1-1-2005

Size and reproductive activity of a geographically-isolated population of Ambystoma jeffersonianum in east-central Illinois

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Size and reproductive activity of a geographically-isolated population of

Ambystoma jeffersonianum in east-central Illinois

by

Sarabeth Klueh

THESIS

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE in BIOLOGICAL SCIENCES

In the Graduate School, Eastern Illinois University

Charleston, Illinois

2005

I hereby recommend that this thesis be accepted as fulfilling this part of the graduate degree cited above

Date	Thesis Director
Date	Department/School Head

Abstract

When utilizing small isolated wetlands, amphibian populations are often small in size, susceptible to stochastic extinction processes, and have little to no contact with other populations. The persistence of such populations can be ascertained only by obtaining data that allow the prediction of the population's growth, trajectory, and propensity to achieve a sustainable size. The success of a salamander population can be determined by the number of metamorphosing larvae leaving a pond, and thus, the number recruited into the terrestrial adult population. The Jefferson salamander, *Ambystoma jeffersonianum*, is a state-threatened species, occurring at fewer than 15 ponds within Illinois. In 2004 and 2005 individuals at a breeding pond in Lincoln Trail State Recreation Area (LTSRA) were captured using a drift fence-pitfall trap array. Once captured, the salamanders were sexed, measured for snout-vent length, and marked using a unique combination of toe clips. I also determined the number of egg masses, average percentage of successfully hatched eggs, and number of juveniles leaving the pond. I incorporated this information into a matrix for a stage-based population model. Model simulations predicted that on average, the population at LTSRA would persist for 4 more years, with survivorship from larvae to juvenile being the most important parameter. Increasing larval to juvenile survivorship increased abundance as well as average persistence time. I suggest that the breeding pond be excavated in order to increase hydroperiod within the pond, and thus increase time needed for successful metamorphosis.

Acknowledgments

I would like to thank my advisor Prof. Stephen J. Mullin, for being so available to answer all of my questions and for his guidance and support as well. I would also like to thank my committee members Prof's. Robert Fischer and Kipp Kruse for providing comments on previous drafts of this thesis. Thanks to members of the herp lab for their assistance in the field; Leroy Walston, Drew Foster, Justin Florey, Melissa Sikich, and Lee Gross.

I would like to thank Robert Szafoni of the Illinois Department of Natural Resources (IDNR) for facilitating this project, and to the IDNR Wildlife Preservation Fund and the Eastern Illinois University (EIU) Council on Faculty Research for providing support. I was also funded with support from the Graduate School at EIU. Thanks also to the staff members at Lincoln Trail State Recreation Area for allowing me access to the field site.

The specimens examined in this study were obtained under the authority of the IDNR Scientific Collecting Permit #NH04.094 and Illinois Endangered Species Permit #03.165. They were handled following guidelines approved by the EIU Institutional Animal Care and Use Committee.

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Introduction

Amphibians are thought to be indicator species of general environmental health of an area (Collins and Storfer 2003, Storfer 2003). Thus, documented worldwide declines in amphibians (Blaustein et al. 1994, Heyer et al. 1994, Blaustein and Kiesecker 2002) have warranted special attention due to three distinct trends: (a) the recent (since the 1980's) increase in reports of declining populations and species extinctions; (b) these declines seem to be occurring simultaneously and over great distances; and, (c) the amphibian populations in protected, natural areas are declining (Collins and Storfer 2003). The leading hypotheses proposed to explain amphibian declines include: introduction of alien species, over-exploitation, habitat fragmentation and degradation (which could result in habitat loss), global climate change, increased use of pesticides and other toxic chemicals, and emerging infectious diseases (e.g., chytridiomycosis; Collins and Storfer 2003, Storfer 2003). Furthermore, these causes can act synergistically, allowing what might have been a subtle effect caused by a single factor to be intensified to harmful levels by other factors (Semlitsch 2000, Boone and Semlitsch 2002, Bridges and Boone 2003).

Of the causes of decline, habitat fragmentation and/or degradation can potentially have the largest impact on amphibian species. Habitat fragmentation occurs when a landscape is separated into smaller more isolated fragments (Harris and Silva-Lopez 1992, Kruess and Tscharntke 1994, Caughley and Gunn 1996) and can result from habitat destruction (filling and drainage of wetlands, channelization of streams, and creation of impoundments). Fragmentation has detrimental effects on many species and is a topic of great concern for conservation biologists (deMaynadier and Hunter 1999). Even relatively small areas of altered land, such as roads, can have profound effects on the species within an area (Reh and Seitz 1990, Fahrig et al. 1995). Increased habitat isolation typically changes community structure and function, including possible loss of species, disruption of the food web (Kruess and Tscharntke 1994) and population isolation (Laan and Verboom 1990).

Studies involving isolated populations of salamanders are few in number. As has been shown in other tetrapod species, however, isolated salamander populations may exhibit a depressed population size (Portnoy 1990), a decline in individual health (Ash et al. 2003), and/or decreased fitness (Fahrig and Merriam 1985). Isolated populations, having reduced size and no contact with other populations can become increasingly susceptible to environmental and demographic stochasticity, and natural catastrophes (Lacy 1992). Small populations are at risk of dying out due to chance alone, even if members are healthy and the environment is favorable. Stochasticity can also cause small populations of many species to suffer erratic swings in size from year to year (Caughley and Gunn 1996). Demographic stochasticity could result in lost reproductive opportunities if mates are few and far between. Furthermore, when only a few individuals reach reproductive maturity each year, there is a chance that all might be the same gender (Lacy 1992).

Small populations are also threatened by the loss of genetic variation. As numbers decline, the probability of inbreeding depression increases leading to higher levels of homozygosity, which can decrease fitness by exposing deleterious recessive alleles (Caughley and Gunn 1996). Inbreeding and the associated increase in homozygosity can also exacerbate demographic problems inherent to the species (Lacy

1992). In addition to these factors, geographic isolates often occupy marginal habitat. The poor quality of this habitat might compromise individual reproductive success and therefore, longevity of the population inhabiting the area (Lesica and Allendorf 1995).

