THE UNIVERSITY OF TENNESSEE KNOXVILLE

Southeastern Fishes Council Proceedings

Volume 1 | Number 63 Article 2

May 2023

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Recommended Citation

McCall, Brittany L. and Fluker, Brook L. (2023) "Aspects of Distribution, Abundance, Habitat, and Life History of the Caddo Madtom (*Noturus taylori*), a Narrow Endemic of the Ouachita Highlands," *Southeastern Fishes Council Proceedings*: No. 63.
https://doi.org/10.7290/sfcp63jwza
Available at: https://trace.tennessee.edu/sfcproceedings/vol1/iss63/2

Aspects of Distribution, Abundance, Habitat, and Life History of the Caddo Madtom (*Noturus taylori*), a Narrow Endemic of the Ouachita Highlands

Abstract

The Caddo Madtom, *Noturus taylori*, is a small catfish endemic to the Ouachita Mountain ecoregion in Arkansas, with habitat altered by land use practices and reservoir dams. We examined aspects of distribution, abundance, habitat, and life history of *N. taylori* during seasonal sampling from winter 2016 through fall 2017. Our sampling data were concordant with previous studies that suggested *N. taylori* is more widespread and has higher catch per unit effort in the Caddo River drainage when compared to the upper Ouachita River drainage. We did not detect *N. taylori* in the Little Missouri River drainage, where it is presumed extirpated. A total of 370 individuals ranging from 14–76 mm (mean = 45.1 mm) standard length (SL) were collected during seasonal samples. Length-frequency analyses estimated a maximum age of 3 years for *N. taylori*, and we identified three discernable age classes with the emergence of young-of-year (age 0 cohort) in summer: age 0 (up to ~40 mm SL); age 1 (~41-60 mm SL); and age 2+ (>60 mm SL). Sites where *N. taylori* was captured had an average depth of 20.6 cm, an average base velocity of 0.18 m/sec, and were dominated primarily by a mix of gravel, pebble, and cobble. Despite the relatively higher abundances of *N. taylori* in the Caddo River, we recommend that long-term, periodic monitoring of *N. taylori* would be an important conservation tool to assess potential future changes in distribution, habitat, occurrence, and abundance. Future studies that implement occupancy and habitat suitability modeling are needed to better understand suitable and preferred habitat of *N. taylori*.

Keywords

Ictaluridae, CPUE, length-frequency analysis, ELEFAN, endemism

Cover Page Footnote

We thank H. K. Canada, K. J. Dineen, T. K. Lee, D. R. Thomas, A. M. Mross, J. A. Bates, K. N. Driskill, K. D. Jones, L. A. Martin, B. S. McCall, I. Sanchez Gonzales, W. A. Smart, C. S. Thigpen, and Pamela and Michael Lambert for assistance with field sampling. This project was funded in part by the State Wildlife Grants Program (Grant #AR-T-60) of the U.S. Fish and Wildlife Service through an agreement with the Arkansas Game and Fish Commission. Additional funding was provided by the Arkansas State University Department of Biological Sciences, Arkansas Center for Biodiversity Collections, and the National Science Foundation (DBI-1561743 and DUE-1564954). We thank Arkansas Game and Fish Commission and U.S. Department of Agriculture Forest Service for collecting permits. Fish sampling, handling, and procedures were approved by the Arkansas State University Institutional Animal Care and Use Committee (IACUC protocol no. 747441-1).

INTRODUCTION

The Caddo Madtom (*Noturus taylori*) is a small catfish species endemic to the upper Caddo, Ouachita, and Little Missouri river drainages in the Ouachita Mountain ecoregion (Douglas 1972, Robison and Buchanan 2020; Figure 1). *Noturus taylori* was first discovered in the upper Caddo River in 1970, and formally described in 1972 from just six localities in the Caddo River upstream of Degray Lake (Douglas 1972). Robison and Harris (1978) later expanded the known range of *N. taylori*, adding six localities in the upper Ouachita River upstream of Lake Ouachita and one locality above Lake Greeson in the Little Missouri River. The discovery of *N. taylori* followed the closure of reservoirs in the upper Ouachita River drainage (Douglas 1972, Dewey and Moen 1978), so there is minimal distributional data for the species prior to reservoir construction. Based on museum records accessed from the FishNet2 Portal (fishnet2.net) and unpublished data from the Arkansas Game and Fish Commission, *N. taylori* has only been collected from approximately 45 locations throughout its distribution (i.e., historic localities; Figure 1). Since 1974, this rare species has informally been considered threatened due to restricted range, habitat fragmentation, vulnerability, and possible extirpation from the Little Missouri River drainage (Robison 1974, Robison and Buchanan 2020, Turner and Robison 2006). More recently, *N. taylori* has been ranked as endangered by the International Union for Conservation of Nature Red List (IUCN 2023), threatened by the American Fisheries Society (AFS, Jelks et al. 2008), critically imperiled globally (G1) by NatureServe (NatureServe 2023), and critically imperiled in Arkansas (S1) by the Arkansas Wildlife Action Plan (Fowler and Anderson 2015). In 2010, *N. taylori* was petitioned for listing under the Endangered Species Act (USFWS 2011).

Genetic studies of *N. taylori* (Turner and Robison 2006, allozymes; McCall and Fluker 2020, mtDNA and microsatellites) found that divergence between Caddo and upper Ouachita river populations has a historical basis, and was established prior to the closure of Blakely Mountain (1953) and DeGray (1969) dams along the Ouachita and Caddo rivers, respectively. While Caddo and upper Ouachita populations show no evidence of recent declines in genetic diversity, within-drainage divergence and low estimated migration rates suggest somewhat limited dispersal capabilities and reservoir-induced population fragmentation in one tributary of the upper the Ouachita River drainage (Turner and Robison 2006, McCall and Fluker 2020, Robison and Buchanan 2020).

Noturus taylori has been described as a habitat specialist with preferences to head water and tributary environments consisting of gravel bottomed pools in regions of moderate flow, shoals with compacted gravel, and at the base of gravel riffles (Robison and Harris 1978, Robison and Buchanan 2020). However, there are no published studies on habitat association of *N. taylori*, and most available information is descriptive. Further, there is limited data on current distribution, abundance, and life-history characteristics for *N. taylori.*

The objectives of this study were to assess basic distributional and abundance patterns, habitat association, and selected life-history attributes for *N. taylori*. To obtain estimates of catch per unit effort (CPUE), seasonal sampling surveys (e.g., winter, spring, summer, and fall) were conducted at six fixed sites for two calendar years. During seasonal surveys, body length measurements and microhabitat assessments were conducted in conjunction with successful captures of *N. taylori*. Length frequency data were used to better understand size, age, and growth

parameters for *N. taylori*. In addition to fixed seasonal sample sites, localities in tributaries of the upper Caddo, Ouachita, and Little Missouri rivers were sampled with the goal of better understanding distributional patterns of *N. taylori*, particularly at sites in the Ouachita River drainage with no known records of *N. taylori*. Results from this study provide updated and novel information for *N. taylori* populations, and should be informative for future conservation and listing decisions.

MATERIALS AND METHODS

Sampling and specimen data collection

Prior to designating fixed sites for seasonal sampling surveys, preliminary fish sampling was conducted at a variety of localities in upper Ouachita River drainages with and without known records of *N. taylori*. These initial sampling sites were selected based on previous collection records (Fishnet2.net, Harris and Douglas 1978, Robison and Harris 1978, Hardman 2004, Turner and Robison 2006) and unpublished data from the Arkansas Game and Fish Commission, and coincided with tissue sampling for genetic studies (McCall and Fluker 2020, 2021). Review of historic collection records and these preliminary sampling efforts helped us identify sites for seasonal sampling with the following attributes: sampling possible at wading depth with backpack electrofishing and seine; repeated history of captures of *N. taylori*; and public accessibility of sites. Fish sampling was conducted with a combination of seine (3.05 x 1.22 m with 3.18 mm mesh), backpack electrofishing, and dip nets for approximately 30-60 minutes per site.

