Management Plan for the Streamside Salamander (*Ambystoma barbouri*) in Middle Tennessee

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EXECUTIVE SUMMARY

Streamside salamanders (*Ambystoma barbouri*) are cryptic, fossorial salamanders found in the inner and outer basin of middle Tennessee. Streamside salamanders are a sibling species to the better-known small-mouthed salamander (*Ambystoma texanum*), and once thought to be the same species. *A. barbouri* are typically found in upland deciduous habitat with significant limestone rock. Each October, they migrate to first and second-order streams to deposit eggs underneath rocks. As of 2004, they are listed as near threatened on the International Union for Conservation of Nature's (IUCN) Red List with a decreasing population, despite actual population numbers being unknown. Primary threats to *A. barbouri* populations include increased development in the Nashville area, agriculture, and climate change. As the population of Nashville increases, new infrastructure is consistently being created to meet the needs of a growing population. Agricultural runoff causes morphological abnormalities, and half of Tennessee's land use consists of farmland. Climate change has also directly impacted *A. barbouri* populations with more frequent drying and flooding events that create casualties during the breeding season. The primary goal of this management plan is to create an increased population trend for *A. barbouri* populations within middle Tennessee. Objectives to achieve this goal include obtaining an accurate population estimate for *A. barbouri*, gaining more insight on *A. barbouri* natural history to make more informed management decisions, raising public concern for the species, and increasing larval survivorship to 10%. As *A. barbouri* populations are very locally distributed, it is integral a management plan be implemented immediately to change the current trajectory of this species.

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INTRODUCTION

Streamside salamanders (*Ambystoma barbouri*) were first described in 1982 by biologist James Petranka after noticing variances of the small-mouthed salamanders (*Ambystoma texanum*) in Kentucky he dubbed a “stream form” and a “pond form” (Petranka 1982). Thereafter, the stream form became known as *Ambystoma barbouri*. *A. barbouri* are listed as near threatened and declining on the International Union for Conservation of Nature (IUCN) Red List (Hammerson 2004). This listing was determined as a result of limited geographic range and declining habitat quality throughout its range (Hammerson 2004). Threats to this species in middle Tennessee include development, agriculture, and climate change (Hammerson 2004). Salamanders play an important ecological role within the environments they inhabit as they maintain soils by burrowing, connect aquatic and terrestrial ecosystems through nutrient uptake and deposition, and serve as environmental indicators (Davic and Welsh 2004). Due to their cryptic nature, their total population size is unknown, but population models indicate extirpation in 30 years using current population and life history data if management is not implemented (Hammerson 2004). More research is to be done on current population status, life history characteristics, and movement patterns to make more informed management decisions.

NATURAL HISTORY

IDENTIFICATION

The streamside salamander, *Ambystoma barbouri*, is an amphibian species belonging to the Ambystomatidae family, or mole salamanders, in the order Caudata (Hammerson 2004). This species possesses a small blunt snout and 15 costal grooves (Kraus and Petranka 1989). Coloring is typically either solidly brownish greyish, or with lichen-like mottling (Figure 1) (Kraus and Petranka 1989). This species is a sister species to *Ambystoma texanum*, the small-mouthed salamander, thus important distinctions must be addressed.

Figure 1. Adult streamside salamander (*Ambystoma barbouri*) color variation in Middle Tennessee, photo taken by Nicole Witzel.

One method of distinguishing *A. barbouri* and *A. texanum* is by dentition (Niemiller et al. 2006). *A. barbouri* has highly numerous maxillar, premaxillar, and vomerine teeth (Kraus and Petranka 1989). Additionally, this species has short blunt lingual cusps on maxillary and premaxillary teeth, but dentary and vomerine teeth become pointed after metamorphosis (Kraus and Petranka 1989). Other distinguishing characteristics include stream breeding, singly laying eggs, laying smaller quantities of larger eggs, and eggs hatching with advanced development (Kraus and Petranka 1989).

DISTRIBUTION and SITE SELECTION

The streamside salamander is found in the southernmost portion of Ohio and Indiana, extending into Tennessee within the inner and outer Nashville Basin (Figure 2) (Petranka 1998, Anderson et al. 2014). They typically inhabit upland deciduous forests in areas of limestone bedrock and breed in first and second order streams (Kraus and Petranka 1989). Individual breeding stream selection is largely dependent on the presence or absence of predatory fish, and there currently exists no information regarding other environmental factors (Petranka 1983, Kats and Sih 1992). In streams that do not contain fish, salamanders are ten times more likely to use that stream for breeding than streams that contain fish. Egg masses in fishless waters are significantly more numerable, and larval populations in fish inhabited streams are less than 10% (X_2= 16.66, P<0.001) of the larvae found in fishless streams (Petranka 1983, Kats and Sih 1992). In *Ambystoma maculatum*, a closely related species, typical emigration from breeding sites to non-breeding sites is 180m (Range= 15.0-210.3m), potentially suggesting a home range size for *A. barbouri* (Madison 1997).

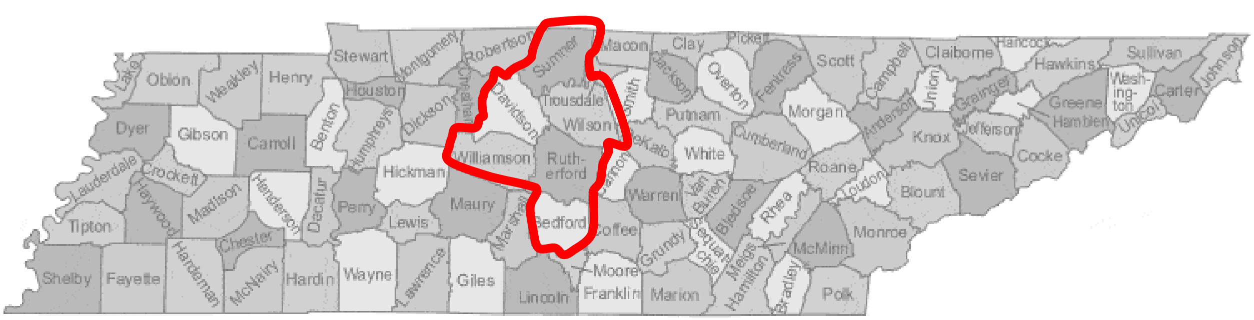

Figure 2. Streamside salamander (*Ambystoma barbouri*) distribution in the inner and outer Nashville Basin in Middle Tennessee (Anderson et al. 2014).

