorsal fin to preopercle; 30 or fewer longitudinal scale rows........................*Lucania parva*

2a. (1a) More than 40 longitudinal scale rows; dark vertical barring; gill slit not extending dorsal to uppermost pectoral fin ray ....*Fundulus zebrinus*

2b. (1a) Fewer than 40 longitudinal scale rows; gill slit extending dorsal to uppermost pectoral fin ray .... *Fundulus grandis*

FAMILY CYPRINODONTIDAE— pupfishes

1a. Abdomen without scales anterior to pelvic fins......................... *Cyprinodon pecosensis*

1b. Abdomen with scales anterior to pelvic fins...2

2a. (1b) Six to 7 anal fin rays..3

2b. (1b) Greater than 8 anal fin rays 4

3a. (2a) Dark blotches form a lateral stripe; found in small springs near Balmorhea, TX .... *Cyprinodon elegans*

3b. (2a) Faint blotches deeper than wide; found in Devils River and Alamito Creek.. *Cyprinidon eximius*

4a. (2b) Five to 8 triangular dark bars wide dorsally, coming to a point ventrally ....*Cyprinodon variegatus*

4b. (2b) Lateral blotches wider than deep; found only in Leon Creek. *Cyprinodon bovinus*

FAMILY POECILIIDAE—livebearers

1a. Origin of dorsal fin anterior to anal fin origin; intestinal canal long with many convolutions..2

1b. Origin of dorsal fin posterior to anal fin origin; intestinal canal short with few convolutions..3

2a. (1a) Dorsal fin rays 12 to 14; dorsal fin base more than ½ predorsal length; rows of dark spots on scales obscure diamond-shaped color pattern ....*Poecilia latipinna*

2b. (1a) Dorsal fin rays 10 to 12; dorsal fin base < ½ predorsal length; dark spots on scales do not obscure diamond-shaped color pattern; only exists as females.......................

....*Poecilia formosa*

3a. (1b) Spines at tip of 3rd anal fin ray of male gonopodium (first enlarged ray) 1 to 3 times longer than wide...4

3b. (1b) Spines at tip of 3rd anal fin ray of male gonopodium 4 to 10 times longer than wide 5

4a. (3a) Dorsal fin rays 6 (rarely 7); distal end of the 4th fin ray of gonopodium in male parallel or curved in only a weak arch...*Gambusia affinis*

4b. (3a) Dorsal fin rays 7; distal end of the 4th fin ray of gonopodium in male curved in a wide arch; found in Devil’s River.. *Gambusia speciosa*

5a. (3b) Dorsal fin rays 9 (rarely 10); predorsal stripe distinct and broad; found in San Felipe Springs ....*Gambusia krumholzi*

5b. (3b) Dorsal fin rays 7 to 8; predorsal stripe thin or absent 6

6a. (5b) Lateral stripe broad; caudal fin without prominent black markings; markings on sides crescentric; tip of anterior branch of 4th ray of male gonopodium does not extend to tip of posterior branch...7

6b. (5b) Lateral stripe thin and threadlike; caudal fin with prominent black markings; markings on sides rounded specks; tip of anterior branch of 4th ray of male gonopodium extends as far as tip of posterior branch...8

7a. (6a) Elbow of gonopodium composed of usually 4 fused segments; no dark markings around anus of mature females. Likely extirpated....................................*Gambusia senilis*

7b. (6a) Elbow of gonopodium composed of usually 2 (rarely 3) fused segments; dark markings on anus of mature females ....*Gambusia gaigei*

8a. (7b) Postanal streak prominent (darker than markings on scale pockets); black markings on mouth; median row of spots on caudal fin; median row of spots on dorsal fin; terminal hook on 4th and 5th rays of gonopodium angular at tip ...... *Gambusia geiseri*

8b. (7b) Postanal streak weaker than markings on scale pockets; dusky or no markings on mouth; no prominent spots in middle of caudal fin; a subbasal row of spots on dorsal fin; terminal hooks on 4th and 5th rays of gonopodium rounded at tip .... *Gambusia nobilis*

FAMILY MORONIDAE—temperate basses

1a. Body depth goes < 3 times in standard length; teeth in single patch on back of tongue.. *Morone chrysops*

1b. Body depth goes > 3 times in standard length; teeth in 2 parallel patches on back of tongue.. *Morone saxatilis*

FAMILY CENTRARCHIDAE—sunfishes

1a. Five to 8 anal spines..2

1b. Three anal spines..3

2a. (1a) Dorsal fin set back on body, length of dorsal fin base < distance from its origin to posterior margin of eye; lateral body with wide to narrow dorsal black bands; ≤ 6 dorsal spines.. *Pomoxis annularis*

2b. (1a) Dorsal fin set forward on body, length of dorsal fin base equal to or greater than distance from its origin to posterior margin of eye; lateral body with checkerboard black and light pattern; ≥7 dorsal spines ....*Pomoxis nigromaculatus*

3a. (1b) Body slender, body depth contained > 3 times into standard length......................4

3b. (1b) Body deep, body depth contained < 3 times into standard length..........................5

4a. (3a) Dorsal fins narrowly joined at base forming a deep notch; upper jaw extends past posterior margin of eye in adults; mid-lateral stripe generally complete, rows of spots ventral to mid-lateral stripe faint and incomplete ....*Micropterus salmoides*

4b. (3a) Dorsal fins broadly joined at base forming a shallow notch; upper jaw does not reach past posterior portion of eye; bases of soft dorsal and anal fins scaled ....

....*Micropterus dolomieu*

5a. (3b) Teeth on tongue; head and opercle with 3 to 5 distinct dark and light longitudinal stripes; red spot on posterior margin of opercle flap in fresh specimens....*Lepomis gulosus*

5b. (3b) No teeth on tongue; head and opercle lacking distinct dark and light longitudinal stripes 6

6a. (5b) Pectoral fins long and pointed, reach anterior portion of eye or beyond when bent forward..7

6b. (5b) Pectoral fins short and rounded, do not reach past eye when bent forward...........8

7a. (6a) Opercle flap stiff to its margin, posterior margin either red or orange in live specimens..*Lepomis microlophus*

7b. (6a) Opercle flap flexible, posterior margin not red or orange in live specimens..*Lepomis macrochirus*

8a. (6b) Black opercle flap stiff near the posterior margin with bone supporting all or majority of the flap..9

8b. (6b) Black opercle flap flexible near the posterior margin without bone supporting majority of the flap...10

9a. (8a) Body elongated with black spot on posterior base of soft dorsal fin........................

....*Lepomis cyanellus*

9b. (8a) Body rounded without black spot on posterior base of soft dorsal fin; lateral body with alternating stripes formed from black and red spots......................... *Lepomis miniatus*

10a. (8b) Opercle flap black to the posterior margin; opercle flap is thin near the opercle bone with the narrowest width of the flexible portion of the flap about the same diameter of the eye pupil..*Lepomis auritus*

10b. (8b) Opercle flap black and surrounded by white on the posterior margin; opercle flap is wide with narrowest width of the flexible flap is about two times the diameter of the eye pupil.. *Lepomis megalotis*

FAMILY PERCIDAE—perches

1a. Upper jaw extending to below the middle of the eye or farther; preopercle strongly serrate; caudal fin forked .... *Sander vitreus*

1b. Upper jaw not extending to beneth middle of eye; preopercle smooth or weakly serrated...2

2a. (1b) Snout conical, extends beyond upper lip; body with thin vertical bars; caudal fin straight, rounded, or slightly emarginate ....*Percina macrolepida*

2b. (1b) Snout less conical, does not extend beyond upper lip..2

3a. (2b) Lateral line arched upward .... *Etheostoma gracile*

3b. (2b) Lateral line straight...*Etheostoma grahami*

FAMILY SCIAENIDAE—drums

Aplodinotus grunniens

FAMILY CICHLIDAE—cichlids

1a. Anal fin spines 5 to 6 ....*Herichthys cyanoguttatus*

1b. Anal fin spines < 5 (usually 3)... 2

2a. (1b) Gill rakers 14 to 20 (usually 17 to 18) on lower part of first gill arch; most teeth in outer row are unicuspid in adults; sides with 3 or 4 dark blotches or with no markings; no yellow on dorsal fin; caudal fin without distinct vertical stripes .... *Oreochromis mossambicus*

2b. (1b) Gill rakers 18 to 26 on lower part of 1st gill arch; outer row of teeth bicuspid in adults; caudal fin unmarked, or with vague, irregular dark markings, caudal fin often with a broad, red distal margin; young often with vertical bands on caudal fin ....*Oreochromis aureus*

FAMILY GOBIIDAE—gobies

1a. Body without scales ....*Gobiosoma bosc*

1b. Body mostly scaled; Scales small, > 70 rows in lateral series...............*Awaous banana*

SABINE AND NECHES RIVER BASINS

KEY TO THE FAMILIES

1a. Jawless, disc-shaped mouth; without pectoral and pelvic fins; 7 pairs of external gill openings .... Lampreys – Petromyzontidae

1b. Jawed mouth; one gill opening on each side of head; with pectoral, pelvic, or both fins..2

2a. (1b) Both eyes on one side of head; without right pectoral fin ....
.... American Soles – Achiridae

2b. (1b) One eye on either side of head; with both pectoral fins 3

3a. (2b) Body long and slender; without pelvic fins ....Freshwater Eels – Anguillidae

3b. (2b) Body truncated or elongated; with pelvic fin 4

4a. (3b) Caudal fin heterocercal or abbreviated heterocercal 5

4b. (3b) Caudal fin homocercal 7

5a. (4a) Caudal fin heterocercal, body appears scaleless, except for a few ganoid scales at the base of caudal fin; long, paddle shaped snout......................Paddlefish – Polyodontidae

5b. (4a) Caudal fin abbreviated heterocercal; body with ganoid or cycloid scales 6

6a. (5b) Body covered with ganoid scales; snout formed into a beak; without gular plate... Gars – Lepisosteidae

6b. (5b) Body covered with cycloid scales, snout not formed into a beak, with a gular plate..Bowfin – Amiidae

7a. (4b) Jaws duckbilled .... Pikerels – Esocidae

7b. (4b) Jaws not duckbilled...8

8a. (7b) One dorsal fin; pelvic fins without uniserial spines 9

8b. (7b) One or two dorsal fins; pelvic fins with uniserial spines 15

9a. (8a) With adipose fin 10
9b. (8a) Without adipose fin 11

10a. (9a) Without barbels .... Trouts – Salmonidae
10b. (9a) With barbels .... Bullhead Catfishes – Ictaluridae

11a. (9b) Long anal fin with ≥ 17 fin rays .... Shads – Clupiedae
11b. (9b) Short anal fin with ≤ 13 rays 12

12a. (11b) Caudal fin forked or emarginated; lateral line usually present 13
12b. (11b) Caudal fin truncated or rounded; lateral line usually absent 14

13a. (12a) Inferior, fleshy mouth modified for sucking; > 7 pharyngeal teeth in main row, usually ≥ 10 dorsal fin rays .... Suckers – Catostomidae
13b. (12a) Mouth usually not fleshy or modified for sucking; < 7 pharyngeal teeth in main row, usually ≤ 10 dorsal fin rays .... Minnows – Cyprinidae

14a. (12b) Mature males with rounded anal fin; males and females with 3rd anal fin ray branched, no gonopodium present .... Killifishes – Fundulidae
14b. (12b) Mature males with pointed anal fin forming a gonopodium; males and females with 3rd anal fin ray unbranched. .... Livebearers – Poeciliidae

15a. (8b) Anus anterior to pelvic fins; > 5 soft rays on each pelvic fin .... Pirate Perch – Aphredoderidae
15b. (8b) Anus posterior to pelvic fins; 5 soft rays on pelvic fins 16

16a. (15b) Pelvic fin position abdominal or sub-thoracic; dorsal fins widely separated ... 17
16b. (15b) Pelvic fin position thoracic; dorsal fins joined or, if separate, closely adjacent to one another 18

17a. (16a) Dorsal fin with 4 thick spines; anal fin with 2-3 spines; adipose eyelids present .... Mullets – Mugilidae
17b. (16a) Dorsal fin with 4 to 8 thin spines; anal fin with 1 spine; adipose eyelids absent .... Silversides – Atherinopsidae

18a. (16b) One nostril (nare) on each side of head; lateral line interrupted ....
....Cichlids – Cichlidae

18b. (16b) Two nostrils (nares) on each side of head; lateral line complete, incomplete, or absent 19

19a. (17b) Dorsal fin with > 23 fin rays; lateral line extends to tip of caudal fin..................
.... Drums – Sciaenidae

19b. (17b) Dorsal fin with < 23 fin rays; lateral line, if present, does not extend to tip of caudal fin...20

20a. (19b) Anal fin with 1 to 2 spines... Perches – Percidae

20b. (19b) Anal fin with 3 to 8 spines 21

21a. (20b) Posterior margin of operculum with a sharp spine; spiny and soft dorsal fin separate or only slightly connected; pseudobranchium present and exposed........................
....Temparate Basses – Moronidae

21b. (20b) Posterior margin of operculum without a sharp spine; spiny and soft dorsal fins connected or with deep notch; pseudobranchium covered or absent..........................22

22a. (21b) Lateral line present or incomplete ....Sunfishes – Centrarchidae

22b. (21b) Lateral line absent ....Pygmy Sunfishes – Elassomatidae

KEY TO THE SPECIES

FAMILY PETROMYZONTIDAE – lampreys

1a. Disc-shaped mouth large, diameter of mouth > body width and about 140 times into total length; with rasping teeth; adults with well-developed intestine..................................

....*Ichthyomyzon castaneus*

1b. Disc-shaped mouth small, diameter of mouth ≤ than body width and about 170 to 250 times into total length; without rasping teeth; adults without well-developed intestine ....

.... *Ichthyomyzon gagei*

FAMILY POLYODONTIDAE—paddlefishes

Polyodon spathula

FAMILY LEPISOSTEIDAE—gars

1a. Large teeth in upper jaw in parallel rows on each side ....*Atractosteus spatula*

1b. Large teeth in upper jaw one row, although another non-parallel row might be present 2

2a. (1b) Beak long and narrow, least width goes about 12 to 20 times in length; width of beak at nostrils < eye diameter; snout > ⅔ of head length...................... *Lepisosteus osseus*

2b. (1b) Beak short and blunt, least width goes about 5 to 7 times in length; width of beak at nostrils > eye diameter; snout < ⅔ of head length .... *Lepisosteus oculatus*

FAMILY AMIIDAE—bowfins

Amia calva

FAMILY ANGUILLIDAE—freshwater eels

Anguilla rostrata

FAMILY CLUPEIDAE—herrings

1a. Twenty-nine to 33 anal fin rays; mouth subterminal and below level of middle of eye; black shoulder spot ≥ pupil of eye .... *Dorosoma cepedianum*

1b. Twenty-four to 28 anal fin rays; mouth terminal and at level of eye; black shoulder spot < pupil of eye ....*Dorosoma petenense*

FAMILY CYPRINIDAE - minnows

1a. More than 15 soft rays on dorsal fin; dorsal and anal fins each with a strong serrated spine 2

1b. Fewer than 10 soft rays on dorsal fin; dorsal and anal fins without spine 3

2a. (1a) Upper jaw with two pairs of barbels.. *Cyprinus carpio*

2b. (1a) Upper jaw without barbels... *Carassius auratus*

3a. (1b) fin near caudal fin, distance from snout to origin of anal fin is > 2.5 times the distance from origin of anal fin to base of caudal fin; pharyngeal teeth with prominent parallel grooves...*Ctenopharyngodon idella*

3b. (1b) Anal fin not noticeably near caudal fin: distance from snout to origin of anal fin is < 2.5 times the distance from origin of anal fin to base of caudal fin; pharyngeal teeth without prominent parallel grooves 4

4a. (3b) Abdomen behind pelvic fins with a fleshy keel lacking scales; lateral line greatly decurved, distance between anterior lateral line scale and ventral most lateral line scale is > 3 scales in height..*Notemigonus crysoleucas*

4b. (3b) Abdomen behind pelvic fin with scales; lateral line not greatly decurved, lateral line descends < 3 scales ventrally from highest point 5

5a. (4b) With maxillary barbels, might be small and not observable without opening the mouth or with magnification...6

5b. (4b) Without maxillary barbels 7

6a. (5a) Mouth terminal; distinct black spot located anteriorly on dorsal fin; pharyngeal teeth on main row 5-4 or 5-5...*Semotilus atromaculatus*

6b. (5a) Mouth subterminal or inferior; no distinct black spot on dorsal fin; pharyngeal teeth on main row 4-4 ....*Macrhybopsis hyostoma*

7a. (5b) Thick lower lip at corners, mouth noticeably ventral; black spot at base of caudal fin .... *Phenacobius mirabilis*

7b. (5b) Lower lip thin or not noticeably thick; with or without black spot at base of caudal fin...8

8a. (7b) Predorsal scales appear crowded, smaller than scales on lateral body or appear as overlapping scales; black spot in the middle, anterior portion of the dorsal fin..................9

8b. (7b) Predorsal scales not crowded; without black spot in the middle, anterior portion of the dorsal fin 10

9a. (8a) Caudal spot, if distinct, continuous with mid-lateral stripe; lateral line incomplete; intestine long, more than twice the standard length........*Pimephales promelas*

9b. (8a) Caudal spot distinct from mid-lateral stripe; lateral line complete, intestine forming a short S-shaped loop ....*Pimephales vigilax*

10a. (8b) Long intestine in a flat coil...11

10b. (8b) Short S-shaped intestine..12

11a. (10a) Terminal mouth; scales are diamond-shaped, most noticeable dorsally; Sabine drainage.. *Hybognathus hayi*

11b. (10a) Sub-terminal mouth; scales not diamond-shaped.............*Hybognathus nuchalis*

12a. (10b) Moderately decurved lateral line; diamond-shaped scales; dark shoulder patch present; melanophores concentrated between rays of dorsal and anal fins 13

12b. (10b) Lateral line incomplete, complete-straight, or complete-slightly decurved; scales not noticeably diamond-shaped; without dark shoulder patch; melanophores concentrated along rays of dorsal and anal fins 14

13a. (12a) Sub-terminal mouth; caudal fin base with a caudal spot larger than eye; no shoulder patch .... *Cyprinella venusta*

13b. (12a) Terminal mouth; no caudal spot...*Cyprinella lutrensis*

14a. (12b) Distinct and separate black dash at base of dorsal fin; apparent when viewed from above; pharyngeal teeth count usually 0,4-4,0..15

14b. (12b) No distinct and separate black dash at base of dorsal fin; pharyngeal teeth count usually 1,4-4,1 or 2,4-4,2 17

15a. (14a) Lateral line scales markedly elevated (taller than wide) anteriorly, elevated scale height 2 to 5 times scale width..16

15b. (14a) Lateral line scales not markedly elevated anteriorly, scale height 1 to 2 times scale width .... *Notropis sabinae*

16a. (15a) Dorsal and lateral body with melanophores outlining scales; with pronounced black lateral stripe; dorsal fin height goes 2.1 or more times in pre-dorsal length; infraorbital canal complete .... *Notropis volucellus*

16b. (15a) Dorsal and lateral body with sparse melanophores; scales outlined with melanophores are rare; pre-dorsal black spot is prominent and distinct from mid-dorsal stripe; dorsal fin height goes 2.0 or fewer times in pre-dorsal length; infraorbital canal incomplete...*Notropis buchanani*

17a. (14b) Depressed dorsal fin longer than head....................................... *Hybopsis amnis*

17b. (14b) Depressed dorsal fin shorter than head 19

18a. (17b) Mouth is sub-terminal; pharyngeal teeth are 0,4-4,0........ *Notropis atrocaudalis*

18b. (17b) Mouth is terminal; pharyngeal teeth are 1,4-4,1 or 2,4-4,2 or 5-5 19

19a. (18b) Dorsal fin origin opposite or anterior to pelvic fin origin 20

19b. (18b) Dorsal fin origin posterior to pelvic fin origin 23

20a. (19a) Prominent mid-lateral stripe, extending through eye 21

20b. (19a) No prominent mid-lateral stripe present............................... *Notropis shumardi*

21a. (20a) Pharyngeal teeth 5-5; mouth small and almost vertical..... *Opsopoeodus emiliae*

21b. (20a) Pharyngeal teeth are 1,4-4,1 or 2,4-4,2; mouth large and oblique 22

22a. (21b) Usually 8 anal fin rays; inside of mouth with black melanophores; dorsal fin insertion is opposite to pelvic fin insertion..*Notropis chalybaeus*

22b. (21b) Usually 7 anal fin rays; inside of mouth without black melanophores; dorsal fin insertion is anterior to pelvic fin insertion... *Notropis texanus*

23a. (19b) Small scales, ≥ 41 lateral line scales, > 25 predorsal scales................................
....*Notropis atherinoides*

23b. (19b) Moderate-sized scales, ≤ 40 lateral line scales, < 24 predorsal scales.............24

24a. (23b) Dorsal fin with black melanophores extending from mid-dorsal stripe into the anterior fin ray; edges of the anterior dorsolateral scales are outlined with black melanophores, producing chevron pattern. .... *Lythrurus umbratilis*

24b. (23b) Dorsal fin with black melanophores not extending from mid-dorsal stripe into the anterior fin ray, lacks chevron pattern .... *Lythrurus fumeus*

FAMILY CATOSTOMIDAE—suckers

1a. Dorsal fin long, base > than ⅓ of standard length; 22 to 30 dorsal fin rays 2

1b. Dorsal fin short, base < than ¼ of standard length; 4 to 18 dorsal fin rays 6

2a. (1a) Small scales, lateral line scales > 50; eye closer to back of head than to tip of snout; head abruptly more slender than body; papillose lips .... *Cycleptus elongatus*

2b. (1a) Large scales, lateral line scales < 45; eye closer to tip of snout than back of head; plicate lips 3

3a. (2b) Subopercle triangular, broadest toward base; knob present at tip of lower lip; blunt snout, forming level with eye .... *Carpiodes carpio*

3b. (2b) Subopercle semicircular, broadest towards middle; knob absent at tip of lower lip; rounded snout, forming below level of eye 4

4a. (3b) Mouth large and oblique; upper jaw length is equal to snout length........................ ....*Ictiobus cyprinellus*

4b. (3b) Mouth small and nearly horizontal; upper jaw shorter than snout 5

5a. (4b) Body elongate and slender, greatest body depth goes 2.6 to 3.3 times in standard length, and height of anterior rays in dorsal and anal fins often less than 2/3 head length in individuals >300 mm; small eye, eye diameter goes ≥ 2 times in snout length of individuals <300 mm .... *Ictiobus niger*

5b. (4b) Body deep and narrow, greatest body depth goes 2.2 to 2.8 times in standard length, and height of anterior dorsal and anal fin rays often greater than 2/3 head length in individuals >300 mm; large eye, eye diameter goes ≤ 2 times in snout length of individuals <300 mm ....*Ictiobus bubalus*

6a. (1b) Lateral line complete and well developed; air bladder with 3 chambers ....*Moxostoma poecilurum*

6b. (1b) Lateral line incomplete or absent; air bladder with 2 chambers 7

7a. (6b) Lateral line incomplete; rows of spots...................................*Minytrema melanops*

7b. (6b) Lateral line absent 8

8a. (7b) Scales larger, lateral scale count 34 to 37; eye larger, eye length ½ of snout length; dorsal fin rays 11 or 12; back with crescentic scale marks............*Erimyzon sucetta*

8b. (7b) Scales smaller, lateral scale count 39 to 43; eye smaller, eye length < ½ of snout length); dorsal fin rays 9 or 10; back without crescentic scale marks *Erimyzon claviformis*

FAMILY ICTALURIDAE—bullhead catfishes

1a. Adipose fin joined to the caudal fin or separated by a shallow notch............................2

1b. Adipose fin free at tip, not joined to caudal fin 3

2a. (1a) Mouth terminal; pectoral fin spine not serrated; lower lip and chin not heavily speckled with black pigment..*Noturus gyrinus*

2b. (1a) Mouth sub-terminal; pectoral spine serrated; lower lip and chin heavily speckled with black pigment...*Noturus nocturnus*

3a. (1b) Head dorso-ventrally compressed; mouth terminal to superior . *Pylodictis olivaris*

3b. (1b) Head rounded; mouth subterminal 4

4a. (3b) Caudal fin rounded or shallowly emarginate...5

4b. (3b) Caudal fin deeply forked 6

5a. (4a) Chin barbels completely or partially black; anal fin rays 17 to 24; anal fin broadly rounded ....*Ameiurus melas*

5b. (4a) Chin barbels white or yellow; anal fin rays 24 to 27; margin of anal fin generally straight

.... *Ameiurus natalis*

6a. (4b) Anal fin rays 30 to 36; anal fin free margin is straight; medial keel-like ridge anterior to dorsal fin forms humped back appearance ....*Ictalurus furcatus*

6b. (4b) Anal fin rays 22 to 29; anal fin free margin is rounded; no humped back appearance...*Ictalurus punctatus*

FAMILY SALMONIDAE—salmons

Oncorhynchus mykiss

FAMILY ESOCIDAE—pikes and pickerels

1a. Snout short, distance from tip of snout to center of eye ≤ distance from center of eye to rear margin of operculum; < 115 scale rows along body .... *Esox americanus*

1b. Snout long, distance from tip of snout to center of eye > distance from center of eye to rearmargin of operculum; > 120 scale rows along body .... *Esox niger*

FAMILY APHREDODERIDAE—pirate perch

Aphredoderus sayanus

FAMILY MUGILIDAE—mullets

1a. Lower jaw rounded, without a symphyseal knob; lower limb of 1st gill arch with 17 to 20 gill rakers; no adipose eyelid; scales ctenoid............................*Agonostomus monticola*

1b. Lower jaw angular, with a prominent symphyseal knob; lower limb of 1st gill arch with 25 to 60 gill rakers; adipose eyelid well developed in adults; scales cycloid in young, ctenoid in adults..*Mugil cephalus*

FAMILY ATHERINOPSIDAE—New World silversides

1a. Scales small, > 60 scales in lateral series, jaws produced into a short beak; snout length > eye length; > 20 anal fin rays..*Labidesthes sicculus*

1b. Scales large, < 50 scales in lateral series; jaws not produced into a beak; snout length ≤ eye length; < 20 anal fin rays..*Menidia audens*

FAMILY FUNDULIDAE—topminnows

1a. Body with a distinct black lateral band..2

1b. Body without a distinct black lateral band..3

2a. (1a) Distinct black spots on anterior dorso-lateral region are as pronounced as lateral stripe; distinct black spots throughout dorsal and caudal fins .... *Fundulus olivaceus*

2b. (1a) Faint black spots on anterior dorso-lateral region are not as pronounced as lateral stripe; distinct black spots near base of dorsal and caudal fins.................*Fundulus notatus*

3a. (1b) Red to dark spots in multiple rows longitudinally along lateral sides; usually with dark subocular bar..*Fundulus blairae*

3b. (1b) Body mottled, barred or irregularly spotted; no dark subocular bar ....*Fundulus chrysotus*

FAMILY POECILIIDAE—livebearers

1a. Origin of dorsal fin anterior to anal fin origin; intestinal canal long with many convolutions..*Poecilia latipinna*

1b. Origin of dorsal fin posterior to anal fin origin; intestinal canal short with few convolutions...2

2a. (1b) Dorsal fin origin slightly behind anal fin origin; dark band on sides with vertical bars; large black spots near bases of dorsal and caudal fins of both sexes and on anal fin of females..*Heterandria formosa*

2b. (1b) Dorsal fin origin well behind anal fin origin; no dark band on sides; median fins without large black spots near their bases...*Gambusia affinis*

FAMILY MORONIDAE—temperate basses

1a. Dorsal fins united at base; 2nd and 3rd anal fin spines approximately equal in length; no teeth on tongue; 9 to 10 anal fin soft rays; stripes along sides usually sharply broken and offset above front of anal fin.. *Morone mississippiensis*

1b. Dorsal fins separated; 2nd anal fin spine much shorter than 3rd; base of tongue with teeth; 11 to 13 anal fin soft rays; stripes along sides usually continuous 2

2a. (1b) Body depth goes < 3 times in standard length; teeth in single patch on back of tongue...*Morone chrysops*

2b. (1b) Body depth goes > 3 times in standard length; teeth in 2 parallel patches on back of tongue ....*Morone saxatilis*

FAMILY CENTRARCHIDAE—sunfishes

1a. Five to 8 anal spines...2

1b. Three anal spines...4

2a. (1a) Eleven to 13 dorsal fin spines.. *Centrarchus macropterus*

2b. (1a) Six to 8 dorsal fin spines 3

3a. (2b) Dorsal fin set back on body, length of dorsal fin base < distance from its origin to posterior margin of eye; lateral body with wide to narrow dorsal black bands; ≤ 6 dorsal spines.. *Pomoxis annularis*

3b. (2b) Dorsal fin set forward on body, length of dorsal fin base equal to or greater than distance from its origin to posterior margin of eye; lateral body with checkerboard black and light pattern; ≥7 dorsal spines ....*Pomoxis nigromaculatus*

4a. (1b) Body slender, body depth contained > 3 times into standard length......................5

4b. (1b) Body deep, body depth contained < 3 times into standard length..........................6

5a. (4a) Dorsal fins narrowly joined at base forming a deep notch; upper jaw extends past posterior margin of eye in adults; mid-lateral stripe generally complete, rows of spots ventral to mid-lateral stripe faint and incomplete............................*Micropterus salmoides*

5b. (4a) Dorsal fins broadly joined at base forming a shallow notch; upper jaw does not reach past posterior portion of eye; bases of soft dorsal and anal fins scaled ....

