Edge Effects of Gated and Ungated Roads on Terrestrial Salamanders

DAVID M. MARSH,[1] *Department of Biology, Washington and Lee University, Lexington, VA 24450, USA*

ABSTRACT Roads through forest habitats reduce the abundance of many animal species. These reductions are often referred to as edge effects and their causes include roadkill, degradation of forest habitat, and changes in biotic interactions. Which of these causes are operating can have important implications for management. Terrestrial salamanders in the southern Appalachians have previously been shown to be subject to edge effects from forest roads that are open to traffic. In this study, I examined edge effects on red-backed salamanders (*Plethodon cinereus*) along forest roads that were either open or gated to prevent vehicle entry. I also included roads that varied in the width of the gravel surface, the width of the roadside verge, and the magnitude of habitat gradients at the forest edge. I found that ungated roads were associated with consistent edge effects on salamanders, whereas no detectable edge effects were found for gated roads. Road width was as good a predictor of the magnitude of edge effects as was the presence of a gate, though the width of the roadside verge was largely unrelated to the magnitude of edge effects. Gradients in habitat variables (soil moisture, temp, leaf litter thickness) were not closely related to the magnitude of edge effects. These results demonstrate that narrow, gated roads do not typically produce edge effects on terrestrial salamanders of the same magnitude as wider, ungated roads. In addition, the apparent importance of road type or road width and the relative unimportance of habitat characteristics suggest that traffic-related factors may be a substantial contributor to edge effects on terrestrial salamanders. These findings provide some support for the closing of redundant forest roads as a low-cost method for diminishing the negative effects of roads on forest ecosystems.
(JOURNAL OF WILDLIFE MANAGEMENT 71(2):389–394; 2007)

DOI: 10.2193/2005-556

KEY WORDS amphibians, edge effects, fragmentation, *Plethodon cinereus*, red-backed salamanders, roads, terrestrial salamanders, traffic.

Roads can have a variety of negative effects on wildlife populations in adjacent forests (Trombulak and Frissell 2000). Roadkill may result in high mortality, particularly for slow-moving taxa like amphibians and reptiles (Ashley and Robinson 1996, Hels and Buchwald 2001, Gibbs and Steen 2005) or for taxa that prefer roadside habitat (Vestjens 1973). Roads can also have more subtle effects on wildlife. Roads can be barriers to animal dispersal (deMaynadier and Hunter 2000, Dyer et al. 2002, Marsh et al. 2005), which can lead to habitat fragmentation and reductions in gene flow and population persistence (Gerlach and Musolf 2000, Keller and Largiader 2003). In addition, roads can degrade habitat near forest-road edges. Roads result in breaks in the forest canopy that can increase light and wind penetration and lead to lower soil moisture, higher temperatures, and changes in plant communities (Chen et al. 1995, Gascon et al. 2000, Watkins et al. 2003). This can alter wildlife communities and reduce the abundance of some species (deMaynadier and Hunter 1998, Ortega and Capen 2002). These reductions in populations near forest edges are commonly called edge effects (Murcia 1995).

Effective road management may require an understanding of the causes behind the edge effects of forest roads. For example, it may be important to know whether edge effects result from vehicle-related factors (e.g., roadkill, pollution, dust) or factors independent of vehicles (e.g., reduced soil moisture, increased wind penetration, disruption of the forest canopy). Most forest roads are constructed for timber sales, and following timber extraction, managers must decide whether to maintain roads for recreation or decommission them and close them to vehicle traffic (United States Department of Agriculture Forest Service 1999). If the edge effects of roads on wildlife are vehicle related, closing roads will remediate these effects at very low cost. Conversely, if the negative effects of roads are primarily related to habitat degradation due to the physical presence of roads, closing roads will do little to ameliorate these effects without substantial habitat restoration. Understanding the relationship between road width, the width of roadside verges, and the magnitude of edge effects may also be important for effective management. If narrow roads cause fewer edge effects than wider roads, newly built roads should not be wider than necessary for vehicle access. If roadside verges are related to the magnitude of edge effects, replanting trees along wider verges might be an effective remediation strategy for decommissioned roads.

