FINAL PERFORMANCE REPORT

Federal Aid Grant No. F18AF00919 (T-108-R-1)

Life History and Ecology of the Ozark Emerald and Associated Crayfishes in the Ouachita Mountains/West Gulf Coastal Plain Region

Oklahoma Department of Wildlife Conservation

October 1, 2018 through June 30, 2021

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Grant Title: Life History and Ecology of the Ozark Emerald and Associated Crayfishes in the Ouachita Mountains/West Gulf Coastal Plain Region

Grant Period: October 1, 2018 – June 30, 2021

Principal Investigator:
Daniel C. Allen, PhD
Assistant Professor
Department of Biology
University of Oklahoma

Co-Principal Investigators:
Brenda D. Smith
Oklahoma Natural Heritage Inventory
Oklahoma Biological Survey
University of Oklahoma

Stephen C. Cook, PhD
Postdoctoral Researcher
Department of Biology
University of Oklahoma

Daniel Nelson, PhD
Postdoctoral Researcher, formerly
Department of Biology
University of Oklahoma

Executive Summary

Surveys for *Somatochlora ozarkensis* (Ozark Emerald) adults were successful as were monitoring efforts. Additionally, we were the first research team to discover and collect a *S. ozarkensis* nymph from the wild. We added new locations for the species and confirmed its continued presence at multiple locations. Encounters in 2021 suggest that local populations may be stable, but the paucity of encounters in 2019 and other data over time indicate that populations fluctuate year to year. This regionally endemic species of conservation concern (ODWC Tier II, S3 NatureServe rank) should continue to be monitored and further research is warranted. During the current project, we learned much about the distribution, life history, and ecology of *S. ozarkensis* as well as other species of conservation concern, including Species of Greatest Conservation Need (SGCN) species of odonates and crayfish. Prior to the project, there were only 103 statewide records of crayfish in the Oklahoma Biodiversity Information System (OBIS), an ODWC-sponsored database. We increased the number of geocoded records to 3,180 statewide, with 2,657 of those from the project area.

Objectives:

This project had two main objectives:
Objective 1 – To discover Ozark Emerald larvae, determine their habitat associations and identify co-occurring crayfish species

Objective 2 – To compile existing distribution and abundance data for crayfish in the Ouachita Mountains/West Gulf Coastal Plain Region

Summary of Progress:

Background

Ozark Emerald (*Somatochlora ozarkensis*) Conservation Status and Research Needs

The Ozark Emerald (*Somatochlora ozarkensis*) is a regional endemic known to occur in only four states (Fig. 1). The species is currently listed as a Tier II species in the Oklahoma Comprehensive Wildlife Conservation Strategy (OCWCS, Appendix E; ODWC 2015). It was previously considered an S1 (imperiled) species, as per NatureServe's methodology (https://www.natureserve.org/), in Oklahoma until research began to indicate that the species is more widespread than once thought (Smith and Patten 2021; Smith-Patten 2017; Smith-Patten and Patten 2016, 2017). It is currently considered an S3 (vulnerable) species by the Oklahoma Natural Heritage inventory, but it remains on the critically imperiled/imperiled lists for Arkansas (S1), Kansas (S1), and Missouri (S1/2). Global conservation ranks for the species roughly correspond, having a NatureServe G3 rank (vulnerable; Smith-Patten 2017) and IUCN rank of Near Threatened (Abbott and Paulson 2017). It was being reviewed by the U.S. Fish and Wildlife Service (USFWS) for potential listing (Federal Register 76:59836, 9-27-2011) until the petitioner inexplicably pulled the petition in 2018 without consulting either of the only two researchers working with the species (Brenda D. Smith and Michael A. Patten).

Although the species has a geographical range extent encompassing much of eastern Oklahoma and possibly one location in the southwestern part of the state, its area of occupancy is *much* smaller, being confined to small highland streams (Smith and Patten 2021). Currently it is confirmed in ten counties in Oklahoma but has a known area of occupancy of only about 145 km^2. Despite its common name, the Ozark Emerald appears to be most common in the Ouachita Highlands. Additionally, the Ozark Emerald has been reported in Comanche County, but these reports have not been confirmed.

Discovering Ozark Emerald larvae (nymphs) in the wild is key to understanding the life history of this species; thus, the impetus for the current project. At the start of the project, we knew of <70 confirmed records of the Ozark Emerald in Oklahoma—nearly half of which were added during Smith-Patten and Patten's (2016) study of the species in 2014–2016. But all of those records were of adults or recently emerged individuals, and fewer than ten records were of ovipositing females.

The nymph of the Ozark Emerald had never been collected in the wild. Our in-situ knowledge about the larvae of this species has come from one nymph that A. Earl Pritchard encountered, probably in 1934, along Fourche Maline Creek in Latimer County (Pritchard 1936).

He observed emergence of a female teneral that he did not collect, but he did collect another exuvia several miles downstream. He used the two exuviae to describe the species' nymph (Pritchard 1936). Later, eggs taken from a *Somatochlora ozarkensis* female captured in Barry County, Missouri, were reared, producing 12 nymphs. Tennessen (2019, *ms*) more clearly described *S. ozarkensis*' nymph from those specimens, noting that Pritchard (1936) had made various errors in his description.

As the project commenced, we had a generally good idea of the habitat associations and phenology for adults but could only surmise larval habitat and phenology. Numerous experts dealing with *Somatochlora* as well as USFWS personnel with whom we work all agree that finding nymphs and determining their phenology and habitat needs is of high importance. Without such a discovery, any conservation strategy for the species will be sorely lacking. Moreover, given recent indication of negative impacts to this species from climate change (Boys et al. 2021), gaining a clear understanding of the species' life history and ecology is a must if we are to ensure its survival in the decades to come.

Crayfish – Inclusion in Study and Need for Data Compilation

Part of the motivation for inclusion of crayfish in the current study was to determine if there is an association of specific crayfish with larval Ozark Emeralds. At the beginning of the project, we and others hypothesized that *Somatochlora ozarkensis* nymphs might behave similarly to *S. hineana* (Hine's Emerald), the federally listed Endangered emerald species whose nymphs take refuge within crayfish burrows. Adding to our hypothesis was the recent discovery of nymphs of *S. margarita* (Texas Emerald), a closely related species to *S. ozarkensis*, in relative association with burrowing crayfish (Abbott 2015). As such, we thought it worthwhile to investigate associations of *S. ozarkensis* nymphs with crayfish. We paid special attention to burrowing crayfish and those designated as Species of Greatest Conservation Need (SGCN): the Kiamichi Crayfish (*Faxonius saxatilis*), a Tier I species, and the Mena, Painted, and Ouachita Mountain Crayfish (*Faxonius menae*, *Faxonius difficilis*, and *Fallicambarus tenuis*), all Tier II species.

<u>Methods</u>

Ozark Emerald (*Somatochlora ozarkensis*) Larval Sampling, Species Associations, and Habitat Assessment

Surveys for larval *Somatochlora ozarkensis* were conducted in the spring and summer of 2019 and the spring of 2021. Surveys were conducted by the D. C. Allen lab, with Daniel Nelson leading collections in 2019 and Stephen Cook in 2021. We surveyed 41 sites that included both areas of historical collection (Pritchard 1936) and potential habitats within the Ouachita Mountains, Arkansas Valley, and South Central Plains Level III ecoregions of southeastern Oklahoma (Fig. 2, red circles). Of these sites, 4 were in Latimer County in the Fourche Maline watershed near where exuvial *S. ozarkensis* were collected historically, 2 in Pushmataha County in the Kiamichi and Little River watersheds, 16 in Le Flore County in the Kiamichi and Mountain Fork River watersheds, and 19 in McCurtain County in the Mountain Fork River watershed.

Because *Somatochlora* larvae may inhabit a variety of aquatic habitats depending on species specific adaptations (Lee et al. 2006; Tennessen 2019), we sampled a variety of lotic habitats that spanned from small, forested streams to open-canopied streams and rivers. We conducted both opportunistic *S. ozarkensis* sampling and whole assemblage macroinvertebrate sampling along 100m of each stream visited and collected reach-wide habitat data using a modified version of the EPA's Rapid Bioassessment Protocols (Barbour et al. 1999) in 2021 to establish potential habitat associations with *S. ozarkensis*. Before biotic sampling, we measured in-stream water temperature (ºC), dissolved oxygen (mg L^{-1}), specific conductivity (µS cm^{-1}), and depth (m) at the thalweg of the sampled reach. We also quantified substrate characteristics (% silt, sand, gravel, cobble, boulder, and bedrock), as well as embeddedness (scored 0–100%) and the degree of sediment deposition (scaled from 0–20).

For opportunistic larval sampling, we sampled all available habitats within 100m of the stream entry point using a combination of dip- and D-frame nets, with special attention to marginal, snag, and underhang habitats. All non-odonate organisms were returned to the stream during this sampling, and candidate *S. ozarkensis* specimens retained in either glass collection vials or whirl-packs (Nasco Whirl-Pak™) and preserved in 75% EtOH. While in 2019 we ceased opportunistic sampling after 30 minutes regardless of if we had collected candidate *S. ozarkensis*, in 2021 we expanded our search effort (30 minutes to 1 hr.) and collected all odonates due to our inability to detect *S. ozarkensis* during the previous sampling year. We also incorporated odonates collected from a concurrent study in the region that ran from 2018 to 2019 which used the same sampling methodology and collection gear as the opportunistic portion of our study (26 additional sites, courtesy of Michelle Busch).

Whole-assemblage macroinvertebrate sampling was conducted using a 500µm mesh surber-style kick-net combined with a 12 by 12 inch sampling square at different locations ($n = 5$ per site) along the same stream reach sampled during targeted *S. ozarkensis* surveys. We sampled all habitats present (primarily riffles, runs, and pools) by placing the sampling square upstream of the kick-net and physically disturbing one cobble or boulder at a time to wash all stream organisms into the net. Once all large substrata were removed, the remaining gravel and sand was disturbed down to a depth of ~10cm and all dislodged organisms and material collected. In habitats where stream flow was not sufficient to carry organisms into the net, one person maintained constant flow by paddling water to prevent back welling and escape of organisms. All organisms and organic matter were combined into a reach-wide composite sample, field-preserved in 75% EtOH, and stored in whirl-packs.

To explore potential associations between larval *S. ozarkensis* and crayfish, at each site, we retained crayfish species sampled during both the targeted *S. ozarkensis* and whole-assemblage macroinvertebrate sampling. At a subset of sites, we also placed traps baited with raw chicken and hot-dog on a 12-hour soak to passively collect crayfish overnight (Appendix A). We distributed traps across the stream reach to sample all available habitats where practical but did not deploy traps in shallow riffles (water depth < depth of the trap) or runs because initial deployments indicated that these habitats yielded very low catch per unit effort. We also searched for crayfish burrows along the riparia during targeted *S. ozarkensis* and whole assemblage macroinvertebrate sampling.

Because COVID-19 related laboratory closures and restricted field activities in 2020 hindered laboratory processing, we restricted macroinvertebrate identification to odonates and crayfish collected from all samples to ensure we generated the highest priority data. All odonates were identified to species using Tennessen (2019) and crayfish were identified to species using

Morehouse and Tobler (2013) with updated phylogeny from Crandall and DeGrave (2017). A selection of odonates, including SGCN taxa, were examined by larval odonate experts Tim E. Vogt and Kenneth J. Tennessen for verification of species determinations. We did not receive conclusive determinations from Tennessen prior to submitting our report.

Ozark Emerald (*Somatochlora ozarkensis*) Adult Surveys, Monitoring, and Investigations of the Species' Life History and Ecology

Surveys in 2019 and 2021 for adult *Somatochlora ozarkensis* were conducted primarily opportunistically, as per previous ODWC project survey protocols (Smith-Patten and Patten 2016). Opportunistic surveys have proven to be an efficient and effective method for covering large areas with limited personpower while still producing large amounts of quality data. The technique has been used with a variety of organisms, including odonates (dragonflies and damselflies; e.g., Bried and Siepielski 2018; Patten et al. 2019). For a stream species like the Ozark Emerald, this survey method entails seeking out suitable or potentially suitable habitat for the species and either walking along a stream course for as far as one could within the given property limits or conducting surveys on dirt roads at times of the day when the species is actively feeding along them.

In addition to opportunistic surveys, timed surveys were conducted at a subset of larval sampling sites. These surveys were done for 20 minutes, watching for adults active within a 50-m reach along the stream. We also searched for exuviae. We chose to survey in 20-minute intervals because our years of experience with adults has indicated that is a sufficient amount of time to detect the species, if present. Known populations of the Ozark Emerald, for example the breeding population at Robbers Cave Wildlife Management Area (WMA), were monitored during the project for continued presence of the species.

All surveys were conducted during the day, starting shortly after dawn and ending around twilight. Surveys were conducted when a minimum ambient temperature of 65°F was reached and were paused during precipitation heavier than light sprinkles. A typical field day would consist of a series of surveys. In the early morning, on-foot surveying along creeks were the norm, with a shift to searching for feeding behavior along dirt roads after about 11:00 am. In the heat of the day, we searched for new suitable creeks that could be surveyed in another morning and for areas that would attract late afternoon/evening feeding swarms. On cloudy days, we could have luck and find feeding individuals along dirt roads earlier in the afternoon, so we were always vigilant for adults flying. Starting around 4:00 or 5:00 pm, individual *Somatochlora* will begin to come to feeding areas. By 6:00 or 7:00 pm, true feeding swarms of one or two dozen *Somatochlora* will form and will generally include other dragonfly species such as gliders (*Pantala* sp.), saddlebags (*Tramea* sp.), darners (Aeshnidae), and occasionally river cruisers (*Macromia* sp.). Active feeding tends to die down by 8:00 pm.

A total of 123 locations were visited at least once during the project period, with some sites visited multiple times (e.g., Ward Creek, in McCurtain County was visited three times). In addition, many hundreds of miles of roads were driven while searching for appropriate habitat and feeding Ozark Emeralds. Smith visited 27 larval sampling sites to assess suitability. Timed surveys were conducted at the majority of those sites. Surveys were conducted in Atoka, Latimer, Le Flore, and McCurtain Counties (Fig. 3; done during 30 days, or 34 "person days," as defined by a combination of the survey day, location, and specific surveyor who conducted the survey.

“Person days” are calculated to account for effort by multiple surveyors in the field on the same day.) between early May and mid-August 2019 and May and June 2021. Adult surveys were conducted independently of the larval sampling team due to scheduling conflicts. The majority of surveys were conducted by Smith (*n* = 27 person days), some of which were done with the assistance of others (mainly David Arbour, but also Bill Carrell, Paige Schmidt, Bruce Hoagland, Alex Cooper, Jona Tucker, and Steve Patterson). In addition, Michael A. Patten, a project collaborator, conducted seven independent person days of surveys within the framework of the grant. He surveyed one day at multiple sites in the Honobia WMA in Pushmataha County in suitable habitat outside of grant activities.

During all surveys, regardless of the survey method, number and sex of adults present were recorded as was the time of day, ambient weather, and behaviors. We paid particular attention to mating, territoriality, mate guarding, and where and on what substrate or surface ovipositing occurred. Adult presence was documented by specimen or photograph, when possible. Specimens were cataloged into the Brenda D. Smith Collection (SP).

Field research was supplemented with other records so that we could summarize the current state of knowledge of the life history and ecology of the Ozark Emerald. For example, the Oklahoma Odonata Project (OOP) database, which is maintained by Smith, was queried for pertinent records. New records of the species that were not associated with project activities were compiled and properly vetted. Smith reviewed records of the species submitted to online portals (iNaturalist, https://www.inaturalist.org and Odonata Central, https://www.odonatacentral.org) as well as those reported directly to her. These data were added to those Smith maintains for rangewide records of the species.

There are 151 rangewide records and reports known for adult *Somatochlora ozarkensis*. For analyses, we truncated these by 1) removing dubious records and 2) only using those with sufficiently precise geographical coordinates (i.e., records georeferenced with high coordinate uncertainty such as county centroids were omitted). The resulting records (*n* = 114) were categorized by activity: breeding, feeding, or unclassified. Breeding records (*n* = 15) were those where mating, ovipositing, tenerals, or exuviae were observed (Arkansas *n* = 3, Oklahoma *n* = 12; Kansas has an additional five records of possible breeding but they were excluded from analyses because they are currently considered dubious). Feeding records (*n* = 36: Arkansas *n* = 12, Oklahoma *n* = 16, Missouri *n* = 8) were those where individuals or groups were observed feeding. A single point could be categorized as both breeding and feeding, if multiple activities have been observed there. Records having no indication of behaviors were marked as “unclassified” (*n* = 63: Arkansas *n* = 23, Oklahoma *n* = 30, Missouri *n* = 10; three unclassified Kansas records were excluded).

Categorized records were used in ArcGIS analyses to examine habitat and physiographic associations with activities of *Somatochlora ozarkensis* adults. We used the National Land Cover Database Conterminous U.S. (NLCD CONUS) layers from 2001 and 2019 to provide broad land cover classes for rangewide data. We then used the Oklahoma Ecological Systems (https://www.wildlifedepartment.com/content/oklahoma-ecological-system-mapping) layer for refined habitat classes specifically for the Oklahoma breeding and feeding records. We used the spatial analysis zonal histogram tool in ArcGIS to create a table of frequency distributions of cell values per input class for each unique input zone. Input rasters consisted of 10-km buffers drawn around points that were differentiated by activity type (breeding versus feeding) defined by each variable examined. Point values were also obtained for elevation, roughness index, and topographic wetness index (twi; Beven and Kirkby 1979; Besnard et al. 2013) for Oklahoma records. We chose these three variables as alternative means of getting at physiographic characters that hold potential of explaining presence of *S. ozarkensis*. For example, elevation alone does not factor in how drastically the terrain may rise at a given location whereas the roughness index can do so (Smith and Patten 2021). Furthermore, twi considers slope and catchment in tandem as a predictor of water accumulation. Once results were obtained, we ran unpaired, two-tailed t-tests to determine statistical significance of differences found between datasets.

