FINAL PERFORMANCE REPORT

Federal Aid Grant No. F13AF01214 (T-69-1)

A General Status Assessment of Blue Suckers in Oklahoma Rivers

Oklahoma Department of Wildlife Conservation

August 1, 2013 - June 30, 2018

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Project Leader: Shannon K. Brewer

Executive Summary

In North America, Blue Sucker is listed as vulnerable and the species is listed as some form of conservation concern in many states. Blue Sucker may be secure in the center of their range, and earlier indications of the species decline could be related to a lack of knowledge of the seasonal distributions of the species Our study objectives were to 1. Conduct an extensive literature review to determine sampling sites and project strategy; 2. Identify potential and current spawning sites and habitat selection by Blue Suckers in Oklahoma; 3. Determine the current distribution of Blue Suckers in the Red River in Oklahoma using a random and systematic sampling approach; 4. Collect basic biological data for population assessment; 5. Tag fish for mark and recapture study to estimate abundances in Red River population. Our literature search was concluded in August 2014 and resulted in 37 relevant peer-reviewed papers that we extensively reviewed. Thirty-two of the papers discussed the ecology of *Cycleptus elongatus*, four focused on the Southeastern Blue Sucker *Cycleptus meridionalis* and one paper focused on both species. Of the six meta-analysis parameters, habitat was the most commonly assessed, whereas movement, growth, and age-0 life history were the least investigated topics. We successfully tagged 119 Blue Suckers from four extensive study reaches. We detected Blue Suckers in the Red River tailwater year-round, but the majority of detections in the tributaries (89 of 97) occurred between February and May 2016, during the spawning period. Tagged Blue Suckers were detected in Muddy Boggy River from February 1 to May 7, 2016, but 50% (9 of 18) of detections occurred between March 9 and April 22, 2016 when water temperatures were 12-20°C. Similarly, we detected Blue Suckers in the Kiamichi River from February 8 to April 29, 2016 and 76% (12 of 18) of detections occurred between March 1 and April 14, 2016 (12-

19°C water temperatures). In 2017, we observed only 19 Blue Suckers and 68% of these fish were detected in the Red River tailwater. Eighty-seven percent of our active tracking detections in 2017 (52 of 60) occurred in the Red River between February 27, 2017, and May 5, 2017. We included 197 observations of 51 individuals in the type I spawning-habitat selection analysis, and determined that the distance upstream from the confluence with the mainstem, mean stream depth, and percent woody debris were the most important variables associated with Blue Sucker habitat selection. We included 23 Blue Suckers that were observed on > 4 occasions in our type II resource selection analysis. Our data suggest Blue Sucker are broadly distributed in the lower Red River basin of Oklahoma when flow patterns support connectivity and available deeper-water habitat. In 2017, we captured 281 Blue Suckers from the Red and Kiamichi rivers, and used pectoral rays to age 126 and 123 individuals from the Red and Kiamichi rivers, respectively. Blue Suckers collected from the Red River were 3-22 yrs old. Typically, we collected slightly older individuals from the Kiamichi River (6-23 yrs old). Catch-curves indicated that adult mortality was lower in the Red River than in the Kiamichi River; however, Blue Suckers recruited to the gear at an earlier age in the Red River (age 5, as opposed to age 6). We determined that Blue Suckers in the Red River had greater recruitment variability and were typically less fecund than fish in the Kiamichi River. We marked and released 492 Blue Suckers, but only recaptured six individuals. Due to the low number of recaptures, creating a model based on our data was inappropriate. We suspect the ability to recapture is related to movement activity and that was highly variable by year and appeared strongly tied to hydrology (i.e., sometimes major floods). We provided the basic information to begin a population assessment, however, monitoring efforts are needed to fully evaluate the Blue Sucker population. We were unable to estimate the abundance of the Blue Sucker population using mark-recapture methods due to low detection efficiency and high variation in movements among years. Dams are often implicated as reason for the decline of big-river fishes, and we commonly observed Blue Suckers in the Hugo Dam and Denison Dam tailwaters. Blue Suckers were likely drawn to the swift water via dam-releases. If done properly, dams could be managed to mitigate the loss of upstream habitats. Ramping the dam releases to mimic natural or quasi-natural flows would likely improve the recruitment and survival of Blue Suckers and other fishes that are drawn to tailwater habitat. Because Blue Sucker spent a lot of their reproductive time in the tributaries, it is important to ensure the persistence of these deeper-water habitats or the available spawning habitat will be further truncated (i.e., in addition to current fragmentation via dams).

I. OBJECTIVES:

1. Conduct an extensive literature review to determine sampling sites and project strategy.
2. Identify potential and current spawning sites and habitat selection by blue suckers in Oklahoma.
3. Determine the current distribution of blue suckers in the Red River of Oklahoma using a random and systematic sampling approach.
4. Collect basic biological data for population assessment.
5. Tag fish for mark and recapture study to estimate abundances in Red River population.

II. SUMMARY OF PROGRESS

A. APPROACH

Literature review

We conducted an extensive literature review of publications focused on Blue Sucker life history and ecology using Web of Science and Google Scholar between the years 1900 and 2014. Three separate searches were conducted, first using specific search terms “Habitat” AND “Cycleptus” and “Cycleptus” AND “Reproduction”, then the broad term “Cycleptus“. The Latin species name *elongatus* was not used because we did not want to exclude the Southeastern Blue Sucker *Cycleptus meridionalis.* We did not use the term “Blue Sucker” because it returned over 37,000 results that were often unrelated to the topic of interest. A meta-analysis was conducted to identify gaps in the literature. We reviewed papers that investigated Blue Sucker habitat, reproduction, age, growth, age-0 life history, and movement. We included all relevant papers returned by our search terms.

We excluded seven hundred and forty papers that discussed occurrence only and were previously summarized by Burr and Mayden (1999).

Spawning sites and habitat selection

We chose four reaches in the lower Red River where we anticipated spawning to occur so we could assess spawning habitat selection. We expected Blue Suckers would be present in the Red River between Denison Dam and the Carpenter's Bluff Bridge (Matt Mauck and Bob Wichers, pers, comm.) and in the Kiamichi River below Hugo Dam (Curtis Tackett, pers. comm.). Based on our literature review, we hypothesized that Blue Suckers would also move into Blue and Muddy Boggy rivers during the spawning season. Therefore, we delineated a study reach in each of the four locations where we would tag and track Blue Suckers (Fig. 1). We focused our efforts in the spring season because we expected Blue Suckers to undergo spawning migrations at that time (Neely et al. 2009). In the Red River, we designated a 20-km study reach between Denison Dam and the Carpenter's Bluff Bridge (hereafter referred to as tailwater reach). We ended our reach at Carpenter's Bluff Bridge because the acoustic environment of the river became comparatively noisy resulting in the detection of an acoustic tag becoming much less likely. In the Kiamichi River, our study reach was between Hugo Dam and the confluence with the Red River 28-km downstream. The confluences with the Red River provided the lower extents of the Blue and Muddy Boggy rivers; however, the upper extents were based on logistic restrictions associated with regular tracking. The upper extent of our study reach in Blue River was at the Highway 22 Bridge, as this resulted in a 40-km study reach that could be tracked in a single day. In Muddy Boggy River, we tracked a 50-km reach starting at the Choctaw County Road 4050 crossing.

Tagging:

Between February 17 and April 11, 2015, we surgically implanted acoustic tags into 30 Blue Suckers in each of the four study reaches. We captured Blue Suckers using boat electrofishing (5.0 GPP Smith-Root, Vancouver, WA). We sampled using direct current and a 60 Hz frequency, except in the Kiamichi River where water conductivities < 75 µS required 120 Hz frequency to achieve the target output of 2500 – 4000 watts recommended by Miranda (2014). Additionally, we used a chase boat to capture Blue Suckers that surfaced behind the electrofishing boat. We anesthetized individual Blue Suckers in a 20-26 mg/L solution of Aqui-S 20e (Aqui-S New Zealand LTE. Lower Hutt, New Zealand) to prepare for the surgical implantation of the acoustic tag. We recorded the total length (1 mm TL), weight (0.01 kg) and gender prior to tagging. We tagged fish on the ventral side between the left pelvic fin and the anal vent. After removing scales at the implantation area, we treated the skin with povidone iodine. We made a 3-5 cm incision and inserted both an acoustic tag (CT-05-36-I; Sonotonics Inc. Tucson, AZ) and a 12-mm HDX passive integrated transponder (PIT) tag (Oregon RFID, Portand, OR). We closed the incision with 2-5 simple interrupted sutures (2-0 PDO absorbable monofilament thread; Unify, AD Surgical, Sunnyvale, CA, USA), and placed Blue Suckers in a dark recovery tank with freshwater. After approximately 30 minutes in recovery, Blue Suckers regained equilibrium and were actively moving in the tank. We then placed Blue Suckers in the river where the current was slow moving.

Tracking:

We tracked Blue Sucker movement both passively and actively to determine spawning site and habitat selection during spring 2016 and 2017. In each of the study reaches, we placed two submersible ultrasonic receivers (SUR-03; Sonotronics Inc. Tucson, AZ, SUR hereafter) within 2 km of the lower extents of the study reaches (Fig. 1). To place the SURs, we deployed an anchor onto the streambed and extended a cable to the water surface where we attached a bullet-shaped Styrofoam fishing buoy. We attached an SUR to the cable directly below the buoy, and weighted the SUR to ensure that the transducer remained underwater. Additionally, we actively tracked the tailwater, Blue, Muddy Boggy and Kiamichi study reaches from March 16 to May 13, 2016, and February 14 to May 5, 2017. In 2016, we attempted to track each reach once every two days; however, weather and technical problems resulted in an average of one tracking event per study reach every 5-6 days. In 2017, we tracked once weekly, but beginning March 13, we began tracking the tailwater reach twice weekly due to the abundance of tagged Blue Suckers in that reach. We conducted active surveys by traveling the length of each study reach with a towable hydrophone (TH-2) and acoustic receiver (USR-08; Sonotronics

Inc. Tucson, AZ). Upon detecting an acoustic tagged fish, we maneuvered the boat into a position where the tag could be heard clearly enough to obtain a positive identity, and marked the location with a GPS waypoint. The accuracy of our tracked location was approximately 10-200 m. Hard surfaces and turbulent water made pinpointing the exact location of a tagged fish difficult in most areas (Adams et al. 2012). However, river bends blocked the acoustic signal so we were confident that a located tagged fish was within the meander or straight river sections (hereafter referred to as ‘river sections’) being tracked (see below).

Habitat Selection:

We created a map of available river sections to compare against the observed habitat use of tagged Blue Suckers. Wildlife habitat selection studies are often based on a raster grid to delineate habitat units. However, a raster grid does not translate well to a meandering stream. So, using QGIS 2.18 (QGIS Development team, 2014), we created a vector of river sections within each of the four study reaches. A meander was defined as an area with > 45° change in the direction of the thaweg, and the habitat between two meanders comprised a straight river section. The delineated river sections incorporated the error associated with the precision of our tracking efforts (see above). In some areas, straight river sections were extensive (>1 km). To make the river sections reflect the distance associated with tag detection, we broke very large sections in the tributaries into several, smaller arbitrary sections that did not exceed 400 m in length. We used 400 m as the upper limit for habitat units, because tag-detection trials indicated that a tag detected in a large, straight river section could be 200 m up or downstream of the acoustic receiver. In the tailwater, the larger rive sections (i.e., > 2 km) resulted in a greater detection range and more uncertainty in the exact location of a tag, so we increased the distance of the tailwater river sections to 600 m. The resulting vector of river sections served a similar function as reference grids to quantify habitat and fish locations in our study.

We used side-scan sonar data and existing geospatial data to classify environmental conditions in each river section. In 2017, we used side-imaging sonar (Lowrance HDS Gen 3; Tulsa, OK) to create sonar images and record average depths throughout the extent of our tracking reaches. We conducted our habitat surveys at moderate to high flows (i.e., 60th – 80th percentiles), by mounting the sonar to the bow of a canoe and traveling the thaweg of each reach downstream at a speed of 7-9 kph. The Red River tailwater was too wide (≈ 200 m) to cover with a single pass, and in most places the middle of the channel was too shallow (< 1 m) for acoustic survey. To compensate, we created separate sonar images of the left and right portions of the river and treated them as representative samples from the channel units. Data were transferred to a computer and processed using Sonar TRX Pro software (Leraand Engineering Inc., Honolulu, HI). With Sonar TRX Pro, we created a gray-scale mosaic of side-image sonar data and extracted a spreadsheet of spatially referenced streambed depths from the down-scan sonar channel. The sonar images were viewed in QGIS, where we delineated patches of coarse substrate (> 250 mm diameter), and woody debris. We calculated the percentage of each habitat unit (straight or meander) that comprised coarse substrate and woody debris. Additionally, using sonar images we included the presence or absence of a riffle as a binomial variable. We calculated mean depths of each river section using multiple points within the river section using the down-scan sonar data. We collected sonar depths on the same day, in each stream, so mean depth within the river section was relative to the mean depth of other habitat units. While we recognize the actual depth may not have been associated with the location of a fish on separate days, it does represent the relative of deep versus shallower locations within the channel (i.e., a deep area will still be deep even though the exact depth would change on different dates). We used the stream slopes (m/m; USEPA & USGS, 2005 http://www.horizon-systems.com) associated with our study reaches as a surrogate for water velocity. Stream slope was measured at a larger scale than our river sections, so we created 1000-m buffers around each river section and assigned the mean stream slope within the buffer to the corresponding mesohabitat. Finally, we numbered mesohabitats beginning with 0 at the lowest extent of the study reach and numbers increased upstream to represent the distance from the river confluence.

