# FINAL PERFORMANCE REPORT

**Federal Aid Grant No. F13AF01327 (T-71-1)**

# Understanding the Impacts of Surface-groundwater Conditions on Stream Fishes under Altered Base-flow Conditions

**Oklahoma Department of Wildlife Conservation**

**Grant Period: January 1, 2014 – December 31, 2018**

**FINAL PERFORMANCE REPORT**

**State:** Oklahoma **Grant Number:** F13AF01327 (T-71-1)

**Grant Program:** State Wildlife Grant

**Grant Title:** Understanding the impacts of surface-groundwater conditions on stream fishes under altered baseflow conditions

**Report Period:** January 1, 2014 – December 31, 2018

**Grant Period:** January 1, 2014 – December 31, 2018

**Project Leaders:** Shannon Brewer, Ph.D. & Garey Fox, Ph.D.

## EXECUTIVE SUMMARY

Persistence of aquatic fauna depends on the conditions and connectivity of surface water and groundwater. In light of altered baseflows and both current and future predicted increases in stream temperatures, it is important to assess current thermal conditions, examine thermal responses of aquatic fauna, and evaluate water-management practices. Our study objectives were to determine (1) how changes in baseflow levels in the Kiamichi River influence hyporheic exchange, which correspondingly influences temperature at the reach scale; (2) temperature tolerances of stream fishes as a means for predicting how habitat complexity influences stream-fish populations; and (3) assess how dam releases influence the downstream temperature and dissolved oxygen regime during the low-flow period. We quantified hyporheic exchange at four reaches and, as expected, found higher groundwater exchange via transient storage occurred at the upstream sites. The net groundwater flux estimation was negative for the majority of reaches indicating that surface water is lost to groundwater during summer (i.e., losing), baseflow conditions. We determined critical thermal maximum (CTMax) for 17 stream fishes and thermal tolerances ranged 32-38°C. We determined the average thermal tolerance for two habitat fish guilds to calculate changes in thermal stress due to hypothetical reservoir release scenarios. We developed a process-based Water Quality Analysis Simulation Program model to predict downstream temperature conditions over 74-km of river in response to reservoir releases that corresponded to discharges of 0.00 (control), 0.34, 0.59, 0.76, 1.13, and 1.50 $m^3/s$. Based on the dissolved oxygen conditions observed in 2015 and 2017 and biological oxygen demand sampling results, reservoir releases did not directly reduce dissolved oxygen concentrations in the Kiamichi River (though dissolved oxygen concentrations are limited to current water-release strategies by the managing agency). We simulated three scenarios using three water-release temperatures: 27.64°C, 26.00°C and 24.07°C that corresponded to average reservoir temperatures at gate locations on the dam. We compared the predicted temperature time series with CTMax of two fish-habitat guilds to quantify the cumulative time when stream fishes experienced severe thermal stress downstream from Sardis Reservoir. According to our simulations, reservoir releases would be capable of regulating downstream water temperature during the summer baseflow period. The 0.00 $m^3/s$ scenario resulted in 130 h of thermal stress for benthic fishes, and 73 h for mid-column fishes. As expected, thermal relief increased with increasing release magnitude and decreasing release water temperature. The 0.34 $m^3/s$ release scenario reduced thermal stress (range is simulations from the top and bottom gate) by 11-18% for mid-column fishes and 8-12% for benthic fishes with an effective distance (where the cumulative time above CTMax was reduced by half) of 1-2 km for both guilds. The 0.59 $m^3/s$ release scenario reduced thermal stress by 18-25% for mid-column fishes and 12-20% for benthic fishes with effective distances of 4-8 km and 2-7 km, respectively. Three releases representing pre-dam flow magnitudes (0.76, 1.13 and 1.50 $m^3/s$ released from top gate) reduced thermal stress up to 46% for mid-column fishes and 41% for benthic fishes with an effective distance of 13-16 km, respectively. Lastly, we quantified temperature-induced stress via whole-body cortisol concentration of six stream fishes in response to prolonged thermal exposure at two temperatures (27°C and 32°C). We found no difference in cortisol levels between temperatures for any of the six species, indicating acclimation to elevated temperatures during the test period. However, Highland Stoneroller *Campostoma spadiceum* expressed cortisol concentrations greater than typical basal levels at both temperatures, suggesting stress from factors other than temperature (i.e., captivity). Our results suggest different reservoir-release options could improve downstream thermal-fish habitat during the summer baseflow period.

## I. BACKGROUND & OBJECTIVES:

Human modifications of rivers, particularly flow modifications, are resulting in the loss of aquatic organisms. Aquatic systems are channelized, dammed, dredged, leveed, and pumped to maximize flood protection, maintain and expand water supplies, and generate power (Wootton, 1990). Across much of Europe, Asia, the United States, and Mexico, the prevalence of stressors on freshwater resources put human water security and biodiversity at risk (Vörösmarty et al., 2010). Water resource development that fragments rivers is a prominent stressor on biodiversity (Vörösmarty et al., 2010). Flows and habitat are fragmented by dams in more than 50% of the world's large rivers (Nilsson et al., 2005) thereby affecting the persistence of downriver organisms (Olden and Naiman, 2010). In addition to river fragmentation, dams affect instream habitat by degrading water quality (Olden and Naimen, 2010), disrupting natural flows (Poff et al., 1997), and altering thermal (Olden and Naimen, 2010) and sediment regimes (Wohl et al., 2015). Reservoirs are typically operated to focus on our growing human water demands despite the importance of natural flow patterns to biota (Poff, 1997).

Efforts to improve conditions in rivers regulated by impoundments have increased in recent years (Tharme, 2003). In fact, more than 30 scientific approaches have been documented to facilitate environmental flow efforts (Annear et al., 2002; McManamay et al., 2016) and many efforts have been ecologically successful. For example, implementation of environmental flows for over 13 years in the Upper Nepean River system, Sydney, Australia, improved macroinvertebrate assemblages at restored sites (Growns, 2016), and Kiernan et al. (2012) show that restoration of seasonal high discharge events in Putah Creek, California, created favorable spawning and rearing habitat. However, the flow-biota relationships observed in many regulated rivers reflects the water-quality conditions of the discharging reservoir (Olden and Naiman, 2010), and consequently there are many examples of environmental flow efforts failing to provide the perceived benefits due to other release-related factors such as sediment (Yarnell et al. 2015), temperature (McManamay et al. 2013), or contaminants (Schwindt et al. 2014). Thus, improving flow conditions without consideration of reservoir water quality or other limiting factors may maintain or improve river hydrologic connectivity, but do little to improve or may even worsen environmental conditions (Krause et al., 2005; Poff et al., 2017).

Though research efforts to improve downriver conditions have focused primarily on hydrologic alteration (Bunn and Arthington, 2002), the significance of riverine water quality on biota, especially temperature, is widely acknowledged (Magnuson et al., 1979; Poole and Berman, 2001; Caissie, 2006). Water releases from dams and diversions often alter the thermal gradients for an extensive distance downstream (Ellis and Jones, 2013) thereby affecting species' phenology (e.g., Sockeye Salmon Oncorhynchus nerka, Quinn et al., 1997), decreasing growth (e.g., Brown Trout Salmo trutta, Saltveit, 1990; Murray cod Maccullochella peelii, Nick et al. 2017), reducing reproduction rate (e.g., Rainbow Trout Oncorhynchus mykiss, Pankhurst, 1997), and even resulting in species' extirpation (e.g., freshwater mussels, Vaughn and Taylor, 1999; fishes, Olden and Naiman, 2010).

Given the coupling between the water quantity and quality, it is critical to identify environmental flow solutions that balance both human and ecological needs (Brewer et al., 2016) and to begin to address the multiple limiting factors affecting some ecosystems (Poff et al. 2017). The specific study objectives were to determine (1) how changes in baseflow levels in the Kiamichi River influence hyporheic exchange, which correspondingly influence temperature at the reach scale; (2) temperature tolerances of stream fishes as a means to predicting how habitat complexity influences stream-fish populations; and (3) how dam releases influence the downstream temperature and dissolved oxygen regime during the low-flow period.

## II. SUMMARY OF PROGRESS

### A. APPROACH

Study Area

The Ouachita Mountain Ecoregion is located in southeast Oklahoma. The ecoregion comprises pine, oak, and hickory forest and land use in the region consists primarily of agriculture, logging, ranching, and recreation (Woods 2005). Streams within the region have steep valleys and primarily bolder and cobble substrates (Splinter et al. 2011). The Kiamichi River, a tributary of the Red River, originates near Pine Mountain in the Ouachita Mountains near the Arkansas border. From its source in LeFlore County, Oklahoma, the Kiamichi River flows approximately 285 km (177 miles) to its confluence with the Red River south of Hugo, Oklahoma.

Hyporheic exchange and stream temperatures

We quantified hyporheic exchange and the thermal profile of reaches across the study area. We used transient storage tracer tests with Rhodamine WT tracers under varying baseflow levels to quantify total transient groundwater storage. Water level and temperature loggers were positioned in the stream for measuring temperature gradients. Cross-section surveys were performed at numerous transects within each reach to document changes in bed topography and channel morphology. Direct push piezometers were used for monitoring pressures in the near-streambed shallow groundwater in an attempt to separate surface and hyporheic storage following Stofleth et al. (2008). Rhodamine WT concentrations were measured using a fluorometer.

*Seepage Runs*

Seepage run is a field technique used for estimating net water fluxes between surface water and groundwater (see Zhou et al. 2018). The seepage run consists of measuring streamflow at multiple transects along the river. The discharge difference between transects is assumed to be the result of groundwater discharge to the stream or loss of stream water to groundwater.

*Tracer Test and OTIS-P*

Tracer tests were performed using Rhodamine WT tracers to quantify the transient storage characteristics. For each site, a tracer was injected at one upstream location and sampled at three downstream monitoring locations. The collected samples were read using a fluorometer and the collected concentration data analyzed using the OTIS-P model to quantify the transient storage characteristics.

OTIS (One-Dimensional Transport with Inflow and Storage) is a model used to characterize the rate of transport of water-borne solutes in stream and river systems that simultaneously solves equations (1) and (2) given the appropriate parameters of the model (Runkel, 1998).

$$\frac{\partial C}{\partial t} = -\frac{Q}{A}\frac{\partial C}{\partial x} + D\frac{\partial^2 C}{\partial x^2} + \alpha_s\left(C_S - C\right) \tag{1}$$

$$\frac{dC_S}{dt} = \alpha_s \frac{A}{A_S}\left(C - C_S\right) \tag{2}$$

where $A$ is the main channel cross-sectional area ($L^2$), $A_s$ is the storage zone cross-sectional area ($L^2$), $C$ is the main channel solute concentration ($M\ L^{-3}$), $C_s$ is the storage zone solute concentration ($M\ L^{-3}$), $D$ is the dispersion coefficient in the main channel ($L^2\ T^{-1}$), $Q$ is the flow rate in the main channel ($L^3\ T^{-1}$), and $\alpha_s$ is the storage zone exchange coefficient ($T^{-1}$) (Runkel, 1998).

In this research, OTIS was inversely (known as OTIS-P) used to estimate main channel and transient storage zone parameters based on data collected from soil pipe tracer tests of Wilson et al. (2015) described below. Typically, for a conservative tracer and constant flow rate the $A$, $D$, $A_s$ and $\alpha_s$ are inversely estimated from tracer breakthrough curves (Stofleth et al., 2008). OTIS-P uses a nonlinear regression method in fitting the advection–dispersion equations (equations 1 and 2) to observed data by minimizing the squared error between observed and modeled concentrations where $A$ is the main channel cross-sectional area ($L^2$), $A_s$ is the storage zone cross-sectional area ($L^2$), $C$ is the main channel solute concentration ($M\ L^{-3}$), $C_s$ is the storage zone solute concentration ($M\ L^{-3}$), $D$ is the dispersion coefficient in the main channel ($L^2\ T^{-1}$), $Q$ is the flow rate in the main channel ($L^3\ T^{-1}$), and $\alpha_s$ is the storage zone exchange coefficient ($T^{-1}$) (Runkel, 1998).

Influence of dam releases on stream temperatures and dissolved oxygen

*WASP Modeling*

We modeled the thermal regime of an extensive segment of the Kiamichi River (Figure 1) using the Water Quality Analysis Simulation Program (WASP).
Hourly averaged weather data for 2013 were obtained from the Oklahoma Mesonet for three nearby sites (Talihina, Clayton and Antlers), including air temperature, dew point, net solar radiation and wind speed. Data were obtained from two existing gages (Clayton and Antlers, U.S. Geological Survey (USGS) gages 07335790 and 07336200, respectively) including hourly averaged gage height and flow rate data for 2013. River water temperature data were collected at four sites on the Kiamichi River via the Oklahoma Department of Wildlife Conservation, at sites designated as Payne Riffle, Pine Spur Riffle, Robins Riffle and NDN Riffle (Figure 1). These data included hourly averaged temperature data from 4/1/2013 to 9/1/2013.

The WASP is a dynamic compartment-modeling program for aquatic systems, including both the water column and the underlying benthos. The time-varying processes of advection, dispersion, point and diffuse mass loading, and boundary exchange are represented in the basic program. The WASP Temperature Module can be used to predict water column temperature based upon atmospheric conditions and heat exchange between the surface, subsurface and benthic layers of the water body. We began using WASP to predict temperature at four observation sites (Payne Riffle, Pine Spur Riffle, Robins Riffle and NDN Riffle) based on weather data, flow data and boundary temperature data (i.e., the observed water temperature data at Payne Riffle and NDN Riffle sites).

In the WASP Temperature Module, the stream water temperature is computed based on the following 1D advection-diffusion equation:

$$\frac{\partial T_s}{\partial t} = -\frac{\partial}{\partial x}(V_x T_s) + \frac{\partial}{\partial x}\left(D_x \frac{\partial T_s}{\partial x}\right) + \frac{H_n A_s}{\rho_w C_p V} + S \qquad (3)$$

where $T_s$ is the stream water temperature ($^o$C), $V_x$ is the advective velocities (m/s), $D_x$ is the diffusion coefficients (m$^2$/s), $V$ is the segment volume (m$^3$), $A_s$ is the segment surface area (m$^2$), $\rho_w$ is the density of water (997 kg/m$^3$), $C_p$ is the specific heat of water (4179

J/kg $^oC$), $H_n$ is the net surface heat flux (W/m$^2$), $S$ is the loading rate include boundary, direct and diffuse loading ($^oC$ /s).

The net surface heat flux includes the effects of a number of processes (Cole et al., 1994) computed as:

$$H_n = H_s + H_a + H_e + H_c - (H_{sr} + H_{ar} + H_{br}) \tag{4}$$

where $H_n$ is the net heat flux across the water surface (W/m$^2$), $H_s$ is the incident short wave solar radiation (W/m$^2$), $H_a$ is the incident long wave atmospheric radiation (W/m$^2$), $H_{sr}$ is the reflected short wave solar radiation (W/m$^2$), $H_{ar}$ is the reflected long wave radiation (W/m$^2$), $H_{br}$ is the back radiation from the water surface (W/m$^2$), $H_e$ is the evaporative heat loss (W/m$^2$), $H_c$ is the heat conduction (W/m$^2$).

The WASP model used a one-dimensional kinematic wave flow option where flow velocity, depth and width were calculated as an exponential function of flow rate, with their multipliers and exponents specified by user. Based on Acoustic Doppler Current Profiler (ADCP, SonTek RiverSurveyor M9) transect measurements, a set of multipliers and exponents was estimated based on the least sum of square of standard error approach to obtain the optimal and realistic flow dynamics. The regression equations are displayed below and plotted in Figure 2.

$$Velocity = 0.0389Q^{0.4000} \tag{5}$$

$$Depth = 0.7034Q^{0.1638} \tag{6}$$

$$Width = 36.528Q^{0.4362} \tag{7}$$

We represented the river within WASP by 74, 1-km segments. Because weather conditions were similar across the study area, we used meteorological data from one mesonet site (Clayton, OK) to calibrate our WASP model. Discharge monitored at USGS gage near Clayton (07335790) was used as hydrology input. Monitored stream water temperature data at Indian Highway (NDN, Figure 1) were used as the upstream boundary. The completed WASP model structure is illustrated in Figure 3.

*Reservoir Release Simulation*

The validated WASP model was used to predict downstream temperature in response to hypothetical reservoir operations during the validation period: 7/22/2017 to 9/1/2017. We first simulated stream water temperature without a release. This simulation served as a control and evaluated the thermal stress that would have been experienced by fishes in the absence of any water release. Next, multiple realistic release scenarios were simulated to assess their effects on both downstream water temperatures and fish-habitat guilds (Table 1). Five constant release levels were chosen: (1) 0.34 $m^3/s$ represented the current longer-term release that was previously provided by the U.S. Army Corps of Engineers and the Oklahoma Water Resources Board (OWRB) to provide limited relief to sensitive freshwater mussels during a drought (note, this release does not provide connectivity from Sardis Reservoir to Lake Hugo); (2) 0.59 $m^3/s$ represented the release that was hypothesized  to adequately restore wetted primary mussel habitat (i.e., provide connectivity and coverage of primary beds) at Clayton; (3) 0.76 $m^3/s$ (~26 cfs), 1.13 $m^3/s$ (~40 cfs)and 1.50 $m^3/s$ (~53 cfs) were chosen to represent the pre-dam median flows of August, September and July, respectively (Fisher et al. 2012). Three water temperatures, 27.64 $^oC$, 26.00 $^oC$ and 24.07 $^oC$, were applied in simulations as the lateral thermal boundary condition to represent releases from three gates at different depths of the reservoir (5, 10 and 20 m). Beginning water-release scenario temperatures were estimated by averaging summertime water temperature data for depths corresponding to the gates located at 5 m, 10 m and 20 m when the conservation pool is full (lake profile data from 1999 to 2015, Oklahoma Water Resources Board, 2016,).

To evaluate the benefits of the reservoir release on the receiving stream, we developed two metrics. Releases were aimed at keeping the stream temperatures below a thermal tolerance for fishes. For these initial simulations, the initial thermal tolerances ($T$*) of organisms were assumed to be 30°C (until the thermal experiments were completed). The metrics were based on the principle of average excessive heat energy and average heat flux:

Time averaged excessive heat energy:

$$h_e(m) = \frac{1}{n}\sum_{i=1}^{n}\left[V(n,m) * \rho * \Delta T(n,m) * C_p\right] \tag{8}$$

Time averaged excessive heat flux:

$$h_{ef}(m) = \frac{1}{n}\sum_{i=1}^{n}\left[Q(n,m) * \rho * \Delta T(n,m) * C_p\right] \tag{9}$$

Time averaged reservoir release heat flux:

$$h_{if}(m) = \frac{1}{n}\sum_{i=1}^{n}\left[Q_r(n,m) * \rho * \Delta T(n,m) * C_p\right] \tag{10}$$

Where $$Q = Q_n + Q_r \tag{11}$$

$n$ is time step during the experiment period, $m$ is the segment number, $V$ is volume of water in the segment, $Q$ is the flow rate in the stream (subscript $n$ indicates natural flow and subscript $r$ indicates reservoir release), $\rho$ is the water density, $C_p$ is the specific heat capacity of water, and $\Delta T$ is a temperature difference.

The first metric, called the energy reduction percentage (ER), was based on the reduction of excessive heat energy above this thermal tolerance (i.e., to what extent is the excessive temperature or heat energy in the stream reduced). The excessive heat energy was calculated using equation (8) for the no reservoir release or base scenario, defined as $h_{e0}$, and for the scenarios with a reservoir release, defined as $h_{er}$, based on times when the temperature in the stream exceeded the thermal tolerance (i.e., $\Delta T = T_s - T^*$). The ER was then calculated as:

$$\text{ER}\ (m) = (h_{e0} - h_{er}) / h_{e0} \tag{12}$$

The second metric, called the energy reduction efficiency (ERE), was used to evaluate the relative benefit of the temperature reduction due to specific reservoir releases relative to the heat flux invested into the stream from the reservoir. For this metric, the invested heat flux from the reservoir ($h_{if}$) was calculated using equation (10) based on the temperature difference between the stream and the reservoir release temperature (i.e., $\Delta T = T_s - T_r$) and then compared to excessive flux reduction. The ERE was calculated as:

$$\text{ERE}\ (m) = (h_{ef0} - h_{efr}) / h_{if} \tag{13}$$

Predicted temperature time series were contrasted against CTMax to identify the time when stream fishes from different habitat guilds (Table 1) experienced severe thermal stress. A cumulative time when stream fish experienced severe thermal stress (hereafter cumulative time above CTMax) was calculated for each fish-habitat guild in every 1-km segment simulated in the Kiamichi River WASP temperature model. The results were plotted as a function of distance from the Sardis Reservoir confluence and cumulative time above CTMax. The areas bounded by the curve of cumulative time above CTMax (km•h) were calculated to quantify the thermal stress experienced by the two fish guilds downstream of Sardis Reservoir. The reduction rates of thermal stress against that of the control were calculated to quantify the ‘cooling effect’ of each release scenario. The distance where the cumulative time above CTMax was reduced by half was calculated as the effective distance indicating the dissipation of the cooling effect. This metric is intended to provide a conservative approach to examining the tradeoff of water use versus cooling as we acknowledge that cooler water pockets exist within the stream and our model is predicting at the one-dimensional scale.

### *Stream Temperature and Dissolved Oxygen Data Collection, and DO Modeling*

Stream temperature and dissolved oxygen (DO) concentration data were collected using 10 temperature data loggers (HOBO U22 Water Temperature Pro v2 Data Logger) and 10 DO data loggers (HOBO U26 Dissolved Oxygen Data Logger) deployed along the river (Figure 4). Temperature loggers were placed in approximately 1-m deep water in areas of pools that would receive adequate mixing of stream water (i.e., main channel). Loggers were anchored to the stream bottom on a paving stone attached via a cable. The HOBO logger was contained within a white polyvinyl chloride (PCV) housing to prevent any direct solar radiation. Prior to use, holes were drilled in the PCV to allow flow through while deployed. DO data loggers were calibrated initially in the laboratory using a 0% oxygen solution and 100% oxygen saturation and calibrated in the field, monthly, according to the factory recommendation. Briefly, a pre-calibrated DO meter, barometer, and thermometer (YSI Pro 2030) were used to record current conditions at each logger's location. These data were recorded and used as a correction factor when offloading data into HOBOware Pro v. 3.7.4.

The WASP model was set up based on the Streeter-Phelps BOD (biochemical oxygen demand)-DO equations to predict downstream DO concentration.

$$\frac{\partial D}{\partial t} = k_1 L_t - k_2 D \tag{14}$$

$$D = \frac{k_1 L_a}{k_2 - k_1}\left(e^{-k_1 t} - e^{-k_2 t}\right) + D_a e^{-k_2 t} \tag{15}$$

Where $D$ is the saturation deficit, $D = DO_{sat} - DO$ (mg/L), $k_1$ is the deoxygenation rate ($s^{-1}$) , $k_2$ is the reaeration rate ($s^{-1}$), $L_a$ is the initial oxygen demand also called ultimate BOD (mg/L), $L_t$ is the oxygen demand at time $t$, $L_t = L_a e^{-k_1 t}$ (mg/L), $D_a$ is the initial oxygen deficit (mg/L).

Temperature tolerances of stream fishes

CTMax is a useful technique to assess thermal tolerances in fishes. It was originally developed by Cowles and Bogert (1944) on lizards and later adapted for use on freshwater fishes (Becker and Genoway 1979). CTMax is an accepted method for measuring temperature tolerance in fishes (Lutterschmidt and Hutchison 1997). During CTMax studies, the water temperature increases at a fast-enough rate (1°C per min - 1°C per h, Becker and Genoway 1979) to prevent acclimation and continues to increase until the fish reaches loss of equilibrium (LOE), onset of spasms (OS), or death (D) (Lutterschmidt and Hutchinson 1997). Given the time to acclimate to rising temperatures, stream fishes may tolerate higher temperature than many CTMax studies suggest (Becker and Genoway 1979). Also, streams experience diel temperature fluctuations where stream temperature decreases during the evening, which could allow fish to better cope with an overall thermal increase (i.e., a nocturnal thermal refuge). A study that both increases temperature at a natural rate and incorporates a diel component would simulate a more realistic physiological response to temperature. Therefore, we also performed a longer-term temperature stress study that mimics a natural stream environment and measured cortisol as an indicator of stress (see *Long-term Thermal Stress*).

*Fish Collection and Acclimation*

Fishes were collected 2015-2018, transported to, and acclimated to laboratory conditions. We collected fishes using a seine (2.44 m in length, 1.83 m in height, with 0.3175 cm diameter mesh) that was pre-soaked in VidaLife (Western Chemical Inc., Ferndale, WA) to minimize handling stress (i.e., reduces friction on the fish). Collected fish were transported in stream water treated with non-iodized salt to 1% (10 g/L) to reduce stress (Swann and Fitzgerald 1992). Fishes remained in hauling containers for up to 12 h until the temperature of the hauling water reached that of the holding tanks, approximately 20.0°C. Fishes were then transferred to 190-L holding tanks covered with a screen on the top. We added airstones to all holding tanks to maintain dissolved oxygen >5 mg/L. Over the first 96 h, fishes were left undisturbed to recover from transportation stress. Brown Trout *Salmo trutta* and Rainbow Trout *Oncorhynchus mykiss* recover from acute emersion and confinement within 24-48 h (Pickering and Pottinger 1989). Fishes remained in holding tanks where they were acclimated to laboratory conditions over a 2-week period.

Following the initial 96 h, fish were fed and water-quality conditions were checked daily. We fed fish flakes (Wardley Advanced Nutrition Perfect Protein Tropical Fish Flake Food, Hartz Mountain Corporation, Secaucus, NJ) and bloodworms (Fish Gum Drops Floating Fish Food Bloodworms, San Francisco Bay Brand, Newark, CA) once daily to satiation (i.e., until fishes ceased eating). Unconsumed food was removed from aquaria daily via siphon. Ammonia, pH, and chloramine were checked twice daily. The temperature of the holding tanks was maintained at approximately 20.0°C. Ammonia was maintained <0.5 ppm. This level was only observed when new fish were added to the holding tanks, and for the first few days of lab acclimation. For the duration of acclimation and experimentation, ammonia was <0.25 ppm, pH was 8-8.5, and chloramine was zero. Water changes of approximately 30% were performed daily after the first 96 h of acclimation.

*Critical Thermal Maximum of Fish-Habitat Guilds used in WASP Modeling*

Each of 10 stream fishes was assigned to one of three habitat guilds and CTMax was averaged for that guild (Alexander 2017). Habitat guilds were assigned as benthic, mid-column or surface occupants (Pflieger, 1997; Miller and Robison, 2004; Cashner et al., 2010) (Table 1). The benthic guild consisted of five species that typically used habitat on the stream bottom. The mid-column guild consisted of four pelagic species that typically occupied the water column. The surface guild was represented by one species which occupied the surface of slackwater habitats. The CTMax for each guild ranged from 34.0 °C to 38.3°C for the thermally sensitive benthic guild and more tolerant surface guild, respectively (Table 1). The CTMax of the 10 species assigned to habitat guilds was determined following the methods outlined below for the Kiamichi River Assemblage. The species were chosen based on 1) abundance, 2) conservation status (i.e., Orangebelly

Darter *Etheostoma radiosum*, Blackside Darter *Percina maculata*, Oklahoma's Comprehensive Wildlife Conservation Strategy 2005), and 3) data gaps. We used these fishes, rather than all species where CTMax was determined because we needed to develop the reservoir scenarios for the WASP model in conjunction with this effort. We continued our CTMax efforts in parallel to have a more robust species-thermal profile for the Kiamichi River.

*Critical Thermal Maximum of the Kiamichi Assemblage*

We determined the CTMax of 17 stream fishes (Table 2) using an incomplete block design with an associated survival control (i.e., the control was not included in the final analyses). Each block consisted of up to six species, each represented by one individual fish. Our goal was to replicate the experiment ten times for each species. We set up a system that routed water from a 189.27-L sump to six 37.85-L acrylic aquaria (Figure 5). Two airstones were added to the sump system to maintain dissolved oxygen above 5 mg/L. Water in the sump system was heated with a 5000-W Smartone heater (OEM Heaters, Saint Paul, MN). We randomly assigned species to aquaria, but haphazardly assigned individual fish to each aquarium (one fish per aquarium). We maintained a survival control using a separate sump system where fish experienced the same handling as the treatment fish but were held at their acclimation temperature for the duration of each trial. Most fishes were held at 20.0°C for 24 h prior to the start of the experiment to allow acclimation to testing conditions and recovery from handling stress (Hutchison and Maness 1979; Pickering and Pottinger 1989). We primarily focused on adult, small-bodied fishes because they are often less tolerant of higher temperatures (Pörtner and Farrell 2008) and would be more likely to represent thermal population bottlenecks. However, we did include juveniles of two subspecies/unique strains of Smallmouth Bass *Micropterus dolomieu* in our trials. Although we have information on the thermal tolerances of the nominal subspecies (Northern Smallmouth Bass), we lack information on these bass lineages and thus, included them in our trials. We recognize that neither species occupies the Kiamichi River, but the Ouachita strain is endemic to the Ouachita Mountain ecoregion and is of interest to the Oklahoma Department of Wildlife Conservation. The Neosho subspecies (endemic to the Ozark Highlands and Boston

Mountains) was also included as a comparison. The two juvenile basses were acclimated to both 25°C and 20°C because they would be anticipated to tolerate warmer temperatures and they hatch/develop under warmer-water conditions (but also completing trials at 20 °C allowed them to also be directly compared to the other species).

All CTMax trials were completed using one critical endpoint, loss of equilibrium (LOE) (Becker and Genoway 1979; Lutterschmidt and Hutchison 1997; Beitinger et al. 2000). During our trials, we increased water temperature 2°C/h until fish experienced LOE. We defined LOE as the point at which an individual lost the ability to maintain dorso-ventral orientation (Becker and Genoway 1979). None of our control fish experienced LOE.

We used robust Bayesian estimation (Kruschke 2013) to estimate CTMax values among the assemblage of stream fishes (17 fishes) where CTMax was determined (Table 2). We fit a single-factor linear model with a covariate in a hierarchical framework, where species was the factor j and total length was the covariate x. This model structure is a Bayesian generalization of an analysis of covariance that imposes sum-to-zero constraints on group-level parameters (Kruschke 2015). Species CTMax were modeled as deflections around the group mean, where we used broad normal priors for both group-level parameters and the total length slope. For these data, we used a t distribution with a shifted exponential prior on the normality parameter ν (Kruschke 2013) to accommodate heavy tails in CTM observations i. Because an equal-variance among groups assumption was not reasonable, we modeled each species standard deviation (SD) j separately. We also included a grouping factor for trial k to account for correlated CTM observations using a broad normal prior (Gelman and Hill 2007).

We used a set of contrasts (Kruschke 2015) to compare differences in CTMs based on both thermal groupings and taxonomy (Table 3). Initially, we divided the stream fishes into two thermal groups, low and high, based on their rank relative to the estimated group mean CTM. We then further divided stream fishes into four subgroups (low-low, low-high, high-low, and high-high) based on the mean estimated CTM of the initial groupings. For the contrasts, we compared the low and high groups and their associated subgroups (i.e. low-low versus low-high; low-high versus high-high). We also compared both the two darter genera (*Etheostoma* and *Percina*) and darters to minnows (Highland

Stoneroller, *Notropis*, *Pimephales*, and Steelcolor Shiner; Table 2). Lastly, we compared each species individually to all other members of their genera when applicable (Table 3). The differences in CTMs were evaluated using 90% highest density intervals (HDIs), where we considered the difference important if the interval did not overlap zero.

We performed the analysis using the program JAGS (Plummer 2003) called from the statistical software R (version 3.5.1, R Core Team, 2018) with the package runjags (Denwood and Plummer 2016). Posterior distributions for parameters were estimated with Markov chain Monte Carlo methods using 50,000 iterations after a 10,000-iteration burn-in phase. We assessed convergence using both the Brooks-Gelman-Rubin statistic ($\hat{R}$; Gelman and Rubin 1992) and effective sample size (ESS; Kruschke 2015), where values <1.1 and >15,000, respectively, indicate adequate mixing of chains. Total length was standardized to a mean of zero and a variance of one such that group-level deflections are interpreted as estimated species CTM at mean total length, and the total length slope represents the estimated change in CTM with a one SD change in total length.

*Long-term Thermal Stress*

We determined whole-body cortisol concentration of six stream fishes (Table 4) in response to thermal exposure using a split-plot design that was blocked by trial. We used a 2x6 factorial treatment structure with two levels of temperature (27.0°C and 32.0°C) and six levels of species (Table 2). We set up four identical sump systems that routed water from a 189.27-L sump to six 37.85-L acrylic aquaria (Figure 5). Two airstones were added to each sump system to maintain dissolved oxygen above 5 mg/L. Water in each sump system was heated with a 1700 W Smartone heater (OEM Heaters, Saint Paul, MN). We randomly assigned temperature treatments to sumps (whole plots). Within each sump, we randomly assigned species to aquaria (our sub-plots). We used 27.0°C as the control temperature because it commonly occurs in our study area during the summer. The control temperature was below the thermal tolerance of our initial group of species whose CTMax was tested (Table 1). We used 32.0°C as the experimental temperature because it was 2.0°C less than CTMax of the most thermally-sensitive species initially tested, but this temperature was anticipated to be stressful to stream fishes. Each temperature-species combination was replicated 10 times.

Fishes were assigned to treatment aquaria, and then acclimated to the new conditions prior to starting each trial. We randomly assigned species to each of six aquaria in each sump system for each trial, and then we haphazardly selected three individual adult fish (pseudoreplicates) to place in each aquarium. We only used adults in these trials because they are often less tolerant of higher temperatures (Pörtner and Farrell, 2008). All fishes were held at 20.0°C for 24 h prior to the start of the experiment to allow acclimation to testing conditions and recovery from handling stress (Hutchison and Maness, 1979; Pickering and Pottinger, 1989).

