ELEVATION, ASPECT, AND COVE SIZE EFFECTS ON SOUTHERN APPALACHIAN SALAMANDERS

W. Mark Ford [1], Michael A. Menzel [2], and Richard H. Odom [3]

ABSTRACT - Using museum collection records and variables computed by digital terrain modeling in a geographic information system, we examined the relationship of elevation, aspect, and "cove" patch size to the presence or absence of 7 common woodland salamanders in mature cove hardwood and northern hardwood forests in the southern Appalachians of Georgia, North Carolina, and South Carolina. Overall, elevation, aspect and patch size were poor discriminators among salamander species presence or absence at collection sites. Increased elevation was an important variable explaining the presence of Ocoee salamanders (*Desmognathus ocoee*) and Jordan's salamanders (*Plethodon jordani*). In contrast, decreased elevation was an important variable explaining the presence of slimy salamanders (*Plethodon glutinosus*). Our study contrasts with recent research indicating that suitable habitat patch size is an important determinant of woodland salamander species richness and abundance at recently disturbed sites. In these mature stands, we believe that cove patch size as determined by modeling either was well above effect-level thresholds for influencing individual species presence or our modeling failed to reflect true collection site conditions.

INTRODUCTION

The ecological importance of woodland salamanders (Family: Plethodontidae) in the Appalachians is well recognized (Burton and Likens 1975). Currently, there are troubling indications of world-wide amphibian declines (including salamanders) attributed to a variety of factors, such as habitat degradation, global climate change, and increased UV radiation (Alford et al. 2001, Blaustein et al. 1994, deMaynadier and Hunter 1995, Houlahan et al. 2000). In the southern Appalachians, Petranka et al. (1993, 1994) asserted that 50–70 years of regrowth after timber harvest was necessary for woodland salamander populations to fully recover from the impacts of clearcutting. Ash (1988) and Harpole and Haas (1999) showed that woodland salamanders declined significantly following timber harvest on xeric to sub-mesic oak (*Quercus*)-dominated forests at mid-elevations in the region.

---

[1] USDA Forest Service, Northeastern Research Station, Box 404, Parsons, WV 26287; mford@fs.fed.us. [2] Division of Forestry, West Virginia University, Box 6125, Morgantown, WV 26506; mamenzel@juno.com. [3] Questerra, Inc., 210 Ridge-McIntire Road, Suite 500, Charlottesville, VA 22903; rhodom @questerra.com.

Using retrospective analysis across a variety of stand-ages on mesic, cove-hardwood sites with museum collection records, Ford et al. (2002) indicated that the abundance and species richness of woodland salamanders was reduced in stands < 50 years old relative to older stands. Moreover, the extent of high-quality cove hardwood habitat and cove patch size as determined by landform analysis also were important factors shaping salamander community recovery after disturbance. Woodland salamander communities may recover more quickly or are less susceptible to localized extirpation if disturbed stands are within a larger matrix of undisturbed cove habitat. Although supported by little quantitative data, woodland salamander communities in the Appalachians are thought to be influenced by environmental factors other than overstory stand-age, such as elevation, overstory type, slope position, and geomorphic surface (Hairston 1949, Harper and Guynn 1999, Moore et al. 2001).

Greater knowledge of these habitat factors from a landscape perspective will be critical to better understand woodland salamander ecology and how forest management, recreation management and mining activities in the southern Appalachians and elsewhere can be modified to minimize negative impacts to woodland salamander communities. The objective of our study was to investigate the influence that elevation, aspect, and cove patch size in mature (> 50 years) cove hardwood and northern hardwood forests, as determined by a geographic information system (GIS), had on the presence and absence of common woodland salamander species in the southern Appalachians of Georgia, North Carolina, and South Carolina.