We used two approaches to examine habitat selection (where use is proportional to availability) by Blue Sucker. First, we considered a type I habitat selection analysis, where the mesohabitat was the experimental unit and the count of fish observed in that area was the response variable. The disadvantage to this approach is that we ignored the potential correlations among multiple observations of an individual. In general, we did not observe individuals often enough to create a problem. However, we also investigated habitat selection by individuals observed on $\geq$ 4 occasions using a type II habitat selection analysis, where the individuals were the experimental unit and the habitats selected were the response variable in the analysis. The disadvantage to the type II approach is that it requires many observations of each individual. The two approaches complement one another and provide more information about how these fish are selecting habitat.

We used a hypothesis testing approach to determine type I habitat selection by Blue Sucker. We created multiple hypotheses to develop a candidate set of models. We developed generalized linear models to represent each of our hypotheses (Johnson and Omland, 2004). We determined that our count data were over-dispersed and the negative binomial distribution was better suited for our data than the Poisson distribution (Lawless, 1987). Using the 'MASS' package (Ripley et al., 2002) in R statistical software (version 3.4.3, R Core Development Team, 2017), we fitted our hypothesized models and ranked them using AIC_c (for small sample size) from the 'AICcmodavg' package (Mazzerolle, 2017). We compared our models using AIC_c because it provided a measure of relative model fit (i.e. compared to the other models being considered) while adjusting for model complexity and a small sample size (Johnson and Omland, 2004). In each hypothesized model, we considered the tracking location as a fixed effect. Our simplest model included only location and served as our null hypothesis, or a baseline model to compare against the effect of additional variables. All continuous variables were standardized to ensure variables were on the same scale, and log-transformed when histograms indicated a log-normal distribution (Zar, 2010). We tested for a polynomial effect with our continuous variables, when we anticipated fish would select for moderate ranges of the variable rather than the extremes (e.g., distance upstream). Our most complicated model could include tracking location, a polynomial effect of upstream distance and its interaction with the polynomial effect of one other variable (Table 1). For each hypothesis, we created the simplest model that best explained these data. We included the effect of distance, polynomial effects, and interactions when the inclusion of additional effects resulted in a lower AIC_c score. Once we created our hypothesized candidate models, we ranked the models by AIC_c and considered the models with the lowest score the best supported by our data (Johnson and Omland, 2004). Additionally, we considered models with < 2-point difference from our top model equally supported (Burnham and Anderson, 2002; Johnson and Omland, 2004). We calculated R^2 as a measure of effect size.

To determine type II habitat selection, we calculated the outlying mean index (OMI), a multivariate approach. The OMI was initially used to differentiate the niches occupied by individual species within an ecosystem (Dolédec et al. 2000). However, the analysis has been adapted to examine habitat selection (Calenge, 2011), where observed habitat used by individuals is compared to the habitat available to the population. We used the 'adehabitatHS' package (Calenge, 2011) in R to complete the analysis. The OMI analysis consisted of two steps. First, river sections were weighted based on the relative availability of habitat variables within them so that commonly available habitat was plotted near the center, and rare habitat occurred near the margins in multivariate space. Each variable defined a dimension in multivariate space. Next, we compared the mean habitat selection of each individual fish to the average availability of the habitat variables. An eigen analysis was used to determine the percent difference between used and available habitat for each individual (marginality score; Calenge, 2011). The marginality of the axes provided a measure of the total variance accounted for in the model, but differences among individual were observed graphically (Calenge, 2011).

Current distribution

To determine the current distribution of Blue Sucker in the Red River catchment, we first focused our efforts in the Red River and its major tributaries. In autumn 2014, we sampled four locations in the Red River between Denison Dam and the Arkansas state line and one location in each the Blue, Clear Boggy, Muddy Boggy, and Kiamichi rivers (Fig. 2). At each of the eight locations, we fished five fyke nets for two nights and checked the nets once every 24 hours. Each fyke net consisted of a double-throated hoop net and two 2.5-m (3 nets) or 5-m (2 nets) wings that extended outward from the mouth at

45° angles. At each net location, we recorded water depth (0.1 m), mean water-column velocity (0.01 m/s at 0.6*depth, or 0.2* depth and 0.8*depth when depth ≥ .8 m; Gordon et al. 2009), conductivity (1 μS/cm), and water temperature (0.1° C). In the spring of 2015, we began electrofishing for Blue Sucker in the Red River (approx. 8 – 13 km below Denison Dam), and in the three major tributaries within 10 km of the confluences with the Red River (see tagging methods in spawning sites and habitat selection section; Fig. 2). Upon capture, we recorded the total lengths (1 mm TL), weight (10 g) and gender of Blue Suckers.

In April 2017, we sampled minor tributaries (< 4 order, Strahler, 1957) within the basin. The combination of previous sampling efforts in conjunction with acoustic telemetry captured the distribution of Blue Suckers in the Red River and the lower reaches of its major tributaries; however, the use of minor tributaries by Blue Sucker remained unknown. We selected sample sites using a stratified-random design to ensure coverage of the Red River basin within the state. We delineated the catchment into four sections: 1) minor tributaries of the Red River in Bryan county, 2) minor tributaries of the Red River in Choctaw and McCurtain counties, 3) tributaries of the Blue River, and the mainstem Blue River upstream of the acoustic study reach, and 4) tributaries of Muddy Boggy and Kiamichi rivers, and the mainstem Muddy Boggy River upstream of the acoustic study reach. We then selected three to five accessible locations from each of the four groups. At each sample location, two fyke nets (2.5-m wings, described above) were fished for two days and nights following rainfall events that provided flow that was assumed adequate to allow fish passage.

Biological data for population assessment

We sampled using electrofishing and fyke nets to collect biological data in spring 2016 and 2017. In 2016, we sampled the reaches in both Red and Muddy Boggy rivers where we successfully tagged Blue Suckers in 2015 (Fig. 2). We sampled via electrofishing (see methods in spawning site and habitat selection section) on two occasions in 2016: the late winter/early spring (Feb 29 – Mar 4; Red River, and Mar 28 – Mar 29; Muddy Boggy River) and again in late spring (May 21 – 24; Red and Muddy Boggy rivers). In the Red

River, two passes were conducted along a 2-km reach when hydropower flow allowed for safe boat travel. In Muddy Boggy, accessing the sample reach was difficult in wetter than normal conditions, so we sampled morning and afternoon for two days in the early spring. In late spring, floods delayed sampling in Muddy Boggy River, and we believe that this resulted in our sampling being too late as we only capture two juvenile Blue Suckers during our four days of sampling. In 2017, we modified and increased our sampling effort to ensure access and an adequate sample size despite the weather conditions that prevented us from sampling Muddy Boggy the previous year. Unlike the aforementioned locations and dates, we sampled Blue and Muddy Boggy rivers using 6-8 fyke nets (2.5-m wings, described in Current Distribution section), respectively. We deployed fyke nets overnight with half of the nets opening downstream and half opening upstream. We also conducted our electrofishing protocol in the Red and Kiamichi rivers (Fig. 2). From Feb 21 to Mar 31, sampling was conducted once weekly at each location. To ensure an adequate sample size, we ceased fyke-net sampling at the end of March and doubled efforts in the Kiamichi and Red rivers, because fyke nets did not capture any Blue Suckers.

Upon capturing Blue Suckers, we collected demographic information (age, growth, reproduction) that we could use to understand population demographics. We measured TL and weight, and documented gender based on the expression of gametes or secondary sexual characteristics. Pronounced tubercles covering the body indicated that a fish was a male and a disproportionately protruding abdomen suggested a female (Lyons et al. 2016). Fish of unknown gender did not display sexual characteristics, and when reproductively active fish were abundant, we assumed fish with unknown gender (and typically smaller) to be juveniles. During late 2016, fish with unknown gender appeared to be either post-spawn (based on their larger size) or larger juveniles. To determine the age of individuals, we collected pectoral rays from Blue Suckers. In 2016, we collected pectoral rays from every other fish in each 25-mm length bin; however, analysis of this data indicated that the length-age relationship was too weak to develop a length-age key. In 2017, we collected pectoral rays from all Blue Suckers. Additionally, we collected the ovaries from three females within each 25-mm length bin in each the Red and Kiamichi rivers and preserved them in 10% formalin to determine potential fecundity. We transported pectoral rays and ovaries to the laboratory for further analysis.

In the laboratory, we processed pectoral rays to estimate the age of individual Blue Suckers and ovaries to estimate the reproductive status and fecundity of fish. We dried pectoral rays for at least one week before setting the proximal portion of the ray in epoxy resin. After the resin had cured, we sectioned pectoral rays (0.6 – 1.2 mm thick) using a Bueler low-speed Isomet saw (Lake Bluff, IL), fixed the sections to a microscope slide with a nitrocellulose-ethyl acetate solution (i.e., clear fingernail polish), and viewed the rays with 40x magnification and transmitted light (Bednarski and Scarnecchia, 2006). Two viewers independently enumerated the annuli (opaque rings). When readers disagreed, we simultaneously viewed the specimen in question and assigned the consensus age to the fish. Additionally, we weighed (0.01 g) three subsamples of 100, early-vitellogenesis to pre-hydrated staged eggs from the anterior, middle, and posterior portion of each ovary. The average egg weight for an individual was then determined from the subsamples and the potential fecundity of an individual was estimated by the combined ovary weight divided by the average weight of the eggs within that individual (Zweiaker 1967; Daugherty et al. 2008).

We determined mortality, recruitment and growth rates separately for the Red River and Kiamichi River populations. We only included data from 2017 in the analysis because previous age data were not representative of all fish in our samples. Annual mortality rates were determined for the two populations using catch curves (Miranda and Betolli 2007). The peak of the age-frequency histograms (modal age) indicated the age that fish recruited to our sampling methods; however, we considered the possibility of the modal age being the result of a strong age-class that may conceal prior age class that had recruited to our sampling. To accommodate, we created two models for each location, 1.) the modal age-class was the earliest recruited, or 2.) the age prior to the modal age class was the earliest recruited. We compared the portion of the variance explained (R^2) by each of the two models and considered the catch-curve model with the largest R^2 to best represent the data. Additionally, we used the R^2 from the catch curves to index recruitment variability with the recruitment coefficient of determination (RCD; Isermann et al. 2002). We described individual growth within each population using a linear model (adults only) or a von Bertalanffy growth model (von Bertalanffy 1938).

We estimated GSI as the percentage of the total body weight accounted for by the gonads (Crim and Glebe 1990; Daugherty et al. 2008).

$$\mathrm{GSI} = \left\{\frac{\text{Gonad weight (g)}}{\text{Body weight (g)}}\right\} * 100$$

Using the ‘nlme’ package in R (Pinheiro et al. 2017), we used a linear mixed model to assess the relationship of GSI with age, and potential fecundity with TL, while controlling random variation associated with location (i.e., we were not interested in the variation directly, but wanted to control for the possibility). We then compared the GSI and potential fecundity of the two populations using ANCOVA. We included either age (GSI analysis) or TL (potential fecundity analysis) as a covariate to control for variance associated with the locations (Zar, 2010). We determined significance in the ANCOVA models at $\alpha \leq 0.05$.

Because GSI is sometimes not reflective of reproductive status (e.g., McAdam et al. 1999; Brewer et al. 2008), we also conducted histological analysis of ovaries from three fish (for verification). GSI provides an index of the relative weight of the gonads, but the method does not distinguish between mature oocytes and other tissues. Alternatively, histological analysis can provide detailed information on the current status of oocytes within the ovaries (i.e., what stage of development). However, the cost and time associated with histology can sometimes diminish the practicality of the technique (depending on the research objective). So, we selected three similarly sized Blue Suckers (620-637 mm TL, 2.41-2.85 kg weight) captured at different times during the spawning season for histological analysis. We used two fish that were captured in early April 2017 during what we perceived to be the peak spawning period. The third Blue Sucker was captured on May 2, 2017, near the end of the perceived spawning period. Specimens were sent to the Oklahoma Animal Disease Diagnostic Laboratory (Stillwater, OK) for tissue preparation where sections were dehydrated, set in paraffin wax, sectioned, stained and mounted to glass slides (3 per individual). We viewed the processed sections under

20x power and transmitted light. We documented the presence of immature eggs (perinuclear and lipid stage), near-mature eggs (early-vitellogenesis to pre-hydrated stage), mature eggs (hydrated stage), post-mature eggs (atretic stage), and empty follicles (Corriero et al. 2003). We were particularly interested detecting empty follicles and stage 5 oocytes, as these observations indicated spawning has occurred or the oocytes are mature and ready for release. The presence of hydrated and some atretic oocytes indicates that the individual is nearing the end of spawning season (i.e., they have spawned and are reabsorbing unspent eggs).

Mark-recapture

We attempted a mark-recapture study to estimate abundance with a multi-state Jolly-Seber model. The design consisted of three primary sampling events (spring 2015, 2016 and 2017) and 11-34 secondary events within each primary event. In the Red River tailwater and in each of the major tributaries, we designated a 2-km reach as our sampling area (see sampling methods described in previous sections; Fig. 2). We were not able to assume a closed population among primary or secondary events. To accommodate for the open system, we considered two states, A.) sampling areas, where fish were detectable, and B.) outside the sampling areas, where fish were not detectable. In a closed population mark-recapture study, it is assumed that all individuals have an equal probability of detection, and the probability of detection is estimated and used to adjust abundance estimates (Schwarz and Arnason, 1996). However, in an open population this assumption is violated. Because fish were only detectable in state A, the probability of detection was dependent on the fish being in state A. Including state B allowed for fish to leave the sampling area by means other than mortality; thus, providing the potential for fish to be detected again given the probability of returning to state A. Maximum likelihood was used to estimate the probability of individuals being in state A and detection probability, conditional on the probability of individuals being in state A. By adjusting the estimated probability of detection with the probability of a fish being in state A at the time of sampling, we offset the closure assumption (Kendall and Bjorkland 2001). We used the Schwarz-Arnason (1996) formulation of Jolly-Seber (*i.e.,* POPAN) to estimate abundance, the probability of fish being detected given the probability of a fish entering or exiting the population through birth, death, or migration.

