AN ABSTRACT OF THE THESIS OF

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While known to be declining in many parts of the Midwest, conservation status of the Mudpuppy (*Necturus maculosus*) is uncertain in Kansas, where almost nothing is known of its distribution and population sizes. I conducted trapping surveys to describe the species' distribution and assessed water chemistry and landscape variables to predict its occurrence. Target sites in rivers of eastern Kansas included locations of known historical occurrence, low-water dams, and access points at bridges along public roads. I also trapped Mudpuppies in two reservoirs—Pomona Lake and Melvern Lake—to study seasonal activity patterns, bait preference, and local population sizes. From June 2017–April 2020, I caught 13 individuals at 12 locations in rivers and 251 individuals in the two reservoirs, with a catch per unit effort of 0.006 and 0.027 per trap night, respectively. Mudpuppy activity was highest between early November and late April and exhibited a bimodal distribution at Melvern Lake, with peaks at the beginning and end of that period. Mudpuppies entered traps with chicken liver slightly more frequently than those with other baits, but they also regularly entered unbaited traps. Study areas at Pomona Lake and Melvern Lake had populations estimated to be 818.5 ± 537.0 and 967.9 ± 507.9 individuals, respectively ($\bar{x} \pm 1$ SE). Mudpuppies were predominantly distributed in the upper reaches of streams. Thirteen of 14 sites were located in the northern half of my study area and over half were in the Marais des Cygnes River drainage, which occupies much of that region.

Keywords: amphibian populations, *Necturus* distribution, live-trapping, mark-recapture

DISTRIBUTION, HABITAT, AND SEASONAL ACTIVITY OF THE MUDPUPPY (*NECTURUS MACULOSUS*) IN EASTERN KANSAS

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PREFACE

This thesis was formatted as two manuscripts for submission to *Herpetological Review*, presented here as two chapters that address related but distinctly different topics.

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CHAPTER 1 – MUDPUPPY CAPTURES IN RIVERS

INTRODUCTION

Natural history, distribution, and conservation status of the Mudpuppy.—The Mudpuppy (*Necturus maculosus*), a rarely seen, fully aquatic salamander of lakes, rivers, and streams, spends most of its time underneath rocks and other large cover objects, from which it ventures mainly at night (Collins et al. 2010; Craig et al. 2015). Mudpuppies can live up to 30 years and do not attain sexual maturity until after 4–6 years (Matson 2005), depending on their geographic location (Holman 2012). They eat diverse prey, including crayfish, worms, fish, and insects (Holman 2012; Beattie et al. 2017; Buchanan et. al. *in prep*.).

The geographic range of the Mudpuppy is the largest of any fully aquatic salamander in North America, extending from southern Quebec to southeastern Manitoba, southward to northern Alabama, and southwest to northern Oklahoma and eastern Kansas (Harding and Mifsud 2017). The species has experienced declines across the Midwest (Hoffman et al. 2014), especially in the Great Lakes region (King et al. 1997; Harding and Mifsud 2017). It is listed as threatened, endangered, or of concern in Illinois, Indiana, Iowa, Maryland, Michigan, and Minnesota (Hoffman et al. 2014; Harding and Mifsud 2017) and as a species of greatest conservation need in Vermont (Chellman et al. 2017). In Kansas, the only data regarding the status of the Mudpuppy are occurrence records, which do not relay information about population sizes. According to submitted reports of observations and museum specimens (which were discovered through opportunistic sampling, not focused studies of distribution), the species is known from 35 localities in Kansas based on 64 records (FHSU 2019). Attempts to assess the species' distribution in Kansas have been made (Taggart 2003), but none has systematically surveyed the eastern third of the state, where the Mudpuppy might be expected. Historically, it occupied rivers and streams in that part of the state, but it is now also known from reservoirs constructed along those rivers. Two forms of Mudpuppies are found in Kansas: the Common Mudpuppy (*N. m. maculosus*) occurs in the Marais des Cygnes River and its tributaries (Missouri River drainage), whereas the Red River Mudpuppy (*N. m. louisianensis*) is found in the Neosho and Verdigris rivers and their tributaries (Arkansas River drainage). Crother (2017) ranks these forms as subspecies, while other experts treat them as full species (e.g. AMNH 2018). We follow the taxonomy of Crother (2017), such that references to *N. maculosus* are inclusive of both subspecies.

Mudpuppy declines and their causes.—Amphibians and reptiles face extinction at unparalleled rates due to threats including habitat destruction, over-exploitation, and water pollution (Dudgeon et al. 2006; Hamer and McDonnell 2008). Evidence of amphibian declines was noted as early as the 1970s, and it has been estimated that 7.4% of amphibian species are critically endangered compared to 1.8% of bird species, 3.8% of mammal species, and 5% of fish species (Stuart et al. 2004). Also, 41% of amphibian species are threatened with extinction compared to 25% of mammals and 14% of birds (Red List category; IUCN 2020). Amphibian populations across the globe are declining at a rate of 3.79% per year (Campbell Grant et al. 2016), and an estimated two-thirds of amphibian species are vulnerable to rapid decline (Hecnar 2004). Of 435 amphibian species worldwide listed in a category of higher threat labeled as "rapidly declining" (IUCN 2020), 183 are threatened by complete loss of habitat, 50 by reduced habitat, 15 by over-exploitation, and some of those by multiple factors (Stuart et al. 2004).

The Mudpuppy, though not globally threatened or endangered, has declined in some portions of its range, as previously described, but reasons for declines have rarely been detailed. Few studies have examined, for example, how environmental variables govern its distribution, effects of anthropogenic changes on its habitat and how its dispersal-related behaviors contribute to population connectivity and its ability to track availability of suitable habitat.

Habitat loss and fragmentation.—Habitat loss plays a role in 60% of known cases of amphibian decline (Hecnar 2004). Decline of the Mudpuppy in Iowa, where it was once considered a persistent and widespread species (Blanchard 1923) but is now threatened (Hoffmann et al. 2014), was likely due to habitat alteration, including eradication of most wetlands during the mid-1900s (Lannoo et al. 1994). In eastern Kansas, the Mudpuppy still occurs in lotic systems within several different drainages (FHSU 2019), but it faces stressors such as habitat fragmentation, habitat alteration, and degradation of water quality. Fragmentation, due to prevalence of dams, degradation of riparian zones, and other anthropogenic changes to river systems, may be especially relevant as a threat to populations in Kansas (Pusey and Arthington 2003; Tiemann et al. 2004; Riedle et al. 2016).

The short-term impacts of habitat loss and fragmentation, and risks of outcomes such as decreased population sizes and connectivity, lessen with an amphibian's ability to disperse because amphibians that can disperse widely can avoid stressors and move to other habitats (Cushman 2005). Amphibian species richness tends to be lower with greater habitat isolation and road density (Fahrig et al. 1994; Lehtinen et al. 1999), suggesting that those factors disrupt exchange between populations. Fully aquatic amphibians, like the Mudpuppy, do not have the ability to disperse over dry land, compounding these problems. Destruction of riparian zones and modification of ecosystems through water contamination pose major threats to all aquatic species (WWF 2016). For the Mudpuppy, QHEI (Qualitative Habitat Evaluation Index) scores of riparian zones, which are based on the quality of the stream channel in relation to stability of the habitat, have been found to be better predictors of its presence than more simplistic analyses of substrate, instream cover, channel morphology, pool quality, riffle quality, and map gradient (Collins et al. 2019).

Pollution threats.—Pollution is involved in 43% of known cases of amphibian decline (Hecnar 2004).Very low concentrations of herbicides and pesticides can contribute to mortality of amphibians (Kiesecker 2002). For example, numbers of larval salamanders in wetlands are significantly reduced by the insecticide carbaryl (Boone and James 2003) and atrazine, the most common herbicide in reservoirs, which can delay metamorphosis, inhibit growth, and suppress foraging and predator avoidance behaviors of aquatic amphibians (Rohr 2018). Amphibians in ponds and streams tend to aggregate, which can exacerbate pollution impacts (Collins and Storfer 2003).

Populations of amphibians in streams are vulnerable to anthropogenic disturbances (Power et al. 1988), which can generate a variety of negative outcomes, all of which might have their own repercussions on the ecosystem. For example, stress due to increased sedimentation, much of which is due to construction and agricultural runoff, is a major factor in amphibian declines due to its propensity to eradicate microhabitats upon which some amphibians are highly dependent (Welsh and Ollivier 1998). The Mudpuppy, like other amphibians, shows susceptibility to heavy siltation and other pollutants from agriculture and industry, which have caused population declines throughout the Midwest (Matson 2005).

Agricultural runoff may also lead to increases in nitrate and nitrite, which cause developmental abnormalities and increased mortality in larval and adult anurans (Marco et al. 1999). Physical and behavioral abnormalities, such as extra limbs and growths, can develop at nitrate concentrations as low as 3 mg/L (Hecnar 1995). In the Great Lakes, 19.8% of water samples contained nitrate at concentrations higher than what is considered lethal to amphibians (Rouse et al. 1999), which could explain some declines of the Mudpuppy in that region

(McDaniel et al. 2009; Craig et al. 2015; Beattie et al. 2017) and why it has become a species of concern in many states (Hoffman et al. 2014; Chellman et al. 2017; Harding and Mifsud 2017). Salamander populations are also significantly less abundant in permanent streams with high phosphate concentrations due to runoff (Ficetola et al. 2011). Other water quality characteristics have been involved in amphibian declines. A study of 122 ponds in Ontario found a weak negative correlation between species richness and both water hardness and conductivity (Hecnar and M'Closkey 1996). The Mudpuppy accumulates polychlorinated biphenyls (PCBs) and other dangerous chemical compounds at sufficiently high levels to serve as a bioindicator of geographic and temporal variation in their concentrations (Bonin et al. 1995).

Objectives and approaches of this study.—Our primary goal in this study was to describe the distribution of the Mudpuppy in eastern Kansas based on live-trapping surveys. Further, we aimed to relate its patterns of occurrence to water chemistry, local physical characteristics of waterways, and landscape variables associated with surveyed sites to model the species' habitat and to explain its distribution in terms of those general characteristics. Water chemistry, channel fragmentation, drainage area, discharge, gradient, and stream order are often valuable dimensions in studies of amphibian occurrence because these abiotic variables can relate to habitat characteristics and other factors that diminish or increase diversity and population sizes of stream assemblages (Adams and Bury 2002, Sheridan and Olson 2003). Similarly, properties of riparian zones, such as land use, can be important for understanding patterns of amphibian occurrence because they can negatively or positively influence water quality by modifying, incorporating, or concentrating substances before they enter lotic systems (Osborne and Kovacic 1993).

RESEARCH METHODS

Capture methods.—We used a live trapping protocol to detect whether Mudpuppies were present at a given location. Trapping was conducted from June 2017–April 2020. We used Gee minnow traps (23×44 cm, model G40M, Memphis Net and Twine, Memphis, Tennessee) made of metal mesh (6-mm) with funnel entrances broadened to approximately 3×6 cm. The funnels extended 7 cm toward the center of the trap so that Mudpuppies could not easily escape while they explored inside edges. We used baits reported in other Mudpuppy studies including chicken liver, dead fish, raw shrimp, and cheese (Gendron et al. 1997; Trauth et al. 2007; Craig et al. 2015). We cut the baits into 2–3 cm^3 chunks and wrapped them in nylon fish net to prevent them from being ingested. We attached each trap to nylon rope died black to make it less likely to be detected by Mudpuppies and people. Traps were set on the bottom of rivers or lakes in a variety of microhabitats with differences in depth, substrate, and vegetation. The rope was then tied around a tree branch or other sturdy structure along the bank, such as rocks or roots.

Upon capture of a Mudpuppy, we photographed its dorsal and ventral sides so that its unique patterns and markings could be used to identify it if recaptured, and we documented physical characteristics, including mass (to nearest 1 g) with a scale (H110, American Weigh Scales, Cumming, Georgia) and total (TL; to nearest mm) and snout-vent lengths (SVL; to nearest mm) with a meter stick (Craig et al. 2015). External physical abnormalities, including wounds and ectrodactyly, were recorded. We took tissue samples as vouchers and for future DNA analyses.

Mudpuppy distribution in Kansas.—To investigate the distribution of the Mudpuppy, we conducted trapping surveys during three field seasons: the first from June 2017–May 2018, the second from June 2018–May 2019, and the third from June 2019–May 2020. We set traps at 144 unique locations (Fig. 1). Each trapping site encompassed 20–400 m of river length, with the number of traps placed at each site varying from two to 16, based on size of the site. Sites fell within two major river basins encompassing four smaller drainages: the Kansas River (total length: 238 km, discharge: 205.0 m^3/s) and Marais des Cygnes River (total length: 349 km, discharge: 62.0 m^3/s) drainages within the Missouri River basin, and the Neosho River (745 km, discharge: 253.5 m^3) and Verdigris River (499 km, discharge: 131.5 m^3) drainages within the Arkansas River basin. We trapped at 16 sites a second time because during the initial effort, river conditions were unsuitable (i.e. high river discharge resulting in traps being lost or beached). We included the Kansas River drainage because a single specimen was collected in Douglas County in 1916 (specimen KU 949 at the University of Kansas Biodiversity Institute and Natural History Museum).

We surveyed sites with past records of Mudpuppy captures to check for the species' continued presence. Museum vouchers (N = 64), dating from 1927–2020, exist from 35 sites in eastern Kansas, 13 of them from the Marais des Cygnes River (FHSU 2019). We visited 28 of those sites (Fig. 2). We could not visit the other seven because three were too shallow for trapping and four were inaccurate GPS locations or no longer held water. We also sampled sites where the Kansas Department of Wildlife, Parks and Tourism (KDWPT) collected water samples to test for the presence of DNA shed into the environment (eDNA) by several species of interest, including the Mudpuppy. [Results of that study were not available in time to further inform our efforts]. We also surveyed locations with easily accessible artificial dams, because such sites proved productive early in our study. We selected additional trapping locations within the river drainages to accomplish relatively even geographic coverage of eastern Kansas.

