# Short-Term Effects of Fuel Reduction Treatments on Herpetofauna from the Southeastern United States

**Eran S. Kilpatrick, Thomas A. Waldrop, Joseph D. Lanham, Cathryn H. Greenberg, and Tom H. Contreras**

**Abstract:** Path analysis of fuel reduction treatments on herpetofauna across four southeastern sites of the National Fire and Fire Surrogate Study provided quantitative evidence relating changes in vegetation and fuels to herpetofauna response. Fuel reduction treatments included prescribed burning (B), a mechanical treatment (M), mechanical treatment followed by prescribed burning (MB), and an untreated control (C). Treatment effects on herpetofauna response variables were predicted by the direct and indirect effects of stand basal area, coarse woody debris volume, native herb cover, and forest floor depth. Path models were solved for lizard, snake, and reptile response to fuel reduction treatments. Lizard and reptile abundance were higher in B and MB plots than in C and M plots. Increasing native herb cover best predicted lizard and reptile abundance within B and MB plots. Native herb cover, lizard, and reptile abundance were highest in B and MB plots, and each of these response variables responded positively to B and MB. FOR. SCI. 56(1):122–130.

**Keywords:** herpetofauna, path analysis, prescribed burning, Southeastern forests, forest management, mechanical

THE NATIONAL FIRE and Fire Surrogate (FFS) study was initiated in 2000 and is currently installed at 12 locations across the United States. It has been proposed that fuel reduction treatments such as prescribed fire and fire "surrogates" such as cutting and mechanical fuel treatments could restore historical ecosystem processes and increase forest sustainability. The FFS study was designed to study the ecological and economic consequences of prescribed burning and mechanical fuel reduction treatments (McIver et al. 2009). If regional trends exist, it is important that they are recognized and understood at an interdisciplinary level (Ringold 2000). Responses to fuel reduction treatments at one site may not be applicable to all other sites. An analysis of multiple study sites using a combined data set from these sites may provide insight that is applicable across a large region. The objective of this study was to detect trends in herpetofauna across four southeastern sites of the FFS study. Path analysis (Wright 1921, 1934), a type of structural equation modeling, is an appropriate tool for this study. Path analysis can determine treatment effects on herpetofauna and environmental response variables across multiple study sites while taking into consideration the interaction between each site and treatment.

Detailed environmental data were collected for each FFS study site and allowed for potentially numerous hypotheses concerning herpetofauna to be tested. However, path analysis is most effective when the path model is built from a parsimonious, but yet meaningful, number of variables (Engel and Irwin 2003). Studies applying path analysis to herpetofauna are lacking. However, path analysis has been applied to a number of other ecological topics that used methodology similar to that used in this study.

Path analysis has been applied to species interactions (Weis and Kapelinski 1994, Maher and Lott 2000), community structure (Smith et al. 1997), and ecosystem modeling (Johnson et al. 1991). Path analysis has also been applied to plant ecology (Diego and Simberloff 2004), avian ecology (Iwata et al. 2003), and anuran growth rates (Arendt 2003). Given the proven utility of path analysis in ecological studies, this technique was used to assess the effects of fire and fire surrogate treatments on herpetofauna across four southeastern FFS study sites. The objectives of this study were to identify trends for herpetofauna response to fuel treatments across four southeastern FFS study sites and determine which habitat variables are most correlated with herpetofauna within FFS study plots.

## Methods

Herpetofauna capture data from the four southeastern FFS study sites (Gulf Coastal Plain [Alabama, AL], Florida Coastal Plain [Florida, FL], Southern Appalachian Mountains [North Carolina, NC], and Southeastern Piedmont [South Carolina, SC]) were summarized and assigned to seven herpetofauna response variables (frogs and toads, salamanders, lizards, snakes, turtles, amphibians, and reptiles). See McIver and Weatherspoon (2010) for a description of study sites and treatments. Captures were grouped in

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this manner to include the different genera collected across sites and species with low numbers of captures. Analysis was conducted only on 4 of the 13 study sites because the remaining 9 sites had insufficient numbers of captures. Mechanical treatments varied across study sites. A low thinning was the mechanical treatment used in AL and SC. The mechanical treatment in NC involved cutting all shrubs and small trees ≤10.2 cm dbh and ≥1.8 m tall and all shrubs regardless of size. Roller chopping was the mechanical treatment used in FL.

