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Reptile, Amphibian, and Small Mammal Species Associated with Natural Gas Development in the Monongahela National Forest, West Virginia

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Abstract

Burgeoning energy demand in the United States has led to increased natural gas exploration in the Appalachian Basin. Despite increasing natural gas development in the region, data about its impacts to wildlife are lacking. Our objective was to assess past and ongoing natural gas development impacts on reptiles, amphibians, and small mammals in the Monongahela National Forest in West Virginia. We sampled 40 gas well sites and compared amphibian, reptile, and small mammal captures among active producing, plugged (inactive), and storage well types. Total species richness and diversity were greater at storage gas well sites than at plugged wells. Although natural gas development adversely impacts moisture-sensitive woodland salamanders, our results suggest that maintained gas well openings may benefit other herpetofauna and small mammal species that use early successional habitat within predominately forested central Appalachian landscapes.

Cover Photo

Gas well on the Fernow Experimental Forest. Photo by the U.S. Forest Service.

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INTRODUCTION

Burgeoning energy demand and concomitant interest in reducing dependence on foreign fossil fuels have prompted increased exploration and production efforts within the United States (U.S. Department of Energy 2003, 2005). The Appalachian Basin, centered along the Appalachian Mountains from New York to Alabama, is receiving increasing attention as an economically recoverable natural gas source with an estimated 2 tcm of undeveloped natural gas resources within the basin (Milici et al. 2003). Over the past decade, advances in drilling technology, increasing natural gas prices, existing pipeline infrastructure, and proximity to natural gas markets in the heavily urbanized northeastern United States have prompted increased exploration and subsequent production in the Appalachian Basin. Consequently, natural gas development in the Appalachian Basin is projected to continue to increase, particularly in the central Appalachian region of Ohio, Pennsylvania, Virginia, and West Virginia (U.S. Department of Energy 2005). Despite the current and projected growth of natural gas development within this region, many of its environmental impacts, particularly on wildlife species, largely are undocumented (Energy and Biodiversity Initiative 2007). Because natural gas development involves a complete clearing of small areas of forest for wellhead installation and associated pipeline and road development, wildlife sensitive to local-scale habitat alterations, such as herpetofauna (deMaynadier and Hunter 1995, Russell et al. 2004) and small mammals (Kaminski et al. 2007, Kirkland 1977), may be affected.

Forest openings associated with natural gas development undoubtedly increase edge and early successional habitats within the predominately forested central Appalachian landscape. Forest edge, defined as a transition zone, abrupt or gradual, between two adjacent ecosystems or vegetative communities (Murcia 1995), and early successional habitat creation and maintenance often enhance diversity of small mammals (Johnson et al. 1979, Lowell and Geis 1983, Menzel et al. 1999) and reptiles (Greenberg 2001, Kjoss and Litvaitis 2001, Pais et al. 1988, Ross et al. 2000). For example, edge habitat between northern hardwood forests and wildlife openings in the southern Appalachians of North Carolina supported greater small mammal diversity than did forest interior habitat (Menzel et al. 1999). Similarly, species richness and diversity of small mammals were greater in powerline rights-of-way and edge than adjacent oak (*Quercus* spp.)-hickory (*Carya* spp.) forest in eastern Tennessee (Johnson et al. 1979). Although edge and early successional habitat use by reptile assemblages in the central Appalachian region has received scant attention, reptile diversity and richness often increase following forest canopy removal (Greenberg 2001, Ross et al. 2000).

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Alternatively, gas well openings can adversely impact species dependent on moist, cool microclimate conditions, such as woodland salamanders, characteristic of continuous woody canopy cover (deMaynadier and Hunter 1995, Russell et al. 2004). In the Appalachian Mountains, woodland salamanders can exhibit drastic population declines after forest canopy removal following disturbances such as timber harvesting (Ash 1997, Ford et al. 2002, Petranka et al. 1993, Ross et al. 2000); subsequent salamander population recovery closely parallels reestablishment of important microhabitats, such as coarse woody debris (CWD) and leaf litter, as the forest regenerates (deMaynadier and Hunter 1995, Pough et al. 1987). However, timber harvest represents a more ephemeral form of forest disturbance than openings associated with natural gas development. Gas well openings are maintained in an early successional state through regular mowing for prolonged periods (i.e., the production life of the well). Such openings, in addition to associated roads for other similar types of disturbance and conversion, have been hypothesized to hinder salamander dispersal (Rittenhouse and Semlitsch 2006, Rothermel and Semlitsch 2002), possibly resulting in long-term declines of local populations (Cushman 2006).