I attempted to determine the factors associated with edge effects on red-backed salamanders (*Plethodon cinereus*) along gated and ungated roads in the southern Appalachians of Virginia. Red-backed salamanders are completely terrestrial and reach extremely high densities in some eastern forests ($>2/m^2$), though most individuals are underground at any given time (Test and Bingham 1948, Bailey et al. 2004). Because of their high densities and role in controlling invertebrate populations, red-backed salamanders are thought to be important components of forest ecosystem function (Burton and Likens 1975, Davic and Welsh 2004). Adult red-backed salamanders defend cover objects and have small home ranges of 10–25 m^2 (Kleeberger and Werner 1982, Mathis 1991). As a result of their moist skin and limited dispersal, terrestrial salamanders such as *P. cinereus* are often sensitive to changes in the quality of forest habitat (Welsh and Droege 2001). Red-backed salamander

[1] *E-mail marshd@wlu.edu*

Table 1. Characteristics of the western Virginia, USA, road sites used in analyses of the effects of gated and open roads on red-backed salamander abundance, April–June 2004.

Site	Type	Road width (m)[a]	Verge width (m)[b]	Description[c]
Blue Ridge	Gated	3.5	4.0	Drive to National Park inholding
Blue Ridge	Open	4.5	5.5	Road to National Park trail access
Golf course	Gated	2.9	6.0	Access to abandoned golf course
Golf course	Open	6.1	6.6	Forest service recreation road
White rocks	Gated	3.2	5.0	Drive to vacation cabins
White rocks	Open	4.0	7.0	Access to open campground
Mountain Lake	Gated	3.5	5.6	Access to closed campground
Mountain Lake	Open	6.1	2.2	Road to biological station
Stuarts Draft	Gated	4.5	3.0	Access to power station
Stuarts Draft	Open	6.0	2.5	Forest service recreation road
Hostel	Gated	4.1	1.6	Road to Appalachian Trail hostel
Hostel	Open	7.6	9.2	State road through National Park

[a] Road width is the width of gravel surface.
[b] Verge width is the summed width of the 2 verges between the road and forest edge.
[c] Description refers to the use and purpose of each road.

counts are reduced in forests with substantial canopy removal (Knapp et al. 2003) and are lower in the vicinity of forest-clearcut edges (deMaynadier and Hunter 1998, Marsh et al. 2004).

In previous work, we found that forest roads generally reduced red-backed salamander abundance within 20 m of forest-road edges (Marsh and Beckman 2004). Although these reductions were correlated with gradients in soil moisture, we surveyed only roads that were open to vehicle traffic and that were very similar in width (5–7 m). As a result, the previous study did not address the potential contributions of vehicle traffic and road width to edge effects in salamanders. In the present study, I determined the effects of both open roads and gated roads on the abundance of red-backed salamanders in adjacent forest. I used this comparison to explore the role of traffic-related versus habitat-related factors in causing edge effects on salamander populations. In addition, I determined the relationship between road width, the width of the roadside verge (i.e., the grassy strip between the road and the forest), gradients in habitat variables, and the magnitude of edge effects on red-backed salamanders.

STUDY AREA

Research sites were located in mature, deciduous forests in central and southwestern Virginia, USA. I used one pair of sites within the Big Levels Management Area in Augusta County, 2 pairs of sites within the Blue Ridge Parkway National Park, and 3 pairs of sites in adjacent areas of the Jefferson National Forest, the Wilderness Conservancy at Mountain Lake, and Mountain Lake Biological Station in Giles County.

Each pair of sites consisted of one gravel-surfaced forest road that was open to traffic and one nearby gravel road that was similar but gated to prevent most traffic from entering. Distances between paired roads ranged from 200 m–12 km. Because few suitable, gated roads were available, I was not able to randomly select across the landscape. Instead, I selected all sites using consistent criteria for inclusion. All roads that I surveyed were on relatively flat terrain (slope $<30°$) and passed through mature deciduous forest (Table 1). Additionally, I avoided sites with nearby streams or obvious signs of disturbance (e.g., cut stumps or fire scars) to reduce potential confounding factors.