.... *Micropterus punctulatus*

6a. (4b) Teeth on tongue; head and opercle with 3 to 5 distinct dark and light longitudinal stripes; red spot on posterior margin of opercle flap in fresh specimens....*Lepomis gulosus*

6b. (4b) No teeth on tongue; head and opercle lacking distinct dark and light longitudinal stripes 7

7a. (6b) Pectoral fins long and pointed, reach anterior portion of eye or beyond when bent forward 8

7b. (6b) Pectoral fins short and rounded, do not reach past eye when bent forward.........10

8a. (7a) Opercle flap stiff to its margin, posterior margin either red or orange in live specimens...*Lepomis microlophus*

8b. (7a) Opercle flap flexible, posterior margin not red or orange in live specimens 9

9a. (8b) Opercle flap black to the margin; black spot on posterior base of soft dorsal fin .... *Lepomis macrochirus*

9b. (8b) Opercle flap outlined with thick white band; lacking black spot on posterior base of soft dorsal fin .... *Lepomis humilis*

10a. (7b) Black opercle flap stiff near the posterior margin with bone supporting all or majority of the flap...11

10b. (7b) Black opercle flap flexible near the posterior margin without bone supporting majority of the flap...13

11a. (10a) Lateral line incomplete; smaller individuals with black spot surrounded by white margin on posterior base of soft dorsal fin ....*Lepomis symmetricus*

11b. (10a) Lateral line complete; black spot, if present, on posterior base of soft dorsal fin without white margin 12

12a. (11b) Body elongated with black spot on posterior base of soft dorsal fin....................

....*Lepomis cyanellus*

12b. (11b) Body rounded without black spot on posterior base of soft dorsal fin; lateral body with alternating stripes formed from black and red spots .... *Lepomis miniatus*

13a. (10b) Opercle flap black to the posterior margin; opercle flap is thin near the opercle bone with the narrowest width of the flexible portion of the flap about the same diameter of the eye pupil..*Lepomis auritus*

13b. (10b) Opercle flap black and surrounded by white on the posterior margin; opercle flap is wide with narrowest width of the flexible flap is about two times the diameter of the eye pupil 14

14a. (13b) Twelve pectoral fin rays, 3 to 5 cheek scales; opercle flap often with white pigment form speckles, distinct red spots (white in preserved specimens) along lateral line...*Lepomis marginatus*

14b. (13b) Thirteen to 15 pectoral fin rays, 5 to 7 cheek scales; opercle flaps with red or white margin; 13 to 15 pectoral fin rays .... *Lepomis megalotis*

FAMILY PERCIDAE—perches

1a. Body depth contained in standard length > 7 times 2

1b. Body depth contained in standard length < 7 times 3

2a. (1a) Lateral blotches longer than deep ....*Ammocrypta clara*

2b. (1a) Lateral blotches deeper than long...*Ammocrypta vivax*

3a. (1b) Snout conical, extends beyond upper lip; body with ≥ 14 black vertical bars..*Percina macrolepida*

3b. (1b) Snout less conical, does not extend beyond upper lip; body with < 14 black vertical bars or with a pattern other than vertical bars..4

4a. (3b) Sides of body with large black blotches; midline of abdomen naked or with enlarged scales 5

4b. (3b) Sides of body without large black blotches; scales on abdomen normal 7

5a. (4a) Upper lip connected to snout by a narrow frenum; blotches on sides of body are rectangle-shaped and bleed downward ....*Percina shumardi*

5b. (4a) Upper lip connected to snout by a broad frenum; blotches on sides of body do not bleed downward...6

6a. (5b) Nape unscaled; blotches on sides of body are rectangle shaped and might appear connected ....*Percina maculata*

6b. (5b) Nape scaled; blotches on sides of body not rectangle shaped..........*Percina sciera*

7a. (4b) Lateral line short, < 6 pored scales; single row of horizontal dashes present..*Etheostoma proeliare*

7b. (4b) Lateral line long (complete or incomplete), > 6 pored scales; if horizontal dashes present, accompanied by vertical bars 8

8a. (7b) Pectoral fin long; pectoral fin folded forward extends past head ....

....*Etheostoma histrio*

8b. (7b) Pectoral fin short, pectoral fin folded forward does not extend past head 9

9a. (8b) Lateral line arched upward 10

9b. (8b) Lateral line straight...11

10a. (9a) Breast without scales; breast and abdomen without black speckles......................
.... *Etheostoma gracile*

10b. (9a) Breast with scales; breast and abdomen with black speckles................................
....*Etheostoma fusiforme*

11a. (9b) Lateral body with distinct series of M-shaped pigments; snout rounded and blunt ....*Etheostoma chlorosoma*

11b. (9b) Lateral body without distinct series of M-shaped pigments; snout not noticeably rounded and blunt 12

12a. (11b) Lateral region with mottling bisected by a light colored lateral stripe.. *Etheostoma parvipinne*

12b. (11b) Lateral region without mottling bisected by a light colored lateral stripe 13

13a. (12b) Gill membranes widely joined across isthmus; lateral region with red or yellow spots ....*Etheostoma artesiae*

13b. (12b) Gill membranes either not joined or barely joined across isthmus; lateral region without spots and with a series of vertical bars located posteriorly ....
....*Etheostoma asprigene*

FAMILY SCIAENIDAE—drums

Aplodinotus grunniens

FAMILY ELASSOMATIDAE—pygmy sunfishes

Elassoma zonatum

FAMILY ACHIRIDAE—American soles

Trinectes maculatus

TRINITY AND SAN JACINTO RIVER BASINS

KEY TO THE FAMILIES

1a. Jawless, disc-shaped mouth; without pectoral and pelvic fins; 7 pairs of external gill openings .... Lampreys – Petromyzontidae

1b. Jawed mouth; one gill opening on each side of head; with pectoral, pelvic, or both fins..2

2a. (1b) Both eyes on one side of head; without right pectoral fin........... American Soles – Achiridae

2b. (1b) One eye on either side of head; with both pectoral fins 3

3a. (2b) Body long and slender; without pelvic fins............Freshwater Eels – Anguillidae

3b. (2b) Body truncated or elongated; with pelvic fins 4

4a. (3b) Caudal fin heterocercal or abbreviated heterocercal 5

4b. (3b) Caudal fin homocercal 7

5a. (4a) Caudal fin heterocercal, body appears scaleless, except for a few ganoid scales at the base of caudal fin; long, paddle shaped snout......................Paddlefish – Polyodontidae

5b. (4a) Caudal fin abbreviated heterocercal; body with ganoid or cycloid scales 6

6a. (5b) Body covered with ganoid scales; snout formed into a beak; without gular plate...Gars – Lepisosteidae

6b. (5b) Body covered with cycloid scales, snout not formed into a beak, with a gular plate...Bowfin – Amiidae

7a. (4b) Jaws duckbilled .... Pikerels – Esocidae

7b. (4b) Jaws not duckbilled..8

8a. (7b) One dorsal fin; pelvic fins without uniserial spines 9

8b. (7b) One or two dorsal fins; pelvic fin with a hard spine 18

9a. (8a) With adipose fin..10
9b. (8a) Without adipose fin 13

10a. (9a) Without barbels...12
10b. (9a) With barbels...11

11a. (10b) Body covered with bony plates; head with one pair of barbels...........................
....Armored Catfishes – Loricariidae
11b. (10b) Scales absent; head with four to eight barbels . Bullhead Catfishes – Ictaluridae

12a. (10a) Scales large, < 50 lateral line scales; incisor teeth present ...Tetras – Characidae
12b. (10a) Scales small, > 60 lateral line scales; incisor teeth absent . Trouts – Salmonidae

13a. (10b) Long anal fin with ≥ 17 fin rays ....Shads – Clupiedae
13b. (10b) Short anal fin with ≤ 13 rays 14

14a. (12b) Caudal fin forked or emarginated; lateral line usually present.........................15
14b. (12b) Caudal fin truncated or rounded; without a distinct lateral line in most 16

15a. (14a) Inferior, fleshy mouth modified for sucking; > 7 pharyngeal teeth in main row, usually ≥ 10 dorsal fin rays ....Suckers – Catostomidae

15b. (14a) Mouth usually not fleshy or modified for sucking; < 7 pharyngeal teeth in main row, usually ≤ 10 dorsal fin rays...Minnows – Cyprinidae

16a. (14b) Mature males with rounded anal fin; males and females with 3rd anal fin ray branched, no gonopodium present 17

16b. (14b) Mature males with pointed anal fin forming a gonopodium; males and females with 3rd anal fin ray unbranched. ....Livebearers – Poeciliidae

17a. (16a) Body robust; teeth in single row are incisor-like and tricuspid (three points on a tooth). .... Pupfishes – Cyprinodontidae

17b. (16a) Body elongate; conical (cone-shaped) pointed teeth in a single row or several rows..Killifishes – Fundulidae

18a. (8b) Anus anterior to pelvic fins; > 5 soft rays on each pelvic fin................................ .... Pirate Perch – Aphredoderidae

18b. (8b) Anus posterior to pelvic fins; 5 soft rays on pelvic fins....................................19

19a. (18b) Pelvic fin position abdominal or sub-thoracic; dorsal fins widely separated...20

19b. (18b) Pelvic fin position thoracic; dorsal fins joined or, if separate, closely adjacent to one another...21

20a. (19a) Dorsal fin with 4 thick spines; anal fin with 2-3 spines; adipose eyelids present...Mullets – Mugilidae

20b. (19a) Dorsal fin with 4 to 8 thin spines; anal fin with 1 spine; adipose eyelids absent ....Silversides – Atherinopsidae

21a. (19b) One nostril (nare) on each side of head; lateral line interrupted ....Cichlids – Cichlidae

21b. (19b) Two nostrils (nares) on each side of head; lateral line complete, incomplete, or absent 22

22a. (21b) Dorsal fin with > 23 fin rays; lateral line extends to tip of caudal fin .... Drums – Sciaenidae

22b. (21b) Dorsal fin with < 23 fin rays; lateral line, if present, does not extend to tip of caudal fin...23

23a. (22b) Anal fin with 1 to 2 spines.. Perches – Percidae

23b. (22b) Anal fin with 3 to 8 spines 24

24a. (23b) Posterior margin of operculum with a sharp spine; spiny and soft dorsal fin separate or only slightly connected; pseudobranchium present and exposed....................... ....Temperate Basses – Moronidae

24b. (23b) Posterior margin of operculum without a sharp spine; spiny and soft dorsal fins connected or with deep notch; pseudobranchium covered or absent..........................24

25a. (24b) Lateral line present or incomplete ....Sunfishes – Centrarchidae

25b. (24b) Lateral line absent ....Pygmy Sunfishes – Elassomatidae

KEY TO THE SPECIES

FAMILY PETROMYZONTIDAE – lampreys

Ichthyomyzon gagei

FAMILY POLYODONTIDAE—paddlefishes

Polyodon spathula

FAMILY LEPISOSTEIDAE—gars

1a. Large teeth in upper jaw in parallel rows on each side ....*Atractosteus spatula*

1b. Large teeth in upper jaw one row, although another non-parallel row might be present 2

2a. (1b) Beak long and narrow, least width goes about 12 to 20 times in length; width of beak at nostrils < eye diameter; snout > ⅔ of head length...................... *Lepisosteus osseus*

2b. (1b) Beak short and blunt, least width goes about 5 to 7 times in length; width of beak at nostrils > eye diameter; snout < ⅔ of head length .... *Lepisosteus oculatus*

FAMILY AMIIDAE—bowfins

Amia calva

FAMILY ANGUILLIDAE—freshwater eels

Anguilla rostrata

FAMILY CLUPEIDAE—herrings

1a. Twenty-nine to 33 anal fin rays; mouth subterminal and below level of middle of eye; black shoulder spot ≥ pupil of eye .... *Dorosoma cepedianum*

1b. Twenty-four to 28 anal fin rays; mouth terminal and at level of eye; black shoulder spot < pupil of eye ....*Dorosoma petenense*

FAMILY CYPRINIDAE - minnows

1a. More than 15 soft rays on dorsal fin; dorsal and anal fins each with a strong serrated spine 2

1b. Fewer than 10 soft rays on dorsal fin; dorsal and anal fins without spine.....................3

2a. (1a) Upper jaw with two pairs of barbels... *Cyprinus carpio*

2b. (1a) Upper jaw without barbels.. *Carassius auratus*

3a. (1b) Anal fin near caudal fin, distance from snout to origin of anal fin is > 2.5 times the distance from origin of anal fin to base of caudal fin; pharyngeal teeth with prominent parallel grooves..*Ctenopharyngodon idella*

3b. (1b) Anal fin not noticeably near caudal fin: distance from snout to origin of anal fin is < 2.5 times the distance from origin of anal fin to base of caudal fin; pharyngeal teeth without prominent parallel grooves 4

4a. (3b) Intestine wound spirally around swim bladder; keratinous ridge on lower jaw..*Campostoma anomalum*

4b. (3b) Intestine not wound spirally around swim bladder; keratinous ridge of lower jaw hardly evident...5

5a. (4b) Abdomen behind pelvic fins with a fleshy keel lacking scales; lateral line greatly decurved, distance between anterior lateral line scale and ventral most lateral line scale is > 3 scales in height..*Notemigonus crysoleucas*

5b. (4b) Abdomen behind pelvic fin with scales; lateral line not greatly decurved, lateral line descends < 3 scales ventrally from highest point 6

6a. (5b) With maxillary barbels, might be small and not observable without opening the mouth or with magnification...7

6b. (5b) Without maxillary barbels..8

7a. (6a) Mouth terminal; distinct black spot located anteriorly on dorsal fin; pharyngeal teeth on main row 5-4 or 5-5...*Semotilus atromaculatus*

7b. (6a) Mouth subterminal or inferior; no distinct black spot on dorsal fin; pharyngeal teeth on main row 4-4 ....*Macrhybopsis hyostoma*

8a. (6b) Thick lower lip at corners, mouth noticeably ventral; black spot at base of caudal fin .... *Phenacobius mirabilis*

8b. (6b) Lower lip thin or not noticeably thick; with or without black spot at base of caudal fin...9

9a. (8b) Predorsal scales appear crowded, smaller than scales on lateral body or appear as overlapping scales; black spot in the middle, anterior portion of the dorsal fin................10

9b. (8b) Predorsal scales not crowded; without black spot in the middle, anterior portion of the dorsal fin 11

10a. (9a) Caudal spot, if distinct, continuous with mid-lateral stripe; lateral line incomplete; intestine long, more than twice the standard length........*Pimephales promelas*

10b. (9a) Caudal spot distinct from mid-lateral stripe; lateral line complete, intestine forming a short S-shaped loop ....*Pimephales vigilax*

11a. (9b) Long intestine in a flat coil...*Hybognathus nuchalis*

11b. (9b) Short S-shaped intestine 12

12a. (11b) Moderately decurved lateral line; diamond-shaped scales; dark shoulder patch present; melanophores concentrated between rays of dorsal and anal fins 13

12b. (11b) Lateral line incomplete, complete-straight, or complete-slightly decurved; scales not noticeably diamond-shaped; without dark shoulder patch; melanophores concentrated along rays of dorsal and anal fins 14

13a. (12a) Sub-terminal mouth; caudal fin base with a caudal spot larger than eye; no shoulder patch .... *Cyprinella venusta*

13b. (12a) Terminal mouth; no caudal spot ....*Cyprinella lutrensis*

14a. (12b) Distinct and separate black dash at base of dorsal fin; apparent when viewed from above; pharyngeal teeth count usually 0,4-4,0...15

14b. (12b) No distinct and separate black dash at base of dorsal fin; pharyngeal teeth count usually 1,4-4,1 or 2,4-4,2 18

15a. (14a) Lateral line scales markedly elevated (taller than wide) anteriorly, elevated scale height 2 to 5 times scale width...16

15b. (14a) Lateral line scales not markedly elevated anteriorly, scale height 1 to 2 times scale width 17

16a. (15a) Dorsal and lateral body with melanophores outlining scales; with pronounced black lateral stripe; dorsal fin height goes 2.1 or more times in pre-dorsal length; infraorbital canal complete .... *Notropis volucellus*

16b. (15a) Dorsal and lateral body with sparse melanophores; scales outlined with melanophores are rare; pre-dorsal black spot is prominent and distinct from mid-dorsal stripe; dorsal fin height goes 2.0 or fewer times in pre-dorsal length; infraorbital canal incomplete...*Notropis buchanani*

17a. (15b) Eye large, eye diameter is > snout length............................*Notropis stramineus*

17b. (15b) Eye small, eye diameter is < snout length...............................*Notropis sabinae*

18a. (14b) Depressed dorsal fin longer than head.......................................*Hybopsis amnis*

18b. (14b) Depressed dorsal fin shorter than head 19

19a. (18b) Mouth is sub-terminal; pharyngeal teeth are 0,4-4,0........ *Notropis atrocaudalis*

19b. (18b) Mouth is terminal; pharyngeal teeth are 1,4-4,1 or 2,4-4,2 or 5-5 20

20a. (19b) Dorsal fin origin opposite or anterior to pelvic fin origin 21

20b. (19b) Dorsal fin origin posterior to pelvic fin origin 25

21a. (20a) Prominent mid-lateral stripe, extending through eye 22

21b. (20a) No prominent mid-lateral stripe present...24

22a. (21a) Pharyngeal teeth 5-5; mouth small and almost vertical.....*Opsopoeodus emiliae*

22b. (21a) Pharyngeal teeth are 1,4-4,1 or 2,4-4,2; mouth large and oblique 23

23a. (22b) Usually 8 anal fin rays; inside of mouth with black melanophores; dorsal fin insertion is opposite to pelvic fin insertion..*Notropis chalybaeus*

23b. (22b) Usually 7 anal fin rays; inside of mouth without black melanophores; dorsal fin insertion is anterior to pelvic fin insertion... *Notropis texanus*

24a. (21b) Usually 8 anal fin rays; head is narrow, depth at occiput more than width at occiput... *Notropis shumardi*

24b. (21b) Usually 7 anal fin rays; head is wide, depth at occiput less than or equal to width at occiput ....*Notropis potteri*

25a. (20b) Moderate-sized scales, ≤ 40 lateral line scales, < 24 predorsal scales .... *Notropis atherinoides*

25b. (20b) Small scales, ≥ 41 lateral line scales, > 25 predorsal scales............................26

26a. (25b) Dorsal fin with black melanophores extending from mid-dorsal stripe into the anterior fin ray; edges of the anterior dorsolateral scales are outlined with black melanophores, producing chevron pattern. .... *Lythrurus umbratilis*

26b. (25b) Dorsal fin with black melanophores not extending from mid-dorsal stripe into the anterior fin ray, lacks chevron pattern .... *Lythrurus fumeus*

FAMILY CATOSTOMIDAE—suckers

1a. Dorsal fin long, base > than ⅓ of standard length; 22 to 30 dorsal fin rays 2

1b. Dorsal fin short, base < than ¼ of standard length; 4 to 18 dorsal fin rays 4

2a. (1a) Small scales, lateral line scales > 50; eye closer to back of head than to tip of snout; head abruptly more slender than body; papillose lips................ *Cycleptus elongatus*

2b. (1a) Large scales, lateral line scales < 45; eye closer to tip of snout than back of head; plicate lips 3

3a. (2b) Subopercle triangular, broadest toward base; knob present at tip of lower lip; blunt snout, forming level with eye .... *Carpiodes carpio*

3b. (2b) Subopercle semicircular, broadest towards middle; knob absent at tip of lower lip; rounded snout, forming below level of eye ....*Ictiobus bubalus*

4a. (1b) Lateral line complete and well developed; air bladder with 3 chambers ....*Moxostoma poecilurum*

4b. (1b) Lateral line incomplete or absent; air bladder with 2 chambers 5

5a. (4b) Lateral line incomplete; rows of spots...................................*Minytrema melanops*

5b. (4b) Lateral line absent 6

6a. (5b) Scales larger, lateral scale count 34 to 37; eye larger, eye length ½ of snout length; dorsal fin rays 11 or 12; back with crescentic scale marks............*Erimyzon sucetta*

6b. (5b) Scales smaller, lateral scale count 39 to 43; eye smaller, eye length < ½ of snout length); dorsal fin rays 9 or 10; back without crescentic scale marks *Erimyzon claviformis*

FAMILY CHARACIDAE—characins

Astyanax mexicanus

FAMILY ICTALURIDAE—bullhead catfishes

1a. Adipose fin joined to the caudal fin or separated by a shallow notch............................2

1b. Adipose fin free at tip, not joined to caudal fin 3

2a. (1a) Mouth terminal; pectoral fin spine not serrated; lower lip and chin not heavily speckled with black pigment..*Noturus gyrinus*

2b. (1a) Mouth sub-terminal; pectoral spine serrated; lower lip and chin heavily speckled with black pigment..*Noturus nocturnus*

3a. (1b) Head dorso-ventrally compressed; mouth terminal to superior . *Pylodictis olivaris*

3b. (1b) Head rounded; mouth subterminal 4

4a. (3b) Caudal fin rounded or shallowly emarginate...5

4b. (3b) Caudal fin deeply forked 6

5a. (4a) Chin barbels completely or partially black; anal fin rays 17 to 24; anal fin broadly rounded ....*Ameiurus melas*

5b. (4a) Chin barbels white or yellow; anal fin rays 24 to 27; margin of anal fin generally straight.. *Ameiurus natalis*

6a. (4b) Anal fin rays 30 to 36; anal fin free margin is straight; medial keel-like ridge anterior to dorsal fin forms humped back appearance ....*Ictalurus furcatus*

6b. (4b) Anal fin rays 22 to 29; anal fin free margin is rounded; no humped back appearance...*Ictalurus punctatus*

FAMILY LORICARIIDAE—suckermouth catfishes

1a. Light spots on a dark background ....*Pterygoplichthys anisitsi*

1b. Dark spots on a light background .... *Pterygoplichthys disjunctivus*

FAMILY SALMONIDAE—salmons

Oncorhynchus mykiss

FAMILY ESOCIDAE—pikes and pickerels

Esox americanus

FAMILY APHREDODERIDAE—pirate perch

Aphredoderus sayanus

FAMILY MUGILIDAE—mullets

1a. Lower jaw rounded, without a symphyseal knob; lower limb of 1st gill arch with 17 to 20 gill rakers; no adipose eyelid; scales ctenoid............................*Agonostomus monticola*

1b. Lower jaw angular, with a prominent symphyseal knob; lower limb of 1st gill arch with 25 to 60 gill rakers; adipose eyelid well developed in adults; scales cycloid in young, ctenoid in adults. ....*Mugil cephalus*

FAMILY ATHERINOPSIDAE—New World silversides

1a. Scales small, > 60 scales in lateral series, jaws produced into a short beak; snout length > eye length; > 20 anal fin rays..*Labidesthes sicculus*

1b. Scales large, < 50 scales in lateral series; jaws not produced into a beak; snout length ≤ eye length; < 20 anal fin rays..2

2a. (1b) Scales ctenoid, rough to the touch; double pairs of black spots on dorsum; bases of dorsal and anal fin covered with scales ....*Membras martinica*

2b. (1b) Scales cycloid, smooth to the touch; dorsum with crosshatching, but not double pairs of black spots; bases of dorsal and anal fins not covered with scales; horizontal distance between spinous dorsal and anal fin origin less than 7% of standard length...*Menidia audens*

FAMILY FUNDULIDAE—topminnows

1a. More than 40 longitudinal scale rows; dark vertical barring; gill slit not extending dorsal to uppermost pectoral fin ray ....*Fundulus zebrinus*

1b. Fewer than 40 longitudinal scale rows; gill slit extending dorsal to uppermost pectoral fin ray...2

2a. (1b) Body with a distinct black lateral band 3

2b. (1b) Body without a distinct black lateral band 4

3a. (2a) Distinct black spots on anterior dorso-lateral region are as pronounced as lateral stripe; distinct black spots throughout dorsal and caudal fins .... *Fundulus olivaceus*

3b. (2a) Faint black spots on anterior dorso-lateral region are not as pronounced as lateral stripe; distinct black spots near base of dorsal and caudal fins.................*Fundulus notatus*

4a. (2b) Red to dark spots in multiple rows longitudinally along lateral sides; usually with dark subocular bar...*Fundulus blairae*

4b. (2b) Body mottled, barred or irregularly spotted; no dark subocular bar ....

....*Fundulus chrysotus*

FAMILY CYPRINODONTIDAE— pupfishes

Cyprinodon variegatus

FAMILY POECILIIDAE—livebearers

1a. Origin of dorsal fin anterior to anal fin origin; intestinal canal long with many convolutions...*Poecilia latipinna*

1b. Origin of dorsal fin posterior to anal fin origin; intestinal canal short with few convolutions..G*ambusia affinis*

FAMILY MORONIDAE—temperate basses

1a. Dorsal fins united at base; 2nd and 3rd anal fin spines approximately equal in length; no teeth on tongue; 9 to 10 anal fin soft rays; stripes along sides usually sharply broken and offset above front of anal fin.. *Morone mississippiensis*

1b. Dorsal fins separated; 2nd anal fin spine < 3rd; base of tongue with teeth; 11 to 13 anal fin soft rays; stripes along sides usually continuous 2

2a. (1b) Body depth goes < 3 times in standard length; teeth in single patch on back of tongue...*Morone chrysops*

2b. (1b) Body depth goes > 3 times in standard length; teeth in 2 parallel patches on back of tongue ....*Morone saxatilis*

FAMILY CENTRARCHIDAE—sunfishes

1a. Five to 8 anal spines..2

1b. Three anal spines...4

2a. (1a) Eleven to 13 dorsal fin spines.. *Centrarchus macropterus*

2b. (1a) Six to 8 dorsal fin spines 3

3a. (2b) Dorsal fin set back on body, length of dorsal fin base < distance from its origin to posterior margin of eye; lateral body with wide to narrow dorsal black bands; ≤ 6 dorsal spines.. *Pomoxis annularis*

3b. (2b) Dorsal fin set forward on body, length of dorsal fin base equal to or greater than distance from its origin to posterior margin of eye; lateral body with checkerboard black and light pattern; ≥7 dorsal spines ....*Pomoxis nigromaculatus*

4a. (1b) Body slender, body depth contained > 3 times into standard length......................5

4b. (1b) Body deep, body depth contained < 3 times into standard length..........................6

5a. (4a) Dorsal fins narrowly joined at base forming a deep notch; upper jaw extends past posterior margin of eye in adults; mid-lateral stripe generally complete, rows of spots ventral to mid-lateral stripe faint and incomplete ....*Micropterus salmoides*

5b. (4a) Dorsal fins broadly joined at base forming a shallow notch; upper jaw does not reach past posterior portion of eye; bases of soft dorsal and anal fins scaled ....

