MONITORING WILDLIFE USE AND DETERMINING STANDARDS FOR CULVERT DESIGN

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FINAL REPORT PRESENTED TO
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SUMMARY OF FINAL REPORT
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Problem Statement

The Florida Department of Transportation (FDOT) has recently taken a proactive approach to construction of underpasses to provide safe passage for certain wildlife from one side of the road to the other (e.g., Alligator Alley for Florida panthers, SR 46 for black bears). Certain issues need to be addressed prior to implementation of a statewide program designed to incorporate these provisions in all FDOT highway projects.

One of these is the fact that little empirical research has been performed to correlate what species will use what type of crossing structure. Another issue involves cost of implementation. Design of new structures specifically for wildlife use is expensive and not cost effective. A preferred approach would be to use existing designs oriented toward hydraulic function, but serve dual purposes as wildlife passages and drainage structures.

Previous research (conducted from 1995 to 1999) included the development of a model/algorithm that identified highway-greenway intersections, and prioritized and ranked these sites as key linkages in the statewide greenways system. Follow-up efforts included the inventory and ecological characterization of high priority road segments. The inventory included the identification of existing highway structures that potentially serve as wildlife movement passages. A logical next step would be to conduct field research monitoring existing culverts for wildlife use; data generated could be used to establish standards for culvert designs that promote or enhance use by various wildlife species.

Objectives

The following research provides an approach to classification of drainage culverts and bridges based on structural characteristics and suitability of use by various wildlife taxa. Objectives of the study included:

1) Identifying specific structure characteristics that enhance or detract from their suitability as wildlife crossing structures.

2) Developing standards for culvert design based on relationships between criteria such as culvert type and configuration, landscape context (including species-habitat associations) and species preference.

Findings and Conclusions

Study sites were established in three regions in the state: central Florida (District 5), northeast Florida (District 2), and panhandle Florida (District 3). Culvert monitoring was conducted from March 2001 to December 2001 and July 2002 to March 2003. For the first study period, 22 camera sites and 247 track sites were monitored; during the second study period, 19 camera sites and 85 track sites were monitored.

Six distinct faunal groups were used for analysis. Similarities and differences regarding use of crossing structures are evident among the groups. Common parameters of all crossing structures are outlined for each faunal group. Three thresholds for each parameter represent liberal to conservative measures of passage success by each faunal group.

A distance of 3.7 to 5.1 m from adjacent habitat to structure entrances is recommended to promote high levels of movement for all species. The width of the verge can be mitigated in part by right-of-way vegetation type and height.

All groups preferred presence of herbaceous vegetation, and in some cases addition of shrubs. Right-of-way vegetation height was a significant factor only for small mammals and herpetofauna. This would coincide with the need for cover from larger mammalian predators and birds of prey. The best recommendation regarding type of right-of-way vegetation would be the use of plant species that are the same as those in adjacent habitat, with slightly greater cover near entrances to crossing structures (to provide security for prey species).

The maximum recommended distance between crossing structures is 325 m within core conservation areas and habitat corridors, corresponding to at least 75% use by small mammals. This is consistent with findings by other studies.

Management and mitigation for the species most frequently encountered in this study should generally focus on improving habitat diversity along road right-of-ways and adjacent land-cover classes 4 (wetlands) and 8 (hardwood forests). Specifically, issues regarding habitat should be addressed on a site-by-site basis.

Annual-average-daily traffic (AADT) was statistically significant for all groups, except birds and ungulates. While tolerance of traffic increased for 75% structure use by meso-mammals and birds (AADT = 3,000), and carnivores and ungulates (AADT > 6,000); small mammals and herptiles were more sensitive, as 250 vehicles daily was still the maximum traffic level that could sustain measured use of culverts of 75%.

Data collected indicates that to maximize use by most wildlife, presence of humans and domestic predators must be minimized at crossing sites.

Culvert width was a significant factor in all regression models except for ungulates. To maintain high passage rates (75%) for all species (especially carnivores), at least 2.7 m width for new structures is encouraged. Culvert height was a significant factor for meso-mammals, herpetofauna, and small mammals. The latter two groups were more abundant using culverts 1.5 m or lower, presumably because larger predators are more hesitant to use them. As a road becomes wider, culvert length increases and openness necessarily goes down. To maintain the same openness value, width and/or height of the culvert must be increased. For large carnivores and ungulates, 3 m minimum height should be used. Preferences for all groups were for dirt or soil substrate and rectangular shape. When comparing bridges to culverts, only bridge height is relatively limiting (because height is similar for the two structure types). Specifically, for locations used by large carnivores (especially Florida black bear) and white-tailed deer, a minimum height of 3.5 m is recommended.

Two groups, herpetofauna and small mammals included species that frequented culverts as part of their primary habitat rather than as movement corridors. Meso-mammals, especially raccoons used water collection areas at culvert and bridge sites for foraging areas for amphibians or trash from motorists and fishermen.

Although frequency of site visits was sufficient for tracks and photographs, twice per week was inadequate to evaluate quantity and types of road-kills occurring on adjacent road segments. The effect of traffic noise is depicted in this study by the precipitous drop in use of culverts as traffic levels increase beyond 6,000 vehicles-per-day.

Future research needs include effects of moisture, temperature and light, and efficacy of drainage culverts to facilitate movement by amphibians in the southeast. Lastly, wildlife movement, in areas where few drainage structures exist (e.g., sandhill and scrub communities), needs to be investigated to assess impacts of road-kills on population levels (i.e., the potential need for crossing structures to improve habitat connectivity).

Benefits

Design standards for drainage structures (that promote use by wildlife within certain landscape/habitat contexts) should improve efficiency for retrofitting existing roads, or construction of new roads with appropriate cost-effective ecopassages. Determining the utility of existing structures, within right-of-ways at identified high-priority, highway-greenway interface zones, also provides opportunity for significant cost savings (associated with adapting these sites for optimal connectivity for wildlife). This research should enhance the ability of transportation agencies to effectively address wildlife issues at public hearings; and to quickly implement the appropriate mitigation measures needed at identified high-priority, highway-greenway interface zones.

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Introduction

The Florida Department of Transportation (FDOT) has recently taken a proactive approach to construction of underpasses to provide safe passage for certain wildlife from one side of the road to the other (e.g., Alligator Alley for Florida panthers, SR 46 for black bears). Certain issues need to be addressed prior to implementation of a statewide program designed to incorporate these provisions in all FDOT highway projects.

One of these is the fact that little empirical research has been performed to correlate what species will use what type of crossing structure. Another issue involves cost of implementation. Design of new structures specifically for wildlife use is expensive and not cost effective. A preferred approach would be to use existing designs oriented toward hydraulic function, but serve dual purposes as wildlife passages and drainage structures (potential examples are provided in Figure 1).

Associated Prior Research

Previous research (conducted from 1995 to 1999) included the development of a model/algorithm that identified highway-greenway intersections, and prioritized and ranked these sites as key linkages in the statewide greenways system (Chapter 4). Follow-up efforts included the inventory and ecological characterization of high priority road segments (Chapter 5). The inventory included the identification of existing highway structures that potentially serve as wildlife movement passages. A logical next step

Figure 1. Variety of existing structures that may function as wildlife underpasses.

would be to conduct field research monitoring existing culverts for wildlife use; data generated could be used to establish standards for culvert designs that promote or enhance use by various wildlife species.

Study Description and Design

Structural characteristics that may affect use by various faunal classes include composition, shape, texture, light penetration, moisture, and dimension (width, length, and height). Certain studies (Krikowski 1989, and Langton 1989) have shown importance of light and moisture on use by amphibian species. Size of structures has also been evaluated (Yanes et al. 1995, Rodriguez et al. 1996, and Hunt et al. 1987).

Some general rules of thumb have been proposed by landscape ecologists (e.g., “bigger is better”, and “more is preferable to less”) with regard to size and number of culverts per distance interval, in areas known for wildlife crossings. The biggest argument against using these rules of thumb, however, is cost effectiveness. Transportation engineers are interested in promoting protection for wildlife and public safety but at optimum efficiency, which involves minimizing costs. With this point in mind, it is therefore necessary to set standards based on the structural characteristics outlined above. The following research provides one approach to classification based on structural characteristics and suitability of use by various wildlife taxa. Objectives of this study include:

1) Identifying specific structure characteristics that enhance or detract from their suitability as wildlife crossing structures.

2) Developing standards for culvert design based on relationships between criteria such as culvert type and configuration, landscape context (including species-habitat associations) and species preference.

This experiment was performed to evaluate use by wildlife according to the combined functions of taxa by body size and by environmental preference. Field data was analyzed by aquatic or terrestrial habitat preferences of each taxon or body size group. A conceptual list of faunal categories found in Florida by environmental preference is presented below (Table 1).

Table 1. Faunal orders predicted to use culverts

Aquatic (moist conditions)	Terrestrial (dry conditions)
Urodela (salamanders)	Testudinata (gopher tortoise & box turtle)
Anura (frogs)	Squamata (lizards & snakes)
Testudinata (aquatic turtles)	Insectivora (moles & shrews)
Crocodilia	Rodentia
Squamata (aquatic snakes)	Carnivora
Carnivora (river otters)	Artiodactyla (deer)

Alternatively groups could be established by the following body weight categories (Table 2).

Table 2. Mammal body weight categories

Body weight	Smallest	Largest
3 – 1000 g	Southwest shrew	Fox squirrel
1000 – 6000 g	Swamp rabbit	Red fox
6000 – 15,000 g	Otter	Nutria
15,000 – 30,000 g	Bobcat	Beaver
30,000 – 179,500 g	Florida panther	Black bear

Note: A listing of herpetofaunal body weights was not available; however, the same approach would apply as with mammals above).

Individuals from the faunal classes above (that were monitored using culverts) were also evaluated to determine preference according to structural characteristics. Three shapes of culverts exist—round, oval, and rectangular. Length of culverts is dependent on roadway width that most commonly varies from 8 m (2 lane) to 60 m (6 lane). Round and oval culvert width ranges from 30 cm to 3.8 m (FDOT 1989). Box culverts have great variability in dimension ranging from 0.30 m to 2.4 m (tall) and 0.30 to 7.3 m (wide); and can be constructed with single or multiple openings or cells (FDOT 1989). An example of potential categories of culverts is shown in Table 3.

Width, length, and height are likely correlated in association with the "tunnel effect" that inhibits animals from passing through culverts. This results from an animal's inability to sufficiently see a substantial area or destination at the other end of the culvert. As length increases, width must be increased to reduce the tunnel effect. Others have attempted to evaluate the impact of tunnel effect by developing an "openness" index (W x H)/L (Yanes et al. 1995, and Rodriguez et al. 1996).

Table 3. Potential categories for culverts

Width (cm):	**61**	**91**	**122**	**183**	**244**	**305**	**488**	**610**
Shape								
Rectangular	—	—	—	—	—	—	—	—
Oval/Round	—	—	—	—	—	—		
Composition								
Concrete	—	—	—	—	—	—	—	—
Metal	—	—	—	—	—	—		
Texture								
Smooth	—	—	—	—	—	—	—	—
Corrugated	—	—	—	—	—	—		
Length								
8 – 61 m (8 m intervals)	—	—	—	—	—	—	—	—
Height								
30 – 365 cm (30 cm intervals)	—	—	—	—	—	—	—	

Note: Additional widths exist (maximum 731 cm); for purposes of this discussion limits were set to eight sizes. An additional variable is median light penetration that occurs on culverts 23 m or longer.

Methods and Study Area

The study design included selection of replicates of two structure types (culverts and bridges) from 7 different land-cover classes. Using bridge and culvert categories reduced variance for explanatory structural variables. Study sites were randomly selected (using *SAS* software, SAS Institute, Cary, N.C.) from a database of previously surveyed structures (see Chapter 5) that included information on structural and contextual parameters. A minimum of five replicates each of bridges and culverts were selected from each habitat/land-cover class (Table 4) at the 210 m^2 level. In some cases, randomly selected sites had to be substituted because of flooding, construction, restricted access, or other uncontrollable factors.

Table 4. Land-cover classes

Category	Description
1	urban mining
2	dry prairie sand pine scrub/forest sandhill xeric oak scrub/forest
3	pinelands
4	cypress swamp hardwood swamp bay swamp shrub swamp cutover wetland forest bottomland hardwood forest freshwater marsh & wet prairie open water
5	grassland/pasture/agriculture intensive agriculture bare soil/clearcut
6	shrub/brush (range) land
7	mixed pine-hardwood forest hardwood hammock & forest

Structures were monitored either twice weekly using track beds, or on a continual basis using remote infrared-camera equipment. The area surrounding culvert entrances was also monitored. This design afforded the ability to evaluate culvert avoidance by particular species or faunal groups. Road-kills were also recorded at each study site. All species were recorded 50 m in each direction from crossing structures, while large mammals and alligators were recorded beyond 50 m. General soil moisture (5-point

Likert response scale: very wet, wet, moist, dry, very dry) within each culvert was recorded during each visit. Height of right-of-way vegetation was recorded once monthly. Weekly rainfall and minimum and maximum temperatures for each site were acquired from National Climate Data Center (NCDC) weather stations closest to each monitoring site (maximum distance of 57 km). Benefits of the design included:

1) monitoring in the natural setting of those species present,
2) documenting simultaneously the effect of structural, environmental and habitat variables on effectiveness as wildlife passageways,
3) evaluating overlapping species-habitat associations to develop generalizations of culvert sizes needed in particular habitat types (e.g., Florida black bear's use of multiple habitat types would overlap many smaller species that exist within the black bear's range—"umbrella effect"),
4) identifying certain sites containing small culverts that are nonfunctional for larger species present in the area, and
5) identifying species that are "culvert avoiders".

Track beds were prepared by clearing vegetation and debris (Figure 2), tilling and loosening existing soil, and when necessary applying substrate additives (e.g., builder's sand) to ensure readable tracks. Problems encountered at various sites included vegetation overgrowth and mowing, rain, flooding, erosion, and washouts (that in some cases interrupted monitoring efforts or required repeated site preparation).

Remote infrared-camera equipment used at camera sites included Trailmaster© Models 550 and 1500, and the Camtrakker™ Wildlife-Pro Model. The Model 1500 is an active-sensor device that has a transmitter and a receiver. The Model 1500 system works by orienting the single infrared beam, emitted by the transmitter, directly toward the receiver. When an object obstructs the path of the infrared beam, the camera is triggered and a photograph is taken. The range of the Model 1500 is approximately 33 m. The Model 550 and the Wildlife-Pro are passive-sensor devices. The Model 550 emits an before

after

Figure 2. Site preparation at track monitoring stations. Steps consisted of 1) Clearing vegetation, 2) Preparing soil (e.g., tilling and loosening), and 3) Applying soil additives (e.g., builder's sand) when needed to ensure readable tracks. Frequent problems included flooding, erosion, and washouts.

infrared array that consists of several beams, directed outward at equal interval angles that form a semicircle. The range of the infrared array is approximately 20 m. When an object interrupts two or more of the infrared rays, the camera is triggered and a photograph is taken. The Wildlife-Pro emits a cone-shaped infrared beam with a range of approximately 20 m. When an object enters the path of the infrared beam, the camera is triggered and a photograph is taken.

To protect the equipment from the elements and to prevent theft, custom lock boxes were constructed out of military ammunition boxes. Figure 3 displays the remote-camera system attached to a bridge. Each lock box was fastened to bridge pilings by Tapcon™ concrete screws and steel cables to deter theft. The Model 1500 system was aligned approximately 30 to 35 cm above ground level. The other models were setup at various positions and angled toward the target area, depending on site characteristics.

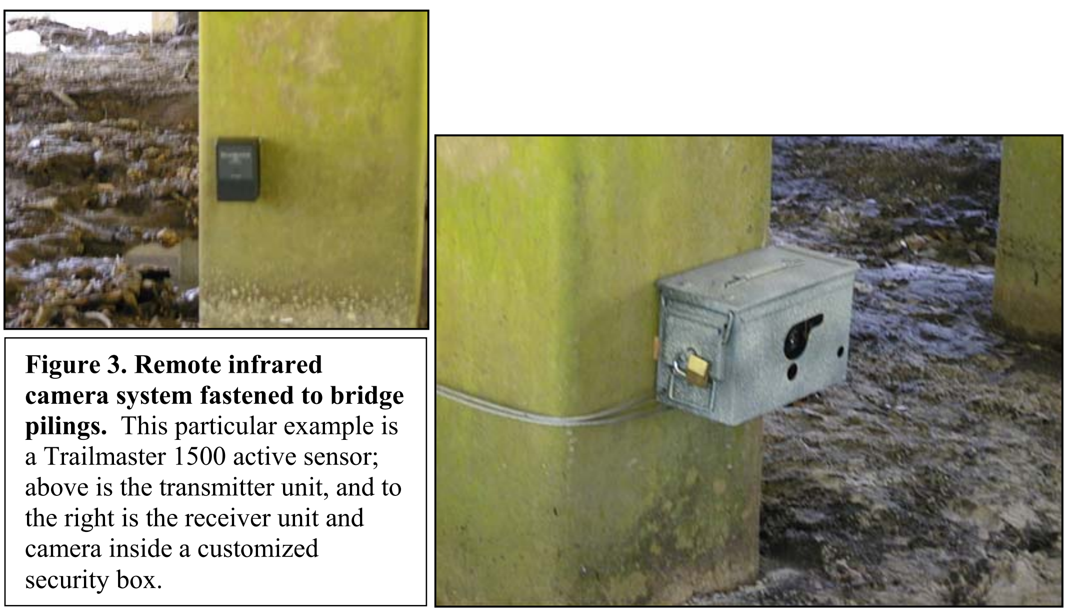

Figure 3. Remote infrared camera system fastened to bridge pilings. This particular example is a Trailmaster 1500 active sensor; above is the transmitter unit, and to the right is the receiver unit and camera inside a customized security box.

Timers on the sensors were set to function on a 24 hour cycle whenever possible. For sites where human activity was prevalent during the day, timers were set for nighttime hours only. Film and batteries were checked every two to three weeks depending on the amount of wildlife traffic at each site.

Statistics were performed (using *SAS*) on numeric variables for each monitoring site. These included basic univariate-statistical measures, tests for normality, and distribution tables and plots. Multiple-logistic regression was performed to determine significance of numeric and class variables governing species use, recorded at each monitoring location. Logistic discrimination performs a logistic regression on the categorical variable, and assigns population membership to observations based on the associated explanatory variables (Khatree and Naik 2000). The function used for this process is described below:

$$logit\,(\pi) = \log_e \left| \frac{\pi}{1 - \pi} \right|$$

In this equation, π represents the probability of an observation for population 1, and $1 - \pi$ represents the probability of an observation for population 2. A dummy variable, y, is used to indicate membership in this binomial distribution:

$$y = \begin{cases} 1 \text{ for population 1} \\ 0 \text{ for population 2} \end{cases}$$

Assuming this to be a linear function the underlying model for the procedure can be written as follows:

$$logit\,(\pi) = \beta_0 + \beta_1 x_1 + \ldots + \beta_k x_k$$ (Khatree and Naik 2000).

Frequency distributions for significant explanatory variables identified in logistic regression models, and thresholds for use by each faunal group were generated.

Independent variables used in the analyses included 34 factors: number of traffic lanes, right-of-way clearance, right-of-way gap, median width (on divided highways), AADT (annual-average-daily traffic), structure—type, composition, substrate, shape, size, and "openness", distance to next nearest culvert, habitat—diversity and dominant types (primary and secondary) at 30, 210, 1020, and 2040 m^2, presence of humans and domestic predators, soil moisture, right-of-way vegetation type and height, rainfall, and minimum and maximum temperatures. The dependent variable measured for each taxon was whether animals that approached culvert entrances, passed through or not.

