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Assessing the distribution of a secretive species using ecological niche and occupancy models

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Submitted by:

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Abstract

One of the primary difficulties in protecting imperiled species is determining their distribution and habitat use. We used ecological niche modeling (MaxEnt) along with occupancy models to examine the distribution and status of Jefferson salamanders (*Ambystoma jeffersonianum*), a threatened species in Illinois. Based on predictive maps generated in MaxEnt, we sampled 57 ponds during the 2008 and 2009 breeding seasons. Results through 2009 resulted in a good fit to the MaxEnt model when assessing both presence and absence localities (AUC=0.8775, 95% C.I.=0.772- 0.983; Kappa = 0.709), with 86% of ponds classified correctly by the model. Model discrimination was hindered by the presence of predatory fish in some ponds with high MaxEnt probability values. When we removed ponds with fish from the analysis, the overall model fit was substantially improved (AUC=0.9427, C.I.=0.863-1.00; Kappa = 0.782)). We considered 17 models to estimate detection probabilities and overall site occupancy using PRESENCE 2.0. The best fit model had constant detection probabilities and predatory fish presence as a site covariate; further elucidating the negative effect of predatory fish on salamander occupancy. The overall estimate of proportion of sites occupied was 0.6267 with a probability of detection of 0.7192. Ecological niche modeling proved useful for quickly and efficiently identifying areas to survey for rare species. Our surveys identified 29 new breeding ponds used by Jefferson Salamanders and verified the continued presence of the species at four historical localities.

INTRODUCTION

Within Illinois, there is concern for apparent local extinctions and widespread decreases in amphibian abundance. Currently, most amphibian sampling is opportunistic, resulting in poorly known distributions for many species. Surveys for pond-breeding salamanders are particularly difficult because they are primarily subterranean and therefore only available for sampling during their short breeding seasons. Jefferson salamanders (*Ambystoma jeffersonianum*) were first documented in Illinois in 1990, and subsequently listed as a state threatened species. The listing was based ontheir restricted range and dependence on rare and vulnerable upland forests and fishless, ephemeral wetlands. From their discovery in 1990 through 2007, Jefferson salamanders were documented from fewer than ten locations, all in the Wabash Border Natural Division, along the Illinois-Indiana border in Clark and Edgar Counties. Because Jefferson salamanders are listed as state threatened and therefore a species in greatest need of conservation, it is important to determine their distribution and abundance within the state of Illinois (Illinois DNR 2006).

This study was initiated in 2007 with an Illinois Wildlife Preservation Fund grant to determine the potential range of the species in Illinois using ecological niche modeling and then conduct field sampling on areas predicted to have the highest likelihood of occurrence for the species. Prior to this project, Jefferson Salamanders were documented from fewer than ten locations along the Illinois-Indiana border in Clark and Edgar Counties, and one disjunct population in Lincoln Trail State Recreation Area. In 2008, we conducted focal surveys of areas with the highest probability of occurrence as determined by the ecological niche models we generated. Results from 2008 identified 12 new wetlands from which Jefferson Salamanders were captured. We were also able to confirm the continued presence of Jefferson Salamander at four historical locations but documented that four other historical breeding ponds are no longer holding enough water for successful recruitment (Kuhns and Crawford 2008).

In 2009, we continued sampling of potential breeding ponds with the following objectives: 1. model the predicted range of Jefferson Salamanders in Illinois. 2. Conduct field surveys and identify breeding ponds of Jefferson Salamanders. 3. Determine detection rates and occupancy estimates for Jefferson Salamanders. 4. Revise the known distribution of the species in Illinois.

In this report, we synthesize the results for both 2008 and 2009 to provide a comprehensive understanding of the project through its completion. Supplemental surveys were conducted in 2010 but, due to a different trapping regime and unanticipated results, information from 2010 will be presented in an appendix at the end of this report.

METHODS

We used the program MaxEnt (Phillips et al. 2006) to generate a predicted distribution based on characteristics of environmental-climatic variables for 145 known localities throughout the range of Jefferson salamanders. Maxent is a free, GIS-compatible program that uses geo-coded environmental data layers, together with known locations for the species, to create a predictive grid/distribution map for the target species. The suitability of each grid cell for the target species is expressed as a function of the environmental variables within that grid cell. Locality information was overlaid onto 20 environmental variables (1 km resolution) available from the WorldClim project (Hijmans et al.