....*Micropterus punctulatus*

6a. (4b) Teeth on tongue; head and opercle with 3 to 5 distinct dark and light longitudinal stripes; red spot on posterior margin of opercle flap in fresh specimens....*Lepomis gulosus*

6b. (4b) No teeth on tongue; head and opercle lacking distinct dark and light longitudinal stripes 7

7a. (6b) Pectoral fins long and pointed, reach anterior portion of eye or beyond when bent forward..8

7b. (6b) Pectoral fins short and rounded, do not reach past eye when bent forward.........10

8a. (7a) Opercle flap stiff to its margin, posterior margin either red or orange in live specimens...*Lepomis microlophus*

8b. (7a) Opercle flap flexible, posterior margin not red or orange in live specimens 9

9a. (8b) Opercle flap black to the margin; black spot on posterior base of soft dorsal fin .... *Lepomis macrochirus*

9b. (8b) Opercle flap outlined with thick white band; lacking black spot on posterior base of soft dorsal fin .... *Lepomis humilis*

10a. (7b) Black opercle flap stiff near the posterior margin with bone supporting all or majority of the flap...11

10b. (7b) Black opercle flap flexible near the posterior margin without bone supporting majority of the flap...13

11a. (10a) Lateral line incomplete; smaller individuals with black spot surrounded by white margin on posterior base of soft dorsal fin ....*Lepomis symmetricus*

11b. (10a) Lateral line complete; black spot, if present, on posterior base of soft dorsal fin without white margin 12

12a. (11b) Body elongated with black spot on posterior base of soft dorsal fin....................

....*Lepomis cyanellus*

12b. (11b) Body rounded without black spot on posterior base of soft dorsal fin; lateral body with alternating stripes formed from black and red spots............... *Lepomis miniatus*

13a. (10b) Opercle flap black to the posterior margin; opercle flap is thin near the opercle bone with the narrowest width of the flexible portion of the flap about the same diameter of the eye pupil..*Lepomis auritus*

13b. (10b) Opercle flap black and surrounded by white on the posterior margin; opercle flap is wide with narrowest width of the flexible flap is about two times the diameter of the eye pupil..14

14a. (13b) Twelve pectoral fin rays, 3 to 5 cheek scales; opercle flap often with white pigment form speckles, distinct red spots (white in preserved specimens) along lateral line..*Lepomis marginatus*

14b. (13b) Thirteen to 15 pectoral fin rays, 5 to 7 cheek scales; opercle flaps with red or white margin; 13 to 15 pectoral fin rays .... *Lepomis megalotis*

FAMILY PERCIDAE—perches

1a. Body depth contained in standard length > 7 times ....*Ammocrypta vivax*

1b. Body depth contained in standard length < 7 times...2

2a. (1b) Snout conical, extends beyond upper lip; body with ≥ 14 black vertical bars 3

2b. (1b) Snout less conical, does not extend beyond upper lip; body with < 14 black vertical bars or with a pattern other than vertical bars..4

3a. (2a) Body with thick vertical bars, bars alternate in length from long to short; 9 to 10 long bars...*Percina carbonaria*

3b. (2a) Body with 14 to 16 thin vertical bars of similar length..........*Percina macrolepida*

4a. (2b) Sides of body with large black blotches; midline of abdomen naked or with enlarged scales 5

4b. (2b) Sides of body without large black blotches; scales on abdomen normal 6

5a. (4a) Nape unscaled; blotches on sides of body are rectangle shaped and might appear connected ....*Percina maculata*

5b. (4a) Nape scaled; blotches on sides of body not rectangle shaped..........*Percina sciera*

6a. (4b) Lateral line short, < 6 pored scales; single row of horizontal dashes present...*Etheostoma proeliare*

6b. (4b) Lateral line long (complete or incomplete), > 6 pored scales; if horizontal dashes present, accompanied by vertical bars 7

7a. (5b) Lateral line arched upward .... *Etheostoma gracile*

7b. (5b) Lateral line straight...8

8a. (6b) Lateral body with distinct series of M-shaped pigments; snout rounded and blunt ....*Etheostoma chlorosoma*

8b. (6b) Lateral body without distinct series of M-shaped pigments; snout not noticeably rounded and blunt 9

9a. (8b) Lateral region with mottling bisected by a light colored lateral stripe.....................

.... *Etheostoma parvipinne*

9b. (8b) Lateral region without mottling bisected by a light colored lateral stripe; lateral region with a series of dashes followed by a series of vertical bars; throat of live males orange... *Etheostoma spectabile*

FAMILY SCIAENIDAE—drums

Aplodinotus grunniens

FAMILY ELASSOMATIDAE—pygmy sunfishes

Elassoma zonatum

FAMILY CICHLIDAE—cichlids

1a. Anal fin spines 5 to 6 ....*Herichthys cyanoguttatus*

1b. Anal fin spines < 5 (usually 3).. *Oreochromis aureus*

FAMILY ACHIRIDAE—American soles

Trinectes maculatus

Appendix 2.1 List of fish species found in raw data with number of drainages sampled and sample size. Drainages represent a major drainage basin with a Hydrologic Unit Code of 4

Family	Species	Drainages found	N
Petromyzontidae	*Ichthyomyzon gagei*	1	169
Lepisosteidae	*Atractosteus spatula*	5	27
	Lepisosteus oculatus	8	374
	Lepisosteus osseus	7	421
	Lepisosteus platostomus	1	4
Amiidae	*Amia calva*	2	7
Hiodontidae	*Hiodon alosoides*	1	1
Anguillidae	*Anguilla rostrata*	1	6
Clupeidae	*Dorosoma cepedianum*	7	4,512
	Dorosoma petenense	5	2,251
Cyprinidae	*Campostoma anomalum*	6	5,356
	Cyprinella lepida	1	614
	Cyprinella lutrensis	8	265,147
	Cyprinella proserpina	1	3,750
	Cyprinella venusta	8	65,309
	Cyprinus carpio	8	553
	Dionda argentosa	1	9,496
	Dionda diaboli	1	1,009
	Dionda episcopa	2	1,630
	Dionda nigrotaeniata	2	5,540
	Dionda serena	1	2,297
	Hybognathus hayi	1	2
	Hybognathus nuchalis	2	1,034
	Hybognathus placitus	2	6,089
	Hybopsis amnis	2	3
	Luxilus chrysocephalus	1	728
	Lythrurus fumeus	6	3,844
	Lythrurus umbratilis	2	356
	Macrhybopsis aestivalis	1	353
	Macrhybopsis australis	1	483
	Macrhybopsis hyostoma	4	2,401
	Macrhybopsis marconis	2	1,528
	Macrhybopsis tetranema	1	762
	Macrhybopsis storeriana	2	10

	Notemigonus crysoleucas	5	210
	Notropis amabilis	4	28,528
	Notropis atherinoides	1	2,129
	Notropis atrocaudalis	3	2,999
	Notropis bairdi	1	6,387
	Notropis braytoni	1	3,716
	Notropis buchanani	6	8,937
	Notropis chalybaeus	1	228
	Notropis chihuahua	1	13
	Notropis girardi	1	2,314
	Notropis jemezanus	1	5
	Notropis oxyrhynchus	1	1
	Notropis potteri	1	29
	Notropis sabinae	2	1,371
	Notropis shumardi	3	2,972
	Notropis stramineus	7	3,562
	Notropis texanus	6	1,237
	Notropis volucellus	4	13,944
	Opsopoeodus emiliae	6	392
	Phenacobius mirabilis	2	122
	Pimephales promelas	6	706
	Pimephales vigilax	8	83,195
	Platygobio gracilis	1	192
	Rhinichthys cataractae	1	40
	Semotilus atromaculatus	2	1,054
Catostomidae	*Carpiodes carpio*	7	2,770
	Cycleptus elongatus	2	94
	Erimyzon claviformis	2	29
	Erimyzon sucetta	1	3
	Ictiobus bubalus	8	440
	Minytrema melanops	5	129
	Moxostoma congestum	4	1,754
	Moxostoma poecilurum	2	73
Characidae	*Astyanax mexicanus*	5	14,395
Ictaluridae	*Ameiurus melas*	7	63
	Ameiurus natalis	8	391
	Ictalurus furcatus	7	1,550
	Ictalurus lupus	2	235
	Ictalurus punctatus	9	6,587
	Noturus gyrinus	5	229
	Noturus nocturnus	3	172

	Noturus phaeus	1	410
	Pylodictis olivaris	8	1,067
Loricariidae	*Hypostomus plecostomus*	1	851
	Pterygoplichthys disjunctivus	2	35
Esocidae	*Esox americanus*	4	32
Aphredoderidae	*Aphredoderus sayanus*	5	182
Mugilidae	*Mugil cephalus*	4	637
	Agonostomus monticola	2	17
Atherinopsidae	*Labidesthes sicculus*	3	1,237
	Membras martinica	1	1
	Menidia audens	7	1,929
Fundulidae	*Fundulus chrysotus*	2	60
	Fundulus grandis	3	131
	Fundulus kansae	1	80
	Fundulus notatus	6	2,981
	Fundulus olivaceus	4	976
	Fundulus zebrinus	3	1,851
	Lucania parva	1	136
Cyprinodontidae	*Cyprinodon eximius*	1	134
	Cyprinodon rubrofluviatilis	1	2,760
	Cyprinodon variegatus	2	910
Poeciliidae	*Gambusia affinis*	9	45,233
	Gambusia geiseri	3	10,688
	Poecilia formosa	1	2,174
	Poecilia latipinna	3	2,814
Moronidae	*Morone chrysops*	4	55
	Morone saxatilis	2	15
Centrarchidae	*Ambloplites rupestris*	1	93
	Centrarchus macropterus	1	3
	Lepomis auritus	7	7,076
	Lepomis cyanellus	9	2,353
	Lepomis gulosus	8	719
	Lepomis humilis	5	1,560
	Lepomis macrochirus	9	7,893
	Lepomis marginatus	3	56
	Lepomis megalotis	9	15,724
	Lepomis microlophus	7	849
	Lepomis miniatus	8	663
	Lepomis symmetricus	1	12
	Micropterus dolomieu	3	530
	Micropterus punctulatus	7	1,354

	Micropterus salmoides	9	6,196
	Micropterus treculii	4	608
	Pomoxis annularis	6	1,142
	Pomoxis nigromaculatus	4	77
Percidae	*Ammocrypta vivax*	2	27
	Etheostoma artesiae	2	439
	Etheostoma asprigene	1	13
	Etheostoma chlorosoma	6	240
	Etheostoma fonticola	1	5,514
	Etheostoma gracile	6	308
	Etheostoma grahami	1	524
	Etheostoma histrio	2	18
	Etheostoma lepidum	3	1,245
	Etheostoma parvipinne	2	4
	Etheostoma proeliare	1	20
	Etheostoma radiosum	3	658
	Etheostoma spectabile	6	4,101
	Percina apristis	1	392
	Percina caprodes	3	277
	Percina carbonaria	3	842
	Percina macrolepida	5	68
	Percina maculata	1	2
	Percina phoxocephala	2	187
	Percina sciera	6	599
	Percina shumardi	2	330
	Sander vitreus	2	27
Sciaenidae	*Aplodinotus grunniens*	6	429
Elassomatidae	*Elassoma zonatum*	4	890
Cichlidae	*Herichthys cyanoguttatus*	5	2,369
	Oreochromis aureus	3	414

Appendix 2.2. Summary statistics for water depth per species and abundance (%) of each species by depth categories.

		Depth (m/s)					Abundance (%)		
Family	Species	N	Mean	SD (±)	Min	Max	Shallow (<0.30 m)	Moderate (0.31 - 0.701 m)	Deep (> 0.701 m)
Petromyzontidae	*Ichthyomyzon gagei*	126	0.1	0.15	0.03	0.87	88.9	8.7	2.4
Lepisosteidae	*Atractosteus spatula*	20	1.5	0.80	0.09	2.83	5.0	15.0	80.0
	Lepisosteus oculatus	277	1.2	1.02	0.08	6.43	11.6	31.0	57.4
	Lepisosteus osseus	340	1.0	0.71	0.06	4.57	20.0	25.6	54.4
	Lepisosteus platostomus	4	1.1	0.58	0.53	1.57	0.0	50.0	50.0
Amiidae	*Amia calva*	6	1.8	1.42	0.80	4.57	0.0	0.0	100.0
Hiodontidae	*Hiodon alosoides*	1	0.9		0.91	0.91	0.0	0.0	100.0
Anguillidae	*Anguilla rostrata*	6	0.7	0.56	0.11	1.74	16.7	33.3	50.0
Clupeidae	*Dorosoma cepedianum*	3,127	0.8	0.59	0.05	4.57	11.8	42.5	45.6
	Dorosoma petenense	1,765	1.3	0.90	0.06	6.43	3.3	22.4	74.3
Cyprinidae	*Campostoma anomalum*	4,490	0.3	0.24	0.03	2.68	72.8	21.6	5.6
	Cyprinella lepida	578	0.2	0.09	0.03	0.88	98.6	0.9	0.5
	Cyprinella lutrensis	185,755	0.5	0.48	0.02	5.97	37.5	40.8	21.8
	Cyprinella proserpina	3,093	0.2	0.17	0.03	0.93	74.5	22.2	3.3
	Cyprinella venusta	48,520	0.5	0.46	0.03	5.97	36.0	42.9	21.1
	Cyprinus carpio	529	0.6	0.48	0.05	3.70	15.3	66.5	18.1
	Dionda argentosa	7,625	0.3	0.23	0.04	1.30	62.2	28.5	9.3
	Dionda diaboli	901	0.7	0.32	0.06	1.30	8.4	48.7	42.8
	Dionda episcopa	1,354	0.4	0.29	0.09	1.52	56.6	25.8	17.7
	Dionda nigrotaeniata	2,817	2.6	1.26	0.06	5.70	2.3	7.0	90.8
	Dionda serena	2,009	0.6	0.29	0.03	1.00	40.5	14.5	44.9
	Hybognathus hayi	2	0.5	0.00	0.55	0.55	0.0	100.0	0.0
	Hybognathus nuchalis	847	0.9	0.26	0.08	3.17	3.5	19.2	77.2

Appendix 2.2. Continued.

		Depth (m/s)					Abundance (%)		
Family	Species	N	Mean	SD (±)	Min	Max	Shallow (<0.30 m)	Moderate (0.31 - 0.701 m)	Deep (> 0.701 m)
	Hybognathus placitus	5,243	0.2	0.14	0.02	1.22	90.3	9.0	0.6
	Hybopsis amnis	3	0.3	0.26	0.18	0.64	66.7	33.3	0.0
	Luxilus chrysocephalus	570	0.3	0.24	0.03	1.11	76.8	21.4	1.8
	Lythrurus fumeus	3,239	0.7	0.51	0.07	3.13	24.0	37.5	38.6
	Lythrurus umbratilis	326	0.3	0.19	0.04	0.92	49.7	44.8	5.5
	Macrhybopsis aestivalis	352	0.4	0.19	0.08	1.01	42.3	50.9	6.8
	Macrhybopsis australis	384	0.2	0.19	0.05	1.22	81.3	15.1	3.6
	Macrhybopsis hyostoma	1,624	0.8	0.56	0.06	2.63	18.7	43.7	37.6
	Macrhybopsis marconis	1,509	0.7	0.49	0.09	3.93	25.0	31.5	43.4
	Macrhybopsis tetranema	753	0.2	0.20	0.02	4.15	86.6	11.7	1.7
	Macrhybopsis storeriana	7	0.5	0.39	0.18	1.07	57.1	0.0	42.9
	Notemigonus crysoleucas	156	0.8	0.62	0.09	2.04	25.0	52.6	22.4
	Notropis amabilis	22,439	0.7	0.48	0.04	4.17	21.2	41.0	37.9
	Notropis atherinoides	689	0.5	0.28	0.04	1.57	12.5	35.3	52.2
	Notropis atrocaudalis	2,666	0.2	0.13	0.03	1.16	89.5	9.6	1.0
	Notropis bairdi	6,241	0.3	0.25	0.03	1.57	59.4	34.0	6.5
	Notropis braytoni	3,422	0.3	0.23	0.04	1.10	60.4	25.3	14.3
	Notropis buchanani	6,509	0.6	0.57	0.03	3.30	30.6	47.4	22.1
	Notropis chalybaeus	131	0.8	0.44	0.12	1.80	16.8	29.0	54.2
	Notropis chihuahua	4	0.3	0.07	0.23	0.48	75.0	25.0	0.0
	Notropis girardi	2,134	0.2	0.17	0.02	4.15	82.2	17.6	0.2
	Notropis jemezanus	5	0.5	0.03	0.44	0.50	0.0	100.0	0.0
	Notropis oxyrhynchus	1	0.4		0.43	0.43	0.0	100.0	0.0

Appendix 2.2. Continued.

		Depth (m/s)					Abundance (%)		
Family	Species	N	Mean	SD (±)	Min	Max	Shallow (<0.30 m)	Moderate (0.31 - 0.701 m)	Deep (> 0.701 m)
	Notropis potteri	18	0.5	0.28	0.21	1.04	27.8	55.6	16.7
	Notropis sabinae	1,044	0.2	0.16	0.04	1.40	82.1	15.4	2.5
	Notropis shumardi	2,362	1.1	0.68	0.07	3.30	5.7	44.7	49.7
	Notropis stramineus	2,848	0.2	0.14	0.03	1.28	75.7	22.4	2.0
	Notropis texanus	886	0.9	0.57	0.09	2.20	30.4	18.4	51.2
	Notropis volucellus	10,630	0.6	0.47	0.05	4.17	18.7	57.7	23.7
	Opsopoeodus emiliae	332	0.7	0.36	0.14	2.83	4.5	34.0	61.4
	Phenacobius mirabilis	122	0.4	0.29	0.09	1.22	42.6	34.4	23.0
	Pimephales promelas	436	2.0	1.08	0.06	3.90	22.0	19.3	58.7
	Pimephales vigilax	48,674	0.5	0.34	0.03	3.64	30.8	41.6	27.5
	Platygobio gracilis	183	0.3	0.19	0.02	0.78	62.3	36.1	1.6
	Rhinichthys cataractae	40	0.2	0.18	0.06	0.77	65.0	30.0	5.0
	Semotilus atromaculatus	724	0.2	0.10	0.03	0.87	85.8	13.7	0.6
Catostomidae	*Carpiodes carpio*	2,232	0.4	0.34	0.04	2.29	55.4	26.3	18.2
	Cycleptus elongatus	94	0.3	0.28	0.11	1.64	67.0	25.5	7.4
	Erimyzon claviformis	27	0.4	0.27	0.04	0.92	63.0	18.5	18.5
	Erimyzon sucetta	3	0.3	0.18	0.15	0.52	66.7	33.3	0.0
	Ictiobus bubalus	402	0.9	0.60	0.06	3.61	11.9	33.3	54.7
	Minytrema melanops	119	0.7	0.46	0.13	2.83	20.2	42.0	37.8
	Moxostoma congestum	1,494	0.6	0.42	0.10	3.70	21.2	53.0	25.8
	Moxostoma poecilurum	72	1.2	0.59	0.08	2.83	13.9	8.3	77.8
Characidae	*Astyanax mexicanus*	10,392	1.5	1.20	0.05	5.38	23.0	19.4	57.5
Ictaluridae	*Ameiurus melas*	63	0.9	0.75	0.07	3.90	23.8	17.5	58.7

Appendix 2.2. Continued.

		Depth (m/s)					Abundance (%)		
Family	Species	N	Mean	SD (±)	Min	Max	Shallow (<0.30 m)	Moderate (0.31 - 0.701 m)	Deep (> 0.701 m)
	Ameiurus natalis	327	0.3	0.25	0.02	2.13	65.1	30.3	4.6
	Ictalurus furcatus	1,286	0.9	0.53	0.08	3.61	14.5	18.2	67.3
	Ictalurus lupus	214	0.9	1.13	0.05	3.90	51.9	23.8	24.3
	Ictalurus punctatus	4,703	0.5	0.39	0.03	3.52	34.6	39.1	26.3
	Noturus gyrinus	216	0.5	0.35	0.06	2.40	35.2	31.0	33.8
	Noturus nocturnus	170	0.6	0.61	0.06	2.80	51.2	27.1	21.8
	Noturus phaeus	350	0.1	0.11	0.03	1.11	95.7	3.7	0.6
	Pylodictis olivaris	858	0.7	0.56	0.06	5.97	29.4	31.1	39.5
Loricariidae	*Hypostomus plecostomus*	556	1.2	0.78	0.10	3.66	16.0	20.0	64.0
	Pterygoplichthys disjunctivus	35	0.5	0.28	0.15	1.33	25.7	42.9	31.4
Esocidae	*Esox americanus*	31	0.6	0.35	0.15	1.34	32.3	29.0	38.7
Aphredoderidae	*Aphredoderus sayanus*	158	0.5	0.26	0.04	1.34	38.0	39.9	22.2
Mugilidae	*Mugil cephalus*	575	1.3	0.83	0.06	6.43	9.6	12.0	78.4
	Agonostomus monticola	17	0.4	0.30	0.17	1.38	58.8	29.4	11.8
Atherinopsidae	*Labidesthes sicculus*	1,093	0.8	0.31	0.11	2.35	11.9	30.0	58.1
	Membras martinica	1	0.6		0.56	0.56	0.0	100.0	0.0
	Menidia audens	1,725	0.8	0.45	0.09	4.57	10.6	47.1	42.3
Fundulidae	*Fundulus chrysotus*	56	0.7	0.22	0.12	0.81	12.5	12.5	75.0
	Fundulus grandis	131	0.9	1.07	0.09	2.55	53.4	10.7	35.9
	Fundulus kansae	80	0.2	0.09	0.03	0.42	97.5	2.5	0.0
	Fundulus notatus	2,795	0.5	0.29	0.04	3.52	44.4	31.8	23.8
	Fundulus olivaceus	869	0.3	0.28	0.03	2.26	70.1	21.2	8.7
	Fundulus zebrinus	1,761	0.4	0.55	0.03	3.90	69.4	9.4	21.1

Appendix 2.2. Continued.

		Depth (m/s)					Abundance (%)		
Family	Species	N	Mean	SD (±)	Min	Max	Shallow (<0.30 m)	Moderate (0.31 - 0.701 m)	Deep (> 0.701 m)
	Lucania parva	128	0.3	0.14	0.12	0.53	32.8	67.2	0.0
Cyprinodontidae	*Cyprinodon eximius*	89	0.1	0.08	0.03	0.43	96.6	3.4	0.0
	Cyprinodon rubrofluviatilis	2,356	0.2	0.14	0.03	0.57	79.2	20.8	0.0
	Cyprinodon variegatus	891	0.2	0.04	0.10	0.81	99.6	0.0	0.4
Poeciliidae	*Gambusia affinis*	33,470	0.4	0.40	0.03	3.93	49.8	32.1	18.1
	Gambusia geiseri	9,279	0.5	0.26	0.06	2.13	31.3	51.4	17.3
	Poecilia formosa	1,617	0.5	0.41	0.06	2.60	28.4	58.8	12.7
	Poecilia latipinna	2,626	0.5	0.40	0.06	3.66	54.0	30.9	15.0
Moronidae	*Morone chrysops*	33	1.2	0.51	0.31	2.69	0.0	12.1	87.9
	Morone saxatilis	15	1.5	1.11	0.36	3.30	0.0	53.3	46.7
Centrarchidae	*Ambloplites rupestris*	88	0.8	0.46	0.15	2.42	5.7	43.2	51.1
	Centrarchus macropterus	3	0.2	0.07	0.15	0.27	100.0	0.0	0.0
	Lepomis auritus	5,269	0.8	0.72	0.04	5.38	18.4	38.8	42.7
	Lepomis cyanellus	2,105	0.6	0.64	0.02	4.70	43.8	29.8	26.4
	Lepomis gulosus	678	0.7	0.47	0.06	5.65	19.0	28.0	52.9
	Lepomis humilis	1,210	0.6	0.36	0.09	2.57	9.7	47.4	43.0
	Lepomis macrochirus	6,185	0.8	0.79	0.04	6.43	21.9	35.0	43.1
	Lepomis marginatus	54	0.3	0.21	0.05	0.76	61.1	33.3	5.6
	Lepomis megalotis	12,559	0.6	0.47	0.03	4.32	29.0	43.2	27.8
	Lepomis microlophus	492	1.3	1.31	0.04	6.43	21.1	36.2	42.7
	Lepomis miniatus	592	0.7	0.53	0.09	5.49	15.7	36.5	47.8
	Lepomis symmetricus	12	0.8	0.07	0.78	0.98	0.0	0.0	100.0
	Micropterus dolomieu	521	0.6	0.44	0.06	2.44	28.8	44.3	26.9

Appendix 2.2. Continued.

		Depth (m/s)					Abundance (%)		
Family	Species	N	Mean	SD (±)	Min	Max	Shallow (<0.30 m)	Moderate (0.31 - 0.701 m)	Deep (> 0.701 m)
	Micropterus punctulatus	1,242	0.7	0.55	0.05	6.43	22.0	43.2	34.8
	Micropterus salmoides	4,700	0.8	0.99	0.02	6.43	46.1	18.1	35.8
	Micropterus treculii	561	0.6	0.41	0.07	2.16	23.9	40.3	35.8
	Pomoxis annularis	771	0.7	0.42	0.16	3.93	15.0	26.1	58.9
	Pomoxis nigromaculatus	63	0.9	0.39	0.22	1.64	1.6	25.4	73.0
Percidae	*Ammocrypta vivax*	27	0.5	0.42	0.12	1.28	29.6	44.4	25.9
	Etheostoma artesiae	402	0.1	0.09	0.03	0.52	99.3	0.7	0.0
	Etheostoma asprigene	13	0.3	0.21	0.15	0.82	69.2	23.1	7.7
	Etheostoma chlorosoma	225	0.7	0.48	0.04	3.13	29.3	22.2	48.4
	Etheostoma fonticola	5,143	1.7	1.07	0.08	5.97	3.3	7.4	89.2
	Etheostoma gracile	278	0.5	0.39	0.06	3.17	44.6	32.7	22.7
	Etheostoma grahami	436	0.4	0.25	0.05	1.15	52.3	42.0	5.7
	Etheostoma histrio	17	0.5	0.23	0.09	0.85	17.6	64.7	17.6
	Etheostoma lepidum	1,192	0.8	0.70	0.03	3.20	45.0	14.6	40.4
	Etheostoma parvipinne	4	0.1	0.05	0.11	0.21	100.0	0.0	0.0
	Etheostoma proeliare	20	0.4	0.10	0.15	0.55	25.0	75.0	0.0
	Etheostoma radiosum	640	0.4	0.31	0.09	2.55	56.4	35.6	8.0
	Etheostoma spectabile	3,485	0.3	0.25	0.02	3.20	67.7	25.7	6.6
	Percina apristis	322	0.6	0.50	0.07	3.05	31.1	40.1	28.9
	Percina caprodes	277	0.5	0.33	0.06	2.02	32.5	52.0	15.5
	Percina carbonaria	774	0.4	0.34	0.08	2.43	43.7	40.1	16.3
	Percina macrolepida	58	0.6	0.41	0.09	1.72	34.5	39.7	25.9
	Percina maculata	2	0.6	0.69	0.09	1.07	50.0	0.0	50.0

Appendix 2.2. Continued.