Study sites were established in three regions in the state: central Florida (District 5), northeast Florida (District 2), and panhandle Florida (District 3). Culvert monitoring was conducted from March 2001 to December 2001 and July 2002 to March 2003. For the first study period, 22 camera sites and 247 track sites were monitored (Figure 4); during the second study period, 19 camera sites and 85 track sites were monitored (Figure 5). Of these, 61 sites were monitored during both study periods.

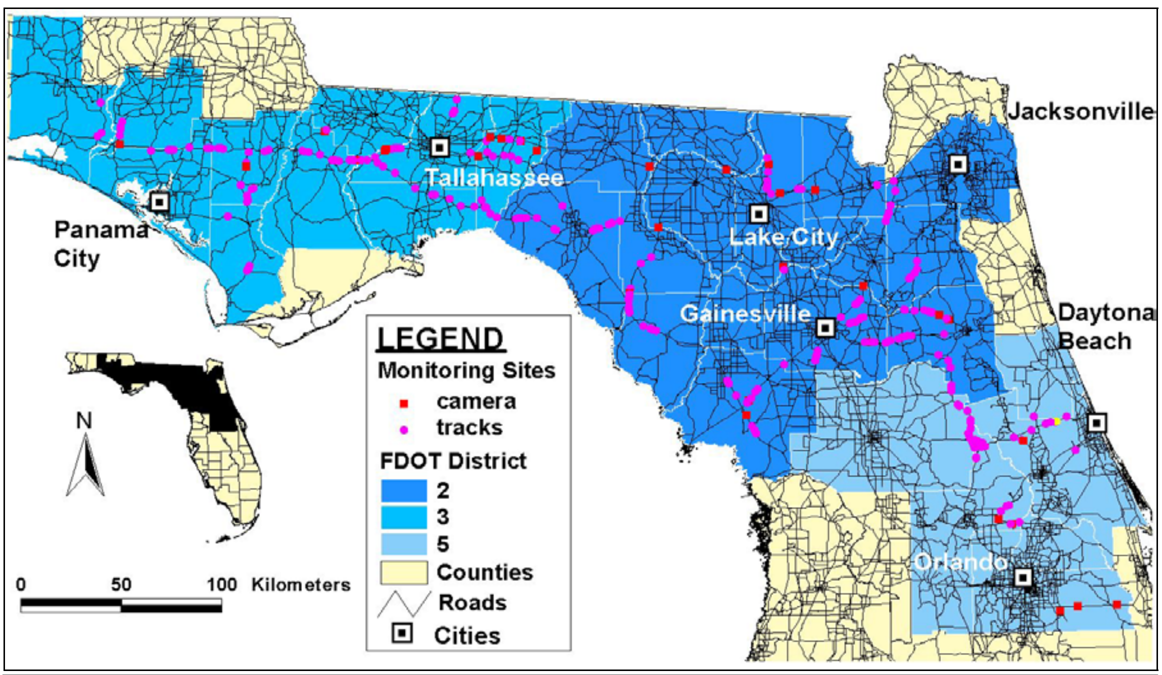

Figure 4. Bridges and culverts monitored for wildlife use from March 2001 to December 2001. Sites were checked for tracks or monitored by infrared remote cameras on 37 roads in 32 counties.

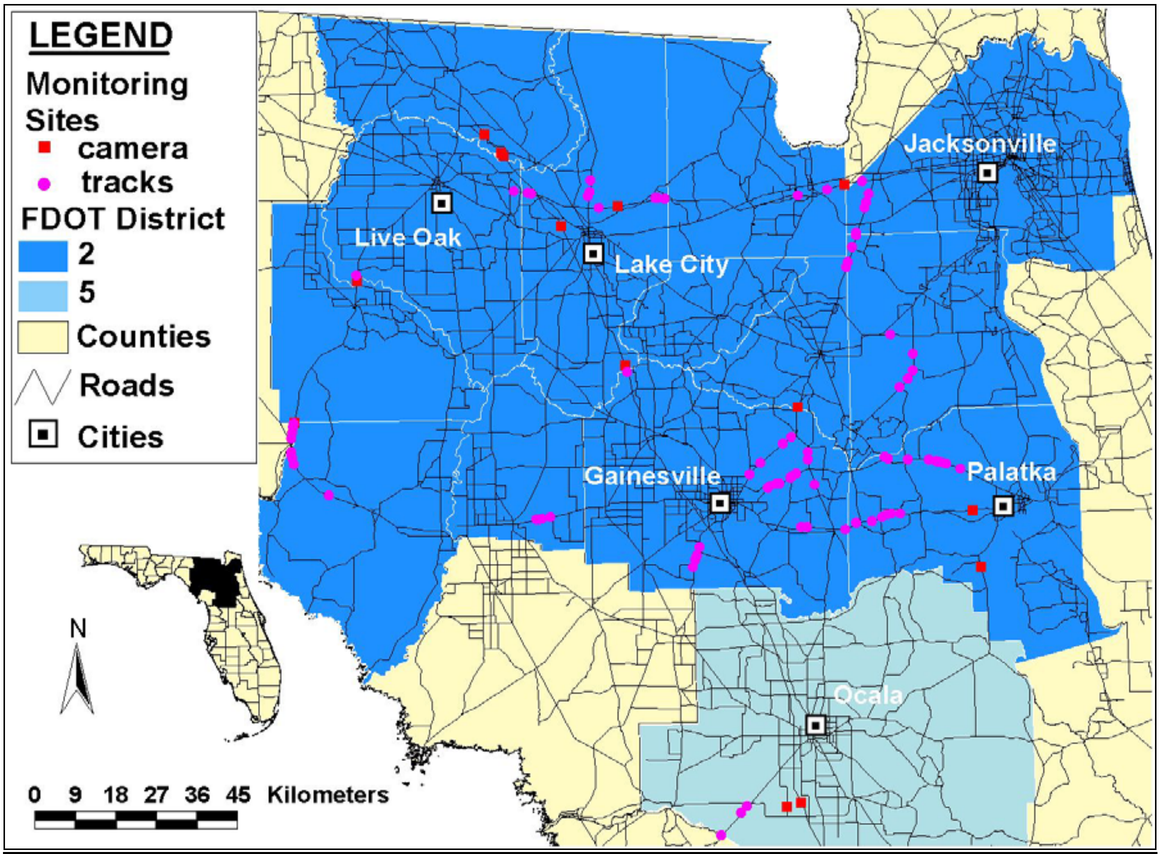

Figure 5. Bridges and culverts monitored for wildlife use from July 2002 to April 2003. Sites were checked for tracks or monitored by infrared remote cameras on 17 roads in 14 counties.

Results

Results from field data collection and statistical analyses include three separate components. First, the selection of site replicates is presented, including univariate measures for each site and associated explanatory variables. Second, general findings and trends are discussed. Third, data reduction using multivariate-logistic regression and frequency distribution analysis are performed on field data.

Assumptions for Multivariate Logistic Regression Analysis

Four assumptions were addressed for discriminant multivariate-logistic regression: independent random sampling, multivariate normality, equality of variance-covariance matrices, and singularity and multicollinearity of explanatory variables.

Suitable replicates were randomly drawn from a sample of 1,232 field sites (discussed in Chapter 4) from across the State. Logistics (e.g., level of funding and staffing for the project) reduced the study area to north-central Florida and the eastern half of the panhandle (Figures 4 and 5). Coordinating driving time with twice-weekly site visits narrowed the sites available to routes that were efficient for timely and consistent data collection. The result included 290 bridge and culvert sites from the various land-cover types (Table 5).

Enough culvert sites were found to provide more than the minimum 5 replicates for each primary land-cover class at the 210 m^2 scale, and included a total of 223 culvert monitoring sites. For bridge sites, suitable replicates were found for all primary land-cover classes except for classes 1 (urban/mining) and 2 (xeric-based land-covers). To obtain sufficient bridge replicates in these land-cover classes, secondary land-cover was included, and resulted in 12 additional sites for class 1 and 2 additional sites for class 2.

Table 5. Replicates found for each structure type by land-cover class

Structure type	**Primary land-cover at the 210 m^2 scale**							
	1	2	3	4	6	7	8	Total
Culverts	12	18	77	27	24	52	13	223
Bridges	1	3	17	24	6	9	7	67
Total	13	21	94	51	30	61	20	290

Notes: 1) shaded yellow cells indicate insufficient replicates for the primary land-cover class, secondary land-cover was included to provide 12 additional sites suitable as replicates for bridges in class 1. Two additional sites had the same secondary land-cover for bridges in class 2 that resulted in availability of five replicates for this category.
2) Table 4 provides land-cover descriptions.

Sample size, mean, standard deviation, and normality of numerical structural, environmental, and ecological explanatory variables for the 290 monitoring sites are shown in Table 6. The variables in the table represent 14 static and 4 dynamic factors.

The 14 static measures had the same value for the duration of the study. Normality curves were not generated for number of lanes, structure number, and the 4 habitat diversity factors that consisted of integer values; mean and standard deviation was rounded to the nearest whole number. The 4 dynamic variables that were measured throughout the study included—rainfall, minimum and maximum temperature, and right-of-way vegetation height. The other 16 explanatory variables included were non-numeric—primary and secondary habitat (30, 210, 1020, 2040 m^2), water feature type, vegetation type, soil moisture, and other structural characteristics (i.e., type, composition, shape, substrate, and number).

Note the significant difference in the means of openness index, width, and height for bridges and culverts (Table 6). This high variability explains why the two structure types were evaluated separately. Plots and goodness-of-fit tests for univariate normality of explanatory variables for bridges (n=67) and culverts (n=223) revealed skewed or peaked distributions. Lognormal and exponential data transformation and removal of extreme observations was used to fit normal data curves. Goodness-of-fit was corrected following data transformation for openness index, width, length, and height on bridge sites and AADT, gap width, and distance for all sites (Table 6).

Although goodness-of-fit values (Kolmogorov-Smirnov Test) were not significantly changed from data transformation, lognormal curves were the closest approximation for culvert—openness, width, length, and height (Figure 6). Rainfall most closely fit an exponential curve (Figure 6), whereas right-of-way vegetation height was most similar to a lognormal distribution (Figure 6). Distribution curves of temperature parameters were not significantly improved through data transformation and/or removal of extreme observations, so original values were used. Although these did not strictly meet univariate normal requirements, they did not grossly violate them either (e.g., minimally elevated skewness and kurtosis values). They were therefore included in the model using the most appropriate data transformation method. Logistic regression still provides a robust method when multivariate distributions are nonnormal (McGarigal et al. 2000).

Table 6. Univariate measures and distributions of explanatory variables

Explanatory variable	***n***	**Mean**	**Standard deviation**	**Goodness-of-fit test for normality** (Kolmogorov-Smirnov)
All sites (n=290)				
Number of lanes	290	3	1	-
Road clearance width, m	290	39.07	20.80	p < 0.01
Gap width, m	269	6.87	4.84	p = 0.058*
Median width, m	290	14.08	5.57	p < 0.01
AADT	275	7165	6916	p > 0.014*
Distance between structures, m	278	921.23	580.11	p > 0.15*
Habitat diversity 30 m^2	290	3	1	-
Habitat diversity 210 m^2	290	3	1	-
Habitat diversity 1020 m^2	290	6	1	-
Habitat diversity 2040 m^2	290	6	1	-
R-O-W vegetation height, cm	13,060	48.47	31.02	p < 0.01
Average minimum temperature, C	15,548	15.18	6.08	p < 0.01
Average maximum temperature, C	15,558	27.47	4.74	p < 0.01
Rainfall, ml	15,671	2.65	4.07	p < 0.01
Bridges (n=67)				
Openness index (w x h / l)	67	12.95	12.07	p > 0.15*
Width (w), m	67	61.94	41.99	p > 0.15*
Length (l), m	67	20.11	13.79	p > 0.15**
Height (h), m	67	3.77	2.79	p = 0.117**
Culverts (n=223)				
Structure number	223	1	1	-
Openness index (w x h / l)	223	0.077	0.12	p < 0.01
Width (w), m	223	1.39	0.99	p < 0.01
Length (l), m	223	25.23	13.21	p < 0.01
Height (h), m	223	0.93	0.48	p < 0.01

* lognormal data conversion ** exponential data conversion

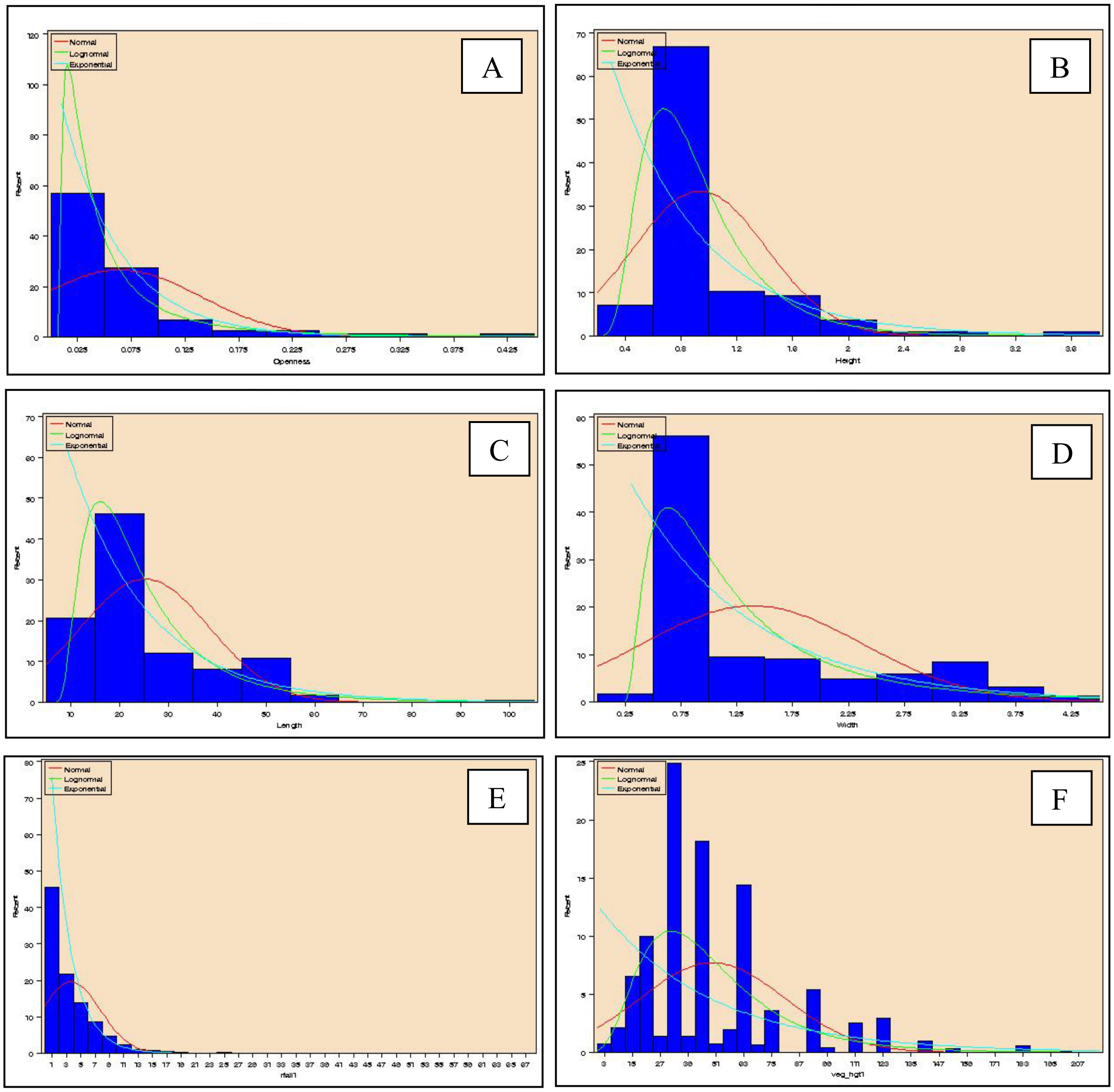

Figure 6. Histograms and normality curves for explanatory variables with sharp, skewed distributions. Each graph displays a histogram of actual data plotted against curves for normal (red), lognormal (green), and exponential (blue) distributions. Panel descriptions: A) openness index (culvert—width x height / length), B) culvert width, C) culvert length, D) culvert height, E) mean weekly rainfall, and F) right-of-way vegetation height.

Levene's test of homogeneity generated in SAS from one-way ANOVA performed on explanatory variables revealed equality for within-group variance for all groups (F statistic, all groups—$p < 0.0001$, ungulates—$p < 0.004$) except the alligator-aquatic mammal group.

Significant overlap was evident between certain explanatory variables. To adhere to singularity and multicollinearity rules for use of logistic regression, and to improve fit of models, it was necessary to remove these. Elements of right-of-way width were expressed in three different variables—number of lanes, median width, clearance, and gap width (pairwise analysis—Pearson's correlation coefficient, $p < 0.0001$). The first three were removed from the analysis, as focus was most appropriately placed on gap width (the distance wildlife must traverse between adjacent habitat and the entrance of the crossing structure). Multicollinearity (Pearson's correlation coefficient, $p = 0.0002$) was also apparent between the openness index and individual structural measurements (i.e., width, length, and height). Recent studies (Bertwhistle 2003, and Garrett and Gordon 2003) reveal that the general nature of the openness index may overlook the importance of specific structural dimensions to use by certain wildlife; as the components of the mathematical function (width x height / length) can be manipulated in each of the three dimensions to derive the same index value. Due to this, it was felt appropriate to delete the openness index from the analysis; even so, its significance was included in the discussion. Concern for potential correlation between soil moisture (categorical) and rainfall (continuous) variables resulted in removal of soil moisture (the least precise of the two variables) from the analysis.

Logistic regression models were optimized using backward stepwise processing to reduce the number of independent factors (determined by Akaike's Information Criterion (AIC) and -2 *log* L model fit criteria in *SAS*). Additional independent variables were removed following initial iterations of the regressions because of insignificance. These included: structure composition, water feature, habitat diversity (1020 and 2040 m^2

resolution), and dominant habitat types (primary and secondary at 1020 and 2040 m^2 resolution, and secondary at 30, 210, 1020, and 2040 m^2 resolution). This reduced the number of explanatory variables used in logistic regression models to 20.

General Findings

Over the course of 10 months in 2001 and 9 months in 2002-03, nearly 48,000 records were collected from monitoring sites (Table 7). These data were divided into three categories: events, nonevents, and road-kills. Events include records of wildlife movement, either through or in proximity to culverts and bridges (evidenced either by photographs or tracks). Among these events, certain records could not be identified and were classified as such. Nonevents include three different types of records: 1) none (refers to site visits when no tracks were present), 2) washouts (site encounters with washed-out track-beds or flooding following rain events), and 3) vehicle downtimes, thunderstorms, or other circumstances when data collection could not conducted (these are not reported here).

