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TERRESTRIAL SALAMANDER ABUNDANCES ALONG AND WITHIN AN ELECTRIC POWER LINE RIGHT-OF-WAY

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Abstract: Electric power line right-of-ways (ROWs) are a relatively understudied form of disturbance in otherwise continuous forested habitats in the southern Appalachian Mountains. At a study site within the Nantahala National Forest, Macon County, NC, we performed repeated daytime searches of natural cover objects and nighttime visual surveys within a ROW and at 15-m intervals up to 50 m into the adjacent forest to examine potential edge effects on the abundances of terrestrial salamanders. Data on a variety of microhabitat features were also collected during each sampling period, but no discernable edge effect was observed. Sunlight intensity was greater and leaf litter thinner in the ROW as compared to the adjacent forest, but no other habitat variable differed significantly. We found 218 surface-active salamanders at night and 21 beneath rotting logs during the day representing five species. Relative abundances of salamanders were similar between the ROW and the forest and did not demonstrate any significant variation with increasing distance from the edge. No salamanders were found in the ROW during the day beneath rotting logs, and those found at night were large adults. Salamanders persisting in ROWs appear to rely on availability of burrows. Although the narrowness of the canopy gaps and associated habitat features in power line right-of-ways appear to mitigate microclimate, mobility of salamanders in such areas may be restricted.

Key Words: Edge effect; electric power line; Plethodontidae; right-of-way; salamanders; southern Appalachians.

INTRODUCTION

Salamanders are important ecological components of many forest ecosystems and are the most abundant forest-floor vertebrates (Burton and Likens 1975; Davic & Welsh 2004). Salamanders in North America reach their peak diversity in the southern Appalachians. Densities in this region may be as high as two animals per m^2 in mature hardwood forests (Petranka et al. 1993, 1994). Terrestrial species are sensitive to habitat loss and degradation because of their ecophysiological requirements (Cushman 2006). Members of the family Plethodontidae are especially vulnerable to desiccation because they respire dermally (Spotila 1972; Feder 1983). Consequently, they are usually restricted to moist microhabitats with generally cooler temperatures (Heatwole and Lim 1961; Grover 1998).

Changes in forests because of disturbance can have profound effects on the forest floor (Matlack 1993; Murcia 1995; Chen et al. 1999), which can decrease its capacity to support salamanders (e.g., Petranka et al. 1993, 1994; Ash 1997; Hicks and Pearson 2003). Leaf litter is a critical microhabitat because it retains water (Ash 1995) and harbors an abundance of invertebrate prey (Gist and Crossley 1975). Large canopy gaps permit increased wind effects, greater penetration of solar radiation, and temperature extremes (Phillips and Shure 1990; Chen et al. 1999) that may cause reductions in leaf litter depth, dry mass, and moisture content (Ash 1995). Such negative effects may extend far into the forest from the edge of the clearing (Chen et al. 1993; Murcia 1995; deMaynadier and Hunter 1998). However, the severity of the edge effect on salamanders is often dependent on the size and scale of the disturbance (Messere and Ducey 1998; Heithecker and Halpern 2007; Strojny and Hunter 2010b) and whether other mitigating microhabitat features are retained (Greenberg 2001; Moseley et al. 2009; Strojny and Hunter 2010a).

Roads are a common form of disturbance in otherwise continuous mature forested habitats in the southern Appalachians (Semlitsch et al. 2007). Associated edge effects have been found to significantly decrease salamander abundances up to 20–35 m from roads (deMaynadier and Hunter 1998; Marsh and Beckman 2004; Semitsch et al. 2007). Roads may also act as a partial barrier to foraging and dispersal (Gibbs 1998; deMaynadier and Hunter 2000; Marsh et al. 2005), and can diminish the richness and abundance of invertebrates on the forest floor (Haskell 2000).

Electric power line right-of ways (ROWs) similarly bisect otherwise intact forests and may produce edge effects comparable to that of roads. However, there has been surprisingly little research on salamanders along power line ROWs (Yahner et al. 2001a,b), and to our knowledge no such study has ever been performed in the southern Appalachians. In this study, we compared microclimate and habitat in a ROW to that of the adjacent forest to examine potential edge effects and impacts on the local abundance of terrestrial salamanders.