Individual sites were chosen opportunistically based in part on ease of access; also, sites conveniently near our base of operations (Emporia, KS) received more attention than they might have otherwise. Exact locations of trap placement varied in depth, substrate, shade, vegetation, and stream width, and we considered this variation to anecdotally gauge attributes of productive locations to inform trap placement subsequently. Special attention was paid to sites with habitat characteristics such as bedrock with crevices and holes and loose boulders in the substrate (Trauth et al. 2007). We aimed to maximize the number of locations where individuals were captured rather than the total number of individuals captured, so locations where we managed to capture at least one Mudpuppy were usually not visited again. However, after a Mudpuppy was captured in a given stream or river, we focused our effort further upstream and downstream in the vicinity to assess the extent of the species' local distribution and whether any nearby tributaries warranted more attention. Reports from fishermen suggested that the Marais des Cygnes River harbored many Mudpuppies because, in contrast to other drainages, they were inadvertently captured with regularity and were used there for bait. Fishermen also claimed that Mudpuppies were sometimes captured along the Cottonwood River. Reports or documented captures from Pomona Lake, Melvern Lake, and Marion Reservoir led us to set traps in those locations as well. We also set traps in Hillsdale Reservoir, John Redmond Reservoir, Council Grove Lake, Toronto Lake, Fall River Lake, Elk City Lake, and Montgomery County State Fishing Lake.

Coordinates of locations where trapping was conducted were obtained with a GPS tracking service on an iPhone (11 Pro, Apple, Cupertino, California). These coordinates were plotted on a projected coordinate system in ArcMap (Esri, Redlands, California) for mapping, to compare to locations of museum records, and for further analyses including habitat modeling.

Water chemistry analysis and habitat modeling.—We aimed to discover how water chemistry, physical habitat characteristics, and landscape-level variables relate to occurrences of Mudpuppies in Kansas. Water quality variables of interest were as follows: temperature, pH, hardness, dissolved oxygen, dissolved carbon dioxide, conductivity, nitrate, phosphate, and water oxidation reduction potential. Temperature, pH, conductivity, dissolved oxygen, and ORP were measured with a portable handheld meter (HI98194) from Hanna Instruments (Woonsocket, Rhode Island). To measure nitrate, phosphate, and carbon dioxide, we used portable photometers (HI96786, HI713), reagents (HI93728-03, HI713-25), and a kit (HI3818) from Hanna Instruments. For hardness measurements, we used a Hach (Loveland, Colorado) total hardness test kit (HA-71A). To obtain water chemistry values and temperature, we walked into the water with the portable meter until the water was waist-high and lowered the probe until it was approximately 0.5 m above the substrate. To give enough time for readings to become stable, we left the probe in the water for 5 minutes while taking other measurements.

To describe physical habitat characteristics of sites, we employed the standard methodology proposed by Heyer et al. (1994) and Craig et al. (2015). We measured stream width and tree-tree bank-full width with a rangefinder (AL11, Nikon, Melville, New York). To estimate stream width, we located a representative spot within the specified trapping area and measured the stream width from the edge of the standing water to its opposite edge (Heyer et al. 1994). To measure bank-full width, we measured the distance between the closest two representative trees growing at the river's edge directly across the river from one another (Heyer et al. 1994). Vegetation along the bank was also quantified as the estimated percentage of tree, shrub, grass, and bare ground cover (Fuselier and Edds 1994). We also visually estimated the amount of water surface in shade present at noon (Fuselier and Edds 1994). We estimated percent of riffle, run, and pool along the length of each site (Fuselier and Edds 1994), with turbulent flow as a riffle, laminar flow as a run, and no visible flow as a pool. Substrate classification was based on a modified Wentworth scale (Cummins 1962; Bain et al. 2012) using visual estimation of clay, mud, sand, gravel, rock, and bedrock. Amounts of submerged and emergent vegetation were visually estimated as a percentage of cover along the site length.

For analyses of watersheds around sites, we acquired landscape-level data, including riparian zones, road density, ecoregions, and HUC8 boundaries (to represent drainage area) from the Kansas Data Access and Support Center (DASC, Lawrence, Kansas). Riparian zones were split into a percentage value of these classes: industrial area, residential area, open land as defined by urban property that is open and without any natural designation, urban woodland, urban water, corn, soybean area, double crop, warm season grass, cool season grass, woodland, and water. We obtained geomorphology, elevation, stream gradient, sedimentation, mean annual discharge, dam locations, and atrazine use from the United States Geological Survey (USGS, Reston, Virginia). We quantified fragmentation using these dam locations as reference points where the distance (m) of each site from these dam locations whether upstream or downstream was measured and assigned to each site. We obtained locations of all wetlands from the United States Fish and Wildlife Service (USFWS, Washington, District of Columbia). Stream order was acquired from the Kansas Biological Survey at the University of Kansas (KBS, Lawrence, Kansas).

To obtain numerical data on landscape-level variables, we used ArcMap (Esri, Redlands, California) to extract values for site coordinates. We imported this tabular data into JMP Pro 11

(SAS Institute, Cary, North Carolina) and used nominal logistic regression to model relationships between these variables and binary Mudpuppy presence/absence from our surveys. Models were judged as best based on a combination of highest R^2 and lowest P and AICc. We compared sites with captures to places where we caught none and to historic sites. We also compared average characteristics of the Arkansas and Missouri river drainages and calculated differences between sites in the north and south of our study region, using 38°N as a dividing line. We modeled relationships between individual variables (separately) and captures using logistic regression.

RESULTS

Mudpuppy captures.—We captured 13 Mudpuppies at 12 river sites in 2141 trap nights for an overall CPUE (captures per trap night) of 0.006 (Table 1). Another five individuals were caught on return visits to two sites where we had already captured Mudpuppies. We caught Mudpuppies at two historic locations and at three low-water dams. Six of 12 river capture locations were directly under or near a fallen log or tree. All capture locations were < 2 m depth. In 1217 trap sets, 47 were lost or stolen and so were excluded from analyses.

We obtained morphometric data from 11 female and seven male Mudpuppies caught in rivers (Table 2). One-way MANOVA showed that the larger mean size of males versus females was not significant ($F_{3,13} = 1.66$, $P = 0.22$; Table 2). Eight individuals were caught on shrimp, six on liver, and three on cheese (bait type for one capture was unrecorded). One female had a spermatophore in her cloaca when captured in the Neosho River (38.4375°N, -96.2078°W) on November 28, 2018. One female displayed syndactyly in the Marais des Cygnes River (38.5877°N, -95.4157°W) on November 26, 2019.

We captured 251 Mudpuppies total in Pomona and Melvern lakes (See Chapter 2 for more details). We trapped for 140 nights at Hillsdale Reservoir because of its proximity to those two reservoirs but found no Mudpuppies. We also trapped for 12–24 trap nights at John Redmond Reservoir, Council Grove Lake, Marion Reservoir, Toronto Lake, Fall River Lake, Elk City Lake, and Montgomery County State Fishing Lake with no success.

Habitat modeling.—To compare habitat at sites where we captured Mudpuppies to sites where none was captured, we ran a multiple logistic regression model and found seven predictors for Mudpuppy presence/absence. We used backward selection to eliminate variables to develop a best fit model ($P < 0.001$, $R^2 = 0.31$). Cool season grass, elevation, residential area, and soybean area were all moderate positive indicators of Mudpuppy presence (Table 3). Shrub area, nitrate, and sand were all negative indicators of Mudpuppy presence (Table 3). Across 46 variables, only sand substrate ($\chi^2 = 3.36$, df = 1, $P = 0.05$) showed any significance with this model. When we ran the multiple logistic regression model again, replacing the dependent variable of Mudpuppies captured with site locations using 38°N to divide them into north and south groups, elevation was the only variable that showed significance ($\chi^2 = 38.06$, df = 1, $P < 0.01$).

When we combined historic sites with our capture sites to compare them to sites where we did not capture Mudpuppies, we generated a best fit model with 10 predictors ($P < 0.001$, $R^2 = 0.33$). Using backwards selection, we found two positive predictors: pool as a function of water flow and open land as a function of riparian zone (Table 4). We found eight negative predictors: stream width, run as a function of water flow, gravel substrate, soybean area, atrazine use, residential area, warm season grass, and nitrate (Table 4).

Using logistic regression with the same 46 variables individually to compare habitat at sites with Mudpuppies from our study plus historic records to sites where they were not captured, we found that 14 were significant predictors of Mudpuppy presence/absence. Some variables that were significant in the nominal logistic model were also significant when evaluated separately;

these were stream width ($\chi^2 = 18.1$, df = 1, $P < 0.01$), run ($\chi^2 = 6.97$, df = 1, $P = 0.01$), pool ($\chi^2 = 6.89$, df = 1, $P = 0.01$), gravel ($\chi^2 = 5.96$, df = 1, $P = 0.01$), soybean area ($\chi^2 = 8.49$, df = 1, $P < 0.01$), atrazine use ($\chi^2 = 4.24$, df = 1, $P = 0.04$), and nitrate ($\chi^2 = 6.07$, df = 1, $P = 0.01$). Other variables that individually showed significance as positive predictors were shade ($\chi^2 = 6.49$, df = 1, $P = 0.01$), grass coverage ($\chi^2 = 5.06$, df = 1, $P = 0.02$), fragmentation ($\chi^2 = 13.35$, df = 1, $P < 0.01$), and stream order ($\chi^2 = 8.52$, df = 1, $P < 0.01$). Other variables that individually showed significance as negative predictors were temperature ($\chi^2 = 6.02$, df = 1, $P = 0.01$), pH ($\chi^2 = 7.72$, df = 1, $P < 0.01$), and bare ground coverage ($\chi^2 = 5.04$, df = 1, $P = 0.02$). When comparing this model between sites north and south of 38°N, atrazine use ($\chi^2 = 36.51$, df = 1, P < 0.01) and warm season grass presence ($\chi^2 = 6.93$, df = 1, P = 0.01) were significantly higher at sites in the south.

When we examined values of the significant variables at both historic sites and our sites of capture to see if there were differences between the means of the major drainages—Arkansas and Missouri—we found pH ($F_{1,51} = 9.91$, $P < 0.01$), run ($F_{1,51} = 6.15$, $P = 0.02$), and gravel ($F_{1,48} = 16.7$, $P < 0.01$) measures were significantly lower at Missouri sites, while pool ($F_{1,51} = 9.51$, $P < 0.01$), atrazine use ($F_{1,53} = 39.91$, $P < 0.01$), and shade ($F_{1,51} = 11.60$, $P < 0.01$) were significantly higher at Missouri drainage sites.

DISCUSSION

We captured 18 Mudpuppies in rivers to add to the previous total of 64 such records from Kansas (FHSU 2019). We also added 12 new localities to the 35 previously known collection localities (FHSU 2019) and confirmed continued presence of the species at two of those historic locations (Miller’s Dam 38.5877°N, -95.4197°W and Ottawa Dam 38.6183°N, -95.2931°W). The Kansas Herpetofaunal Atlas (FHSU 2019) shows 18 Mudpuppy locations in the Marais des

Cygnes drainage, 13 in the Neosho, and four in the Verdigris. With this study, we add six more to the Marais des Cygnes (two in reservoirs), three to the Neosho, and three to the Verdigris river drainages. We captured an individual in Elk County off the Elk River, which lacked previous records, and we found that populations of the Mudpuppy exist in at least two reservoirs in eastern Kansas.

Mudpuppy captures and trapping success.—We captured 13 Mudpuppies in rivers upon initial survey, plus another five at two sites where we had already verified their presence but continued, or to which we returned, to set traps. Leaving out those additional captures (to avoid bias from resampling occupied sites) and captures from reservoirs, our CPUE trap success rates of 0.010 in the Marais des Cygnes, 0.004 in the Neosho, and 0.007 in the Verdigris river drainages were similar overall to some of those reported elsewhere; for example 0–0.17 in Ontario (McDaniel et al. 2009), 0.048 in western Michigan (Beattie et al. 2017), 0.008 in Detroit, Michigan (Sutherland 2019), 0–0.026 also in Detroit (Craig et al. 2015), and 0.006 in Indiana (Hoffman et al. 2014). Those studies involved catching Mudpuppies where Mudpuppies had been captured before, whereas our study focused more on surveying locations (116 of 144) with no prior history of known occurrence. Consequently, we do not take our consistently low catch rates (as compared to the high ends of the ranges reported by some other studies) as evidence that the Mudpuppy is less abundant overall in the drainages it inhabits in Kansas.

The number of river locations where we successfully caught Mudpuppies decreased in successive years (7 sites to 5 sites to 0 sites), likely because we visited historic sites and other sites with apparently good habitat first and then ventured to less likely sites to fill in geographic gaps. Again, for the present study our priority was to find Mudpuppies at as many sites as possible with our available time while still ensuring even coverage throughout the study area over the course of the three seasons. To conduct a more robust study of abundance by drainage, we would control for interannual variation by sampling each drainage and reach in equal proportions each year.

