Occupancy Rates and Detection Probabilities of Red-Backed Salamanders on the Virginia Fall Line

Jay D. McGhee

Department of Natural Sciences, Northwest Missouri State University, Maryville, Missouri, 64468

ABSTRACT

To meet the conservation needs of declining amphibian populations, there is a need to assess monitoring techniques in various habitat types and seasons. I assessed detection rates and proportion of area occupied via transect monitoring for red-backed salamanders at a site along the Virginia Fall Line in Doswell, Virginia. I established 24 transects in a 3.2-ha area in both riparian and upland habitats. Objects providing natural cover along these transects were sampled 3 times a week in fall and spring over a two-year period. Models of occupancy and detection were developed and compared using Akaike's Information Criterion. Based on 113 captures, model selection indicated a low fixed initial occupancy of transects with seasonal changes in colonization and extinction. Detection probability was uniformly low, possibly contributing to model uncertainty in determining the best explanatory variables. I infer that the increased colonization of transect cover objects during fall and increased emigration from cover objects during spring is a result of changing moisture conditions and feeding opportunities. It is likely that occupancy and detection will vary substantially for survey sites based on habitat, season, or even by transect placement, and thus managers will need to estimate these parameters for any population monitoring program of red-backed salamanders.

INTRODUCTION

In view of the worldwide decline of amphibian populations and the increased interest to conserve these populations, biologists have been highly interested in developing robust monitoring methods for specific populations, habitats, or sites of conservation interest (Dodd and Barichivich, 2007; Adams et al., 2013; Petitot et al., 2014). One problem in developing these methods is that, regardless of the sampling technique, there is a possibility that an observer will fail to detect an individual of the population of interest when they are present on the sampling site. Thus, the apparent absence of a taxon could mean that members of the population of interest are truly absent from the sampling site or that they are present but not detected. Because this problem has significant implications for whether management strategies are implemented, any robust monitoring method will require the estimation of detection probabilities, the probability (ranging between $0 - 1$) that an individual will be detected by a survey procedure, given that is available to be found (Schmidt, 2003). Unfortunately, the detection probability is likely to vary extensively based on a suite of environmental

variables, species differences, population size differences, and even individual behavioral differences (Lancia et al., 1996; Dodd and Dorazio, 2004; Tanadini and Schmidt, 2011).

Monitoring is especially needed for a species integral to specific ecosystem functions (Davic and Welsh, 2004). Red-backed salamanders (*Plethodon cinereus*) are one such species, serving as a potentially useful candidate for long-term monitoring because they are fairly common within their range, often represent a high biomass in specific habitats, and may be tightly linked to the health of their environment (Welsh and Droege, 2001). Red-backed salamanders are likely to have low detection rates, however, largely as a function of their ecology. Bailey et al. (2004a), for example, have attempted to determine detection rates for the congener southern red-backed salamander (*Plethodon serratus*) using a Pollock's Robust Design for mark-recapture estimation, but found that because the majority of the population remained below ground, the likelihood of a red-backed salamander being available (above ground) to be found and then actually being detected could be as low as 4%. In addition, there was a tendency for individuals to be "trap-shy", and thus unlikely to be recaptured, biasing abundance estimates. These results led Bailey et al. (2004a) to suggest using count data to determine the proportion of an area occupied instead of estimating abundance. This reduces the sampling effort required while still allowing for the estimation of detection probabilities and occupancy rates (MacKenzie et al., 2002). This means that larger areas can be sampled with less intensity for the same amount of effort, which may be more functional for conservation management purposes than more intensive studies on smaller sites. Indeed, Bailey et al. (2004b) accomplished this for multiple species in an area in the Great Smoky Mountains. For researchers wishing to establish long-term monitoring at a particular field site, using the proportion of area occupied (PAO) survey seems a robust possibility.

Given their current conservation needs, it is desirable that long-term monitoring projects for amphibians, including the red-backed salamander, are initiated in multiple habitat types to gain a better picture of patterns in occupancy and detectability. Red-backed salamanders are particularly associated with well-drained mature montane forest with extensive leaf-litter and deep, pH-neutral soils, with plenty of cover objects (Burger, 1935; Petranka, 1998; Milanovich et al., 2010; McGhee and Killian, 2013). Many studies establishing monitoring methods are understandably in these types of habitats (Dodd and Dorazio, 2004; Hyde and Simons, 2005; Williams and Berkson, 2004). To establish a complete picture of occupancy for a species, however, a wide variety of habitats should be assessed, along with estimates of the amount of effort required to establish occupancy for these sites (Mackenzie and Royle, 2005). For example, the Randolph-Macon College Environmental Field Station occurs along the Virginia Fall Line, demarcating the eastern boundary between the piedmont and coastal region of the state. In hopes of testing the potential of a long-term monitoring protocol on this site, my objective was to assess occupancy and detection rates for a series of transects on a small subsection of the field station. The estimation of a detection rate is important to determine the likelihood of detecting an individual of a monitored species if present, and so it is helpful to translate the number of individual transect surveys that would be required to detect an individual that is actually present. To accomplish this I calculated the amount of sampling effort

that would be required to establish occupancy for a given transect (O'Connell et al., 2006).

