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Local and landscape scale factors influencing edge effects on woodland salamanders

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Abstract We examined local and landscape-scale variable influence on the depth and magnitude of edge effects on woodland salamanders in mature mixed mesophytic and northern hardwood forest adjacent to natural gas well sites maintained as wildlife openings. We surveyed woodland salamander occurrence from June–August 2006 at 33 gas well sites in the Monongahela National Forest, West Virginia. We used an information-theoretic approach to test nine a priori models explaining landscape-scale effects on woodland salamander capture proportion within 20 m of field edge. Salamander capture proportion was greater within 0–60 m than 61–100 m of field edges. Similarly, available coarse woody debris proportion was greater within 0–60 m than 61–100 m of field edge. Our ASPECT model, that incorporated the single variable aspect, received the strongest support for explaining landscape-scale effects on salamander capture proportion within 20 m of opening edge. The ASPECT model indicated that fewer salamanders occurred within 20 m of opening edges on drier, hotter southwestern aspects than in moister, cooler northeastern aspects. Our results suggest that forest habitat adjacent to maintained edges and with sufficient cover still can provide suitable habitat for woodland salamander species in central Appalachian mixed mesophytic and northern hardwood forests. Additionally, our modeling results support the contention that edge effects are more severe on southwesterly aspects. These results underscore the importance of distinguishing among different edge types as well as placing survey locations within a landscape context when investigating edge impacts on woodland salamanders.

Keywords *Desmognathus* · Edge · Field–forest interface · Gas well · Microclimate · Mixed mesophytic · *Plethodon* · Salamander

Introduction

For nearly a century forest edge influence on wildlife fauna has received considerable attention by land managers (Harris 1988). Forest edge is defined as a transition zone, abrupt or gradual, between two adjacent ecosystems or vegetative communities (Murcia 1995). Forest edge is often viewed by land managers as beneficial to wildlife due, in part, to observed increases in species abundance and diversity within this habitat (Leopold 1933). However, forest edge creation and maintenance can contribute to forest fragmentation, adversely impacting fauna requiring

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interior forest habitat conditions (Harris 1988). This has resulted in efforts to limit or reduce edge habitat within many forested landscapes (Yahner 1988; Gates 1991; Saunders et al. 1991). Edge effects include all biotic and abiotic changes resulting from the interaction between two adjacent ecosystems or vegetative communities (Murcia 1995). Differences in vegetative structure at forest edges often result in altered microclimatic conditions relative to interior forest habitat (Geiger 1957). If microclimatic conditions within or near forest edges exceed a target organism's physiological tolerance, then edge often results in reduced occurrence or lower viability at local and possibly landscape scales (Murcia 1995; Esseen and Renhorn 1998; Chen et al. 1999; Urbina-Cardona et al. 2006). This is especially true for moisture sensitive vertebrate species, such as woodland salamanders, that are believed to show great sensitivity to microclimatic alteration arising from edge effects (deMaynadier and Hunter 1995; Petranka 1998; Russell et al. 2004).

Lacking lungs, woodland salamanders in the family Plethdontidae require moist habitats to facilitate sufficient cutaneous respiration (Spight 1968; Spotila 1972; Feder 1983), thereby making them highly sensitive to changes in temperature and moisture (Heatwole 1962; Sugalski and Claussen 1997; Grover 1998; Grover and Wilbur 2002). During daylight hours, microclimatic conditions within forest edges often exhibit higher air and soil temperatures (Williams-Linera 1990; Chen et al. 1995; Gehlhausen et al. 2000) lower soil moisture (Brothers and Spingarn 1992; Matlack 1993; Jose et al. 1996; Marchand and Houle 2006) and humidity (Chen et al. 1995; Gehlhausen et al. 2000) relative to interior forest areas. However, microclimatic gradients within forest edge can vary drastically depending on edge type examined (Murcia 1995; Ries et al. 2004). There have been few investigations examining maintained field opening edge effects on woodland salamander species distribution (Ries et al. 2004). Most research to date in eastern deciduous forests has focused on edge effects on woodland salamanders produced by roads (Marsh and Beckman 2004; Marsh 2007; Semlitsch et al. 2007) and/or timber harvesting (deMaynadier and Hunter 1998; DeGraaf and Yamasaki 2002). For example, in northern hardwood forests of Maine, deMaynadier and Hunter (1998) observed increasing redback salamander (*Plethodon cinereus*) abundance with increasing distance from edges along recent clearcuts (<11 years). The authors estimated that edge effect depth extended 25–35 m into adjacent mature forest. Similarly, Semlitsch et al. (2007) observed lower woodland salamander abundance 1 m from permanent gravel and paved roads than 80 m into the surrounding woodlands in western North Carolina. Reduced salamander occurrence near edges often is attributed to reduction in moisture (Schlaepfer and Gavin 2001; Marsh and Beckman 2004) and reduced microhabitat quality (deMaynadier and Hunter 1998; DeGraaf and Yamasaki 2002; Semlitsch et al. 2007; Riedel et al. 2008). However, edge effects observed for road and harvest induced edges may not be directly comparable to other edge types, such as those created and maintained for agriculture, found within heterogeneous landscapes of the eastern US (Ries et al. 2004; Harper et al. 2005). Additionally, edge effect investigations on wildlife species often suffer from low replication and do not sufficiently address landscape-scale variables influencing edge effect depth and magnitude (Murcia 1995).