Mudpuppy captures at Pomona and Melvern lakes (Chapter 2) prompted us to sample other reservoirs in southeastern Kansas. Hillsdale Lake was geographically closest to Pomona and Melvern lakes and was the only other lake that we surveyed that was, like them, within the Marais des Cygnes drainage, so it was targeted most heavily. Despite having a variety of substrates similar to Melvern Lake (mud, gravel, large rocks), it yielded no Mudpuppies or even any bycatch (e.g. fish, crayfish). Anecdotally, the water there was clearer than at the other reservoirs and it was quite deep (10–12 m) at our trapping location. Local marina owners had never seen or heard of a Mudpuppy being caught at Hillsdale Lake. We received a report and picture of a Mudpuppy from Marion Reservoir, but our lone trapping effort at that reservoir was unsuccessful. We placed traps near a gravel beach in some shallow water ~1 m deep, which may not have matched the habitat where the Mudpuppy was captured, which was reportedly at a depth >5 m. We also trapped at John Redmond Reservoir, Council Grove Lake, Toronto Lake, Fall River Lake, Elk City Lake, and Montgomery County State Fishing Lake with no success. During de-watering events at Fall River Lake and Elk City Lake, we sampled the outlet channels with dip nets with no success. None of these reservoirs except Elk City Lake had any known history of Mudpuppy presence, based on specimens or reports from fishermen or agency employees. Altogether, these results suggest to us that Mudpuppy populations are not universal features of lakes in the region.

Different methods, such as seining, electroshocking, trapnets, or setlines, can be effective for capturing Mudpuppies at similar success rates (Murphy et al. 2016). We focused on the use of modified minnow traps, as we had had success with them previously and because we wanted to standardize our trapping protocol as much as possible across sites. A study to test different methods and other trap designs to discover what works best in our area would be worth pursuing in the future.

Mudpuppy habitat modeling.—Except at three low-water dams, no Mudpuppies were captured at a site with riffle habitat (turbulent flow), which we found surprising given that Mudpuppies reportedly prefer sites just downstream from riffles (Matson 2013). Only three sites had a measurable sand component (5%, 5%, and 7% of substrate at those sites), hence its statistical significance as a predictor of absence. Sand substrate may interfere with the ability of Mudpuppies to find cavities underneath logs and rocks and larger bulkier substrate, which they prefer (Collins et al. 2010, Craig et al. 2015). The predominant substrates at most sites we visited were mud (31.62 ± 31.22%) and rock (24.46 ± 29.72%), neither of which was a significant predictor. Seven of 14 capture sites were located within the Wabaunsee geological group, but it was not a significant predictor. We observed riparian zone erosion along the river bank in spots along the Cottonwood River and the Verdigris River, many of which were due to human activities. We did not quantify this erosion but did note that we did not find Mudpuppies anywhere downstream of these locations. Stream width was insignificantly different, but it was more consistent across capture sites (26.77 ± 11.26 m) compared to non-capture sites (32.54 ± 27.54 m). All other variables exhibited no noteworthy differences, significant or not.

Using nominal logistic regression, we predicted the presence of Mudpuppies with four positive indicators: cool season grass, elevation, residential area, and soybean area; and three negative indicators: shrub area, nitrate, and sandy substrate (Table 3). Some of these predictors matched prior expectations. Sand substrate also showed significance when examined separately, again suggesting that Mudpuppies avoid it or are unable to persist in locations where sand is prevalent. Nitrate can cause developmental abnormalities and increased mortality in larval and adult anurans (Marco et al. 1999), so it was not surprising that it was negatively related to Mudpuppy presence.

Residential areas tend to carry more sediment load and chemical runoff than undisturbed areas (Line et al. 2002), so we expected that Mudpuppies would be less frequent in those locations, but that was not the case. Likewise, soybean crop area is associated with the use of pesticides, herbicides, and fungicides known to pollute rivers and cause negative impacts to stream ecosystems (Ronco et al. 2008), yet it was a positive predictor. We think that the unexpected positive association between those land uses and Mudpuppies is a spurious correlation resulting from Mudpuppies being most common in the northern half our study region (for unknown unrelated reasons) which also has a higher density of human populations and soybean farming.

The other predictors also appear to be tied to overall differences between the northern and southern halves of our study area, which were likely confounded with the actual variables that explain differences in abundance within those regions, so we used 38°N as an approximate dividing line between these roughly equal-sized areas and used it as the dependent variable when comparing north and south to landscape-level variables in the nominal logistic regression model. Thirteen of 14 capture sites (including the reservoirs) were in the northern half of our study area. This region of Kansas has a higher yield of cool season grass compared to warm season grass in the south (Peterson et al. 2002), yet our specific sites did not show any significant difference in cool season grass between the north and south ($\chi^2 = 0.02$, df = 1, P = 0.89). Elevation was significantly higher at sites in the north versus south of our study region ($F_{1,363} = 145.3$, $P <$

0.01), so although higher elevation was a positive predictor for Mudpuppy presence, this result does not necessarily indicate that Mudpuppies prefer higher elevations. Associations with stream order are hard to interpret because Mudpuppy sites were located within the upper reaches of streams, yet nine of 12 were still in the main stems of the Marais des Cygnes, Neosho, and Verdigris rivers. Shrub cover, as opposed to tree, grass, or bare earth, was negatively predictive of Mudpuppy presence, but we can offer no explanation.

Our sample size based on our field work was lower than desired for statistical analyses, but by including historic Mudpuppy sites in the analysis, which increased the number of sites with Mudpuppies to 38 from 12, we increased statistical power and generated a better fit regression model with 10 total predictors. Stream width and laminar flow (run) were negative predictors and no visible flow (pool) was a positive predictor. Gravel was a negative predictor, which could be because Mudpuppies prefer to hide underneath large logs and larger, bulkier substrate (Collins et al. 2010, Craig et al. 2015). Atrazine can delay metamorphosis, inhibit growth, and suppress foraging and predator avoidance behaviors of aquatic amphibians (Rohr 2018), so it makes sense as a negative predictor. Roles of grass type and nitrate were as previously described, but residential area had an opposite effect in this model, being negative as expected, perhaps because of the tendency of residential areas to carry higher sediment load and runoff (Line et al. 2002).

When analyzing variables separately, we found that stream width, nitrate, run, pool, gravel, soybean area, and atrazine use were again significant, but seven others were also significant predictors. Lower temperature and pH were likely significant due to the confounding nature of trapping during different periods of the year. Higher percentage shade over the water due to tree presence could be correlated with fallen tree and log presence, which Mudpuppies prefer for hiding (Collins et al. 2010, Craig et al. 2015). This model also suggests that vegetation cover along the bank could influence the presence of Mudpuppies where sites with more grass are more likely to have populations than are sites with bare soil. More grass could prevent erosion which could help with lowering sedimentation levels. Sedimentation can stress amphibians and has been a major factor in their declines due to its propensity to eradicate microhabitats (Welsh and Ollivier 1998). If fragmentation can isolate and eliminate amphibian populations (Cushman 2005), then an increase in fragmentation would be expected to be bad for Mudpuppies, yet anecdotally we did capture three Mudpuppies at low-water dams and many historic sites were located at or near dams. These dams could be more relevant as a source of structure, higher dissolved oxygen, and increased food. Our calculations for fragmentation used distance from artificial dams as its metric, which should be kept in mind when interpreting the effect of that variable in models. Lastly, changes in stream order can increase diversity and population size in amphibian assemblages depending upon the species (Sheridan and Olson 2003), as was reflected in more captures at higher number stream orders.

Lastly, we compared the Missouri and Arkansas drainage capture sites according to all variables that were found significant in earlier analyses to describe overall differences in sites occupied by the two named subspecies. We captured more *N. m. maculosus* per CPUE in the Missouri drainage (0.010) than *N. m. louisianensis* in the Arkansas drainage (0.005 when pooling the Neosho and Verdigris together) so we would expect that significant variables affecting Mudpuppy capture rates would also be significant between the drainages. The Missouri had significantly higher means for pool and shade and significantly lower means for pH, run, and gravel compared to the Arkansas drainage. Whether these differences translate to differences in overall suitability for Mudpuppies, or to consistent differences in the preferred habitats of the two subspecies, or are simply inconsequential regional differences, we cannot say.

Conclusion.—Overall, our research demonstrates that the Mudpuppy is still present in eastern Kansas. Low capture rates are smaller than, but comparable to, studies elsewhere, so were not themselves cause for concern about the health of populations. Nevertheless, the small absolute number of captures makes it impossible to even anecdotally speculate as to how widely the species is distributed throughout the drainages in which we found it, or to speculate on population trends. We lacked the statistical power needed to properly test whether or which water quality or landscape level variables predict Mudpuppy presence using our capture records alone, but by combining them with historic records, we identified 10 different variables that together best predicted presence and 14 variables that were predicative individually, perhaps defining a starting point for a better understanding of the species' distribution in Kansas.

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Table 1. Mudpuppy trapping effort and success at river locations by drainage from June 2017–April 2020 in eastern Kansas (excluding reservoirs or repeat visits to sites where Mudpuppies had already been captured).

Drainage	Trapping locations (N)	Trap nights (N)	Capture locations (N)	Mudpuppies caught (N)	CPUE (captures per trap night)
Kansas	11	301	0	0	0
Marais des Cygnes	53	685	6	7	0.010
Neosho	57	749	3	3	0.004
Verdigris	23	406	3	3	0.007
Survey-wide	144	2,141	12	13	0.006

Table 2. Body measurements ($\bar{x} \pm 1$ SE) of Mudpuppies caught June 2017–April 2020 in rivers in eastern Kansas, comparing means (mass, total length (TL), and snout-vent length (SVL)) of females and males (MANOVA: $F_{3,13} = 1.66$, $P = 0.22$).

	Females N = 11	Males N = 7
Mass (g)	101.8 ± 13.9	119.6 ± 20.0
TL (mm)	255.2 ± 12.3	278.4 ± 14.4
SVL (mm)	147.5 ± 7.1	180.4 ± 11.0

Table 3. Summary of nominal logistic regression analysis ($R^2 = 0.31$, $AIC_c = 78.36$, $P < 0.001$) using backward selection for variables predicting Mudpuppy presence in eastern Kansas, June 2017–April 2020.

Variable	Estimate (intercept)	Standard error	Probability
Cool season grass (%)	10.54	3.88	< 0.01
Elevation (m)	0.03	0.01	< 0.01
Residential (%)	7.78	3.41	0.02
Soybean area (%)	3.65	1.85	0.05
Shrub (%)	-0.06	0.04	0.10
Nitrate (mg/L)	-0.11	0.06	0.09
Sand (%)	-0.20	0.12	0.08

Table 4. Summary of nominal logistic regression analysis ($R^2 = 0.33$, $AIC_c = 161.52$, $P < 0.001$) using backward selection for variables predicting Mudpuppy presence using both sites of capture from this study, June 2017–April 2020, and past records in eastern Kansas.

Variable	Estimate (intercept)	Standard error	Probability
Stream width (m)	-0.05	2.08	< 0.01
Run (%)	-0.05	0.02	< 0.01
Pool (%)	0.04	0.01	< 0.01
Gravel (%)	-0.03	0.01	< 0.01
Soybean area (%)	-4.26	1.11	< 0.01
Residential (%)	-9.12	2.71	< 0.01
Atrazine use (ml)	-0.01	0.01	0.01
Warm season grass (%)	-4.11	1.87	0.03
Open land (%)	13.5	7.6	0.07
Nitrate (mg/L)	-0.01	0.01	0.26

Fig. 1. Locations where Mudpuppy specimens were obtained historically (triangles) and where they were captured (squares) or not detected (circles) during this study, June 2017–April 2020, in eastern Kansas.