The spring 2015, 2016, and 2017 sampling events described in the previous sections of this report were used in our mark-recapture analysis. We were challenged to continuously adapt as we learned about the variability of conditions in the study area. As a result, sampling methods were not consistent among years. In 2015, we used boat electrofishing to sample the Blue, Muddy Boggy, Kiamichi, and Red rivers (i.e., below Denison Dam; Fig. 2). We sampled via boat electrofishing in the Muddy Boggy and Red rivers again in 2016, and in 2017, we increased our efforts to maximize the likelihood of detecting tagged fish (see current distribution section). All Blue Suckers captured and released during these sampling events were checked for a PIT tag, and we tagged fish (12-mm HDX) if no tag was detected. We injected PIT tags into the peritoneum behind the left pelvic fin of Blue Suckers using a 12 ga hypodermic needle (Oregon RFID, Portland, OR).

RESULTS

Literature review

Meta-analysis:

Our literature search was concluded in August 2014 and resulted in 37 relevant peer-reviewed papers that we extensively reviewed. In Web of Science, specific queries "Habitat" AND "Cycleptus" produced six papers and "Cycleptus" AND "Reproduction" yielded only two articles. The broad query "Cycleptus" resulted in 17 documents. Specific queries in Google Scholar yielded an additional eight papers and the broad search (Cycleptus) provided five more papers. Papers published on Blue Sucker first became prevalent in the 1980's but the majority was published between 2000 and 2010. The most recent publication was in 2011. Thirty-two of the papers discussed *Cycleptus elongatus,* four focused on the Southeastern Blue Sucker *Cycleptus meridionalis* and one paper discussed both species. Of the six meta-analysis parameters, habitat was the most commonly assessed, whereas movement, growth, and age-0 life history were the least investigated (Fig. 3).

History of *Cycleptus*:

Blue Sucker *Cycleptus elongatus* is an ancestral member of the Catostomidae family. The genus *Cycleptus* was once thought to be most closely related to *Myxocyprinus,* a monotypic genus that is indigenous to central China, and the two genera were considered the first group of Catostomids to break out of the Cyprinidae family (Miller, 1959). However, recent genetics studies revealed that *Cycleptus* was more closely related to Buffalo *Ictiobus* spp. and Carpsucker *Carpiodes* spp. (Harris & Mayden, 2001; Sun et al. 2007).

Until recently, the genus *Cycleptus* was described as monotypic. The spatial distribution of *C. elongatus* was considered the Mississippi River catchment, the Gulf Slope drainage, and the Rio Grande basin (Burr & Mayden, 1999). Burr & Mayden (1999) used scale counts and body-shape morphometrics to differentiate Blue Suckers in the Gulf Slope drainage (Southeastern Blue Sucker *C. meridionalis)* from *C. elongatus*. The Rio Grande population did not display significant differences in scale counts or morphometrics (Burr & Mayden, 1999), but allozymic and isozymic evidence suggested Rio Grande populations were genetically unique (Buth & Mayden, 2001). At the time of our review, the Rio Grande population had not yet been classified taxonomically as a unique species.

Age and Growth:

The longevity of Blue Sucker has been documented across much of its distribution. In Montana, the oldest *C. elongatus* from the Milk River was 37 years of age (Bednarski & Scarnecchia, 2006). In the southern distribution, *C. elongatus* may not live as long. Vokoun et al. (2003) found the oldest members of the Grand River, Missouri population were 22 years old; however, Peterson et al. (1999) found *C. meridionalis* as old as 33 years in Pearl and Pascagoula rivers, Mississippi. The methods used to age the fish may relate to some of the discrepancies. Pectoral rays and otoliths were the preferred method of aging because scales often under represent the true age of catostomids (Beamish & McFarland, 1987). Studies documenting fish > 30 years old all used either pectoral rays or otoliths to age fish. Studies using scales reported maximum ages in the low 20's. Unfortunately, the only studies using pectoral rays or otoliths in the southern portion of the distribution were conducted on *C. meridionalis*. Thus, reported ages of fish in the

Arkansas, Red and Rio Grande basins are potentially biased, and fish may live longer than reported.

Only six studies have investigated growth rates, but these studies span across the entire distribution. Von Bertalanffy growth curve was the most commonly used method, but Fraiser-Lee, repeated measure and length-weight relationship were also used. In general, females grew larger than males at any given age. The maximum total length of *C. elongatus* was 700 – 800 mm (Layher, 1998; Hand, 2003; Bednarski & Scarnecchia, 2006) and 4700 g was the largest weight reported (Hand, 2003; Bednarski & Scarnecchia, 2006). Growth appeared rapid in the first 15 years of life in Montana populations (Bednarski & Scarnecchia, 2006); whereas, it appeared to truncate after 10 years in southern populations (e.g., Wabash River, Indiana; Bacula et al. 2009). Both of the studies estimated age using pectoral rays. Conversely, Zymonas & Propst (2007) estimated age using scales and reported most growth occurred until age 2 in New Mexico populations.

Movement Patterns:

Of the five papers addressing Blue Sucker movement, four papers relied on acoustic or a combination of acoustic and radio telemetry, and the remaining paper used genetic analyses. Due to commonly-reported low sample size and recapture rates, one paper was unable to make any inferences about Blue Sucker movement (Zymonas & Probst, 2007). Two papers used the same dataset from the middle Missouri River (Neely et al. 2009 & 2010), and one of the papers focused on *C. meridionalis* rather than *C. elongatus* (Mettee et al. 2004). Neely et al. (2010) reported Blue Sucker habitat selection varied seasonally. In the spring, Blue Suckers most often used tributaries of the Missouri River, NE. During summer, margins of the Missouri River main channel were the most common habitat selected and in autumn, Blue Suckers were found in the main channel and its margins (Neely et al. 2010). Neely et al. (2009 & 2010) were not able to observe winter habitat use due to ice cover. Movements within seasons were greatest in the spring (>160 km), least in the summer (<10 km), and moderate in autumn (approx. 80 km; Neely et al. 2009). Mettee et al. (2004) observed *C. meridionalis* movements to exceed 480 km during the spawning season, despite multiple lock and dam systems within the river.

Finally, Bessert (2006) reported significant genetic isolation among Blue Suckers separated by dams on the upper Missouri River. The level of genetic isolation in the upper Missouri River was not observed in undammed reaches of similar length on the Mississippi River (Bessert, 2006).

Reproduction:

Environmental cues thought to initiate spawning may vary across the Blue Sucker distribution. Water temperature for the duration of spawning activity was reported in eight of the papers we reviewed. Spawning initiated at temperatures as low as 10°C (Neely et al. 2009) and as high as 19°C (Layher, 1998 & 2007) suggesting these fish, like most species, have multiple spawning cues. Similarly, water temperatures at the end of the spawn ranged 12° to 25°C (Neely et al. 2009; Adams et al. 2006, respectively). Spawning seemed to begin in March for southern populations (Yeager et al. 1987; Layher, 1998; Mettee et al. 2004; Layher, 2007; Zymonas & Probst, 2007), and in late April – May for northern populations (Moss, 1983; Vokoun et al. 2003; Adams et al. 2006; Neely et al. 2009). A rise in discharge in conjunction with rising water temperature was thought to trigger spawning in the Grand River, Missouri (Vokoun et al. 2003). Reports of fine-scale spawning habitat were consistent among studies. Blue Sucker used areas with strong current (1.0 – 2.6 m/sec), depths > 1m and hard substrate (Moss, 1983; Layher, 1998; Vokoun et al. 2003; Zymonas & Probst, 2007).

Age-0 Life History:

Age-0 Blue Suckers have been observed in the lab and the field; however, little information about habitat selection or movement exists for juvenile Blue Sucker. Semmens (1985) successfully reared Blue Sucker in the lab and Yeager and Semmens (1987) described their development from egg to fry. Six days after fertilization, Blue Sucker eggs hatched and by day 10 the yolk-sac was completely absorbed (Semmens, 1985; Yeager & Semmens, 1987). Semmens (1985) and Yeager and Semmens (1987) kept the eggs suspended during development and made no indication as to whether the eggs naturally drift, sink or adhere to vegetation. However, catostomids are typically lithophilic spawners (Page & Johnston, 1990) and although Blue Sucker eggs have not been observed in riverine systems (Adams et al. 2006), it is hypothesized that eggs develop in coarse substrate where Blue Suckers spawn. In the Milk River, Montana, Bednarski and Scarnecchia (2006) captured larval Blue Suckers in drift nets following a spring flood and began to capture juvenile Blue Suckers two months later. Larval Blue Suckers were reported to occupy shorelines of the main channel and islands within the main channel of the Mississippi River (Fisher & Willis, 2000; Adams et al. 2006). Adams et al. (2006) found the highest densities of larval Blue Suckers in sloughs of islands within the main channel of the Mississippi River. Additionally, the connection points between backwaters and the main channel (Fisher & Willis 2000) and vegetated margins (Eder, 2009) may be important habitat for larval and juvenile Blue Sucker. Although larval Blue Suckers have not been documented in backwater habitats (Fisher & Willis, 2000; Adams et al. 2006), juveniles have been collected from backwater and side-channel habitats (Eder, 2009).

Status and Potential Threats:

In North America, Blue Sucker is listed as vulnerable (Jelks et al. 2008). Blue Sucker may be secure in the center of their range, and earlier indications of the species decline could be related to a lack of knowledge of the seasonal distributions of the species (Burr & Mayden, 1999). Because Blue Suckers migrate during the spawning season, their abundance varies spatially and temporally (e.g., Neely et al. 2010). The Wabash River in Indiana and Illinois harbors perhaps the best-monitored population of Blue Suckers. Monthly monitoring over several years led to the state-level delisting of Blue Sucker (Bacula et al. 2009), and Indiana is the only state where Blue Sucker appear to be stable (Hammerson et al. 2011). Declines are reported in the margins of the Blue Sucker distribution. In Pennsylvania, Blue Suckers are presumed extirpated (Cooper, 1983), and in New Mexico, Ohio, West Virginia and Nebraska, the species is critically imperiled (Hammerson et al. 2011).

Like most freshwater organisms, human alteration is implicated as the likely cause of Blue Sucker declines. Dams and sedimentation are among the most commonly hypothesized threats (Burr & Mayden, 1999). Several reports described an abundance of Blue Suckers in tailwaters and the extirpation of the species above reservoirs (Walburg et al. 1971; Layher, 1998). Spawning is likely triggered by flood pulses, so modified flow regimes associated with dams may be detrimental to Blue Suckers (Burr & Mayden, 1999; Vokoun et al. 2003). The lack of seasonal flooding or the short duration of flooding (*e.g.*, hydro-electric dams) may reduce the submerged vegetation potentially needed for age-0 Blue Sucker habitat (Fisher & Willis, 2000; Adams et al. 2006). Finally, excessive sedimentation associated with flow suppression and disturbance in the watershed, reduces habitat quantity and quality. For example, in the Platte River, NE, channel depth and width have decreased due to sedimentation increases in the main channel (Collier et al. 1996). Excessive sedimentation is cited as the cause of Blue Sucker decline in Kansas (Cross, 1967).

Spawning sites and habitat selection

Tagging:

We successfully tagged 119 Blue Suckers from our four study reaches. We initially tagged 120 fish with acoustic tags, but one fish died post tagging. We suspect that the mortality was due to a gill injury that occurred during weighing. We tagged 29 Blue Suckers in the Red River tailwater and 30 Blue Suckers each in the Blue, Muddy Boggy and Kiamichi rivers (Table 2). Known tagged male to female ratio was 1:1 (n = 110), with 10 fish of unknown gender. One-third of the males we tagged were ≤ 533 mm total length (TL), whereas only 9% of females were ≤ 533 mm TL (Fig. 4). The mean TL and weight of tagged males was 564 mm (± 42 SD) and 1357 g (± 357 SD) and females were 587 mm (± 40 SD) and 1651 g (± 391 SD).

Blue Suckers were abundant in the tributaries in March and April, 2015. We collected Blue Suckers below Hugo Dam as early as March 15; however, females were rare in our samples until April 8 (only two females were tagged as of March 27). Between April 7-10, we captured male and female Blue Suckers in approximately equal numbers (15:14 M:F ratio). On April 11, we captured males and females (14:12 M:F ratio) from the Muddy Boggy River. Many of the Blue Suckers captured from the Muddy Boggy River were in post-spawn condition, as they possessed secondary sexual characteristics (i.e., tubercles), but did not readily express gametes. Males and females were still distinguishable by the abundance of tubercles on the males. The mean water temperature recorded April 7-11 was 20.7° C.