METHODS

We obtained woodland salamander records from the University of Georgia Museum of Natural History for 50 sites in the Blue Ridge physiographic province of the southern Appalachians in northern Georgia (Fannin, Gilmer, Lumpkin, Rabun, Towns, Union, and White Counties), southwestern North Carolina (Cherokee, Clay, Macon, and Jackson counties), and northwestern South Carolina (Pickens County). We selected collection sites where we had *a priori* knowledge of forest type as determined by previous site visits and vegetation classification (Barker 1997, Ford et al. 2000, Ford et al. 2002, Laerm et al. 1999) and condition and completeness of museum specimen accession. Woodland salamanders were an unintentional by-product collected in pitfall traps during a large soricid ecology study of the southern Appalachians over the past decade (Laerm et al. 1999). Soricid collection methods using 946 cm^2 plastic containers set along emergent rock and coarse woody debris are described elsewhere (McCay et al. 1998). Overall, these surveys encompassed >100,000 trapnights (range = 420 to 4,620 trapnights across 50 sites) and recorded 7,945 specimens of 17 plethodontid species. However, we restriced our analyses to 7 species that were distributed throughout most (≥ 75%) of the region and were present at ≥10 collection sites. These included: seepage salamanders (*Desmognathus aeneus*), seal salamanders (*D. monticola*), Ocoee salamanders (*D. ocoee*), black-bellied salamanders (*D. quadramaculatus*), northern two-lined salamanders (*Eurycea bislineata*), slimy salamanders (*Plethodon glutinosus*) and Jordan's salamanders (*P. jordani*). Examples of excluded species included the green salamander (*Aneides aeneus*) that occurred regionally in small disjunct populations in rock crevice habitat (Hafer and Sweeny 1993; Corser 2001) not sampled in the aforementioned surveys and the southern red-backed salamander (*P. serratus*) that was distributed only in the western portion of the region (Barker 1997, Petranka 1998). Many salamanders in the southern Appalachians, such as slimy salamander and Jordan's salamander are members of semi-species complexes that show considerable genetic differentiation across their distributions (Highton 2000). However, for the purpose of this paper, we follow the conservative single-species designation provided by Petranka (1998). Our study avoids taxonomic problems with the northern two-lined salamander, as our museum collection data were gathered completely within the range of the *E. bislineata wilderae* subspecies (Petranka 1998).

Salamander collection sites were located in cove hardwood and northern hardwood forests. Cove hardwood overstories were dominated by yellow poplar (*Liriodendron tulipifera*), northern red oak (*Q. rubra*), red maple (*Acer rubrum*), yellow buckeye (*Aesculus octandra*), white ash (*Fraxinus americana*), basswood (*Tilia heterophylla*) and silverbell (*Halesia carolina*). Except along larger creeks where an eastern hemlock (*Tsuga canadensis*) overstory sometimes was present, these sites had sparse ericaceous shrub layers and abundant understory herbaceous cover (Ford et al. 2000, Ford et al. 2002). Regionally, cove hardwoods occurred at low to mid-elevations (400 m to 1,200 m) in sheltered ravines, hollows, and north-facing sideslopes. Northern hardwood sites were dominated by yellow birch (*Betula alleghaniensis*), black birch (*B. lenta*), American beech (*Fagus grandifolia*), and eastern hemlock, along with moderate to dense striped maple (*Acer pennsylvanicum*), mountain maple (*A. spicatum*) and rhododendron (*Rhododendron maximum*) shrub layers. Northern hardwoods occurred at high elevations (1,200 m to 1,600 m) at a variety of aspects and slope positions, but were most common on north-facing sites in landforms similar to cove hardwoods, especially where relict Pleistocene boulderfields were present (Wharton 1978). Regionally, these forest stands that are located in north-facing sheltered ravines and hollows are known as "coves." Creeks, springs, and seeps that could influence salamander abundance and species richness in the region, were common landscape features within or near all collections sites.

For each collection site, we used digital terrain modeling within a GIS to compute elevation, aspect and landform metrics following techniques described by McNab (1993). Aspect was linearized using the formula [1-cosine(aspect in degrees)]+[1-sine(aspect in degrees)] so that mesic, northeasterly aspects had the lowest values and xeric, southwesterly aspects had the highest values. We calculated the contiguous cove patch size that we believed to constitute good woodland salamander habitat for a variety of species using landform index and plot surface shape values (Odom and McNab 2000). Landform index was a measure of the degree to which a site is sheltered by surrounding landforms. Plot surface shape was a measure of site convexity or concavity. Coves were defined as any area with a landform index ≥ 0.25 or landform index < 0.25 but > 0.15 with a plot surface shape < -0.25. Odom and McNab (2000) found that elevation and landform metrics correctly predicted cove hardwood, northern hardwood and red spruce (*Picea rubens*) forest types in the Balsam Mountains of western North Carolina at a classification rate of 85%.