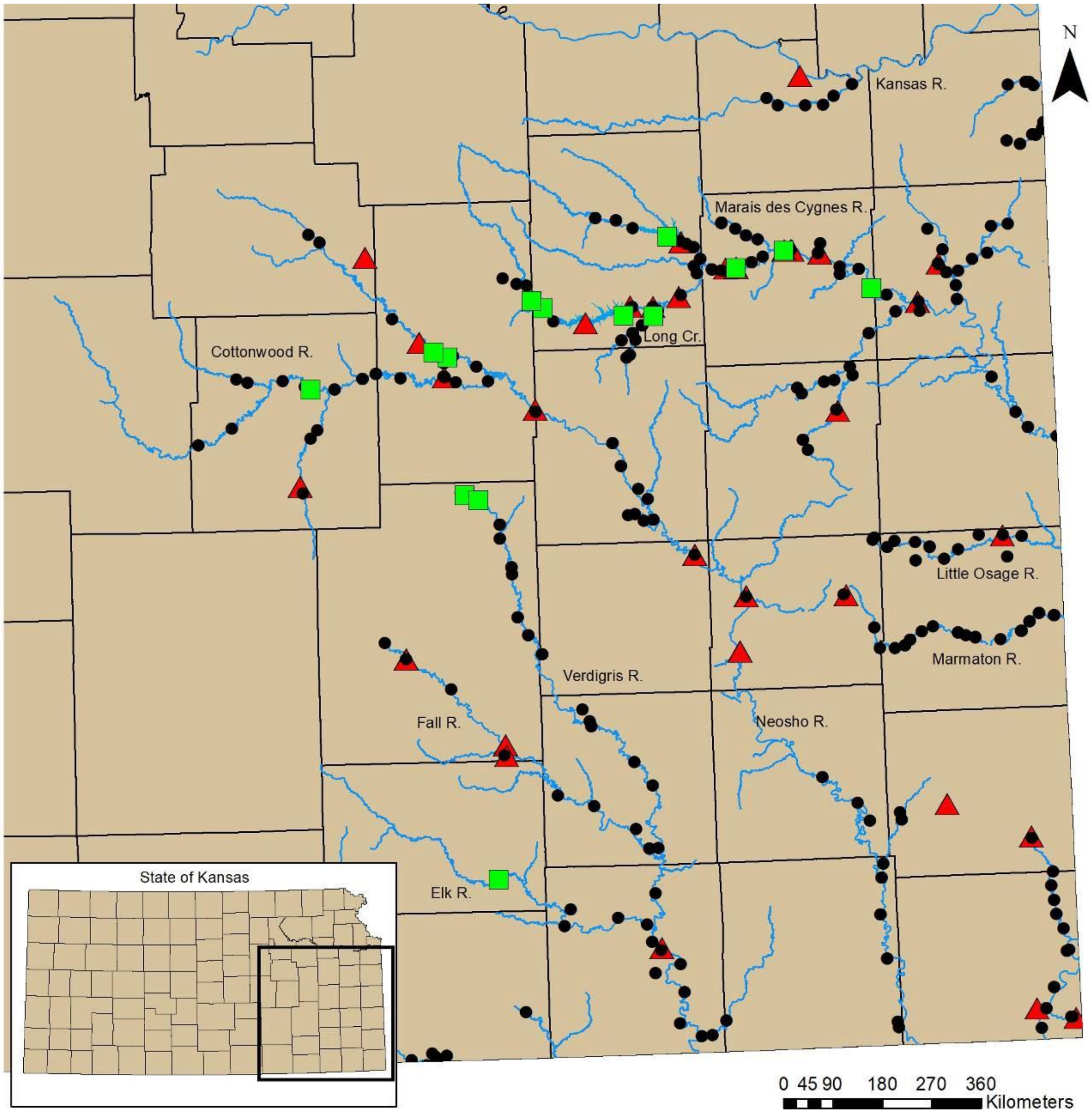
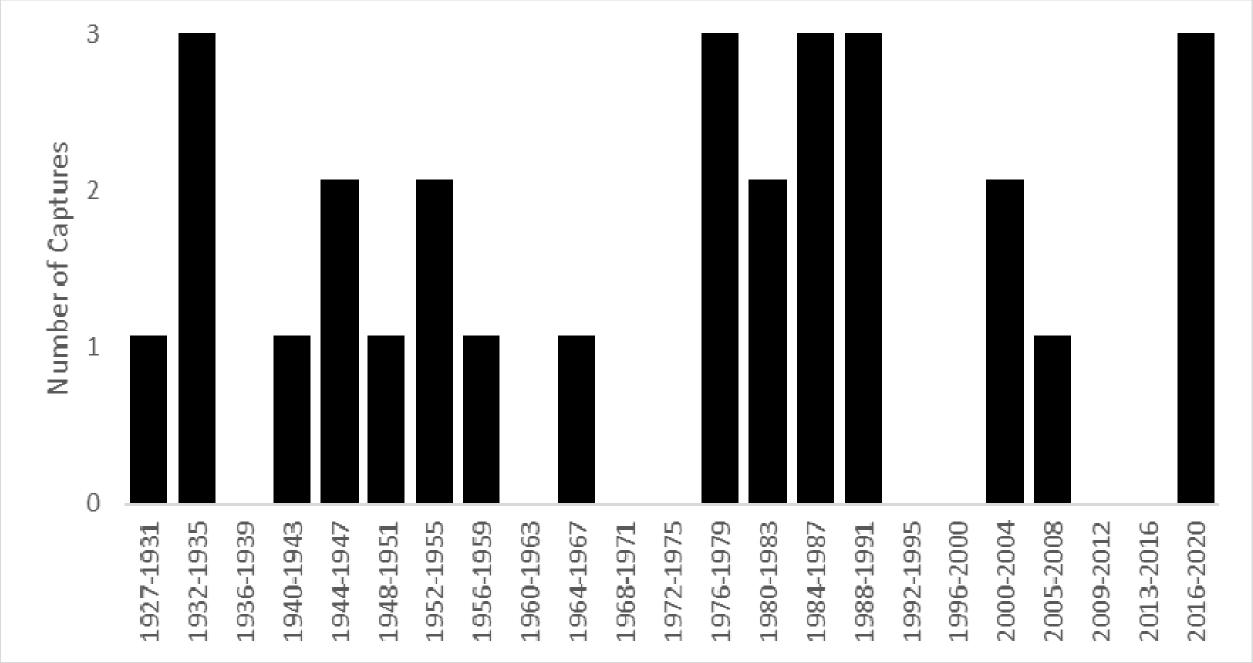


Fig. 2. Temporal distribution of historic Mudpuppy capture records in eastern Kansas (excluding those captured in the present study) from 1927–2020.



CHAPTER 2 – MUDPUPPY CAPTURES IN RESERVOIRS

Seasonal activity, bait preference, and sizes of lake populations of the Mudpuppy.— Seasonal activity patterns of the Mudpuppy are not well known, but Mudpuppies are captured most frequently during colder months (Craig et al. 2015; Beattie et al. 2017). Water temperatures of 3–6°C are optimal for trapping success, whereas at temperatures over 10°C capture rates drop to near zero (Chellman et al. 2017). Reasons why Mudpuppies are more frequently captured in winter are poorly understood but have been attributed to increased activity during the breeding season, to avoiding predators that are active in the warm months, and to increased foraging in winter (Neill 1963; Shoop and Gunning 1967; Matson 2005; Chellman et al. 2017). Mudpuppies can exist at very high densities, but local population sizes have rarely been assessed, and usually only as relative abundances based on catch per unit effort (CPUE; e.g. McDaniel et al. 2009) or spawning rates (Craig et al. 2015), not as absolute population sizes estimated from capture-recapture data (but see Chellman et al. 2017). Consideration of seasonal changes in capture success is paramount when comparing results of different studies of abundance (Beattie et al. 2017). Studies have also differed in the baits used to capture Mudpuppies (e.g. dead fish, live fish, cat food, dog food, chicken liver, cheese cubes; Gendron et al. 1997; Trauth et al. 2007; Hoffman et al. 2014; Craig et al. 2015; Beattie et al. 2017; Sutherland 2019), but none has attempted to ascertain which bait is most effective.

Movement patterns of the Mudpuppy, which could inform interpretation of apparent differences in detection or activity based on rates of capture, or estimates of local population size, are almost entirely unknown. Chellman et al. (2017) found that displacement averaged 81.8 ± 21.3 m upstream or downstream between captures during a two-year study in the Lamoille River, Vermont. Hellbenders, which are not closely related to the Mudpuppy but like it are large and permanently aquatic salamanders that live in eastern North American rivers, moved an average 27.5 ± 6.5 m over a year (Burgmeier et al. 2011) in the Blue River in southern Indiana and 35.8 ± 3.6 m over two years (Humphries and Pauley 2005) in the New River in Ohio.

Objectives of the study.—We aimed to describe (1) patterns of seasonal activity of the Mudpuppy and (2) its bait preferences, as reflected by rates of trapping success at continuously monitored sites, and to (3) estimate local population sizes at those sites.

RESEARCH METHODS

From June 2017–April 2020, we sampled Mudpuppy populations in Kansas at Melvern Lake at the Melvern Marina (38.4999°N, -95.7139°W) and in Pomona Lake at the Lighthouse Bay Marina (38.6569°N, -95.5934°W). Both lakes are artificial reservoirs within the Marais des Cygnes River watershed. Pomona Lake impounds Dragoon and 110 Mile creeks. It was established in 1963 and has a surface area of 1643 hectares and a maximum depth of 15.2 m (USACE, Washington, District of Columbia). Melvern Lake impounds the Marais des Cygnes River, filled in 1975, and has a water surface area of 2804 hectares and a maximum depth of 18.3 m (USACE, Washington, District of Columbia). From June 2017–March 2018, we set 6 traps at each lake (with some brief interruptions of the effort) but subsequently, through June 2020, we used 12 traps at each lake without interruption. We used Gee minnow traps (23×44 cm, model G40M, Memphis Net and Twine, Memphis, Tennessee) made of metal mesh (6-mm) with funnel entrances broadened to approximately 3×6 cm. These funnels extended 7 cm toward the center of the trap so that Mudpuppies could not easily escape while they explored inside edges.

Traps were set year-round at 8–10 m depth at Melvern Lake and at 2–4 m at Pomona Lake and were checked once every 7–14 days during the high activity period (November 1–May 1) and once every 14–21 days during the low activity period (May 1–November 1) each year.

Traps rested on the lake bed and were attached by nylon ropes to the pier at each marina. Six traps at Melvern Lake were located at a heated dock for the first two years of the study, then moved to another location outside of the heated dock near the other traps due to repeated theft. Lake level rises left some traps suspended above the bottom on occasion, so we switched them to longer ropes. Catch per unit effort (CPUE) was measured as captures per trap night. Traps that were stolen or lost were removed from analysis.

In each lake, three traps were not baited and the other nine traps were baited—three with chicken liver (Murphy et al. 2016), three with Colby-Jack cheese (Craig et al. 2015), and three with raw shrimp. Baits were cut into 2–3 cm^3 chunks and placed in nylon mesh bags. Traps were spaced approximately 3–7 m apart in fixed locations on the marina docks depending on space available. Baits were placed in a predetermined order—chicken liver, raw shrimp, cheese, no bait—starting at trap 1 and ending on trap 4, then repeating through trap 12. The baiting order shifted one position each time traps were checked, so the sequence started at trap 2 on the second visit, and so on.

Each visit, all 12 traps at each site were lifted out of the water and the number of Mudpuppies captured was recorded along with trap number and bait type. We separated Mudpuppies into buckets and took the water temperature (°C) and following water quality measures: pH, hardness, dissolved oxygen, dissolved carbon dioxide, conductivity, nitrate, phosphate, and water oxidation reduction potential (ORP). Temperature, pH, conductivity, dissolved oxygen, and ORP were measured with a portable handheld meter (model HI98194, Hanna Instruments, Woonsocket, Rhode Island) after lowering the probe 2 m into the water for 5 minutes. Temperature was also obtained from the United States Army Corps of Engineers (USACE, Washington, District of Columbia). To measure nitrate and phosphate, we used portable photometers (HI96786, HI713) and reagents (HI93728-03, HI713-25), and to measure carbon dioxide, we used a kit (HI3818), all from Hanna Instruments. For total hardness, we used a Hach (Loveland, Colorado) test kit (HA-71A).

For each Mudpuppy captured, we measured mass (to nearest 1 g) with a scale (H110, American Weigh Scales, Cumming, Georgia), and total length (TL; to nearest mm) and snout-vent length (SVL; to nearest mm) with a meter stick (Craig et al. 2015). External physical abnormalities, including wounds and ectrodactyly, were recorded. Each individual was marked using a unique pattern of toe-clipping following a methodology used by Heyer et al. (1994). We clipped toes starting with the front left and moving clockwise around the dorsal side of the Mudpuppy. After all toes had been used once, we began removing two toes per Mudpuppy, starting with the front left combined with all others, then the second from front left and so on. This procedure allowed us to unambiguously mark up to 136 individuals per site. We saved toes as tissue samples for future DNA analysis.

We conducted statistical analyses using JMP (Esri, Redlands, California). To visualize seasonal changes in Mudpuppy activity levels, we plotted CPUE during the study period. Using that plot, we estimated the timing (calendar dates) of transitions between activity levels by reading where the plotted line crossed the x-axis or by projecting where the beginnings and ends of increased activity fell along the x-axis. We coded the range between those values as “peak” and dates outside of those ranges as “valley.” We estimated body condition as the cube root of mass divided by length. We used one-way and two-way MANOVAs to investigate relationships between Mudpuppy mass, length, sex, and bait type, as well as between the reservoirs. We used one-way ANOVA to investigate individual variables from significant MANOVAs. To avoid compounding Type I error, we applied a Bonferroni correction when interpreting results of sets of ANOVAs. We used chi-square goodness of fit to determine whether the numbers of Mudpuppies entering baited versus unbaited traps were significantly different.

Capture-recapture data were subjected to the POPAN model, a parameterization of the Jolly-Seber stochastic method (Southwood and Henderson 2009), using program MARK (White and Burnham 2009) to calculate a population estimate for an open population. Unlike Jolly-Seber models, this model assumes a single set of survival and catchability parameters to provide a robust model intended to estimate population size and the probability of entry into the population from outside.

RESULTS

Lake captures.—We captured 251 Mudpuppies at the lakes—109 at Pomona Lake and 142 at Melvern Lake—with a CPUE of 0.023 and 0.030, respectively (Table 1). We caught 41 Mudpuppies at Pomona Lake and 13 at Melvern Lake during our first winter trapping season, 52 and 58, respectively, in the second winter, and 13 and 71 in the third. We captured only three Mudpuppies outside of these winter trapping periods (all at Pomona Lake in summer). We found three Mudpuppies at Pomona Lake with abnormalities (2.8% of the total) such as extra or missing toes, spinal disfigurements, or injuries. At Melvern Lake, 25 Mudpuppies had abnormalities (17.6% of the total). We captured two Mudpuppies with spermatophores in their cloaca—one on March 13, 2018, at Pomona Lake and one on January 8, 2019, at Melvern Lake.

We were able to sex 104 females and 137 males (Table 2), whereas 10 individuals appeared to be juveniles and could not be sexed. Two-way MANOVA comparing lakes and sexes for differences in size according to mass, TL, and SVL, was significant between lakes ($F_{3,376} = 8.93$, $P < 0.01$) but not sexes ($F_{3,376} = 1.01$, $P = 0.38$). With individual ANOVAs, males were, overall, not significantly larger than females ($F_{3,377} = 1.25$, $P = 0.29$), but when we analyzed the sizes of sexes within individual reservoirs, males at Pomona Lake were significantly larger than females in terms of mass ($F_{1,125} = 7.32$, $P < 0.01$), but not TL ($F_{1,125} = 1.16$, $P = 0.28$) and, with Bonferroni correction, not SVL ($F_{1,125} = 4.11$, $P = 0.04$), whereas the sexes at Melvern Lake showed no significant size difference ($F_{3,146} = 0.76$, $P = 0.52$).