Six sites were selected in the Caddo and upper Ouachita rivers for seasonal sampling to estimate CPUE, habitat association, and life-history attributes of *N. taylori* over a two-year period. There were two sampling localities in the Ouachita River and four in the Caddo River. The Ouachita River localities were both on the main stem of the river (Ouachita River at Oden Access Area [O] and Ouachita River at Rocky Shoals Recreation Area [R]); whereas, the Caddo River localities were throughout the drainage in the headwaters (Upper Caddo River [U]), the main stem (Caddo Gap [C]), and tributaries (Lick Creek [L] and South Fork Caddo River [S]; Table 1, Figure 1). Sites O, R, C, and S were sampled at night and sites U and L were sampled during daylight hours. This sampling scheme was established in conjunction with an ongoing survey for *Etheostoma pallididorsum* (Paleback Darter) that was being conducted during daylight hours at sites U and L; otherwise, seasonal sampling was standardized across all sites, and fishes were sampled each season (winter, spring, summer, and fall) during 2016 and 2017. Fish sampling was performed by setting the seine faced upstream, while two kickers (one with backpack electroshocker) dislodged substrate in a 2 x 2 m plot immediately in front of the net, and maintained a constant directional kick current into the net. Each sampling "event" was set to approximately one hour, covering approximately 75 m of stream reach. During each sampling event, sampling "efforts" were performed in all available habitat types within stream reaches, including riffles, runs, glides, and pools. Number of sample efforts (i.e., each kick-set) and total shock time were recorded for each site. Captured fishes were identified and enumerated, and *N. taylori* were measured for standard length (SL) in hand using a plastic ruler, without anesthesia. Captured individuals of *N. taylori* were not sexed due to the difficulty of reliably determining sex without lethal procedures (dissection). Most individuals were released live at the point of capture following data acquisition, but select individuals were euthanized in MS-222, preserved in 10% formalin as vouchers, and cataloged in the Arkansas State University Museum of Zoology (ASUMZ). For each

sampling event, we defined CPUE for *N. taylori* as the number of individuals captured divided by the number of efforts (kick-sets) completed in that sampling event. Occurrence was estimated by dividing the number of sampling events with successful capture of *N. taylori* by the total number of sampling events. Differences in CPUE and occurrence were assessed between the Caddo and Ouachita drainages using Wilcoxon Mann-Whitney tests. Associate species were identified, enumerated, and released during the collection surveys. Statistical tests were conducted in R (version 3.6.3; R Core Team 2020).

Length Frequency Analysis

Length-frequency data were constructed from individual SL measurements over the course of the study. We used the 'TropFishR' package (Mildenberger et al. 2017) in R to estimate growth-related parameters for *N. taylori* with an optimized electronic length frequency analysis (ELEFAN; Pauly 1980, Taylor and Mildenberger 2017) as described in McCall and Fluker (2022). Briefly, our length-frequency data were restructured into optimal bin sizes using the method of Wang et al. (2020), and subjected to simulated annealing (SA) and genetic (GA) algorithms. The following parameters were estimated simultaneously using the seasonally oscillating von Bertalanffy growth function (soVBGF; von Bertalanffy 1938, Somers 1988): (1) L_∞, asymptotic length; (2) K, growth rate (curving coefficient); (3) t_{anchor}, time point anchoring growth curves (time point when yearly repeating growth curves cross length equal to zero); (4) C, amplitude of growth oscillations (seasonal growth model); (5) t_s, summer point of oscillation (time point when growth turns positive); (6) ϕL, growth performance index; (7) $n_{cohorts}$, number of cohorts; and (8) agemax, maximum age of species. Starting values for parameter estimates were as follows: L_∞ was based on maximum length +/- 10 mm for *N. taylori* (76 mm +/- 10 mm); K ranged from 0.1–2.0 (initial = 1.0); and all other parameters varied from 0.0–1.0 (initial = 0.5). Plots of raw and restructured (binned) length frequency data were generated for visual representation of size distributions and seasonal growth curves. Best runs among SA and GA analyses were evaluated by the Rn_max score; a fitting score to evaluate searches in parameter space, with higher values representing best runs that were less likely to be trapped in local maxima (Taylor and Mildenberger 2017).

Microhabitat assessment

Upon capture of *N. taylori* during efforts of seasonal surveys from spring 2016 to winter 2017, a flag was used to mark the location for habitat assessment following the one-hour sampling period. The delay between the collection survey and the microhabitat assessment allowed time for disturbed areas to resettle for more accurate measurements of habitat variables. At each flag marker, a 2 x 2 m plot was measured, representing the disturbed area during the kick-set. Within each plot, eight habitat variables were measured at the center, left margin, and right margin of the plot. Water depth was recorded, and velocity was measured at the stream bed interface and at 60% depth with a Marsh-McBirney Flo-Mate™ Model 2000 portable flowmeter. Turbidity was measured with a Hach Model 2100P Turbidimeter. Temperature, dissolved oxygen, conductivity, total dissolved solids, and pH were measured with an YSI Professional Plus multi-parameter meter. Substrate was visually characterized by percent composition within the plot following a modified classification scheme of Cummins (1962): sand (0.13–1.0 mm), gravel (2–16 mm), pebble (16–64 mm), cobble (64–256 mm), boulder (>256 mm), and bedrock.

Table 1. Seasonal sampling sites for *Noturus taylori* conducted during 2016 and 2017. Each sampling event is shown by site and by season (e.g., Winter 2016 = W-16). Number of individual *N. taylori* captured is shown for each sampling event followed by number of sample efforts in parentheses. Mean (± standard deviation) catch per unit effort (CPUE) is shown for each site over all seasonal samples.

Drainage/Site	Latitude	Longitude	W-16	Sp-16	Su-16	F-16	W-17	Sp-17	Su-17	F-17	CPUE
Caddo R. Drainage											
(U) Upper Caddo R.	34.45104	-93.84297	0 (15)	5 (17)	6 (21)	8 (24)	7 (23)	8 (30)	2 (30)	2 (30)	0.20±0.12
(L) Lick Creek	34.47675	-93.73674	0 (18)	3 (16)	18 (24)	17 (25)	10 (33)	10 (27)	2 (23)	12 (33)	0.34±0.25
(C) Caddo Gap	34.38327	-93.60539	2 (20)	3 (20)	3 (25)	7 (18)	13 (17)	7 (28)	6 (21)	12 (23)	0.32±0.21
(S) South Fork Caddo R.	34.35514	-93.67970	5 (19)	14 (26)	49 (15)	21 (18)	7 (21)	16 (21)	18 (19)	2 (20)	0.92±0.95
Ouachita R. Drainage											
(O) Oden Access	34.61108	-93.77790	0 (14)	0 (21)	0 (16)	0 (14)	6 (17)	0 (18)	0 (14)	1 (18)	0.05±0.12
(R) Rocky Shoals	34.61138	-93.69796	4 (15)	3 (18)	4 (16)	1 (7)	17 (17)	4 (19)	1 (13)	5 (20)	0.30±0.27