<div align="center">STUDY SITE</div>

Fourteen of Virginia's salamander species (approximately 28% of Virginia species) occur within the York River drainage (Mitchell and Reay, 1999). The Randolph-Macon College Environmental Field Station (EFS), owned by Martin Marietta Quarry, encompasses a small ridge in this drainage, next to a local rock quarry and bordering the Little River in Doswell, Virginia. The EFS is a 26.7 hectare (66 acres) property in northern Hanover County, Virginia, located about 8 miles from Ashland, Virginia (Randolph-Macon College, 2010). This site is located on the Fall Line, a sharp rise in elevation that runs through the state that acts as a geological border between the piedmont and coastal ecoregions of Virginia. It contains mature hardwood forest. Elevation ranges between 150 – 220 m.

<div align="center">METHODS</div>

In August 2011, I established 24 permanent transects, each 25m in length. These transects were arranged in groups of four, radiating from the corners of a central silt fence enclosure being used for a related study (McGhee, 2013). Each array of 4 transects was established from a randomly located line moving perpendicular to the Little River through both a riparian and upland zone (elevation difference = ~50m). From randomly selected points along this line, I placed the center points of these arrays (a 25-m^2 silt fence enclosure) between 0 – 50 m away, only constraining the center of the transect arrays to be a minimum of 25 m away from each other. This resulted in 3 arrays of 4 transects in the upland zone, and 3 arrays of 4 transects in the riparian zone, over an area covering approximately 3.2 ha.

I sampled transects following Pollock's Robust Design (1982), wherein primary sampling periods are comprised of a series of secondary sampling occasions occurring over a short enough time period that a closed population can be assumed. An open population can be assumed across primary sampling periods (MacKenzie et al., 2003). Within an occupancy modeling framework, this allows for the estimation of 4 probabilities: initial occupancy of transect (ψ), colonization of transect (γ), extinction (or emigration) from transect (ε), and detection at transect (p: MacKenzie et al., 2003). The colonization and extinction parameters allow for testing changes in occupancy over the time of the study. Primary samples were taken between 17 August – 4 December of 2011, 16 February – 23 May of 2012, 3 October – 6 December of 2012, and 26 February – 8 May 2013, with each separated by a 10-day period on average, and comprised of 3 secondary samples occurring over a 3 – 4 day period. A sample consisted of walking each 25m transect and searching under each natural cover object intersecting the transect. Salamanders found under natural cover objects were measured for total length (TL), snout-vent length (SVL), and identified to species. I assigned an age to red-backed salamanders (juvenile or adult) based on their SVL (adult SVL $\geq$ 34 mm; Petranka, 1998), and documented the color morphology of the individual (red-stripe on dorsum, or unstriped morph; Petranka,1998). Only detections of red-backed salamanders were used

in our analysis. After measuring, salamanders were gently returned to their original position.

I developed a series of models to explain the number of times salamanders were detected in each transect over the study period. Each model serves as a mathematically specific hypothesis about how occupancy and detection function for the entire suite of transects. These models were then compared using Akaike's Information Criterion (AIC) in program PRESENCE (Bailey et al., 2004b), which compares competing models using the statistical likelihood for each model combined with a penalty term for the number of parameters in that model (Williams et al. 2002). To obtain specific models, model parameters (ψ, γ, ε, p) were allowed to vary by year (2011 – 12, 2012 – 13), season (spring or fall), habitat (upland or riparian), array (each set of four transects), or by individual transect, or some combination thereof. In some models, parameters were also held constant in primary samples (ψ, γ, ε) or primary and secondary samples (p). This resulted in 16 *a priori* models to consider as best describing red-backed salamander occurrence on site (Table 1). Finally, I calculated the number of surveys required to detect a red-backed salamander with 95% probability for a given occupied transect using Mackenzie and Royle's (2005) estimator $1 - (1 - p)^K$, where p is the detection probability estimated from the top-performing model(s) and K is the number of surveys undertaken.