When individuals of the same sex were compared between lakes, both females ($F_{3,148} = 14.01$, $P < 0.01$) and males ($F_{3,157} = 3.34$, $P = 0.02$) were larger in Melvern Lake than in Pomona Lake. Females at Melvern Lake were significantly larger than those in Pomona Lake for all three metrics (mass: $F_{1,150} = 36.65$, $P < 0.01$; TL: $F_{1,153} = 18.53$, $P < 0.01$, SVL: $F_{1,153} = 28.89$, $P < 0.01$), as were males (mass: $F_{1,159} = 8.82$, $P < 0.01$; TL: $F_{1,162} = 10.04$, $P < 0.01$; SVL: $F_{1,162} = 7.87$, $P < 0.01$; Table 2). We captured significantly more males than females ($\chi^2 = 4.35$, df = 1, $P = 0.04$). We captured more than one Mudpuppy in 54 traps, of which 39 contained both sexes (48 males and 50 females total), eight traps contained only males, and seven contained only females.

Seasonal activity.—Mudpuppies were most active from November to May; activity at Melvern Lake was bimodal with peaks at the beginning and end of each season of high activity (Figs. 1–6). Mudpuppies started appearing in traps in mid- to late November (28 November 2017 in year one, 16 November 2018 in year two, 13 November 2019 in year three) but became inactive in the spring at different times (1 April 2018 in year 1, 25 April 2019 in year 2, and 19 March 2020 in year 3). The high activity period corresponded to a change in water temperature; when the temperature dropped below 10°C, Mudpuppies started appearing in traps in small numbers, and vice-versa once it rose above 10°C in the spring. We captured only three Mudpuppies outside of the high activity period, each during the summer at Pomona Lake (11

July 2018, 15 August 2018, and 23 August 2018). Melvern Lake was the main contributor to the bimodality of peak activity. Mudpuppies caught between the peaks (November–December and March–April) compared to the valleys (January–February) showed no statistical significance in mass, TL, or SVL ($F_{3,288} = 1.49$, $P = 0.22$). However, body condition ($\bar{x} \pm$ SE) of Mudpuppies in the peaks (1.52 ± 0.007) was significantly higher than in the valleys (1.49 ± 0.014; $t = -2.14$, df = 292, $P = 0.03$).

Bait preference.—Analysis of bait preferences was conducted using data from 244 captures of Mudpuppies in the reservoirs. Chi-square goodness of fit showed that Mudpuppies demonstrated a bait preference ($\chi^2 = 9.95$, df = 3, $P = 0.02$; Table 3). Individual chi-square tests comparing a chosen bait to the rest of the model showed that Mudpuppies preferred traps with chicken liver over all others ($\chi^2 = 9.02$, df = 1, $P < 0.01$) but had no preferences among raw shrimp, cheese, and unbaited traps. When the data were analyzed according to trap success (i.e. ignoring the number of Mudpuppies in the traps and considering only whether a trap captured at least one Mudpuppy), we found no difference between any of the bait types or unbaited traps ($\chi^2 = 1.39$, df = 3, $P = 0.71$). Analysis of traps containing multiple Mudpuppies versus traps with a single Mudpuppy or none showed a bait preference ($\chi^2 = 17.57$, df = 3, $P < 0.01$), with individual tests demonstrating that multiple Mudpuppies were more likely to be caught with chicken liver ($\chi^2 = 15.53$, df = 1, $P < 0.01$) and less likely to be caught with no bait ($\chi^2 = 6.58$, df = 1, $P = 0.01$). A chi-square goodness of fit showed females were more likely to enter traps with liver ($\chi^2 = 10.44$, df = 1, $P = 0.01$) and to avoid traps with cheese ($\chi^2 = 10.82$, df = 1, $P = 0.01$) whereas males showed no preference for bait type ($\chi^2 = 2.60$, df = 3, $P = 0.46$).

Population size assessment.—We recaptured 22 different Mudpuppies (12 males and 10 females) at least once (12 at Pomona Lake and 10 at Melvern Lake); three were recaptured twice (at Pomona Lake), two were recaptured three times (at Pomona Lake), and one was recaptured four times (at Melvern Lake, over a 13-month period) for a total of 32 recaptures, from which data were obtained from 31 (Table 5). We estimated the local population of Mudpuppies ($\bar{x}$ ± 1 SE) at Pomona and Melvern lakes to be 818.5 ± 537.0 and 967.9 ± 507.9 with 95% confidence intervals of 296.0–2754.9 and 408.9–2635.8 individuals, respectively (Table 4).

Mudpuppies apparently decreased in mass ($\bar{x}$ ± SE change per week), between capture and recaptures at both Melvern Lake (-0.91 ± 0.81 g) and Pomona Lake (-0.16 ± 0.57 g), increased in TL and SVL at Melvern Lake (0.38 ± 1.16 mm SVL, 0.56 ± 0.93 mm SVL), decreased in TL at Pomona Lake (-1.27 ± 0.89 mm), and increased there in SVL (0.35 ± 0.50; Table 5). None of these changes was significant ($F_{3,27} = 0.81$, $P = 0.50$). When comparing differences between time between captures, Melvern Lake averaged 15.67 ± 4.38 weeks and Pomona Lake averaged 12.26 ± 4.04, but the difference between them was not significant ($t = 0.53$, df = 29, $P = 0.60$).

DISCUSSION

Overview.—We captured 251 Mudpuppies at the two reservoirs and recaptured 22 of them (six of those more than once). We discovered that although they were more likely to enter traps with chicken liver, they also regularly entered traps with other baits or unbaited traps. We found that Mudpuppies were most easily captured using our methods between November–May but that a few could be captured outside this period. Mudpuppy capture rates had a bimodal temporal distribution at Melvern Lake with peaks at the beginning and end of the cold season.

Lake captures.—Our overall CPUE of 0.027 was notably higher than for river captures during our study (Chapter 1) as well as rates reported by other studies in rivers and lakes, for example 0.008 in Detroit, Michigan (Sutherland 2019), 0–0.026 also in Detroit (Craig et al.

2015), and 0.006 in Indiana (Hoffman et al. 2014). The higher capture rate in the lakes was expected because in those cases we were resampling locations where the species was present. Mudpuppy captures at Melvern Lake increased each year of the study (13 to 58 to 71) while they increased between year one and two and then decreased at Pomona Lake (42 to 54 to 13) for unknown reasons. The region experienced drought in summer of 2018 and heavy flooding during summer of 2019, so perhaps the large changes in water levels in Pomona Lake caused them to relocate. A study to track movements of Mudpuppies in the lakes is needed to discern if they move long distances when we do not catch them (possibly leaving the area) or whether they are simply not moving at all (i.e. not active) at those times.

Mudpuppies prefer depths of 1–2 m but can be found up to 30 m deep (Craig et al. 2015). The average depth of Pomona Lake was around 2–3 m at our trapping location, and our trap depth was an average of 8–10 m at Melvern Lake, so both sites were well within the reported range. Because of its larger water column, and because the anglers at Melvern Lake were very active and dropped biomass into the lake including, but not limited to, bait worms, minnows, and fish body parts, Mudpuppies there may have had more food available to them than those at Pomona Lake. Our trapping location at Melvern Lake had several artificial structures (trees, plastic objects) in the water to provide habitat for fish, which may have been attractive to Mudpuppies, together with diverse natural substrates (mud, rocks, gravel) at that site. By contrast, at Pomona Lake, the only cover objects were small rocks which were not large enough for hiding, and the primary substrate was mud (personal observation). Better access to food, a variety of substrates, and artificial cover could explain why Mudpuppies at Melvern Lake were more reliably present and larger than those at Pomona Lake.

Physical abnormality rates were 3% and 18% at Pomona and Melvern lakes, respectively. Deformity rates over 5% are considered elevated in Mudpuppy populations (Ouellet 2000), but we did not qualify the exact nature of the abnormalities of Mudpuppies in these reservoirs. Users of the Melvern Lake marina regularly dumped fish parts there (we pulled up traps covered in fish scales), the decomposition of which likely drove changes in local water quality, including increased nitrate. Nitrate can raise Mudpuppy mortality rates (Marco et al. 1999), and extra limbs and growths can develop due to nitrate concentrations as low as 3 mg/L (Hecnar 1995). We found no significant differences in water quality between Pomona Lake and Melvern Lake, but mean nitrate readings were 16.3 ± 2.1 mg/L at Melvern Lake and 12.9 ± 2.2 mg/L at Pomona Lake. Without ruling out other factors and accounting for differences in nitrate between the surface and near the substrate of the reservoir, we cannot know that this difference contributed to the differing rates of disfigurements and growths.

We found two female Mudpuppies that had a spermatophore in their cloaca, one in January and one in March, which is consistent with accounts that they mate during our winter trapping period (Holman 2012; Harding and Mifsud 2017). For tiger salamanders (*Ambystoma tigrinum)* in North Dakota, multiple males readily enter traps where females are present during mating season (personal observation). However, with a nearly 50:50 split of the sexes in traps with both males and females (48 males and 50 females), our results do not suggest that male Mudpuppies were entering traps to attempt to mate with females. Of the males captured, 35% were found with a female, and it was impossible to know whether they entered the trap before the female or after. The number of males captured was significantly greater than the number of females, yet mixed-sex traps contained fewer males than females.

Seasonal activity.—We captured 98.8% (248/251) of our Mudpuppies from November–May (Figs. 1–6). Our catch rates showed a bimodal distribution at Melvern Lake (Figs. 4 and 6) that has not been illustrated in any other study. The bimodal activity pattern was missing at Pomona Lake, so Melvern Lake may be a unique case. It is well documented that Mudpuppies can be found much more easily in colder months (Neill 1963; Shoop and Gunning 1967; Matson 2005; Chellman et al. 2017), but little is known about the distribution and frequency of Mudpuppy activity within the cold season. The winter period between December and March is when they are captured at highest numbers in other regions (Sajdak 1982; Gendron 2000; Craig et al. 2015). We discovered a 10°C threshold for Mudpuppy capture, the same as found by Chellman et al. (2017) in the Lamoille River in Vermont, suggesting that Mudpuppies respond to the same cues in different regions, a result consistent with claims that Mudpuppy activity is highly related to water temperature (Craig et al. 2015; Beattie et al. 2017) rather than time of year or amount of daylight.

Mudpuppies caught during the activity peaks (November–December and March–April), as compared to the valleys (Jan.–Feb.) in the bimodal distribution, did not differ in average size, but we noticed that those captured during those peak periods looked and felt fuller in body structure, which we confirmed by calculating and statistically analyzing body condition. This result could indicate that they were eating more during these time periods, which might relate to why they were more active during those times of the year.

Bait preference.—A variety of different bait types have been used to catch Mudpuppies, but no previous study has evaluated the effectiveness of different baits. We found that Mudpuppies were more likely to enter traps with chicken liver, yet they entered any trap, even those without bait, which was just as effective as shrimp and cheese. The higher capture rates with chicken liver were due to its propensity to attract multiple mudpuppies to the same trap, not greater likelihood of traps with liver catching a mudpuppy, a pattern of success that is hard to explain but suggests that Mudpuppies are drawn to liver at short distances and that liver-baited traps set near clusters of sheltering mudpuppies draw them to the trap. Lone Mudpuppies might enter any trap primarily in search of cover.

Mark-recapture and population assessment.—Mark-recapture techniques have proven challenging with Mudpuppies when insertion techniques such as pit tags and radio telemetry have been used (McDaniel et al. 2009), but we successfully recaptured 22 Mudpuppies (12 at Pomona Lake and 10 at Melvern Lake) out of the 251 caught at the marinas by using toe clipping to mark individuals. The population estimates of 818 ± 537 at Pomona Lake and 968 ± 508 at Melvern Lake had high standard errors, which is to be expected for an open population. These estimates were calculated over the entirety of the three years of the study and thus represent an average population size over that time period which could be very inaccurate at any given time if Mudpuppies migrate out of the area (e.g. possibly during the summer low activity period). The fact that we recaptured six individuals across trapping seasons (with 38, 39, 43, 48, 53, and 55 weeks between recapture), indicated that they either remain in, or return to, certain areas from year to year. We did not observe regrowth of Mudpuppy toes after clipping for any individual.

Pomona Lake had a higher population estimate initially, but in the final season, Melvern Lake reached a higher number. Pomona Lake’s standard error went down between the second and third seasons while Melvern Lake’s increased. Those changes in estimates likely reflect the fact that we caught most Pomona Lake Mudpuppies early in the first season, whereas at Melvern Lake most were caught late in the second season. Such timing of captures at Melvern limited their opportunity to be recaptured. The population estimate for Melvern Lake was only 18.3%

higher than that of Pomona Lake even though Melvern Lake’s final capture count was 30.3% higher than Pomona Lake’s, perhaps because the POPAN model assumes the survival of captured individuals after they are released. Pomona Lake had more recaptures with fewer total captures, so we could reasonably expect its population estimate to be lower. At least 90%, maybe as high as 98%, of our captures were adults. Although 10 individuals could not be sexed with confidence, only four were certainly juveniles out of the 251 total captures, so recruitment could not be estimated without additional strategies to trap for juveniles.

Mudpuppies apparently, on average, decreased in mass (15 of 31 individuals) and TL but not SVL between captures. This unexpected finding could be an outcome of the fact that each individual had its stomach flushed for a separate study of mudpuppy diet (see Buchanan et. al. *in prep.*); 18 of 31 were recaptured within four weeks after initial capture, so they might not have had time to replenish their gut contents, losing mass in the process. It is also possible that females laid eggs between captures or that Mudpuppies lost a significant amount of their slime coat during handling. Some individuals increased substantially in mass—one at Pomona Lake grew by 38 g from its original mass of 77.5 g in 48 weeks while another at Melvern Lake grew by 40 g from its original mass of 121.2 g within 16 weeks, for increases of 49% and 33%, respectively, of their original body mass. On the other hand, apparent decreases in TL (14 captures) and SVL (nine captures) were more likely a result of measuring error because taking length measurements of squirming slimy Mudpuppies with precision is quite difficult.