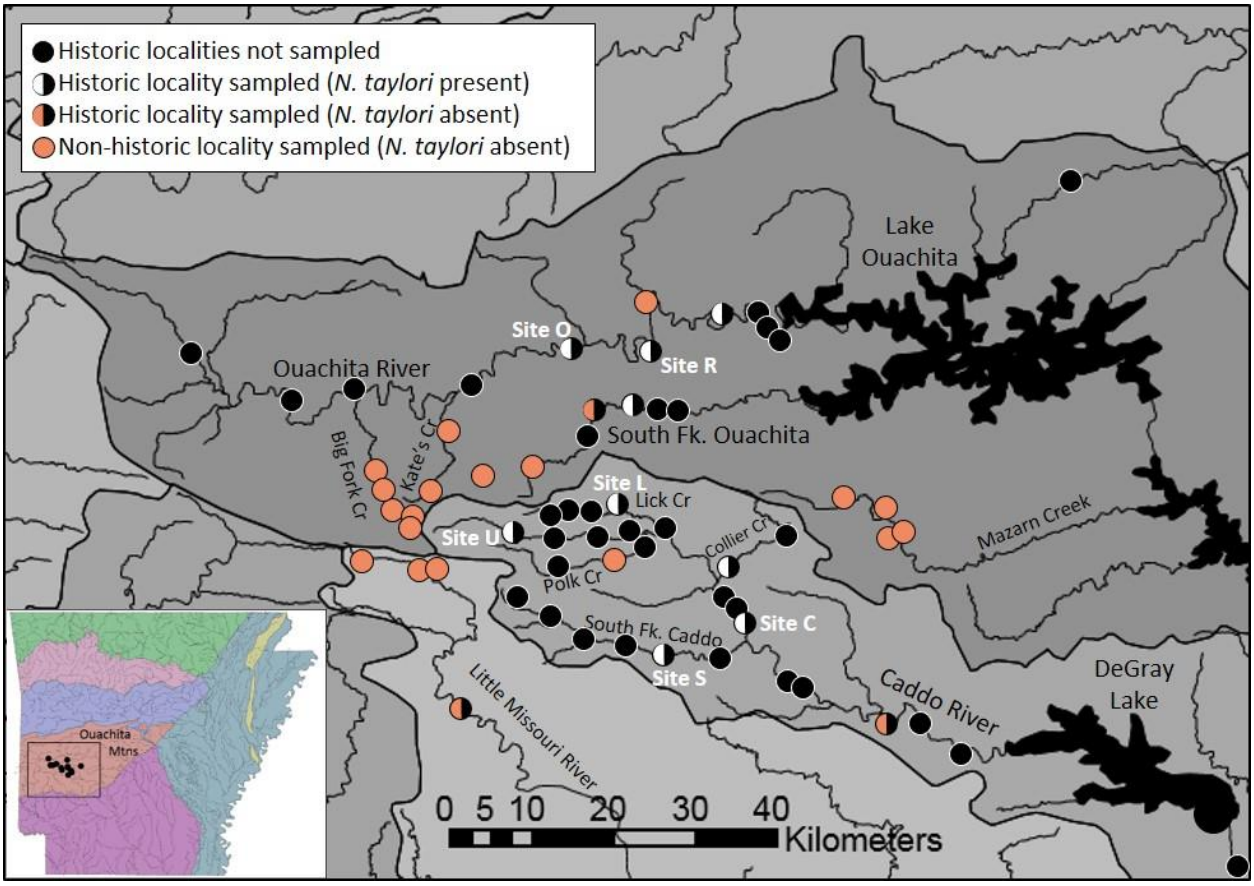

Figure 1. Map of the upper Ouachita, Caddo, and Little Missouri river watersheds showing sample sites for *Noturus taylori* during this study. Points indicate historic localities for *N. taylori* that were not sampled (black circles), historic localities where *N. taylori* was present (black and white circles), historic localities where *N. taylori* was absent (black and orange circles), and non-historic localities where *N. taylori* was absent. Seasonal sampling sites in the Caddo River drainage were (U) Upper Caddo River, (L) Lick Creek, (C) Caddo Gap, and (S) South Fork Caddo River. Seasonal sampling sites in the Ouachita River drainage were (O) Oden Access and (R) Rocky Shoals Recreation Area. Inset shows the study area situated within the Ouachita Mountain ecoregion in Arkansas.

Data accessibility

Raw data files with individual SL measurements and collected habitat variables for *N. taylori*, in addition to R scripts for the ELEFAN analyses are available in the Dryad Data Platform (https://doi.org/10.5061/dryad.f7m0cfz20).

RESULTS

Distributional sampling

Over the duration of the project, we sampled a total of 32 sites targeting *N. taylori* with the following results: 9 historical sites where present; 3 historical sites where absent; and 20 non-historical sites where absent (Figure 1; Appendix 1). We did not detect *N. taylori* at sampled sites in the Little Missouri River drainage (Figure 1; Appendix 1).

Seasonal surveys

A total of 48 sampling events were made at the six seasonal sites from 2016 to 2017, yielding 14,216 individuals of 38 species (Appendix 2). Number of sample efforts per site, per season ranged from 7–33 ($\bar{x}$ = 20.4; Table 1). The two most abundant species were *Etheostoma radiosum* (Orangebelly Darter) and *Campostoma spadiceum* (Highland Stoneroller), which constituted approximately 61% of the total individuals captured (Appendix 2).

A total of 341 *N. taylori* were captured over the 48 seasonal sampling events (Table 1; Appendix 2). *Noturus taylori* was present in 40 (83%) of the events with an overall mean CPUE of 0.36 (SD ± 0.51) individuals per effort. When compared between drainages, occurrence of *N. taylori* was higher for Caddo River sites (mean ± SD: 0.94 ± 0.24) than Ouachita River sites (mean ± SD: 0.63 ± 0.48), but this difference was not significant (z = 1.74, p = 0.082; Figure 2). CPUE of *N. taylori* from Caddo River sites (mean ± SD: 0.45 ± 0.58) was higher than Ouachita River sites (mean ± SD: 0.17 ± 0.24), and despite high standard deviation of the samples, this difference was significant (z = 2.91, p = 0.003; Table 1, Figure 2). Although significance of CPUE among seasons was not evaluated because of small sample sizes, there was a trend of higher CPUE of *N. taylori* at Ouachita River sites in winter compared to Caddo River sites, but CPUE at Caddo River sites was generally higher in all other seasons (Figure 2).

Length Frequency Analysis

A total of 370 *N. taylori* were measured for Standard Length (SL) during the study; the 341 that were captured during seasonal sample events, and an additional 29 individuals. These 29 individuals were sampled just after some seasonal sampling events for tissue samples for genetic analysis (not re-captured individuals). Combined 2016 and 2017 sample sizes for each season were as follows: winter (January 29–March 2, n = 96); spring (May 11–26, n = 74); summer (July 29–August 4, n = 110); and fall (October 8–15, n = 90). Individuals ranged in size from 14–76 mm SL (mean = 45.1 mm SL).

We used maximum length (L_{max}) of 76 mm and maximum age (A) of 3 years with the equation 1.86 x $(L_{max}/A)^{0.45}$ (Wang et al. 2020) to obtain an optimal bin size of 7.96 (rounded to 8) for ELEFAN analyses of *N. taylori*. Because there are no formal age estimates for *N. taylori*, we used maximum age of 3 from the closely related *Noturus miurus* (Brindled Madtom) (Burr and Mayden 1982a), as a surrogate for the bin size calculation. The default moving average (MA = 5) was retained in our analyses since this value closely approximated the number of bins spanning the size range of the youngest cohort (~40 mm/8bins = 5) upon recruitment into the population in the summer season. Length frequency data are shown in Figure 3 as raw and restructured using the above settings. ELEFAN (SA) runs of 1, 5, and 10 minutes converged on identical results. Initial GA runs with 500 iterations yielded inconsistent results compared to other runs, but runs with 900 and 2,000 iterations were very comparable to SA runs (Table 2). Restructured length frequency data overlaid with soVBGF curves from final SA and GA analyses (Figure 4) both show higher rates of growth in spring and summer, followed by slowed growth from late fall to early spring. The age 0 cohort exhibits a steep growth curve over the first spring and summer, attaining lengths of approximately 40 mm SL (Figure 4). When ELEFAN results are extrapolated to the raw length frequency histograms by season (Figure 5), emergence of young-of-year (age 0 cohort) is clearly visible in summer and we see at least three discernable age classes with the following approximate size ranges: age 0 (up to ~40 mm SL); age 1 (~41-60 mm SL); and age 2+ (>60 mm SL).