2005). We also incorporated information on slope, landscape position, and canopy cover (30 m resolution). We mapped the output to obtain isopleths of suitability and used the resulting maps to determine suitable sampling locations focused in the areas with the highest probabilities of occurrence (Fig. 1).

We used the resulting map to guide us in searching for appropriate ponds to trap. Within areas deemed suitable by Maxent, we used topographic maps, and aerial photographs to identify potential ponds which we then ground-truthed; subsequently, landowners were contacted to gain permission to trap suitable ponds. We selected 57 ponds (including 7 historical ponds) to sample for Jefferson salamanders. Each pond was sampled with double-throated minnow traps for two consecutive nights on two separate occasions in 2008 and three consecutive nights in 2009. In 2008, trapping at each pond was conducted over two sessions of two nights, to ensure that we did not conclude trapping prior to salamanders entering the ponds. In 2009, we began trapping at sites where we captured Jefferson Salamanders in 2008, and once we began capturing salamanders in good numbers at those sites, we began trapping new locations. In 2009, some sites were trapped for four continuous nights. Abundance is presented as captures per trap night.

To investigate the relationships between salamander detection and occupancy rates and environmental variables, we used an information-theoretic approach to model selection (Burnham and Anderson, 2002). The information-theoretic approach allows one to select a ‘‘best’’ model and to rank the remaining models (Burnham and Anderson, 2002). Burnham and Anderson (2002) suggest the information-theoretic approach should be used in observational studies where other hypothesis testing methods may lead to ‘‘data dredging’’ and over-fitted models. Using four environmental variables, we built 17 *a priori* models to test hypotheses predicting salamander detection and occupancy. The environmental variables we selected (and subsequent models we built) were based on previous studies detailing their importance to salamanders. The environmental variables we considered were: 1) presence/absence of fish in breeding ponds; 2) daytime temperature during sampling; 3) nighttime temperature during sampling; 4) total rainfall in 24 hours preceding sampling.

For each model, we calculated the AIC value corrected for small sample sizes (AIC_c), which is a measure of model fit adjusted for the number of parameters (Burnham and Anderson, 2002). We ranked all candidate models according to their AIC_c values, and the best model had the smallest AIC_c value (Burnham and Anderson, 2002). We also calculated ΔAIC_c, which is the difference in AIC between each model and the best model in the set. AIC differences less than two are considered to indicate little difference between models, while differences of 4–7 indicate considerably less support for the model with the higher AIC value although it may have some empirical support (Burnham and Anderson, 2002). Last, we calculated Akaike weights (ω_i) to determine the weight of evidence in favor of each model and to estimate the relative importance of each individual parameter (Burnham and Anderson, 2002).

RESULTS

We sampled 57 wetlands for the presence of Jefferson Salamanders in 2008-09 (Figure 1). Four pond breeding salamander species were documented in our surveys (Plate 2): Jefferson Salamanders, *Ambystoma* jeffersonianum; Smallmouth Salamanders, *A.* texanum; Tiger Salamanders, *A.* tigrinum; and Spotted Salamanders, *A. maculatum.* Jefferson Salamanders were detected at 33 of these sites, 29 of which were novel locations in Illinois (Table 1). Capture rates varied from 0 to 9.58 Jefferson Salamanders per trap night (Tables 2 & 3).

A null model test with 1000 replicates (Raes & ter Steege 2007) showed that our model was significantly different from random (MaxEnt AUC = 0.910; $p < 0.001$). Results through 2009 resulted in a good fit to the MaxEnt model when assessing both presence and absence localities (AUC=0.8775, 95% C.I.=0.772- 0.983; Kappa = 0.709) with 86% of ponds classified correctly by the model, but model discrimination was hindered by the presence of predatory fish in some ponds with high probability values. When we removed ponds with fish from the analysis, the overall model fit was substantially improved (AUC=0.9427, C.I.=0.863-1.00; Kappa = 0.782).

We considered 17 models to estimate detection probabilities and overall site occupancy using PRESENCE 2.0. The best fit model had constant detection probabilities and predatory fish presence as a site covariate; further elucidating the negative effect of predatory fish on salamander occupancy (Table 4). The overall estimate of proportion of sites occupied was 0.6267 with a probability of detection of 0.7192. Covering all four surveys, we can therefore state with 99.4% accuracy that Jefferson salamanders do not use the ponds where we did not catch them.