Of our Melvern Lake recaptures, 54% (7 of 12) occurred at least 12 weeks after the original capture, while at Pomona Lake, only 26% (5 of 19) were recovered after that period. This difference in the timing of recaptures might result from water depths at the marinas. Mudpuppies were released at the site of capture at both marinas, but they had a tendency after release to move horizontally through the water column before turning to move vertically towards the bottom (personal observation). Mudpuppies at Pomona Lake only had a 2 m depth so their displacement from the release point to the trap was smaller compared to Melvern Lake where they had 8–10 m of water column to move through before they reached the bottom. We visually estimated their travel path several times and noted that they could travel up to ~3–4 m horizontally before descending ~1 m and being lost from view due to turbid water, which would mean that Mudpuppies might travel up to ~32–40 m horizontally before reaching the bottom at Melvern Lake but only ~8–10 m horizontally at Pomona Lake. If they move great distances on the substrate after release, this point would be moot, but if not, then their chance of rapid recapture would be less likely at Melvern Lake.

Conclusion.—Mudpuppies maintain populations at the Lighthouse Bay Marina at Pomona Lake and the Melvern Lake Marina where we had a CPUE of 0.023 and 0.030 in winter, respectively. Tracking methods, such as radio telemetry, would be worthwhile to determine how far they move and might explain why they could be captured more frequently during some years than others. We were able to recapture them 33 times, six of those across different trapping seasons, so at least some individuals do frequent the same area in different years. Our research also indicated that Mudpuppies preferred chicken liver as a bait, however they also entered traps while foraging or searching. Their seasonal activity was mostly limited to November through May, as suggested by other research, but they had a bimodal pattern of activity at Melvern Lake, with peaks at the beginning and end of the cold season, also corresponding to higher body condition.

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Table 1. Mudpuppy captures at Pomona and Melvern lakes, Osage County, Kansas, June 2017–April 2020, with trap success listed as CPUE (captures per trap night).

	Pomona Lake	Melvern Lake
Total captures	109	142
Trap nights (November 1–May 1)	4770	4696
Trap nights (year-round)	9342	9268
Trap success (November 1–May 1)	0.023	0.030
Trap success (year-round)	0.012	0.015

Table 2. Body measurements ($\bar{x}$ ± 1 SE) of adult Mudpuppies caught in Pomona and Melvern lakes, eastern Kansas, June 2017–April 2020, comparing lakes ($F_{3,376} = 8.93$, $P < 0.01$) and sexes ($F_{3,376} = 1.01$, $P = 0.38$) according to morphological data (mass, total length, (TL) and snout-vent length (SVL)).

	All captures (both lakes)		Pomona Lake		Melvern Lake	
	Females	Males	Females	Males	Females	Males
Total (N)	104	144	49	59	55	85
Mass (g)	83.62 ± 2.57	94.49 ± 1.91	75.95 ± 2.51	86.69 ± 2.95	89.97 ± 4.30	97.6 ± 2.39
TL (mm)	252.6 ± 2.40	261.6 ± 1.77	244.5 ± 3.24	249.3 ± 2.94	256.5 ± 3.38	260.4 ± 2.07
SVL (mm)	170.1 ± 1.68	178.5 ± 1.27	163.7 ± 2.11	170.0 ± 2.20	173.6 ± 2.46	177.1 ± 1.44

Table 3. Number of Mudpuppies caught on different baits, June 2017–April 2020, in Pomona and Melvern lakes, Osage County, Kansas, showing chi-square goodness of fit (df = 3) for (A) total number Mudpuppies, (B) binary trap success, and (C) trap success in terms of traps containing more than one Mudpuppy.

	A	B	C
Chicken liver	82	45	27
Raw shrimp	54	38	12
Cheese	49	39	9
No bait	59	47	6
N	244	169	54
X^2	9.95	1.39	17.57
P	0.02	0.71	0.01

Table 4. Population estimate of Mudpuppies ($\bar{x}$ ± 1 SE) at Pomona and Melvern lake marinas, Osage County, Kansas, June 2017–April 2020, using POPAN model in Program Mark.

	Pomona Lake	Melvern Lake
Population estimate	818 ± 537	968 ± 508
Confidence interval (95%)	296–2755	409–2636
Survivorship	0.87 ± 2.33	0.90 ± 2.05
Confidence interval (95%)	0.65–0.93	0.84–0.93
P of recapture	0.06 ± 0.45	0.04 ± 0.65
Confidence interval (95%)	0.01–0.14	0.01–0.08
P of entry	0.01 ± 0.01	0.01 ± 0.01
Confidence interval (95%)	0.00–0.27	0.00–0.12

Table 5. Size differences ($\bar{x}$ ± 1 SE) per week after recapture of individual Mudpuppies (including repeated recaptures of the same individuals) in Pomona and Melvern lakes, Osage County, Kansas, June 2017–April 2020.

	Pomona Lake	Melvern Lake
Total (N)	19	12
Mass (g)	-0.16 ± 0.57	-0.92 ± 0.81
Length (mm)	-1.27 ± 0.89	0.38 ± 1.16
Snout-vent length (mm)	0.35 ± 0.50	0.56 ± 0.93
Weeks between recapture	12.26 ± 4.04	15.67 ± 4.38

Fig. 1. CPUE (captures per trap night; black line) of Mudpuppies, with temperature (gray line) caught, by calendar date during year 1 (June 2017–June 2018) at Pomona Lake, Osage County, Kansas.

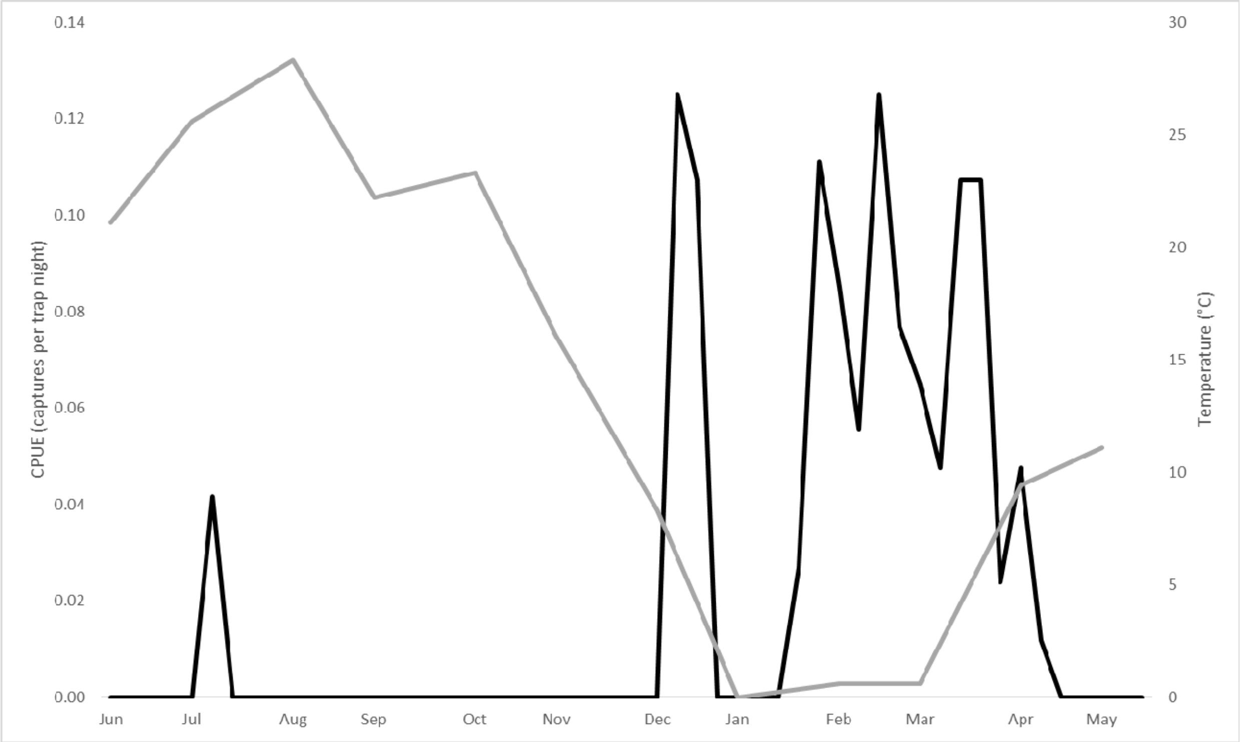


Fig. 2. CPUE (captures per trap night; black line) of Mudpuppies with temperature (gray line) caught by calendar date during year 1 (June 2017–June 2018) at Melvern Lake, Osage County, Kansas.

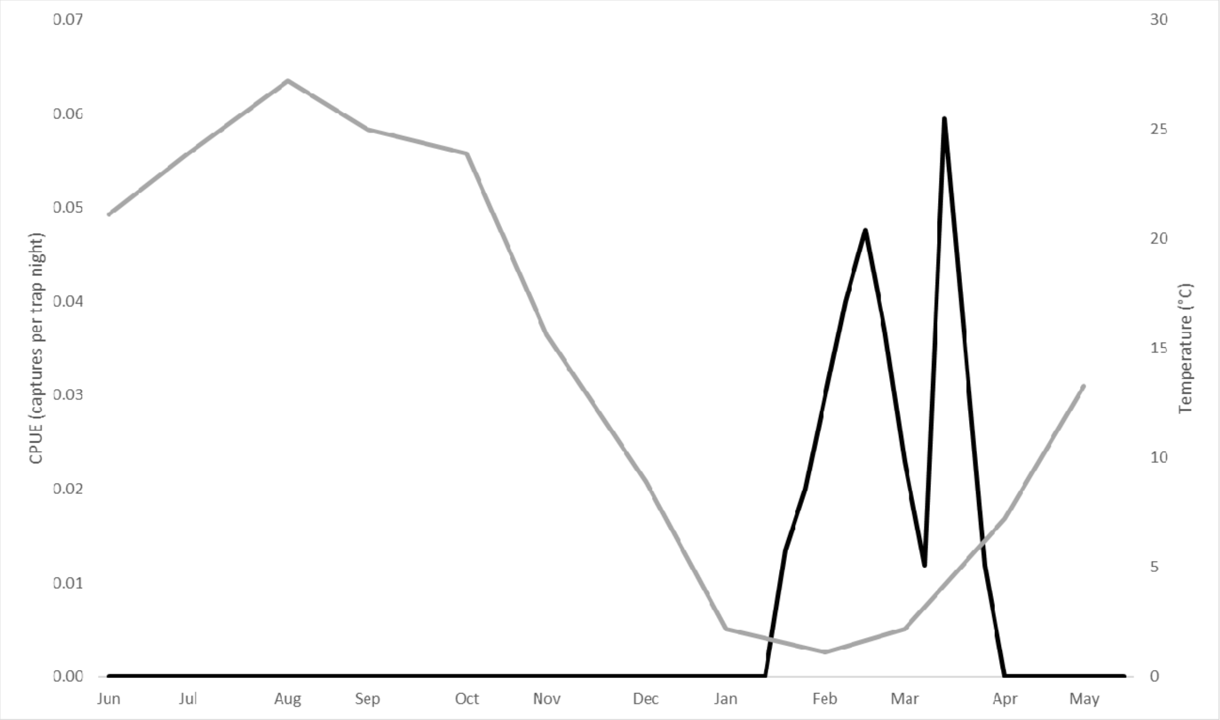


Fig. 3. CPUE (captures per trap night; black line) of Mudpuppies with temperature (gray line) caught by calendar date during year 2 (June 2018–June 2019) at Pomona Lake, Osage County, Kansas.

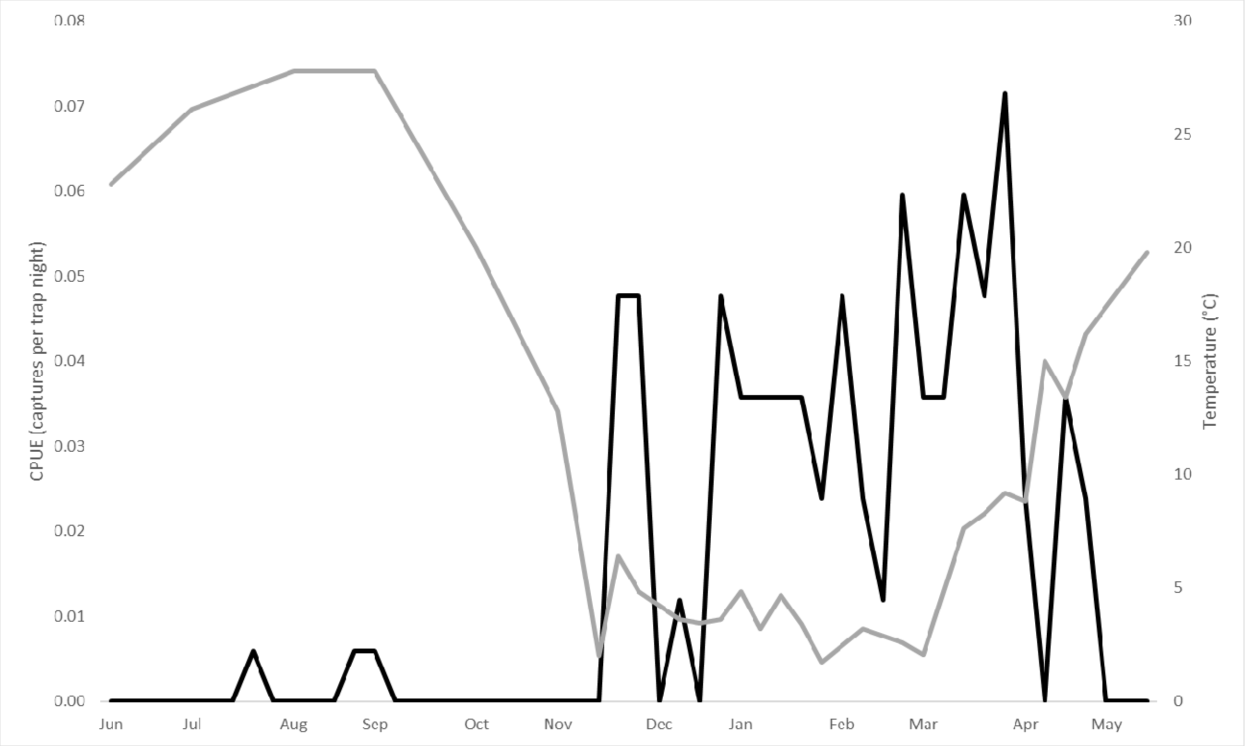


Fig. 4. CPUE (captures per trap night; black line) of Mudpuppies with temperature (gray line) caught by calendar date during year 2 (June 2018–June 2019) at Melvern Lake, Osage County, Kansas.