		Depth (m/s)					Abundance (%)		
Family	Species	N	Mean	SD (±)	Min	Max	Shallow (<0.30 m)	Moderate (0.31 - 0.701 m)	Deep (> 0.701 m)
	Percina phoxocephala	187	0.6	0.39	0.09	1.77	26.2	33.7	40.1
	Percina sciera	524	0.5	0.36	0.04	2.40	45.4	34.7	19.8
	Percina shumardi	321	0.4	0.44	0.07	2.63	44.9	47.0	8.1
	Sander vitreus	26	0.7	0.38	0.27	1.52	15.4	38.5	46.2
Sciaenidae	*Aplodinotus grunniens*	416	1.8	0.73	0.18	2.74	1.0	13.7	85.3
Elassomatidae	*Elassoma zonatum*	863	0.5	0.45	0.05	3.66	37.1	40.6	22.4
Cichlidae	*Herichthys cyanoguttatus*	1,907	0.8	0.75	0.05	4.18	28.8	36.2	34.9
	Oreochromis aureus	315	1.0	0.51	0.06	3.30	14.3	13.3	72.4

Appendix 2.3. Summary statistics for current velocity per species and abundance (%) of each species by current velocity categories.

	Current velocity (m/s)					Abundance (%)			
Species	N	Mean	SD (±)	Min	Max	Slack (<0.049 m/s)	Slow (0.049 - 0.2 m/s)	Moderate (0.21 - 0.46 m/s)	Swift (> 0.46 m/s)
Ichthyomyzon gagei	151	0.19	0.165	0.00	0.53	29.1	42.4	27.2	1.3
Atractosteus spatula	20	0.16	0.178	0.00	0.50	45.0	25.0	20.0	10.0
Lepisosteus oculatus	275	0.16	0.196	0.00	0.97	45.1	21.5	24.4	9.1
Lepisosteus osseus	328	0.19	0.217	0.00	0.96	37.8	24.7	24.1	13.4
Lepisosteus platostomus	4	0.09	0.108	0.00	0.25	25.0	50.0	25.0	0.0
Amia calva	6	0.14	0.143	0.00	0.29	50.0	0.0	50.0	0.0
Hiodon alosoides	1	0.43		0.43	0.43	0.0	0.0	100.0	0.0
Anguilla rostrata	6	0.11	0.149	0.01	0.41	50.0	33.3	16.7	0.0
Dorosoma cepedianum	3,093	0.18	0.268	0.00	1.49	40.8	22.2	17.7	19.3
Dorosoma petenense	1,782	0.14	0.142	0.00	1.08	24.0	51.2	23.1	1.6
Campostoma anomalum	4,895	0.25	0.282	0.00	1.47	36.4	20.7	21.8	21.2
Cyprinella lepida	578	0.23	0.202	0.00	1.35	16.3	43.4	30.3	10.0
Cyprinella lutrensis	181,203	0.26	0.267	0.00	1.79	23.7	29.2	25.8	21.3
Cyprinella proserpina	3,086	0.28	0.232	0.00	1.38	13.2	32.7	30.6	23.6
Cyprinella venusta	50,997	0.22	0.254	0.08	1.49	37.0	20.8	25.1	17.0
Cyprinus carpio	533	0.16	0.226	0.00	1.23	24.6	55.0	10.1	10.3
Dionda argentosa	7,623	0.16	0.193	0.00	1.38	33.8	36.2	20.1	9.9
Dionda diaboli	901	0.06	0.086	0.00	0.77	59.8	35.2	4.0	1.0
Dionda episcopa	1,354	0.16	0.154	0.00	1.19	40.6	23.7	24.2	11.5
Dionda nigrotaeniata	2,776	0.15	0.165	0.00	0.92	35.1	39.4	20.2	5.3
Dionda serena	2,009	0.07	0.117	0.03	0.86	53.7	41.5	2.8	1.9
Hybognathus hayi	2	0.03	0.000	0.00	0.03	100.0	0.0	0.0	0.0
Hybognathus nuchalis	854	0.10	0.078	0.00	0.73	15.2	79.2	4.9	0.7

Appendix 2.3. Continued.

		Current velocity (m/s)					Abundance (%)			
Family	Species	N	Mean	SD (±)	Min	Max	Slack (<0.049 m/s)	Slow (0.049 - 0.2 m/s)	Moderate (0.21 - 0.46 m/s)	Swift (> 0.46 m/s)
	Hybognathus placitus	5,243	0.13	0.155	0.14	1.49	23.0	59.7	11.4	5.8
	Hybopsis amnis	3	0.40	0.231	0.00	0.54	0.0	33.3	0.0	66.7
	Luxilus chrysocephalus	656	0.08	0.113	0.00	0.53	53.0	29.4	16.5	1.1
	Lythrurus fumeus	3,331	0.06	0.087	0.00	0.90	67.6	26.7	5.1	0.6
	Lythrurus umbratilis	347	0.13	0.176	0.00	0.90	42.9	34.6	18.4	4.0
	Macrhybopsis aestivalis	352	0.50	0.328	0.00	1.30	6.5	11.6	34.4	47.4
	Macrhybopsis australis	384	0.16	0.174	0.00	0.66	33.3	24.5	32.0	10.2
	Macrhybopsis hyostoma	1,641	0.35	0.244	0.00	1.36	6.6	18.4	48.0	26.9
	Macrhybopsis marconis	1,434	0.35	0.315	0.00	1.79	10.5	26.9	32.6	30.0
	Macrhybopsis tetranema	749	0.44	0.327	0.01	1.78	4.4	16.4	44.6	34.6
	Macrhybopsis storeriana	7	0.06	0.038	0.00	0.10	42.9	57.1	0.0	0.0
	Notemigonus crysoleucas	154	0.03	0.089	0.00	0.51	79.2	16.2	1.9	2.6
	Notropis amabilis	21,502	0.18	0.201	0.00	1.37	31.8	35.3	21.1	11.7
	Notropis atherinoides	689	0.08	0.116	0.00	0.69	44.7	31.8	17.6	6.0
	Notropis atrocaudalis	2,684	0.14	0.147	0.00	0.91	36.3	30.1	31.3	2.3
	Notropis bairdi	6,243	0.24	0.189	0.00	0.69	20.9	27.2	24.3	27.7
	Notropis braytoni	3,426	0.23	0.258	0.00	1.39	18.2	45.8	20.3	15.6
	Notropis buchanani	6,466	0.14	0.184	0.00	1.12	42.4	31.8	18.7	7.2
	Notropis chalybaeus	131	0.33	0.350	0.00	0.98	22.9	32.1	10.7	34.4
	Notropis chihuahua	4	0.03	0.093	0.00	0.34	75.0	0.0	25.0	0.0
	Notropis girardi	2,133	0.30	0.285	0.26	1.79	19.4	17.9	40.8	21.9
	Notropis jemezanus	5	0.57	0.285	0.39	0.78	0.0	0.0	40.0	60.0
	Notropis oxyrhynchus	1	0.39		0.10	0.39	0.0	0.0	100.0	0.0

Appendix 2.3. Continued.

		Current velocity (m/s)					Abundance (%)			
Family	Species	N	Mean	SD (±)	Min	Max	Slack (<0.049 m/s)	Slow (0.049 - 0.2 m/s)	Moderate (0.21 - 0.46 m/s)	Swift (> 0.46 m/s)
	Notropis potteri	19	0.22	0.091	0.00	0.39	0.0	36.8	63.2	0.0
	Notropis sabinae	1,053	0.14	0.201	0.00	0.91	47.4	27.8	16.9	7.9
	Notropis shumardi	2,380	0.14	0.154	0.00	1.12	38.4	34.8	22.0	4.8
	Notropis stramineus	2,837	0.12	0.182	0.00	0.98	62.2	19.7	8.4	9.7
	Notropis texanus	886	0.12	0.212	0.00	1.08	54.4	13.2	21.9	10.5
	Notropis volucellus	10,579	0.26	0.249	0.00	1.37	26.7	30.0	20.2	23.2
	Opsopoeodus emiliae	332	0.07	0.109	0.06	0.67	60.5	31.6	5.1	2.7
	Phenacobius mirabilis	122	0.71	0.439	0.00	1.36	0.0	9.8	26.2	63.9
	Pimephales promelas	436	0.10	0.115	0.00	1.25	35.3	48.2	10.3	6.2
	Pimephales vigilax	47,784	0.15	0.197	0.00	1.79	40.5	22.7	26.8	10.0
	Platygobio gracilis	182	0.49	0.381	0.04	1.40	4.9	15.9	31.9	47.3
	Rhinichthys cataractae	39	0.67	0.336	0.00	1.31	5.1	2.6	23.1	69.2
	Semotilus atromaculatus	739	0.06	0.085	0.00	0.90	59.9	31.3	7.4	1.4
Catostomidae	*Carpiodes carpio*	2,230	0.12	0.180	0.01	1.36	34.4	47.5	12.6	5.5
	Cycleptus elongatus	93	0.20	0.307	0.00	1.46	52.7	22.6	9.7	15.1
	Erimyzon claviformis	29	0.08	0.118	0.09	0.40	58.6	27.6	13.8	0.0
	Erimyzon sucetta	3	0.15	0.065	0.00	0.22	0.0	66.7	33.3	0.0
	Ictiobus bubalus	388	0.20	0.248	0.00	1.49	39.9	20.6	23.2	16.2
	Minytrema melanops	119	0.11	0.116	0.00	0.53	42.0	31.9	24.4	1.7
	Moxostoma congestum	1,517	0.31	0.278	0.00	1.46	19.2	32.5	18.7	29.6
	Moxostoma poecilurum	72	0.30	0.193	0.00	0.67	8.3	23.6	43.1	25.0
Characidae	*Astyanax mexicanus*	10,383	0.17	0.204	0.00	1.38	26.9	40.8	21.9	10.3
Ictaluridae	*Ameiurus melas*	62	0.29	0.268	0.00	0.90	24.2	22.6	24.2	29.0

Appendix 2.3. Continued.

		Current velocity (m/s)					Abundance (%)			
Family	Species	N	Mean	SD (±)	Min	Max	Slack (<0.049 m/s)	Slow (0.049 - 0.2 m/s)	Moderate (0.21 - 0.46 m/s)	Swift (> 0.46 m/s)
	Ameiurus natalis	329	0.13	0.163	0.00	0.91	44.7	29.8	20.1	5.5
	Ictalurus furcatus	1,248	0.32	0.229	0.00	1.49	5.5	25.0	52.9	16.6
	Ictalurus lupus	214	0.37	0.258	0.00	1.22	21.0	8.4	37.4	33.2
	Ictalurus punctatus	4,519	0.38	0.346	0.00	1.49	19.1	17.9	28.4	34.7
	Noturus gyrinus	216	0.24	0.208	0.01	0.97	25.9	18.5	37.5	18.1
	Noturus nocturnus	170	0.33	0.242	0.00	1.30	5.3	26.5	45.9	22.4
	Noturus phaeus	410	0.16	0.137	0.00	0.53	26.3	41.5	26.6	5.6
	Pylodictis olivaris	807	0.35	0.295	0.00	1.49	17.6	22.9	27.4	32.1
Loricariidae	*Hypostomus plecostomus*	540	0.26	0.279	0.01	1.33	15.6	46.9	14.8	22.8
	Pterygoplichthys disjunctivus	35	0.26	0.229	0.00	1.00	11.4	37.1	31.4	20.0
Esocidae	*Esox americanus*	31	0.06	0.063	0.00	0.31	64.5	32.3	3.2	0.0
Aphredoderidae	*Aphredoderus sayanus*	163	0.05	0.060	0.00	0.31	58.3	38.0	3.7	0.0
Mugilidae	*Mugil cephalus*	574	0.15	0.167	0.08	0.88	53.8	13.8	24.6	7.8
	Agonostomus monticola	17	0.57	0.332	0.00	1.10	0.0	17.6	29.4	52.9
Atherinopsidae	*Labidesthes sicculus*	1,098	0.06	0.078	0.02	0.58	68.4	21.9	9.3	0.4
	Membras martinica	1	0.02		0.00	0.02	100.0	0.0	0.0	0.0
	Menidia audens	1,749	0.08	0.147	0.00	1.18	58.8	28.8	7.7	4.7
Fundulidae	*Fundulus chrysotus*	56	0.02	0.051	0.00	0.20	83.9	16.1	0.0	0.0
	Fundulus grandis	131	0.09	0.122	0.00	0.60	63.4	29.0	6.1	1.5
	Fundulus kansae	80	0.24	0.298	0.00	1.40	40.0	16.3	22.5	21.3
	Fundulus notatus	2,796	0.06	0.123	0.00	1.02	70.4	19.2	8.3	2.1
	Fundulus olivaceus	958	0.08	0.115	0.00	0.67	59.8	26.1	12.3	1.8
	Fundulus zebrinus	1,797	0.14	0.187	0.01	0.94	53.7	20.0	15.8	10.5

Appendix 2.3. Continued.

		Current velocity (m/s)					Abundance (%)			
Family	Species	N	Mean	SD (±)	Min	Max	Slack (<0.049 m/s)	Slow (0.049 - 0.2 m/s)	Moderate (0.21 - 0.46 m/s)	Swift (> 0.46 m/s)
	Lucania parva	128	0.20	0.186	0.00	0.65	32.0	41.4	13.3	13.3
Cyprinodontidae	*Cyprinodon eximius*	89	0.02	0.043	0.00	0.35	97.8	0.0	2.2	0.0
	Cyprinodon rubrofluviatilis	2,382	0.07	0.105	0.00	0.90	52.1	38.7	7.4	1.8
	Cyprinodon variegatus	891	0.01	0.009	0.00	0.04	100.0	0.0	0.0	0.0
Poeciliidae	*Gambusia affinis*	32,765	0.13	0.200	0.00	1.37	55.7	21.9	13.4	9.1
	Gambusia geiseri	9,319	0.14	0.185	0.00	1.30	44.4	33.3	16.9	5.5
	Poecilia formosa	1,074	0.28	0.232	0.00	1.04	16.6	24.3	40.2	18.9
	Poecilia latipinna	2,408	0.13	0.219	0.00	0.98	58.2	22.5	8.2	11.1
Moronidae	*Morone chrysops*	33	0.18	0.288	0.00	1.49	21.2	54.5	9.1	15.2
	Morone saxatilis	15	0.11	0.129	0.00	0.40	46.7	40.0	13.3	0.0
Centrarchidae	*Ambloplites rupestris*	90	0.13	0.167	0.04	0.98	41.1	36.7	16.7	5.6
	Centrarchus macropterus	3	0.05	0.018	0.00	0.07	66.7	33.3	0.0	0.0
	Lepomis auritus	5,484	0.13	0.184	0.00	1.35	46.6	30.9	14.4	8.0
	Lepomis cyanellus	2,126	0.11	0.166	0.00	1.34	55.8	25.0	12.6	6.6
	Lepomis gulosus	597	0.07	0.148	0.00	0.76	73.7	15.4	5.0	5.9
	Lepomis humilis	1,182	0.06	0.124	0.00	1.06	65.1	27.5	4.5	3.0
	Lepomis macrochirus	6,383	0.08	0.148	0.00	1.49	64.2	22.4	8.6	4.9
	Lepomis marginatus	56	0.05	0.064	0.00	0.27	73.2	21.4	5.4	0.0
	Lepomis megalotis	12,481	0.14	0.202	0.00	1.49	50.0	25.8	12.9	11.3
	Lepomis microlophus	492	0.13	0.155	0.00	0.90	45.3	38.4	11.6	4.7
	Lepomis miniatus	598	0.08	0.140	0.00	0.78	64.5	23.7	7.2	4.5
	Lepomis symmetricus	12	0.02	0.032	0.00	0.07	66.7	33.3	0.0	0.0
	Micropterus dolomieu	496	0.25	0.236	0.00	1.00	28.2	26.8	21.4	23.6

Appendix 2.3. Continued.

		Current velocity (m/s)					Abundance (%)			
Family	Species	N	Mean	SD (±)	Min	Max	Slack (<0.049 m/s)	Slow (0.049 - 0.2 m/s)	Moderate (0.21 - 0.46 m/s)	Swift (> 0.46 m/s)
	Micropterus punctulatus	1,236	0.24	0.246	0.00	1.49	29.4	25.7	29.3	15.6
	Micropterus salmoides	4,731	0.19	0.184	0.00	1.46	34.6	19.5	43.2	2.7
	Micropterus treculii	580	0.16	0.219	0.00	1.24	42.6	28.1	20.0	9.3
	Pomoxis annularis	767	0.03	0.080	0.00	1.08	77.2	19.9	2.5	0.4
	Pomoxis nigromaculatus	63	0.09	0.159	0.02	0.90	74.6	0.0	22.2	3.2
Percidae	*Ammocrypta vivax*	27	0.23	0.079	0.00	0.40	3.7	14.8	81.5	0.0
	Etheostoma artesiae	421	0.21	0.152	0.03	0.57	21.9	24.2	49.2	4.8
	Etheostoma asprigene	13	0.14	0.103	0.00	0.31	15.4	61.5	23.1	0.0
	Etheostoma chlorosoma	224	0.04	0.070	0.00	0.40	77.7	19.2	3.1	0.0
	Etheostoma fonticola	5,195	0.06	0.112	0.00	1.12	68.4	23.3	6.7	1.7
	Etheostoma gracile	275	0.19	0.214	0.00	1.09	43.3	22.2	20.4	14.2
	Etheostoma grahami	436	0.26	0.272	0.02	1.36	28.0	21.1	22.9	28.0
	Etheostoma histrio	17	0.17	0.111	0.00	0.32	5.9	52.9	41.2	0.0
	Etheostoma lepidum	1,192	0.20	0.277	0.11	1.37	46.6	20.1	16.9	16.5
	Etheostoma parvipinne	4	0.32	0.392	0.03	0.91	0.0	75.0	0.0	25.0
	Etheostoma proeliare	20	0.08	0.063	0.00	0.31	20.0	75.0	5.0	0.0
	Etheostoma radiosum	633	0.16	0.254	0.00	1.18	64.0	13.9	7.6	14.5
	Etheostoma spectabile	3,581	0.52	0.293	0.00	1.47	6.3	10.0	26.7	57.0
	Percina apristis	322	0.55	0.271	0.00	1.32	1.2	14.0	22.7	62.1
	Percina caprodes	264	0.35	0.315	0.00	1.36	12.9	34.5	18.2	34.5
	Percina carbonaria	771	0.58	0.297	0.00	1.27	4.2	8.9	28.1	58.8
	Percina macrolepida	56	0.23	0.237	0.12	0.75	35.7	23.2	8.9	32.1
	Percina maculata	2	0.14	0.041	0.00	0.17	0.0	100.0	0.0	0.0

Appendix 2.3. Continued.

		Current velocity (m/s)					Abundance (%)			
Family	Species	N	Mean	SD (±)	Min	Max	Slack (<0.049 m/s)	Slow (0.049 - 0.2 m/s)	Moderate (0.21 - 0.46 m/s)	Swift (> 0.46 m/s)
	Percina phoxocephala	187	0.43	0.373	0.00	1.36	30.5	9.6	7.0	52.9
	Percina sciera	515	0.31	0.231	0.00	1.09	13.6	26.2	38.6	21.6
	Percina shumardi	314	0.89	0.274	0.00	1.47	2.5	0.0	4.1	93.3
	Sander vitreus	23	0.13	0.100	0.00	0.35	21.7	56.5	21.7	0.0
Sciaenidae	*Aplodinotus grunniens*	416	0.11	0.243	0.00	1.49	74.3	7.0	10.1	8.7
Elassomatidae	*Elassoma zonatum*	624	0.19	0.209	0.00	1.30	28.8	39.1	17.5	14.6
Cichlidae	*Herichthys cyanoguttatus*	1,958	0.17	0.215	0.00	1.38	40.6	31.6	12.5	15.3
	Oreochromis aureus	315	0.24	0.200	0.00	0.78	29.8	14.6	44.1	11.4

Appendix 2.4. Summary statistics for temperature per species and abundance (%) of each species by temperature categories.

		Water temperature (°C)					Abundance (%)		
Family	Species	N	Mean	SD (±)	Min	Max	Cold (<21.5 °C)	Cool (21.6 - 25.7 °C)	Warm (>25.7 °C)
Lepisosteidae	*Atractosteus spatula*	8	26.7	3.89	18.9	30.3	12.5	25.0	62.5
	Lepisosteus oculatus	172	25.6	5.65	6.3	34.0	18.0	20.9	61.0
	Lepisosteus osseus	206	27.3	5.83	8.8	34.0	16.0	18.4	65.5
	Lepisosteus platostomus	4	30.1	0.92	28.7	30.5	0.0	0.0	100.0
Amiidae	*Amia calva*	4	22.4	7.06	12.8	29.5	25.0	50.0	25.0
Hiodontidae	*Hiodon alosoides*	1	18.9		18.9	18.9	100.0	0.0	0.0
Anguillidae	*Anguilla rostrata*	4	31.0	1.43	29.8	33.0	0.0	0.0	100.0
Clupeidae	*Dorosoma cepedianum*	1,847	27.8	5.98	6.3	35.7	19.4	11.4	69.2
	Dorosoma petenense	1,413	25.2	4.54	8.8	34.0	46.2	23.3	30.5
Cyprinidae	*Campostoma anomalum*	2,323	24.4	5.80	5.7	33.5	23.7	14.9	61.4
	Cyprinella lepida	48	22.9	3.13	16.0	32.0	20.8	72.9	6.3
	Cyprinella lutrensis	121,122	22.1	8.57	2.6	37.6	40.0	16.7	43.3
	Cyprinella proserpina	1,127	22.9	4.15	10.2	36.5	32.7	53.9	13.4
	Cyprinella venusta	22,245	22.8	7.36	5.7	37.6	36.3	18.3	45.4
	Cyprinus carpio	388	17.4	5.32	6.7	31.6	77.8	8.8	13.4
	Dionda argentosa	4,426	23.6	2.30	10.1	36.5	12.0	78.4	9.6
	Dionda diaboli	707	23.0	4.26	10.0	30.6	24.5	51.9	23.6
	Dionda nigrotaeniata	2,347	22.3	0.82	19.2	26.1	0.3	99.6	0.1
	Dionda serena	2,005	21.7	0.88	20.0	26.7	45.5	53.5	1.0
	Hybognathus nuchalis	809	25.2	4.73	6.3	34.0	8.0	58.0	34.0
	Hybognathus placitus	5,233	26.2	7.01	2.6	31.5	29.0	2.6	68.5
	Lythrurus fumeus	2,515	22.0	8.75	6.3	34.0	29.8	17.3	52.9
	Macrhybopsis aestivalis	20	21.2	0.63	20.3	21.7	40.0	60.0	0.0

Appendix 2.4. Continued.

		Water temperature (°C)					Abundance (%)		
Family	Species	N	Mean	SD (±)	Min	Max	Cold (<21.5 °C)	Cool (21.6 - 25.7 °C)	Warm (>25.7 °C)
	Macrhybopsis australis	384	24.5	4.66	16.1	31.5	44.8	2.1	53.1
	Macrhybopsis hyostoma	1,280	23.5	7.25	8.4	34.2	36.1	27.0	37.0
	Macrhybopsis marconis	1,157	26.4	4.68	10.7	33.5	13.6	38.9	47.5
	Macrhybopsis tetranema	749	17.2	7.45	0.1	31.6	70.2	17.5	12.3
	Macrhybopsis storeriana	8	28.0	4.28	22.3	31.5	0.0	37.5	62.5
	Notemigonus crysoleucas	79	23.8	5.44	6.3	35.6	25.3	44.3	30.4
	Notropis amabilis	11,710	22.9	5.18	9.6	36.5	31.6	30.1	38.3
	Notropis atherinoides	689	24.4	7.16	16.1	31.5	89.3	0.1	10.6
	Notropis bairdi	6,243	18.6	8.34	5.4	33.0	67.1	11.5	21.4
	Notropis braytoni	19	20.5	0.52	20.3	21.7	84.2	15.8	0.0
	Notropis buchanani	4,955	21.0	7.89	6.3	34.2	42.8	21.3	35.9
	Notropis chalybaeus	184	22.6	0.50	21.4	24.1	6.5	93.5	0.0
	Notropis girardi	2,116	17.7	7.18	0.4	31.7	66.2	16.3	17.5
	Notropis potteri	10	32.8	0.74	30.7	33.0	0.0	0.0	100.0
	Notropis sabinae	3	22.2	0.00	22.2	22.2	0.0	100.0	0.0
	Notropis shumardi	1,680	21.0	6.57	6.3	34.7	57.6	32.8	9.6
	Notropis stramineus	650	19.6	6.66	3.4	37.6	60.3	12.8	26.9
	Notropis texanus	37	25.2	2.80	15.5	31.2	18.9	24.3	56.8
	Notropis volucellus	7,136	21.0	7.01	5.7	34.0	44.9	16.9	38.2
	Opsopoeodus emiliae	219	24.4	8.58	6.3	34.0	27.4	9.1	63.5
	Phenacobius mirabilis	57	25.1	4.80	17.5	30.2	33.3	0.0	66.7
	Pimephales promelas	434	27.8	3.11	14.3	31.5	11.1	6.7	82.3
	Pimephales vigilax	31,666	22.7	9.83	5.7	35.8	25.3	9.3	65.4

Appendix 2.4. Continued.

		Water temperature (°C)					Abundance (%)		
Family	Species	N	Mean	SD (±)	Min	Max	Cold (<21.5 °C)	Cool (21.6 - 25.7 °C)	Warm (>25.7 °C)
	Platygobio gracilis	181	18.8	4.85	5.7	30.9	75.1	14.4	10.5
	Rhinichthys cataractae	2	21.7	0.00	21.7	21.7	0.0	100.0	0.0
Catostomidae	*Carpiodes carpio*	586	29.0	4.84	10.0	34.7	11.8	19.1	69.1
	Cycleptus elongatus	50	21.7	0.20	20.3	21.7	2.0	98.0	0.0
	Ictiobus bubalus	188	25.1	6.26	10.3	33.9	26.1	22.3	51.6
	Minytrema melanops	45	25.9	6.14	8.9	34.0	11.1	31.1	57.8
	Moxostoma congestum	521	25.0	5.14	6.2	33.5	19.2	31.9	48.9
Characidae	*Astyanax mexicanus*	8,883	23.0	3.64	12.8	36.5	31.4	41.2	27.4
Ictaluridae	*Ameiurus melas*	48	21.6	4.08	7.3	28.6	37.5	54.2	8.3
	Ameiurus natalis	87	23.7	5.73	6.0	32.1	23.0	35.6	41.4
	Ictalurus furcatus	953	30.0	4.19	8.4	34.0	5.0	2.0	93.0
	Ictalurus lupus	90	23.5	5.14	10.3	36.5	31.1	22.2	46.7
	Ictalurus punctatus	3,975	27.6	5.82	1.2	35.5	16.1	9.1	74.8
	Noturus gyrinus	203	23.6	6.36	6.3	33.2	36.5	23.6	39.9
	Noturus nocturnus	2	27.9	0.71	27.4	28.4	0.0	0.0	100.0
	Pylodictis olivaris	595	28.7	5.40	7.7	34.0	8.7	7.1	84.2
Loricariidae	*Hypostomus plecostomus*	571	24.4	3.82	17.2	35.5	12.8	62.0	25.2
	Pterygoplichthys disjunctivus	35	28.0	3.45	17.2	31.9	2.9	28.6	68.6
Esocidae	*Esox americanus*	10	22.3	2.12	20.5	25.5	50.0	50.0	0.0
Aphredoderidae	*Aphredoderus sayanus*	38	25.3	6.58	6.3	31.0	10.5	23.7	65.8
Mugilidae	*Mugil cephalus*	461	23.8	4.44	15.1	35.8	30.8	50.3	18.9
	Agonostomus monticola	15	14.9	5.41	9.9	26.7	80.0	13.3	6.7
Atherinopsidae	*Labidesthes sicculus*	926	22.8	8.73	5.7	34.0	31.7	3.2	65.0

Appendix 2.4. Continued.

