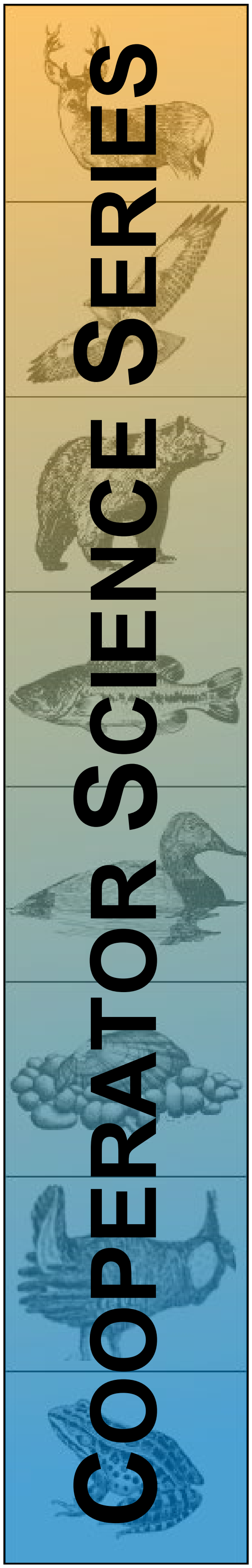

Recruitment dynamics and reproductive ecology of Blue Sucker in Texas, with a focus on the Big Bend region of the Rio Grande

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Recruitment dynamics and reproductive ecology of Blue Sucker in Texas, with a focus on the Big Bend region of the Rio Grande

Final Project report to Texas Parks and Wildlife Department and the U.S. Fish and Wildlife Service

June 2019

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Executive Summary:

Blue Sucker *Cycleptus elongatus* is a state-listed threatened species in Texas and is considered vulnerable throughout its range. Once considered a single, wide-ranging species, blue suckers are now recognized as a complex of closely related, but genetically and morphologically distinct species within the genus *Cycleptus*, including an undescribed species within the Rio Grande Basin. Numerous factors likely are driving the decline of blue suckers in Texas, including flow alteration, water quality, habitat fragmentation, and changing land-use patterns, but it is not clear how these factors interact to influence the abundance and distribution of the species. Our research integrates a variety of methodologies to provide information critical to the conservation and management of Blue Sucker in the Sabine River (Texas and Louisiana) and Colorado River (Texas) and Rio Grande Blue Sucker *Cycleptus* sp. cf. *elongatus* in the Rio Grande.

The objectives of this report are to 1) determine the habitat associations of the young-of-year (YOY) Rio Grande Blue Sucker; 2) assess the effects of flow regime on growth and recruitment of Blue Sucker in the lower Sabine River; and 3) examine differences in life-history traits of Blue Suckers and flow regime across river basins in Texas. This study is the first to quantitatively address the sequence of YOY blue sucker mesohabitat use and increases our understanding of early life history of blue suckers, and the results of this work will help to develop conservation and management strategies, e.g., prioritizing conservation areas, developing flow recommendation, etc., for blue suckers throughout their geographic distribution.

Key findings of this study were:

- The body size of YOY Rio Grande Blue Sucker in pool habitats were significantly lower than in other mesohabitats, suggesting that YOY Rio Grande Blue Sucker undergo ontogenetic habitat shifts from low current velocity habitats into higher current velocity habitats as they grow.
- Slow current areas, such as pools, could be important nursery habitats for small YOY Rio Grande Blue Sucker (total length ≤ 45 mm).
- YOY Rio Grande Blue Sucker move into riffles and runs as they grow from April to June, suggesting that extreme low flow conditions during early summer may negatively affect habitat quality or availability for YOY Rio Grande Blue Sucker.
- Growth and recruitment of Blue Sucker in the lower Sabine River increased with increasing river discharge from early summer to fall in our study areas.
- Life-history traits of Blue Sucker differed between the lower Sabine River and the lower Colorado River: the total length and age of Blue Sucker in the lower Colorado River were larger than those of Blue Sucker in the lower Sabine River, and the growth and mortality rates of Blue Sucker of the lower Sabine River tended to be higher than those of the lower Colorado River.
- Our results suggest that mesohabitat area and flow regime could be important factors determining the growth and recruitment of blue suckers, and the importance of these environmental factors could change according to the life-history stage (larval stage, juvenile stage, and adult stage).
- Important areas for future research efforts include 1) quantifying differences in the mesohabitat area/quality/density among the three river basins; 2) examining interactions

between the spatial distributions of potential spawning habitat relative to suitable YOY mesohabitat and how variations in river flow influence their quality and connectivity to each other; and 3) continuing to monitor the effects of flow regime on blue suckers for longer time periods.

Introduction

The three blue sucker species within the genus *Cycleptus* are considered vulnerable throughout their range from the Rio Grande along the Mexican border of Texas to the Mobile Bay drainage in Alabama and northward into the upper Mississippi, Missouri, and Ohio rivers (Yeager and Semmens 1987; Jelks et al. 2008). Once considered a single, wide-ranging species, blue suckers are now recognized as a complex of closely related, but genetically and morphologically distinct, species within *Cycleptus* (Burr and Mayden 1999; Buth and Mayden 2001; Bessert 2006), including Blue Sucker *Cycleptus elongatus*, Southeastern Blue Sucker *Cycleptus meridionalis*, and Rio Grande Blue Sucker *Cycleptus* sp. cf. *elongatus*. In this study, we focus on Blue Sucker in the Sabine River (Texas and Louisiana) and Colorado River (Texas) and Rio Grande Blue Sucker in the Rio Grande.

Blue suckers are thought to be threatened at multiple life history stages, similar to most imperiled catostomids (Cooke et al. 2005). Blue suckers are long-lived (≥ 22 years, Vokoun et al. 2003) and late-maturing (5–6 years, Rupprecht and Jahn 1980) benthic invertivores (Rupprecht and Jahn 1980; Cowley and Sublette 1987). However, it is not yet clear if there is interspecific or intraspecific geographical variation in ecological or life history traits. Blue suckers are associated with big-river ecosystems and are highly potadromous, potentially making spawning migrations of ≥ 500 km (Mettee 2000). Spawning seems to be restricted to riffle complexes with large cobble substrate (Moss et al. 1983; Vokoun et al. 2003). Young-of-year (YOY) blue suckers have been reported to occur in habitats that are shallower, with lower current velocities than those occupied by adults (Moss et al. 1983; Adams et al. 2006). These life-history characteristics suggest that blue suckers may be vulnerable to flow alteration and habitat fragmentation and degradation due to the prevention of spawning migration and the loss of spawning and feeding habitats (Hand and Jackson 2003; Eitzmann et al. 2007; Neely et al. 2009). It is unclear what specific factors are driving the decline of blue suckers in Texas, e.g., flow alteration, water quality, habitat fragmentation, and changing land use, and how such factors interact to influence abundance and distribution.

Rio Grande Blue Sucker is identified as a species of greatest conservation need in the Texas Conservation Action Plan (https://tpwd.texas.gov/landwater/land/tcap/sgcn.phtml), of special concern by Hubbs et al. (2008), and threatened by Jelks et al. (2008). Rio Grande Blue Sucker likely is locally abundant in the Big Bend reach of the Rio Grande according to recent surveys (Heard et al. 2012; Miyazono et al. 2015); however, populations seem to have decreased in other areas of the Rio Grande system, e.g., the Rio Conchos and Pecos River (Zymonas and Propst 2007; Lozano-Vilano 2010; Dombrosky et al. 2016). Water quality deterioration and habitat degradation and fragmentation associated with reservoir construction may be responsible for the declines of Rio Grande Blue Sucker (Lozano-Vilano 2010; Dombrosky et al. 2016), but specific factors that are affecting populations are still unknown. In addition, the detailed ecological traits of Rio Grande Blue Sucker are poorly understood.

The early life history of blue suckers is poorly understood throughout their geographical distribution. Juveniles, particularly YOY, rarely are found in the Sabine (Mayes 2015) and Colorado Rivers (Biowest, Inc. 2011; Acre 2019), but they are relatively common in the Big Bend region of the Rio Grande (Heard et al. 2012; Miyazono et al. 2015). Thus, this study focused on the habitat associations of YOY Rio Grande Blue Sucker to increase our understanding of early life history of blue suckers throughout their geographical distribution. Previous studies suggest that larval blue suckers tend to inhabit slow current velocity areas, e.g., side channels, of riverine systems and could shift their habitats to fast-moving water once they develop into juveniles (Adams et al. 2006; Eder 2009). However, no studies quantitatively address the sequence of YOY blue sucker mesohabitat use. Thus, we examined the temporal sequence of mesohabitat use of YOY Rio Grande Blue Sucker using river segments with pool, run, and riffle complexes. We predicted that the habitat use of YOY Rio Grande Blue Sucker would change from pool habitats to riffle habitats after the spawning month.

Flow regime, e.g., increase or decrease in flow magnitude, alteration in timing, and fluctuation in duration patterns, affects the ecological integrity of river ecosystems by controlling water quality, energy sources, physical habitat, and biotic interactions (Poff et al. 1997). Changes in hydrologic conditions by anthropogenic activities is one of primary environmental problems in lotic systems (Poff et al. 1997). Although the effects of flow regime on other big-river fishes are well-reported (e.g., Grabowski et al. 2012; Quist and Spiegel 2012; Jacquemin et al. 2015), the effects of flow regime on blue suckers are less studied.

Blue Sucker, *C. elongatus*, is a state-listed threatened species in Texas (Hubbs et al. 2008). The Sabine River Blue Sucker population has experienced many of the same anthropogenic habitat alterations as other populations in Texas, e.g., Colorado River. However, the lower Sabine River is unique in being one of the few rivers in Texas also impacted by hydropower generation. In particular, the lower Sabine River experiences rapid, daily fluctuations in discharge, i.e., hydropeaking. Previous studies suggest that a rising hydrograph may be a cue that initiated the spawning migration of Blue Sucker in the lower Sabine River (Mayes 2015). While recent surveys suggest that Blue Sucker are consistently undertaking spawning migrations and accessing spawning habitats in the lower Sabine River (Biowest, Inc. 2011; Mayes 2015), there has not been a successful attempt to characterize recruitment in this population. We hypothesized that changes in flow regime could affect the growth and recruitment of Blue Sucker in the lower Sabine River.

Life-history traits of blue suckers likely vary across watersheds in Texas. For example, whereas juvenile Blue Sucker occasionally have been captured from the lower Sabine in recent surveys (Biowest, Inc. 2011; Mayes 2015), there are indications that larger individuals are less common in the lower Sabine River downstream of Toledo Bend Reservoir than in the lower Colorado River downstream of the Highland Lakes in Austin, Texas (Mayes 2015; Acre 2019). Further, based on preliminary data, individuals in the lower Sabine River may be smaller than those of the same age from the lower Colorado River (Mayes 2015; Acre 2019), suggesting that the growth rate in the lower Colorado River may be higher than that in the lower Sabine River. These observations across the multiple river basins underscore the importance of landscape-level scale analyses to understand the effects of flow regime on the growth and recruitment of blue suckers in Texas.

The objectives of this report are to 1) determine the habitat associations of the YOY Rio Grande Blue Sucker; 2) assess the effects of flow regime on growth and recruitment of Blue Sucker in the lower Sabine River; and 3) examine differences in life-history traits of blue suckers and flow regime across river basins in Texas. This study is the first to quantitatively address the sequence of YOY blue sucker mesohabitat use and increases our understanding of their early life history of blue suckers. Results of this work will help to develop conservation and management strategies (e.g., prioritizing conservation areas, developing flow recommendation, etc.) for blue suckers throughout their geographic distribution.

Chapter 1: Habitat associations of the young-of-year Rio Grande Blue Sucker

Objective

The objective of this chapter is to determine the habitat associations of young-of-year (YOY) Rio Grande Blue Sucker.

Methods

Study Area

The Rio Grande is the fourth longest river (2,830 km) in North America, and its watershed area is approximately 870,000 km^2 (Calamusso et al. 2005). The Rio Grande originates in the San Juan Mountains of southern Colorado, flows across New Mexico, and forms the border between Texas and Mexico for the remainder of its length (Calamusso et al. 2005). The Rio Grande is identified as one of the most imperiled rivers in North America (American Rivers 1993). The natural flux of water and sediment in the Rio Grande has been affected by anthropogenic activities, e.g., irrigation diversion dams, groundwater pumping, etc., which has channelized the river and inhibited connections with its floodplain (Bestgen and Platania 1988; Everitt 1993; Schmidt et al. 2003; Calamusso et al. 2005; Small et al. 2009; Dean and Schmidt 2011). The Rio Grande in the Big Bend region of Texas, the study area of this research, receives water from a series of tributaries including the Rio Conchos, Cibolo, Alamito, Terlingua, and Tornillo creeks. The discharge of the Rio Conchos, the largest tributary in the region, is the primary water source for the mainstem Rio Grande in the Big Bend region (Bestgen and Platania 1988; Miyazono et al. 2015).