Small mammals (Carey and Harrington 2001, Pearce and Venier 2005) and amphibians (Welsh and Ollivier 1998, Welsh and Droege 2001) often serve as indicators of sustainable forest management. Therefore, we need to understand how habitat alterations associated with natural gas development within predominately forested landscapes influence abundance and diversity of these taxonomic groups so that natural resource managers can more effectively mitigate natural gas development impacts in the central Appalachians and elsewhere. Accordingly, our goal was to conduct a survey of amphibians, reptiles, and small mammals associated with natural gas development in the Monongahela National Forest (MNF) in West Virginia. Additionally, we examined (1) differences in amphibian and reptile captures between gas well openings and adjacent forest habitat, (2) differences in small mammal captures among gas well openings, gas well opening/forest edge, and adjacent forest habitat, and (3) influence of gas well site status and aspect on sampled taxa and species diversity and richness. Because amphibians require moist, cool microhabitats (Duellman and Trueb 1994), we hypothesized that amphibian capture rate would be greater in adjacent forested habitat than in gas well openings. Conversely, we predicted that reptile capture rate would be greater in gas well openings because increased solar radiation would allow increased basking opportunity (Greenberg 2001, Seigel et al. 1987). For small mammals, we predicted that total captures would not differ among gas well openings, gas well opening/forest edge, and adjacent forest because, as a taxonomic group, small mammals exhibit broad habitat selection in the central Appalachian Mountain region (Kirkland 1977, 1990, Lidicker 1999). For the influence of gas well site status, we hypothesized that reptile and amphibian capture rate, small mammal captures, and species diversity and richness would be greater at plugged well sites because these sites do not experience repeated mechanized disturbance, therefore providing increased microhabitat.

STUDY SITE

The 364,225-ha MNF is located within the central Appalachian Mountains of West Virginia in portions of 10 counties. Most 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 saccharum*), red maple (*A. rubrum*), 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 to 1,100 m elevation and 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). Annual precipitation is approximately 152 cm, much of which occurs as snow in the winter. The frost-free period ranges from 90 to 150 days depending on elevation (Stephenson 1993).