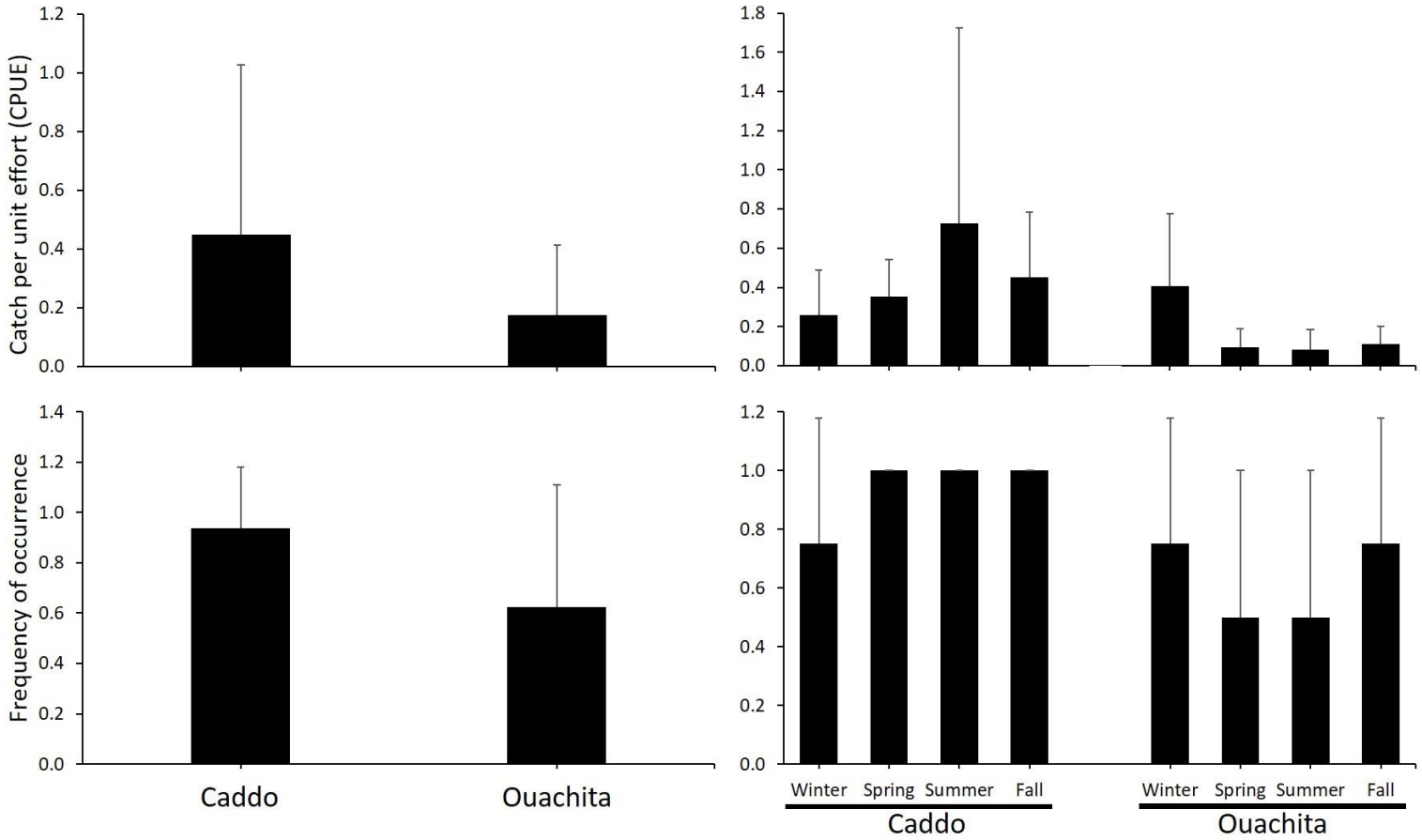

Figure 2. (Above) average catch per unit effort (CPUE ± SD) of *Noturus taylori* summarized by drainage and by season for combined 2016 and 2017 seasonal samples. (Below) average occurrence (± SD) of *Noturus taylori* summarized by drainage and by season for combined 2016 and 2017 seasonal samples.

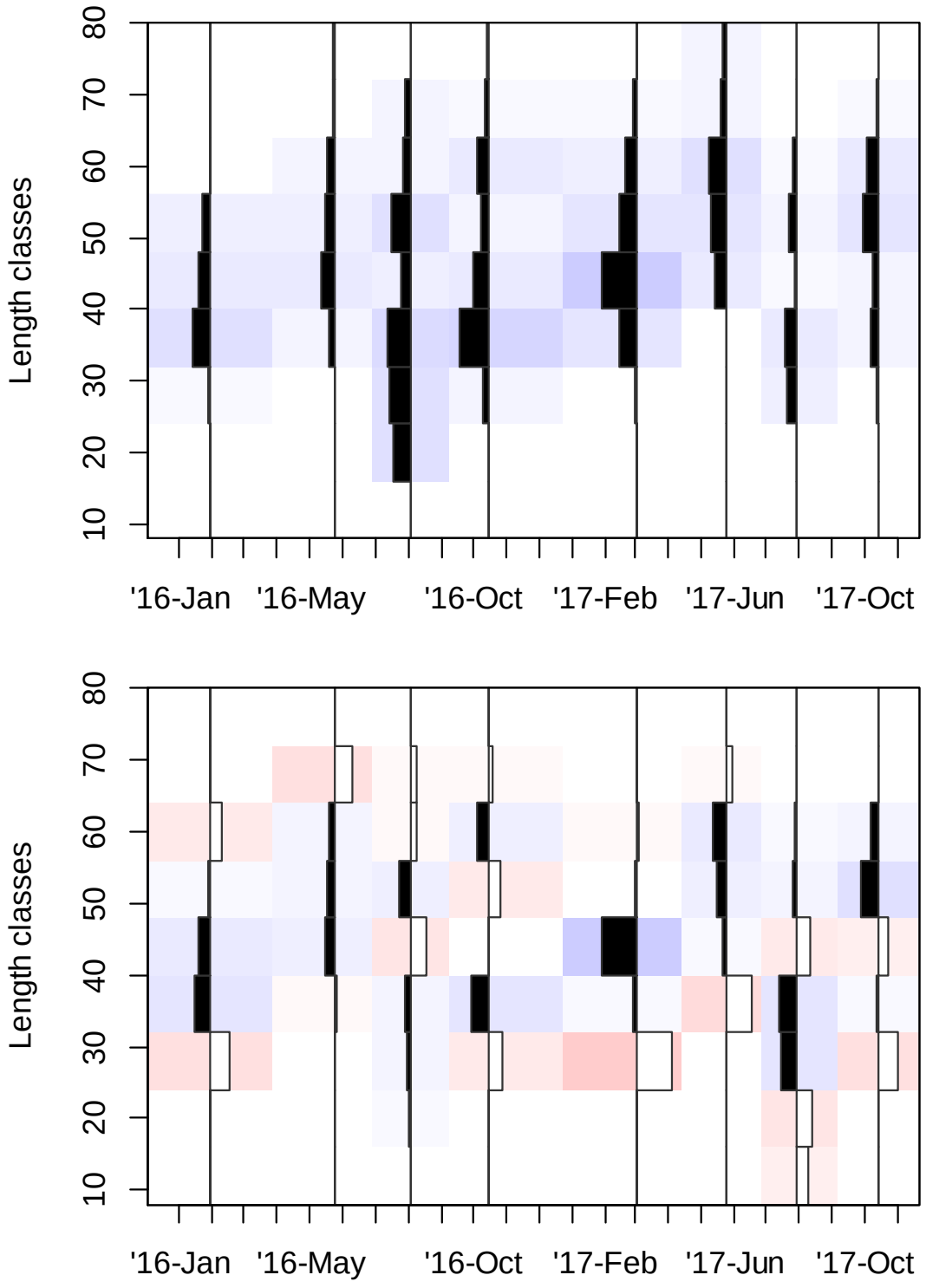

Figure 3. Raw (top) and restructured (bottom) length frequency data of *Noturus taylori* measured from seasonal samples during 2016 and 2017 (*n* = 370; bin size = 8 mm). The restructured plot shows positively (black peaks with purple shading) and negatively (white peaks with red shading) scored bins calculated used a moving average of five (MA = 5). Positive peaks are used by the seasonally oscillating von Bertalanffy growth function to estimate yearly repeating growth curves.