		Water temperature (°C)					Abundance (%)		
Family	Species	N	Mean	SD (±)	Min	Max	Cold (<21.5 °C)	Cool (21.6 - 25.7 °C)	Warm (>25.7 °C)
	Membras martinica	1	26.9		26.9	26.9	0.0	0.0	100.0
	Menidia audens	810	23.0	7.06	9.4	35.7	36.8	4.1	59.1
Fundulidae	*Fundulus chrysotus*	55	23.1	6.99	12.8	29.2	34.5	10.9	54.5
	Fundulus grandis	131	11.7	5.16	9.6	31.4	93.9	0.0	6.1
	Fundulus kansae	77	20.7	5.96	9.3	31.1	51.9	18.2	29.9
	Fundulus notatus	1,668	23.2	6.66	6.0	34.0	23.1	46.9	30.0
	Fundulus olivaceus	30	28.1	4.94	12.2	32.1	6.7	26.7	66.7
	Fundulus zebrinus	1,689	23.4	5.69	5.4	33.0	37.1	12.4	50.4
	Lucania parva	41	23.8	1.13	21.5	25.4	0.0	100.0	0.0
Cyprinodontidae	*Cyprinodon rubrofluviatilis*	2,382	25.5	6.13	5.4	33.0	40.8	3.0	56.3
	Cyprinodon variegatus	890	21.7	8.54	11.3	29.2	40.0	0.0	60.0
Poeciliidae	*Gambusia affinis*	24,803	24.5	7.09	5.7	37.6	33.0	20.4	46.6
	Gambusia geiseri	7,179	22.4	0.88	18.0	29.7	17.4	82.1	0.5
	Poecilia formosa	1,310	30.2	2.48	15.6	34.0	1.8	3.9	94.3
	Poecilia latipinna	2,323	27.0	5.06	9.4	33.3	10.6	12.7	76.8
Moronidae	*Morone chrysops*	25	21.5	8.07	10.0	31.4	48.0	8.0	44.0
	Morone saxatilis	15	25.6	3.94	16.3	30.5	13.3	40.0	46.7
Centrarchidae	*Ambloplites rupestris*	85	22.4	0.81	20.7	23.9	16.5	83.5	0.0
	Lepomis auritus	2,644	23.8	3.43	8.3	31.4	16.2	57.4	26.4
	Lepomis cyanellus	1,166	23.3	7.26	5.7	37.6	42.7	13.5	43.8
	Lepomis gulosus	550	23.8	6.86	6.3	33.5	24.7	22.2	53.1
	Lepomis humilis	1,123	17.9	9.54	6.3	34.9	47.6	25.5	27.0
	Lepomis macrochirus	4,007	23.4	6.71	5.7	37.6	29.2	32.6	38.2

Appendix 2.4. Continued.

		Water temperature (°C)					Abundance (%)		
Family	Species	N	Mean	SD (±)	Min	Max	Cold (<21.5 °C)	Cool (21.6 - 25.7 °C)	Warm (>25.7 °C)
	Lepomis marginatus	6	22.4	5.90	10.5	25.5	16.7	83.3	0.0
	Lepomis megalotis	8,626	23.4	8.16	5.7	35.8	30.2	17.6	52.3
	Lepomis microlophus	314	24.3	4.16	6.2	34.9	12.4	42.4	45.2
	Lepomis miniatus	496	22.8	2.42	7.7	32.4	16.9	77.2	5.8
	Lepomis symmetricus	12	18.5	7.94	12.8	29.2	66.7	0.0	33.3
	Micropterus dolomieu	462	24.5	7.38	10.2	33.7	31.6	3.9	64.5
	Micropterus punctulatus	519	26.8	6.04	6.2	34.9	12.9	20.2	66.9
	Micropterus salmoides	3,865	23.1	3.03	6.7	37.6	7.2	79.3	13.5
	Micropterus treculii	247	27.4	4.91	6.2	35.7	10.5	10.5	78.9
	Pomoxis annularis	751	25.8	5.34	6.3	34.0	12.8	29.8	57.4
	Pomoxis nigromaculatus	70	23.0	5.45	8.9	31.2	31.4	41.4	27.1
Percidae	*Etheostoma chlorosoma*	158	17.4	10.09	6.3	32.2	51.9	15.2	32.9
	Etheostoma fonticola	4,821	22.7	1.00	20.2	25.3	9.3	90.7	0.0
	Etheostoma gracile	183	18.7	8.10	5.7	34.0	64.5	10.4	25.1
	Etheostoma grahami	195	22.4	3.68	14.7	30.5	37.4	47.2	15.4
	Etheostoma lepidum	866	22.5	2.27	11.9	29.4	24.9	70.3	4.7
	Etheostoma radiosum	613	26.1	5.21	9.6	30.4	8.8	9.5	81.7
	Etheostoma spectabile	1,797	17.9	7.54	5.7	32.7	66.6	14.6	18.8
	Percina apristis	311	22.2	4.27	10.8	32.3	20.9	66.6	12.5
	Percina caprodes	157	25.9	4.80	10.6	33.2	11.5	26.8	61.8
	Percina carbonaria	316	23.0	5.43	9.6	32.3	32.3	28.2	39.6
	Percina macrolepida	49	24.5	7.44	7.7	33.5	22.4	8.2	69.4
	Percina phoxocephala	60	29.0	2.20	22.7	30.4	0.0	10.0	90.0

Appendix 2.3. Continued.

		Water temperature (°C)					Abundance (%)		
Family	Species	N	Mean	SD (±)	Min	Max	Cold (<21.5 °C)	Cool (21.6 - 25.7 °C)	Warm (>25.7 °C)
	Percina sciera	401	23.2	7.54	5.7	34.0	37.4	10.5	52.1
	Percina shumardi	301	22.9	8.54	10.2	32.3	43.9	11.6	44.5
	Sander vitreus	26	27.0	6.44	14.1	33.5	15.4	19.2	65.4
Sciaenidae	*Aplodinotus grunniens*	61	24.9	8.10	5.7	31.5	23.0	13.1	63.9
Elassomatidae	*Elassoma zonatum*	821	28.4	5.04	10.4	33.5	12.4	5.7	81.9
Cichlidae	*Herichthys cyanoguttatus*	980	24.9	3.61	9.6	32.5	10.2	44.6	45.2
	Oreochromis aureus	355	24.1	2.09	14.5	33.8	2.3	67.9	29.9

Appendix 2.5. Summary statistics for dissolved oxygen per species and abundance (%) of each species by dissolved oxygen categories.

		Dissolved oxygen (mg/l)					Abundance (%)	
Family	Species	N	Mean	SD (±)	Min	Max	Hypoxic (<3.0 mg/l)	Oxic (>3.0 mg/l)
Lepisosteidae	*Atractosteus spatula*	8	8.6	3.10	4.1	14.1	0.6	99.4
	Lepisosteus oculatus	167	6.9	2.08	2.8	15.0	0.5	99.5
	Lepisosteus osseus	204	7.6	2.13	2.4	13.9	0.0	100.0
	Lepisosteus platostomus	4	7.8	0.94	6.4	8.3	33.3	66.7
Amiidae	*Amia calva*	3	6.6	3.50	2.8	9.7	0.0	100.0
Hiodontidae	*Hiodon alosoides*	1	12.7		12.7	12.7	0.0	100.0
Anguillidae	*Anguilla rostrata*	4	7.0	1.12	6.0	8.5	1.4	98.6
Clupeidae	*Dorosoma cepedianum*	1,804	7.7	2.29	2.6	13.5	0.6	99.4
	Dorosoma petenense	1,410	7.3	1.54	2.6	15.0	0.8	99.2
Cyprinidae	*Campostoma anomalum*	2,135	7.4	2.75	0.8	13.8	0.0	100.0
	Cyprinella lepida	43	7.7	0.48	6.5	8.0	0.3	99.7
	Cyprinella lutrensis	117,315	8.8	2.25	1.0	15.4	0.0	100.0
	Cyprinella proserpina	361	7.4	1.68	6.0	13.2	3.4	96.6
	Cyprinella venusta	19,361	7.8	2.93	1.7	14.7	1.7	98.3
	Cyprinus carpio	116	6.9	1.93	2.6	13.8	0.0	100.0
	Dionda argentosa	618	6.6	1.90	3.2	13.2	0.0	100.0
	Dionda nigrotaeniata	2,629	6.2	1.59	3.5	12.3	0.0	100.0
	Dionda serena	2,009	5.6	1.54	1.3	8.8	6.5	93.5
	Hybognathus nuchalis	793	6.0	1.06	4.1	11.4	0.0	100.0
	Hybognathus placitus	5,243	7.7	1.38	2.1	12.9	0.2	99.8
	Lythrurus fumeus	2,513	7.4	2.70	2.0	13.0	5.5	94.5
	Macrhybopsis aestivalis	20	9.0	0.52	8.2	9.4	0.0	100.0
	Macrhybopsis australis	380	8.5	1.41	4.3	12.7	0.0	100.0

Appendix 2.5. Continued.

			Dissolved oxygen (mg/l)				Abundance (%)	
Family	Species	N	Mean	SD (±)	Min	Max	Hypoxic (<3.0 mg/l)	Oxic (>3.0 mg/l)
	Macrhybopsis hyostoma	1,263	9.5	2.17	4.1	15.4	0.0	100.0
	Macrhybopsis marconis	1,200	7.2	1.29	4.1	12.2	0.0	100.0
	Macrhybopsis tetranema	753	8.3	1.35	2.6	12.9	0.3	99.7
	Macrhybopsis storeriana	8	9.4	2.67	7.3	12.9	0.0	100.0
	Notemigonus crysoleucas	79	5.8	3.77	0.8	10.6	36.7	63.3
	Notropis amabilis	9,027	6.3	2.61	1.3	13.2	1.4	98.6
	Notropis atherinoides	627	8.4	1.45	6.0	12.8	0.0	100.0
	Notropis bairdi	6,197	8.5	2.04	4.3	12.8	0.0	100.0
	Notropis braytoni	19	8.4	0.44	8.2	9.4	0.0	100.0
	Notropis buchanani	4,712	9.2	2.05	2.8	15.4	0.5	99.5
	Notropis chalybaeus	171	9.1	1.18	7.2	12.3	0.0	100.0
	Notropis girardi	2,134	8.3	1.57	2.1	12.8	0.4	99.6
	Notropis potteri	10	4.5	1.19	4.1	7.8	0.0	100.0
	Notropis sabinae	3	2.8	0.00	2.8	2.8	100.0	0.0
	Notropis shumardi	1,655	9.1	1.84	4.3	15.4	0.0	100.0
	Notropis stramineus	122	8.7	1.50	1.9	11.2	1.6	98.4
	Notropis texanus	30	6.9	2.40	2.3	13.2	10.0	90.0
	Notropis volucellus	6,913	7.9	2.62	2.0	13.3	0.8	99.2
	Opsopoeodus emiliae	212	6.6	3.07	2.3	13.0	21.7	78.3
	Phenacobius mirabilis	52	9.6	2.15	6.4	12.8	0.0	100.0
	Pimephales promelas	433	7.3	0.93	2.8	12.8	0.2	99.8
	Pimephales vigilax	31,360	8.9	2.62	1.0	15.4	0.2	99.8
	Platygobio gracilis	183	8.3	1.31	5.0	12.4	0.0	100.0

Appendix 2.5. Continued.

		Dissolved oxygen (mg/l)					Abundance (%)	
Family	Species	N	Mean	SD (±)	Min	Max	Hypoxic (<3.0 mg/l)	Oxic (>3.0 mg/l)
	Rhinichthys cataractae	2	9.4	0.00	9.4	9.4	0.0	100.0
Catostomidae	*Carpiodes carpio*	578	8.1	1.87	2.6	15.0	0.5	99.5
	Cycleptus elongatus	50	9.4	0.17	8.2	9.4	0.0	100.0
	Ictiobus bubalus	186	8.1	2.21	2.8	13.8	2.2	97.8
	Minytrema melanops	44	6.8	2.42	3.2	13.0	0.0	100.0
	Moxostoma congestum	500	7.5	1.98	2.4	14.7	0.2	99.8
Characidae	*Astyanax mexicanus*	7,633	6.9	1.89	0.2	14.8	1.0	99.0
Ictaluridae	*Ameiurus melas*	47	7.6	1.36	4.7	10.9	0.0	100.0
	Ameiurus natalis	86	6.0	2.25	1.0	10.1	16.3	83.7
	Ictalurus furcatus	952	7.6	1.49	2.8	14.1	0.4	99.6
	Ictalurus lupus	77	7.3	1.49	5.7	13.2	0.0	100.0
	Ictalurus punctatus	3,877	7.2	1.89	1.9	14.7	0.4	99.6
	Noturus gyrinus	198	6.8	2.00	2.0	14.7	3.0	97.0
	Noturus nocturnus	2	9.8	0.49	9.4	10.1	0.0	100.0
	Pylodictis olivaris	586	7.9	1.84	1.5	14.2	0.9	99.1
Loricariidae	*Hypostomus plecostomus*	499	7.7	1.34	4.4	10.6	0.0	100.0
	Pterygoplichthys disjunctivus	35	6.5	0.83	5.2	8.1	0.0	100.0
Esocidae	*Esox americanus*	10	6.8	1.57	2.8	7.8	10.0	90.0
Aphredoderidae	*Aphredoderus sayanus*	38	4.9	1.68	2.8	12.9	5.3	94.7
Mugilidae	*Mugil cephalus*	457	9.0	1.42	3.7	15.0	0.0	100.0
	Agonostomus monticola	15	9.4	1.00	8.3	11.9	0.0	100.0
Atherinopsidae	*Labidesthes sicculus*	845	7.9	2.74	2.8	13.0	0.1	99.9
	Membras martinica	1	7.0		7.0	7.0	0.0	100.0

Appendix 2.5. Continued.

		Dissolved oxygen (mg/l)					Abundance (%)	
Family	Species	N	Mean	SD (±)	Min	Max	Hypoxic (<3.0 mg/l)	Oxic (>3.0 mg/l)
	Menidia audens	783	8.0	2.31	2.8	14.6	0.1	99.9
Fundulidae	*Fundulus chrysotus*	41	7.8	2.23	5.1	9.8	0.0	100.0
	Fundulus grandis	128	13.6	2.59	4.0	14.9	0.0	100.0
	Fundulus kansae	80	8.0	1.28	3.4	10.1	0.0	100.0
	Fundulus notatus	1,629	7.2	3.36	1.0	13.1	1.7	98.3
	Fundulus olivaceus	30	6.0	1.11	4.7	9.5	0.0	100.0
	Fundulus zebrinus	1,689	6.7	2.93	0.7	10.5	14.3	85.7
	Lucania parva	45	7.5	0.65	7.2	9.5	0.0	100.0
Cyprinodontidae	*Cyprinodon rubrofluviatilis*	2,382	7.2	2.35	4.3	10.5	0.0	100.0
	Cyprinodon variegatus	886	6.9	3.92	2.7	11.3	43.8	56.2
Poeciliidae	*Gambusia affinis*	23,646	7.1	2.57	0.1	14.9	6.1	93.9
	Gambusia geiseri	6,768	8.3	1.76	0.1	14.8	0.6	99.4
	Poecilia formosa	1,310	6.5	2.04	1.0	12.1	0.1	99.9
	Poecilia latipinna	2,322	6.7	1.97	2.7	12.3	10.6	89.4
Moronidae	*Morone chrysops*	22	9.7	2.61	5.2	12.5	0.0	100.0
	Morone saxatilis	15	9.0	0.83	6.9	10.5	0.0	100.0
Centrarchidae	*Ambloplites rupestris*	73	8.1	1.27	2.5	12.3	1.4	98.6
	Lepomis auritus	2,336	7.0	2.28	0.1	14.8	6.3	93.8
	Lepomis cyanellus	1,065	7.3	2.15	0.5	12.9	2.7	97.3
	Lepomis gulosus	535	6.8	2.85	0.1	13.8	6.9	93.1
	Lepomis humilis	1,001	6.9	2.26	2.6	13.5	0.1	99.9
	Lepomis macrochirus	3,664	6.8	2.74	0.1	14.7	7.1	92.9
	Lepomis marginatus	6	7.5	2.64	6.4	12.9	0.0	100.0

Appendix 2.5. Continued.

		Dissolved oxygen (mg/l)					Abundance (%)	
Family	Species	N	Mean	SD (±)	Min	Max	Hypoxic (<3.0 mg/l)	Oxic (>3.0 mg/l)
	Lepomis megalotis	8,056	7.2	2.62	1.0	14.8	2.8	97.2
	Lepomis microlophus	315	6.0	1.65	0.9	11.6	4.4	95.6
	Lepomis miniatus	471	7.3	2.38	0.1	14.8	6.8	93.2
	Lepomis symmetricus	6	10.9	1.70	9.8	13.1	0.0	100.0
	Micropterus dolomieu	402	7.7	2.39	3.1	14.7	0.0	100.0
	Micropterus punctulatus	504	7.4	2.09	2.8	14.7	0.2	99.8
	Micropterus salmoides	3,686	6.1	1.83	0.5	14.8	5.6	94.4
	Micropterus treculii	210	6.7	2.72	1.5	13.5	15.2	84.8
	Pomoxis annularis	749	6.4	2.00	2.6	12.9	1.7	98.3
	Pomoxis nigromaculatus	69	6.3	2.81	2.3	13.0	21.7	78.3
Percidae	*Etheostoma chlorosoma*	152	6.4	2.80	2.0	13.0	13.8	86.2
	Etheostoma fonticola	3,669	7.6	1.60	2.5	14.8	0.1	99.9
	Etheostoma gracile	181	7.9	2.65	0.5	13.3	6.6	93.4
	Etheostoma grahami	15	7.3	1.94	3.2	13.2	0.0	100.0
	Etheostoma lepidum	820	7.4	2.10	1.3	13.1	4.0	96.0
	Etheostoma radiosum	512	5.4	2.93	3.3	14.7	0.0	100.0
	Etheostoma spectabile	1,725	9.4	2.47	2.4	14.0	1.0	99.0
	Percina apristis	279	8.4	1.37	4.6	13.8	0.0	100.0
	Percina caprodes	156	6.6	1.77	3.9	12.7	0.0	100.0
	Percina carbonaria	292	7.5	2.49	2.0	13.5	8.9	91.1
	Percina macrolepida	40	7.9	2.22	3.2	11.9	0.0	100.0
	Percina phoxocephala	59	5.2	1.30	3.2	6.6	0.0	100.0
	Percina sciera	383	7.8	2.49	2.0	13.1	6.3	93.7

Appendix 2.5. Continued.

		Dissolved oxygen (mg/l)					Abundance (%)	
Family	Species	N	Mean	SD (±)	Min	Max	Hypoxic (<3.0 mg/l)	Oxic (>3.0 mg/l)
	Percina shumardi	297	9.4	1.55	4.8	13.8	0.0	100.0
	Sander vitreus	26	8.4	2.17	4.5	12.5	0.0	100.0
Sciaenidae	*Aplodinotus grunniens*	60	8.3	2.23	2.8	12.9	3.3	96.7
Elassomatidae	*Elassoma zonatum*	821	6.9	1.68	3.8	12.9	0.0	100.0
Cichlidae	*Herichthys cyanoguttatus*	774	6.7	2.37	0.1	14.8	1.6	98.4
	Oreochromis aureus	318	6.8	1.73	1.3	10.6	0.9	99.1

Appendix 2.6. Summary statistics for conductivity per species and abundance (%) of each species by conductivity categories.

		Conductivity (µS/cm)					Abundance (%)			
Family	Species	N	Mean	SD (±)	Min	Max	Oligohaline (< 8,959 µS/cm)	Mesohaline (8,959 – 29,158 µS/cm)	Polyhaline (29,158 – 46,248 µS/cm)	Euhaline (> 46,248 µS/cm)
Lepisosteidae	*Atractosteus spatula*	7	946	390.1	520	1,519	100.0	0.0	0.0	0.0
	Lepisosteus oculatus	160	822	353.5	100	2,270	100.0	0.0	0.0	0.0
	Lepisosteus osseus	170	1,438	1,782.5	195	11,740	98.2	1.8	0.0	0.0
	Lepisosteus platostomus	4	2,644	747.5	2,270	3,765	100.0	0.0	0.0	0.0
Amiidae	*Amia calva*	4	857	667.5	100	1,519	100.0	0.0	0.0	0.0
Hiodontidae	*Hiodon alosoides*	1	7,877		7,877	7,877	100.0	0.0	0.0	0.0
Anguillidae	*Anguilla rostrata*	4	1,042	132.5	912	1,219	100.0	0.0	0.0	0.0
Clupeidae	*Dorosoma cepedianum*	1,660	2,110	2,136.4	100	26,408	98.3	1.7	0.0	0.0
	Dorosoma petenense	1,402	658	534.2	195	1,784	100.0	0.0	0.0	0.0
Cyprinidae	*Campostoma anomalum*	1,708	725	356.1	115	2,398	100.0	0.0	0.0	0.0
	Cyprinella lepida	48	412	46.9	318	561	100.0	0.0	0.0	0.0
	Cyprinella lutrensis	118,046	1,380	1,836.8	71	31,270	98.2	1.8	0.0	0.0
	Cyprinella proserpina	390	1,119	144.0	740	1,375	100.0	0.0	0.0	0.0
	Cyprinella venusta	20,214	698	412.6	78	4,746	100.0	0.0	0.0	0.0
	Cyprinus carpio	100	2,052	3,019.7	100	26,408	98.0	2.0	0.0	0.0
	Dionda argentosa	764	1,082	112.7	740	1,296	100.0	0.0	0.0	0.0
	Dionda nigrotaeniata	2,759	591	36.7	534	893	100.0	0.0	0.0	0.0
	Dionda serena	2,009	414	21.3	384	464	100.0	0.0	0.0	0.0
	Hybognathus nuchalis	809	568	262.6	195	2,325	100.0	0.0	0.0	0.0
	Hybognathus placitus	5,243	7,441	7,513.7	716	49,968	68.7	30.2	1.1	0.0
	Lythrurus fumeus	2,562	641	421.7	78	1,784	100.0	0.0	0.0	0.0
	Lythrurus umbratilis	71	142	36.8	78	218	100.0	0.0	0.0	0.0
	Macrhybopsis aestivalis	20	3,087	232.9	2,635	3,241	100.0	0.0	0.0	0.0

Appendix 2.6. Continued.

		Conductivity (µS/cm)					Abundance (%)			
Family	Species	N	Mean	SD (±)	Min	Max	Oligohaline (< 8,959 µS/cm)	Mesohaline (8,959 – 29,158 µS/cm)	Polyhaline (29,158 – 46,248 µS/cm)	Euhaline (> 46,248 µS/cm)
	Macrhybopsis australis	384	13,630	6,242.4	2,215	26,408	32.0	68.0	0.0	0.0
	Macrhybopsis hyostoma	1,262	1,686	2,085.7	394	8,308	100.0	0.0	0.0	0.0
	Macrhybopsis marconis	1,200	1,004	247.3	362	1,380	100.0	0.0	0.0	0.0
	Macrhybopsis tetranema	753	3,585	2,689.7	717	13,970	90.4	9.6	0.0	0.0
	Macrhybopsis storeriana	8	1,647	621.3	947	2,215	100.0	0.0	0.0	0.0
	Notemigonus crysoleucas	75	530	591.1	74	1,750	100.0	0.0	0.0	0.0
	Notropis amabilis	9,177	605	139.6	318	1,375	100.0	0.0	0.0	0.0
	Notropis atherinoides	689	4,820	2,718.8	2,215	13,100	97.7	2.3	0.0	0.0
	Notropis atrocaudalis	2,471	115	45.7	64	224	100.0	0.0	0.0	0.0
	Notropis bairdi	6,243	19,590	9,901.5	2,215	38,420	17.2	55.5	27.3	0.0
	Notropis braytoni	19	2,777	245.0	2,635	3,200	100.0	0.0	0.0	0.0
	Notropis buchanani	4,971	1,695	2,184.3	100	8,308	100.0	0.0	0.0	0.0
	Notropis chalybaeus	184	587	11.7	559	602	100.0	0.0	0.0	0.0
	Notropis girardi	2,134	5,012	3,761.6	716	14,410	82.3	17.7	0.0	0.0
	Notropis potteri	10	1,030	23.1	964	1,037	100.0	0.0	0.0	0.0
	Notropis sabinae	764	123	42.3	71	224	100.0	0.0	0.0	0.0
	Notropis shumardi	1,673	862	306.8	360	2,325	100.0	0.0	0.0	0.0
	Notropis stramineus	148	4,428	4,309.2	115	14,100	70.3	29.7	0.0	0.0
	Notropis texanus	265	209	160.8	100	777	100.0	0.0	0.0	0.0
	Notropis volucellus	6,659	792	254.9	248	2,398	100.0	0.0	0.0	0.0
	Opsopoeodus emiliae	220	725	450.2	251	2,325	100.0	0.0	0.0	0.0
	Phenacobius mirabilis	57	3,616	1,908.7	1,124	6,517	100.0	0.0	0.0	0.0
	Pimephales promelas	434	3,899	3,030.3	231	15,502	81.1	18.9	0.0	0.0

Appendix 2.6. Continued.

		Conductivity (µS/cm)					Abundance (%)			
Family	Species	N	Mean	SD (±)	Min	Max	Oligohaline (< 8,959 µS/cm)	Mesohaline (8,959 – 29,158 µS/cm)	Polyhaline (29,158 – 46,248 µS/cm)	Euhaline (> 46,248 µS/cm)
	Pimephales vigilax	29,525	1,009	595.8	78	11,817	100.0	0.0	0.0	0.0
	Platygobio gracilis	183	3,662	2,657.0	716	13,950	95.1	4.9	0.0	0.0
	Rhinichthys cataractae	2	3,200	-	3,200	3,200	100.0	0.0	0.0	0.0
	Semotilus atromaculatus	646	106	26.0	64	194	100.0	0.0	0.0	0.0
Catostomidae	*Carpiodes carpio*	513	1,471	994.0	100	7,877	100.0	0.0	0.0	0.0
	Cycleptus elongatus	50	3,190	80.2	2,635	3,217	100.0	0.0	0.0	0.0
	Erimyzon claviformis	8	113	14.8	94	147	100.0	0.0	0.0	0.0
	Ictiobus bubalus	146	1,247	1,300.8	100	13,100	99.3	0.7	0.0	0.0
	Minytrema melanops	54	496	294.0	100	1,680	100.0	0.0	0.0	0.0
	Moxostoma congestum	482	863	469.7	398	2,752	100.0	0.0	0.0	0.0
	Moxostoma poecilurum	8	171	55.8	115	224	100.0	0.0	0.0	0.0
Characidae	*Astyanax mexicanus*	7,809	1,465	951.7	370	4,917	100.0	0.0	0.0	0.0
Ictaluridae	*Ameiurus melas*	60	1,677	4,059.0	78	22,689	96.7	3.3	0.0	0.0
	Ameiurus natalis	117	458	774.6	88	8,215	100.0	0.0	0.0	0.0
	Ictalurus furcatus	949	1,396	697.6	100	7,802	100.0	0.0	0.0	0.0
	Ictalurus lupus	81	2,284	733.6	442	2,887	100.0	0.0	0.0	0.0
	Ictalurus punctatus	3,764	1,012	790.1	100	14,647	99.8	0.2	0.0	0.0
	Noturus gyrinus	200	745	323.5	231	1,393	100.0	0.0	0.0	0.0
	Noturus nocturnus	26	152	180.1	71	760	100.0	0.0	0.0	0.0
	Pylodictis olivaris	537	1,021	337.0	100	1,735	100.0	0.0	0.0	0.0
Loricariidae	*Hypostomus plecostomus*	572	714	207.7	538	1,295	100.0	0.0	0.0	0.0
	Pterygoplichthys disjunctivus	35	1,073	96.6	799	1,320	100.0	0.0	0.0	0.0
Esocidae	*Esox americanus*	10	283	146.9	100	546	100.0	0.0	0.0	0.0

Appendix 2.6. Continued.