Drift fence/pitfall arrays similar to those used in SC were used in AL and NC to sample herpetofauna. In addition to drift fence/pitfall arrays, snake arrays and funnel traps were used in AL and funnel traps in NC. The snake arrays in AL were composed of four 10-m arms at right angles to each other and a box trap in the center (Rall 2004). Funnel traps in NC and AL were placed along the drift/fence arms. Area/time constrained searches, PVC pipes and coverboards were used to sample herpetofauna in FL. Drift fence/pitfall arrays were not used at the FL site because of time constraints, flooding, and interference with small mammal sampling devices. Only data collected from 2002 to 2004 (AL and FL) and from 2003 to 2004 (NC and SC) were used in this analysis. In winter 2003, sampling in SC block 1 control was discontinued because of extensive southern pine beetle damage.

The data were sorted so that correlation and regression analyses would detect each data point. Because of the response variable sample size ($N$ = 1 array or 2 arrays/treatment area) and number of missing values for habitat variables, initial analyses using unsorted data were underestimating sample size. FFS study plots contained 40 gridpoints spaced 50 m apart. They were numbered from the northeast corner and went from east to west in a zigzag pattern. Sorting was done by assigning environmental data corresponding to gridpoints 1–20 to array 1 and assigning environmental data corresponding to gridpoints 21–40 to array 2. Pearson correlation coefficients in PROC CORR were used to measure the strength and direction of the linear relationships between response variables and habitat variables. Each significant correlation was noted and summarized for each pair of variables.

NC and SC captures from gridpoints 1–20 were assigned to array 1 and captures from gridpoints 21–40 were assigned to array 2. The snake array captures were combined with drift fence/pitfall captures in AL. AL only had one drift fence/pitfall array per site, so captures were assigned to array 1. Captures from FL were combined and assigned to gridpoint 20 within each study site.

Statistical analyses were initially conducted on seven herpetofauna response variables and four sites. Because of the small sample size in AL and FL, statistical analyses could not be performed but generalizations were made concerning mean abundance. The small sample size in AL ($n$ = 12) and FL ($n$ = 12) compromised statistical power. More importantly, the high number of captures in AL combined with the low sample size introduced large amounts of variation into the study. Homogeneous variance is one of the main assumptions in ordinary regression models. If this assumption is violated the resulting errors are heteroscedastic (having heterogeneous variance). Although the regression may produce consistent parameter estimates, inferences from the standard errors are misleading. This was experienced in preliminary attempts to analyze data from all four sites together. Regression estimates produced for paths were not feasible and could not be interpreted in the context of this study. Residual variance was extremely high, and plots of the residuals showed distinct patterns. Numerous attempts at variable transformations did not improve this problem. When AL was removed from the analysis the overall residual variance was reduced by 61%. Extreme reductions in residual variance (>99%) were found for frogs, toads, and amphibians. The low sample size in FL was an issue because herpetofauna surveys were only conducted in block 1 and block 2. Bias due to the different sampling methods also resulted in the exclusion of FL from the analysis. Sampling techniques used to collect herpetofauna in FL were largely biased toward frogs and diurnal reptiles compared with the passive techniques that adequately sampled the herpetofauna community in AL, NC, and SC. These differences compromised comparison in preliminary tests, and FL was eventually removed from the analysis. NC and SC had adequate sample sizes and consistent sampling methods. They were appropriate for this analysis and their combined data into the path model produced meaningful results. The path analysis of NC and SC and visual inspection of mean abundance from AL and FL were used to determine trends from fuel reduction treatments on herpetofauna in the four FFS study sites.

