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Author(s): David A. Patrick, Christopher M. Schalk, James P. Gibbs, and Hara W. Woltz
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Effective Culvert Placement and Design to Facilitate Passage of Amphibians across Roads

David A. Patrick,[1,2] Christopher M. Schalk,[1,3] James P. Gibbs,[1] and Hara W. Woltz[4]

[1] *State University of New York, College of Environmental Science and Forestry, Department of Environmental and Forest Biology, 241 Illick Hall, 1 Forestry Drive, Syracuse, New York 13210 USA*
[3] *Department of Wildlife Fisheries and Science, Texas A & M University, 221 Old Herman Heep Building, College Station, Texas 77843-2258 USA*
[4] *Center for Environmental Research and Conservation Schermerhorn Extension, Columbia University, 1200 Amsterdam Avenue, New York, New York 10027-5557 USA*

Abstract.—**Efficient deployment of culverts to mitigate mortality of amphibians on roadways requires identification of locations within road networks where animals cross (hotspots), points within identified hotspots for culvert placement, and attributes of culverts that make them behaviorally palatable to migrating individuals. In this study, we assessed road crossing frequency of Spotted Salamanders, *Ambystoma maculatum*, and American Toads, *Anaxyrus americanus*, along a 700-m transect within a known crossing hotspot, and related these distributions to habitat variables within the hotspot including the presence of existing culverts. We also placed experimental arrays of culverts of varying attributes in the path of migrating Spotted Salamanders to examine culvert preference by salamanders under typical movement environments and appropriate animal behavioral states. Our studies of patterns of road occurrence demonstrated that both species avoided crossing where there was a wetland within 15 m of the downslope of the road and that neither species showed a strong preference for crossing near existing culverts. When considering the choice for experimental culverts by Spotted Salamanders, we found no preference for culverts of varying aperture size, length, or substrate. Our results indicate that patterns of occurrences of the two species of amphibian within a crossing hotspot may be linked to the physical attributes at the site. For Spotted Salamanders in particular, predicting where they will cross within a hotspot may not be easy. Spotted Salamanders showed little preference for culverts of different design, indicating that a variety of culvert designs can suffice for mitigation if placed in appropriate locations.**

Road traffic kills or injures considerable numbers of amphibians and reptiles (herpetofauna) each year (Ashley and Robinson, 1996; Aresco, 2005; Andrews et al., 2007; Langen et al., 2009). In addition to mortality of individuals, road-kill can reduce population viability and lead to extirpation of local populations (Fahrig et al., 1995; Gibbs and Shriver, 2002). Because of the effects of roads on populations and the safety issues associated with drivers encountering animals, reducing animal–vehicle interactions has become an important research focus (Aresco, 2005; Clevenger and Waltho, 2005).

Studies in the northeastern United States have shown that amphibians and reptiles are more likely to be found on roads close to wetlands, especially where suitable terrestrial habitat is found on the aquatic-terrestrial interface (Smith and Dodd, 2003; Aresco, 2005; Compton et al., 2007; Langen et al., 2009). Occurrence of wide-ranging species, such as Blanding's Turtle, *Emydoidea blandingii*, on roads tends to be linked with locations where roads bisect annual migration routes (Beaudry et al., 2008), with aquatic turtle species such as the Common Snapping Turtle, *Chelydra serpentina*, linked to the location of suitable nesting sites (often roadside margins). Temporal patterns of occurrence are clearly linked to species' biology; the Spotted Salamander, *Ambystoma maculatum*, has explosive breeding migrations, with the majority of adults found crossing roads on a few nights in early spring (Gibbs and Shriver, 2005). Similar patterns are seen in the Eastern Tiger Salamander, *Ambystoma tigrinum* (Glista et al., 2007). Conversely, terrestrial turtle species may have several periods of movement activity (and subsequent exposure to roads) during the year as they migrate to access food resources, to aestivate, or to nest (Beaudry, 2007).

