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Exploratory Modeling Indicates Red-Backed Salamander Detections are Sensitive to Soil pH at C. F. Phelps Wildlife Management Area, Virginia

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ABSTRACT

Red-backed salamanders represent an important component of Virginia ecosystems, but there are few habitat models that can reliably predict the presence/absence of this species. We surveyed the habitats of red-backed salamanders at one site in the Piedmont region of Virginia and collected data on an array of habitat variables with which this species is normally associated. We used logistic regression to develop a model predicting the presence or absence of the species at a given 50m-transect. Our final model incorporated soil organic layer pH variability and mineral layer average pH, and accounted for 30% of the variation in our data. We conclude that soil pH is a limiting determinant of habitat use for this study site, and that it may affect adaptive behaviors for highly acidic soils.

INTRODUCTION

As researchers address the issues of amphibian decline, there is an increasing need to better understand how salamanders in terrestrial ecosystems interact with their habitat. Greater understanding of the habitat ecology of these species would likely improve our ability to manage and conserve amphibian diversity in local watersheds, thereby reducing the ecosystem damage that would result from the loss of these species (Cushman 2005, Wyman 1990).

In the Rappahannock River watershed of Northern Virginia, both Mitchell (1998) and McGhee and Killian (2010) have surveyed amphibian, and specifically, salamander diversity, but little has been done to assess the habitat relationships of commonly detected species. To address this need, we conducted a preliminary study of salamander habitat for a single site in the Rappahannock River drainage at the C. F. Phelps Wildlife Management Area (WMA) concurrent with a species diversity survey and developed a simple habitat model for our most commonly detected terrestrial salamander, *Plethodon cinereus* Green 1818 (red-backed salamander).

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The red-backed salamander is common to Virginia forests and the Rappahannock River watershed, and is considered an important component of the local ecosystems in which they occur (Burton and Likens 1975, Davic and Welsh 2004). While several studies have noted particular habitat features associated with this species, such that a hypothetical niche-gestalt can be conceptualized (James 1971), only a few studies have actually developed predictive models of habitat use, primarily to compare the effects of silviculture treatments (Demaynadier and Hunter 1998, Morneault et al. 2004, McKenney et al. 2006).

The red-backed salamander occurs in the leaf-litter and well-drained soil underlying deciduous, northern conifer, and mixed deciduous-coniferous forests with numerous cover objects (logs and rocks) and little underbrush (Burger 1935, Petranka 1998, Richmond and Trombulak 2009). This lungless salamander is dependent on gas exchange through the skin for respiration, and is sensitive to moisture and temperature shifts, typically adjusting to these changes by moving vertically through the soil column (Taub 1961, Heatwole 1962, Spotila 1972). They tend to prefer a neutral soil pH, cooler temperatures and ready access to lower soil layers as predation refugia (Bogert 1952, Heatwole 1962, Spotila 1972, Wyman and Hawksley-Lescault 1987). Females attach eggs within natural crevices or beneath embedded rocks or decaying logs (Petranka 1998).

We wished to determine whether we could successfully predict red-backed salamander occurrence at a given site using variables associated with these general habitat features known to be key components in their ecology. We hypothesized that red-backed salamanders would be detected in leaf litter associated with cover objects and moist, cool soil conditions of neutral pH. We predicted that a logistic regression model would include variables measuring the amount of coverage by cover objects, soil moisture, and soil ph.

METHODS

We used transect sampling to locate salamanders (Jaeger 1994, Jaeger and Inger 1994, Mitchell 2000). We randomly selected the starting location of transects using a GPS. We sampled transects by searching five 1-m^2 quadrats placed randomly within 10m increments (Jaeger 1994, Jaeger and Inger 1994, Mitchell 2000). We searched quadrats by removing large cover objects (rocks and decaying wood) and searching leaf litter (Mitchell 2000). We identified captured salamanders to species, and measured snout-vent length and total length to estimate and assign age-classes (Petranka 1998, Moore and Wyman 2010).