METHODS

Transect Surveys

Along each road, I used transect surveys of natural cover objects to estimate the relative abundance of terrestrial salamanders. Transect and plot surveys of natural cover objects are highly repeatable and generally give consistent results across habitat types (Smith and Petranka 2000, Hyde and Simons 2001). Additionally, red-backed salamander surface activity does not appear to vary with distance from road (Marsh and Beckman 2004). Thus, changes in surface activity are not likely to bias estimates of relative abundance from surface counts.

I established transects on both sides of each road at 5 m, 20 m, and 40 m from the forest-road edge. Transects were 50×4 m and ran parallel to the road. A team of 12 observers searched all 6 transects at a site simultaneously. Along each transect, one observer turned every potential cover object (rocks, logs, or bark) to search for salamanders. The other observer recorded cover object types and sizes and the snout-vent length of any salamanders captured. Both observers collected soil samples at regular intervals along the transect. I dehydrated these samples and used weight change to estimate soil water content for each transect. Additionally, observers determined the thickness of the leaf litter layer with a ruler and soil temperature at 3 cm depth with a Reotemp soil thermometer (Reotemp Instruments, San Diego, CA) at 4 evenly spaced locations across each transect. Finally, observers measured the width of each road and the width of each roadside verge (i.e., the distance from the road to the forest edge). Observers surveyed all sites between 17 April and 3 June 2004 and surveyed each site exactly once.

On each survey date, observers surveyed one gated site and one nearby ungated site in a randomly determined order. I randomly assigned 12 observers to transects at the first site and then rotated through all transects over the course of the

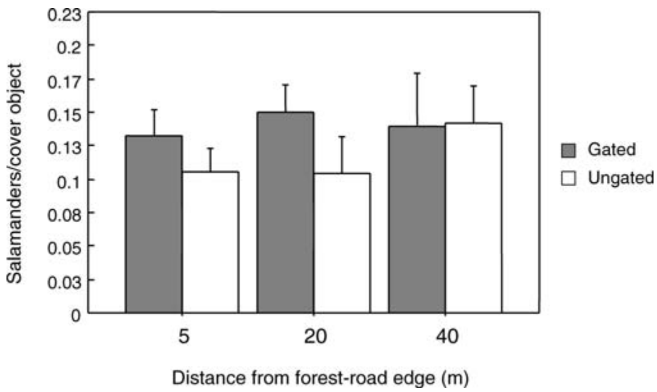

Figure 1. Effects of distance from the forest-road edge on counts of red-backed salamanders per cover object near roads in western Virginia, USA, from April to June 2004. Shaded bars indicate counts at gated roads and unshaded bars indicate counts at ungated roads. Error bars represent one standard error.

study to ensure that each observer surveyed salamanders exactly once at each distance at one gated and one ungated road. I did this to average inter-observer differences in searching ability across transect distances and road types. National Park Service permit no. BLRI-2004-SCI-0023, Virginia State collecting permit no. 21066, and Washington and Lee University Animal Care Protocol 0204b-DM covered all handling of salamanders during surveys.

Data Analysis

For each transect, I first calculated the number of red-backed salamanders per cover object. I then did a regression of salamanders per cover object on transect distance as a measure of the strength of edge effects at each site (Marsh and Beckman 2004). A regression slope of zero indicates no edge effects at a site, a positive slope indicates an increase in counts with distance from the road, and a negative slope indicates a decrease in counts with distance from road. I used these regression slopes as the dependent variable (i.e., the magnitude of edge effects at each site) in most successive analyses. Using salamanders per cover object instead of raw salamander counts reduced error variance due to differences in sampling effort, but it yielded similar patterns to the raw count data. In addition, there were no significant differences in cover object density among road types ($F_{1,27} = 0.45$, $P = 0.51$) and there was no interaction between road type and transect distance on cover object density ($F_{1,27} = 0.004$, $P = 0.95$). Thus, variation in cover objects among road types was unlikely to have biased our results.