Discussion

Initially our plan was to overlay National Wetland Inventory (NWI) shape files of Illinois ephemeral pools on the ecological niche model we constructed. In this way, we could quickly and effectively select ponds with the highest likelihood of harboring salamanders. The NWI was most recently updated in 1992 and we found that a large percentage of the ponds were no longer present on the landscape. In fact, it seems that much of the area that we surveyed provided appropriate terrestrial habitat for Jefferson Salamanders but suitable ponds were uncommon. The majority of ponds where we found Jefferson Salamanders were located at the tops of dammed ravines (Plate 1a). Many of these ponds either have old earthen dams that have washed out and no longer hold enough water to support larvae through metamorphosis or have been stocked with fish (Plate 1b). In fact, three of the historical localities for this species had been drained by 2008. One site that was first documented in 2008 (Kuhns and Crawford 2008) had a new culvert installed sometime prior to March 2009 and no longer holds water.

Our occupancy estimate of 0.6267 indicates that Jefferson salamanders may be more prevalent on the landscape than prior surveys have indicated. In 2007, District 19 DHB Roger Jansen had three ephemeral ponds created on LTSRA property. During our 2009 surveys, we captured Jefferson Salamanders in all three of these created ponds (denoted as Scrape North, Scrape Mid, and Scrape South in the tables). The nearest known pond to these newly created ponds is over 1 km away. The fact that breeding adults used these ponds less than 2 years after pond creation suggests Jefferson Salamanders might be quite common on the landscape in suitable terrestrial habitats.

While our surveys did document numerous previously unknown breeding ponds in the area, they did little to expand the range of the species in Illinois. Only one new population was documented in Edgar County although this is likely partially due to lack of sampling in the county. We found fewer ponds in Edgar County that appeared suitable for ambystomatid salamanders and the ones we did find we were unable to secure landowner permission to sample.

Summary

Maximum Entropy modeling appears to be a useful tool for quickly and efficiently identifying areas in which to survey for rare species and eliminate the need for haphazard sampling. While effective, models can only predict the suitability of the surrounding landscape in which a pond occurs. Models provide no information about the suitability of the pond itself as demonstrated by the increase in predictive ability when ponds with fish were removed from analysis. Presence of fish proved to be the most informative character in assessing occupancy rates for Jefferson Salamanders and was present in all five of the most supported models. Occupancy rates indicate that the paucity of known locations for Jefferson salamanders in Illinois appears, in part, due to inadequate and haphazard sampling, as we were able to capture Jefferson Salamanders in 29 new ponds during our surveys. Despite the multiple new sites documented in this study conservation concerns remain for this species in Illinois. Their range remains restricted to a small portion of the state. Habitat loss remains a concern for both salamander breeding habitat (through dam removal, draining, and fish stocking) and loss of closed canopy wooded areas by logging and home construction. Additionally, we reported the first records of infestation of the cyst forming parasite *Clinostomum marginatum* (Plate 3) on both Jefferson Salamanders and Smallmouth Salamanders (McAllister et al. 2010). It is unknown what effect these parasites may have on salamander survival.

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Figure 1. Predicted distribution of Jefferson salamanders in Illinois based on MaxEnt models, with localities of sites sampled.