HABITAT

Diet

In *A.* texanum “pond form” and “stream form,” microzooplankton and chironomid larvae constitute almost 90% of their diet, but large benthic prey made up more than half of the volume (Smith and Petranka 1987). Food intake is likely limited by gape size, such that small crustacean consumption (*Lirceus*) increases 20-fold as salamanders near first metamorphosis at 23-24 mm SVL (Smith and Petranka 1987).

Cover

A. barbouri typically inhabits upland deciduous forests in areas of limestone bedrock and streams. During reproduction, eggs are attached to the bottom of rocks for cover, and in streams with natural barriers to prevent contact with predatory fish (Kraus and Petranka 1989). In areas where limestone rock is unavailable as cover for eggs, logs and leaf packs are also used (Petranka 1982). Larvae take cover under limestone rock, but during the day they are often freely swimming in the stream without cover, even in the presence of predators (Petranka 1983). There is currently no information regarding cover for non-breeding habitat in adult salamanders, or other environmental information for breeding sites (J. W. Petranka, UNC Asheville, personal communication). In *A. maculatum,* over 80% of overwintering refuges are small mammal runways, and other refuges include a rocky area with significant leaf cover (Madison 1997).

REPRODUCTION and DEVELOPMENT

Typically, breeding occurs in first and second-order limestone streams between October and April, with peak reproduction occurring in late October and early March (Petranka 1982, 1984*a*). In some cases, breeding can also occur in nearby pools (Petranka 1982). Eggs are often deposited individually underneath limestone rock, or logs and leaf packs when sufficient limestone is unavailable (Petranka 1982) Reproductive movement is correlated with rainfall, but unlike other salamanders, *A. barbouri* reproduction is not heavily dependent on rainfall (Petranka 1984*a*). Egg masses range from 1-211, with an average of 46.6±54.8 (Niemiller et al. 2009). However, egg masses can be highly variable, so other studies have suggested an average of 122-±97 (Petranka 1984*a*). Incubation typically lasts less than 80 days, and even as short as 29 (Petranka 1984*b*). Larvae develop for approximately 7-9 weeks, then metamorphosize into juveniles (Petranka 1984*b*). Reproductive maturity occurs around 60mm SVL (snout-vent length), or roughly two years of age (Figure 3) (Kraus and Petranka 1989, Harding 1997).

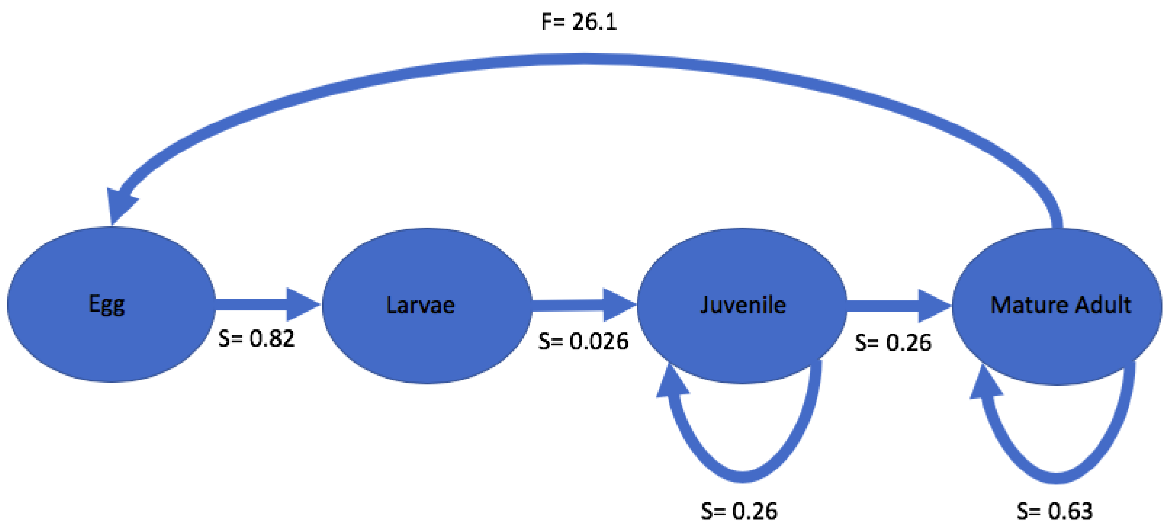

Figure 3. Life-stage diagram for the streamside salamander (*Ambystoma barbouri*). This diagram was constructed utilizing known survivability for the egg and larval stages from Petranka 1984b, whereas juvenile and adult stages were calculated based on the adult survivability of a closely related species, *Ambystoma maculatum*, by Madison 1997. Note larval survivorship of only 2.6%, and adults are the only age class contributing to the next generation.

MORTALITY

More than 3/4 of all *A. barbouri* eggs make it through to hatching, but no more than 5% of larvae make it to metamorphosis (Petranka 1984*b*). The primary cause of death during embryonic development is unknown, but speculation includes genetic defects, infections, and environmental factors (Petranka 1984*b*). Less than 5% of salamander eggs experienced confirmed depredation in streams (Petranka 1984*b*). In larvae, threats include depredation, drying, and flooding (Petranka 1984*b*). Main predatory threats could include predatory fish and invertebrates, such as green sunfish in pools (*Lepomis cyanellus*) and crayfishes (*Orconectes* and *Cambarus*) (Petranka 1984*b*, Kats and Sih 1992). Depradation by sunfish is thought to rarely occur in adult populations (Petranka 1984*b*). There is no study confirming adult mortality in *A. barbouri*, but urban or agricultural development could increase mortality in adults if it unknowingly occurs in non-breeding habitat as it is currently unknown. In *A. maculatum*, large cases of adult mortality can occur after storm events such as sudden drops in environmental temperature without sufficient cover (Madison 1997).