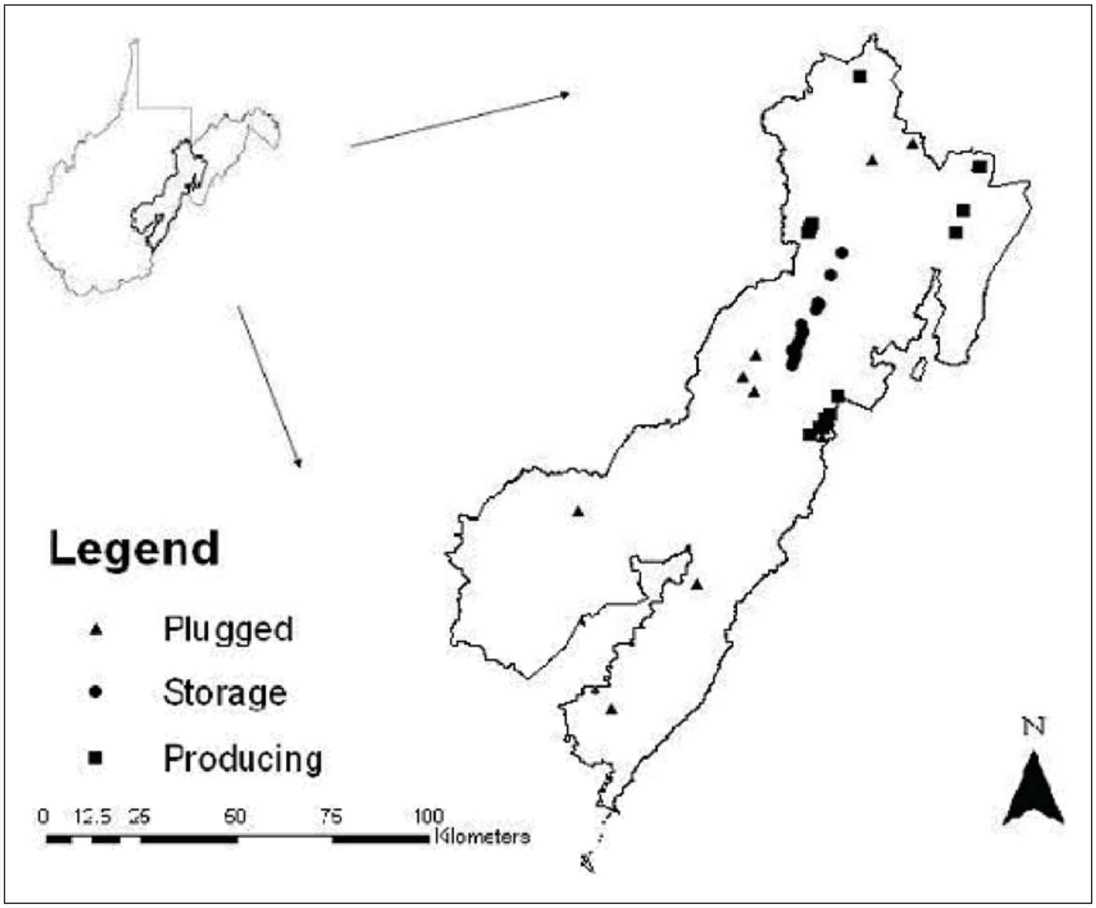

Figure 1.—Plugged (inactive; n = 11), storage (n = 16), and producing (n = 13) gas well sites sampled for reptiles, amphibians, and small mammals within the Monongahela National Forest in West Virginia, June-August 2006.

Approximately 93 percent of the MNF is forested, but it also contains small nonforested areas limited to small livestock grazing allotments, wildlife food plots or maintained grassy openings, and natural gas well sites (U.S. Forest Service 2006). Currently, there are 96 gas wells on the MNF consisting of actively producing, plugged (inactive), and storage sites. Storage sites are natural underground cavities where methane gas is maintained in reserve during periods of low demand, such as the summer. Gas well sites were established between 1957 and 2001 with the majority established before 1970. Since establishment, active producing and storage gas well sites have been maintained as grass- and forb-dominated openings by biennial mowing. Gas well opening area on sampled sites ranged from 0.15 to 1.44 ha and elevation ranged from 648 to 1,185 m. Gas well opening distance from streams ranged from 30 to 645 m. All gas well openings are connected by gas well pipeline rights-of-way or gravel access roads.

METHODS

We used ArcMAP 9.0 (ESRI, Redlands, CA) to randomly select a subsample of the 96 natural gas well sites on the MNF representing equal numbers of the three main well types: plugged, producing, and storage wells. However, due to logistical constraints, we could not survey some selected sites. Overall, we sampled 11 plugged, 13 producing, and 16 storage natural gas well sites. We conducted amphibian, reptile, and small mammal surveys at all 40 natural gas well sites throughout the MNF from June to August 2006 (Fig. 1). We sampled reptiles and amphibians along four 1-m-wide strip transects originating from the center of each gas well and extending 100 m into the forest interior from the gas well edge. Each transect was oriented toward one of the four cardinal directions. Some transect locations deviated from cardinal directions (maximum 45°) to maintain a distance of at least 50 m from connected linear openings of roads and gas lines. We overturned and searched all cover items encountered along each transect for reptile and amphibian presence between 0800 and 1800 hr. We conducted searches of each transect only once during our study and did not conduct searches during precipitation events. Therefore, our salamander capture estimates are conservative relative to similar studies in the region that sampled during cooler, moister weather conditions. We did not search leaf litter due to time constraints. However, amphibian captures under natural cover objects have been correlated with independent estimates of abundance (DeGraaf and Yamasaki 1992, Smith and Petranka 2000). When we encountered an animal, we identified it to species and recorded the location of capture as forest or gas well opening habitat. Precipitation during our sampling period totaled 55.1 cm (20-yr average = 40.4 cm).