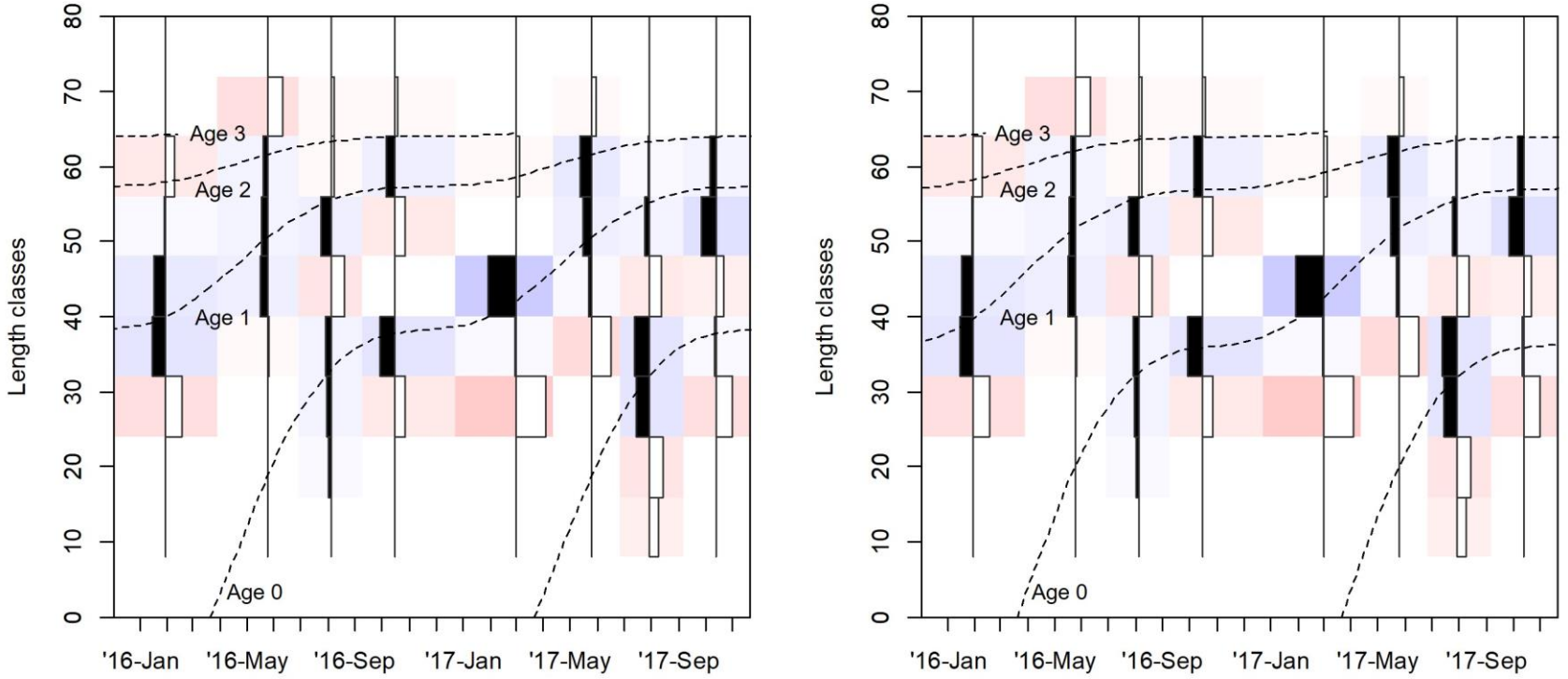

Figure 4. Restructured length frequency data of *Noturus taylori* measured from seasonal samples during 2016 and 2017 (n = 370; bin size = 8 mm), shown with yearly repeating growth curves from the seasonally oscillating von Bertalanffy growth function. Yearly repeating growth curves are shown from the genetic algorithm (GA, left) and simulated annealing (SA, right) optimization methods.

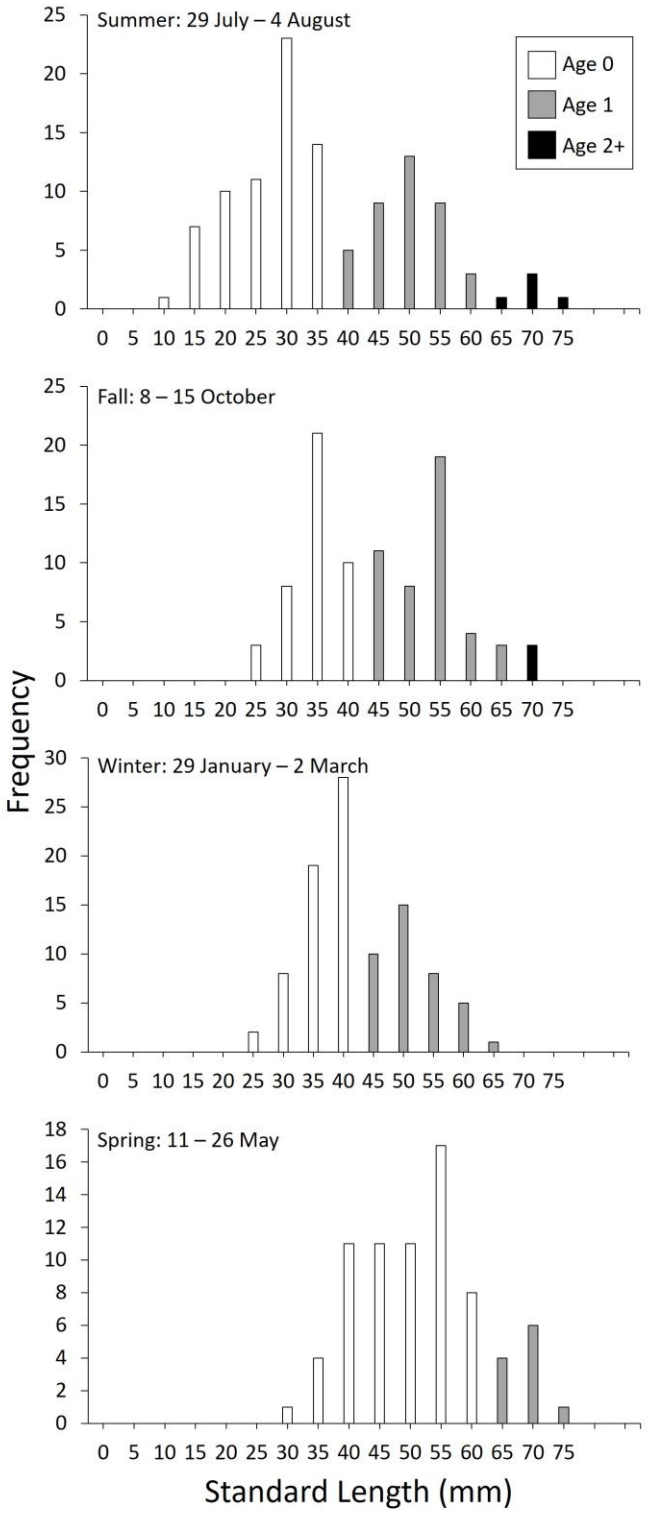

Figure 5. Length frequencies of *Noturus taylori* measured from seasonal samples during 2016 and 2017 (*n* = 370, 5 mm length groups). Individuals from 2016 and 2017 were combined and seasons are shown with date ranges encompassing both sample years. Ages are estimated from the Electronic Length Frequency Analysis (ELEFAN) and the combined histograms show progression of age classes through a calendar year, beginning with the first detection of the age 0 cohort in summer.

Table 2. Parameter estimates obtained from the Electronic Length Frequency Analysis (ELEFAN) using the seasonally oscillating von Bertalanffy growth function with Simulated Annealing (SA) and Genetic Algorithm (GA) optimization.

Parameter	ELEFAN (SA)	ELEFAN (GA)
L_∞	67.38	67.58
K	1.10	1.05
t_{anchor}	0.22 (late March)	0.22 (late March)
C	0.87	0.91
t_s	0.33 (early May)	0.39 (mid May)
ϕL	3.70	3.68
$n_{cohorts}$	6	6
agemax	3	3
Rn_max	0.75	0.76

L_∞, asymptotic length (mm SL); K, growth rate (curving coefficient); t_{anchor}, time point anchoring growth curves (time point when yearly repeating growth curves cross length equal to zero); C, amplitude of growth oscillations (seasonal growth model); t_s, summer point of oscillation (time point when growth turns positive); ϕL, growth performance index; $n_{cohorts}$, number of cohorts; agemax, maximum age of species; Rn_max, fitting score.

Microhabitat assessment

Average habitat variables for each drainage, site, and season are shown in Appendices 3 and 4. Sample plots where *N. taylori* was present in the Caddo River varied in average depth from 11.8–43.6 cm (overall mean = 19.2 cm), average base flow from 0.05–0.78 m/s (overall mean = 0.18 m/s), and average conductivity from 38.6–606.1 µS/cm (overall mean = 185.5 µS/cm). Sample plots where *N. taylori* was present in the Ouachita River varied in average depth from 16.4–42.1 cm (overall mean = 24.9 cm), average base flow from 0.10–0.28 m/s (overall mean = 0.18 m/s), and average conductivity from 88.7–201.8 µS/cm (overall mean = 142.1 µS/cm). Sample plots where *N. taylori* was present were dominated primarily by a mix of gravel, pebble, and cobble (Figure 6, Appendix 4). Pebble constituted the highest proportion of substrate where *N. taylori* was captured in the Caddo (32%) and Ouachita (42%) rivers, with an overall average of 35% for both drainages (Appendix 2).