Another issue taken into consideration was the role of adjacent amphibian breeding wetlands to treatment areas. This was a factor for all four study sites and compromised the interpretation of treatment effects. Stream or beaver pond proximity in SC was found to influence the capture of frogs, toads, and most salamanders more than did treatments. As a result, any correlation or prediction with amphibians with habitat variables in the regional analysis would be difficult to interpret. Proximity was included in preliminary path analyses but was not correlated with the amphibian data. This lack of correlation may have resulted from missing proximity data from block 2 in NC, which reduced the ability to correlate amphibian data with wetland proximity. In addition, amphibian variables were not significantly correlated with the variables chosen for the final path model. Evidence relating wetland proximity to amphibian captures is better suited for interpretation at the site level. Therefore, amphibian taxa were removed from the analysis.

Path models are most effective when the variable structure is parsimonious by using a small number of correlated predictor variables that have notable effects on each response variable. Using numerous variables that are highly correlated with each other complicates the analysis and masks the influence of predictors on response variables. One preliminary model for this analysis used standardized ($z$ score) constructs with all habitat variables or various combinations of variables, but this model was not parsimonious and did not provide meaningful path coefficients. Coefficients expressed as $z$ scores would not be readily applicable for management decisions. The unit of measure for an influential variable and the effect would be standardized with other variables in the construct.

The final hypothesized path model for NC and SC used forest floor depth, coarse woody debris volume, basal area of live trees, and native herb cover to predict herpetofauna response (Figure 1). These four habitat variables were logical choices because they are known to be important habitat components for herpetofauna (Lee 1974, Ash 1988; Hassinger 1989; Mitchell et al. 1997). In each model herpetofauna response refers to four herpetofauna response variables (lizards, snakes, turtles, and reptiles) selected for use in the path analysis.

The experimental units for this analysis were composed of site (FFS study site) and treatment. There were two levels for site (1 = NC and 2 = SC) and four levels for treatment (1 = burn [B], 2 = control [C], 3 = mechanical [M], and 4 = mechanical/burn [MB]). Response variables were screened for the assumptions of normality and homogeneity of variance using normal probability plots, Shapiro-Wilk W statistics (PROC UNIVARIATE), and kernel density plots (PROC GPLOT). PROC PLOT was used to assess the spread of residuals. The SPEC and INFLUENCE options in PROC REG were used to test for heteroscedasticity, calculate residual variance, and inspect residuals. Because of the response variable sample size ($N$ = 2/study site) and number of missing values for habitat variables, data were sorted so that correlation and regression procedures would detect each data point. Pearson correlation coefficients in PROC CORR were used to measure the strength and direction of the linear relationships between the chosen predictors and herpetofauna response variables (Table 1). The variables in the path diagram were chosen based on their significant correlation with herpetofauna response variables and each other. In path analysis, correlation produces a matrix that is the foundation for the regression equations in the path model.

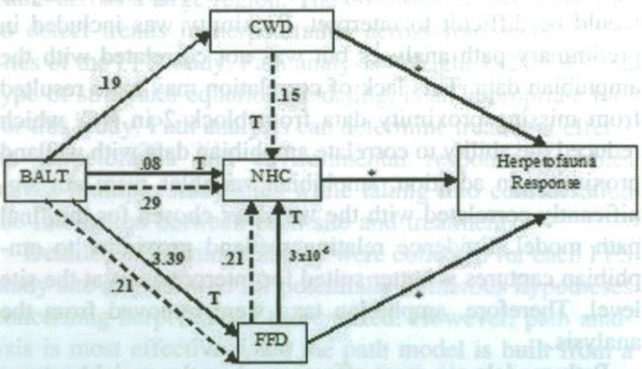


**Figure 1. Solved path diagram with environmental predictors for herpetofauna response to fuel reduction treatments on the NC and SC FFS study sites. Solid lines denote positive effects; dashed lines denote negative effects. Values for path coefficients are above the direction of the effect (the line). Paths with two coefficients represent a site interaction. The coefficient for NC is above (or right) of the line and the coefficient for SC is below (or left) of the line. Paths with a significant treatment interaction are indicated with a "T." CWD, course woody debris volume ($m^3$/ha); BALT, basal area of live trees ($m^2$/ha); FFD, forest floor depth (mm); NHC, native herb cover (%). *Effect of environmental variable on herpetofauna response.**