Table 1. Mean elevation (m), transformed aspect (see text), and cove patch size (ha) at 50 mature cove hardwood and northern hardwood forest collection sites by woodland salamander presence and absence categories in the southern Appalachians of Georgia, North Carolina, and South Carolina, 1993-1999.

	Present		Absent		
	$\bar{X}$	*SE*	$\bar{X}$	*SE*	*P*[1]
Seepage salamander (24, 26)[2]					
Elevation	972.17	26.04	1088.23	54.75	0.24
Transformed aspect	1.77	0.17	1.92	0.20	0.65
Cove patch	37.66	16.46	142.67	40.69	0.44
Seal salamander (10, 40)					
Elevation	919.00	52.84	1060.90	35.50	0.08
Transformed aspect	2.19	0.27	1.77	0.02	0.14
Cove patch	45.25	28.68	104.01	28.44	0.46
Ocoee salamander (34, 16)					
Elevation	1094.26	35.14	901.31	54.01	0.01
Transformed aspect	1.86	0.15	1.82	0.27	0.81
Cove patch	88.76	24.38	99.69	53.84	0.19
Black-bellied salamander (11, 39)					
Elevation	1025.55	41.31	1034.49	39.41	0.76
Transformed aspect	1.91	0.18	1.83	0.16	0.71
Cove patch	71.47	33.41	98.12	28.86	0.37
Northern two-lined salamander (37, 13)					
Elevation	1016.54	34.82	1078.00	73.36	0.46
Transformed aspect	1.82	0.16	1.94	0.23	0.72
Cove patch	66.41	21.49	165.86	64.69	0.36
Slimy salamander (29, 21)					
Elevation	952.68	32.26	1142.76	53.58	0.003
Transformed aspect	1.76	0.18	1.98	0.25	0.44
Cove patch	57.08	28.91	140.84	37.76	0.08
Jordan's salamander (27, 23)					
Elevation	1147.07	45.14	898.04	23.95	0.001
Transformed aspect	1.95	0.18	1.73	0.20	0.47
Cove patch	133.11	32.56	44.31	32.10	0.09

[1] Wilcoxon test. [2] Sites present and sites absent.

Because our data were non-normally distributed, we used non-parametric Wilcoxon tests (Steel and Torrie 1980) to compared elevation, aspect, and cove patch size of sites by woodland salamander species' presence or absence. When Wilcoxon tests indicated significant differences ($P < 0.05$) in median values between presence and absence categories among woodland salamander species, we used logistic regression to examine the strength of the relationship (SAS 1995).

RESULTS

Elevation, aspect or cove patch size did not differ among collection sites with and without seepage salamanders, seal salamanders, black-bellied salamanders, and northern two-lined salamanders (Table 1). Ocoee salamander and Jordan's salamander presence increased in frequency at collection sites with higher elevations (Table 1). Slimy salamanders occurred at sites of lower elevations (Table 1). Higher elevations were related to a higher probability with a good model fit for Ocoee salamander presence (rescaled $R^2 = 0.24$, $\chi^2 = 12.04$, $df = 8$, $P = 0.15$) and Jordan's salamander presence (rescaled $R^2 = 0.42$, $\chi^2 = 3.28$, $df = 8$, $P = 0.92$). The opposite relationship (with a good model fit) was true for slimy salamanders (rescaled $R^2 = 0.23$, $\chi^2 = 8.34$, $df = 8$, $P = 0.40$) (Fig. 1). Correct classification rates for determining presence and absence of Ocoee sala-