RESULTS

Over the course of two years I conducted 23 primary sampling periods (69 secondary samples) with 7 primary samples (21 secondary) in fall 2011, 5 primary samples (15 secondary) in spring 2012, 5 primary samples (15 secondary) in fall 2012, and 6 primary samples (18 secondary) in spring 2013. Each transect averaged ($\pm$ standard error (SE)) 4.79 ± 0.47 cover objects. I detected red-backed salamanders a total of 113 times, with juveniles comprising 50% of detections. Unstriped morphs comprised 35% of total detections. Model selection indicated that those models showing a fixed initial occupancy followed by a seasonal change in colonization and extinction were most descriptive of the data, with combined model weight for γ (seasonal), ε (seasonal) models totaling 99%. There was less clarity, however, regarding detection probabilities, with 3 models performing at a similar level (ΔAIC ≤ 2, Burnham and Anderson 2002). Each model assumes a constant initial occupancy with strongly seasonal colonization and emigration rates (Table 2). Each model varied, however, in its treatment of the detection rate. In model 1, p differed between upland (0.16 ± 0.02 SE) and riparian (0.10 ± 0.02 SE), and in model 2, p differed between transect arrays (A: 0.20 ± 0.04 SE; B: 0.16 ± 0.04 SE; C: 0.09 ± 0.03 SE; D: 0.11 ± 0.03 SE; E: 0.05 ± 0.03 SE; F: 0.08 ± 0.03 SE). Finally, in model 3, p is assumed to be constant (0.14 ± 0.02 SE). Using these estimates of p, the number of single transect surveys required to achieve a 95% confidence of detecting an individual given its occupancy varied from 13 – 57 surveys, with a weighted mean of 26.24 ± 3.94 SE (Figure 1).

TABLE 1. Model selection results for estimating occupancy (ψ), colonization (γ), extinction (ε) and detection (p) rates for red-backed salamanders captured at the Little River, Hanover County, Virginia, 2011 – 2013. For each model, estimated parameters vary according to a covariate shown in parentheses, where (.) means the parameter was held constant for the primary sample, and (.,.) means the parameter was held constant for both primary and secondary samples. ΔAIC represents the difference between each model and the lowest AIC score model, w, represents the AIC model weight, and K represents the number of parameters in each model.

Model #	Model	ΔAIC	w	K
1	ψ (.), γ(season), ε (season), p (habitat)	0.00	0.45	7
2	ψ (.), γ(season), ε (season), p (array)	1.35	0.23	11
3	ψ (.), γ(season), ε (season), p (.,.)	1.49	0.22	6
4	ψ (.), γ(season), ε (season), p (seasonal)	3.41	0.08	7
5	ψ (site), γ(season), ε (season), p (.,.)	7.75	0.01	11
6	ψ (.), γ(season, habitat), ε (season, habitat), p (season, habitat)	9.88	<0.01	13
7	ψ (.), γ(season, year), ε (season, year), p (season, year)	10.49	<0.01	13
8	ψ (.), γ(season), ε (seasonal), p (declining)	11.69	<0.01	6
9	ψ (.), γ(season, array), ε (season, array), p (season, array)	14.56	<0.01	25
10	ψ (.), γ(.), ε (.), p (habitat)	16.43	<0.01	5
11	ψ (habitat), γ(habitat), ε (habitat), p (.)	16.98	<0.01	7
12	ψ (.), γ(.), ε (.), p (.,.)	18.05	<0.01	4
13	ψ (.), γ(habitat), ε (habitat), p (habitat)	18.27	<0.01	7
14	ψ (.), γ(habitat), ε (habitat), p (season)	18.30	<0.01	7
15	ψ (.), γ(season), ε (season), p (transect)	27.17	<0.01	28
16	ψ (habitat, array), γ(habitat, array, transect), ε (habitat, array, transect), p (habitat, array, transect, survey)	85.57	<0.01	144

TABLE 2. Parameter estimates for occupancy (ψ), colonization (γ), and emigration (ε) rates for red-backed salamanders captured at the Little River, Hanover County, Virginia, 2011 – 2013, based on the three most competitive models.