Little information exists regarding diseases specific to *A. barbouri*. Exposure to some agricultural chemicals can cause low growth rates, increased limb deformities, delayed hatching, respiratory distress, and potential lethargy and nervous system malfunction in salamanders (Rohr et al. 2003). Additionally, infections of iridovirus have been known to effect other species of the *Ambystoma* genus within Tennessee, and it is likely *A. barbouri* could also become affected (Green et al. 2002). This virus occurs primarily in the summer months, effecting mostly larvae and recently metamorphosized salamanders, causing mass die-off (Green et al. 2002).

CONSERVATION STATUS

A. barbouri is listed as near threatened (Hammerson 2004). In 2006, it was only found in 66.7% of historical breeding sites (Niemiller et al. 2006). Streamside salamanders are found in less than 1% of all alleged suitable habitat within the Nashville Basin (Anderson et al. 2014). Published population surveys are lacking, therefore exact population is unknown (Hammerson 2004). Without intervention, *Ambystoma barbouri* could become extirpated from middle Tennessee within 30 years (Figure 4).

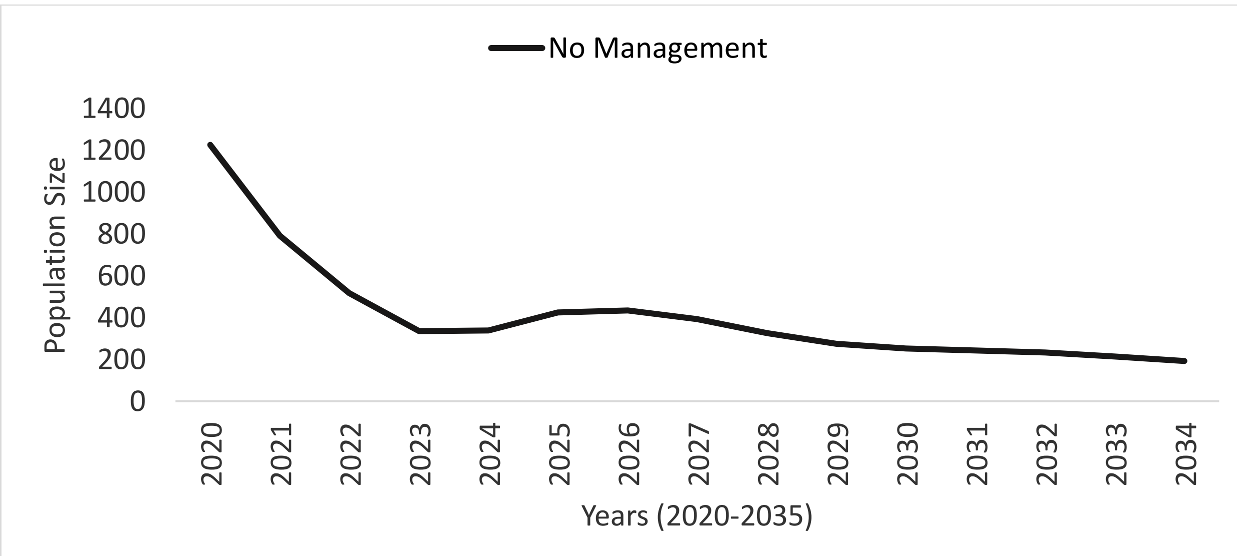

Figure 4. Population diagram for the streamside salamander (*Ambystoma barbouri*) from 2020-2035, indicating a steadily decreasing population trend. This model was created utilizing a loose population estimate, a life stage diagram (Figure 3), survivability for each life stage, and fecundity (Nicole Witzel, *unpubl. data*). Where information was lacking, *Ambystoma maculatum* was used as a surrogate species as they are closely related and share similar life histories.

CONSERVATION NEEDS

DEVELOPMENT

Populations of several counties within middle Tennessee are expected to nearly double by 2040, including localities utilized as breeding grounds for *A. barbouri* (Niemiller et al. 2006, GNRC 2017). With prospects of over a 100% increase in population, the Greater Nashville Regional Council is already discussing the need for increased infrastructure to support the growing population, including but not limited to increased modes of transit (GNRC 2017). The largest conservation concern of *A. barbouri* in middle Tennessee is development.

There is little mention of protecting natural areas with increased development within this plan, suggesting they could be at risk (GNRC 2017). With increased urbanization comes a degradation of abiotic and biotic factors within streams, including algae and invertebrates these salamanders rely on (Walsh et al. 2005). Salamanders that inhabit both woodlands and streams, such as *A. barbouri*, also require proper corridors for migrations to breed (Dodd and Smith 2003). This could be threatened with habitat fragmentation due to railroads, roads, and other developments. Fragmentation and habitat loss have been shown to isolate populations, causing bottlenecking effects and inbreeding depressions that reduce the genetic diversity and fitness of amphibian species (Andersen et al. 2004, Allentoft and O'Brien 2010). In *A. texanum*, highly fragmented populations showed a decrease in genetic differentiation and an increase in inbreeding as streams became more distal (Rhoads et al. 2017). Even when these inbred populations increase, their genetic differentiation will be low and still experience the effects of inbreeding if no new individuals are introduced to the population to diversify the gene pool.

AGRICULTURE

Almost half of all acreage within Tennessee is agricultural land (Tennessee Secretary of State 2017). Exposure to some agricultural chemicals can cause physiological complications in *A. barbouri* throughout development and adulthood (Rohr et al. 2003). These effects could negatively affect survivorship of the species, although there is no information regarding how much of these chemicals *A. barbouri* encounters in the wild (Rohr et al. 2003). Limiting pesticide usage on corn or soybean farms can result in decreased revenue for farmers, giving them little incentive to pursue other methods without regulation (Whittaker et al. 1995). Farmers and ranchers tend to react negatively on increased regulations, posing potential challenges in implementing regulations (Geltman 2018).

CLIMATE CHANGE

As climate change worsens, the United States is expected to experience more frequent droughts (Strzepek et al. 2010). Stream drying and flooding pose threats to salamander populations, causing death during the breeding season (Petranka 1984*b*). As these events become more frequent, we can expect more frequent mortality. Additionally, in streams experiencing drought salamander body condition and size decreases, potentially decreasing survivability (Currinder et al. 2014).