Tracking:

We detected Blue Suckers in the Red River tailwater year-round, but the majority of detections in the tributaries (89 of 97) occurred between February and May 2016. A flood in 2015 resulted in the loss of all but one SUR that was positioned in the Kiamichi River. The remaining SUR detected 27 out of 30 Blue Suckers that were previously tagged in the Kiamichi River, indicating that Blue Suckers left the Kiamichi River by May 19, 2015. We replaced our lost SURs in December 2015, and our next detection came on December 19, 2015, where a Blue Sucker moved into the Red River tailwater below Denison Dam. We detected Blue Suckers in the Red River tailwater at all times of year, throughout our study, indicating either a potential resident population or fish are regularly attracted via hydropower releases (or some other reason). Tagged Blue Suckers were detected in Muddy Boggy River from February 1 to May 7, 2016, but 50% (9 of 18) of detections occurred between March 9 and April 22, 2016 when water temperatures were 12-20°C. Similarly, we detected Blue Suckers in the Kiamichi River from February 8 to April 29, 2016 and 76% (12 of 18) of detections occurred between March 1 and April 14, 2016 (12-19°C water temperatures). We were unable to maintain SURs in Blue River, and as a result all detections corresponded to active tracking events. The majority of detections (63%, 5 of 8) in the Blue River occurred on the first tracking event (March 16, 2016). The latest we detected fish in the Blue River was May 13, 2016 (24°C water temperature). Stream flows were relatively high during the 2016 season and were not likely a limiting factor for Blue Sucker movements (Red River median discharge 413.4 cms, 84th percentile; Blue River median discharge 8.7 cms, 85th percentile; Muddy Boggy River median discharge 47.3 cms, 80th percentile; Kiamichi River median discharge 102.1 cms, 82nd percentile; Fig.5).

In 2017, we observed only 19 Blue Suckers and 68% of these fish were detected in the Red River tailwater. Eighty-seven percent of our active tracking detections in 2017 (52 of 60) occurred in the Red River between February 27, 2017, and May 5, 2017. Four fish were detected in Kiamichi River from February 15, 2017 to May 4, 2017, accounting for only 6 detections. We observed one Blue Sucker in Blue River on February 21, 2017 (13° C water temperature), and one Blue Sucker in Muddy Boggy River on April 20, 2017 (21° C water temperature). Dam releases supplemented flows in the Red and Kiamichi rivers (median discharge 164.2 cms, 67th percentile and 18.2 cms, 59th percentile, respectively), but flows on the Blue and Muddy Boggy rivers were low throughout the spring (median discharge 1.6 cms, 41st percentile and 4.3 cms, 39th percentile, respectively). The detection in Blue River was made following a small flow pulse (2.8 to 5.7 cms, 59th to 76th percentile). Similarly, SUR detections indicate that the fish were in Muddy Boggy River April 17 – 21 and April 22 – 24, following the largest flow pulse of the season (April 17; 1.7 to 19.8 cms, 19th to 69th percentile).

Habitat Selection:

We included 197 observations of 51 individuals in the type I habitat selection analysis, and determined that the distance upstream, mean stream depth, and percent woody debris were the most important variables associated with Blue Sucker habitat selection. In our comparison of candidate models, the top ranked model included the interaction between the polynomial effect of depth and the polynomial effect of upstream distance (‘depth model’, $AIC_c = 600.7$; Table 3). The second ranked model was within 2 points of the depth model ($AIC_c = 602.6$) so was equally supported by our data; this model included a polynomial relationship with percent woody debris (‘wood model’). The interaction in the depth model indicated that Blue Suckers had a stronger relationship with deeper mesohabitats as they moved further upstream (Fig. 6). Mean depth had a moderate, negative correlation with upstream distance (Pearson’s $r = -0.64$), indicating that deep habitats became rare further upstream. Additionally, our results indicated that the abundance of Blue Suckers was expected to increase upriver (quantified by number of river section), but decline after reaching ≈ 150 river sections (corresponds to ≈ 35 rkm). The dams in Red River and Kiamichi River resulted in the reaches being less than 50 river sections long (corresponding to ≈ 22 rkm). Our results suggest that the dams may truncate Blue Sucker spawning migrations. Our wood model indicated a positive polynomial relationship with percent woody debris; however, we rarely observed mesohabitats with > 30% woody debris (Fig. 6). Although, our candidate models each ranked higher than our null model, the associated R^2 values indicated relatively weak effect size (depth model $R^2 = 0.16$). This is likely due to the differences between the Red River tailwater and the tributaries. The Red River tailwater accounted for 53% of fish observations (109 of 206) in our study, and the habitats in the tailwater were different from that of the tributaries. Including random slopes in our model would address differences among study locations; unfortunately, we did not observe enough Blue Suckers in Blue and Muddy Boggy rivers to include random slopes.

We included 23 Blue Suckers that were observed on $\geq$ 4 occasions in our type II resource selection analysis. Of the 23 individuals, 90 observations occurred in the Red River tailwater, 33 in the Kiamichi River, 17 in Blue River and 9 in the Muddy Boggy River. Only one female was detected in multiple reaches; she was observed in the Red River tailwater, Muddy Boggy and Kiamichi rivers (fish P; Table 4). The eigen analysis indicated that the first axis (x-axis in Fig. 7) explained most of the variation in our habitat data (74%) and the second (y-axis in Fig. 7) and third (not shown) axes explained an additional 20% of the variation (11% and 9%, respectively). The analysis indicated Blue Sucker habitat selection was dependent on multiple variables. Percent woody debris, upstream distance, mean depth, stream slope, and riffle presence each had a strong influence on Blue Sucker habitat selection (Fig. 7). Blue Suckers in the Red and Kiamichi rivers selected riffles and deeper mesohabitats (upper left quadrant, Fig. 7). However, several Blue Suckers in the Red River selected for moderate stream slopes, with the greatest stream slopes being near Denison Dam (lower left quadrant, Fig.7). Blue Suckers in Blue and Muddy Boggy rivers selected for low to moderate amounts of woody debris and distances upstream (lower right quadrant, Fig. 7). Surprisingly, the only variable with a weak influence on habitat was percent coarse substrate.

Our two approaches to resource selection produced complementary results. In our type I analysis, we estimated a positive relationship between use and woody debris; however, in the type II analysis we determined that Blue Suckers used areas with a low to moderate amount of wood. This was potentially caused by the abundance of Blue Suckers detected in the Red River tailwater where woody debris occurred in lower abundances than in the tributaries. When tracking, we often detected Blue Suckers near sparse woody cover in the Red River tailwater. In the tributaries, particularly Blue and Muddy Boggy rivers, woody debris was much more abundant, often making river navigation difficult. The fish associated with woody debris in our OMI analysis (lower right quadrant Fig. 7) were all from Blue and Muddy Boggy rivers. The two analyses suggest that Blue Suckers selected for deeper stream habitat (upper left quadrant Fig. 7). The type II analysis indicated that riffles were important to Blue Sucker habitat selection during the spawning season, and the riffle model had the second highest R^2 value of all models ($R^2 = 0.15$). Additionally, stream slope was important in our type II analysis, and ranked third in the type I analysis. Although riffles have a comparatively steeper stream slope than the surrounding habitat, riffles were not correlated to stream slope because stream slope was measured at a greater scale than riffles. Percent coarse substrate had the least influence in either analysis.

Current distribution

Our data suggest Blue Sucker are broadly distributed in the lower Red River basin when flow patterns support connectivity and deeper-water habitat. We documented Blue Sucker presence and movements throughout the lower Red River and the lower extents of the major tributaries in Oklahoma (Fig. 8). Throughout autumn 2014 – spring 2017, we detected Blue Suckers in the Red River between Denison Dam and Carpenter's Bluff. We most frequently encountered Blue Suckers in the major tributaries during the springs, 2015 ($n > 90$ sampling), 2016 ($n = 53$ acoustic telemetry and $n = 29$ sampling), and 2017($n = 19$ acoustic telemetry and $n = 136$ sampling). However, we also detected one acoustic tagged Blue Sucker in each tributary in autumn, 2016 ($n=3$). Although we did not capture Blue Suckers outside of the Red River tailwater and major tributaries, acoustic telemetry results indicate that individuals can move throughout the lower Red River and the lower extents of the tributaries (Fig. 8). In summer 2015, we detected four acoustic tagged Blue Suckers, from each of the major tributaries, between the highway 259 bridge and Oklahoma – Arkansas border (lower 50 km). Three of these fish returned to Muddy Boggy River and one to Kiamichi River in spring 2016. Additionally, seven Blue Suckers moved between the tributaries and the Red River tailwater during our study.

Sampling upstream of our tracking reaches and in the minor tributaries during spring, 2017, did not yield detections of Blue Suckers; however, there is still recent evidence that Blue Sucker do move upstream of those locations under different environmental conditions. We did not observe many Blue Suckers near the upper extents of our tracking reaches, but we have no reason to conclude that Blue Suckers do not move further upstream. Blue Suckers have been documented below the low-head dam in Blue River (T. Patton pers. comm.), in Clear Boggy River (B. Matthews pers. comm.), and in Muddy Boggy River upstream of the confluence (S. Brewer, Unpublished data). Prior to April 17, the small tributaries were intermittent and did not appear to be habitable by Blue Suckers. On April 17, a 5-cm rainfall event provided stream flow to these areas and we began sampling. Low-flow conditions returned within four days of our sampling thereby reducing connectivity. Additionally, many of the smaller tributaries of the lower Red River never received enough precipitation to have connectivity during our sampling period in 2017. We conclude that Blue Sucker would likely not use these smaller tributaries during low-flow years, but the use of minor tributaries remains unknown during wet years. Unfortunately, during our sampling efforts, conditions were either notable flooding or extremely dry thereby limiting our observations.

Biological data for population assessment

In 2017, we captured 281 Blue Suckers from the Red and Kiamichi rivers, and used pectoral rays to age 126 and 123 individuals from the Red and Kiamichi rivers, respectively (e.g., Fig. 9). Blue Suckers collected from the Red River were 3-22 yrs old (mean = 9.4 yr). Typically, we collected slightly older individuals from the Kiamichi River (mean = 12.6, 6-23 years old).

We determined the GSI and potential fecundities of 14 individuals from the Red River, and 18 individuals from the Kiamichi River. Sex ratios differed between the two populations. We captured 15 males, 55 females, and 75 juveniles in the Red River, and 102 males, 33 females, and one fish of unknown gender in the Kiamichi River.

Catch-curves indicated that adult mortality was lower in the Red River than in the Kiamichi River; however, Blue Suckers recruited to the gear at a much earlier age in the Red River. We determined that Blue Suckers in the Red River recruited to our sampling efforts at age 5, as opposed to age 6 ($R^2 = 0.52$ vs. 0.46, respectively; Fig. 10). This indicated that the age-6 class was a stronger than average year class. The instantaneous mortality rate for the Red River population was 0.11 and annual mortality was 10.5%. We determined that members of the Kiamichi River population recruited to our sampling method at age 13 rather than age 12. Both models explained a similar portion of the variation ($R^2 = 0.79$, age 13 recruitment and $R^2 = 0.77$, age 13 recruitment); however, when age 12 was considered the age of full recruitment, comparison of the residuals to the plotted line revealed that the line was biased low (i.e., more positive residuals than negative). We estimated the instantaneous mortality rate to be 0.27 and the annual mortality rate at 24% for the Kiamichi River population.

We determined that adult Blue Suckers in Kiamichi River grew at a faster rate than those in the Red River, but our von Bertalanffy growth functions were not valid. The linear relationships between TL and age for adult Blue Suckers indicated that adult Blue Suckers in the Red River grew slower than those in the Kiamichi River (slope = 2.09 $^{\pm}$ 0.73 SE vs. slope = 4.35 $^{\pm}$ 0.89 SE respectively; Fig. 11). Females generally grew larger than males in both populations. In the Red River, the median TL for a male was 555 mm (525-585 mm, 5-95 percentiles) and 591 mm (562-627 mm) for females. Similarly, in the Kiamichi River, median total length for males was 567 mm (525-626 mm) and 619 mm (555-679 mm) for females. We did not fit a von Bertalanffy growth function to the Kiamichi River population because we only captured adults with age $\geq$ 6 and TL > 500 mm. The initial curve associated with a von Bertalanffy growth function of the Kiamichi River fish would have been based on extrapolation, and therefore inappropriate. In the Red River, we captured 75 juveniles in addition to 70 adult Blue Suckers, but we observed a TL threshold of 500 mm between adults and juveniles, and juveniles as old as 12 years. The high variability of Blue Sucker sizes between the ages of 5 and 12 resulted in a nearly linear growth curve and a mean maximum TL (L^{∞}) value that was 48 mm greater than the largest fish we observed in either population ($L^{\infty} = 762$ mm vs. max observed TL = 714 mm; Fig. 13).

We determined that Blue Suckers in the Red River had greater variability in recruitment and were on average less fecund than fish in the Kiamichi River. The RCD = 0.52 (high variability) for Red River populations, compared to RCD = 0.79 (moderate variability) for the Kiamichi River fish. Because it is possible that the greater number of year classes in the Red River model could result in greater variability, we considered a model of the Red River with ages > 12. This did not increase the estimated RCD of the population (RCD = 0.48).

GSI values did not differ between the Red River and Kiamichi River populations; however, fecundity differed among the two systems. The GSI for Red River Blue Suckers ranged 2.4%-19.0% (mean = 13.3%) compared to 7.2%-18.7% (mean = 12.3%) in Kiamichi River fish. Our model of GSI indicated that Blue Sucker GSI was not related to age (Fig. 13), and the GSI between the two populations was not significantly different ($F_{2,27} = 0.84$, $P = 0.48$). Potential fecundity for Red River fish was 6,728-82,521 eggs (mean = 52,391 eggs), and 26,396-131,894 eggs (mean = 64,014) in the Kiamichi River, and we determined that potential fecundity of the two populations was significantly different ($F_{2,27} = 8.83$, $p < 0.01$).