To both identify whether certain mechanisms of decline are actually capable of causing declines in a population and ensure that conservation efforts are focused on the most likely cause of decline, a quantitative link needs to be made between observed reductions in certain life history stages and overall population effects (Akcakaya et al. 1999, Biek et al. 2002). Quantitative models of amphibian population dynamics can provide useful examinations of management and monitoring programs by placing perturbations measured for different life history stages in the context of the population's overall population growth rate (Biek et al. 2002). Population modeling can be used as an effective conservation tool because it allows for the evaluation of management options for each life history stage and can predict the chances of decline or recovery of the population. If, for example, competition affects juveniles but juvenile survival is not a factor in the growth or decline of the population, then controlling species that compete with juveniles is unlikely to be of much use in changing population size (Akcakaya et al. 1999).

To effectively model the probability of a given population's persistence requires sufficient data to predict the trajectory of population growth and its capacity to increase from low numbers (Blaustein et al. 1994). The success of a salamander population can be determined by the number of metamorphosing larvae leaving a pond, and thus, the number recruited into the terrestrial adult population. Effective methods for assessing an amphibian population include a combination of aquatic sampling for eggs and aquatic larvae, and terrestrial sampling with a drift fence and pitfall traps for metamorphs and adults (Semlitsch 2002).

In order to assess the population status of the Jefferson salamander (*Ambystoma jeffersonianum*), a state-threatened species, I conducted a study at Lincoln Trail State Recreation Area (LTSRA). The purpose of my research was to estimate the size and structure of the *A. jeffersonianum* population and, using a stage-based population model, identify any needed conservation efforts. The demographic parameters that I measured in this study included sex ratio, body size, clutch size, fecundity, and percent hatching success.

Species Description and Life History

Ambystoma jeffersonianum is a medium-sized gray to brown colored salamander with bluish lichen-like markings on the sides of the body and tail. Its head is distinctly wider than its body and has a wide and rounded snout. The trunk is slender and rounded with 12-14 costal grooves. It has a laterally-compressed tail with a bluntly-pointed tip. The tail length is 49-52% of the total length in males and 44-51% in females. The snout-vent length (SVL) typically ranges from 7.3–8.9 cm for an adult male is and from 7.7-10.1 cm for an adult female is (Minton 2001).

The Jefferson salamander is found in southern New York, southern Vermont, western Massachusetts, Connecticut, northwestern New Jersey, portions of Virginia and West Virginia, Ohio, central Kentucky, and west central Indiana (Thompson et al. 1980). Isolated populations are found in two counties in east-central Illinois (Petranka 1998, IDNR 2003) and breed at fewer than 15 ponds, most of which are small and unprotected (occurring on privately owned property; IDNR 2003). The restricted nature of this species' distribution in Illinois has led to its being designated as state-threatened. The threatened status denotes any breeding species that is likely to become a state endangered species within the foreseeable future (Phillips et al. 2001).

The Jefferson salamander is associated with hardwood forests and requires woodland ponds for breeding (Minton 2001). These ponds are usually seasonal, making them unsuitable for fish predators that would otherwise compromise survival in salamander populations by preying upon egg and/or larvae (Petranka and Sih 1986). Being ephemeral, the ponds usually contain a greater amount of living emergent plants as well as dead plant debris, providing a refuge for breeding adults and developing larvae from invertebrate predators (larval dragonflies, larval and adult diving beetles, larval and adult backswimmers, and caddisfly larvae; Rowe et al. 1994) and other amphibians (*Rana catesbeiana* and *R. clamitans* [Thompson et al. 1980]). Refuges are an important aspect of breeding ponds because the reproductive method of laying eggs in an aquatic environment reflects high larval and/or juvenile mortality and low adult recruitment due to predation on eggs and/or larvae (Thompson et al. 1980).

In west central Indiana, the Jefferson salamander is known as a winter breeder, laying its eggs in February. It will lay eggs as early as mid-January if weather conditions are mild (air temp ≈ 12.2 °C, water temp ≈ 8.8 °C) and egg laying may be delayed into the first few weeks of March during seasons of exceptionally dry or cold weather (Minton 2001). The first early warm spring rains or other conditions of high humidity as well as temperatures above freezing, are thought to trigger breeding activity (Thompson et al. 1980, Petranka 1998). Breeding migrations occur over a period of several weeks (Downs 1989), and mating and egg laying may take place over a few nights to a week (Thompson et al. 1980). Male *A. jeffersonianum* arrive at the breeding ponds earlier than females (Douglas 1979), and due to a longer period of sexual activity, may stay at the breeding pond up to twice as long (Shoop 1960, Williams 1973, as cited in Downs 1989). Male to female ratios at a breeding pond are uncertain due to varying accounts. According to Bishop (1969), females often outnumber males, and will compete for the males' attention during the breeding season. Conversely, Petranka (1998) states that males may outnumber females at a ratio of 3:1 or greater. They have internal fertilization, using spermatophores for gamete transfer (Bishop 1969). Downs (1989) suggested that males breed annually, but females often skip one or more years before breeding again.

The egg mass of *A. jeffersonianum* is globular to sausage-shaped (20-40 mm in diameter) when oviposited in close proximity to other masses on firm structures such as submerged tree branches (Petranka 1998, Minton 2001). If they are scattered about the pond on submerged sticks or plants, the eggs will be in individual masses (Petranka 1998). Egg masses are positioned at least 2.5 cm below the surface of the water (Petranka 1998, Minton 2001) common around the pond perimeter in sunny locations (Thompson et al. 1980) with algae often present on the egg mass (Petranka 1998, Minton 2001). The number of eggs per mass varies from 7 to 40, with an average of 16 eggs per mass. Individual eggs are 2-2.5 mm in diameter.