Data Collection

We obtained fish and habitat data by sampling nine sites in the Big Bend region of the Rio Grande, Texas, USA (Figure 1) in April, May, and June of 2016 and 2017. We collected fish during daytime (07:13-18:40) within each site (~100 m river segment) using a seine (4.57 m long × 1.82 m deep; 3.1-mm mesh). We selected river segments with riffle, run, and pool complexes where the river was safely and legally accessible from public roads, trails, or boat ramps. We defined each mesohabitat based on flow patterns. Riffle habitats had swift-moving water where most of the water surface was broken, run habitats had swift-moving water where most of the water surface was not broken, and pool habitats had slow-moving water where most of the water surface was not broken. We conducted 10 seine hauls (each seine haul: ~10 m) in each river segment during each daily sampling event. We replicated the fish and habitat samplings once each day during a 3-day period each month to decrease the bias by heterogeneity in capture probability (Pollock 1982). Fish and habitat sampling in June 2016 and May 2017 were affected by flood events (Figure 2), and we could not conduct one sampling event in site 9 in June 2016 and three sampling events in site 6 and 7 in May 2017. We measured water temperature and specific conductance with a YSI Pro 2030 meter (Yellow Springs Instrument, Yellow Springs, Ohio), turbidity with an Oakton TN-100 portable turbidimeter (Oakton, Vernon Hills, Illinois), and maximum depth, and recorded dominant substrate type from three types of mesohabitats (riffle, run, and pool) in each river segment. We recorded the spatial position (the edges) of the mesohabitats using a handheld GPS unit (GPSMAP78, Garmin International, Olathe, Kansas). We obtained mean daily river discharge data from the stream gage within the study area (USGS 08374550 Rio Grande near Castolon, TX).

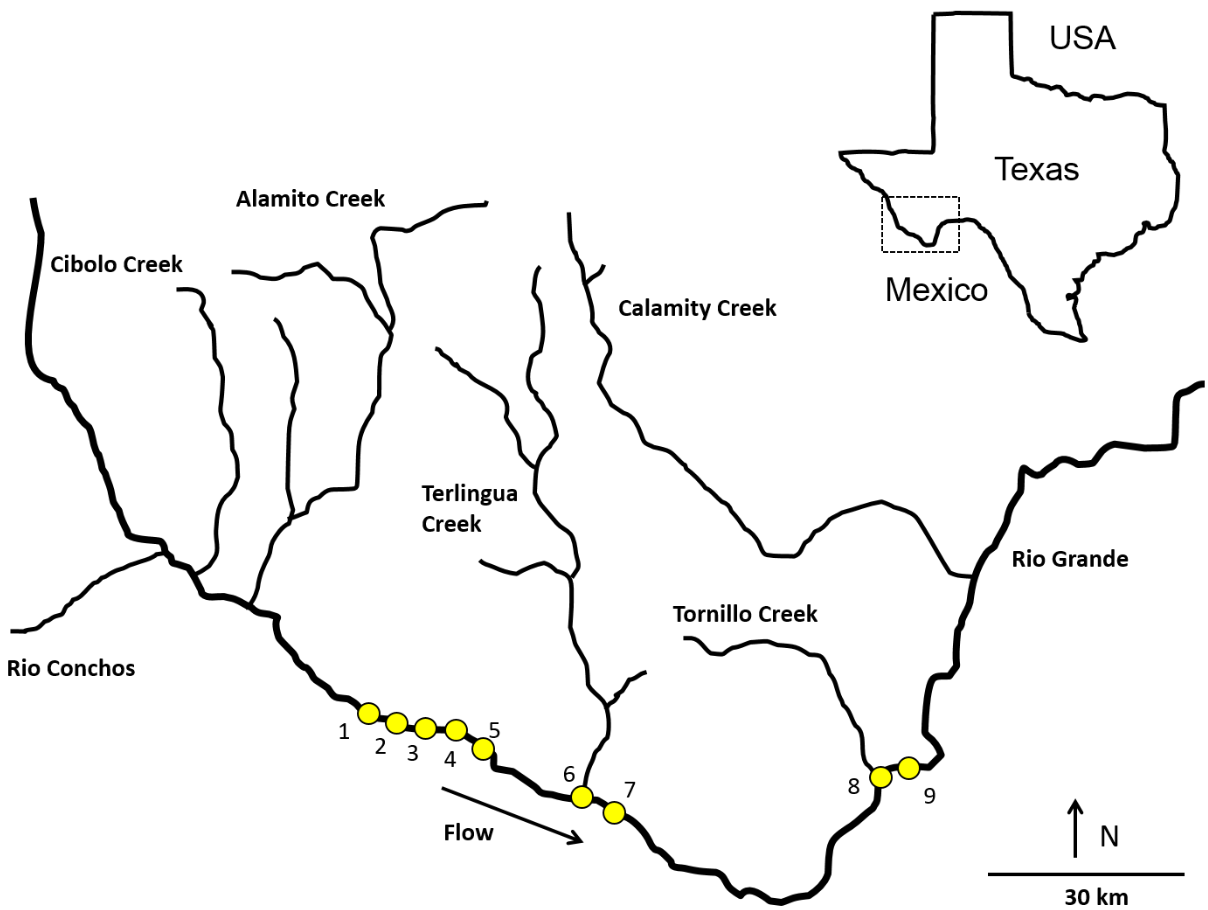

Figure 1. Spatial position of nine seining sites in the Trans-Pecos region of the Rio Grande, Texas, USA sampled during April–June in 2016–2017. The stream gage near Castolon, TX (USGS 08374550) is located near site 7. Sites 1–5 were located in Big Bend Ranch State Park and sites 6–9 were located in Big Bend National Park.

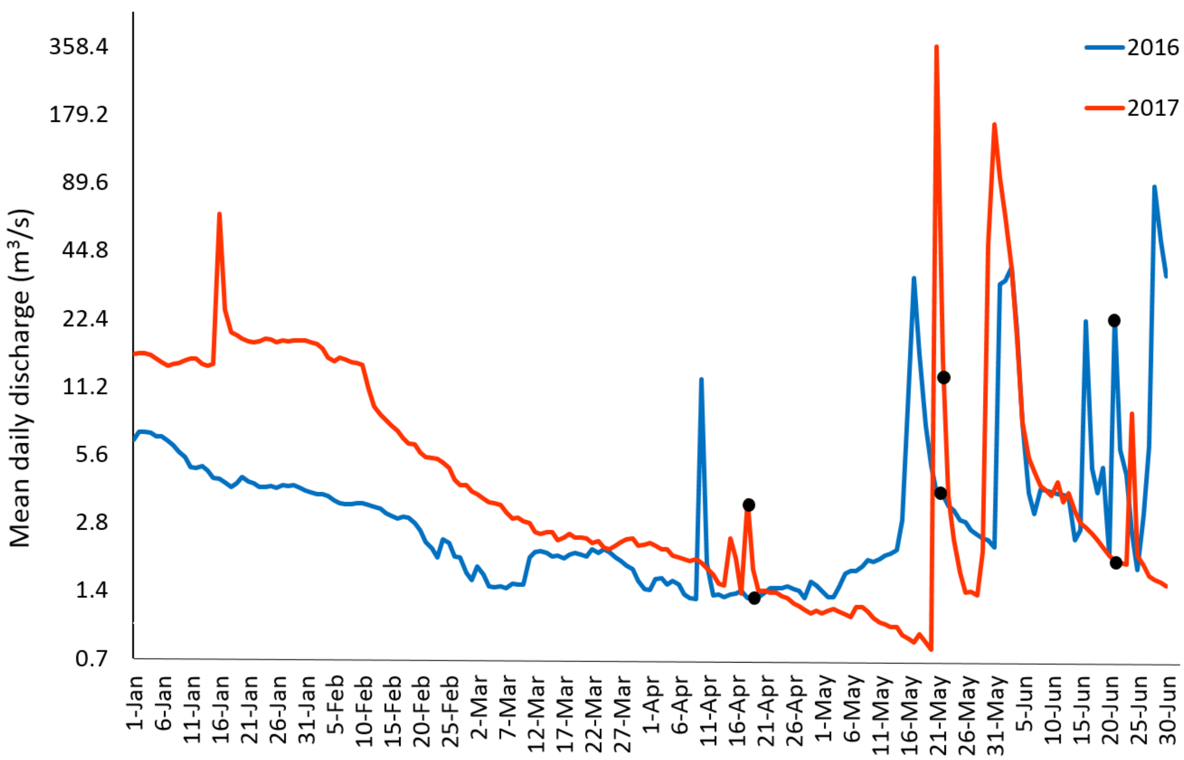

Figure 2. Mean daily discharge in the Rio Grande near Castolon, Texas (USGS 08374550) from January to June in 2016 and 2017. Black points in the plot indicate sampling events.

Data Analyses

We used *N*-mixture modeling generalized for open populations (Royle 2004; Dail and Madsen 2011) to examine the abundance patterns of YOY Rio Grande Blue Sucker along various abiotic variables: water temperature, specific conductance, riffle area, run area, pool area, maximum depth, and maximum discharge between sampling months. The open *N*-mixture model uses spatiotemporal replication in count data to estimate demographic parameters (e.g., population growth) and attributes observation error to the inability to detect all individuals during sampling (Dail and Madsen 2011; Zipkin et al. 2014). In these models, we assumed populations were closed among repeated daily samplings of each month but open between months. We used open *N*-mixture models parameterized for exponential population growth. This modeling approach is appropriate for our YOY Rio Grande Blue Sucker data because the temporal abundance patterns of YOY Rio Grande Blue Sucker in our study sites showed negative exponential trends from April to June. We standardized covariates before analysis. To estimate the parameters, we used the pcountOpen function in the unmarked 0.12-2 package (Fiske et al. 2017) implemented using the statistical program R v. 3.51 (R Development Core Team 2018).

We visually assessed the size structure of YOY Rio Grande Blue Sucker of each month with length-relative frequency histograms. We examined difference in size structure between the years using the Kolmogorov-Smirnov (K-S) two-sample test (Neumann and Allen 2007). In addition, we used a one-way analysis of variance (ANOVA) to examine differences in total length (TL) of captured Rio Grande Blue Sucker among the three mesohabitats (pool, riffle, and run). When ANOVA models were significant (α = 0.05), we used Tukey's studentized range test to estimate mean total length differences among the three mesohabitats. We conducted all analyses in statistical program R v. 3.51 (R Development Core Team 2018).

Results

We captured 179 YOY Rio Grande Blue Sucker during the study period. Total length (TL; mean (± SD)) of YOY Rio Grande Blue Sucker collected during the study period was 56 ± 26 mm (range: 22–142 mm; n=159). The body size (total length) data of a total of 20 YOY Rio Grande Blue Sucker captured in April 2016 were not available. We captured the majority of YOY Rio Grande Blue Sucker in April of each year (Figure 3). The length-relative frequency histograms of the April samplings showed that the relative frequency (71.4%) of small individuals (TL ≤ 45 mm) of 2017 was greater than that (45.2%) of 2016 (Figure 3). In addition, YOY Rio Grande Blue Sucker ≤ 45 mm were not collected in the May samplings of both years. The mean TL of YOY Rio Grande Blue Sucker in 2016 was greater than that in 2017 (K-S test, D = 0.330, P < 0.001).

The results of the open *N*-mixture modeling suggest that the detection probability decreased with increasing maximum flow among sampling months (β estimate = –0.923, 95% CI: –1.128, –0.717, Table 1). The initial abundance of YOY Rio Grande Blue Sucker increased with increasing pool area (β estimate = 0.308, 95% CI: 0.108, 0.507) and decreased with increasing maximum depth (β estimate = –0.255, 95% CI: –0.470, –0.039), indicating that YOY Rio Grande Blue Sucker were more abundant in study sites with large, shallow pool habitats during April compared to sites with smaller and/or deeper pool habitat. In addition, the catch per unit effort (CPUE) of YOY Rio Grande Blue Sucker decreased with increasing riffle area (β estimate = –0.138, 95% CI = –0.231, –0.044). The mean total length of YOY Rio Grande Blue Sucker differed among the mesohabitats (ANOVA, $F_{2, 156} = 19.43$, $P < 0.001$). The mean total length of YOY Rio Grande Blue Sucker captured from pool habitats was 30 mm and 19 mm smaller than that of individuals captured from riffle and run habitats, respectively (Figure 4). The relative abundances of YOY Rio Grande Blue Sucker in pool and run habitats decreased from April to June of each year whereas the relative abundance of YOY Rio Grande Blue Sucker in riffle habitats increased from April to June of each year (Figure 5).

Discussion

Over the course of each sampling season, the CPUE of YOY Rio Grande Blue Sucker decreased from April to June. This temporal pattern is possibly due to downstream displacement by floods, natural mortality, and a decrease in capture efficiency (see Heard et al. 2012). The Big Bend region of the Rio Grande experienced high flows between sampling events, and the detection probability of YOY Rio Grande Blue Sucker exhibited a strong negative correlation with these high flow events. Previous studies also reported that populations of fish species with small body size in the Big Bend reach of the Rio Grande or other riverine systems tended to decrease after flood events due to downstream displacement (Collins et al. 1981; Minckley and Meffe 1987; Heard et al. 2012). In general, the abundance of YOY individuals decreases following spawning due to the loss of individuals through natural mortality (Houde 2002). Further, the capture efficiency of seining may have decreased from April to June because swimming performance of YOY Blue Suckers should increase as they grow (Bayley and Herendeen 2000) or move to deeper pool habitats where seining can be ineffective.

The size structure of YOY Rio Grande Blue Sucker differed between 2016 and 2017. This may be because of differences in reproductive timing/success between the years. The length-relative frequency histograms showed that the range of YOY Rio Grande Blue Sucker TL in April was 22–114 mm and we did not catch YOY Rio Grande Blue Sucker TL ≤ 45 mm in May, suggesting that the spawning of Rio Grande Blue Sucker likely was between January and

Table 1. Results of open *N*-mixture modeling with the abundance data for young-of-year Rio Grande Blue Sucker in the Rio Grande in the Big Bend region in 2016–2017.