We used data from OOP to find odonate species associations with *Somatochlora ozarkensis* breeding locations within Oklahoma. From the near 55,000 records contained within OOP, we retained 8,915 by omitting centroid coordinates, records without species-level identification, and other problematic records. We used ArcGIS's clipping tool to determine which odonate species occurred within 1-km buffer zones of the breeding sites. We conducted a similar analysis to determine which crayfish species were associated with *S. ozarkensis* breeding sites. We used our dataset of crayfish found within the project area and performed a spatial join to the 1-km breeding site buffers to obtain specific species lists for each location within the project area. Additionally, we checked distances of approximately 2 km along stream courses for other crayfish records that were on shared streams of *S. ozarkensis* breeding sites that may have fallen just outside the buffer zone.

Compilation of Crayfish Data

We compiled data for the 22 crayfish species/species complexes known to occur within the Ouachita Highlands and the West Gulf Coastal Plains of Oklahoma (Table 1; Morehouse and Tobler 2013; Bloomer and Taylor 2020). Smith scoured databases and available literature as well as obtained unpublished data. Cook provided additional data from studies conducted by the D. C. Allen lab.

We accessed various data portals for crayfish records, including iDigBio (Integrated Digitized Biocollections, https://www.idigbio.org/portal/search), SCAN (Symbiota Collections of Arthropods Network, https://scan-bugs.org/portal/collections/index.php), Global Biodiversity Information Facility (www.gbif.org), Illinois Natural History Survey crustaceans database (https://biocoll.inhs.illinois.edu/portal/collections/index.php), Museum of Comparative Zoology at Harvard University (https://mczbase.mcz.harvard.edu/SpecimenSearch.cfm), National Museum of Natural History/Smithsonian Institution (USNM) invertebrate zoology collection (https://collections.nmnh.si.edu/search/iz), Invert E Base (https://invertebase.org/portal/collections/index.php), ARCTOS (https://arctos.database.museum), the American Crayfish Atlas (https://americancrayfishatlas.web.illinois.edu), and OBIS (the Oklahoma Biodiversity Information System, https://obis.ou.edu). We conducted searches for currently accepted taxonomy as well as known synonyms for each of the taxa. Geographic identifiers used in searches included "Oklahoma," "Indian Territory," and "Choctaw Nation" to capture contemporary records and those collected pre-statehood.

Additionally, some museums were contacted directly for data not yet published online or for clarification of specimen data: Biodiversity Institute & Natural History Museum, University of Kansas, Lawrence, Kansas; Biodiversity Research and Teaching Collections, Texas A & M University, College Station, Texas; Carnegie Museum of Natural History, Pittsburgh, Pennsylvania; Illinois Natural History Survey, Fishes and Crustaceans collection, University of

Illinois at Urbana-Champaign, Champaign, Illinois; and Smithsonian Institution, Department of Invertebrate Zoology, Washington, D. C. The D. C. Allen lab provided previously unpublished data including those obtained during their study of "Native and non-native crayfishes in southeastern Oklahoma" (F18AF00929, T-109-R-1) as well as previously unidentified material collected during a study of fish in the Clear Boggy, Muddy Boggy, Kiamichi and Little River Drainages (Matthews et al. 2016).

Table 1. Ouachita and West Gulf Coastal Plain crayfish (Cambaridae) species/species complexes for which data were compiled independent of project field sampling.

species/subspecies/complex	synonym(s)
Cambarellus puer	
Creaserinus fodiens	*Cambarus hedgpethi, Fallicambarus fodiens, F. hedgpethi, F. uhleri*
Fallicambarus schusteri	
Fallicambarus tenuis	*Procambarus tenuis, Cambarus tenuis*
Faxonius causeyi	*Orconectes causeyi*
Faxonella clypeata	*Cambarus clypeatus*
Faxonius difficilis	*Cambarus difficilis, Orconectes difficilis*
Faxonius lancifer	*Cambarus lancifer, C. faxonii, Orconectes lancifer*
Faxonius leptogonopodus	
Faxonius menae	*Orconectes menae*
Faxonius nais	*Cambarus nais, Orconectes nais*
Faxonius palmeri longimanus	*Orconectes palmeri, O. palmeri longimanus*
Faxonius saxatilis	*Orconectes saxatilis*
Faxonius virilis	*Orconectes virilis*
Lacunicambarus diogenes/ludovicianus	*Cambarus diogenes, C. diogenes ludovicianus, C. ludovicianus*
Procambarus acutus	*Procambarus (Ortmannicus) acutus, O. acutus, P. (Girardiella) curdi* (in part), *P. curdi* (in part), *G. curdi, Cambarus blandingi acutus, P. blandingi acutus*
Procambarus clarkii	*Cambarus clarkii*
Procambarus curdi	*Procambarus curdi, P. (Girardiella) curdi*
Procambarus dupratzi	*Procambarus dupratzii*
Procambarus gracilis	*Cambarus gracilis, P. (Girardiella) gracilis, Girardiella gracilis*
Procambarus liberorum	*Procambarus ferrugineus*
Procambarus simulans simulans	*P. (Girardiella) simulans simulans, Girardiella simulans simulans*

To obtain unpublished data we contacted Elizabeth A. Bergey, University of Oklahoma; Shannon K. Brewer, Auburn University; Wyatt Hoback, Oklahoma State University James M. Long, U.S. Geological Survey, Oklahoma Cooperative Fish and Wildlife Research Unit; Reid L. Morehouse, Ivy Tech Community College; Christopher A. Taylor, Illinois Natural History Survey, University of Illinois at Urbana-Champaign; and Michi Tobler, Kansas State University. We tried to contact Henry W. Robison, formerly of Southern Arkansas University, but were unable to reach him in his retirement. Chris T. McAllister, Eastern Oklahoma State College, was not able to provide additional data.

We data mined published and unpublished literature for crayfish data taken within the project area. These included: Bergey et al. (2005), Bouchard and Bouchard (1976), Crandall and De Grave (2017), Crandall et al. (2009), Creaser (1933), Creaser and Ortenburger (1933), Dunlap (1951), Faxon (1914), Hayes and Reimer (1975), Hobbs (1950, 1989), Hobbs and Robison (1989), Jones (2004), Jones et al. (2005), McAllister et al. (2011, 2016), Morehouse and Tobler (2013), Reimer (1968), Robison (2000, 2001), Robison and Crandall (2005), Robison et al. (2009), Robison and McAllister (2006, 2008, 2020), Taylor et al. (2004), Taylor and Robison (2016), and Williams (1951, 1954).

To avoid duplication of records, we took several precautions. For example, different data portals can contain the same specimen records; as such, we compared data downloads and culled duplicated records. Further, when records of genetic samples could be matched to their source specimen(s), data were combined into one record. When a specimen record could be matched with a literature record, the literature citation was added to the specimen record rather than entering as a separate line of data. We excluded data that could not be verified, such as iNaturalist (https://www.inaturalist.org) records that were part of some data portal downloads.

All resulting records were checked for data quality and corrected as necessary, including updating taxonomy, fixing obvious typographic errors, placing data within appropriate data fields, and noting inscrutable data quality issues. We ensured proper geographic placement of records by either plotting geographic coordinates provided by the source data custodian and correcting as needed or newly georeferencing collecting localities. These data were then used to plot distribution for all species known to occur in the study area (Appendix B). As requested by ODWC, all data will be imported to the Oklahoma Biodiversity Information System (OBIS), housed at the Oklahoma Natural Heritage Inventory.

Results

Ozark Emerald (*Somatochlora ozarkensis*) Larval Sampling, Species Associations, and Habitat Assessment

From 41 core sites and data from opportunistic collections from another 26 we catalogued 355 individuals of 24 odonate species (Appendix C). Though *Somatochlora ozarkensis* were quite rare, we collected a single specimen from Ward Creek west of the Ouachita National Forest within the Three Rivers WMA, McCurtain County (inset of Fig. 2; photographed, Fig. 4; identified by S. C. Cook and verified by T. E. Vogt, under examination by K. J. Tennessen at time of report and possibly disputed; cataloged as SP 3054 in the Brenda D. Smith Collection). Ward Creek is a well-oxygenated (10.84 mg L^{-1} dissolved oxygen), cool (12.7º C), forested stream (82.29% canopy cover) of medium size (5–10m wetted width; Appendix D).

The larval *S. ozarkensis* (Fig. 4) was collected during opportunistic sampling from a shallow, slack-water pool that is part of the main stem of Ward Creek (Fig. 5, lower right pane). While the pool was hydrologically connected to up- and downstream portions of the stream during our April visit (0.12m deep), flow likely becomes intermittent during drier times of the year. Gravel, sand, and silt comprised over half of the benthic substrate, which we believe provides suitable habitat for this elusive nymph. There was very little overhang and snag habitat, and no emergent vegetation near where the nymph was collected. *Somatochlora* larvae were best captured by kicking up fine sediment then sweeping the dislodged larvae into D-frame sampling nets. Extensive sampling of upstream riffle habitat yielded no *Somatochlora* species.

Both *Faxonius palmeri logimanus*, the Western Painted Crayfish ($n = 5$) and *Faxonius leptogonopodus*, the Little River Creek Crayfish ($n = 7$) were collected from Ward Creek (Appendix A), though, given both species' wide distribution in the region and the rareness of *S. ozarkensis*, it is unlikely that Ozark Emeralds preferentially use burrows as refugia during drying events (as in the case of *Somatochlora hineana*; Pintor and Soluk 2006).

Larval *Somatochlora linearis* co-occurred with *S. ozarkensis*, and might have similar overall habitat preferences as the latter, rarer species, although there may be microhabitat differences. Nineteen *S. linearis* were collected from 8 of the surveyed streams; 6 of which we also collected ancillary habitat data from (Table 2). All were well-oxygenated (> 10 mg L^{-1} DO), generally shallow streams with high proportions of smaller substrate sizes and generally more sediment than other streams in the region. The most robust populations of *S. linearis* were also collected in heavily canopied streams. We also collected several species of conservation concern in Oklahoma (Appendix C) including 11 *Zoraena talaria* (Ouachita Spiketail, syn. *Cordulegaster talaria*) from 5 locations, 2 *Helocordulia uhleri* (Uhler's Sundragon) from 1 location, 3 *Macromia pacifica* (Gilded River Cruiser) from 2 locations, and one specimen each of *Gomphurus ozarkensis* (Ozark Clubtail) and *Chromagrion conditum* (Aurora Damsel).

Table 2. Habitat data from sites where Somatochlora linearis were collected during 2021. S. linearis were less rare than S. ozarkensis, and likely have similar habitat preferences.

site code	**OZEM-21**	**OZEM-32**	**OZEM-36**	**OZEM-37**	**OZEM-40**	**OZEM-41**
date	2021-03-19	2021-04-20	2021-04-23	2021-04-23	2021-04-23	2021-04-23
watershed	Kiamichi R.	Mtn. Fk. R.	Mtn. Fk. R.	Mtn. Fk. R.	Mtn. Fk. R.	Mtn. Fk. R.
stream	Caney Cr.	UNT Cow Cr.	Hurricane Cr.	UNT Mtn. Fk. R.	Ward Cr.	UNT Roosevelt Cr.
depth (m)	0.46	0.18	0.18	0.09	0.12	0.15
temp (°C)	13.1	13.5	12.1	11.0	12.7	12.2
DO (%)	100.4	109.6	101.1	105.2	102.2	111.5
DO (mg/L)	10.56	11.43	10.87	11.61	10.84	11.96
sp. cond. (µS cm^{-1})	60.3	40.3	36.6	56.7	27.9	36.2
silt (%)	0	20	5	10	15	15
sand (%)	0	15	5	10	15	20
gravel (%)	10	30	15	30	30	40
cobble (%)	65	25	20	40	25	20
boulder (%)	25	10	40	10	5	5
bedrock (%)	0	0	15	0	10	0
CWD (%)	0	0	0	0	0	0
embeddedness (%)	10	30	10	40	15	25
sediment (0-20)	16	13	13	11	16	13
canopy cover (%)	5.21	100.00	26.05	100.00	82.29	91.67
no. of *S. linearis*	1	7	1	1	1	1

abbreviations: Cr. = Creek, CWD = coarse woody debris, DO = dissolved oxygen, Fk. = Fork, Mtn. = Mountain, R. = River, UNT = unnamed tributary

Ozark Emerald (*Somatochlora ozarkensis*) Adult Surveys, Monitoring, and Investigations of the Species' Life History and Ecology

Adult Ozark Emeralds were encountered positively at eight locations (1 in Atoka, 1 in Latimer, 2 in Le Flore, and 4 in McCurtain Counties; Table 3) during the project. Five of these were new locations for the species. Possible encounters occurred on four occasions at three locations in Le Flore and McCurtain Counties. Of the 30 days surveys occurred in 2019 (n = 23) and 2021 (n = 7), nine produced definite or possible encounters with *S. ozarkensis*. Encounter rate varied by year, with 2019, despite many more surveys, having the species encountered a mere 22% of the time versus 57% in 2021. Numbers of individuals encountered were also lower in 2019, with only 1–2 individuals observed at a time, whereas in 2021, multiple small (n = 5) to large-size ($n \geq 20$) feeding swarms were encountered as well as single individuals. Encounters with adults among years occurred between 1 June and 16 August. One nymph was collected in 2021 (see larval results above) but no exuviae were found in either year.

Table 3. Results of survey and monitoring activities for adult Ozark Emerald (Somatochlora ozarkensis) during the project.

	2019	**2021**
locations species encountered	4	4
locations species possibly encountered	1	3
counties	Atoka, Le Flore, McCurtain	Latimer, Le Flore, McCurtain
# of days surveyed	23	7
# of days species was or possibly was encountered	5	4
Somatochlora ozarkensis individuals encountered	6	35
definite	3♂, 2♀	5♀
possible/probable	1♂	3♂, 1♀, 26 unsexed
specimens collected	2	3

Of the new locations documented for the species during the project, two can be considered potential breeding sites given that each had one female ovipositioning. Smith witnessed the first occurrence on 16 August 2019, when a female oviposited in two bouts between approximately 10:10–10:20 am. Ovipositioning occurred in a side channel (Fig. 5) near where it met an unnamed creek (Fig. 5) in the Ouachita National Forest, McCurtain County. About 20 m above the junction was a dirt road with a drainage pipe through which water from a seep on the other side of the road drained down to the creek. The first bout of egg laying was done within damp moss that was on a small rock. There was just a trickle of clear water to the side of the rock. After laying eggs, she flew to a nearby tree and hung on a bare branch for about 3 minutes. She then returned to the same general area but this time she oviposited in a pooled area that was about 12 cm in diameter with a trickle of water moving through the pool. The main creek was of bedrock substrate with piled rock along its course. Portions of the creek were no longer flowing and there were intermittent pools. Downstream Smith encountered an ovipositing female *Somatochlora linearis* (Mocha Emerald) who laid eggs on mossy rocks near moderate flow of clear water. Within a few seconds of her leaving, a male *S. tenebrosa* (Clamp-tipped Emerald) began patrolling a couple of meters from where she laid her eggs. Shortly after, a second male *S. tenebrosa* flew in, the two males fought, with one flying away and the other being caught by Smith as a voucher (SP 2906; approximately 10:30 am). The overall seep/spring and creek complex was within hardwood forest, thus mostly shaded, and the main creek was about 1–5 m wide and had generally moderate flow of clear water that was 2–4 cm deep.

Intermittent pools were found along the creek and portions of the course had abrupt (about 1 m high) rocky slopes whereas others would be gently sloping and less rocky. Weather conditions at the site during observations of the three emerald species was 74° F and no wind or cloud cover. The only other odonates detected were *Calopteryx maculata* (Ebony Jewelwing, 8♂, 6♀) and *Argia translata* (1♂).

The second site at which ovipositioning was witnessed was at Ward Creek, Three Rivers WMA, McCurtain County, at the same road crossing where the *Somatochlora ozarkensis* nymph (SP 3054) was collected on 22 April 2021. Smith visited the site with ODWC biologist, Alex Cooper, on 22 July 2021 while conducting fieldwork for another project. This encounter (at 9:54 am) was much briefer, as the emerald dipped only 4–5 times before flying downstream. She oviposited in a gravelly and rocky (mostly walnut-sized to two fist-sized gravel/rocks) spot with 1–2 cm deep clear water. Flow was not readily perceptible, being minor at best but there was flowing water within about 20–30 cm. The ovipositing site (Fig. 5) was near a rock face that was 10–12 m high and that had a small pool at its base. This was within 100 m upstream of the collection site of the *S. ozarkensis* nymph, which was one of the intermittent pools along the creek. The creek itself was 5–10 m wide and has low to moderate flow of clear or slightly cloudy water. Trees were between 15 and 30 m tall and were mostly hardwoods with a smattering of evergreens. A good number of trees overhung the creek, shading it and boxing it in to some extent. Earlier in the year (16 and 24 June 2021) the creek was quite a bit higher with a stronger flow, but on the 22 July 2021 visit, there were portions of the gravely, rocky, bedrock, and sandy substrate exposed. During this visit, the weather conditions were 78–84° F, no wind or cloud cover. Fourteen other odonate species were seen along the creek or on the nearby road during the three visits to the creek by Smith in 2021 (Table 4).