Depending on the date that the eggs are laid, the incubation period may last anywhere from 30 to 45 days (Bishop 1969) with hatching typically occurs in early to mid-March. Larvae average around 12 mm at hatching and feed primarily on zooplankton and larval insects (Semlitsch 1998). The larval stage of the salamander lasts 2-4 months, with metamorphosis occurring at approximately 6.0 cm total length

(Brandon 1964, Petranka 1998, Minton 2001). After metamorphosis, juveniles emigrate into the terrestrial habitat (Semlitsch et al. 1996) and reach sexual maturity in the following year at a total length of approximately 10.7 cm (Bishop 1969).

After mating and ovipositing, adult *A. jeffersonianum* migrate away from the breeding ponds into the surrounding forest. Many utilize small mammal tunnels as retreats, with horizontal tunnels being the most commonly used (Faccio 2003). Individuals of this species have been observed to return to the same area of forest after mating (Douglas and Monroe 1981) and appear to move a greater distance away from breeding sites compared to other *Ambystoma* species. Individual *A. jeffersonianum* have been found as far away as 1600 m (Downs 1989), as compared to only 150 m by *A. maculatum* (Douglas 1979).

Conservation

From an ecological perspective, small wetlands are crucial for maintaining regional biodiversity. To conserve species that utilize wetlands, however, the spatial structure of the entire landscape in which the species is found must be considered (Fahrig and Merriam 1994, Marsh and Trenham 2001). The dynamics of the local population are influenced by the quality of the aquatic environment (e.g., hydroperiod, food availability, presence of predators, etc.) as well as the quality of the terrestrial environment (e.g., microhabitat for refugia, food availability, etc.). If the goal of salamander conservation is to increase the numbers of declining populations then it will require increasing the quality of both the aquatic and terrestrial habitats to assure the production of metamorphs from a single wetland (Semlitsch 2002).

A majority of amphibians depend on both terrestrial and aquatic environments to complete their life cycle. Pond hydroperiod, the length of time a wetland continuously holds water, is a critical factor in determining whether or not juveniles will successfully reach metamorphosis. Hydroperiod is influenced by the quantity, frequency, and types of hydrologic inputs and outputs over a year's time (Novitzki 1989, Semlitsch 2002). Pond levels are also influenced by seasonal variation in evapotranspiration rates (Golet et al. 1993, as cited in Paton and Crouch 2002) as well as the composition of the geologic deposits underlying the basin and the basin's position in the landscape (Pyle 1998, as cited in Paton and Crouch 2002).

Hydroperiod preference differs between species depending on certain life history traits and development needs (Semlitsch 2002). Temporary (also called ephemeral) ponds will usually fill and dry at least once a year, whereas more permanent wetlands may dry only once or twice a decade (Semlitsch 2002). Pond drying varies annually and between ponds, making hydroperiods unpredictable and unstable. Amphibian larvae must attain a critical minimum body size before undergoing metamorphosis. If the pond dries before that minimum body size is reached, the larvae will desiccate (Shoop 1974, Smith 1983), or become easy prey for predators (Stangel 1983). Species capable of reaching metamorphosis quickly will benefit if the pond dries early in the season or has a short hydroperiod (Paton and Crouch 2002). Conversely increased hydroperiod duration provides more time for development, giving newly metamorphosed juveniles a survivorship advantage as they head into the terrestrial environment (Shoop 1974). More permanent ponds host a suite of predators, however, including fish (Pechmann et al. 1989, Skelly 1996, Laurilla 1998, Semlitsch 2000) that are capable of eliminating larvae from a pond (Semlitsch 2000). The variability of pond hydroperiod causes amphibian populations at a breeding pond to go through natural fluctuations in numbers between years. The number of metamorphosing juveniles is more accurately predicted by hydroperiod than by the number of breeding females (Pechmann et al. 1989) or number of eggs deposited (Shoop 1974). In a study by Pechmann et al. (1989), *Ambystoma talpoideum* and *Pseudacris ornata* juveniles were successfully produced in only 2 out of 8 study years. Populations persist not because they have constant reproductive success every year, but rather because they experience 'boom' years periodically where large numbers of metamorphs are produced (Semlitsch 1983, Pechmann et al. 1989, Berven 1990).

Management practices that focus solely on breeding ponds are going to exclude other important facets of amphibian habitat (i.e., the terrestrial environment). The forest habitat is where the Jefferson salamander acquires enough food to grow, prepares for the breeding season, and seeks protection from predation, dehydration, and freezing (Downs 1989). Maintenance of a forest buffer around breeding pools offers cover for juveniles emigrating from the pond. A forest buffer can also serve as primary nursery habitat for young-of-the-year during their first postmetamorphic season (Semlitsch et al. 1996, deMaynadier and Hunter 1999). In order for amphibian populations to remain stable or increase, it is essential to maintain the upland landscape immediately surrounding the breeding pool (deMaynadier and Hunter 1999, Marsh and Trenham 2001, Faccio 2003). This will not only serve to improve the quality of the breeding pools, it will also protect the closed-canopy forested habitat utilized by pond-breeding amphibians (Semlitsch 1998, deMaynadier and Hunter 1999).

Materials and Methods

Study Site

The breeding pond at LTSRA (8 km south of Marshall, Clark County, Illinois) is triangular in shape, semi-permanent, and lies along the southwestern edge of the park property. The eastern side of the pond is 32.8 m, and is the only side that is contiguous with intact woodland forest within the park boundaries. The forest consists of mixed deciduous hardwood trees (e.g., tulip poplar, cherry, white oak, American elm, cottonwood, pin oak, and black locust). The pond periphery is dominated by grasses and forbs. Surrounding forest understory contains Virginia creeper (*Parthenocissus*), poison ivy (*Toxicodendron*), and multiflora rose (*Rosa*), with occasional stinging nettles (*Urtica*) and mayapple (*Podophyllum*). The terrain on the eastern side is sloped, allowing the water to drain into the pond. The western side of the pond is 23.2 m, and is situated on a ridge that starts a strip of forest edge that is bordered by a county road. The strip of forest slopes downward leading into a drainage ditch next to the road. The south side of the pond measured 22.3 m long. A ridge on this side consisted of a strip (~15 m wide) of forest edge adjacent to a pine tree plantation extending beyond the LTRSA property boundary (Fig. 1).