Table 7. Events, nonevents and road-kills recorded at culverts and bridges

	Total	**Events**	Tracks	Photographs	Unidentified	**Nonevents**	Washouts	None	**Road-kills**
Total	47,955	36,870	33,678	852	2,340	10,822	3,835	6,987	263
Percent		77	70	2	5	23	8	15	0.5
# sites	290		278	39	211		127	243	125
Yr 02-03	21,400	18,607	17,557	515	535	2,650	2,523	127	143
Percent		87	82	2	3	13	12	1	0.3
# sites	97		67	18	43		81	31	44
Yr 01	26,555	18,263	16,121	337	1,805	8,172	1,312	6,860	120
Percent		69	61	1	7	31	5	26	0.25
# sites	254		211	21	168		46	212	81

Overall, track records (n=33,678) accounted for 70% of data collected (Figure 7); photographs accounted for only 2% of the data (Figure 8), and more or less served as a verification method for identification of tracks at certain sites. Five percent of

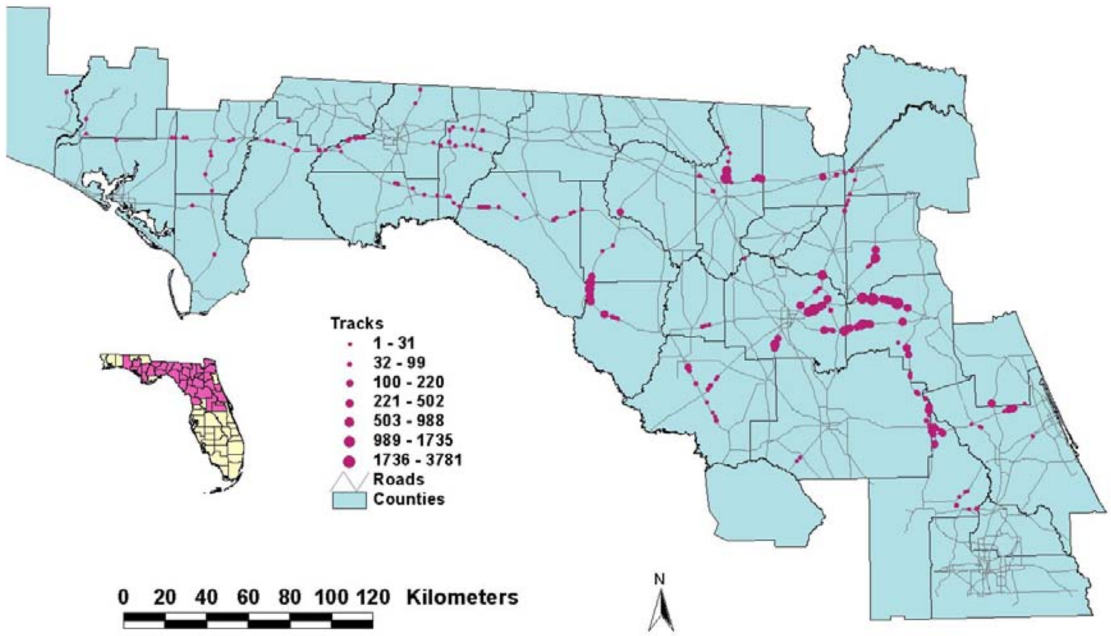

Figure 7. Tracks recorded at culverts and bridges from 3/01 to 12/01 and 7/02 to 4/03. Relative dot size represents quantity of tracks recorded at individual monitoring sites. Sites where larger dots are shown had more records for two possible reasons—most were included in both study periods, and some correspond to bridge locations that consistently had more wildlife use.

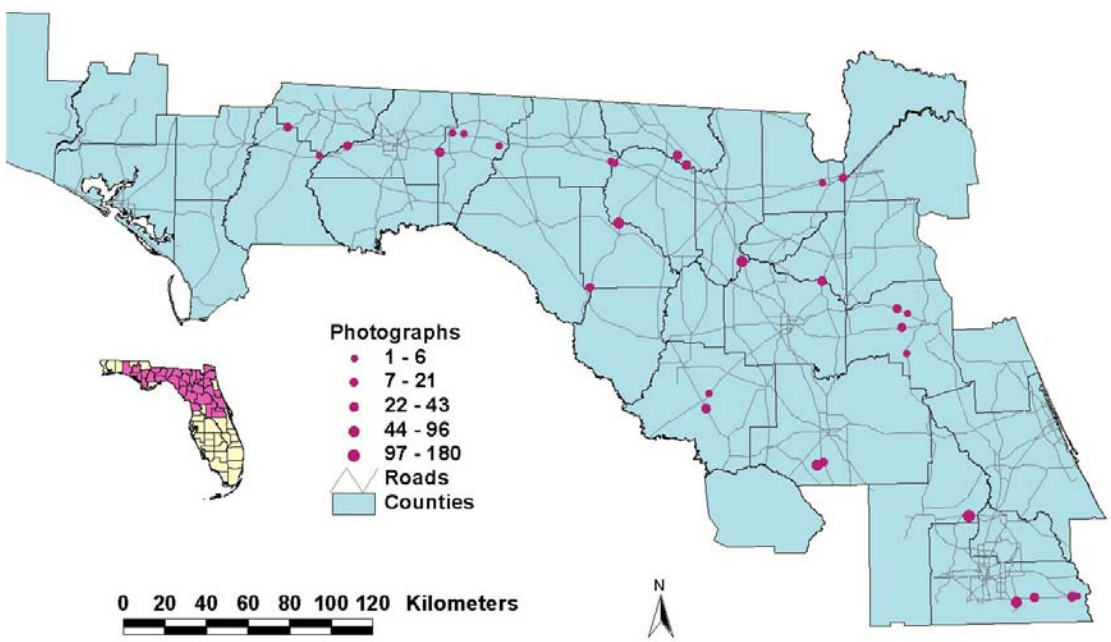

Figure 8. Photographs taken at culverts and bridges from 3/01 to 12/01 and 7/02 to 4/03. Relative dot size represents quantity of photographs recorded at individual monitoring sites.

records collected could not be identified (Figure 9) and were not used in statistical analyses. No tracks were found at monitoring sites 6,987 times (Figure 10), and washouts occurred 3,835 times (Figure 11). Road-kills recorded included 263 individual vertebrates, accounting for less than one percent of the data collected (Figure 12). The infrequency of visits to field sites (twice per week) proved inadequate for effectively estimating road-kill counts on road segments (where structures were monitored for tracks). This limited the ability to evaluate culvert avoidance by specific wildlife.

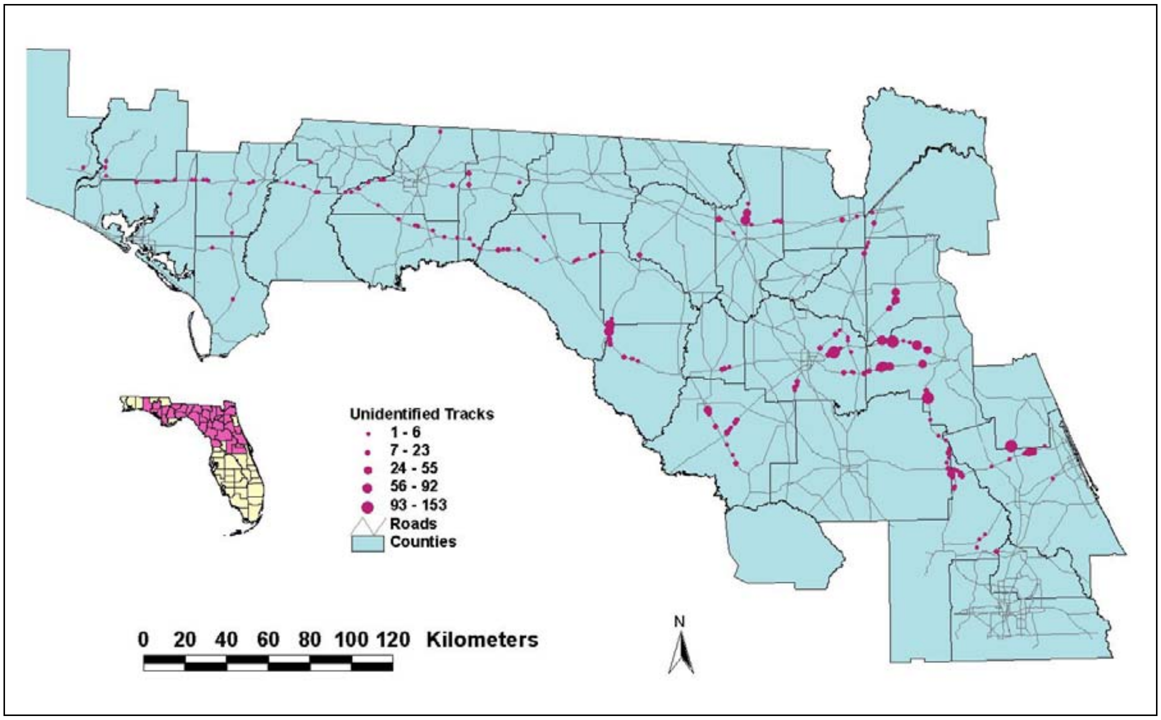

Figure 9. Unidentified tracks recorded at culverts and bridges from 3/01 to 12/01 and 7/02 to 4/03. Relative dot size represents quantity of unidentified tracks recorded at individual monitoring sites. Sites where larger dots are shown had more records for two possible reasons—most were included in both study periods, and some correspond to bridge locations that consistently had more wildlife use.

Certain field sites produced exceptional results. Nine sites were flooded and impassable on average for 58% (42 of 72) of site visits, and only included road-kill records (n=19). No tracks or photographs were recorded at 24 separate sites.

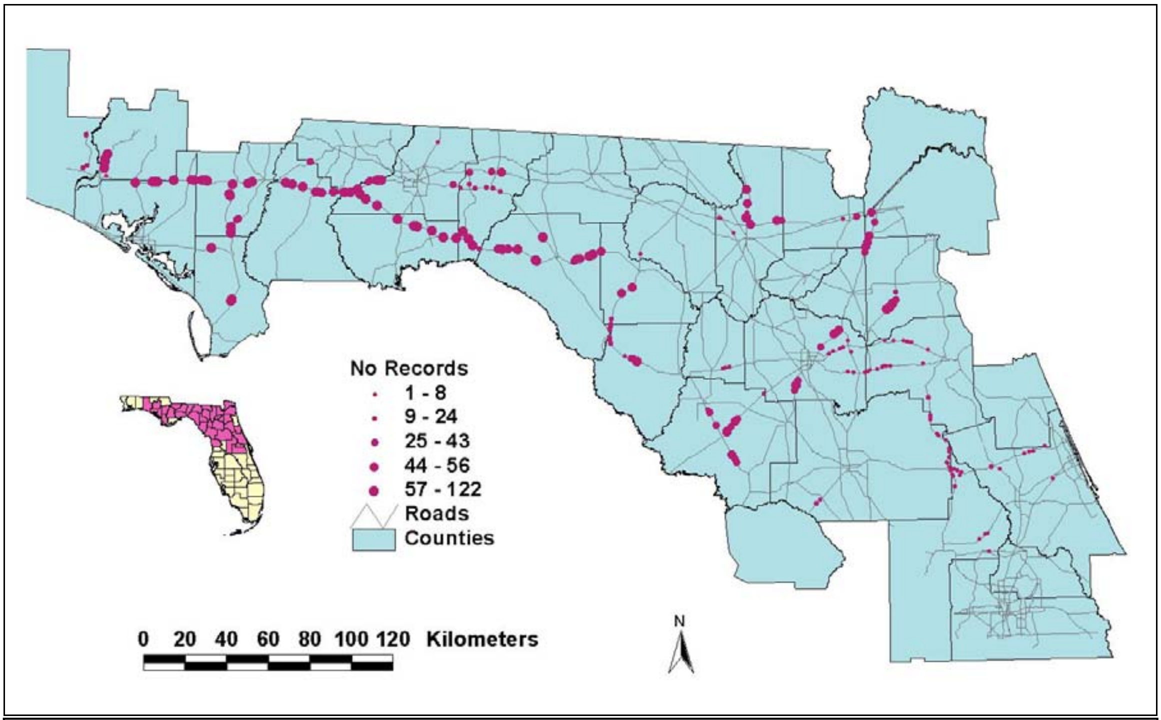

Figure 10. Number of visits when no tracks were found at culverts and bridges from 3/01 to 12/01 and 7/02 to 4/03. Relative dot size represents quantity of tracks recorded at individual monitoring sites. Sites in the central peninsula and panhandle were only monitored during the first study period.

In 2001 and 2002-03, 16,458 (48%) and 18,072 (52%) tracks and photographs, respectively were recorded. A total of 14,751 track records were recorded from 55 bridge sites, an average of 268 per site. Culvert sites produced 18,927 track records from 222 sites (site average = 85).

Findings by Faunal Groups

For all monitoring sites, 41 different organisms or categories were recorded. To perform statistical analysis, these were consolidated into 14 general groups (Table 8). Faunal groups were determined according to taxa and body size (discussed previously), mode of movement, and environmental preference. Logistics of monitoring and resource availability restricted the focus of the study to terrestrial organisms, the exception being those aquatic dependents (e.g., river otter, alligator) that used terrestrial areas for movement (either adjacent to aquatic systems or to get from one water source to the next). Faunal groups of interest included: meso-mammal, carnivore, bird, ungulate, herpetofauna, and small mammal. Statistics regarding use or avoidance of culverts and bridges were performed on these six categories.

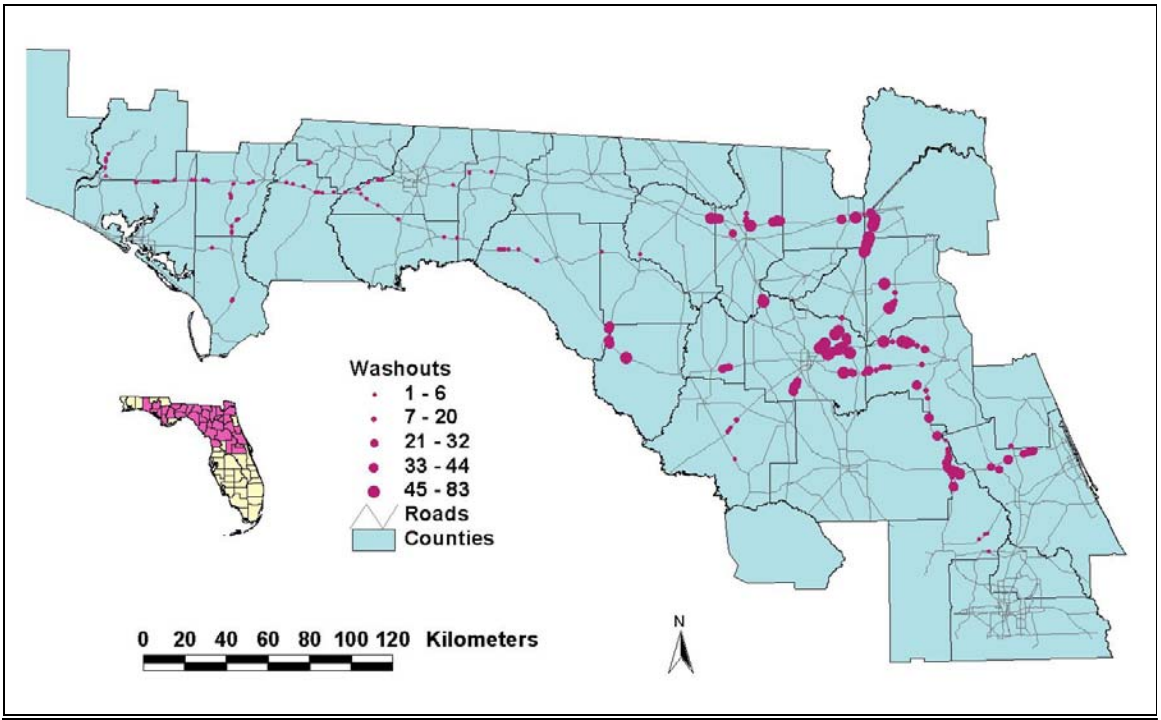

Figure 11. Number of visits when culvert and bridge sites were flooded or washed out from 3/01 to 12/01 and 7/02 to 4/03. Relative dot size represents quantity of site flooding/washouts at individual monitoring sites. Sites in the central peninsula and panhandle were only monitored during the first study period. Annual-average rainfall was much higher (ml) during the second monitoring period and corresponds to the location and number of flood events shown in the figure. Most flooded sites were associated with surface water features.

The other eight categories recorded were either discarded or used in the analysis of the other categories of interest. The category "none" referred to site visits when no tracks were detected; and were not applicable to the analysis unless a particular site revealed no movement for the course of the study. These were reviewed separately to examine why no movement was evident. The category "alligator" and "aquatic mammal" did not produce enough samples (n=25 and n=41, respectively) to perform

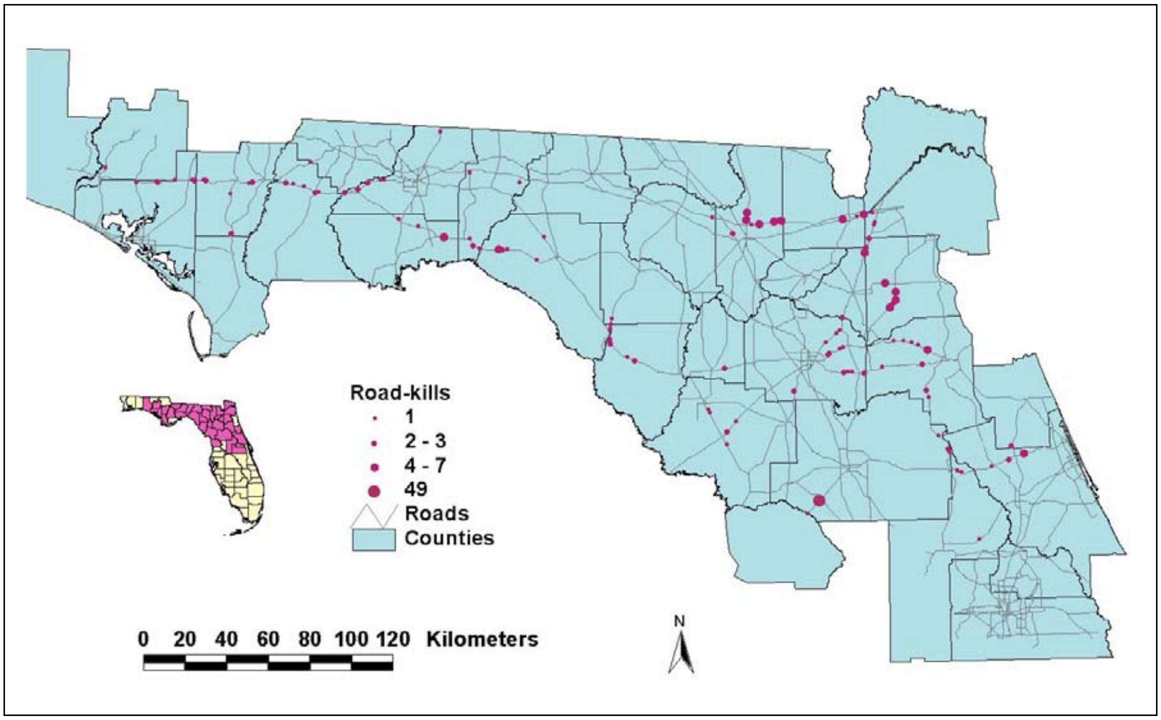

Figure 12. Road-kills recorded at culverts and bridges from 3/01 to 12/01 and 7/02 to 4/03. Relative dot size represents quantity of road-kills recorded at individual monitoring sites. On average, less than two road-kills were recorded at each site.

multivariate statistics. Recording tracks in the category "arthropod" proved too intensive a task at the scale of the study and frequency of site visits. The importance of this group's use of connecting structures along roads is recognized; however, a separate study would be necessary to properly evaluate this faunal group. Records of presence and use by "domestics" and "humans" were applied as explanatory variables for the other categories. The category "other" represented those that could not be identified, and therefore could not be included in the regression analysis; additionally "n/a" represents failed attempts to perform monitoring duties and were also ignored in the analysis.