**Table 1. Pearson correlation coefficients and corresponding $P$ values for selected herpetofauna response variables and environmental predictors for the analysis of herpetofauna on the North Carolina and South Carolina Fire and Fire Surrogate study sites**

| Herpetofauna response | Environmental predictor FFD | CWD | BALT | NHC |
|---|---|---|---|---|
| Frogs/toads | −0.17242 | −0.0889 | −0.0864 | −0.1282 |
| $P$ | 0.2519 | 0.5569 | 0.5683 | 0.3960 |
| Salamanders | 0.0068 | −0.0195 | 0.1875 | −0.0349 |
| $P$ | 0.9641 | 0.8976 | 0.2122 | 0.8177 |
| Lizards | −0.3880 | −0.2884 | −0.4883 | 0.3714 |
| $P$ | 0.0077 | 0.0520 | 0.0006 | 0.0110 |
| Snakes | −0.3538 | −0.1458 | −0.2970 | 0.0929 |
| $P$ | 0.0159 | 0.3335 | 0.0450 | 0.5392 |
| Turtles | −0.3461 | −0.3205 | 0.0400 | 0.5703 |
| $P$ | 0.0185 | 0.0299 | 0.0058 | <0.0001 |
| Amphibians | −0.1508 | −0.0819 | −0.0429 | −0.1192 |
| $P$ | 0.3170 | 0.5887 | 0.7770 | 0.4301 |
| Reptiles | −0.4050 | −0.2665 | −0.4621 | 0.3191 |
| $P$ | 0.0052 | 0.0734 | 0.0012 | 0.0306 |
| Total herpetofauna | −0.3112 | −0.1878 | −0.2289 | 0.0127 |
| $P$ | 0.0353 | 0.2114 | 0.1260 | 0.9334 |
| FFD | 1.0000 | 0.2165 | 0.4447 | −0.3706 |
| $P$ | | 0.1394 | 0.0015 | 0.0095 |
| CWD | 0.2165 | 1.0000 | 0.2655 | −0.3050 |
| $P$ | 0.1394 | | 0.0682 | 0.0351 |
| BALT | 0.4447 | 0.2655 | 1.0000 | −0.3892 |
| $P$ | 0.0015 | 0.0682 | | 0.0063 |
| NHC | −0.3706 | −0.3050 | −0.3892 | 1.0000 |
| $P$ | 0.0095 | 0.0351 | 0.0063 | |

Data are Pearson correlation coefficients and $P$ values for significance of Pearson correlation coefficient. FFD, forest floor depth (mm); CWD, coarse woody debris ($m^3$/ha); BALT, basal area of live trees ($m^2$/ha); NHC, native herb cover (%).

PROC GLM was used to model an omnibus test for site and treatment path interactions. The model statements included site or treatment and a combination of site or treatment interaction terms with predictor and response variables. PROC REG was then used to obtain the interaction coefficients for NC and SC if a site interaction was detected. PROC REG was also used to obtain the interaction coefficients for B, C, M, and MB plots if a treatment interaction was detected (SAS Institute, Inc. 2002). Because of the small sample size, ordinary least-squares estimates were used instead of the maximum likelihood method of estimation. The regression coefficients and corresponding standard errors from site or treatment interactions were used to calculate a $t$ statistic from

$$t = \beta_1 - \frac{\beta_2}{\mathrm{SQRT}(\mathrm{SE}_1 + \mathrm{SE}_2)}$$

$$\text{with df} = N - 2 \quad \text{and} \quad \alpha = 0.05$$

where $\beta_1$ and $\beta_2$ are regression coefficients from a pair of site or treatment levels, $SE_1$ and $SE_2$ are standard errors from $\beta_1$ and $\beta_2$, and $N$ = (sample size from $\beta_1$ + sample size from $\beta_2$) − 2.

This formula tests the difference between two independent regression coefficients (Cohen et al. 2003) where the $t$ statistic is compared against the critical values of the *t* distribution in a two-tailed test. In this study, a significant *t* indicated that a path in the model was moderated by site or treatment. If a pair was significantly different, then the regression coefficients from their respective model level were indicated on the path of the interaction. Site interactions for a path determined the overall influence of a predictor across treatments. Treatment interaction coefficients for a particular path determined the influence of a predictor within treatments and were used to assess treatment differences in herpetofauna abundance. The sign and magnitude of a treatment interaction coefficient was used to describe how herpetofauna abundance differed across treatments.