PROTECTIONS

In 2017 fewer than 10% of vernal pools within Tennessee were on protected lands, and less than half of all pools maintained proper tree cover (Evans et al. 2017). With rollbacks of the 2015 Clean Water Rule enacted during the Obama administration that protected more than half of waters in the United States, there is potential for even less of these waters to be protected (Alexander 2015). Additionally, current administration continues to rollback other environmental protections in addition to water quality such as withdrawing from the Paris Climate Agreement that intended to reduce greenhouse gas emissions and address climate change and reversing public land protections (Konisky and Woods 2018). All of these decisions put several species at risk, salamanders included. Luckily, the streamside salamander is listed as endangered under the Tennessee Nongame and Endangered or Threatened Wildlife Species Conservation Act of 1974 (T. C. A. § 70-8-101 to 112), so it is unlawful to harvest or kill the species. Habitat protection is allotted under this act, yet the full distribution of the species is not fully documented, and therefore proper habitat protection is questionable.

PUBLIC SUPPORT

Compared to other groups, attention paid to amphibians in both research, funding, and overall public concern is considerably less that other vertebrates (Gibbons 1988, Czech and Krausman 1999). This is due, in part, to several factors including their negligible economic impact and lack of anthropogenic utility (Gibbons 1988). Neutral to negative public attitude, typically due to feelings of disgust, toward herpetofauna yields difficulty in garnering public support for management (Tomažič 2011). Negative feelings toward amphibians were less in those who experienced them, showing that exposure is a good method, but most reported no contact (Gibbons 1988). In determining species importance, the public values ecological importance, rarity, and intelligence, serving as unfavorable for salamanders due to the lack of education and outreach (Czech and Krausman 1999). So far, there has been poor communication to the public of salamander ecological importance (Gibbons 1988).

NEEDS STATEMENT

Management for *Ambystoma barbouri* is needed to increase larval survivability to at least 10% to restore populations, and prevent extirpation (Figure 5). Significant public outreach is needed to gain support for funding population distribution surveys and establishing critical habitat for this species. Following more research study, effort must be put into establishing legislation and land protections to mitigate the negative effects associated with agriculture and the projected population and infrastructure development of middle Tennessee that will continue to affect *A. barbouri* populations.

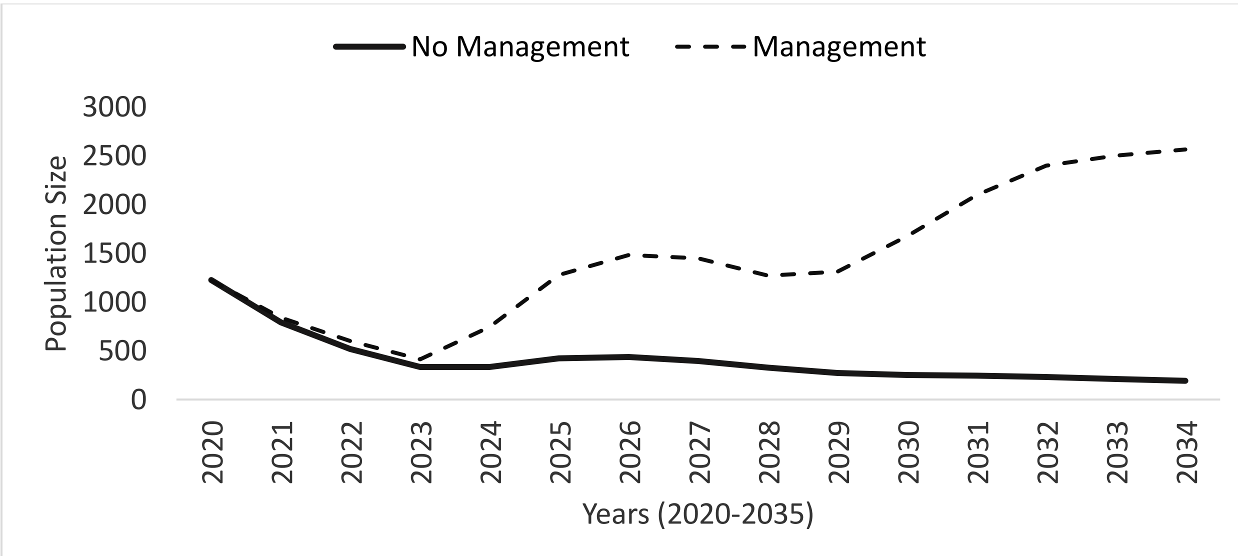

Figure 5. Population model for the streamside salamander (*Ambystoma barbouri*) indicating an increasing population trend after implementation of management plan, with an increase in larval survivorship to 10%.

GOALS AND OBJECTIVES

Goal: Recover and increase *A. barbouri* Populations in Middle Tennessee, USA.

Objective 1: Estimate the current population, age structure, mortality for each age-class, and sex ratio for A. barbouri within Middle Tennessee each year of management plan.

Objective 2: Determine the habitat requirements of A. barbouri throughout their range in Middle Tennessee.

Objective 3: Increase and maintain larval survivability of A. barbouri to 10% in Middle Tennessee in 10 years.

Objective 4: Make 30-40% of the public indicate they would reasonably take action or mitigate their own effects on A. barbouri populations, and/or understand their ecological role and benefits.

COURSE OF ACTIONS

Goal: Recover and increase *A. barbouri* populations in Middle Tennessee, USA.

Objective 1: Estimate the current population, age structure, mortality for each age-class, and sex ratio for A. barbouri within Middle Tennessee each year of management plan.

Action 1.1: Implement breeding surveys every breeding season (October-April) using an active time-constrained survey method (Barr and Babbitt 2001). Technicians should monitor populations throughout the breeding season to determine population fluctuations and monitor the development and mortality of egg and larvae. Rocks can be numbered and used as identifiers for egg masses, as they would otherwise be difficult to mark (Petranka 1984*b*). Preexisting studies have a small sample size or only account for survivability and mortality during the larval stage, and no study has determined life expectancy for this species (Petranka 1984*b*). Additionally, cause of death should be determined during survivability studies as the majority of larval deaths are from unknown causes (Petranka 1984*b*).