To sample small mammal populations at gas well sites, we established three trap lines: one at the center, one at the edge of gas well openings, and one 50 m from the gas well edge within adjacent mixed mesophytic, northern hardwood, or red spruce forest (Menzel et al. 1999). Trap lines consisted of 20 snap traps separated by 1 m and baited with peanut butter. We opened traps for one 3-day period at each gas well site, checking traps daily and reapplying bait as necessary. We recorded species for each individual captured. In the Northeast and mid-Atlantic region, deer mice (*Peromyscus maniculatus*) and white-footed mice (*P. leucopus*) are difficult to distinguish based on pelage and external morphology (Aquadro and Patton 1980, Laerm and Boone 1994). Therefore, we grouped these species as *Peromyscus* spp. for analyses. We conducted trapping and collection under West Virginia Department of Natural Resources scientific research permit 2006.036 and West Virginia University ACUC number 06-0506.

We used ArcMAP 9.0 to determine elevation, aspect, road density, gas well opening area (m^2), and gas well site distance to nearest stream (m; any intermittent or perennial lotic waterbody identified on the USGS National Hydrography Dataset http://nhd.usgs.gov/). U.S. Forest Service personnel recorded gas well site locations using a global positioning system. We derived values for elevation and aspect using a 30 × 30 m digital elevation model (West Virginia GIS technical center, West Virginia University). We calculated road density as total road length (m) within 100-m buffers around sample sites. We calculated combined amphibian, reptile, and small mammal species richness and Shannon's Diversity Index (H') for each gas well site. We categorized gas well sites as mesic, xeric, and intermediate based on aspect. Mesic northern aspects ranged from 315 to 45°, xeric southern aspects ranged from 135 to 225°, and others were intermediate (Menzel et al. 2006). These habitat variables are commonly recorded for small mammal and herpetofaunal studies because of their influence on species occurrence and diversity (e.g., Ford et al. 2002, 2006; Francl et al. 2004; Yates et al. 1997).

We examined scatter and residual plots to assess if variables met assumptions of analyses (i.e., linearity, normality, colinearity). Because all variables deviated from normality, we ranked transformed variables and performed analysis on the ranked data (Conover and Iman 1981a). Untransformed values are presented. We standardized amphibian and reptile captures to account for differences in transect length among gas well openings. We compared total reptile, total amphibian, red-backed salamander (*Plethodon cinereus*), Allegheny mountain dusky salamander (*Desmognathus ochrophaeus*), small mammal, *Peromyscus* spp., and meadow vole (*Microtus pennsylvanicus*) captures and total species richness and diversity using a two-way analysis of covariance with gas well status, aspect, and an interaction term as independent variables (Steel and Torrie 1980). Because elevation, distance to stream, gas well opening area, and road density influence small mammal, reptile, and amphibian captures (Ford et al. 2002, 2006; Pais et al. 1988), and because these variables differed among sampled gas well sites, we included these as covariates. If the analysis of covariance indicated differences ($P < 0.05$), we used adjusted Tukey's Honestly Significant Difference tests to determine differences among independent variables. Additionally, we used linear contrasts to compare combined storage and producing sites to plugged sites to determine differences between actively maintained and unmaintained well sites. Mean values of dependent variables are reported using treatment means adjusted for covariates.

Table 1.—Adjusted means (± SE) for amphibian, reptile, red-backed salamander (*Plethodon cinereus*), Allegheny mountain dusky salamander (*Desmognathus ochrophaeus*), small mammal, *Peromyscus* spp., meadow vole (*Microtus pennsylvanicus*) captures and total species diversity (H') and richness on plugged (inactive; n = 11), storage (n = 16), and producing (n = 13) gas well sites and adjacent forest sites within the Monongahela National Forest, West Virginia, June–August 2006

	Status				
	Plugged	Storage	Producing	$F_{2,27}$	P
Herpetofauna					
Total amphibians	14.48 ± 3.71	23.89 ± 3.12	21.88 ± 4.22	1.59	0.223
Total reptiles	18.96 ± 2.91	22.29 ± 2.45	16.92 ± 3.31	0.91	0.414
Red-backed salamanders	14.32 ± 4.26	25.17 ± 3.59	20.35 ± 4.85	1.54	0.233
Allegheny Mountain dusky salamander	16.57 ± 3.36	25.99 ± 2.83	22.99 ± 3.82	1.87	0.173
Small Mammals					
Total small mammals	18.97 ± 3.81	20.13 ± 3.21	19.70 ± 4.34	0.02	0.978
Peromyscus spp.	18.51 ± 3.74	20.36 ± 4.26	20.36 ± 4.26	0.08	0.920
Meadow vole	18.35 ± 2.71	21.29 ± 2.28	22.63 ± 3.08	0.55	0.585
Shannon-Weiner Diversity Index (H')	13.50 ± 3.61	24.45 ± 3.04	23.51 ± 4.11	2.45	0.105
Species richness	11.64 ± 3.28A	24.32 ± 2.76B	24.56 ± 3.74AB	4.34	0.023