Our histology analysis provided valuable insight to the reproductive condition of Blue Suckers during spring, 2017. Each of the Blue Suckers possessed an abundance of late-vitellogenesis oocytes indicating that Blue Suckers were preparing to spawn. Additionally, we detected perinuclear stage eggs in each of the three individuals although the abundance of these eggs was comparatively fewer in the Blue Sucker captured in May. The Blue Suckers captured in early April possessed lipid and early-vitellogenesis stage eggs, indicating that Blue Suckers may be capable of multiple spawns during the spring. Conversely, The Blue Sucker captured in May did not have lipid and early-vitellogenesis staged eggs, but possessed hydrated eggs and an abundance of atretic eggs, indicating that the individual was nearing the end of its spawning season (and resorbing some unspent oocytes).

Mark-recapture

During the study, we marked and released 492 Blue Suckers, but only recaptured six individuals. In 2015, 126 Blue Suckers were released with either an acoustic or PIT tag.

Although we sampled on 11 separate occasions, only one individual was recaptured in the 2015 season and the recapture occurred within the same day that the fish was tagged. An additional 142 Blue Suckers were marked and released in 2016, and three individuals were recaptured from 2015. No fish tagged in 2016 were recaptured during the 2016 sampling season despite conducting 15 sampling events and up to five consecutive sampling days at the same location. Sampling was conducted on 34 occasions in 2017 and 223 Blue Suckers were tagged and released. Although we increased our sampling effort, we only recaptured two individuals in 2017 (tagged in 2016 and 2017). We recaptured the Blue Sucker that was tagged in 2017 eight days after it was released. Due to the low number of recaptures, creating a model based on our data was inappropriate. We suspect the ability to recapture is related to movement activity and that was highly variable by year and appeared strongly tied to hydrology.

III. RECOMMENDATIONS

We recommend a monitoring protocol that allows managers to observe Blue Sucker and other big river species for several years. Although we found that Blue Suckers were relatively abundant during certain times of the year, population changes occur among years and as such, a population must be observed over several years to fully understand its status (Ricker 1975). We provided the basic information to begin a population assessment, however, monitoring efforts are needed to fully evaluate the Blue Sucker population. We were unable to estimate the abundance of the Blue Sucker population using mark-recapture methods due to low detection efficiency and high variation in movements among years. Moss et al. (1983) speculated that Blue Suckers learn to avoid the electrical field associated with electrofishing. As a consideration, we recommend using fyke nets to complement electrofishing efforts during monitoring as these nets were effective at capturing Blue Suckers in autumn 2014. The turbidity of Red River will likely prevent Blue Suckers from avoiding the nets and if there is sufficient flow, fish should be moving. Further, sampling multiple sites in the lower Red River during the autumn, when Blue Suckers potentially move to winter habitats (Neely et al. 2009), may prove successful without disrupting actively spawning fish. Low detection rates of Blue

Sucker may prevent estimations of abundance using mark-recapture (e.g. Moss et al. 1983, Lyons et al. 2016), and monitoring trends in capture rates may be a better option (*e.g.*, biomass and yield estimation; Hayes et al. 2007). It may be beneficial to include other big-river obligate fishes of concern in the protocol. While conducting our research, we observed Alligator Gar *Atractosteus spatula*, Paddlefish *Polyodon spathula*, and Shovelnose Sturgeon *Scaphirynchus platorynchus*, and observed the invasive Bighead Carp *Hypophthalmichthys nobilis* and Silver Carp *H. molitrix*.

We reported that dams were often implicated as reason for the decline of big-river fishes, and we commonly observed Blue Suckers in the Hugo Dam and Denison Dam tailwaters. Blue Suckers were likely drawn to the swift water and coarse substrates provided by dam-release waters. If done properly, dams can be managed to mitigate the loss of upstream habitats (King et al. 1998, Jager and Smith 2008). However, dams can also introduce a myriad of other problems including poor water quality associated with the hypolimnion of a reservoir (Mϋeller et al. 2008; Olden and Naimen 2010), stunted juvenile growth due to water-level fluctuation (Weyers et al. 2003), or desiccation of spawned eggs due to the rapid drop in water level following spawning (Grabowski and Isely 2007). We note that low dissolved oxygen conditions commonly occur below Lake Texoma and several fish kills have occurred in that area. Further, although Blue Sucker used the tailwater reach, these fish were typically located about 10-km below Denison Dam where water-quality conditions were likely ameliorated. If fish are attracted by flows immediately below the dam, they would likely suffer the same fate as other fishes found in this area. Stranding eggs are also a consideration in these tailwater systems. When sampling below Hugo Dam during a dam release, we observed Blue Suckers actively spawning over riprap. The riprap was above the water line within an hour after spawning when the dam gates closed. Additionally, many of the gravel flats in the Denison Dam tailwater that appear suitable for spawning when there is sufficient water become dry once the hydropower flows cease. Ramping the dam releases to mimic natural or quasi-natural flows would likely improve the recruitment and survival of Blue Suckers and other fishes that are drawn to tailwaters to spawn.

We observed several individuals traveling throughout the Red River catchment in Oklahoma indicating that Blue Suckers take advantage of the connectivity and flow patterns of the lower basin. This indicates that the mechanisms for a metapopulation are in place and any management actions would benefit from consideration of connectivity with the population in the Arkansas portion of the Red River described by Layher (1998). Collaborating with Arkansas and Louisiana biologists to obtain tissue for genetic analysis could be used to determine geneflow through the Red River and used to better understand migration rates within and among adjacent states (e.g., Morán et al. 1995; Bertrand et al. 2016). Without consideration for interstate migrations, successful management of the Blue Sucker population in Oklahoma will be challenging.

The structure of biotic assemblages typically changes in a predictable fashion along a downstream continuum in relation to environmental gradients (Vannote et al. 1980). Although general upstream-downstream trends associated with coarse-scale environmental characteristics (e.g., stream slope) are common for stream fishes, species distributions at finer scales are often patchy due to variability of instream habitat (e.g., water depth, current velocity, and available cover; Grossman et al. 1990; Schlosser 1991; Fausch et al. 2002). Every reach of stream also has unique geomorphic characteristics (e.g., channel dimensions, substrate, and channel unit diversity), which can result in considerable habitat diversity along the stream continuum (Leopold 1994). We observed this in our habitat analyses where deeper pools became important to Blue Sucker spawning distributions as they used habitat further upstream in the major tributaries. Because Blue Sucker spent a lot of their reproductive time in these tributaries, it is important to ensure the persistence of these deeper-water habitats or the available spawning habitat will be further truncated (i.e., in addition to current fragmentation via dams). River channels typically become more homogenous (i.e., wider and shallower) under different land-use practices and as such, Blue Sucker populations would benefit from best management practices in these areas (e.g., protection of stream banks, maintaining riparian areas). Based on straying rates to Muddy Boggy (and the unregulated flows), this system is likely an area where monitoring of both habitat and flow changes over time might be worth consideration.

IV. SIGNIFICANT DEVIATIONS

No significant deviations.

V. EQUIPMENT

NA

VI. PREPARED BY:

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Oklahoma Department of Wildlife Conservation

VII. REFERENCES

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Table 1 The hypotheses and candidate models tested in our type I habitat selection analysis. A single word name is assigned to each hypothesis (column 1), the hypothesis is stated (column 2), and the model created to represent each hypothesis is given (column 3). In each model, Y_i indicated the expected number of Blue Suckers in mesohabitat i, and β is the associated coefficient estimated for each fixed effect. The multiple β coefficients associated with location correspond to the Kiamichi, Muddy Boggy and Red river, and Blue River was the reference variable. The error with each model was independent and followed a negative binomial distribution.

Name	Hypothesis	Model
null	Location alone explains selection	$Y_i = \beta_0 + \beta_{1,2,3} location_i$
distance	The distance upstream explains selection	$Y_i = \beta_0 + \beta_1 distance_i + \beta_2 distance_i^2 + \beta_{3,4,5} location_i$
riffle	The presence of riffles explains selection	$Y_i = \beta_0 + \beta_1 riffle_i + \beta_{2,3,4} location_i$
coarse	The percent of coarse substrate explains selection	$Y_i = \beta_0 + \beta_1 coarse_i + \beta_{2,3,4} location_i + \beta_{5,6,7} coarse_i * location_i$
slope	The mean stream slope explains selection	$Y_i = \beta_0 + \beta_1 slope_i + \beta_2 distance_i + \beta_3 distance_i^2 + \beta_{4,5,6} location_i$
wood	The percent of wood explains selection	$Y_i = \beta_0 + \beta_1 wood_i + \beta_2 wood_i^2 + \beta_{3,4,5} location_i$
depth	Mean depth explains selection	$Y_i = \beta_0 + \beta_1 depth_i + \beta_2 depth_i^2 + \beta_3 distance_i + \beta_4 distance_i^2 + \beta_{5,6,7} location_i + \beta_8 depth_i * distance_i + \beta_9 depth_i * distance_i^2 + \beta_{10} depth_i^2 * distance_i + \beta_{11} depth_i^2 * distance_i^2$

Table 2. Locations and number of Blue Suckers acoustically tagged in 2015. See also Fig. 2.

River	Local name	Latitude	Longitude	Number of fish tagged
Blue	Smith-Lee corner	33.89228	96.01984	10
Blue	Smith-Lee corner	33.89292	96.03231	8
Blue	NA	33.91076	96.04978	12
Red	Carpenter’s bluff	33.92488	95.65471	29
Muddy Boggy	NA	33.77737	96.47704	30
Kiamichi	Hugo Dam	34.00678	95.38027	22
Kiamichi	Big Shoal	33.94701	95.29504	8

Table 3. AIC_c model results associated with spawning habitat selection by Blue Sucker. The model names (first column) correspond to the model names provided in Table 1. We provide the number of parameters estimated in each model (K), log-likelihood estimate, AIC_c score, difference in AIC_c score from the top ranked model (ΔAIC_c) and the R^2 value for each model.

Model	K	Log-likelihood	AIC_c	ΔAIC_c	R^2
Depth	12	-573.9	600.7	0.0	0.16
Wood	6	-588.4	602.6	1.9	0.13
Slope	7	-588.5	604.8	4.2	0.13
Distance	6	-591.0	605.3	4.6	0.13
Riffle	5	-594.9	607.2	6.5	0.15
Coarse	8	-589.6	608.0	7.3	0.13
Null	4	-598.0	608.2	7.5	0.11

Table 4. Biological data of Blue Suckers included in our Type II habitat selection analysis. The fish code corresponds to the letter assigned to individual fish in Fig. 7. Demographics are coded as Gender (M = male; F = female); TL (total length); and wet weight (WW). Tag Location refers to the study reach in which an individual was capture and tagged.

Fish Code	Gender	TL (mm)	WW (g)	Tag Location
A	F	621	1900	Red
B	F	514	900	Red
C	M	511	1050	Blue
D	M	515	1200	Kiamichi
E	U	549	1130	Muddy Boggy
F	M	561	1200	Red
G	F	610	2260	Kiamichi
H	M	629	1900	Red
I	M	518	900	Kiamichi
J	F	606	1600	Red
K	F	576	1400	Red
L	F	580	1300	Red
M	F	660	2570	Muddy Boggy
N	F	610	1700	Red
O	M	577	1300	Red
P	F	549	1200	Red
Q	F	575	1300	Red
R	M	574	1500	Red
S	F	519	1150	Blue
T	F	625	2350	Kiamichi
U	F	572	1500	Red
V	M	563	1350	Blue
W	M	533	1340	Kiamichi

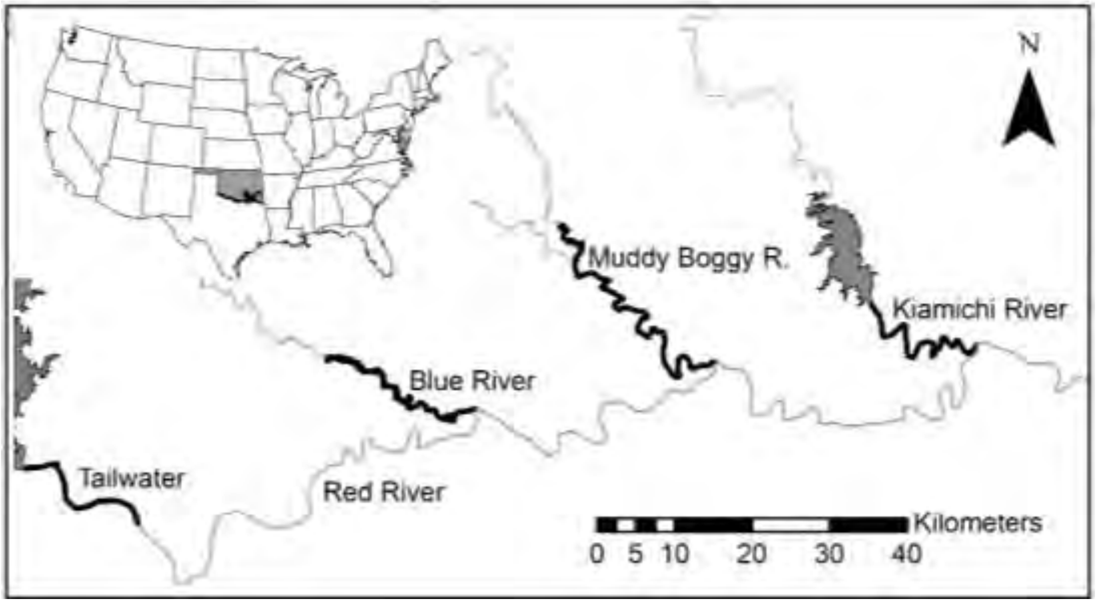

Figure 1. Lower Red River catchment with the study reaches for the habitat selection objective designated in bold. The reservoirs from west to east are: Lake Texoma, and Hugo Lake on the Kiamichi River.