Action 1.2: Implement annual breeding surveys (October-April) as outlined above, but instead utilizing electrofishing in place of the active time-constrained method. This method yields more accurate population numbers due to a high detection probability of over 75% (95% CI range= 0.55-0.94) for two stream-dwelling, cryptic salamander species (Cossel et al. 2012). But, concerns regarding damage to eggs may be too great of a risk for an already declining species (Nickerson et al. 2003).

Action 1.3: A short-term captive breeding operation can be created to gain insight on egg and larval mortality without environmental variability, as well as sex ratio and recruitment. For as little disruption to the already decreasing population, only five total salamanders (male and female) can be harvested from breeding sites, and placed in aquariums made to resemble the habitat they were taken from. Limestone rock, loose logs and leaf litter can be placed in aquariums for natural egg deposition sites and sufficient cover (Petranka 1984*a*, Kraus and Petranka 1989). Aquariums should be clear for appropriate observation of egg-laying and development (Petranka 1984*a*). Adult salamanders should be returned to original sites after mating and laying eggs, as they do not invest time into raising young.

No Action: The only data currently available is breeding site use and not actual population numbers (Niemiller et al. 2006, Anderson et al. 2014). Population models are currently inaccurate as studies being used are from surrogate species, conflicting data, or low sample sizes (Petranka 1984*a*, *b*, Harding 1997, Madison 1997, Niemiller et al. 2009). To make more accurate management decisions, actual population numbers and trends would be beneficial.

Final Course of Action: Action 1.1 will be initiated immediately. There are currently no population estimates for *A. barbouri* in middle Tennessee, and population estimates are needed to influence appropriate management decisions (Hammerson 2004). Action 1.2 will not be used due to the potential for increased larval mortality, and 1.3 will not be used as it requires removing salamanders from an already small population size and requires more man-hours and experimental resources.

Assessment: Objective will be met when complete annual reports, beginning after the first season of management plan implementation, estimates population size, age structure, mortality, and sex ratio for breeding locations within Middle Tennessee following a typical standard error curve. Annual reports establish population trends over the course of the management plan, and more accurate population models. Objective will not be met when standard error is high (most data over 2 standard errors of the mean). Possible causes of high standard errors include the cryptic and fossorial nature of the species that may make detection challenging, and thus, highly variable population counts. Even still, if the surveys are consistently inaccurate assuming a constant detectability, relative abundance can be utilized to determine overall population trends.

Objective 2: Determine the habitat requirements of A. barbouri throughout their range in Middle Tennessee.

Action 2.1: Construct a habitat suitability index (HSI) for breeding streams, migration corridors, and fossorial non-breeding sites. Conduct a two year scientific study to determine critical habitat of *A. barbouri* throughout their range in Middle Tennessee. For all sites, these studies should determine key habitat features such as tree, rock, and log cover, leaf litter, stream characteristics, water quality, and turbulence from both confirmed breeding sites and other randomly-selected bodies of water within the Nashville Basin that do not contain *A. barbouri* populations (Petranka 1982, Kraus and Petranka 1989). BD-2 radio transmitters should be modified and fitted to salamanders to track migration corridors and fossorial overwintering habitat as these are currently unknown (J. W. Petranka, UNC Asheville, personal communication, Devries and Bartelt

2018). Mapping critical habitat is crucial for preventing the expected development within their habitat (GNRC 2017).

Action 2.2: Construct a habitat suitability index for breeding streams, migration corridors, and fossorial non-breeding sites following guidelines stated in Action 2.1, but utilize harmonic direction finding to track adult salamanders instead of transmitters (Rowley and Alford 2007). Considering the fossorial nature of this species, the risk of death due to impaired movements is more prominent in this method and therefore may not be preferential (Rowley and Alford 2007).

No Action: The surrogate species used had significant life history overlap, however, some less-understood differences could misguide management decisions (Kraus and Petranka 1989). Without information regarding

Final Course of Action: Planning for action 2.1 should begin immediately, and the study should begin next breeding season. Action 2.2 will not be used due to increased risk of mortality (Rowley and Alford 2007).

Assessment: Action 2.1 will be considered successful when a scientific paper is published in 5-7 years. Validity of the habitat suitability index can be determined by comparing population abundance (Action 1.1) with respective habitat suitability scores to determine a significant positive correlation ($P<1.0$) (Tirpak et al. 2009). Shortfalls of this method include potentially inaccurate HSI estimates because population estimates may be too variable due to the cryptic nature of this species, or the duration of the study may be too short, thus making HSI validity inaccurate (Roloff and Kernohan 1999). Should this be the case, studies should continue until sufficient data is taken to produce statistically significant results.

Objective 3: Increase and maintain larval survivability of A. barbouri to 10% in Middle Tennessee in 10 years.

Action 3.1: Establish *A. barbouri* as a federally endangered species within ten years on the basis of declining population trends and limited range. Since the enactment of the Endangered Species Act in 1973, over 200 species have thought to have been saved from extinction as a result of the act (Scott et al. 2007).

Action 3.2: Map critical habitat for protection under the Tennessee Nongame and Endangered or Threatened Wildlife Species Conservation Act of 1974 (T. C. A. § 70-8-101 to 112) of streams currently used or historically used for breeding, migration corridors, and forested fossorial habitat to reduce direct human interference on habitat and cover (results from action 2.1). Currently, only 10% of vernal pools are protected in Tennessee (Evans et al. 2017). There is no protections for non-breeding forested habitat or migration corridors at this time, as it is unknown (Hammerson 2004). Fragmentation of habitat can lead to high instances of inbreeding (Allentoft and O'Brien 2010). A do-not-disturb period can be implemented especially during the breeding season to reduce human-driven incidental deaths.

Action 3.3: Ensure sufficient cover for salamander larvae from predatory fish, and consider the use of predator exclosures to reduce depredation from upstream fish. Streamside salamanders prefer breeding sites with natural barriers that protect them from upstream predatory fish, or avoid streams all together with predatory fish and can also sense the presence of a predator in the water to take necessary cover (Kraus and Petranka 1989, Kats and Sih 1992). If necessary cover is not available, or natural barriers do not already exist, these should be reconstructed in streams.