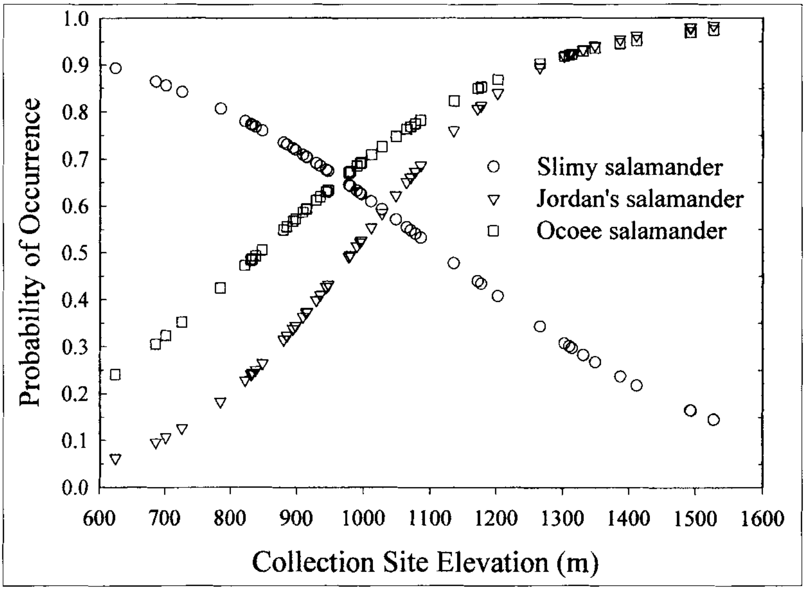

Figure 1. Probability of slimy salamander, Jordan's salamander, and Ocoee salamander presence along an elevational gradient at 50 mature cove hardwood and northern hardwood forest collection sites in the southern Appalachians of Georgia, North Carolina, and South Carolina, 1993-1999.

mander, Jordon's salamander, and slimy salamander as determined by collection site elevation were 76%, 76%, and 72%, respectively.

DISCUSSION

The occurrence of many terrestrial species and species richness values as linked to habitat patch size has been demonstrated in numerous landscapes across a range of taxa (Davies et al. 2000, Jansson and Anglestam 1999, Heaney 2001, Yates et al. 1997). Moreover, delineations of minimum patch size thresholds where species extirpation occurs have become central issues in wildlife ecology and conservation biology, particularly with rare, threatened, endangered, and sensitive non-game species (Conner et al. 2000, Forys and Humphrey 1999, Lindemayer et al. 1999). Within the southern Appalachians, woodland salamander communities rank high in conservation concern (Bratton and Meier 1998); therefore, determining these habitat patch size relationships and effect thresholds could be critical for long-term management and conservation.

Based on cove size and woodland salamander species richness relationships discovered by Ford et al. (2002) and woodland salamander-habitat fragmentation dynamics described by Bratton and Meier (1998), we expected to see strong relationships between woodland salamander species presence and cove size. We believe this failure represented our inability to fully predict or link mesic forest conditions to our generated landform metrics. Our GIS analytical techniques have been shown to correctly classify southern Appalachian overstory types based on landform metrics (Odom and McNab 2000). However, many collection site metrics indicated sub-mesic conditions even though overstories actually were cove hardwood or northern hardwood communities. Small cove patches were joined to form large patches of suitable woodland salamander habitat by the numerous seeps and 1st order streams found throughout our collection areas, similar to riparian corridor linkages noted for other habitat types and herpetofaunal communities (Burbrink et al. 1998). Most woodland salamander species we studied had small core territories ($\leq$ 10 m^2) and probably were linked closely to microsite conditions (Petranka 1998, Harper and Guynn 1999). Accordingly, we believe our estimates of suitable habitat patch size were overly conservative for many collection sites. From a functional perspective, any discernable cove size effect on salamander presence and absence was masked by the mixed scale and resolution of our data.

Being largely confined within or adjacent to riparian habitat in most southern Appalachian forests, seepage salamander, seal salamander and black-bellied salamander presence was linked to collection site location relative to seeps or streams rather than elevation, aspect, or cove patch size (Ford et al. 2002). To a lesser degree, the same could be true for northern two-lined salamanders, although this species will range far from water in the region (Wilson 1995). Ocoee salamanders also are associated with riparian areas at lower elevations, but can become abundant away from seeps and streams at elevations above 1,000 m as overall temperatures decrease and more moist conditions prevail (Petranka 1998). This readily explained the increased probability of Ocoee salamander presence with increasing elevation. Superficially, Jordan's salamanders and slimy salamanders are sympatric in distribution over the region covered by our collection sites. In reality, our data showed that these species largely were found at mutually exclusive sites. Based on the results of our logistic regression analyses, we suspect they exhibit a pattern of contiguous allopatry, as has been proposed for other taxa in the region (Ford et al. 2001, Pagels and Handley 1989). There is evidence to suggest that Jordan's salamander is a superior resource competitor to other species in the genus *Plethodon* in the slimy salamander complex at high elevations (Hairston 1980a, Hairston 1980b). The results of our study could aid future inquiries into these and other instances of interspecific competition or separation in woodland salamanders in the southern Appalachians.