Table 4. Odonate species encountered by Brenda D. Smith during surveys at Ward Creek, Three Rivers WMA, McCurtain County, Oklahoma, in 2021.

16 June 2021, 10:20–10:55 am
Calopteryx maculata 1♂, *Epiaeschna heros* 1♂, *Neurocordulia xanthosoma* 1♀ (photo), 1 possible ♂ *S. ozarkensis*, *Cordulegaster obliqua* 2 unsexed, *Libellula vibrans* 1♂
24 June 2021, 8:20–9:55 am*
on creek: *Calopteryx maculata* 12♂, 8♀; nearby or on road: *Phanogomphus graslinellus* 1♀ (photos, specimen as SP 3008), *Somatochlora linearis* 1 unsexed, *S. ozarkensis* 1♀ (photo; Fig. 6), at least 1 *S. ozarkensis/tenebrosa*, *Cordulegaster obliqua* 1♂ (photos), *Plathemis lydia* 1♂, 1♀, *Erythemis simplicicollis* 1♀, *Tramea lacerata* 1 unsexed, *Pantala hymenaea* 1 unsexed
22 July 2021, 9:30–11:00 am
Argia apicalis 2♀, *A. translata* 1♂, *Macromia illinoiensis georgina*, cf 1♂, *Plathemis lydia* 2♂, *Libellula vibrans* 1♂

*surveyed at creek and along dirt road

We found no statistically significant differences between breeding and feeding sites of land cover quantifications within 10-km buffers using 2019 NLCD data alone or comparing 2001 and 2019 NLCD to examine land cover change over time (Table 5). One land cover designation in the Oklahoma Ecological Systems, i.e., Ozark-Ouachita: Dry Oak Woodland, produced a statistically significantly result (Table 6).

Oklahoma breeding sites (n = 12) were found at elevations between 117–379 m (mean = 231.8), within a mean roughness index of 11.6 (SD 3.09; min 5, max 18), and a mean topographic wetness index (twi) of 8.3 (SD 1.66, min 6.3, max 11.6). Feeding sites (n = 16) were found between 140–791 m (mean = 335.8), within a mean roughness index of 13.3 (SD 4.6, min 6, max 22) and a mean twi of 7.5 (SD 1.7, min 5.3, max 12.4). Calculated p values of elevation, roughness index, or twi (0.29, 0.08, 0.21, respectively) were not statistically significant between breeding and feeding sites.

Table 5. Association and changes over time of National Land Cover Database (NLCD, 2001 v. 2019) designations to adult *Somatochlora ozarkensis* records rangewide[1] for breeding and feeding activities. Values are percentages of classified land cover data within 10-km buffers.

NCLD type	breeding_2019	breeding_2001	*p* value	feeding_2019	feeding_2001	*p* value
development	7.1	5.5	0.20	5.9	5.8	0.64
evergreen forest	41.3	39.8	0.78	44.9	43.8	0.48
mixed forest	37.5	40.5	0.16	38.1	40.3	0.87
cropland	14.1	14.2	0.73	11.1	10.2	0.62

[1]Arkansas, Oklahoma, and Missouri records were used. Kansas records, which are still considered dubious, were excluded. Breeding records: NLCD2001 (n = 15), NLCD2019 (n = 14); feeding records: NLCD2001 (n = 32), NLCD2019 (n = 34).

Table 6. Oklahoma Ecological Systems habitat classifications associated with breeding (n = 11) and feeding (n = 14) records of adult *Somatochlora ozarkensis* in Oklahoma. Values are percentages of habitat type within 10-km buffers of all points for each activity type.

Oklahoma Ecological Systems habitat type	breeding	feeding	*p* value
Ozark-Ouachita: Pasture/Prairie	7.8	4.9	0.10
Ozark-Ouachita: Dry-Mesic Oak Forest	10.6	12.7	0.43
Pine Plantation	13.9	19.0	0.77
Pine Plantation - 1 - 3 meters	3.8	5.4	0.84
Ozark-Ouachita: Shortleaf Pine - Oak Forest	14.5	24.2	0.82
Ozark-Ouachita: Dry Oak Woodland	21.2	11.7	0.01*

*statistically significant defined as <0.05

Compilation of Crayfish Data

Prior to the project, there were only 103 statewide records of crayfish in the OBIS database, with 26 from southeastern Oklahoma (Fig. 7). During the project, we increased the number of records in OBIS to 3,180 statewide, with 2,657 of those from the southeastern corner of the state (Fig. 7, Table 7, Appendix B). Species of Greatest Conservation Need (SGCN) species accounted for 263 records. *Faxonius saxatilis* (Kiamichi Crayfish), a Tier I SGCN species, comprised 90 records, with 173 found for the three Tier II SGCN species of *Fallicambarus tenuis* (Ouachita Mountain Crayfish), *Faxonius difficilis* (Painted Crayfish), and *Faxonius menae* (Mena Crayfish).

Table 7. Results of compilation of crayfish (Cambaridae) data for project area in southeastern Oklahoma.

species/subspecies	known rangewide records	project area records	notes
Cambarellus puer	2	2	
Creaserinus fodiens	5	5	
Fallicambarus schusteri	4	4	
Fallicambarus tenuis	86	86	ODWC Tier II
Faxonius causeyi	17	1	
Faxonella clypeata	3	3	
Faxonius difficilis	60	42	ODWC Tier II
Faxonius lancifer	3	3	
Faxonius leptogonopodus	158	158	
Faxonius menae	27	27	ODWC Tier II
Faxonius nais	167	11	
Faxonius palmeri longimanus	2,096	2,043	
Faxonius saxatilis	90	90	ODWC Tier I
Faxonius virilis	76	2	
Lacunicambarus diogenes/ ludovicianus	4	4	species complex
Procambarus acutus	165	108	
Procambarus clarkii	5	2	
Procambarus curdi	19	12	
Procambarus dupratzi	4	4	
Procambarus gracilis	11	11	
Procambarus liberorum	12	11	
Procambarus simulans simulans	166	28	
total	3,180	2,657	

Discussion

Somatochlora ozarkensis (Ozark Emerald)

Surveys for *Somatochlora ozarkensis* (Ozark Emerald) adults were successful as were monitoring efforts. Additionally, we were the first research team to discover and collect a *S. ozarkensis* nymph from the wild.

We added new locations for the species (e.g., Bee Seep, Three Rivers WMA) and confirmed its continued presence at Atoka WMA, in the Broken Bow Lake area, along the Talimena Highway, and at Robbers Cave WMA (Fig. 6). Encounters along the Talimena Highway in 2021 suggest that the local population remains healthy. But, the paucity of encounters in 2019 and other data over time indicate that the population fluctuates year to year. Seeking out feeding swarms in areas known to host such swarms, e.g., the Talimena Highway and dirt roads near Broken Bow Lake, is a useful way to gauge relative abundance in a given year. These swarms contain both young and older individuals and data suggest that females may predominate. Additional research investigating sex ratio in swarms is needed and would be useful in characterizing the population structure of this species. Feeding swarms provide valuable data points, too, by allowing for investigators to radiate out searches for the species at nearby creeks. Swarms are most successfully found in the late afternoon/early evening (especially 6:30–8:00 pm; occasionally late morning from 10:30 or 11:00 am until noon) along east-west roads. Areas along these roads at which a grassy area occurs or a dirt road crosses can cause a “crossroads effect” that pins in swarms and their prey of small flying insects. Smaller numbers of adult can be found on creeks, which are where most encounters with males have occurred.

Despite being hopeful that surveys in May would produce early season records of adults of the species, encounters were only noted between 1 June and 16 August, which is consistent with what was previously known of the species’ adult phenology in southeastern Oklahoma (28 May to 23 August). The *Somatochlora ozarkensis* nymph we recovered was taken on 22 April but it needed some further development before it would have been ready to emerge, which likely would have been in the summer of 2021. We continue to suspect that this species has a 2-year aquatic life span. Further, our hypothesis that nymphs would be found in pools just downstream of ovipositing sites was confirmed by encounters on Ward Creek. Previous discovery of a teneral at Robbers Cave WMA also indicates that larval development occurs on ovipositing creeks, as opposed to there being a need to develop/emerge on a larger stream; as such, the close physical association (tens of meters) of these provide evidence for shared overall habitat of lifestages.

We lack sufficient records of nymphs to say for certain, but we feel the idea of nymphs taking refuge within crayfish burrows is not likely. The pool where the larval *S. ozarkensis* was collected was dominated by fine silt, sand, and gravel. The specimen also required extensive cleaning to remove fine sediment particles from setae prior to identification. This, combined with the lack of emergent vegetation and under-hang marginal habitat suggests *S. ozarkensis* hides, during optimal habitat conditions, in finer sediments both to avoid predation and for hunting activity. We now suspect that during less optimal conditions, such as times of the year when creeks lose flow and become virtually dry, nymphs may take harbour within bedrock crevices where moisture can remain. To investigate this hypothesis, it would be necessary to devise a way to vacuum such crevices to extract hiding nymphs.

It may still be that *Somatochlora ozarkensis* nymphs are associated, at least broadly, with some crayfish species. For example, multiple *Faxonius* species have been taken along *S. ozarkensis* breeding streams in southeastern Oklahoma. *Faxonius palmeri longimanus*, the Western Painted Crayfish, was present at/near all five breeding sites with associated crayfish data. *Faxonius leptogonopodus*, the Little River Creek Crayfish, was at/near two breeding locations. Cooper Creek produced the most species of *Faxonius* (*palmeri longimanus*, *virilis*, the Virile Crayfish, and *menae*, the Mena Crayfish, the latter an SGCN species) as well as a burrowing crayfish, *Procambarus acutus*, the White River Crawfish. It is unclear if there is an ecological relationship here, but this is not the first time crayfish and *Somatochlora* nymphs have been found in association. Abbott (2015), for instance, reported crayfish of the *Lacunicambarus diogenes/ludovicianus* complex and those identified only to genus/subgenus as *Procambarus* (*Girardiella*) at one location where they found a nymph of *S. margarita* (Texas Emerald), an emerald of the *S. filosa* species group that also includes *S. ozarkensis*. Larval odonates reported from *S. margarita* nymph collection sites were *Calopteryx maculata* (Ebony Jewelwing), *Cordulegaster obliqua* (Arrowhead Spiketail), and *Epiaeschna heros* (Swamp Darner). These odonate species, in various lifestages, have been found in association with *S. ozarkensis* as well.

Looking specifically at *Somatochlora ozarkensis* breeding sites in Oklahoma, we note that there are about 90 odonate species found within 1-km buffers of those sites. Not surprisingly, some are primarily lotic (flowing water) species, such as *Calopteryx maculata*, *Hetaerina titia* (Smoky Rubyspot), *Boyeria vinosa* (Fawn Darner), *Stylogomphus sigmastylus* (Least Interior Clubtail), *Macromia pacifica* (Gilded River Cruiser), *Neurocordulia xanthosoma* (Orange Shadowdragon), *Somatochlora tenebrosa* and *linearis* (Clamp-tipped and Mocha Emeralds). Most of these lotic species are not terribly tolerant of poor water quality or severe habitat disturbance and/or are species of conservation concern (Smith and Patten 2021). Four other associated species are classified as Tier II SGCN: *Argia bipunctulata* (Seepage Dancer), *Cordulegaster* (*Zoraena*) *talaria* (Ouachita Spiketail), *Gomphurus ozarkensis* (Ozark Clubtail), and *Phanogomphus oklahomensis* (Oklahoma Clubtail). Not all of the SGCN species are directly associated with *Somatochlora ozarkensis* breeding sites (e.g., the first two are seep species), but their presence in the area attests to the sensitivity of habitat at and near *S. ozarkensis* breeding locations.

Adding two additional breeding and a handful of feeding sites during the project extended our knowledge of the elevational range of the species, currently known from 117–791 m, and added to our understanding of overall terrain associations. The Ozark Emerald is indeed a highland species of rather rugged terrain where, as indicated by low twi values, there is little water accumulation. The latter may help explain why previous habitat assessments (Smith-Patten and Patten 2016; Smith and Patten 2021) have shown that the streams the species occurs on can dry, at least partially but sometimes fully, by the time the species stops flying for the year. Although we did not conduct habitat assessments to the same extent, sites at which *S. ozarkensis* was detected in 2019 and 2021 were consistent with how Smith and Patten (2021:454) described the adult habitat:

> Substrate varies from bedrock exposure to streambeds full of gravel and boulders. Stream width tends to be about 0.5–5 m (~1.5–16 ft) but can be as wide as 12 m (~40 ft). Water depth can be just a trickle to >1 m (~3 ft), although it appears that males defend territory where the water is about 2 cm to <1 m (<1 inch to <3 ft) and females may have a preference of ovipositing where there is just a trickle of water over gravel or pebbles. The overall water regime of streams can be flowing or dried to the point where but a few pools exist along its length. Water temperature varies enormously (16.0–35.85°C [60.8–96.53°F]), as does pH (6.30–8.91). And streams can be found within hardwood or mixed forest.

Our examination of land cover classifications across the range of *Somatochlora ozarkensis* as well as that at a finer scale specifically for Oklahoma confirmed that the species is found in mixed pine-oak forest and nearby pine plantations. Although there may be some habitat differences between breeding and feeding *S. ozarkensis* sites, our analyses were not able to detect them.

There are several conservation and management implications for *Somotachlora ozarkensis*. These include the concern that water flow may decrease from climate change or from other activities. Increased drying of these streams, e.g., within the bedrock crevices we suspect *S. ozarkensis* nymphs harbour during periods of limited to no water flow, will cause extirpation of this species from their breeding streams. Extirpation anywhere within this regionally endemic species' relatively tiny range would have dire consequences. Climate change scenarios (Boys et al. 2021) indicate that this species will experience significant range constriction and that the Ouachitas will be the species' primary refuge. Therefore, it is critical for this species' survival that habitat within the Ouachitas is conserved.

Surrounding habitat structure and composition is also of concern. For example, a non-trivial amount of habitat within 10 km of known *Somatochlora ozarkensis* localities consists of pine plantations, which could affect this species. Pine plantations, given their standardized growth and eventual clear-cutting, obviously cannot mimic the natural environment of the Ozark Emerald, but they do offer feeding opportunities because of the number of smaller insects they attract. If pine plantation operations can assure, for example, that chemical use (e.g., pesticides, herbicides) and disturbed sediments do not get carried into streams and that riparian zones are left unaltered, then perhaps those operations will have limited negative impact on the Ozark Emerald. But, further study is warranted to determine if structure of plantations and other activities may adversely affect this species' long-term survival. Other activities in the Ouachitas that may restrict water flow, increase sedimentation, or introduce pollutants should be strictly limited. If they do occur, then habitat and water quality monitoring should be implemented and activities should be halted whenever adverse conditions arise.

Tangential benefits of project aquatic sampling

Additional benefits of this project were that we discovered new breeding locations in Oklahoma for *Cordulegaster* (*Zoraena*) *talaria*, a Tier II SGCN. Prior to this project we knew of only 16 records of the species at 10 locations within its entire range; only two of these records were in Oklahoma. We now have a handful of occurrences within Oklahoma, including multiple breeding sites in McCurtain and Le Flore Counties.

All told, although our target was the nymph of *Somatochlora ozarkensis*, we tangentially were able to make significant contributions to the distribution, life history, and ecology of this SGCN species. For example, we thought this species' entire life history occurred within forested seeps, but it now appears that later instar nymphs may migrate down to streams for emergence. We now know that we should seek tenerals at stream edges as well as within seep complexes. Other species of conservation concern, including SGCN species, we learned more about during the project include *Helocordulia uhleri*, *Macromia pacifica*, *Gomphurus ozarkensis*, and *Chromagrion conditum*.

Manuscripts detailing the life history and ecology of *Somatochlora ozarkensis* and *Cordulegaster* (*Zoraena*) *talaria* will be submitted for publication (Smith et al., mss. in prep).

Crayfish

Field collections and data compilation greatly added to our knowledge of the distribution of the crayfish of southeastern Oklahoma. The Oklahoma Biodiversity Information System was considerably enhanced by the almost 2,700 records from southeastern Oklahoma we added to it. These data have been and will continue to be used to refine species distributions in the American Crayfish Atlas (https://americancrayfishatlas.web.illinois.edu). Further, Smith plans to review conservation ranks of crayfish for the state as part of the Oklahoma Natural Heritage Inventory's work with the NatureServe ranking schema.

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Significant Deviations:

Restrictions to fieldwork and closures of research spaces due to the COVID-19 pandemic significantly altered the research timeline and scope that was originally proposed. After consultation with ODWC personnel, we revised the project budget and rolled the remaining travel funds from 2020 into 2021 for a final sampling bout. After campus reopening, no additional personnel funds were available for the project. To ensure that valuable occurrence and distribution data for *Somatochlora ozarkensis* larvae was still generated from this project, we devoted the remainder of available resources to the identification and enumeration of larval Odonates collected from all samples collected in 2019 and 2021, and the additional sampling bout in spring 2021.

Equipment: No equipment was purchased.

Prepared by: Brenda D. Smith Oklahoma, Natural Heritage Inventory, Oklahoma Biological Survey, University of Oklahoma, Norman Oklahoma

Stephen C. Cook' Department of Biology, University of Oklahoma, Norman, Oklahoma

Daniel C. Allen, Department of Biology, University of Oklahoma, Norman, Oklahoma; Department of Ecosystem Science Management and, Penn State, University Park, Pennsylvania

Date Prepared: September 10, 2021

Approved by: Ken Cunningham, Assistant Chief of Fisheries
Oklahoma Department of Wildlife Conservation

Andrea K. Crews, Federal Aid Coordinator
Oklahoma Department of Wildlife Conservation

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Figures:

Figure 1. Known geographical range of the Ozark Emerald (*Somatochlora ozarkensis*) plotted within ecoregions. Localities with breeding indicators (e.g., mating, ovipositioning, teneral, exuviae) are shown. Note that most Kansas records are considered dubious pending further investigation as are the small number of reports of the species in the coastal plains (South Central Plains shown on the map). The two Comanche County, Oklahoma, reports of the species are also considered dubious until physical evidence is obtained.