The different organisms recorded and their respective group assignments are shown in Table 9. Forty-four were identified to the species level, two to the family level, five to the order/suborder level, four to the class level, and 4 other types. Results are presented for each faunal group by structure type (bridge or culvert) and the three groups of explanatory variables—structural, environmental, and ecological.

Table 8. Faunal groups

Group name	Group code
none	0
alligator	1
meso-mammal	2
arthropod	3
carnivore	4
bird	5
ungulate	6
domestic	7
herpetofauna	8
human	9
small mammal	10
aquatic mammal	11
other	12
n/a	30

Table 9. Species recorded and group assignments

Group name	Code	Common name	Scientific name
none	0	none	
alligator	1	alligator	*Alligator mississippiensis*
meso-mammal	2	armadillo	*Dasypus novemcinctus*
meso-mammal	2	opossum	*Didelphis marsupialis*
meso-mammal	2	raccoon	*Procyon lotor*
meso-mammal	2	skunk	*Mephitis sp., Spilogale sp.*
arthropod	3	insect	Insecta
arthropod	3	spider	Arachnida
arthropod	3	centipede	Chilopoda
carnivore	4	bear	*Ursus americanus*
carnivore	4	bobcat	*Lynx rufus*
carnivore	4	coyote	*Canis latrans*
carnivore	4	fox	*Urocyon sp., Vulpes sp.*
bird	5	wild turkey	*Meleagris gallopavo*
bird	5	great blue heron	*Ardea herodias*
bird	5	common bobwhite	*Colinus virginianus*
bird	5	wading bird	Ardeidae
bird	5	perching bird	Passeriformes
ungulate	6	white-tailed deer	*Odocoileus virginianus*
ungulate	6	wild pig / hog	*Sus scrofa*
domestic	7	domestic cat	*Felis catus*

Table 9. continued

Group name	Code	Common name	Scientific name
domestic	7	domestic dog	*Canis familiaris*
herpetofauna	8	frog / toad	Anura
herpetofauna	8	s. leopard frog	*Rana utricularia*
herpetofauna	8	southern toad	*Bufo terrestris*
herpetofauna	8	green tree frog	*Hyla cinerea*
herpetofauna	8	Cuban tree frog	*Osteopilus septentrionalis*
herpetofauna	8	lizard	Squamata: Lacertilia
herpetofauna	8	6-lined racerunner	*Cnemidophorus sexlineatus*
herpetofauna	8	5-lined skink	*Eumeces spp.*
herpetofauna	8	anole	*Anolis spp.*
herpetofauna	8	fence lizard	*Sceloporus undulatus*
herpetofauna	8	snake	Squamata: Serpentes
herpetofauna	8	cottonmouth	*Agkistrodon piscivorus*
herpetofauna	8	timber rattlesnake	*Crotalus horridus*
herpetofauna	8	s. black racer	*Coluber constrictor*
herpetofauna	8	yellow rat snake	*Elaphe obsoleta*
herpetofauna	8	e. garter snake	*Thamnophis sirtalis*
herpetofauna	8	turtle / tortoise	Testudines
herpetofauna	8	snapping turtle	*Chelydra serpentina*
herpetofauna	8	alligator snapper	*Macroclemys temminckii*
herpetofauna	8	Florida cooter	*Pseudemys floridana*
herpetofauna	8	striped mud turtle	*Kinosternon baurii*
herpetofauna	8	box turtle	*Terrapene carolina*
human	9	human	*Homo sapiens*
sm mammal	10	rabbit	*Sylvilagus spp.*
sm mammal	10	eastern cottontail	*Sylvilagus floridana*
sm mammal	10	mouse	Cricetidae
sm mammal	10	rat	Cricetidae
sm mammal	10	Fl. water rat	*Neofiber alleni*
sm mammal	10	mole	*Scalopus aquaticus*
sm mammal	10	gray squirrel	*Sciuris carolinensis*
aquatic mammal	11	river otter	*Lutra canadensis*
aquatic mammal	11	beaver	*Castor canadensis*
other	12	livestock	Bovidae
other	12	mammal	Mammalia
other	12	other	
other	12	unknown	
n/a	30	n/a	

Note: Table excludes recorded road-kill species that are discussed separately.

Meso-mammal use of bridges

Meso-mammal presence at 58 bridge sites included records (n=6,480) of five different species: armadillo *Dasypus novemcinctus*, Virginia opossum *Didelphis marsupialis*, raccoon *Procyon lotor*, and skunk *Mephitis sp*. or *Spilogale sp.*

Logistic regression model. The backwards, stepwise, logistic regression for meso-mammals and bridges generated the following model equation from the significant factors identified in Table 10:

Logit (π) = 10.29 + 0.068*Gap_Width - 1.41*AADT + 1.17*Width + 7.63E-18*Length - 0.0042*Height + 1.70*Distance + 1.04*Habdiv_30 - 4.21* Pr_hab210 (2) + 1.07*Pr_hab210 (3) + 1.12* Pr_hab210 (4) - 0.025*Veg_Height + 0.082*Hi_Temp - 0.015*Dom_Pred.

The model was significant in predicting use of bridges by meso-mammals, Wald X^2: 390.01 (df—18, p <.0001), Nagelkerke's R^2 (0.4005), and Hosmer and Lemeshow Goodness-of-Fit Test, X^2: 14.52 (df—8, p = 0.0014). Eleven of 21 factors were found significant by the model in predicting use of bridges by meso-mammals. Percentage of movement under bridges correctly predicted by the model was 91.1%.

Table 10. Maximum likelihood estimates for meso-mammals and bridges

Parameter	DF	Estimate	Standard error	Chi-square	Pr > ChiSq
Intercept	1	-10.2941	3.1960	10.3746	0.0013
Gap Width	1	0.6837	0.1263	29.3055	<.0001
AADT_log	1	-1.4148	0.2187	41.8593	<.0001
Width_log	1	1.1690	0.5053	5.3520	0.0207
Length_exp	1	7.63E-18	1.37E-18	30.8759	<.0001
Height_exp	1	-0.00422	0.000755	31.2878	<.0001
Distance_log	1	1.7069	0.3299	26.7694	<.0001
Hab_div30	1	1.0353	0.3285	9.9296	0.0016
Pr_hab210 2	1	-4.2140	1.0925	14.8782	0.0001
Pr_hab210 3	1	1.0697	0.4205	6.4722	0.0110
Pr_hab210 4	1	1.1229	0.3353	11.2142	0.0008
Veg_Height	1	-0.0249	0.00277	80.9526	<.0001
Hi_Temp	1	0.0815	0.0231	12.4192	0.0004
Dom_Predators	1	-0.0149	0.00367	16.4290	<.0001

Response to structural characteristics. Six structural parameters—gap width (distance between bridge entrance and adjacent habitat), annual-average-daily traffic (annual-average of number of vehicles-per-day), bridge width (width of bridge opening), bridge length (distance that organisms had to travel to pass through the structure), bridge height, and distance to next nearest crossing structure—were significant in the logistic regression model for meso-mammal use of bridges.

The majority of meso-mammals using bridges (75.76%, n=4,687 of 6,186) were recorded when gap width was 8.5 m or less; presence but not passage (84.69%, n=249 of 294) was also associated with gap widths of 8.5 m or less. Gap width (distance from adjacent habitat to bridge entrance) ranged from 0 – 31.1 m.

When AADT was greater than 7,500, passage under bridges by meso-mammals (n=6,179) occurred only 13.9% during the period monitored. The highest percentage of passages by meso-mammals (28.39%) were recorded when AADT was at 250 vehicles-per-day. Presence recorded near bridges, but not crossing from one side to the other, primarily occurred (61.56%, 181 of 294) when AADT was 3,000. Range of AADT on roads where meso-mammals were recorded was 250 to 69,374. Of 6,186 records of meso-mammals using bridges, three peaks occurred when bridge width (width of bridge opening) was 19 – 60 m (89.09%).

Sixty-two percent of records of presence but not passage (n=182 of 294) occurred at two bridge widths, 41 and 60 m. Where meso-mammals were recorded, bridge widths ranged from 7.3 – 200 m. Of 6,186 records of meso-mammals using bridges, most occurred (75.45%) when bridge length was less than 15 m. Presence but not passage (n=294) was also associated predominantly with bridge lengths less than 15 m (84.69%).

Bridge length used by meso-mammals ranged from 6.4 – 80 m. Of 6,186 records of meso-mammals using bridges, most occurred (92.65%) when bridge height was between 1.5 to 3.7 m. Presence but not passage (n=294) was associated primarily (75.17%) with bridge heights of 3.1 – 3.7 m. Bridge height ranged from 1.2 – 15 m.

When distance between structures was greater than 1,000 m, presence (but not passage under) bridges by meso-mammals (n=294) occurred 76.53% during the period monitored. Records of passage under bridges (n=6,174) were relatively even across all distances. Range of distance between structures was 130 to 3,450 m.

Response to environmental characteristics. Recorded passage under bridges (n=6,186) occurred 73.68% of the time during fall and summer months. High passage rates occurred for all seasons for meso-mammals (minimum of 88.85% in winter). Of 6,480 that approached bridge entrances, 6,186 passed through to the other side.

When average maximum weekly temperature was 20 degrees C or higher, meso-mammals passing under bridges occurred 91.12% (n=5,637 of 6,186) of the time recorded. Presence at (but not passage under) bridges showed an opposite trend regarding high temperatures; 88.44% of these records occurred when temperatures were 27 degrees C or less. Average maximum weekly temperature at bridges used by meso-mammals ranged between 12 and 34 degrees C.

Response to ecological characteristics. Four ecological characteristics—habitat diversity at 30 m^2 resolution, primary habitat type at 210 m^2 resolution, right-of-way vegetation height, and presence of domestic predators—were significant in the logistic regression model for meso-mammal use of bridges.

Meso-mammals recorded using (n=6,186) and present at (n=294) bridges were greatest (80.71% and 90.14%, respectively) when 3 land-cover types existed at the 30 m^2 cell resolution. Habitat diversity ranged from 1 to 4 land-cover types at the 30 m^2 scale. Passage under bridges by meso-mammals (n=6,186) was the highest for 210 m^2 scale land-cover classes 3 (pinelands, 18.96%), 4 (wetlands, 50.74%), and 6 (shrub and brushlands, 16.86%). Presence at (but not passage under) bridges (n=294) was greatest for land-cover classes 4 (58.84%) and 5 (grasslands and agriculture, 23.47%). Passage rates were high (minimum of 86.71%) for all classes (n=7).

Meso-mammal movement under bridges (n=585) was recorded most frequently (86.67%) when vegetation height was between 30 and 61 cm. Right-of-way vegetation height at monitoring sites ranged from 0 to 150 cm.

Use by meso-mammals was greatest (n=4,841 of 6,186, 78.25%) when recorded presence of domestic predators was 3 or less. Contrary to this observation, use and occurrence of meso-mammals was high when number of domestic predators recorded was 32 and 104 (32—21.77% and 6.66%, and 104—39.80% and 10.05%, respectively). This demonstrates an anomaly to the general downward trend in meso-mammal use as a result of increased presence of domestic predators. Presence of domestic predators ranged from 0 – 104 records at bridges used by meso-mammals.

Meso-mammal use of culverts

Presence of meso-mammals at 162 culvert sites included records (n=5,957) of five different species: armadillo *Dasypus novemcinctus*, Virginia opossum *Didelphis marsupialis*, raccoon *Procyon lotor*, and skunk *Mephitis sp*. or *Spilogale sp.*

Logistic regression model. The backwards, stepwise, logistic regression for meso-mammals and culverts generated the following model equation from the significant factors identified in Table 11:

> Logit (π) = 5.01 - 0.44*Season (f) + 0.77*Season (sp) - 0.051*Gap_Width - 0.53*AADT + 1.17*Width - 0.075*Height + 0.23*Distance - 0.76* Pr_hab210 (1) - 0.71*Pr_hab210 (3) - 1.00* Pr_hab210 (4) - 0.081*Rainfall + 0.069*Hi_Temp - 0.24*Human_Pr.

The model was significant in predicting use of culverts by meso-mammals, Wald X^2: 577.04 (df—17, p <.0001), Nagelkerke's R^2 (0.3447), and Hosmer and Lemeshow Goodness-of-Fit Test, X^2: 61.55 (df—8, p < 0.0001). Note that R^2 is less significant for meso-mammals using culverts than in the previous model for meso-mammals using bridges. Ten of 21 factors were found significant by the model in predicting use of culverts by meso-mammals. Percentage of movement through culverts correctly predicted by the model was 82.4%.

Table 11. Maximum likelihood estimates for meso-mammals and culverts

Parameter	DF	Estimate	Standard error	Chi-square	Pr > ChiSq
Intercept	1	5.0115	1.1969	17.5330	<.0001
Season f	1	-0.4357	0.1098	15.7399	<.0001
Season sp	1	0.7767	0.1823	18.1566	<.0001
Gap Width	1	-0.0512	0.00745	47.1845	<.0001
AADT_log	1	-0.5305	0.1282	17.1378	<.0001
Width_log	1	1.1741	0.1181	98.9071	<.0001
Height_exp	1	-0.0750	0.0202	13.8469	0.0002
Distance_log	1	0.2290	0.0971	5.5605	0.0184
Pr_hab210 1	1	-0.7597	0.1941	15.3249	<.0001
Pr_hab210 3	1	-0.7127	0.1523	21.8914	<.0001
Pr_hab210 4	1	-0.9994	0.1817	30.2502	<.0001
Hi_Temp	1	0.0691	0.0208	11.0297	0.0009
Rainfall	1	-0.0814	0.0226	12.9300	0.0003
Human_Presence	1	-0.2418	0.1089	4.9299	0.0264

Response to structural characteristics. Five structural characteristics were significant in multiple logistic regression analysis. The majority of meso-mammals using culverts (77.44%, n=4,271 of 5,515) were recorded when gap width was 7.5 m or less;

presence but not passage (52.72%, n=232 of 442) was frequently associated with gap widths of 8.5 m or more. Gap width (distance from adjacent habitat to culvert entrance) ranged from 0 – 39.3 m.

When AADT was from 3,200 to 8,400, records of passage through culverts by meso-mammals (n=5,472) occurred 76.9% of the time. Presence recorded near culverts, but not crossing from one side to the other, was primarily recorded (76.02%) when AADT was 6,400 or higher. Range of AADT on roads where meso-mammals were recorded was 250 to 42,500.

For meso-mammals using culverts (n=5,515), most occurred (93.36%) when culvert width was between the range of 0.5 to 3.5 m. Highest percentage of passage (19.37%) occurred at 3.1 m width. Presence but not passage (n=442) was also associated predominantly (98.64%) with culvert widths of 0.5 to 3.5 m. Highest percentage of presence but not passage (42.08%) occurred at 0.9 m width. Width of culverts used by meso-mammals ranged from 0.3 – 4.3 m. Seventeen meso-mammals were recorded passing through culverts at the minimum width monitored of 0.3 m. Of 5,515 records of meso-mammals using culverts, most occurred (87.86%) when culvert height was between 0.6 to 1.5 m. Presence but not passage (n=442) was also associated (89.83%) with culvert heights of 0.6 m to 1.5 m. Culvert height ranged from 0.3 – 3.7 m.

Passage (n=5,515) by meso-mammals through culverts occurred relatively even across all distances between crossing structures, with the exception of 950 m (16.77%). Presence (n=442) by meso-mammals at culvert entrances was also recorded evenly, with one peak at 1,330 m (18.78%). Range of distance between structures was 110 to 5,750 m.

Response to environmental characteristics. Effects of three environmental measures identified from the logistic process are reported. Recorded passage through culverts (n=5,515) was high during spring (26.24%), summer (33.42%) and fall (26.59%) months. Presence at (but not passage through) culverts (n=442) was recorded mostly in fall and summer months (81.67%).

Of meso-mammals passing through culverts (n=5,489) and present at culvert entrances (n=440), most occurred (83.41% and 65.22%, respectively) when average maximum weekly temperature was 24 degrees C or higher. When average maximum weekly temperature was from 26 to 33 degrees C, 70.91% of movement through culverts was recorded. Average maximum weekly temperature at monitoring sites used by meso-mammals ranged between 12 and 35 degrees C.

Of 5,492 records of meso-mammals using culverts, most occurred (92.43%) when rainfall was 6 ml or less; and presence but not passage was also recorded predominantly (90.23%, n=398 of 441) when rainfall was 6 ml or less. Average weekly rainfall at monitoring sites used by meso-mammals ranged between 0 and 25 ml.

Response to ecological characteristics. Primary habitat type at 210 m^2 scale and influence of presence of humans and domestic predators were identified as significant factors regarding culvert use by meso-mammals.

Passage through culverts (n=5,515) by meso-mammals was the highest for 210 m^2 scale land-cover class 3 (pinelands, 22.41%) and lowest for class 2 (hardwood forests, 4.1%). Presence at (but not passage through) culverts (n=442) was greatest for land-cover classes 3 (52.26%) and 4 (16.06%). Passage rates were high (minimum of 84.25%) for all classes (n=7).

When presence of humans increased at monitored sites, use by meso-mammals decreased. Use of culverts (n=5,515) occurred 90.79% of the time when no humans were recorded. Similarly, presence at (but no passage through) the culvert was greatest (90.95%, n=402 of 442) when no human presence was recorded. Presence of humans ranged from 0 – 4 records at sites used by meso-mammals.

When presence of domestic predators increased at monitored sites, use by meso-mammals also decreased. Use of culverts (n=5,515) occurred 76.28% of the time when one or less domestic predators were recorded. Similarly, presence at (but no passage through) the culvert was greatest (95.25%, n=421 of 442) when recorded domestic predator presence was less than 2. Presence of domestic predators ranged from 0 – 4 records at culverts frequented by meso-mammals.

Carnivore use of bridges

Carnivore presence at 34 bridge sites included records (n=384) of five species: black bear *Ursus americanus*, coyote *Canis latrans*, bobcat *Lynx rufus*, and fox *Urocyon sp.* or *Vulpes sp*.

Logistic regression model. The backwards, stepwise, logistic regression for carnivores and bridges generated the following model equation from the significant factors identified in Table 12:

$$\text{Logit}(\pi) = 1.95 - 3.34\text{*Season (su)} - 0.0017\text{*Height} - 0.99\text{*Distance} + 0.304\text{*Rainfall} + 0.34\text{*Hi\_Temp} - 0.035\text{*Dom\_Pred.}$$

The model was significant in two of three tests for predicting use of bridges by carnivores, Wald X^2: 45.30 (df—8, p <.0001), Nagelkerke's R^2 (0.5375), and Hosmer and Lemeshow Goodness-of-Fit Test, X^2: 12.79 (df—8, p = 0.1193). Other combinations of explanatory variables were used in model simulations without improvement to the score for goodness-of-fit test. Partitions created for the goodness-of-fit test encountered too many zeros (for observed values in the nonuse category) and predicted 26% false negatives. Thus the model fit is questionable. Only 31 records were documented for nonuse of bridges, likely accounting for the weak score for the goodness-of-fit test. Only 6 of 21 factors were found significant by the model in predicting use of bridges by carnivores. Percentage of movement under bridges correctly predicted by the model was 90.9%.