We used a 12h:12h diel cycle to gradually heat each sump to its treatment temperature and maintained a 2.5°C nightly refuge during the trials. During each trial, we increased water temperature 2.5°C over 12 h (0700-1900), daily, and decreased water temperature 1.5°C over 12 h (1900-0700), nightly. The net water temperature increase was 1.0°C/d until the treatment temperature of 27.0°C (control) or 32.0°C (experimental) was reached. All sumps were provided with a 2.5°C nightly (1900-0700) thermal refuge but returned to the treatment temperature each day. We maintained each sump at this thermal regime for 14 d. After 14 d at the treatment temperatures, we sacrificed all fishes by freezing them in liquid nitrogen. The fish samples were then stored at -80°C until homogenization.

*Whole-body Cortisol Concentration*

To quantify whole-body cortisol, we weighed and homogenized individuals, extracted cortisol, and performed an enzyme-linked immunosorbent assay (ELISA). We measured whole-body cortisol because sampling blood in my study fishes was impractical and holding water was shared among species in each trial (Belanger et al., 2016; Zuberi et al., 2014). Fish samples were weighed (0.001 g), partially thawed, and homogenized in 1x phosphate buffered saline (PBS) (1-part fish tissue, 5-parts 1x PBS). We combined 1 mL of homogenate with 5 mL diethyl ether in a glass centrifuge tube and vortexed for 1 min to extract cortisol. We then centrifuged samples at 3,500 rpm for 5 min and removed the organic layer containing cortisol. We repeated the extraction process three times for each sample. Following extraction, diethyl ether was allowed to evaporate overnight in a fume hood, leaving behind only proteins. We reconstituted samples with 1 mL of 1x PBS and incubated them overnight at 4°C. We performed ELISAs according to manufacturer's instructions to determine cortisol concentrations using a human salivary cortisol kit (Salimetrics LLC, College Station, PA). Each kit included cortisol standards, blanks, and high and low controls. We assayed samples in triplicate. We used a Cytation 5 cell imaging multi-mode reader (Biotek U.S., Winooski, VT) with Gen5 software (version 3.03, Biotek U.S., Winooski, VT) to measure sample optical density. We quantified whole-body cortisol concentrations of our samples using a 4-parameter sigmoid minus curve fit based on optical density of cortisol standards. High and low controls included in the kit verified values for standards. Cortisol concentrations were normalized by weight of the whole-body sample and reported as absolute cortisol concentrations (ng/g body weight). Values of pseudoreplicates were averaged to represent conditions in each aquarium.

We used a generalized linear mixed model (GLMM) to analyze the whole-body cortisol concentrations following a split-plot design with trial as a blocking factor, sump as the whole plot and aquarium as the subplot. In our model, whole-body cortisol concentration was the dependent variable, and temperature, species, and the temperature-species interaction were fixed effects. We checked for homogeneity of variance of the fixed effects. We used sump and trial as random effects in our model to control for differences among sumps and trials that were not directly of interest. The random effects, sump and trial, were assumed normally distributed as $N(0, \tau^2)$, where $\tau^2$ was the population variance among levels of sump and $N(0, \beta^2)$, where $\beta^2$ was the population variance among levels of trial. We performed a Tukey Kramer Honest Significant Difference (HSD) post hoc test when an effect was significant. We assessed significance at $\alpha \leq 0.05$. These analyses were performed in SAS (version 9.4, SAS Institute, Cary, NC).

## B. RESULTS

<u>Hyporheic exchange and stream temperatures</u>

*Seepage Runs*

The distance and number of transects were chosen to minimize error, accommodate access points, and avoid tributary confluences. ADCP error was minimized at ≤ ± 0.015 $m^3/s$). We found using three transects was sufficient to minimize error (error ≤ ± 1.5E-5 $m^2/s$) in groundwater flux across sites, while allowing us to avoid tributary inflows.

We completed six seepage runs on the Kiamichi River at six locations (Figure 4: Indian Riffle, Robins Riffle, Confupstrm, Confdownstrm, Pine Spur, and Payne Riffle). At each reach, we measured discharge using an ADCP at three transects spaced 500-m apart. We established a discharge-distance relationship and the slope of the regression represented the net flux between surface water and groundwater at each reach. According to groundwater flux estimations, the upstream reaches tended to have a higher recharge rate than downstream reaches (Table 5). The net groundwater flux estimation was negative for most of the reaches, indicating loss of stream water (surface waters) to groundwater (losing reaches).

*Tracer Test and OTIS-P*

We performed tracer tests at 4 locations along the river between Pine Spur Riffle, and Robins Riffle (Figure 1) to quantify hyporheic exchange longitudinally. We finished data analyses and model fitting for data collected at Pine Spur Riffle (PS). Model predictions via OTIS-P were contrasted to monitored concentration (Figure 6). Parameter estimates via the OTIS-P simulations indicated model convergence was successful for both the first (PS2) and second reaches (PS3). The maximum residual sum of squares (i.e., describes the quality of the estimator) had a mean square error (MSE) < 0.2 suggesting good model fit of the breakthrough curve (i.e., concentration curve versus time). The fraction of median travel time due to storage ($F_{med200}$) of PS2 was higher than PS3 (70.23 > 63.56), indicating the groundwater exchange through transient storage was higher upstream.

<u>Influence of dam releases on stream temperatures and dissolved oxygen</u>

*WASP model*

Predicted values of velocity, depth, and width were confirmed to be within a realistic range when compared to data collected using an ADCP at riverine locations. Because of minor differences in the weather between the four sites, the weather data were set constant along the river using observations from the Clayton Mesonet site in the middle of the modeled reach.

Simulated temperatures simulated by the WASP model more closely matched measured values after accounting for groundwater (Figure 7 and 8). The model tended to predict cooler than expected temperatures during warmer periods (Figure 7) until groundwater inflow was incorporated in the model (Figure 8). Specifically, we introduced a dispersive groundwater exchange process to the model. We set groundwater temperature at 15°C (average air temperature during the research period). The modeled predictions were closer to measured values at the upstream sites and the error increased in the downstream direction. The model was improved at all sites by including a surrogate for groundwater in the model (Tables 6 and 7).

*Reservoir Release Simulation*

According to our initial simulation results, a reservoir release has a significant effect of regulating downstream water temperature during the summer baseflow period (i.e., also known as drought flow, referencing the portion of streamflow that comes from the sum of deep subsurface flow and delayed shallow subsurface flow) (Figure 9).

The WASP predicted temperatures were used to calculate energy reduction (ER) and energy reduction efficiency (ERE) with respect to spatial distance downstream from the Indian HWY site (Figures 10-12). We show excess energy is reduced at various release temperatures, and as expected, with the coolest release temperature reducing the most excess energy. However, the temperatures generally converge regardless of temperature release at approximately 100-km downstream (due to other heat processes). The trend is the same across figures but is represented by different processes (Figures 10-12).

In the absence of a reservoir release (i.e., the control scenario), downstream fishes were expected to experience an approximately uniform thermal stress throughout the simulated reach of Kiamichi River (Figure 13). The control scenario indicated the benthic guild was expected to experience 130 h of thermal stress, while mid-column guild was expected to experience 73 h thermal stress. The surface guild never experienced temperatures exceeding their CTMax; thus, temperatures were expected to be tolerated by that fish guild so that guild was not investigated further.

As expected, the thermal relief increased as indicated by thermal stress (Table 8), reduction rate of thermal stress (Table 9) and effective distance (Table 10) with the increase of the release magnitude and the depth of the release location (i.e., the lower release locations had cooler water, Figure 14). In recent years, the only time a release has been provided for ecological purposes, only 0.34 $m^3/s$ was released from the top gate (Gates et al., 2015). This release scenario only reduced thermal stress by 11% for mid-column fishes and 8% for benthic fishes. The effective distance (i.e., distance where cumulative time above CTMax was reduced by half) of the release was only 1 km for both guilds. A release hypothesized in the literature (0.59 $m^3/s$ released from the top gate) to provide relief for downstream mussel habitat (Spooner et al., 2005) reduced thermal stress by 18% for mid-column fishes and 12% for benthic fishes. The effective distance increased to 4 and 2 km for mid-column fishes and benthic fishes, respectively. Three releases that represented pre-dam flow magnitudes (0.76, 1.13 and 1.50 $m^3/s$ released from top gate) reduced thermal stress up to 33% for mid-column fishes and 29% for benthic fishes. The effective distance increased to approximately 10 km for both fish guilds. In comparison, the 0.34 $m^3/s$ release was expected to cause an increase in thermal stress of up to 20% for both guilds. Consideration of different release locations (and access to cooler water) improved the cooling results and downstream effects considerably (Figure 14). Surface releases resulted in ~30% reduction rate in thermal stress at the highest modeled flow release. Similar results could be achieved at half that flow volume if the lowest available gate on the dam was used to initiate the release. The three release scenarios that represented pre-dam flow magnitudes (0.76, 1.13 and 1.50 $m^3/s$) reduced thermal stress by 21-46% for mid-column fishes and 15-41% for benthic fishes, depending on water temperatures associated with the gate location on the dam. The effective distance (i.e., where thermal stress was reduced by 50%) extended to 16-km downriver of the Jack Fork Creek confluence if releases were made from the deepest gate on the dam and the greatest flow magnitude simulated (1.50 $m^3/s$). The other pre-dam flow magnitudes (0.76, 1.13 $m^3/s$) increased the effective distance to 5-12 km for the mid-column guild, and 5-10 km for the benthic guild, depending on release temperature (i.e., gate location).

*Stream Water Temperature and Dissolved Oxygen Data Collection*

The DO time series observed in 2015 represented summer conditions of a relatively warm year with few water releases (Figure 15). The DO concentrations observed at the confluence were above 5 mg/L uniformly more than 95% time. The DO concentrations observed at the sites located downstream of the dam influence were above 5 mg/L during releases, except for the most downriver site. At Payne, DO had a major shift where variances increased substantially during a low-flow period starting 10/13/2017. Because there were no dam releases during that period, and the site immediately upstream (Pine Spur) showed suitable DO conditions, it seems the low DO (near 2 mg/L) at night were likely related to an algae bloom. Algae blooms are relatively common from May through October and negatively affect the DO conditions at night when the plants experience high rates of respiration (i.e., use oxygen). Another possible explanation is that the loggers fouled at that location, which is a common limitation of polarographic membrane-type sensors (Wagner et al., 2000).

The DO concentration time series observed in 2017 represented DO patterns during a higher-flow period because of considerable water releases from Sardis Reservoir due to repeated storm events (Figure 16). The DO concentrations observed at the Jack Fork-Kiamichi rivers confluence were above 5 mg/L during these release scenarios but dropped significantly following releases.

The BOD sampling also supported our findings that DO was only low immediately following discharge events. BOD samples reflected low values (less than 2 mg/L) during the decreasing of discharge (while discharge was above 1.0 $m^3/s$) and higher values (2.9 mg/L and 3.8 mg/L observed at most upstream and downstream sites, respectively) immediately following the return to low-flow conditions (when discharge dropped below detectable limit).

Temperature tolerances of stream fishes

We summarized CTMax values from the existing literature (Table S1). Most studies focused on sport fish and common species. However, a few studies did determine thermal tolerances of diminutive fishes (e.g., Johnny Darter *Etheostoma nigrum* and Southern Redbelly Dace *Chrosomus erythrogaster*).

*Critical Thermal Maximum of the Kiamichi River Assemblage*

CTMax values differed significantly between thermal groupings, between taxonomic groups, and between species and subspecies of the same genera. The estimated group mean CTMax was 34.72 °C (90% HDI: 34.60, 34.83), and estimated CTM among the stream fishes ranged from 32.43 to 38.26 °C (Table 2). Kiamichi Shiner *Notropis ortenburgeri* had the lowest estimated thermal tolerance, and Blackspotted Topminnow *Fundulus olivaceus* had the highest. Although darters tended to have a lower thermal tolerance than minnows, the difference in estimated CTMax values was not significant (Table 2 and Table 3). Similarly, 4 of 10 stream fishes, along with six darters, in the low thermal guild (raw mean CTMax ± SD: 34.09 ± 0.66 °C) were minnows, and Logperch *Percina caprodes* was included in the high thermal guild (raw mean CTMax ± SD: 35.71 ± 1.24 °C) along with three minnows, both Smallmouth Bass subspecies/genetic lineages, and Blackspotted Topminnow (Table 2). The difference in estimated CTMax values between the low and high thermal guilds was significant (Table 3). When broken into four different thermal guilds, the low-low guild comprised Kiamichi Shiner, Etheostoma, Blackside Darter, and Channel Darter (Table 2), and the low-high guild comprised Dusky Darter, Bigeye Shiner, Emerald Shiner, Slenderhead Darter, and Steelcolor Shiner (Table 3). The high-low guild comprised Pimephales, Neosho Smallmouth Bass, Highland Stoneroller, and Logperch, and the high-high group comprised Ouachita Smallmouth Bass and Blackspotted Topminnow. Thermal tolerances were significantly different between the four thermal guilds, where the magnitude of the difference in estimated CTMax was ~1°C higher between the guilds in the high thermal group compared to the low thermal group. Among all darter species, *Etheostoma* had a significantly lower thermal tolerance than *Percina*. Among members of *Percina*, Blackside Darter *Percina maculate* and Channel Darter *Percina copelandi* had a significantly lower thermal tolerance, and Logperch had a significantly higher thermal tolerance. Estimated CTMax did not differ significantly between Johnny Darter *Etheostoma nigrum* and Orangebelly Darter *Etheostoma radiosum*. Among members of *Notropis*, Bigeye Shiner *Notropis boops* and Emerald Shiner *Notropis atherinoides* had a significantly higher thermal tolerance, and Kiamichi Shiner had a significantly lower thermal tolerance. Estimated CTMax did not differ significantly between Bluntnose Minnow *Pimephales notatus* and Bullhead Minnow *Pimephales vigilax*. As expected, estimated CTMax was higher for both genetically-distinct Smallmouth Bass populations at the higher acclimation temperature (Table 2). Neosho Smallmouth Bass had a significantly lower thermal tolerance than Ouachita Smallmouth Bass at both acclimation temperatures; however, the magnitude of the difference was ~0.5 °C higher at the higher acclimation temperature. Estimated CTMax decreased with increasing total length in the assemblage-level analysis (slope: -0.31, 90% HDI: -0.47, -0.15). The 90% HDI for the total length slope in the Smallmouth Bass analysis overlapped zero and was subsequently removed.

Model diagnostics indicated adequate mixing of chains and good fit. $\hat{R}$ was 1.0 and ESS was >15,000 for all model coefficients in both analyses. Posterior predictive plots indicated good fit using a t-distribution ($\nu = 11.2$ and $\nu = 9.5$ for the assemblage analysis and Smallmouth Bass-only analysis, respectively).

*Whole-body Cortisol Concentration*

Assumptions of normality and homoscedasticity were not met by our model. Natural-log transformation of whole-body cortisol concentrations improved skewness. However, unequal variances of the fixed effects were still apparent; thus, were modeled to account for heteroscedasticity.

Whole-body cortisol concentrations varied among the species we examined, but not between the two treatment temperatures. The fixed effect of species was significant in our model ($F_{5, 36.86} = 62.46$, $P < 0.01$) indicating a significant difference in stress response for at least one species. Interestingly, the fixed effect of temperature ($F_{1, 17.57} = 0.84$, $P = 0.37$), and the interaction of the fixed effects were not significant ($F_{5, 36.86} = 0.55$, $P = 0.74$). Results from Tukey Kramer HSD indicated there were differences in whole-body cortisol concentrations among species (Figure 17). Highland Stoneroller *Campostoma* *spadiceum* had the highest cortisol concentration (67.61 ng/g body weight at the treatment temperature, 56.38 ng/g body weight at the control temperature) regardless of temperature ($P < 0.01$). Channel Darter had the lowest cortisol concentration (1.64 ng/g body weight at the treatment temperature, 2.07 ng/g body weight at the control temperature), significantly different from Steelcolor Shiner ($P = 0.02$) and Bluntnose Minnow ($P = 0.04$), but not significantly different from Orangebelly Darter ($P = 0.79$) or Blackspotted Topminnow ($P = 0.46$). Cortisol concentrations in all other species were statistically similar among one another (Figure 17) and ranged 3.45-9.12 ng/g body weight in treatment fishes and 3.04-5.55 ng/g body weight in control fishes.

## III. DISCUSSION & RECOMMENDATIONS

The impoundment of Sardis Lake significantly altered the downstream thermal regime of the Kiamichi River and increased thermal stress by up to 20% for benthic and mid-column fish species. However, we show the only flow released to benefit biota in recent years (0.34 $m^3/s$, Gates et al. 2015) was insufficient to recover the downstream thermal regime to even near pre-dam conditions, and that flow does not connect the entire length of river between Sardis Reservoir and Lake Hugo. In addition to providing little improvement to thermal conditions, this scenario also prevents fish movement via lack of connectivity across the riverscape. If the desired outcome is to improve habitat for fishes and freshwater mussels, flow releases would benefit from consideration of the results presented in this report. We demonstrate that thermal improvements via flow releases could improve conditions for fishes for a considerable distance downriver of the confluence. The benefits of thermal improvement via cooling is observed across the entire 74-km river segment but providing a 50% reduction in thermal stress for fishes varied by volume of water released and release location. Monitoring of dissolved oxygen is recommended to establish better relationships with water releases as there have not been any releases of water at those locations to sufficiently evaluate the resulting dissolved oxygen conditions. Specifically, the water-management agency does not currently make water releases from the lower gates so the dissolved oxygen conditions we observed cannot account for that uncertainty.

Dissolved oxygen concentration is also an essential component of aquatic ecosystems that are affected by the magnitude of release. However, based on the in-stream DO concentrations observed in 2015 and 2017 and BOD sampling results, the observed reservoir releases did not directly reduce DO concentrations in the Kiamichi River. DO concentration of reservoir water tended to decrease with depth (Townsend, 1999), as shown in existing lake profile data (Oklahoma Water Resources Board, 2016, unpublished data 1999-2015). As a result, hypolimnetic release with low DO concentration may degrade fish habitat by reducing DO concentration downstream of the dam (Hoback and Barnhart, 1996; Marshall et al., 2006), especially when releases are made continuously during extremely hot years. In this study, the reservoir was likely to have released water from the upper gate expected to have the highest DO, which did not introduce any moderate or severe DO stress. However, DO conditions at depth may change (e.g., climate change, different use of water volumes over time), and releases of larger magnitudes can affect downstream DO concentrations by causing resuspension of oxygen demanding materials. DO monitoring efforts are recommended to ensure suboptimal conditions are not created if hypolimnetic releases are used as a management option.

The DO observations revealed some unexpected patterns at certain sites. For example, the DO variances increased substantially during a low-flow period at the Payne site starting 10/13/2015 (Figure 15). Because there were no dam releases during that period, and the site immediately upstream (Pine Spur) showed suitable DO conditions, it seems the low DO at Payne (near 2 mg/L) at night were likely related to local conditions such as an algae bloom (Jacobsen and Marín, 2008) (see page 23). In 2017, the DO at the confluence dropped to less than 1 mg/L following releases while the sites upstream and downstream of the confluence were less effected. Possible causes for these changes in DO include aquatic ecosystems disturbed by high flows causing reduced capacity for photosynthesis, or dam releases transporting or resuspending oxygen demanding materials whose effects are felt after the flood crest (Graczyk and Sonzogni 1991).

The DO concentrations observed at the Jack Fork-Kiamichi rivers confluence were above 5 mg/L during these release scenarios but dropped significantly following releases. This was likely to result from disturbed aquatic ecosystems by high flows with reduced capacity of photosynthesis and influx or resuspension of oxygen demanding materials as a result of the storm water input (Graczyk and Sonzogni 1991). This pattern was also observed on upstream sites but dissipated downstream and was not observed at the downstream sites.

The WASP model offered a more comprehensive method to predict water temperature (compared to published regression equations, Spooner et al. 2005), taking into account the heat transfer mechanisms (i.e., solar radiation, bottom heat conduction and evaporation), which we then used to simulate reservoir releases. However, we found a continued discrepancy between the predicted and observed water temperatures when discharge decreased to base-flow conditions in the summer months, and two processes may be responsible. First, as discharge decreased, groundwater replenishment accounted for much of the available water source. As a result, the thermal regime of the river was also largely influenced by groundwater temperature. Second, the WASP model did not account for the heating of bank and bottom sediments when the water level was low. In the model, the bank temperature was set to a constant value. Yet, when discharge was low, the temperature of the surrounding river bank and bottom was likely higher due to more bank area being directly exposed to solar radiation. As a result, more heat exchange than simulated will occur on the river bank and bottom interface that may replenish the heat loss that occurred in the current simulation. This missing process could not be added to the current model, but we compensated by using a higher stream bottom temperature and that provided much more accurate temperature comparisons.

The root mean square errors (RMSE, difference between predicted and observed values) representing the prediction modeled temperature discrepancy averaged about 1.6 °C and were similar to other research using deterministic thermal models (e.g., Caissie et al., 2007); therefore, we believe our model performance is acceptable based on the research objective. The WASP model is one dimensional and represents *average water temperature* of each model segment, but the actual thermal heterogeneity within the stream would offer some patches of warmer or cooler water (Ebersole et al., 2001). Thus, although the error associated with the thermal predictions could be problematic for fishes during extremely hot periods if absolute (i.e., there was no thermal patchiness), it was expected to be less than the spatial variance created by fine-scale thermal heterogeneity (Kanno et al., 2014) that provides thermal refugia for fishes. Moreover, the importance of our WASP model was to understand the magnitude of effect that could be achieved with different reservoir releases (i.e., what is the net gain for stream fishes from using a certain volume of water and a certain release gate).

The predicted stream water temperature time series initially had greater diurnal variance when compared to the observed temperatures. Two main factors may have contributed to the prediction discrepancy. The first potential source of bias was associated with the stream water temperature being monitored at the bottom of the river while the Kiamichi temperature model predicted average stream water temperature across the entire stream segment volume due to the one-dimensional simplification. An additional contributing factor is the model limitation in accounting for the buffering effect of stream bottom in response to atmospheric heating conditions. For a shallow stream, a portion of the incoming radiation heat is absorbed by the stream bottom, which in turn heats up the stream water slowly, creating a heat buffer. In contrast, the model only allowed incoming radiation heat to be absorbed only by water column. To try to account for the incoming radiation heat absorbed by stream bottom, we used a high light extinction coefficient, allowing the water column to absorb a larger portion of incoming radiation heat. One consequence of this solution was increased diurnal variance due to faster heat transfer. However, for this research, the absolute accuracy of the temperatures was less critical than the relative differences across the water-release scenarios (i.e., the effect of different release options), and for the scenarios modeled, the error rate was acceptable. Evaluating the effects of dam releases was completed to examine how thermal conditions could be improved under different release scenarios.

The 1-D WASP model predicts water temperature as an average over a model segment, and to provide decision-making tools to evaluate dam releases over a 74-km reach consisting of 1 km stream segments, a one-dimensional model is probably the preferred option because of its high data efficiency. The model predictions are likely conservative as the thermal conditions predicted do not account for the patchy stream environment. This is probably beneficial given CTMax represents morbid conditions for fishes that does not allow fishes to acclimate and, of course, all models have some inherent error. It is important to recognize that even when CTMax values are not exceeded, fish may still experience reduced growth and survival due to exposure to suboptimal temperatures (Coutant, 1976). From the perspective of fish habitat, there may still be cooler-water patches available that provide refuge during thermally-stressful conditions and predicting those is not possible with a 1-D model. This study used a 1-D model, but if improved resolution of thermal conditions is desired, a two-dimensional model could be developed. However, significantly higher data requirement (e.g., vertical temperature stratification profiles) and computational cost is expected for 2-D models. Use of a 2-D model would likely be most beneficial for identifying greater resolution of thermal conditions at freshwater mussel beds, as an example, where organisms are generally sessile. A 2-D model would also be useful if there is interest in examining thermal refugia related to other land-use practices (i.e., maintaining riparian corridors, fencing cattle to prevent DO decreases). Lastly, increased thermal resolution of some stream segments might be useful to agencies developing monitoring strategies to target areas during severe drought or other thermally-stressful periods.

Interestingly, none of the fishes in this study showed increased cortisol concentrations resulting from the experimental temperature. Disregarding Highland Stoneroller, which is specifically discussed below, whole-body cortisol levels among the species in this study ranged from 3.4-7.1 ng/g body weight in response to control temperature and 2.2-10.1 ng/g body weight in response to treatment conditions. Sutherland et al. (2008) found similar basal whole-body cortisol values for Whitetail Shiner *Cyprinella galactura* (5-20 ng/g body weight, depending on age) and Spotfin Chub *Erimonax monachus* (10 ng/g body weight). Li et al. (2009) found whole-body cortisol levels of 6.3 ng/g body weight in Golden Shiner *Notemigonus crysoleucas* immediately sacrificed after seining from aquaculture ponds. The similarity of cortisol concentrations in our study to previous studies implies only a basal stress response at each temperature. The lack of significant temperature effect to acclimation to water temperatures may relate to a slow rate of temperature increase. Slower rates of temperature increase allow acclimation to occur (Lutterschmidt and Hutchison 1997).

The net increase in temperature of 1°C/d that we used likely allowed acclimation to occur. A stress response may not be elicited until much higher temperatures.

Cortisol concentrations found in Highland Stoneroller in this study (70.8 ng/g body weight in response to control temperature, 75.8 ng/g body weight in response to experimental temperature) imply that individuals of this species were exhibiting stress response higher than basal levels and equal in magnitude at each treatment level. This level of stress appears to relate to species-specific intolerance of confinement in the laboratory setting. Confinement can cause increased levels of plasma cortisol (Clearwater and Pankhurst 1997, Murray et al. 2017). Due to their exaggerated stress response in captivity, it may be advisable to avoid using Highland Stoneroller to determine sources of stress in a laboratory setting. For the same reason, it may also be advisable to question the validity of lab-determined CTMax for Highland Stoneroller and Central Stoneroller *Campostoma anomalum,* a closely related species.

A variety of factors relates to species-specific thermal tolerances (e.g., life history, dispersal ability); however, at the most basic level, we lack information on the thermal tolerances of many warmwater stream fishes (Smale and Rabeni 1995, Lutterschmidt and Hutchison 1997, Beitinger et al. 2000). Understanding the thermal tolerances of species and assemblages will allow improved predictions of how species persist or thrive under changing stream temperatures. With water temperatures currently approaching the CTM of multiple species, further increases may threaten the health and persistence of many stream fishes. Increasing atmospheric temperatures will cause a 2-3°C water temperature increase in the south-central United States over the next 50-100 years (Morrill et al., 2005; van Vliet et al., 2013). Dewatering of streams also causes water temperature increases and reduction of suitable habitat for stream fishes (Luttrell et al., 1999; Bonner and Wilde, 2000). Dewatering can occur as a result of limited reservoir releases, overexploitation of groundwater and surface water, or extended drought (Muehlbauer et al., 2011). The resulting increases in water temperature stress fish and put them at risk for reduced or delayed reproduction (Tveiten and Johnsen, 1999; Auer, 2004), increased susceptibility to disease (Yin et al., 1995), weight loss (Whitledge et al., 2002), and even death (Allan & Castillo, 2007).

Because stream fishes have different thermal tolerances, it is difficult to evaluate assemblage-level responses to thermal changes in aquatic systems. A fundamental challenge is to reduce assemblage data in a way that is meaningful to detect patterns among fish assemblage members or groups. An increasingly common approach for simplifying assemblage data is to group species information based on common traits. Although useful for allowing generalization of ecological relationships and reducing data dimensionality, use of guilds or traits can be arbitrary and result in classifications that may not be ecologically meaningful. Fish exhibit behaviors, physiological characteristics, and life-history strategies which correspond to their sensitivity to and exploitation of water temperatures. For example, temperature influences reproductive effort (e.g., Pumpkinseed Sunfish *Lepomis gibbosus*, Masson et al. 2015), egg size, and the timing of ovulation in some fishes (e.g., Common Wolffish *Anarhichas lupus*, Tveiten and Johnsen 1999). Whereas general patterns in how fishes respond to changing temperatures are evident, different populations exhibit differences in these and other traits. Generalization of thermal sensitivity based on shared habitat (such as used in our WASP model), surrogate-species relationships, proxies to estimate the fundamental thermal niche (e.g., swimming performance, aerobic scope, Allen-Ankins and Stoffels 2017), or other estimated field-based parameters (e.g., realized thermal maxima, Stuart-Smith et al. 2017; Day et al. 2018) may not best represent similar thermal responses among species assemblages. Although multiple techniques may be useful for estimating species responses to changing thermal environments, laboratory estimates of thermal tolerances are useful because they isolate the species' response due specifically to changing temperature. It is surprising that our CTMax values covered such a broad range (32-38 ˚C) suggesting sensitivity of some assemblage members is much higher than others. This information may be useful for determining which species may be useful in monitoring for thermal stresses (e.g., minnow) including those associated with water releases (or lack thereof) and climate change. We found a mix of minnows and darters in the lowest thermal guild suggesting taxonomy is generally not a good way to examine thermal responses by fishes.

## IV. SIGNIFICANT DEVIATIONS

No significant deviations.

## V. EQUIPMENT

No equipment was purchased during this reporting period.

## VI. PREPARED BY:

Shannon K. Brewer, Garey Fox, Yan Zhou, and Justin Alexander
Oklahoma Cooperative Fish and Wildlife Research Unit,
Oklahoma State University Stillwater, Oklahoma

**DATE:** April 19, 2019

**APPROVED BY:** ______________________

Fisheries Division Administration
Oklahoma Department of Wildlife Conservation

______________________

Andrea Crews, Federal Aid Coordinator
Oklahoma Department of Wildlife Conservation

## VII. REFERENCES

Acreman, M., Dunbar, M.J., 2004. Defining environmental river flow requirements? A review. *Hydrology and Earth System Sciences Discussions*, **8**(5): 861-876.

Alexander, J.R., 2017. Determining the effects of thermal increases on stream fishes of the Ouachita Mountain ecoregion, Master's Thesis: Oklahoma State University, Stillwater, OK.

Allan, J.D., Castillo, M.M., 2007. Stream ecology: structure and function of running waters. *Springer Science & Business Media*.

Allen-Ankins, Stoffels, R., 2017. Contrasting fundamental and realized niches: two fishes with similar thermal performance curves occupy different thermal habitats. *Freshwater Science* **36**:635-652.

Annear, T. et al., 2002. Instream flows for riverine resource stewardship. *Instream Flow Council, Cheyenne, WY*.

Arthington, A.H., Bunn, S.E., Poff, N.L., Naiman, R.J., 2006. The challenge of providing environmental flow rules to sustain river ecosystems. *Ecological Applications*, **16**(4): 1311-1318.

Becker, C.D., Genoway, R.G., 1979. Evaluation of the critical thermal maximum for determining thermal tolerance of freshwater fish. *Environmental Biology of Fishes*, **4**: 245-256.

Beitinger, T.L., Bennett, W.A., McCauley, R. 2000. Temperature tolerances of North American freshwater fishes exposed to dynamic changes in temperature. *Environmental Biology of Fishes* **58**: 237-275.

Beitinger, T.L., Bennett, W.A., McCauley, R.W., 2000. Temperature tolerances of North American freshwater fishes exposed to dynamic changes in temperature. *Environ. Biol. Fishes* **58**: 237–275.

Beitinger, T.L., Fitzpatrick. L., 1979. Physiological and ecological correlates of preferred temperature in fish. *American Zoologist* **19**: 319-329.

Brewer, S.K. et al., 2016. Advancing environmental flow science: developing frameworks for altered landscapes and integrating efforts across disciplines. *Environmental management*, **58**: 175-192.

Bunn, S.E., Arthington, A.H., 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. *Environmental management*, **30**(4): 492-507.

Caissie, D., 2006. The thermal regime of rivers: a review. *Freshwater Biology*, **51**(8): 1389-1406.

Caissie, D., Satish, M.G., El-Jabi, N., 2007. Predicting water temperatures using a deterministic model: Application on Miramichi River catchments (New Brunswick, Canada). *Journal of Hydrology*, **336**(3): 303-315.

Cashner, R., Matthews, W., Marsh-Matthews, E., Unmack, P., Cashner, F., 2010. Recognition and redescription of a distinctive stoneroller from the Southern Interior Highlands. *Copeia*, **2010**(2): 300-311.

Clearwater, S.J., Pankhurst, N.W., 1997. The response to capture and confinement stress of plasma cortisol, plasma sex steroids and vitellogenic oocytes in the marine teleost, red gurnard. *Journal of Fish Biology*, **50**:429-441.

Cole, T.M., Buchak, E., 1994. ACE-QUAL-W2: A two-dimensional, laterally averaged, hydrodynamic and water quality model, Version 2.0, User Manual,@ Draft Instruction Report, Station, Vicksburg, MS.

Cole, T., Wells, S., 2002. CE_QUALW2: a two-dimensional, laterally averaged hydrodynamic and water quality model, version 3.1. User manual. *US Army Corps of Engineers, Instruction Report EL-02–1, Washington, DC*.

Coulter, D., Sepúlveda, M., Troy, C., Höök, T., 2014. Thermal habitat quality of aquatic organisms near power plant discharges: potential exacerbating effects of climate warming. *Fisheries management and ecology*, **21**(3): 196-210.

Coutant, C.C., 1976. Thermal effects on fish ecology, book chapter: 891-896. https://pubs.er.usgs.gov/publication/70119547

Cowles, R.B., Bogert, C., 1944. A preliminary study of the thermal requirements of desert reptiles. *Iguana* **83**:53.