Based on this research, it is possible to predict likely locations of hotspots of herpetofaunal occurrence on roads within the landscape (Beaudry et al., 2008; Langen et al., 2009). However, for predicting where herpetofauna will be most concentrated within a hotspot (i.e., the spatial scale at which decisions for most mitigation

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[2] Corresponding Author. Present address: Paul Smith's College, Routes 86 and 30, Paul Smiths, New York 12970 USA. E-mail: dpatrick@paulsmiths.edu

projects involving barrier fences and crossing structures are made) much less information is available (Aresco, 2005). Once road locations where animals are likely to cross have been identified, the next step for successful mitigation is to determine the attributes of crossing structures that make them behaviorally palatable to herpetofauna. Research into effective mitigation structures has both employed experimental approaches and monitored the efficacy of existing structures for wildlife-crossings. Experimental research has shown species-specific preferences for culverts depending on diameter and substrate (Woltz et al., 2008), with field research indicating that a wide variety of attributes relating to both the surrounding landscape and the tunnel construction itself can also influence choice (Yanes et al., 1995; Puky, 2003; Andrews et al., 2007). Such experimental approaches permit large samples using animals captured in the field and placed within enclosures; however, one concern is that the pattern of choice exhibited by animals under experimental conditions may not be the same as that under natural conditions. Conversely, research based on monitoring arrays of already installed crossing structures affords a view of animals under ''natural'' conditions but does not permit control of site-specific variables.

Our study combined an experimental approach with unmanipulated study subjects to advance two goals: (1) to determine factors predicting where concentrations of herpetofauna will occur within a hotspot; and (2) to evaluate how animals in active migration mode respond to differences in the characteristics of culverts, specifically length, substrate, and diameter. To address these issues, we studied Spotted Salamanders and American Toads, *Anaxyrus americanus*, at Labrador Hollow, Apulia, Onondaga County, New York. We predicted that patterns of occurrence within this well-known hotspot (Gibbs and Shriver, 2005) would relate to the location of both suitable upland habitat for overwintering and suitable breeding habitat, with higher numbers of road-crossings in closer proximity to these features. We did not expect microhabitat features such as the presence of streams or seeps to determine abundance because movement invariably occurs when it is raining and the ground is saturated and often still covered by snow in the study region (DAP, pers. obs.). Furthermore, we predicted that animals would prefer to cross through wider and shorter culverts and avoid movement over concrete.

MATERIALS AND METHODS

Study Species.—The Spotted Salamander is a widespread species of forest-associated Mole Salamander (Ambystomatidae) found in the eastern United States and Canada (Petranka, 1998; Rothermel, 2004). Breeding typically occurs in temporary wetlands in early spring. American Toads occur in a variety of habitats including both forested and open areas throughout the central and eastern regions of North America (Gibbs et al., 2007). Sexual maturity is reached in 2–3 years, with large numbers of eggs laid in both temporary and permanent wetlands. This rapid early development can lead to large numbers of small juvenile toads, with high rates of mortality before sexual maturity is reached (Harper and Semlitsch, 2007).

Study Site.—The study was conducted at Labrador Hollow Unique Area, Apulia, Onondaga County, New York State (Fig. 1). Labrador Hollow features a centrally located shallow lake along a valley bottom bordered by forested wetlands in which Spotted Salamanders and American Toads breed. State Route 91, a two-lane highway with a speed limit of 88 kph, is situated on the east side of the lake. Amphibians must cross the highway when migrating between terrestrial habitats on the steep wooded slopes to breed in the lake's fringing wetlands. A drainage channel on the upslope side borders the road, with culverts under the road allowing the flow of run-off into the wetlands from the valley sides.

Predicting Patterns of Occurrence.—From March to June 2007, a team of volunteers sampled amphibians crossing Route 91 along a 700-m transect divided into 70 10-m long sections. The transect was patrolled continuously and with equal effort per 10-m section from sundown on peak migration nights (heavy rain, low wind, warm conditions) and ended when the number of salamanders crossing the road had decreased (most animals moved within a period of a few hours each night). The number of volunteers varied depending on the night with a maximum of 12 and a minimum of 3; thus, the sample effort varied among nights but not along the transect. All species of herpetofauna observed crossing the road at each segment were collected in buckets and then released on the opposite side of the road. During the sampling period, the vast majority of salamanders were travelling into the breeding site, greatly reducing the probability of double-counting the same individuals.