Once the site and treatment interactions were interpreted, PROC REG was used to obtain the regression coefficients for paths that did not interact with site or treatment. If a model did not interact with site or treatment then the coefficients for the predictors could be taken directly from the full model. This path coefficient could be used to describe the prediction of a response across sites or treatments. After analysis was complete path coefficients were labeled on their respective paths in the path diagram models. Analysis of variance was also used to determine whether predictor and response variables were different across treatments and to aid in the interpretation of interactions (SAS Institute, Inc. 2002).

## Results

A total of 12,042 reptiles and amphibians was captured in 1,065 trap nights from Apr. 9, 2002, to Mar. 10, 2005, in AL, FL, NC, and SC combined. Frogs and toads were most abundant and made up 77% of total captures. Lizards (11%), snakes (5%), salamanders (4%), and turtles (3%) made up the remaining portion of captures. AL had the highest number of captures (9,061), followed by SC (1,023), NC (1,004), and FL (954) (Table 2). Southern toad (*Bufo terrestris* Bonnaterre), eastern narrow-mouthed toad (*Gastrophryne carolinensis* Holbrook), eastern spadefoot (*Scaphiopus holbrookii* Harlan), and green frog (*Rana clamitans* Latreille) comprised 82% of all captures in AL. The two most commonly captured species in SC were the fence lizard (*Sceloporus undulatus* Bosc and Daudin) and Fowler's toad (*Bufo fowleri* Hinckley). American toad (*Bufo americanus* Holbrook) and eastern newt (*Notophthalmus viridescens* Rafinesque) comprised 64% of captures in NC. FL captures were dominated by the gopher tortoise (*Gopherus polyphemus* Daudin) and squirrel treefrog (*Hyla squirella* Bosc).

Across sites, the MB plots had the highest number of captures (3,423), followed by B (3,237), C (2,772), and M (2,610) plots. In NC, lizard ($P = 0.0004$) and reptile ($P = 0.0013$) abundance was significantly higher in MB plots than in M, B, or C plots, and abundance in M plots was significantly higher than that in B plots (Table 3). Two lizard species, the five-lined skink (*Eumeces fasciatus* Linnaeus) and fence lizard, dominated reptile captures in NC. Snake abundance in NC was similar for each treatment. Lizard, snake, and reptile abundance was similar for each treatment in SC where the fence lizard and southeastern crowned snake (*Tantilla coronata* Baird and Girard) were the most commonly captured reptiles. The green anole (*Anolis carolinensis* Voigt), broadhead skink (*Eumeces laticeps* Schneider), and fence lizard were the most commonly captured lizard species in AL. Although significance tests were not conducted, lizard abundance in B and M plots was approximately 24% lower than that of C and MB plots in AL. The black racer (*Coluber constrictor* Linnaeus) comprised the majority of snake captures in AL and FL. Snake and reptile abundance in AL was lowest in B plots and similar between C, M, and MB plots. Lizard, snake, and reptile abundance in FL was similar for each treatment (Table 2).

**Table 2. Total herpetofauna captures for the Alabama, Florida, North Carolina, and South Carolina Fire and Fire Surrogate study sites**