For habitat variables (soil moisture, leaf litter thickness, and soil temp), I calculated regression slopes of transect means on distance from the forest-road edge. I used these regression slopes as an index of habitat gradients associated with forest-road edges and I compared them between gated and ungated roads. In addition, I compared overall habitat variable means for gated versus ungated roads to ensure that there were no major differences in the types of habitats through which these roads passed.

I used a randomized-block analysis of variance to test the a priori hypothesis that gradients in salamander abundance (i.e., edge effects) would differ between gated and ungated roads. I blocked sites by region and day because one gated and one ungated road in the same region were surveyed on each date. Thus, the block removes variation in edge effects due to geographical location or weather. I used a similar model to ask whether gradients in habitat variables differed between gated and ungated roads.

I also analyzed the effects of road type on the salamander age distribution at each distance from the road. Differences in age distributions could result from differential road mortality among size classes of salamanders. For this analysis, I summed salamander captures from each pair of transects at a given distance within a site. I then divided salamanders into adults (>3.4 cm snout-vent length) and juveniles (<3.4 cm snout-vent length). For each distance, I calculated the proportion of adults and arcsin square root transformed this variable for normality (Sokal and Rohlf 1995). I used a General Linear Model to ask whether there was a significant interaction between distance and the presence of a gate on the proportion of adults present. A significant interaction term would indicate differential edge effects on adults or juveniles between gated and ungated roads. I conducted these analyses using PROC GLM in SAS 8.2 (SAS Institute, Cary, NC).

For a broader analysis of the relationships between road type (gated vs. ungated), road width, habitat gradients, and edge effects on salamander abundance, I used an information-theoretic approach to model selection (Akaike's Information Criterion adjusted for small sample size [AIC_c]; Burnham and Anderson 1998). I compared 1) models including site and road type (gated vs. ungated); 2) models including site and several measures of road width; 3) models including site, road type, and road width; and 4) models that used habitat variables (soil moisture, leaf litter, temp) to explain edge effects in salamander abundance. For each candidate model from this set, I calculated the AIC corrected for small sample sizes (Sugiura 1978), a measure of model fit adjusted for the number of parameters (Burnham and Anderson 1998). I also calculated and the difference in AIC between each model and the best model within the set (i.e., ΔAIC_c). AIC differences <2 are considered to indicate little difference among models, while differences of 4–7 indicate considerably less support for the model with the higher AIC, and differences >10 indicate little or no support for the model with the higher AIC (Burnham and Anderson 1998). From ΔAIC_c values, I calculated model weights, which serve as estimates of the weight of evidence in favor of each model scaled to one for the entire set. I calculated likelihoods using PROC GENMOD in SAS (SAS Institute), and I calculated corrected AICs and model weights in Microsoft Excel (Microsoft, Redmond, WA).

RESULTS

Edge effects on salamander abundance were significantly reduced near gated roads as compared to open roads ($F_{1,5} = 19.49$, $P = 0.007$; Fig. 1). The mean regression slope for

Table 2. Comparisons of habitat and site characteristics between gated and ungated forest roads, collected in western Virginia, USA, from 17 April to 3 June 2004.

Variable[a]	Gated roads $\bar{x}$	Gated roads SE	Open roads $\bar{x}$	Open roads SE	F	P
Soil moisture gradient	0.140	0.026	0.072	0.122	0.245	0.64
Leaf litter gradient	0.004	0.004	0.002	0.003	0.098	0.77
Temp gradient	0.023	0.023	−0.003	0.012	2.115	0.20
Road width (m)	3.617	0.240	5.417	0.528	19.80	0.007
Total width (m)	7.817	0.505	11.633	1.189	5.659	0.063

[a] Gradients for habitat variables refer to the slope of the regression of the habitat variable on distance from the forest-road edge.