We quantified microhabitat on the steep wooded slopes to the west of the highway (''upslope'') and between the road and the breeding wetlands (''downslope'') for each 10-m road section. Variables measured included distance to the nearest culvert, whether flowing water was present on the upslope side of the road (including both streams with surface water

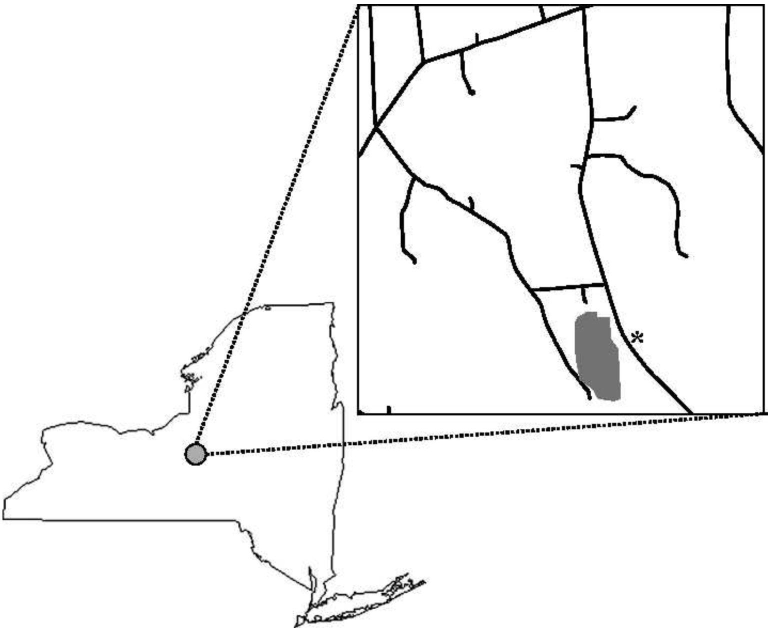

FIG. 1. Location of the study site at Labrador Hollow in New York State. The pond is shown by the grey shape in the inset map, with the approximate position of the arrays represented by the asterisk. Roads are shown as black lines.

flowing in a clearly defined channel and seeps where flowing water was present but with no clear channel); and whether any wetlands were found within 15 m of the road's edge on the downslope side of the road, as indicated by the presence of hydrophytic vegetation and standing water. We chose 15 m because further downslope from the road's edge there was a continuous strip of wetlands bordering the edge of Labrador Pond. Wetlands closer to the road (i.e., within the 15-m distance we assessed) represented seeps or drainages down which we postulated salamander may prefer to travel during migration. Roadside vegetation (i.e., grasses and herbs), forest canopy cover, and the presence of a drainage ditch remained constant along the transect. Thus, we did not include these covariates in our analyses.

Preference for Culvert Attributes.—To assess preference for culvert attributes, we established experimental arrays on the forested upslope adjacent to Route 91 and monitored their use during the 2008 migration period from 19 March to 27 April. Animals encountered these arrays before crossing the highway on their way to breeding sites. We constructed four arrays, approximately 30–100 m apart from one another, each of which consisted of two 9-m long wing fences (1-m high silt fencing buried ~5 cm) arranged at a slight angle to the downslope direction of migration (Fig. 2). Animals were funneled into a bay, also constructed of silt fencing, where they were then confronted with three choices of culverts. All culverts consisted of the corrugated black PVC (polyvinyl chloride) pipes typically employed in road construction for drainage. The culverts used in experiments were obtained from the New York State Department of Transportation; thus, apertures were within the range used in actual mitigation measures. At each culvert's terminus, a 5-gallon/19-L bucket was placed as a pitfall trap to capture migrating animals. Plastic sheeting and 0.5-m wooden stakes were used to connect the end of the culvert to the rim of the bucket to ensure that all animals were captured. Traps were opened before nightfall when conditions were suitable for amphibian movement. Animals were collected at daybreak the next morning and released into the nearest breeding habitat.

Each of our four arrays consisted of a different treatment. Experiment 1: Position—three, 3-m long culverts, each 0.6 m in diameter. As arrays were oriented along a north-south gradient, this treatment was used to assess whether animals tended to move in one direction along this gradient (for example south). Individual culverts in this array were identical to allow detection of any such directionality (i.e., no variation in aperture, diameter, or length). We termed these positions, north, central, and south. Experiment 2: Substrate—three, 3-m long culverts, each 0.6 m in diameter.