Day et al., 2018. Species' thermal ranges predict changes in reef fish community structure during 8 years of extreme temperature variation. *Divers Distrib*. 2018;1036-1046.

Denwood, M., Plummer, M., 2016. runjags: interface utilities, model templates, parallel computing methods and additional distributions for MCMC models in JAGS. Available: https://www.r-project.org/conferences/DSC-2003/Proceedings/Plummer.pdf (December 2018).

Eberle, M.E., Stark, W.J., 2000. Status of the Arkansas darter in south-central Kansas and adjacent Oklahoma. *Prairie Naturalist*, **32**(2): 103-114.

Ebersole, J., Liss, W., Frissell, C., 2001. Relationship between stream temperature, thermal refugia and rainbow trout *Oncorhynchus mykiss* abundance in arid land streams in the northwestern United States. *Ecology of freshwater fish*, **10**(1): 1-10.

Ellis, L.E., Jones, N.E., 2013. Longitudinal trends in regulated rivers: a review and synthesis within the context of the serial discontinuity concept. *Environmental Reviews*, **21**(3): 136-148.

Fisher, W.L., Seilheimer, T.S., Taylor, J.M., 2012. , Biological assessment of environmental flows for Oklahoma: U.S. Geological Survey Open-File Report 2012–1114, 43 p., available at http://pubs.usgs.gov/of/2012/1114/.

Gates, K.K., Vaughn, C.C., Julian, J.P., 2015. Developing environmental flow recommendations for freshwater mussels using the biological traits of species guilds. *Freshwater Biology*, **60**(4): 620-635.

Gelman, A., Hill, J., 2007. Data analysis using regression and multilevel/ hierarchical models. Cambridge University Press.

Gelman, A., Rubin, D., 1992. Inference from iterative simulation using multiple sequences. *Statistical Science* **7**:457-472.

Graczyk, D.J., Sonzogni, W.C., 1991. Reduction of dissolved oxygen concentration in Wisconsin streams during summer runoff. *Journal of environmental quality*, **20**(2): 445-451.

Hoback, W.W., Barnhart, M.C., 1996. Lethal limits and sublethal effects of hypoxia on the amphipod *Gammarus pseudolimnaeus*. *Journal of the North American Benthological Society*, **15**(1): 117-126.

Hutchison, V.H., Maness, J.D., 1979. The role of behavior in temperature acclimation and tolerance in ectotherms. *Am. Zool.* **19**: 367–384.

Jacobsen, D., Marín, R., 2008. Bolivian Altiplano streams with low richness of macroinvertebrates and large diel fluctuations in temperature and dissolved oxygen. *Aquatic Ecology*, **42**(4): 643-656.

Kanno, Y., Vokoun, J., Letcher, B., 2014. Paired stream–air temperature measurements reveal fine scale thermal heterogeneity within headwater brook trout stream networks. *River research and applications*, **30**(6): 745-755.

Krause, P., Boyle, D., Bäse, F., 2005. Comparison of different efficiency criteria for hydrological model assessment. *Advances in geosciences*, **5**: 89-97.

Kruschke, J. K., 2013. Bayesian estimation supersedes the t test. *Journal of Experimental Psychology*: **142**:573-603.

Kruschke, J.K., 2015. Doing Bayesian analysis: a tutorial with R, JAGS, and Stan. Elsevier, Amsterdam.

Li, P., Ray, B., Gatlin, D. M., Sink, T., Chen, R., Lochmann, R., 2009. Effect of handling and transport on cortisol response and nutrient mobilization of Golden Shiner, *Notemigonus crysoleucas*. J*ournal of the World Aquaculture Society*, **40**: 803-809.

Lutterschmidt, W., Hutchison, V., 1997. The critical thermal maximum: history and critique. *Canadian Journal of Zoology* **75**: 1561-1574.

Magnuson, J.J., Crowder, L.B., Medvick, P.A., 1979. Temperature as an ecological resource. *American Zoologist*, **19**(1): 331-343.

Marshall, D.W. et al., 2006. Effects of hypolimnetic releases on two impoundments and their receiving streams in southwest Wisconsin. *Lake and Reservoir Management*, **22**(3): 223-232.

Masson, G, Valente, E., Fox, M.G., Copp, G.H., 2015. Thermal influences on life-history traits and reproductive effort of introduced pumpkinseed sunfish *Lepomis Gibbosus* in the River Moselle Basin (northeastern France). *River Res. Applic.*, **31**: 563– 575.

McManamay, R.A., Brewer, S.K., Jager, H.I., Troia, M.J., 2016. Organizing environmental flow frameworks to meet hydropower mitigation needs. *Environmental management*, **58**(3): 365-385.

Miller, R.J., Robison, H.W., 2004. *Fishes of Oklahoma*. University of Oklahoma Press.

Murray, L., Rennie, M.D., Svendsen, J.C., Enders, E.C., 2017. Respirometry increases cortisol levels in rainbow trout *Oncorhynchus mykiss*: implications for measurements of metabolic rate. Journal of Fish Biology, **90**: 2206-2213.

Nelson, K.C., Palmer, M.A., 2007. Stream temperature surges under urbanization and climate change: data, models, and responses. *JAWRA Journal of the American Water Resources Association*, **43**(2): 440-452.

Nilsson, C., Reidy, C.A., Dynesius, M., Revenga, C., 2005. Fragmentation and flow regulation of the world's large river systems. *Science*, **308**(5720): 405-408.

Oklahoma Department of Wildlife Conservation (ODWC), 2004 June - 2006 June. Fluvial geomorphology analysis of the Kiamichi River, Oklahoma. Federal Aid Grant No. T-19-P1. 293 p. Available from https://www.wildlifedepartment.com/wildlifemgmt/swg/T19P1.PDF. Accessed 2018 March 13.

Oklahoma's Comprehensive Wildlife Conservation Strategy. 2005. http://www.wildlifedepartment.com/CWCS.htm, Accessed June 2014.

Olden, J.D., Naiman, R.J., 2010. Incorporating thermal regimes into environmental flows assessments: modifying dam operations to restore freshwater ecosystem integrity. *Freshwater Biology*, **55**(1): 86-107.

OWRB, 2017. *Lakes of Oklahoma*. Oklahoma Water Resources Board, Oklahoma City, OK.

Pankhurst, N., 1997. Temperature effects on the reproductive performance of fish. *Global warming: implications for freshwater and marine fish*, **61**: 159.

Perkin, J.S., Gido, K.B., Johnson, E., Tabor, V.M., 2010. Consequences of stream fragmentation and climate change for rare Great Plains fishes. *Final Report to USFWS Great Plains Landscape Conservation Cooperative Program*.

Pflieger, W., 1997. The fishes of Missouri, rev. ed. *Missouri Department of Conservation, Jefferson City, MO*.

Pickering, A.D., Pottinger, T.G., 1989. Stress responses and disease resistance in salmonid fish: Effects of chronic elevation of plasma cortisol. *Fish Physiol. Biochem*. **7**: 253–258.

Pigg, J., 1974. Fishes in the Kiamichi River, Oklahoma, *Proceedings of the Oklahoma Academy of Science*, **54**: 121-130.

Pluhowski, E.J., 1970. Urbanization and its effect on the temperature of the streams on Long Island, New York. 627D.

Plummer, M., 2003. JAGS: A program for analysis of Bayesian graphical models using Gibbs sampling. *Proceedings of the 3rd International Workshop on Distributed Statistical Computing*, 124, No. 125.10.
Available: https://cran.r-project.org/web/packages/runjags/index.html (December 2018)

Poff, N.L., 1997. Landscape filters and species traits: towards mechanistic understanding and prediction in stream ecology. *Journal of the North American Benthological Society*, **16**(2): 391-409.

Poff, N.L. et al., 2010. The ecological limits of hydrologic alteration (ELOHA): a new framework for developing regional environmental flow standards. *Freshwater Biology*, **55**(1): 147-170.

Poole, G.C., Berman, C.H., 2001. An ecological perspective on in-stream temperature: natural heat dynamics and mechanisms of human-caused thermal degradation. *Environmental management*, **27**(6): 787-802.

Pörtner, H.O., Knust, R., 2007. Climate change affects marine fishes through the oxygen limitation of thermal tolerance. *Science* **315**: 95-97.

Pyron, M., Vaughn, C.C., Winston, M.R., Pigg, J., 1998. Fish assemblage structure from 20 years of collections in the Kiamichi River, Oklahoma. *The Southwestern Naturalist*: 336-343.

Quinn, T.P., Hodgson, S., Peven, C., 1997. Temperature, flow, and the migration of adult sockeye salmon (*Oncorhynchus nerka*) in the Columbia River. *Canadian Journal of Fisheries and Aquatic Sciences*, **54**(6): 1349-1360.

Richter, B.D., Warner, A.T., Meyer, J.L., Lutz, K., 2006. A collaborative and adaptive process for developing environmental flow recommendations. *River Research and Applications*, **22**(3): 297-318.

Runkel R.L., 1998. One-dimensional transport with inflow and storage (OTIS): a solute transport model for streams and rivers. U.S. Geological Survey Water-Resources Investigations Report 98-4018, 73 p.

Rust, S., W.L. Fisher, Marston, R.A., 2006. Final report: Fluvial geomorphology analysis of the Kiamichi River, Oklahoma. Oklahoma Department of Wildlife Conservation.

Saltveit, S.J., 1990. Effect of decreased temperature on growth and smoltification of juvenile Atlantic salmon (*Salmo salar*) and brown trout (*Salmo trutta*) in a Norwegian regulated river. *River Research and Applications*, **5**(4): 295-303.

Sanford II, D.R., Boyd, S., 2012. Watershed Assessment for the Kiamichi Basin of Oklahoma.

Seager, R., Vecchi, G.A., 2010. Greenhouse warming and the 21st century hydroclimate of southwestern North America. *Proceedings of the National Academy of Sciences*, **107**(50): 21277-21282.

Splinter D.K., Dauwalter D.C., Marston R.A., and Fisher W.L. 2011. Watershed morphology of highland and mountain ecoregions in eastern Oklahoma. *Professional Geographer* **63**:131–43.

Spooner, D.E., Vaughn, C.C., Galbraith, H.S., 2005. Physiological determination of mussel sensitivity to water management practices in the Kiamichi River and review and summarization of literature pertaining to mussels of the Kiamichi and Little River watersheds, Oklahoma. *Oklahoma Department of Wildlife Conservation*.

Stofleth J.M., Shields F.D., Fox G.A., 2008. Hyporheic and total transient storage in small, sand-bed streams. *Hydrological Processes* **22**:1885–1894. DOI: 10.1002/hyp.6773.

Stuart-Smith et al., 2017. Thermal limits to the geographic distributions of shallow water marine species. *Nature Ecology & Evolution*, **1**: 1846.

Sutherland, A., Maki, J., Vaughan, V., 2008. Effects of suspended sediment on whole-body cortisol stress response of two southern Appalachian minnows, *Erimonax Monachus* and *Cyprinella Galactura*. *Copeia*, **2008**: 234-244.

Swann, L., Fitzgerald, S., 1992. Use and application of salt in aquaculture. NCRAC Extension Fact Sheets. 9. http://lib.dr.iastate.edu/ncrac_factsheets/9

Tharme, R.E., 2003. A global perspective on environmental flow assessment: emerging trends in the development and application of environmental flow methodologies for rivers. *River research and applications*, **19**(5 6): 397-441.

Townsend, S.A., 1999. The seasonal pattern of dissolved oxygen, and hypolimnetic deoxygenation, in two tropical Australian reservoirs. *Lakes & Reservoirs: Research & Management*, **4**(1 2): 41-53.

Vaughn, C.C., Atkinson, C.L., Julian, J.P., 2015. Drought-induced changes in flow regimes lead to long-term losses in mussel-provided ecosystem services. *Ecology and Evolution*. **5**(6): 1291–1305.

Vaughn, C.C., Taylor, C., 1999. Impoundments and the decline of freshwater mussels: a case study of an extinction gradient. *Conservation Biology*, **13**: 912-920.

Vörösmarty, C.J., Salisbury, G., Lammers, J., 2010. Global water resources: Vulnerability from climate change and population growth. *Science* **289**: 284-288.

Wagner, R.J., Mattraw, H.C., Ritz, G.F., Smith, B.A. 2000. Guidelines and standard procedures for continuous water-quality monitors: Site selection, field operation, calibration, record computation, and reporting. U.S. Geological Survey Water-Resources Investigations Report 00-4252, 53.

Webb, B.W., Zhang, Y., 1999. Water temperatures and heat budgets in Dorset chalk water courses. *Hydrological Processes*, **13**(3): 309-321.

Wilson G.V., Neiber J.L., Fox G.A., 2013. Internal erosion during soil pipeflow: State of the science for experimental and numerical analysis. *Transactions of the ASABE* **56**(2): 465-478.

Wohl et al., 2015. The natural sediment regime in rivers: Broadening the foundation for ecosystem management, *BioScience*, **65**: 358–371.

Woods A.J., Omernik J.M., Butler D.R., Ford J.G., Henley J.E., Hoagland B.W. and Al. E., 2005. Ecoregions of Oklahoma (color poster with map, descriptive text, summary tables, and photographs). U.S.Geological Survey), Vol. 9/1/2013, Reston, VA.

Wool, T.A., Ambrose, R.B., Martin, J.L., Comer, E.A., Tech, T., 2006. Water quality analysis simulation program (WASP). *User's Manual, Version*, **6**.

Wootton, R., 2012. Ecology of teleost fishes, 1. *Springer Science & Business Media*.

Zhou, Y., et al., 2018. Groundwater flux estimation in streams: a thermal equilibrium approach. *Journal of Hydrology* **561**:822-83.

**Table 1**. Critical thermal maxima (CTMax) was obtained from Alexander (2017). CTMax was determined by increasing temperature 2 °C/h above acclimated temperature (20.0°C) for 10 fish species that occupied the Ouachita Mountain ecoregion. The average value of species within each of three habitat guilds was used to determine a fish-habitat guild. Species were assigned to each habitat guild using existing ecological information (references provided). The CTMax for each guild was used to determine when fish will experience thermal stress as part of our Water Quality Analysis Simulation Program simulations.

| Habitat Guild | Guild CTMax (°C) | Common Name | Scientific Name | n | CTMax (°C) | Typical Habitat | Reference |
|---|---|---|---|---|---|---|---|
| Surface | 38.30 | Blackspotted topminnow | *Fundulus olivaceus* | 10 | 38.30 | Surface water, backwaters, edgewaters | Pflieger, 1997 |
| Mid-column | 34.72 | Bigeye shiner | *Notropis boops* | 10 | 34.42 | Mid-column, run, pool | Pflieger, 1997 |
| | | Bluntnose minnow | *Pimephales notatus* | 10 | 35.26 | Mid-column, backwaters, pools | Miller and Robison, 2004 |
| | | Highland stoneroller | *Campostoma spadiceum* | 10 | 34.78 | Mid-column, riffle, run, pool | Cashner et al., 2010 |
| | | Steelcolor shiner | *Cyprinella whipplei* | 10 | 34.42 | Mid-column, riffle, run, pool | Pflieger, 1997 |
| Benthic | 34.34 | Channel darter | *Percina copelandi* | 10 | 34.09 | Benthic, riffle, run, pool | Miller and Robison, 2004 |
| | | Common logperch | *Percina caprodes* | 10 | 35.00 | Benthic, riffle, run, pool | Miller and Robison, 2004 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Dusky darter | *Percina sciera* | 10 | 34.30 | Benthic, riffle, run, pool | Miller and Robison, 2004 |
| | Orangebelly darter | *Etheostoma radiosum* | 10 | 33.97 | Benthic, riffle, run, pool | Miller and Robison, 2004 |
| | Slenderhead darter | *Percina phoxocephala* | 10 | 34.32 | Benthic, riffle, run, pool | Miller and Robison, 2004 |

**Table 2**. Critical thermal maxima (CTMax) of 17 stream fishes that occupy Ouachita Mountain streams. Most fishes were acclimated to 20.0°C and exposed to a 2.0°C/h increase in temperature until loss of equilibrium. *The two unique strains of Smallmouth Bass (SMB) were also acclimated to 25.0°C because tested individuals were juveniles and more tolerant of thermal stress.

| Scientific name | Common name | CTM (˚C), 90% HDI | Thermal group | Thermal subgroup |
|---|---|---|---|---|
| *Notropis ortenburgeri* | Kiamichi Shiner | 32.50 (32.04, 33.02) | Low | Low-low |
| *Etheostoma nigrum* | Johnny Darter | 33.52 (33.09, 33.91) | Low | Low-low |
| *Etheostoma radiosum* | Orangebelly Darter | 33.84 (33.60, 34.08) | Low | Low-low |
| *Percina maculata* | Blackside Darter | 33.87 (33.49, 34.32) | Low | Low-low |
| *Percina copelandi* | Channel Darter | 33.98 (33.61, 34.34) | Low | Low-low |
| *Percina sciera* | Dusky Darter | 34.36 (34.02, 34.70) | Low | Low-high |
| *Notropis boops* | Bigeye Shiner | 34.43 (33.95, 34.91) | Low | Low-high |
| *Notropis atherinoides* | Emerald Shiner | 34.49 (34.09, 34.88) | Low | Low-high |
| *Percina phoxocephala* | Slenderhead Darter | 34.55 (34.28. 34.83) | Low | Low-high |
| *Cyprinella whipplei* | Steelcolor Shiner | 34.71 (34.11, 35.24) | Low | Low-high |
| *Pimephales vigilax* | Bullhead Minnow | 34.73 (34.22, 35.21) | High | High-low |

| | | | | |
|---|---|---|---|---|
| *Micropterus dolomieu velox* | Neosho Smallmouth Bass | 34.92 (34.40, 35.50) | High | High-low |
| *Campostoma spadiceum* | Highland Stoneroller | 35.08 (34.71, 35.42) | High | High-low |
| *Pimephales notatus* | Bluntnose Minnow | 35.13 (34.90, 35.41) | High | High-low |
| *Percina caprodes* | Logperch | 35.61 (35.14, 36.06) | High | High-low |
| *Micropterus dolomieu* | Ouachita Smallmouth Bass | 36.24 (35.64, 36.77) | High | High-high |
| **Micropterus dolomieu velox* | Neosho Smallmouth Bass | 35.84 (34.93, 36.75) | NA | NA |
| **Micropterus dolomieu* | Ouachita Smallmouth Bass | 37.71 (36.81, 38.63) | NA | NA |
| *Fundulus olivaceus* | Blackspotted Topminnow | 38.28 (37.82, 38.71) | High | High-high |

**Table 3.** Multiple comparison tests of critical thermal maximums (CTMax) based on thermal groupings and taxonomy, where contrast describes the test (see Methods and Table 2 for a detailed description of contrasts and groupings). The 90% highest-density interval (HDI) represents the posterior distribution of the credible difference (i.e., the effect size) in CTMax (˚C), where asterisks indicate HDIs that do not overlap zero. Most of the stream fishes were acclimated to 20°C, but genetically-distinct populations of Smallmouth Bass (SMB) were acclimated to both 20°C and 25°C (*).

| Contrast | 90% HDI |
|---|---|
| Low versus high | *-1.91, -1.45 |
| Low-low versus low-high | *-1.23, -0.68 |
| High-low versus high-high | *-2.55, -1.72 |
| Darters versus minnows | -0.41, 0.03 |
| *Etheostoma* versus *Percina* | *-1.17, -0.45 |
| Johnny Darter versus Orangebelly Darter | -0.76, 0.11 |
| Blackside Darter versus *Percina* | *-1.18, -0.25 |
| Channel Darter versus *Percina* | *-1.08, -0.18 |
| Dusky Darter versus *Percina* | -0.53, 0.23 |
| Logperch versus *Percina* | *0.95, 1.90 |
| Slenderhead Darter versus *Percina* | -0.23, 0.40 |
| Bigeye Shiner versus *Notropis* | *0.33, 1.52 |
| Emerald Shiner versus *Notropis* | *0.48, 1.55 |
| Kiamichi Shiner versus *Notropis* | *-2.54, -1.34 |
| Bluntnose Minnow versus Bullhead Minnow | -0.15, 1.01 |
| Neosho SMB versus Ouachita SMB | *-2.08, -0.44 |

| | |
|---|---|
| *Neosho SMB versus Ouachita SMB | *-2.79, -0.95 |

**Table 4.** Whole-body cortisol concentrations from chronic thermal stress trials were measured on six fishes: Blackspotted Topminnow *Fundulus olivaceus*, Bluntnose Minnow *Pimephales notatus*, Channel Darter *Percina copelandi*, Highland Stoneroller *Campostoma spadiceum*, Orangebelly Darter *Etheostoma radiosum*, and Steelcolor Shiner *Cyprinella whipplei*. Fishes were expected to exhibit stress responses associated with habitat guilds defined by documented habitat use. Experimental fishes were collected from the Kiamichi River in autumn 2016 and spring 2017. Fish were acclimated to laboratory conditions of 20.0°C and exposed to a 1.0°C/d increase in temperature until reaching the treatment temperatures (i.e., 27.0°C control; 32.0°C experimental). Fish remained at treatment temperatures for 14 days but were all provide a thermal refuge of 2.5°C each night during trials.

| Common Name | Scientific Name | Habitat Guild | Typical Habitat | Reference |
|---|---|---|---|---|
| Blackspotted Topminnow | *Fundulus olivaceus* | Surface | Surface water, backwaters, edgewaters | Pflieger, 1997 |
| Bluntnose Minnow | *Pimephales notatus* | Mid-column | Mid-column, backwaters, pools | Miller and Robison, 2004 |
| Channel Darter | *Percina copelandi* | Benthic | Benthic, riffle, run, pool | Miller and Robison, 2004 |
| Highland Stoneroller | *Campostoma spadiceum* | Mid-column | Mid-column, riffle, run, pool | Cashner et al., 2010 |
| Orangebelly Darter[1] | *Etheostoma radiosum* | Benthic | Benthic, riffle, run, pool | Miller and Robison, 2004 |
| Steelcolor Shiner | *Cyprinella whipplei* | Mid-column | Mid-column, riffle, run, pool | Pflieger, 1997 |

[1]Oklahoma Species of Greatest Conservation Concern

**Table 5.** Estimated groundwater fluxes from our seepage run data. Sites are listed in downstream order and the distance downstream was measured from the start of the reach in interest (i.e., Indian).

| Reach | Downstream distance (km) | Net Groundwater Flux ($m^2/s$) |
|---|---|---|
| Indian | 0.00 | -4.45E-05 |
| Robins | 9.69 | -6.42E-05 |
| ConfUpstrm | 34.28 | 3.76E-05 |
| ConfDwnstrm | 34.28 | -3.00E-06 |
| Pine Spur | 59.88 | -4.82E-05 |
| Payne | 73.34 | -5.10E-06 |

**Table 6.** Statistics evaluating the predicted versus observed water temperatures using the WASP model without conceptualized groundwater inflow: sample size (n), R squared ($R^2$), squared errors of prediction (SSE), mean squared error (MSE), and Nash-Sutcliffe model efficiency coefficient (NSE). Statistics for each of four sites are included in the table.

| | Indian HWY Pool | Robins Pool | Pine Spur Pool | Payne Pool |
|---|---|---|---|---|
| n | 3696 | 3696 | 3696 | 3696 |
| $R^2$ | 0.911 | 0.896 | 0.628 | 0.643 |
| SSE | 10516.398 | 19746.481 | 108988.067 | 104742.476 |
| MSE | 2.8E+00 | 5.3E+00 | 2.9E+01 | 2.8E+01 |
| NSE | 0.906 | 0.829 | 0.201 | 0.173 |

Table 7. Statistics evaluating predicted versus observed water temperatures using the WASP model with conceptualized groundwater inflow**:** sample size (n), R squared ($R^2$), squared errors of prediction (SSE), mean squared error (MSE), and Nash-Sutcliffe model efficiency coefficient (NSE). Statistics for each of four sites are included in the table.

| | Indian HWY Pool | Robins Pool | Pine Spur Pool | Payne Pool |
|---|---|---|---|---|
| n | 3673 | 3673 | 3673 | 3673 |
| $R^2$ | 0.999 | 0.942 | 0.817 | 0.786 |
| SSE | 170.048 | 8819.775 | 41059.483 | 48092.314 |
| MSE | 0.05 | 2.40 | 11.18 | 13.09 |
| NSE | 0.999 | 0.933 | 0.710 | 0.641 |

**Table 8.** Thermal stress of fishes was evaluated by calculating the area under the curve of cumulative time above CTMax downstream of the release (km•h). The CTMax used to represent the thermal tolerances of a mid-column fish habitat guild was 34.72°C and the value used to represent the thermal tolerances of the benthic guild was 34.34°C. The thermal tolerances of fishes included in each guild were: mid column- Bigeye Shiner, Bluntnose Minnow, Highland Stoneroller, and Steelcolor Shiner; benthic- Channel Darter, Common Logperch, Dusky Darter, Orangebelly Darter, and Slenderhead Darter. Release scenarios were simulated based on the combination of five different release magnitude (0.34, 0.59, 0.76, 1.13 and 1.50 $m^3/s$) and three gate levels (5, 10 and 20 m deep representing release water temperature of 27.64°C, 26.00°C, and 24.07°C, respectively).

| | Mid-column Guild | | | | Benthic Guild | | | |
|---|---|---|---|---|---|---|---|---|
| Depth of water release from dam (m) | Control | 5 | 10 | 20 | Control | 5 | 10 | 20 |
| Discharge ($m^3/s$) | 2914 | | | | 5206 | | | |
| 0.34 | | 2607 | 2516 | 2401 | | 4808 | 4679 | 4557 |
| 0.59 | | 2392 | 2290 | 2197 | | 4579 | 4360 | 4153 |
| 0.76 | | 2309 | 2214 | 2118 | | 4401 | 4162 | 3949 |
| 1.13 | | 2119 | 1980 | 1831 | | 4027 | 3776 | 3534 |
| 1.50 | | 1953 | 1785 | 1583 | | 3698 | 3409 | 3077 |

**Table 9.** The reduction rate of thermal stress compared to the control with no release (calculated as the ratio of thermal stress reduction to the thermal stress of the control). The CTMax used to represent the thermal tolerances of a mid-column fish habitat guild was 34.72°C and the value used to represent the thermal tolerances of the benthic guild was 34.34°C The thermal tolerances of fishes included in each guild are provided in Table 8. Release scenarios were simulated based on the combination of five different release magnitude (0.34, 0.59, 0.76, 1.13 and 1.50 $m^3/s$) and three gate levels (5, 10 and 20 m deep representing release water temperature of 27.64°C, 26.00°C and 24.07°C, respectively).

| | Mid-column Guild | | | Benthic Guild | | |
|---|---|---|---|---|---|---|
| Depth of water release from dam (m) | 5 | 10 | 20 | 5 | 10 | 20 |
| Discharge ($m^3/s$) | | | | | | |
| 0.34 | 11% | 14% | 18% | 8% | 10% | 12% |
| 0.59 | 18% | 21% | 25% | 12% | 16% | 20% |
| 0.76 | 21% | 24% | 27% | 15% | 20% | 24% |
| 1.13 | 27% | 32% | 37% | 23% | 27% | 32% |
| 1.50 | 33% | 39% | 46% | 29% | 35% | 41% |

**Table 10.** The distance downstream of the Jack Fork Creek and Kiamichi River where the cumulative time above CTMax was reduced by half (provided in km). The CTMax used to represent the thermal tolerances of a mid-column fish habitat guild was 34.72°C and the value used to represent the thermal tolerances of the benthic guild was 34.34°C. The thermal tolerances of fishes included in each guild are provided in Table 8. Release scenarios were simulated based on the combination of five different release magnitude (0.34, 0.59, 0.76, 1.13 and 1.50 $m^3/s$) and three gate levels (5, 10 and 20 m deep representing release water temperature of 27.64°C, 26.00°C and 24.07°C, respectively).

| | Mid-column Guild | | | Benthic Guild | | |
|---|---|---|---|---|---|---|
| Depth of water release from dam (m) | 5 | 10 | 20 | 5 | 10 | 20 |
| Discharge ($m^3/s$) | | | | | | |
| 0.34 | 1 | 1 | 2 | 1 | 1 | 2 |
| 0.59 | 4 | 6 | 8 | 2 | 5 | 7 |
| 0.76 | 5 | 7 | 8 | 5 | 7 | 7 |
| 1.13 | 9 | 11 | 12 | 8 | 9 | 10 |
| 1.50 | 10 | 13 | 16 | 10 | 11 | 13 |

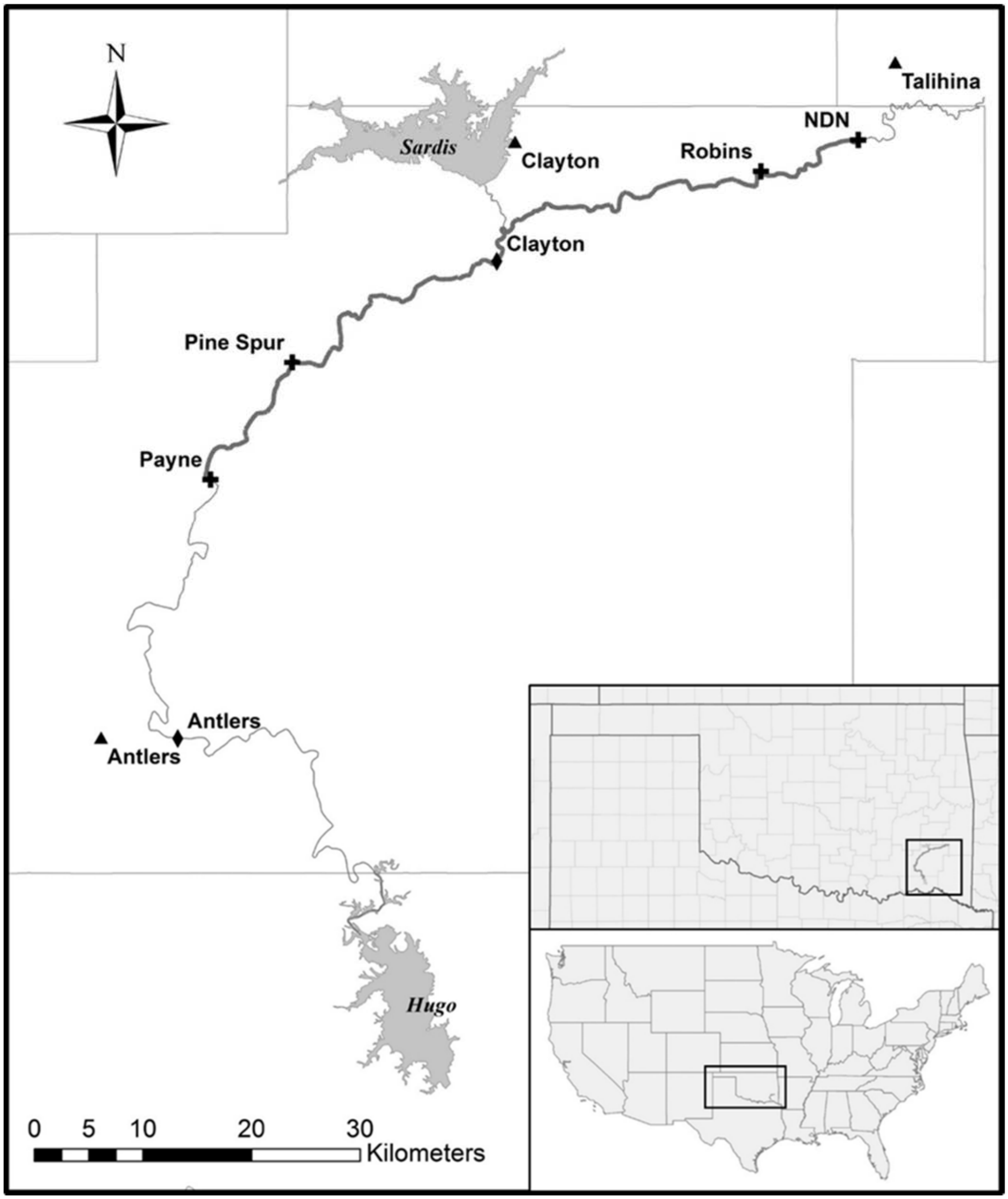


**Figure 1.** Map of the Kiamichi River showing our study reach (thick gray line). Mesonet stations and U.S. Geological Survey (USGS) stream gages are represented by triangle and diamond markers, respectively. Cross markers indicate monitoring sites where stream water temperature data were collected.