Parameter	Covariate	Estimate	SE	z	P-value
Initial abundance	(Intercept)	3.91	0.21	18.94	<0.001
	Pool area	0.31	0.10	3.02	<0.01
	Maximum depth	-0.26	0.11	-2.33	0.02
Population growth rate	(Intercept)	-0.14	0.06	-2.53	0.01
	Riffle area	-0.14	0.05	-2.91	<0.01
Detection probability	(Intercept)	-3.97	0.21	-18.53	<0.001
	Maximum flow	-0.92	0.11	-8.81	<0.001

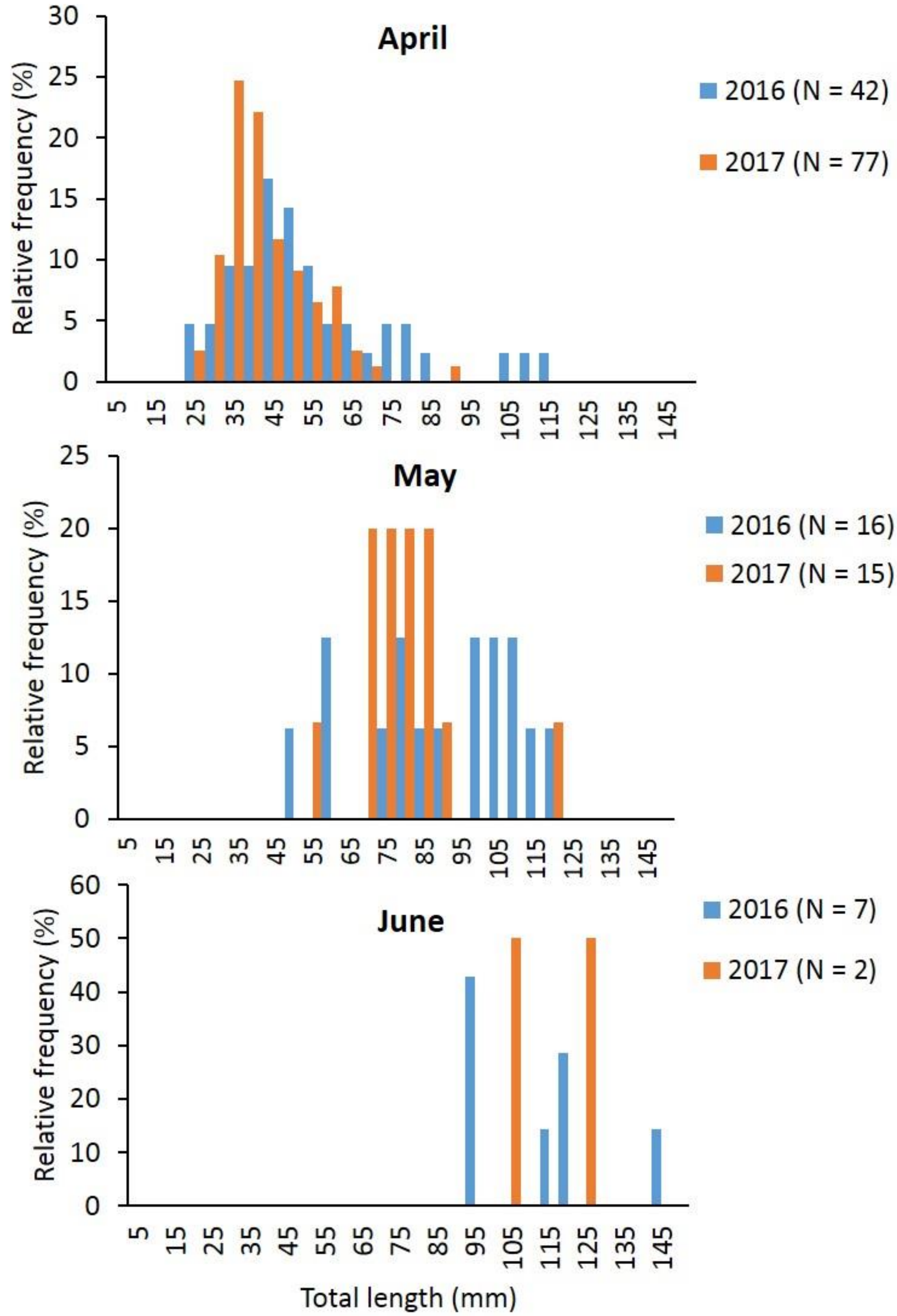

Figure 3. Length-relative frequency histogram of the young-of-year Rio Grande Blue Sucker across all habitats in the Big Bend region of the Rio Grande during 2016 and 2017.

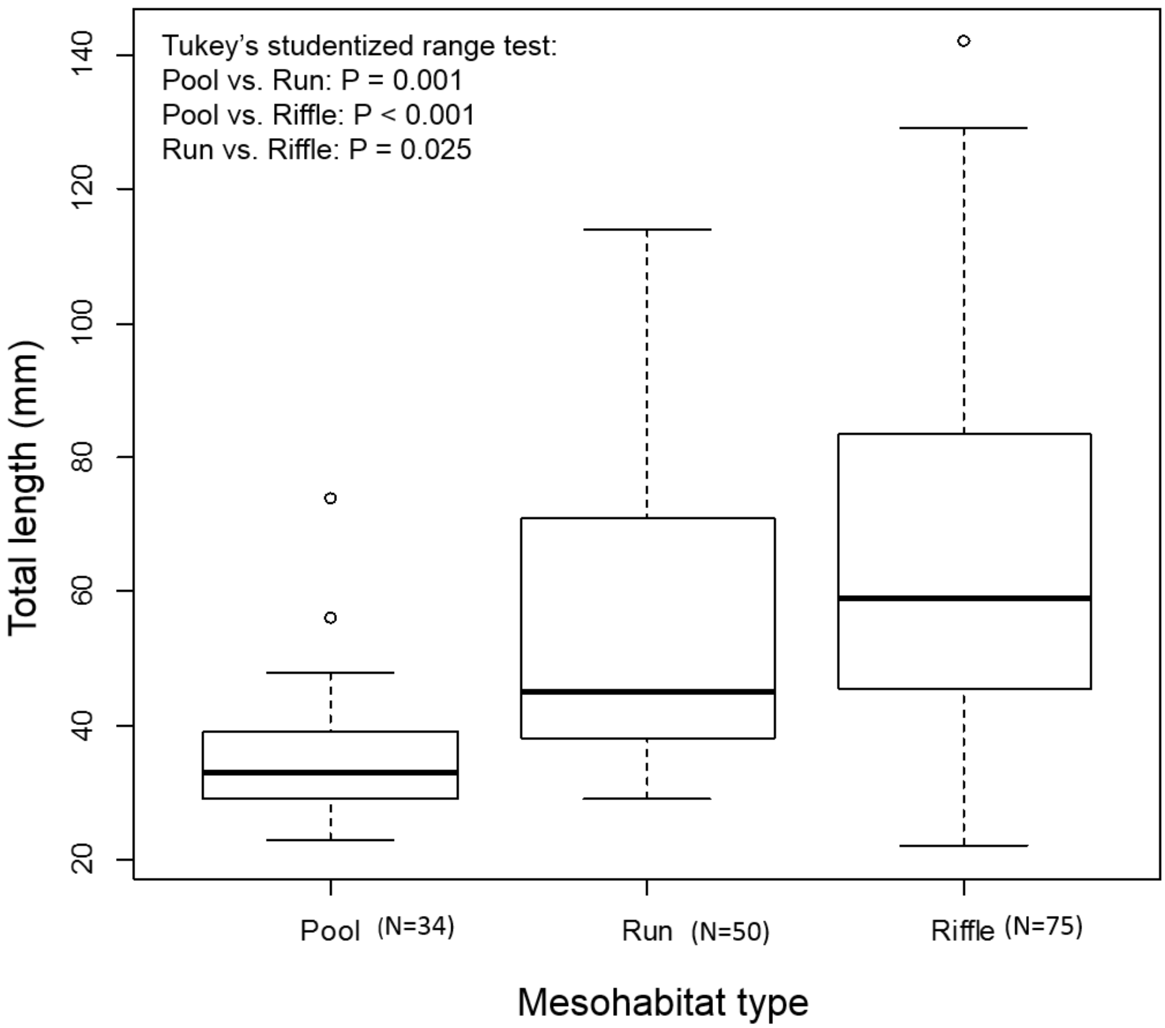

Figure 4. Boxplots for the total lengths of the young-of-year Rio Grande Blue Sucker collected from different mesohabitat types (riffle, run, pool) in the Big Bend region of the Rio Grande during April–June during 2016–2017.

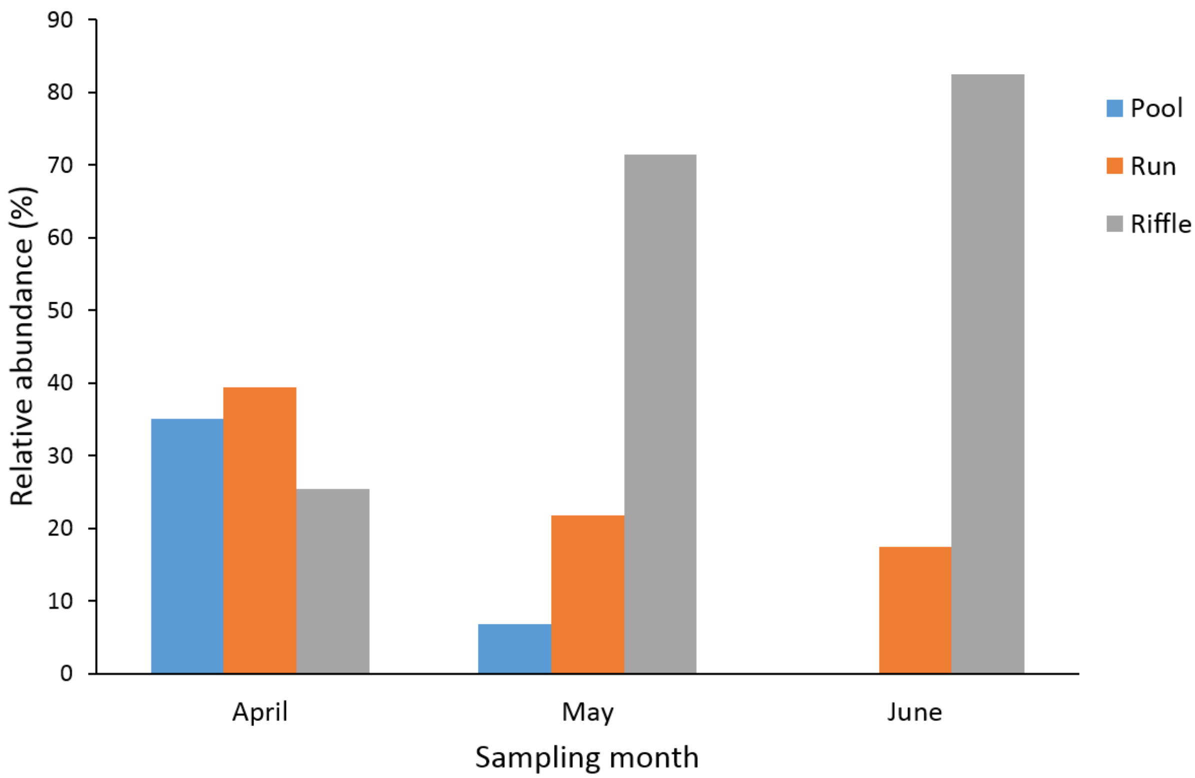

Figure 5. Relative abundance of young-of-year Rio Grande Blue Sucker in three mesohabitat types in the Big Bend region of the Rio Grande during April–June in 2016–2017.

April in the study sites. Previous studies have suggested that water temperature could affect Blue Sucker reproduction (Rupprecht and Jahn 1980; Moss et al. 1983; Vokoun et al. 2003; Acre 2019). The stream gage at Rio Grande Village in Big Bend National Park (USGS 08375300) reported that the mean daily water temperature (mean = 15.6˚C; SD = 1.4˚C) in January 2016 was greater than in January 2017 (mean = 13.9˚C; SD = 1.4˚C). The difference in water temperature may have affected the start of Rio Grande Blue Sucker spawning in our study area; however, the water temperature of both years likely was within the optimal range (12–18˚C) for Blue Sucker reproduction (Rupprecht and Jahn 1980; Moss et al. 1983; Adams et al. 2006). We hypothesize that differences in river discharge between January 2016 and 2017 could have affected spawning of Rio Grande Blue Sucker. The mean daily discharge in January 2017 (mean = 18.1 m^3/s; SD = 9.0 m^3/s) was greater than in January 2016 (mean = 4.9 m^3/s; SD = 1.1 m^3/s) at the USGS Rio Grande near Castolon, TX gage (USGS 08374550), and the river discharge may have affected the spawning of Rio Grande Blue Sucker in 2017. Information on the effects of flow regime on the spawning of blue suckers is still limited. Some studies suggested that rising river discharge may initiate or enhance the spawning of Blue Sucker (Fisher and Willis 2000; Mayes 2015). However, Adams et al. (2006) reported that the reproduction of Blue Sucker was likely better in a year with little to no flooding during spawning. Further research to determine the spawning cues for Rio Grande Blue Sucker is needed in our study system.

Our results suggest small YOY Rio Grande Blue Sucker (TL < 40 mm) select shallow, low current velocity pool habitats. Eder (2009) also reported age-0 Blue Sucker tended to select shallow, slow current areas in the side channels of Missouri River. Our results also suggest that the TL of YOY Rio Grande Blue Sucker varied among the mesohabitats. The TL of YOY Rio Grande Blue Sucker in pool habitats were lower than that in other mesohabitats, suggesting that

YOY Rio Grande Blue Sucker undergo ontogenetic habitat shifts into higher current velocity habitats as they grow. Adams et al. (2006) studied the ecology of larval Blue Sucker in off-channel habitats of the Mississippi River and suggested that juvenile YOY Blue Sucker use habitats with higher current velocities. Our results concur with the findings in the different river systems, suggesting that the early life history of Rio Grande Blue Sucker is similar to that of other blue suckers.