Table 12. Maximum likelihood estimates for carnivores and bridges

Parameter		DF	Estimate	Standard error	Chi-square	Pr > ChiSq
Intercept		1	1.9528	4.7791	0.1670	0.6828
Season	su	1	-3.3404	0.9360	12.7351	0.0004
Height_exp		1	-0.00165	0.000534	9.5801	0.0020
Distance_log		1	-0.9941	0.5070	3.8449	0.0499
Hi_Temp		1	0.3410	0.0965	12.5000	0.0004
Rainfall		1	0.3043	0.1308	5.4129	0.0200
Dom_Predators		1	-0.0353	0.00808	19.0587	<.0001

Response to structural characteristics. Two significant structural parameters are described here that were identified by the regression model. Records of carnivores using bridges (n=353) occurred most often (92.91%) when bridge height was less than 4 m. Presence but not passage (n=31) was also associated predominantly (83.88%) with bridge heights less than 4 m. Height of bridges used by carnivores ranged from 1.5 – 15 m.

Of 353 records of carnivores using bridges, two peaks occurred when distance to next nearest crossing structure was either 575 – 600 m (41.77%), or greater than 1,500 m (34.81%). Presence but not passage (n=31) was notable regarding one distance, 1,050 m (53.33% of occurrences). Where carnivores were found, distance between structures ranged from 200 – 3,450 m.

Other notable factors include bridge length, bridge width, and gap width. Records of carnivores using bridges (n=353) occurred most often (85.26%) when bridge length was less than 15 m. Presence but not passage (n=31) was also associated predominantly (77.42%) with bridge lengths less than 15 m. One individual carnivore each was recorded passing under 80 m and 43.1 m long bridge openings. Length of bridges used by carnivores ranged from 7.3 – 80 m. Of 353 records of carnivores using bridges, three peaks occurred when bridge width (width of bridge opening) was 7.3 m (33.99%), 32 – 40 m (20.39%), and 54 – 60 m (17.57%). Presence but not passage (n=31) was notable regarding one bridge width, 60 m (51.61% of occurrences). Where carnivores were found, bridge widths ranged from 7.3 – 161 m. The majority (86.69%) of carnivores using bridges were recorded when gap width was less than 10 m. Gap width (distance from adjacent habitat to bridge entrance) ranged from 0 – 31.1 m.

Response to environmental characteristics. Season, temperature, and rainfall were all identified as significant factors associated with carnivore activity recorded near bridges. Carnivore passage under bridges (n=353) occurred mostly during summer (25.21%), fall (36.83%), and winter (23.23%) months. Upon approach to bridge entrances carnivore passage rates were high for all seasons, 353 of 384 (91.93%). Presence at (but not passage under) bridges (n=31) was recorded most frequently in fall and winter (80.64%).

Of 341 records of carnivores passing under bridges, most occurred (72.14%) when average, maximum, weekly temperature was 24 degrees C or higher. Presence at, (but not passage under) bridges (n=31) showed a reverse trend where most movement (80.63%) was recorded when average, maximum, weekly temperature was 25 degrees C or less. Average, maximum, weekly temperature at these sites ranged between 12 and 34 degrees C.

Of 341 records of carnivores using bridges, most occurred (87.38%) when rainfall was 5 ml or less; and presence but not passage was also recorded predominantly (96.77%, n=30 of 31) when rainfall was 5 ml or less. Average weekly rainfall at monitoring sites where carnivores were recorded ranged between 0 and 18 ml.

Response to ecological characteristics. Only domestic predators were identified in the regression analysis as a significant factor. When presence of domestic predators increased at monitored sites, use by carnivores decreased. Passage by carnivores (n=302 of 353, 85.55%) coincided with 6 or less records of domestic predators. Approximately 51% of carnivores, that approached but did not pass under bridges, were recorded at sites where 104 domestic predators had been recorded. Presence of domestic predators ranged from 0 – 104 records at sites monitored.

Other factors of importance may include human presence, right-of-way vegetation height, and primary habitat type at 30 and 210 m^2. As presence of humans increased at monitored sites, use by carnivores decreased. Use of bridges (n=353) occurred 53.27% of the time when 8 or less humans were recorded, and 68.56% of the time when 11 or less humans were recorded. Presence of humans ranged from 0 – 110 records at sites where carnivores occurred. A reverse trend existed (with presence at but no passage under the bridge) where 68.02% (n=21 of 31) occurred when 11 or more humans were recorded over the course of the study. Carnivore movement under bridges (n=353) was recorded most frequently (75.4%) when vegetation height was between 25 and 61 cm. Right-of-way vegetation height at monitoring sites ranged from 0 to 150 cm. Passage under, and presence at bridges occurred almost entirely in 30 m^2 scale land-cover classes 4 (wetlands, 39.38% and 19.35%), 6 (shrub and brushlands, 35.41% and 3.23%), and 7 (hardwood forests, 21.53% and 77.42%). Passage under, and presence at bridges occurred almost entirely in 210 m^2 scale land-cover classes 4 (wetlands, 35.69% and 67.74%) and 5 (grasslands and agriculture, 37.11% and 16.13%).

Carnivore use of culverts

Records (n=315) of carnivores at 51 culvert sites included five species: black bear *Ursus americanus*, coyote *Canis latrans*, bobcat *Lynx rufus*, and fox *Urocyon sp.* or *Vulpes sp*.

Logistic regression model. The backwards, stepwise, logistic regression for carnivores and culverts generated the following model equation from the significant factors identified in Table 13:

Logit (π) = 14.46 - 2.12*AADT - 1.00*Str_Number + 3.26*Width + 1.08*Distance - 0.58*Dom_Pred.

Table 13. Maximum likelihood estimates for carnivores and culverts

Parameter	DF	Estimate	Standard error	Chi-square	Pr > ChiSq
Intercept	1	14.4586	3.7127	15.1664	<.0001
AADT_log	1	-2.1221	0.4357	23.7196	<.0001
Str_Number	1	-0.9953	0.3462	8.2656	0.0040
Width_log	1	3.2615	0.5849	31.0891	<.0001
Distance_log	1	1.0786	0.4250	6.4400	0.0112
Dom_Predators	1	-0.5785	0.2075	7.7701	0.0053

The model was significant in two of three tests for predicting use of culverts by carnivores: Wald X^2: 59.95 (df—5, p <.0001), Nagelkerke's R^2 (0.6462), and Hosmer and Lemeshow Goodness-of-Fit Test, X^2: 12.74 (df—8, p = 0.1211). Other combinations of explanatory variables were used in model simulations without improvement to the score for goodness-of-fit test. Partitions created for the goodness-of-fit test encountered too many zeros (for observed values in the nonuse category) and predicted 24% false negatives. Thus the model fit is questionable. Only 57 records were documented for nonuse of bridges, likely accounting for the weak score for the goodness-of-fit test. Only 5 of 21 factors were found significant by the model in predicting use of culverts by carnivores. Percentage of movement through culverts correctly predicted by the model was 91.9%.

Response to structural characteristics. Four structural factors were identified in regression analysis. Carnivore movement (n=258) through culverts was greater the less culvert cells were available (i.e., 1—41.85%, 2—32.55%, 3—25.58%). Carnivore presence (n=57) at culvert entrances was highest for single and three cell configurations (50.88% and 42.11%, respectively).

When AADT was from 3,200 to 11,000, records of passage through culverts by carnivores (n=258) occurred 90.32% of the time. Presence recorded near culverts, but not crossing from one side to the other, was primarily recorded (84.23%) when AADT was 6,900 or higher. Range of AADT on roads where carnivores were recorded was 250 to 31,500.

Of 258 records of carnivores using culverts, most occurred (84.3%)when culvert width was greater than 1 m. Highest percentage of passage (36.78%) occurred at 2.4 m width. Presence but not passage (n=57) increased as culvert widths decreased (94.43% occurrence at widths less than 2 m). Highest frequency (53.7%) of presence (but not passage) occurred at 0.9 m width. Culvert widths where carnivores were recorded ranged from 0.3 – 3.7 m.

Of 258 records of carnivores using culverts, most occurred (86.03%) when distance to next nearest crossing structure was 875 m or more. Presence but not passage (n=57) was notable regarding distances from 900 to 1,360 m (65% of occurrences). Where carnivores were found, distance between structures ranged from 125 – 5,750 m.

Other notable factors may include culvert height and gap width. Records of carnivores using culverts (n=258) occurred most often (86.82%) when culvert height was 0.9 m or more. Presence but not passage (n=57) was associated predominantly (80.71%) with culvert heights less than 1 m. Height of culverts used by carnivores ranged from 0.3 – 3.4 m. When gap width was 8 m or less, most records (89.66%, n=231 of 258) of carnivores using culverts occurred. Presence but not passage was associated principally (62.96%, n=36 of 57) with gap widths greater than 8 m. Gap width at culverts, where carnivores were recorded, ranged from 1.2 – 39.3 m.

Response to environmental characteristics. None were significant within the logistic regression model for ungulates and bridges.

Response to ecological characteristics. When presence of domestic predators increased at culvert sites, use by carnivores decreased. Most passage by carnivores (92.15%, n=238 of 258) coincided with 2 or less records of domestic predators. Presence of domestic predators ranged only from 0 – 4 records at culvert sites where carnivores were recorded.

Other factors that may influence culvert use by carnivores include human presence, right-of-way vegetation type, and primary habitat at 30 m^2 resolution. Use of bridges (n=258) by carnivores primarily occurred (80.23%) when humans were absent. Presence of humans only ranged from 0 – 4 records at culvert sites where carnivores occurred. Passage by carnivores through culverts (n=258) occurred most often (93.03%) when herbaceous groundcover (either alone or combined with barren areas or shrubs) was present. Passage through, and presence at (n=57) culverts by carnivores occurred almost entirely in 30 m^2 scale land-cover classes 3 (pinelands, 29.45% and 28.07%), 4 (wetlands, 26.36% and 43.86%), and 7 (hardwood forests, 27.52% and 17.54%).

Avian use of bridges

Avian presence at 27 bridge sites included records (n=208) of three species—wild turkey *Meleagris gallopavo*, common bobwhite *Colinus virginianus*, and great blue heron *Ardea herodias*; one family of wading birds—*Ardeidae* (herons and egrets); and one order—*Passeriformes* (songbirds or perching birds).

Logistic regression model. The backwards, stepwise, logistic regression for birds and bridges generated the following model equation from the significant factors identified in Table 14:

Logit (π) = - 6.02 + 1.50*Gap_Width - 2.71*Width - 0.0073*Height + 2.52*Habdiv_30 + 0.16*Lo_Temp.

Table 14. Maximum likelihood estimates for birds and bridges

Parameter	DF	Estimate	Standard error	Chi-square	Pr > ChiSq
Intercept	1	-6.0153	4.0325	2.2252	0.1358
Gap_Width	1	1.5022	0.4278	12.3300	0.0004
Width_log	1	-2.7102	0.8843	9.3938	0.0022
Height_exp	1	-0.00733	0.00208	12.3633	0.0004
Habdiv_30	1	2.5209	0.9497	7.0467	0.0079
Lo_Temp	1	0.1613	0.0553	8.5163	0.0035

The model was significant for predicting use of bridges by birds: Wald X^2: 22.27 (df—5, p <.0001), Nagelkerke's R^2 (0.5386), and Hosmer and Lemeshow Goodness-of-Fit Test, X^2: 33.28 (df—7, p < 0.0001). Only 5 of 21 factors were found significant by the model in predicting use of bridges by birds. Percentage of movement under bridges correctly predicted by the model was 91%.

Response to structural characteristics. Three structural factors were identified in regression analysis for birds and bridges. The majority (75.68%) of birds using bridges (n=177) were recorded when gap width was 8.5 m or less; presence but not passage was also associated mostly (83.87%, n=26 of 31) with gap widths of 8.5 m or less. Gap width (distance from adjacent habitat to bridge entrance) ranged from 5.3 – 28.4 m.

Records of birds using bridges occurred most often (81.89%) when bridge width was less than 50 m. Presence but not passage (n=31) was associated principally (80.65%) with bridge widths of 38 to 60 m. Bridge width of sites monitored ranged from 7.3 – 200 m. Of 177 records of birds using bridges, most occurred (92.64%) when bridge height was between 1.5 to 3.7 m. Presence but not passage (n=31) was associated primarily (16.13%) with bridge heights of 3.1 m (74.19%) and 7.3 to 7.6 m. Bridge height ranged from 1.2 – 7.6 m.

Response to environmental characteristics. Only average, minimum, weekly temperature was a significant factor from logistic regression analysis. Records of birds using bridges (n=165) were distributed relatively even; average, minimum, weekly temperature at monitoring sites ranged between -2 and 23 degrees C. For birds only recorded at bridge entrances (n=30), most occurred (86.66%) when average, minimum, weekly temperature was 10 degrees C or lower.

Response to ecological characteristics. Habitat diversity at 30 m^2 resolution was the single significant factor identified in logistic regression. Birds recorded (n=177) using bridges were greatest (89.93%) when 3 land-cover types were present at the 30 m^2 cell resolution. Similarly, presence of birds (n=31) near bridge entrances was greatest (93.55%) when 3 land-cover types were present. Only 1 record occurred at sites where the maximum 4 land-cover types existed.

Avian use of culverts

Avian presence from 16 culvert sites included records (n=115) of one species—wild turkey *Meleagris gallopavo*; one family of wading birds—*Ardeidae* (herons and egrets); and one order—*Passeriformes* (songbirds or perching birds).

Logistic regression model. The backwards, stepwise, logistic regression for birds and culverts generated the following model equation from the significant factors identified in Table 15:

$$\text{Logit}(\pi) = -2.58 + 15.93*\text{Width} - 0.42*\text{Hi\_Temp}.$$

Table 15. Maximum likelihood estimates for birds and culverts

Parameter	DF	Estimate	Standard error	Chi-square	Pr > ChiSq
Intercept	1	-2.5798	4.0480	0.4062	0.5239
Width_log	1	15.9279	5.4112	8.6641	0.0032
Hi_Temp	1	-0.4168	0.1430	8.4927	0.0036

The model was significant in two of three tests for predicting use of culverts by birds: Wald X^2: 11.59 (df—2, p= 0.003), Nagelkerke's R^2 (0.8582), and Hosmer and Lemeshow Goodness-of-Fit Test, X^2: 0.51 (df—5, p = 0.99). Large sample sizes are preferred for conducting logistic regression analysis and thus the small sample size (n=115) likely accounts for the poor score for the goodness-of-fit test. Accuracy of the model is questionable. Only 2 of 21 factors were found significant by the model in predicting use of culverts by birds. Percentage of movement through culverts correctly predicted by the model was 96.2%.

Response to structural characteristics. Culvert width was the only structural measure of importance in the logistic model for birds and culverts. Of 81 records of birds using culverts, nearly all occurred (98.76%) when culvert width was greater than 2 m. Presence but not passage (n=34) was more variable (e.g., 0.6 m—32.35% and 2.4 m—47.06%). No birds were recorded passing through culverts less than 1.5 m wide. Culvert width ranged from 0.3 – 3.1 m.

Other important factors may include culvert length and height. Of 81 records of culvert use by birds, the majority occurred (98.77%) when culvert length was 15 m or less. Culvert lengths for sites used by birds ranged from 11 – 45.7 m. Most occurrences of birds using culverts (98.77%) were recorded when culvert height was 1.4 m or greater. Presence but not passage (n=34) was recorded only when culvert heights were 1.4 m or less. In this case, culvert height ranged from 0.3 – 3.4 m.

Response to environmental characteristics. Birds passing through culverts (n=81) occurred most often (75.31%) when average, maximum, weekly temperature was 25 degrees C or lower. Bird presence at culvert entrances (n=33) frequently occurred (75.75%) when average, maximum, weekly temperature was greater than 20 degrees C. Average, maximum, weekly temperature at monitoring sites ranged between 13 and 34 degrees C.

Response to ecological characteristics. No ecological factors included were significant within the logistic regression model for birds and culverts. However, the following may have some measure of importance regarding use of culverts by ground dwelling birds—right-of-way vegetation type, presence of humans and domestic predators, primary habitat type at 30 and 210 m^2, and habitat diversity at 210 m^2.

Passage by birds through culverts (n=81) only occurred when herbaceous groundcover (either alone or combined with barren areas or shrubs) was present.

Use of culverts (n=81) occurred 75.31% of the time when no humans were recorded. Similarly, presence at (but no passage through) the culvert was greatest (73.53%, n=25 of 34) when no human presence was recorded. Presence of humans ranged from 0 – 4 records at sites monitored where birds were recorded. Birds recorded passing through culverts preferred absence of domestic predators. Most occurred when domestic predator records were zero (60.49%) or two (35.80%). The range of records of domestic predators where birds occurred was only 0 – 4 at sites monitored.

Passage through, and presence at (n=32) culverts by birds occurred almost entirely in 30 m^2 scale land-cover classes 4 (wetlands, 50.62% and 52.94%) and 7 (hardwood forests, 49.38% and 26.47%). Bird use of culverts was highest for 210 m^2 scale land-cover classes 4 (wetlands, 37.04%), 6 (shrub and brushlands, 24.69%), and 7 (hardwood forests, 34.57%).

Birds recorded using culverts (n=81) was highest (60.49%) with habitat diversity comprised of 3 different land-covers at the 210 m^2 cell resolution. When 2 land-cover types were present, passage through culverts was recorded 28 times (34.57%). Similar percentages occurred for those individuals that were present at culvert entrances only (i.e., class 3—70.59% and class 2—23.53%).

Ungulate use of bridges

The ungulate group included records (n=522) of two species—white-tailed deer *Odocoileus virginianus*, and wild pig/hog *Sus scrofa*—from 41 bridge sites.

Logistic regression model. The backwards, stepwise, logistic regression for ungulates and bridges generated the following model equation from the significant factors identified in Table 16:

Logit (π) = 3.33 - 0.00044*Height + 1.41*Habdiv_30 - 0.68* Habdiv_210 - 0.027*Dom_Pred.

Table 16. Maximum likelihood estimates for ungulates and bridges

Parameter	DF	Estimate	Standard error	Chi-square	Pr > ChiSq
Intercept	1	3.3318	1.7181	3.7609	0.0525
Height_exp	1	-0.00044	0.000148	8.9282	0.0028
Habdiv_30	1	1.4075	0.6693	4.4220	0.0355
Habdiv_210	1	-0.6808	0.2947	5.3354	0.0209
Dom_Predators	1	-0.0272	0.00940	8.3734	0.0038

The model was significant in one of three tests for predicting use of bridges by ungulates: Wald X^2: 17.96 (df—4, p =.0013), Nagelkerke's R^2 (0.2610), and Hosmer and Lemeshow Goodness-of-Fit Test, X^2: 5.42 (df—8, p = 0.71). Large sample sizes are preferred for conducting logistic regression analysis; although we had over 500 records of ungulates crossing under bridges, only 13 records were documented for nonuse of bridges, likely accounting for the poor scores for the goodness-of-fit and R^2 tests. Accuracy of the model is questionable. Only 4 of 21 factors were found significant by the model in predicting use of bridges by ungulates. Percentage of movement under bridges correctly predicted by the model was 79.6%.

Response to structural characteristics. Bridge height was the only significant structural factor identified in logistic regression analysis. Of 509 records of ungulates using bridges, most occurred (84.87%) when bridge height was between 2.1 and 6.1 m. Presence but not passage (n=13) occurred mainly (76.92%) with bridge heights of 3.1 to 3.7 m. Bridge height ranged from 1.5 – 9.2 m.