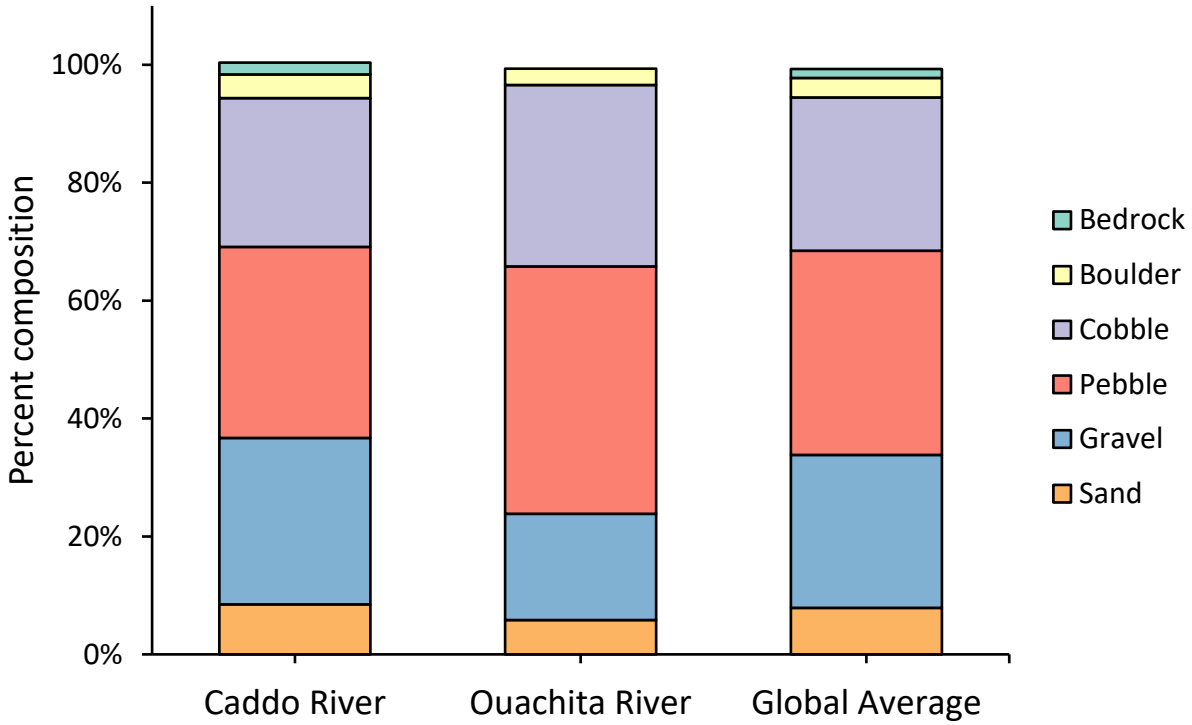

Figure 6. Stacked bar plot showing percent composition of substrate types in plots where *Noturus taylori* was present for each drainage and the global average of both drainages. Substrate type follows a modified classification scheme of Cummins (1962). Values correspond to those listed in Appendix 4.

DISCUSSION

Distribution, abundance, and size structure

Noturus taylori was first discovered in the Caddo River drainage (Douglas 1972), and subsequently discovered in the Ouachita River drainage six years later (Robison and Harris 1978). The secondary discovery in an adjacent drainage has been hypothesized as a possible stream capture event (Robison and Harris 1978). *Etheostoma pallididorsum* has a similar distribution, including the secondary discovery within the Ouachita River drainage, further corroborating the hypothesis of a potential stream capture (Robison 1974). Therefore, it was expected for the Caddo River drainage to have a higher relative abundance if the Caddo River is a source population. The higher occurrence and CPUE of *N. taylori* at Caddo River drainage sites, compared to Ouachita River sites are important findings for management and conservation decisions, but come with some caveats. First, our sample design included more sites in the Caddo (four) compared to the Ouachita drainage (two), which could bias our occurrence and CPUE results. Most of the documented historical localities for *N. taylori* in the upper Ouachita River drainage are restricted to the reach from Rocky Shoals Recreation Area (site R) downstream to the confluence of Lake Ouachita (Robison and Harris 1978). We conducted preliminary surveys at historic localities within this reach of the Ouachita River with little success in detecting *N. taylori*, and access to many of these sites was restricted. Thus, the two sites chosen for this survey were publicly accessible, with a known history of occurrence for the species. There are no documented records of *N. taylori* in tributaries to the mainstem of the Ouachita River, differing from the Caddo River drainage, and

further limiting sampling accessibility of *N. taylori* in the Ouachita River drainage. Sample sites in the Caddo River also had relatively lower depths and velocities, potentially favoring capture of *N. taylori* when compared to Ouachita River sites. Second, sites U and L in the Caddo River drainage were sampled during daylight hours, while sites C and S (Caddo) and O and R (Ouachita) were sampled at night. This sampling scheme was established to accommodate an ongoing survey for *E. pallididorsum* that was being conducted during daylight hours at sites U and L in conjunction with this study. It is possible that potential differences in relative abundance among localities sampled during day vs. night may be attributable to the nocturnal nature of catfish, with more individuals freely foraging during night rather than nested in cavities and crevices of substrate and debris during the day. In light of these differences in time of sampling, CPUE was not significantly different ($z = 1.696$, $p = 0.0891$) for Caddo River sites sampled during the day (U and L) when compared to those sampled at night (C and S). Further, when CPUE was compared among sites that were only sampled at night (Caddo River sites C and S vs. Ouachita River sites O and R), differences between the drainages remained significant ($z = 2.99$, $p = 0.003$). Despite the caveats listed above, our results are concordant with previously published sample data that suggest *N. taylori* has a broader distribution, higher occurrence, and higher abundance in the Caddo River drainage (Robison and Harris 1978).

A total of 38 fish species were collected with *N. taylori* (Appendix 2). The species most commonly associated with *N. taylori* were, *Campostoma spadiceum*, *Cyprinella whipplei* (Steelcolor Shiner), *Notropis boops* (Bigeye Shiner), *Etheostoma radiosum*, and *Etheostoma zonale* (Banded Darter). All other associate species were either caught infrequently with *N. taylori* or in adjacent habitat. When compared to associate species listed by Douglas (1972), all species were detected within plots where *N. taylori* were caught or in adjacent habitat with exception to *Erimystax x-punctatus* (Gravel Chub) and *Minytrema melanops* (Spotted Sucker). Our survey added 4 new associate species that have not been previously documented to occur with *N. taylori*: *Erimyzon claviformis* (Western Creek Chubsucker), *Pylodictis olivaris* (Flathead Catfish), *Etheostoma collettei* (Creole Darter), and *Percina brucethompsoni* (Ouachita Darter).

Noturus taylori is genetically dimorphic (LeGrande 1981) but not morphologically dimorphic, requiring necropsy for sex confirmation. Since *N. taylori* is a species of greatest conservation need in Arkansas, sex determination was not conducted in this study and we do not report on sex-specific size characteristics. Robison and Buchanan (2020) reported the maximum size of *N. taylori* as 64.7 mm SL. During our sampling, we encountered 14 individuals ≥ 70 mm SL, and one individual from the upper Caddo River (site U; 24-May-2016) that was 76 mm SL. This specimen was released, as it appeared to be a gravid female based on the presence of a distended abdomen and developed genital papillae (Burr and Stoeckel 1999). The largest specimen preserved during this study was 72 mm SL from the upper Caddo River (site U) in spring 2017 (ASUMZ 20190). Seasonal size distribution data suggest that these larger individuals (≥ 70 mm SL) are age 2 adults that may persist through summer and fall, but likely do not survive through winter to produce an age 3 cohort (Figures 4 and 5).

Ideally, monthly sampling (as opposed to seasonal sampling) would be conducted for analysis of age structure via length frequency data. Although our sampling schedule was not ideal for tracking size classes through time, our length frequency data provided some insight into the age structure, growth, and spawning activity period for *N. taylori*. Emergence of young-of-year

was clearly identified during summer samples (Figure 5). Our interpretation of three age classes from ELEFAN analysis and differing frequency distributions in summer samples is consistent with closely related species such as *N. miurus* (Hardman 2004). For example, Burr and Mayden (1982a) found that *N. miurus* averaged 16.4 mm SL at 24 days post-hatch and about half of the annual growth was attained in the first eight weeks (i.e., approximately 30 mm SL), age 1+ individuals (13-24 months) averaged approximately 60 mm SL, and age 2+ individuals were > 60 mm SL. Neither spawning activity, nor nests have been observed for *N. taylori* in previous studies or within the duration of this study. Robison and Buchanan (2020) estimated the spawning period for *N. taylori* to occur from late April to May based on examination of gonads. This is earlier than most *Noturus* species, which spawn mid-June to late-July (i.e., Mountain Madtom, *N. eleutherus* [Starnes and Starnes 1985], *N. miurus* [Burr and Mayden 1982a], and Freckled Madtom, *N. nocturnus* [Burr and Mayden 1982b]). If *N. taylori* experiences growth rates similar to *N. miurus* in the three months post-hatch, results from our estimated age 0 class in summer samples (~14-40 mm SL) suggest that *N. taylori* likely spawns from late April to late June and possibly into July. However, this is somewhat out of sync with respect to our t_{anchor} estimation (Table 2), which corresponds to the fraction of the year when growth curves pass size zero, and should roughly reflect peak spawning time. Our t_{anchor} estimation (365 days x 0.22 = day 80.3) roughly corresponds to day 80 of the year or late March. We suspect that the relatively earlier estimation of spawning time in the ELEFAN analysis is a product of our seasonal sampling scheme and additional sampling on a monthly basis would improve t_{anchor} estimations. Despite this discrepancy in estimated peak spawning time, our ELEFAN analysis indicated that growth turns positive in mid to late May (see t_s values in Table 2), which corresponds closely with timing of the rapid growth period of the newly spawned age 0 cohort (Figure 4). Without more frequent sampling during the spawning season or identification of nests, no further speculations can be made about the spawning activity of *N. taylori*.