		Conductivity (µS/cm)					Abundance (%)			
Family	Species	N	Mean	SD (±)	Min	Max	Oligohaline (< 8,959 µS/cm)	Mesohaline (8,959 – 29,158 µS/cm)	Polyhaline (29,158 – 46,248 µS/cm)	Euhaline (> 46,248 µS/cm)
Aphredoderidae	*Aphredoderus sayanus*	39	676	348.6	100	1,254	100.0	0.0	0.0	0.0
Mugilidae	*Mugil cephalus*	290	1,288	357.7	360	1,650	100.0	0.0	0.0	0.0
	Agonostomus monticola	15	764	195.2	501	935	100.0	0.0	0.0	0.0
Atherinopsidae	*Labidesthes sicculus*	924	801	411.6	100	1,697	100.0	0.0	0.0	0.0
	Membras martinica	1	492		492	492	100.0	0.0	0.0	0.0
	Menidia audens	719	4,275	3,084.1	245	14,647	96.4	3.6	0.0	0.0
Fundulidae	*Fundulus chrysotus*	57	777	351.7	457	1,305	100.0	0.0	0.0	0.0
	Fundulus grandis	9	2,526	1,496.6	2,027	6,517	100.0	0.0	0.0	0.0
	Fundulus kansae	80	5,546	4,568.2	896	14,700	80.0	20.0	0.0	0.0
	Fundulus notatus	2,361	473	444.8	78	2,398	100.0	0.0	0.0	0.0
	Fundulus olivaceus	30	1,053	756.0	195	1,784	100.0	0.0	0.0	0.0
	Fundulus zebrinus	1,689	12,797	10,312.4	115	49,968	42.5	49.4	6.3	1.8
	Lucania parva	54	925	122.5	798	1,149	100.0	0.0	0.0	0.0
Cyprinodontidae	*Cyprinodon rubrofluviatilis*	2,382	28,206	12,228.2	2,441	49,968	0.5	42.2	47.5	9.8
	Cyprinodon variegatus	890	930	316.4	542	1,305	100.0	0.0	0.0	0.0
Poeciliidae	*Gambusia affinis*	22,576	1,337	2,215.4	77	31,422	97.7	2.3	0.1	0.0
	Gambusia geiseri	8,105	639	153.5	510	1,375	100.0	0.0	0.0	0.0
	Poecilia formosa	1,313	1,156	208.0	398	1,570	100.0	0.0	0.0	0.0
	Poecilia latipinna	2,335	1,001	318.9	455	2,325	100.0	0.0	0.0	0.0
Moronidae	*Morone chrysops*	16	846	233.2	251	1,303	100.0	0.0	0.0	0.0
	Morone saxatilis	15	2,532	3,091.2	774	11,740	93.3	6.7	0.0	0.0
Centrarchidae	*Ambloplites rupestris*	85	585	16.6	539	616	100.0	0.0	0.0	0.0
	Lepomis auritus	2,709	615	346.5	78	5,754	100.0	0.0	0.0	0.0

Appendix 2.6. Continued.

		Conductivity (µS/cm)					Abundance (%)			
Family	Species	N	Mean	SD (±)	Min	Max	Oligohaline (< 8,959 µS/cm)	Mesohaline (8,959 – 29,158 µS/cm)	Polyhaline (29,158 – 46,248 µS/cm)	Euhaline (> 46,248 µS/cm)
	Lepomis cyanellus	1,327	1,229	1,526.4	64	14,647	98.9	1.1	0.0	0.0
	Lepomis gulosus	536	927	878.4	100	3,146	100.0	0.0	0.0	0.0
	Lepomis humilis	1,122	1,179	929.9	145	13,100	99.8	0.2	0.0	0.0
	Lepomis macrochirus	4,197	946	1,273.3	64	18,212	100.0	0.0	0.0	0.0
	Lepomis marginatus	13	257	117.9	102	410	100.0	0.0	0.0	0.0
	Lepomis megalotis	7,551	882	534.6	71	15,502	100.0	0.0	0.0	0.0
	Lepomis microlophus	413	607	375.7	64	5,754	100.0	0.0	0.0	0.0
	Lepomis miniatus	498	574	111.9	86	2,441	100.0	0.0	0.0	0.0
	Lepomis symmetricus	8	881	453.3	457	1,305	100.0	0.0	0.0	0.0
	Micropterus dolomieu	357	844	304.0	442	1,570	100.0	0.0	0.0	0.0
	Micropterus punctulatus	514	704	419.1	77	2,862	100.0	0.0	0.0	0.0
	Micropterus salmoides	3,946	578	576.8	64	14,647	99.8	0.2	0.0	0.0
	Micropterus treculii	216	698	279.1	195	1,881	100.0	0.0	0.0	0.0
	Pomoxis annularis	746	1,077	1,275.4	88	11,740	99.7	0.3	0.0	0.0
	Pomoxis nigromaculatus	61	413	220.7	78	1,305	100.0	0.0	0.0	0.0
Percidae	*Etheostoma artesiae*	219	90	28.8	71	194	100.0	0.0	0.0	0.0
	Etheostoma chlorosoma	148	603	279.4	100	1,410	100.0	0.0	0.0	0.0
	Etheostoma fonticola	4,909	571	17.6	528	893	100.0	0.0	0.0	0.0
	Etheostoma gracile	190	568	385.4	100	1,680	100.0	0.0	0.0	0.0
	Etheostoma grahami	23	1,155	54.8	1,003	1,244	100.0	0.0	0.0	0.0
	Etheostoma lepidum	866	526	81.7	370	993	100.0	0.0	0.0	0.0
	Etheostoma parvipinne	1	108		108	108	100.0	0.0	0.0	0.0
	Etheostoma radiosum	45	580	16.0	547	591	100.0	0.0	0.0	0.0

Appendix 2.6. Continued.

		Conductivity (µS/cm)					Abundance (%)			
Family	Species	N	Mean	SD (±)	Min	Max	Oligohaline (< 8,959 µS/cm)	Mesohaline (8,959 – 29,158 µS/cm)	Polyhaline (29,158 – 46,248 µS/cm)	Euhaline (> 46,248 µS/cm)
	Etheostoma spectabile	1,797	752	427.3	244	2,398	100.0	0.0	0.0	0.0
	Percina apristis	312	571	56.1	400	893	100.0	0.0	0.0	0.0
	Percina caprodes	157	909	224.8	199	1,750	100.0	0.0	0.0	0.0
	Percina carbonaria	315	644	222.0	312	1,627	100.0	0.0	0.0	0.0
	Percina macrolepida	49	1,486	747.8	420	3,146	100.0	0.0	0.0	0.0
	Percina sciera	433	625	381.6	78	2,057	100.0	0.0	0.0	0.0
	Percina shumardi	301	563	149.8	308	1,221	100.0	0.0	0.0	0.0
	Sander vitreus	18	1,084	413.3	510	1,570	100.0	0.0	0.0	0.0
Sciaenidae	*Aplodinotus grunniens*	61	1,944	1,526.8	100	7,802	100.0	0.0	0.0	0.0
Elassomatidae	*Elassoma zonatum*	815	1,077	204.9	386	1,570	100.0	0.0	0.0	0.0
Cichlidae	*Herichthys cyanoguttatus*	844	600	142.3	396	1,296	100.0	0.0	0.0	0.0
	Oreochromis aureus	320	584	83.8	406	1,039	100.0	0.0	0.0	0.0

Appendix 2.7. Summary statistics for pH per species and abundance (%) of each species by pH categories.

		pH					Abundance (%)		
Family	Species	N	Mean	SD (±)	Min	Max	Acidic (<5 pH)	Neutral (5-9 pH)	Alkaline (>9 pH)
Lepisosteidae	*Atractosteus spatula*	8	8.2	0.41	7.63	8.62	0.0	100.0	0.0
	Lepisosteus oculatus	171	8.0	0.33	7	8.64	0.0	100.0	0.0
	Lepisosteus osseus	199	8.2	0.30	7	8.91	0.0	100.0	0.0
	Lepisosteus platostomus	4	8.2	0.28	7.77	8.32	0.0	100.0	0.0
Amiidae	*Amia calva*	3	8.4	0.39	7.98	8.75	0.0	100.0	0.0
Hiodontidae	*Hiodon alosoides*	1	8.0		7.99	7.99	0.0	100.0	0.0
Anguillidae	*Anguilla rostrata*	4	8.1	0.27	7.9	8.51	0.0	100.0	0.0
Clupeidae	*Dorosoma cepedianum*	1,788	8.1	0.57	5.59	9	0.0	100.0	0.0
	Dorosoma petenense	1,413	7.7	0.45	7.2	8.77	0.0	100.0	0.0
Cyprinidae	*Campostoma anomalum*	2,269	8.0	0.39	6.9	9.53	0.0	98.1	1.9
	Cyprinella lepida	48	8.1	0.07	8.03	8.41	0.0	100.0	0.0
	Cyprinella lutrensis	120,888	8.2	0.36	3.19	10.666	0.0	99.1	0.9
	Cyprinella proserpina	388	8.1	0.35	7.23	8.6	0.0	100.0	0.0
	Cyprinella venusta	22,088	8.1	0.57	4.93	10.75	0.6	89.0	10.5
	Cyprinus carpio	122	8.0	0.25	7.06	8.48	0.0	100.0	0.0
	Dionda argentosa	473	7.9	0.34	7.23	8.6	0.0	100.0	0.0
	Dionda nigrotaeniata	2,671	7.4	0.51	5.8	8.69	0.0	100.0	0.0
	Dionda serena	2,009	8.0	0.11	7.5	8.27	0.0	100.0	0.0
	Hybognathus nuchalis	809	7.9	0.18	7.31	8.64	0.0	100.0	0.0
	Hybognathus placitus	5,060	8.2	0.17	7.3	9	0.0	100.0	0.0
	Lythrurus fumeus	2,552	7.8	0.43	6.43	9.64	0.0	98.9	1.1
	Lythrurus umbratilis	71	8.1	0.85	6.43	9.64	0.0	78.9	21.1
	Macrhybopsis aestivalis	20	8.0	0.05	7.9	8	0.0	100.0	0.0

Appendix 2.7. Continued.

		pH					Abundance (%)		
Family	Species	N	Mean	SD (±)	Min	Max	Acidic (<5 pH)	Neutral (5-9 pH)	Alkaline (>9 pH)
	Macrhybopsis australis	384	8.2	0.16	7.3	8.37	0.0	100.0	0.0
	Macrhybopsis hyostoma	1,280	8.3	0.50	5.15	9.16	0.0	91.4	8.6
	Macrhybopsis marconis	1,201	8.0	0.35	7.27	9.35	0.0	98.5	1.5
	Macrhybopsis tetranema	628	8.5	0.26	6.02	9	0.0	100.0	0.0
	Macrhybopsis storeriana	8	8.1	0.15	7.89	8.23	0.0	100.0	0.0
	Notemigonus crysoleucas	71	8.1	0.41	7.17	9.64	0.0	98.6	1.4
	Notropis amabilis	9,092	7.9	0.54	6.2	9.25	0.0	99.8	0.2
	Notropis atherinoides	689	8.1	0.16	7.3	8.49	0.0	100.0	0.0
	Notropis atrocaudalis	2,472	8.4	0.71	6.43	9.64	0.0	88.5	11.5
	Notropis bairdi	6,243	7.8	0.49	6.95	8.37	0.0	100.0	0.0
	Notropis braytoni	19	7.9	0.04	7.9	8	0.0	100.0	0.0
	Notropis buchanani	4,949	8.0	0.44	6.76	9.48	0.0	97.7	2.3
	Notropis chalybaeus	183	7.7	0.28	7.2	8.11	0.0	100.0	0.0
	Notropis girardi	1,563	8.4	0.27	6.02	9	0.0	100.0	0.0
	Notropis potteri	10	8.5	0.08	8.32	8.56	0.0	100.0	0.0
	Notropis sabinae	931	8.7	0.49	6.43	9.64	0.0	78.3	21.7
	Notropis shumardi	1,680	8.4	0.70	5.15	9.16	0.0	76.3	23.8
	Notropis stramineus	141	8.2	0.13	7.77	8.4	0.0	100.0	0.0
	Notropis texanus	262	8.8	0.62	7.37	9.64	0.0	46.9	53.1
	Notropis volucellus	6,941	7.9	0.46	4.93	9.53	0.1	98.7	1.2
	Opsopoeodus emiliae	220	7.8	0.45	7.17	8.77	0.0	100.0	0.0
	Phenacobius mirabilis	57	7.9	0.24	7.3	8.36	0.0	100.0	0.0
	Pimephales promelas	434	8.0	0.19	7.3	8.65	0.0	100.0	0.0

Appendix 2.7. Continued.

		pH					Abundance (%)		
Family	Species	N	Mean	SD (±)	Min	Max	Acidic (<5 pH)	Neutral (5-9 pH)	Alkaline (>9 pH)
	Pimephales vigilax	32,081	8.1	0.42	4.93	10.666	0.0	98.7	1.3
	Platygobio gracilis	135	8.5	0.24	7.1	9	0.0	100.0	0.0
	Rhinichthys cataractae	2	8.0	-	8	8	0.0	100.0	0.0
	Semotilus atromaculatus	646	8.4	0.48	6.43	9.64	0.0	96.3	3.7
Catostomidae	*Carpiodes carpio*	582	8.2	0.29	5.94	9.11	0.0	99.3	0.7
	Cycleptus elongatus	50	8.0	0.01	7.9	8	0.0	100.0	0.0
	Erimyzon claviformis	8	8.5	0.12	8.23	8.62	0.0	100.0	0.0
	Ictiobus bubalus	183	8.2	0.27	7.22	8.77	0.0	100.0	0.0
	Minytrema melanops	54	8.0	0.38	7.39	8.73	0.0	100.0	0.0
	Moxostoma congestum	511	8.1	0.30	6.7	9.48	0.0	99.6	0.4
	Moxostoma poecilurum	8	8.8	0.34	8.57	9.64	0.0	87.5	12.5
Characidae	*Astyanax mexicanus*	7,570	7.7	0.55	6.1	9.2	0.0	99.8	0.2
Ictaluridae	*Ameiurus melas*	46	7.9	0.43	6.43	8.62	0.0	100.0	0.0
	Ameiurus natalis	128	8.1	0.63	6.88	9.64	0.0	89.1	10.9
	Ictalurus furcatus	950	8.1	0.36	5.15	9.2	0.0	99.9	0.1
	Ictalurus lupus	80	7.9	0.25	7.23	8.6	0.0	100.0	0.0
	Ictalurus punctatus	3,890	8.1	0.37	4.93	9.53	0.0	99.6	0.4
	Noturus gyrinus	203	7.8	0.35	7.2	8.6	0.0	100.0	0.0
	Noturus nocturnus	26	8.1	0.89	6.43	9.35	0.0	88.5	11.5
	Pylodictis olivaris	562	8.2	0.41	5.24	9.45	0.0	98.9	1.1
Loricariidae	*Hypostomus plecostomus*	566	7.7	0.37	6.2	9.78	0.0	99.8	0.2
	Pterygoplichthys disjunctivus	35	7.9	0.09	7.7	8.26	0.0	100.0	0.0
Esocidae	*Esox americanus*	9	7.8	0.11	7.56	7.83	0.0	100.0	0.0

Appendix 2.7. Continued.

		pH					Abundance (%)		
Family	Species	N	Mean	SD (±)	Min	Max	Acidic (<5 pH)	Neutral (5-9 pH)	Alkaline (>9 pH)
Aphredoderidae	*Aphredoderus sayanus*	38	7.7	0.34	7.31	9.35	0.0	97.4	2.6
Mugilidae	*Mugil cephalus*	461	8.3	0.26	5.15	9.09	0.0	99.8	0.2
	Agonostomus monticola	15	7.6	0.57	7.1	8.42	0.0	100.0	0.0
Atherinopsidae	*Labidesthes sicculus*	925	8.0	0.35	6.92	8.84	0.0	100.0	0.0
	Membras martinica	1	7.5		7.45	7.45	0.0	100.0	0.0
	Menidia audens	810	8.1	0.41	5.59	9.2	0.0	99.9	0.1
Fundulidae	*Fundulus chrysotus*	57	7.9	0.65	7.17	8.75	0.0	100.0	0.0
	Fundulus grandis	131	8.0	0.64	5.59	8.68	0.0	100.0	0.0
	Fundulus kansae	62	8.4	0.26	7.7	8.8	0.0	100.0	0.0
	Fundulus notatus	2,453	8.2	0.69	6.43	9.64	0.0	85.1	14.9
	Fundulus olivaceus	30	7.9	0.22	7.41	8.12	0.0	100.0	0.0
	Fundulus zebrinus	1,689	8.0	0.30	6.95	8.47	0.0	100.0	0.0
	Lucania parva	33	7.9	0.09	7.86	8.14	0.0	100.0	0.0
Cyprinodontidae	*Cyprinodon rubrofluviatilis*	2,382	8.1	0.15	6.95	8.37	0.0	100.0	0.0
	Cyprinodon variegatus	890	7.8	0.31	7.47	8.75	0.0	100.0	0.0
Poeciliidae	*Gambusia affinis*	24,195	8.1	0.45	5.15	9.78	0.0	98.2	1.8
	Gambusia geiseri	7,135	7.5	0.32	6.2	8.4	0.0	100.0	0.0
	Poecilia formosa	1,268	8.1	0.27	7.3	8.6	0.0	100.0	0.0
	Poecilia latipinna	2,070	8.1	0.35	6.8	9.35	0.0	100.0	0.0
Moronidae	*Morone chrysops*	25	8.3	0.28	7.76	8.77	0.0	100.0	0.0
	Morone saxatilis	15	7.6	0.71	6.76	8.37	0.0	100.0	0.0
Centrarchidae	*Ambloplites rupestris*	81	7.5	0.32	6.7	8.82	0.0	100.0	0.0
	Lepomis auritus	2,320	7.8	0.57	6.1	9.64	0.0	99.1	0.9

Appendix 2.7. Continued.

		pH					Abundance (%)		
Family	Species	N	Mean	SD (±)	Min	Max	Acidic (<5 pH)	Neutral (5-9 pH)	Alkaline (>9 pH)
	Lepomis cyanellus	1,342	8.0	0.45	5.59	9.35	0.0	99.5	0.5
	Lepomis gulosus	558	7.7	0.47	6.2	9.11	0.0	99.8	0.2
	Lepomis humilis	1,124	8.2	0.38	6.2	9.2	0.0	99.8	0.2
	Lepomis macrochirus	4,134	7.9	0.53	6.1	10.666	0.0	99.1	0.9
	Lepomis marginatus	13	8.3	0.77	7.31	9.05	0.0	53.8	46.2
	Lepomis megalotis	8,492	8.1	0.39	3.19	10.666	0.0	99.0	0.9
	Lepomis microlophus	408	8.0	0.54	6.2	9.64	0.0	97.8	2.2
	Lepomis miniatus	483	7.4	0.49	6.1	9.18	0.0	99.8	0.2
	Lepomis symmetricus	12	8.1	0.71	7.17	8.75	0.0	100.0	0.0
	Micropterus dolomieu	414	8.1	0.26	6.8	8.66	0.0	100.0	0.0
	Micropterus punctulatus	566	8.1	0.44	6.43	9.64	0.0	97.0	3.0
	Micropterus salmoides	3,823	7.8	0.49	5.59	9.64	0.0	99.5	0.5
	Micropterus treculii	243	8.2	0.56	6.9	9.53	0.0	89.3	10.7
	Pomoxis annularis	750	7.9	0.40	6.76	9.16	0.0	99.6	0.4
	Pomoxis nigromaculatus	69	7.6	0.39	6.43	9.3	0.0	98.6	1.4
Percidae	*Etheostoma artesiae*	219	7.6	0.92	6.43	8.77	0.0	100.0	0.0
	Etheostoma chlorosoma	146	7.8	0.35	7.17	8.77	0.0	100.0	0.0
	Etheostoma fonticola	4,554	7.2	0.52	5.8	8.61	0.0	100.0	0.0
	Etheostoma gracile	188	7.9	0.52	6.98	9.64	0.0	95.2	4.8
	Etheostoma grahami	23	8.0	0.21	7.59	8.6	0.0	100.0	0.0
	Etheostoma lepidum	823	7.5	0.70	5.8	9.2	0.0	99.4	0.6
	Etheostoma parvipinne	1	8.0		8	8	0.0	100.0	0.0
	Etheostoma radiosum	481	7.9	0.18	7.56	8.68	0.0	100.0	0.0

Appendix 2.7. Continued.

		pH					Abundance (%)		
Family	Species	N	Mean	SD (±)	Min	Max	Acidic (<5 pH)	Neutral (5-9 pH)	Alkaline (>9 pH)
	Etheostoma spectabile	1,797	7.9	0.49	6.9	9.53	0.0	94.9	5.1
	Percina apristis	302	7.8	0.38	6.7	8.98	0.0	100.0	0.0
	Percina caprodes	157	8.0	0.22	7.4	8.63	0.0	100.0	0.0
	Percina carbonaria	315	8.2	0.46	7.08	9.45	0.0	93.7	6.3
	Percina macrolepida	49	8.1	0.28	7.71	8.53	0.0	100.0	0.0
	Percina phoxocephala	35	7.9	0.14	7.61	8.07	0.0	100.0	0.0
	Percina sciera	433	8.0	0.47	6.43	9.64	0.0	98.2	1.8
	Percina shumardi	301	8.2	0.29	7.1	9.35	0.0	97.0	3.0
	Sander vitreus	23	8.3	0.17	8.01	8.65	0.0	100.0	0.0
Sciaenidae	*Aplodinotus grunniens*	59	8.1	0.40	6.76	8.49	0.0	100.0	0.0
Elassomatidae	*Elassoma zonatum*	821	8.1	0.26	7.3	9.78	0.0	99.5	0.5
Cichlidae	*Herichthys cyanoguttatus*	542	7.3	0.56	6.1	9.01	0.0	99.8	0.2
	Oreochromis aureus	100	7.5	0.61	6.1	8.53	0.0	100.0	0.0

Appendix 2.8. Summary statistics for substrate per species and abundance (%) of each species by substrate categories.

			Abundance (%)									
Family	Species	N	Clay	Silt	Sand	Gravel	Cobble	Boulder	Bedrock	Taylor Marl	Cement	Detritus
Petromyzontidae	*Ichthyomyzon gagei*	169	0.0	0.0	93.4	1.2	4.6	0.0	0.8	0.0	0.0	0.0
Lepisosteidae	*Atractosteus spatula*	16	10.9	23.4	55.6	8.8	0.0	1.3	0.0	0.0	0.0	0.0
	Lepisosteus oculatus	150	13.6	29.9	36.7	9.4	4.1	3.2	3.0	0.0	0.0	0.0
	Lepisosteus osseus	162	2.1	46.5	32.5	8.0	4.5	3.8	2.6	0.0	0.0	0.0
	Lepisosteus platostomus	4	0.0	56.3	42.5	0.0	0.0	1.3	0.0	0.0	0.0	0.0
Amiidae	*Amia calva*	3	30.0	40.0	30.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hiodontidae	*Hiodon alosoides*	1	0.0	0.0	95.0	0.0	0.0	5.0	0.0	0.0	0.0	0.0
Anguillidae	*Anguilla rostrata*	2	0.0	0.0	43.8	5.0	0.0	22.5	22.5	0.0	0.0	6.3
Clupeidae	*Dorosoma cepedianum*	2,245	5.6	57.8	22.6	10.5	1.4	0.7	0.2	0.0	0.0	1.3
	Dorosoma petenense	1,885	3.7	19.1	48.7	15.2	3.3	1.4	8.7	0.0	0.0	0.0
Cyprinidae	*Campostoma anomalum*	3,023	0.1	10.4	2.2	27.1	30.0	2.5	23.5	0.0	0.0	4.3
	Cyprinella lepida	581	0.0	0.0	0.4	1.2	0.9	0.2	96.9	0.0	0.0	0.4
	Cyprinella lutrensis	153,203	8.0	32.0	37.6	14.6	3.9	1.7	1.9	0.0	0.0	0.2
	Cyprinella proserpina	3,480	0.0	7.8	0.4	34.4	27.1	1.8	28.5	0.0	0.0	0.0
	Cyprinella venusta	17,599	4.5	14.6	19.4	22.4	10.6	4.1	22.3	0.1	0.0	2.1
	Cyprinus carpio	427	2.6	17.9	5.4	4.6	60.0	7.3	2.1	0.0	0.0	0.1
	Dionda argentosa	9,001	0.0	17.1	0.5	35.8	28.1	0.6	17.8	0.0	0.0	0.1
	Dionda diaboli	989	0.0	49.0	0.0	7.5	33.2	0.1	10.2	0.0	0.0	0.0
	Dionda episcopa	1,603	0.0	0.0	0.0	0.0	0.0	0.0	99.7	0.0	0.0	0.3
	Dionda nigrotaeniata	1,975	0.1	51.4	1.4	28.7	6.2	2.8	4.5	0.0	0.0	4.9
	Dionda serena	2,279	0.0	25.4	0.0	21.8	18.3	9.9	24.6	0.0	0.0	0.0
	Hybognathus nuchalis	974	2.9	40.2	49.8	4.9	1.5	0.3	0.3	0.0	0.0	0.0
	Hybognathus placitus	5,247	0.0	48.5	47.1	3.2	0.2	0.1	0.0	0.0	0.0	1.0

Appendix 2.8. Continued.

			Abundance (%)									
Family	Species	N	Clay	Silt	Sand	Gravel	Cobble	Boulder	Bedrock	Taylor Marl	Cement	Detritus
	Hybopsis amnis	1	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0
	Luxilus chrysocephalus	722	0.0	0.6	98.4	0.3	0.2	0.0	0.6	0.0	0.0	0.0
	Lythrurus fumeus	3,353	10.5	17.0	48.1	11.6	4.0	1.3	7.5	0.0	0.0	0.0
	Lythrurus umbratilis	352	0.0	7.2	70.1	3.4	7.0	0.0	12.2	0.0	0.0	0.0
	Macrhybopsis aestivalis	176	0.0	14.2	6.9	28.6	46.0	2.5	1.8	0.0	0.0	0.0
	Macrhybopsis australis	483	0.0	56.6	30.7	12.4	0.2	0.0	0.0	0.0	0.0	0.0
	Macrhybopsis hyostoma	1,026	0.3	41.3	37.6	20.3	0.3	0.1	0.2	0.0	0.0	0.0
	Macrhybopsis marconis	285	40.7	0.3	4.7	35.9	14.4	0.8	3.2	0.0	0.0	0.0
	Macrhybopsis tetranema	724		11.1	84.8	3.8	1.1	0.3	0.0	0.0	0.0	0.0
	Macrhybopsis storeriana	5	6.0	64.0	20.0	2.0	2.0	0.0	6.0	0.0	0.0	0.0
	Notemigonus crysoleucas	170	3.3	48.4	5.8	7.9	11.6	0.6	7.8	0.0	0.0	14.7
	Notropis amabilis	22,220	0.0	23.5	2.8	25.7	19.8	4.5	22.4	0.0	0.0	1.3
	Notropis atherinoides	2,118	0.0	62.3	36.7	0.4	0.0	0.5	0.0	0.0	0.0	0.0
	Notropis atrocaudalis	2,989	0.0	10.8	14.6	24.0	7.8	0.0	40.0	0.0	0.0	2.8
	Notropis bairdi	6,383	0.2	31.2	51.2	14.3	0.1	0.3	0.0	0.0	0.0	2.7
	Notropis braytoni	3,697	0.0	41.1	4.5	21.7	29.6	1.8	1.2	0.0	0.0	0.0
	Notropis buchanani	5,713	4.8	36.5	36.0	21.4	0.4	0.5	0.0	0.0	0.0	0.3
	Notropis chalybaeus	122	0.3	67.0	8.0	20.6	3.2	0.5	0.0	0.4	0.0	0.0
	Notropis chihuahua	13	0.0	80.0	1.5	6.2	12.3	0.0	0.0	0.0	0.0	0.0
	Notropis girardi	2,158		29.2	69.1	1.1	0.1	0.7	0.0	0.0	0.0	0.0
	Notropis jemezanus	5	0.0	10.0	8.0	66.0	16.0	0.0	0.0	0.0	0.0	0.0
	Notropis sabinae	1,339	0.0	13.5	36.0	13.8	6.4	0.0	28.7	0.0	0.0	1.7
	Notropis shumardi	1,961	5.0	41.1	41.2	12.3	0.1	0.2	0.1	0.0	0.0	0.0

Appendix 2.8. Continued.