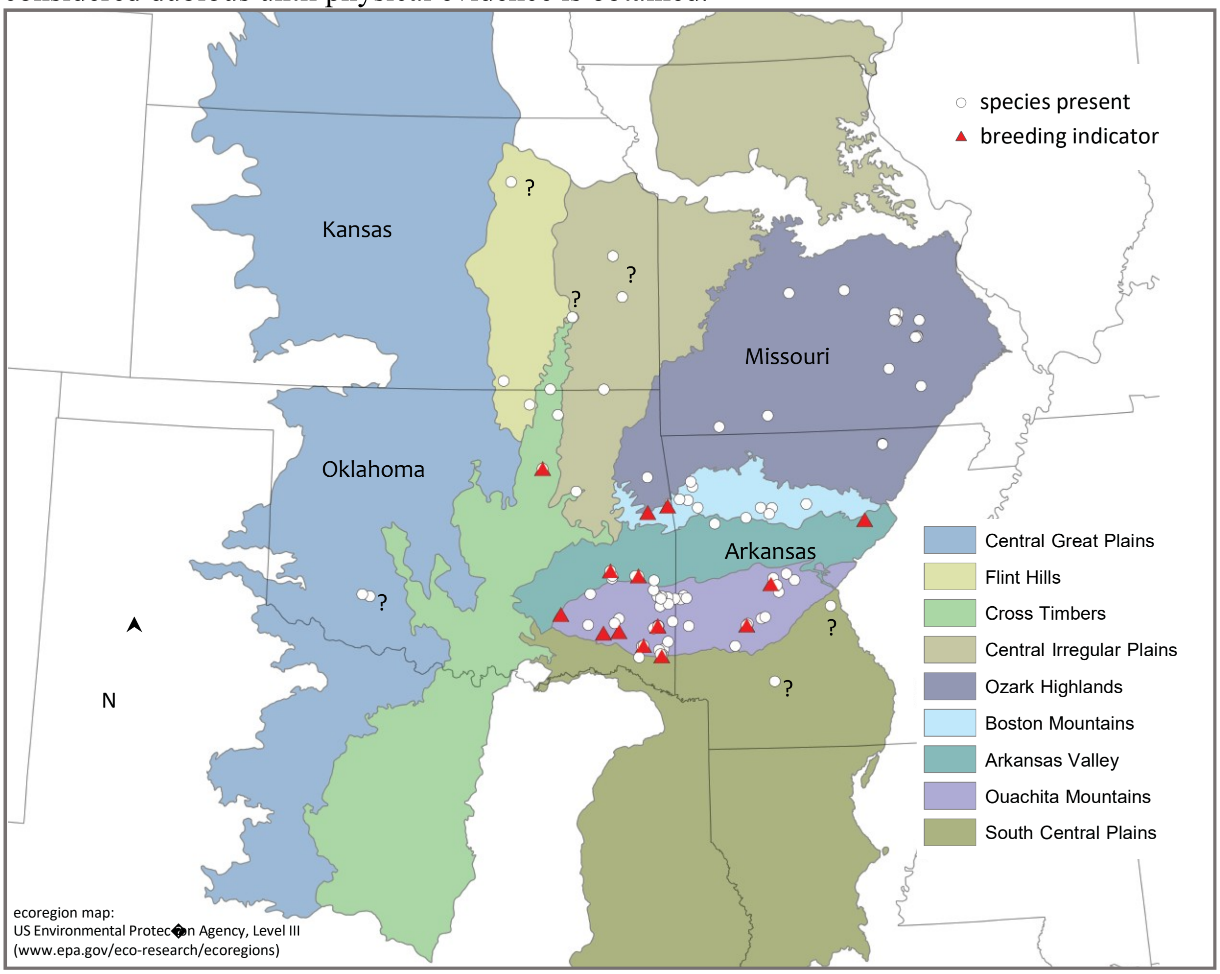


Figure 2. Locations of larval *Somatochlora ozarkensis* sampling sites during 2019 and 2021. Orange circles denote sites where full opportunistic and quantitative sampling was conducted (*n* = 40), and purple triangles denote sites where only opportunistic sampling occurred (*n* = 26). The inset is an expanded map to show the dotted-line region on the map where a larval *Somatochlora ozarkensis* (SP 3054) was collected in April 2021 (red star).

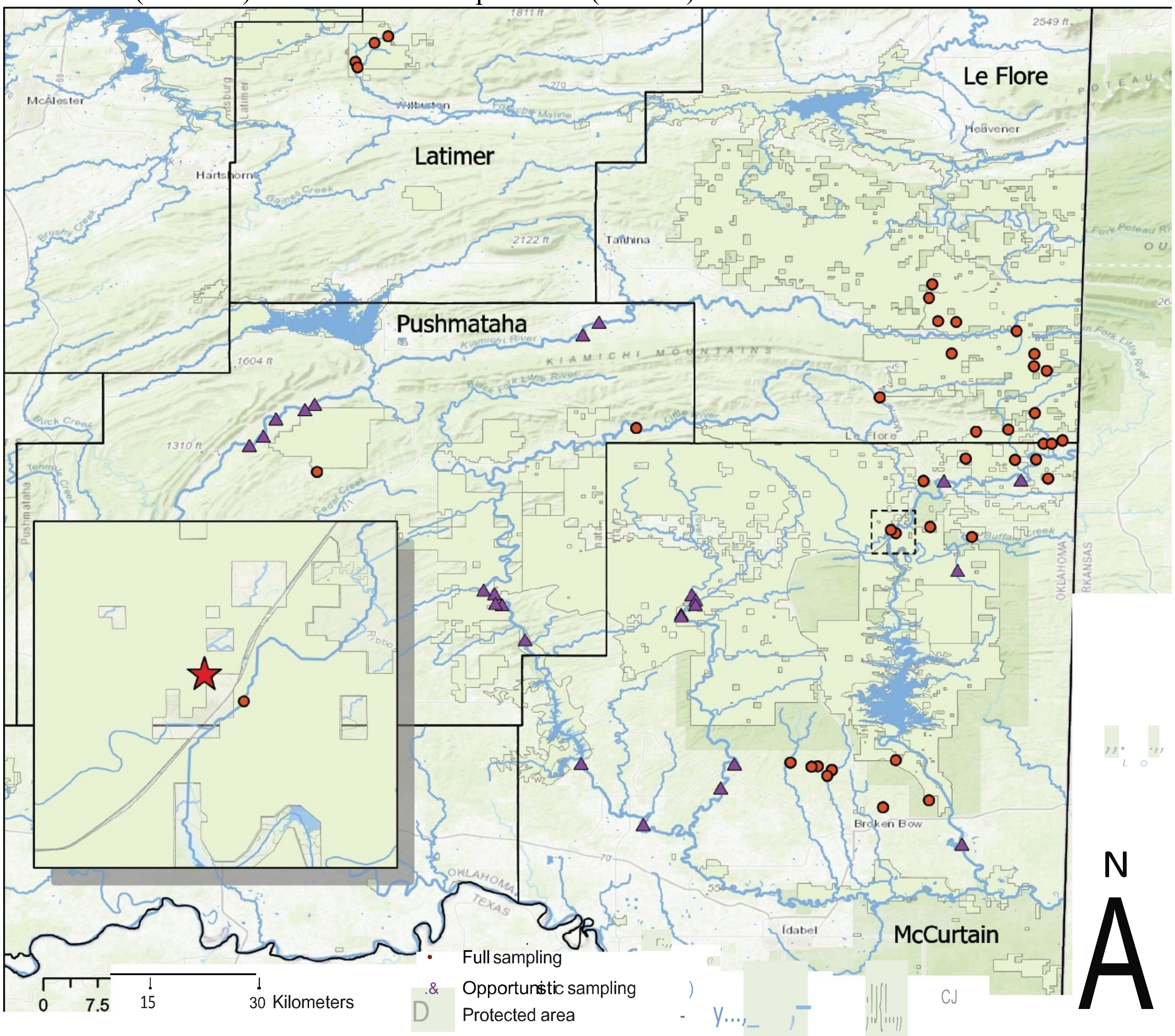


Figure 3. Locations of adult *Somatochlora ozarkensis* survey sites during 2019 and 2021. Red triangles denote survey sites where adult *S. ozarkensis* were or potentially were observed during the project.

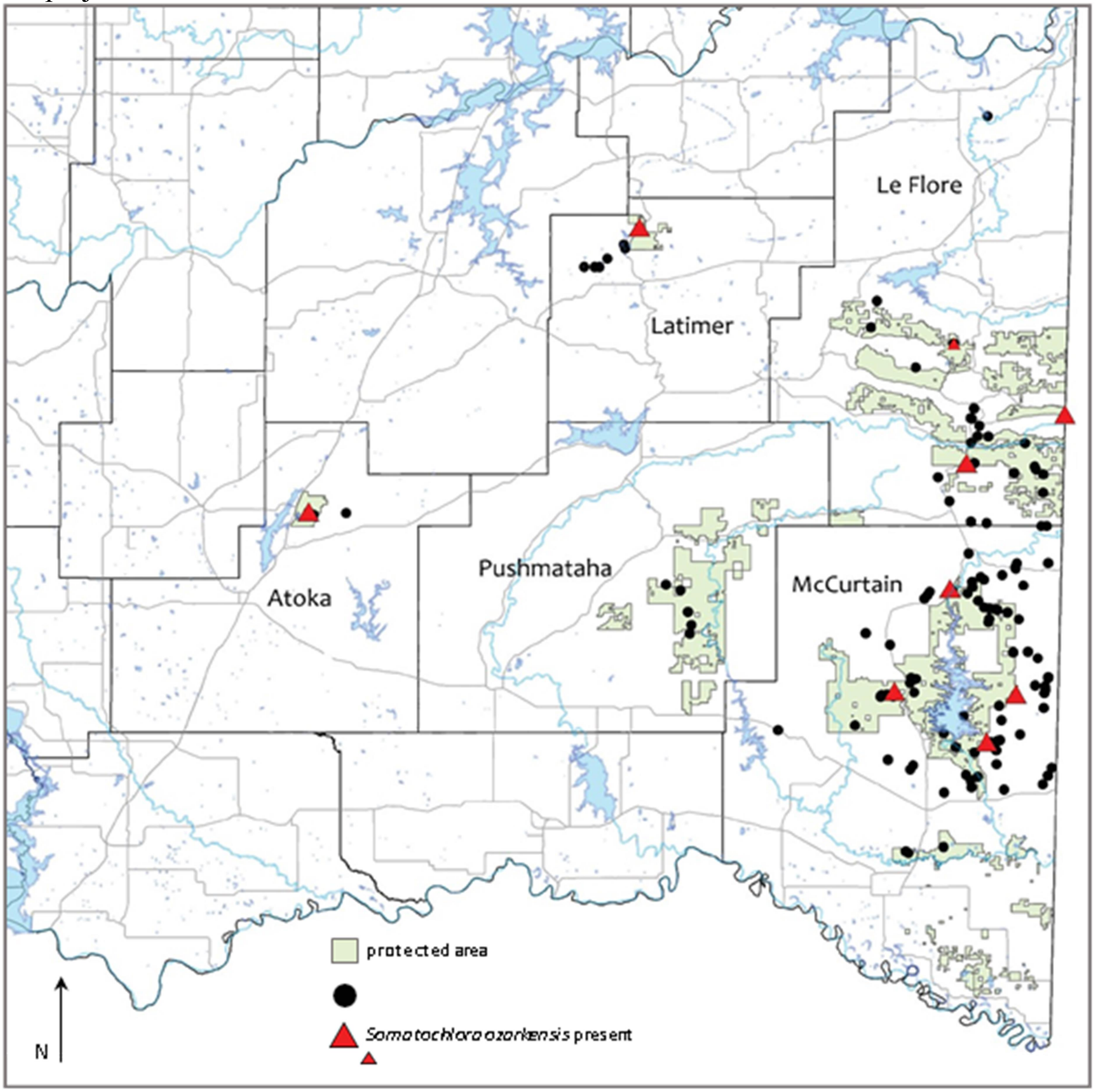


Figure 4. Photographs of the larval *Somatochlora ozarkensis* (F-0 instar, SP 3054) collected from Ward Creek, Three Rivers WMA, McCurtain County, Oklahoma, in April 2021 (A). Prominent mid-dorsal hooks are present on abdominal segments (S) 6–9, and S9 posterolateral spine has a basal W:L=0.79 (measured in pixels, inset of pane A). *Somatochlora ozarkensis* differs from congeneric species in having only short setae behind the eye (B, left pane) and having many short setae lining the posterior margins of S6–S8 (B, right pane).

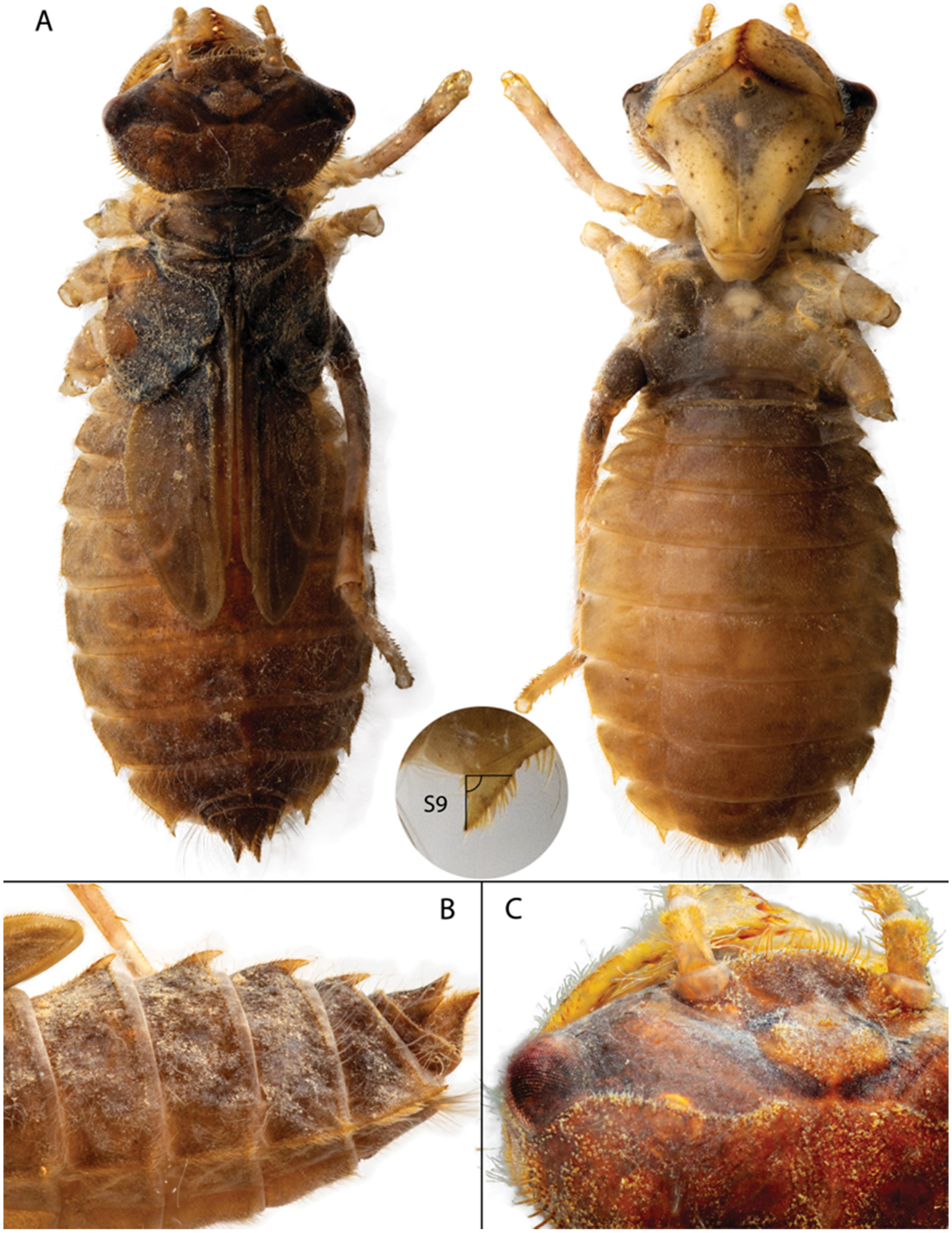
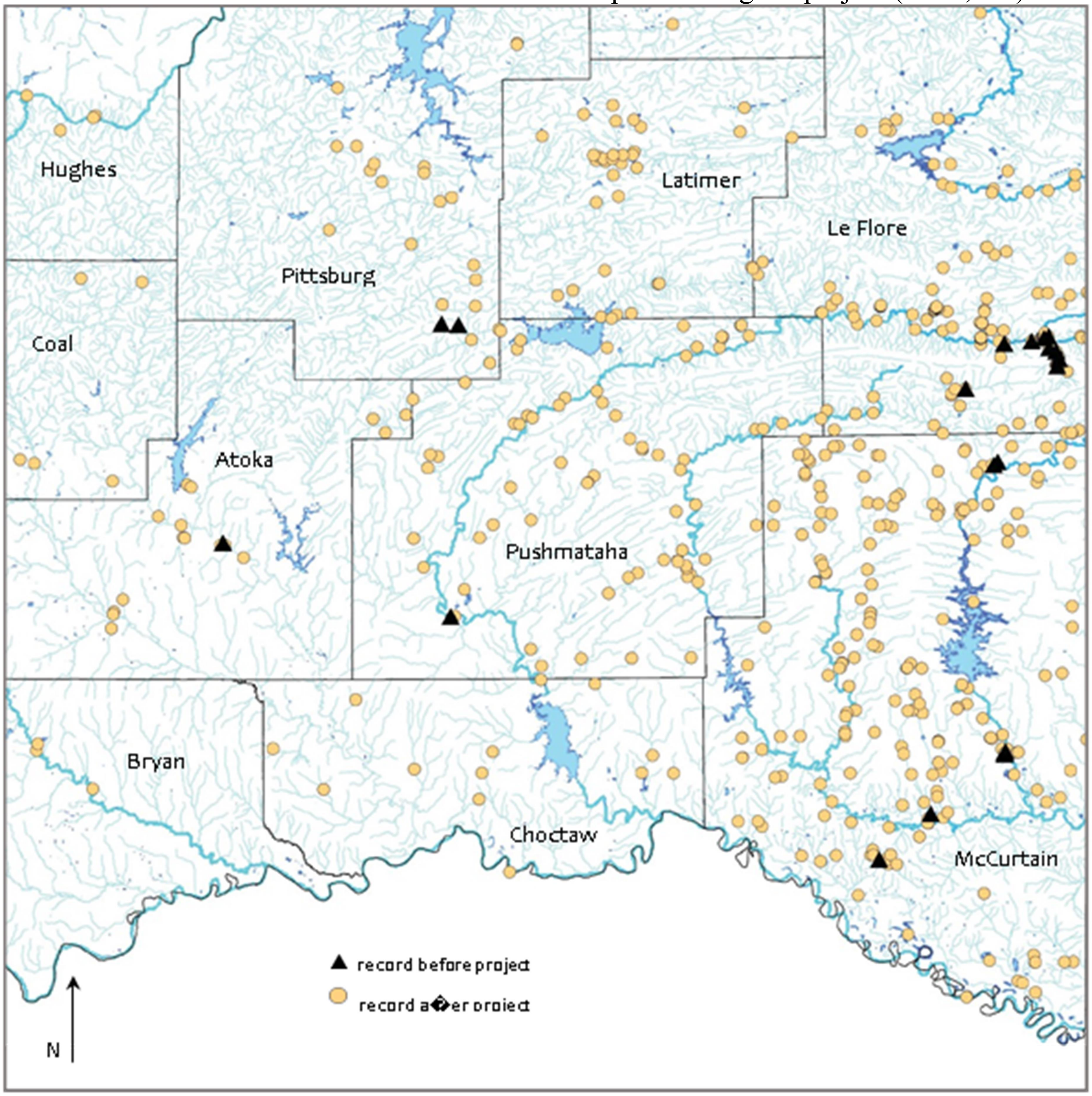