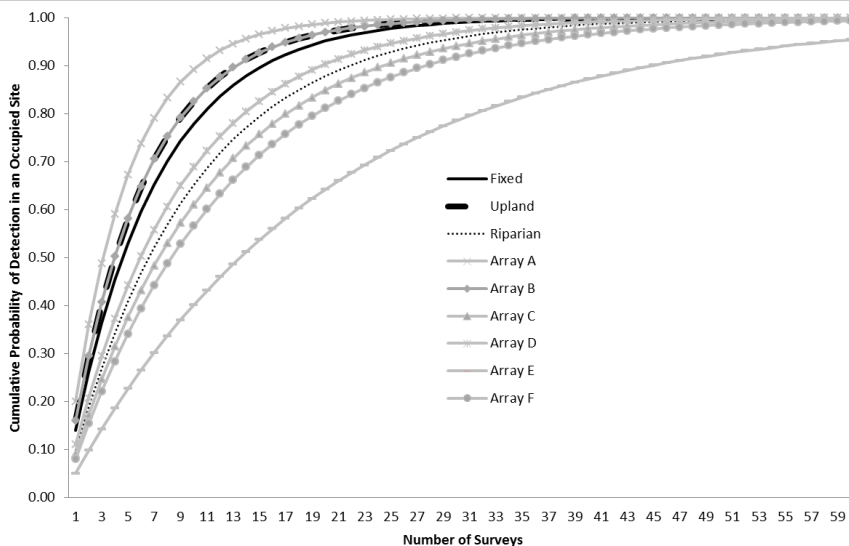| Model #	ψ. (SE)	γ_{fall} (SE)	γ_{spring} (SE)	ε_{fall} (SE)	ε_{spring} (SE)
1	0.08 (0.08)	0.23 (0.05)	0 (0)	0 (0)	0.21 (0.05)
2	0.09 (0.09)	0.28 (0.07)	0 (0)	0 (0)	0.20 (0.05)
3	0.08 (0.07)	0.21 (0.04)	0 (0)	0 (0)	0.21 (0.05)
Average	0.08 (0.08)	0.24 (0.07)	0 (0)	0 (0)	0.21 (0.07)

Figure 1. The relationship between the number of surveys completed for a given transect and the cumulative probability of detecting an individual assuming it is occupying a natural cover object in that transect. Each line is based on the detection probability estimated for the three top performing models for data collected on red-backed salamanders captured at the Little River, Hanover County, Virginia, 2011 – 2013. Model 1 detection rates differed by habitat (upland v. riparian, model 2 detection rates differed by transect array location (A – F), and model 3 detection rate was fixed for all transects. On average, 26.24 ± 3.94 SE surveys would be required to detect an occupying individual with 95% confidence.

DISCUSSION

Based on the best performing models, occupancy rates were low at the beginning of the study but improved through colonization during autumn, with no emigration from transects until spring when emigration rates rose with no new colonizations.   Moore et al. (2001) also found a peak in red-backed salamander detections under cover objects in autumn. Males establish territories for feeding associated with cover objects, using them as moisture refuges during short dry periods rather than migrating below the soil surface where prey is presumably limiting (Jaeger, 1980; Kleeburger and Werner, 1982). The increase in detections and colonization of cover objects in autumn may be a response to improving moisture conditions or feeding opportunities, with the loss of those conditions in late spring likely resulting in a movement below ground (Blanchard, 1928; Taub, 1961).

Initial occupancy rates were consistent across models and relatively low in comparison to Bailey et al. (2004b) for the congener *Plethodon serratus* ($\psi = 0.76 \pm 0.07$

SE) in the Great Smoky Mountain National Park (GSMNP). This highlights the need to estimate independent occupancy parameters for monitoring programs. Our fall line study site habitat differs from the montane forest habitat of GSMNP, and is likely much poorer habitat for red-backed salamanders. If multi-site monitoring programs can be established for a region of interest, a short-term intensive study to establish parameter estimates may offset some uncertainty in subsequent monitoring and management actions (Grant et al., 2013).

The model uncertainty in this study was associated with detection probabilities, which may primarily be a function of habitat, location of transects, or simply constant. Burnham and Anderson (2002) suggest that in situations where similarly competitive models differ by only 1 parameter, and have similar maximized log likelihoods, the most parsimonious model should be preferred. This would imply that the constant p model (model 3) may be preferred over the habitat model (model 1). My study site is rather flat, with upland and riparian sites differing by only about 50 m, and thus the constant p does not markedly differ between the upland and riparian estimates. The array model (model 2), however, differs from the habitat model by 3 parameters, incurring a substantial cost under an AIC rubric while still performing as well. The high performance of this model suggests that p differs not only by habitat, but also by the sites in which transects are placed. Arrays were not far away from each other, with all arrays within an area of 3.2 ha. This would imply that even highly localized conditions can affect the probability of detection, supporting Bailey et al. (2004b) in their inference that multiple factors are acting to vary detection probabilities. This creates a problem for designing sampling protocols because the detection probability is likely to vary substantially across survey sites. Determining occupancy will require substantial survey replication, particularly in areas that will have low detection probabilities. Unfortunately, those areas likely to suffer from both low occupancy and low detection rates may also be those in most need of active management and monitoring (Lesica and Allendorf, 1995; Channell, 2004; Hampe and Petit, 2005). Researchers monitoring salamander species near the edge of their ranges or close to poor quality habitat may need to allocate their surveys accordingly. Our results suggest this can be accomplished on average with 26 surveys, though possibly more may be required if site-specific differences are substantial.

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