Table 3. Informatic-theoretic analysis of models explaining the magnitude of edge effects on red-backed salamander abundance across sites in western Virginia, USA, April–June 2004.[a]

Model	K	ΔAIC_c	w_i
Site, road width	4	0.00	0.480
Site, gate	4	0.36	0.401
Site, gate, road width	5	3.43	0.086
Site, gate, total width	5	5.57	0.030
Site, total width	4	9.88	0.003
Site, soil moisture	4	17.50	0.000
Site, all habitat variables	6	28.77	0.000
Site, gate, road width, all habitat variables	8	33.83	0.000
Site, gate, total width, all habitat variables	8	40.93	0.000

[a] K indicates the total number of parameters (including an intercept and error term). ΔAIC_c indicates the difference in corrected Akaike's Information Criterion (AIC) between each model and the best model in the set. w_i indicates the model wt, the relative evidence in favor of each model.

gated roads was −0.061 ± 0.059 (SE), indicating that there were no detectable edge effects along these roads. In contrast, the mean regression slope for ungated roads was 0.180 ± 0.77, which is consistent with the magnitude of edge effects found in previous studies (Marsh and Beckman 2004). Salamander age distributions across transects did not differ significantly between gated roads and ungated roads ($F_{2,27} = 0.46$, $P = 0.64$). Habitat gradients also did not differ between gated roads and ungated roads (Table 2). In addition, there were no significant overall differences in habitat parameters between gated and ungated roads ($F_{1,27} = 1.29$, $P = 0.27$ for soil moisture; $F_{1,27} = 0.86$, $P = 0.36$ for soil temp; $F_{1,27} = 0.12$, $P = 0.73$ for leaf litter thickness). However, road width and total width (road plus roadside verges) were significantly lower for gated roads versus ungated roads (Table 2).

In the information-theoretic analysis, I found that the best models for explaining the magnitude of edge effects were the model that included only site and road width and the model that included only site and road type (i.e., gated vs. ungated, Table 3). The model including site, road width, and road type performed somewhat more poorly considering the added parameter ($\Delta AIC = 3.43$, model wt = 0.086). Models including road width always fit the data better than models including total width (total model wt for road width = 0.57 vs. 0.03 for total width), suggesting that road width per se, and not the width or the roadside verge or the total width of the break in the forest canopy is associated with the magnitude of edge effects on salamander abundance. Models including habitat variables (soil moisture alone or all habitat variables) provided a much poorer explanation for the magnitude of edge effects (Table 3).

DISCUSSION

Narrow and gated roads, unlike wider and ungated roads, did not appear to contribute to edge effects on terrestrial salamanders. This result is strengthened by the fact that I selected the widest and best maintained gated roads that I could find in order to match these with ungated roads. Most gated roads that were left unsurveyed were simply dirt tracks with vegetation growing in the center. Based on the above results, edge effects along these roads would be expected to be even less severe. In a similar finding, deMaynadier and Hunter (2000) reported significant edge effects for salamanders along a heavily trafficked logging road (12-m width) but no edge effects along a narrow, partially vegetated road (5-m width). These combined results suggest that existing forest roads may vary considerably in their impacts on forest species, and that narrow, gated tracks may be substantially less harmful to terrestrial salamanders than wider, ungated roads.

Our results provide some support for the hypothesis that vehicle traffic may be an important factor in determining the strength of road-edge effects on terrestrial salamanders. Although road width was as good a predictor of the magnitude of edge effects as was the presence of a gate, narrow roads are likely to have less traffic than wider roads. Thus, the association of both of these variables with the magnitude of edge effects could be taken to suggest that vehicle traffic is likely important in determining the magnitude of road-edge effects on salamanders. This interpretation is further suggested by 1) the fact that road width explained the magnitude of edge effects much better than did the total break in the forest canopy and 2) the lack of strong associations between habitat variables and the magnitude of edge effects.

Nevertheless, there are several important limitations of this study. First, I attempted to infer the effects of closing existing roads based on edge effects at roads that were gated sometime in the past. This inference is only valid if gated roads are identical to ungated roads in all other respects. Transects near gated and ungated roads were in fact similar in terms of soil moisture, soil temperature, leaf litter thickness, and cover object density. However, gated roads were significantly narrower than ungated roads, so it is impossible to know to what extent gates alone were responsible for the observed results. Future studies should attempt to examine changes in edge effects before and after road closures, as this approach may be more directly applicable to real management scenarios.