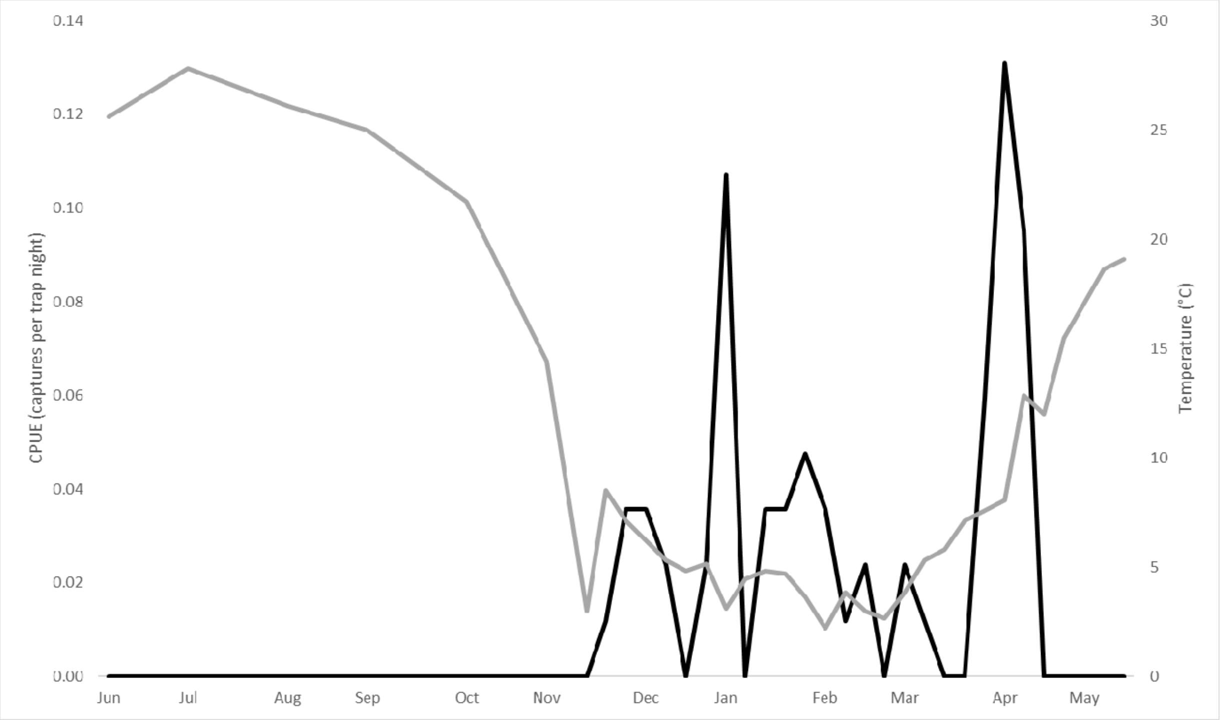


Fig. 5. CPUE (captures per trap night; black line) of Mudpuppies with temperature (gray line) caught by calendar date during year 3 (June 2019–June 2020) at Pomona Lake, Osage County, Kansas.

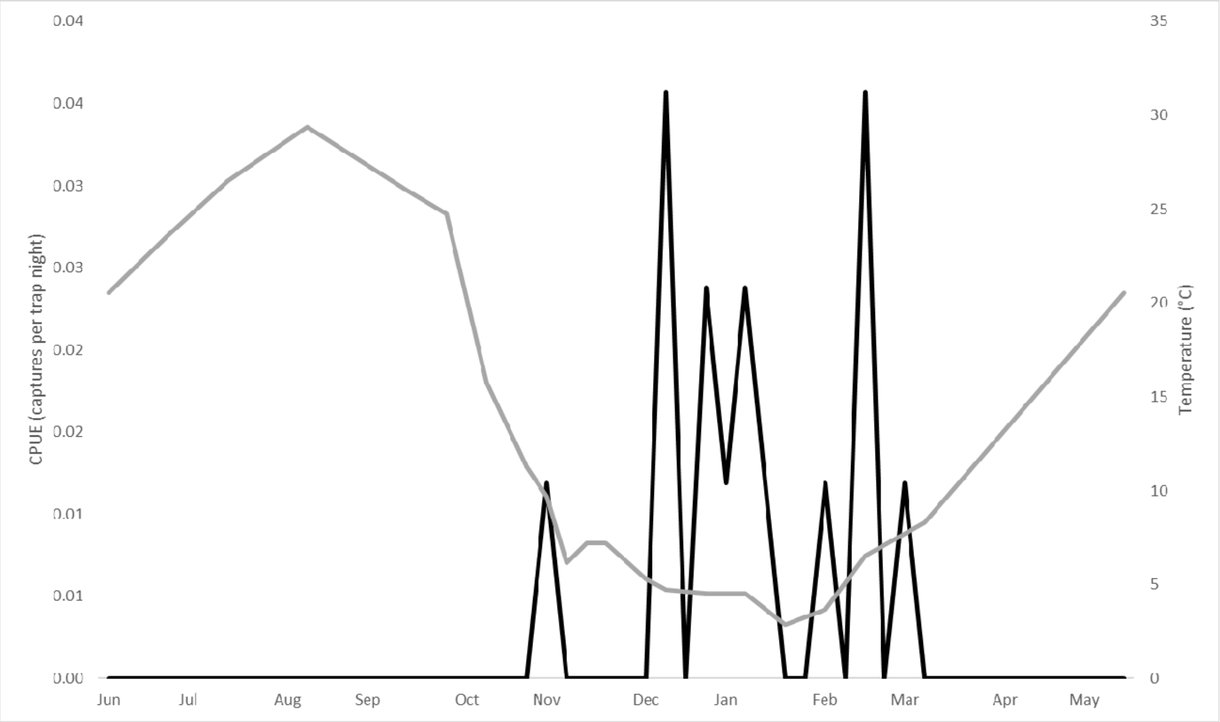
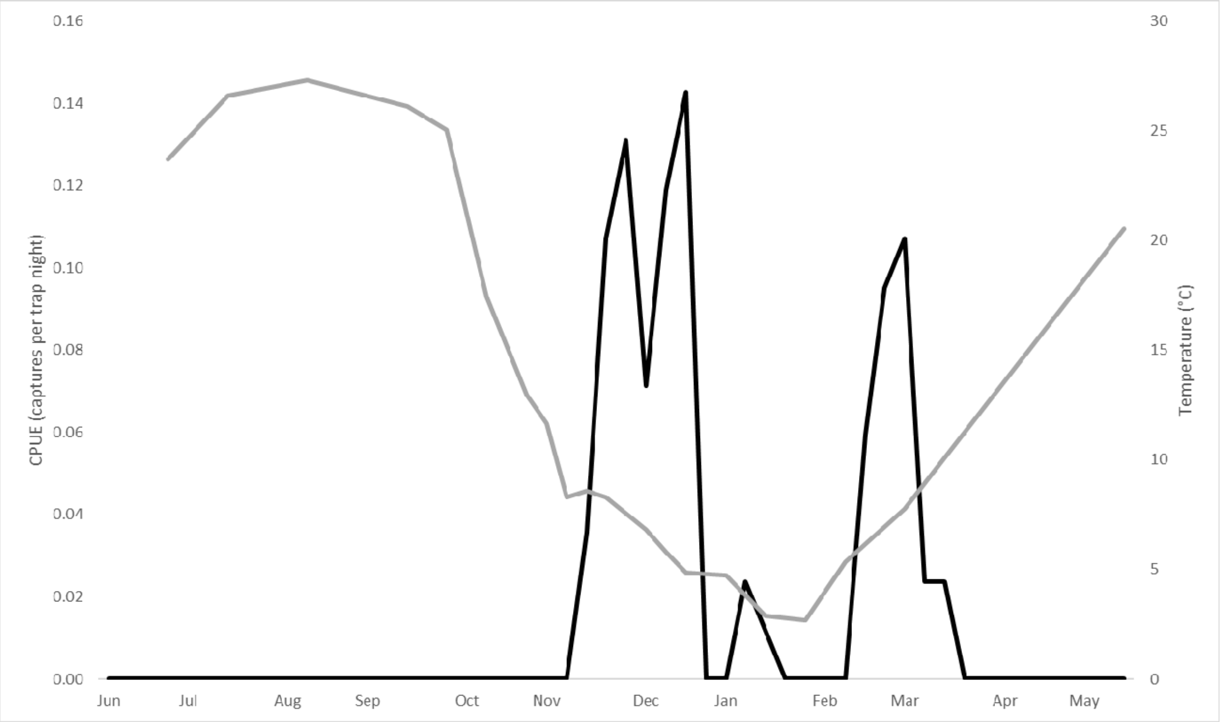


Fig. 6. CPUE (captures per trap night; black line) of Mudpuppies with temperature (gray line) caught by calendar date during year 3 (June 2019–June 2020) at Melvern Lake, Osage County, Kansas.



Appendix A. Summary list of survey sites for the Mudpuppy in eastern Kansas, 2017–2020.

Site	**County**	**Date first assessed**	**Trap nights**	**Reach**	**Basin**	**Latitude**	**Longitude**	**Mudpuppy captures (N)**	**Historic sites**
ST-18-219	Johnson	2019-01-26	28	Indian	Kansas	38.93837	-94.6402	0	0
ST-18-220	Johnson	2019-01-26	28	Indian	Kansas	38.93839	-94.6432	0	0
ST-18-221	Johnson	2019-01-26	28	Indian	Kansas	38.93889	-94.6488	0	0
ST-19-241	Johnson	2019-01-26	28	Indian	Kansas	38.93108	-94.6298	0	0
ST-19-242	Johnson	2019-01-26	28	Indian	Kansas	38.93428	-94.6955	0	0
ST-19-256	Douglas	2019-04-04	21	Wakarusa	Kansas	38.95024	-95.0992	0	0
ST-19-257	Douglas	2019-04-04	28	Wakarusa	Kansas	38.92778	-95.1488	0	0
ST-19-258	Douglas	2019-04-04	28	Wakarusa	Kansas	38.91	-95.1769	0	0
ST-19-259	Douglas	2019-04-04	28	Wakarusa	Kansas	38.91099	-95.2239	0	0
ST-19-261	Douglas	2019-04-04	28	Wakarusa	Kansas	38.92891	-95.323	0	0
ST-19-260	Douglas	2019-04-04	28	Washington	Kansas	38.91338	-95.2939	0	0
ST-18-073	Osage	2018-02-02	8	110 Mile	Marais des Cygnes	38.64611	-95.5625	0	1
ST-18-074	Osage	2018-02-02	36	110 Mile	Marais des Cygnes	38.63273	-95.5266	0	1
ST-18-172	Franklin	2018-11-20	8	110 Mile	Marais des Cygnes	38.60818	-95.5116	0	0
ST-18-222	Osage	2018-11-20	8	110 Mile	Marais des Cygnes	38.63995	-95.5459	0	0
ST-18-105	Lyon	2018-04-10	8	142 Mile	Marais des Cygnes	38.57111	-95.9869	0	0
ST-18-106	Lyon	2018-04-10	8	142 Mile	Marais des Cygnes	38.58237	-96.0228	0	0
ST-18-177	Miami	2019-01-22	8	Bull	Marais des Cygnes	38.50531	-94.8534	0	0
ST-18-179	Miami	2019-01-22	8	Bull	Marais des Cygnes	38.56052	-94.8776	0	0
ST-19-240	Miami	2019-01-24	140	Hillsdale Lake	Marais des Cygnes	38.6499	-94.9215	0	0
DGKP-17-004	Osage	2019-03-21	20	Long	Marais des Cygnes	38.49702	-95.6376	1	1
DGKP-17-011	Osage	2019-03-21	20	Long	Marais des Cygnes	38.5066	-95.6253	0	0
DGKP-17-014	Osage	2019-03-21	20	Long	Marais des Cygnes	38.478	-95.6667	0	0
ST-18-173	Osage	2019-03-21	20	Long	Marais des Cygnes	38.46318	-95.6918	0	0
DGKP-17-053	Linn	2017-11-26	16	Marais des Cygnes	Marais des Cygnes	38.24027	-94.6855	0	0
DGKP-17-054	Linn	2017-12-18	8	Marais des Cygnes	Marais des Cygnes	38.34508	-94.773	0	0
DGKP-17-031	Franklin	2017-12-31	8	Marais des Cygnes	Marais des Cygnes	38.6196	-95.2761	0	0
DGKP-17-062	Franklin	2017-12-31	8	Marais des Cygnes	Marais des Cygnes	38.6196	-95.2761	0	0
DGKP-17-063	Franklin	2017-12-31	16	Marais des Cygnes	Marais des Cygnes	38.59705	-95.3786	0	0
DGKP-17-030	Franklin	2018-01-26	12	Marais des Cygnes	Marais des Cygnes	38.5877	-95.4197	3	1
ST-18-071	Franklin	2018-01-26	12	Marais des Cygnes	Marais des Cygnes	38.60852	-95.3499	0	0
DGKP-17-029	Franklin	2018-02-02	8	Marais des Cygnes	Marais des Cygnes	38.5831	-95.4578	0	1
ST-18-075	Franklin	2018-02-02	23	Marais des Cygnes	Marais des Cygnes	38.58642	-95.4814	0	0
ST-18-072	Franklin	2018-02-16	32	Marais des Cygnes	Marais des Cygnes	38.61834	-95.2931	1	1