Microclimate gradient depth and magnitude within forest edge is dependent on a variety of topographic and physiognomic factors (Wales 1972; Palik and Murphy 1990; Matlack 1993; Fraver 1994; Murcia 1995; Harper et al. 2005; Hylander 2005). For example, north-facing edges in a southeastern Pennsylvania hardwood forest experienced more moderated increases in ground temperature and decreases in leaf litter moisture than did south-facing edges (Matlack 1993). Although largely speculative for woodland salamanders, forest edge microclimate gradients may lessen through successional time as adventitious tree limbs bordering edges become highly developed, thereby producing a "side canopy" that reduces solar penetration into forest interior (Williams-Linera 1990; Matlack 1993; Matlack 1994; Didham and Lawton 1999).

The objective of our study was to determine local and landscape-scale influence on edge effect depth and magnitude on woodland salamanders in mixed mesophytic and northern hardwood forest adjacent to maintained natural gas well openings. Specifically, we wanted to determine edge effect depth on woodland salamanders in forested stands adjacent to gas well openings and how landscape-scale factors, such as aspect and elevation, influenced edge effect magnitude. Based on previous investigations regarding road and clearcut edge effects on woodland salamanders, we hypothesized that woodland salamander capture proportion would be reduced within 20–30 m of forest edge. We also hypothesized that woodland salamander capture proportion within 20 m of gas well opening edge would be lower at sites with southwesterly aspects.

Study site

We surveyed woodland salamander occurrence within mature (51–108 year old) second-growth mixed mesophytic and northern hardwood forest adjacent to 33 natural gas well sites throughout the Monongahela National Forest (MNF) from June to July 2006 (Fig. 1). The 364,225 ha MNF is located within the central Appalachian Mountains of West Virginia in portions of 10 counties. The majority of the MNF is located in the Allegheny Mountains and Plateau physiographic subprovince, where forests at lower to mid-elevations are dominated by the mixed mesophytic hardwood type consisting of sugar maple (*Acer saccharinum*), red maple (*A. rubra*), northern red oak (*Quercus rubra*), chestnut oak (*Q. prinus*), yellow-poplar (*Liriodendron tulipifera*), American beech (*Fagus grandifolia*), sweet birch (*Betula lenta*), black cherry (*Prunus serotina*), and basswood (*Tilia Americana*; Madarish et al. 2002). At approximately 900–1,100 m elevation depending upon aspect and landform position, the forest transitions to northern hardwood or northern hardwood–montane boreal assemblages of sugar maple, American beech, yellow birch (*B. alleghaniensis*), eastern hemlock (*Tsuga canadensis*), and red spruce (*Picea rubens*; Stephenson 1993). Common woodland salamander species occurring in the MNF include the redback salamander, slimy salamander