We collected habitat data at both the transect-level and the quadrat-level. Transect-level data included air temperature, air pressure, relative humidity, vapor pressure deficit (vapor pressure deficit represents the difference between the actual moisture in the air and the amount of moisture the air could hold when saturated at a given temperature: Bellis 1962), degree and direction of slope, general weather (clear, partly cloudy, overcast, light rain, heavy rain), and habitat (coniferous, mixed deciduous, mixed coniferous-deciduous, open-field/*Rosa multiflora* brush). Quadrat-level data included soil pH, soil moisture, soil temperature, leaf litter depth, and percent cover (bare ground, leaf litter, natural cover, ground vegetation, and woody stem).

We determined soil pH and soil moisture of cored soil samples in a laboratory. Soil samples were obtained by taking 31.7 mm diameter soil probe cores from a quadrat until sufficient soil was obtained to fill two collection tubes (50 mL centrifuge tubes) with separate organic and mineral fractions. In the laboratory each fraction was thoroughly mixed followed by division into two approximately equal parts—one for percent soil moisture and one for ph. Percent soil moisture was determined by massing the wet samples followed by drying for 24 hours in a 50˚C oven. Soil pH was determined using a Barnant 20 digital pH meter. The sample (placed in the centrifuge tube) was covered with enough distilled water to keep the pH probe above the sediment. We waited for 20 minutes to allow the more coarse soil particles to settle out. We then measured the pH after the reading stabilized, but not to exceed 1 minute. We measured leaf litter depth using a ruler placed once within a randomly chosen quadrant of the quadrat. We used the Daubenmire (1959) method to estimate ground cover within quadrats.

As we had little information from which to base hypotheses regarding habitat selection at this site, we used logistic regression as an exploratory modeling approach to determine which predictor variables were most associated with captured salamanders at the transect level. For variables measured at the quadrat level, we tested both mean values and their standard deviations as predictors. From our data we created new multiplicative variables where synergistic effects seemed likely (synergistic variable 1: soil temperature*organic layer soil moisture*mineral layer soil moisture, synergistic variable 2: organic-layer soil pH*organic layer soil moisture). We used forward stepwise selection ($P = 0.05$ to enter and 0.10 to remove) in SPSS (SPSS Inc., Chicago IL). Variable coefficients were assessed using the change in -2 loglikelihood (Hosmer and Lemeshow 1989). The explanatory value of the selected model was evaluated using Nagelkerke's r^2 (Hosmer and Lemeshow 1989, Nagelkerke 1991, Ryan 1997). For all statistical analyses, detection refers to whether a species was captured or not, as opposed to the number of captures; $\alpha = 0.05$.

RESULTS

From 13 April 2007 – 21 April 2009, we sampled 91 transects and 455 quadrats, locating 42 red-backed salamanders. We found individuals in 26 of 91 transects (29% encounter rate). Mean SVL for captured adults was 40.06mm ± 0.90 SE while mean SVL for captured juveniles was 27.33mm ± 1.40 SE. Our logistic regression selected a model that explained 30% of the variation in the data ($r^2 = 0.30$) and produced two predictor variables. The first was the standard deviation of organic soil layer pH (SDOrgpH: 6.50 ± 2.38 SE, change in -2 log likelihood = 9.350, df = 1, $P = 0.002$, Fig. 1). The second was the average mineral soil layer pH (AvgMinpH: -1.80 ± 0.92 SE, change in -2 log likelihood = 6.376, df = 1, $P = 0.012$, Fig 2). The model defined the probability of predicting the detectable presence of a red-backed salamander within a transect as equal to

$$\frac{1}{1 + e^{-(5.42 + 6.50\ \text{SDorph} - 1.80\ \text{Avg Min pH})}}$$

. It correctly predicted the absence of salamanders in 81% of cases, and correctly predicted their presence in 37% of cases.

Soils throughout the study site tended to be acidic. The average organic layer soil pH across all transects was 4.62 ± 0.10 SE, and the average mineral layer soil pH was