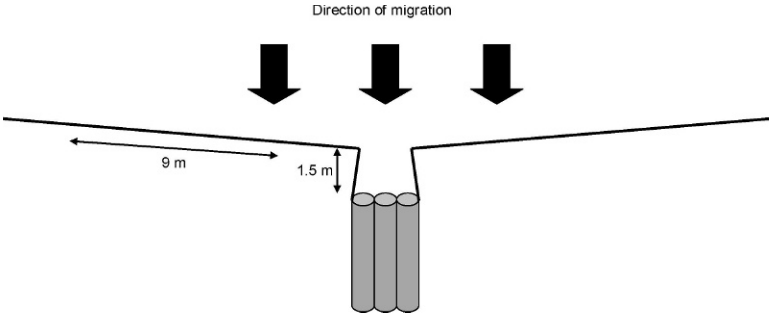

FIG. 2. Example of one of the four arrays used to test the influence of culvert attributes on selection by migrating adult spotted salamanders at Labrador Hollow, New York. The example shown is for the position array (where all culverts were the same). Culverts are shown as gray tubes, drift fences as solid black lines.

One pipe remained bare; one contained fine sand/gravel (typically <1 cm in diameter) gathered from a streambed within 500 m of the study site and placed throughout the base of the culverts to a depth of 5 cm; and one contained a 5-cm deep layer of set quick-drying concrete. Experiment 3: Length—three culverts, each 0.6 m in diameter. One consisted of a single 3-m pipe; the second two pipes joined to form a 6-m length; and the third three pipes joined to form a 9-m length. Experiment 4: Aperture diameter—three 3-m long culverts, one 0.3 m in diameter, one 0.6 m, and one 0.8 m.

To ensure independence between each nightly sample, we moved each of the treatments within an array between each sample to give us five unique combinations, one for each night of the study (being careful to minimize disturbance by replacing leaf-litter). One exception was the treatment in which we assessed whether position of a culvert within the array influenced choice; this treatment was left unaltered between nights because all of the culverts were the same.

Statistical Analyses.—Analyses of patterns of occurrence within the hotspot focused on the number of captures of Spotted Salamanders and American Toads in each 10-m road section, summed across all nights. We initially evaluated spatial correlation among the number of animals of each species crossing within each 10-m section using semivariograms. Because the sill associated with this analysis did not occur until 600 m, we were unable to use a systematic resampling approach to avoid spatial dependence and instead opted for autocovariate regression (Augustin et al., 1996).

We applied general linear models (GLM) with the response variable being the number of animals of each species crossing within each 10-m section of the transect during the study period and with an inversely distance-weighted autocovariate included in all models to account for spatial dependence among samples. Akaike's Information Criterion (AIC) was used to choose models that best explained the variation in the data while minimizing the number of parameters in the model. We estimated overdispersion using the $\hat{c}$-function in the AICcmodavg package for Program R (Mazerolle, 2009), with a criterion of $\hat{c} > 4$ indicating that a negative binomial rather than Poisson distribution of errors was appropriate. If there were more than one model with a ΔAIC ≤ 2, we used multimodel inference to derive a weighted model averaged estimate for each parameter (Mazerolle, 2006). We provide average parameter estimates and unconditional standard errors for focal variables to allow assessment of biological importance.

To assess preference for culvert attributes, we applied contingency table analyses using chi-squared tests with the number of Spotted Salamanders captured per trap night as our response variable (the only species with a sufficiently large sample size for analysis). Expected frequencies captured at each culvert per night were calculated as a third of the total captures at the array on that night given the null expectation of equivalent use of each of the three culvert choices. We applied chi-square rather than a log-likelihood or *G*-test because our average expected frequencies were >5 (Zar, 1999).

We initially tested whether position of the culvert within the array influenced choice by salamanders in the ''position'' array. Because no changes were made in this array between each sample night, we compared the observed versus expected distributions of captures between culverts summing over all nights to avoid repeated tests for each night. We then tested the remaining arrays (length, diameter, and substrate) separately, using the treatments within each array as ''columns'' and the three nights with sufficient sample sizes as ''rows''

TABLE 1. Autocovariate generalized linear models of the number of Spotted Salamander (a) and American Toad (b) observed crossing Route 91 at Labrador Hollow, Apulia, New York ($N = 70$ for both species). Spotted Salamanders were modeled with a Poisson distribution of errors, and American Toads with a negative binomial distribution. Variables in candidate models include distance to the nearest culvert (''dist_culvert''); the presence of flowing water on the upslope (''water''), and the presence of a wetland within 15 m on the downslope of the road (wetland).