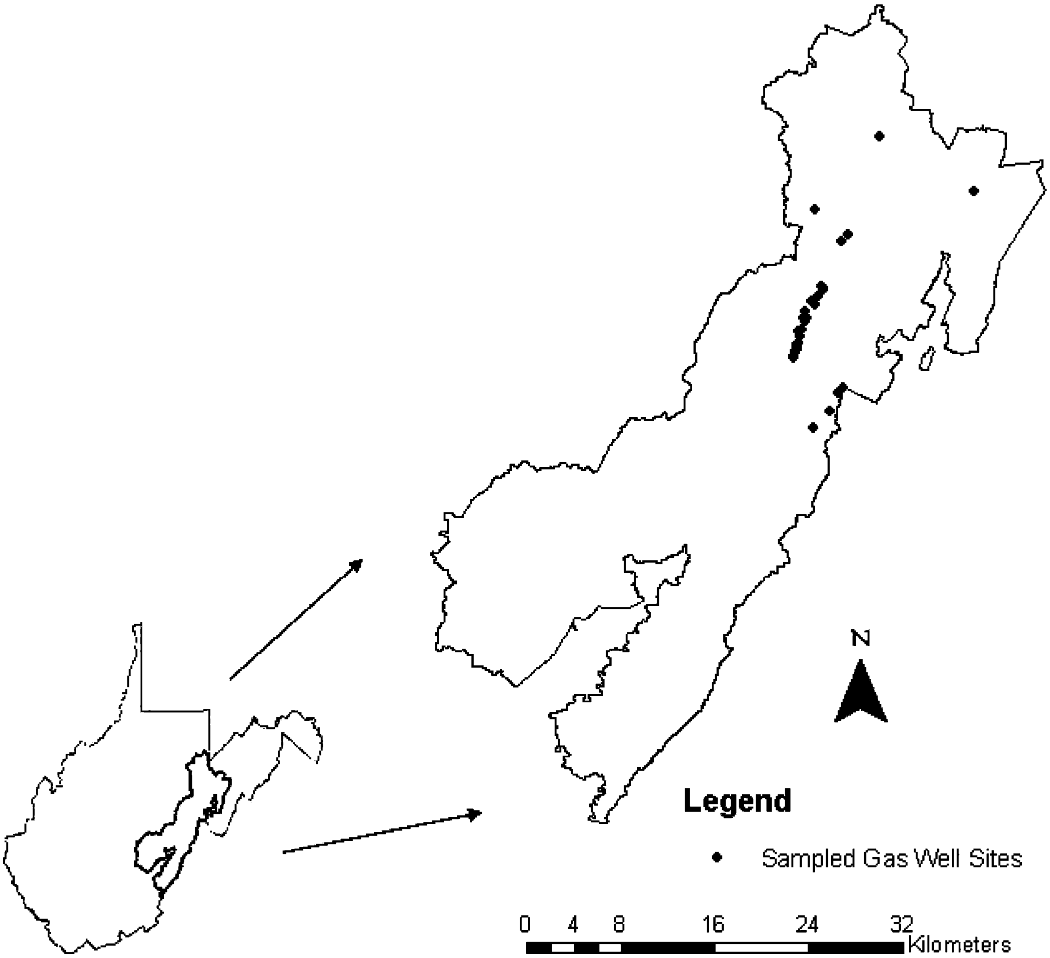

Fig. 1 Sampled natural gas well site locations within the MNF, West Virginia, June–August 2006

(*P. glutinosus*), Wehrle's salamander (*P. wehrlei*), and Allegheny mountain dusky salamander (*Desmognathus ochrophaeus*) in upland forest stands and northern two-lined salamander (*Eurycea bislineata*), northern dusky salamander (*D. fuscus*), and seal salamander (*D. monticola*) in forest stands adjacent to rivers and streams (Madarish et al. 2002). Approximately 93% of the MNF is forested with nonforested area primarily consisting of livestock grazing allotments, wildlife food plots or maintained grassy openings, and natural gas well production sites (US Forest Service 2006). Gas well sites were established between 1957 and 2001 with a mean age of 39 years. Since establishment, both active and inactive gas well sites have been maintained as grass and forb-dominated wildlife openings by biennial or semiannual mowing. For gas well sites surveyed, elevations ranged from 821–1,188 m and slopes ranged from 5–32%. Gas well sites ranged in size from 0.09–1.44 ha. Annual precipitation is approximately 152 cm and the frost-free period ranges from 90 to 150 days depending on elevation (Stephenson 1993).