Other important factors may include bridge length and gap width. Passage under bridges by ungulates occurred principally (82.7%) when bridge length was 24 m or less. Almost 63% of bridge use was recorded when length was 15 m or less. Bridge length ranged from 7.3 – 43.1 m for structures where ungulates were recorded. Of 509 records of ungulates using bridges, most (86.83%) occurred when gap width was 16.5 m or less. Gap width ranged from 5.3 – 36.4 m.

Response to environmental characteristics. None were significant within the logistic regression model for ungulates and bridges.

Response to ecological characteristics. Three significant factors were identified from logistic regression analysis: habitat diversity at 30 and 210 m^2 scales and frequency of presence of domestic predators. Ungulates recorded (n=509) using bridges were greatest (67.39%) when 3 land-cover types were present at the 30 m^2 cell resolution. Bridges with 2 land-cover types had the second highest number of ungulate use (23.18%). Presence of ungulates (n=13) near bridge entrances was recorded only when 2 – 3 land-cover types were present. Habitat diversity ranged from 1 to 4 land-cover types present at the 30 m^2 scale. Most movement under bridges by ungulates (84.03%) occurred at sites where 4 or less land-cover groups were present at the 210 m^2 level. Presence of ungulates (n=13) near bridge entrances was recorded when 3 – 6 land-cover types were present. Habitat diversity ranged from 1 to 7 distinct land-cover groups.

When presence of domestic predators increased at monitored sites, use by ungulates decreased. Bridge use (90.17%, n=459 of 509) coincided with 6 or less records of domestic predators. When 2 or less domestic predators were recorded, predator use and presence was 73.08% and 84.61%, respectively. Records of domestic predators ranged from 0 – 104 records at sites monitored.

Other factors of importance may include right-of-way vegetation type and height, primary habitat type at 30 and 210 m^2, and human presence. Passage by ungulates under bridges (n=509) principally occurred (89.58%) when herbaceous groundcover (either alone or combined with barren areas or shrubs) was present. Ungulate movement under bridges was recorded most frequently (88.76%) when vegetation height was equal or greater than 30 cm. Right-of-way vegetation height at monitoring sites ranged from 0 to 150 cm. Use of bridges (n=509) by ungulates was the highest for 30 m^2 scale land-cover classes 4 (wetlands, 44.79%), 6 (shrub and brushlands, 30.45%) and 7 (hardwood forests, 18.86%). Ungulate use of bridges was highest for 210 m^2 scale land-cover classes 3 (pinelands, 31.24%) and 5 (grasslands and agriculture, 24.36%). Notably, 40.67% of passage by ungulates under bridges took place at sites where no human presence was evident.

Ungulate use of culverts

Two species of ungulates (n=43)—white-tailed deer *Odocoileus virginianus*, and wild pig/hog *Sus scrofa*—were recorded at 19 culvert sites. Due to small sample size, logistic regression analysis could not be performed for the ungulate-culvert group. As such, only general trends from the data collected are reported.

Response to structural characteristics. Of six factors, the following were most notable: culvert substrate, width, and height, and distance between structures. For passage, ungulates preferred culverts with soil substrates to concrete floors (n=27 of 32, 84.38%).

Ungulates were recorded using culverts (n=32) only when culvert width was 1.2 m or wider. Presence but not passage (n=11) was associated largely (81.82%) with culvert widths 1.2 m or less. Culvert width ranged from 0.3 – 3.7 m. Most ungulate use of culverts occurred (96.87%) when culvert height was 1.4 m or greater. Presence but not passage (n=11) was associated only with culvert heights of 1.5 m or less. Culvert height ranged from 0.3 – 3.7 m.

Distance between structures, where ungulates were recorded, ranged from 125 to 2,250 m. Passage through culverts by ungulates was greatest (96.87%) when distance between structures was greater than 850 m. To the contrary, on occasions of presence but not passage the trend was reversed (72.72% recorded at 850 m or less).

Response to environmental characteristics. Seasonality was the only parameter that demonstrated any obvious trend. Recorded passage through culverts (n=32) was high during spring (50%) and summer (21.88%) months. Presence at (but not passage through) culverts (n=11) was also recorded mostly in spring and summer months (45.45% and 54.55%, respectively). Only nine records of ungulates were recorded in fall and winter months using culverts.

Response to ecological characteristics. Six different ecological parameters may be relevant. These include primary habitat at 30 and 210 m^2 scale, right-of-way vegetation type and height, and presence of humans and domestic predators.

Passage through culverts (n=32) by ungulates was the highest for 30 m^2 scale land-cover classes 3 (pinelands, 25%), 4 (wetlands, 31.25%), and 7 (hardwood forests, 43.75%). Ungulate use of culverts was highest for 210 m^2 scale land-cover classes 5 (grasslands and agriculture, 18.75%) and 6 (shrub and brushlands, 56.25%).

Movement through culverts (n=32) occurred 100% of the time when herbaceous groundcover, either alone or combined with barren areas or shrubs was present. A combination of herbaceous groundcover and shrub layers was preferred (65.63%). Ungulate movement through culverts (n=32) was recorded most frequently (92.87%) when vegetation height was greater than 60 cm. Presence at culvert entrances (no passage) corresponded to heights of 60 cm or less (81.82%). Right-of-way vegetation height at monitoring sites ranged from 22 to 214 cm.

Absence (value = 0) of human or domestic predators at culverts corresponded to usage (95.88% and 78.13% for humans and domestic predators, respectively) and presence (100% and 81.82% for humans and domestic predators, respectively) by ungulates.

Herpetofaunal use of bridges

Herptile presence at 28 bridge sites included records (n=1,989) of 15 species—southern leopard frog *Rana utricularia*, southern toad *Bufo terrestris*, green tree frog *Hyla cinerea*, Cuban tree frog *Osteopilus septentrionalis*, six-lined racerunner *Cnemidophorus sexlineatus*, anole *Anolis spp*., fence lizard *Sceloporus undulatus*, cottonmouth *Agkistrodon piscivorus*, timber rattlesnake *Crotalus horridus*, southern black racer *Coluber constrictor*, yellow rat snake *Elaphe obsoleta*, alligator snapping turtle *Macroclemys temminckii*, snapping turtle *Chelydra serpentina*, Florida cooter *Pseudemys floridana* and Florida box turtle *Terrapene carolina bauri*; and four orders/suborders—frog/toad *Anura*, lizard *Squamata: Lacertilia*, snake *Squamata: Serpentes*, and turtle/tortoise *Testudines*.

Logistic regression model. The backwards, stepwise, logistic regression for herpetofauna and bridges generated the following model equation from the significant factors identified in Table 17:

> Logit (π) = 13.15 + 5.19*Season (f) - 1.95*Season (sp) - 1.42*Season (su) + 0.45*Gap_Width - 1.75*AADT - 4.08*Width + 1.16*Pr_hab30 (4) - 0.064*Veg_Height + 0.13*Rainfall + 0.91*Hi_Temp - 0.36*Lo_Temp - 0.017*Human_Pr.

Table 17. Maximum likelihood estimates for herpetofauna and bridges

Parameter		DF	Estimate	Standard error	Chi-square	Pr > ChiSq
Intercept		1	13.1501	6.4460	4.1618	0.0413
Season	f	1	5.1928	0.5151	101.6388	<.0001
Season	sp	1	-1.9549	0.2169	81.2484	<.0001
Season	su	1	-1.4233	0.5473	6.7639	0.0093
Gap_Width		1	0.4458	0.1527	8.5272	0.0035
AADT_log		1	-1.7545	0.7204	5.9305	0.0149
Width_log		1	-4.0765	0.9085	20.1346	<.0001
Pr_hab30	4	1	1.1634	0.3133	13.7892	0.0002
Veg_Height		1	-0.0642	0.00880	53.1887	<.0001
Lo_Temp		1	-0.3640	0.0637	32.6733	<.0001
Hi_Temp		1	0.9097	0.1198	57.6775	<.0001
Rainfall		1	0.1309	0.0558	5.5112	0.0189
Human_Pr		1	-0.0169	0.00776	4.7590	0.0291

The model was highly significant for predicting use of bridges by herpetofauna: Wald X^2: 210.92 (df—12, p <.0001), Nagelkerke's R^2 (0.7472), and Hosmer and Lemeshow Goodness-of-Fit Test, X^2: 30.62 (df—6, p < 0.0001). Ten of 21 factors were found significant by the model in predicting use of bridges by herpetofauna. Percentage of movement under bridges correctly predicted by the model was 92.9%.

Response to structural characteristics. Five structural variables were found significant in the logistic regression: gap width, AADT, bridge width, bridge length, and bridge height. Of 848 records of herpetofauna using bridges, most occurred (82.54%) when gap width was 7.9 to 8.5 m. Records of presence but not passage (94.66%, n=1,080 of 1,141) were also associated with gap widths of 7.9 to 8.5 m. Passage rate at these gap widths was 64.8%. Gap width (distance from adjacent habitat to bridge entrance) ranged from 4.9 – 16.5 m.

When AADT was greater than 6,400, passage under bridges by herpetofauna (n=848) occurred only 11.09% during the period monitored. Most passage occurrences by herpetofauna (39.27%, and 34.67%, respectively) were recorded when AADT was at 2 separate levels, 250 and 6,400. Presence recorded near bridges, but not crossing from one side to the other, was primarily recorded (88.96%, 1,015 of 1,141) when AADT was 6,400. At 6,400 AADT, passage rate was only 22.46%. Range of AADT on roads where herptiles were recorded was 250 to 24,000.

Passage under bridges by herptiles occurred largely (82.32%) when bridge width was less than 40 m. Presence but not passage (n=1,141) was associated chiefly (89%) with 38 m bridge width. Bridge width of sites monitored ranged from 19.2 – 152.5 m. Of 848 records of herpetofauna using bridges, the majority occurred (82.45%) when bridge length (distance that organisms had to travel to pass through the structure) was 8.5 m or less. Presence but not passage (n=1,141) was also associated predominantly (94.66%) with bridge lengths less than 8.5 m. Bridge lengths at sites used by herptiles ranged from 7.3 – 38.4 m. Of 848 records of herpetofauna using bridges, most occurred when bridge height was between two size ranges, 1.5 to 1.8 m (48.94%) and 3.1 to 3.7 m (47.52%). Presence but not passage (n=1,141) was associated primarily (98.25%) with bridge heights of 3.1 to 3.7 m. In this case, bridge height ranged from 1.2 – 7.3 m.

Response to environmental characteristics. Four significant environmental parameters were reported in the logistic regression model and include seasonality, minimum and maximum temperature, and rainfall. Passage under bridges (n=848) and presence at (but not passage under) bridges (n=1,141) by herpetofauna occurred 77.6% and 86.59% of the time during spring and summer months. The highest passage rate was recorded in fall (154 of 204, 75.49%), and the highest number of passages occurred in spring (383 of 848, 45.17%).

Of 840 records of herpetofauna passing under bridges most occurred (90.82%) when average, minimum, weekly temperature was 10 degrees C or higher. Presence at (but not passage under) bridges showed the same trend (93.86% occurred at average, minimum, weekly temperatures of 10 degrees C and above). Average, minimum, weekly temperature at monitoring sites ranged between 1 and 24 degrees C. Records (n=840) of herpetofauna passing under bridges occurred most often (89.17%) when average, maximum, weekly temperature was 25 degrees C or higher. When average, maximum, weekly temperature was from 26 to 28 degrees C, 45.59% of movement under bridges was recorded. Presence at (but not passage under) bridges (n=1,141) were similar, as 78.43% occurred when average, maximum, weekly temperature was 25 degrees C or higher. Average, maximum, weekly temperature at monitoring sites ranged between 15 and 34 degrees C.

Of 843 records of herpetofauna using bridges, nearly all occurred (90.75%) when rainfall was 5 ml or less; and presence (but not passage) was also recorded principally (85.19%, n=972 of 1,141) when rainfall was 5 ml or less. Average weekly rainfall at monitoring sites ranged between 0 and 14 ml.

Response to ecological characteristics. Three important response variables were identified from logistic regression analysis. These include right-of-way vegetation height, primary habitat at 30 m^2 resolution, and human presence. Herpetofaunal movement under bridges (n=731) was recorded most frequently (77.98%) when vegetation height was between 31 and 50 cm. Right-of-way vegetation height at monitoring sites ranged from 5 to 122 cm.

Bridges where herptiles were recorded occurred in only two 30 m^2 scale primary habitat types, 4 (wetlands) and 7 (hardwood forests). Higher passage rates for herpetofauna were recorded at bridges in habitat type 4 (86.54%) than type 7 (23.58%).

Use of bridges (n=848) occurred 52.47% of the time when 5 or less humans were recorded. To the contrary, another peak in culvert use (43.04%) occurred when 73 or more humans were recorded. Presence of humans ranged from 0 – 110 records at sites monitored. Similar to the latter, 94.31% (n=1,076 of 1,141) of records of herptile presence at bridge entrances occurred when 73 or more humans were recorded over the course of the study.

Herpetofaunal use of culverts

Presence of herptiles at 106 culvert sites included records (n=1,489) of twelve species—southern leopard frog *Rana utricularia*, green tree frog *Hyla cinerea*, six-lined racerunner *Cnemidophorus sexlineatus*, five-lined skink *Eumeces spp.*, anole *Anolis spp*., fence lizard *Sceloporus undulatus*, cottonmouth *Agkistrodon piscivorus*, southern black racer *Coluber constrictor*, eastern garter snake *Thamnophis sirtalis*, striped mud turtle *Kinosternon baurii*, snapping turtle *Chelydra serpentina*, and alligator snapping turtle *Macroclemys temminckii*; and four orders/suborders—frog/toad *Anura*, lizard *Squamata*: *Lacertilia*, snake *Squamata*: *Serpentes*, and turtle/tortoise *Testudines*.

Logistic regression model. The backwards, stepwise, logistic regression for herpetofauna and culverts generated the following model equation from the significant factors identified in Table 18:

Logit (π) = 9.33 - 1.05*Season (su) + 0.66*Season (sp) + 0.082*Gap_Width - 2.03*AADT - 0.45*Str_Number + 3.39*Width - 0.20*Height + 1.27*Distance - 1.30* Pr_hab210 (1) - 1.09*Pr_hab210 (2) + 1.23* Pr_hab210 (6) + 1.53*ROW_Veg (herb_shrub) + 1.53* ROW_Veg (herbaceous) + 0.13*Lo-Temp - 0.17*Hi_Temp.

Table 18. Maximum likelihood estimates for herpetofauna and culverts

Parameter		DF	Estimate	Standard error	Chi-square	Pr > ChiSq
Intercept		1	9.3329	3.2284	8.3569	0.0038
Season	sp	1	0.6586	0.3363	3.8342	0.0502
Season	su	1	-1.0452	0.5143	4.1304	0.0421
Gap_Width		1	0.0821	0.0279	8.6678	0.0032
AADT_log		1	-2.0347	0.2834	51.5404	<.0001
Str_Number		1	-0.4475	0.1659	7.2736	0.0070
Width_log		1	3.3911	0.2856	141.0011	<.0001
Height_exp		1	-0.1967	0.0779	6.3671	0.0116
Distance_log		1	1.2746	0.2658	23.0012	<.0001
Pr_hab210	1	1	-1.2974	0.4419	8.6199	0.0033
Pr_hab210	2	1	-1.0921	0.4091	7.1264	0.0076
Pr_hab210	6	1	1.2307	0.3783	10.5830	0.0011
ROW_Veg	herb_shr	1	1.5327	0.4807	10.1673	0.0014
ROW_Veg	herbaceo	1	1.5271	0.4383	12.1383	0.0005
Veg_Height		1	0.0221	0.00523	17.9259	<.0001
Lo_Temp		1	0.1273	0.0391	10.6186	0.0011
Hi_Temp		1	-0.1687	0.0691	5.9655	0.0146

The model was highly significant for predicting use of culverts by herpetofauna: Wald X^2: 330.78 (df—23, p <.0001), Nagelkerke's R^2 (0.7730), and Hosmer and Lemeshow Goodness-of-Fit Test, X^2: 49.68 (df—8, p < 0.0001). Twelve of 21 factors were found significant by the model in predicting use of culverts by herpetofauna. Percentage of movement through culverts correctly predicted by the model was 94.9%.

Response to structural characteristics. Six structural factors were found significant by the model of logistic regression: gap width, AADT, culvert width, height, and number of cells, and distance to next nearest structure. Of 580 records of herpetofauna using culverts, most occurred (80.84%) when gap width was 3.7 to 7.3 m.

Presence but not passage was associated principally (97.8%, n=889 of 909) with gap widths less than 9 m. Gap width ranged from 0 – 39.3 m.

When AADT was 8,400 or greater, passage through culverts by herpetofauna (n=580) occurred only 7.91% during the period monitored. Most passage occurrences by herpetofauna were recorded when AADT was at 4 separate levels: 250, 3,900, 6,500 and 8,100 (16.72%, 14.14%, 13.10% and 16.72%, respectively). Presence near culverts, but not crossing from one side to the other, was most frequently recorded when AADT was 3900 (21.35%) and 7,700 (25.06%). Range of AADT on roads at sites monitored was 250 to 42,500.

Herpetofauna were recorded using culverts most frequent (84.15%) when culvert width was 1.5 m or wider. Presence but not passage (n=909) was associated largely (95.34%) with culvert widths less than 1 m. Culvert width ranged from 0.3 – 3.7 m. Of 580 records of herptiles using culverts, most occurred (95.34%) when culvert height ranged between 0.6 and 1.5 m. Presence but not passage (n=909) was associated predominantly (83.71%) with culvert heights less than 1 m. Culvert height ranged from 0.3 – 3.4 m. Passage rate (72%) through culverts was greatest when multiples of 2 – 3 cells were present; passage rate at sites with 1 or 4 cells was less than 25%. Presence at (but not passage through) culverts was recorded mostly (82.84%) with single cell culverts.

Records of passage through culverts (n=580) by herpetofauna coincided most often (72.07%) with distances between structures of 875 to 1,225 m. Range of distance between structures was 125 to 3,150 m.

Response to environmental characteristics. Three environmental factors of significance to herptiles using culverts include seasonality, and minimum and maximum temperature. Recorded passage through culverts (n=580) was high during spring (43.28%) and summer (41.55%) months. Presence at (but not passage through) culverts (n=909) was recorded mostly (73.82%) in summer months. Only ten records of herpetofauna were recorded in the winter months.

Regarding herpetofauna passing through culverts (n=578) or present at culvert entrances (n=908), most occurred (97.23% and 99.45%, respectively) when average, minimum, weekly temperature was 10 degrees C or higher. Average, minimum, weekly temperature at monitoring sites ranged between 0 and 24 degrees C. Of herpetofauna passing through culverts (n=578) and present at culvert entrances (n=908), nearly all occurred (94.29% and 95.71%, respectively) when average, maximum, weekly temperature was 26 degrees C or higher. Average, maximum, weekly temperature at monitoring sites ranged between 15 and 35 degrees C.

Response to ecological characteristics. Three different ecological parameters were significant in logistic regression analysis. These include primary habitat at 210 m^2 scale, and right-of-way vegetation type and height. Passage through culverts (n=580) by herpetofauna was the highest for 210 m^2 scale land-cover classes 3 (pinelands, 18.28%), 4 (wetlands, 14.31%), 6 (shrub and brushlands, 37.93%), and 7 (hardwood forests, 17.93%). Presence at (but not passage through) culverts (n=909) was greatest for land-cover classes 2 (xeric lands, 29.70%), 3 (18.81%), 4 (16.94%) and 6 (15.07%). Passage rates were greatest for classes 6 (220 of 357, 61.62%) and 7 (104 of 124, 83.37%).