Figure 5. Two new *Somatochlora ozarkensis* breeding sites discovered during the project. An unnamed creek (left photos) in the Cedar Creek area of the Ouachita National Forest, McCurtain County, produced an ovipositing record on 16 August 2019. A second site, Ward Creek (right photos), in Three Rivers WMA, McCurtain County, also produced an ovipositing record as well as the first *S. ozarkensis* nymph (SP 3054) collected in the wild.

Figure 6. Adult male *Somatochlora ozarkensis* patrolling territory at Robbers Cave WMA, Latimer County, on 25 June 2021 (top, left) and a female feeding along a road at Three Rivers WMA, McCurtain County, on 24 June 2021 (top, right). Although these photographs (bottom, Ozark Plateau WMA, Adair County, 7 July 2016) were taken during a different project, they illustrate how females oviposit in gravel and moss within shallow trickles.

Figure 7. Records of crayfish known from the region prior to the project (black triangles, *n* = 26) versus those now known to occur from records compiled during the project (*n* = 2,657).



Appendices:

Appendix A – Crayfish collected and identified from Ozark Emerald larval survey sites from 2019 to 2021. Taxa were identified using Morehouse and Tobler (2013) with updated phylogeny from Crandall and DeGrave (2019).

site code	co-located site	date sampled	watershed	stream name	taxon	count
OZEM 08	CRAY-063	2019-04-16	Kiamichi River	UNT of Beach Creek	*Fallicambarus tenuis*	1
OZEM 09	CRAY-064	2019-04-16	Kiamichi River	Pigeon Creek	*Fallicambarus tenuis*	2
OZEM 11	CRAY-066	2019-04-16	Kiamichi River	Big Branch	*Fallicambarus tenuis*	1
OZEM 24	CRAY-184	2021-04-20	Mountain Fork River	UNT of Beech Creek	*Fallicambarus tenuis*	5
OZEM 25	CRAY-185	2021-04-20	Mountain Fork River	Big Eagle Creek	*Fallicambarus tenuis*	1
OZEM 29	CRAY-189	2021-04-20	Mountain Fork River	Cow Creek	*Fallicambarus tenuis*	21
OZEM 41	CRAY-024	2021-04-23	Mountain Fork River	UNT of Roosevelt Cr.	*Faxonius leptogonopodus*	6
OZEM 16	CRAY-071	2019-05-10	Little River	Stephens Branch	*Faxonius leptogonopodus*	2
OZEM 23	CRAY-183	2021-04-20	Kiamichi River	Pigeon Creek	*Faxonius leptogonopodus*	10
OZEM 25	CRAY-185	2021-04-20	Mountain Fork River	Big Eagle Creek	*Faxonius leptogonopodus*	8
OZEM 26	CRAY-186	2021-04-20	Mountain Fork River	UNT of Rock Creek	*Faxonius leptogonopodus*	1
OZEM 28	CRAY-188	2021-04-20	Mountain Fork River	Beech Creek	*Faxonius leptogonopodus*	5
OZEM 29	CRAY-189	2021-04-20	Mountain Fork River	Cow Creek	*Faxonius leptogonopodus*	7
OZEM 31	CRAY-191	2021-04-20	Mountain Fork River	Cow Creek	*Faxonius leptogonopodus*	2
OZEM 32	CRAY-192	2021-04-20	Mountain Fork River	UNT of Cow Creek	*Faxonius leptogonopodus*	5
OZEM 35	CRAY-195	2021-04-23	Mountain Fork River	Beech Creek	*Faxonius leptogonopodus*	4
OZEM 38	CRAY-198	2021-04-23	Mountain Fork River	Buffalo Creek	*Faxonius leptogonopodus*	1
OZEM 40	CRAY-200	2021-04-23	Mountain Fork River	Ward Creek	*Faxonius leptogonopodus*	7
OZEM 27	CRAY-187	2021-04-20	Mountain Fork River	Hurricane Creek	*Faxonius leptogonopodus/menae*	12
OZEM 36	CRAY-196	2021-04-23	Mountain Fork River	Hurricane Creek	*Faxonius leptogonopodus/menae*	2
OZEM 41	CRAY-024	2021-04-23	Mountain Fork River	UNT of Roosevelt Cr.	*Faxonius palmeri longimanus*	19
OZEM 05	CRAY-060	2019-04-16	Kiamichi River	Big Cedar Creek	*Faxonius palmeri longimanus*	6
OZEM 06	CRAY-061	2019-04-16	Kiamichi River	Big Cedar Creek	*Faxonius palmeri longimanus*	4
OZEM 07	CRAY-062	2019-04-16	Kiamichi River	Pigeon Creek	*Faxonius palmeri longimanus*	2
OZEM 10	CRAY-065	2019-04-16	Kiamichi River	UNT of Kiamichi R.	*Faxonius palmeri longimanus*	3
OZEM 12	CRAY-067	2019-04-16	Kiamichi River	Big Branch	*Faxonius palmeri longimanus*	8

OZEM 13	CRAY-068	2019-04-16	Little River	Yashau Creek	*Faxonius palmeri longimanus*	3
OZEM 14	CRAY-069	2019-05-10	Little River	Long Branch	*Faxonius palmeri longimanus*	4
OZEM 18	CRAY-073	2019-05-10	Mountain Fork River	Cooper Creek	*Faxonius palmeri longimanus*	2
OZEM 19	CRAY-074	2019-05-10	Mountain Fork River	Beaver Creek	*Faxonius palmeri longimanus*	1
OZEM 21	CRAY-162	2021-03-19	Kiamichi River	Caney Creek	*Faxonius palmeri longimanus*	2
OZEM 24	CRAY-184	2021-04-20	Mountain Fork River	UNT of Beech Creek	*Faxonius palmeri longimanus*	2
OZEM 26	CRAY-186	2021-04-20	Mountain Fork River	UNT of Rock Creek	*Faxonius palmeri longimanus*	9
OZEM 27	CRAY-187	2021-04-20	Mountain Fork River	Hurricane Creek	*Faxonius palmeri longimanus*	3
OZEM 29	CRAY-189	2021-04-20	Mountain Fork River	Cow Creek	*Faxonius palmeri longimanus*	22
OZEM 30	CRAY-190	2021-04-20	Mountain Fork River	Caney Creek	*Faxonius palmeri longimanus*	3
OZEM 31	CRAY-191	2021-04-20	Mountain Fork River	Cow Creek	*Faxonius palmeri longimanus*	1
OZEM 32	CRAY-192	2021-04-20	Mountain Fork River	UNT of Cow Creek	*Faxonius palmeri longimanus*	2
OZEM 33	CRAY-193	2021-04-23	Mountain Fork River	Sixmile Creek	*Faxonius palmeri longimanus*	4
OZEM 34	CRAY-194	2021-04-23	Mountain Fork River	Mountain Fork River	*Faxonius palmeri longimanus*	9
OZEM 35	CRAY-195	2021-04-23	Mountain Fork River	Beech Creek	*Faxonius palmeri longimanus*	8
OZEM 36	CRAY-196	2021-04-23	Mountain Fork River	Hurricane Creek	*Faxonius palmeri longimanus*	2
OZEM 37	CRAY-197	2021-04-23	Mountain Fork River	UNT of Mountain Fork River	*Faxonius palmeri longimanus*	10
OZEM 38	CRAY-198	2021-04-23	Mountain Fork River	Buffalo Creek	*Faxonius palmeri longimanus*	6
OZEM 40	CRAY-200	2021-04-23	Mountain Fork River	Ward Creek	*Faxonius palmeri longimanus*	5
OZEM 19	CRAY-074	2019-05-10	Mountain Fork River	Beaver Creek	*Procambarus acutus*	1

Appendix B – Known crayfish records within general project area.

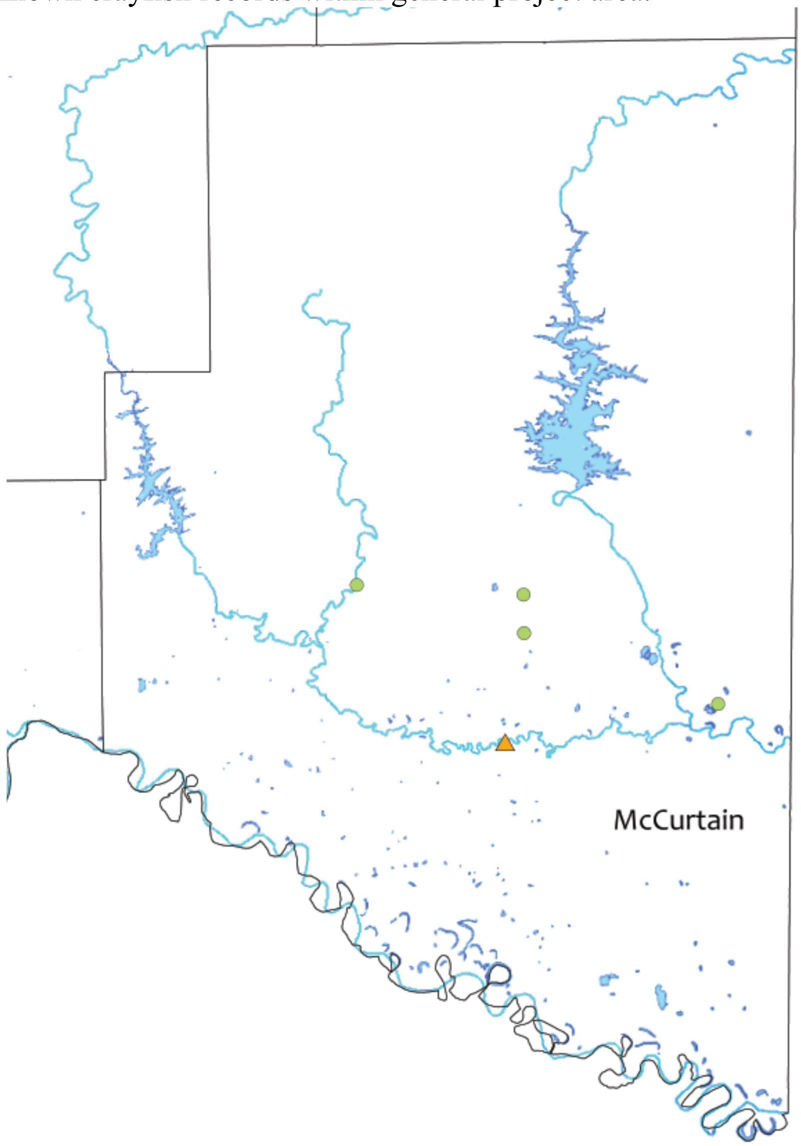


Figure B.1. Distribution of *Cambarellus puer* (orange triangle) and *Lacunicambarus Diogenes/ludiovicianus* complez (green dots) localities within southeastern Oklahoma.

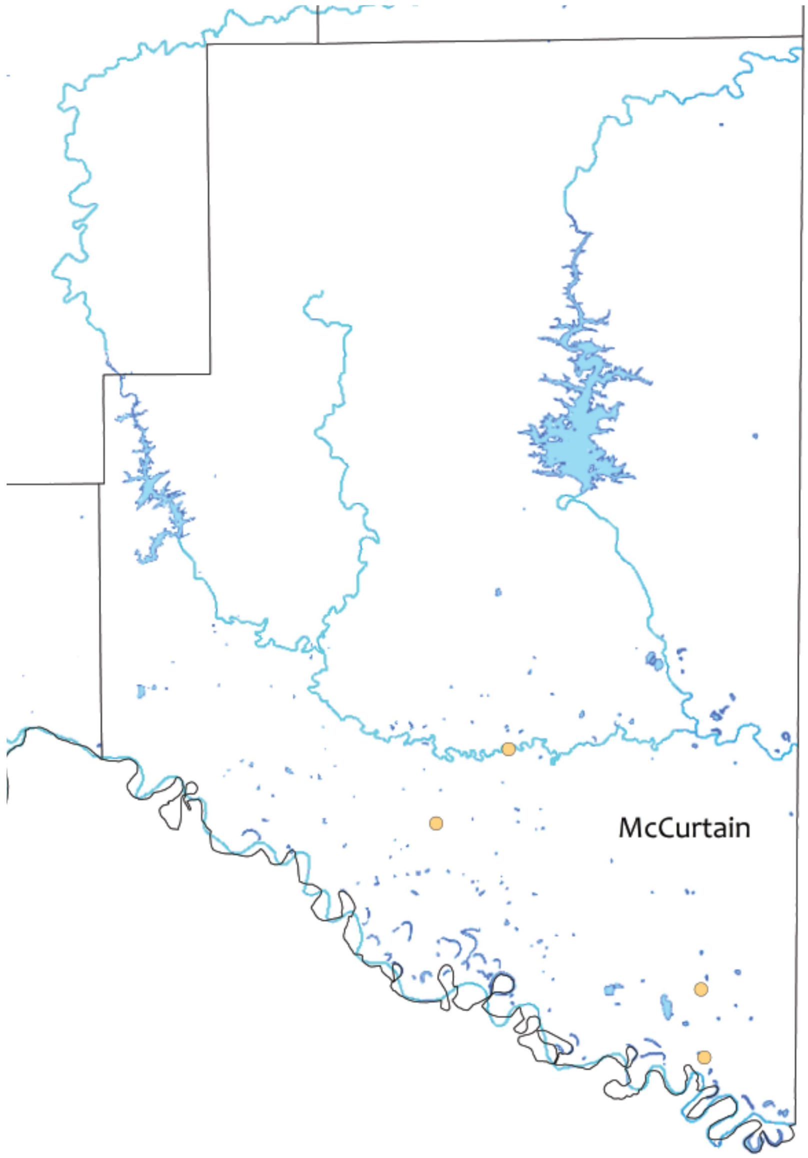


Figure B.2. Distribution of *creaserinus fodiens* (orange dots) localities within southeastern Oklahoma.