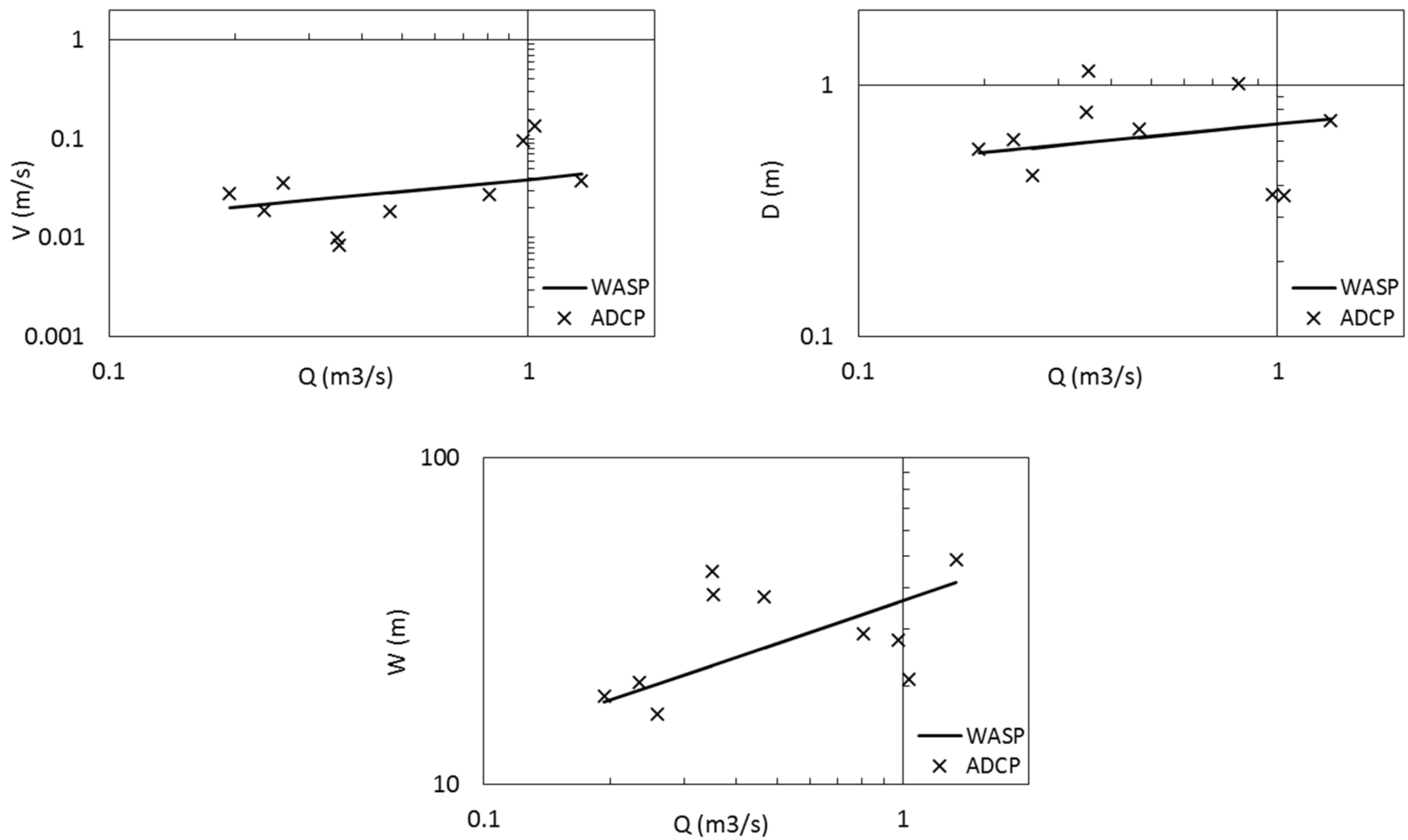


**Figure 2.** Regression between velocity (V), depth (D) and stream width (W) and discharge (Q). Acoustic Doppler Current Profiler (ADCP) transect measurement results are represented by markers (x) and regression equations are represented by the solid line.

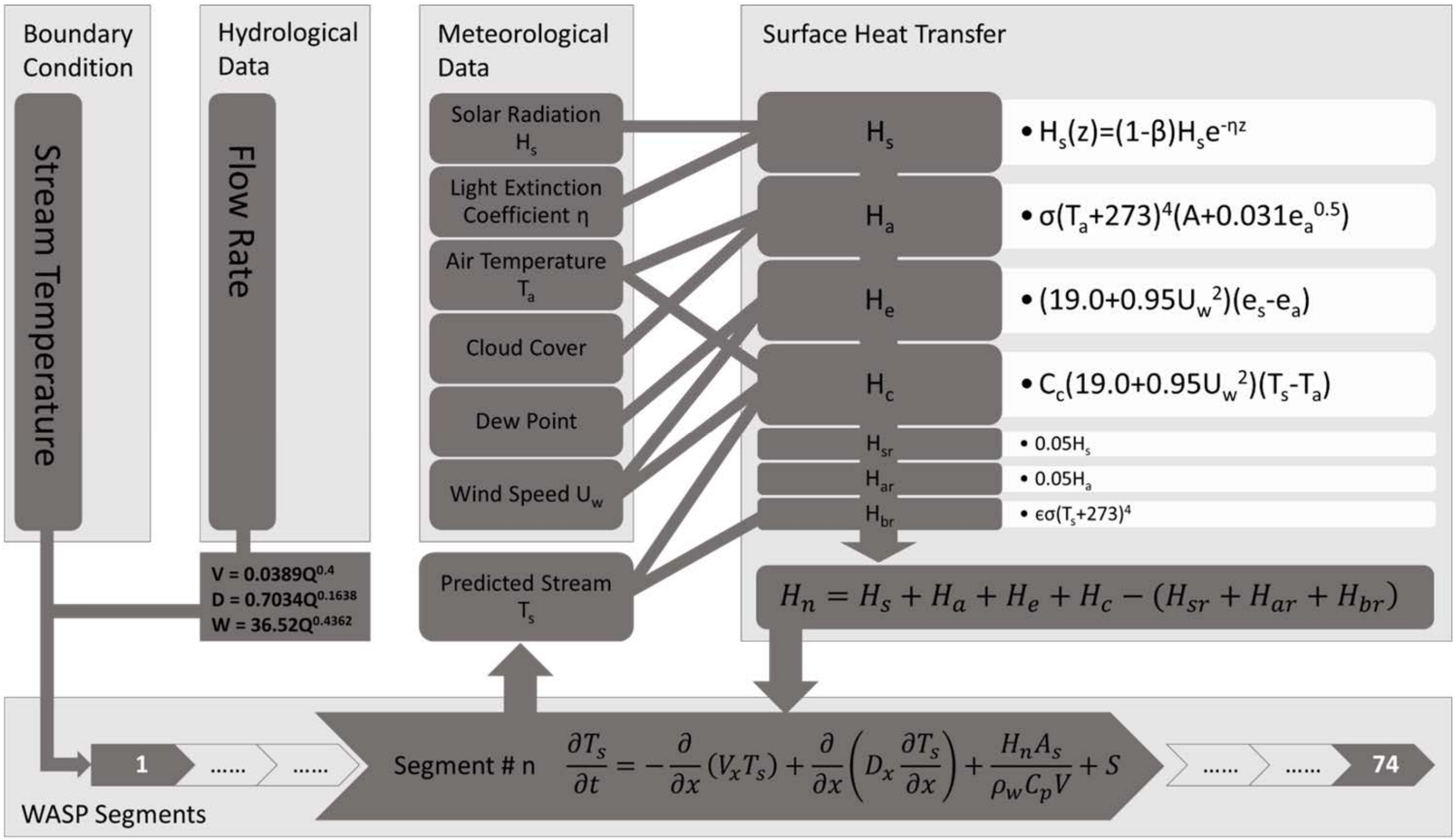


**Figure 3.** Water Quality Analysis Simulation Program (WASP) Temperature Module Structure. The WASP temperature module uses a partial differential equation (shown in the bottom) to calculate stream water temperature based on upstream boundary condition (shown in the top left) and surface heat transport processes (shown in the top right).

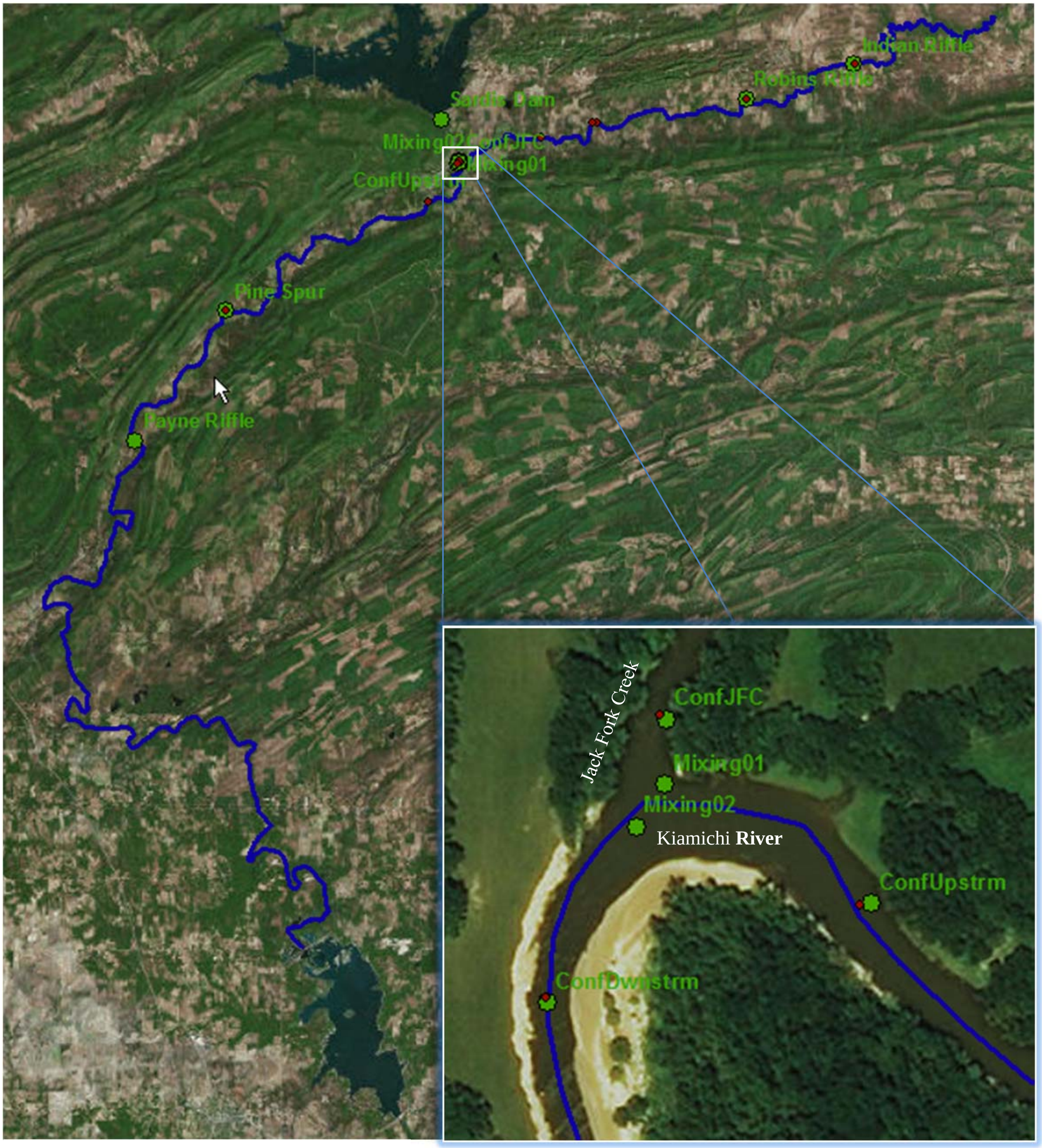


**Figure 4.** A map of our study area that shows the locations of dissolved oxygen (DO) loggers (green markers) and temperature loggers (red markers). The closely located loggers near the confluence are shown in subfigure (e.g., there are 5 DO data loggers and 3 stream temperature data loggers located just downstream of Sardis Reservoir on Jack Fork Creek).

**Figure 5.** Sump system for testing critical thermal maximum (CTMax) and long-term thermal stress. A pump discharges water into the 37.85-L aquariums and a gravity fed system discharges water into the 189.27-L sump. During CTMax trials, water is heated in the sump by a 5000-W Smartone heater (OEM Heaters, Saint Paul, MN). During long-term thermal stress trials, water is heated in the sump by a 1700-W Smartone heater (OEM Heaters, Saint Paul, MN).

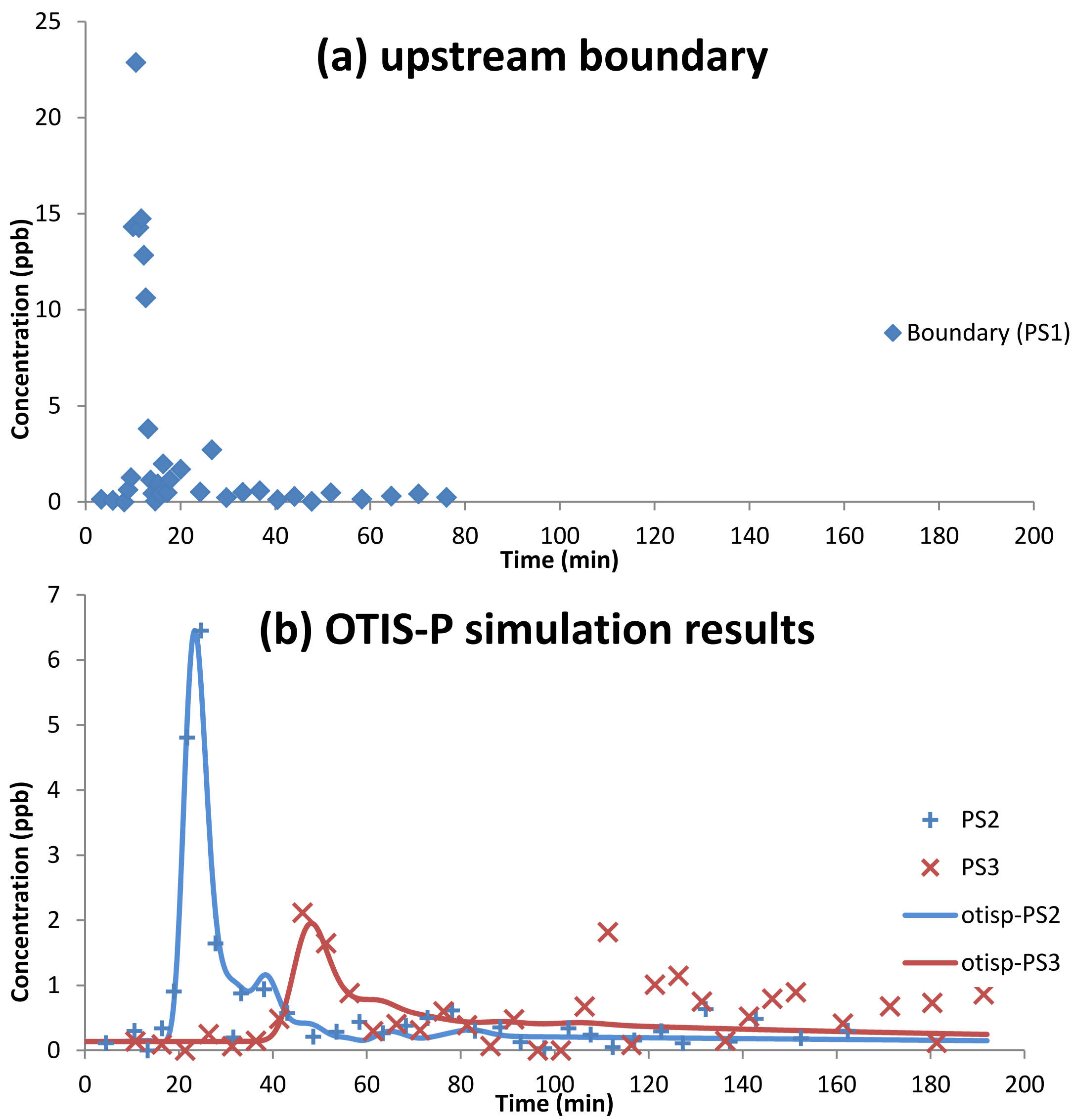


**Figure 6.** The relationship between tracer concentrations over time. (a) The first location (PS1, blue squares) was used to make predictions at the downstream sites (PS2, PS3) that would account for unknown mixing caused by river characteristics (i.e., hyporheic exchange, flow characteristics). (b) The blue and red crosses represent the actual measured concentration at PS2 and PS3, respectively.  The blue and red curves are the corresponding OTIS-P modeled predictions associated with the raw data at each site (PS2 and PS3). These predictions are estimated tracer concentrations after accounting for hyporheic exchange.

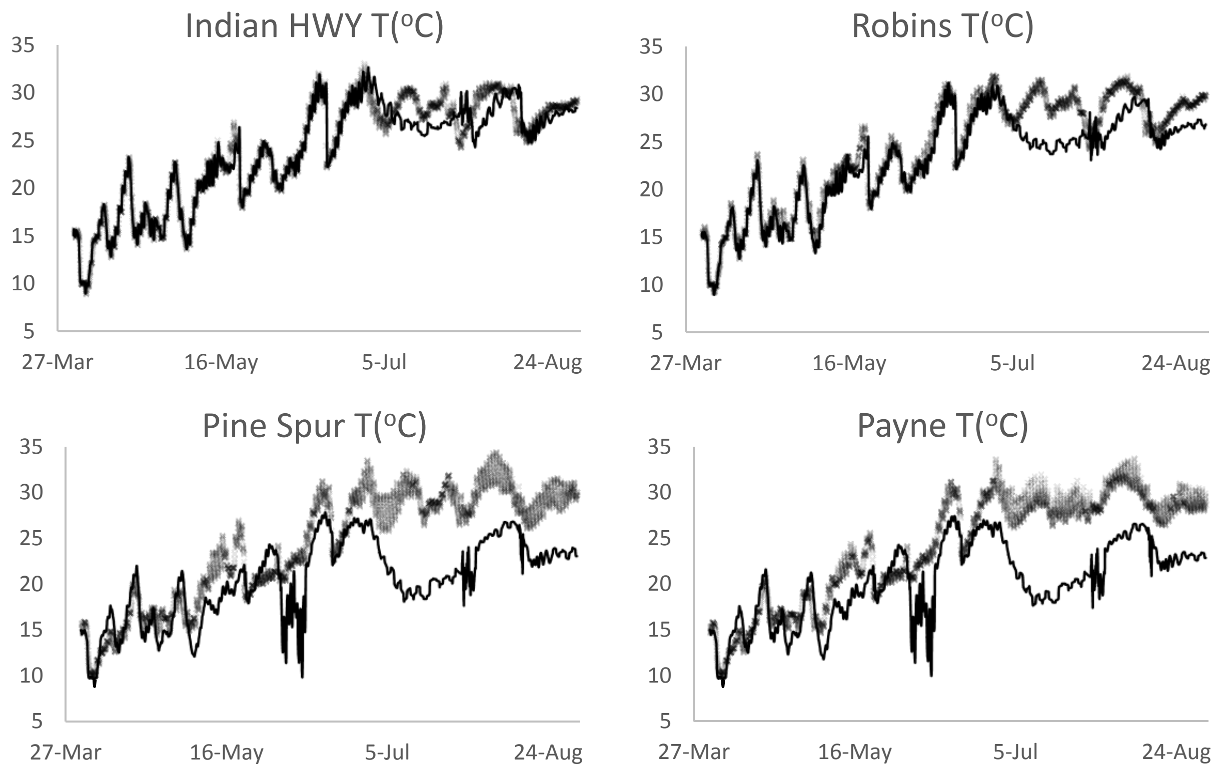


**Figure 7**. Predicted stream temperature without groundwater inflow using the WASP model. Calibration data are represented by the partly transparent markers whereas the model-predicted stream temperature is represented by the solid line.

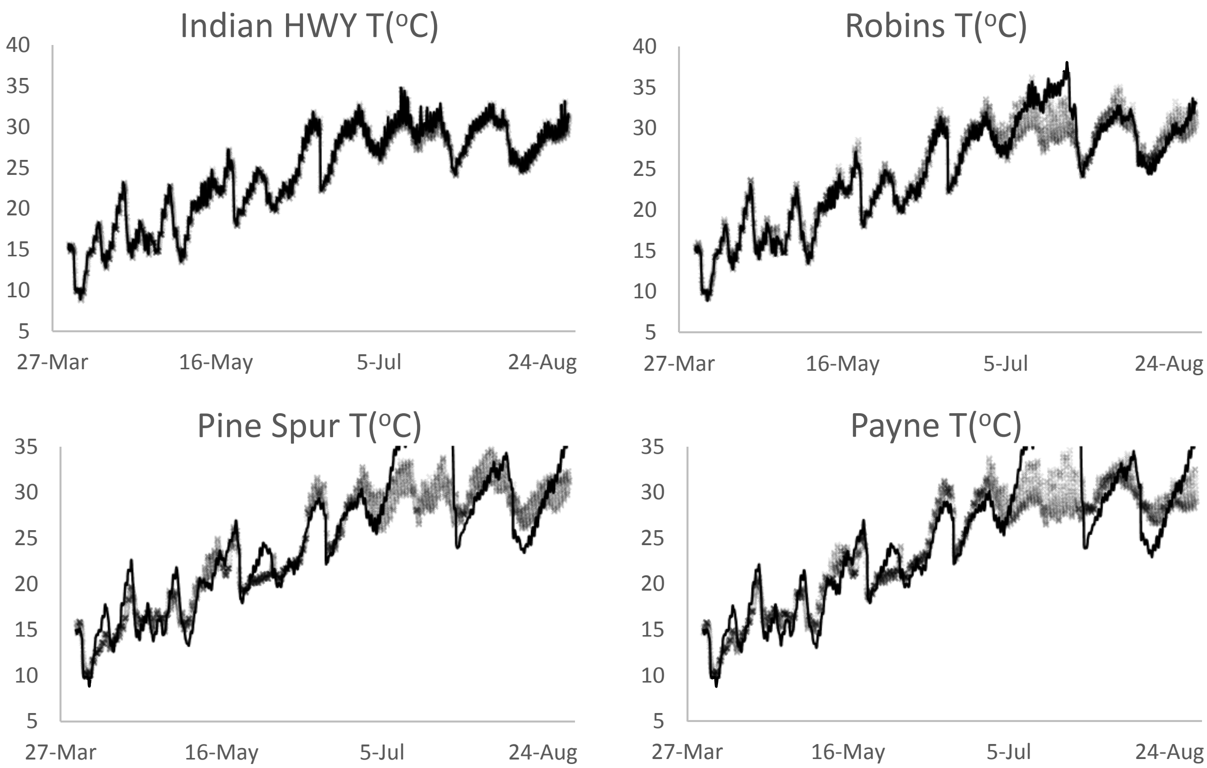


**Figure 8**. Predicted stream temperature with groundwater inflow using the WASP model. Calibration data are represented by the partly transparent markers whereas the model-predicted stream temperature is represented by the solid line.

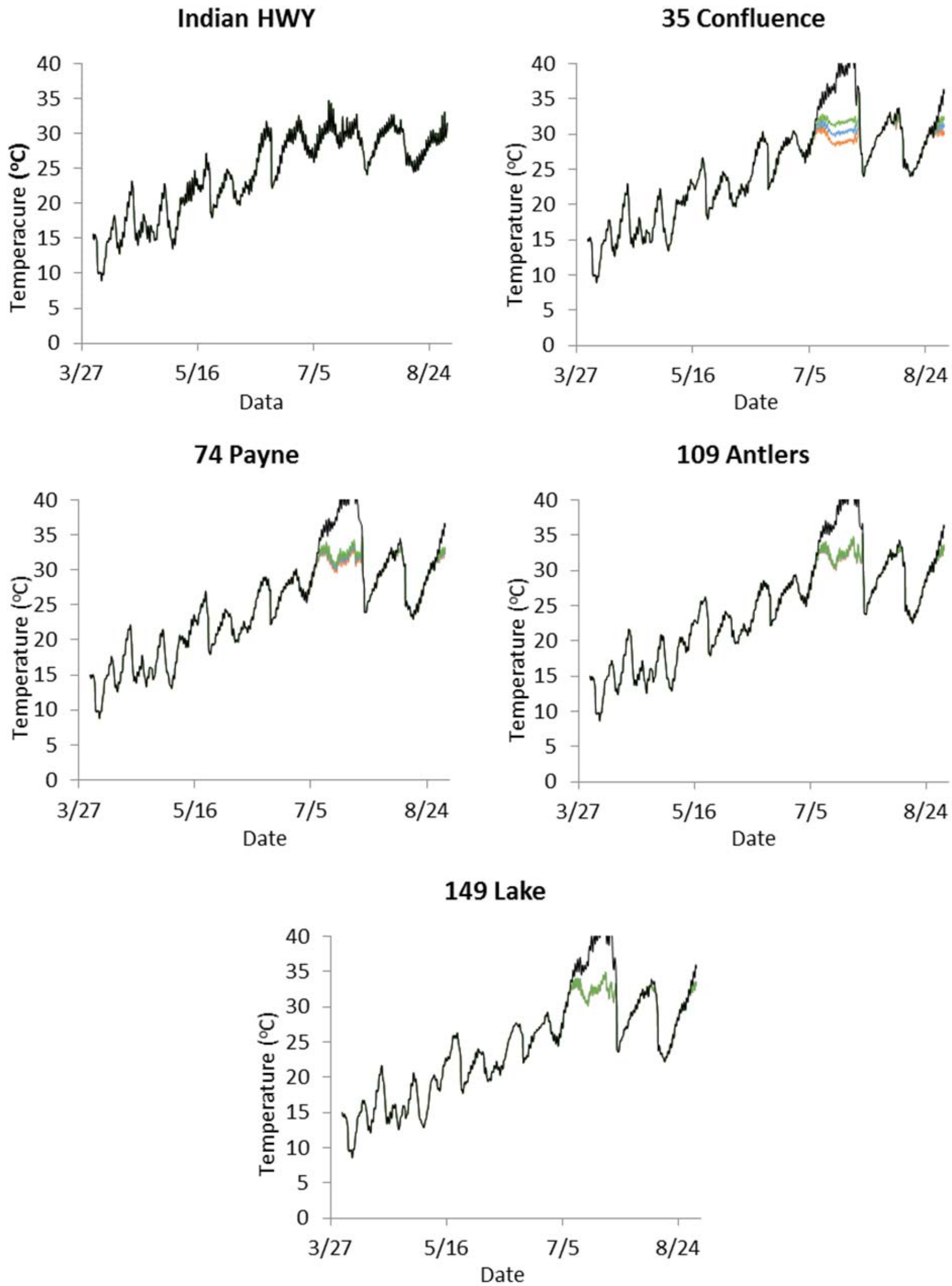


**Figure 9.** Initial predictions of stream temperature by the WASP model. The control discharge (i.e., without reservoir release) is represented by the black solid line and reservoir releases of 29°C, 27°C, and 25°C are represented by orange, blue, and red lines, respectively. The number before each site name is the distance in km from the start of the research river reach (Indian HWY is located at 0).

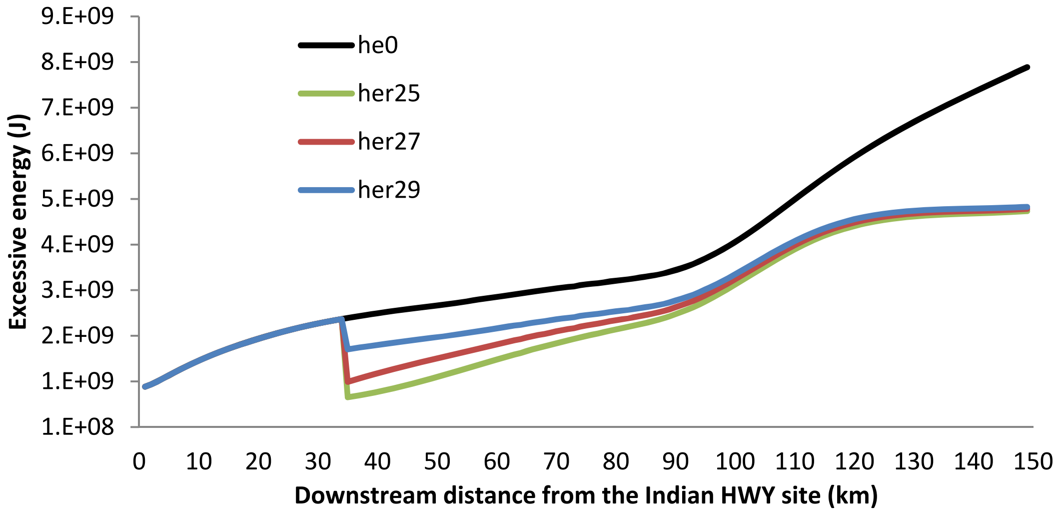


**Figure 10.** Predicted excessive energy. $h_{e0}$ is initial excessive energy above the target temperature limit; $h_{er}$ is excessive energy after reduction using reservoir release of 25°C, 27°C, and 29°C. He0 indicates no water release. At the reservoir release confluence (x=35), excessive energy was substantially reduced by released water. However, the difference in excessive energy for each temperature of released water diminishes with downstream distance.

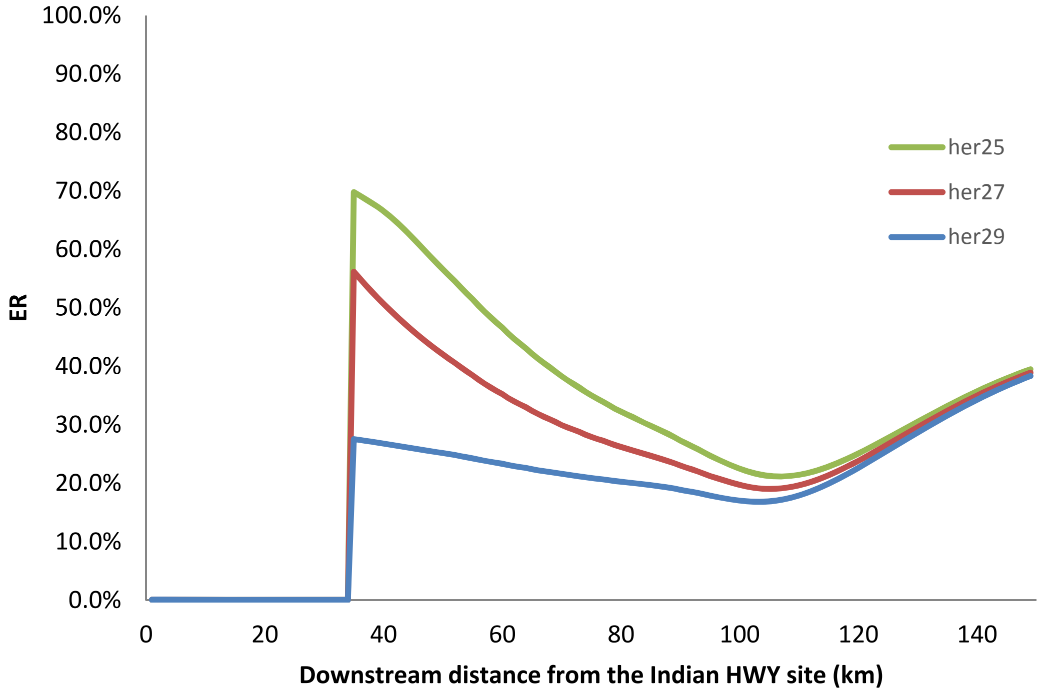


**Figure 11.** Predicted energy reduction (ER) as a function of distance downstream for a reservoir release temperature of 25°C (her25), 27°C (her27), and 29°C (her29). Similar to the previous figure, energy reduction (ER) happens at the reservoir release confluence (x=35).

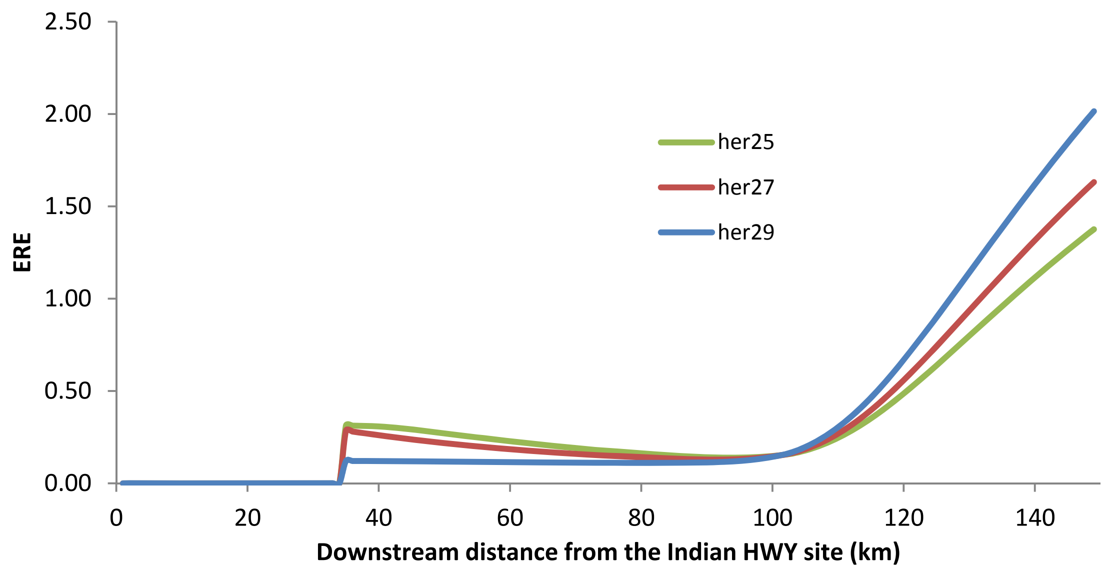


**Figure 12.** Predicted energy reduction efficiency (ERE) as a function of distance downstream for a reservoir release temperature of 25°C, 27°C, and 29°C. Energy reduction happens at the reservoir release confluence (x=35). Initially, cooler released water results in a higher energy reduction efficiency (ERE) due to greater temperature difference from natural stream water. However, after the intersection point downstream, warmer released water results in a higher ERE because water with less temperature difference from natural stream water was released to reduce excessive energy to a similar level.