Action 3.4: Map point and non-point pollution sources within entire watershed, largely contributing to nutrient, pesticide, and chemical runoff and implement an incentive-based >25m buffer zone along agricultural parcels. Common pesticide chemicals cause detrimental effects to salamanders, especially during vulnerable life stages (Rohr et al. 2003). 25m buffer zones can eliminate up to 80% of nitrates in streams and waterways if implemented by farmers (Dickson and Schaeffer 1997). Monetary incentives, be it tax breaks or stipends, will increase participation. Buffers for individual streams have proven to be relatively ineffective as compared to evaluating use for entire watersheds (Willson and Dorcas 2003). Yet, they may be the most cost-effective and easily-implemented option which is why they have been chosen method of action.

Action 3.5: Develop an urban land-use management plan for Middle Tennessee (especially the Nashville area) for all future construction that encourages less than 10% impermeable surfaces. Trends show that as urban imperviousness approaches 10%, water quality in nearby streams begins to degrade. After 30%, degradation is inevitable (Liu et al. 2013).

No Action: According to the projected population model created using known survivorship for all life stages (Figure 3), *A. barbouri* populations in middle Tennessee will be almost completely extirpated in 30 years if no action is taken (Figure 4). Sensitivity matrixes indicate larval life stages are most sensitive to change (Appendix A).

Final Course of Action: Process should immediately be started for 3.1 and 3.2. Restoration planning and evaluation for 3.3 and 3.4 should also begin immediately. Greater Nashville Regional Council should be contacted immediately to begin motion on 3.5.

Assessment: These actions will be considered successful when annual breeding survey results and population models yield at least a 10% survivorship for the larval stage, and indicate an overall increasing population trend (Figure 5). Action 3.1 will be considered successful when *A. barbouri* is federally listed as a threatened/endangered species in 10 years. This may take longer than 10 years as extra surveys and survivorship information may be needed to make a strong case for listing, which should be evaluated. Action 3.2 will be considered successful when critical habitat is mapped and protected under Tennessee Nongame and Endangered or Threatened Wildlife Species Conservation Act of 1974 within 5 years. This, again, may take extra time contingent upon studies from earlier actions. Even while protections are not yet established, educational signs at breeding locations from earlier objectives could foster voluntary adherence to respecting *A. barbouri* habitat.

Objective 4: Make 30-40% of the public indicate they would reasonably take action or mitigate their own effects on A. barbouri populations, and/or understand their ecological role and benefits.

Action 4.1: Perform outreach annually targeted at hikers during and prior to breeding season of *A. barbouri*. This outreach can include signs posted at breeding and non-breeding sites, and brochures detailing the ecological importance of *A. barbouri* and bring awareness to their species status with a call to action (Appendix I).

Action 4.2: For farmers, ranchers, and land developers, specific informational texts should be prepared to indicate the negative effects of pesticide use, runoff, and land development on populations, and encourage limiting the aforementioned effects utilizing available incentives. In the case of farmers and ranchers, a voluntary approach to conservation is more effective than regulation, as otherwise they may choose to opt out of programs and increase sales on their land to mitigate losses due to regulation (Knapp et al. 2015).

Action 4.3: Environmental educators should lead guided, interactive walks during breeding season to educate the public and agriculturists alike about the species and conservation challenges. Specialized walks can be scheduled with agriculturists who's practices may have a direct impact on populations and habitat. This style of outreach has shown to more effectively communicate the benefits of conservation to the public and increase trust between the public and biologists than written forms of communication (Lutter et al. 2018).

No Action: If no action is taken to educate the public on *A. barbouri* management needs, it is likely it will not be supported. Public outreach can increase conservation support by almost 60% (van der Ploeg et al. 2011) Additionally, public outreach leads to increased environmental stewardship and action (Stern et al. 2008). These effects will be lacking if outreach is not conducted.

Final Course of Action: Educational materials (4.1-4.3) should be prepared immediately, and begin in the following breeding season.

Assessment: Administer self-reporting surveys to the public before and after each breeding season to determine outreach progress for *A. barbouri* conservation and management practices. Responses will be on a voluntary basis, posted on social media and official Tennessee TDEC websites, mailed, and administered after interactive walks. Web surveys bias the demographic of survey respondents to the young, college degree recipients, and those with a higher income, which is why both mail and internet administration is recommended to remove that bias

(Campbell et al. 2018). Action 4.1 will be considered successful when signs are constructed and placed in breeding and non-breeding sites, 4.2 will be successful when more than half of all farmers received educational materials, and 4.3 will be successful when a minimum of 5 educational walks are conducted at one or several breeding locations for the public. Also, all actions will be considered successful when survey results reflect that 30-40% of stakeholders support the conservation and management of *A. barbouri* by indicating they would reasonably take action or mitigate their own effects on their populations, and/or understand their ecological role and benefits. All actions would be considered mostly successful when public knowledge of the species increases following outreach.

CONCLUSION

Streamside salamanders provide important ecological services, and are in need of immediate intervention in middle Tennessee as limited distributions increase the risk of complete extinction within 30 years. Populations are declining due to increased anthropogenic alteration including development, agriculture, and climate change. Population estimates and additional research are needed to develop more accurate population models, and lack thereof thus creates some limitations within this plan. But, educating the public, limiting stream destruction and degradation by managing for entire watersheds, and constructing predator exclosures during the breeding season will help meet current management goals. By implementing the final courses of action outlined in this management plan and targeting larval survivorship, *A. barbouri* populations can increase to more sustainable levels and persist for generations.

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LITERATURE CITED

Alexander, L. C. 2015. Science at the boundaries: Scientific support for the Clean Water Rule. Freshwater Science 34:1588–1594.

Allentoft, M. E., and J. O'Brien. 2010. Global amphibian declines, loss of genetic diversity and fitness: A review. Diversity 2:47–71.

Anderson, M. A., J. R. Campbell, A. N. Carey, D. R. Dodge, R. A. Johnston, E. R. Mattison, R. J. Seddon, N. L. Singer, and B. T. Miller. 2014. Population survey of the streamside salamander in the Nashville Basin of Tennessee. Southeastern Naturalist 13:101–107.

Barr, G. E., and K. J. Babbitt. 2001. A comparison of 2 techniques to sample larval stream salamanders. Wildlife Society Bulletin 29:1238–1242.