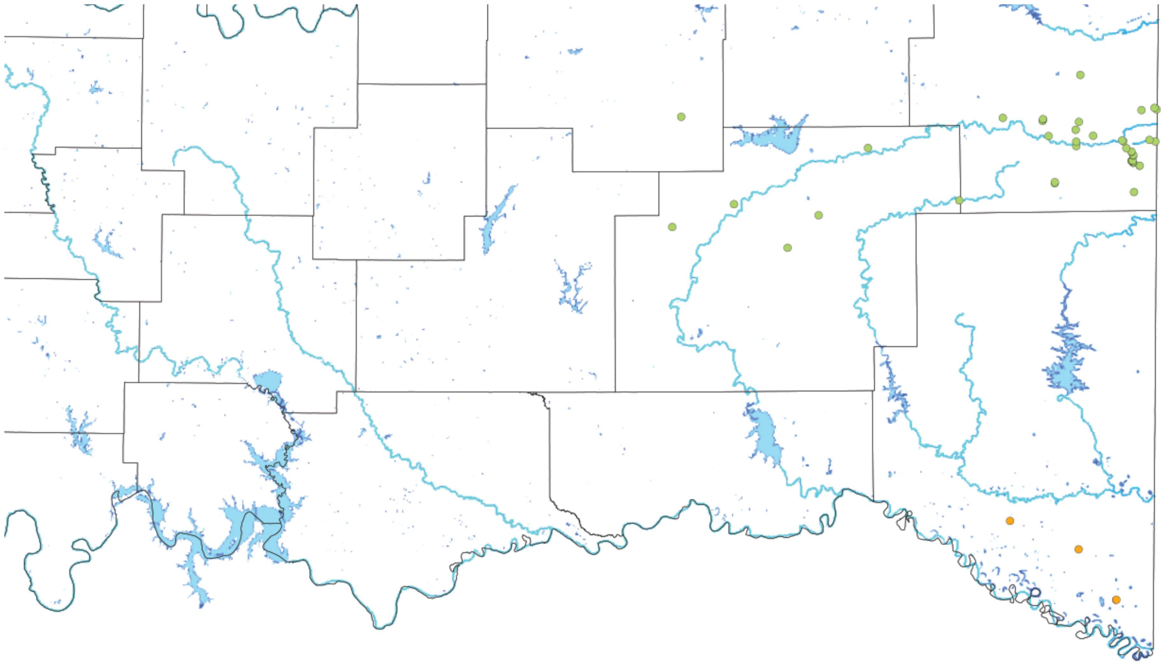


Figure B.3. Distribution of *Fallicambarus schusteri* (orange dots) and *Fallicambarus tenuis* (green dots) localities within southeastern Oklahoma.

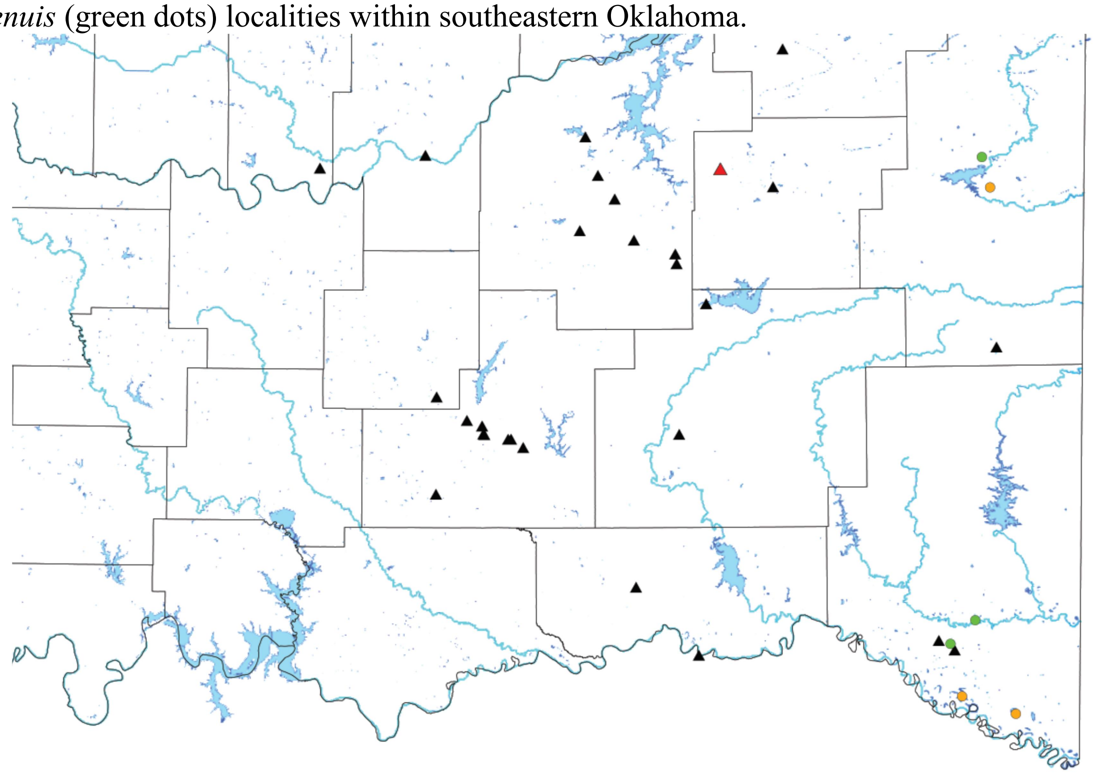


Figure B.4. Distribution of *Faxonella clypeata* (green dots), *Faxonius causeyi* (red triangle), *Faxonius difficilis* (black triangles), and *Faxonius lancifer* (orange dots) localities within southeastern Oklahoma.

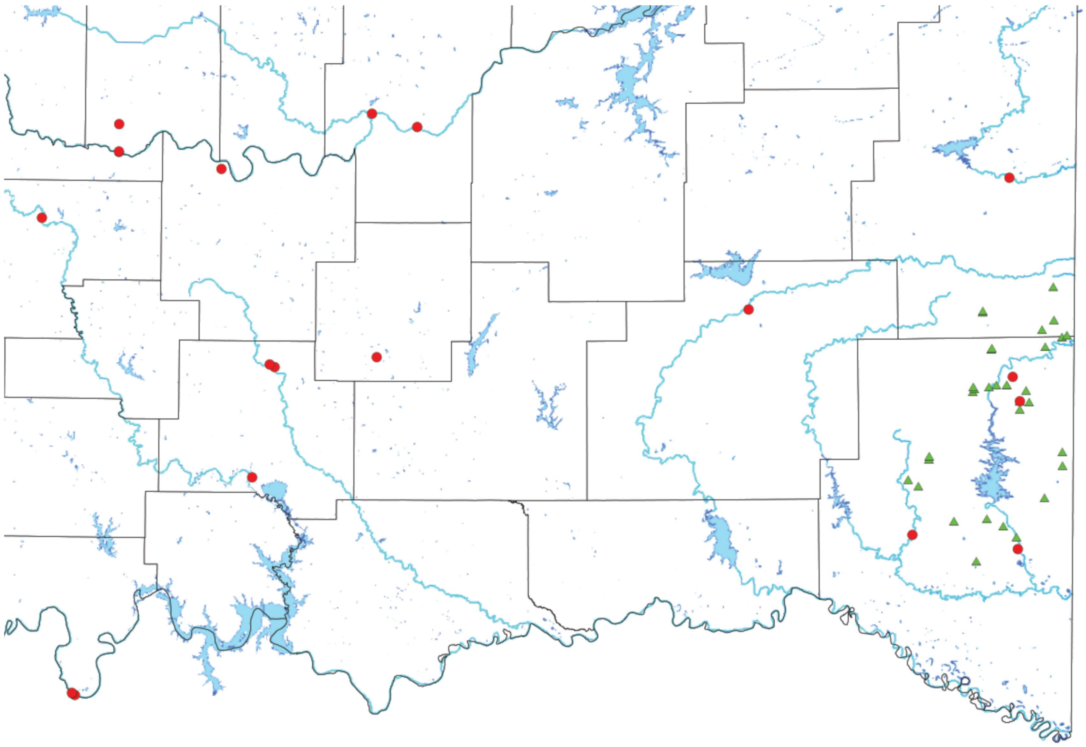


Figure B.5. Distribution of *Faxonius leptogonopodus* (green triangles) and *Faxonius nais* (red dots) localities within southeastern Oklahoma.

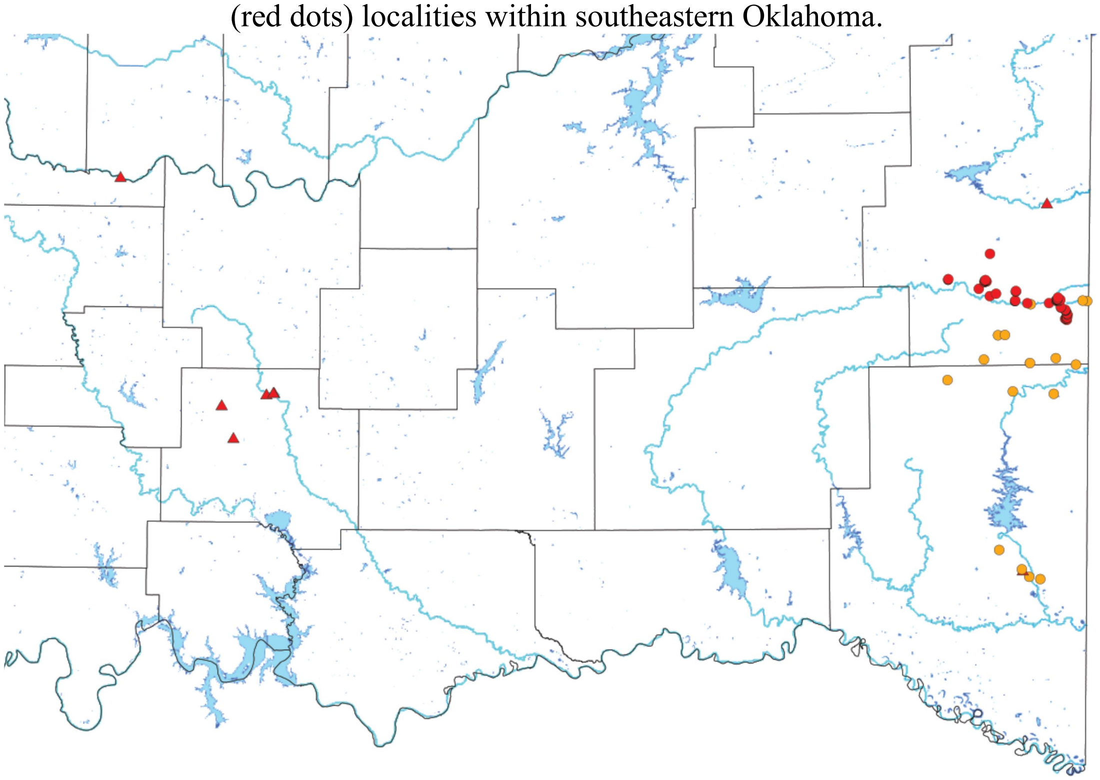


Figure B.6. Distribution of *Faxonius menae* (orange dots), *Faxonius saxatilis* (red dots), and *Faxonius virilis* (red triangles) localities within southeastern Oklahoma.

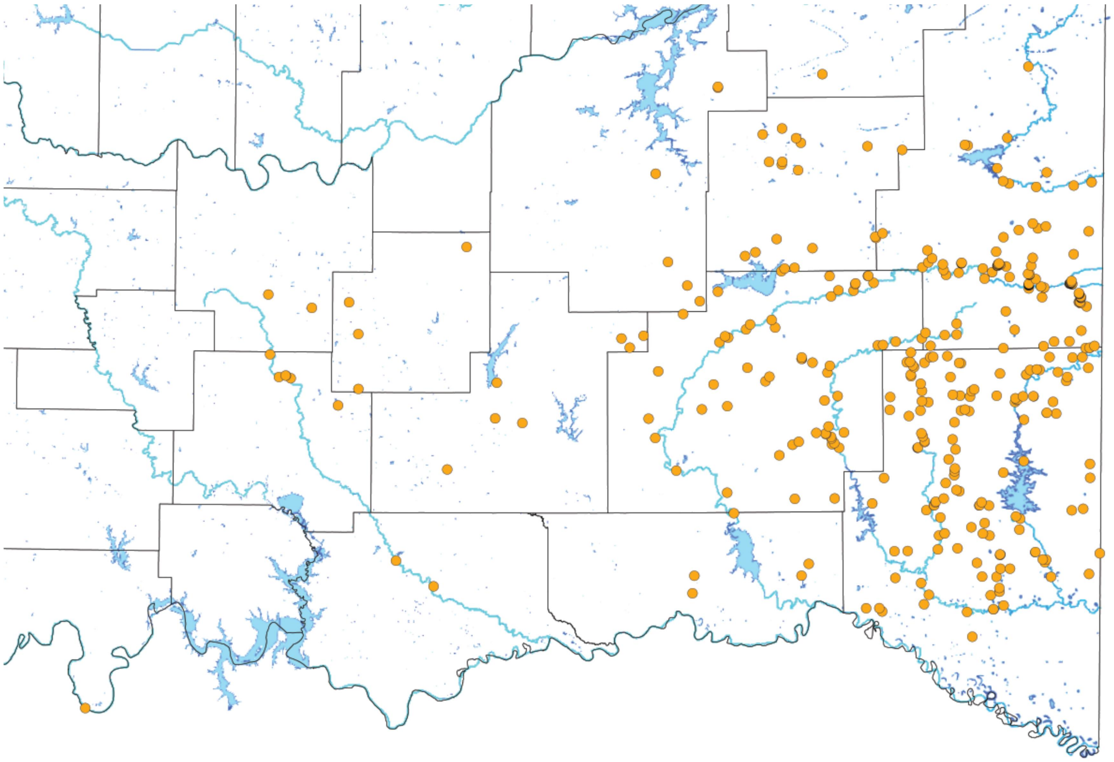


Figure B.7. Distribution of *Faxonius palmeri longimanus* (orange dots) localities within southeastern Oklahoma.

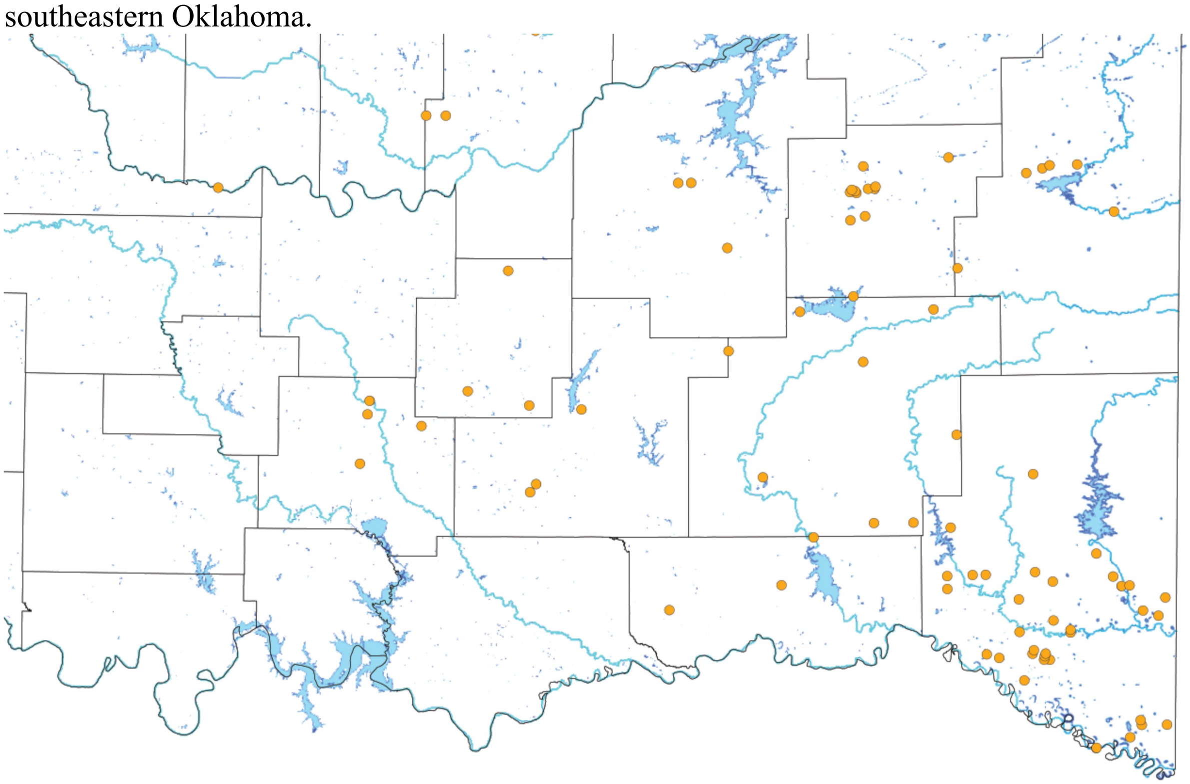


Figure B.8. Distribution of *Procambarus acutus* (orange dots) localities within southeastern Oklahoma.