Rio Grande Blue Sucker successfully reproduced in the Big Bend region of the Rio Grande during the study period. Our results suggest that shallow, slow current areas could be important nursery habitats for YOY Rio Grande Blue Sucker in our study system. In addition, our results suggest that YOY Rio Grande Blue Sucker move into riffles and runs as they grow from April to June, suggesting that extreme low flow conditions during early summer may negatively affect the habitat quality or availability for YOY Rio Grande Blue Sucker as the availability and quality of riffle and run habitats tend to be affected by low flows (Heard et al. 2012, Blythe 2018). It is also interesting to note the contrast in the relative abundance of YOY blue suckers in the Big Bend region of the Rio Grande relative to other systems in Texas, such as the Colorado and Sabine Rivers. Even though these river systems seem to have an abundance of suitable habitat to support small YOY Blue Sucker, e.g., large pools, these early life history stages are rarely, if ever, encountered. Further, the availability of riffle and run habitats similar to that used by larger YOY Rio Grande Blue Sucker is more limited in the Colorado and Sabine Rivers. There may be interactions between the spatial distributions of potential spawning habitat relative to suitable YOY habitat and how variations in stream flow influence their quality and connectivity to each other.

Chapter 2: Effects of flow regime on growth and recruitment in Sabine River Blue Sucker

Objective

The objective of this chapter is to assess the effects of flow regime on growth and recruitment of Blue Sucker in the lower Sabine River.

Methods

Study Area

The Sabine River originates in northwestern Hunt County, Texas and empties into Sabine Lake in Orange County, Texas, forming the border between Texas and Louisiana for much of its length (Figure 6). Its watershed is approximately 25,267 km^2 and encompasses three ecoregions, i.e., Blackland Prairie, East Texas Timberlands, and Coastal Prairie. Toledo Bend Dam is the terminal dam on the system and was completed in 1969. Toledo Bend Dam is one of the few hydropower dams in Texas and regularly releases water for hydropeaking typically during the summer months (Phillips 2003; Mayes 2015). Our study reach in the lower Sabine River encompassed about 60 river km from Toledo Bend Dam to Bon Weir, Texas (Figure 6). The upper part (Toledo Bend tailrace; Figure 6) of the study reach (river km 238 to river km 222) was characterized by pools, riffles, and runs with extensive areas of bedrock and boulder substrate and also included the spillway channel (river km 236 to river km 226) that contained two large bedrock riffles (BIO-WEST, Inc. 2013). This channel typically has lower flows (water is only released from the gates during flooding events), but when generation is occurring backflow from the tailrace can back up the spillway channel inundating both riffles (BIO-WEST, Inc. 2013). The downstream areas, i.e., Bayou Anacoco and Bon Wier (Figure 6), of the study reach from river km 178–222 were sinuous with sandy substrates and large woody debris was the most common instream structure (BIO-WEST, Inc. 2013).

Data Collection

We collected Blue Sucker from three primary areas (Toledo Bend tailrace, Bayou Anacoco, and Bon Wier) in the lower Sabine River using boat-mounted electrofishers (Smith-Root 5.0/7.5 gpp), settings at pulsed DC power at 60 pulses s^{-1} (Hz) with voltage and pulse width adjusted to maintain an output of approximately 8 amperes, in October 2016 and 2017 and May–June 2018 (Table 2; Figure 6). Each Blue Sucker received a uniquely coded half duplex passive integrated transponder (PIT) tag (Oregon RFID, Portland, OR). We measured each Blue Sucker to the nearest mm TL and recorded its capture location with a WAAS-enabled handheld GPS unit (GPSMAP78, Garmin International, Olathe, Kansas). We determined sex based on the presence of tubercles or tubercle scars. We collected pectoral fin rays from each fish to estimate age and reconstruct growth history. We removed a 0.5–1.0 cm section of the first pectoral fin ray as close to the body as possible using bone cutters and stored it in ethanol. We cleaned the fin rays, mounted them in epoxy resin, and sectioned each using a low-speed saw (Model 650 Low Speed Diamond Wheel Saw, South Bay Technology, San Clemente, California). We mounted the resulting thin sections to glass slides and photographed using a binocular dissecting microscope equipped with a digital camera (Olympus SZX16, Infinity 1, Olympus, Tokyo, Japan). We assessed age by counting the annuli from the center of the fin ray section and measured the radius of the entire cross sections as well as to each annulus using ImageJ v. 1.48 (Abramoff et al. 2004). We back-calculated length at age using the direct proportion method (Campana 1990; Schramm et al. 1992). Two independent readers assessed the age. A third reader resolved any discrepancies between the first two readers, and we excluded the sample from further analysis if a consensus estimate was not reached.

Table 2. The sampling date, electrofishing effort, and Blue Sucker capture number of each study area in the lower Sabine River in 2016–2018. Missing data in the table indicate no sampling effort.

Date	Electrofishing effort (s)	Toledo Bend tailrace	Bayou Anacoco	Bon Wier
10/22/2016	1,677		3	
10/25/2017	2,289	13		
10/26/2017	3,325			15
5/30/2018	26,380			28
5/31/2018	32,865		22	
6/1/2018	3,078	15		

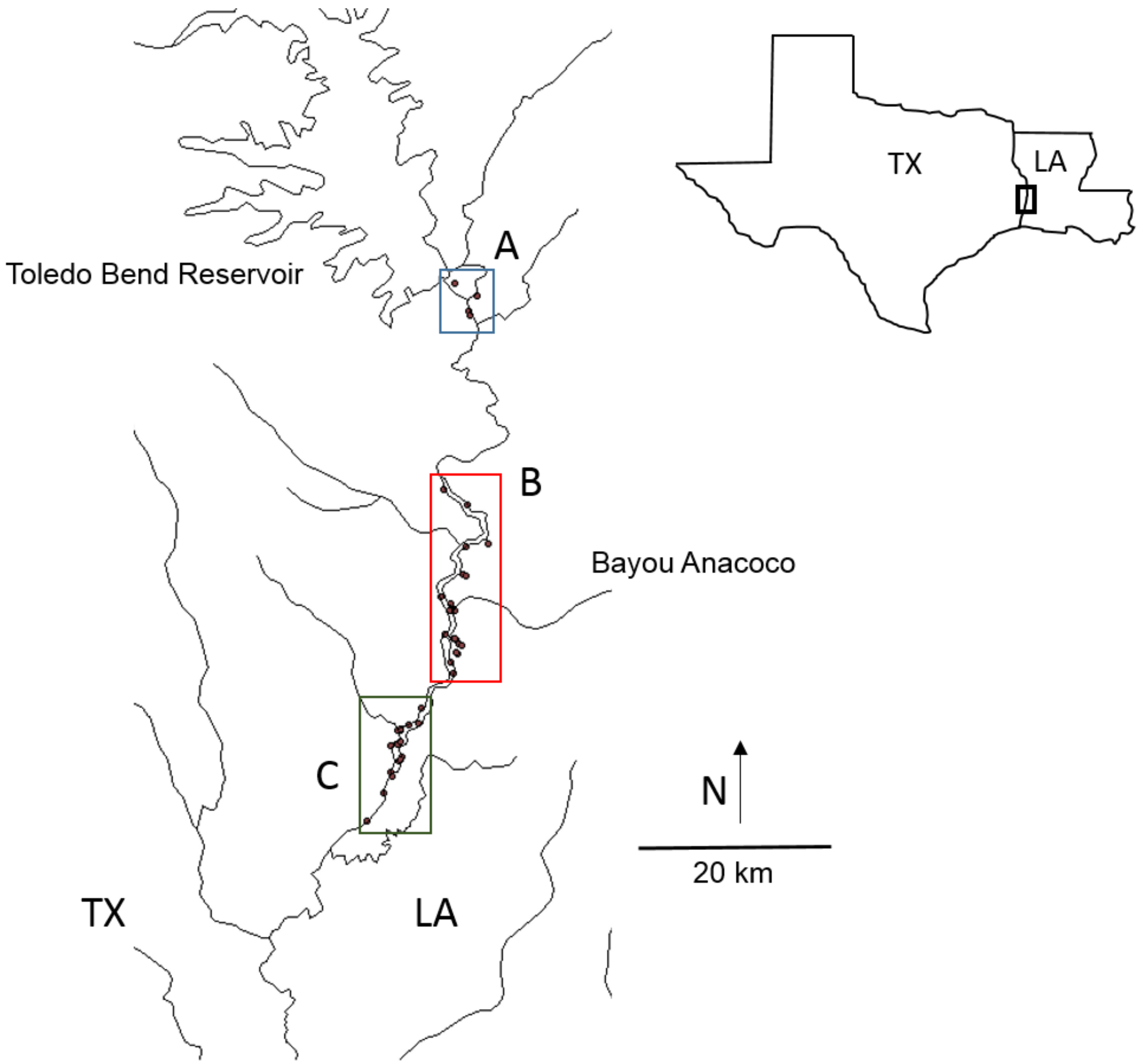

Figure 6. Blue Sucker sampling areas in the lower Sabine River including Toledo Bend tailrace area (A), Bayou Anacoco area (B), and Bon Wier area (C). Small points in the map indicate the spatial positions of electrofishing sampling locations.

Data Analyses

To assess Blue Sucker growth, we fitted a von Bertalanffy growth function (VBGF), $L_t = L_\infty(1 - e^{-k(t)})$, where L_t = length at time t, L_∞ = asymptotic length, k is a growth coefficient, t is age, to the length at age data back-calculated from measurements on the pectoral fin rays. We set the initial condition parameter (t_0) for the VBGF to zero due to a paucity of short young fish (Bednarski and Scarnecchia 2006). To assess Blue Sucker recruitment, we used the studentized residuals from a catch curve as an index of year-class strength (Maceina 1997). For these analyses, we used the FSA 0.8.19 package (Ogle 2018) implemented using the statistical program R v. 3.51 (R Development Core Team 2018).

We analyzed the mean daily discharge data (1956–2017) from the stream gage at Burkeville, Texas (USGS 08026000) using Indicators of Hydrological Alteration v. 7.1 (IHA; Richter et al. 1996). The IHA calculates a total of 33 IHA parameters including five groups: 1) magnitude of monthly water conditions, 2) magnitude and duration of annual extreme water conditions, 3) timing of annual extreme water conditions, 4) frequency and duration of high and low pulses, and 5) rate and frequency of water condition changes. We performed a principal component analysis (PCA) to reduce the dimensionality of the IHA parameters and solve the problem of collinearity among the parameters (Jacquemin et al. 2015). We used PC-ORD v. 6 (McCune and Mefford 1999) to perform the PCA.

We tested the IHA parameters (PCA axis scores) and individual age for influence on standardized growth of Blue Sucker using linear mixed effects models. The IHA parameters were represented as covariates, back-calculated age as an independent variable and individual as the random effect in the models. We also tested the IHA parameters for influence on the recruitment of Blue Sucker using Spearman’s rank correlation. We used the residuals of VBGF curves for the response variable of the linear mixed effects models and the index of year-class strength for the response variable of the Spearman's rank correlation. For the linear mixed effects models, we used the lme4 1.1-15 package (Bates et al. 2017) implemented using the statistical program R v. 3.51 (R Development Core Team 2018).

Results

We captured 96 Blue Sucker from the lower Sabine River sites during the study period (Table 2). The overall CPUE (catch per hour electrofishing) at all sites was 4.92 fish/hr. The CPUE of Toledo Bend tailrace, Bayou Anacoco, and Bon Wier areas were 18.78, 2.58, and 5.16 fish/hr, respectively. Blue Sucker ranged from 294–636 mm in total length. The majority (97%) of Blue Sucker collected were TL > 420 mm (Figure 7). Although the age of the captured Blue Sucker ranged from 2–9 years, most of the fish collected were 3–5 years old (Figure 8).

The L_∞ and K of VBGF for the length at age data back-calculated from measurements on the pectoral fin rays was 515.3 mm (95% CI: 502.9 mm, 528.4 mm) and 0.58 (95% CI: 0.54, 0.62), respectively. The index of year-class strength for 2009 was strongest whereas the index of year-class strength of 2011 was weakest (Figure 9). The PCA axes 1 and 2 explained a total of 53.9 % of the variation of the IHA parameters (Table 3). The PCA axis 1 was positively related to the river discharge of each month and the minimum and maximum flows and was negatively related to fall rate. The PCA axis 2 was positively related to base flow and reversal. The flow data from 2008–2017 (years used for our data analyses) were widely scattered in the PCA biplot (Figure 10), indicating that this time period had a wide range of hydrological conditions. Blue Sucker growth was positively related to axis 1 of the PCA (Table 4), suggesting that the growth increased with increasing river discharges in June–July and increasing 30- and 90-day minimum flow (estimate = 0.03, P = 0.04). The index of the year-class strength was positively and negatively related to the PCA axis 1 (r = 0.67, P = 0.11) and axis 2 (r = -0.75, P = 0.07), respectively.

Discussion

Blue Sucker > 420 mm TL dominated the length–relative frequency distribution of fish collected during the study period. The scarcity of Blue Sucker collected less than this size range was also reported in previous studies in the lower Sabine River (BIO-WEST, Inc. 2011; Mayes 2015) and other river basins (Eitzmann et al. 2007; Bacula et al. 2009; Acre 2019). This may be related to gear biases associated with electrofishing, young Blue Sucker rarely occupying habitats sampled, and low recruitment of Blue Sucker in recent years (Morey and Berry 2003; Eitzmann et al. 2007; Bacula et al. 2009).