Methods

Field sampling

At each gas well opening, we established four 1× 100 m transects extending perpendicular to gas well opening edge. We defined edge origination (0 m) as the point where a mature treeline met maintained field habitat (Murcia 1995). Because orientation influences depth of microclimate influences from edge (Matlack 1993; Fraver 1994; Chen et al. 1995; Gehlhausen et al. 2000; Hylander 2005), we established transects at each of the four cardinal directions (N,S,E,W). Some transect locations deviated left or right from cardinal directions (maximum 45°) to maintain a distance of at least 50 m from connected linear openings of roads and gas lines. From June to August 2006, we overturned and searched all cover objects [rocks and coarse woody debris (CWD)] within each 1×100 m transect for salamander presence between 0800–1800 hours. We believe our sampling period was sufficient because woodland salamanders exhibit temporally stable population structure (Hairston 1987). We conducted searches of each transect only once during our study and did not conduct searches during precipitation events. In the central Appalachians, edge influence on woodland salamander detectability is negligible (Marsh and Beckman 2004). We did not search leaf litter. However, salamander captures under natural cover objects has been correlated with independent estimates of abundance (DeGraaf and Yamasaki 1992; Smith and Petranka 2000). For all captured salamanders we recorded species, mass (g), snout-vent-length (SVL; cm) and distance from edge (m). We measured mass using a 10-g pesola scale (Pesola AG, Baar, Switzerland). We recorded cover type (rock or CWD) and cover dimensions (cm) of objects occupied by salamanders. To determine if cover availability changed with distance from edge, we randomly selected a subsample of five gas well sites and recorded cover object type and size (cm^2) within transects. We used ArcMAP 9.0 (ESRI, Redlands, California) to determine elevation, aspect, total road distance (m) within 100 m buffers around sample sites, gas well opening area (m^2), and percent slope for each gas well site surveyed. We derived values for elevation, aspect, and slope using a 30×30 digital elevation model (West Virginia GIS Technical Center). We calculated road and gas line length (m) within 100 m buffers of gas well sites to determine if presence of additional edge influenced woodland salamander occurrence within adjacent forest (Ries et al. 2004).

Statistical analysis

We examined scatterplots and residual plots to ensure that variables met assumptions of analyses (i.e., linearity, normality, colinearity). We arcsin-squareroot transformed all proportional variables to approximate normality (Sokal and Rohlf 1987). Aspect was transformed following Beers et al. (1966)

$$A' = \cos(45 - A) + 1$$

where A = aspect and A' = aspect code. The resulting values ranged from 0 to 2, with 2 indicative of northeast facing slopes and 0 of southwest facing slopes (Beers et al. 1966). For null hypothesis testing, if variables could not be successfully transformed, we performed analysis on ranked data (Ott 1993). Untransformed values are reported. We compared distance to edge and occupied cover object size among species captured with a two-way analysis of variance (ANOVA), with gas well site serving as a random effect. When comparisons were significant

($P<0.05$), we used least square means pairwise comparisons to determine specific differences among species. Additionally, we used Spearman's rank correlation to determine relations between distance to edge, rock and CWD surface area used, SVL, and mass for each species.

Determining edge effect depth is somewhat subjective because response variables usually exhibit a gradual change along the edge to interior gradient (Chen et al. 1992; Murcia 1995; Harper et al. 2005). Therefore, we calculated proportion of salamander captures, CWD and rock available and cover area (cm^2) within ten 10 m bands to 100 m into the forest for each site. Because many transects yielded low ($n<3$) salamander captures and cover object abundance, we combined these variables for all transects within gas well sites. We calculated proportion by dividing salamander captures or cover object abundance within each 10 m band by total salamander captures or total cover abundance, respectively. We compared distance bands using a two-way ANOVA, with gas well site serving as a random effect. Additionally, we used linear contrast statements to determine how far into the interior edge effects extended by systematically grouping distance bands for comparison (e.g. 0–10 m vs 11–100 m, 0–20 m vs 21–100 m, etc.). We interpreted the greatest distance group from edge exhibiting a significant difference ($P<0.05$) as the maximum extent of edge effects.

In eastern deciduous forests presence of hard edges can alter microclimatic conditions as far as 40–50 m into adjacent forest (Wales 1972; Matlack 1993), but impacts typically are most profound within approximately 20–30 m of edge for woodland salamanders (deMaynadier and Hunter 1998; DeGraaf and Yamasaki 2002; Marsh and Beckman 2004; Semlitsch et al. 2007). Therefore, to determine how landscape-scale variables impact edge effect magnitude on woodland salamanders we examined the relation between salamander capture proportion within 20 m of edge and landscape-scale variables with a series of linear regression models in an information-theoretic approach. Because distance from edge was similar among salamander species captured ($P>0.05$), we combined all species for landscape-scale analysis for sufficient sample size. For model selection, we used Akaike's Information Criterion corrected for small sample size (AIC*c*), as overall sample size divided by total parameter units examined was <40 (Burnham and Anderson 2002). Prior to model selection, we examined global model fit following recommendations of Burnham and Anderson (2002). We constructed a series of a priori models based on a review of pertinent published literature about depth and magnitude of edge effects on woodland salamander and microclimate variable in forested environments. We constructed the following nine models to explain salamander capture proportion within 20 m of edge: (1) ASPECT (transformed aspect), (2) ROAD (road length (m) within 100 m buffer around gas well sites), (3) AREA (area (m^2) of gas well site sampled), (4) ELEVATION (mean elevation of gas well site sampled), (5) SLOPE (mean slope of gas well site sampled, (6) AGE (age of forest adjacent to gas well site), (7) MOISTURE (ELEVATION + ASPECT), (8) TOTALEDGE (AREA + ROAD), and (9) GLOBAL (a global model containing all parameters). Prior to linear regression analyses, we determined that no continuous variables were highly correlated using Spearman's rank correlation with values of $r_s>0.7$ as thresholds. We ranked all candidate models according to their AIC*c* scores. Although models within 4–7 units of $AICc_{\min}$ are believed to have some empirically-based, explanatory support, we drew primary inference from competing models within two units of $AICc_{\min}$ (Burnham and Anderson 2002). We evaluated models based on $AICc_{\min}$ differences ($\Delta AICc$) and Aikaike's weights (w_i). All statistical analyses were conducted using SAS statistical software (SAS Institute 2003).