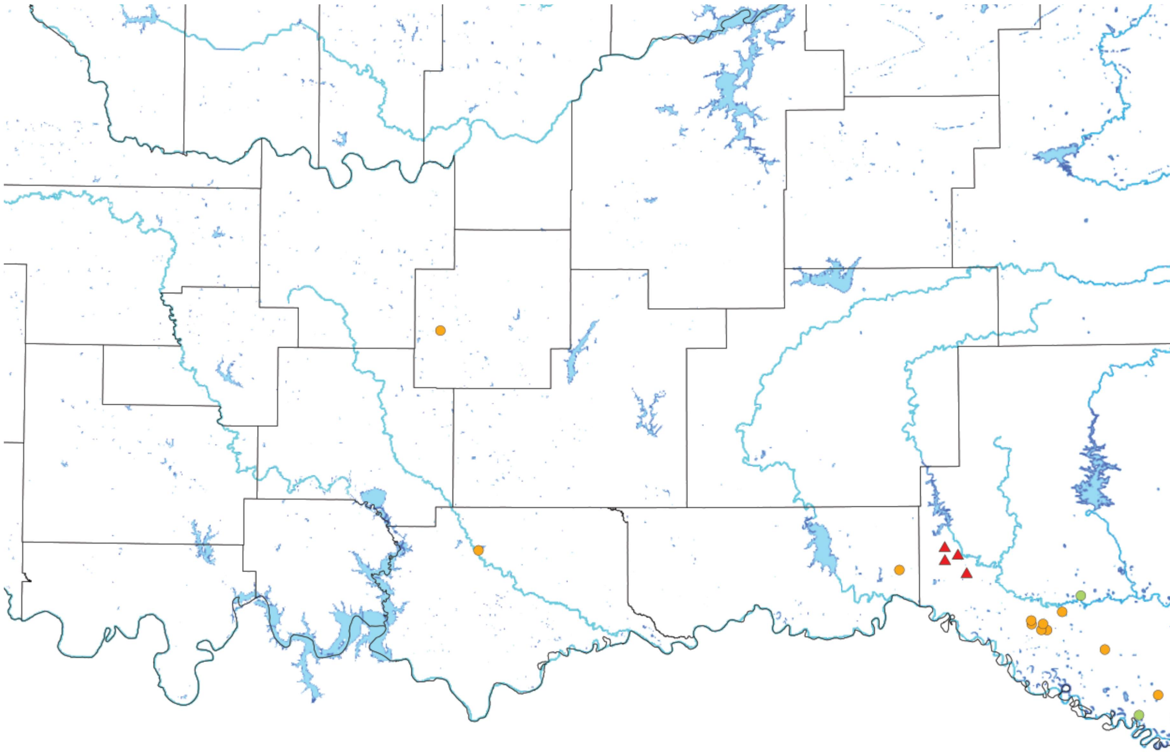


Figure B.9. Distribution of *Procambarus clarkia* (green dots), *P. curdi* (orange dots), and *P. dupratzi* (red triangles) localities within southeastern Oklahoma.

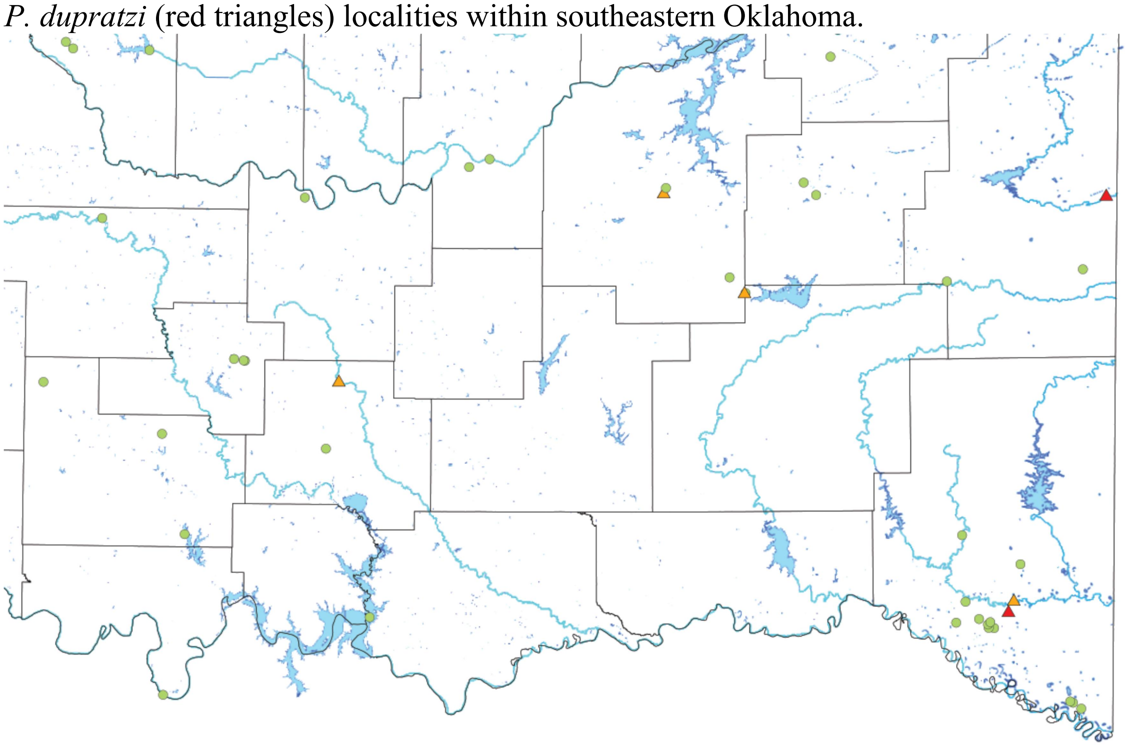


Figure B.10. Distribution of *Procambarus gracilis* (orange triangles), *P. liberorum* (red triangles), and *P. simulans* (green dots) localities within southeastern Oklahoma.

Appendix C – Odonates collected and identified in southeastern Oklahoma from 2018 to 2021. Taxa were identified to species when possible. Individuals recorded at lower taxonomic resolution than species were either too immature or too damaged to identify. Identifications were made following Tennessen (2019).

site code	co-located site	date sampled	watershed	stream name	method	family	taxon	count
OZEM 33	CRAY-193	2021-04-23	Mtn. Fk. R.	Sixmile Creek	d-net	Calopterygidae	*Calopteryx maculata*	2
OZEM 34	CRAY-194	2021-04-23	Mtn. Fk. R.	Mountain Fork River	d-net	Calopterygidae	*Calopteryx maculata*	2
OZEM 37	CRAY-197	2021-04-23	Mtn. Fk. R.	UNT of Mtn. Fk. R.	d-net	Calopterygidae	*Calopteryx maculata*	6
OZEM 38	CRAY-198	2021-04-23	Mtn. Fk. R.	Buffalo Creek	d-net	Calopterygidae	*Calopteryx maculata*	3
OZEM 40	CRAY-200	2021-04-23	Mtn. Fk. R.	Ward Creek	d-net	Calopterygidae	*Calopteryx maculata*	2
OZEM 41	CRAY-024	2021-04-23	Mtn. Fk. R.	UNT of Roosevelt Cr.	d-net	Calopterygidae	*Calopteryx maculata*	1
OZEM 32	CRAY-192	2021-04-20	Mtn. Fk. R.	UNT of Cow Creek	d-net	Calopterygidae	*Calopteryx maculata*	6
OZEM 33	CRAY-193	2021-04-23	Mtn. Fk. R.	Sixmile Creek	d-net	Calopterygidae	*Hetaerina americana*	6
OZEM 34	CRAY-194	2021-04-23	Mtn. Fk. R.	Mountain Fork River	d-net	Calopterygidae	*Hetaerina americana*	11
OZEM 38	CRAY-198	2021-04-23	Mtn. Fk. R.	Buffalo Creek	d-net	Calopterygidae	*Hetaerina americana*	4
OS 21	BDC 45	2019-07-18	Kiamichi R.	Kiamichi River	d-net	Calopterygidae	*Hetaerina americana*	4
OS 6	BDC 21	2018-07-26	Little River	Little River	d-net	Calopterygidae	*Hetaerina americana*	4
OS 19	BDC 39	2019-07-26	Mtn. Fk. R.	Mountain Fork River	surber	Calopterygidae	*Hetaerina sp.*	1
OZEM 36	CRAY-196	2021-04-23	Mtn. Fk. R.	Hurricane Creek	d-net	Coenagrionidae	*Argia moesta*	2
OZEM 18	CRAY-073	2019-05-10	Mtn. Fk. R.	Cooper Creek	surber	Coenagrionidae	*Argia tibialis*	3
OZEM 18	CRAY-073	2019-05-10	Mtn. Fk. R.	Cooper Creek	d-net	Coenagrionidae	*Argia tibialis*	3
OS 23	BDC 58	2019-08-02	Kiamichi R.	Kiamichi River	d-net	Coenagrionidae	*Argia translata*	1
OS 24	BDC 59	2019-08-02	Kiamichi R.	Kiamichi River	d-net	Coenagrionidae	*Argia translata*	1
OZEM 18	CRAY-073	2019-05-10	Mtn. Fk. R.	Cooper Creek	surber	Coenagrionidae	*Argia translata*	2
OZEM 18	CRAY-073	2019-05-10	Mtn. Fk. R.	Cooper Creek	d-net	Coenagrionidae	*Argia translata*	1
OS 12	BDC 17	2018-07-21	Little River	Little River	d-net	Coenagrionidae	*Argia translata*	4
OZEM 38	CRAY-198	2021-04-23	Mtn. Fk. R.	Buffalo Creek	d-net	Coenagrionidae	*Argia sp.*	1
OS 25	BDC 61	2019-08-03	Kiamichi R.	Kiamichi River	d-net	Coenagrionidae	*Argia sp.*	3
OS 24	BDC 59	2019-08-02	Kiamichi R.	Kiamichi River	d-net	Coenagrionidae	*Argia sp.*	1
OS 2	BDC 33	2019-07-09	Mtn. Fk. R.	Mountain Fork River	surber	Coenagrionidae	*Argia sp.*	1
OZEM 07	CRAY-062	2019-04-16	Kiamichi R.	Pigeon Creek	surber	Coenagrionidae	*Argia sp.*	5
OZEM 07	CRAY-062	2019-04-16	Kiamichi R.	Pigeon Creek	d-net	Coenagrionidae	*Argia sp.*	5

OS 17	BDC 27	2018-07-30	Glover River	Glover River	d-net	Coenagrionidae	*Argia sp.*	2
OS 7	BDC 27	2018-07-30	Glover River	Glover River	surber	Coenagrionidae	*Argia sp.*	1
OS 5	BDC 25	2018-07-29	Glover River	Glover River	surber	Coenagrionidae	*Argia sp.*	2
OS 5	BDC 25	2018-07-29	Glover River	Glover River	d-net	Coenagrionidae	*Argia sp.*	1
OS 6	BDC 21	2018-07-26	Little River	Little River	d-net	Coenagrionidae	*Argia sp.*	7
OS 15	BDC 23	2018-07-25	Little River	Little River	surber	Coenagrionidae	*Argia sp.*	2
OS 12	BDC 17	2018-07-21	Little River	Little River	surber	Coenagrionidae	*Argia sp.*	1
OS 13	BDC 18	2018-07-21	Little River	Little River	surber	Coenagrionidae	*Argia sp.*	2
OS 11	BDC 14	2018-07-19	Glover River	Glover River	d-net	Coenagrionidae	*Argia sp.*	1
OS 9	BDC 07	2018-07-15	Little River	Little River	d-net	Coenagrionidae	*Argia sp.*	2
OZEM 34	CRAY-194	2021-04-23	Mtn. Fk. R.	Mountain Fork River	d-net	Coenagrionidae	*Chromagrion conditum*	1
OZEM 36	CRAY-196	2021-04-23	Mtn. Fk. R.	Hurricane Creek	d-net	Coenagrionidae	*Enallagma sp.*	2
OS 6	BDC 21	2018-07-26	Little River	Little River	d-net	Coenagrionidae	*Enallagma sp.*	1
OZEM 37	CRAY-197	2021-04-23	Mtn. Fk. R.	UNT of Mtn. Fk. R.	d-net	Coenagrionidae	*Coenagrionidae*	1
OZEM 38	CRAY-198	2021-04-23	Mtn. Fk. R.	Buffalo Creek	d-net	Coenagrionidae	*Coenagrionidae*	1
OZEM 41	CRAY-024	2021-04-23	Mtn. Fk. R.	UNT of Roosevelt Cr.	d-net	Coenagrionidae	*Coenagrionidae*	1
OS 22	BDC 57	2019-08-02	Kiamichi R.	Kiamichi River	d-net	Coenagrionidae	*Coenagrionidae*	1
OS 3	BDC 28	2019-07-31	Glover River	Glover River	d-net	Coenagrionidae	*Coenagrionidae*	2
OS 19	BDC 39	2019-07-26	Mtn. Fk. R.	Mountain Fork River	d-net	Coenagrionidae	*Coenagrionidae*	1
OS 18	BDC 29	2018-07-31	Glover River	Glover River	d-net	Coenagrionidae	*Coenagrionidae*	3
OS 16	BDC 26	2018-07-30	Glover River	Glover River	d-net	Coenagrionidae	*Coenagrionidae*	1
OS 7	BDC 27	2018-07-30	Glover River	Glover River	d-net	Coenagrionidae	*Coenagrionidae*	2
OS 13	BDC 18	2018-07-21	Little River	Little River	d-net	Coenagrionidae	*Coenagrionidae*	7
OZEM 33	CRAY-193	2021-04-23	Mtn. Fk. R.	Sixmile Creek	d-net	Aeshnidae	*Boyeria vinosa*	1
OZEM 37	CRAY-197	2021-04-23	Mtn. Fk. R.	UNT of Mtn. Fk. R.	d-net	Aeshnidae	*Boyeria vinosa*	1
OZEM 38	CRAY-198	2021-04-23	Mtn. Fk. R.	Buffalo Creek	d-net	Aeshnidae	*Boyeria vinosa*	5
OZEM 27	CRAY-187	2021-04-20	Mtn. Fk. R.	Hurricane Creek	d-net	Aeshnidae	*Boyeria vinosa*	1
OS 4	BDC 55	2019-07-25	Mtn. Fk. R.	Mountain Fork River	d-net	Aeshnidae	*Boyeria vinosa*	2
OZEM 35	CRAY-195	2021-04-23	Mtn. Fk. R.	Beech Creek	d-net	Aeshnidae	*Boyeria sp.*	1
OZEM 32	CRAY-192	2021-04-20	Mtn. Fk. R.	UNT of Cow Creek	d-net	Aeshnidae	*Boyeria sp.*	2
OZEM 15	CRAY-070	2019-05-10	Little River	UNT of Lukfata Cr.	surber	Aeshnidae	*Nasiaeschna pentacantha*	1

OS 26	BDC 62	2019-08-03	Kiamichi R.	Kiamichi River	d-net	Gomphidae	*Arigomphus submedianus*	1
OZEM 12	CRAY-067	2019-04-16	Kiamichi R.	Big Branch	surber	Gomphidae	*Arigomphus sp.*	3
OZEM 12	CRAY-067	2019-04-16	Kiamichi R.	Big Branch	d-net	Gomphidae	*Arigomphus sp.*	3
OZEM 37	CRAY-197	2021-04-23	Mtn. Fk. R.	UNT of Mtn. Fk. R.	d-net	Gomphidae	*Dromogomphus spinosus*	1
OZEM 38	CRAY-198	2021-04-23	Mtn. Fk. R.	Buffalo Creek	d-net	Gomphidae	*Dromogomphus spinosus*	2
OS 25	BDC 61	2019-08-03	Kiamichi R.	Kiamichi River	d-net	Gomphidae	*Dromogomphus spinosus*	1
OS 21	BDC 45	2019-07-18	Kiamichi R.	Kiamichi River	d-net	Gomphidae	*Dromogomphus spinosus*	1
OZEM 02	na	2019-04-15	Fourche Maline	UNT of Fourche Maline	d-net	Gomphidae	*Dromogomphus spinosus*	1
OS 18	BDC 29	2018-07-31	Glover River	Glover River	d-net	Gomphidae	*Dromogomphus spinosus*	3
OS 7	BDC 27	2018-07-30	Glover River	Glover River	d-net	Gomphidae	*Dromogomphus spinosus*	1
OS 5	BDC 25	2018-07-29	Glover River	Glover River	d-net	Gomphidae	*Dromogomphus spinosus*	1
OS 15	BDC 23	2018-07-25	Little River	Little River	d-net	Gomphidae	*Dromogomphus spinosus*	1
OS 12	BDC 17	2018-07-21	Little River	Little River	d-net	Gomphidae	*Dromogomphus spinosus*	5
OS 26	BDC 62	2019-08-03	Kiamichi R.	Kiamichi River	d-net	Gomphidae	*Gomphurus ozarkensis*	1
OZEM 33	CRAY-193	2021-04-23	Mtn. Fk. R.	Sixmile Creek	d-net	Gomphidae	*Hagenius brevistylus*	1
OZEM 36	CRAY-196	2021-04-23	Mtn. Fk. R.	Hurricane Creek	d-net	Gomphidae	*Hagenius brevistylus*	1
OZEM 38	CRAY-198	2021-04-23	Mtn. Fk. R.	Buffalo Creek	d-net	Gomphidae	*Hagenius brevistylus*	1
OS 4	BDC 55	2019-07-25	Mtn. Fk. R.	Mountain Fork River	d-net	Gomphidae	*Hagenius brevistylus*	1
OS 20	BDC 44	2019-07-18	Kiamichi R.	Kiamichi River	d-net	Gomphidae	*Hagenius brevistylus*	1
OS 21	BDC 45	2019-07-18	Kiamichi R.	Kiamichi River	d-net	Gomphidae	*Hagenius brevistylus*	1
OS 6	BDC 21	2018-07-26	Little River	Little River	d-net	Gomphidae	*Hagenius brevistylus*	1
OS 12	BDC 17	2018-07-21	Little River	Little River	d-net	Gomphidae	*Hagenius brevistylus*	1
OS 13	BDC 18	2018-07-21	Little River	Little River	d-net	Gomphidae	*Hagenius brevistylus*	1
OZEM 33	CRAY-193	2021-04-23	Mtn. Fk. R.	Sixmile Creek	d-net	Gomphidae	*Stylogomphus sigmastylus*	13
OZEM 34	CRAY-194	2021-04-23	Mtn. Fk. R.	Mountain Fork River	d-net	Gomphidae	*Stylogomphus sigmastylus*	6
OZEM 35	CRAY-195	2021-04-23	Mtn. Fk. R.	Beech Creek	d-net	Gomphidae	*Stylogomphus sigmastylus*	4
OZEM 38	CRAY-198	2021-04-23	Mtn. Fk. R.	Buffalo Creek	d-net	Gomphidae	*Stylogomphus sigmastylus*	3
OZEM 23	CRAY-183	2021-04-20	Kiamichi R.	Pigeon Creek	d-net	Gomphidae	*Stylogomphus sigmastylus*	1
OZEM 27	CRAY-187	2021-04-20	Mtn. Fk. R.	Hurricane Creek	d-net	Gomphidae	*Stylogomphus sigmastylus*	1
OZEM 29	CRAY-189	2021-04-20	Mtn. Fk. R.	Cow Creek	d-net	Gomphidae	*Stylogomphus sigmastylus*	6
OZEM 05	CRAY-060	2019-04-16	Kiamichi R.	Big Cedar Creek	surber	Gomphidae	*Stylogomphus sigmastylus*	1