Means within rows with different letters differ P < 0.05

We compared amphibian, reptile, red-backed salamander, and Allegheny mountain dusky salamander captures between forest and gas well opening with a two-tailed t-test (Conover and Iman 1981a). We compared total mammal captures, *Peromyscus* spp., and meadow vole captures among gas well opening, edge, and forest with a one-way analysis of variance (Conover and Iman 1981b). If the analysis of variance indicated differences ($P < 0.05$), we used the adjusted Tukey's Honestly Significant Difference test to determine individual differences among independent variables. All statistical analyses were conducted using SAS statistical software (SAS 2003).

RESULTS

We captured 122 amphibians and 11 reptiles at 40 gas well sites, including 66 red-backed salamanders (25 sites), 35 Allegheny mountain dusky salamanders (15 sites), 16 slimy salamanders (*P. glutinosus*; 11 sites), 2 Wehrle's salamanders (*P. wehrlei*; 2 sites), 1 northern two-lined salamander (*Eurycea bislineata*), 1 American toad (*Bufo americana*), 1 eastern red newt (*Notophthalmus viridescens*), 1 eastern garter snake (*Thamnophis sirtalis*), 7 ringneck snakes (*Diadophus punctatus*; 3 sites), 1 red-bellied snake (*Storeria occipitomaculata*), 1 black rat snake (*Elaphe obsoleta*), and 1 eastern fence lizard (*Sceloporus undulatus*). Amphibian, reptile, red-backed salamander, and Allegheny Mountain dusky salamander captures did not differ among gas well status types (Table 1). Amphibian ($F_{2,27} = 0.74$; $P = 0.489$), reptile ($F_{2,27} = 0.45$; $P = 0.643$), red-backed salamander ($F_{2,27} = 0.59$; $P = 0.563$), and Allegheny Mountain dusky salamander ($F_{2,27} = 1.63$; $P = 0.215$) captures did not differ among mesic, xeric, and intermediate aspects. Additionally, we did not detect an interaction between gas well status and aspect for captures of amphibian ($F_{4,27} = 1.20$; $P = 0.333$), reptile ($F_{4,27} = 0.72$; $P = 0.588$), red-backed salamander ($F_{4,27} = 0.69$; $P = 0.603$), and Allegheny Mountain dusky salamander ($F_{4,27} = 1.27$; $P = 0.308$). Amphibian captures increased with increasing road densities ($F_{1,27} = 4.32$; $P = 0.047$). Amphibian, red-backed salamander, and Allegheny Mountain dusky salamander captures were greater along forested transects than along gas well opening transects (Table 2).

Table 2.—Mean (± SE) captures of amphibians, reptiles, red-backed salamanders (*Plethodon cinereus*), and Allegheny Mountain dusky salamanders (*Desmognathus ochrophaeus*) along transects in gas well opening and forested habitat at gas well sites (n = 40) within the Monongahela National Forest, West Virginia, June-August 2006

	Forest	Gas well	t	P
Amphibians	0.030 ± 0.004	0.002 ± 0.001	8.26	<0.001
Reptiles	0.001 ± 0.000	0.007 ± 0.003	-0.88	0.384
Red-backed salamanders	0.017 ± 0.003	0.000 ± 0.000	7.76	<0.001
Allegheny Mountain dusky salamanders	0.009 ± 0.002	0.000 ± 0.000	4.80	<0.001

Table 3.—Mean (± SE) captures of small mammals, *Peromyscus* spp., and meadow voles (*Microtus pennsylvanicus*) within gas well opening, edge, and forested habitat at gas well sites (n = 40) within the Monongahela National Forest, West Virginia, June-August 2006

	Opening	Edge	Forest	F	P
Total small mammals	0.65 ± 0.36	0.30 ± 0.11	0.40 ± 0.11	0.32	0.728
Peromyscus spp.	0.03 ± 0.03A	0.15 ± 0.07AB	0.35 ± 0.10B	5.65	0.005
Meadow voles	0.60 ± 0.36A	0.05 ± 0.05B	0.00 ± 0.00B	6.18	0.003