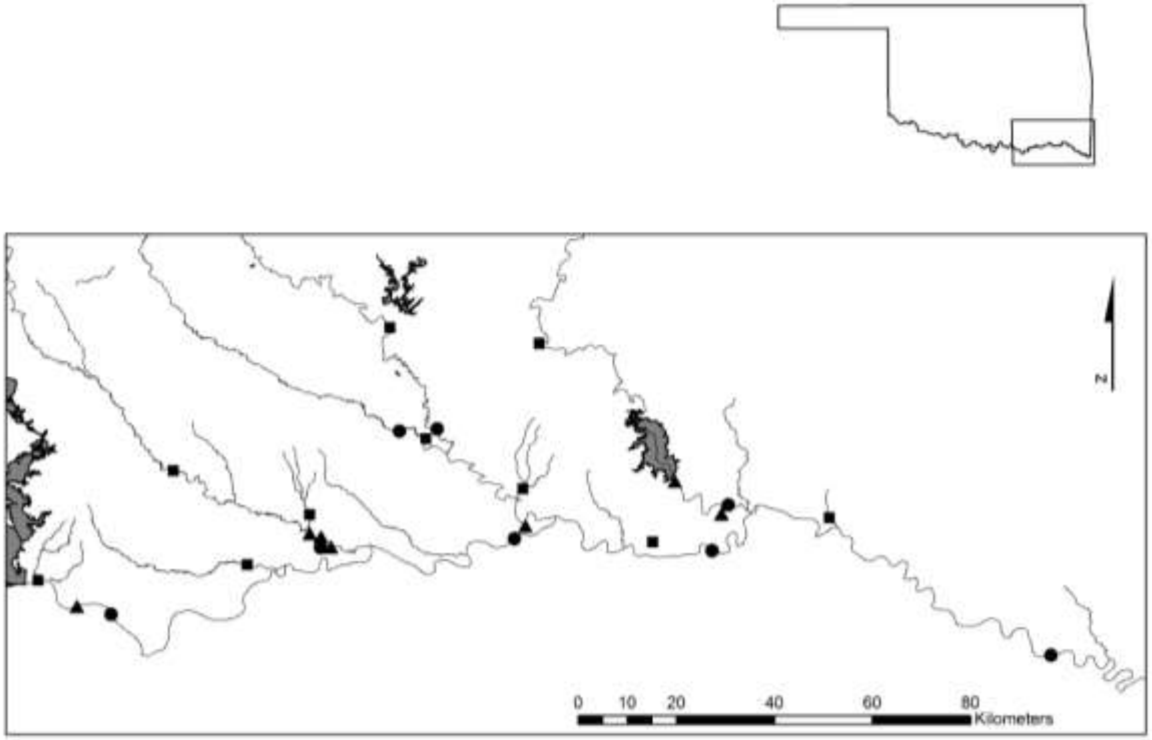

Figure 2. Sampling locations in the lower Red River, Oklahoma. From left to right, the major tributaries are: Blue, Muddy Boggy and Kiamichi rivers. The reservoir in the west is Lake Texoma, McGee Creek is in the center and Hugo Lake is to the east (on the last major tributary, Kiamichi River). The primary tributaries are (west to east): Blue River, Muddy Boggy, and Kiamichi River. Circles represent 2014 sampling locations, triangles correspond to 2015 sampling locations, where we implanted Blue Suckers with acoustic transmitters, and squares depict 2017 sampling locations.

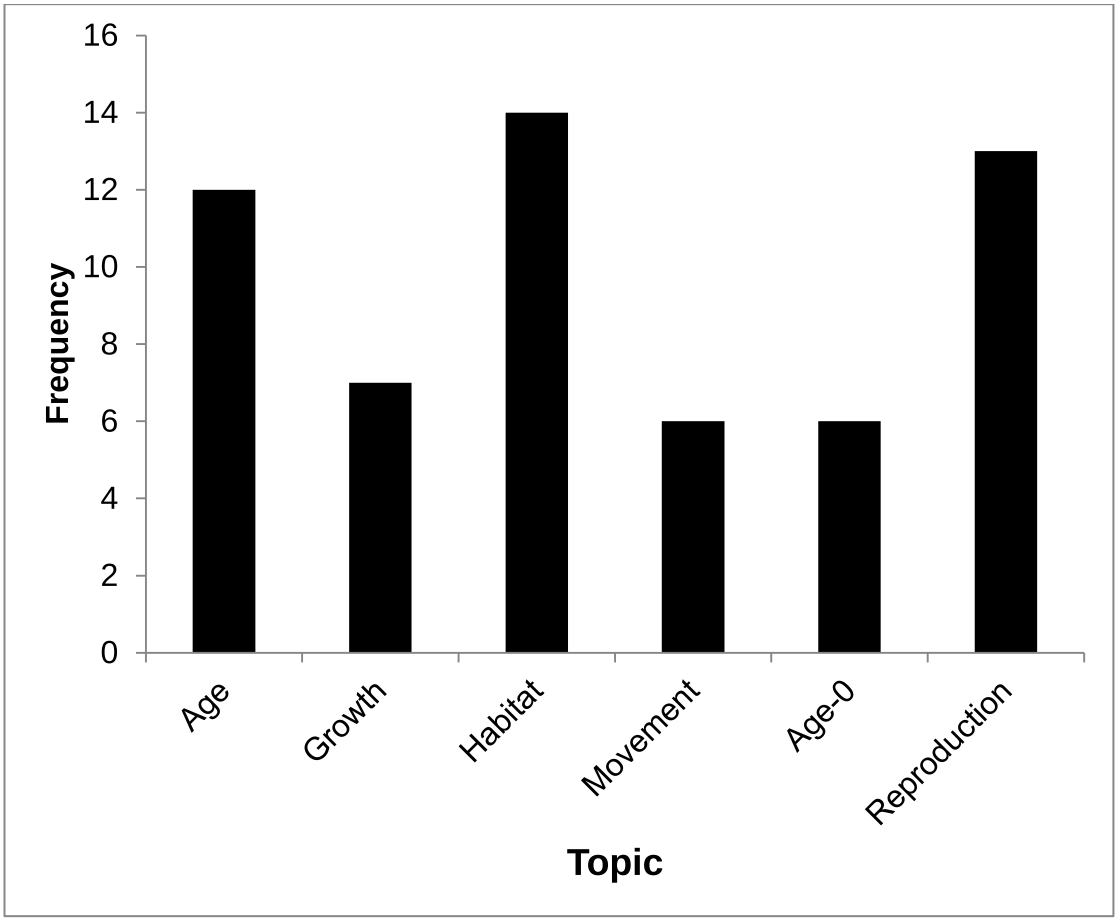

Figure 3. The number of papers (black bars) investigating the ecology and life history of Blue Sucker. Ecological elements reviewed (x axis) included age, growth, habitat, movement, early life history (age 0), and reproduction.

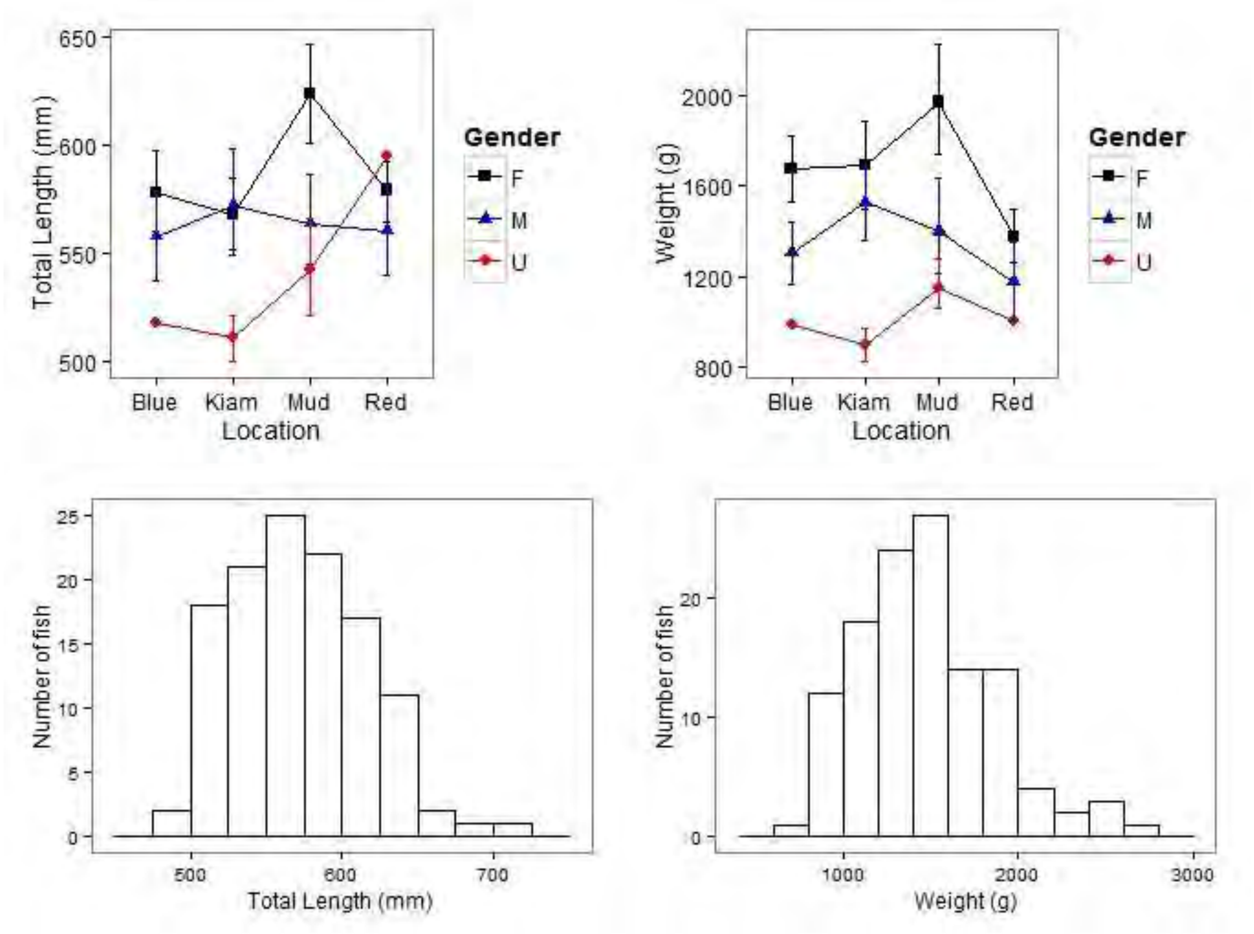

Figure 4. The size distribution of Blue Suckers tagged in the spawning site and habitat selection study. Top panel: mean size of female (black), male (blue) and unknown gender (red) Blue Suckers that were implanted with acoustic tags. Errors bars indicate 90% confidence intervals. Blue Suckers were tagged in the Blue, Kiamichi (Kiam), Muddy Boggy (Mud) and Red rivers. Bottom panel: total length and weight distributions of all tagged Blue Suckers.

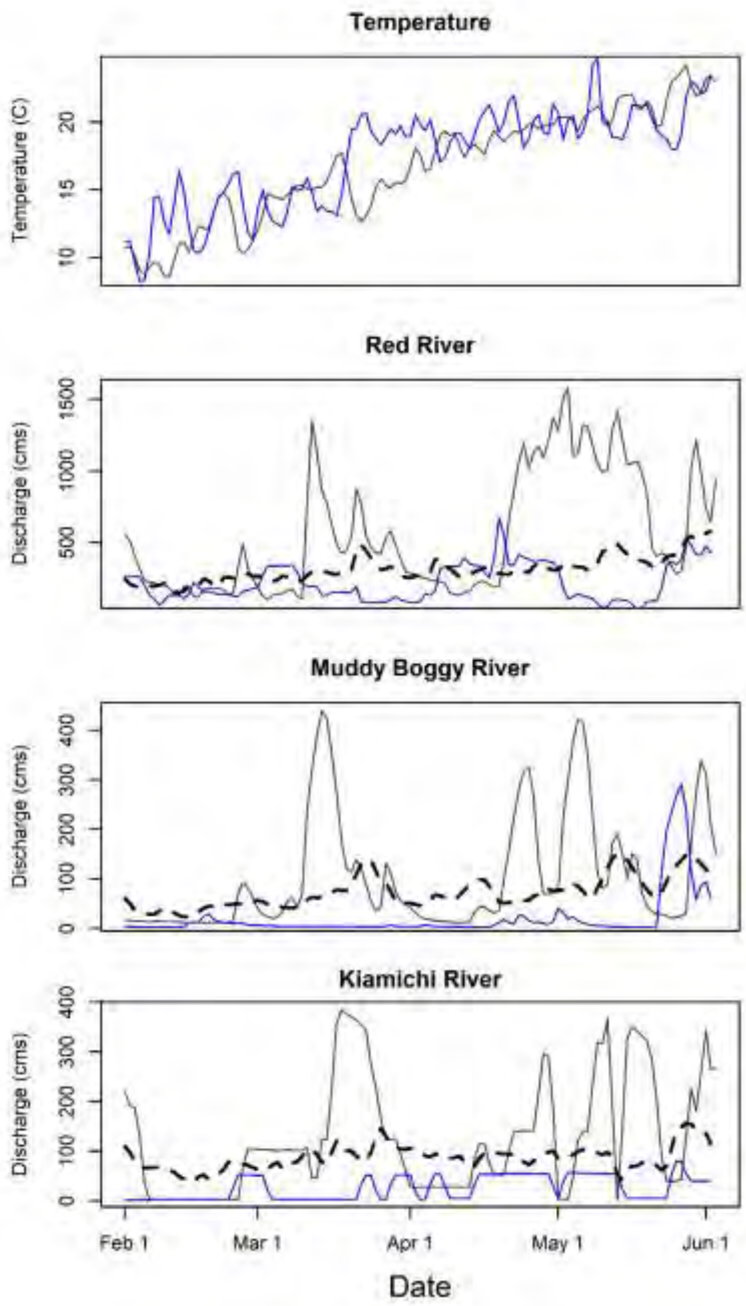

Figure 5. Water temperature at the Red River (Hwy 271 bridge, collected using a HOBO, Onset), and hydrographs representing stream discharge (cms) in the Red, Muddy Boggy, and Kiamichi rivers during the early-seasons 2016 (gray), 2017 (blue), and the 20-year average (1998 – 2017, dashed) (https://waterdata.usgs.gov/ok/nwis/uv?site_no=07335500, accessed 2/27/18).