OZEM 07	CRAY-062	2019-04-16	Kiamichi R.	Pigeon Creek	surber	Gomphidae	*Stylogomphus sigmastylus*	6
OZEM 07	CRAY-062	2019-04-16	Kiamichi R.	Pigeon Creek	d-net	Gomphidae	*Stylogomphus sigmastylus*	7
OZEM 12	CRAY-067	2019-04-16	Kiamichi R.	Big Branch	surber	Gomphidae	*Stylogomphus sigmastylus*	1
OZEM 12	CRAY-067	2019-04-16	Kiamichi R.	Big Branch	d-net	Gomphidae	*Stylogomphus sigmastylus*	1
OZEM 15	CRAY-070	2019-05-10	Little River	UNT of Lukfata Cr.	surber	Gomphidae	*Stylurus sp.*	21
OZEM 15	CRAY-070	2019-05-10	Little River	UNT of Lukfata Cr.	d-net	Gomphidae	*Stylurus sp.*	19
OZEM 15	CRAY-070	2019-05-10	Little River	UNT of Lukfata Cr.	surber	Gomphidae	*Gomphidae*	4
OZEM 15	CRAY-070	2019-05-10	Little River	UNT of Lukfata Cr.	d-net	Gomphidae	*Gomphidae*	4
OZEM 07	CRAY-062	2019-04-16	Kiamichi R.	Pigeon Creek	surber	Gomphidae	*Gomphidae*	4
OZEM 07	CRAY-062	2019-04-16	Kiamichi R.	Pigeon Creek	d-net	Gomphidae	*Gomphidae*	4
OS 6	BDC 21	2018-07-26	Little River	Little River	d-net	Gomphidae	*Gomphidae*	1
OZEM 35	CRAY-195	2021-04-23	Mtn. Fk. R.	Beech Creek	d-net	Cordulegastridae	*Cordulegaster (Zoraena) talaria*[*]	1
OZEM 41	CRAY-024	2021-04-23	Mtn. Fk. R.	UNT of Roosevelt Cr.	d-net	Cordulegastridae	*Cordulegaster (Zoraena) talaria*[*]	3
OZEM 24	CRAY-184	2021-04-20	Mtn. Fk. R.	UNT of Beech Creek	d-net	Cordulegastridae	*Cordulegaster (Zoraena) talaria*[*]	4
OZEM 29	CRAY-189	2021-04-20	Mtn. Fk. R.	Cow Creek	d-net	Cordulegastridae	*Cordulegaster (Zoraena) talaria*[*]	1
OZEM 08	CRAY-063	2019-04-16	Kiamichi R.	UNT of Beach Creek	surber	Cordulegastridae	*Cordulegaster (Zoraena) talaria*[*]	1
OZEM 08	CRAY-063	2019-04-16	Kiamichi R.	UNT of Beach Creek	d-net	Cordulegastridae	*Cordulegaster (Zoraena) talaria*[*]	1
OS 8	BDC 01	2018-07-12	Little River	Little River	d-net	Macromiidae	*Didymops transversa*	1
OZEM 35	CRAY-195	2021-04-23	Mtn. Fk. R.	Beech Creek	d-net	Macromiidae	*Macromia illinoiensis*	1
OS 4	BDC 55	2019-07-25	Mtn. Fk. R.	Mountain Fork River	d-net	Macromiidae	*Macromia illinoiensis*	1
OS 21	BDC 45	2019-07-18	Kiamichi R.	Kiamichi River	d-net	Macromiidae	*Macromia illinoiensis*	1
OZEM 38	CRAY-198	2021-04-23	Mtn. Fk. R.	Buffalo Creek	d-net	Macromiidae	*Macromia pacifica*	2
OZEM 41	CRAY-024	2021-04-23	Mtn. Fk. R.	UNT of Roosevelt Cr.	d-net	Macromiidae	*Macromia pacifica*	1
OZEM 34	CRAY-194	2021-04-23	Mtn. Fk. R.	Mountain Fork River	d-net	Macromiidae	*Macromia taeniolata*	1
OZEM 34	CRAY-194	2021-04-23	Mtn. Fk. R.	Mountain Fork River	d-net	Macromiidae	*Macromia taeniolata*	7
OZEM 22	CRAY-178	2021-04-09	Little RIver	Little River	d-net	Macromiidae	*Macromia taeniolata*	1
OS 18	BDC 29	2018-07-31	Glover River	Glover River	d-net	Macromiidae	*Macromia sp.*	1
OS 15	BDC 23	2018-07-25	Little River	Little River	d-net	Macromiidae	*Macromia sp.*	1
OS 11	BDC 14	2018-07-19	Glover River	Glover River	d-net	Macromiidae	*Macromia sp.*	3
OS 10	BDC 11	2018-07-18	Glover River	Glover River	d-net	Macromiidae	*Macromia sp.*	1
OS 9	BDC 07	2018-07-15	Little River	Little River	d-net	Macromiidae	*Macromia sp.*	4

OS 8	BDC 01	2018-07-12	Little River	Little River	d-net	Macromiidae	*Macromia sp.*	1
OS 12	BDC 17	2018-07-21	Little River	Little River	d-net	Macromiidae	*Macromia sp.*	1
OS 1	CRAY-028	2019-06-20	Mtn. Fk. R.	UNT of Big Hudson Cr.	d-net	Corduliidae	*Helocordulia uhleri*	2
OS 6	BDC 21	2018-07-26	Little River	Little River	d-net	Corduliidae	*Neurocordulia xanthosoma*	1
OZEM 36	CRAY-196	2021-04-23	Mtn. Fk. R.	Hurricane Creek	d-net	Corduliidae	*Somatochlora linearis*	1
OZEM 37	CRAY-197	2021-04-23	Mtn. Fk. R.	UNT of Mtn. Fk. R.	d-net	Corduliidae	*Somatochlora linearis*	1
OZEM 40	CRAY-200	2021-04-23	Mtn. Fk. R.	Ward Creek	d-net	Corduliidae	*Somatochlora linearis*	1
OZEM 41	CRAY-024	2021-04-23	Mtn. Fk. R.	UNT of Roosevelt Cr.	d-net	Corduliidae	*Somatochlora linearis*	1
OZEM 32	CRAY-192	2021-04-20	Mtn. Fk. R.	UNT of Cow Creek	d-net	Corduliidae	*Somatochlora linearis*	7
OZEM 21	CRAY-162	2021-03-19	Kiamichi R.	Caney Creek	d-net	Corduliidae	*Somatochlora linearis*	1
OZEM 14	CRAY-069	2019-05-10	Little River	Long Branch	d-net	Corduliidae	*Somatochlora linearis*	1
OZEM 17	CRAY-072	2019-05-10	Little River	Yashau Creek	surber	Corduliidae	*Somatochlora linearis*	2
OZEM 17	CRAY-072	2019-05-10	Little River	Yashau Creek	d-net	Corduliidae	*Somatochlora linearis*	4
OZEM 40	CRAY-200	2021-04-23	Mtn. Fk. R.	Ward Creek	d-net	Corduliidae	*Somatochlora ozarkensis**	1
OZEM 41	CRAY-024	2021-04-23	Mtn. Fk. R.	UNT of Roosevelt Cr.	d-net	Corduliidae	*Somatochlora sp.*	1
OS 6	BDC 21	2018-07-26	Little River	Little River	d-net	Corduliidae	*Corduliidae*	1
OS 14	BDC 19	2018-07-24	Little River	Little River	d-net	Corduliidae	*Corduliidae*	1
OS 9	BDC 07	2018-07-15	Little River	Little River	d-net	Libellulidae	*Ladona sp.*	1
OZEM 17	CRAY-072	2019-05-10	Little River	Yashau Creek	surber	Libellulidae	*Libellula auripennis*	1
OZEM 18	CRAY-073	2019-05-10	Mtn. Fk. R.	Cooper Creek	d-net	Libellulidae	*Libellula incesta*	1
OS 15	BDC 23	2018-07-25	Little River	Little River	d-net	Libellulidae	*Libellulidae*	2

abbreviations: Cr. = Creek, Fk. = Fork, Mtn. = Mountain, R. = River, sp. = undetermined species, UNT = unnamed tributary
notes: Crayfish sites that were co-located with Ozark Emerald sampling were associated with ODWC project number F18AF00929 (F-109-R-1).
*Stephen C. Cook and Tim E. Vogt identification, but determinations may be disputed by Kenneth J. Tennessen although final word of such was not received prior to report submission.

Appendix D – Habitat assessment characteristics measured at aquatic sampling locations for the project.

site code	co-located site	date	watershed	stream name	depth (m)	temp (°C)	DO (%)	DO (mg/L)	sp. cond	silt	sand	grav	cob	bdr	bedr	cwd	emb (%)	sed	canopy cover (%)
OZEM 21	CRAY-162	2021-03-19	Kiamichi R.	Caney Creek	0.46	13.1	100.4	10.56	60.3	0	0	10	65	25	0	0	10	16	5.21
OZEM 22	CRAY-178	2021-04-09	Little River	Little River	0.19	18.2	99.4	9.36	27.6	0	5	15	60	20	0	0	10	15	1.04
OZEM 23	CRAY-183	2021-04-20	Kiamichi R.	Pigeon Creek	0.36	11.1	102	11.23	17.5	0	0	5	20	75	0	0	5	19	44.79
OZEM 24	CRAY-184	2021-04-20	Mtn. Fk. R.	UNT of Beech Cr.	0.21	11.7	94.1	10.23	6.3	10	0	30	20	30	0	10	40	13	94.79
OZEM 25	CRAY-185	2021-04-20	Mtn. Fk. R.	Big Eagle Creek	0.52	13.7	104.8	10.94	17.4	0	0	5	75	20	0	0	5	17	0
OZEM 26	CRAY-186	2021-04-20	Mtn. Fk. R.	UNT of Rock Cr.	0.42	15.5	114.6	11.44	25.5	10	5	35	40	10	0	0	50	11	76.9
OZEM 27	CRAY-187	2021-04-20	Mtn. Fk. R.	Hurricane Creek	0.13	13.1	104.3	10.98	26	0	5	40	25	30	0	0	20	17	100
OZEM 28	CRAY-188	2021-04-20	Mtn. Fk. R.	Beech Creek	0.19	15.6	106.3	10.57	17.9	0	0	10	60	30	0	0	5	18	95.83
OZEM 29	CRAY-189	2021-04-20	Mtn. Fk. R.	Cow Creek	0.27	14.7	103.9	10.54	18	0	0	5	15	80	0	0	0	18	84.38
OZEM 30	CRAY-190	2021-04-20	Mtn. Fk. R.	Caney Creek	0.33	16.1	107.6	10.6	43.8	15	15	45	15	10	0	0	60	11	80.2
OZEM 31	CRAY-191	2021-04-20	Mtn. Fk. R.	Cow Creek	0.34	15.4	107.1	10.72	22.7	0	5	10	30	40	15	0	10	15	1.05
OZEM 32	CRAY-192	2021-04-20	Mtn. Fk. R.	UNT of Cow Cr.	0.18	13.5	109.6	11.43	40.3	20	15	30	25	10	0	0	30	13	100
OZEM 33	CRAY-193	2021-04-23	Mtn. Fk. R.	Sixmile Creek	0.22	13.1	99.5	10.46	41.7	10	0	25	15	20	30	0	20	12	98.96
OZEM 34	CRAY-194	2021-04-23	Mtn. Fk. R.	Mtn. Fk. R.	0.21	14	100	10.32	35.4	0	5	40	50	5	0	0	15	17	0
OZEM 35	CRAY-195	2021-04-23	Mtn. Fk. R.	Beech Creek	0.5	11.6	107.3	11.68	20.9	5	5	5	10	20	55	0	15	15	95.83
OZEM 36	CRAY-196	2021-04-23	Mtn. Fk. R.	Hurricane Creek	0.18	12.1	101.1	10.87	36.6	5	5	15	20	40	15	0	10	13	26.05
OZEM 37	CRAY-197	2021-04-23	Mtn. Fk. R.	UNT of Mtn. Fk. R.	0.09	11	105.2	11.61	56.7	10	10	30	40	10	0	0	40	11	100
OZEM 38	CRAY-198	2021-04-23	Mtn. Fk. R.	Buffalo Creek	0.56	13.8	110.1	11.4	40.7	5	10	15	30	20	20	0	20	13	0
OZEM 41	CRAY-024	2021-04-23	Mtn. Fk. R.	UNT Roosevelt Cr.	0.15	12.2	111.5	11.96	36.2	15	20	40	20	5	0	0	25	13	91.67
OZEM 39	CRAY-199	2021-04-23	Mtn. Fk. R.	Mtn. Fk. R.	1.22	15.3	110.2	11.13	32.9	10	5	25	40	0	20	0	5	16	0
OZEM 40	CRAY-200	2021-04-23	Mtn. Fk. R.	Ward Creek	0.12	12.7	102.2	10.84	27.9	15	15	30	25	5	10	0	15	16	82.29
OS 2	BDC 33	2019-07-09	Mtn. Fk. R.	Mtn. Fk. R.	1.09	na	na	na	na	0	10	20	30	30	20	na	na	na	2
OS 3	BDC 28	2019-07-31	Glover R.	Glover River	0.24	na	na	na	19.7	0	5	20	35	30	10	na	na	na	0
OS 4	BDC 55	2019-07-25	Mtn. Fk. R.	Mtn. Fk. R.	0.69	na	na	na	na	0	10	30	60	0	0	na	na	na	10
OS 5	BDC 25	2018-07-29	Glover R.	Glover River	0.15	na	na	na	41.1	2	15	40	20	8	3	na	na	na	35
OS 6	BDC 21	2018-07-26	Little River	Little River	0.33	na	na	na	50.7	0	20	20	35	20	5	na	na	na	30
OS 7	BDC 27	2018-07-30	Glover R.	Glover River	0.38	na	na	na	23.7	0	0	10	20	20	50	na	na	na	1
OS 8	BDC 01	2018-07-12	Little River	Little River	0.34	na	na	na	35.7	0	0	0	5	5	90	na	na	na	5

OS 9	BDC 07	2018-07-15	Little River	Little River	0.18	na	na	na	81.3	5	50	15	15	10	0	na	na	na	70
OS 10	BDC 11	2018-07-18	Glover R.	Glover River	0.11	na	na	na	62.1	0	10	40	40	5	5	na	na	na	30
OS 11	BDC 14	2018-07-19	Glover R.	Glover River	0.09	na	na	na	67.5	0	20	60	20	0	0	na	na	na	35
OS 12	BDC 17	2018-07-21	Little River	Little River	0.23	na	na	na	46	0	15	5	20	30	30	na	na	na	1
OS 13	BDC 18	2018-07-21	Little River	Little River	0.49	na	na	na	48.4	0	10	15	30	35	10	na	na	na	0
OS 14	BDC 19	2018-07-24	Little River	Little River	0.6	na	na	na	48.5	0	5	2	5	73	5	na	na	na	0
OS 15	BDC 23	2018-07-25	Little River	Little River	0.27	na	na	na	49.5	0	10	5	60	20	5	na	na	na	5
OS 16	BDC 26	2018-07-30	Glover R.	Glover River	0.21	na	na	na	55.3	0	10	10	20	20	40	na	na	na	10
OS 17	BDC 27	2018-07-30	Glover R.	Glover River	0.38	na	na	na	23.7	0	0	10	20	20	50	na	na	na	1
OS 18	BDC 29	2018-07-31	Glover R.	Glover River	0.3	na	na	na	36.1	0	10	10	10	30	40	na	na	na	10
OS 19	BDC 39	2019-07-26	Mtn. Fk. R.	Mtn. Fk. R.	0.58	na	na	na	na	0	10	10	10	10	60	na	na	na	2
OS 20	BDC 44	2019-07-18	Kiamichi R.	Kiamichi River	0.65	na	na	na	na	0	25	50	5	10	10	na	na	na	20
OS 21	BDC 45	2019-07-18	Kiamichi R.	Kiamichi River	0.99	na	na	na	na	0	25	50	25	0	0	na	na	na	5
OS 22	BDC 57	2019-08-02	Kiamichi R.	Kiamichi River	0.72	na	na	na	na	0	10	20	30	20	20	na	na	na	0
OS 23	BDC 58	2019-08-02	Kiamichi R.	Kiamichi River	0.68	na	na	na	na	0	0	30	40	30	0	na	na	na	1
OS 24	BDC 59	2019-08-02	Kiamichi R.	Kiamichi River	0.81	na	na	na	na	0	10	60	20	10	0	na	na	na	2
OS 25	BDC 61	2019-08-03	Kiamichi R.	Kiamichi River	0.85	na	na	na	na	0	10	30	50	10	0	na	na	na	5
OS 26	BDC 62	2019-08-03	Kiamichi R.	Kiamichi River	0.76	na	na	na	na	5	20	50	20	0	5	na	na	na	0