ACKNOWLEDGMENTS

We thank K. Barker, T. Carter, N. Castleberry, S. Castleberry, N. Hicks, L. Lepardo, and L. Lewis for field and lab assistance. Access to archived museum records at the University of Georgia Museum of Natural History was graciously provided by L. McGhee. This study was funded by the USDA Forest Service's Chattahoochee National Forest, Southern Research Station's Wine Springs Ecosystem Management Project and the Northeastern Research Station's Timber and Watershed Laboratory.

LITERATURE CITED

ALFORD, R.A., P.M. DIXON, and J.H.K. PECHMAN. 2001. Global amphibian population declines. Nature 404:752-755.

ASH, A.N. 1988. Disappearance of salamanders from clearcut plots. Journal of the Elisha Mitchell Scientific Society 104:116–122.

BARKER, K.G. 1997. Relationships between salamander communities and cove hardwood stand age in the southern Appalachians. Unpubl. M.S. Thesis, University of Georgia, Athens, GA.

BLAUSTEIN, A.R., D.B. WAKE, and W.P. SOUSA. 1994. Amphibian declines: judging stability, persistence, and susceptibility of populations to local and global extinctions. Conservation Biology 8:60–71.

BRATTON, S.P., and A.J. MEIER. 1998. Restoring wildflowers and salamanders in southeastern deciduous forests. Restoration Management Notes 16:158–165.

BURBRINK, F.T., C.A. PHILLIPS, and E.J. HESKE. 1998. A riparian zone in southern Illinois as a potential dispersal corridor for reptiles and amphibians. Biological Conservation 86:107–115.

BURTON, T.M., and G.E. LIKENS. 1975. Salamander populations and biomass in the Hubbard Brook Experimental Forest, New Hampshire. Copeia 1975:541–546.

CONNER, E.F., A.C. COURTNEY, and J.M. YODER. 2000. Individuals-area relationships: the relationship between animal population density and area. Ecology 81:734–748.

CORSER, J.D. 2001. Decline of disjunct green salamander (*Aneides aeneus*) populations in the southern Appalachians. Biological Conservation 97:119–126.

DAVIES, K.F., C.R. MARGULES, and J.F. LAWRENCE. 2000. Which traits of species predict population declines in experimental forest fragments. Ecology 81:1450–1461.

deMAYNADIER, P.G., and M.L. HUNTER. 1995. The relationship between forest management and amphibian ecology: a review of the North American literature. Environmental Review 3:230–261.

FORD, W.M., R.H. ODOM, P.E. HALE, and B.R. CHAPMAN. 2000. Stand-age, stand characteristics, and landform effects on understory herbaceous communities in southern Appalachian cove-hardwoods. Biological Conservation 93:237–246.

FORD, W.M., M.A. MENZEL, T.S. McCAY, and J. LAERM. 2001. Contiguous allopatry of the masked shrew and southeastern shrew in the southern Appalachians: segregation along an elevation and habitat gradient. Journal of the Elisha Mitchell Scientific Society 117:20–28.

FORD, W.M., B.R. CHAPMAN, M.A. MENZEL, and R.H. ODOM. 2002. Stand-age and habitat influences on salamanders in Appalachian cove hardwood forests. Forest Ecology and Management 155:131–141.

FORYS, E., and S.R. HUMPHREYS. 1999. The importance of patch attributes and context to the management and recovery of an endangered lagomorph. Landscape Ecology 14:177–185.

HAFER, M.L.A., and J.R. SWEENY. 1993. Status of the green salamander in South Carolina. Proceedings of the Annual Conference of Southeastern Association of Fish and Wildlife Agencies 47:414–418.

HAIRSTON, N.G. 1949. The local distribution and ecology of the plethodontid salamanders of the southern Appalachians. Ecological Monographs 19:47–73.

HAIRSTON, N.G. 1980a. The experimental test of an analysis of field distributions: competition in terrestrial salamanders. Ecology 61:817–826.

HAIRSTON, N.G. 1980b. Evolution under interspecific competition: field experiments of terrestrial salamanders. Evolution 34:409–420.

HARPER, C.A., and D.C. GUYNN. 1999. Factors affecting salamander density and distribution within four forest types in the southern Appalachian Mountains. Forest Ecology and Management 114:245–252.

HARPOLE, D.N., and C.A. HAAS. 1999. Effects of seven silvicultural treatments on terrestrial salamanders. Forest Ecology and Management 114:349–356.