METHODS

Our study site (35.086°N, 83.262°W; elevation 1,182 m) was established in autumn 2013 along a power line right-of-way close to Skitty Creek in the Nantahala National Forest near Highlands, Macon County, North Carolina. The ROW was approximately 16 m wide and ran perpendicular to contours on a slight, northwest-facing slope for a distance of approximately 1.5 km. It was created in 1949, but had been most recently cut in 2006 and treated with herbicide in 2012 (Duke Energy, pers. comm.) so that virtually no ground vegetation existed in the ROW other than some mosses and lichens. Surrounding forest stand age was 101 yr (USDA Forest Service, pers. comm.), and consisted primarily of red maple (*Acer rubrum*), chestnut oak (*Quercus prinus*), red oak (*Q. rubra*), and Fraser magnolia (*Magnolia fraseri*) with an understory of rhododendron (*Rhododendron maximum*) and a dense ground cover of huckleberry (*Gaylussacia baccata*). One 50-m transect was established along the center of the ROW and four parallel transects were located in the adjacent forest at 15-m intervals at 5, 20, 35, and 50 m away from one side of the edge.

We performed eight nighttime surveys regularly from August through October 2013 using visual encounter searches for surface-active salamanders (Crawford and Semlitsch 2008). Beginning approximately thirty minutes after sunset, we walked the length of each transect and recorded the number of each species observed on the forest floor or on vegetation within 2.5 m on either side. Search time varied depending on the number of salamanders encountered.

Eight daytime surveys of salamanders were also conducted on each of the following days during this period. Area-constrained searches of natural cover objects have been shown to generate valid indices of salamander diversity (Smith and Petranka 2000). Coarse woody debris (CWD), especially in the latter stages of decay, serves as daytime refuges for salamanders (Whiles and Grubaugh 1996). All CWD ≥10 cm in diameter and in decay classes 3, 4, and 5 was turned within 2.5 m along each transect and the number of each salamander species found was recorded (Petranka et al. 1994). These decay classes range from moderate to severe state of decomposition, and were considered to be "usable" microhabitat because they lie completely on the ground and often retain high levels of moisture (Whiles and Grubaugh 1996). Numbers of salamanders found on each transect were converted to encounter rate (# salamanders per log), because search effort was dependent upon the amount of CWD present (Brannon and Rogers 2005). During the initial survey, the dimensions of each log were measured in cm to obtain average area of CWD cover available for salamanders. Logs were returned to their original positions and generally a minimum of six days' recovery time elapsed between surveys to minimize disturbance (Brannon and Rogers 2005).

Measurements of other habitat variables were collected nine times from August through October 2013. We recorded measurements of temperature (°C) and sunlight intensity (lumens/m^2) at ground level at three points along each transect during each sampling period using a digital thermometer and Apogee® basic quantum meter, respectively. Two 16 × 16 cm samples of leaf litter were also taken from randomly selected points along each transect at this time. Each sample was weighed to obtain wet mass, dried at 65°C for 24 hr, and then re-weighed to obtain dry mass (Brannon and Rogers 2005). Litter moisture content was calculated as wet mass minus dry mass and expressed as a percentage of wet mass. Leaf litter depths for each sampling period were obtained by pressing a metric ruler through the litter to the point of resistance of the soil at 10-m intervals along each transect (Brannon and Rogers 2005). Although leaf litter is essential as foraging microhabitat, salamanders may spend considerable time in burrows (Ash 1995). Because of our frequent observations of salamanders emerging from holes during nighttime searches, on the last day of our study we also took readings of percentage soil moisture at 10-m intervals along each transect using a Kelway® soil tester.