Model	*N* parameters (K)	AIC_c	ΔAIC	Akaike weight (w_i)
(a) Spotted Salamander				
Dist_culvert, water, wetland	5	351.519	1.476	0.224
Water, wetland	4	352.360	2.317	0.147
Dist_culvert, wetland	4	350.043	0	0.469
Dist_culvert, water	4	361.677	11.635	0.001
Water	3	360.473	10.430	0.003
Wetland	3	352.258	2.215	0.155
Dist_culvert	3	362.707	12.665	0.008
(b) American Toad				
Dist_culvert, water, wetland	5	430.52	1.86	0.176
Water, wetland	4	428.66	0	0.447
Dist_culvert, wetland	4	437.60	8.94	0.005
Dist_culvert, water	4	431.52	2.86	0.107
Water	3	429.80	1.14	0.253
Wetland	3	437.32	8.66	0.006
Dist_culvert	3	437.3	8.64	0.006

(i.e., a 3 × 3 contingency table for each test). However, lack of a fully balanced design (where each treatment was tested in each position on a different night) means that any differences within arrays represents the effect of position and treatment on choice; thus, we were unable to test for an interaction between these factors. To address this issue, for arrays where a statistically significant difference between observed and expected choice was found, we tested the effects of treatment only by summing captures in the same treatment across all of the sample nights and position only by summing captures in the same position across all nights. Statistical analyses were conducted using Program R version 2.10.0. (R Development Core Team, Vienna, Austria, 2006).

RESULTS

Predicting Patterns of Occurrence.—During the four sample nights, we observed 551 Spotted Salamanders and 92 American Toads crossing within the 700-m transect. For Spotted Salamanders, Poisson autocovariate GLM indicated two models provided the best explanations for patterns in the data (Table 1a). Model-averaged parameter estimates demonstrated a weak relationship between salamander abundance and distance to the nearest culvert, with a marginally higher abundance found where there was a culvert nearby. Also, fewer salamanders were seen to cross where wetlands were present within 15 m of the road (Table 2a). There was no clear relationship between the presence of flowing water on the upslope of the road and salamander crossing (Table 2a).

For American Toads, negative binomial autocovariate GLM indicated that three competing models best explained patterns of abundance (Table 1b). More toads were found on sections of road without a wetland within 15 m of the downslope side of the road, where there was no

TABLE 2. Parameter estimates of the distance to the nearest culvert (''dist_culvert''); the presence of flowing water on the upslope (''water''), and the presence of a wetland within 15 m on the downslope of the road (wetland), based on Poisson autocovariate generalized linear models of the number of Spotted Salamander (a) and American Toad (b) observed crossing Route 91 at Labrador Hollow, Apulia, New York ($N = 70$ for both species). Model-averaged estimates for parameters were calculated for models with $\Delta AIC_c < 2$.

Name of variable	Model-averaged estimate	Unconditional SE
(a) Spotted Salamander		
Dist_culvert	0.0023	0.0011
Water	−0.0984	0.1069
Wetland	−0.431	0.1142
(b) American Toad		
Dist_culvert	−0.005	0.003
Water	−0.699	0.312
Wetland	−0.555	0.319

TABLE 3. Captures of Spotted Salamander following selection for one of three culverts within each of four experimental arrays. Choices within the ''Position'' array included identical 3-m long culverts, each 0.6 m in diameter; ''Substrate'' included one bare culvert; one containing fine sand/gravel and one containing a 5-cm deep layer of set quick-drying concrete; ''Length'' contained a 3-m, 6-m, and 9-m length of culvert; and ''Aperture diameter'' involved a choice between culverts 0.3 m, 0.6 m, and 0.8 m in diameter. Captures are shown pooled over all sample nights, whereas analyses were only based on a subset of nights for which sufficient sample size was acquired. Treatments within all arrays except position were rearranged between sample nights.