ST-18-081	Franklin	2018-02-16	10	Marais des Cygnes	Marais des Cygnes	38.53528	-95.0715	1	0
ST-18-078	Franklin	2018-02-16	10	Marais des Cygnes	Marais des Cygnes	38.61092	-95.2061	0	0
ST-18-079	Franklin	2018-02-16	8	Marais des Cygnes	Marais des Cygnes	38.58141	-95.151	0	1
ST-18-080	Franklin	2018-02-16	8	Marais des Cygnes	Marais des Cygnes	38.57557	-95.1026	0	0
ST-18-089	Osage	2018-03-09	12	Marais des Cygnes	Marais des Cygnes	38.52016	-95.9217	1	0
ST-18-090	Osage	2018-03-09	14	Marais des Cygnes	Marais des Cygnes	38.53526	-95.9492	1	0
ST-18-088	Osage	2018-03-09	14	Marais des Cygnes	Marais des Cygnes	38.49209	-95.8952	0	0
ST-18-104	Lyon	2018-04-10	8	Marais des Cygnes	Marais des Cygnes	38.56702	-95.9616	0	0
ST-19-238	Linn	2019-01-22	8	Marais des Cygnes	Marais des Cygnes	38.21863	-94.6127	0	0
ST-19-239	Linn	2019-01-22	8	Marais des Cygnes	Marais des Cygnes	38.27145	-94.7149	0	0
DGKP-17-021	Bourbon	2019-01-03	20	Marmaton	Marais des Cygnes	37.8086	-95.0248	0	0
DGKP-17-022	Bourbon	2019-01-03	32	Marmaton	Marais des Cygnes	37.8309	-94.8874	0	0
ST-18-187	Bourbon	2019-01-03	12	Marmaton	Marais des Cygnes	37.8202	-95.0108	0	0
ST-19-230	Bourbon	2019-01-03	16	Marmaton	Marais des Cygnes	37.82462	-94.8691	0	0
ST-19-232	Bourbon	2019-01-03	4	Marmaton	Marais des Cygnes	37.81891	-94.8444	0	0
ST-19-233	Bourbon	2019-01-03	24	Marmaton	Marais des Cygnes	37.84527	-94.9517	0	0
DGKP-17-023	Bourbon	2019-12-31	14	Marmaton	Marais des Cygnes	37.8561	-94.6404	0	0
ST-18-159	Bourbon	2019-12-31	7	Marmaton	Marais des Cygnes	37.86304	-94.679	0	0
ST-18-161	Bourbon	2019-12-31	14	Marmaton	Marais des Cygnes	37.82826	-94.7265	0	0
ST-19-231	Bourbon	2019-12-31	21	Marmaton	Marais des Cygnes	37.81321	-94.7801	0	0
DGKP-17-008	Osage	2017-06-08	9268	Melvern Lake	Marais des Cygnes	38.49999	-95.7139	142	0
DGKP-17-006	Osage	2017-06-07	9342	Pomona Lake	Marais des Cygnes	38.65694	-95.5934	109	0
DGKP-17-017	Anderson	2019-02-19	8	Pottawatomie	Marais des Cygnes	38.2342	-95.2652	0	0
DGKP-17-034	Anderson	2019-02-19	8	Pottawatomie	Marais des Cygnes	38.2917	-95.1747	0	0
ST-18-191	Anderson	2019-02-19	8	Pottawatomie	Marais des Cygnes	38.37761	-95.1366	0	0
ST-18-194	Anderson	2019-02-19	8	Pottawatomie	Marais des Cygnes	38.34908	-95.2034	0	0
ST-18-195	Anderson	2019-02-19	8	Pottawatomie	Marais des Cygnes	38.33952	-95.2729	0	0
ST-18-114	Miami	2019-02-19	8	Pottawatomie	Marais des Cygnes	38.4853	-94.9509	0	0
ST-18-115	Miami	2019-02-19	8	Pottawatomie	Marais des Cygnes	38.48646	-95.012	0	0
ST-18-116	Franklin	2019-02-19	8	Pottawatomie	Marais des Cygnes	38.44377	-95.0838	0	0
ST-19-250	Coffey	2019-02-12	8	Big	Neosho	38.08259	-95.6804	0	0
ST-19-251	Coffey	2019-02-12	8	Big	Neosho	38.0966	-95.7032	0	0
ST-19-252	Coffey	2019-02-12	8	Big	Neosho	38.09492	-95.7209	0	0
DGKP-17-048	Lyon	2017-11-26	28	Cottonwood	Neosho	38.38611	-96.1811	0	1
ST-18-069	Chase	2018-01-21	40	Cottonwood	Neosho	38.3747	-96.5413	0	0
ST-18-076	Chase	2018-02-13	16	Cottonwood	Neosho	38.38802	-96.3919	0	0
ST-18-077	Chase	2018-02-13	16	Cottonwood	Neosho	38.39771	-96.3566	0	0

ST-18-082	Chase	2018-02-23	12	Cottonwood	Neosho	38.15894	-96.5533	0	0
ST-18-083	Chase	2018-02-23	22	Cottonwood	Neosho	38.26911	-96.5301	0	1
ST-18-084	Chase	2018-02-23	12	Cottonwood	Neosho	38.28562	-96.512	0	0
DGKP-17-052	Lyon	2018-02-27	8	Cottonwood	Neosho	38.37611	-96.0683	0	0
ST-18-085	Lyon	2018-02-27	8	Cottonwood	Neosho	38.37487	-96.1525	0	0
ST-18-087	Lyon	2018-03-06	22	Cottonwood	Neosho	38.41467	-96.1809	0	0
ST-18-107	Lyon	2018-04-15	8	Cottonwood	Neosho	38.388	-96.1834	0	0
ST-18-109	Chase	2018-11-27	16	Cottonwood	Neosho	38.3697	-96.5261	1	0
ST-18-110	Chase	2018-11-27	8	Cottonwood	Neosho	38.36825	-96.4648	0	0
ST-19-243	Chase	2019-02-05	8	Cottonwood	Neosho	38.38779	-96.5974	0	0
ST-19-246	Chase	2019-02-05	6	Cottonwood	Neosho	38.29388	-96.732	0	0
ST-19-247	Chase	2019-02-05	8	Cottonwood	Neosho	38.26196	-96.8189	0	0
ST-18-102	Morris	2018-04-03	16	Council Grove Lake	Neosho	38.68247	-96.5219	0	0
ST-18-223	Cherokee	2018-12-17	12	Cow	Neosho	37.33833	-94.6738	0	0
ST-18-224	Cherokee	2018-12-17	8	Cow	Neosho	37.30966	-94.6803	0	1
ST-18-225	Cherokee	2018-12-17	8	Cow	Neosho	37.28062	-94.6746	0	0
ST-18-226	Cherokee	2018-12-17	8	Cow	Neosho	37.25143	-94.6704	0	0
ST-18-227	Cherokee	2018-12-17	8	Cow	Neosho	37.22216	-94.6534	0	0
ST-19-249	Coffey	2019-02-12	8	Long	Neosho	38.1256	-95.6693	0	0
ST-19-244	Chase	2019-02-05	8	Middle Creek	Neosho	38.38633	-96.6883	0	0
ST-19-245	Chase	2019-02-05	8	Middle Creek	Neosho	38.3933	-96.7181	0	0
DGKP-17-049	Lyon	2017-11-26	38	Neosho	Neosho	38.4375	-96.2078	5	0
DGKP-17-042	Woodson	2017-12-18	13	Neosho	Neosho	38.08381	-95.6559	0	1
DGKP-17-043	Woodson	2017-12-20	5	Neosho	Neosho	38.0089	-95.5533	0	0
DGKP-17-057	Coffey	2017-12-20	12	Neosho	Neosho	38.19465	-95.7346	0	0
DGKP-17-058	Coffey	2017-12-20	28	Neosho	Neosho	38.24195	-95.7542	0	0
DGKP-17-059	Lyon	2017-12-20	13	Neosho	Neosho	38.31046	-95.9487	0	1
ST-18-064	Labette	2018-01-09	12	Neosho	Neosho	37.03666	-95.0807	0	0
ST-18-065	Labette	2018-01-09	12	Neosho	Neosho	37.17622	-95.1031	0	0
ST-18-068	Lyon	2018-01-21	8	Neosho	Neosho	38.50714	-96.3114	0	0
ST-18-070	Coffey	2018-01-25	8	Neosho	Neosho	38.1475	-95.6928	0	0
ST-18-086	Lyon	2018-02-27	8	Neosho	Neosho	38.40599	-96.0981	0	0
DGKP-17-001	Lyon	2018-03-02	12	Neosho	Neosho	38.42175	-96.1754	0	1
DGKP-17-002	Lyon	2018-03-04	12	Neosho	Neosho	38.42669	-96.172	1	1
ST-18-091	Allen	2018-03-13	42	Neosho	Neosho	37.92105	-95.4267	0	1
ST-18-092	Labette	2018-03-19	12	Neosho	Neosho	37.26593	-95.1153	0	1
ST-18-093	Labette	2018-03-19	12	Neosho	Neosho	37.34056	-95.109	0	0

ST-18-094	Neosho	2018-03-19	12	Neosho	Neosho	37.45694	-95.133	0	0
ST-18-095	Neosho	2018-03-19	12	Neosho	Neosho	37.49398	-95.1631	0	0
ST-18-096	Neosho	2018-03-19	12	Neosho	Neosho	37.54909	-95.2487	0	0
ST-18-103	Morris	2018-04-03	8	Neosho	Neosho	38.66641	-96.4935	0	0
ST-18-108	Lyon	2018-04-15	8	Neosho	Neosho	38.42391	-96.1851	0	1
ST-19-248	Lyon	2019-02-12	8	Neosho	Neosho	38.42844	-96.1581	0	0
ST-18-127	Cherokee	2018-12-18	8	Shawnee	Neosho	37.10432	-94.6842	0	0
DGKP-17-037	Cherokee	2018-02-01	20	Shoal	Neosho	37.0419	-94.6412	0	1
ST-18-128	Cherokee	2018-12-18	8	Shoal	Neosho	37.04212	-94.6439	0	0
ST-18-229	Cherokee	2018-12-18	8	Shoal	Neosho	37.02273	-94.7201	0	0
DGKP-17-025	Cherokee	2018-02-01	12	Spring	Neosho	37.1765	-94.6473	0	0
DGKP-17-026	Cherokee	2018-02-01	28	Spring	Neosho	37.0621	-94.7063	0	1
ST-18-228	Cherokee	2018-12-17	12	Spring	Neosho	37.1786	-94.6419	0	0
ST-18-146	Greenwood	2019-02-26	20	Cedar	Verdigris	37.8182	-95.9525	0	0
ST-19-236	Elk	2019-01-08	21	Duck	Verdigris	37.3001	-95.9018	0	0
ST-18-099	Montgomery	2018-03-20	8	Elk	Verdigris	37.26429	-95.7091	0	1
ST-19-235	Elk	2019-01-08	28	Elk	Verdigris	37.36545	-96.0824	1	0
ST-19-234	Elk	2019-01-08	28	Elk	Verdigris	37.27984	-95.7813	0	0
ST-19-237	Elk	2019-01-08	21	Elk	Verdigris	37.2664	-95.9187	0	0
DGKP-17-041	Greenwood	2017-12-27	6	Fall	Verdigris	37.8169	-96.3007	0	1
DGKP-17-060	Wilson	2017-12-27	12	Fall	Verdigris	37.417	-95.6964	0	1
ST-19-254	Montgomery	2019-02-26	40	Sandy Creek	Verdigris	37.70403	-95.854	0	0
ST-19-255	Montgomery	2019-02-26	10	Sandy Creek	Verdigris	37.67912	-95.8364	0	0
ST-18-066	Montgomery	2018-01-09	12	Verdigris	Verdigris	37.06119	-95.6345	0	0
ST-18-067	Montgomery	2018-01-09	12	Verdigris	Verdigris	37.12387	-95.62	0	0
ST-18-097	Montgomery	2018-03-20	8	Verdigris	Verdigris	37.18117	-95.6278	0	0
ST-18-098	Montgomery	2018-03-20	12	Verdigris	Verdigris	37.22853	-95.6969	0	0
ST-18-100	Montgomery	2018-03-20	8	Verdigris	Verdigris	37.32675	-95.6852	0	0
ST-18-101	Wilson	2018-03-20	10	Verdigris	Verdigris	37.41763	-95.6728	0	0
ST-18-117	Greenwood	2018-12-10	8	Verdigris	Verdigris	38.14613	-96.1387	1	0
ST-18-118	Greenwood	2018-12-10	8	Verdigris	Verdigris	38.13484	-96.1029	1	0
ST-18-119	Greenwood	2018-12-10	16	Verdigris	Verdigris	38.0845	-96.0505	0	0
ST-18-120	Greenwood	2018-12-10	8	Verdigris	Verdigris	38.05613	-96.0512	0	0
ST-18-144	Greenwood	2019-02-26	40	Verdigris	Verdigris	37.89529	-96.0126	0	1
ST-18-145	Greenwood	2019-02-26	40	Verdigris	Verdigris	37.85823	-95.9861	0	0
ST-19-253	Greenwood	2019-02-26	30	Verdigris	Verdigris	37.99673	-96.024	0	0

Justin Autz
Typed Signature of Author

20 July 2020
Date

Distribution, Habitat, and Seasonal Activity of the
Mudpuppy (*Necturus maculosus*) in Eastern Kansas
Title of Thesis