| Study site | Treatment B | C | M | MB | Total |
|---|---|---|---|---|---|
| Alabama | | | | | |
| Frogs/toads | 2,020 | 1,935 | 1,707 | 2,209 | 7,871 |
| Salamanders | 42 | 46 | 66 | 56 | 210 |
| Lizards | 107 | 179 | 126 | 197 | 813 |
| Snakes | 48 | 89 | 128 | 95 | 481 |
| Turtles | 4 | 4 | 0 | 3 | 14 |
| Amphibians | 2,062 | 1,981 | 1,773 | 2,265 | 8,081 |
| Reptiles | 159 | 272 | 254 | 295 | 980 |
| Total | 2,221 | 2,253 | 2,027 | 2,560 | 9,061 |
| Florida | | | | | |
| Frogs/toads | 166 | 147 | 107 | 64 | 484 |
| Salamanders | 0 | 0 | 0 | 0 | 0 |
| Lizards | 50 | 30 | 28 | 35 | 143 |
| Snakes | 4 | 4 | 1 | 4 | 13 |
| Turtles | 108 | 48 | 37 | 121 | 314 |
| Amphibians | 166 | 147 | 107 | 64 | 484 |
| Reptiles | 162 | 82 | 66 | 160 | 470 |
| Total | 328 | 229 | 173 | 224 | 954 |
| North Carolina | | | | | |
| Frogs/toads | 313 | 52 | 48 | 261 | 674 |
| Salamanders | 94 | 33 | 48 | 28 | 203 |
| Lizards | 8 | 21 | 31 | 50 | 110 |
| Snakes | 7 | 2 | 3 | 5 | 17 |
| Turtles | 0 | 0 | 0 | 0 | 0 |
| Amphibians | 407 | 85 | 96 | 289 | 877 |
| Reptiles | 15 | 23 | 34 | 55 | 127 |
| Total | 422 | 108 | 130 | 344 | 1,004 |
| South Carolina | | | | | |
| Frogs/toads | 60 | 56 | 50 | 72 | 238 |
| Salamanders | 15 | 6 | 20 | 38 | 79 |
| Lizards | 138 | 72 | 159 | 144 | 513 |
| Snakes | 50 | 47 | 50 | 34 | 181 |
| Turtles | 3 | 1 | 1 | 7 | 12 |
| Amphibians | 75 | 62 | 70 | 110 | 317 |
| Reptiles | 191 | 120 | 210 | 185 | 706 |
| Total | 266 | 182 | 280 | 295 | 1,023 |
| Grand total | 3,237 | 2,772 | 2,610 | 3,423 | 12,042 |

The site omnibus test detected interactions between site and three predictor variables: basal area of live trees, forest floor depth, and native herb cover (Figure 1b). The path between basal area of live trees predicting forest floor depth was significant for site ($P = 0.0036$). The paths between basal area predicting native herb cover ($P = 0.0369$) and between forest floor depth predicting native herb cover were significant for site ($P < 0.0001$). For every unit increase in

**Table 3. Treatment effects on herpetofauna and habitat variables in the North Carolina and South Carolina Fire and Fire Surrogate study sites**

| Study site | Treatment B | C | M | MB | *P* |
|---|---|---|---|---|---|
| North Carolina | | | | | |
| BALT ($m^2$/ha) | 26.36 (1.29)a | 27.76 (1.07)a | 28.79 (0.98)a | 21.00 (1.67)b | 0.0001 |
| FFD (mm) | 45.43 (1.70)c | 92.77 (2.22)b | 99.66 (2.33)a | 34.16 (1.75)d | <0.0001 |
| NHC (%) | 2.59 (0.48) | 4.44 (1.15) | 2.20 (0.55) | 2.74 (0.44) | 0.0913 |
| CWD ($m^3$/ha) | 10.24 (2.63) | 8.88 (1.73) | 12.49 (3.21) | 11.13 (2.00) | 0.7665 |
| Lizard | 1.33 (0.49)c | 3.50 (1.18)bc | 5.17 (0.87)b | 8.33 (0.99)a | 0.0004 |
| Snake | 1.17 (0.60) | 0.33 (0.21) | 0.50 (0.22) | 0.83 (0.31) | 0.4057 |
| Turtle | — | — | — | — | — |
| Reptile | 2.50 (0.76)c | 3.83 (1.19)bc | 5.67 (0.80)b | 9.17 (1.25)a | 0.0013 |
| South Carolina | | | | | |
| BALT ($m^2$/ha) | 13.02 (1.81) | 17.67 (2.18) | 17.32 (1.50) | 17.44 (1.25) | 0.1077 |
| FFD (mm) | 38.21 (1.66)c | 59.04 (1.88)a | 49.78 (1.95)b | 29.69 (1.25)d | <0.0001 |
| NHC (%) | 8.47 (1.21)a | 1.21 (0.19)b | 3.00 (0.63)b | 10.89 (1.30)a | <0.0001 |
| CWD ($m^3$/ha) | 8.37 (1.38) | 6.08 (0.94) | 8.74 (1.89) | 4.26 (0.85) | 0.0557 |
| Lizard | 23.00 (5.82) | 18.00 (5.20) | 26.50 (5.43) | 24.00 (3.90) | 0.5952 |
| Snake | 8.33 (2.55) | 11.75 (2.98) | 8.33 (2.81) | 5.67 (1.05) | 0.5946 |
| Turtle | 0.50 (0.34) | 0.25 (0.25) | 0.17 (0.17) | 1.17 (0.40) | 0.1099 |
| Reptile | 31.83 (7.79) | 30.00 (8.04) | 35.00 (7.76) | 30.83 (4.22) | 0.8637 |