Salamander species data for each transect were pooled during each survey. Potential edge effects related to distance from the ROW were examined by separately comparing salamander abundances (for nighttime visual searches) and encounter rates (for daytime searches of CWD) between the four forested transects, using a one-way analysis of variance (ANOVA). Differences in salamander abundances or capture rates between the forest and the ROW were analyzed using planned-contrast ANOVAs (Zar 1999). Amount of available CWD between transects was compared using χ^2 goodness-of-fit tests. One-way and planned-contrast ANOVAs were also used to examine differences for each of the other habitat variables between the four forested transects, and between the ROW and the forest as a whole, respectively. All percent values were arcsine-transformed prior to analyses (Zar 1999).

RESULTS

With the absence of vegetation, light intensity was significantly greater in the ROW than in the forest

($F_{1,130} = 106.43$, $p < 0.01$). Mean light intensity (±1 SE) was 83.00 ± 9.87 lumens/m^2 in the ROW compared to only 7.99 ± 0.87 in the forest. However, ROW temperatures remained similar to those of the forest ($F_{1,130} = 0.10$, $p > 0.05$) for our autumn sampling period. Light intensity ($F_{3,104} = 0.58$, $p > 0.05$) and temperature ($F_{3,104} = 0.04$; $p > 0.05$) did not vary significantly among the forested transects (Table 1).

Leaf litter depth was significantly reduced in the ROW ($F_{1,265} = 7.19$, $p < 0.01$). Mean litter depth was 70.41 ± 4.13 mm in the ROW but 116.44 ± 2.27 mm in the forest. Litter depth also differed significantly within the forest ($F_{3,212} = 6.53$, $p < 0.01$), although it did not show an increasing trend with distance from the edge. Rather, litter depth was actually deepest closest to the ROW at 5 m (Table 1).

Leaf litter was drier in the ROW than in the forest, but not significantly so ($F_{1,75} = 1.31$, $p > 0.05$; Table 1). Percentage leaf litter moisture was also not significantly different among the forested transects ($F_{3,60} = 0.06$, $p > 0.05$). Percent soil moisture also did not differ significantly within the forest ($F_{3,20} = 1.15$, $p > 0.05$), and was similar between the forest and the ROW ($F_{1,25} = 0.23$, $p > 0.05$; Table 1). Number of rotting logs (Table 2) also did not differ significantly between transects ($\chi^2 = 5.61$, df = 4, $p > 0.05$), nor did their coverage area (Table 1).

A total of 239 salamanders representing five species were observed during our sampling period (Tables 2 and 3). Of this total, 218 (91.2%) were encountered during nighttime searches. The most abundant species in both the ROW and forested transects was the Southern Gray-cheeked Salamander (*Plethodon metcalfi*), which accounted for 61.9% of all day observations (Table 2) and 92.2% of all night observations (Table 3). Overall salamander abundances at night did not differ significantly within the forest ($F_{3,28} = 0.14$; $p > 0.05$; Table 3) or between the forest and the ROW ($F_{1,35} = 1.02$; $p > 0.05$). Average number of salamanders observed at night was 4.91 ± 0.62 in the forest and 7.63 ± 1.16 in the right-of-way. Daytime salamander encounter rates were similar between the four forested transects ($F_{3,28} = 1.17$; $p > 0.05$; Table 2), but were significantly lower in the ROW than in the forest ($F_{1,35} = 5.04$; $p < 0.05$). Mean encounter rate was 0.04 ± 0.01 salamanders per log in the forest, whereas no salamanders were found in the ROW during the day. Nearly all salamanders encountered in the ROW at night were large adults, many of which were seen emerging from burrows. In contrast, in the forest a wide variety of age classes were found, with a few small individuals observed climbing plants during our nighttime searches.

DISCUSSION

Salamanders have sensitive ecological requirements and can respond dramatically to forest disturbances and

Table 1. Means (±1 SE) for measured habitat variables with results for one-way analysis of variance (ANOVA) between the four forested transects and for planned contrast ANOVAs between the forest and the power line right-of-way (ROW). Asterisks denote significance level of $p < 0.01$.