The IHA parameters were correlated with the growth of Blue Sucker in our study sites. Our results showed that the growth of Blue Sucker increased with increasing the river discharge (especially from early summer to fall) in our study areas. Research on effects of flow regime on Blue Sucker growth is still limited; however, relationships between flow regime and growth were reported in other catostomids (Grabowski et al. 2012; Quist and Spiegel 2012). Grabowski et al. (2012) studied the growth of several riverine catostomids in the Apalachicola River, Florida and reported that the growth in these species had positive responses to high flows (75^{th}–90^{th} percentile range). Quist and Spiegel (2012) studied the growth of eight riverine catostomids in Iowa rivers and found that high flows (> 75^{th} percentile) were positively related to the growth of these fish species. Our results concur with these findings, supporting the hypothesis that the

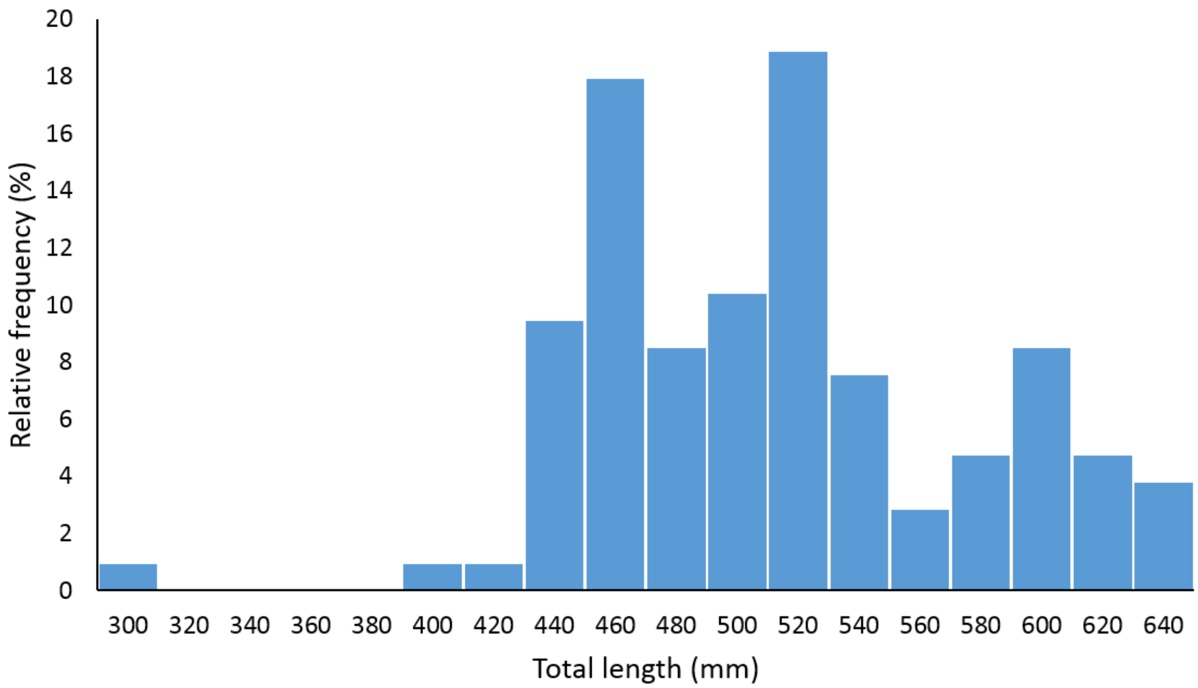

Figure 7. Length-relative frequency histogram of Blue Sucker (N=106) in the lower Sabine River.

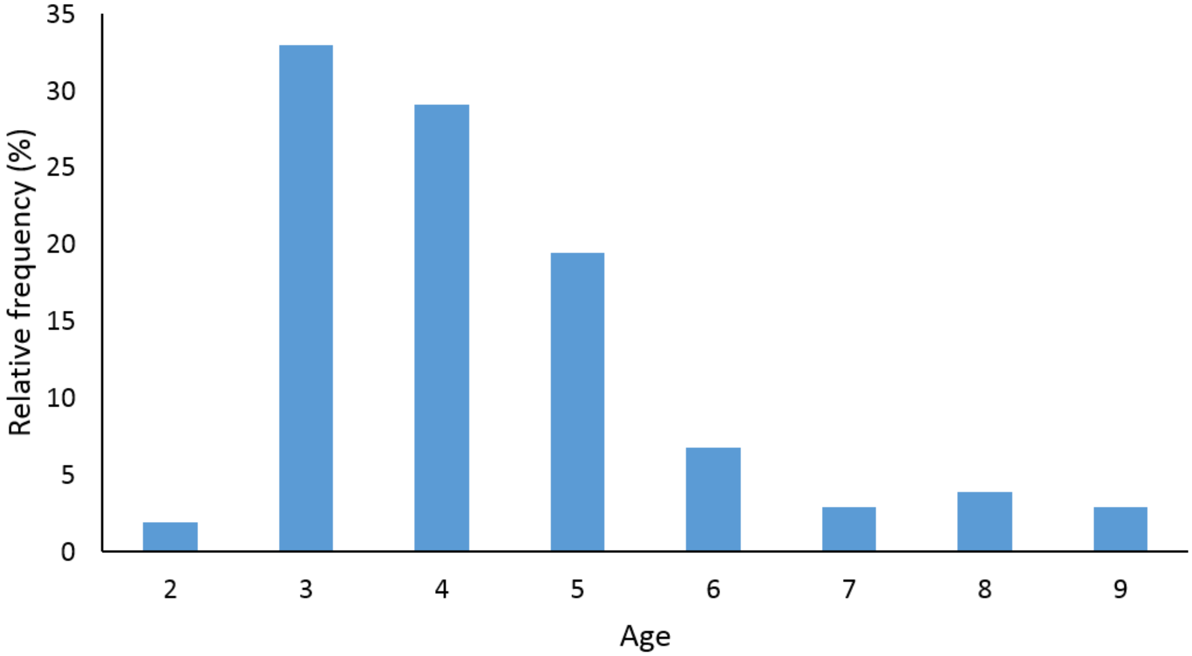

Figure 8. Age-relative frequency distribution of Blue Sucker (N=103) in the lower Sabine River.

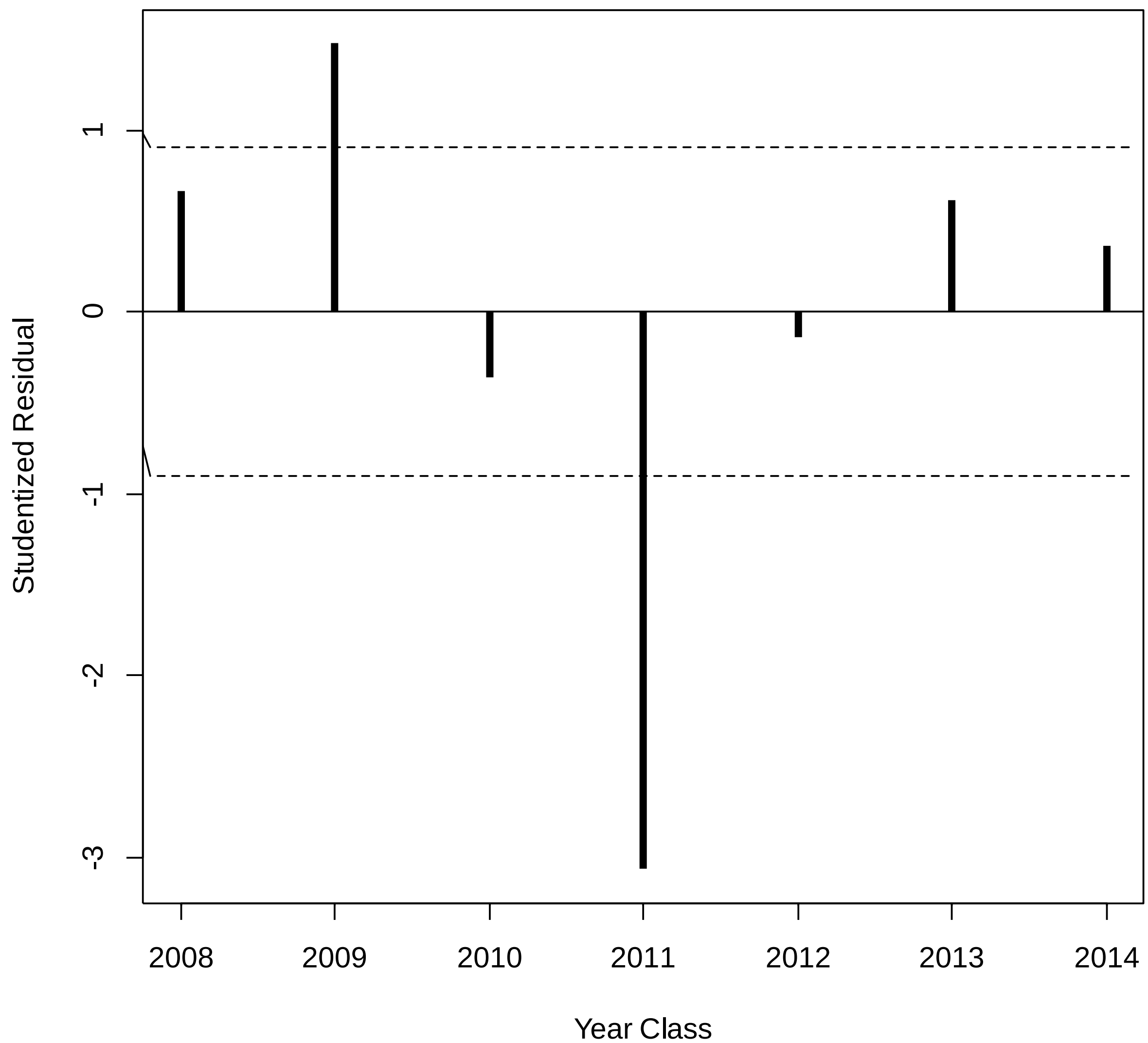

Figure 9. Studentized residuals from the weighted catch curve for Blue Sucker in the lower Sabine River. Horizontal dotted lines represent the upper and lower 20% of residuals. Year-classes above the upper dotted line are considered to be “strong” and year-classes below the lower dotted line are considered to be “weak.”

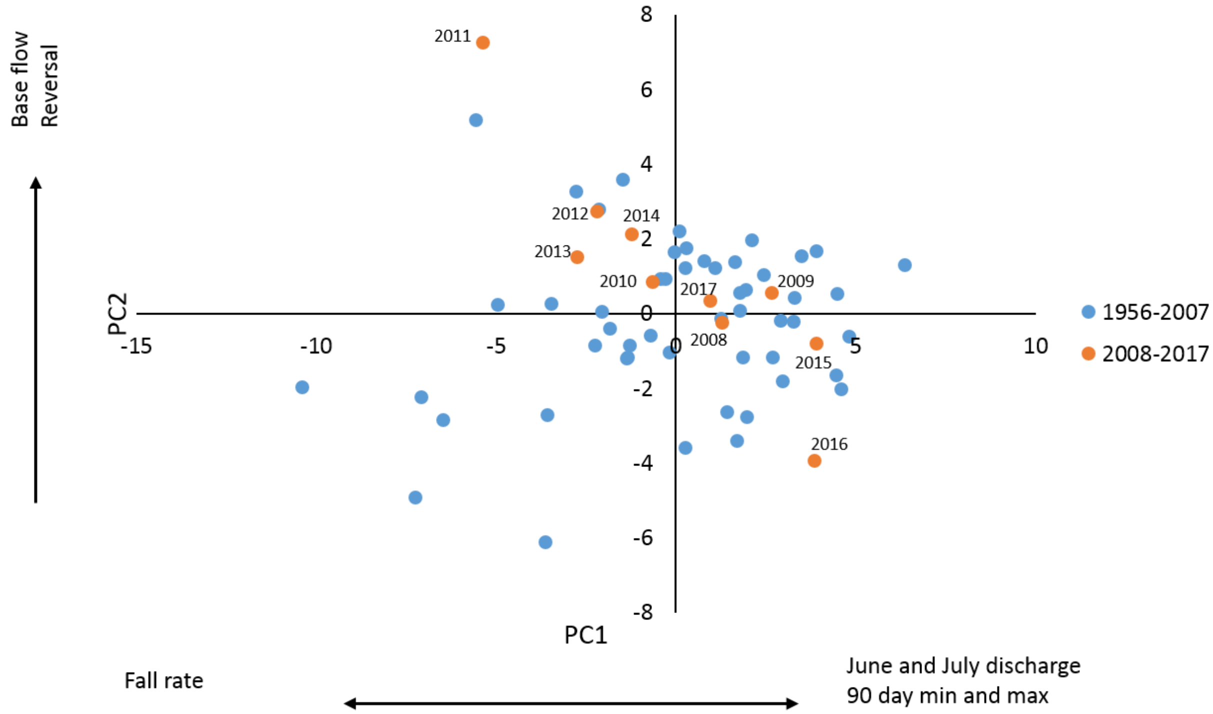

Figure 10. The biplot with axis 1 and 2 of the principal components analysis for the hydrological parameters from Indicators of Hydrological Alteration (IHA). Daily discharge data (1956–2017) from the stream gage at Burkeville, Texas (USGS 08026000) for IHA.

Table 3. Results of hydrology principal components analysis. Eigenvector values are arranged by major hydrological grouping.