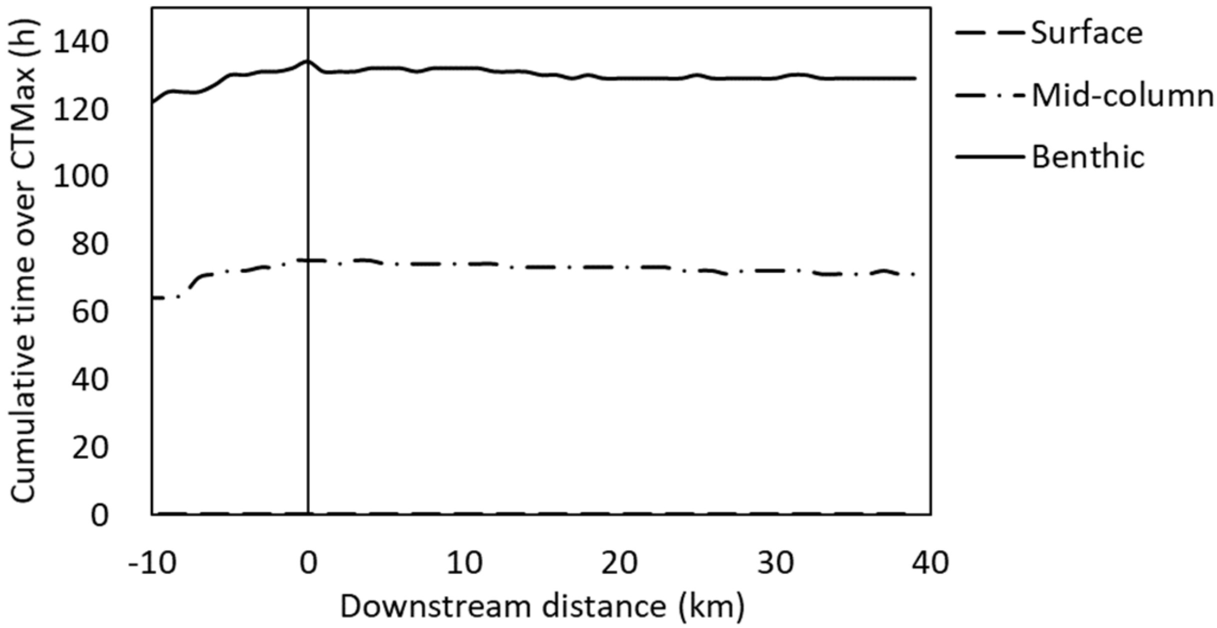


**Figure 13.** The cumulative time above thermal critical maxima (CTMax) of three fish guilds versus downstream distance from the reservoir confluence calculated with the occurred release removed from the model. This simulation served as a control and evaluated the thermal stress that would have been experienced by fishes in the absence of the water release. The surface guild never experienced temperatures exceeding their CTMax (showing as y = 0 h that overlays with x-axis).

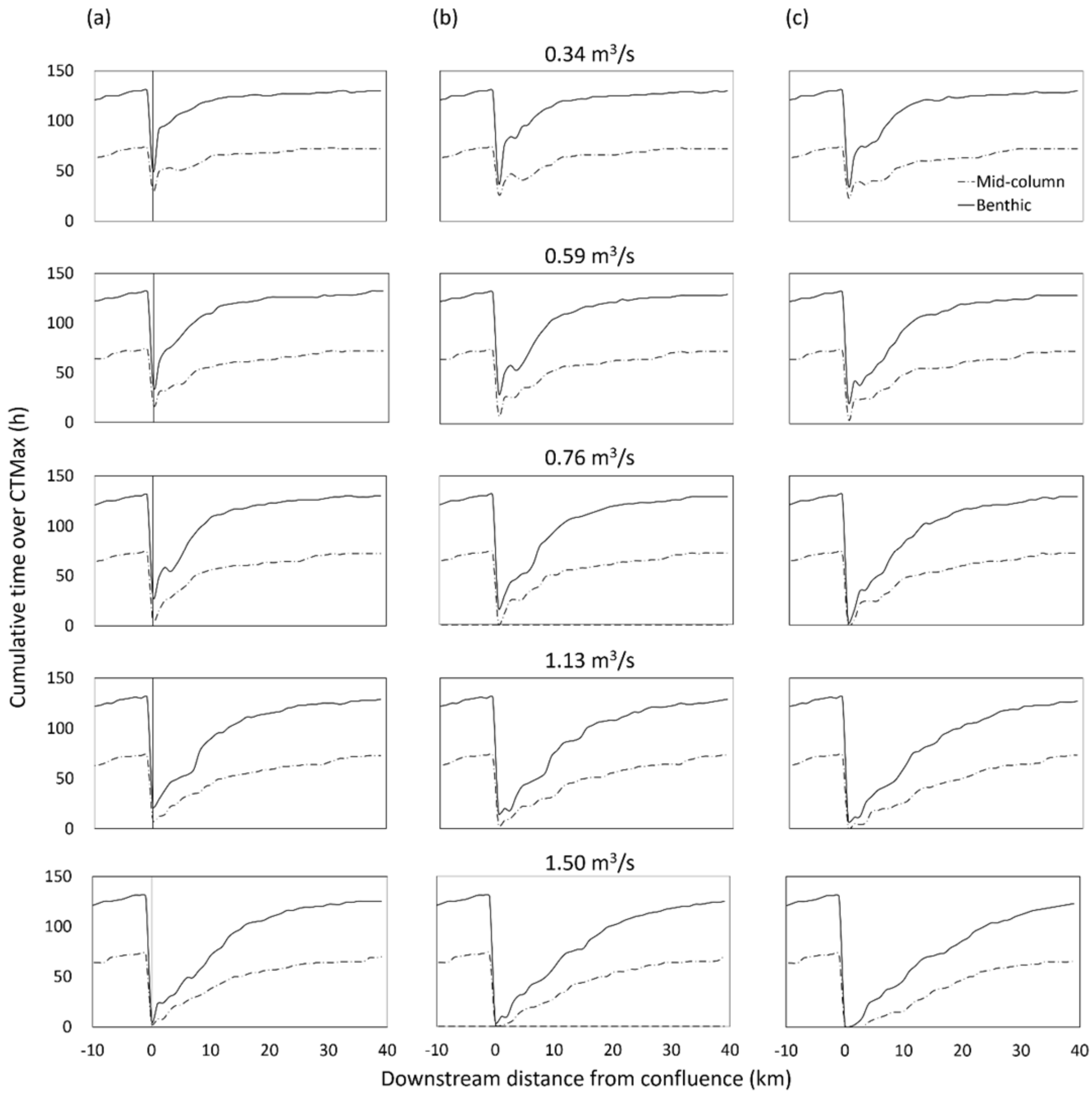


**Figure 14.** The cumulative time above critical thermal maxima (CTMax) for two fish-habitat guilds: mid-column and benthic guilds. The cumulative time about CTMax is shown 10-km upstream of the Jack Fork Creek and Kiamichi River confluence (indicated as 0 on the X axis). Each water-release scenario (second Y axis) is simulated showing the cumulative time above CTMax from the confluence downriver for 40 km. Each water-release scenario was simulated using three different upstream thermal boundary conditions (i.e., water temperature from the dam) that reflect the gate locations where releases could occur from the dam (5, 10 and 20 m), represented by a, b and c, respectively. The temperatures of simulated water releases at each gate location were: 27.64 °C, 26.00 °C and 24.07 °C, respectively.

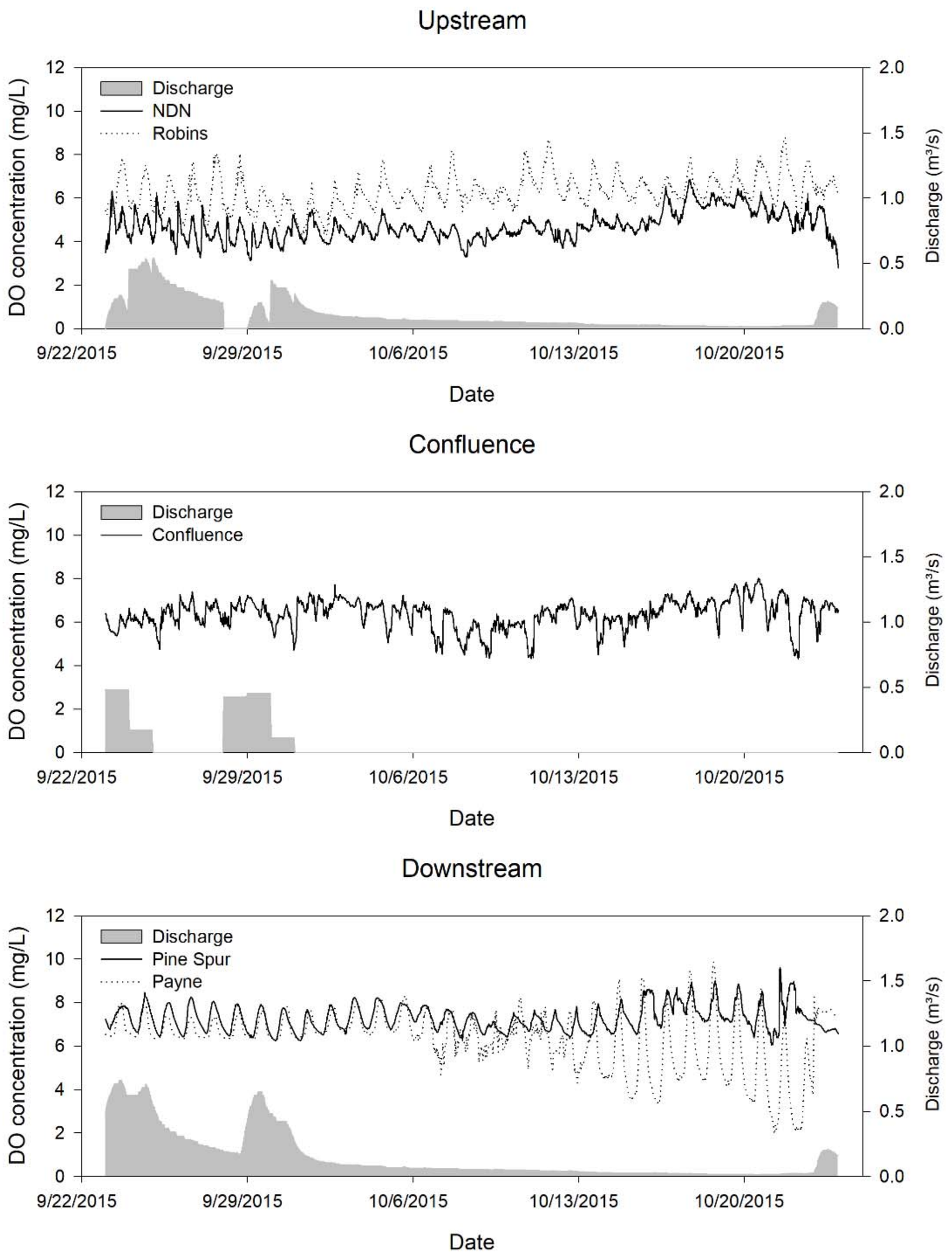


**Figure 15.** Monitored dissolved oxygen (DO) concentrations at sites upstream of the confluence (Kiamichi River and Jack Fork Creek), at the confluence, and downstream of the confluence. Data were collected during summer 2015 representing DO conditions during a baseflow period with minimal water released from Sardis Dam.

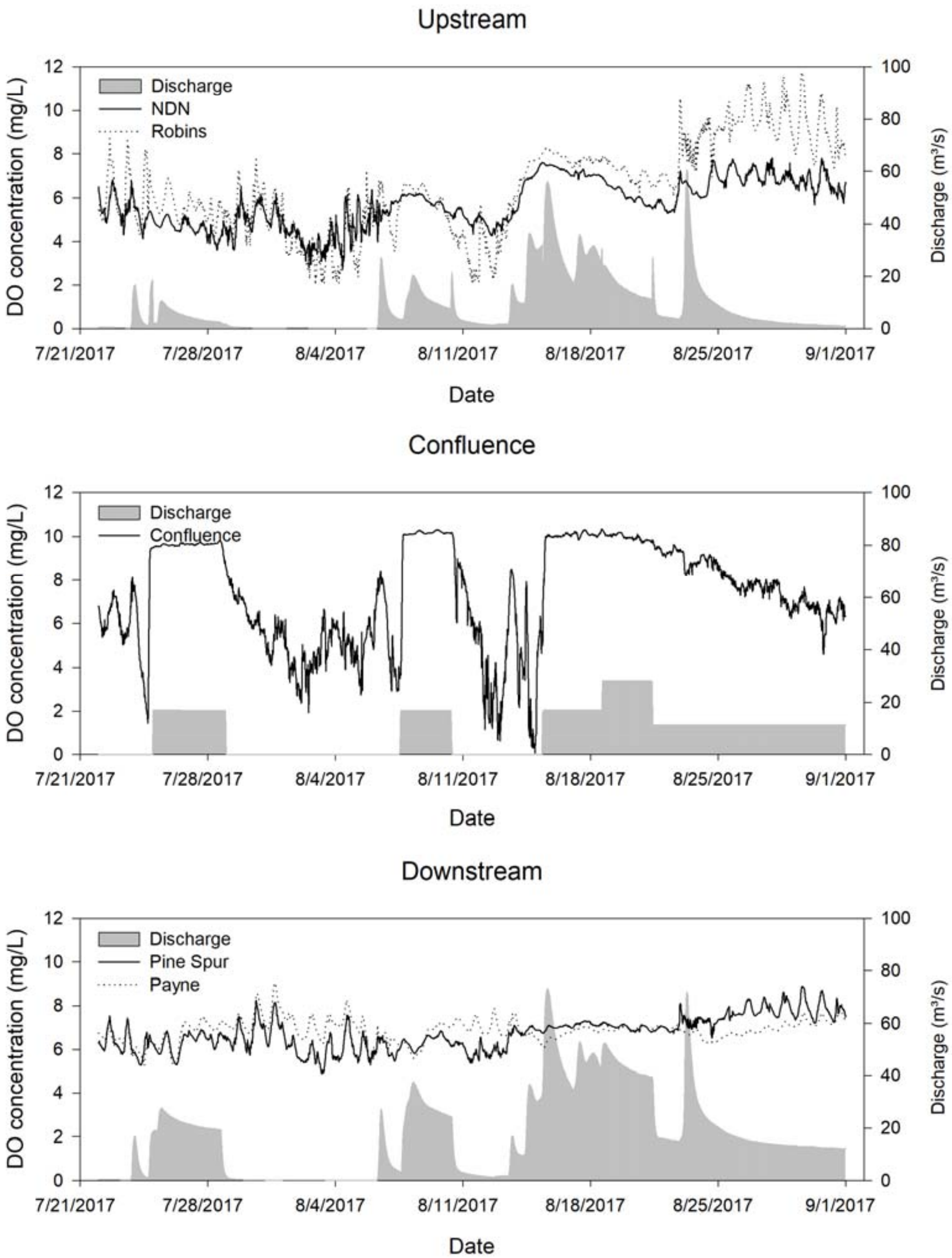


**Figure 16.** Monitored dissolved oxygen (DO) concentrations at sites upstream of the confluence (Kiamichi River and Jack Fork Creek), at the confluence, and downstream of the confluence. Data were collected during summer 2017 representing DO conditions during a higher flow period with considerable released water from Sardis Dam.

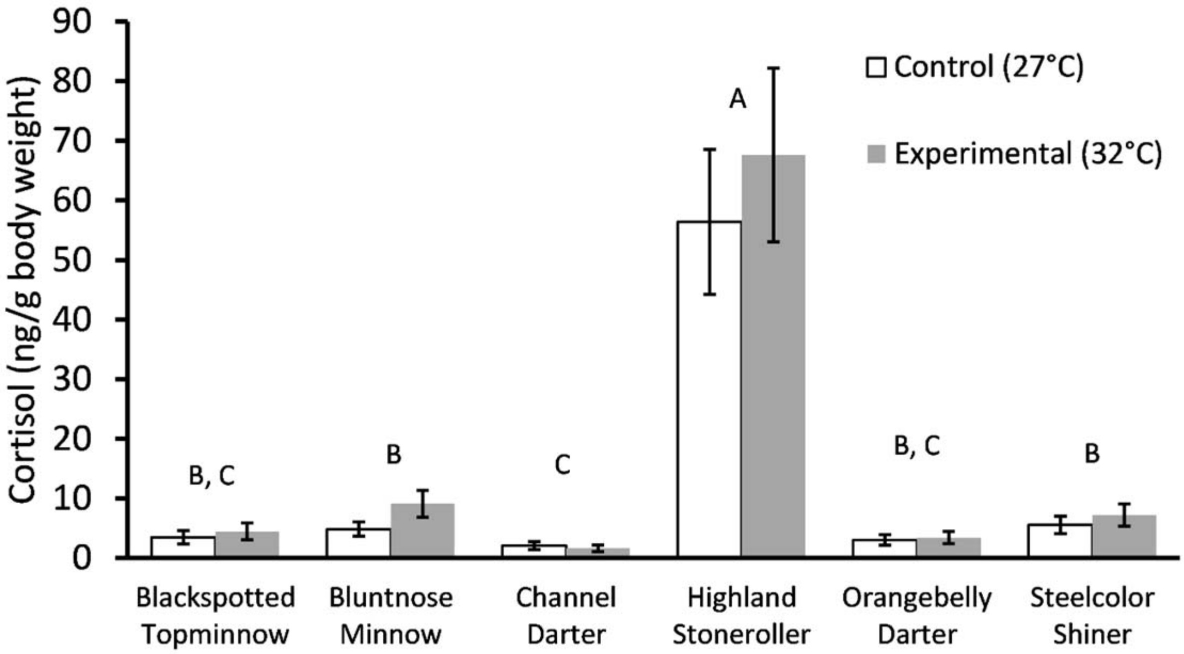


**Figure 17.** Average (± standard error) whole-body cortisol concentrations from chronic thermal stress trials on six stream fishes: Blackspotted Topminnow *Fundulus olivaceus*, Bluntnose Minnow *Pimephales notatus*, Channel Darter *Percina copelandi*, Highland Stoneroller *Campostoma spadiceum*, Orangebelly Darter *Etheostoma radiosum*, and Steelcolor Shiner *Cyprinella whipplei*. Experimental fishes were collected from the Kiamichi River in autumn 2016 and spring 2017. Fish were acclimated to laboratory conditions of 20.0°C and exposed to a 1.0°C/d increase in temperature until reaching the treatment temperatures (i.e., 27.0°C control; 32.0°C experimental). Fish remained at treatment temperatures for 14 days but were provided a thermal refuge of 2.5°C each night during trials. Letters over each bar indicate species differences in whole-body cortisol concentration from the Tukey Kramer Honest Significant Difference post-hoc analysis.

**Table A1.** Published critical thermal maximum (CTMax), optimal temperature, or upper incipient lethal limit in fishes that occupy or are closely related to species in the Kiamichi River. Tests in the laboratory (L) or field (F) are reported and blanks indicate this information was not reported.