Sampling Procedure

Individuals of the *A. jeffersonianum* population inhabiting LTSRA were expected to migrate to the breeding pond as early as mid-February. To capture and process specimens (identify, measure, and sex) that left and entered the breeding site, a drift fence-pitfall trap array was constructed around the LTSRA pond. This method of sampling operates on the idea that the animal had a reason to enter or leave the encircled area (in this case, a pond for reproduction and development). This technique provided a yearly census of breeding adults and juvenile recruitment (the number of juveniles produced per adult entering the pond to breed at the beginning of that particular activity season; Semlitsch et al. 1996).

To construct the drift fence, all vegetation and debris were removed from a 30 cm wide strip where the fence was placed; a narrow trench (5 cm deep) was dug in the middle of this cleared area. The fence itself consisted of a 45 cm tall silt cloth. The bottom 5 cm of the fence was buried into the trench to prevent any salamanders from passing underneath it. Stakes were placed every 2.5 m along the fence to support it upright. Buckets that were 30 cm deep and 13 cm in diameter were inserted on both sides of the fence every 5 - 7.5 m. The buckets were inserted immediately adjacent to the fence, flush with the ground (Fig. 2), and had holes in the bottom to allow for drainage. The buckets were sealed with lids during the non-activity season to prevent the capture of any non-target animals.

The drift fence was monitored on an alternate-day schedule from mid-February until mid-December of 2004, and early January until early June of 2005. *Ambystoma jeffersonianum* caught in the traps were sexed, measured for SVL, and marked using a unique combination of toe clips for each individual (Heyer et al. 1994) before being released on the opposite side of the fence. Individuals of other amphibian species caught were sexed, measured for SVL, and marked by year. Because Jefferson salamanders are sexually dimorphic (Petranka 1998, Phillips et al. 1999), and sex is easily determined in the breeding season (males have a swollen cloacal region that is absent in females), the sex ratio of breeding adults was determined. Egg masses were counted once females had oviposited and breeding adults had stopped entering the pond, but before any larvae had hatched. To count egg masses, I carefully made several regularly spaced transects from the edge of the pond to the center and back to the edge, ensuring that all areas of the pond were covered. While walking these transects, all visible *A. jeffersonianum* egg masses were counted. Limbs positioned out of sight from the water's surface were gently pulled up and assessed for egg masses. All egg masses remained attached to their original substrate. I counted eggs in a sub-sample of four haphazardly-chosen masses to determine the mean number of eggs per mass. *Ambystoma jeffersonianum* egg masses were distinguishable from other ambystomatid egg masses present in the pond by their globular nature and firm consistency. By comparison, to those of *A. texanum* were soft and flimsy, and those of *A. maculatum* were larger and much more dense (Petranka 1998, Minton 2001).

I determined the percentage of *A. jeffersonianum* eggs that hatched successfully by removing a sub-sample of egg masses from the LTSRA pond. Once removed, the egg masses were placed in a 38-l aquarium into four quadrants. If any masses were attached to substrate, resided under debris, or were associated with living aquatic material, those objects were included with the egg mass as well. The number of eggs present in the mass was counted visually and the aquarium was placed back in the pond at a depth of at least 15 cm and covered with a wire mesh screen. The design allowed the enclosed eggs to be protected from predation, but utilized the same water as the unprotected eggs. The egg masses also experienced the same water temperature and light levels as the eggs remaining in the pond. Water in the aquarium was changed once a week. The number of larvae present after hatching indicated how many eggs were viable. The mean percentage for all four masses was then used to estimate the viability for all egg masses within the pond. Because egg masses were counted at the beginning of the breeding season, and a mean number of eggs per mass was known, this percentage could then be applied to the whole pond. The percentage was then used to determine how many larvae were in the pond.

Newly hatched Jefferson salamanders grow rapidly and reach the juvenile stage in 2-4 months (Petranka 1998). Once the juvenile stage is reached, the new metamorphs will exit the pond. By comparing the number of juveniles leaving, and the number of adults entering the pond, fecundity could be calculated.

Because the breeding pond has a ridge along two sides and the fence was positioned on top of these ridges, it is possible that some adult Jefferson salamanders were able to bypass the drift fence or overwinter in the ridge underneath the fence, and arrive at the breeding pond unaccounted for. In 2004, a net was used to make several sub-sample sweeps of adults once they were in the pond. Sub-sample sweeps did not detect any unmarked individuals. In 2005, three minnow traps were placed in the pond, one on the west side of the pond and two on the south side of the pond. These sides were used because the water levels were less variable than on the forest-side of the pond, and because they were bordered by the ridges (where trespassing possibly occurred). All adults in the minnow traps that had not been previously caught were measured, sexed, and marked, and placed into the water outside of the minnow traps. The ratio of unclipped to clipped adults revealed how many breeding adults bypassed the pitfall trap array. Accounting for as many adults as possible made my estimate of the adult population size more accurate.

Stage-based Population Model

Data collected at LTSRA along with data from the literature (Williams 1973, as cited in Downs 1989) were placed in a matrix for use in a stage-based population model (Fig. 4). When developing their population models, Halley et al. (1996) used a similar application of life history parameters from other studies involving the common toad, *Bufo bufo,* and the crested newt, *Triturus cristatus*. This type of model was appropriate because it allowed individuals to be grouped according to the developmental stages that are important to survival and reproduction of the population. Utilizing this type of model allowed me to make predictions about the population's response to changes in survivorship in each life history stage (Akcakaya et al. 1999). All population modeling was performed using RAMAS EcoLab (RAMAS EcoLab Software 1999).