Habitat association

There has been a call to quantify madtom habitat requirements (Chan and Parsons 2000) since the greatest risk to conservation of the genus *Noturus* is considered to be habitat destruction. Therefore, we collected basic water quality, habitat, and substrate variables within the 2 x 2 m plots where *N. taylori* was collected. For water quality variables to be informative, measurements need to be taken along multiple points within a riverine system and monitored regularly to address seasonal patterns (e.g., Lee et al. 2009, Pan et al. 2004); whereas, water quality parameters for the current study were taken from single points of capture each season. In addition, habitat variables assessed were also restricted to plots where *N. taylori* was present in seasonal surveys and we made no attempt to characterize available habitat where *N. taylori* was not present. Thus, we present our habitat data for *N. taylori* with no assumptions or inferences of habitat preference. Despite these limitations, we provide important baseline habitat and water quality data associated with *N. taylori* presence (Appendices 3 and 4). In general, measures of average plot depth, base and mid-column velocity, and substrate composition were similar between the Caddo and Ouachita drainages. Average depth of capture for *N. taylori* (20.9 cm) is similar, but anecdotally shallower compared to close relatives Neosho Madtom, *N. placidus* (34 cm; Bulger and Edds 2001) and Carolina Madtom, *N. furiosus* (42 cm; Midway et al. 2010). Average stream base and mid-column velocities for *N. taylori* (0.18 m/s and 0.31 m/s) fall in between *N. furiosus* (0.14 m/s and 0.22 m/s; Midway et al. 2010) and *N. placidus* (0.23 m/s and 0.52 m/s; Bulger and Edds 2001). Future studies that implement occupancy and habitat suitability modeling (e.g., Simonson and Neves 1992,

Midway et al. 2010, Moore et al. 2018) are needed to better understand preferred and suitable habitat of *N. taylori*.

Conclusions

Although the scope of our sampling was limited, our seasonal sampling efforts at six fixed sites during 2016 and 2017 suggest that *Noturus taylori* has higher CPUE at sites sampled in the Caddo River drainage when compared to sites in the upper Ouachita River drainage. These findings are consistent with historical records and with the hypothesis of Robison and Harris (1978) that *N. taylori* likely colonized the upper Ouachita River via stream capture events involving the source population in the Caddo River drainage. Our length frequency analysis of 370 individuals extends the known maximum length for *N. taylori* to 76 mm SL, with an estimated asymptotic length of approximately 67 mm SL. Maximum age of three years was estimated for *N. taylori*, and we identified at least three age classes present during summer: age 0 (up to ~40 mm SL); age 1 (~41-60 mm SL); and age 2+ (>60 mm SL). ELEFAN analyses further suggested that spawning may extend from April to June, instead of April to May as previously estimated by Robison and Buchanan (2020). Despite the relatively moderate abundance of *N. taylori*, especially at our sites in the Caddo River, its restricted distribution and presumed extirpation from the Little Missouri River renders the species vulnerable to habitat alterations from local land use activities. Thus, we recommend long-term, periodic monitoring of *N. taylori* would be an important conservation tool to assess potential future changes in distribution, habitat, occurrence, and abundance.

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Appendix 1. Sample sites visited over the duration of the study. Historic localities are indicated for *Noturus taylori*, whether *N. taylori* was present at a site during our sampling, followed by an identifier for the 6 seasonal sites sampled throughout 2016 and 2017. Sites correspond to Figure 1.

Site	Locality	Historic Locality?	*N. taylori* Present?	Latitude	Longitude	Drainage	Seasonal Site
1	Caddo River at Forest Service Rd 913A (FS 542), approximately 8 mi W of Black Springs	Yes	Yes	34.45104	-93.84297	Caddo	U
2	Boxx Springs off of Polk Creek Rd. (FS 73)			34.44402	-93.78268	Caddo	
3	Tributary to Polk Creek at Mt Gilead Rd, W of junction with Polk Creek Rd			34.43200	-93.73778	Caddo	
4	Lick Creek at Gaston Dr, 2 mi NW of Black Springs	Yes	Yes	34.47675	-93.73674	Caddo	L
5	Unnamed tributary (ditch) to Collier Creek at AR Hwy 8 at Caddo Hills High School			34.41810	-93.63232	Caddo	
6	Collier Creek at AR Hwy 8, approximately 1.5 mi NW of Caddo Gap	Yes	Yes	34.41432	-93.63073	Caddo	
7	Caddo River at Hwy 240 (Caddo Gap, Arrowhead Canoe)	Yes	Yes	34.38327	-93.60539	Caddo	C
8	South Fork Caddo River at Oak Grove Rd off of St Hwy 240	Yes	Yes	34.35514	-93.67970	Caddo	S
9	Caddo River at AR Hwy 182, approximately 1.8 mi N of Amity	Yes		34.28978	-93.45899	Caddo	
10	Big Fork Creek, 1 mi NW of Big Fork on Co. Rd 67 off of AR Hwy 8			34.49740	-93.97200	Ouachita	
11	Unnamed spring tributary to Big Fork Creek at AR Hwy 8			34.49076	-93.97192	Ouachita	
12	Butcherknife Creek at AR Hwy 8			34.48630	-93.96864	Ouachita	
13	Abernathy Spring and Unnamed tributary to Big Fork Cr. at AR Hwy 8 bridge			34.46817	-93.94798	Ouachita	
14	Unnamed tributary to Big Fork Creek at AR Hwy 8 bridge			34.46802	-93.94767	Ouachita	
15	Kate's Creek at Co. Rd. 69/Southside Rd, 4 mi E of Opal			34.54905	-93.91298	Ouachita	
16	Big Hill Creek at Martin Simpson Rd.			34.50427	-93.86908	Ouachita	
17	Tributary to Kate's Creek at Big Fork Rd.			34.49390	-93.91429	Ouachita	
18	Ouachita River at Hwy 379; Oden access area	Yes	Yes	34.61108	-93.77790	Ouachita	O
19	Ouachita River at Rocky Shoals Recreation Area, off of Hwy 270 bridge	Yes	Yes	34.61138	-93.69796	Ouachita	R
20	Ouachita River at River Haven Resort			34.65093	-93.70160	Ouachita	
21	Ouachita River at Riverbluff Recreation Area	Yes	Yes	34.63982	-93.62603	Ouachita	
22	South Fork Ouachita River at Murphy Rd.			34.50995	-93.81843	Ouachita	
23	South Fork Ouachita River off of Gaston Rd., 1 mile N of Gaston	Yes		34.56184	-93.75334	Ouachita	
24	South Fork Ouachita River at Hwy 379/South Fork Rd bridge	Yes	Yes	34.56102	-93.71602	Ouachita	
25	Mazarn Creek at Logan Gap Rd.			34.48465	-93.48695	Ouachita	
26	Wake Creek at Meyer Creek Rd bridge			34.47059	-93.46321	Ouachita	
27	Coldwater Creek at Campbell (Cutoff) Road			34.45629	-93.45324	Ouachita	
28	Mazarn Creek at jct. Old Dallas Rd. and Cutoff Rd.			34.46036	-93.44906	Ouachita	
29	Little Missouri River at Little Missouri Trail, off of County Rd. 601			34.43668	-93.99796	Little Missouri	
30	Little Missouri River at Little Missouri Falls off of County Rd. 260			34.42264	-93.91952	Little Missouri	
31	Crooked Creek at jct. Mine Creek Rd. and Albert Pike Rd.			34.42390	-93.90839	Little Missouri	
32	Little Missouri River at Hwy 84	Yes		34.31137	-93.89964	Little Missouri	

Appendix 2. Species and total number of individuals collected at each site during the 48 seasonal sample events spanning both 2016 and 2017. Site abbreviations correspond to Appendix 1 and Figure 1.