Results

We captured a total of 178 salamanders comprising four species: 77 *Desmognathus ochropheus*, 81 *P. cinereus*, 16 *P. glutinosus*, and 4 *P. wehrli*. Because of small sample size, we excluded *P. wehrli* from analyses. Occupied CWD cover area did not differ among individual species ($F_{2,41}=2.44$, $P=0.100$; Table 1). Occupied rock cover area differed among species ($F_{2,35}=3.41$, $P=0.044$; Table 1). However, mean separation tests failed to detect a difference among species ($P>0.05$), but *P. cinereus* occupied the smallest mean rock cover area followed by *D. ochropheus* and *P. glutinosus* (Table 1). CWD cover area occupied by *P. cinereus* was positively correlated with weight ($n=46$, $r=0.32$, $P=0.033$). Additionally, rock cover area occupied by *P. cinereus* was negatively

Table 1 Comparison of habitat variables associated with *Plethodon cinereus* (n=81), *Plethodon glutinosus* (n=16), and *Desmognathus ochropheus* (n=77) captured in mature mixed mesophytic and northern hardwood forests adjacent to natural gas well openings in the MNF, West Virginia, from June–August 2006

	P cinereus (n=81)	*P. glutinosus* (n=16)	*D. ochropheus* (n=77)	*F*	*P*
CWD cover area (cm^2)	1,048.19±95.38	975.83±240.64	1,701.40±232.74	2.44	0.100
Rock cover area (cm^2)	549.54±96.85	963.31±259.23	795.11±80.01	3.41	0.044
Distance to edge (m)	45.98±3.20	42.52±6.28	46.13±3.39	0.03	0.970

correlated with distance to edge (n=35, r=−0.53, P=0.001). Salamander capture proportion did not differ among distance classes ($F_{9,320}$=0.81, P=0.609; Fig. 2). Linear contrasts revealed that capture proportion was greater from 0–60 m than from 61–100 m ($F_{1,40}$=4.17, P=0.042).

At our five subsampled gas well sites, CWD proportion did not differ among distance classes ($F_{9,40}$=1.73, P=0.114; Fig. 3). However, linear contrasts revealed that CWD cover proportion was greater from 0–60 m than from 61–100 m ($F_{1,40}$=5.30, P=0.027; Fig. 3). CWD surface area did not differ among distance classes ($F_{9,24}$=1.59, P=0.175; Fig. 3). Rock proportion ($F_{9,40}$=0.81, P=0.612; Fig. 3) and rock surface area ($F_{9,21}$=1.18, P=0.357; Fig. 3) did not differ among distance classes.

Of the nine linear regression models we constructed, ASPECT was the best approximating model explaining woodland salamander capture proportion within 20 m of edge (w_i=0.72; Table 2). Salamander capture proportion within 20 m of edge increased from southwest to northeast aspects (Table 3). The second-best approximating model, MOISTURE, also received empirical support (ΔAICc<4; Table 2) and indicated that in addition to aforementioned aspect effects, salamander capture proportion within 20 m of edge decreased with increasing elevation (Table 3). Weight of evidence ($w_{\text{best model}}/w_{\text{second best model}}$) for the ASPECT model was 2.8 times greater than the MOISTURE model, indicating some uncertainty in model selection (Burnham and Anderson 2002). However, Akaike weight sum for the two supported models was 0.98 (Table 2) indicating strong evidence for aspect effects on capture proportion within 20 m of edge.