In the data matrix, fecundities are entered in the top row, and survival rates from one stage to the next are entered in the subdiagonal. In the model diagram (Fig. 3), the survival from one stage to the next was represented by the arrows going from one box to another. The subscripts E, L, J, and A refer to egg, larvae, juvenile, and adult, respectively. For example, S_{EL} is the proportion of eggs that survive to be larvae, and F_{AE} is the fecundity for adults of both sexes to egg. Fecundity is the number of offspring per individual, in this case, the number of juveniles per breeding adult. Because adults may remain in the adult stage for multiple years, the survival arrow loops back on itself.

Assumptions —

1. The initial population is stable. The number of adults entering the pond does not change between years.

2. The population is closed. This assumption is met as there is no emigration or immigration at the isolated pond.
3. Chance of surviving, chance of reproducing, and number of offspring produced does not vary among individuals in the same stage.
4. There is no demographic or environmental stochasticity. This assumption is corrected for within the model.
5. There is no density dependence. Even though this assumption is not true, this parameter is not corrected for in this study.

Results

Demographics

In 2004, I marked 104 *A. jeffersonianum* adults entering the pond. The ratio of female to male was 2:1 (68 females, 32 males, and 4 of indeterminate sex). There were 487 egg masses present in the LTSRA pond with an average of 18 eggs per mass, for a total of 8766 eggs. Each breeding female laid an average of 7 egg masses (approximately 129 eggs per female). Subsample egg masses in the aquarium had a 77% survival rate. Therefore, there were 6750 larvae in the pond. In the middle of May the breeding pond completely dried and most larvae did not have adequate time to metamorphose and leave. Only 4 juveniles were found under logs within the pond basin. Two of the juveniles were caught in pitfall traps as they attempted to leave the pond; one was dead. Fecundity was calculated at 0.0288 by taking the number of juveniles divided by the number of breeding adults.

In 2005, egg masses were observed in the pond prior to my opening the trap array in early February, presumably a result of breeding migrations during a few days of uncharacteristically warm and rainy weather in early January. All census data were recorded after this early migration; thus the estimate of population size is conservative. There were 69 new captures and 15 recaptures from the previous year, for a total of 84 individuals. Of these captures, 11 were from minnow traps (all were males). Female to male ratio was 1.3:1 (47 females, 37 males). There were 393 egg masses, for a total of 7074 eggs. Using the 77% survival probability in 2004 for eggs to juvenile, there was 5447 larvae in 2005. The pond dried in April and all larvae perished prior to metamorphosis. Recruitment and fecundity were both 0.0.

The Jefferson salamander belongs to the *jeffersonianum* complex, consisting of two diploid species, *A. jeffersonianum* and *A. laterale,* along with two hybrid species, *A. platineum* and *A. tremblayi.* The two diploid species are not sympatric within Illinois, and the *A. jeffersonianum* population at LTSRA does not co-occur with either hybrid species either. Therefore, all data collected at LTSRA is for a pure species of *A. jeffersonianum*. Averaged over the study period, there were 7920 eggs, 6098 larvae, 2 juveniles, and 94 adults; these values were used in the population model (described below). The mean (± 1 standard error) SVL and total length for all adults captured at the pond during both study years was 84.5 ± 0.90 mm and 171.0 ± 2.10 mm, respectively for males, and 82.0 ± 0.71 mm and 167.0 ± 1.60 mm, respectively for females.

I recorded 11 amphibian species other than *A. jeffersonianum* that used the LTSRA breeding pond. In 2004, 93 *Ambystoma texanum*, 14 *Ambystoma maculatum*, 4 *Bufo americanus*, and 1 *Pseudacris triseriata* were captured in pitfall traps. *Pseudacris crucifer, Acris crepitans,* and *Rana utricularia* were identified by their respective breeding choruses, but were not caught in the pitfall traps. A single *Plethodon cinereus* (leadback variety) was found dead in a trap. In 2005, 44 new and 2 recaptured *A. texanum* were recorded, as well as 2 new and 3 recaptured *A. maculatum*. Also captured in pitfall traps were 2 *P. triseriata*. Two species (*P. crucifer,* and *R. utricularia*), were captured in minnow traps. The breeding chorus of *A. crepitans* was again heard, but no individuals were caught in traps. This relatively small pond is an important, although ephemeral, resource for amphibians that breed in wetlands.

Population modeling

Based on the data collected over the two years of the study (Table 1), the value in the matrix for fecundity of adults for both years was 0.0144. The survival rate of egg to larvae (77%) was determined in the subsample hatchability study described above. Survival from larvae to juvenile was observed at the breeding pond in both years (0.04% in 2004 and 0% in 2005, an average of 0.02%). Because survival from juvenile to adult and interannual survival of adults could not be determined in this study, values from Williams (1973, as cited in Downs 1989) were used (50% and 25%, respectively). The model was repeated for 1000 repetitions to simulate demographic stochasticity. A standard deviation matrix (Fig. 5) was used to simulate environmental stochasticity by

Table 1. Numbers in each stage (percent representation) in 2004 and 2005 of the Jefferson salamander (*Ambystoma jeffersonianum*) at Lincoln Trail State Recreation Area, Clark County, Illinois.

	Census Year	
Stage	2004	2005
Egg	8766 (56%)	7074 (56%)
Larvae	6750 (43%)	5447 (43%)
Juvenile	3 (0%)	0 (0%)
Adult	104 (1%)	84 (1%)
Total	15623	12605

taking 10% of the survival rates (including those obtained from Williams [1973, as cited in Downs 1973]), and by calculating the standard deviation of the fecundity rates (Akcakaya et al. 1999). The model predicted the population trajectory for 15 years, beyond which time all of the iterations predicted extinction of the population under realistic survivorship values.

The stage-based population model predicted that, on average, the Jefferson salamander population at LTSRA could persist for another 4 years (Fig. 6). In year 4 however, there would be only 1 individual. The maximum number of years the population would have at least 1 individual was 9 and the minimum was 2. The finite rate of increase (λ) was 0.2566. Increasing the juvenile survivorship from 0.02% successfully increased the number of individuals per year (Table 2).