Campbell, R. M., T. J. Venn, and N. M. Anderson. 2018. Cost and performance tradeoffs between mail and internet survey modes in a nonmarket valuation study. Journal of Environmental Management 210:316–327. Elsevier Ltd. <https://doi.org/10.1016/j.jenvman.2018.01.034>.

Cossel, J. O., M. G. Gaige, and J. D. Sauder. 2012. Electroshocking as a survey technique for stream-dwelling amphibians. Wildlife Society Bulletin 36:358–364.

Currinder, B., K. K. Cecala, R. M. Northington, and M. E. Dorcas. 2014. Response of stream salamanders to experimental drought in the southern Appalachian Mountains, USA. Journal of Freshwater Ecology 29:579–587. Taylor & Francis. <http://dx.doi.org/10.1080/02705060.2014.938135>.

Czech, B., and P. R. Krausman. 1999. Public opinion on endangered species conservation. Ecosystem Health. *Endangered Species Update* 5.6 (1997): 7-10.

Davic, R. D., and H. H. Welsh. 2004. On the ecological roles of salamanders. Annual Review of Ecology, Evolution, and Systematics 35:405–434.

Devries, A. T., and P. E. Bartelt. 2018. Promising surgical implantation method for radio-tracking Eastern Tiger Salamanders (*Ambystoma tigrinum tigrinum*). Herpetological Review 49:466–469.

Dickson, B. C., and D. J. Schaeffer. 1997. Ecorestoration of riparian forests for non-point source pollution control: Policy and ecological considerations in agroecosystem watersheds. Buffer zones: Their Processes and Potential in Water Protection. Quest Environmental, Hertfordshire.

Dodd, C. K., and L. L. Smith. 2003. Habitat destruction and alteration: Historical trends and future prospects for amphibians. Amphibian conservation. Smithsonian Institution, Washington DC, USA.

Evans, J. P., K. K. Cecala, B. R. Scheffers, C. A. Oldfield, N. A. Hollingshead, D. G. Haskell, and B. A. McKenzie. 2017. Widespread degradation of a vernal pool network in the southeastern United States: Challenges to Current and Future Management. Wetlands 37:1093–1103. Wetlands.

Geltman, E. G. 2018. North Dakota law review The new Anti-Federalism : Late term Obama environmental regulations and the rise of Trump. North Dakota Law Review 93:243–261.

Gibbons, J. W. 1988. The management of amphibians, reptiles and small mammals in North America: the need for an environmental attitude adjustment. General Technical Report - US Department of Agriculture, Forest Service 4–10.

Green, D. E., K. A. Converse, and A. K. Schrader. 2002. Epizootiology of sixty-four amphibian morbidity and mortality events in the USA, 1996-2001. Annals of the New York Academy of Sciences 969:323–339.

GNRC [Greater Nashville Regional Council]. 2017. Comprehensive Economic Development Strategy for the Greater Nashville Region. <https://www.gnrc.org/DocumentCenter/View/656/Comprehensive-Economic-Development-Strategy-FY18-22>. Accessed 10 Feb 2020.

Hammerson, G. 2004. *Ambystoma barbouri*. The IUCN Red List of Threatened Species.

<https://www.iucnredlist.org/species/59053/11875949>. Accessed 24 Jan 2020.

Harding, J. H. 1997. Amphibians and reptiles of the Great Lakes Region. University of Michigan Press.

Kats, L. B., and A. Sih. 1992. Oviposition site selection and avoidance of fish by streamside salamanders (*Ambystoma barbouri*). Copeia 468–473.

Knapp, C. N., F. Stuart Chapin, and J. O. Cochran. 2015. Ranch owner perceptions and planned actions in response to a proposed endangered species act listing. Rangeland Ecology and Management 68:453–460.

Konisky, D. M., and N. D. Woods. 2018. Environmental federalism and the Trump presidency: A preliminary assessment. Publius 48:345–371.

Kraus, F., and J. W. Petranka. 1989. A new sibling species of *Ambystoma* from the Ohio River Drainage. Copeia 94–110.

Liu, Z., Y. Wang, Z. Li, and J. Peng. 2013. Impervious surface impact on water quality in the process of rapid urbanization in Shenzhen, China. Environmental Earth Sciences 68:2365–2373.

Lutter, S. H., A. A. Dayer, E. Heggenstaller, and J. L. Larkin. 2018. Effects of biological monitoring and results outreach on private landowner conservation management. PLoS ONE 13.

Madison, D. M. 1997. Society for the Study of Amphibians and Reptiles The emigration of radio-implanted spotted salamanders, *Ambystoma maculatum*. Journal of Herpetology 31:542–551.

Nickerson, M. A., K. L. Krysko, and R. D. Owen. 2003. Habitat differences affecting age class distributions of the hellbender salamander, *Cryptobranchus alleganiensis*. Southeastern

Naturalist 2:619–629.

Niemiller, M. L., B. M. Glorioso, C. Nicholas, J. Phillips, J. Rader, E. Reed, K. L. Sykes, J. Todd, G. R. Wyckoff, E. L. Young, and B. T. Miller. 2006. Status and distribution of the streamside salamander, *Ambystoma barbouri*, in Middle Tennessee. The American Midland Naturalist 156:394–399.

Niemiller, M. L., B. M. Glorioso, C. Nicholas, J. Phillips, J. Rader, E. Reed, K. L. Sykes, J. Todd, G. R. Wyckoff, E. L. Young, and B. T. Miller. 2009. Notes on the reproduction of the streamside salamander, *Ambystoma barbouri*, from Rutherford County, Tennessee. Southeastern Naturalist 8:37–44.

Petranka, J. W. 1982. Geographic variation in the mode of reproduction and larval characteristics of the small- mouthed salamander (*Ambystoma texanum*) in the East-Central United States. Herpetologica 38:475–485.

Petranka, J. W. 1983. Fish Predation: A factor affecting the spatial distribution of a stream-breeding salamander. Copeia 624–628. Copeia.

Petranka, J. W. 1984*a*. Breeding migrations, breeding season, clutch size, and oviposition of stream-breeding *Ambystoma texanum*. Journal of Herpetology 18:106–112.