Habitat Variable	Distance from Edge				One-Way ANOVA				Planned Contrast ANOVA	
	5 m	20 m	35 m	50 m	df	*F*	Forest	ROW	df	*F*
Sunlight Intensity (lumens/m^2)	6.07 ± 1.66	9.19 ± 2.12	8.52 ± 1.55	8.19 ± 1.56	3, 104	0.58	7.99 ± 0.87	83.00 ± 9.87	1, 130	106.43 *
Temperature (°C)	17.04 ± 0.58	17.17 ± 0.61	17.18 ± 0.56	17.36 ± 0.53	3, 104	0.04	17.19 ± 0.28	18.43 ± 0.73	1, 130	0.10
Leaf Litter Depth (mm)	131.44 ± 5.23	117.94 ± 4.38	105.91 ± 3.81	110.44 ± 3.92	3, 212	6.53 *	116.44 ± 2.27	70.41 ± 4.13	1, 265	7.19 *
Leaf Litter Moisture (%)	53.96 ± 3.67	53.63 ± 3.56	52.79 ± 3.97	51.48 ± 3.37	3, 60	0.06	52.97 ± 1.78	42.06 ± 4.12	1, 75	1.31
Soil Moisture (%)	15.00 ± 3.22	10.00 ± 2.21	14.67 ± 1.56	11.50 ± 1.71	3, 20	1.15	12.79 ± 1.15	10.00 ± 2.82	1, 25	0.23
CWD Area (m^2)	73.74 ± 22.64	75.51 ± 28.67	35.51 ± 4.86	66.74 ± 16.88	3, 65	0.93	58.18 ± 10.02	83.99 ± 24.83	1, 78	0.57

Table 2. Summary of salamander observations during daytime searches of coarse woody debris. Encounter rates were defined as number of salamanders/number of logs.

Species	Common Name	ROW	5 m	20 m	35 m	50 m	Total
Eurycea wilderae	Blue Ridge Two-lined Salamander	0	1	1	0	0	2
Notophthalmus viridescens	Eastern Newt (eft)	0	1	2	1	1	5
Plethodon metcalfi	S. Gray-cheeked Salamander	0	2	3	3	5	13
P. teyahalee	S. Appalachian Salamander	0	0	1	0	0	1
Totals		0	4	7	4	6	21
Salamander Encounter Rate		0	0.04 ± 0.01	0.07 ± 0.03	0.03 ± 0.01	0.03 ± 0.01	
Number of Rotting Logs		14	13	13	19	24	

associated changes to microhabitat structure, moisture content, and prey availability (Ash 1995; Grover 1998; Jaeger 1980a; Haskell 2000). For example, in large clear-cuts populations of plethodontid salamanders may disappear completely and take decades to recover (Petranka et al. 1994; Ash 1997). However, in smaller canopy gaps the presence of a partial canopy and other forest habitat features can often mitigate temperature and humidity levels (Greenberg 2001; Brooks and Kyker-Snowman 2008; Strojny and Hunter 2010b). Narrow roads, for example, demonstrate a much less severe impact on terrestrial salamanders than do wider roads (Marsh 2007). Litter dynamics in such areas may resemble that of the surrounding forested areas (Clinton 2003) because of the accumulation of allochthonous leaf fall (Shure and Phillips 1987). Adequate volumes of moist CWD may also be retained (Strojny and Hunter 2010a).

Similarly, in this study no discernable edge effects on salamander abundance or forest habitat variables were observed, presumably due to the narrowness of the power line right-of-way. Shading from well-developed side canopies may greatly curtail edge effects on microclimate within the tolerable physiological limits of woodland salamanders (Moseley et al. 2009). Transition zones from forest temperature and moisture conditions have been found to extend as far as 15 m into clearings (Redding et al. 2003), which is well beyond the distance of eight meters to the center of the ROW at our study site. The degree of contrast in microenvironment between cut and uncut areas may also be greatly influenced by site orientation (Matlack 1993) and season (DeGraaf and Yamasaki 2001; Brooks and Kyker-Snowman 2008). Our study was conducted on a somewhat north-facing and more mesic slope, and during the autumn months. Edge effects on terrestrial salamanders are generally more pronounced where there is longer and more direct sunlight exposure, such as on southwesterly aspects (Moseley et al. 2009) and during the summer (Brooks and Kyker-Snowman 2008).