| Species | Life stage | Acclimation Temp (°C) | field or lab | CTMax | Optimal temp | Upper Incipient Lethal | Reference | |
|---|---|---|---|---|---|---|---|---|
| Creek chub | | 21-21.9 | | | | 31.8 | Carlander1973 | Brett 1944 cited in Carlander 1969 |
| Creek chub | | 22.8 | | | | 32.1 | Carlander1974 | Brett 1944 cited in Carlander 1969 |
| Creek chub | | 25-26 | | | | 32.6 | Carlander1975 | Brett 1944 cited in Carlander 1969 |
| Creek chub | adult | | | | | | | Brett 1944; Hart 1947, as cited in McMahon 1982 |
| Creek chub | adult | 5 | | | | 24.7 | Brown1974 | Hart 1947, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Creek chub | adult | 10 | | | | 27.3 | Brown1974 | Hart 1947, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Creek chub | adult | 15 | | | | 29.3 | Brown1974 | Hart 1947, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Creek chub | adult | 20 | | | | 30.3 | Brown1974 | Hart 1947, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Creek chub | adult | 25 | | | | 30.3 | Brown1974 | Hart 1947, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Creek chub | adult | 10 | | | | 27.5 | Brown1974 | Hart 1952, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Creek chub | adult | 15 | | | | 29 | Brown1974 | Hart 1952, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Creek chub | adult | 20 | | | | 30.5 | Brown1974 | Hart 1952, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Creek chub | adult | 25 | | | | 31.5 | Brown1974 | Hart 1952, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Creek chub | adult | 30 | | | | 31.5 | Brown1974 | Hart 1952, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Creek chub | adult | 7.2 | | | | 31.1 | Brown1974 | Trembley 1961, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Creek chub | nesting | | | | 26.7 | | Brown1974 | Hankinson 1919, as cite in Brown 1974, as cited in Wismer and Christie 1987 |
| Creek chub | Spawning | | | | 14 | | Brown1974 | Moshenko and Gee 1973, as citd in Brown 1974, as cited in Wismer and Christie 1987 |
| Creek chub | hatching | | | | | | | Clark 1943; Moshenko and Gee 1973; Copes 1978, as cited in McMahon 1982 |
| Creek chub | adult | 5 | | | | | | Hart 1947, as cited in NAS/NAE 1973 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Creek chub | adult | 10 | | | | | | Hart 1947, as cited in NAS/NAE 1973 |
| Creek chub | adult | 15 | | | | | | Hart 1947, as cited in NAS/NAE 1973 |
| Creek chub | adult | 20 | | | | | | Hart 1947, as cited in NAS/NAE 1973 |
| Creek chub | adult | 25 | | | | | | Hart 1947, as cited in NAS/NAE 1973 |
| Creek chub | adult | 10 | | | | | | Hart 1952, as cited in NAS/NAE 1973 |
| Creek chub | adult | 15 | | | | | | Hart 1952, as cited in NAS/NAE 1973 |
| Creek chub | adult | 20 | | | | | | Hart 1952, as cited in NAS/NAE 1973 |
| Creek chub | adult | 25 | | | | | | Hart 1952, as cited in NAS/NAE 1973 |
| Creek chub | adult | 30 | | | | | | Hart 1952, as cited in NAS/NAE 1973 |
| Creek chub | | | | | | | | McFarlane et al 1976, as cited in Wismer and Christie1987 |
| Creek chub | adult | | | | | | | Miller 1964; Moshenko and Gee 1973, as cited in McMahon 1982 |
| Creek chub | Spawning | | F | | 12.8 | | Scott&Crossman1973 | Scott and Crossman 1973, p508 |
| Creek chub | | 26 | | | | | | Smale and Rabeni 1995, as cited in Beitinger et al 2000 |
| Creek chub | | 5 | | | | 24.7 | Carlander1969 | Strawn 1958 cited in Carlander 1969 |
| Creek chub | | 10 | | | | 27 | Carlander1970 | Strawn 1958 cited in Carlander 1969 |
| Creek chub | | 17.1-17.5 | | | | 30.5 | Carlander1971 | Strawn 1958 cited in Carlander 1969 |
| Creek chub | | 15 | | | | | | Strawn 1958 cited in Carlander 1969 |
| Creek chub | | 25 | | | | | | Strawn 1958 cited in Carlander 1969 |
| Creek chub | hatching | | | | | | | Washburn 1945, as cited in McMahon 1982 |
| Johnny Darter | | | | | 20 | | floy84 | Floye et al 1984, as cited in Wismer and Christie 1987 |
| Johnny darter | | | F | | | | | Hankinson 1919 cited in Carlander 1997 |
| Johnny Darter | | 15 | | | | | | Ingersoll and Clauseen 1984, as cited in Beitinger et al. 2000 |
| Johnny Darter | | 15 | | | | | | Ingersoll and Clauseen 1984, as cited in Beitinger et al. 2000 |
| Johnny Darter | | 15 | L | 30.7 | | | Kowalski1978 | Kowalski et al. 1978 |
| Johnny Darter | | 15 | L | 31.4 | | | Kowalski1978 | Kowalski et al. 1978 |
| Johnny Darter | | 15 | | | | | | Kowalski et al. 1978, as cited in Beitinger et al. 2000 |
| Johnny darter | | | F | | | | | Lutterbie 1976 cited in Carlander 1997 |
| Johnny Darter | | 20 | | | | | | Lydy and Wissing 1988, as cited in Beitinger et al. 2000 |
| Johnny Darter | hatching | | F | | 24 | | Scott&Crossman1973 | Scott and Crossman 1973, p796 |
| Johnny Darter | | 26 | | | | | | Smale and Rabeni 1995, as cited in Beitinger et al 2000 |
| Johnny Darter | | 20-30 | | | | | | Smith and Fausch 1997, as cited in Beitinger et al. 2000 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Johnny darter | | | F | | | | Speare 1958 cited in Carlander 1997 |
| Johnny darter | | | F | | | | Speare 1965 cited in Carlander 1997 |
| Johnny darter | | | F | | | | Winn 1958 cited in Carlander 1997 |
| Sauger | | | | 7.2 | | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Sauger | | | | 21.1 | | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Sauger | | | | 20 | | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Sauger | | | | | | | Coutant 1977 cited in Carlander 1997 |
| Sauger | | | | | | | Dendy 1948 cited in Carlander 1997 |
| Sauger | | | | 19.2 | | Carlander1977 | Dendy 1948 cited in Coutant 1977 |
| Sauger | | | | 29 | | epa74 | EPA 1974, as cited in Wismer and Christie 1987 |
| Sauger | spawning | | | 10 | | epa74 | EPA 1974, as cited in Wismer and Christie 1987 |
| Sauger | incubation | | | 15 | | epa74 | EPA 1974, as cited in Wismer and Christie 1987 |
| Sauger | juvenile | 26 | 26 | | 31 | eps74 | EPA 1974, as cited in Wismer and Christie 1987 |
| Sauger | | | | 19 | | pea74 | EPA 1974, as cited in Wismer and Christie 1987 |
| Sauger | adult | | | 19.2 | | Hokanson et al 1977 | Feruson, 1958 as cited in Hokanson, K.E.F., 1977 |
| Sauger | | | | | | | Gammon 1973 cited in Coutant 1977 |
| Sauger | | | F | 28 | | y&g76 | Gammon 1973, as cited in Yoder and Gammon 1976 |
| Sauger | adult | | | 28 | | Hokanson et al 1977 | Gammon, 1971 as cited in Hokanson, K.E.F., 1977 |
| Sauger | | | | | | | Hokanson 1977 cited in Carlander 1997 |
| Sauger | | | | | | | Hokanson 1977 cited in Carlander 1997 |
| Sauger | | | | | | | Hokanson 1977 cited in Carlander 1997 |
| Sauger | | | F | | | | Hokanson 1977 cited in Carlander 1997 |
| Sauger | | | F | | | | Hokanson 1977 cited in Carlander 1997 |
| Sauger | | | | | | | Hokanson 1977 cited in Carlander 1997 |
| Sauger | juvenile | | L | | 20.9 | Hokanson et al 1977 | Hokanson et al 1977 |
| Sauger | spawning | | | 15 | | Hokanson et al 1977 | Hokanson et al 1977, as cited in Wismer and Christie 1987 |
| Sauger | incubation | | | 15 | | Hokanson et al 1977 | Hokanson et al 1977, as cited in Wismer and Christie 1987 |
| Sauger | spawning | | | | | | Hokanson et al 1977, as cited in Wismer and Christie 1987 |
| Sauger | | | F | | | | Medlin 1990 cited in Carlander 1997 |
| Sauger | | | F | | | | Nelson 1968 cited in Carlander 1997 |
| Sauger | | | | | | | Nelson 1968 cited in Carlander 1997 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Sauger | | | | | | | | Nelson 1968 cited in Carlander 1997 |
| Sauger | | | F | | | | | Priegel 1969 cited in Carlander 1997 |
| Sauger | | | | | 22.6 | | Jinks1981 | Smith and Koenst 1975, as cited in Jobling 1981, as cited in Wismer and Christie 1987 |
| Sauger | | | | | 21.3 | | Jinks1981 | Smith and Koenst 1975, as cited in Jobling 1981, as cited in Wismer and Christie 1987 |
| Sauger | juvenile | 10.1 | L | | | 26.36 | s&k75 | Smith and Koenst 1975, as cited in Wismer and Christie 1987 |
| Sauger | juvenile | 12 | L | | | 26.7 | s&k75 | Smith and Koenst 1975, as cited in Wismer and Christie 1987 |
| Sauger | juvenile | 13.9 | L | | | 28.4 | s&k75 | Smith and Koenst 1975, as cited in Wismer and Christie 1987 |
| Sauger | juvenile | 16 | L | | | 28.6 | s&k75 | Smith and Koenst 1975, as cited in Wismer and Christie 1987 |
| Sauger | juvenile | 18.3 | L | | | 28.7 | s&k75 | Smith and Koenst 1975, as cited in Wismer and Christie 1987 |
| Sauger | juvenile | 19.9 | L | | | 29.5 | s&k75 | Smith and Koenst 1975, as cited in Wismer and Christie 1987 |
| Sauger | juvenile | 22 | L | | | 29.9 | s&k75 | Smith and Koenst 1975, as cited in Wismer and Christie 1987 |
| Sauger | juvenile | 23.9 | L | | | 30.4 | s&k75 | Smith and Koenst 1975, as cited in Wismer and Christie 1987 |
| Sauger | juvenile | 25.8 | L | | | 30.4 | s&k75 | Smith and Koenst 1975, as cited in Wismer and Christie 1987 |
| Sauger | spawning | | | | 9 | | S&K75 | Smith and Koenst 1975, as cited in Wismer and Christie 1987 |
| Sauger | juvenile | | L | | | | | Smith and Koenst 1975, as cited in Wismer and Christie 1987 |
| Sauger | juvenile | 25.8 | | | | 30.4 | Hokanson et al 1977 | Smith, L.L., and Koenst, W.M., 1975 as cited in Hokanson, K.E.F., 1977 |
| Sauger | | | F | | 21 | | y&g76 | Yoder and Gammon 1976 |
| Sauger | | | F | | 11 | | y&g76 | Yoder and Gammon 1976 |
| Sauger | | | F | | | | | Eaton and Scheller 1996 |
| Sauger | spawning | | | | | | | Bell 1990 |
| Sauger | | | | | 25 | | | U.S. EPA 1976 |
| Sauger | Spawning | | | | 12 | | | U.S. EPA 1976 |
| Sauger | Embryo Survival | | | | 18 | | | U.S. EPA 1976 |
| Sauger | | | F | 31.2 | | | | 3 |
| Southern redbelly dace | | 26 | | | | | | Smale and Rabeni 1995, as cited in Beitinger et al 2000 |
| Spottail Shiner | adult | | | | 20 | | Crowder1981 | Crowder et al 1981 |
| Spottail Shiner | adult | | | | 18 | | Crowder1981 | Crowder et al 1981 |
| Spottail Shiner | spawning | | F | | 20 | | Carlander1969 | Cuinat 1960 cited in Carlander 1969 |
| Spottail Shiner | | 25 | L | | 28.5 | | Kellogg&Gift11983 | Kellogg and Gift 1983 |
| Spottail Shiner | young | 25 | L | | 29.9 | | Kellogg&Gift11983 | Kellogg and Gift 1983 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Spottail Shiner | young | 25 | L | 29 | Kellogg&Gift11983 | Kellogg and Gift 1983 |
| Spottail Shiner | 6-8 wk | 20 | L | | | Kellogg and Gift 1983 |
| Spottail Shiner | 6-8 wk | 22.5 | L | | | Kellogg and Gift 1983 |
| Spottail Shiner | 6-8 wk | 25 | L | | | Kellogg and Gift 1983 |
| Spottail Shiner | 6-8 wk | 27.3 | L | | | Kellogg and Gift 1983 |
| Spottail Shiner | 6-8 wk | 29.6 | L | | | Kellogg and Gift 1983 |
| Spottail Shiner | 6-8 wk | 32.2 | L | | | Kellogg and Gift 1983 |
| Spottail Shiner | 6-8 wk | 34.7 | L | | | Kellogg and Gift 1983 |
| Spottail Shiner | Young | 25 | L | | | Kellogg and Gift 1983 |
| Spottail Shiner | Spawning | none | F | 18 | Mansfield1984 | Mansfield 1984 |
| Spottail Shiner | | | | 14 | Spotila1979 | Meldrim and Gift, 1971 as cited in Spotila, J.R., et al., 1979 |
| Spottail Shiner | adult | | L | 9 | Reutter&Herdendorf1996 | Reutter and Herdendorf 1976 |
| Spottail Shiner | adult | 21.7 | L | 14.3 | Reutter&Herdendorf1996 | Reutter and Herdendorf 1976 |
| Spottail Shiner | adult | | | | | Reutter and Herdendorf, 1974 as cited in Spotila, J.R., et al., 1979 |
| Spottail Shiner | adult | | | | | Reutter and Herdendorf, 1974 as cited in Spotila, J.R., et al., 1979 |
| Spottail Shiner | | | | | | Reutter and Herdendorf, 1976 as cited in Spotila, J.R., et al., 1979 |
| Spottail Shiner | | | F | | | Trembley 1960 cited in Carlander 1969 |
| Spottail Shiner | young | | | 20.1 | Marcy1976 | Marcy 1976 |
| Spottail Shiner | | | | 13 | Brandt1980 | Brandt et al. 1980, as cited in Wismer an dChristie 1987 |
| Spottail Shiner | | | | 16 | Brandt1980 | Brandt et al. 1980, as cited in Wismer an dChristie 1987 |
| Spottail Shiner | | | | 20 | Brandt1980 | Brandt et al. 1980, as cited in Wismer an dChristie 1987 |
| Spottail Shiner | adult | 15 | L | 13.9 | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Spottail Shiner | hatching | | F | 20 | Brown1974 | CFR 1961, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Spottail Shiner | fry | | | | | Trembley 1960, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Spottail Shiner | | | F | | | Wells 1968, as cited in Brown 1974 |
| Spottail Shiner | | | F | | | Trembley 1960, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Spottail Shiner | | 7.2 | L | | | Trembley 1960, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Spottail Shiner | | 11.1 | L | | | Trembley 1960, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Spottail Shiner | YOY | 9 | | | | Ecological Analysts, Inc. 1978a., as cited in Jinks et al. 1981 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Spottail Shiner | YOY | 17 | | | | Ecological Analysts, Inc. 1978a., as cited in Jinks et al. 1981 |
| Spottail Shiner | YOY | 23-24 | | | | Ecological Analysts, Inc. 1978a., as cited in Jinks et al. 1981 |
| Spottail Shiner | YOY | 26 | | | | Ecological Analysts, Inc. 1978a., as cited in Jinks et al. 1981 |
| Spottail Shiner | | | | | | Prince and Mengel 1981, as cited in Wismer and Christie 9187 |
| Spottail Shiner | adult | winter | | 10.2 | Houston1982 | Reutter and herdendorf 1974, as cited in Houston 1982 |
| Spottail Shiner | adult | spring | | | | Reutter and herdendorf 1974, as cited in Houston 1982 |
| Spottail Shiner | spawning | | | | | Talmage 1978, as cited in Wismer and Christie 1987 |
| Spottail Shiner | adult | | | 20 | Talmage&Coutant1980 | Talmage and Coutant1980, as cited in Wismer and Christie 1987 |
| Stoneroller | | 7.5 | | | | Chagnon and Hlohowskyj 1989, as cited in Beitinger et al. 2000 |
| Stoneroller | | 23 | | | | Chagnon and Hlohowskyj 1989, as cited in Beitinger et al. 2000 |
| Stoneroller | | | | 29 | Carlander1977 | Cherry et al. 1975 cited in Coutant 1975 |
| Stoneroller | | 9 | L | 15.2 | Spotila1979 | Cherry et al., 1975 as cited in Spotila, J.R., et al., 1979 |
| Stoneroller | | 6 | L | 13.4 | Spotila1979 | Cherry et al., 1975 as cited in Spotila, J.R., et al., 1979 |
| Stoneroller | | 24 | L | 25.3 | Spotila1979 | Cherry et al., 1975 as cited in Spotila, J.R., et al., 1979 |
| Stoneroller | | 27 | L | 28.6 | Spotila1979 | Cherry et al., 1975 as cited in Spotila, J.R., et al., 1979 |
| Stoneroller | | 21 | L | 23.6 | Spotila1979 | Cherry et al., 1975 as cited in Spotila, J.R., et al., 1979 |
| Stoneroller | | 12 | L | 20.7 | Spotila1979 | Cherry et al., 1975 as cited in Spotila, J.R., et al., 1979 |
| Stoneroller | | 15 | L | 21.7 | Spotila1979 | Cherry et al., 1975 as cited in Spotila, J.R., et al., 1979 |
| Stoneroller | | 18 | L | 22.3 | Spotila1979 | Cherry et al., 1975 as cited in Spotila, J.R., et al., 1979 |
| Stoneroller | | 12 | L | 16.5 | Cherry1977 | Cherry et al., 1977 |
| Stoneroller | | 18 | L | 21 | Cherry1977 | Cherry et al., 1977 |
| Stoneroller | | 21 | L | 22.4 | Cherry1977 | Cherry et al., 1977 |
| Stoneroller | | 24 | L | 25.1 | Cherry1977 | Cherry et al., 1977 |
| Stoneroller | | 27 | L | 28.2 | Cherry1977 | Cherry et al., 1977 |
| Stoneroller | | 30 | L | 27.4 | Cherry1977 | Cherry et al., 1977 |
| Stoneroller | | 15 | L | | | Cherry et al., 1977 |
| Stoneroller | | 10 | | | | Lutterschmidt and Hutchison 1997a, as cited in Beitinger 2000 |
| Stoneroller | spawning | | | | | Miller 1964 cited in Carlander 1969 |
| Stoneroller | | 24 | F | | | Mundahl 1990, as cited in Beitinger et al. 2000 |
| Stoneroller | | 26 | | | | Smale and Rabeni 1995, as cited in Beitinger et al al 2000 |
| Stoneroller | spawning | | | | | Smith 1935 cited in Carlander 1969 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Stoneroller | | | | 26.8 | | Carlander1977 | Stauffer et al. 1975 cited in Coutant 1977 |
| Stoneroller | | | | | | | Stauffer et al. 1975 cited in Coutant 1977 |
| Stoneroller | | | | 27 | | Spotila1979 | Stauffer et al., 1974 as cited in Spotila, J.R., et al., 1979 |
| Stoneroller | Spawning | | | 21 | | Carlander69\ | Carlander69\ |
| Stoneroller | hatching | | | 24.3 | | Carlanderm83 | Carmichael 1983, as cited in Wismer and Christie 1987 |
| Stoneroller | hatching | | | 17.7 | | Carlanderm83 | Carmichael 1983, as cited in Wismer and Christie 1987 |
| Stoneroller | hatching | | | 13.9 | | Carlanderm83 | Carmichael 1983, as cited in Wismer and Christie 1987 |
| Stoneroller | Spawning | | | 24.3 | | Carlanderm83 | Carlanderm83 |
| Stoneroller | Spawning | | | 17.7 | | Carlanderm83 | Carlanderm83 |
| Stoneroller | Spawning | | | 13.9 | | Carlanderm83 | Carlanderm83 |
| Stoneroller | | | | 28.5 | | H82 | Opuszynski 1971, as cited in Houston 1982 |
| Stoneroller | | | | 26.2 | | H82 | Cherry et al. 1977, as cited in Houston 1982 |
| White Crappie | | | F | | | | Al-Rawi 1971 cited in Carlander 1977 |
| White Crappie | | | F | | | | Agersborg 1930, as cited in Brown 1974 |
| White Crappie | | | F | | | | Proffitt and Benda 1971, as cited in Brown 1974 |
| White Crappie | | | | | | | Bell 1990 |
| White crappie | adult | | | | | | Biesinger, personal communication, as cited by Edwards et al. 1982 |
| White crappie | juvenile | 29 | | | | | Brungs and Jones 1977, as cited in Edwards et al. 1982 |
| White crappie | juvenile | 27 | | | | | Brungs and Jones 1977, as cited in Edwards et al. 1982 |
| White crappie | juvenile | | | | | | Brungs and Jones 1977, as cited in Edwards et al. 1982 |
| White Crappie | | | F | | | | Eaton and Scheller 1996 |
| White Crappie | juvenile | | L | | 33 | EPA74 | Kleiner and Hikanson 1973, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| White Crappie | Spawning | | | 20 | | EPA74 | EPA 1974, as cited in Wismer and Christie 1987 |
| White Crappie | Spawning | | | 20 | | EPA74 | EPA 1974, as cited in Wismer and Christie 1987 |
| White Crappie | | | | | | | Gammon 1973 cited in Coutant 1977 |
| White Crappie | | | | | | | Gammon 1973, as cited in Yoder and Gammon 1976 |
| White Crappie | nesting | | F | | | | Hansen 1957 cited in Carlander 1977 |
| White Crappie | hatching | | | | | | Morgan 1954, as cited in Brown 1974 |
| White Crappie | | | F | 23 | | o'b | o'b |
| White Crappie | Spawning | | F | 16 | | o'b84 | o'b84 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| White Crappie | | | F | | 24 | | o'b | O'Brien et al. 1984 |
| White Crappie | Adult | | | | 19.8 | | Carlander1977 | Reutter and Herdendorf 1974 cited in Coutant 1977 |
| White Crappie | Adult | | | | 18.3 | | Carlander1977 | Reutter and Herdendorf 1974 cited in Coutant 1977 |
| White Crappie | Adult | | | | 10.4 | | Carlander1977 | Reutter and Herdendorf 1974 cited in Coutant 1977 |
| White Crappie | Adult | | L | 32.8 | 19.4 | | Reutter&Herdendorf76 | Reutter and Herdendorf 1976 |
| White Crappie | Adult | | L | | | | Reutter&Herdendorf76 | Reutter and Herdendorf 1976 |
| White Crappie | Adult | | L | | | | | Reutter and Herdendorf 1976 |
| White Crappie | Adult | | L | | | | | Reutter and Herdendorf 1976 |
| White Crappie | Spawning | | F | | | | | Siefert 1968 cited in Carlander 1977 |
| White Crappie | hatching | | | | | | | Siefert 1968 cited in Carlander 1977 |
| White crappie | embryo | | | | | | | Siefert 1968, as cited in Edwards et al. 1982 |
| White Crappie | hatching | | | | | | | Swingle 1952 cited in Carlander 1977 |
| White Crappie | | | | | 28 | | | U.S. EPA 1976 |
| White Crappie | Spawning | | | | 18 | | | U.S. EPA 1976 |
| White Crappie | Embryo Survival | | | | 23 | | | U.S. EPA 1976 |
| White Crappie | | | F | | | | | Witt 1952 cited in Carlander 1977 |
| White Crappie | | | F | | | | | Walburg 1969, as cited in Brown 1974 |
| White Crappie | | summer | F | | | | | Yoder and Gammon 1976 |
| White Crappie | | fall | F | | | | | Yoder and Gammon 1976 |
| White Crappie | | winter | F | | | | | Yoder and Gammon 1976 |
| White Crappie | | | | | | | | 2 |
| White Crappie | | | F | 32.3 | | | | 3 |
| White Crappie | | | F | | | | | Marcy 1976 |
| White sucker | | | | | | | | 2 |
| White Sucker | | | F | 28 | 27.8 | | | 3 |
| White sucker | 1&2 yr | | L | | | | | Adelman 1980, as cited in Wismer and Christie 1987 |
| White sucker | Juvenile | 5 | | | | 26 | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| White sucker | Juvenile | 10 | | | | 28 | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| White sucker | Juvenile | 15 | | | | 29 | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| White sucker | Juvenile | 20 | | | | 29 | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| White sucker | Juvenile | 25-26 | | | | 31 | Brown1974 | Brett 1944, as cited in Brown 1974, as cited in |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | | Wismer and Christie 1987 |
| White sucker | 1-2yr | 5 | | | 26.3 | Brown1974 | Hart 1947, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| White sucker | 1-2yr | 10 | | | 27.7 | Brown1974 | Hart 1947, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| White sucker | 1-2yr | 15 | | | 29.3 | Brown1974 | Hart 1947, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| White sucker | 1-2yr | 20 | | | 29.3 | Brown1974 | Hart 1947, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| White sucker | 1-2yr | 25 | | | 28.3 | Brown1974 | Hart 1947, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| White sucker | juvenile | | | | 31.4 | Brown1974 | Huntsman 1946, as cited in Brown 1974 |
| White sucker | juvenile | | | | 33.3 | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| White sucker | juvenile | 32.2 | | | 35 | Brown1974 | Trembley 1961, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| White sucker | juvenile | 7.2 | | | 30 | Brown1974 | Trembley 1961, as cited in Brown1974 |
| White sucker | juvenile | 11.1 | | | 31 | Brown1974 | Trembley 1961, as cited in Brown1974 |
| White sucker | | | | 18.3 | | Brown1974 | Cooper and Fuller 1945, as cited in Brown 1974 |
| White sucker | | | F | | | | Hile and Juday 1941, as cited in Brown 1974 |
| White sucker | | | F | 23.9 | | Brown1974 | Trembley 1960, as cited in Brown 1974 |
| White sucker | spawning | | F | | | | Trautman 1957, as cited in Brown 1974 |
| White sucker | spawning | | | | | | Trautman 1957, as cited in Brown 1974 |
| White sucker | spawning | | | | | | Webster 1941, as cited in Brown 1974 |
| White sucker | larve | | | | | | McCormick et al. 1972, as cited in Brown 1974 |
| White sucker | fry | 21 | F | | | | Trembley 1960, as cited in Brown 1974 |
| White sucker | juveniles | | L | | | | Huntsman 1946, as cited in Brown 1974 |
| White sucker | adult | | F | | | | Horak and Tanner 1964, as cited in Brown 1974 |
| White sucker | | | F | 18.3 | | Coutant1977 | Cooper and Fuller 1945, as cited in Coutant 1977 |
| White sucker | spawning | | | | | | Corbett and Powels 1983, as cited in Wismer and Christie 1987 |
| White sucker | larval devel | | | | | | Corbett and Powels 1983, as cited in Wismer and Christie 1987 |
| White sucker | spawning | | | 16.8 | | Corbett&Powles1983 | Corbett and Powles 1983 |
| White sucker | larval | | | | | | Corbett and Powles 1983, as cited in Wismer and Christie 1987 |
| White sucker | larvae | | | | 30.2 | Crippen&Fahmy1981 | Crippen and Fahmy 1981 |
| White Sucker | | | F | | | | Eaton and Scheller 1996 |
| White sucker | larvae | 15 | | | 31 | EPA1974 | EPA 1974, as cited in Wismer and Christie 1987 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| White sucker | Juvenile | 15 | | | 29 | EPA1974 | EPA 1974, as cited in Wismer and Christie 1987 |
| White sucker | larvae | 21 | | | 30 | EPA1974 | EPA 1974, as cited in Wismer and Christie 1987 |
| White sucker | spawning | | | 10 | | EPA1974 | EPA 1974, as cited in Wismer and Christie 1987 |
| White sucker | hatch | | | 15 | | EPA1974 | EPA 1974, as cited in Wismer and Christie 1987 |
| White sucker | | | | 24 | | EPA1978 | EPA 1978a, as cited in Wismer and Christie 1987 |
| White sucker | juvenile | | L | | | | EPA 1978b, as cited in Wismer and Christie 1987 |
| White sucker | spawning | | | 11.16 | | Fuiman&Witman1979 | Fuiman 1979, as cited in Wismer and Christie 1987 |
| White sucker | adult (1-2yr) | 5 | | | | | Hart 1947, as cited in NAS/NAE 1973 |
| White sucker | adult (1-2yr) | 10 | | | | | Hart 1947, as cited in NAS/NAE 1973 |
| White sucker | adult (1-2yr) | 15 | | | | | Hart 1947, as cited in NAS/NAE 1973 |
| White sucker | adult (1-2yr) | 20 | | | | | Hart 1947, as cited in NAS/NAE 1973 |
| White sucker | adult (1-2yr) | 25 | | | | | Hart 1947, as cited in NAS/NAE 1973 |
| White sucker | | | | | | | Haymes 1984, as cited in Wismer and Christie 1987 |
| White sucker | | | F | 20.6 | | Coutant1977 | Hile and Juday 1941, as cited in Coutant 1977 |
| White sucker | large | | F | 21.1 | | Coutant1977 | Horak and Tanner 1964, as cited in Coutant 1977 |
| White sucker | larval development | | | 23.8 | | Marcy1976 | Marcy, B.C., 1976 |
| White sucker | spawning | | | 23.4 | | Marcy1976 | Marcy, B.C., 1976 |
| White sucker | | | L | 15.2 | | McCormick1977 | McCormick 1977 |
| White sucker | newly hatched | 21.1 | L | | 28.2 | McCormick1977 | McCormick et al 1977 |
| White sucker | swim-up | 21.1 | L | | 30.5 | McCormick1977 | McCormick et al 1977 |
| White sucker | swim-up | 15.8 | L | | 30.7 | McCormick1977 | McCormick et al 1977 |
| White sucker | swim-up | 10 | L | | 28.1 | McCormick1977 | McCormick et al 1977 |
| White sucker | newly hatched | 15.2 | L | | 30 | McCormick1977 | McCormick et al 1977 |
| White sucker | newly hatched | 8.9 | L | | 28.6 | McCormick1977 | McCormick et al 1977 |
| White sucker | newly hatched | 21.1 | L | | | | McCormick et al 1977 |
| White sucker | newly hatched | 21.1 | L | | | | McCormick et al 1977 |
| White sucker | newly hatched | 15.2 | L | | | | McCormick et al 1977 |
| White sucker | newly hatched | 15.2 | L | | | | McCormick et al 1977 |
| White sucker | newly hatched | 8.9 | L | | | | McCormick et al 1977 |
| White sucker | newly hatched | 8.9 | L | | | | McCormick et al 1977 |
| White sucker | newly hatched | 21.1 | L | | | | McCormick et al 1977 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| White sucker | newly hatched | 10 | L | | | | | McCormick et al 1977 |
| White sucker | larval | 9-10 | | | | 28.8 | Jinks1981 | McCormick et al. 1977 cited in Jinks et al. 1981 |
| White sucker | larval | 15-16 | | | | 31.1 | Jinks1981 | McCormick et al. 1977 cited in Jinks et al. 1981 |
| White sucker | newly hatched | 21 | | | | 31.7 | Jinks1981 | McCormick et al. 1977 cited in Jinks et al. 1981 |
| White sucker | | | F | | | | | Michaud 1981 |
| White sucker | | | | | | | | Michaud 1981, as cited in Wismer and Christie 1987 |
| White sucker | spawning | | | | 17.8 | | McCormick1977 | Raney 1943 cited in McCormick 1977 |
| White sucker | | 23 | | | 24.1 | | Reynolds&Casterlin1978 | Renyolds and Casterlin 1978 |
| White sucker | adult | | L | | 22.4 | | Coutant1977 | Reutter and Herdendorf 1974, as cited in Coutant 1977 |
| White sucker | adult | 19 | L | | | | Reutter&Herdendorf1976 | Reutter and Herdendorf 1976 |
| White sucker | spawning | | F | | | | | Scott and Crossman 1973, p540 |
| White sucker | hatching | | L | | | | | Scott and Crossman 1973, p540 |
| White sucker | | 26 | | | | | | Smale and Rabeni 1995, as cited in Beitinger et al 2000 |
| White sucker | | | | | 26.7 | | Reynolds&Casterlin1978 | Stauffer et al 1976, as cited in Reynolds and Casterlin 1978 |
| White sucker | | | | | 28 | | | U.S. EPA 1976 |
| White sucker | Spawning | | | | 10 | | | U.S. EPA 1976 |
| White sucker | Embryo Survival | | | | 20 | | | U.S. EPA 1976 |
| White sucker | adult | | | | 21 | | Wyman1981 | Wyman 1981, as cited in Wismer and Christie 1987 |
| White sucker | | | F | | 27 | | Yoder&Gammon1976 | Yoder and Gammon 1976 |
| White sucker | | | F | | 19 | | Yoder&Gammon1976 | Yoder and Gammon 1976 |
| White sucker | | | | | 14.4 | | Marcy1976 | |
| White sucker | juvenile | | | | | | Brown1974 | |
| Bigmouth shiner | | 26 | | | | | | Smale and Rabeni 1995, as cited in Beitinger et al 2000 |
| Bluegill | | | F | 36 | 31.7 | | | 3 |
| Bluegill | | | | 36 | 32.5 | | | 2* |
| Bluegill | | | | | | | | Anderson 1958 cited in Carlander 1977 |
| Bluegill | adult | | | | | | | Anderson 1959; Emig 1966, as cited in Stuber et al. 1982 |
| Bluegill | | 12.1 | | | | | | Banner and Van Arman 1973 cited in Carlander 1977 |
| Bluegill | | 19 | | | | | | Banner and Van Arman 1973 cited in Carlander 1977 |
| Bluegill | | 26 | | | | | | Banner and Van Arman 1973 cited in Carlander 1977 |
| Bluegill | | 32.9 | | | | | | Banner and Van Arman 1973 cited in Carlander 1977 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Bluegill | | 26 | | | | | | Banner and Van Arman 1973 cited in Carlander 1977 |
| Bluegill | | | | | | | | Banner and Van Arman 1973 cited in Carlander 1977 |
| Bluegill | embryo | | | | | | | Banner and Van Arman 1973, as cited in Stuber et al. 1982 |
| Bluegill | fry | | | | | | | Banner and Van Arman 1973, as cited in Stuber et al. 1982 |
| Bluegill | | | | | | 33.8 | Spotila1979 | Banner and Van Arman, 1973 as cited in Spotila, J.R., et al., 1979 |
| Bluegill | | | | | 23.9 | | Spotila1979 | Banner and Van Arman, 1973 as cited in Spotila, J.R., et al., 1979 |
| Bluegill | | | | | 31.2 | | Carlander1977 | Beitinger 1974 cited in Coutant 1977 |
| Bluegill | | | | | | | | Beitinger 1976, as cited in Wismer and Christie 1987 |
| Bluegill | | | | | | | | Beitinger and Magnuson, 1976 as cited in Spotila, J.R., et al., 1979 |
| Bluegill | | | | | | | | Beitinger, T.L., 1974 as cited in Spotila, J.R., et al., 1979 |
| Bluegill | | | | | | | | Bell 1990 |
| Bluegill | spawning | | | | | | | Bell 1990 |
| Bluegill | | 15 | | | | | | Brett, J.R., 1956 as cited in Spotila, J.R., et al., 1979 |
| Bluegill | | 20 | | | | | | Brett, J.R., 1956 as cited in Spotila, J.R., et al., 1979 |
| Bluegill | | 30 | | | | | | Brett, J.R., 1956 as cited in Spotila, J.R., et al., 1979 |
| Bluegill | adult | | | | | | | Brown 1974, as cited in Wismer and Christie 1987 |
| Bluegill | | | | | | | | Anderson 1959,as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Bluegill | | | | | | 33.8 | B77 | Brown 1974, as cited in Wismer and Christie 1987 |
| Bluegill | | | | 41.4 | | 38.3 | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Bluegill | | | | | 30 | | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Bluegill | | | F | | | | | Byrd 1951, as cited in Brown 1974 |
| Bluegill | spawning | | | | | | | Stevenson et al 1969, as cited in Brown 1974 |
| Bluegill | spawning | | | | | | | Clugston 1966, as cited in Brown 1974 |
| Bluegill | spawning | | | | | | | Breder 1936, as cited in Brown 1974 |
| Bluegill | | | | | | | | Speakmand and Krenkel 1972, as cited in Brown 1974 |
| Bluegill | | | | | | | | Proffitt and Benda 1971, as cited in Brown 1974 |
| Bluegill | | | | | | | | Buck and Thoits 1970 cited in Carlander 1977 |
| Bluegill | | | | | | | | Cairns 1956, as cited in Brown 1974 |
| Bluegill | | | | | | 35.5 | Carlander77 | Carlander77 |
| Bluegill | | | | | | 33 | Carlander77 | Carlander77 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Bluegill | | | | | | 33.8 | Carlander77 | Carlander77 |
| Bluegill | | | | | | 34 | Carlander77 | Carlander77 |
| Bluegill | | | | 41.5 | | | Carlander77 | Carlander77 |
| Bluegill | | | | | 18.7 | | Carlander77 | Carlander77 |
| Bluegill | | | | | 19.6 | | Carlander77 | Carlander77 |
| Bluegill | | 6 | | | | | | Cherry et al. 1975 cited in Carlander 1977 |
| Bluegill | | 30 | | | | | | Cherry et al. 1975 cited in Carlander 1977 |
| Bluegill | | | | | 32 | | Carlander1977 | Cherry et al. 1975 cited in Coutant 1975 |
| Bluegill | | 6 | | | | | | Cherry et al., 1975 as cited in Spotila, J.R., et al., 1979 |
| Bluegill | | 9 | | | | | | Cherry et al., 1975 as cited in Spotila, J.R., et al., 1979 |
| Bluegill | | 12 | | | | | | Cherry et al., 1975 as cited in Spotila, J.R., et al., 1979 |
| Bluegill | | 15 | | | | | | Cherry et al., 1975 as cited in Spotila, J.R., et al., 1979 |
| Bluegill | | 18 | | | | | | Cherry et al., 1975 as cited in Spotila, J.R., et al., 1979 |
| Bluegill | | 21 | | | | | | Cherry et al., 1975 as cited in Spotila, J.R., et al., 1979 |
| Bluegill | | 24 | | | | | | Cherry et al., 1975 as cited in Spotila, J.R., et al., 1979 |
| Bluegill | | 27 | | | | | | Cherry et al., 1975 as cited in Spotila, J.R., et al., 1979 |
| Bluegill | | 30 | | | | | | Cherry et al., 1975 as cited in Spotila, J.R., et al., 1979 |
| Bluegill | | | | | | 36 | Cherry1977 | Cherry et al., 1977 |