A second limitation of this study is that traffic was not measured directly. Instead, I assumed that gated roads would have less traffic on average than ungated roads. This is probably a safe assumption, though traffic volume likely varied quite a bit among the roads. Three of the 6 gated roads were driveways to private inholdings which probably received at least a little traffic each day. Other gated roads led to abandoned campgrounds or firing ranges and appeared to be rarely used. Measuring traffic directly would be useful, though one would need to consider that a few vehicles on warm, rainy nights (when salamanders are dispersing) could have disproportionate effects on mortality.

A third limitation is that these results are based on analysis of only one species of terrestrial salamander. Although several other species were found (*P. glutinosus*, *Desmognathus fuscus*, *Pseudotriton ruber*, and *Notophthalmus viridescens*) no other salamanders were sufficiently abundant to permit statistical analysis. Responses of other amphibians may differ in ways that are hard to predict. For example, deMaynadier and Hunter (2000) found that the edge effects of a large logging road on anuran amphibians (i.e., frogs and toads) were generally less pronounced than the edge effects on salamanders. Additionally, Marsh and Beckman (2004) found that edge effects of forest roads on red-backed salamanders were stronger than those on slimy salamanders (*Plethodon glutinosus*). Studies on a wider range of taxa could provide a broader set of information on which to base decisions about gating or closing roads.

In a previous study, we observed that variation in soil moisture was associated with the magnitude of edge effects for red-backed salamanders (Marsh and Beckman 2004). In the current study, road width and road type explained edge effects better than did soil moisture or other habitat variables. These results are not necessarily contradictory. In the previous study, we surveyed only open roads with very similar widths (5–7 m). In the current study, the range of variation in road width (and consequent traffic volume) was much larger. Thus, in the current set of sites, traffic and road width may be the best predictors of edge effects. In the previous study, where roads had similar widths and traffic volumes, soil moisture may have been a more important predictor. In fact, soil moisture in the current study did show patterns of variation within road types that were qualitatively similar to the patterns observed in our previous study (e.g., positive correlations with distance from the forest-road edge; Table 2).

MANAGEMENT IMPLICATIONS

These results suggests that narrow, gated roads like those included in this study are less of a conservation concern for red-backed salamanders than are wider, ungated roads. With respect to new road construction, these results suggest that building roads as narrow as possible might be beneficial for forest-dwelling salamanders. It would be useful for managers to consider gating a sample of redundant forest roads and then studying the responses of a broad range of taxa to better elucidate this important management issue.

ACKNOWLEDGMENTS

I thank M. Aldrich, R. Corritone, N. Jetter, E. Lyman, E. Little, K. Sanford, W. Nickels, N. Gorham, J. Hau, J. Grahe, A. Stokan, and M. Craig for assistance in the field. F. Huber (United States Forest Service), J. Basinger (National Park Service), and D. Deschler (Mountain Lake Conservancy) were helpful with finding and gaining permission to use gated road sites. P. Trenham and R. Page commented on earlier versions of the manuscript. This research was funded by National Science Foundation DEB-0235695.

LITERATURE CITED

Ashley, E. P., and J. T. Robinson. 1996. Road mortality of amphibians, reptiles and other wildlife on the long point causeway, Lake Erie, Ontario. Canadian Field-Naturalist 110:403–412.

Bailey, L. L., T. R. Simons, and K. H. Pollock. 2004. Estimating site occupancy and species detection probability parameters for terrestrial salamanders. Ecological Applications 14:692–702.

Burnham, K. P., and D. R. Anderson. 1998. Model selection and multimodel inference. Springer-Verlag, New York, New York, USA.

Burton, T. M., and G. E. Likens. 1975. Energy flow and nutrient cycling in salamander populations in the Hubbard Brook Experimental Forest, New Hampshire. Ecology 56:1068–1080.

Chen, J., J. F. Franklin, and T. A. Spies. 1995. Growing-season microclimatic gradients from clearcut edges in old-growth Douglas-fir forests. Ecological Applications 5:74–86.

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

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

deMaynadier, P. G., and M. L. Hunter, Jr. 2000. Road effects on amphibian movements in a forested landscape. Natural Areas Journal 20: 56–65.