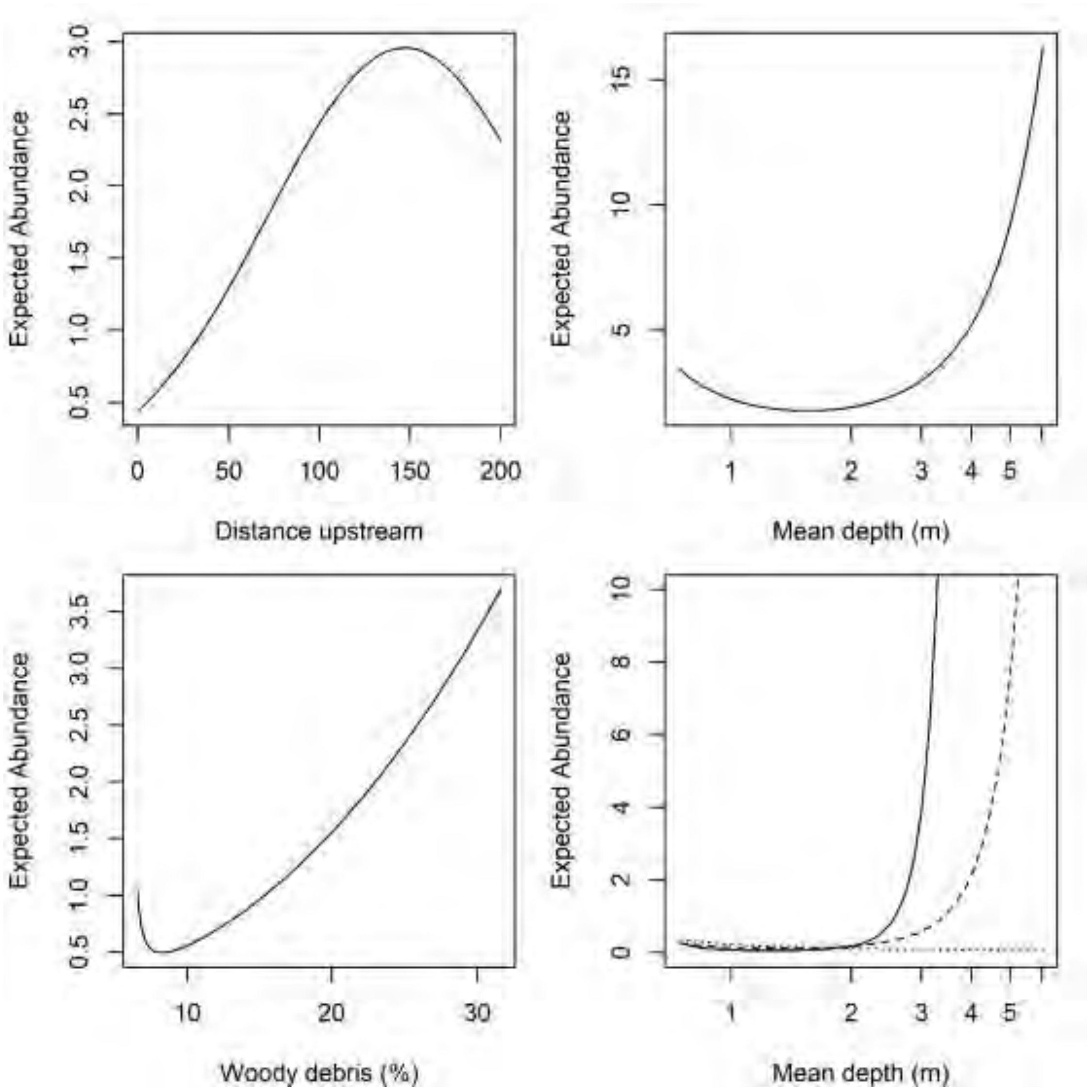

Figure 6. Relationship between Blue Sucker habitat selection and distance upstream (top left), mean mesohabitat depth (top right), the percentage of woody debris (bottom left), and the interaction between mean depth and distance upstream (bottom right; depths plotted on log-scale). The lines represent the model estimates for the Kiamichi River, as it represents approximately the average across the study areas. In the interactive plot, the three lines correspond to 150 (solid), 100 (dashed), and 50 (dotted) river sections upstream of the Red River confluence (corresponds to rkm of ≈ 35, 29, and 22 respectively). Estimates in the Red River were much larger (i.e., range 10 – 70) than those in the Kiamichi River, whereas estimates in Blue and Muddy Boggy Rivers were much lower (i.e., < 1).

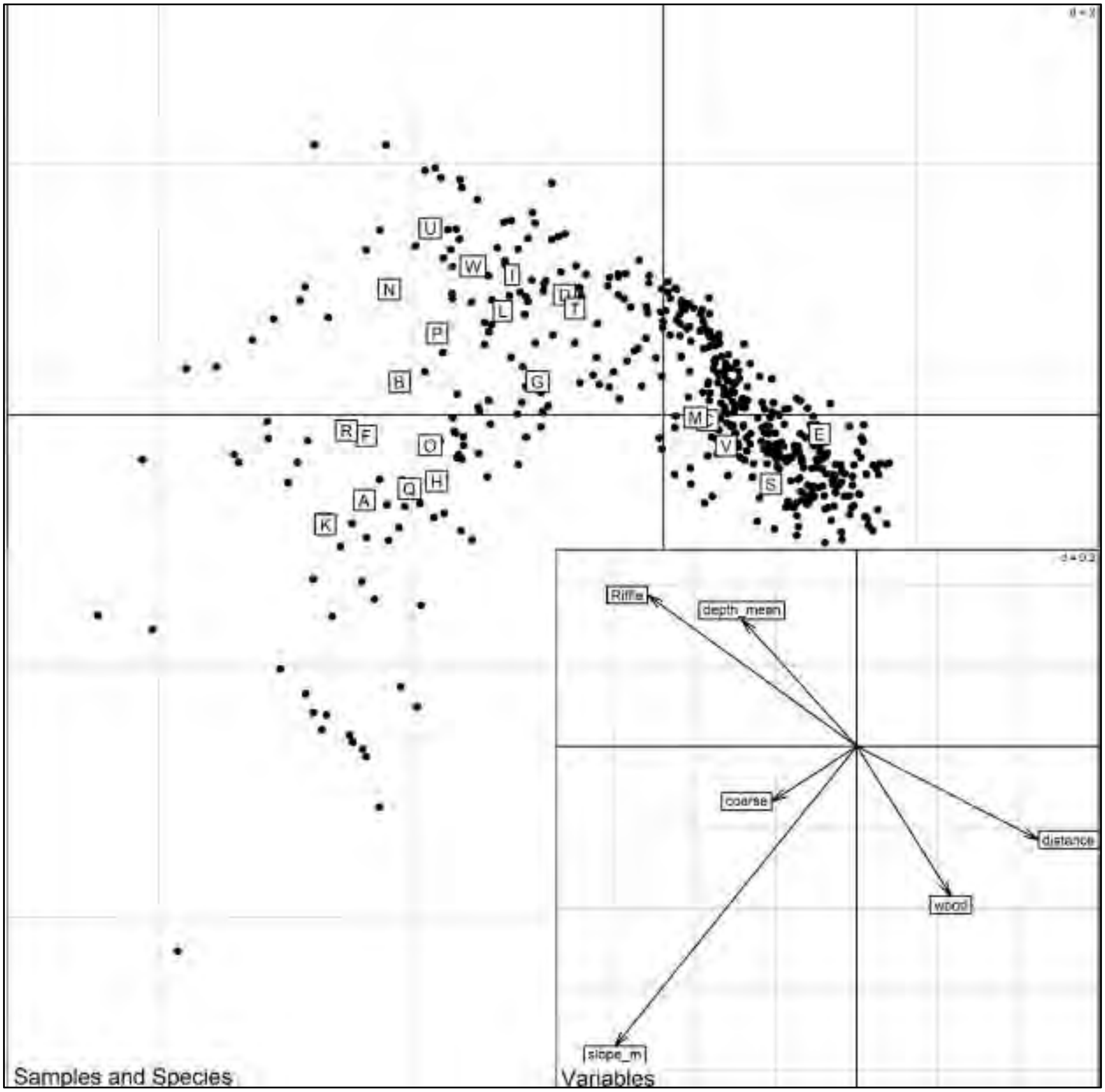

Figure 7. Results from the outlying mean index analysis. The axes associated with the habitat variables are given in the lower right panel. The length of the arrows indicates the influence of variables and the direction indicates the relationships among the variables. Additionally, the lower right panel depicts the multivariate space in which the data are plotted in the main panel. The main panel depicts the available habitat (dots) and habitat selection by individual fish (letters). Individual Blue Sucker codes are provided in Table 4.

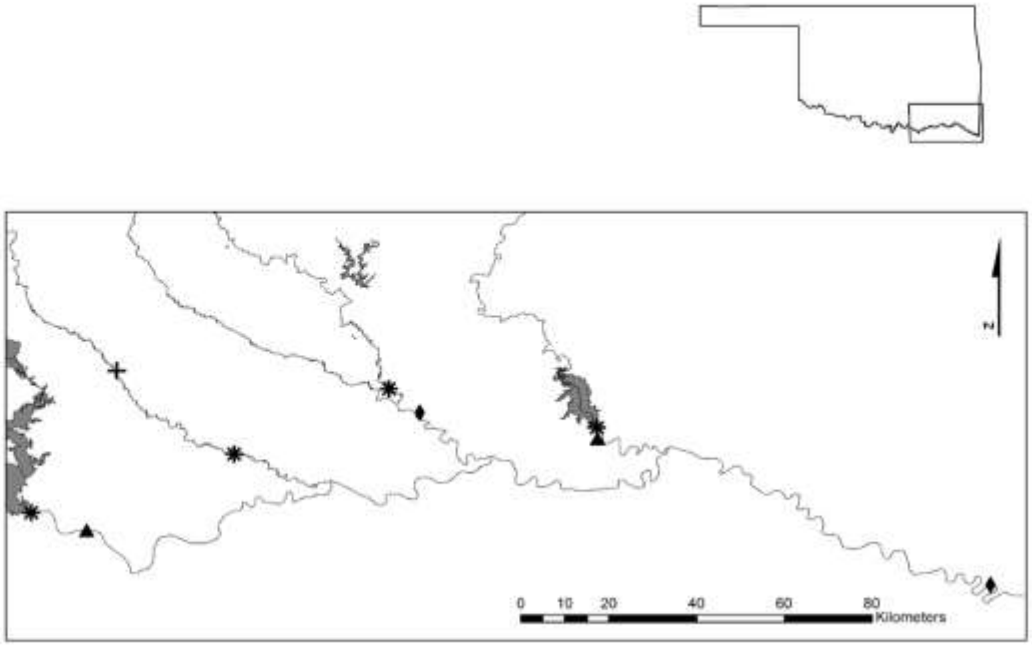

Figure 8. Blue suckers are currently distributed throughout the lower Red River basin truncated by dams or dry river sections. From left to right, the major tributaries are Blue, Muddy Boggy and Kiamichi rivers. The reservoirs (west to east) are: Lake Texoma, McGee Creek, and Hugo Lake. The cross on Blue River represents a low head dam that creates a migratory boundary. Bold asterisks represent the upstream-most detection of a telemetered Blue Sucker in each tributary, and roughly correspond to the upstream extent of our acoustic-tracking reaches. Triangles and diamonds each represent point locations of select individuals. The individual depicted as a triangle was observed in the tailwater reach in 2016 after being tagged in Kiamichi River in 2015. The individual represented with a diamond was detected near the Arkansas state line after being tagged in Muddy Boggy River earlier that year. It was detected again in Muddy Boggy River in spring 2016.