Movement through culverts (n=580) occurred 80.69% of the time when herbaceous groundcover (either alone or combined with barren areas or shrubs) was present. Presence at but not movement through culverts (n=909) was also significant (91.08%), still showing preference for some level of herbaceous groundcover presence. Herpetofaunal movement through culverts (n=580) was recorded most frequently (86.93%) when vegetation height was greater than 30 cm. Right-of-way vegetation height at monitoring sites ranged from 0 to 183 cm.

Small mammal use of bridges

The small mammal group included records (n=5,142) of three species—rabbit *Sylvilagus spp*., gray squirrel *Sciuris carolinensis*, and eastern mole *Scalopus aquaticus*; and members of one family—*Cricetidae* (mice, rats, voles) from 39 bridge sites.

Logistic regression model. The backwards, stepwise, logistic regression for small mammals and bridges generated the following model equation from the significant factors identified in Table 19:

$$\text{Logit}(\pi) = -3.85 - 0.55*\text{Season (f)} + 1.33*\text{Season (sp)} + 0.45*\text{Gap\_Width} - 1.97*\text{AADT} - 1.91*\text{Width} - 307\text{E-}17*\text{Length} + 0.10*\text{Height} + 1.33*\text{Distance} + 0.014*\text{Veg\_Height} - 0.34*\text{Lo\_Temp} + 0.70*\text{Hi\_Temp} - 0.031*\text{Human\_Pr} - 0.012*\text{Dom\_Pred}.$$

The model was highly significant for predicting use of bridges by small mammals: Wald X^2: 445.43 (df—19, p <.0001), Nagelkerke's R^2 (0.8126), and Hosmer and Lemeshow Goodness-of-Fit Test, X^2: 43.79 (df—8, p < 0.0001). Twelve of 21 factors were found significant by the model in predicting use of bridges by small mammals. Percentage of movement under bridges correctly predicted by the model was 96.8%.

Response to structural characteristics. Six structural variables were identified in the logistic regression model that includes: gap width, AADT, bridge width, length and height, and distance to next nearest structure. Of 618 records of small mammals using bridges, nearly all occurred (90.3%) when gap width was 8.5 m or less; and presence but not passage was also associated predominantly (92.27%, n=4,174 of 4,524) with gap widths of 8.5 m or less. Gap width ranged from 3.1 – 16.5 m.

Table 19. Maximum likelihood estimates for small mammals and bridges

Parameter		DF	Estimate	Standard error	Chi-square	Pr > ChiSq
Intercept		1	-3.8486	89.9572	0.0018	0.9659
Season	f	1	-0.5487	0.2338	5.5068	0.0189
Season	sp	1	1.3293	0.2518	27.8724	<.0001
Gap_Width		1	0.4516	0.0962	22.0502	<.0001
AADT_log		1	-1.9699	0.3124	39.7511	<.0001
Width_log		1	-1.9078	0.7143	7.1337	0.0076
Length_exp		1	-307E-17	7.8E-16	15.5347	<.0001
Height_exp		1	0.0995	0.0255	15.2611	<.0001
Distance_log		1	1.3329	0.3084	18.6766	<.0001
Veg_Height		1	0.0142	0.00492	8.2704	0.0040
Lo_Temp		1	-0.3427	0.0372	84.8550	<.0001
Hi_Temp		1	0.7030	0.0598	138.1749	<.0001
Human_Pr		1	-0.0305	0.00797	14.6054	0.0001
Dom_Pred		1	-0.0121	0.00596	4.1473	0.0417

When AADT was greater than 6,400, passage under bridges by small mammals occurred only 6.31% (39 of 618) during the period monitored. Most passage occurrences by small mammals were recorded (51.78%, 320 of 618) when AADT was only 250. Presence recorded near bridges, but not crossing from one side to the other, was significantly reduced (12.45%, 563 of 4,255) when AADT was higher than 9,900. Range of AADT on roads at sites monitored was 250 to 42,054.

Of 618 records of small mammals using bridges, most occurred (88.02%) when bridge width was less than 50 m. Presence but not passage (n=4,524) was associated principally (89%) with bridge widths of 60 m or less. Bridge width of sites monitored ranged from 19.2 – 200 m. Small mammals using bridges were recorded primarily (89.33%) when bridge length was less than 14 m. Almost 70% of bridge use occurred when length was 8.2 m or less. Presence but not passage (n=4,524) was also associated predominantly (92.29%) with bridge lengths less than 14 m. Bridge length ranged from 7.3 – 41.5 m. Of 618 records of small mammals using bridges, most occurred when bridge height was between two size ranges, 1.5 to 2.4 m (64.56%) and 3.1 to 3.7 m (33.01%). Presence but not passage (n=4,524) was also associated predominantly with bridge heights of 1.5 to 2.4 m (19.12%) and 3.1 to 3.7 m (80.59%). Bridge height ranged from 3.1 – 7.6 m.

When distance between structures was greater than 1,000 m, passage under bridges by small mammals occurred only 25.56% (158 of 618) during the period monitored. Most passage occurrences by small mammals (55.97%, 346 of 618) were recorded when distance was less than 700 m. Range of distance between structures was 130 to 3,450 m.

Response to environmental characteristics. Three environmental parameters of significance include seasonality, and minimum and maximum temperature. Passage under bridges (n=618) occurred 86.25% of the time during spring and summer months. Spring months exhibited the highest passage rate, where 375 of 1,231 (30.46%) that approached bridge entrances passed through to the other side. Passage upon approach to bridge entrances for other seasons was less than 13%. Presence at (but not passage under) bridges (n=4,524) showed no significant seasonal differences.

Of 618 records of small mammals passing under bridges most occurred (95.31%) when average, minimum, weekly temperature was 10 degrees C or higher. Presence at (but not passage under) bridges showed no significant difference regarding low temperature. Average, minimum, weekly temperature at monitoring sites ranged between -1 and 24 degrees C. Small mammal passage under bridges, occurred most often (94.5%)

when average, maximum, weekly temperature was 25 degrees C or higher. When average, maximum, weekly temperature was from 26 to 28 degrees C, 62.31% of movement under the bridge was recorded. Presence at (but not passage under) bridges showed no significant difference regarding high temperature. Average, maximum, weekly temperature at monitoring sites ranged between 12 and 34 degrees C.

Response to ecological characteristics. Four significant factors were found from logistic regression analysis: right-of-way vegetation type and height, and frequency of disturbance from humans and domestic predators. Movement under bridges (n=618) occurred 95.63% of the time when herbaceous groundcover (either alone or combined with barren areas or shrubs) was present. Presence at (but not movement under) bridges (n=4,524) was less significant (75.55%); but still showed preference for some level of herbaceous groundcover presence. Small mammal movement under bridges (n=585) was recorded most frequently (88.54%) when vegetation height was between 30 and 50 cm. Right-of-way vegetation height at monitoring sites ranged from 0 to 122 cm.

When presence of humans increased at monitored sites, use by small mammals decreased. Use of culverts (n=618) occurred 55.18% of the time when 1 or less humans were recorded; 68.61% of the time when 5 or less humans were recorded; and 83.66% of the time when 27 or less humans were recorded. Presence of humans ranged from 0 – 110 records at sites monitored. A reverse trend existed with presence at (but no passage under) bridges, where 72.86% (n=3,296 of 4,524) occurred when 16 or more humans were recorded over the course of the study. When presence of domestic predators increased at monitored sites, use by small mammals decreased. Use (88.9%) and occurrence (82.28%) coincided with 3 or less records of domestic predators. Presence of domestic predators ranged from 0 – 104 records at sites monitored.

Small mammal use of culverts

The small mammal group that used culverts included records (n=10,656) of four species—eastern cottontail *Sylvilagus floridanus*, rabbit *Sylvilagus spp*., Florida water rat *Neofiber alleni*, and eastern mole *Scalopus aquaticus*; and members of one family—*Cricetidae* (mice, rats, voles) from 108 monitoring sites.

Logistic regression model. The backwards, stepwise, logistic regression for small mammals and culverts generated the following model equation from the significant factors identified in Table 20:

Logit (π) = – 1.19 - 1.16*Season (f) + 1.35*Season (sp) + 0.93*Season (su) - 0.94*AADT + 0.76*Str_Number + 0.78*Width + 8.03E-22*Length - 0.82*Habdiv_30 - 0.62*Pr_hab30 (3) + 0.63*Pr_hab30 (4) - 2.14*Pr_hab30 (6) + 0.33*Habdiv_210 + 1.33*Pr_hab210 (1) + 1.67*Pr_hab210 (2) + 1.70*Pr_hab210 (3) - 3.73*Pr_hab210 (4) + 1.65*Pr_hab210 (6) + 1.59*Pr_hab210 (7) + 0.021*Veg_Height + 0.077*Rainfall - 0.24*Lo_Temp + 0.069*Hi_Temp - 1.71*Human_Pr - 0.23*Dom_Pred.

The model was highly significant for 2 of 3 tests in predicting use of culverts by small mammals: Wald X^2: 480.74 (df—31, p <.0001), Nagelkerke's R^2 (0.3914), and Hosmer and Lemeshow Goodness-of-Fit Test, X^2: 35.95 (df—8, p < 0.0001). Note that R^2 is less significant for small mammals using culverts than in the previous model for small mammals using bridges. Fifteen of 21 factors were found significant by the model in predicting use of culverts by small mammals. Percentage of movement through culverts correctly predicted by the model was 86.6%.

Response to structural characteristics. The four explanatory variables selected by the logistic regression model were AADT, number of culverts cells, culvert width and length. Records of passage through culverts (n=270) by small mammals occurred primarily (87.05%) at sites where AADT was less than 8,000 vehicles-per-day; and most occurrences without passage through the culvert (69.63%, n=7,232 of 10,386) were recorded at sites with AADTs of 5,800 to 9,900. Annual-average-daily traffic for sites where small mammals were recorded ranged from 250 to 29,500.

Table 20. Maximum likelihood estimates for small mammals and culverts

Parameter		DF	Estimate	Standard error	Chi-square	Pr > ChiSq
Intercept		1	-1.1919	148.1	0.0001	0.9936
Season	f	1	-1.1570	0.1909	36.7373	<.0001
Season	sp	1	1.3533	0.1542	77.0341	<.0001
Season	su	1	0.9290	0.2617	12.6002	0.0004
AADT_log		1	-0.9424	0.1697	30.8210	<.0001
Str_Number		1	0.7621	0.1471	26.8405	<.0001
Width_log		1	0.7837	0.1745	20.1713	<.0001
Length_exp		1	8.03E-22	3.18E-22	6.3633	0.0117
Habdiv_30		1	-0.8204	0.1728	22.5492	<.0001
Pr_hab30	3	1	-0.6157	0.2459	6.2672	0.0123
Pr_hab30	4	1	0.6279	0.2688	5.4578	0.0195
Pr_hab30	6	1	-2.1395	0.4937	18.7832	<.0001
Habdiv_210		1	0.3332	0.1167	8.1483	0.0043
Pr_hab210	1	1	1.3335	0.3178	17.6082	<.0001
Pr_hab210	2	1	1.6682	0.3788	19.3937	<.0001
Pr_hab210	3	1	1.7012	0.2457	47.9246	<.0001
Pr_hab210	4	1	-3.7257	0.3768	97.7739	<.0001
Pr_hab210	6	1	1.6584	0.2879	33.1742	<.0001
Pr_hab210	7	1	1.5853	0.3150	25.3319	<.0001
Veg_Height		1	0.0208	0.00337	38.1414	<.0001
Lo_Temp		1	-0.2401	0.0316	57.6271	<.0001
Hi_Temp		1	0.1123	0.0410	7.5077	0.0061
Rainfall		1	0.0765	0.0372	4.2350	0.0396
Human_Pr		1	-1.7058	0.1936	77.6478	<.0001
Dom_Pred		1	-0.2334	0.1173	3.9589	0.0466

Passage rate (88.89%) through culverts was greatest when multiples of four cells were present; sites with 1 to 3 cells were negligible (approximately 1 – 3%). Presence at (but not passage through) culverts was recorded mostly (50.33%) with single cell culverts. Of 270 records of small mammals using culverts, most occurred (90.73%) when culvert width was from 0.6 to 3.1 m. Presence but not passage (n=10,386) was associated predominantly with culvert widths of 0.5 to 1.2 m and 2.4 m (50.81% and 32.34%, respectively). Culvert width ranged from 0.3 – 4.3 m. Culvert use by small mammals was primarily recorded (84.8%) when culvert length was 22 m or less. Presence near culvert entrances (n=10,386) was largely connected (88.4%) with culvert lengths of 14 to 22 m. Culvert length ranged from 9.2 – 49.4 m.

Response to environmental characteristics. Four significant environmental factors include seasonality, minimum and maximum temperature, and rainfall. Passage through culverts (n=270) occurred 73.7% of the time during spring and summer months. Presence at (but not passage through) culverts (n=10,386) was recorded mostly (64.46%) in fall and spring months.

Regarding small mammals passing through culverts (n=270) or present at culvert entrances (n=10,386), most occurred (90.74% and 90.94%, respectively) when average, minimum, weekly temperature was 5 degrees C or higher. Average, minimum, weekly temperature at monitoring sites ranged between -1 and 24 degrees C. Of small mammals passing through culverts (n=270) and present at culvert entrances (n=10,386), most occurred (76.29% and 74.38%, respectively) when average, maximum, weekly temperature was 25 degrees C or higher. When average, maximum, weekly temperature varied from 26 to 32 degrees C, 62.95% of movement through culverts was recorded. Average, maximum, weekly temperature at monitoring sites ranged between 12 and 35 degrees C.

Of 270 records of small mammals using culverts, most occurred (94.82%) when rainfall was 6 ml or less; and presence but not passage was also recorded predominantly (93.88%) when rainfall was 6 ml or less. Average weekly rainfall at monitoring sites ranged between 0 and 22 ml.

Response to ecological characteristics. Seven different ecological variables were significant by logistic regression analysis. These include primary habitat at 30 and 210 m^2 scales, right-of-way vegetation type and height, habitat diversity at 30 and 210 m^2 scales, and frequency of disturbance from human presence and domestic predators. Passage through culverts (n=270) by small mammals was the highest for 30 m^2 scale land-cover classes 2 (xeric lands, 14.81%), 3 (pinelands, 25.56%), 4 (wetlands, 18.52%), and 7 (hardwood forests, 38.15%). Presence at (but not passage through) culverts (n=10,386) was also greatest for land-cover classes 2 (17.56%), 3 (21.54%), 4 (27.68%), and 7 (27.65%). Passage through culverts (n=270) by small mammals was the highest for 210 m^2 scale land-cover classes 3 (22.59%), 4 (17.04%), 5 (grasslands and agriculture, 14.44%), and 6 (shrub and brushlands, 24.81%). Presence at (but not passage through) culverts (n=10,386) was greatest for land-cover classes 3 (22.33%), 4 (21.26%), and 6 (22.67%).

Movement through culverts (n=270) occurred 97.41% of the time when herbaceous groundcover (either alone or combined with barren areas or shrubs) was present. Presence at but no movement through culverts (n=10,386) was also significant (91.28%); still showing preference for some level of herbaceous groundcover presence. Small mammal movement through culverts (n=260) was recorded most frequently (73.44%) when vegetation height was between 20 and 50 cm. Right-of-way vegetation height at monitoring sites ranged from 0 to 208 cm.

Small mammal use of culverts was highest (65.56%) when habitat diversity comprised 3 different land-covers at the 30 m^2 cell resolution. When 2 land-cover types were present, passage through culverts was recorded 75 times (27.78%). Similar percentages occurred (3—60.79%, 2—33.42%) for those individuals that were present at culvert entrances only. Insufficient records occurred at sites where the maximum 5 land-cover types existed. Small mammals recorded using culverts was highest (40%) with habitat diversity comprised of 3 different land-covers at the 210 m^2 cell resolution. When 2 land-cover types were present, passage through culverts was recorded 75 times (27.78%). Similar percentages occurred (3—48.29%, 2—21.33%) for those individuals that were present at culvert entrances only. Insufficient records occurred at sites where the maximum 6 land-cover types existed.

When presence of humans increased at monitored sites, use by small mammals decreased. Use of culverts (n=270) occurred 90.37% of the time when no humans were recorded. Similarly, presence at (but no passage through) the culvert was greatest (78.87%, n=8,191 of 10,386) when no human presence was recorded. Presence of humans ranged from 0 – 4 records at sites monitored where small mammals were recorded. Small mammals preferred sites where domestic predators were absent, whether present at or passing through culverts. Most occurred when domestic predator records were zero (63.97% and 59.26%, respectively) or one (15.97% and 27.04%, respectively). The range of records of domestic predators, where small mammals occurred, was only 0 – 4 at sites monitored.

Alligator and aquatic mammal use of culverts and bridges

Due to small sample sizes the three species—alligator *Alligator mississippiensis* (n=25), river otter *Lutra canadensis* (31), and beaver *Castor canadensis* (5)—were consolidated into one group (dependents of aquatic systems) with 61 records from 15 culvert and 13 bridge sites. Even with this measure, logistic regression could not be performed; therefore only summary results are reported.

Response to structural characteristics. Alligators (n=12) and aquatic mammals (n=15) did not display preferences regarding bridge dimensions; however, minimum width (29.3 m), minimum height (1.5 m), and maximum length (38.4 m) were not physically limiting. For culverts, alligators (n=13) were recorded primarily using widths greater than 1.5 m (92.3%) and heights 0.9 m or more (92.3%). Aquatic mammals (n=21) used culvert widths of 1 m or higher, lengths of 15 m or less, and heights of 0.9 m or higher most often (90%, 75% and 65%, respectively). Other structural parameters do not appear relevant given the small sample sizes.

Response to environmental characteristics. Aquatic mammals were mainly documented using highway structures in spring, summer, and fall (n=29, 96.35%), whereas presence without use was recorded in winter (n=7, 85.71%). Recorded passage through culverts (n=32) was high during spring (50%) and summer (21.88%) months. Alligators were recorded moving through highway structures only in spring, summer and fall.

Regarding aquatic mammals, movement within or presence near highway structures was only recorded when average weekly rainfall was slight (1 ml or less, 79.31 and 85.71%, respectively). No patterns were observed regarding rainfall or temperature on alligator activity associated with highway structures.

Response to ecological characteristics. Minimal disturbance by humans and domestic predators (0 to 4 occurrences) corresponded to usage (82.76% and 93.1%, respectively) by aquatic mammals. Maximum number of humans and domestic predators recorded at individual sites (where aquatic mammals were recorded) was 110 and 104, respectively. Other ecological factors showed no apparent effects for aquatic mammals given the small sample size. Ecological factors showed no significance regarding alligator activity at highway structures.