Means within rows with different letters differ P < 0.05

Overall trap success for small mammals was low as we captured only 50 individuals over 7,200 trap nights at 40 gas well sites, including 25 meadow voles (*Microtus pennsylvanicus*; 8 sites), 19 *Peromyscus* spp. (15 sites), 2 northern short-tailed shrews (*Blarina brevicauda*; 2 sites), 2 southern red-backed voles (*Myodes gapperi*; 2 sites), 1 woodland vole (*Microtus pinetorum*), and 1 eastern chipmunk (*Tamias striatus*). Total captures of small mammals, *Peromyscus* spp., and meadow voles did not differ among gas well site status (Table 1). Total mammal ($F_{2,27}$ = 1.87; P = 0.174), *Peromyscus* spp. ($F_{2,27}$ = 1.35; P = 0.276), and meadow vole ($F_{2,27}$ = 1.70; P = 0.202) captures did not differ among mesic, xeric, and intermediate aspects. Additionally, we did not detect an interaction between gas well status and aspect for total number of captures of small mammal ($F_{4,27}$ = 0.33; P = 0.854), *Peromyscus* spp. ($F_{4,27}$ = 0.69; P = 0.605), or meadow voles ($F_{4,27}$ = 0.68; P = 0.611). Meadow vole captures were negatively related to stream distance ($F_{1,27}$ = 4.37; P = 0.046). *Peromyscus* spp. captures were greater in forested habitat than on gas well sites (Table 3). Meadow vole captures were greater on gas well sites than on forest or edge sites (Table 3).

Combined small mammal and herpetofaunal species richness was greater at storage sites than at plugged sites (Table 1). Species diversity ($F_{2,27}$ = 1.10; P = 0.347) and richness ($F_{2,27}$ = 0.69; P = 0.512) did not differ among xeric, mesic, or intermediate aspects. Total species diversity was negatively related to stream distance ($F_{1,27}$ = 5.33; P = 0.029). Additionally, we did not detect an interaction for species diversity ($F_{4,27}$ = 0.25; P = 0.906) and richness ($F_{4,27}$ = 0.51; P = 0.728). Linear contrasts revealed that species diversity ($F_{1,27}$ = 4.79; P = 0.038) and species richness ($F_{1,27}$ = 8.65; P = 0.007) were greater in combined storage and producing sites than in plugged sites.

DISCUSSION

Our results support the contention that central Appalachian forested habitats harbor greater population densities of woodland salamanders than those lacking canopy cover (Ash 1997, Ford et al. 2002, Harpole and Haas 1999, Petranka et al. 1993). In our study, 98 percent of salamander captures occurred along forest transects, although overall captures were low. During daylight hours, microclimatic conditions within forest openings are characterized by increased fluctuations in solar radiation, ground temperature, and humidity relative to forested habitats (Chen et al. 1999, Geiger et al. 1995). Because woodland salamanders require moist microclimatic conditions to facilitate efficient cutaneous respiration (Spotila 1972), moisture and temperature fluctuations may surpass their tolerance thresholds within gas well openings. However, sufficient rock and CWD cover availability may mitigate adverse microclimatic fluctuations by providing moist refugia (Marsh et al. 2004, Riedel et al. 2008, Young and Yahner 2003). Riedel et al. (2008) observed frequent red-backed salamander occurrence within unmowed hay meadows adjacent to woodlots in southern West Virginia, attributing their occurrence within this habitat to cover object availability retained within meadows. Although we did not quantify cover object abundance within gas well openings and forest habitats, we observed significantly fewer large pieces of CWD or rock within openings. Therefore, if sufficient cover availability was retained within gas well openings during development, it may mitigate, to some extent, adverse microclimatic conditions.

Reduced woodland salamander abundance along forest edges has been attributed to unfavorable microclimatic conditions from adjacent forest openings, particularly those created from timber harvest (DeGraaf and Yamasaki 2002, deMaynadier and Hunter 1998) and roads (Marsh and Beckman 2004, Marsh 2007, Semlitsch et al. 2007). However, we found greater amphibian captures with increasing road densities, providing additional support for lack of adverse edge effects on woodland salamanders observed by Moseley et al. (2009), where woodland salamander occurrence was greater within 60 m of gas well opening edge. Similarly, DeGraaf and Yamasaki (2002) observed increasing red-backed salamander abundance 5 to 20 m from edge into mature northern hardwood forests in New Hampshire. Moreover, we observed the presence of American toad tadpoles within many roadside ditches containing standing water adjacent to well openings, suggesting these areas may serve as breeding habitat (Barry et al. 2008, Cromer et al. 2002).