IHA Type	IHA Parameter	PC1	PC2
Magnitude of monthly conditions	January	0.56	-0.13
	February	0.58	-0.19
	March	0.59	-0.31
	April	0.59	-0.32
	May	0.52	-0.49
	June	0.70	-0.14
	July	0.75	0.19
	August	0.54	0.15
	September	0.67	0.07
	October	0.57	0.43
	November	0.60	0.31
	December	0.48	0.16
Magnitude and duration of annual extremes	1-day min	0.54	0.33
	3-day min	0.63	0.56
	7-day min	0.62	0.61
	30-day min	0.71	0.55
	90-day min	0.81	0.31
	1-day max	0.79	-0.40
	3-day max	0.80	-0.44
	7-day max	0.80	-0.48
	30-day max	0.78	-0.45
	90-day max	0.83	-0.41
	Base flow	-0.33	0.73
Timing of annual extreme conditions	Date of min	0.02	-0.20
	Date of max	-0.16	-0.15
Frequency and duration of pulses	Low pulse number	-0.10	0.69
	Low pulse duration	-0.43	-0.66
	High pulse number	0.62	0.00
Rate and frequency of water condition changes	Rise rate	0.72	0.20
	Fall rate	-0.70	-0.21
	Reversal	0.05	0.78
% Variance explained		37.0	16.8

Table 4. Results of the linear mixed effects model with principal components analysis scores (PC1) and Blue Sucker age in the lower Sabine River.

	Estimate	SE	Z-value	P-value
(Intercept)	0.132	0.120	1.100	0.271
PC1	0.030	0.015	1.981	0.048
Age	-0.076	0.037	-2.037	0.042

maintenance of high flows could be important for maintaining high growth rates in riverine catostomids. In contrast, Acre (2019) examined relationships between flow regime and Blue Sucker growth in the lower Colorado River in Texas and reported that hydrological parameters such as the rise rate and one-day maximum flow were negatively related to the first year of the growth. Grabowski et al. (2012) also suggested that extreme flows ($\geq 90^{th}$ percentile) may negatively affect the growth during ages 1–3 in certain catostomids. Thus, further research to examine if high flow extremes could negatively affect the growth of blue suckers is needed.

Cohort strength varied among years with the weakest observed year class occurring in 2011. Texas experienced the peak of the drought of record for the state in 2011 and the river discharge was lower than other years. This suggest that spawning and recruitment may be negatively related to low flows. The information on the effects of flow regime on the spawning and recruitment of blue suckers is also still limited and the information likely varied across Blue Sucker studies. Previous studies suggest that a rising hydrograph may be a cue that initiate the spawning migration of Blue Sucker in the lower Sabine River and other riverine systems (LaBay et al. 2007; Mayes 2015). The cohort strength of Blue Sucker in the lower Colorado River in Texas was positively related to river discharge in September and high flow pulse frequency (Acre 2019). Adams et al. (2006) reported that the reproduction of blue suckers is likely better in a year with little to no flooding during spawning. These results suggest that the importance of flow regime (e.g., high flow vs. low flow) could vary with the life stage of blue suckers (e.g., before spawning, during spawning, and after spawning). Further research on effects of flow regime on Blue Sucker spawning and recruitment is also needed.

The flow regime in the lower Sabine River has been substantially affected by dam operations, and Blue Sucker in this area may have been affected by this flow alteration. This study found that the flow alterations could affect the growth and recruitment of Blue Sucker in the lower Sabine River. Our results suggest that decreases in river discharge in certain seasons (early summer to fall) could negatively affect the growth and recruitment of Blue Sucker in the lower Sabine River. Thus, decreases in flows released by the dam operation in early summer–fall season may negatively affect Blue Sucker growth and recruitment in the lower Sabine River. However, it is difficult to determine the appropriate timing and amount of flow release for Blue Sucker in the lower Sabine River in this short-term study. Long-term monitoring designed to assess the effects of flow alterations on growth and recruitment of Blue Sucker is needed in the lower Sabine River.

Chapter 3: Life-history Trait Variation in Blue Suckers across River Basins

Objective

The objective of this chapter is to examine differences in life-history traits of Blue Suckers and flow regimes across river basins in Texas.

Method

Study Areas

In this chapter, we focused on blue suckers in three study areas: the Rio Grande in Big Bend region in Texas, the lower Sabine River in Texas and Louisiana, and the lower Colorado River in Texas (Figure 11). Study areas for the Rio Grande in Big Bend region and the lower Sabine River were described in previous chapters. Acre (2019) described the lower Colorado River study area in in detail. To summarize, the Colorado River runs through the Texas Hill Country and drops off the Edwards Plateau where it flows into a series of reservoirs collectively known as the Highland Lakes; the lakes regulate discharge into the lower Colorado River downstream of Austin, Texas. Significant alterations to discharge have been reported since the construction of the first major dams along the Colorado River above Austin, Texas including more severe and frequent low flows throughout the basin (e.g., Mosier and Ray 1992). The study area in the lower Colorado River encompasses a 292-river km reach downstream of Longhorn Dam (river km 460) to Altair, Texas (river km 168).

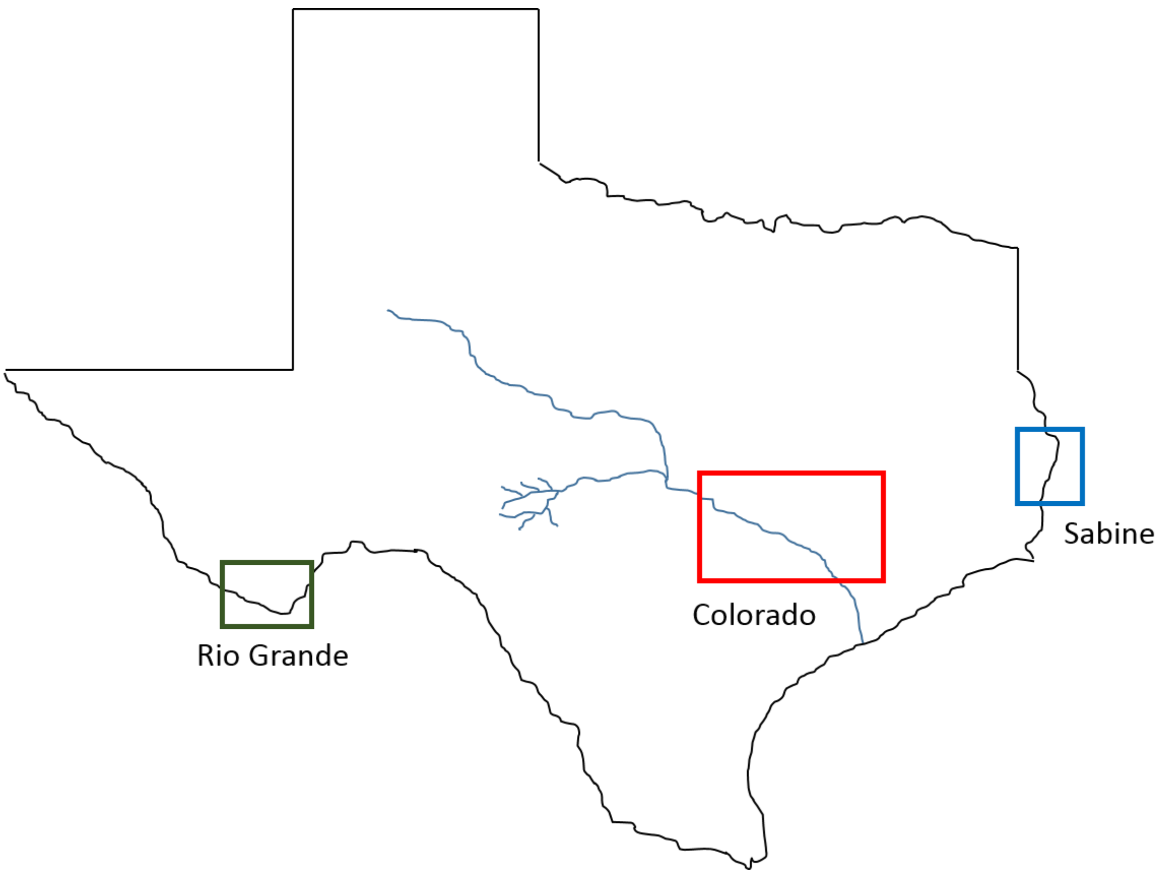

Figure 11. Spatial positions of the Blue Sucker study areas in the Rio Grande, Colorado, and Sabine rivers in Texas.

Data Collection

The Blue Sucker data in the lower Sabine River for this chapter were the same as the previous chapter. We collected Rio Grande Blue Sucker for this chapter by boat electrofishing and gill netting in the Rio Grande in the Big Bend region (Figure 12, Table 5). In December 2016, we conducted adult Rio Grande Blue Sucker sampling using a boat electrofisher (Smith Root 5.0 gpp), settings at pulsed DC power at 60 pulses s^{-1} (Hz) with voltage and pulse width adjusted to maintain an output of approximately 8 amperes, in the Rio Grande at Arenosa, La Cuesta, Madera, and Grassy Banks sites in Big Bend Ranch State Park, Texas. In April–June 2018, we conducted adult Rio Grande Blue Sucker samplings using three gill nets (24.5 m long × 2.56 m deep, 12.5-cm mesh; 26.3 m long × 2.28 m deep, 9.5-cm mesh; 31.0 m long × 2.74 m deep, 7.62-cm mesh) and two experimental gill nets (24.3 m long × 1.82 m deep, 5-8.8 cm mesh) in the Rio Grande at Colorado Canyon, La Cuesta, Madera, Grassy Banks, and Santa Elena Canyon sites. Each Blue Sucker received a uniquely coded half duplex PIT tag (Oregon RFID, Portland, OR). We measured each Blue Sucker TL to the nearest mm and recorded its capture location with a WAAS-enabled handheld GPS unit (GPSMAP78, Garmin International, Olathe, Kansas). We determined sex based on the presence of tubercles or tubercle scars. We collected pectoral fin rays from each fish to estimate age and reconstruct growth history. We removed a 0.5–1.0 cm section of the first pectoral fin ray as close to the body as possible using bone cutters and stored it in ethanol. We cleaned the fin rays, mounted them in epoxy resin, and sectioned each using a low-speed saw (Model 650 Low Speed Diamond Wheel Saw, South Bay Technology, San Clemente, California). We mounted the resulting thin sections to glass slides and photographed using a binocular dissecting microscope equipped with a digital camera (Olympus SZX16, Infinity 1, Olympus, Tokyo, Japan). We assessed age by counting the annuli from the center of the fin ray section and measured the radius of the entire cross sections as well as to each annulus using ImageJ v. 1.48 (Abramoff et al. 2004). We back-calculated length at age using the direct proportion method (Campana 1990; Schramm et al. 1992). Two independent readers assessed the age. A third reader resolved any discrepancies between the first two readers, and we excluded the sample from further analysis if a consensus estimate was not be reached.

We used the Blue Sucker data (N = 200) in the lower Colorado River (Figure 13) in Texas from Acre (2019). The Blue Sucker sampling design in the lower Colorado River has been described in detail from Acre (2019). To summarize, a total of 30 sites were randomly selected from all available riffles (N = 298) which were identified as areas with swift-moving water where most of the water surface was broken and ≤ 1.5 m in depth. Sites were then subdivided into three mesohabitats (riffle, run, pool) which were sampled independently. Each mesohabitat at every site was sampled using electrofishing boats for approximately 600 seconds for a total of 1800 seconds per site.

Data Analyses

Because only five Rio Grande Blue Sucker fin rays were available, we used only Blue Sucker data from the Sabine and Colorado rivers samplings for the following data analyses. We visually assessed the size and age structures of the Blue Sucker from Sabine and Colorado rivers with length/age-relative frequency histograms. We examined if there was significant difference in size/age structure between the Sabine and Colorado rivers using the Kolmogorov-Smirnov (K-S) two-sample test (Neumann and Allen 2007). For assessing growth, we fitted a VBGF, $L_t = L_\infty(1-e^{-k(t)})$, where L_t = length at time t, L_∞ = asymptotic length, k is a growth coefficient, t = age, to the length at age data of the Blue Sucker in the two river basins, respectively. We set the initial