Discussion

Our results failed to support our initial hypothesis that woodland salamander capture proportion would increase with increasing distance from edge. Indeed, we observed the opposite trend, with salamander capture proportion decreasing with increasing distance from edge (Fig. 2), contrasting with results of observations from road (DeGraaf and Yamasaki 2002; Semlitsch et al. 2007) and clearcut (deMaynadier and Hunter 1998) induced edges in eastern deciduous forests. However, although DeGraaf and Yamasaki (2002) observed increasing *P. cinereus* abundance 5–20 m from edge into mature New Hampshire northern hardwood forests, abundance decreased 20–40 m from road edge. Similarly, in our study salamander capture proportion actually declined 61–100 m from gas well opening edge. Distance to edge and SVL of salamander species analyzed were not correlated, therefore we believe it is unlikely that increased capture proportion within 60 m of edge was attributable to juvenile displacement by adults to less suitable edge habitat (Petranka 1998). Our conflicting results with those of other investigations examining edge impacts on salamander species (deMaynadier and Hunter 1998; DeGraaf and Yamasaki 2002; Marsh and Beckamn 2004; Semlitsch et al. 2007) may be due, in part, to differences in the edge type examined.

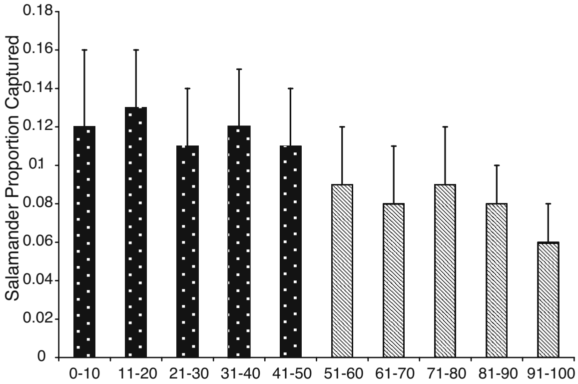

Fig. 2 Salamander capture proportion within 10 m transect distance bands sampled (n=33) within mixed mesophytic and northern hardwood forests adjacent to natural gas well opening edge in the MNF, West Virginia, June–August 2006