| Bluegill | | | | | | | | Childers 1967 cited in Carlander 1977 |
| Bluegill | | | | | | | | Clugston 1966 cited in Carlander 1977 |
| Bluegill | | 26 | | | | | | Cox 1974, as cited in Beitinger et al. 2000 |
| Bluegill | | 26 | | | | | | Cox 1974, as cited in Beitinger et al. 2000 |
| Bluegill | | 26 | | | | | | Cox 1974, as cited in Beitinger et al. 2000 |
| Bluegill | | | | | | | | Cravens 1981, as cite in Wismer and Christie 1987 |
| Bluegill | | | | | | 28.5 | Spotila1979 | Cvancara et al., 1976 as cited in Spotila, J.R., et al., 1979 |
| Bluegill | | | | | | | | Durham 1957 cited in Carlander 1977 |
| Bluegill | | | F | | | | | Eaton and Scheller 1996 |
| Bluegill | adult | 15 | | | | 31 | EPA74 | EPA 1974, as cited in Wismer and Christie 1987 |
| Bluegill | juvenile | 12 | | | | 27 | EPA74 | EPA 1974, as cited in Wismer and Christie 1987 |
| Bluegill | adult | 20 | | | | | | EPA 1974, as cited in Wismer and Christie 1987 |
| Bluegill | adult | 25 | | | | 33 | EPA74 | EPA 1974, as cited in Wismer and Christie 1987 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Bluegill | juvenile | 26 | | | | 36 | EPA74 | EPA 1974, as cited in Wismer and Christie 1987 |
| Bluegill | adult | 30 | | | | 34 | EPA74 | EPA 1974, as cited in Wismer and Christie 1987 |
| Bluegill | juvenile | 33 | | | | 37 | EPA74 | EPA 1974, as cited in Wismer and Christie 1987 |
| Bluegill | Spawning | | | | 25 | | EPA74 | EPA 1974, as cited in Wismer and Christie 1987 |
| Bluegill | hatching | | | | 24 | | EPA74 | EPA 1974, as cited in Wismer and Christie 1987 |
| Bluegill | | | | | 32.3 | | Carlander1977 | Fry and Pearson 1952 / Ferguson 1958, as cited in Brown 1974 and Coutant 1977 |
| Bluegill | | | | | | | | Ferguson, R.G., 1958 as cited in Spotila, J.R., et al., 1979 |
| Bluegill | | 21.5 | | | | | | Hallam 1959 cited in Carlander 1977 |
| Bluegill | fry | | | | | | | Hardin and Bovee 1978, as cited in Stuber et al. 1982 |
| Bluegill | adult | 15 | NR | | | | | Hart 1952, as cited in NAS/NAE 1973 |
| Bluegill | | 20 | NR | | | | | Hart 1952, as cited in NAS/NAE 1973 |
| Bluegill | | 25 | NR | | | | | Hart 1952, as cited in NAS/NAE 1973 |
| Bluegill | | | | 37.3 | | | B&M79 | Hart, 1952; Cairns, 1956; Speakman and Krenkel, 1971; and Banner Van Arman, 1973 as cited in Beitinger and Magnuson, 1979 |
| Bluegill | 1-2 yr | 22-23 | | | | | | Hathaway 1927, as cited in Brown 1974 |
| Bluegill | | 10 | | | | | | Hathaway 1928 cited in Carlander 1977 |
| Bluegill | | 30 | | | | | | Hathaway 1928 cited in Carlander 1977 |
| Bluegill | | 21.5 | | | | | | Hickman and Dewey 1973, as cited in Brown 1974 |
| Bluegill | | 25 | | | | | | Holland et al. 1974, as cited in Beitinger et al. 2000 |
| Bluegill | | 30 | | | | | | Holland et al. 1974, as cited in Beitinger et al. 2000 |
| Bluegill | | 35 | | | | | | Holland et al. 1974, as cited in Beitinger et al. 2000 |
| Bluegill | | 35 | | 43.4 | | | Spotila1979 | Holland et al., 1974 as cited in Spotila, J.R., et al., 1979 |
| Bluegill | | 25 | | 37.8 | | | Spotila1979 | Holland et al., 1974 as cited in Spotila, J.R., et al., 1979 |
| Bluegill | | 30 | | 40 | | | Spotila1979 | Holland et al., 1974 as cited in Spotila, J.R., et al., 1979 |
| Bluegill | | | | | | | | Kitchell et al. 1974 cited in Carlander 1977 |
| Bluegill | | | | | | | | Kitchell et al. 1974 cited in Carlander 1977 |
| Bluegill | Juvenile | | | | | | | Lemke 1977, as cited in Stuber et al. 1982 |
| Bluegill | | 10 | | | | | | Lutterschmidt and Hutchison 1997a, as cited in Beitinger 2000 |
| Bluegill | juvenile | | | | | | | McCauley and Casselman 1980, as cited in Wismer and Christie 1987 |
| Bluegill | subadult | | | | | | | McCauley and Casselman 1980, as cited in Wismer and Christie 1987 |
| Bluegill | | | | | | | | McCauley and Casselman 1980, as cited in Wismer and Christie 1987 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Bluegill | Adult | 26 | | | 31 | | CRAV82 | Medvick, P.A., et al., 1981 as cited in Cravens 1982 |
| Bluegill | | 16 | F | 31.5 | | | MUR76 | Murphy et al. 1976 |
| Bluegill | | 24 | F | 37.5 | | | MUR76 | Murphy et al. 1976 |
| Bluegill | | 32 | F | 41.4 | | | MUR76 | Murphy et al. 1976 |
| Bluegill | | 16 | F | | | | | Murphy et al. 1976 |
| Bluegill | | 24 | F | | | | | Murphy et al. 1976 |
| Bluegill | | 32 | F | | | | | Murphy et al. 1976 |
| Bluegill | | | | | 31.3 | | Carlander1977 | Neill 1971 cited in Coutant 1977 |
| Bluegill | | | | | 31.2 | | Carlander1977 | Neill 1971 cited in Coutant 1977 |
| Bluegill | | | | | 29 | | Carlander1977 | Neill 1971 cited in Coutant 1977 |
| Bluegill | | | | | 32.6 | | Carlander1977 | Neill 1971 cited in Coutant 1977 |
| Bluegill | | | | | 29 | | Carlander1977 | Neill 1971 cited in Coutant 1977 |
| Bluegill | | | | | 30.2 | | Carlander1977 | Neill 1971 cited in Coutant 1977 |
| Bluegill | | | | | 31.5 | | Carlander1977 | Neill 1971 cited in Coutant 1977 |
| Bluegill | | 29 | | | | | | Neill and Magnuson 1974 cited in Carlander 1977 |
| Bluegill | | 33 | | | | | | Neill and Magnuson 1974 cited in Carlander 1977 |
| Bluegill | young | | | | | | | Neill and Magnuson 1974, as cited in Brown 1974 |
| Bluegill | | | | | 30.7 | | P&S76 | P&S76 |
| Bluegill | | | | | 24.6 | | P&S76 | P&S76 |
| Bluegill | | 27 | L | | | 35.8 | P&S76 | Peterson and Schutsky 1976 |
| Bluegill | | 13 | L | | | 29.3 | P&S76 | Peterson and Schutsky 1976 |
| Bluegill | | 1 | L | | | 23.3 | P&S76 | Peterson and Schutsky 1976 |
| Bluegill | | | | | 27.4 | | Carlander1977 | Reutter and Herdendorf 1974 cited in Coutant 1977 |
| Bluegill | | 22.8 | L | 38.3 | | | Reutter&Herdendorf76 | Reutter and Herdendorf 1976 |
| Bluegill | adult | | | | | | | Reutter and Herdendorf, 1974 as cited in Spotila, J.R., et al., 1979 |
| Bluegill | | | | | | | | Reutter and Herdendorf, 1976 as cited in Spotila, J.R., et al., 1979 |
| Bluegill | | | | | 32.3 | | Carlander1977 | Reynolds and Casterlin 1976 cited in Coutant 1977 |
| Bluegill | adult | | | | | | | Reynolds and Casterlin 1976, as cited in Stuber et al. 1982 |
| Bluegill | | | | | 30.5 | | Carlander1977 | Reynolds et al. 1976 cited in Coutant 1977 |
| Bluegill | | | | | | | | Salmon Research Trust of Ireland 1960 cited in Carlander 1977 |
| Bluegill | | 26 | | | | | | Smale and Rabeni 1995, as cited in Beitinger et al 2000 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Bluegill | | | | | | | Stevenson et al. 1969 cited in Carlander 1977 |
| Bluegill | | 15 | | | | | Strawn 1958 cited in Carlander 1977 |
| Bluegill | | 20 | | | | | Strawn 1958 cited in Carlander 1977 |
| Bluegill | | 30 | | | | | Strawn 1958 cited in Carlander 1977 |
| Bluegill | | | | | | | Stuntz and Magnuson 1976, as cited in Wismer and Christie 1987 |
| Bluegill | | | | | | | Swingle 1949 cited in Carlander 1977 |
| Bluegill | | | | | | | Swingle 1949 cited in Carlander 1977 |
| Bluegill | juvenile | 25 | | | 31.2 | Talmage&Coutant1978 | Talmage and Coutant 1978, as cited in Wismer and Christie 1987 |
| Bluegill | | | | | 31 | Talmage&Coutant1978 | Talmage and Coutant 1978, as cited in Wismer and Christie 1987 |
| Bluegill | | | | | 31.4 | Talmage&Coutant1978 | Talmage and Coutant 1978, as cited in Wismer and Christie 1987 |
| Bluegill | juvenile | 25 | | | | | Talmage and Coutant 1978, as cited in Wismer and Christie 1987 |
| Bluegill | | | | | | | Talmage and Coutant 1978, as cited in Wismer and Christie 1987 |
| Bluegill | juvenile | | | | | | Talmage and Coutant 1978, as cited in Wismer and Christie 1987 |
| Bluegill | | | | | | | Trembley 1960 cited in Carlander 1977 |
| Bluegill | | 24.4 | | | | | Trembley 1961, as cited in Brown 1974 |
| Bluegill | | | | 35 | 32 | | U.S. EPA 1976 |
| Bluegill | | | | | 25 | | U.S. EPA 1976 |
| Bluegill | | | | | 34 | | U.S. EPA 1976 |
| Bluegill | | summer | F | | | | Yoder and Gammon 1976 |
| Bluegill | | fall | F | | | | Yoder and Gammon 1976 |
| Bluegill | | winter | F | | | | Yoder and Gammon 1976 |
| Brassy minnow | Spawning | | F | | 12.8 | scott1973 | Scott and Crossman 1973, p416 |
| Channel Catfish | | | | 35 | 32.8 | | 2 |
| Channel catfish | fry | | | | | | Moss and Scott 1961; Allen and Strawn 1968, as cited in McMahon and Terrell 1982 |
| Channel Catfish | juvenile (44-57d) | 26 | | | | | Allen and Strawn 1968, as cited in NAS/NAE 1973 |
| Channel Catfish | juvenile (44-57d) | 30 | | | | | Allen and Strawn 1968, as cited in NAS/NAE 1973 |
| Channel Catfish | juvenile (44-57d) | 34 | | | | | Allen and Strawn 1968, as cited in NAS/NAE 1973 |
| Channel Catfish | juvenile (11.5 mo) | 25 | | | | | Allen and Strawn 1968, as cited in NAS/NAE 1973 |
| Channel Catfish | juvenile (11.5 mo) | 30 | | | | | Allen and Strawn 1968, as cited in NAS/NAE 1973 |
| Channel Catfish | juvenile (11.5 mo) | 35 | | | | | Allen and Strawn 1968, as cited in NAS/NAE 1973 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Channel Catfish | | 26 | | | | Allen and Strawn, 1967 as cited in Spotila, J.R., et al., 1979 |
| Channel Catfish | | 30 | | | | Allen and Strawn, 1967 as cited in Spotila, J.R., et al., 1979 |
| Channel Catfish | | 34 | | | | Allen and Strawn, 1967 as cited in Spotila, J.R., et al., 1979 |
| Channel catfish | Juvenile | | | | | Andrews et al. 1972; Andrews and Stickney 1972, as cited in McMahon and Terrell 1982 |
| Channel Catfish | | | | | | Bell 1990 |
| Channel Catfish | spawning | | | | | Bell 1990 |
| Channel Catfish | hatching | | | | | Bell 1990 |
| Channel Catfish | | 10 | | | | Bennett et al. 1998, as cited in Beitinger et al. 2000 |
| Channel Catfish | | 20 | | | | Bennett et al. 1998, as cited in Beitinger et al. 2000 |
| Channel Catfish | | 30 | | | | Bennett et al. 1998, as cited in Beitinger et al. 2000 |
| Channel Catfish | | 35 | | | | Bennett et al. 1998, as cited in Beitinger et al. 2000 |
| Channel catfish | embryo | | | | | Brown 1942; Clemens and Sneed 1957, as cited in McMahon and Terrell 1982 |
| Channel catfish | juvenile | 26 | | 36.6 | Brown1974 | Allen and Strawn 1968, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Channel catfish | juvenile | 34 | | 37.8 | Brown1974 | Allen and Strawn 1968, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Channel catfish | juvenile | 30 | | 38 | Brown1974 | Allen and Strawn 1968, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Channel catfish | juvenile | 25 | | 35.5 | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Channel catfish | juvenile | 30 | | 37 | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Channel catfish | juvenile | 35 | | 38 | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Channel catfish | adult | 15 | | 30.4 | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Channel catfish | adult | 20 | | 32.8 | Brown1974 | Hart 1952, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Channel catfish | adult | 25 | | 33.5 | Brown1974 | Hart 1952, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Channel catfish | | 7.2 | | 32.8 | Brown1974 | Trembley 1961, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Channel catfish | | 11 | | 35 | Brown1974 | Trembley 1961, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Channel catfish | larvae | | | | | West 1966, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Channel catfish | fry | | | | | West 1966, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Channel catfish | fry | | 29 | | Brown1974 | West 1966, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Channel catfish | juvenile | | | | | Drew and Tilton 1970, as cited in Brown 1974 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Channel catfish | juvenile | | | | | | Tiemeir and Deyoe 1967, as cited in Brown 1974 |
| Channel catfish | juvenile | | | | | | Hokanson 1969, as cited in Brown 1974 |
| Channel catfish | juvenile | | | | | | Kilambri et al. 1970, as cited in Brown 1974 |
| Channel catfish | juvenile | | | | | | NTAC 1968, as cited in Brown 1974 |
| Channel catfish | fingerling | | | | | | Andrews et al. 1972, as cited in Brown 1974 |
| Channel catfish | Spawning | | | | 22 | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Channel catfish | spawning | | | | | | Katz 1954, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Channel catfish | spawning | | F | | | | McClellan 1954, as cited in Brown |
| Channel catfish | spawning | | | | | | Sneed and Hokanson 1969, as cited in Brown 1974 |
| Channel catfish | hatching | | | | | | Brown 1974, as cited in Wismer and Christie 1987 |
| Channel catfish | larvae | | | | | | Brown 1974, as cited in Wismer and Christie 1987 |
| Channel catfish | juvenile | | | | | | Brown 1974, as cited in Wismer and Christie 1987 |
| Channel Catfish | | 12 | | | 17 | Spotila1979 | Cheetham et al., 1976 as cited in Spotila, J.R., et al., 1979 |
| Channel Catfish | | 16 | | | 21 | Spotila1979 | Cheetham et al., 1976 as cited in Spotila, J.R., et al., 1979 |
| Channel Catfish | | 20 | | | 22 | Spotila1979 | Cheetham et al., 1976 as cited in Spotila, J.R., et al., 1979 |
| Channel Catfish | | 24 | | | 28 | Spotila1979 | Cheetham et al., 1976 as cited in Spotila, J.R., et al., 1979 |
| Channel Catfish | | 28 | | | 26 | Spotila1979 | Cheetham et al., 1976 as cited in Spotila, J.R., et al., 1979 |
| Channel Catfish | | 12 | | 34.5 | | Spotila1979 | Cheetham et al., 1976 as cited in Spotila, J.R., et al., 1979 |
| Channel Catfish | | 16 | | 34.2 | | Spotila1979 | Cheetham et al., 1976 as cited in Spotila, J.R., et al., 1979 |
| Channel Catfish | | 20 | | 35.5 | | Spotila1979 | Cheetham et al., 1976 as cited in Spotila, J.R., et al., 1979 |
| Channel Catfish | | 24 | | 37.7 | | Spotila1979 | Cheetham et al., 1976 as cited in Spotila, J.R., et al., 1979 |
| Channel Catfish | | 28 | | 39.2 | | Spotila1979 | Cheetham et al., 1976 as cited in Spotila, J.R., et al., 1979 |
| Channel Catfish | | 32 | | 41 | | Spotila1979 | Cheetham et al., 1976 as cited in Spotila, J.R., et al., 1979 |
| Channel Catfish | | 32 | | | 30 | Spotila1979 | Cheetham et al., 1976 as cited in Spotila, J.R., et al., 1979 |
| Channel Catfish | | 12 | | | | | Cheetham st al. 1976, as cited in Beitinger et al. 2000 |
| Channel Catfish | | 16 | | | | | Cheetham st al. 1976, as cited in Beitinger et al. 2000 |
| Channel Catfish | | 20 | | | | | Cheetham st al. 1976, as cited in Beitinger et al. 2000 |
| Channel Catfish | | 24 | | | | | Cheetham st al. 1976, as cited in Beitinger et al. 2000 |
| Channel Catfish | | 28 | | | | | Cheetham st al. 1976, as cited in Beitinger et al. 2000 |
| Channel Catfish | | 32 | | | | | Cheetham st al. 1976, as cited in Beitinger et al. 2000 |
| Channel Catfish | | | | | 30.5 | Carlander1977 | Cherry et al. 1975 cited in Coutant 1975 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Channel Catfish | | 30 | | 30.5 | | Spotila1979 | Cherry et al., 1975 as cited in Spotila, J.R., et al., 1979 |
| Channel Catfish | | 6 | | 18.9 | | Spotila1979 | Cherry et al., 1975 as cited in Spotila, J.R., et al., 1979 |
| Channel Catfish | | 9 | | 20.4 | | Spotila1979 | Cherry et al., 1975 as cited in Spotila, J.R., et al., 1979 |
| Channel Catfish | | 12 | | 19.9 | | Spotila1979 | Cherry et al., 1975 as cited in Spotila, J.R., et al., 1979 |
| Channel Catfish | | 15 | | 21.7 | | Spotila1979 | Cherry et al., 1975 as cited in Spotila, J.R., et al., 1979 |
| Channel Catfish | | 18 | | 22.9 | | Spotila1979 | Cherry et al., 1975 as cited in Spotila, J.R., et al., 1979 |
| Channel Catfish | | 21 | | 26.1 | | Spotila1979 | Cherry et al., 1975 as cited in Spotila, J.R., et al., 1979 |
| Channel Catfish | | 24 | | 29.4 | | Spotila1979 | Cherry et al., 1975 as cited in Spotila, J.R., et al., 1979 |
| Channel Catfish | | 27 | | 29.5 | | Spotila1979 | Cherry et al., 1975 as cited in Spotila, J.R., et al., 1979 |
| Channel Catfish | | | | | | | Cravens 1981, as cite in Wismer and Christie 1987 |
| Channel Catfish | | 20 | | | | | Currie et al. 1998, as cited in Beitinger et al. 2000 |
| Channel Catfish | | 25 | | | | | Currie et al. 1998, as cited in Beitinger et al. 2000 |
| Channel Catfish | | 30 | | | | | Currie et al. 1998, as cited in Beitinger et al. 2000 |
| Channel Catfish | | | F | | | | Eaton and Scheller 1996 |
| Channel Catfish | Spawning | | | 27 | | EPA74 | EPA 1974, as cited in Wismer and Christie 1987 |
| Channel Catfish | Spawning | | | | | | EPA 1974, as cited in Wismer and Christie 1987 |
| Channel Catfish | | | | | | | Gammon 1973 cited in Coutant 1977 |
| Channel Catfish | | | | | | | Gammon 1973, as cited in Yoder and Gammon 1976 |
| Channel Catfish | adult | 15 | | | | | Hart 1952, as cited in NAS/NAE 1973 |
| Channel Catfish | adult | 20 | | | | | Hart 1952, as cited in NAS/NAE 1973 |
| Channel Catfish | adult | 25 | | | | | Hart 1952, as cited in NAS/NAE 1973 |
| Channel Catfish | | | | | | | Leidy and Jenkins, as cited in Wismer and Christie 1987 |
| Channel Catfish | | 10 | | | | | Lutterschmidt and Hutchison 1997a, as cited in Beitinger 2000 |
| Channel Catfish | | | F | 15.2 | | Marcy1976 | Marcy 1976 |
| Channel Catfish | | | | | | | McClellan 1954 cited in Carlander 1969 |
| Channel Catfish | | | | | 35 | Carlander69\ | Moss and Scott 1961 cited in Carlander 1969 |
| Channel Catfish | | | | | | | Proffitt 1969 cited in Coutant 1977 |
| Channel Catfish | | | | 25.2 | | Carlander1977 | Reutter and Herdendorf 1974 cited in Coutant 1977 |
| Channel Catfish | | | | 25.3 | | Carlander1977 | Reutter and Herdendorf 1974 cited in Coutant 1977 |
| Channel Catfish | | 22.7 | L | | | | Reutter and Herdendorf 1976 |
| Channel Catfish | | | L | | | | Reutter and Herdendorf 1976 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Channel Catfish | adult | | | | | | | Reutter and Herdendorf, 1974 as cited in Spotila, J.R., et al., 1979 |
| Channel Catfish | adult | | | | | | | Reutter and Herdendorf, 1974 as cited in Spotila, J.R., et al., 1979 |
| Channel Catfish | | 22.7 | | 38 | | | Spotila1979 | Reutter and Herdendorf, 1976 as cited in Spotila, J.R., et al., 1979 |
| Channel catfish | adult | | | | | | | Schrable et al. 1969; Chen 1976, as cited in MacMahon and Terrell 1982 |
| Channel Catfish | Spawning | | F | | 26.7 | | Scott&Crossman1973 | Scott and Crossman 1973, p607 |
| Channel Catfish | hatching | | F | | | | | Scott and Crossman 1973, p607 |
| Channel Catfish | | | | | 32.5 | | Spotila1979 | Stauffer et al., 1974 as cited in Spotila, J.R., et al., 1979 |
| Channel Catfish | | | | | 32 | | Spotila1979 | Stauffer et al., 1974 as cited in Spotila, J.R., et al., 1979 |
| Channel Catfish | | 15 | | | | 30.3 | Carlander69\ | Strawn 1958 cited in Carlander 1969 |
| Channel Catfish | | 20 | | | | 32.8 | Carlander69\ | Strawn 1958 cited in Carlander 1969 |
| Channel Catfish | | 25 | | | | 33.5 | Carlander69\ | Strawn 1958 cited in Carlander 1969 |
| Channel Catfish | | 15 | | | | | | Strawn, K., 1958 as cited in Spotila, J.R., et al., 1979 |
| Channel Catfish | | 20 | | | | | | Strawn, K., 1958 as cited in Spotila, J.R., et al., 1979 |
| Channel Catfish | | 25 | | | | | | Strawn, K., 1958 as cited in Spotila, J.R., et al., 1979 |
| Channel Catfish | | | | 32 | 35 | | | U.S. EPA 1976 |
| Channel Catfish | | | | | 27 | | | U.S. EPA 1976 |
| Channel Catfish | | | | | 29 | | | U.S. EPA 1976 |
| Channel Catfish | | 20 | | | | | | Watenpaugh and Beitinger 1985, as cited in Beitinger et al. 2000 |
| Channel catfish | fry | | | | | | | West 1966, as cited in McMahon and Terrell 1982 |
| Channel Catfish | | summer | F | | 36 | | Y&G76 | Yoder and Gammon 1976 |
| Channel Catfish | | fall | F | | 32 | | Y&G76 | Yoder and Gammon 1976 |
| Channel Catfish | | winter | F | | 14 | | | Yoder and Gammon 1976 |
| Channel Catfish | | | F | 35 | 32.8 | | | |
| Channel Catfish | Spawning | | | | 23.9 | | Carlander69 | |
| Channel Catfish | | | | | | 36.1 | Jinks1981 | |
| Channel Catfish | | | | | | 36.4 | Jinks1981 | |
| Common shiner | | 25-26 | | | | | | Brett 1944 cited in Carlander 1969 |
| Common shiner | adult | 10 | L | | 29 | | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Common shiner | adult | 15 | L | | 30.5 | | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Common shiner | adult | 20 | L | | 31 | | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Common shiner | adult | 25 | L | | 31 | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Common shiner | adult | 25 | L | | 31 | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Common shiner | adult | 30 | L | 31 | 31 | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Common shiner | adult | 5 | | | 26.7 | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Common shiner | adult | 10 | | | 28.6 | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Common shiner | adult | 15 | | | 30.3 | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Common shiner | adult | 20 | | | 31 | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Common shiner | adult | 25 | | | 31 | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Common shiner | adult | 7.2 | | | 30.6 | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Common shiner | adult | 11.1 | | | 31.1 | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Common shiner | Spawning | | | | 25.5 | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Common shiner | Spawning | | | | 15.6 | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Common shiner | Spawning | | | | 21.1 | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Common shiner | Spawning | | | | 28 | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Common shiner | Spawning | | | | 18 | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Common shiner | adult | | | | 32 | Brown1974 | Carlander 1969, as cited in Wismer and Christie 1987 |
| Common shiner | inshore migration | | | | 15.5 | Dodson&Young1977 | Dodson and Young 1917, as cited in Wismer and Christie 1987 |
| Common shiner | Spawning | | | | 18 | Dodson&Young1977 | Dodson and Young 1917, as cited in Wismer and Christie 1987 |
| Common shiner | adult (mostly 2 yr) | 5 | | | | | Hart 1947, as cited in NAS/NAE 1973 |
| Common shiner | adult (mostly 2 yr) | 10 | | | | | Hart 1947, as cited in NAS/NAE 1973 |
| Common shiner | adult (mostly 2 yr) | 15 | | | | | Hart 1947, as cited in NAS/NAE 1973 |
| Common shiner | adult (mostly 2 yr) | 20 | | | | | Hart 1947, as cited in NAS/NAE 1973 |
| Common shiner | adult (mostly 2 yr) | 25 | | | | | Hart 1947, as cited in NAS/NAE 1973 |
| Common shiner | adult | 10 | | | | | Hart 1952, as cited in NAS/NAE 1973 |
| Common shiner | adult | 15 | | | | | Hart 1952, as cited in NAS/NAE 1973 |
| Common shiner | adult | 20 | | | | | Hart 1952, as cited in NAS/NAE 1973 |
| Common shiner | adult | 25 | | | | | Hart 1952, as cited in NAS/NAE 1973 |
| Common shiner | adult | 25 | | | | | Hart 1952, as cited in NAS/NAE 1973 |
| Common shiner | adult | 30 | | | | | Hart 1952, as cited in NAS/NAE 1973 |
| Common shiner | adult | 25 | | | | | Hart 1952, as cited in NAS/NAE 1980 |
| Common shiner | adult | 30 | | | | | Hart 1952, as cited in NAS/NAE 1980 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Common shiner | | 15 | L | 30.6 | | Kowalski1978 | Kowalski et al. 1978 |
| Common shiner | | 15 | L | 31.9 | | Kowalski1978 | Kowalski et al. 1978 |
| Common shiner | | 15 | | | | | Kowalski et al. 1978, as cited in Beitinger et al. 2000 |
| Common shiner | | 15 | | | | | Kowalski et al. 1978, as cited in Beitinger et al. 2000 |
| Common shiner | | | | | | | Miller 1964 cited in Carlander 1969 |
| Common shiner | | | | | 21 | Carlander1969 | Nurnberger 1931 cited in Carlander 1969 |
| Common shiner | | 15 | | | | | Schubauer et al 1980, as cited in Beitinger et al. 2000 |
| Common shiner | Spawning | | F | | 18.3 | Scott&Crossman73 | Scott and Crossman 1973, p450 |
| Common shiner | Spawning | | F | | 28.3 | Scott&Crossman73 | Scott and Crossman 1973, p450 |
| Common shiner | | 26 | | | | | Smale and Rabeni 1995, as cited in Beitinger et al 2000 |
| Common shiner | | 5 | | | 27 | Carlander1969 | Strawn 1958 cited in Carlander 1969 |
| Common shiner | | 10 | | | 29 | Carlander1969 | Strawn 1958 cited in Carlander 1969 |
| Common shiner | | 15 | | | 30.3 | Carlander1969 | Strawn 1958 cited in Carlander 1969 |
| Common shiner | | 20 | | | 32.3 | Carlander1969 | Strawn 1958 cited in Carlander 1969 |
| Common shiner | | 25 | | | 33.5 | Carlander1969 | Strawn 1958 cited in Carlander 1969 |
| Largemouth bass | | 8 | | | | | Fields et al. 1987, as cited in Beitinger et al. 2000 |
| Largemouth bass | | 16 | | | | | Fields et al. 1987, as cited in Beitinger et al. 2000 |
| Largemouth bass | | 24 | | | | | Fields et al. 1987, as cited in Beitinger et al. 2000 |
| Largemouth bass | | 32 | | | | | Fields et al. 1987, as cited in Beitinger et al. 2000 |
| Freshwater Drum | | | | 35.3 | | | 2 |
| Freshwater Drum | | | | | 26.1 | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Freshwater Drum | | | | | 22 | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Freshwater Drum | | | | | 31 | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Freshwater Drum | | | F | | | | Brown 1974, as cited in Wismer and Christie 1987 |
| Freshwater Drum | spawning | | | | 21 | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Freshwater Drum | spawning | | | | 23.9 | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Freshwater Drum | | | | | | | Brown 1974, as cited in Wismer and Christie 1987 |
| Freshwater Drum | hatching | | | | | | Brown 1974, as cited in Wismer and Christie 1987 |
| Freshwater Drum | larvae | | | | 28 | cada and her80 | Cada and Hergenrader 1980 |
| Freshwater Drum | | | | | 22.2 | Carlander1977 | Dendy 1948 cited in Coutant 1977 |
| Freshwater Drum | | | F | | | | Eaton and Scheller 1996 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Freshwater Drum | | | | | 21 | | epa74 | EPA 1974, as cited in Wismer and Christie 1987 |
| Freshwater Drum | incubation | | | | 22 | | | EPA 1974, as cited in Wismer and Christie 1987 |
| Freshwater Drum | | | | | | | | Gammon 1973 cited in Coutant 1977 |
| Freshwater Drum | | 29-35 | | | | 32.8 | Houston1982 | Cvancara et al. 1977, as cited in Houston 1982, as cited in Wismer and Christie 1987 |
| Freshwater Drum | | | | | 30.3 | | Carlander1977 | Neill 1971 cited in Coutant 1977 |
| Freshwater Drum | | | | | | | | Neill 1971 cited in Coutant 1977 |
| Freshwater Drum | young | | | | 31.3 | | Carlander1977 | Reutter and Herdendorf 1974 cited in Coutant 1977 |
| Freshwater Drum | Adult | | | | 26.5 | | Carlander1977 | Reutter and Herdendorf 1974 cited in Coutant 1977 |
| Freshwater Drum | Adult | | | | 19.6 | | Carlander1977 | Reutter and Herdendorf 1974 cited in Coutant 1977 |
| freshwater drum | Adult | 21.2 | L | | | | | Reutter and Herdendorf 1976 |
| freshwater drum | Adult | | | | | | | Reutter and Herdendorf 1976 |
| freshwater drum | YOY | | | | | | | Reutter and Herdendorf 1976 |
| Freshwater Drum | | | F | | 30 | | y&g76 | Yoder and Gammon 1976 |
| Freshwater Drum | | | F | | 11 | | y&g76 | Yoder and Gammon 1976 |
| Freshwater Drum | | | F | 32.6 | 32.5 | | 3 | 3 |
| Freshwater Drum | | | | | | 32.8 | Jinks1981 | |
| Gizzard Shad | | | | 35.3 | 32.3 | | | 2 |
| Gizzard shad | spawning | | F | | | | | Bodola 1966, as cited in Scott and Crossman 1973, p135 |
| Gizzard Shad | Underyearling | 25 | | | | 34.5 | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Gizzard Shad | Underyearling | 30 | | | | 36 | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Gizzard Shad | Underyearling | 35 | | | | 36.5 | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Gizzard Shad | Spawning | | | 31.7 | | | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Gizzard Shad | Spawning | | | 35.7 | | | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Gizzard Shad | | | | 37.5 | | | Brown 74 | Brown 1974, as cited in Wismer and Christie 1987 |
| Gizzard Shad | | | | | | | | Brown 1974, as cited in Wismer and Christie 1987 |
| Gizzard shad | adult | | | | | | | Clark 1969; Brungs and Jones 1977, as cited in Williamson and Nelson 1985 |
| Gizzard Shad | | | F | | | | | Eaton and Scheller 1996 |
| Gizzard Shad | | | | | | | | Ellis 1984, as cited in Wismer and Christie 1987 |
| Gizzard shad | adult | | | | | | | Gammon 1973, as cited in Williamson and Nelson 1985 |
| Gizzard shad | | summer | | | | | | Gammon 1973, as cited in Yoder and Gammon 1976 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Gizzard shad | underyearling | 25 | F | | | | | Hart 1952, as cited in NAS/NAE 1973 |
| Gizzard shad | underyearling | 30 | F | | | | | Hart 1952, as cited in NAS/NAE 1973 |
| Gizzard shad | underyearling | 35 | F | | | | | Hart 1952, as cited in NAS/NAE 1973 |
| Gizzard shad | underyearling | 25 | | | | | | Hart 1952, as cited in NAS/NAE 1973 |
| Gizzard shad | underyearling | 30 | | | | | | Hart 1952, as cited in NAS/NAE 1973 |
| Gizzard shad | underyearling | 35 | | | | | | Hart 1952, as cited in NAS/NAE 1973 |
| Gizzard shad | adult | | | | | | | Hart 1952;Strawn 1958, as cited in Williamson and Nelson 1985 |
| Gizzard shad | hatching | | L | | | | | Miller 1960,as cited in Scott and Crossman 1973, p135 |
| Gizzard shad | adult | | | | | | | Proffitt and Benda 1971, as cited in Williamson and Nelson 1985 |
| Gizzard Shad | Adult | 15.9 | | 31.7 | | | Reutter and Haerendorf 1976 | Reutter and Herdendorf 1976 |
| Gizzard Shad | Adult | | | | | | | Reutter and Herdendorf 1976 |
| Gizzard Shad | | | | | | | | Talmage and Coutant 1980, as cited in Wismer and Christie 1987 |
| Gizzard Shad | | | | | | | This Study | This Study |
| Gizzard Shad | | | | | | | This Study | This Study |
| Gizzard Shad | | | | | | | | Wyman 1981, as cited in Wismer and Christie 1987 |
| Gizzard shad | | summer | F | | | | | Yoder and Gammon 1976 |
| Gizzard shad | | fall | F | | | | | Yoder and Gammon 1976 |
| Gizzard shad | | winter | F | | | | | Yoder and Gammon 1976 |
| Gizzard Shad | | | F | 34 | 32.3 | | 3 | 3 |
| Gizzard Shad | Underyearling | | | 31 | | | Talmage 78 | Talmage 1978, as cited in Wismer and Christie 1987 |
| Golden shiner | | | | 35.3 | | | | 2 |
| Golden shiner | | 22 | | | | 40 | Beltz1974 | Beltz et al 1974, as cited in Wismer and Christie 1987 |
| Golden shiner | | 17.1-17.5 | | | | 31.6 | Carlander1969 | Brett 1944 cited in Carlander 1969 |
| Golden shiner | | 22.8 | | | | 32.7 | Carlander1969 | Brett 1944 cited in Carlander 1969 |
| Golden shiner | | 25-26 | | | | 33.2 | Carlander1969 | Brett 1944 cited in Carlander 1969 |
| Golden shiner | | | | | | 30.4 | Spotila1979 | Brett, J.R., 1944 as cited in Spotila, J.R., et al., 1979 |
| Golden shiner | | | | | | 31.6 | Spotila1979 | Brett, J.R., 1944 as cited in Spotila, J.R., et al., 1979 |
| Golden shiner | | | | | | 30.3 | Spotila1979 | Brett, J.R., 1944 as cited in Spotila, J.R., et al., 1979 |
| Golden shiner | | | | | | 32.8 | Spotila1979 | Brett, J.R., 1944 as cited in Spotila, J.R., et al., 1979 |
| Golden shiner | 3.49 in | | | | | 33.4 | Spotila1979 | Brett, J.R., 1944 as cited in Spotila, J.R., et al., 1979 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Golden shiner | | | | | 33.2 | Spotila1979 | Brett, J.R., 1944 as cited in Spotila, J.R., et al., 1979 |
| Golden shiner | | | | | 31.8 | Spotila1979 | Brett, J.R., 1944 as cited in Spotila, J.R., et al., 1979 |
| Golden shiner | | | | | 33.5 | Spotila1979 | Brett, J.R., 1944 as cited in Spotila, J.R., et al., 1979 |
| Golden shiner | 10 | | | | | | Brett, J.R., 1956 as cited in Spotila, J.R., et al., 1979 |
| Golden shiner | 15 | | | | | | Brett, J.R., 1956 as cited in Spotila, J.R., et al., 1979 |
| Golden shiner | 20 | | | | | | Brett, J.R., 1956 as cited in Spotila, J.R., et al., 1979 |
| Golden shiner | 25 | | | | | | Brett, J.R., 1956 as cited in Spotila, J.R., et al., 1979 |
| Golden shiner | 30 | | | | | | Brett, J.R., 1956 as cited in Spotila, J.R., et al., 1979 |