			Abundance (%)									
Family	Species	N	Clay	Silt	Sand	Gravel	Cobble	Boulder	Bedrock	Taylor Marl	Cement	Detritus
	Notropis stramineus	1,772	0.0	12.7	6.5	23.7	12.7	4.3	36.4	0.0	0.0	3.9
	Notropis texanus	738	0.0	37.4	18.4	32.3	1.9	0.0	9.4	0.0	0.0	0.5
	Notropis volucellus	6,536	7.0	17.0	9.2	25.4	18.9	6.8	13.5	0.0	0.5	1.7
	Opsopoeodus emiliae	246	17.0	28.9	19.7	14.5	11.5	1.4	6.9	0.0	0.0	0.0
	Phenacobius mirabilis	57	0.0	12.0	17.1	46.3	4.0	20.6	0.0	0.0	0.0	0.0
	Pimephales promelas	687	0.1	78.8	5.9	1.6	10.9	2.5	0.2	0.0	0.0	0.0
	Pimephales vigilax	39,223	10.3	36.8	27.0	21.1	1.3	0.5	2.3	0.0	0.0	0.7
	Platygobio gracilis	183		12.6	82.5	1.0	0.5	3.2	0.0	0.0	0.0	0.0
	Rhinichthys cataractae	38	0.0	2.6	0.3	41.1	55.8	0.3	0.0	0.0	0.0	0.0
	Semotilus atromaculatus	1,054	0.0	2.8	9.5	13.4	3.2	0.0	70.0	0.0	0.0	1.2
Catostomidae	*Carpiodes carpio*	1,400	0.0	86.0	1.6	8.1	4.1	0.1	0.1	0.0	0.0	0.1
	Cycleptus elongatus	22	0.0	40.9	5.5	18.6	31.4	3.6	0.0	0.0	0.0	0.0
	Erimyzon claviformis	29	0.0	1.9	72.5	6.0	2.5	0.0	17.1	0.0	0.0	0.0
	Ictiobus bubalus	188	2.6	19.9	67.2	7.7	0.1	0.4	2.1	0.0	0.0	0.0
	Minytrema melanops	82	16.0	12.0	27.4	6.5	32.7	0.5	4.9	0.0	0.0	0.0
	Moxostoma congestum	458	3.1	8.8	6.6	44.4	14.7	2.6	15.0	0.0	0.0	4.8
	Moxostoma poecilurum	14	0.0	10.0	11.4	22.5	3.2	0.0	52.9	0.0	0.0	0.0
Characidae	*Astyanax mexicanus*	9,834	0.1	55.0	2.4	10.9	10.8	1.1	18.8	0.0	0.0	1.0
Ictaluridae	*Ameiurus melas*	61	5.7	40.1	18.5	7.8	6.0	12.1	9.2	0.0	0.0	0.7
	Ameiurus natalis	312	0.3	10.0	38.8	16.9	11.9	1.5	13.9	0.0	0.0	6.8
	Ictalurus furcatus	1,000	11.7	23.8	48.4	10.7	4.1	0.9	0.4	0.0	0.0	0.0
	Ictalurus lupus	186	0.0	28.5	4.1	29.3	29.1	5.0	4.0	0.0	0.0	0.0
	Ictalurus punctatus	2,282	5.6	24.5	20.9	21.7	14.7	2.7	9.6	0.0	0.0	0.3

Appendix 2.8. Continued.

			Abundance (%)									
Family	Species	N	Clay	Silt	Sand	Gravel	Cobble	Boulder	Bedrock	Taylor Marl	Cement	Detritus
	Noturus gyrinus	128	17.8	9.6	20.5	26.2	15.5	6.8	1.3	0.0	0.0	2.2
	Noturus nocturnus	81	0.0	1.0	65.0	10.4	12.7	2.5	8.4	0.0	0.0	0.1
	Noturus phaeus	410	0.0	1.0	81.1	3.8	10.6	0.0	3.4	0.0	0.0	0.0
	Pylodictis olivaris	361	1.4	26.2	35.0	11.3	17.7	5.3	3.2	0.0	0.0	0.0
Loricariidae	*Hypostomus plecostomus*	278	2.7	33.1	14.8	28.7	12.3	2.0	1.0	5.0	0.0	0.3
	Pterygoplichthys disjunctivus	2	85.0	10.0	0.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0
Esocidae	*Esox americanus*	12	2.5	40.0	18.3	0.8	19.8	17.5	0.0	0.0	0.0	1.0
Aphredoderidae	*Aphredoderus sayanus*	70	10.6	24.4	27.7	9.0	18.4	9.3	0.5	0.0	0.0	0.2
Mugilidae	*Mugil cephalus*	232	35.0	28.8	28.8	4.3	0.1	0.7	2.1	0.0	0.0	0.1
	Agonostomus monticola	11	0.0	0.0	0.0	38.2	18.2	0.0	43.6	0.0	0.0	0.0
Atherinopsidae	*Labidesthes sicculus*	1,162	22.0	24.7	21.2	8.5	3.5	2.1	17.8	0.0	0.0	0.0
	Membras martinica	1	0.0	0.0	20.0	60.0	20.0	0.0	0.0	0.0	0.0	0.0
	Menidia audens	1,297	1.1	66.0	19.3	8.4	1.8	3.2	0.2	0.0	0.0	0.0
Fundulidae	*Fundulus chrysotus*	46	44.6	43.5	9.3	2.6	0.0	0.0	0.0	0.0	0.0	0.0
	Fundulus grandis	9	0.0	67.8	22.2	10.0	0.0	0.0	0.0	0.0	0.0	0.0
	Fundulus kansae	55	0.0	33.3	65.2	1.5	0.0	0.0	0.0	0.0	0.0	0.0
	Fundulus notatus	2,742	20.0	23.0	26.9	10.6	3.8	1.4	13.5	0.0	0.0	0.8
	Fundulus olivaceus	924	0.0	1.1	93.1	1.3	1.9	0.0	2.0	0.0	0.0	0.6
	Fundulus zebrinus	1,844	0.1	47.8	20.8	9.6	3.0	0.1	5.6	0.0	0.0	13.0
	Lucania parva	129	0.0	31.7	0.0	49.6	12.8	6.0	0.0	0.0	0.0	0.0
Cyprinodontidae	*Cyprinodon eximius*	84	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0
	Cyprinodon rubrofluviatilis	2,760	0.0	63.5	25.8	2.2	0.1	0.0	0.0	0.0	0.0	8.3
	Cyprinodon variegatus	910	0.2	50.0	48.7	1.0	0.0	0.0	0.0	0.0	0.0	0.0

Appendix 2.8. Continued.

			Abundance (%)									
Family	Species	N	Clay	Silt	Sand	Gravel	Cobble	Boulder	Bedrock	Taylor Marl	Cement	Detritus
Poeciliidae	*Gambusia affinis*	28,164	9.2	40.4	19.3	15.4	5.6	1.1	6.9	0.0	0.0	2.1
	Gambusia geiseri	10,127	0.7	57.8	10.5	18.3	8.5	0.6	3.1	0.3	0.0	0.3
	Poecilia formosa	182	18.1	22.1	3.4	52.9	2.5	0.4	0.0	0.0	0.0	0.5
	Poecilia latipinna	1,479	1.9	44.8	34.3	17.0	1.0	0.2	0.0	0.0	0.0	0.7
Moronidae	*Morone chrysops*	19	4.2	2.1	91.6	2.1	0.0	0.0	0.0	0.0	0.0	0.0
	Morone saxatilis	15	0.0	53.3	37.7	0.3	0.7	0.0	8.0	0.0	0.0	0.0
Centrarchidae	*Ambloplites rupestris*	89	0.3	63.0	15.8	15.0	3.5	0.8	0.7	0.2	0.0	0.7
	Lepomis auritus	3,577	0.1	37.3	5.4	21.8	10.0	2.3	18.4	0.1	0.0	4.5
	Lepomis cyanellus	1,677	4.6	27.7	17.2	18.0	11.9	2.9	14.0	0.0	0.0	3.7
	Lepomis gulosus	520	21.1	44.7	19.9	8.0	1.7	2.4	1.4	0.0	0.0	0.9
	Lepomis humilis	1,303	30.0	40.2	6.2	13.7	4.9	4.8	0.3	0.0	0.0	0.0
	Lepomis macrochirus	5,219	9.2	31.9	12.7	17.7	9.2	2.8	13.9	0.0	0.0	2.5
	Lepomis marginatus	56	7.5	5.1	78.0	0.4	0.8	0.0	2.9	0.0	0.0	5.4
	Lepomis megalotis	8,112	10.0	19.3	16.6	19.8	9.4	2.9	19.9	0.0	0.0	2.1
	Lepomis microlophus	63	2.1	32.3	7.1	9.2	7.7	1.8	38.9	0.2	0.0	0.6
	Lepomis miniatus	557	0.8	56.5	8.5	14.3	11.1	1.5	3.3	0.6	0.0	3.4
	Lepomis symmetricus	8	50.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Micropterus dolomieu	56	0.0	7.4	1.0	13.4	18.6	6.2	45.4	0.0	0.0	8.2
	Micropterus punctulatus	697	13.6	12.0	27.7	32.6	5.1	1.7	6.5	0.0	0.0	0.7
	Micropterus salmoides	4,206	1.3	21.3	5.4	21.2	21.0	1.2	26.5	0.1	0.0	2.0
	Micropterus treculii	245	0.0	10.5	14.8	25.0	21.9	5.1	21.3	0.0	0.0	1.4
	Pomoxis annularis	1,043	17.8	61.9	9.1	7.6	0.6	2.5	0.3	0.0	0.0	0.2
	Pomoxis nigromaculatus	58	34.2	34.2	18.1	2.6	3.4	5.3	1.6	0.0	0.0	0.5

Appendix 2.8. Continued.

			Abundance (%)									
Family	Species	N	Clay	Silt	Sand	Gravel	Cobble	Boulder	Bedrock	Taylor Marl	Cement	Detritus
Percidae	*Ammocrypta vivax*	2	0.0	0.0	0.0	0.0	0.0	50.0	50.0	0.0	0.0	0.0
	Etheostoma artesiae	420	0.0	1.3	23.5	27.1	39.5	0.0	8.1	0.0	0.0	0.4
	Etheostoma chlorosoma	206	30.0	24.8	27.5	11.6	1.7	3.6	0.7	0.0	0.0	0.0
	Etheostoma fonticola	5,461	0.2	56.4	7.2	18.8	9.1	2.7	1.8	0.1	0.0	3.7
	Etheostoma gracile	214	10.1	21.6	25.4	28.7	6.1	6.5	0.7	0.0	0.0	0.7
	Etheostoma grahami	451	0.0	17.9	1.2	25.7	43.3	0.7	11.2	0.0	0.0	0.0
	Etheostoma histrio	9	0.0	0.0	0.0	0.0	44.4	44.4	11.1	0.0	0.0	0.0
	Etheostoma lepidum	1,006	0.0	22.8	3.0	36.9	18.9	6.9	10.4	0.0	0.0	1.2
	Etheostoma parvipinne	4	0.0	0.0	71.3	7.5	1.3	0.0	20.0	0.0	0.0	0.0
	Etheostoma spectabile	2,529	0.1	2.0	6.9	45.3	30.5	2.4	12.3	0.0	0.0	0.5
	Percina apristis	331	0.3	10.8	20.5	42.3	23.1	1.1	0.5	1.2	0.0	0.2
	Percina caprodes	18	0.0	1.7	3.6	5.8	47.9	38.9	0.0	0.0	0.0	2.1
	Percina carbonaria	348	2.9	5.7	10.4	30.7	35.4	6.7	7.3	0.6	0.0	0.2
	Percina macrolepida	57	5.2	14.3	28.4	32.1	10.4	3.1	6.5	0.0	0.0	0.0
	Percina maculata	2	0.0	0.0	0.0	0.0	50.0	50.0	0.0	0.0	0.0	0.0
	Percina sciera	355	1.8	10.5	30.2	21.0	20.2	7.7	7.7	0.0	0.0	0.9
	Percina shumardi	326	3.3	1.0	8.5	47.1	39.4	0.6	0.0	0.0	0.0	0.1
Sciaenidae	*Aplodinotus grunniens*	129	4.8	39.0	45.2	6.8	1.5	1.1	1.7	0.0	0.0	0.0
Elassomatidae	*Elassoma zonatum*	15	0.0	0.0	96.7	3.3	0.0	0.0	0.0	0.0	0.0	0.0
Cichlidae	*Herichthys cyanoguttatus*	1,653	1.9	36.1	1.8	20.4	19.4	1.2	15.6	0.0	0.4	3.2
	Oreochromis aureus	307	0.0	66.0	0.5	6.3	11.8	3.1	10.3	0.0	1.9	0.2

Appendix 2.9. Summary statistics for substrate per species and abundance (%) of each species by substrate categories.

			Abundance (%)			
Family	Species	N	Run	Riffle	Pool	Backwater
Lepisosteidae	*Atractosteus spatula*	18	83.3	0.0	0.0	16.7
	Lepisosteus oculatus	287	38.3	1.0	43.2	17.4
	Lepisosteus osseus	379	48.5	3.2	30.9	17.4
	Lepisosteus platostomus	2	50.0	0.0	0.0	50.0
Amiidae	*Amia calva*	4	0.0	0.0	75.0	25.0
Hiodontidae	*Hiodon alosoides*	1	100.0	0.0	0.0	0.0
Anguillidae	*Anguilla rostrata*	6	33.3	16.7	50.0	0.0
Clupeidae	*Dorosoma cepedianum*	4,298	34.6	6.2	22.1	37.7
	Dorosoma petenense	1,454	55.3	5.2	16.2	23.2
Cyprinidae	*Campostoma anomalum*	4,894	22.3	39.6	14.2	24.0
	Cyprinella lepida	613	39.5	38.7	14.7	7.2
	Cyprinella lutrensis	237,868	53.1	19.7	11.4	15.9
	Cyprinella proserpina	3,692	55.3	25.0	10.5	9.1
	Cyprinella venusta	17,313	50.4	19.3	17.7	12.6
	Cyprinus carpio	527	68.9	1.1	21.3	8.7
	Dionda argentosa	9,269	63.0	13.3	10.1	13.6
	Dionda diaboli	984	54.9	0.3	27.7	17.1
	Dionda episcopa	1,602	47.8	26.3	25.2	0.6
	Dionda nigrotaeniata	3,133	8.8	1.2	85.2	4.8
	Dionda serena	2,169	76.6	1.9	11.5	10.0
	Hybognathus hayi	2	100.0	0.0	0.0	0.0
	Hybognathus nuchalis	275	21.5	1.8	56.7	20.0
	Hybognathus placitus	5,289	80.5	4.2	9.8	7.4

Appendix 2.9. Continued.

			Abundance (%)			
Family	Species	N	Run	Riffle	Pool	Backwater
	Hybopsis amnis	3	100.0	0.0	0.0	0.0
	Luxilus chrysocephalus	6	66.7	16.7	16.7	0.0
	Lythrurus fumeus	1,374	45.6	0.7	40.6	13.1
	Lythrurus umbratilis	75	88.0	2.7	5.3	4.0
	Macrhybopsis aestivalis	185	77.9	14.7	6.2	1.1
	Macrhybopsis australis	483	83.4	5.2	7.0	4.3
	Macrhybopsis hyostoma	1,899	62.3	30.8	2.0	4.9
	Macrhybopsis marconis	1,528	21.7	70.5	1.2	6.6
	Macrhybopsis tetranema	762	68.7	7.4	8.4	9.2
	Macrhybopsis storeriana	9	77.8	0.0	0.0	22.2
	Notemigonus crysoleucas	201	24.9	1.0	10.9	63.2
	Notropis amabilis	25,328	60.3	8.0	25.5	6.2
	Notropis atherinoides	2,125	70.3	0.4	0.0	29.2
	Notropis atrocaudalis	2,801	71.7	23.3	1.7	3.3
	Notropis bairdi	6,384	73.6	6.2	7.7	12.5
	Notropis braytoni	3,716	62.2	11.4	19.8	6.6
	Notropis buchanani	7,606	48.7	9.6	14.3	27.4
	Notropis chalybaeus	146	89.7	6.2	4.1	0.0
	Notropis chihuahua	13	23.1	0.0	0.0	76.9
	Notropis girardi	2,314	69.0	7.4	8.5	9.3
	Notropis jemezanus	5	100.0	0.0	0.0	0.0
	Notropis oxyrhynchus	1	100.0	0.0	0.0	0.0
	Notropis potteri	29	89.7	3.4	0.0	6.9

Appendix 2.9. Continued.

			Abundance (%)			
Family	Species	N	Run	Riffle	Pool	Backwater
	Notropis sabinae	1,275	82.2	17.0	0.0	0.8
	Notropis shumardi	2,489	58.1	0.7	10.2	30.9
	Notropis stramineus	3,480	52.2	4.8	17.0	26.8
	Notropis texanus	1,166	31.9	1.8	31.3	35.0
	Notropis volucellus	12,864	56.5	14.7	16.1	12.7
	Opsopoeodus emiliae	245	33.5	0.4	53.9	12.2
	Phenacobius mirabilis	122	58.2	41.8	0.0	0.0
	Pimephales promelas	702	80.3	2.6	9.7	7.5
	Pimephales vigilax	77,475	39.3	8.2	23.0	29.6
	Platygobio gracilis	186	100.0	0.0	0.0	0.0
	Rhinichthys cataractae	40	45.0	50.0	5.0	0.0
	Semotilus atromaculatus	961	96.4	3.1	0.5	0.0
Catostomidae	*Carpiodes carpio*	2,764	34.1	2.9	8.6	54.3
	Cycleptus elongatus	94	35.1	8.5	54.3	2.1
	Erimyzon claviformis	8	87.5	12.5	0.0	0.0
	Erimyzon sucetta	3	100.0	0.0	0.0	0.0
	Ictiobus bubalus	402	50.2	3.0	21.4	25.4
	Minytrema melanops	101	48.5	0.0	22.8	28.7
	Moxostoma congestum	1,618	44.6	11.2	15.9	28.2
	Moxostoma poecilurum	67	73.1	3.0	1.5	22.4
Characidae	*Astyanax mexicanus*	10,133	47.7	8.9	41.7	1.7
Ictaluridae	*Ameiurus melas*	52	54.7	28.8	17.3	0.0
	Ameiurus natalis	358	35.5	20.4	41.1	3.1

Appendix 2.9. Continued.

			Abundance (%)			
Family	Species	N	Run	Riffle	Pool	Backwater
	Ictalurus furcatus	1,352	84.2	0.8	8.7	6.3
	Ictalurus lupus	233	51.9	30.9	14.6	2.6
	Ictalurus punctatus	6,147	39.4	48.1	8.9	3.8
	Noturus gyrinus	170	14.1	65.9	14.7	5.3
	Noturus nocturnus	172	41.3	56.4	0.6	1.7
	Pylodictis olivaris	1,003	54.2	33.4	6.6	5.8
Loricariidae	*Hypostomus plecostomus*	547	66.7	27.2	1.5	4.6
	Pterygoplichthys disjunctivus	33	33.3	57.6	9.1	0.0
Esocidae	*Esox americanus*	28	32.1	3.6	64.3	0.0
Aphredoderidae	*Aphredoderus sayanus*	149	45.6	2.7	37.6	14.1
Mugilidae	*Mugil cephalus*	424	50.5	0.2	27.6	21.7
	Agonostomus monticola	8	37.5	62.5	0.0	0.0
Atherinopsidae	*Labidesthes sicculus*	307	18.2	0.0	56.0	25.7
	Menidia audens	1,846	58.7	2.5	13.1	25.7
Fundulidae	*Fundulus chrysotus*	20	25.0	0.0	50.0	25.0
	Fundulus grandis	131	6.1	55.7	0.0	38.2
	Fundulus kansae	80	69.2	7.3	8.5	9.3
	Fundulus notatus	2,085	47.5	1.5	41.9	9.1
	Fundulus olivaceus	76	23.7	0.0	36.8	39.5
	Fundulus zebrinus	1,851	35.7	15.7	33.1	15.6
	Lucania parva	136	47.8	15.4	27.2	9.6
Cyprinodontidae	*Cyprinodon eximius*	134	3.7	0.0	84.3	11.9
	Cyprinodon rubrofluviatilis	2,760	56.9	2.1	10.1	30.9

Appendix 2.9. Continued.

			Abundance (%)			
Family	Species	N	Run	Riffle	Pool	Backwater
	Cyprinodon variegatus	34	2.9	0.0	41.2	55.9
Poeciliidae	*Gambusia affinis*	38,430	31.0	6.3	27.9	34.9
	Gambusia geiseri	7,526	78.4	3.2	9.2	9.3
	Poecilia formosa	2,170	21.2	24.3	9.4	45.2
	Poecilia latipinna	1,805	29.0	9.4	8.3	53.4
Moronidae	*Morone chrysops*	39	46.2	2.6	35.9	15.4
	Morone saxatilis	15	53.3	0.0	26.7	20.0
Centrarchidae	*Ambloplites rupestris*	43	90.7	2.3	4.7	2.3
	Centrarchus macropterus	3	100.0	0.0	0.0	0.0
	Lepomis auritus	5,540	50.2	4.2	30.1	15.5
	Lepomis cyanellus	1,946	38.8	7.0	42.2	12.1
	Lepomis gulosus	472	33.1	0.8	47.2	18.9
	Lepomis humilis	1,214	49.2	0.9	37.1	12.9
	Lepomis macrochirus	6,134	42.5	2.3	39.0	16.3
	Lepomis marginatus	13	7.7	0.0	46.2	46.2
	Lepomis megalotis	12,733	38.9	7.5	35.3	18.3
	Lepomis microlophus	80	37.6	0.3	54.7	7.4
	Lepomis miniatus	331	27.4	1.7	32.3	38.6
	Lepomis symmetricus	4	0.0	50.0	50.0	0.0
	Micropterus dolomieu	524	40.5	12.2	34.2	13.2
	Micropterus punctulatus	1,115	56.1	6.4	16.3	21.2
	Micropterus salmoides	4,800	19.7	2.0	68.8	9.6
	Micropterus treculii	514	35.1	16.1	34.9	14.0

Appendix 2.9. Continued.

			Abundance (%)			
Family	Species	N	Run	Riffle	Pool	Backwater
	Pomoxis annularis	946	29.0	0.0	57.3	13.7
	Pomoxis nigromaculatus	51	29.4	0.0	52.9	17.6
Percidae	*Ammocrypta vivax*	26	96.2	0.0	3.8	0.0
	Etheostoma artesiae	238	55.9	44.1	0.0	0.0
	Etheostoma asprigene	13	61.5	30.8	7.7	0.0
	Etheostoma chlorosoma	153	14.4	2.6	56.2	26.8
	Etheostoma fonticola	1,113	43.1	0.2	54.7	2.0
	Etheostoma gracile	244	27.9	32.0	29.9	10.2
	Etheostoma grahami	518	39.6	27.4	23.9	9.1
	Etheostoma histrio	17	70.6	17.6	5.9	5.9
	Etheostoma lepidum	729	26.9	45.1	25.5	2.5
	Etheostoma parvipinne	4	75.0	25.0	0.0	0.0
	Etheostoma proeliare	20	70.0	5.0	15.0	10.0
	Etheostoma radiosum	658	4.1	88.0	7.0	0.9
	Etheostoma spectabile	3,382	16.0	77.9	4.5	1.7
	Percina apristis	243	33.3	65.4	0.8	0.4
	Percina caprodes	277	31.0	36.5	9.4	23.1
	Percina carbonaria	790	24.2	73.0	2.2	0.6
	Percina macrolepida	57	31.6	36.8	19.3	12.3
	Percina maculata	2	100.0	0.0	0.0	0.0
	Percina phoxocephala	187	29.9	52.4	11.8	5.9
	Percina sciera	466	35.6	48.5	6.4	9.4
	Percina shumardi	330	3.3	96.7	0.0	0.0

Appendix 2.9. Continued.

			Abundance (%)			
Family	Species	N	Run	Riffle	Pool	Backwater
	Sander vitreus	27	51.9	0.0	37.0	11.1
Sciaenidae	*Aplodinotus grunniens*	156	62.6	3.2	9.0	25.2
Elassomatidae	*Elassoma zonatum*	875	27.4	29.4	26.3	16.9
Cichlidae	*Herichthys cyanoguttatus*	1,970	44.2	16.0	22.5	17.3
	Oreochromis aureus	326	41.3	2.2	28.9	27.6

Appendix 2.10. Summary statistics for woody debris, cover, and vegetation per species and abundance (%) of each species by each variable.

		Abundance (%)					
Family	Species	N	Woody debris	N	Cover	N	Vegetation
Petromyzontidae	*Ichthyomyzon gagei*	169	6.1	169	0.0	169	0.0
Lepisosteidae	*Atractosteus spatula*	21	56.5	21	28.8	21	10.0
	Lepisosteus oculatus	366	39.5	366	28.1	366	18.3
	Lepisosteus osseus	203	31.3	203	22.7	204	4.7
	Lepisosteus platostomus	4	100.0	4	17.5	4	0.0
Amiidae	*Amia calva*	6	58.3	6	33.0	6	33.3
Hiodontidae	*Hiodon alosoides*	1	0.0	1	0.0	1	0.0
Anguillidae	*Anguilla rostrata*	2	37.5	2		2	0.0
Clupeidae	*Dorosoma cepedianum*	2,572	46.9	2,572	16.4	2,572	1.9
	Dorosoma petenense	2,105	19.3	2,105	19.5	2,105	2.2
Cyprinidae	*Campostoma anomalum*	5,356	6.2	5,356	7.7	5,356	12.9
	Cyprinella lepida	581	2.0	581	1.6	581	9.5
	Cyprinella lutrensis	263,964	14.8	263,964	5.9	263,964	6.7
	Cyprinella proserpina	3,524	0.1	3,524	9.6	3,524	12.6
	Cyprinella venusta	19,607	11.3	19,607	15.5	19,607	12.0
	Cyprinus carpio	552	6.7	552	23.4	552	9.3
	Dionda argentosa	9,496	0.2	9,496	6.1	9,496	35.6
	Dionda diaboli	1,009	0.0	1,009		1,009	75.0
	Dionda episcopa	1,606	12.5	1,606	50.2	1,606	73.3
	Dionda nigrotaeniata	1,939	0.9	1,972	38.1	1,961	57.9
	Dionda serena	2,297	0.0	2,297	1.2	2,297	54.3
	Hybognathus nuchalis	988	23.0	988	28.1	988	3.6
	Hybognathus placitus	5,250	13.7	5,250	1.0	5,250	1.5

Appendix 2.10. Continued.