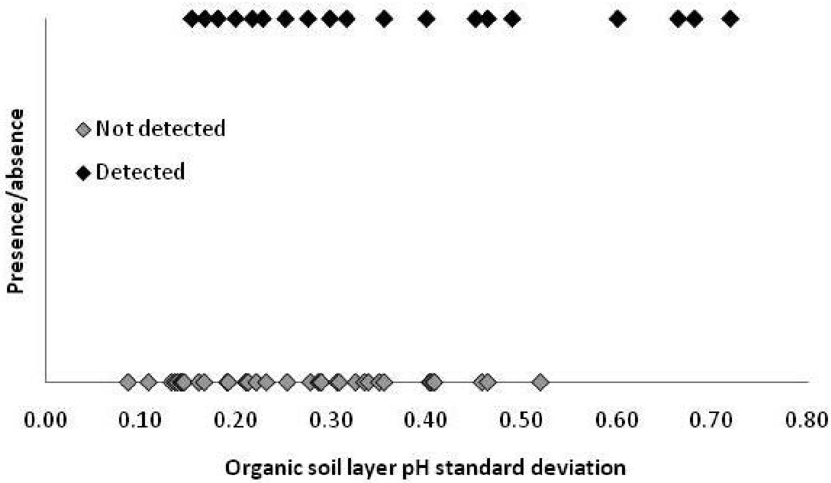

FIGURE 1. Detection of red-backed salamanders as a function of the variability (standard deviation) in pH of the organic layer of soil for transects on C. F. Phelps Wildlife Management Area, Fauquier and Culpeper County, Virginia, April 2007 – April 2009. Detections tend to increase with increased variation in soil acidity.

4.57 ± 0.08 SE. The pH of the organic and mineral layers were highly correlated ($r = 0.93$) and 77% of our sites had organic fractions with pH $\leq$ 5 and 83% of the sites had mineral fractions with pH $\leq$ 5. All of our captures were in soils with a pH between 3.5 and 6.5 for the organic layer and between 3.9 and 5.3 for the mineral layer.

DISCUSSION

The model explained a substantial amount of the variation in presence and absence data. Haan et al. (2007) found similar results in their investigation of *Aneides hardii* Taylor 1941 (Sacramento salamander) where the best of 18 models were able to explain only up to 37% of the variation in salamander detections. Their models tended to focus on soil moisture and soil temperature. However, Faccio (2003) found that *Ambystoma jeffersonianum* Green 1827 (Jefferson salamander) and *Ambystoma maculatum* Shaw 1802 (spotted salamander) presence could be correctly predicted 93.5% of the time based on leaf litter cover, natural cover objects, soil moisture, slope and vertical tunnel abundance. This suggests habitat is a complex multivariate component of terrestrial salamander ecology and that a wide array of habitat features is required to predict their presence. However, our model was more narrow than Faccio (2003) and Haan et al. (2007), focusing entirely on soil pH. This implies that soil pH is particularly important for this area, at least in terms of determining the habitat red-backed salamanders tended to avoid. The low pH in this area may have been a limiting factor that effectively drowned out the signal of all other important habitat features. Our results showing that red-backed salamanders were found only in the sites with lowest mineral soil pH was unexpected. Salamanders are generally thought to prefer neutral soils (Wyman and

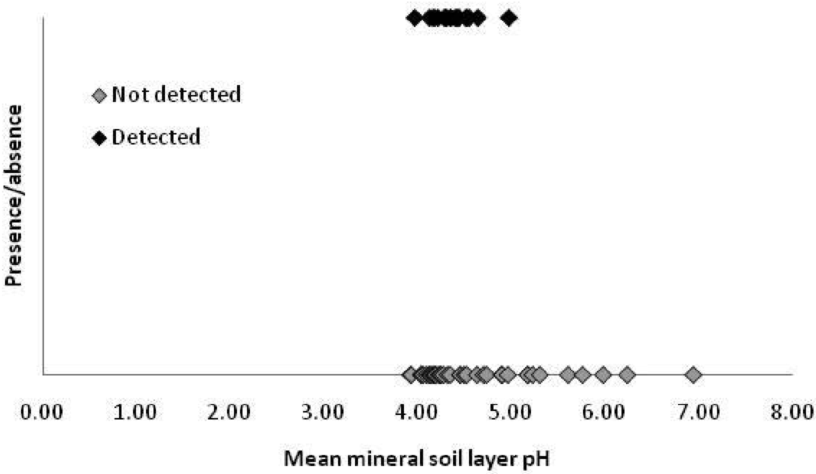

FIGURE 2. Detection of red-backed salamanders as a function of the average pH of the mineral layer of soil for transects on C. F. Phelps Wildlife Management Area, Fauquier and Culpeper County, Virginia, April 2007 – April 2009. Detections tend to decrease as soils become increasingly neutral.