| Golden shiner | 10 | L | | | 29.3 | Brown1974 | Hart 1952, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Golden shiner | 15 | L | | | 30.5 | Brown1974 | Hart 1952, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Golden shiner | 20 | L | | | 31.8 | Brown1974 | Hart 1952, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Golden shiner | 25 | L | | | 33.2 | Brown1974 | Hart 1952, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Golden shiner | 30 | L | | | 34.7 | Brown1974 | Hart 1952, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Golden shiner | 22 | | 39.5 | | | Brown1974 | Alpaugh 1972, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Golden shiner | 22 | | 40 | | | Brown1974 | Alpaugh 1972, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Golden shiner | | | | | 26.7 | Brown1974 | Nickum 1966, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Golden shiner | | | | | 35 | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Golden shiner | | | | | | | Trembley 1961, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Golden shiner | | F | | | | | Bailey 1955, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Golden shiner | | | 800 | | | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Golden shiner | | | | 28.9 | | Brown1974 | Trembley 1961, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Golden shiner | | | | 15.6 | | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Golden shiner | | | | | | | Trembley 1960, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Golden shiner | | | | | | | Trembley 1961, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Golden shiner | | | | | | | Brown 1974, as cited in Wismer and Christie 1987 |
| Golden shiner | | F | | | | | Eaton and Scheller 1996 |
| Golden shiner | | | | 21 | | Carlander1969 | Forney 1957 cited in Carlander 1969 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Golden shiner | adult | 10 | | | | | | Hart 1952, as cited in NAS/NAE 1973 |
| Golden shiner | adult | 15 | | | | | | Hart 1952, as cited in NAS/NAE 1973 |
| Golden shiner | adult | 20 | | | | | | Hart 1952, as cited in NAS/NAE 1973 |
| Golden shiner | adult | 25 | | | | | | Hart 1952, as cited in NAS/NAE 1973 |
| Golden shiner | adult | 30 | | | | | | Hart 1952, as cited in NAS/NAE 1973 |
| Golden shiner | | | | 33 | | | Hutchison1976 | Hutchison 1976 |
| Golden shiner | | | | 35 | | | Hutchison1976 | Hutchison 1976 |
| Golden shiner | | | | 36 | | | Hutchison1976 | Hutchison 1976 |
| Golden shiner | | | | 38 | | | Hutchison1976 | Hutchison 1976 |
| Golden shiner | | | | 39 | | | Hutchison1976 | Hutchison 1976 |
| Golden shiner | | | | 40 | | | Leidy&Jenkins1977 | Leidy and Jenkins 1977, as cited in Wismer and Christie 1987 |
| Golden shiner | | 10 | | | | | | Lutterschmidt and Hutchison 1997a, as cited in Beitinger 2000 |
| Golden shiner | | | f | | 24 | | Marcy1976a | Marcy 1976 |
| Golden shiner | | | | | 18 | | McAllister | McAllister |
| Golden shiner | | | | 30.5 | 23.9 | | R&R1976 | R&R1976 |
| Golden shiner | | | L | | 16.8 | | Reutter&Herdendorf1976 | Reutter and Herdendorf 1976 |
| Golden shiner | | | L | | 23.7 | | Reutter&Herdendorf1976 | Reutter and Herdendorf 1976 |
| Golden shiner | | 14.4 | L | | 22.3 | | Reutter&Herdendorf1976 | Reutter and Herdendorf 1976 |
| Golden shiner | | | L | | 21 | | Reutter&Herdendorf1976 | Reutter and Herdendorf 1976 |
| Golden shiner | Spawning | | F | | 20 | | Scott&Crossman73 | Scott and Crossman 1973, p436 |
| Golden shiner | | 26 | | | | | | Smale and Rabeni 1995, as cited in Beitinger et al 2000 |
| Golden shiner | | 15 | | | | | | Strawn 1958 cited in Carlander 1969 |
| Golden shiner | | 20 | | | | | | Strawn 1958 cited in Carlander 1969 |
| Golden shiner | | 25 | | | | | | Strawn 1958 cited in Carlander 1969 |
| Golden shiner | | 30 | | | | | | Strawn 1958 cited in Carlander 1969 |
| Golden shiner | | | | | 20 | 35 | Carlander1969 | Swingle 1952 cited in Carlander 1969 |
| Golden shiner | | | | | 27 | | Talmage78 | Talmage78 |
| Golden shiner | | | | | | 35 | Carlander1969 | Trembley 1960 cited in Carlander 1969 |
| Golden shiner | | | F | 30.9 | | | 3 | 3 |
| Golden shiner | | 10 | | 30 | | | Brown1974 | Brown1974 |
| Golden shiner | | 15 | | 15 | | | Brown1974 | Brown1974 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Green Sunfish | | | | 34 | 19.8 | | 2 |
| Green sunfish | | | F | 34 | 32.6 | | 3 |
| Green sunfish | | | | | 28.2 | Carlander1977 | Beitinger et al. 1975 cited in Coutant 1977 |
| Green sunfish | adult | | | | | | Beitinger et al. 1975, as cited in Stuber et al. 1982 |
| Green sunfish | | | | | 26.8 | Beltz1974 | Beltz et al 1974, as cited in Wismer and Christie 1987 |
| Green sunfish | | | | | 22.7 | Carlander77 | Carlander77 |
| Green sunfish | | 20 (1day) | | | | | Carrier and Beitinger 1988a, as cited in Beitinger et al. 2000 |
| Green sunfish | | 20 (5 day) | | | | | Carrier and Beitinger 1988a, as cited in Beitinger et al. 2000 |
| Green sunfish | | 20 (10 day) | | | | | Carrier and Beitinger 1988a, as cited in Beitinger et al. 2000 |
| Green sunfish | | 6 | | | 15.9 | Carlander77 | Cherry et al. 1975 cited in Carlander 1977 |
| Green sunfish | | 30 | | | 30.6 | Carlander77 | Cherry et al. 1975 cited in Carlander 1977 |
| Green sunfish | | 6 | | | | | Cherry et al. 1975 cited in Carlander 1977 |
| Green sunfish | | 27 | | | | | Cherry et al. 1975 cited in Carlander 1977 |
| Green sunfish | | | | | 30.6 | Carlander1977 | Cherry et al. 1975 cited in Coutant 1975 |
| Green sunfish | hatching | | | | | | Childers 1967 cited in Carlander 1977 |
| Green sunfish | spawning | | | | | | Childers 1967, as cited in Stuber et al 1982 |
| Green sunfish | | | F | | | | Eaton and Scheller 1996 |
| Green sunfish | spawning | | F | | | | Hunter 1963, as cited in Brown 1974 |
| Green sunfish | spawning | | | | | | Hunter 1963, as cited in Stuber et al. 1982 |
| Green sunfish | | | | | 27.3 | Carlander1977 | Jones and Irwin 1965 cited in Coutant 1977 |
| Green sunfish | | | | | | | Jude 1973 cited in Carlander 1977 |
| Green sunfish | | 10 | | | | | Lutterschmidt and Hutchison 1997a, as cited in Beitinger 2000 |
| Green sunfish | | | | | | | Proffitt and Benda 1971 cited in Carlander 1977 |
| Green sunfish | Spawning | | | | 29.1 | Carlander77 | Salyer 1958 cited in Carlander 1977 |
| Green sunfish | fry | | | | | | Siewert 1973;Soutant 1977; Hardin and Bovee 1978, as cited in Stuber 1982 |
| Green sunfish | | | | | | | Sigler and Miller 1963 cited in Carlander 1977 |
| Green sunfish | adult | | F | | | | Sigler and Miller 1963; Proffitt and Benda 1971, as cited in Stuber et al. 1982 |
| Green sunfish | | 26 | | | | | Smale and Rabeni 1995, as cited in Beitinger et al 2000 |
| Green sunfish | hatching | | | | | | Strawn 1958 cited in Carlander 1977 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Green sunfish | | 20 | | | | | | Witford 1970, as cited in Brown 1974 |
| Green sunfish | | 30 | | | | | | Witford 1970, as cited in Brown 1974 |
| Hornyhead chub | | 26 | | | | | | Smale and Rabeni 1995, as cited in Beitinger et al 2000 |
| Iowa darter | hatching | | F | | | | | Scott and Crossman 1973, p785 |
| Largemouth Bass | | | | 35.5 | 34.7 | | | 2 |
| Largemouth Bass | | | F | 35.5 | 34.7 | | | 3 |
| Largemouth Bass | | | | | | | | Badenhuizen 1969 cited in Carlander 1977 |
| Largemouth Bass | | | | | | | | Badenhuizen 1969 cited in Carlander 1977 |
| Largemouth Bass | | | | | | | | Bell 1990 |
| Largemouth Bass | spawning | | | | | | | Bell 1990 |
| Largemouth Bass | hatching | | | | | | | Bell 1990 |
| Largemouth Bass | | | F | | | | | Bennett 1954a cited in Carlander 1977 |
| Largemouth Bass | | | | | | | | Bennett 1954b cited in Carlander 1977 |
| Largemouth Bass | | | | | | | | Bennett, G.W., 1965 as cited in Spotila, J.R., et al., 1979 |
| Largemouth Bass | | 20-21 | | | | | | Black 1953 |
| Largemouth Bass | | 20-21 | | | | 28.9 | Spotila1979 | Black, E.C., 1953 as cited in Spotila, J.R., et al., 1979 |
| Largemouth Bass | | | | | | | | Breder 1936 cited in Carlander 1977 |
| Largemouth Bass | | 20 | | | | | | Brett, J.R., 1956 as cited in Spotila, J.R., et al., 1979 |
| Largemouth Bass | | 25 | | | | | | Brett, J.R., 1956 as cited in Spotila, J.R., et al., 1979 |
| Largemouth Bass | | 30 | | | | | | Brett, J.R., 1956 as cited in Spotila, J.R., et al., 1979 |
| Largemouth Bass | 9-11 mo | 20 | | | | 32 | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Largemouth Bass | 9-11 mo | 25 | | | | 33 | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Largemouth Bass | 9-11 mo | 30 | L | | | 33.7 | Brown1974 | Hart 1952, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Largemouth Bass | | 30 | L | | | | | Hart 1952, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Largemouth Bass | adult | 20 | L | | | 32.5 | Brown1974 | Hart 1952, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Largemouth Bass | | 20 | L | | | | | Hart 1952, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Largemouth Bass | adult | 25 | | | | 34.5 | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Largemouth Bass | adult | 30 | | | | 36.4 | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Largemouth Bass | under yearling | 30 | | | | 36.4 | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Largemouth Bass | | 35 | | | 36.4 | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Largemouth Bass | | 22 | | | 31.5 | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Largemouth Bass | | 7.2 | L | | 30.6 | Brown1974 | Trembley 1961, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Largemouth Bass | | 11.1 | L | | 36 | Brown1974 | Trembley 1961, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Largemouth Bass | | 15 | | | 35 | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Largemouth Bass | | | | 29.1 | | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Largemouth Bass | fry | | | | | | Strawn 1961, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Largemouth Bass | eggs | | | | 32.5 | Brown1974 | Strawn 1961, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Largemouth Bass | Spawning | | | | | | Clugston 1966, as cited in Brown 1974 |
| Largemouth Bass | fry | | | | | | Fry 1950?, as cited in Brown 1974 |
| Largemouth Bass | juvenile | 25 | | | | | Meldrim and Gift 1971, as cited in Brown 1974 |
| Largemouth Bass | | | F | | | | Trembley 1960, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Largemouth Bass | | | | | 36.7 | Carlander77 | Carlander77 |
| Largemouth Bass | Spawning | | | 21 | | Carlander77 | Carlander77 |
| Largemouth Bass | Spawning | | | 20 | | Carlander77 | Carlander77 |
| Largemouth Bass | | | | | | | Carlson and Hale 1972 cited in Carlander 1977 |
| Largemouth Bass | | | | 30.4 | 36 | Cherry 1982 | Cherry et al. 1982 |
| Largemouth Bass | | | F | | | | Chew 1974 cited in Carlander 1977 |
| Largemouth Bass | | | F | | | | Clugston 1966 cited in Carlander 1977 |
| Largemouth Bass | | | | 30 | | Carlander1977 | Clugston 1973 cited in Coutant 1977 |
| Largemouth Bass | | | | 27 | | Carlander1977 | Coutant 1975 cited in Coutant 1977 |
| Largemouth Bass | | | | | | | Coutant and DeAngelis 1983, as cited in Wismer and Christie 1987 |
| Largemouth Bass | | | | | | | Coutant, C.C., 1975 as cited in Spotila, J.R., et al., 1979 |
| Largemouth Bass | | | | | 35.6 | Spotila1979 | Cvancara et al., 1976 as cited in Spotila, J.R., et al., 1979 |
| Largemouth Bass | | | | 27.7 | | Carlander1977 | Dendy 1948 cited in Coutant 1977 |
| Largemouth Bass | | | F | | | | Eaton and Scheller 1996 |
| Largemouth Bass | | | | | | | Eddy and Surber 1947 cited in Carlander 1977 |
| Largemouth Bass | subadult | | | | | | EPA 1974, as cited in Wismer and Christie 1987 |
| Largemouth Bass | juvenile | | | | | | EPA 1974, as cited in Wismer and Christie 1987 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Largemouth Bass | spawning | | | | | EPA 1974, as cited in Wismer and Christie 1987 |
| Largemouth Bass | juvenile | 20 | | 33 | EPA74 | EPA 1974, as cited in Wismer and Christie 1987 |
| Largemouth Bass | juvenile | 25 | | 35 | EPA74 | EPA 1974, as cited in Wismer and Christie 1987 |
| Largemouth Bass | juvenile | 30 | | 36 | EPA74 | EPA 1974, as cited in Wismer and Christie 1987 |
| Largemouth Bass | juvenile | 35 | | 36 | EPA74 | EPA 1974, as cited in Wismer and Christie 1987 |
| Largemouth Bass | Spawning | | 20 | | EPA74 | EPA 1974, as cited in Wismer and Christie 1987 |
| Largemouth Bass | | | 32 | | Carlander1977 | Ferguson 1958 cited in Coutant 1977 |
| Largemouth Bass | | | | | | Ferguson 1958, as cited in Yoder and Gammon 1976 |
| Largemouth Bass | | | | | | Ferguson, R.G., 1958 as cited in Spotila, J.R., et al., 1979 |
| Largemouth Bass | | 8 | | | | Fields et al. 1987, as cited in Currie et al. 1998 |
| Largemouth Bass | | 16 | | | | Fields et al. 1987, as cited in Currie et al. 1998 |
| Largemouth Bass | | 24 | | | | Fields et al. 1987, as cited in Currie et al. 1998 |
| Largemouth Bass | | 32 | | | | Fields et al. 1987, as cited in Currie et al. 1998 |
| Largemouth Bass | | 8 | | | | Fields et al. 1987, as cited in Currie et al. 1998 |
| Largemouth Bass | | 16 | | | | Fields et al. 1987, as cited in Currie et al. 1998 |
| Largemouth Bass | | 24 | | | | Fields et al. 1987, as cited in Currie et al. 1998 |
| Largemouth Bass | | 32 | | | | Fields et al. 1987, as cited in Currie et al. 1998 |
| Largemouth Bass | | 32 | | | | Fields et al. 1987, as cited in Currie et al. 1998 |
| Largemouth Bass | | 32 | | | | Fields et al. 1987, as cited in Currie et al. 1998 |
| Largemouth Bass | | 30 or 36 | | | | Guest 1985, as cited in Currie et al. 1998 |
| Largemouth Bass | | 30 or 36 | | | | Guest 1985, as cited in Currie et al. 1998 |
| Largemouth Bass | | | | | | Harland and Speaker 1956 cited in Carlander 1977 |
| Largemouth Bass | | 10 | | | | Hart 1952 cited in Carlander 1977 |
| Largemouth Bass | | 20 | | | | Hart 1952 cited in Carlander 1977 |
| Largemouth Bass | | 20 | | | | Hart 1952 cited in Carlander 1977 |
| Largemouth Bass | | 20-21.8 | | | | Hart 1952 cited in Carlander 1977 |
| Largemouth Bass | | 25 | | | | Hart 1952 cited in Carlander 1977 |
| Largemouth Bass | | 25 | | | | Hart 1952 cited in Carlander 1977 |
| Largemouth Bass | | 30 | | | | Hart 1952 cited in Carlander 1977 |
| Largemouth Bass | | 30 | | | | Hart 1952 cited in Carlander 1977 |
| Largemouth Bass | | 30 | | | | Hart 1952 cited in Carlander 1977 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Largemouth Bass | | 30 | | | | | Hart 1952 cited in Carlander 1977 |
| Largemouth Bass | 9-11 mo age. | 20 | | | | | Hart 1952, as cited in NAS/NAE 1977 |
| Largemouth Bass | | 20 | | | | | Hart 1952, as cited in NAS/NAE 1977 |
| Largemouth Bass | 9-11 mo age. | 25 | | | | | Hart 1952, as cited in NAS/NAE 1978 |
| Largemouth Bass | | 25 | | | | | Hart 1952, as cited in NAS/NAE 1978 |
| Largemouth Bass | 9-11 mo age. | 30 | | | | | Hart 1952, as cited in NAS/NAE 1979 |
| Largemouth Bass | | 30 | | | | | Hart 1952, as cited in NAS/NAE 1979 |
| Largemouth Bass | Under yearling | 30 | | | | | Hart 1952, as cited in NAS/NAE 1979 |
| Largemouth Bass | Under yearling | 35 | | | | | Hart 1952, as cited in NAS/NAE 1980 |
| Largemouth Bass | | 22 | | | | | Hart 1952, as cited in NAS/NAE 1980 |
| Largemouth Bass | | 10 | | | | | Hathaway 1927, as cited in Currie et al 1998 |
| Largemouth Bass | | 22-23 | | | | | Hathaway 1927, as cited in Currie et al 1998 |
| Largemouth Bass | | 30 | | | | | Hathaway 1927, as cited in Currie et al 1998 |
| Largemouth Bass | | | | | | | Johnson 1971 cited in Carlander 1977 |
| Largemouth Bass | | | | | | | Jurgens and Brown 1954 cited in Carlander 1977 |
| Largemouth Bass | | | | | | | Kramer and Smith 1960, as cited in Brwon 1974 |
| Largemouth Bass | | | | | | | Lawrence 1957 cited in Carlander 1977 |
| Largemouth Bass | | 10 | | | | | Lutterschmidt and Hutchison 1997a, as cited in Beitinger 2000 |
| Largemouth Bass | | | | 21.3 | | Marcy | Marcy 1976 |
| Largemouth Bass | juvenile | | | | | | McCauley and Casselman 1980, as cited in Wismer and Christie 1987 |
| Largemouth Bass | subadult | | | | | | McCauley and Casselman 1980, as cited in Wismer and Christie 1987 |
| Largemouth Bass | Spawning | | | | 32.1 | CRAV82 | McCormick and Wegner 1981 |
| Largemouth Bass | Spawning | 20 | <L> | | | CRAV82 | McCormick and Wegner 1981 |
| Largemouth Bass | Spawning | 24 | | | | CRAV82 | McCormick and Wegner 1981 |
| Largemouth Bass | Spawning | 27 | | | | CRAV82 | McCormick and Wegner 1981 |
| Largemouth Bass | Spawning | 30 | | | | CRAV83 | McCormick and Wegner 1981 |
| Largemouth Bass | | | | | | | Miller and Kramer 1971 cited in Carlander 1977 |
| Largemouth Bass | | | | | | | Miller and Kramer 1971 cited in Carlander 1977 |
| Largemouth Bass | | | | | | | Miller and Kramer 1971 cited in Carlander 1977 |
| Largemouth Bass | | | | | | | Mraz 1957 cited in Carlander 1977 |
| Largemouth Bass | | | | | | | Mraz 1957 cited in Carlander 1977 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Largemouth Bass | | | | | | | | Mraz et al. 1961 cited in Carlander 1977 |
| Largemouth Bass | | | | | | | | Mraz et al. 1961 cited in Carlander 1977 |
| Largemouth Bass | | | | | | | | Mraz et al. 1961 cited in Carlander 1977 |
| Largemouth Bass | | | | | | | | Neil and Magnnson, as cited in Yoder and Gammon 1976 |
| Largemouth Bass | | | | | 30.9 | | Carlander1977 | Neill 1971 cited in Coutant 1977 |
| Largemouth Bass | | | | | 32 | | Carlander1977 | Neill 1971 cited in Coutant 1977 |
| Largemouth Bass | | | | | 29.1 | | Carlander1977 | Neill 1971 cited in Coutant 1977 |
| Largemouth Bass | | | | | 29 | | Carlander1977 | Neill 1971 cited in Coutant 1977 |
| Largemouth Bass | | | | | | | | Nelson 1974 cited in Carlander 1977 |
| Largemouth Bass | | | | | | | | Newell 1960 cited in Carlander 1977 |
| Largemouth Bass | | | | | | | | Otto 1973, as cited in Yoder and Gammon 1976 |
| Largemouth Bass | | | | | 30 | | Carlander1977 | Reynolds and Casterlin 1976 cited in Coutant 1977 |
| Largemouth Bass | | | | | 29.5 | | Talmage&Coutant1979 | Reynolds and Casterlin, 1978 as cited in Talmage and Coutant, 1979 |
| Largemouth Bass | | | | | 30.1 | | Carlander1977 | Reynolds et al. 1976 cited in Coutant 1977 |
| Largemouth Bass | | | | | 30.2 | | Carlander1977 | Reynolds et al. 1976 cited in Coutant 1977 |
| Largemouth Bass | | | | | | | | Reynolds et al., 1976 as cited in Spotila, J.R., et al., 1979 |
| Largemouth bass | | 22 | L | | | | | Reynolds, W., and Casterlin, M.E., 1978 |
| Largemouth Bass | | | | | | | | Salyer 1958 cited in Carlander 1977 |
| Largemouth Bass | | | | | | | | Siler and Clugston 1975 cited in Coutant 1977 |
| Largemouth Bass | fry | | | | | | | Smagula and Adelman 1982, as cited in Wismer and Christie 1987 |
| Largemouth Bass | | 26 | | | | | | Smale and Rabeni 1995, as cited in Beitinger et al 2000 |
| Largemouth Bass | | 20 | | | | | | Smith and Scott 1975, as cited in Beitinger et al. 2000 |
| Largemouth Bass | | 28 | | | | | | Smith and Scott 1975, as cited in Beitinger et al. 2000 |
| Largemouth Bass | | 20 | | 36.7 | | | | Smith and Scott, 1975 as cited in Spotila, J.R., et al., 1979 |
| Largemouth Bass | | 28 | | 40.1 | | | | Smith and Scott, 1975 as cited in Spotila, J.R., et al., 1979 |
| Largemouth Bass | | | | | | | | Strawn 1961 cited in Carlander 1977 |
| Largemouth Bass | | | | | | | | Strawn 1961 cited in Carlander 1977 |
| Largemouth Bass | | | | | | 32.5 | Spotila1979 | Strawn, K., 1961 as cited in Spotila, J.R., et al., 1979 |
| Largemouth Bass | | | | | | | | Swingle 1952 cited in Carlander 1969 |
| Largemouth Bass | | | | | | | | Swingle 1956 cited in Carlander 1977 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Largemouth Bass | | | | | 27.1 | | Talmage&Coutant1979 | Talmage and Coutant 1979, as cited in Wismer and Christie 1987 |
| Largemouth Bass | | | | | | | | Trembley 1960 cited in Carlander 1977 |
| Largemouth Bass | | | | | | | | Trembley 1960 cited in Carlander 1977 |
| Largemouth Bass | | | | 34 | 32 | | | U.S. EPA 1976 |
| Largemouth Bass | | | | | 21 | | | U.S. EPA 1976 |
| Largemouth Bass | | | | | 27 | | | U.S. EPA 1976 |
| Largemouth Bass | fingerling | 11.1 | L | | | 35 | VEN78 | Venables et al 1978, as cited in Wismer and Christie 1987 |
| Largemouth Bass | fingerling | 15 | L | | | 35 | VEN78 | Venables et al 1978, as cited in Wismer and Christie 1987 |
| Largemouth Bass | fingerling | 20 | L | | | 40 | VEN78 | Venables et al 1978, as cited in Wismer and Christie 1987 |
| Largemouth Bass | fingerling | 25 | L | | | 40 | VEN78 | Venables et al 1978, as cited in Wismer and Christie 1987 |
| Largemouth Bass | fingerling | 30 | L | | | 40 | VEN78 | Venables et al 1978, as cited in Wismer and Christie 1987 |
| Largemouth Bass | Spawning | 35 | L | | | 26.7 | VEN78 | Venables et al 1978, as cited in Wismer and Christie 1987 |
| Largemouth Bass | | | | | 32 | | Talmage&Coutant1979 | Venables et al., 1978 as cited in Talmage&Coutant, 1979 |
| Largemouth Bass | | summer | F | | | | | Yoder and Gammon 1976 |
| Largemouth Bass | | fall | F | | | | | Yoder and Gammon 1976 |
| Quillback | large | | | | | | | Coutant 1977a, as cited in Wismer and Christie 1987 |
| Quillback | | 24 | | | | | | Mundahl 1990, as cited in Beitinger et al. 2000 |
| Quillback | Adult | 23.3 | L | | | | | Reutter and Herdendorf 1976 |
| Quillback | | | | | | | | Yoder and Gammon 1976 |
| Quillback | | | | | | | | Yoder and Gammon 1976 |
| Red shiner | | 20 (day 1) | | | | | | Carrier and Beitinger 1988a, as cited in Beitinger et al. 2000 |
| Red shiner | | 20 (day 5) | | | | | | Carrier and Beitinger 1988a, as cited in Beitinger et al. 2000 |
| Red shiner | | 20 (day 10) | | | | | | Carrier and Beitinger 1988a, as cited in Beitinger et al. 2000 |
| Red shiner | | 25 | | | | | | King et al. 1985, as cited in Beitinger et al. 2000 |
| Red shiner | | 10 | | | | | | Lutterschmidt and Hutchison 1997a, as cited in Beitinger 2000 |
| Red shiner | | 15 | | | | | | Maness and Hutchinson 1980, as cited in Beitinger et al. 2000 |
| Red shiner | | 25 | | | | | | Matthews and Maness 1979, as cited in Beitinger et al. 2000 |
| Red shiner | | 30 | | | | | | Rutledge and Beitinger 1989, as cited in Beitinger et al. 2000 |
| Red shiner | | 26 | | | | | | Smale and Rabeni 1995, as cited in Beitinger et al 2000 |
| Red shiner | | 22 | | | | | | Takle et al. 1983, as cited in Beitinger et al. 2000 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| River carpsucker | | summer | | | | | Gammon 1973, as cited in Yoder and Gammon 1976 |
| River carpsucker | | summer | F | | | | Yoder and Gammon 1976 |
| River carpsucker | | fall | F | | | | Yoder and Gammon 1976 |
| River carpsucker | | winter | F | | | | Yoder and Gammon 1976 |
| Sand shiner | | 15 | | | | | Kowalski et al. 1978, as cited in Beitinger et al. 2000 |
| Sand shiner | | 26 | | | | | Smale and Rabeni 1995, as cited in Beitinger et al 2000 |
| Smallmouth Bass | | | | 24 | | Carlander1977 | Barans and Tubb 1973 cited in Coutant 1977 |
| Smallmouth Bass | | | | 31 | | Carlander1977 | Barans and Tubb 1973 cited in Coutant 1977 |
| Smallmouth Bass | | | | 27 | | Carlander1977 | Barans and Tubb 1973 cited in Coutant 1977 |
| Smallmouth Bass | | | | 13 | | Carlander1977 | Barans and Tubb 1973 cited in Coutant 1977 |
| Smallmouth Bass | | | | 16 | | Carlander1977 | Barans and Tubb 1973 cited in Coutant 1977 |
| Smallmouth Bass | | | | 30 | | Carlander1977 | Barans and Tubb 1973 cited in Coutant 1977 |
| Smallmouth Bass | | | | 23 | | Carlander1977 | Barans and Tubb 1973 cited in Coutant 1977 |
| Smallmouth bass | juvenile | | | | | | Barans and Tubb 1973, as cited in Edwards et al. 1983 |
| Smallmouth Bass | | | | 18 | | Carlander1977 | Barans and Tubb 1976 cited in Coutant 1977 |
| Smallmouth Bass | | | | | | | Bell 1990 |
| Smallmouth Bass | spawning | | | | | | Bell 1990 |
| Smallmouth Bass | hatching | | | | | | Bell 1990 |
| Smallmouth Bass | | | | | | | Brown 1960 cited in Carlander 1977 |
| Smallmouth Bass | | | | | | | Brown 1960 cited in Carlander 1977 |
| Smallmouth Bass | | | | | | | Cherry et al. 1975 cited in Carlander 1977 |
| Smallmouth Bass | | | | 31.3 | | Carlander1977 | Cherry et al. 1975 cited in Coutant 1975 |
| Smallmouth bass | | | | | | | Cherry et al. 1975, as cited in Edwards et al. 1983 |
| Smallmouth Bass | | | | | 35 | Cherry1977 | Cherry et al., 1977 |
| Smallmouth Bass | | | | 30.3 | | Cherry1977 | Cherry et al., 1977 |
| Smallmouth Bass | | 15 | L | | | | Cherry et al., 1977 |
| Smallmouth Bass | | 18 | L | | | | Cherry et al., 1977 |
| Smallmouth Bass | | 21 | L | | | | Cherry et al., 1977 |
| Smallmouth Bass | | 24 | L | | | | Cherry et al., 1977 |
| Smallmouth Bass | | 27 | L | | | | Cherry et al., 1977 |
| Smallmouth Bass | | 30 | L | | | | Cherry et al., 1977 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Smallmouth Bass | | 33 | L | | | Cherry et al., 1977 |
| Smallmouth Bass | | | | | | Christie and Regier 1973 cited in Carlander 1977 |
| Smallmouth bass | Adult | | F | | | Clancey 1980, as cited in Edwards et al. 1983 |
| Smallmouth bass | Adult | | | | | Coble 1975, as cited in Edwards et al. 1983 |
| Smallmouth bass | embryo | | | | | Coble 1975, as cited in Edwards et al. 1983 |
| Smallmouth bass | juvenile | | | | | Coutant 1975, as cited in Edwards et al. 1983 |
| smallmouth bass | | | | | | Crippen and Fahmy 1981 |
| Smallmouth Bass | | | F | | | Eaton and Scheller 1996 |
| Smallmouth Bass | | | | | | Emig 1966 cited in Carlander 1977 |
| Smallmouth Bass | | | | 28 | Carlander1977 | Ferguson 1958 cited in Coutant 1977 |
| Smallmouth Bass | | | | | | Ferguson 1958 cited in Coutant 1977 |
| Smallmouth Bass | | | | 21.3 | | Hile and Juday 1941, as cited in Brown 9174 |
| Smallmouth bass | juvenile | | | | | Horning and Pearson 1973, as cited in Brown 1974 |
| Smallmouth Bass | | | | | | Hubbs and Bailey 1938 cited in Carlander 1977 |
| Smallmouth bass | fry | | | | | Larimore and Duever 1968, as cited in Edwards et al. 1983 |
| Smallmouth Bass | | | | | | Lowrey 1958 cited in Carlander 1977 |
| Smallmouth Bass | | 10 | | | | Lutterschmidt and Hutchison 1997a, as cited in Beitinger 2000 |
| Smallmouth bass | Adult | 2.2 | | | | Mathur et al. 1981, as cited in Edwards et al. 1983 |
| Smallmouth bass | Adult | 30 | | | | Mathur et al. 1981, as cited in Edwards et al. 1983 |
| Smallmouth bass | fry | | L | | | Munther 1970; Shuter et al. 1980, as cited in Edwards et al. 1983 |
| Smallmouth Bass | | | | | | Neves 1975 cited in Carlander 1977 |
| Smallmouth Bass | | | | | | Newell 1960 cited in Carlander 1977 |
| Smallmouth bass | Adult | | L | | | Peek 1965; Shuter et al. 1980; Wrenn 1980, as cited in Edwards et al. 1983 |
| Smallmouth Bass | | | | | | Rawson 1945 cited in Carlander 1977 |
| Smallmouth Bass | | | | | | Rawson 1945 cited in Carlander 1977 |
| Smallmouth Bass | | | | 26.6 | Carlander1977 | Reutter and Herdendorf 1974 cited in Coutant 1977 |
| Smallmouth Bass | | | L | | | Reutter and Herdendorf 1976 |
| Smallmouth Bass | | | L | | | Reutter and Herdendorf 1976 |
| Smallmouth Bass | | | L | | | Reutter and Herdendorf 1976 |
| Smallmouth Bass | | | L | | | Reutter and Herdendorf 1976 |
| Smallmouth Bass | | | L | | | Reutter and Herdendorf 1976 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Smallmouth Bass | | | L | | | | | Reutter and Herdendorf 1976 |
| Smallmouth Bass | | | L | | | | | Reutter and Herdendorf 1976 |
| Smallmouth Bass | | | L | | | | | Reutter and Herdendorf 1976 |
| Smallmouth Bass | | | | | 31.1 | | Carlander1977 | Reynolds and Casterlin 1976 cited in Coutant 1977 |
| Smallmouth Bass | | none | F | | | 30 | SHUT80 | Shuter et al. 1980 |
| Smallmouth Bass | | none | F | | 29 | | SHUT80 | Shuter et al. 1980 |
| Smallmouth Bass | | none | F | | 18 | | SHUT80 | Shuter et al. 1980 |
| Smallmouth Bass | | none | F | | 21 | | SHUT80 | Shuter et al. 1980 |
| Smallmouth Bass | | none | F | | | 30 | SHUT80 | Shuter et al. 1980 |
| Smallmouth Bass | | 26 | | | | | | Smale and Rabeni 1995, as cited in Beitinger et al 2000 |
| Smallmouth Bass | | | F | | | | | Smitherman and Ramsey 1972 cited in Carlander 1977 |
| Smallmouth Bass | | | F | | | | | Smitherman and Ramsey 1972 cited in Carlander 1977 |
| Smallmouth Bass | | | | | | | | Trautman 1957 cited in Carlander 1977 |
| Smallmouth Bass | | | | | | | | Trembley 1960 cited in Carlander 1977 |
| Smallmouth Bass | | 12.8 | | | | | | Trembley 1960, as cited in Brown 1974 |
| Smallmouth Bass | | | F | | | | | Trembley 1960, as cited in Brown 1974 |
| Smallmouth Bass | | | | | | | | Turner and MacCrimmon 1970 cited in Carlander 1977 |
| Smallmouth bass | Spawning | | | | | | | Turner and MacCrimmon 1970; Scott and Crossman 1973; Shuter et al. 1980, as cited in Edwards et al. 1982 |
| Smallmouth Bass | | | | | 29 | | | U.S. EPA 1976 |
| Smallmouth Bass | | | | | 17 | | | U.S. EPA 1976 |
| Smallmouth Bass | | | | | 23 | | | U.S. EPA 1976 |
| Smallmouth Bass | | | | | | | | Webster 1954 cited in Carlander 1977 |
| Smallmouth Bass | | n/s | F | | | 37 | WRENN80 | Wrenn 1980 |
| Smallmouth Bass | | n/s | F | | | 38 | WRENN80 | Wrenn 1980 |
| Smallmouth Bass | | n/s | F | | | 35 | WRENN80 | Wrenn 1980 |
| Smallmouth Bass | | n/s | F | | 31 | | WRENN80 | Wrenn 1980 |
| Smallmouth Bass | | | F | | 32 | | 3 | 3 |
| Smallmouth Bass | | | | 35 | 32.32.2 | | 2* | 2* |
| Smallmouth Bass | | 12.8 | | | | 32.2 | Brown1974 | Brown 1974, as cited in Wismer and Christie 1987 |
| Smallmouth Bass | egg | 19 | | | | 29 | Brown1974 | Wallace 1973, as cited in Brown 1974, as cited in Wismer and Christie 1987 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Smallmouth Bass | egg | 16.1 | | | 23.1 | Brown1974 | Tester 1930, as cited in Brown 1974, as cited in Wismer and Christie 1987 |
| Smallmouth Bass | spawning | | | | | | Henderson and Foster 1956, as cited in Brown 1974 |
| Smallmouth Bass | egg | 12.8 | | | | | Webster 1945, as cited in Brown 1974 |
| Smallmouth Bass | spawning | | | | | | Nesley 1913, as cited in Brown 1974 |
| Smallmouth Bass | spawning | | | | | | Hubbs and Bailey 1938, cited in Brown 1974 |
| Smallmouth Bass | spawning | | | | | | Wiebe 1935, as cited in Brown 1974 |
| Smallmouth Bass | incubation | | | | | | Webster 1945, as cited in Brown 1974 |
| Smallmouth Bass | juveniles | | | | | | Peek 1965, as ctied in Brown 9174 |
| Smallmouth Bass | juveniles | | | | | | Hokanson 1969, as cited in Brown 1974 |
| Smallmouth Bass | | | | 21.4 | | Carlander1977 | Carlander1977 |
| Suckermouth minnow | | 10 | | | | | Lutterschmidt and Hutchison 1997a, as cited in Beitinger 2000 |
| White Bass | | | | | | | Barans and Tubb 1973 cited in Carlander 1997 |
| White Bass | | | | | | | Barans and Tubb 1973 cited in Carlander 1997 |
| White Bass | | | | | | | Barans and Tubb 1973 cited in Carlander 1997 |
| White Bass | | | | | | | Barans and Tubb 1973 cited in Carlander 1997 |
| White Bass | | | | | | | Barans and Tubb 1973 cited in Carlander 1997 |
| White Bass | | | | | | | Barans and Tubb 1973 cited in Carlander 1997 |
| White Bass | | | | | | | Barans and Tubb 1973 cited in Carlander 1997 |
| White Bass | | | | | | | Barans and Tubb 1973 cited in Carlander 1997 |
| White bass | | summer | L | | | | Barans and Tubb 1973, as cited in Joder and Gammon 1976 |
| White bass | | fall | L | | | | Barans and Tubb 1973, as cited in Joder and Gammon 1976 |
| White bass | | winter | L | | | | Barans and Tubb 1973, as cited in Joder and Gammon 1976 |
| White bass | | spring | L | | | | Barans and Tubb 1973, as cited in Joder and Gammon 1976 |
| White Bass | | | F | | | | Commercial Fisheries Review 1961 cited in Carlander 1997 |
| White Bass | | | F | | | | Eaton and Scheller 1996 |
| White bass | adults | | | | | | Gammon 1973, as cited in Hamilton and Nelson 1984 |
| White bass | | | | | | | Gammon 1973, as cited in Yoder and Gammon 1976 |
| White bass | adults | | L | | | | Horrall 1961, as cited in Hamilton and Nelson 1984 |
| White bass | hatching | | L | | | | Horrall 1961; Ruelle 1971; Siefert et al. 1974, as cited in Hamilton and Nelson 1984 |
| White Bass | | | F | | | | McCormick 1978 cited in Carlander 1997 |

| | | | | | | |
|---|---|---|---|---|---|---|
| White Bass | | | F | | | McCormick 1978 cited in Carlander 1997 |
| White Bass | | | F | | | McCormick 1978 cited in Carlander 1997 |
| white bass | | | | | | McCormick 1978 cited in Carlander 1997 |
| White Bass | | | F | | | Nelson 1980 cited in Carlander 1997 |
| white bass | | 21.7 | L | | | Reutter and Herdendorf 1976 |
| White bass | spawning | | | | | Riggs 1955; Webb and Moss 1968; Ruells 1971, as cited in Hamilton and Nelson 1984 |
| White Bass | | | F | | | Vincent 1967 cited in Carlander 1997 |
| White bass | incubation | | | | | Yellayi and Kilambi 1970, as cited in Hamilton and Nelson 1984 |
| White bass | | summer | F | | | Yoder and Gammon 1976 |
| White bass | | fall | F | | | Yoder and Gammon 1976 |
| White bass | | winter | F | | | Yoder and Gammon 1976 |
| White Bass | | | F | 31.4 | 29.9 | 3 |