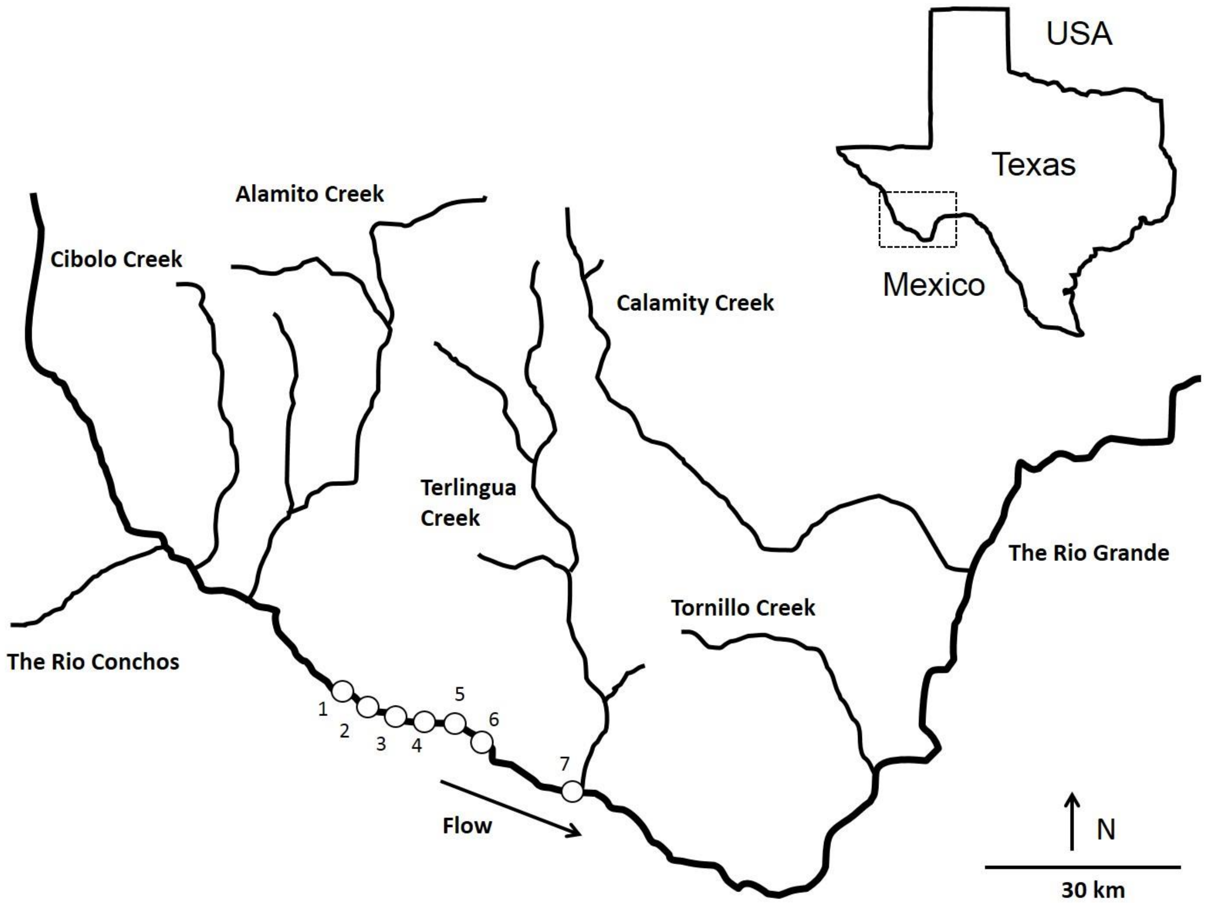

Figure 12. Spatial positions of adult Rio Grande Blue Sucker sampling sites. Site 1, 2, 3, 4, 5, 6, and 7 indicate Arenosa, Colorado Canyon, La Cuesta, Madera, Grassy Banks, Contrabando, and Santa Elena Canyon sites, respectively. Site 1–6 are in Big Bend Ranch State Park and site 7 is in Big Bend National Park.

Table 5. Sampling date, method, and hour and the number of captures during Rio Grande Blue Sucker sampling in the Rio Grande in 2016–2018. The site number corresponds to the site number in Figure 12. Missing data in the table indicate no sampling effort.

Date	Sampling method	Sampling hour	Site1	Site2	Site3	Site4	Site5	Site6	Site7
12/13/2016	Electrofishing	0.52					0		
12/14/2016	Electrofishing	1.6	0		0	2			
4/13/2018	Gill netting	2						0	
4/14/2018	Gill netting	5			0	0			
4/15/2018	Gill netting	4					0		
5/21/2018	Gill netting	8				0			
5/22/2018	Gill netting	8.6		0		0			0
5/23/2018	Gill netting	1.3							0
6/22/2018	Gill netting	2							2
6/23/2018	Gill netting	4							2
6/24/2018	Gill netting	3							2

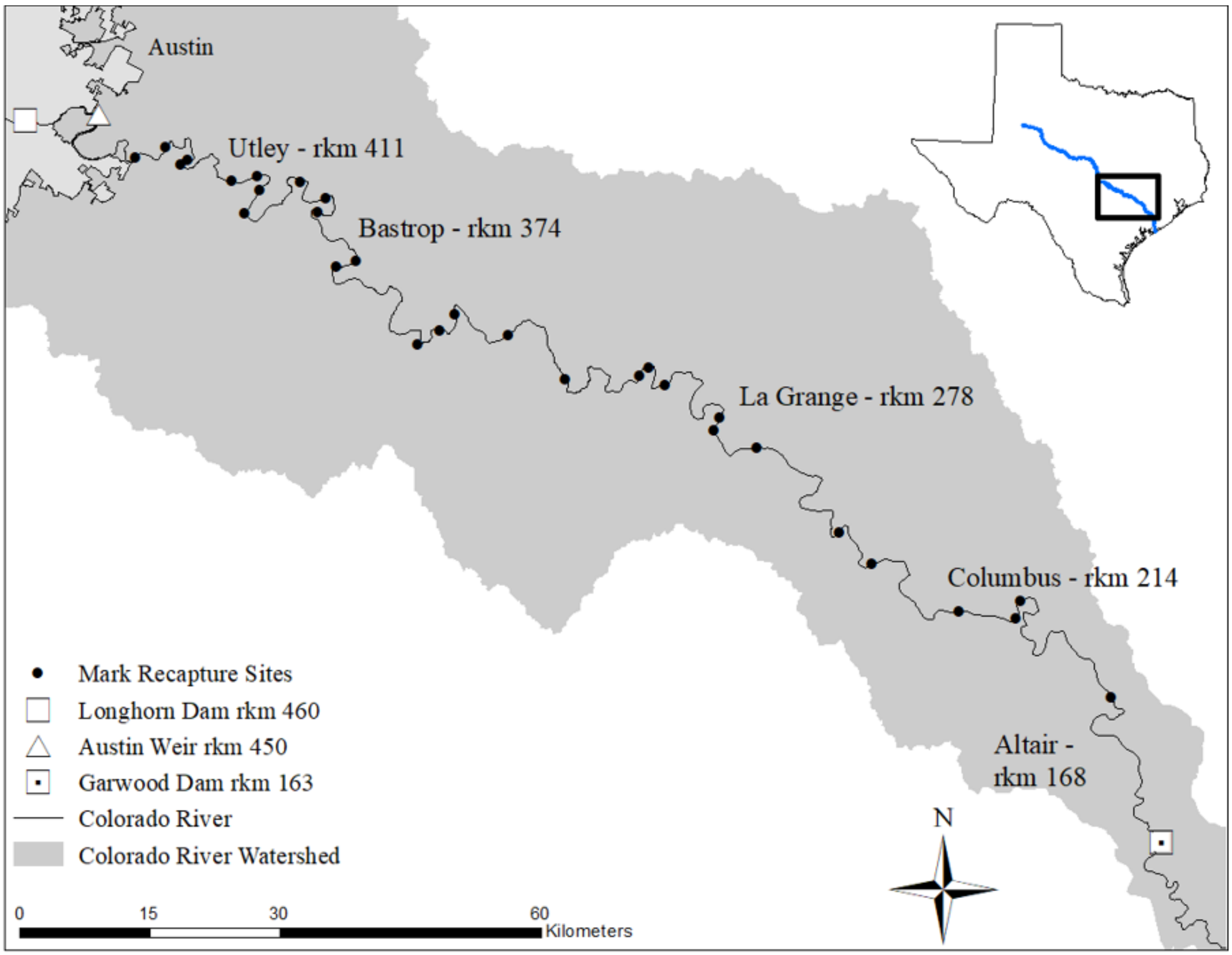

Figure 13. Spatial locations of Blue Sucker sampling sites in the lower Colorado River (Acre 2019).

condition parameter (t_0) for the VBGF to zero due to a paucity of short young fish (Bednarski and Scarnecchia 2006). We used non-linear regression to determine the von Bertalanffy growth curve.

To estimate the instantaneous total mortality rate (*Z*), we used the negative slope of a linear regression model fit to the natural logarithm of catch at each age on the descending limb (Miranda and Bettoli 2007). We used a weighted regression to reduce the relative effect of older ages with fewer fish on estimated *Z* (Maceina and Bettoli 1998). We used the youngest cohort with the highest frequency of catch as the age of fish that are fully vulnerable to the gear for the mortality estimate (Ricker 1975). Thus, we included fish aged ≥ 3 for the Blue Sucker mortality estimate in the lower Sabine River. For the mortality estimate, we used age 8–24 of Blue Sucker in the lower Colorado River (Acre 2019). The selection of the cohorts (age 8–24) in the lower Colorado River has been described in detail from Acre (2019). We used analysis of covariance (ANCOVA) to examine differences in mortality between Sabine and Colorado rivers in the slopes of catch curve regressions (i.e., examined difference in mortality rate between the rivers).

We analyzed the USGS river gage data of Sabine and Colorado rivers using IHA (Richter et al. 1996) software (ver. 7.1, The Nature Conservancy). For the IHA, we used mean daily river discharge data from the Burkeville USGS gaging station (USGS 08026000, 1956–2017) in the lower Sabine River and the Bastrop USGS gaging station (USGS 08159200, 1961–2017) in the lower Colorado River. We used multi-response permutation procedures (MRPP) to determine the statistical differences in the IHA parameters in the two river basins. Multi-response permutation procedure is a nonparametric procedure that examines group differences (McCune and Grace, 2002). We used PC-ORD version 6 (McCune and Mefford 1999) to perform the PCA and MRPP.

Results

We captured eight Rio Grande Blue Sucker in the Rio Grande during the study period (refer to table). We captured two Rio Grande Blue Sucker (TL 283 mm and 311 mm) in riffle habitats in Madera site by boat electrofishing and six Rio Grande Blue Sucker (TL range: 442–650 mm) in pool habitats at Santa Elena Canyon site by gill netting. The electrofishing CPUE (catch per hour electrofishing) during the study period was 0.94. We collected five pectoral fin rays (age 3–8) of Rio Grande Blue Sucker using the gill net sampling. During gill net sampling, we also captured other fish species including Smallmouth Buffalo *Ictiobus bubalus* (n = 28), Gizzard Shad *Dorosoma cepedianum* (n = 20), Common Carp *Cyprinus carpio* (n = 5), Freshwater Drum *Aplodinotus grunniens* (n = 4), River Carpsucker *Carpiodes carpio* (n = 2), and Longnose Gar *Lepisosteus osseus* (n = 2).

The size and age structures of Blue Sucker in the lower Sabine River were different from those of Blue Sucker in the lower Colorado River (Figure 14 and 15, K-S tests: $P < 0.001$). The total length (mean ± SD) and age (mean ± SD) of Colorado River Blue Sucker were 665.4 ± 47.2 mm (range: 496–774 mm; n = 200) and 11.6 ± 1.5 (range: 3–24; n = 200) whereas the total length (mean ± SD) and age (mean ± SD) of Sabine River Blue Sucker were 504.1 ± 62.2 mm (range: 294–636 mm; n = 106) and 4.3 ± 4.2 (range: 2–9; n = 103). The L_{∞} and K of VBGF for the length at age data of Sabine River Blue Sucker were 592.9 mm (95% CI: 567.4 mm, 621.9 mm) and 0.48 (95% CI: 0.41, 0.55) whereas those of VBGF for the length at age of Colorado River Blue Sucker were 687.9 mm (95% CI: 681.1, 694.7) and 0.37 (95% CI: 0.34, 0.40). The Z of Sabine River Blue Sucker was 0.50 ± 0.07 whereas the Z of Colorado River Blue Sucker was 0.16 ± 0.03 (Acre 2019). The slopes of catch curves of Blue Sucker between Sabine and Colorado rivers were different (ANCOVA: parallelism, $F = 7.5$, $P = 0.012$). Flow regime differed between the river basins (MRPP: T = -30.4, P < 0.001). March river discharge, maximum flow, and rise/fall rates in the lower Sabine River tended to be higher than those in the lower Colorado River (Table 6, Figure 16).

Discussion

We captured eight adult Rio Grande Blue Sucker during the study period. The electrofishing CPUE of our Rio Grande Blue Sucker sampling was lower than those of other study systems (lower Sabine River and lower Colorado River). The low capture rate of adult Rio Grande Blue Sucker was possibly because the river discharge (9.0–13.5 m^3/s) and turbidity (243–585 NTU) were too high to effectively conduct boat electrofishing in the region. The Rio Grande in the Big Bend region tends to have high flow from fall to winter. Although the high-water season (fall to winter) seems to be appropriate for boating in the Rio Grande, we suggest that winter to spring season could be more appropriate season for electrofishing (especially for barge electrofishing) because the river discharge and turbidity were lower than other seasons (personal observations in 2016–2018). Using gill net sampling, we caught Rio Grande Blue Sucker from only Santa Elena Canyon area and the Rio Grande Blue Sucker were captured by wedging (fish held by the mesh around the body). Because our sampling effort and season were limited, our data do not provide a clear explanation as to the reason that we caught adult Rio Grande Blue Sucker from only one study area. Miranda and Colvin (2017) suggest that gill net sampling can be highly size-selective if wedging is the primary means of retention of target fishes. Thus, we need to select appropriate gill net mesh size according to our target Rio Grande Blue Sucker size. To our knowledge, adult Rio Grande Blue Sucker studies are very limited in the Rio Grande. Although we could not catch

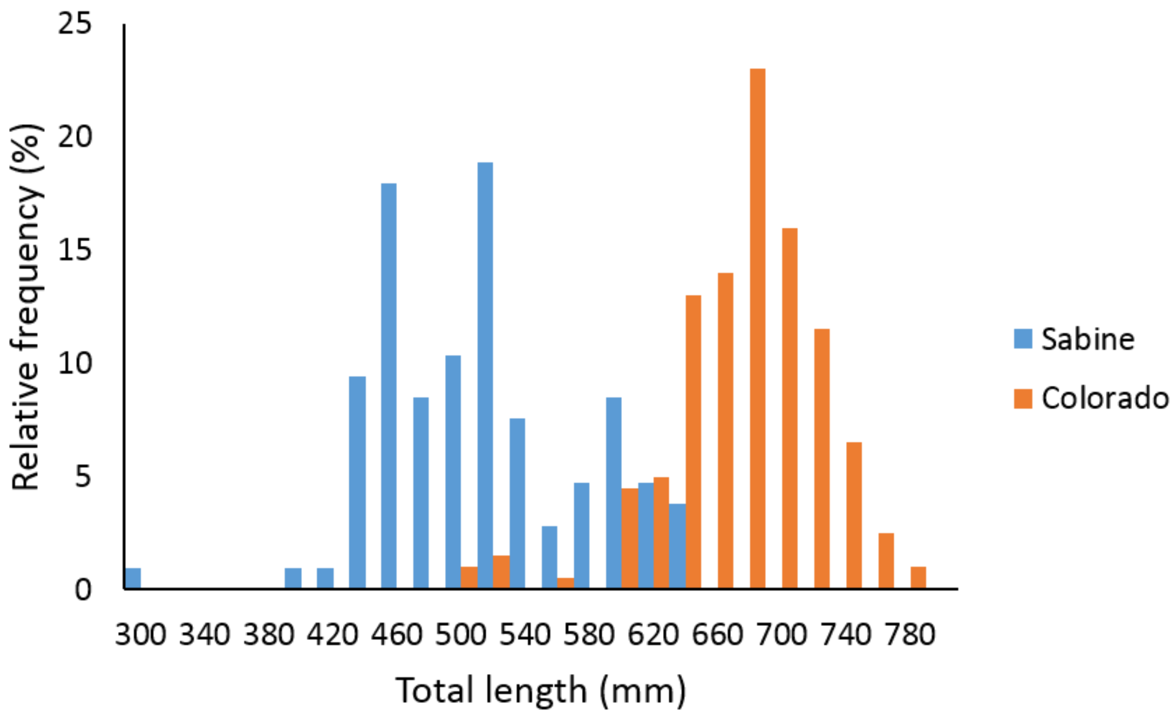

Figure 14. Length-relative frequency histogram of Blue Sucker in the lower Sabine River (N = 106) and the lower Colorado River (N = 200).