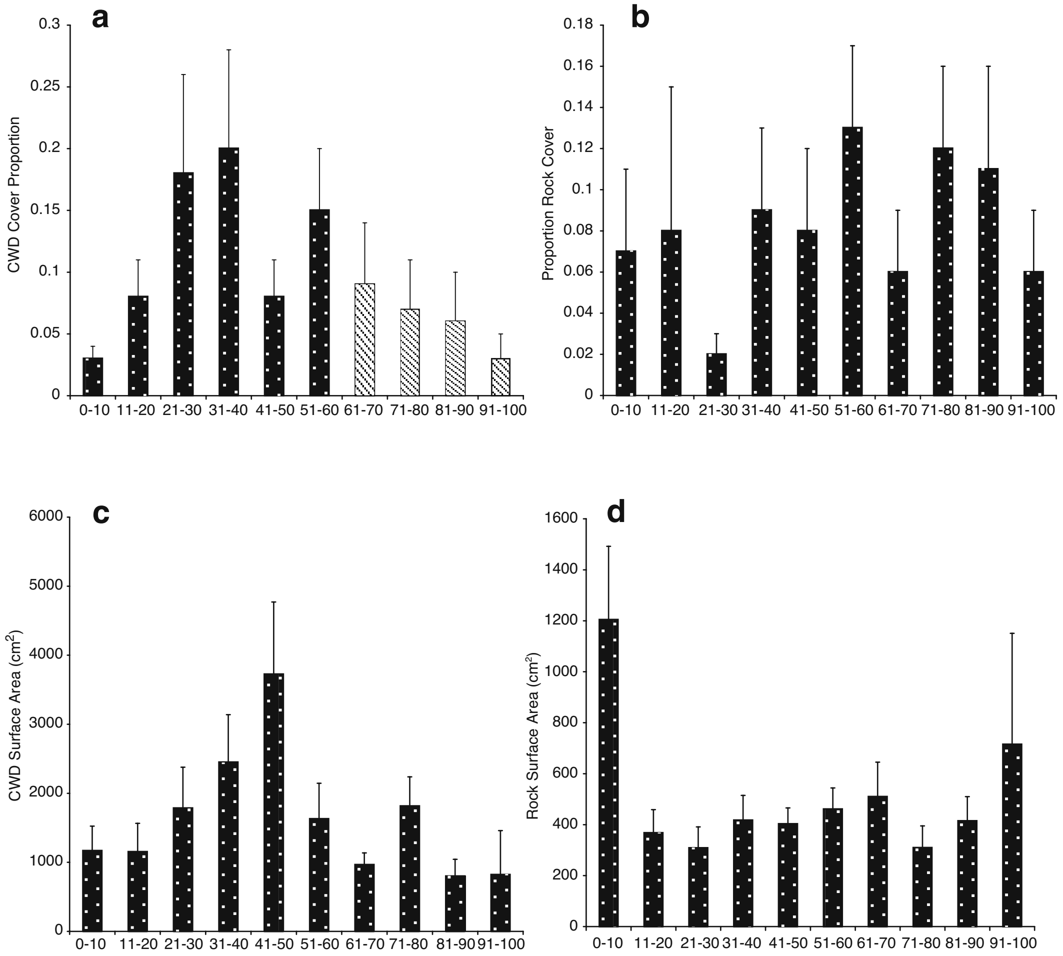

Fig. 3 CWD (**a**) and rock (**b**) occurrence proportion and CWD (**c**) and rock (**d**) cover area within 10 m transect distance bands sampled (n=5) within mixed mesophytic and northern hardwood forests adjacent natural gas well opening edge in the MNF, West Virginia, June–August 2006

In eastern deciduous forests, research on road edge effects on woodland salamanders has focused primarily on permanent secondary roads within lands managed by the USDA Forest Service (Marsh and Beckman 2004; Marsh 2007; Semlitsch et al. 2007). In these settings, road maintenance likely results in reduced cover items immediately adjacent to roads and vegetation removal retards side canopy development reducing shading effects (USDA Forest Service 1998). Moreover, such roads serve as sources of pollutants such as dust and chemicals that may further inhibit salamander occupancy of forested area adjacent to roads (Forman and Alexander 1998; Trombulak and Frissell 2000). Forest edges created through timber harvesting activity also exhibit qualities different from more permanent edges as those in our study. At least temporarily, edges created by clearcutting often posses extreme microclimatic gradients between recently cut area and adjacent forest due, in part, to absence of vertical vegetation which reduces solar penetration of forest interior from adjacent cut sites and insulates forest interior from moisture loss (Harper et al. 2005).

At our sample sites, we observed well developed side canopies that provided overstory shade to forested edge ground surface. Side canopy has been found to reduce, and sometimes eliminate, microclimate gradient within forest edges (Williams-Linera 1990; Matlack 1993; Matlack 1994; Didham and Lawton 1999), perhaps retaining microclimatic conditions within physiological threshold limits tolerable for woodland salamander species. Additionally, we observed increased CWD within the first 60 m of field edges at our five sampled sites (Fig. 3) that

Table 2 Linear regression models explaining proportion of salamander captures within 20 m of natural gas well opening edge adjacent to mixed mesophytic and northern hardwood forest in the MNF, West Virginia, June–August 2006

Model[a]	K[b]	AICc	ΔAICc[c]	w_i[d]
ASPECT	3	−62.56	0.00	0.72
MOISTURE	6	−60.54	2.20	0.26
GLOBAL	8	−51.39	11.17	0.00
SLOPE	3	−51.24	11.33	0.00
AREA	3	−50.95	11.61	0.00
AGE	3	−50.89	11.67	0.00
ROAD	3	−50.89	11.67	0.00
ELEVATION	3	−50.61	11.96	0.00
TOTALEDGE	4	−48.52	14.04	0.00

Model rankings were based on AIC*c*

[a] See text for model parameter description

[b] Number of estimable parameters + 2 in approximating model

[c] Difference in value between AIC*c* of the current model versus the best approximating model (minimum AIC*c*)

[d] Akaike weight. Probability that the current model (*i*) is the best-approximating among those considered

undoubtedly facilitated salamander occupancy near edges despite possible adverse microclimatic conditions. Because woodland salamander densities are limited, in part, by cover object availability (Grover 1998), forest edges containing sufficient cover objects may support resident woodland salamander populations despite reduced moisture availability (Grover 1998). Moreover, occupied rock cover area was negatively correlated with distance from edge suggesting that salamanders near edges used larger cover objects, likely due to greater moisture retention (Jaeger 1980).