		Abundance (%)					
Family	Species	N	Woody debris	N	Cover	N	Vegetation
	Hybopsis amnis					3	37.5
	Luxilus chrysocephalus	725	7.8	725	0.0	725	12.5
	Lythrurus fumeus	3,703	24.4	3,721	29.7	3,721	11.1
	Lythrurus umbratilis	352	4.0	352	7.7	352	0.0
	Macrhybopsis aestivalis	180	12.5	180	12.5	180	0.0
	Macrhybopsis australis	483	19.7	483	0.8	483	0.3
	Macrhybopsis hyostoma	1,158	39.9	1,158	0.6	1,158	6.6
	Macrhybopsis marconis	1,528	15.8	1,528	7.8	1,528	19.9
	Macrhybopsis tetranema	0		278	2.5	0	
	Macrhybopsis storeriana	1	0.0	1	0.0	6	6.3
	Notemigonus crysoleucas	171	24.2	171	23.1	171	0.8
	Notropis amabilis	22,653	0.8	22,653	3.4	22,653	20.3
	Notropis atherinoides	2,118	14.7	2,118	0.6	2,118	0.3
	Notropis atrocaudalis	2,997	5.7	2,997	4.6	2,997	0.0
	Notropis bairdi	6,383	28.4	6,383	2.6	6,383	2.1
	Notropis braytoni	3,702	12.5	3,702	8.7	3,702	0.0
	Notropis buchanani	6,393	12.1	6,393	5.5	6,393	7.4
	Notropis chalybaeus	122	3.2	122	0.0	122	56.0
	Notropis chihuahua	13	0.0	13	0.0	13	0.0
	Notropis girardi	0		877	4.4	0	
	Notropis jemezanus	5	0.0	5	0.0	5	0.0
	Notropis sabinae	1,360	9.2	1,360	5.0	1,360	0.6
	Notropis shumardi	2,207	31.6	2,199	2.3	2,199	3.2

Appendix 2.10. Continued.

		Abundance (%)					
Family	Species	N	Woody debris	N	Cover	N	Vegetation
	Notropis stramineus	1,947	1.7	1,945	8.6	1,947	14.8
	Notropis texanus	1,114	17.5	1,114	9.8	1,114	1.7
	Notropis volucellus	6,684	9.0	6,684	10.9	6,683	13.5
	Opsopoeodus emiliae	283	25.6	283	20.2	283	11.1
	Phenacobius mirabilis	23	30.4	23	1.5	57	3.8
	Pimephales promelas	693	8.6	693	4.4	693	43.9
	Pimephales vigilax	57,217	10.3	57,771	6.9	57,911	8.4
	Platygobio gracilis	0		47	8.6	0	
	Rhinichthys cataractae	40	12.5	40	12.5	40	0.0
	Semotilus atromaculatus	1,054	4.7	1,054	2.0	1,054	0.0
Catostomidae	*Carpiodes carpio*	1,562	22.9	1,556	16.0	1,562	4.8
	Cycleptus elongatus	71	12.5	71	12.5	71	0.0
	Erimyzon claviformis	29	5.3	8	28.5	8	0.0
	Erimyzon sucetta	3	50.0	0		0	
	Ictiobus bubalus	234	41.7	234	36.2	234	2.3
	Minytrema melanops	111	29.3	116	30.6	116	10.8
	Moxostoma congestum	861	13.9	873	18.1	873	18.2
	Moxostoma poecilurum	49	34.4	49	16.3	49	19.3
Characidae	*Astyanax mexicanus*	9,908	1.1	9,898	8.2	9,913	43.6
Ictaluridae	*Ameiurus melas*	31	4.4	37	18.4	62	23.2
	Ameiurus natalis	353	21.6	353	14.6	353	34.3
	Ictalurus furcatus	1,181	36.2	1,180	16.4	1,184	3.9
	Ictalurus lupus	191	0.3	191	4.4	191	31.3

Appendix 2.10. Continued.

		Abundance (%)					
Family	Species	N	Woody debris	N	Cover	N	Vegetation
	Ictalurus punctatus	2,741	19.4	2,741	16.7	2,741	7.7
	Noturus gyrinus	140	23.4	140	34.3	140	14.6
	Noturus nocturnus	172	52.9	172	10.7	172	3.8
	Noturus phaeus	410	4.7	410	0.0	410	0.0
	Pylodictis olivaris	413	32.2	412	18.0	411	5.3
Loricariidae	*Hypostomus plecostomus*	283	11.5	283	12.5	284	20.0
	Pterygoplichthys disjunctivus	2	30.0	2	20.0	2	15.0
Esocidae	*Esox americanus*	27	33.6	27	27.1	27	25.3
Aphredoderidae	*Aphredoderus sayanus*	120	31.3	120	38.6	120	11.3
Mugilidae	*Mugil cephalus*	365	30.6	364	40.7	369	33.7
	Agonostomus monticola	11	5.6	11	2.2	11	28.9
Atherinopsidae	*Labidesthes sicculus*	1,065	15.6	1,065	20.0	1,065	8.3
	Membras martinica	1	30.0	1	100.0	1	0.0
	Menidia audens	1,496	17.1	1,496	6.5	1,496	5.0
Fundulidae	*Fundulus chrysotus*	51	27.7	52	37.3	52	53.3
	Fundulus grandis	9	0.0	9	0.0	9	0.0
	Fundulus kansae	0		24	7.7	0	
	Fundulus notatus	2,887	23.8	2,888	29.4	2,886	12.3
	Fundulus olivaceus	976	7.0	976	41.3	975	7.3
	Fundulus zebrinus	1,844	8.1	1,844	1.0	1,844	21.5
	Lucania parva	129	0.0	129	5.0	129	66.8
Cyprinodontidae	*Cyprinodon eximius*	134	0.0	134	14.2	134	59.5
	Cyprinodon rubrofluviatilis	2,760	5.2	2,760	0.4	2,760	4.3

Appendix 2.10. Continued.

		Abundance (%)					
Family	Species	N	Woody debris	N	Cover	N	Vegetation
	Cyprinodon variegatus	910	0.1	910	0.2	910	26.4
Poeciliidae	*Gambusia affinis*	29,697	12.9	29,745	13.0	29,745	15.2
	Gambusia geiseri	10,352	3.3	10,352	10.7	10,352	50.9
	Poecilia formosa	261	16.5	182	8.4	303	25.6
	Poecilia latipinna	1,579	3.9	1,480	2.5	1,520	33.6
Moronidae	*Morone chrysops*	29	35.9	29	51.7	29	0.0
	Morone saxatilis	15	40.0	15	3.6	15	0.0
Centrarchidae	*Ambloplites rupestris*	89	3.2	89	0.0	89	58.9
	Lepomis auritus	3,700	7.6	3,700	6.5	3,700	24.8
	Lepomis cyanellus	1,884	13.6	1,808	17.2	1,808	18.3
	Lepomis gulosus	577	24.6	577	27.2	577	30.5
	Lepomis humilis	1,345	17.1	1,345	6.7	1,345	2.0
	Lepomis macrochirus	6,034	19.3	6,034	15.6	6,034	21.0
	Lepomis marginatus	56	4.7	56	32.7	56	4.6
	Lepomis megalotis	8,647	18.9	9,197	22.8	9,324	17.4
	Lepomis microlophus	78	15.1	78	10.1	78	16.4
	Lepomis miniatus	602	11.1	602	18.4	602	53.3
	Lepomis symmetricus	8	30.0	8	40.0	8	60.0
	Micropterus dolomieu	56	1.9	56	5.6	56	20.5
	Micropterus punctulatus	929	24.8	929	24.3	929	16.3
	Micropterus salmoides	4,130	5.0	4,396	50.1	4,381	31.7
	Micropterus treculii	270	6.3	270	24.2	270	12.2
	Pomoxis annularis	1,109	22.4	1,109	19.9	1,109	6.5

Appendix 2.10. Continued.

		Abundance (%)					
Family	Species	N	Woody debris	N	Cover	N	Vegetation
	Pomoxis nigromaculatus	71	18.4	71	32.3	71	14.1
Percidae	*Ammocrypta vivax*	11	15.3	11	37.5	11	12.5
	Etheostoma artesiae	438	9.2	438	6.7	438	0.0
	Etheostoma asprigene	8	43.8	8	0.0	8	0.0
	Etheostoma chlorosoma	173	23.3	177	17.3	177	2.5
	Etheostoma fonticola	3,348	3.6	0		5,452	67.4
	Etheostoma gracile	173	28.3	179	18.1	206	9.5
	Etheostoma grahami	185	0.0	181	5.5	463	49.6
	Etheostoma histrio	14	51.8	1	12.5	1	37.5
	Etheostoma lepidum	1,072	0.7	1,072	1.2	1,072	47.9
	Etheostoma parvipinne	4	0.0	4	1.3	4	0.0
	Etheostoma proeliare	8	43.8	8	0.0	8	0.0
	Etheostoma spectabile	2,546	7.2	2,546	16.7	2,546	16.0
	Percina apristis	392	8.9	392	0.0	392	12.6
	Percina caprodes	25	33.8	25	0.0	26	8.3
	Percina carbonaria	829	15.5	831	5.6	833	11.7
	Percina macrolepida	56	36.9	50	11.0	56	2.5
	Percina maculata	1	62.5	0		0	
	Percina sciera	599	21.6	599	25.5	599	6.8
	Percina shumardi	330	18.8	330	4.1	330	5.3
Sciaenidae	*Aplodinotus grunniens*	415	57.7	415	14.4	415	2.9
Elassomatidae	*Elassoma zonatum*	15	20.7	15	6.7	15	29.3
Cichlidae	*Herichthys cyanoguttatus*	987	5.4	1,351	8.7	1,729	42.9
	Oreochromis aureus	404	1.5	404	4.9	404	13.1

Appendix 2.11. Demonstration of ACFOR scale for current velocity per species and abundance (%) of each species by current velocity categories.

		Current velocity (m/s)					Abundance (%)			
							Slack	Slow	Moderate	Swift
Family	Species	N	Mean	SD (±)	Min	Max	(<0.049 m/s)	(0.049 - 0.2 m/s)	(0.21 - 0.46 m/s)	(> 0.46 m/s)
Petromyzontidae	*Ichthyomyzon gagei*	151	0.19	0.165	0.00	0.53	frequent	frequent	frequent	rare
Lepisosteidae	*Atractosteus spatula*	20	0.16	0.178	0.00	0.50	frequent	frequent	occasional	occasional
	Lepisosteus oculatus	275	0.16	0.196	0.00	0.97	frequent	occasional	occasional	occasional
	Lepisosteus osseus	328	0.19	0.217	0.00	0.96	frequent	occasional	occasional	occasional
	Lepisosteus platostomus	4	0.09	0.108	0.00	0.25	frequent	common	frequent	
Amiidae	*Amia calva*	6	0.14	0.143	0.00	0.29	common		common	
Hiodontidae	*Hiodon alosoides*	1	0.43		0.43	0.43			abundant	
Anguillidae	*Anguilla rostrata*	6	0.11	0.149	0.01	0.41	common	frequent	occasional	
Clupeidae	*Dorosoma cepedianum*	3,093	0.18	0.268	0.00	1.49	frequent	occasional	occasional	occasional
	Dorosoma petenense	1,782	0.14	0.142	0.00	1.08	occasional	common	occasional	rare
Cyprinidae	*Campostoma anomalum*	4,895	0.25	0.282	0.00	1.47	frequent	occasional	occasional	occasional
	Cyprinella lepida	578	0.23	0.202	0.00	1.35	occasional	frequent	frequent	occasional
	Cyprinella lutrensis	181,203	0.26	0.267	0.00	1.79	occasional	frequent	frequent	occasional
	Cyprinella proserpina	3,086	0.28	0.232	0.00	1.38	occasional	frequent	frequent	occasional
	Cyprinella venusta	50,997	0.22	0.254	0.08	1.49	frequent	occasional	frequent	occasional
	Cyprinus carpio	533	0.16	0.226	0.00	1.23	occasional	common	occasional	occasional
	Dionda argentosa	7,623	0.16	0.193	0.00	1.38	frequent	frequent	occasional	occasional
	Dionda diaboli	901	0.06	0.086	0.00	0.77	common	frequent	rare	rare
	Dionda episcopa	1,354	0.16	0.154	0.00	1.19	frequent	occasional	occasional	occasional
	Dionda nigrotaeniata	2,776	0.15	0.165	0.00	0.92	frequent	frequent	occasional	occasional
	Dionda serena	2,009	0.07	0.117	0.03	0.86	common	frequent	rare	rare
	Hybognathus hayi	2	0.03	0.000	0.00	0.03	abundant			
	Hybognathus nuchalis	854	0.10	0.078	0.00	0.73	occasional	abundant	rare	rare

Appendix 2.11. Continued.

		Current velocity (m/s)					Abundance (%)			
Family	Species	N	Mean	SD (±)	Min	Max	Slack (<0.049 m/s)	Slow (0.049 - 0.2 m/s)	Moderate (0.21 - 0.46 m/s)	Swift (> 0.46 m/s)
	Hybognathus placitus	5,243	0.13	0.155	0.14	1.49	occasional	common	occasional	occasional
	Hybopsis amnis	3	0.40	0.231	0.00	0.54		frequent		common
	Luxilus chrysocephalus	656	0.08	0.113	0.00	0.53	common	frequent	occasional	rare
	Lythrurus fumeus	3,331	0.06	0.087	0.00	0.90	common	frequent	occasional	rare
	Lythrurus umbratilis	347	0.13	0.176	0.00	0.90	frequent	frequent	occasional	rare
	Macrhybopsis aestivalis	352	0.50	0.328	0.00	1.30	occasional	occasional	frequent	frequent
	Macrhybopsis australis	384	0.16	0.174	0.00	0.66	frequent	occasional	frequent	occasional
	Macrhybopsis hyostoma	1,641	0.35	0.244	0.00	1.36	occasional	occasional	frequent	frequent
	Macrhybopsis marconis	1,434	0.35	0.315	0.00	1.79	occasional	frequent	frequent	frequent
	Macrhybopsis tetranema	749	0.44	0.327	0.01	1.78	rare	occasional	frequent	frequent
	Macrhybopsis storeriana	7	0.06	0.038	0.00	0.10	frequent	common		
	Notemigonus crysoleucas	154	0.03	0.089	0.00	0.51	abundant	occasional	rare	rare
	Notropis amabilis	21,502	0.18	0.201	0.00	1.37	frequent	frequent	occasional	occasional
	Notropis atherinoides	689	0.08	0.116	0.00	0.69	frequent	frequent	occasional	occasional
	Notropis atrocaudalis	2,684	0.14	0.147	0.00	0.91	frequent	frequent	frequent	rare
	Notropis bairdi	6,243	0.24	0.189	0.00	0.69	occasional	frequent	occasional	frequent
	Notropis braytoni	3,426	0.23	0.258	0.00	1.39	occasional	frequent	occasional	occasional
	Notropis buchanani	6,466	0.14	0.184	0.00	1.12	frequent	frequent	occasional	occasional
	Notropis chalybaeus	131	0.33	0.350	0.00	0.98	occasional	frequent	occasional	frequent
	Notropis chihuahua	4	0.03	0.093	0.00	0.34	abundant		frequent	
	Notropis girardi	2,133	0.30	0.285	0.26	1.79	occasional	occasional	frequent	occasional
	Notropis jemezanus	5	0.57	0.285	0.39	0.78			frequent	common
	Notropis oxyrhynchus	1	0.39		0.10	0.39			abundant	

Appendix 2.11. Continued.

		Current velocity (m/s)					Abundance (%)			
Family	Species	N	Mean	SD (±)	Min	Max	Slack (<0.049 m/s)	Slow (0.049 - 0.2 m/s)	Moderate (0.21 - 0.46 m/s)	Swift (> 0.46 m/s)
	Notropis potteri	19	0.22	0.091	0.00	0.39		frequent	common	
	Notropis sabinae	1,053	0.14	0.201	0.00	0.91	frequent	frequent	occasional	occasional
	Notropis shumardi	2,380	0.14	0.154	0.00	1.12	frequent	frequent	occasional	rare
	Notropis stramineus	2,837	0.12	0.182	0.00	0.98	common	occasional	occasional	occasional
	Notropis texanus	886	0.12	0.212	0.00	1.08	common	occasional	occasional	occasional
	Notropis volucellus	10,579	0.26	0.249	0.00	1.37	frequent	frequent	occasional	occasional
	Opsopoeodus emiliae	332	0.07	0.109	0.06	0.67	common	frequent	occasional	rare
	Phenacobius mirabilis	122	0.71	0.439	0.00	1.36		occasional	frequent	common
	Pimephales promelas	436	0.10	0.115	0.00	1.25	frequent	frequent	occasional	occasional
	Pimephales vigilax	47,784	0.15	0.197	0.00	1.79	frequent	occasional	frequent	occasional
	Platygobio gracilis	182	0.49	0.381	0.04	1.40	rare	occasional	frequent	frequent
	Rhinichthys cataractae	39	0.67	0.336	0.00	1.31	occasional	rare	occasional	common
	Semotilus atromaculatus	739	0.06	0.085	0.00	0.90	common	frequent	occasional	rare
Catostomidae	*Carpiodes carpio*	2,230	0.12	0.180	0.01	1.36	frequent	frequent	occasional	occasional
	Cycleptus elongatus	93	0.20	0.307	0.00	1.46	common	occasional	occasional	occasional
	Erimyzon claviformis	29	0.08	0.118	0.09	0.40	common	frequent	occasional	
	Erimyzon sucetta	3	0.15	0.065	0.00	0.22		common	frequent	
	Ictiobus bubalus	388	0.20	0.248	0.00	1.49	frequent	occasional	occasional	occasional
	Minytrema melanops	119	0.11	0.116	0.00	0.53	frequent	frequent	occasional	rare
	Moxostoma congestum	1,517	0.31	0.278	0.00	1.46	occasional	frequent	occasional	frequent
	Moxostoma poecilurum	72	0.30	0.193	0.00	0.67	occasional	occasional	frequent	frequent
Characidae	*Astyanax mexicanus*	10,383	0.17	0.204	0.00	1.38	frequent	frequent	occasional	occasional
Ictaluridae	*Ameiurus melas*	62	0.29	0.268	0.00	0.90	occasional	occasional	occasional	frequent

Appendix 2.11. Continued

		Current velocity (m/s)					Abundance (%)			
Family	Species	N	Mean	SD (±)	Min	Max	Slack (<0.049 m/s)	Slow (0.049 - 0.2 m/s)	Moderate (0.21 - 0.46 m/s)	Swift (> 0.46 m/s)
	Ameiurus natalis	329	0.13	0.163	0.00	0.91	frequent	frequent	occasional	occasional
	Ictalurus furcatus	1,248	0.32	0.229	0.00	1.49	occasional	frequent	common	occasional
	Ictalurus lupus	214	0.37	0.258	0.00	1.22	occasional	occasional	frequent	frequent
	Ictalurus punctatus	4,519	0.38	0.346	0.00	1.49	occasional	occasional	frequent	frequent
	Noturus gyrinus	216	0.24	0.208	0.01	0.97	frequent	occasional	frequent	occasional
	Noturus nocturnus	170	0.33	0.242	0.00	1.30	occasional	frequent	frequent	occasional
	Noturus phaeus	410	0.16	0.137	0.00	0.53	frequent	frequent	frequent	occasional
	Pylodictis olivaris	807	0.35	0.295	0.00	1.49	occasional	occasional	frequent	frequent
Loricariidae	*Hypostomus plecostomus*	540	0.26	0.279	0.01	1.33	occasional	frequent	occasional	occasional
	Pterygoplichthys disjunctivus	35	0.26	0.229	0.00	1.00	occasional	frequent	frequent	occasional
Esocidae	*Esox americanus*	31	0.06	0.063	0.00	0.31	common	frequent	rare	
Aphredoderidae	*Aphredoderus sayanus*	163	0.05	0.060	0.00	0.31	common	frequent	rare	
Mugilidae	*Mugil cephalus*	574	0.15	0.167	0.08	0.88	common	occasional	occasional	occasional
	Agonostomus monticola	17	0.57	0.332	0.00	1.10		occasional	frequent	common
Atherinopsidae	*Labidesthes sicculus*	1,098	0.06	0.078	0.02	0.58	common	occasional	occasional	rare
	Membras martinica	1	0.02		0.00	0.02	abundant			
	Menidia audens	1,749	0.08	0.147	0.00	1.18	common	frequent	occasional	rare
Fundulidae	*Fundulus chrysotus*	56	0.02	0.051	0.00	0.20	abundant	occasional		
	Fundulus grandis	131	0.09	0.122	0.00	0.60	common	frequent	occasional	rare
	Fundulus kansae	80	0.24	0.298	0.00	1.40	frequent	occasional	occasional	occasional
	Fundulus notatus	2,796	0.06	0.123	0.00	1.02	common	occasional	occasional	rare
	Fundulus olivaceus	958	0.08	0.115	0.00	0.67	common	frequent	occasional	rare
	Fundulus zebrinus	1,797	0.14	0.187	0.01	0.94	common	occasional	occasional	occasional

Appendix 2.11. Continued

		Current velocity (m/s)					Abundance (%)			
Family	Species	N	Mean	SD (±)	Min	Max	Slack (<0.049 m/s)	Slow (0.049 - 0.2 m/s)	Moderate (0.21 - 0.46 m/s)	Swift (> 0.46 m/s)
	Lucania parva	128	0.20	0.186	0.00	0.65	frequent	frequent	occasional	occasional
Cyprinodontidae	*Cyprinodon eximius*	89	0.02	0.043	0.00	0.35	abundant		rare	
	Cyprinodon rubrofluviatilis	2,382	0.07	0.105	0.00	0.90	common	frequent	occasional	rare
	Cyprinodon variegatus	891	0.01	0.009	0.00	0.04	abundant			
Poeciliidae	*Gambusia affinis*	32,765	0.13	0.200	0.00	1.37	common	occasional	occasional	occasional
	Gambusia geiseri	9,319	0.14	0.185	0.00	1.30	frequent	frequent	occasional	occasional
	Poecilia formosa	1,074	0.28	0.232	0.00	1.04	occasional	occasional	frequent	occasional
	Poecilia latipinna	2,408	0.13	0.219	0.00	0.98	common	occasional	occasional	occasional
Moronidae	*Morone chrysops*	33	0.18	0.288	0.00	1.49	occasional	common	occasional	occasional
	Morone saxatilis	15	0.11	0.129	0.00	0.40	frequent	frequent	occasional	
Centrarchidae	*Ambloplites rupestris*	90	0.13	0.167	0.04	0.98	frequent	frequent	occasional	occasional
	Centrarchus macropterus	3	0.05	0.018	0.00	0.07	common	frequent		
	Lepomis auritus	5,484	0.13	0.184	0.00	1.35	frequent	frequent	occasional	occasional
	Lepomis cyanellus	2,126	0.11	0.166	0.00	1.34	common	frequent	occasional	occasional
	Lepomis gulosus	597	0.07	0.148	0.00	0.76	common	occasional	occasional	occasional
	Lepomis humilis	1,182	0.06	0.124	0.00	1.06	common	frequent	rare	rare
	Lepomis macrochirus	6,383	0.08	0.148	0.00	1.49	common	occasional	occasional	rare
	Lepomis marginatus	56	0.05	0.064	0.00	0.27	common	occasional	occasional	
	Lepomis megalotis	12,481	0.14	0.202	0.00	1.49	frequent	frequent	occasional	occasional
	Lepomis microlophus	492	0.13	0.155	0.00	0.90	frequent	frequent	occasional	rare
	Lepomis miniatus	598	0.08	0.140	0.00	0.78	common	occasional	occasional	rare
	Lepomis symmetricus	12	0.02	0.032	0.00	0.07	common	frequent		
	Micropterus dolomieu	496	0.25	0.236	0.00	1.00	frequent	frequent	occasional	occasional

Appendix 2.11. Continued

		Current velocity (m/s)					Abundance (%)			
Family	Species	N	Mean	SD (±)	Min	Max	Slack (<0.049 m/s)	Slow (0.049 - 0.2 m/s)	Moderate (0.21 - 0.46 m/s)	Swift (> 0.46 m/s)
	Micropterus punctulatus	1,236	0.24	0.246	0.00	1.49	frequent	frequent	frequent	occasional
	Micropterus salmoides	4,731	0.19	0.184	0.00	1.46	frequent	occasional	frequent	rare
	Micropterus treculii	580	0.16	0.219	0.00	1.24	frequent	frequent	occasional	occasional
	Pomoxis annularis	767	0.03	0.080	0.00	1.08	abundant	occasional	rare	rare
	Pomoxis nigromaculatus	63	0.09	0.159	0.02	0.90	common		occasional	rare
Percidae	*Ammocrypta vivax*	27	0.23	0.079	0.00	0.40	rare	occasional	abundant	
	Etheostoma artesiae	421	0.21	0.152	0.03	0.57	occasional	occasional	frequent	rare
	Etheostoma asprigene	13	0.14	0.103	0.00	0.31	occasional	common	occasional	
	Etheostoma chlorosoma	224	0.04	0.070	0.00	0.40	abundant	occasional	rare	
	Etheostoma fonticola	5,195	0.06	0.112	0.00	1.12	common	occasional	occasional	rare
	Etheostoma gracile	275	0.19	0.214	0.00	1.09	frequent	occasional	occasional	occasional
	Etheostoma grahami	436	0.26	0.272	0.02	1.36	frequent	occasional	occasional	frequent
	Etheostoma histrio	17	0.17	0.111	0.00	0.32	occasional	common	frequent	
	Etheostoma lepidum	1,192	0.20	0.277	0.11	1.37	frequent	occasional	occasional	occasional
	Etheostoma parvipinne	4	0.32	0.392	0.03	0.91		abundant		frequent
	Etheostoma proeliare	20	0.08	0.063	0.00	0.31	occasional	abundant	occasional	
	Etheostoma radiosum	633	0.16	0.254	0.00	1.18	common	occasional	occasional	occasional
	Etheostoma spectabile	3,581	0.52	0.293	0.00	1.47	occasional	occasional	frequent	common
	Percina apristis	322	0.55	0.271	0.00	1.32	rare	occasional	occasional	common
	Percina caprodes	264	0.35	0.315	0.00	1.36	occasional	frequent	occasional	frequent
	Percina carbonaria	771	0.58	0.297	0.00	1.27	rare	occasional	frequent	common
	Percina macrolepida	56	0.23	0.237	0.12	0.75	frequent	occasional	occasional	frequent
	Percina maculata	2	0.14	0.041	0.00	0.17		abundant		

Appendix 2.11. Continued

		Current velocity (m/s)					Abundance (%)			
Family	Species	N	Mean	SD (±)	Min	Max	Slack (<0.049 m/s)	Slow (0.049 - 0.2 m/s)	Moderate (0.21 - 0.46 m/s)	Swift (> 0.46 m/s)
	Percina phoxocephala	187	0.43	0.373	0.00	1.36	frequent	occasional	occasional	common
	Percina sciera	515	0.31	0.231	0.00	1.09	occasional	frequent	frequent	occasional
	Percina shumardi	314	0.89	0.274	0.00	1.47	rare		rare	abundant
	Sander vitreus	23	0.13	0.100	0.00	0.35	occasional	common	occasional	
Sciaenidae	*Aplodinotus grunniens*	416	0.11	0.243	0.00	1.49	common	occasional	occasional	occasional
Elassomatidae	*Elassoma zonatum*	624	0.19	0.209	0.00	1.30	frequent	frequent	occasional	occasional
Cichlidae	*Herichthys cyanoguttatus*	1,958	0.17	0.215	0.00	1.38	frequent	frequent	occasional	occasional
	Oreochromis aureus	315	0.24	0.200	0.00	0.78	frequent	occasional	frequent	occasional

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