	Site					
Species	U	L	C	S	O	R
Ichthyomyzon gagei	2	–	1	–	2	1
Campostoma spadiceum	57	535	638	916	1262	851
Cyprinella whipplei	–	3	77	12	217	134
Luxilus chrysocephalus	106	5	–	1	–	–
Lythrurus umbratilis	–	–	–	5	–	–
Notropis boops	2	27	218	59	422	274
Notropis sp. cf. *rubellus*	–	–	31	13	231	114
Pimephales notatus	–	4	183	17	83	118
Pimephales vigilax	–	–	1	–	–	–
Semotilus atromaculatus	65	104	–	2	–	–
Erimyzon claviformis	2	2	–	–	–	–
Hypentelium nigricans	1	1	8	1	7	42
Moxostoma sp. (juvenile)	–	–	–	–	5	8
Ameiurus natalis	–	13	1	3	–	–
Ictalurus punctatus	–	–	–	–	1	3
Noturus nocturnus	–	–	–	–	91	102
Noturus taylori	38	72	53	132	7	39
Pylodictis olivaris	–	–	1	–	–	1
Labidesthes sicculus	–	–	19	9	11	22
Fundulus catenatus	4	79	74	40	55	44
Fundulus notatus	–	1	–	–	–	–
Fundulus olivaceus	–	17	1	6	–	–
Gambusia affinis	–	–	5	–	1	2
Ambloplites ariommus	–	–	–	–	–	1
Lepomis cyanellus	–	3	16	23	12	2
Lepomis macrochirus	–	–	1	–	5	–
Lepomis megalotis	–	15	39	42	89	63
Micropterus dolomieu	–	–	2	3	–	–
Micropterus punctulatus	–	–	–	1	–	1
Etheostoma blennioides	–	21	119	46	262	291
Etheostoma clinton	–	–	–	–	14	12
Etheostoma nigrum	–	–	–	–	1	3
Etheostoma pallididorsum	22	44	–	2	–	–
Etheostoma radiosum	782	743	787	509	799	841
Etheostoma zonale	–	–	245	7	261	235
Percina brucethompsoni	–	–	–	–	–	1
Percina caprodes	–	2	22	–	–	4
Percina copelandi	–	–	1	–	1	4

Appendix 3. Aquatic variables, shown as averages for each respective level (Drainage/site/season), from sample plots where *Noturus taylori* was present during the seasonal sample events from spring 2016 to winter 2017. Site abbreviations correspond to Table 1 and Figure 1.

Drainage/*site*/season	**Depth (cm)**	**Turbidity (NTU)**	**Flow (m/s)**		**Temp (°C)**	**DO (mg/L)**	**Conductivity (µS/cm)**	**TDS (mg/L)**	**pH**
			Base	**60%**					
Caddo River	**19.2**	**0.48**	**0.18**	**0.30**	**19.30**	**10.65**	**185.5**	**137.46**	**8.07**
(U) Upper Caddo R.	*17.8*	*0.26*	*0.10*	*0.17*	*17.62*	*10.22*	*131.5*	*99.60*	*8.26*
Spring 2016	22.0	0.38	0.05	0.15	17.32	—	86.4	65.76	10.17
Summer 2016	16.1	0.28	0.12	0.16	23.02	—	117.9	75.69	9.23
Fall 2016	15.5	0.12	0.09	0.10	17.33	8.50	155.8	116.38	6.87
Winter 2017	17.7	0.26	0.15	0.26	12.82	11.93	165.9	140.57	6.78
(L) Lick Creek	*13.6*	*0.30*	*0.13*	*0.19*	*19.51*	*10.83*	*241.9*	*178.03*	*8.36*
Spring 2016	14.0	0.21	0.15	0.27	20.30	—	205.0	146.25	9.55
Summer 2016	11.8	0.39	0.09	0.12	27.72	—	237.7	144.30	9.08
Fall 2016	12.8	0.15	0.11	0.09	16.72	8.31	229.7	174.48	7.16
Winter 2017	15.9	0.45	0.15	0.26	13.32	13.35	295.2	247.11	7.65
(C) Caddo Gap	*28.0*	*0.58*	*0.36*	*0.62*	*21.44*	*9.89*	*289.1*	*216.46*	*8.63*
Spring 2016	29.4	0.46	0.23	0.48	21.79	—	146.7	101.47	10.37
Summer 2016	19.7	0.57	0.18	0.29	30.14	—	195.6	116.06	9.44
Fall 2016	19.4	0.53	0.78	1.20	19.65	8.53	208.1	150.73	7.75
Winter 2017	43.6	0.76	0.24	0.50	14.16	11.24	606.1	497.57	6.98
(S) South Fork Caddo R.	*17.4*	*0.77*	*0.15*	*0.23*	*18.62*	*11.66*	*79.4*	*55.74*	*7.01*
Spring 2016	19.7	1.26	0.18	0.30	19.26	—	67.0	46.58	7.46
Summer 2016	14.4	0.63	0.09	0.14	26.80	—	84.7	51.51	8.44
Fall 2016	18.6	0.45	0.08	0.13	18.52	7.53	127.1	91.92	6.40
Winter 2017	17.0	0.74	0.26	0.37	9.90	15.78	38.6	32.93	5.73
Ouachita River	**24.9**	**0.93**	**0.18**	**0.35**	**20.75**	**11.16**	**142.1**	**97.57**	**8.54**
(O) Oden Access	*42.1*	*0.94*	*0.15*	*0.34*	*12.37*	*12.35*	*141.8*	*119.38*	*7.93*
Spring 2016	—	—	—	—	—	—	—	—	—
Summer 2016	—	—	—	—	—	—	—	—	—
Fall 2016	—	—	—	—	—	—	—	—	—
Winter 2017	42.1	0.94	0.15	0.34	12.37	12.35	141.8	119.38	7.93
(R) Rocky Shoals	*20.6*	*0.92*	*0.18*	*0.35*	*22.84*	*10.56*	*142.2*	*92.12*	*8.69*
Spring 2016	22.0	0.77	0.18	0.41	24.45	—	88.7	58.08	9.81
Summer 2016	16.6	0.61	0.10	0.16	31.43	—	114.6	63.50	9.50
Fall 2016	27.3	1.10	0.18	0.39	22.03	8.67	163.5	78.68	8.17
Winter 2017	16.4	1.21	0.28	0.44	13.45	12.46	201.8	168.22	7.29
Global Average	**20.6**	**0.58**	**0.18**	**0.31**	**19.64**	**10.79**	**175.1**	**127.96**	**8.18**

Appendix 4. Percent composition of substrate, shown as averages for each respective level (Drainage/site/season), from sample plots where *Noturus taylori* was present during the seasonal sample events from spring 2016 to winter 2017. Site abbreviations correspond to Table 1 and Figure 1.

	Substrate %					
Drainage/*site*/season	**Sand**	**Gravel**	**Pebble**	**Cobble**	**Boulder**	**Bedrock**
Caddo River	**9%**	**28%**	**32%**	**25%**	**4%**	**2%**
(U) Upper Caddo R.	*11%*	*32%*	*28%*	*27%*	*2%*	*0%*
Spring 2016	8%	34%	21%	37%	0%	0%
Summer 2016	15%	27%	32%	24%	2%	0%
Fall 2016	12%	32%	30%	23%	3%	0%
Winter 2017	8%	35%	31%	24%	2%	0%
(L) Lick Creek	*16%*	*35%*	*29%*	*17%*	*2%*	*1%*
Spring 2016	21%	44%	19%	15%	1%	0%
Summer 2016	20%	33%	27%	15%	2%	3%
Fall 2016	12%	33%	34%	18%	2%	1%
Winter 2017	12%	30%	34%	19%	5%	0%
(C) Caddo Gap	*4%*	*33%*	*41%*	*19%*	*3%*	*0%*
Spring 2016	0%	36%	53%	11%	0%	0%
Summer 2016	0%	33%	37%	29%	1%	0%
Fall 2016	9%	38%	27%	23%	2%	1%
Winter 2017	7%	24%	46%	14%	9%	0%
(S) South Fork Caddo R.	*3%*	*13%*	*32%*	*38%*	*7%*	*7%*
Spring 2016	2%	10%	38%	47%	3%	0%
Summer 2016	1%	16%	32%	38%	12%	1%
Fall 2016	9%	20%	30%	22%	8%	11%
Winter 2017	1%	6%	27%	46%	4%	16%
Ouachita River	**6%**	**18%**	**42%**	**31%**	**3%**	**0%**
(O) Oden Access	*0%*	*10%*	*43%*	*43%*	*4%*	*0%*
Spring 2016	—	—	—	—	—	—
Summer 2016	—	—	—	—	—	—
Fall 2016	—	—	—	—	—	—
Winter 2017	0%	10%	43%	43%	4%	0%
(R) Rocky Shoals	*7%*	*21%*	*42%*	*28%*	*2%*	*0%*
Spring 2016	0%	26%	52%	21%	1%	0%
Summer 2016	1%	29%	46%	22%	2%	0%
Fall 2016	15%	15%	30%	35%	5%	0%
Winter 2017	13%	13%	39%	33%	2%	0%
Global Average	**8%**	**26%**	**35%**	**26%**	**3%**	**2%**