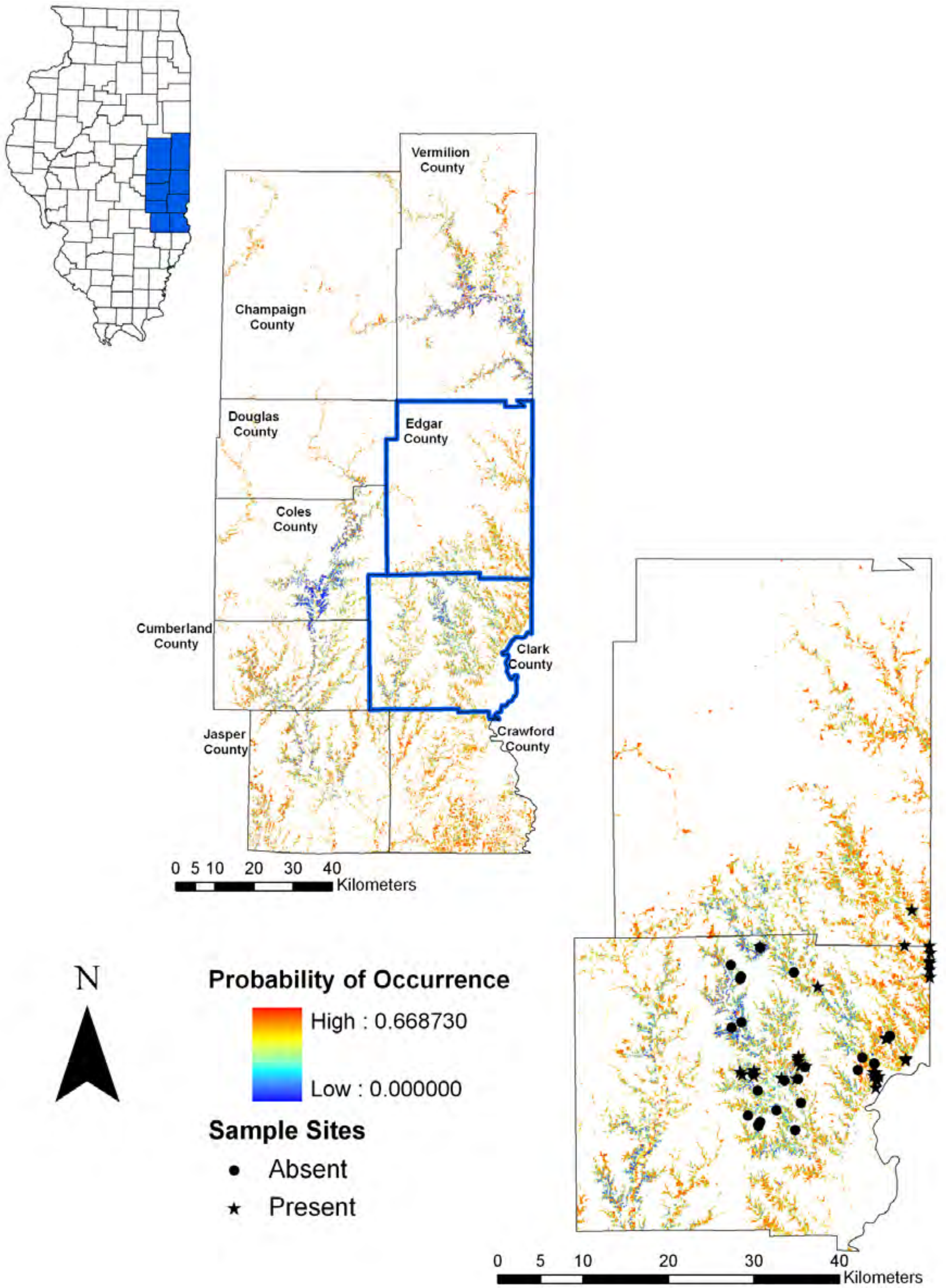

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Table 4. Best fit regression models explaining the influence of abiotic and biotic factors on detection probabilities and overall site occupancy for Jefferson salamanders.

Model[a]	*(-2 Loglike)*	K^b	AIC_c	$\Delta AIC_c{}^c$	$\omega_i{}^d$
psi(fish), p(.)	183.81	2	187.81	0	0.35
psi(fish), p(daytemp)	184.80	2	188.8	0.99	0.22
psi(fish), p(nighttemp)	185.04	2	189.04	1.23	0.19
psi(fish), p(precip,daytemp)	184.29	3	190.29	2.48	0.10
psi(fish), p(precip,nighttemp)	184.39	3	190.39	2.58	0.10

Model rankings were based on Akaike's Information Criterion.
[a]Model names correspond to abiotic and biotic data described in the methods.
[b]Number of estimable parameters in approximating model.
[c]Difference in value between AIC of the current model vs. the best-approximating model.
[d]Akaike weight. Probability that the current model (i) is the best-approximating model among those tested.

Plate 1. Representative images of ponds that were used (A) and were not used (B) by Jefferson Salamanders in a study conducted by A.R. Kuhns and J.A. Crawford in Clark and Edgar Counties, Illinois in 2008 and 2009. Note that pond A is surrounded by wooded ravines and pond B is open canopy habitat with fish present. These two ponds are located within 100m of each other on the property of Robin Ernst.