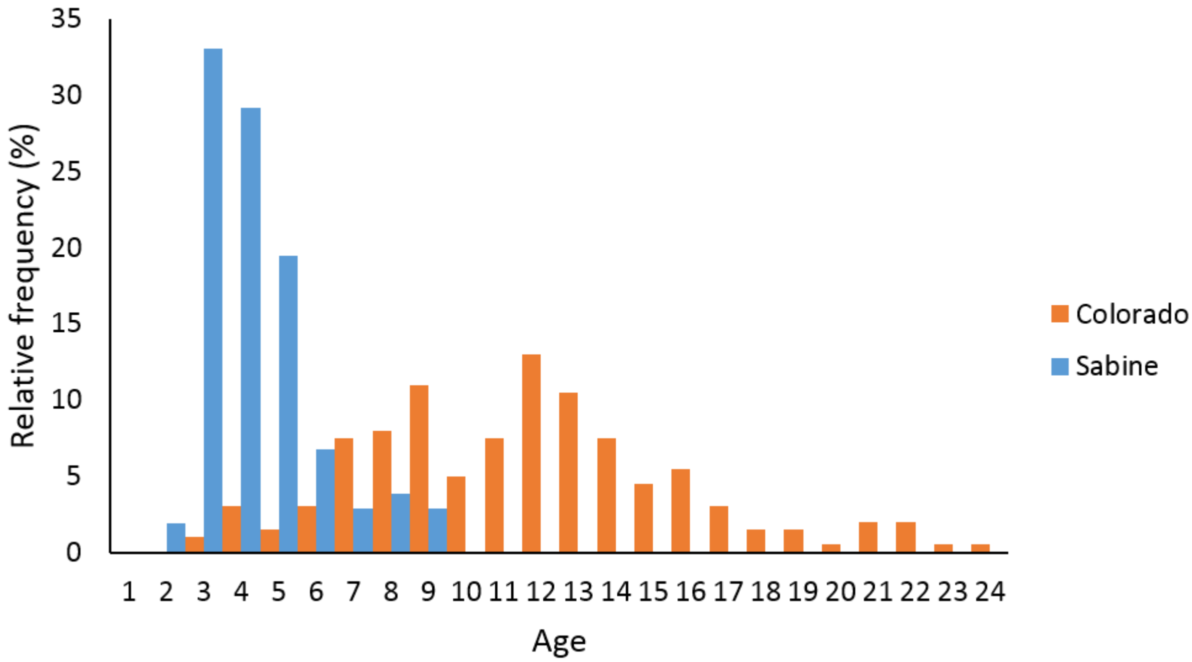

Figure 15. Age-relative frequency histogram of Blue Sucker in the lower Sabine River (N = 103) and the lower Colorado River (N = 200).

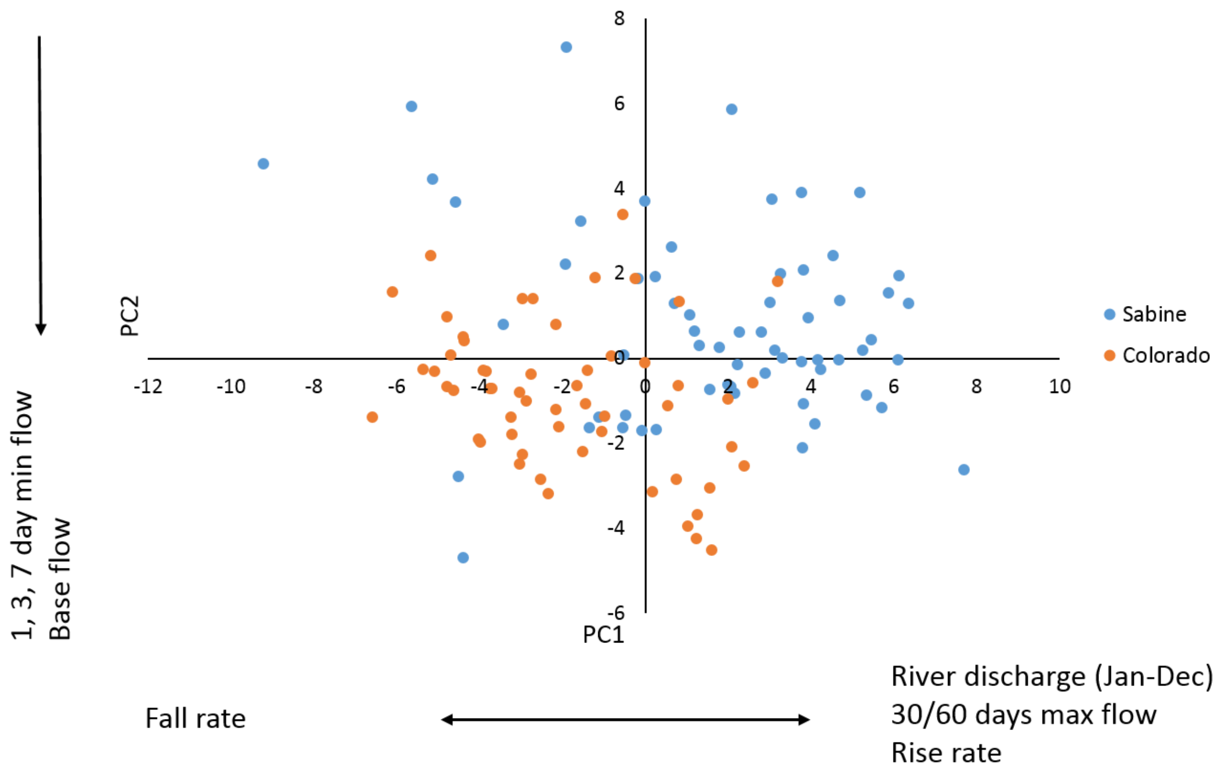

Figure 16. The biplot of principal components analysis with IHA parameters of discharges in the lower Sabine (Burkeville, 1956–2017) and the lower Colorado (Bastrop, 1961–2017) rivers.

Table 6. Results of hydrology principal components analysis for flow regime of lower Sabine and Colorado rivers. Eigenvector values are arranged by major hydrological grouping.

IHA Type	IHA Parameter	PC1	PC2
Magnitude of monthly conditions	January	0.69	0.25
	February	0.69	0.38
	March	0.74	0.33
	April	0.67	0.30
	May	0.57	0.40
	June	0.62	0.07
	July	0.66	-0.15
	August	0.59	0.06
	September	0.55	-0.05
	October	0.49	-0.64
	November	0.60	-0.44
	December	0.63	-0.20
Magnitude and duration of annual extremes	1-day min	0.48	-0.69
	3-day min	0.54	-0.71
	7-day min	0.59	-0.68
	30-day min	0.73	-0.57
	90-day min	0.83	-0.33
	1-day max	0.76	0.13
	3-day max	0.83	0.19
	7-day max	0.86	0.24
	30-day max	0.89	0.30
	90-day max	0.86	0.36
	Base flow	-0.47	-0.67
Timing of annual extreme conditions	Date of min	0.02	0.42
	Date of max	-0.20	-0.37
Frequency and duration of pulses	Low pulse number	0.05	0.00
	Low pulse duration	-0.44	0.41
	High pulse number	0.16	-0.36
Rate and frequency of water condition changes	Rise rate	0.81	0.12
	Fall rate	-0.77	-0.07
	Reversal	-0.16	-0.51
% Variance explained		39.1	15.5

many adult Rio Grande Blue Sucker during our study, this study is a first step in providing adult Rio Grande Blue Sucker sampling information in the mainstem Rio Grande. Because our sampling effort and season were limited, our data do not provide a clear explanation as to the reason that we caught adult Rio Grande Blue Sucker from only one study area. Miranda and Colvin (2017) suggest that gill net sampling can be highly size-selective if wedging is the primary means of retention of target fishes. Thus, we need to select appropriate gill net mesh size according to our target Rio Grande Blue Sucker size. To our knowledge, adult Rio Grande Blue Sucker studies are very limited in the Rio Grande. Although we could not catch many adult Rio Grande Blue Sucker during our study, this study is a first step in providing adult Rio Grande Blue Sucker sampling information in the mainstem Rio Grande.

Our results suggested that the life-history traits of the captured Blue Sucker differed between the lower Sabine River and the lower Colorado River. The total length and age of Blue Sucker in the lower Colorado River were larger than those of Blue Sucker in the lower Sabine River. Age 3 and 4 Blue Sucker dominated our lower Sabine River samples; however, the proportion of these age classes was lower in the lower Colorado samplings, suggesting that the lower Sabine River likely had better Blue Sucker recruitment than the lower Colorado River during recent years. In addition, the growth of Blue Sucker of the lower Sabine River tended to be higher than those of the lower Colorado River. Our results showed that our study area in the lower Sabine River had higher river discharge and higher flood peak than the study area in the lower Colorado River, suggesting that the growth and recruitment of Blue Sucker may be positively related to the river discharge and size. However, the results of our study should be interpreted with caution. Although the flow regime could be an important factor determining the life-history traits of Blue Sucker, other environmental factors (e.g., water quality, temperature, substrate composition, etc.) we did not examine may also be related to the life-history trait differences between the river basins. Further, the sampling design and effort between the river basins differed even though the personnel and equipment used during sampling were the same. In the lower Colorado River sampling, study sites were subdivided into three mesohabitats (riffle, run, pool) which were sampled independently whereas we subjectively sampled only riffle or run habitats in the lower Sabine River. In addition, the sampling effort of lower Colorado sampling was greater than that of the lower Sabine sampling. The differences in the sampling design and effort may bias age-structure and growth estimates (Miranda and Colvin 2017).

Blue Sucker recruitment could vary across the river basins in Texas. We captured many YOY Rio Grande Blue Sucker during our study period (see Chapter 1); however, YOY Blue Sucker were rarely found in the lower Sabine River and the lower Colorado River. BIO-WEST, Inc. (2011) conducted juvenile Blue Sucker sampling in the lower Sabine River in April-July, 2010, but did not catch any YOY Blue Sucker. In contrast, they collected abundant larval and juvenile specimens of other riverine catostomids (Blacktail Redhorse *Moxostoma poecilurum* and Spotted Sucker *Minytrema melanops*) in their surveys. This may suggest that the recruitment of Blue Sucker was low in their study area of the lower Sabine River. Acre (2019) conducted YOY Blue Sucker sampling in the lower Colorado River from 2015–2017, and did not catch any YOY Blue Sucker, but did collect other YOY catostomids during the study period.

This study is the first to quantitatively compare Blue Sucker life history traits across river basins in Texas. We found differences in the life-history traits of blue suckers and flow conditions across the river basins and suggest the importance of landscape-level scale analyses to understand the effects of environmental manipulations on the life history of blue suckers.

Although certain environmental factors such as mesohabitat area and flow regime could be related to the life-history trait variation of blue suckers among the river basins, our data do not provide a clear explanation as to the reason that Rio Grande had better Blue Sucker recruitment than other river systems in Texas. Important areas for future research include 1) quantifying the differences in the mesohabitat area/quality/density among the three river basins; 2) examining interactions between the spatial distributions of potential spawning habitat relative to suitable YOY habitat and how variations in river flow influence their quality and connectivity to each other; 3) continuing to monitor the effects of flow regime on blue suckers for longer time periods.

Our results suggest that mesohabitat area and flow regime could be important factors determining the growth and recruitment of blue suckers, and the importance of these environmental factors could change according to the life-history stage (larval stage, juvenile stage, and adult stage). The management implication for blue suckers is that it may be possible to regulate river flows to enhance recruitment of blue suckers, but that this will require a more complex and adaptive management plan than the one that was implemented in the lower Colorado River (Acre 2019). Our results also suggest that the life-history traits of blue suckers varied across the river basins. Thus, the timing, amount, and duration of flow regulation also need to adjust according to the blue sucker life-history traits of each river basin.

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