HEANEY, L.R. 2001. Small mammal diversity along elevational gradients in the Phillipines: an assessment of patterns and hypotheses. Global Ecology and Biogeography 10:15–39.

HIGHTON, R.C. 2000. Detecting cryptic species using allozyme data. Pp. 215–241, *In* R.C. Bruce, R.G. Jaeger and L.D. Houck (Eds). The biology of plethodontid salamanders. Kluwer Academic/Plenum Publishers, New York, NY.

HOULAHAN, J.E., C.S. FINDLAY, B.R. SCHMIDT, A.H. MEYER, and S.L. KUZMIN. 2000. Quantitative evidence for global amphibian declines. Nature 404:752–755.

JANSSON, G., and P. ANGLESTAM. 1999. Threshold levels of habitat composition for the presences of the long-tailed tit (*Aegithalos caudatus*) in a boreal landscape. Landscape Ecology 14:283–290.

LAERM, J., W.M. FORD, T.S. McCAY, M.A. MENZEL, L.T. LEPARDO, and J.L. BOONE. 1999. Soricid communities in the southern Appalachians. Pp. 177–193, *In* R.O. Eckerlin (Ed.) Proceedings of the Appalachian Biogeography Symposium. Virginia Museum of Natural History Special Publication # 7.

LINDENMAYER, D.B., R.B. CUNNINGHAM, M.L. POPE, and C.F. DONNELLY. 1999. The response of arboreal marsupials to landscape context: a large-scale fragmentation study. Ecological Applications 9:594–611.

McCAY, T.S., W.M. FORD, J. LAERM, and D. KRISHON. 1998. Comparison of methods used to sample shrews and the importance of habitat structure. Brimleyana 25:110–119.

McNAB, W.H. 1993. A topographic index to quantify the effect of mesoscale landform on site productivity. Canadian Journal of Forest Research 23:1100–1107.

MOORE, A.L., C.E. WILLIAMS, T.H. MARTIN, and W.J. MORIARITY. 2001. Influence of season, geomorphic surface and cover item on capture, size, and weight of *Desmognathus ochrophaeus* and *Plethodon cinereus* in Allegheny Plateau riparian forests. American Midland Naturalist 145:39–45.

ODOM, R.H., W.M. FORD, J.W. EDWARDS, C.W. STIHLER, and J.M. MENZEL. 2001. Developing a habitat model of the endangered Virginia northern flying squirrel (*Glaucomys sabrinus fuscus*) in the Allegheny Mountains of West Virginia. Biological Conservation 99:245–252.

ODOM, R.H., and W.H. McNAB. 2000. Using digital terrain modeling to predict ecological types in the Balsam Mountains of western North Carolina. USDA Forest Service Research Note SRS-8. 11 pp.

PAGELS, J.F., and C.O. HANDLEY. 1989. Distribution of the southeastern shrew, *Sorex longirostris* Bachman, in western Virginia. Brimleyana 15:123–131.

PETRANKA, J.W. 1998. Salamanders of the United States and Canada. Smithsonian Press, Washington, DC. 587 pp.

PETRANKA, J.W., M.P. BRANNON, M.E. HOPEY, and C.K. SMITH. 1994. Effects of timber harvesting on low elevation populations of southern Appalachian salamanders. Forest Ecology and Management 67:135–147.

PETRANKA, J.W., M.E. ELDRIDGE, and K.F. HALEY. 1993. Effects of timber harvesting on southern Appalachian salamanders. Conservation Biology 7:363–370.

SAS INSTITUTE. 1995. Logistic regression: examples using the SAS system. SAS Institute, Cary N. C. 163 pp.

STEEL, R.G.D., and J.H. TORRIE. 1980. Principles and procedures of statistics: a biometrical approach. McGraw-Hill, New York, NY. 633 pp.

WHARTON, C.H. 1978. The natural environmental of Georgia. Georgia Department of Natural. Resources, Atlanta, GA. 227 pp.

WILSON, L.A. 1995. Land manager's guide to the amphibians and reptiles of the South. The Nature Conservancy, Southeast Region, Chapel Hill, NC. 324 pp.

YATES, M.D., S.C. LOEB, and D.C. GUYNN. 1997. The effect of habitat patch size on small mammal populations. Proceedings of the Annual Conference of Southeastern Association of Fish and Wildlife Agencies 51:501–510.