A.

B.

Plate 2. Pond breeding Ambystomatid salamanders documented in surveys of wetlands in Clark and Edgar Counties, Illinois by J.A. Crawford and A.R. Kuhns in 2009. **A.** Jefferson Salamander (*Ambystoma jeffersonianum*), **B.** Smallmouth Salamander (*Ambystoma texanum*); **C.** Tiger Salamander (*Ambystoma tigrinum*); **D.** Spotted Salamander (*Ambystoma maculatum*). All photographs from Clark County, IL, taken in March 2009.

A

B

C

D

Plate 3. Jefferson Salamander with an infestation of metacercariae of *Clinostomum marginatum* (3 of the > 40 cysts visible in this picture are denoted by arrows). This project provided the first documentation of *Clinostonum marginatum* infections in both Jefferson Salamanders and Smallmouth Salamanders. See McAllister et al. 2010 for a full review and description.

Appendix I. Assessing the Distribution of a Secretive Species Using Ecological Niche and Occupancy Models: Results from 2010

In 2010, we expanded our surveys south in an attempt to more accurately determine the distribution of the Jefferson Salamanders in Illinois. The majority of our efforts in 2010 focused on Crawford County Conservation Area, the protected habitat nearest to known locations of Jefferson Salamanders. Herein we report the results of our trapping in Clark and Crawford Counties in March 2010.

We documented one additional Jefferson Salamanader breeding pond (39.289900 -87.639267; Figure 1, Tennis) expanding the range of Jefferson Salamanders approximately 5 km south of what we documented in 2009. We sampled 17 ponds within CCCA from 15-18 March 2010 (Figure 2). We captured four species of Ambystomatid Salamanders: Tiger Salamanders, *Ambystoma tigrinum*,; Spotted Salamanders, *Ambystoma maculatum;* Smallmouth Salamanders, *Ambystoma* texanum; and Silvery Salamanders, *Ambystoma platineum* (unisexual triploids-JJL). All four species were cpatured from recently created amphibian ponds placed on the landscape in 2006.

Silvery Salamanders are an all female species thought to have originated through hybridization and back crossing between Blue-Spotted Salamanders, *Ambystoma* laterale and Jefferson Salamanders. Silvery Salamanders are listed as endangered in Illinois and were known from only a small handful of ponds in the Middle Fork Vermilion River drainage, northeast of Oakwood, Vermilion Co., IL. In Vermilion Co., IL where neither of their parental species is present, they use Smallmouth Salamander spermatophores to stimulate egg development. The presence of silvery salamanders in Crawford County, IL, 120 km away from the only other known populations, is a surprise.

Although superficial differences between Jefferson Salamanders and Silvery Salamanders can become apparent to the trained eye, the only way to definitive way to identify Silvery Salamanders is by counting chromosomes. We ran a PCR on the tail clips of all six Silvery Salamanders captured in CCCA along with a Jefferson Salamander from Clark Co, IL and a Silvery Salamander from Vermilion Co, IL (Plate 1). Results support that the salamanders from CCCA are Silvery Salamanders having incorporated Blue-spotted Salamander alleles into their genome.

Currently we are unaware of any ponds where Silvery Salamanders are sympatric with either of their parental species (Jefferson Salamanders and Blue-spotted Salamanders) in Illinois. Since Silvery Salamanders poach the spermatophores of other Ambystomatid species there is a concern that they can drive down population numbers of other Ambystomatid species by outcompeting the females of other species for the spermatophores.

Unfortunately, our discovery came at the end of the pond salamander breeding season in 2010 and we were unable to conduct additional surveys. Surveys in the 23 km separating the known Jefferson Salamander range in Illinois from CCCA, in addition to surveys in and around CCCA, are warranted.

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Plate 1. Gel of a Silvery (JJL) Salamander (Ap), the six salamanders collected from Crawford County Conservation Area (CCCA) (1-6), and a Jefferson Salamander from Clark Co (Aj). Primers Aje94 & 346 aplify in in Ambystoma laterale are showing that *A. laterale* have been incorporated into the genome. Aje212 was a marker that amplified in *A. texanum* and was included to see if Smallmouth Salamanders had been incorporated into the genome. This gel implies that the 6 individuals from CCCA are in fact JJL Silvery Salamanders.