A deep layer of dead organic material retains moisture required by terrestrial plethodontid salamanders for cutaneous respiration (Spotila 1972; Feder 1983) and for deposition and development of eggs (Heatwole 1961). Leaf litter also harbors an abundance of invertebrate prey (Gist and Crossley 1975). However, accessibility of prey is variable because foraging time in salamanders is restricted by humidity levels (Jaeger 1980a). If the litter becomes too thin, patchy, or dry as in the ROW at our study site, then populations of salamanders may be reduced (Ash 1995). Smaller salamanders such as juveniles are less able to withstand drier and sparser litter cover, which may partially explain, as in our study, their relative absence in some canopy gaps (Ash 1997).

Rotting logs can serve as important cover objects and as moisture refuges during dry periods (Whiles and Grubaugh 1996; Grover 1998). Abundant large coarse

Table 3. Summary of observations during nighttime visual encounter searches for surface-active salamanders.

Species	Common Name	ROW	5 m	20 m	35 m	50 m	Total
Eurycea wilderae	Blue Ridge Two-lined Salamander	3	2	2	1	0	8
Notophthalmus viridescens	Eastern Newt (eft)	0	0	1	1	0	2
Plethodon metcalfi	S. Gray-cheeked Salamander	56	39	27	40	39	201
P. serratus	S. Red-backed Salamander	0	0	0	1	0	1
P. teyahalee	S. Appalachian Salamander	2	0	4	0	0	6
Totals		61	41	34	43	39	218
Mean (±1 SE)		7.63 ± 1.16	5.13 ± 1.51	4.25 ± 0.90	5.38 ± 1.05	4.88 ± 1.56	

woody debris often persists in smaller clearings, especially in natural wind-disturbed or otherwise unsalvaged gaps (Greenberg 2001; Strojny and Hunter 2010b). Unlike timber harvests, felled trees are usually left intact in power line right-of-ways (Duke Energy, pers. comm.). However, under extended xeric conditions food in these retreats can be depleted (Jaeger 1980b) and salamanders may be forced underground to avoid desiccation (Rothermel and Luhring 2005).

Soil moisture often remains unchanged after vegetation is removed (Ash 1995), especially in smaller forest clearings (Heithecker and Halpern 2006, 2007). Most salamanders do not dig burrows themselves, but instead rely on existing spaces such as earthworm tunnels (Caceres-Charneco and Ransom 2010), rock fissures and root channels (Welsh and Droege 2001). Vegetation in power line right-of-ways is usually cut by hand and left in place (Duke Energy, pers. comm.). Consequently, underground retreats may be more plentiful because there is not the level of soil compaction associated with vehicle traffic along logging roads (Semlitsch et al. 2007) or with the heavy machinery used for timber removal in clear-cuts (Vora 1988; Quesnel and Curran 2000). The use of burrows by large adults may partially explain the persistence of salamanders in ROWs, albeit a suboptimal habitat (Yahner et al. 2001a,b). Food is generally scarce in burrows and movement of salamanders is greatly limited (Jaeger 1980a,b). Salamanders remain undetectable during the day (Caceres-Charneco and Ransom 2010) and may only be able to emerge and forage at night when the humidity is higher (Grover 1998). Furthermore, immobility may be exacerbated by the periodic application of herbicides in ROWs (Duke Energy, pers. comm.) which could harm salamanders directly (Relyea 2005) and reduce vegetative cover used as foraging spaces (Jaeger 1978) or as perch sites to escape predators (Roberts and Liebgold 2008).

Our findings, like those of Yahner et al. (2001a,b), suggest that environmental conditions and microhabitat found within and along ROWs are adequate to support populations of plethodontid salamanders, even if somewhat limiting. However, such forest gaps may still serve as a partial barrier to movement (Marsh et al. 2005; Rittenhouse and Semitsch 2006), disrupt dispersal in juvenile amphibians (deMaynadier and Hunter 1999, 2000), or affect population age distribution (Ash et al. 2003) and species diversity (Ash 1997). Further research that incorporates a wider geographic area, a variety of forest communities, and a longer duration of study may better elucidate the effects of power line right-of-ways on terrestrial salamanders in the southern Appalachians.

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