A sensitivity analysis was used to measure the change in population trajectory when different parameters were varied (Akcakaya et al. 1999). Varying parameters other than larval survivorship in the model had little to no effect on the population trajectory. These parameters included increasing fecundity from 0.0144, increasing juvenile to adult survivorship to 75%, and increasing egg survivorship to 99%. The only other matrix element besides juvenile survival that had an effect on the population trajectory was adult survival. Increasing adult survivorship to 50% yielded 7 adults in year 4, 3 in year 5, and 2 in year 6. The model also predicted that there was a 100% chance that all of the individuals at the LTSRA breeding pond could die, resulting in extinction of that population.

Table 2. Number of individuals (regardless of ontogenetic stage) in each year when juvenile survival rate is increased from 0.02%. Data was generated in a stage-based population model for the Jefferson salamander (*Ambystoma jeffersonianum*) at Lincoln Trail State Recreation Area, Clark County, Illinois.

	Number of individuals						
Juvenile survival rate	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
0.10%	2	-	-	-	-	-	-
0.50%	6	2	-	-	-	-	-
0.70%	8	2	1	-	-	-	-
0.90%	10	3	1	-	-	-	-
1%	11	3	1	-	-	-	-
5%	52	15	4	1	-	-	-
30%	312	90	27	9	3	1	-
50%	518	155	52	18	6	2	1

Discussion

Demographics

I recorded 15 individuals in 2005 that had been marked from 2004, resulting in 17.8% survivorship for adults. Williams (1973, as cited in Downs 1989), reported a 25% survivorship for adult *A. jeffersonianum* interannually. Because there were individuals that migrated to the pond before the traps were open, and because trespassing is a problem at the LTSRA breeding pond, the total number of captures and recaptures is assumed to be a conservative estimate. Given that 17.8% is not that much lower than 25%, I felt that Williams' survivorship value would be representative of the population at LTSRA if more adults had been encountered. Williams' also reported a 90% hatching success for the eggs, compared to 77% at LTSRA, and a larvae to juvenile survival rate of 0.075%, compared to 0.02% at LTSRA.

The ratio of males to females in the LTSRA breeding pond varied between years and when compared to different studies. In 2004, I recorded a male to female ratio of 1:2, and in 2005, a ratio of 1:1.3. Petranka (1998), stated that males outnumber females 3:1 or greater and Williams (1973, as cited in Downs 1989) recorded ratios of 1.2:1, 1.6:1, 1.8:1, as well as 1.04:1. Bishop (1969) stated that females often outnumber males, but no ratios were given.

Pond dynamics

Semlitsch (2002) noted the critical role of pond hydroperiod in determining whether or not amphibian larvae can reach metamorphosis successfully. My study of *A. jeffersonianum* at the LTSRA pond supports this finding, as only 3 living juveniles were marked and recorded (from underneath logs) in 2004 and none in 2005. In 2005, migrations to the breeding pond started as early as the first week in January. Based on the time of drawdown in 2004 (first week of June), the hydroperiod would have been adequate for many larvae to metamorphose successfully. Hydroperiod is not the same every year, however, and in 2005, the pond was dry by early April. Variability in hydroperiod, and therefore fluctuations in recruitment and population size, are well documented for amphibians (Shoop 1974, Pechmann et al. 1989, Skelly 1996). A 16 year study by Semlitsch et al. (1996) documented 4 years of short hydroperiod (≤ 100 days) with complete or nearly complete reproductive failure for most species at their study sites. They also confirmed that juvenile production for all species was erratic with large numbers of metamorphs being produced in only a small number of the 16 years (as few as 1 for some species).

Small populations, such as the one at LTSRA, are even more sensitive to fluctuations in population size and are susceptible to going extinct due to chance alone should the numbers of individuals be further reduced (Caughley and Gunn 1996). In particular, because the LTSRA adult population is likely to be smaller than the minimum viable population size (MVP), such factors as environmental and demographic stochasticity, and reduced genetic variance will greatly influence whether or not the population continues to decline and if it will eventually go extinct (Gilpin and Soulé 1986).

Stage-based population model

Based on the data available during the study period (Fig. 4), the Jefferson salamander population at LTSRA is likely to go extinct in 4 years. Short pond hydroperiods resulted in a very low average recruitment for both years. I considered the importance of increasing hydroperiod length, and thus increasing larvae to juvenile survival, by running several different stage-based population models. The only matrix element in the model (Fig. 4) that had any substantial affect on abundance was larval survivorship. Increasing adult survivorship to 50% increased population abundance, but the results were comparable to increasing larval survivorship to 0.7%. Modeling also indicated that increasing fecundity, egg survivorship, or juvenile to adult survival would have no impact on individual abundance within the population.

In a study by Williams (1973, as cited in Downs 1989), egg survival rates of 90% (compared to 77% at LTSRA) did not affect larval survival, as only 0.075% of the larvae successfully completed metamorphosis. Similarly, Thompson et al. (1980) reported no survival of *A. jeffersonianum* larvae at a Maryland study site. Taken together, these results indicate that survivorship at the larval stage in *A. jeffersonianum* is the most critical for assuring persistence of its populations, a finding similar to that reported for other ambystomatid species (Anderson et al. 1971, Petranka 1989).

Conservation and management options

Reproductive rates of pond breeding amphibians typically fluctuate between years. Only rarely do these species experience a year in which large numbers of metamorphs are produced (Semlitsch 1983, Pechmann et al. 1989, Berven 1990). In many instances, the few good reproductive years are enough to sustain the population. There is, however, always a risk of extinction when population size gets low. For some populations, low reproductive success may be offset by immigration from neighboring populations (Brown and Kodric-Brown 1977).