Contrary to our initial hypothesis, reptile capture rates did not differ among forest and gas well openings. However, because reptiles are ectothermic, they are dependent on habitat attributes, such as forest canopy openings, that enable efficient body temperature regulation to facilitate optimal foraging, breeding, and predator avoidance behavior (Seigel et al. 1987). Ringneck snakes were the most common reptile captured (n = 7) on our gas well sites. Although ringneck snakes often are associated with mesic forest habitat in southeastern Piedmont and Coastal Plain regions (Willson and Dorcas 2004), 85 percent of our captures occurred within gas well openings. Our sampling techniques may have been insufficient for sampling reptile species, particularly lizards and large snakes (Ryan et al. 2002), and small sample size precludes strong inference regarding gas well opening use by reptiles. Nonetheless, because the MNF is 97 percent forested, experiences cooler, moister conditions relative to more xeric Appalachian regions, and has extended periods below optimal temperature thresholds for reptile species (Seigel et al. 1987, U.S. Forest Service 2006), gas well openings may serve as important basking and egg-laying habitat (Kjoss and Litvaitus 2001). Pais et al. (1988) reported greater herpetofauna richness in 0.2- to 1.0-ha wildlife openings relative to mature hardwood forest in Kentucky. As with woodland salamanders, large cover items within openings may have been limiting for smaller snakes. Because our sampling occurred during summer, when temperatures were likely above a threshold maximum for basking, reptiles may not use gas well openings as much as during fall and spring when temperatures are cooler. Further seasonal investigations examining reptile use of gas well openings and other early successional habitats in the central Appalachian mountain region are needed.

In the central Appalachian Mountains, meadow voles are strongly associated with old-field and meadow habitats (Ford et al. 2007, Francl et al. 2004). Indeed, all meadow vole captures in our study occurred within gas well openings. Moreover, 56 percent of all meadow vole captures occurred at one site where a thick debris layer was present, which may also account for the observed negative relationship between increasing meadow vole captures and decreasing stream distance; this particular well site was located only 573 m from a stream. Meadow voles can be abundant where a thick layer of grass provides greater cover (M'Closkey and Fieldwick 1975). Overall, meadow vole captures in our study were low and therefore conclusions about gas well opening habitat quality must be made with caution. Also, semi-annual mowing, in addition to soil compaction within well openings (Adams 2007, Moseley et al. 2009), may be suppressing establishment of suitable vegetative cover, and thus reducing meadow vole abundance. Inadequate vegetative cover may increase predation risk from meso-mammalian predators that frequently hunt in forest openings (Parker et al. 1992).

Many of our sampled gas well openings may not be large enough to support viable meadow vole populations. Despite their preponderance, we successfully trapped meadow voles at only 8 of 40 sites sampled. In West Virginia, meadow voles were generally absent from early successional wetland habitats less than 1.3 ha (Francl et al. 2004). Furthermore, Francl et al. (2004) found meadow vole captures were greater at wetlands with increased road density. Similarly, small mammal species associated with early successional habitats occurred at higher densities in larger clearcut openings (> 25 ha) than smaller openings (< 6 ha) within pine (*Pinus* spp.) stands in the Upper Coastal Plain of South Carolina (Yates et al. 1997). Because lower density small mammal populations within small habitat patches are more susceptible to local extinction, migration corridors that facilitate recolonization and augmentation of existing populations within patches are necessary for long-term persistence (Menzel et al. 2005, Yates et al. 1997). Indeed, Menzel et al. (2005) attributed skid roads associated with timber harvest to increased small mammal richness and diversity within bottomland hardwood forest gaps in the South Carolina Coastal Plain. We did not sample adjacent roads and gas pipeline rights-of-way, which likely serve as important migration routes for meadow voles and other small mammals (Cummings and Vessey 1994, Francl et al. 2004, Getz et al. 1978) within the predominately forested MNF landscape.