Array	Treatment	*N* Spotted Salamanders
Position	North	34
	Central	54
	South	51
Substrate	Bare	41
	Sand/gravel	44
	Concrete	33
Length	3 m	17
	6 m	18
	9 m	22
Aperture diameter	0.3 m	31
	0.6 m	37
	0.8 m	44

flowing water on the upslope of the road, and further from culverts (Table 2b). However, the latter variable represented a weak trend in the data.

Preference for Culvert Attributes.—We captured 446 Spotted Salamanders in the pitfall traps during the five nights of sampling, although only three nights yielded sufficiently large samples for analyses (Table 3). Analyses of the position treatment (where position within the array was the only factor) revealed a marginally significant relationship between the number of salamanders and the location of the culvert within the array ($X^2_2 = 5.02$, $P = 0.08$). Also, we observed a marginally significant difference in captures within the substrate arrays ($X^2_4 = 8.77$, $P = 0.07$), with fewer captures in the concrete-lined culvert (Table 3). No differences were seen between observed and expected frequencies of captures in the diameter treatment ($X^2_4 = 2.79$, $P = 0.59$). However, we did observe a difference in the length array ($X^2_4 = 45.41$, $P < 0.01$). We captured 26% fewer animals than expected at the northernmost trap, 16% fewer in the middle trap, and 42% more at the southern trap. When testing treatment within the length array individually (summing all captures per treatment over the sample nights), no difference between observed and expected captures was seen ($X^2_2 = 0.74$, $P = 0.69$). However a marginally significant difference was seen when assessing the role of position independent of treatment ($X^2_2 = 5.16$, $P = 0.08$).

DISCUSSION

Predicting Patterns of Occurrence.—Our results showed that the occurrence of Spotted Salamanders and American Toads varied along the length of the transect at Labrador Hollow and that, when considering the relationships between microhabitat and patterns of occurrence, the two species showed similar trends. However, the large differences in the magnitude of these trends have important implications for our ability to predict the locations of crossings at this site for the focal species.

An important question when developing approaches to mitigating the effects of roads on amphibians is whether species will use existing culverts not specifically designed for animal passage. Previous research has shown that amphibians will use preexisting culverts, particularly if a barrier is used to direct them to the culvert entrance (Puky, 2003; Dodd et al., 2004; Jochimsen et al., 2004). In comparison, our results indicate it is unlikely that large numbers of animals are migrating through existing culverts at Labrador Hollow, with neither of the focal species showing a strong preference for crossing locations based on the location of the nearest culvert. This result is not surprising given that peak migration for these two species at the study site corresponds with an extremely high volume of water flow related to snowmelt; under these conditions, the rushing torrent of water through the culverts is extremely unfavorable for amphibian passage.

Patterns of occurrence of amphibians on roadways are also likely to reflect differences in surrounding habitat (Smith and Dodd, 2003; Langen et al., 2009). Previous research has clearly shown that amphibian species differ in their patterns of habitat use (Guerry and Hunter, 2002; Houlahan et al., 2006; Patrick et al., 2006), with variation in occurrence of our two focal species along the transect likely to reflect differences in overwintering locations, habitat preferences during migration, or breeding habitat. Because our study was conducted within a crossing hotspot with intact forest and wetlands continually present along the length of the transect, habitat configuration at a landscape scale is likely to be less of a factor than has been shown in previous research (deMaynadier and Hunter, 1998; Gibbs, 1998). The only variable that was found to be an important driver of patterns of abundance of Spotted Salamanders was the presence of wetland within 15 m on the downslope of the road, with fewer salamanders found where a wetland was present. However, American Toads showed a strong negative correlation between upslope water and occurrence, indicating that this species was not using these areas at Labrador Hollow. As migration occurs on rainy nights during peak snowmelt time, it seems hard to imagine that either species is selecting where to move based on avoiding desiccation risk as has been indicated by previous research (Rothermel and Semlitsch, 2002). Existing studies suggest that, for Spotted Salamanders, the deciduous forest that is uniformly present on the upslope at Labrador Hollow (i.e., where the species is overwintering) is likely to represent suitable habitat (Faccio, 2003; Regosin et al., 2005). Research has shown that Spotted Salamanders do not tend to select for movement through streambeds (Gibbs, 1998), but it is not clear why they actively avoided downslope wetlands at the study site.