The breeding pond at LTSRA is both isolated and small, making the population susceptible to extinction. If all of the population's adults died one year, there would be no chance of recolonization from other populations. The Jefferson salamander is threatened in Illinois and, as such, management efforts need to be implemented in order to assure the species' persistence. This study reinforces the importance of the larval stage to survivorship within amphibian populations. Because hydroperiod is vital to larval survival, increasing the amount of time the LTSRA pond holds water is essential. This could be done by digging the breeding pond deeper so that it could potentially hold more water for longer periods of time. The pond should not be dug so deep however, as to make the pond permanent where aquatic predators could thrive (Pechmann et al. 1989). Another management option would be to remove some of the trees from the outskirts of the pond. This would reduce water loss due to evapotranspiration. A third option would be the creation of one or more new breeding ponds that could provide suitable habitat for more *A. jeffersonianum*, and thus increase numbers as well as create sources from which ponds with extinct populations could receive new residents (Semlitsch 2000). Establishing new ponds would be a step towards the long-term goal of ensuring the population's persistence at LTSRA into the future. A fourth option would be to do a combination of the other three suggestions.

As mentioned previously, amphibian species differ in the durations of their egg and larval development periods within the breeding pond before metamorphosis (Semlitsch 2002). *Ambystoma jeffersonianum* requires a hydroperiod of 2-3 months in order for the larvae to attain a minimum critical size (Phillips et al. 1999). Although the average recruitment during both study years was minimal for this species, other amphibian species experienced adequate hydroperiod lengths to successfully reach metamorphosis. *Pseudacris crucifer* and *P. triseriata* both breed from February to May, their eggs hatch within a few days, and tadpoles take approximately 2 months to reach metamorphosis (Phillips et al. 1999). *Ambystoma laterale* has been shown to predate upon *P. triseriata* (Smith 1983) and it is likely that *P. triseriata* and *P. crucifer* tadpoles would both serve as a food source for *A. jeffersonianum*. Although no *P. crucifer* or *P. triseriata* individuals were caught in pitfall traps, both species probably reached metamorphosis successfully in 2004, and possibly in 2005 as well. Subsequent breeding seasons, and different hydroperiods, may be beneficial to other species using LTSRA. Both *B. americanus* and *A. crepitans* would benefit if the breeding pond held water from April until June, *A. texanum* and *R. utricularia* need a similar hydroperiod as *A. jeffersonianum*, and *A. maculatum* needs water from March-April through July (Phillips et al. 1999).

The breeding pond at LTSRA is an important breeding site for several different amphibian species. Because of the variability in breeding migrations, time to hatching, and time to metamorphosis, different species may benefit more than others in certain years. Future directions of study should include a re-evaluation of the population if the pond is excavated to lengthen its hydroperiod. This would provide a more accurate assessment of the status of the *A. jeffersonianum* population and its probability of survival.

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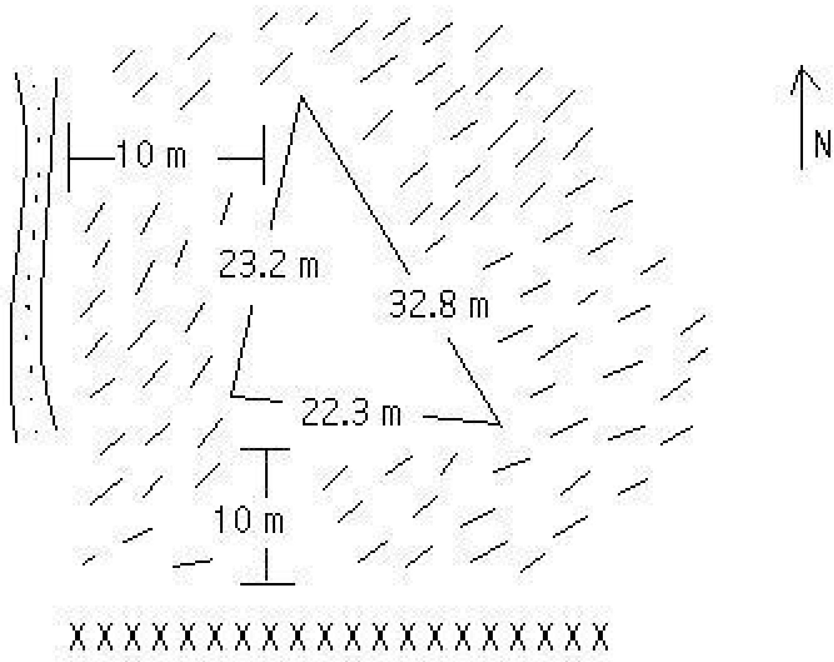

Figure 1. Breeding pond of the Jefferson salamander (*Ambystoma jeffersonianum*) in the southwest corner of Lincoln Trail State Recreation Area, Clark County, Illinois. Data collected at the pond are for activity seasons 2004 and 2005. Pond dimensions are indicated within the pond. Hash marks indicate deciduous forest, X marks indicate pine forest. The structure on the left side of the figure is a county road.

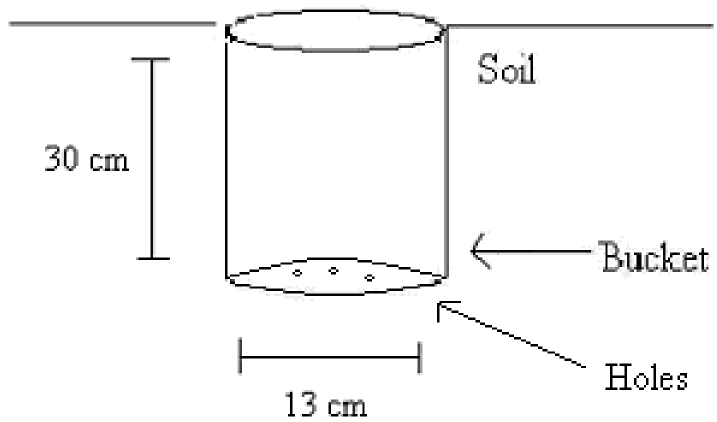

Figure 2. Diagram of a pitfall trap used to capture Jefferson salamanders (*Ambystoma jeffersonianum*) at Lincoln Trail State Recreation Area, Clark County, Illinois during the 2004 and 2005 activity seasons.