In the eastern U.S., *Peromyscus* spp. occur in a variety of habitats with particular affinity for areas with diverse vegetative structure (Dueser and Shugart 1978, Myton 1974, Osbourne et al. 2005). We captured *Peromyscus* spp. more often in edge and forest habitats than in gas well openings. Similarly, deer mouse captures increased with increasing distance from wildlife openings within northern hardwood forests in the southern Appalachians of North Carolina (Menzel et al. 1999). Although not quantified, edge habitats at most of our sites had well-developed vegetative structure or "side-canopy" (Didham and Lawton 1999, Matlack 1994) that may account for greater numbers of *Peromyscus* spp. captures within edge and forest interior habitats. However, our low sample size precluded examination of demographic parameters between habitat types, thereby limiting inferences about habitat quality associated with gas well sites (Van Horne 1983).

Our results suggest maintained gas well sites support greater species richness and diversity than non-maintained plugged well sites. Although not maintained, plugged wells had greater soil compaction than in storage well openings (Adams 2007), which may have reduced long-term availability of underground burrow habitat for small mammals and herpetofauna. Additionally, because plugged sites are no longer mowed, these sites had greater tree cover than storage or producing wells (Adams 2007). Therefore, plugged sites may have provided less suitable basking sites to reptile species and inadequate grass/forb structure to meadow voles as succession has transitioned these sites beyond old-field habitats.

CONCLUSION

Maintained forest openings and other early successional habitats are among the most rapidly declining habitats throughout the Appalachian Mountains (Litvaitis 2001). Recruitment and maintenance of early successional habitat have declined as farm abandonment progresses to forest cover, and as fire suppression increases, and even-aged timber harvesting is increasingly limited (Trani et al. 2001). Although gas well development represents a more permanent form of disturbance relative to natural perturbations, our results suggest that gas well openings can contribute to increased species richness and diversity within predominately forested central Appalachian landscapes. Additionally, natural gas development generally requires less land disturbance than development for other fossil fuels, such as petroleum and coal (U.S. Department of Energy 2003), thereby minimizing its impact on forest interior associated species. The utility of gas well openings as wildlife habitat may be further improved by adhering to West Virginia Best Management Practice guidelines, particularly with regard to alleviating soil compaction (West Virginia Department of Natural Resources 2006) to facilitate burrowing and development of dense vegetation. Furthermore, management of gas well sites as wildlife openings will benefit popular game species such as the eastern wild turkey (*Meleagris gallopavo*), American black bear (*Ursus americanus*), and white-tailed deer (*Odocoileus virginianus*; Kammermeyer and Moser 1990, Parker et al. 1992, Wentworth et al. 1990). Wildlife opening maintenance for game species also benefits numerous songbird species by increasing habitat heterogeneity and food resources (Parker et al. 1992). Investigations regarding vegetation manipulation through altered mowing regimes and increasing cover item (e.g., CWD and rocks) availability within gas well openings are needed to facilitate a better understanding of gas well openings as early successional habitat in the central Appalachian Mountains. Also, more research is needed on other wildlife species with varying habitat requirements before attributing overall wildlife benefits to natural gas development. In particular, the potential for negative impacts to aquatic biota from surface and groundwater contamination and to cave-dwelling organisms where karst geology is encountered (Goodbar 1997) requires further examination. Ongoing natural gas development on the Monongahela National Forest in karst geology and on the Allegheny National Forest offers opportunities for such investigations. (U.S. Forest Service 2007).

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Burgeoning energy demand in the United States has led to increased natural gas exploration in the Appalachian Basin. Despite increasing natural gas development in the region, data about its impacts to wildlife are lacking. Our objective was to assess past and ongoing natural gas development impacts on reptiles, amphibians, and small mammals in the Monongahela National Forest in West Virginia. We sampled 40 gas well sites and compared amphibian, reptile, and small mammal captures among active producing, plugged (inactive), and storage well types. Total species richness and diversity were greater at storage gas well sites than at plugged wells. Although natural gas development adversely impacts moisture-sensitive woodland salamanders, our results suggest that maintained gas well openings may benefit other herpetofauna and small mammal species that use early successional habitat within predominately forested central Appalachian landscapes.

KEY WORDS: Allegheny Mountains, *Microtus*, natural gas, *Peromyscus*, *Plethodon cinereus*

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