We noted significant remnant slash and rock along gas well openings/forest borders, likely originating from site establishment. Increased number of cover objects along gas well edge borders following site establishment may have provided sufficient inputs to promote increased occupancy within forested edge habitat. Also, standing dead and downed woody debris is more abundant near forest edges as tree mortality is higher in these areas (Williams-Linera 1990; Chen et al. 1992; Harper et al. 2005). Leaf litter depth, another important microhabitat component for woodland salamanders (deMaynadier and Hunter 1995), and invertebrate prey can be reduced near road edges (Haskell 2000; Semlitsch et al. 2007). However, *P. cinereus* and *D. ochropheus*, comprising the majority of our captures, are more strongly associated with CWD and rock cover relative to leaf litter (Moore et al. 2001). Indeed, sufficient cover object availability has been found to enable woodland salamanders to occupy habitat traditionally considered inhospitable (Marsh et al. 2004; Riedel et al. 2008).

Woodland salamanders, particularly *P. cinereus*, may be more tolerant of microclimate alteration than previously suspected (Gibbs 1998). Riedel et al. (2008) observed frequent *P. cinereus* occurrence within unmowed hay meadow habitats adjacent to woodlots in southern West Virginia, despite being a habitat often considered inhospitable to salamander species (Rothermel and Semlitsch 2002; Rittenhouse and Semlitsch 2006). The authors attributed *P. cinereus* occurrence within this habitat to cover object availability retained within meadows. Similarly, Marsh et al. (2004) reported cover board occupancy on an abandoned golf course, and suggested that cover objects mitigated adverse climatic conditions within open habitats. Therefore, sufficient cover availability in forest edge habitat likely mitigates adverse microclimatic conditions.

Our study supports Schlaepfer and Gavin's (2001) contention that abiotic and biotic conditions are unlikely to be consistent among forest edges because variation as a function of distance and magnitude likely is affected by landscape variables. Woodland salamander habitat suitability is strongly associated with onsite moisture (deMaynadier and Hunter 1995). For example, in the southern Appalachians, woodland salamander abundance is often greatest in mesic cove-hardwood assemblages (Harper and Guynn 1999; Ford et al. 2002a). At the landscape-scale, forest

Table 3 Linear regression parameter estimates explaining salamander capture proportion within 20 m of natural gas well opening edge adjacent to mixed mesophytic and northern hardwood forest in the MNF, West Virginia, June–August 2006

Model[a]	B	SE	R^2	*P*	Relationship
ASPECT			0.31		
Intercept	0.09	0.11		0.453	
A'	0.33	0.09		0.001	+
MOISTURE			0.32		
Intercept	0.69	0.85		0.418	
A'	0.35	0.09		0.001	+
Elevation	−0.0006	0.0008		0.473	–

[a] See text for model parameter description

overstory assemblages are associated with topographic characteristics such as aspect and elevation (Odom and McNab 2000). Because of high moisture levels, salamander populations may be less sensitive to habitat alteration in mesic forests relative to more xeric forest types (Petranka et al. 1993; Petranka et al. 1994; Ford et al. 2002b). Similarly, our modeling efforts suggest that edge effect magnitude is influenced most by landform attributes associated with moisture, particularly aspect. Southwesterly aspects, that tend to be hotter, and drier than those facing northeast, had reduced salamander capture proportions within 20 m of field edge. Orientation influence on microclimatic variables within forest edge has been well documented (Matlack 1993; Fraver 1994; Chen et al. 1995; Gehlhausen et al. 2000; Hylander 2005). However, small sample size precluded an analysis of edge orientation effects on woodland salamanders in our study. Nonetheless, because of diverse topography throughout the Appalachian Mountain region, forest edge effect magnitude may be exacerbated when located on southwesterly slopes. Conversely, edge impacts on woodland salamander populations on northeastern slopes may be negligible, particularly with presence of well developed side-canopy and sufficient cover object availability.

Conclusion

Burgeoning energy demand, rising prices, and increased interest in exploring domestic fossil fuel sources has prompted renewed interest in natural gas production in Appalachian coalfields (US Department of Energy 2003; US Department of Energy 2005). Moreover, advances in drilling technology now allow natural gas deposits to be extracted from greater depths, making previously unrecoverable and/or unprofitable gas deposits in the central Appalachian Mountains attractive for extraction (US Department of Energy 2001). On state and federal lands in the region, where subsurface rights remain in private ownership, restrictions placed on natural gas production are not extensive and impact of increased activity on the regions biota largely is speculative. Although gas well openings themselves represent marginal habitat for woodland salamander species (Moseley et al., Unpublished Data), impacts on populations within adjacent forest edge habitat appear negligible, particularly on northeastern aspects. However, impacts to woodland salamander species of high conservation value in the region, such as the federally threatened Cheat mountain salamander (*P. nettingi*) or the Cow Knob salamander (*P.punctatus*), a sensitive species of concern, warrants further investigation.

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