Compared to Spotted Salamanders, less ecological information is available relating to patterns of terrestrial habitat use by American Toads (Forester et al., 2006). It has been shown that this species prefers forest when available (Rothermel and Semlitsch, 2002; Forester et al., 2006) but readily occurs in open areas including agricultural and urban sites (Kolozsvary and Swihart, 1999). The avoidance of upslope wetlands we observed in our study seem more likely to reflect selection for overwintering sites at Labrador Hollow, indicating that American Toads may be choosing to overwinter outside of the upslope drainages. Similarly to Spotted Salamanders, however, the reason for avoidance of wetlands close to the downslope side of the road is less clear. Overall, our assessment of the factors determining occurrence of the two focal species on roads at Labrador Hollow suggests that, for Spotted Salamanders in particular, predicting the location of crossing hotspots within the overall hotspot is problematic.

Culvert Characteristics.—Our assessment of the choices made by migrating Spotted Salamanders for experimental culverts suggests that during migration, this species is relatively tolerant of the differences in length, substrate, diameter, and position we evaluated. Although we did see marginally significant relationships between culvert attributes and choice, none of the culverts was strongly selected against, suggesting that all options evaluated would permit road passage. To date, experimental research conducted with other species of herpetofauna outside of their normal seasonal movement has found choice to be more dependent on the attributes of crossing structures. For example, culvert characteristics (e.g., diameter, substrate type, and length) have been found to influence choice for at least some amphibians (Lesbarrères et al., 2004; Woltz et al., 2008). The differences seen between these studies and our own may well represent inherent interspecific variation, but there is also potential for animals translocated into experimental arenas outside of the breeding season to behave differently from those undergoing natural movements.

Differences in patterns of habitat selection by amphibians depending on life-history mode (i.e., dispersing compared with settled phases) have been seen in Wood Frogs, *Lithobates sylvaticus*, with animals in migration mode demonstrating habitat selection over larger spatial scales and less discrimination among habitat at finer scales (Patrick et al., 2008). Also, our results provide support for existing studies with Spotted Salamanders that have shown that they will readily move through culverts (Jackson and Tyning, 1989) and that for amphibians in general (with the exception of treefrogs), a combination of drift fences and culverts is an effective approach to mitigation (Puky, 2003; Dodd et al., 2004; Andrews et al., 2007), although see Allaback and Laabs (2003).

One aspect of this study may hinder generalizing its results to other sites and species: our longest culvert treatment of 9 m is still shorter than many of the culverts actually placed by management agencies under roads, and it may be that we did not reach a length threshold unpalatable to Spotted Salamanders. The substrate treatments we tested were also relatively suitable for amphibian movement compared to the desiccation risk presented by concrete and gravel in long dry tunnels. We know that amphibians are extremely prone to water loss (Mazerolle and Desrochers, 2005; Rittenhouse et al., 2008), and an animal moving long distances over a dry surface is likely to be more affected than one traveling over a moist surface. Bearing these caveats in mind, however, research has shown that amphibians are willing to cross long distances through culverts. For example, Dodd et al., (2004) found widespread use of 44-m long culverts by amphibians.

The combined analysis of the factors driving patterns of occurrence within a known amphibian crossing hotspot, and the attributes of culverts through which they will choose to travel provides valuable information to road-managers. Because the occurrence of our focal species on the roadway at Labrador Hollow is not confined to a small number of clearly defined locations, and the two focal species differ in their spatial distributions, we cannot pinpoint the exact location where mitigation strategies such as culverts would be best located. Because of this, an effective approach to mitigating mortality of amphibians at Labrador Hollow is likely to necessitate mitigation placed along much of the length of the crossing hotspot. However, the combination of our research findings and that of others suggests that amphibians can be readily funneled along barrier fences toward culverts and that Spotted Salamanders at least are willing to cross through tunnels with a variety of attributes, making it more feasible for transportation managers to construct effective mitigation. However, an important consideration when establishing culverts for mitigation at Labrador Hollow is that animals are not choosing to use existing culverts for under-road passage, possibly because the water volume and velocity is high during their period of migration. This finding has been supported also by previous research with Spotted Salamanders (Jackson and Tyning, 1989). Because of this, culverts created for mitigation of amphibian road mortality should have components that remain above the level of peak water flow.

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