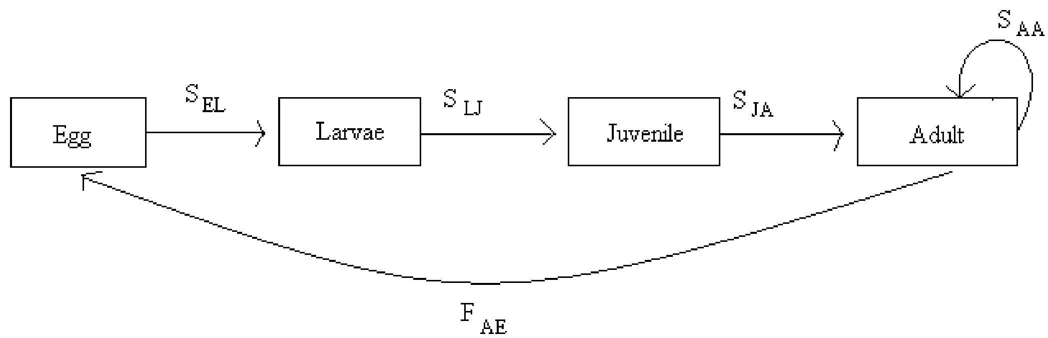

Figure 3. Diagram for a stage-based population model of the Jefferson salamander (*Ambystoma jeffersonianum*) at Lincoln Trail State Recreation Area, Clark County, Illinois. The subscripts E, L, J, and A refer to egg, larvae, juvenile, and adult, respectively. Survival from one stage to the next is represented by arrows going from one box to another. Fecundity is represented by the arrow going from adult to egg.

	Egg	Larvae	Juvenile	Adult
Egg	0	0	0	0.0144
Larvae	0.77	0	0	0
Juvenile	0	0.0002	0	0
Adult	0	0	0.5	0.25

Figure 4. Matrix for a stage-based population model of the Jefferson salamander (*Ambystoma jeffersonianum*) at Lincoln Trail State Recreation Area, Clark County, Illinois. Fecundity is in the top row, and survival from one stage to the next is in the sub-diagonal. Values for juvenile to adult and interannual adult survival were obtained from Williams (1973, as cited in Downs 1989).

	Egg	Larvae	Juvenile	Adult
Egg	0	0	0	0.0204
Larvae	0.077	0	0	0
Juvenile	0	.00002	0	0
Adult	0	0	0.050	0.025

Figure 5. Standard deviation matrix for a stage-based population model of the Jefferson salamander (*Ambystoma jeffersonianum*) at Lincoln Trail State Recreation Area, Clark County, Illinois. Fecundity is in the top row, and survival from one stage to the next is in the sub-diagonal.

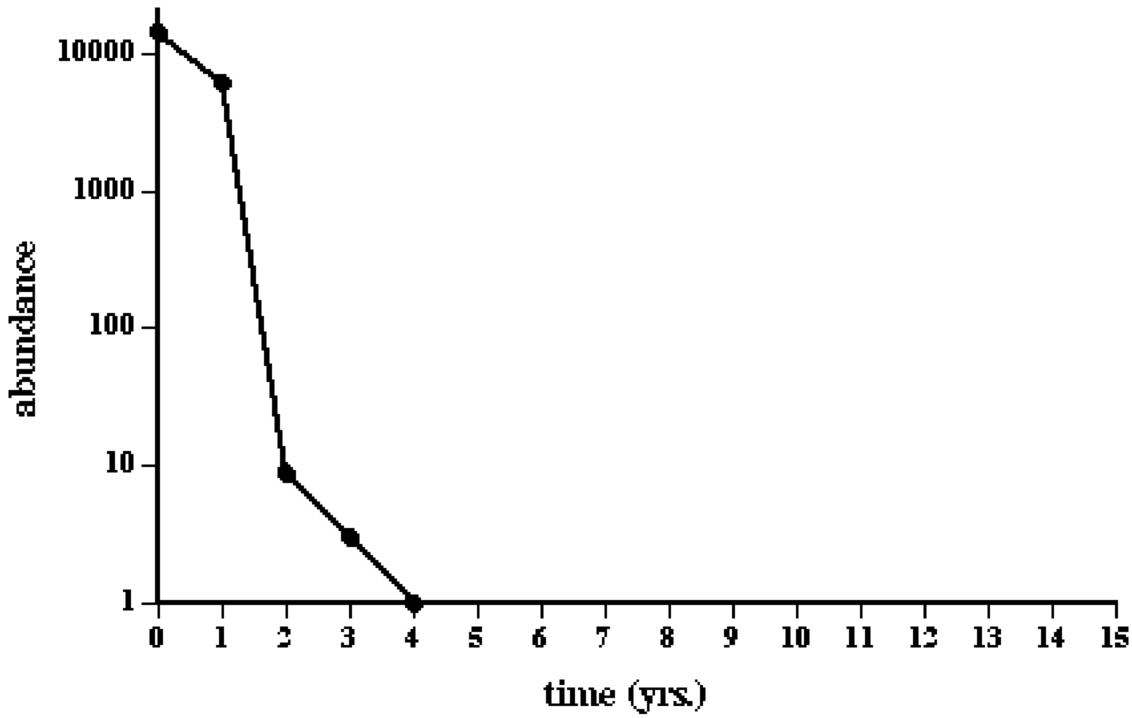

Figure 6. Population trajectory summary (logarithmic scale) for the Jefferson salamander (*Ambystoma jeffersonianum*) at Lincoln Trail State Recreation Area, Clark County, Illinois for 15 years. The stage-based model generating these values used 1000 repetitions to account for stochasticity, the solid line is the average abundance.