Hawksley-Lescault 1987, Wyman 1990, Sugalski and Claussen 1997). Sugalski and Claussen found that pH was a primary determinant of wild-caught red-backed salamander location in environmental sub-chambers with varying levels of pH, soil moisture and light levels. Wyman and Hawksley-Lescault (1987) found that soils with pH ranging 2.5 – 3 could be lethal for red-backed salamanders and that growth was chronically reduced 45 – 60% in soils of pH 3 – 4. Moore and Wyman (2010) however, described a seemingly healthy population of red-backed salamanders using coverboards overlaying low pH soils (3.1 – 5.2). Our SVL measurements and capture rates are very similar to theirs, implying our population is comparably healthy in generally low pH soils. Moore and Wyman (2010) suggested two hypotheses to explain their findings: 1) other soil constituents counterbalanced the low pH, and 2) the population was locally adapted to low pH soils.

Our model suggests a third: that highly acidic soil is harmful, but individual red-backed salamanders avoid these areas by moving into microhabitats with higher pH's. The variability in organic soil pH across quadrats within in a transect may be picking up on a pattern of soil pH variation that allows individuals to take refuge in high pH sites away from chronically low pH sites, such as movements from chronically low pH mineral soil layers, to more variable (and favorable) organic soil layers, thereby becoming more detectable. This would simultaneously explain the great importance of soil pH in the model, the positive relationship between detections and organic layer soil pH variation and the negative relationship between detections and mean mineral layer soil pH.

The Rappahannock River watershed overlays the Virginia Gold-Pyrite Belt, a geologic formation extending from Fairfax County 225 km southwest to Buckingham County. Gold mining occurred in the watershed region, primarily in the mid-1800's (Sweet 1971). C.F. Phelps WMA contains some abandoned open-pit gold mines, which may explain, in part, the low pH there (Sweet 1980), but because there is little information regarding how extensive the tailings from these mines were, their contribution to the preponderance of low pHs observed at our site is unclear. Nevertheless, our findings imply that a site-specific condition such as pH is an important determinant of the habitat ecology of local amphibian populations. The need to determine the behavioral and adaptive responses of amphibians to soil pH is even more urgent given increasing forest acidification, whether due to mining activity or acidic precipitation (Fenn et al. 2006, Connelly et al. 2007).

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LITERRURE CITED

Bellis, E.D. 1962. The influence of humidity on wood frog activity. American Midland Naturalist 68:139–148.

Bogert, C.M. 1952. Relative abundance, habitats, and normal thermal levels of some Virginia salamanders. Ecology 33:16–30.

Burger, J.W. 1935. *Plethodon cinereus* (Green) in eastern Pennsylvania and New Jersey. The American Naturalist 64:578–586.

Burton, T.M., and G.E. Likens. 1975. Salamander populations and biomass in the Hubbard Brook Experimental Forest, New Hampshire. Ecology 56:1068–1080.

Connolly, S.J., T.C. Cain, J.S. Vestal, and P.J. Edwards. 2007. The potential effects of acid deposition: What's a national forest to do? Pp. 428–437, *In* M. Furniss, C. Clifton, and K. Ronnenberg (Eds.) Advancing the Fundamental Sciences: Proceedings of the Forest Service National Earth Sciences Conference.

Cushman, S.A. 2005. Effects of habitat loss and fragmentation on amphibians: A review and prospectus. Biological Conservation 128:231–240.

Daubenmire, R.F. 1959. Canopy coverage method of vegetation analysis. Northwest Science 33:43-64.

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

Demaynadier, P.G. and M.L. Hunter Jr. 1998. Effects of silvicultural edges on the distribution and abundance of amphibians in Maine. Conservation Biology 12:340–352.

Faccio, S.D. 2003. Postbreeding emigration and habitat use by Jefferson and spotted salamanders in Vermont. Journal of Herpetology 37:479–489.

Fenn, M.E., T.G. Huntington, S.B. McLaughlin, C. Eagar, A. Gomez, and R.B. Cook. 2006. Status of soil acidification in North America. Journal of Forest Science 52:3–13.