Dyer, S. J., J. P. O'Neill, S. M. Wasel, and S. Boutin. 2002. Quantifying barrier effects of roads and seismic lines on movements of female woodland caribou in northeastern Alberta. Canadian Journal of Zoology 80:839–845.

Gascon, C., G. B. Williamson, and G. A. B. Da Fonseca. 2000. Ecology: receding forest edges and vanishing reserves. Science 288:1356–1358.

Gerlach, G., and K. Musolf. 2000. Fragmentation of landscape as a cause for genetic subdivision in bank voles. Conservation Biology 14:1066–1074.

Gibbs, J. P., and D. A. Steen. 2005. Trends in sex ratios of turtles in the United States: implications of road mortality. Conservation Biology 19: 552–556.

Hels, T., and E. Buchwald. 2001. The effect of road kills on amphibian populations. Biological Conservation 99:331–340.

Hyde, E. J., and T. R. Simons. 2001. Sampling plethodontid salamanders: sources of variability. Journal of Wildlife Management 65:624–632.

Keller, I., and C. R. Largiader. 2003. Recent habitat fragmentation caused by major roads leads to reduction of gene flow and loss of genetic variability in ground beetles. Proceedings of the Royal Society of London B 270:417–423.

Kleeberger, S. R., and J. K. Werner. 1982. Home range and homing behavior of *Plethodon cinereus* in Northern Michigan. Copeia 1982:409–415.

Knapp, S. M., C. A. Haas, D. N. Harpole, and R. L. Kirkpatrick. 2003. Initial effects of clearcutting and alternative silvicultural practices on terrestrial salamander abundance. Conservation Biology 17:752–762.

Marsh, D. M., and N. G. Beckman. 2004. Effects of forest roads on the abundance and activity of terrestrial salamanders. Ecological Applications 14:1882–1891.

Marsh, D. M., G. S. Milam, N. Gorham, and N. G. Beckham. 2005. Forest roads as partial barriers to terrestrial salamander movement. Conservation Biology 19:2004–2008.

Marsh, D. M., K. A. Thakur, K. C. Bulka, and L. B. Clarke. 2004. Dispersal and colonization through open fields by a terrestrial woodland salamander. Ecology 85:3396–3405.

Mathis, A. 1991. Territories of male and female terrestrial salamanders: costs, benefits, and intersexual spatial associations. Oecologia 86:433–440.

Murcia, C. 1995. Edge effects in fragmented forests: implications for conservation. Trends in Ecology & Evolution 10:58–62.

Ortega, Y. K., and D. E. Capen. 2002. Roads as edges: effects on birds in forested landscapes. Forest Science 48:381–390.

Smith, C. K., and J. W. Petranka. 2000. Monitoring terrestrial salamanders: repeatability and validity of area-constrained cover object searches. Journal of Herpetology 34:547–557.

Sokal, R. R., and F. J. Rohlf. 1995. Biometry. W. H. Freeman, New York, New York, USA.

Sugiura, N. 1978. Further analysis of the data by Akaike's information criterion and the finite corrections. Communications in Statistics, Theory and Methods A7:13–26.

Test, F. H., and B. A. Bingham. 1948. Censuses of a population of the red-backed salamander (*Plethodon cinereus*). The American Midland Naturalist 39:362–372.

Trombulak, S. C., and C. A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conservation Biology 14: 18–30.

United States Department of Agriculture Forest Service. 1999. Roads Analysis. Informing Decisions About Managing the National Forest Transportation System. Misc. Rep. FS-643. U.S. Dept. of Agriculture Forest Service, Washington, D.C., USA.

Vestjens, W. J. M. 1973. Wildlife mortality on a road in New South Wales. Emu 73:107–112.

Watkins, R. Z., J. Chen, J. Pickens, and K. D. Brosofske. 2003. Effects of forest roads on understory plants in a managed hardwood landscape. Conservation Biology 17:411–419.

Welsh, H. H., and S. Droege. 2001. A case for using plethodontid salamanders for monitoring biodiversity and ecosystem integrity of North American forests. Conservation Biology 15:558–569.

Associate Editor: Rodewald.