Petranka, J. W. 1984*b*. Incubation, larval growth, and embryonic and larval survivorship of smallmouth salamanders (*Ambystoma texanum*) in streams. Copeia 862–868. American Society of Ichthyologists and Herpetologists.

Petranka, J. W. 1998. Salamanders of the United States and Canada. Smithsonian Institution, Washington DC, USA.

van der Ploeg, J., M. Cauilan-Cureg, M. van Weerd, and W. T. De Groot. 2011. Assessing the effectiveness of environmental education: Mobilizing public support for Philippine crocodile conservation. Conservation Letters 4:313–323.

Rhoads, E. A., P. K. Williams, and C. M. Krane. 2017. High inbreeding and low connectivity among *Ambystoma texanum* populations in fragmented Ohio forests. Ecology and Evolution 7:11135–11147.

Rohr, J. R., A. A. Elskus, B. S. Shepherd, P. H. Crowley, T. M. McCarthy, J. H. Niedzwiecki, T. Sager, A. Sih, and B. D. Palmer. 2003. Lethal and sublethal effects of atrazine, carbaryl, endosulfan, and octylphenol on the streamside salamander (*Ambystoma barbouri*). Environmental Toxicology and Chemistry 22:2385–2392.

Roloff, G. J., and B. J. Kernohan. 1999. Evaluating reliability of habitat suitability index models. Wildlife Society Bulletin 27:973–985. <http://www.jstor.org/stable/3783655>.

Rowley, J. J. L., and R. A. Alford. 2007. Techniques for tracking amphibians: The effects of tag attachment, and harmonic direction finding versus radio telemetry. Amphibia Reptilia 28:367–376.

Scott, M. J., D. D. Goble, L. K. Svancara, and A. Pidgorna. 2007. By the Numbers. The Endangered Species Act at thirty, volume 1: Renewing the Conservation Promise. Volume 1. Island Press, Washington.

Smith, C. K., and J. W. Petranka. 1987. International Association for Ecology prey size-distributions and size-specific foraging success of *Ambystoma* larvae. Oecologia 71:239–244.

Stern, M. J., R. B. Powell, and N. M. Ardoin. 2008. What difference does it make? Assessing outcomes from participation in a residential environmental education program. Journal of Environmental Education 39:31–43.

Strzepek, K., G. Yohe, J. Neumann, and B. Boehlert. 2010. Characterizing changes in drought risk for the United States from climate change. Environmental Research Letters 5:1–9.

Tennessee Secretary of State. 2017. Tennessee Blue Book. Volume 2.

Tirpak, J. M., D. T. Jones-Farrand, F. R. Thompson, D. J. Twedt, C. K. Baxter, J. A. Fitzgerald, and W. B. Uihlein. 2009. Assessing ecoregional-scale habitat suitability index models for priority landbirds. Journal of Wildlife Management 73:1307–1315.

Tomažič, I. 2011. Seventh graders' direct experience with, and feelings toward, amphibians and some other nonhuman animals. Society and Animals 19:225–247.

Walsh, C. J., A. H. Roy, J. W. Feminella, P. D. Cottingham, P. M. Groffman, and R. P. Morgan. 2005. The urban stream syndrome: Current knowledge and the search for a cure. Journal of the North American Benthological Society 24:706–723.

Whittaker, G., B.-H. Lin, and U. Vasavada. 1995. Restricting pesticide use: The impact on profitability by farm size. Journal of Agricultural and Applied Economics 27:352–262.

Willson, J. D., and M. E. Dorcas. 2003. Effects of habitat disturbance on stream salamanders: Implications for buffer zones and watershed management. Conservation Biology 17:763–771.

APPENDIX A

SENSITIVITY MATRIX

	F(E)	F(L)	F(NA)	F(J)	F(MA)
Egg	**0.0226**	**0.1178**	**0.0033**	**0.0051**	**0.0046**
Larvae	**0.1472**	**0.1317**	**0.0037**	**0.0057**	**0.0052**
N/A	**5.1883**	**4.6417**	**0.1317**	**0.2006**	**0.1820**
Juvenile	**4.7553**	**4.2544**	**0.1207**	**0.1838**	**0.1668**
Mature Adults	**12.0081**	**10.7431**	**0.3048**	**0.4642**	**0.4212**

APPENDIX B


HELP PROTECT THE STREAMSIDE SALAMANDER
(*Ambystoma barbouri*)
Streamside salamanders are very important to our ecosystem as they serve to connect terrestrial and aquatic ecosystems, create healthier soils, and indicate the health of our environment[1]. Sadly, their populations are decreasing[2]. From late October through April, we want YOU to do your part in helping us conserve this species!
Please avoid disturbing this stream from October-April as it is crucial breeding habitat.
Please do not remove rocks, logs, or leaves from the stream. Maintain a 10m buffer when hiking near this stream. Do not disturb any vegetation alongside this stream. As always, do not litter in or near this stream.
The streamside salamander migrates to streams such as this to begin breeding in late October, and will sometimes breed until early April[3]. When they mate, females deposit jelly-like sacs underneath limestone rocks or logs that contain eggs of the next generation[3].
The salamanders will continue to grow within the egg, risking depredation from larger fish until they are ready to hatch in 4-12 weeks[4].
When the salamanders hatch, they are called "larvae." In this stage, they will continue to develop until they are ready for life on land in 7-9 weeks![4] Unfortunately, over 90% of these salamanders die during this stage, which is why we need YOUR help![4]
[1]Davic, R. D., and H. H. Welsh. 2004. On the ecological roles of salamanders. Annual Review of Ecology, Evolution, and Systematics 35:405–434.
[2]Hammerson, G. 2004. Ambystoma barbouri. The IUCN red list of threatened species. <https://www.iucnredlist.org/species/59053/11875949>. Accessed 24 Jan 2020.
[3]Petranka, J. W. 1984*a*. Breeding migrations, breeding season, clutch Size, and oviposition of stream-breeding *Ambystoma texanum*. Journal of Herpetology 18:106–112
[4]Petranka, J. W. 1984*b*. Incubation, larval growth, and embryonic and larval survivorship of smallmouth salamanders (*Ambystoma texanum*) in Streams. Copeia 862–868. American Society of Ichthyologists and Herpetologists.
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