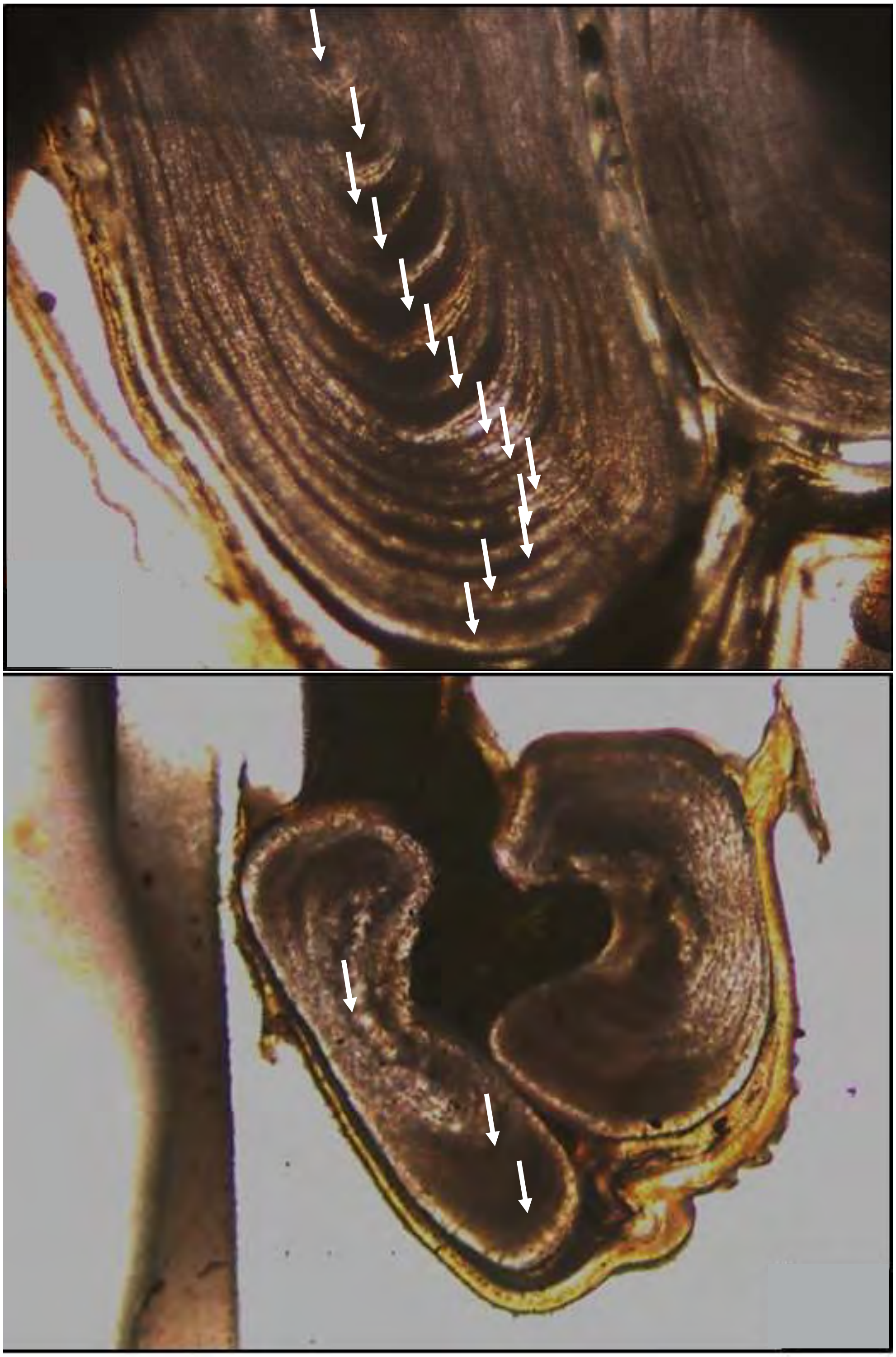

Figure 9. Pectoral ray sections of Blue Suckers captured in Red River during spring 2016. Estimated ages of fish were: 14 (top) and 3 (bottom) years of age. Annuli are indicated by white arrows.

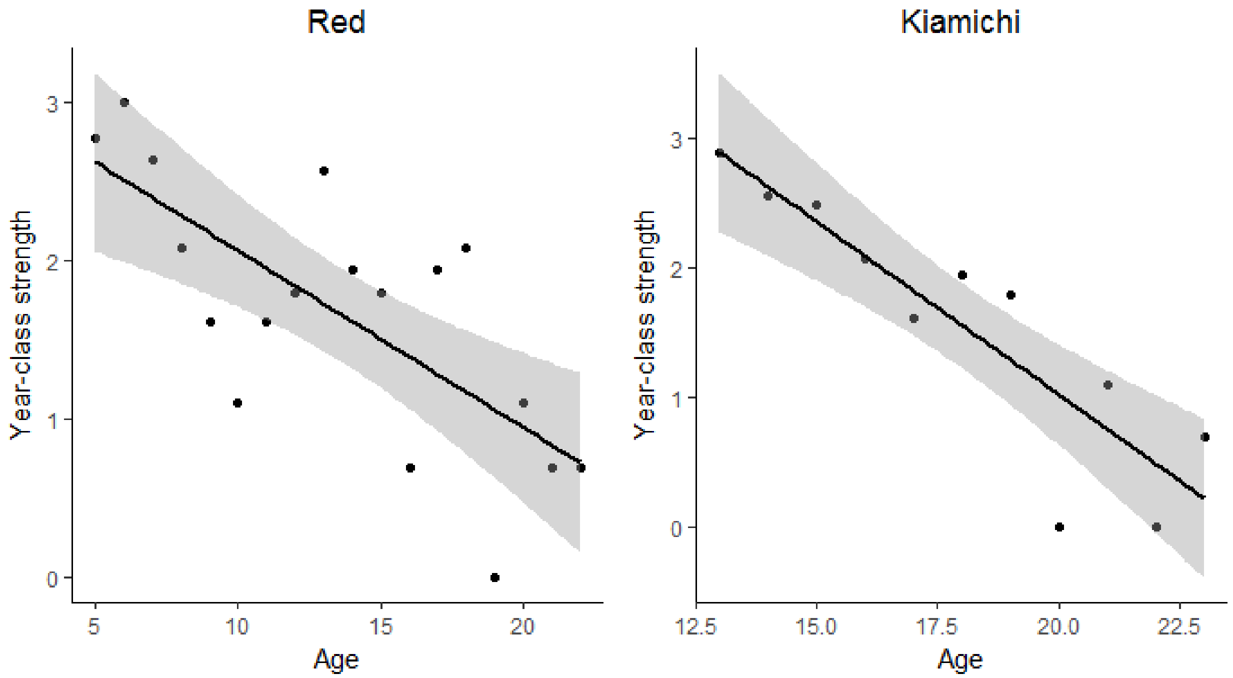

Figure 10. Catch-curve models associated with the Red and Kiamichi river populations. Gray bands represent the standard error associated with the estimated regression line.

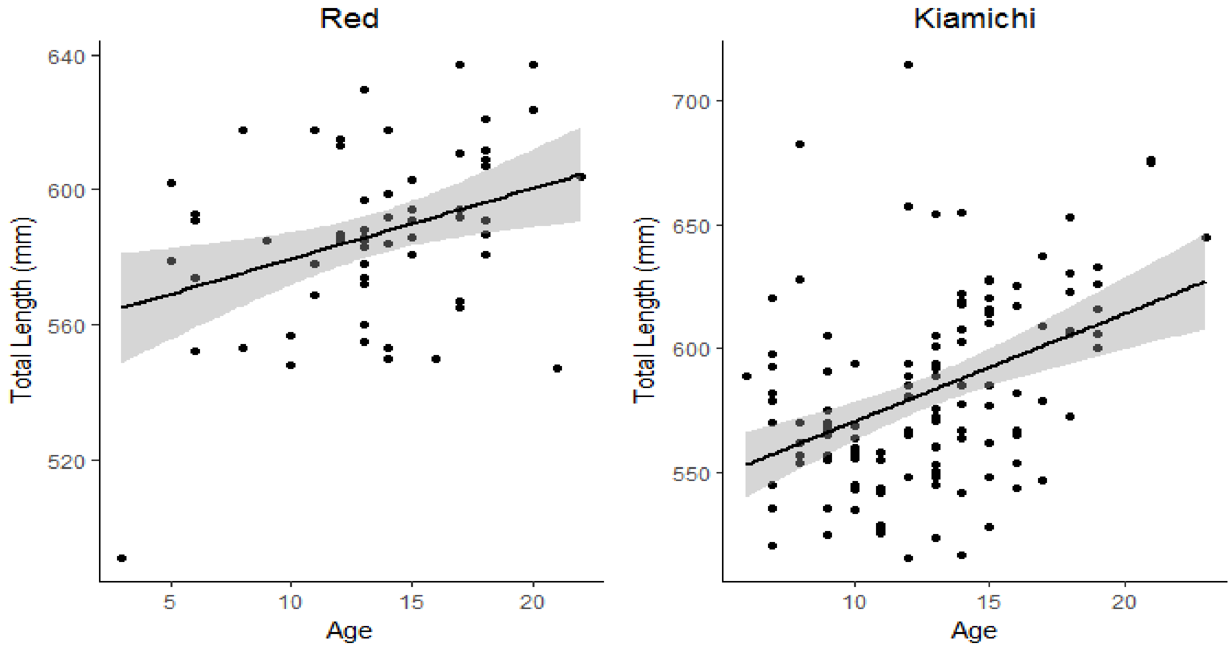

Figure 11. Relationship between total length (mm) and age (year) of adult Blue Suckers in the Red (left) and Kiamichi (right) rivers. Gray bands represent the standard error associated with the estimated regression line shown in black.

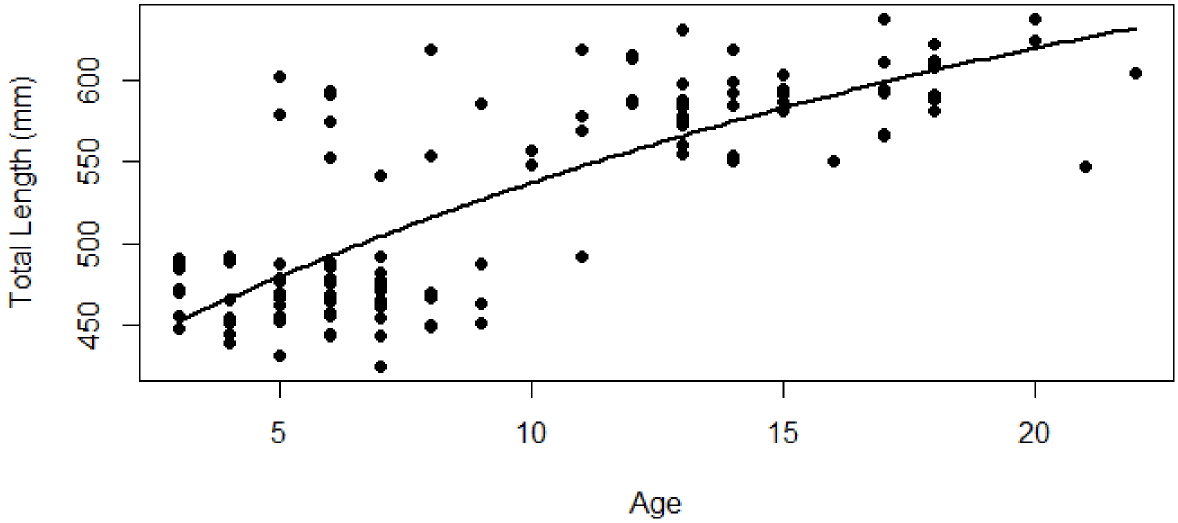

Figure 12. Growth of Blue Suckers in the Red River, Oklahoma. Black dots indicate the size at age of Blue Suckers and the line represents the von Bertalanffy Growth function fitted to the population (L_t = 762 * 1- $e^{-0.045(t--16.837)}$).

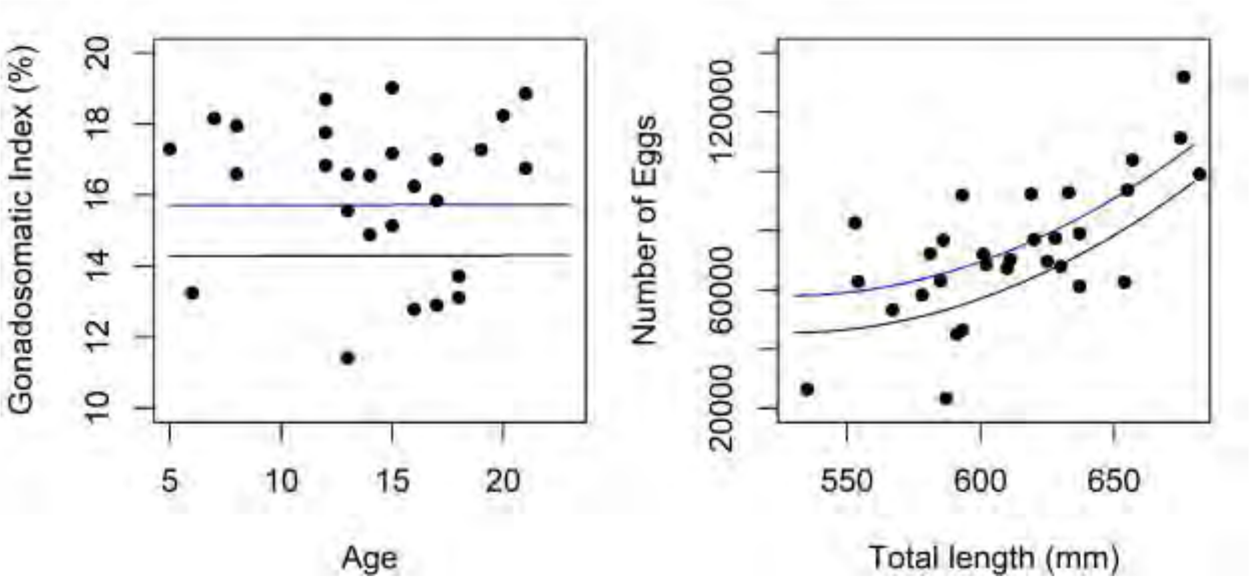

Figure 13. Blue Sucker fecundity in the lower Red River catchment. Results suggest there is no relationship between gonosomatic index and Blue Sucker age (left). The relationship between potential fecundity and total length (right) appears to be slightly curvilinear. Black lines represent Red River and blue lines represent Kiamichi River.