Discussion

Several studies have demonstrated wildlife movement through culverts and bridges under roadways. Most case studies have shown use by specific species of specific structures, e.g. Florida panther—I-75 bridges, Florida black bear—2.4 x 7.3 m culvert, bobcat and raccoon—1.8 x 1.8 m (Hewitt et al. 1998, Norman et al. 1998, and Boarman et al. 1996). Other studies involved use of wildlife ecopassages designed for large targeted species (Clevenger and Waltho 2000, Foster and Humphrey 1996, and Roof et al. 1996). Yet smaller concrete culverts and tunnels originally designed for drainage under roadways have also been used as wildlife passages by a wide variety of small to medium size mammals (Rodriguez et al. 1996, Yanes et al. 1995, and Hunt et al. 1987) and many species of amphibians (Brehm 1989, Dexel 1989, and Norden 1990). All these studies agree that culverts are useful mitigation measures for movement of animals under roadways; however, none have provided comprehensive evaluations of effectiveness according to a wide distribution of structure sizes and contexts.

The objective of this study was broader; specifically, it was set up to determine design standards for drainage culverts and bridges (to enhance and improve use by a wide variety of wildlife). Yet additionally it addressed larger issues, such as improving overall landscape connectivity of important large-scale ecological linkages. This structure classification system would serve as a reference for transportation agencies when programming mitigation measures for wildlife mortality on highways (based on type of species present and landscape context).

Comparison of Structure Use Among Faunal Groups

Six distinct faunal groups were used for analysis. Similarities and differences regarding use of crossing structures are evident among the groups. Table 21 summarizes findings of common parameters for all structures by each faunal group. Three thresholds for each parameter represent liberal to conservative measures of passage success by each faunal group.

Thresholds for contextual parameters

To sustain 90% of crossings made by each faunal group, only 3.7 m of open right-of-way separated the structure entrances from the adjacent habitat (Table 21). As the level of sustainability is decreased, differences occur among groups for maximum gap distance. At 75%, the gap width increases to 5.1 and 7.7 m for small mammals and ungulates, respectively. Gap width was statistically significant for the smaller species recorded using crossing structures: meso-mammals, small mammals, herpetofauna, and birds. A distance of 3.7 to 5.1 m from adjacent habitat to structure entrances is recommended to promote high levels of movement for all species.

The gap width can be mitigated in part by right-of-way vegetation type and height. All groups preferred presence of herbaceous vegetation, and in some cases addition of shrubs. Right-of-way vegetation height generally consisted of three minimum thresholds among the faunal groups: 5 cm for birds and ungulates, 10 cm for carnivores, and 20 cm for meso-mammals, herptiles, and small mammals (Table 21). Maximum height preferences varied from 50 to 92 cm. Right-of-way vegetation height was a significant factor only for small mammals and herpetofauna. This would coincide with

Table 21. Levels of use by faunal groups for common parameters of all study sites

Threshholds: 90% (upper), 75% (middle), 60% (lower)	**Meso-mammals** (n=11,701)	**Carnivores** (n=611)	**Birds** (n=258)	**Ungulates** (n=573)	**Herpeto-fauna** (n=1,428)	**Small mammals** (n=888)
gap width (distance to habitat), m	3.7 5.3 5.8	3.7 5.8 7	3.7 6.8 7.9	5.8 7.7 8.1	3.7 6.4 7.8	3.7 5.1 7.9
AADT, annual avg. vehicles / day	250 3000 5000	3200 6400 6500	250 3000 3200	3400 6100 6709	250 250 3900	250 250 1900
distance between structures, m	250 560 775	585 600 875	250 600 775	200 600 670	260 625 875	250 325 585
human presence, no. / year.	4 46 69	3 7 30	3 10 46	3 7 17	3 17 46	1 8 46
domestic predators, no. / year	1 1 20	1 1 3	1 1 1	1 1 4	1 1 1	1 1 20
Preferences						
row vegetation type	herbaceous	herbaceous	herb – shrub	herb – shrub	herb – shrub	herb – shrub
row vegetation height, cm	20 – 70, 82%	10 – 75, 79%	5 – 60, 85%	5 – 91, 78%	20 – 92, 79%	20 – 50, 85%
soil moisture and precipitation	dry – moist	dry – moist	dry	dry – moist	dry	dry
habitat diversity 30m^2	3	3	3	3	3	2 – 3
primary habitat 30m^{2} *	4, 8	4, 7, 8	4, 8	4, 7, 8	4, 8	4, 8
habitat diversity 210m^2	2 – 4	1 – 4	3 – 4	3 – 4	2 – 4	3 – 4
primary habitat 210m^{2} *	3, 4, 7	3, 4, 6	3, 4, 7	3, 6, 7	3, 4, 7	4, 7
season	fall, summer	-	winter	-	spring, summer	spring

Notes: Preferences are based on a minimum of 70% structure use for each faunal group.
* Table 4 provides habitat class descriptions.

the need for cover from larger mammalian predators and birds of prey. Given specific exceptions, at least 20 cm groundcover should be maintained at all crossing sites; with addition of larger shrubs strategically placed to provide cover for larger, sensitive species, such as white-tailed deer. An example of one exception would include xeric habitats, where open sandy areas are preferred by certain species. The best recommendation regarding type of right-of-way vegetation would be the use of plant species that are the same as those in adjacent habitat, with slightly greater cover near entrances to crossing structures (to provide security for prey species).

Distance between structures was a significant factor regarding use by meso-mammals, carnivores, herpetofauna, and small mammals. A maximum distance of 200 to 250 m between crossing structures was necessary to sustain 90% passage for all groups, except carnivores. The maximum recommended distance is 325 m within core conservation areas and habitat corridors, corresponding to at least 75% use by small mammals. This distance is similar to that recommended by Clevenger et al. (2001).

Crossing structures located in areas with three land-cover types at the 30 and 210 m^2 scales were most frequently used by all groups. All groups used structures most often located in wetlands (4) or hardwood forests (8) at the 30 m^2 scale. Slight differences were apparent at the 210 m^2 scale, with crossing structures in pinelands (3), wetlands (4), and shrub and brushlands (7) most commonly used by five of six faunal groups. Habitat type and diversity (30 m^2) were significant factors in logistic regression for meso-mammals, small mammals, ungulates, and herptiles. This likely corresponds to use of road verges for foraging and the crossing structures as shelter. Surrounding habitat type and diversity (210 m^2) were significant factors for meso-mammals, ungulates, herptiles, and small mammals. Management and mitigation for the species most frequently encountered in this study should generally focus on improving habitat diversity along road right-of-ways and adjacent land-cover classes 4 (wetlands) and 8 (hardwood forests). Specifically, issues regarding habitat should be addressed on a site-by-site basis.

Thresholds for disturbance parameters

Three factors can be considered measures of tolerance by faunal groups to disturbance, specifically AADT (traffic level), human presence, and presence of domestic predators. Meso-mammals, birds, small mammals, and herptiles made 90% of crossings when traffic levels were 250 or fewer vehicles-per-day (Table 21). Carnivores and ungulates were more tolerant, with 90% of structure use occurring when over 3,000 vehicles were present per day. While tolerance of traffic increased for 75% structure use by meso-mammals and birds (AADT = 3,000), and carnivores and ungulates (AADT > 6,000); small mammals and herptiles were more sensitive, as 250 vehicles daily was still the maximum traffic level that could sustain measured use of culverts of 75%. Herptiles appear most sensitive to traffic, which is most likely associated with traffic noise; other groups appear more tolerant. Annual-average-daily traffic was statistically significant for all groups, except birds and ungulates. Traffic level was an important factor in culvert avoidance by wildlife in other studies: Banff National Park, Alberta, Canada (Clevenger et al. 2001), and Denali National Park, Alaska (Yost and Wright 2001). Sites where herptiles and small mammals are present require more stringent restrictions or mitigation for traffic and traffic-related noise. Based on the results presented here, none of the groups could sustain more than 60% use of structures when daily traffic levels were over 6,709.

Presence of humans was measured simply as the number of people (or signs of people) recorded over the 19 months of monitoring; therefore, representing the relative human impact that recorded wildlife would tolerate (Table 21, values in table were converted to number per year). Greatest number of humans recorded at any single site was 104 over 19 months (1 every 5.5 days). This factor was found significant in regression analysis for meso-mammals, herptiles, and small mammals; however, small mammals, ungulates, and carnivores appeared most sensitive to frequency of human presence (probably reacting to persistence of human scent). Meso-mammals were the least inhibited (75% structure use with 73 total records of human presence, 1 every 8 days). Ninety percent of structure use by all groups, except small mammals, occurred when only 4 – 6 humans were encountered (1 every 95 days; excludes track recorders). This finding echoes that of Clevenger and Waltho (2000), who found that wolves avoided culverts near areas of human activity. Grizzly bears also displayed avoidance of humans associated with logging activities (McClellan and Shackleton 1988). Certainly, the data here indicate that to maximize use by most wildlife, human presence needs to be restricted at crossing sites.

All groups can be considered sensitive to activity by domestic predators near crossing structures (Table 21, values in table were converted to number per year). Presence of domestic predators was as high as 110 over 19 months (1 every 5 days). Ninety percent use of crossing structures by each group occurred when 1 or less domestic predators were present over 19 months. Carnivores, birds, ungulates, and herptiles only used crossing structures at a 60% rate when 2 – 6 domestic predators were encountered during the course of the study. Fencing or other devices should be used to restrict access to crossing sites from the road by domestic predators.

Thresholds for structural parameters

All groups showed a preference for dry soil conditions within structures (Table 21), which was statistically significant for meso-mammals, carnivores, herpetofauna, and small mammals; however, caution should be used regarding herpetofauna because some bias in sampling could affect this measure. During rainy periods, tracks were either hard to read or lost from washouts of track-beds, and thunderstorms restricted activities by field technicians. Though commonly-found lizard species seem to prefer dry conditions; intuitively, the movement of amphibian species should increase with wetter conditions.

Although openness was not included in the logistic regression, it is still useful as a reference for general size requirements for each faunal group. Ninety percent of use by meso-mammals, carnivores, ungulates, and small mammals occurred in structures with openness index values of approximately 0.40 (Table 22). Birds preferred larger openness values (0.86) and herpetofauna smaller openness values (0.28) for 90% of culvert use recorded. A breakdown of the openness index into its components may be more informative.

Table 22. Levels of use by faunal groups for structural parameters of culverts

Threshholds: 90% (upper), 75% (middle), 60% (lower)	**Meso-mammals** (n=5,515)	**Carnivores** (n=258)	**Birds** (n=81)	**Ungulates** (n=32)	**Herpeto-fauna** (n=580)	**Small mammals** (n=270)
openness index value (w x h / l)	.43 .28 .18	0.41 0.23 0.23	0.86 0.43 0.23	0.41 0.25 0.25	0.28 0.28 0.23	0.42 0.18 0.08
width, m	3.4 3.1 2.7	3.1 2.7 2.4	3.1 3 > 2.4	3.7 3 3	3.4 3.1 2.7	3.1 2.7 1.5
length, m	11 14 18	12.8 14.5 14.5	11 12 14.6	12.8 13.7 19.2	11.6 14.5 14.5	11.6 13.7 18.3
height, m	1.7 1.5 1.4	1.8 1.5 1.5	3.4 1.5 1.4	3.7 3.7 3.4	1.5 1.4 1.4	1.5 1.4 1.2
Preferences						
structure number, #	▽ trend	▽ trend	△ trend	1 – 2	▽ trend	1
structure shape	rectangular	rectangular	rectangular	rectangular	rectangular	rectangular
structure substrate	dirt	-	-	dirt	dirt	dirt

Response to culvert width was similar for all faunal groups (Table 22). All groups exhibited 90% usage when culvert width was 3 m or greater and 60% usage at 2.4 – 2.7 m, except small mammals (1.5 m). Culvert width was a significant factor in all regression models except for ungulates. The low level of variability among groups of differing body size indicates that minimum width may play a role in passage success, but in a general sense. Thus to maintain high passage rates (75%) for all species (especially carnivores) at least 2.7 m width for new structures is encouraged (for comparison, 3 – 5 m was recommended for white-tailed deer by Norman et al. 1998). Note that of 63 Florida black bears recorded, only 5 approached culverts, and only three of these actually crossed through from one side of the road to the other. The culverts used by these individuals had minimum openness index values of 0.23 and heights of 1.5 m.

Culvert height displayed greater variance with regard to use among faunal groups (Table 22). Culvert height was a significant factor for meso-mammals, herpetofauna, and small mammals. The latter two groups were more abundant using culverts 1.5 m or lower, presumably because larger predators are more hesitant to use them. All but three individuals in the carnivore group that used culverts either were bobcats, coyotes, or foxes. For areas where only smaller prey are abundant, lower heights should be used. For large carnivores and ungulates, 3 m minimum height should be used. Ungulates did not use culverts with any significant frequency (n=32 over 19 months). Other studies (Garrett and Gordon 2003) indicate that preference for higher openness values may limit usefulness of standard drainage culverts for deer. Foster and Humphrey (1995) found use of 2.1 m high bridges by ungulates and large carnivores; however, these structures had openness values of 0.92 – 1.12.

Culvert use among groups was similar with regard to culvert length (Table 22). Frequency of usage was 90% for all groups if culvert length was 11 m or less. Due to road construction standards, length of culvert is difficult to change; it is entirely dependent on the width of the road itself. Openness index can be used as a mechanism to adjust for length. As a road becomes wider, culvert length increases and openness necessarily goes down. To maintain the same openness value, width and or height of the culvert must be increased.

Other influential factors associated with culverts include number of culverts (e.g., single and multi-cell units), culvert shape, and substrate. Preferences for all groups were for dirt or soil substrate and rectangular shape. Number of structures was more variable among groups; and statistically significant for only carnivores, herptiles, and small mammals. These three groups preferred single to multi-cell configurations.

Influence of structural factors of bridges on faunal groups is shown in Table 23. Differences between results for bridges and culverts reflect the significant differences between the two structure types. Bridges were much less limiting on use by faunal groups. All three dimensions (width, length and height) were significant factors for small mammals and meso-mammals, width and height for birds, width for herptiles, and height for ungulates and carnivores.

When comparing bridges to culverts, only bridge height is relatively limiting (because height is similar for the two structure types). Specifically, for locations used by carnivores (especially Florida black bear) and white-tailed deer, a minimum height of 3.5 m is recommended. Predicting use as a result of structure width and length is not as clear. For the groups mentioned above with significant maximum likelihood scores for bridge width, most are likely a result of increased habitat availability.

Table 23. Levels of use by faunal groups for structural parameters of bridges

Threshholds: 90% (upper), 75% (middle), 60% (lower)	**Meso-mammals** (n=6,186)	**Carnivores** (n=353)	**Birds** (n=177)	**Ungulates** (n=541)	**Herpeto-fauna** (n=848)	**Small mammals** (n=618)
openness index value (w x h / l)	17.89 14.38 9.66	21.35 17.08 15.25	17.08 17.08 9.66	25.42 16.37 13.14	19 17.08 17.08	17.08 12.2 8
width, m	82.4 54.9 41.2	96.1 60.4 41.2	60.4 41.2 38.4	152.5 82.4 58	54.9 38.4 38.4	54.9 40.3 32
length, m	7.3 7.3 8.2	8.2 8.5 12	7.3 7.3 8.2	8.2 9.2 11.9	7.3 7.3 8.2	7.3 7.3 7.3
height, m	3.7 3.1 3.1	3.7 3.7 3.1	3.7 3.7 3.1	6.1 4.6 3.7	3.7 3.7 3.1	3.7 3.1 1.8

Crossing Structures as Primary Habitat Features

Two groups, herpetofauna and small mammals included species that frequented culverts as part of their primary habitat rather than as movement corridors. These included lizards (n=2,635), primarily six-lined racerunner and five-lined skink; and rodents (n=15,637), i.e., various mice and rats. Lizards commonly used culverts and bridge faces for sunning areas; and mice used crevices and cracks in the structure for shelter. When controlled for these species, each group’s presence is reduced significantly (other herptiles, n=843, other small mammals, n=161). A more detailed analysis that divides these groups into relevant categories is recommended to separate primary habitat needs of local species from species with larger movement requirements (e.g., snakes and turtles).

Meso-mammals, especially raccoons used water collection areas at culvert and bridge sites for foraging areas for amphibians or trash from motorists and fishermen.

Specific planning for movement under roads by this group is probably unnecessary because they are already quite successful using existing configurations without need for modification.

Road-kills and Culvert Avoidance

Although frequency of site visits was sufficient for tracks and photographs, twice per week was inadequate to evaluate quantity and types of road-kills occurring on adjacent road segments. Persistence of road-kill depends on factors such as weather, traffic density, frequency of road cleanup or maintenance, and depredation rates by scavengers. Studies of culvert avoidance should include road-kill information; without a complete complement of these data, inferences about avoidance by certain species could not be made. Additionally, surveys of abundance in habitat areas adjacent to monitoring sites may provide evidence of other species present that do not approach structure entrances where track beds were situated. Two studies (Clevenger et al. 2001, and Yanes et al. 1995) performed abundance surveys that provided better information regarding avoidance, and allowed for comparisons between culvert use frequency and total population size.

Effects of Light Penetration and Traffic Noise

Certain characteristics such as light and moisture content have been evaluated for amphibians (Krikowski 1989, and Langton et al. 1989). Amount of light available within culverts can help counter tunnel effects. Certain amphibian species would not enter when sufficient light was not present (Krikowski 1989). Light availability within drainage culverts has tremendous variability based on two factors: size of culvert opening that affects quantity of light and depth of penetration; and the length of the culvert, where quantity of light decreases as distance from the opening increases. Another potential vector affecting light availability occurs on divided highways that incorporate median drainage grates allowing light penetration at the center of the culvert. Although this study did not evaluate the influence of light availability on structure use, visibility is of obvious importance to many species that were recorded. Most specifically, openness index values that were calculated have a relationship with the amount of light penetration. This is inherently reflected in the results here, where most species preferred higher openness values.

Noise is another influential factor that has been investigated by other researchers (Clevenger et al. 2001, and Reijnen et al. 1995). These studies found significant road avoidance associated with the effects of traffic noise, particularly for small carnivores and birds. A direct relationship between traffic noise and traffic volume would indicate a similar relationship between traffic volume and avoidance by species sensitive to noise. This relationship is depicted in this study by the precipitous drop in use of culverts as traffic levels increase beyond 6,000 vehicles-per-day.

Current Research Benefits and Future Directions

Design standards for drainage structures (that promote use by wildlife within certain landscape/habitat contexts) should improve efficiency for retrofitting existing roads, or construction of new roads with appropriate cost-effective ecopassages. Determining the utility of existing structures, within right-of-ways at identified high-priority, highway-greenway interface zones, also provides opportunity for significant cost savings (associated with adapting these sites for optimal connectivity for wildlife). This research should enhance the ability of transportation agencies to effectively address wildlife issues at public hearings; and to quickly implement the appropriate mitigation measures needed at identified high-priority, highway-greenway interface zones.

Future research needs include effects of moisture, temperature and light, and efficacy of drainage culverts to facilitate movement by amphibians in the southeast. Some work has been conducted in the northeast and Europe (Jackson 1996, and Langton 1989), but applicability of those finding to this region has not been researched. Also, a similar study to this one needs to be performed on aquatic culverts; to assess connectivity for fish and other aquatic obligates in the many streams in Florida (potentially obstructed by roads). Significant research in this area has been conducted in the northwest (Ruediger 2001, and Carey 1996).

Lastly, wildlife movement, in areas where few drainage structures exist (e.g., sandhill and scrub communities), needs to be investigated to assess impacts of road-kills on population levels (i.e., the potential need for crossing structures to improve habitat connectivity). Potential study sites include Guana River State Park, Goldhead Branch State Park – Camp Blanding MTS, Marjorie Carr Cross Florida Greenway – Ross Prairie State Forest, and parts of Ocala National Forest; where park staff has collected significant road-kill data.

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