Haan, S.S., M.J. Desmond, W.R. Gould, and J.P. Ward, Jr. 2007. Influence of habitat characteristics on detected site occupancy of the New Mexico endemic Sacramento Mountains salamander, *Aneides hardii*. Journal of Herpetology 41:1–8.

Heatwole, H. 1962. Environmental factors influencing local distribution and activity of the salamander, *Plethodon cinereus*. Ecology 43:460–472.

Hosmer Jr., D.W. and S. Lemeshow. 1989. Applied Logistic Regression. John Wiley and Sons, New York.

Jaeger, R.G. 1994. Transect sampling. Pages 103–106 *in* W. R. Heyer, M.A. Donnelly, R.W. McDiarmid, L.C. Hayek, and M.S. Foster, editors. Measuring and monitoring biological diversity: standard methods for amphibians. Smithsonian Institution Press, Washington, D. C.

Jaeger, R.G. and R. F. Inger. 1994. Quadrat sampling. Pages 97–102 *in* W. R. Heyer, M.A. Donnelly, R.W. McDiarmid, L.C. Hayek, and M.S. Foster, editors. Measuring and monitoring biological diversity: standard methods for amphibians. Smithsonian Institution Press, Washington, D. C.

James, F.C. 1971. Ordinations of habitat relationships among breeding birds. Wilson Bulletin 83:215–236.

McGhee, J.D. and M.D. Killian. 2010. Salamander diversity at C. F. Phelps wildlife management area, Fauquier and Culpeper counties, Virginia. Northeastern Naturalist 17:629–638.

McKenney, H.C., W.S. Keeton, T.M. Donovan. 2006. Effects of structural complexity enhancement on eastern red-backed salamander (*Plethodon cinereus*) populations in northern hardwood forests. Forest Ecology and Management 230:186–196.

Mitchell, J.C. 1998. Amphibian decline in the Mid-Atlantic Region: monitoring and management of a sensitive resource. Final Report, Legacy Resource Management Program, U. S. Department of Defense, Arlington, Virginia.

Mitchell, J.C. 2000. Amphibian monitoring methods & field guide. Smithsonian National Zoological Park Conservation and Research Center, Front Royal, Virginia.

Moore, J.D. and R.L. Wyman. 2010. Eastern red-backed salamanders (*Plethodon cinereus*) in a highly acid forest soil. American Midland Naturalist 163:95–105.

Morneault, A.E., B.J. Naylor, L.S. Schaeffer, and D.C. Othmer. 2004. The effect of shelterwood harvesting and site preparation on eastern red-backed salamanders in white pine stands. Forest Ecology and Management 199:1–10.

Nagelkerke, N.J.D. 1991. A note on the general definition of the coefficient of determination. Biometrika, 78:691-692.

Petranka, J.W. 1998. Salamanders of the United States and Canada. Smithsonian Institution Press, Washington, D. C.

Richmond, L.S. and S. C. Trobulak. 2009. Distribution of red-backed salamander (*Plethodon cinereus*) with respect to cover-object characteristics inthe Green Mountains of Vermont. Northeastern Naturalist 16:13–26.

Ryan, T.P. 1997. Modern regression methods. John Wiley and Sons, Inc. New York.
Spotila, J.R. 1972. Role of temperature and water in the ecology of lungless salamanders. Ecological Monographs 41:95–125.

SPSS for Windows, Rel. 11.0.1. 2001. Chicago: SPSS Inc.

Sugalski M. T. and D. L. Claussen. 1997. Preference for soil Moisture, soil pH, and light intensity by the salamander, *Plethodon cinereus*. Journal of Herpetology 31:245-250.

Sweet, P.C. 1971. Gold mines and prospects in Virginia. Virginia Minerals 17:25–33.

Sweet, P.C. 1980. Gold in Virginia. Virginia Division of Mineral Resources Publication 19. Charlottesville, Virginia.

Taub, F.B. 1961. The distribution of the red-backed salamander, *Plethodon cinereus*, within the soil. Ecology 42:681–698.

Wyman, R.L. 1990. What's happening to the amphibians? Conservation Biology 4:350–352.

Wyman, R.L. and D. S. Hawksley-Lescault. 1987. Soil acidity affects distribution, behavior, and physiology of the salamander *Plethodon cinereus*. Ecology 68:1819–1827.