The treatment mean is followed by the SD in parentheses. For $P \leq 0.05$, means were separated with the least-squares means procedure; those means followed by the same letter within rows are not significantly different. FFD, forest floor depth; CWD, coarse woody debris; BALT, basal area of live trees; NHC, native herb cover.

basal area in NC, forest floor depth and native herb cover increased by 3.39 mm and 0.08%, respectively (Figure 1B). For every unit increase in basal area in SC, forest floor depth and native herb cover decreased by 0.2 mm and 0.29%, respectively. When forest floor depth increased in NC, there was a marginal increase in native herb cover. However, for every unit increase in forest floor depth in SC, native herb cover decreased by 0.21%. Coarse woody debris volume predicting native herb cover was consistent across sites. Native herb cover decreased by 0.15% for every unit increase in coarse woody debris volume (Figure 1B). Basal area of live trees was consistent across each site and treatment for predicting coarse woody debris volume. Coarse woody debris volume increased by 0.19 $m^3$/ha for every unit increase in basal area.

The treatment omnibus test detected interactions between treatment and three predictor variables: basal area of live trees, forest floor depth, and native herb cover. The path between basal area predicting forest floor depth was significant for treatment ($P = 0.0002$), and the path between native herb cover predicting coarse woody debris volume ($P = 0.0464$), basal area of live trees ($P = 0.0005$), and forest floor depth ($P = 0.0168$) was significant for treatment. For each unit increase in basal area, forest floor depth increased in B, C, and M plots but decreased in MB plots (Figure 1B). The increase in forest floor depth was larger in M plots than in B, C, and MB plots. For each unit increase in coarse woody debris volume, native herb cover decreased in C, M, and MB plots but increased in B plots. The increase in native herb cover in B plots was significantly different from the decrease in native herb cover in C, M, and MB plots. For each unit increase in basal area of live trees, native herb cover decreased in B, M, and MB plots but increased in C plots. The increase in native herb cover in C plots was significantly different from the decrease in native herb cover in B and MB plots. For each unit increase in forest floor depth, native herb cover increased in B, C, and M plots but decreased in MB plots. The increase in native herb cover for C and M plots was significantly different from the decrease in native herb cover in MB plots (Figure 1B).

Treatment interactions were detected between two herpetofauna response variables (lizard and reptile abundance) and two predictor variables (native herb cover and forest floor depth). Lizard and reptile abundance was significant for treatment with $P = 0.0267$ and $P = 0.0323$, in that order. Coarse woody debris volume and forest floor depth predicting lizard and reptile abundance were consistent across site and treatment. Lizard and reptile abundance decreased with each unit increase in coarse woody debris volume and forest floor depth (Figure 2).

Coarse woody debris volume and forest floor depth predicting snake and turtle abundance were consistent across site and treatment (Figure 2). Snake and turtle abundance decreased for each unit increase in coarse woody debris volume and forest floor depth. Native herb cover predicting snake and turtle abundance was consistent across site and treatment. Snake abundance decreased, but turtle abundance increased for each unit increase in native herb cover.

# Discussion

## *Habitat Variables*

Forest floor depth decreased in SC but increased in NC as basal area of live trees increased. This was probably due to the removal of forest floor material by the burn but retention of high levels of basal area in MB plots in SC. MB and B plots in NC had the lowest basal areas and lowest values for forest floor depth. C and M plots had the highest basal area and highest forest floor depths. When forest floor

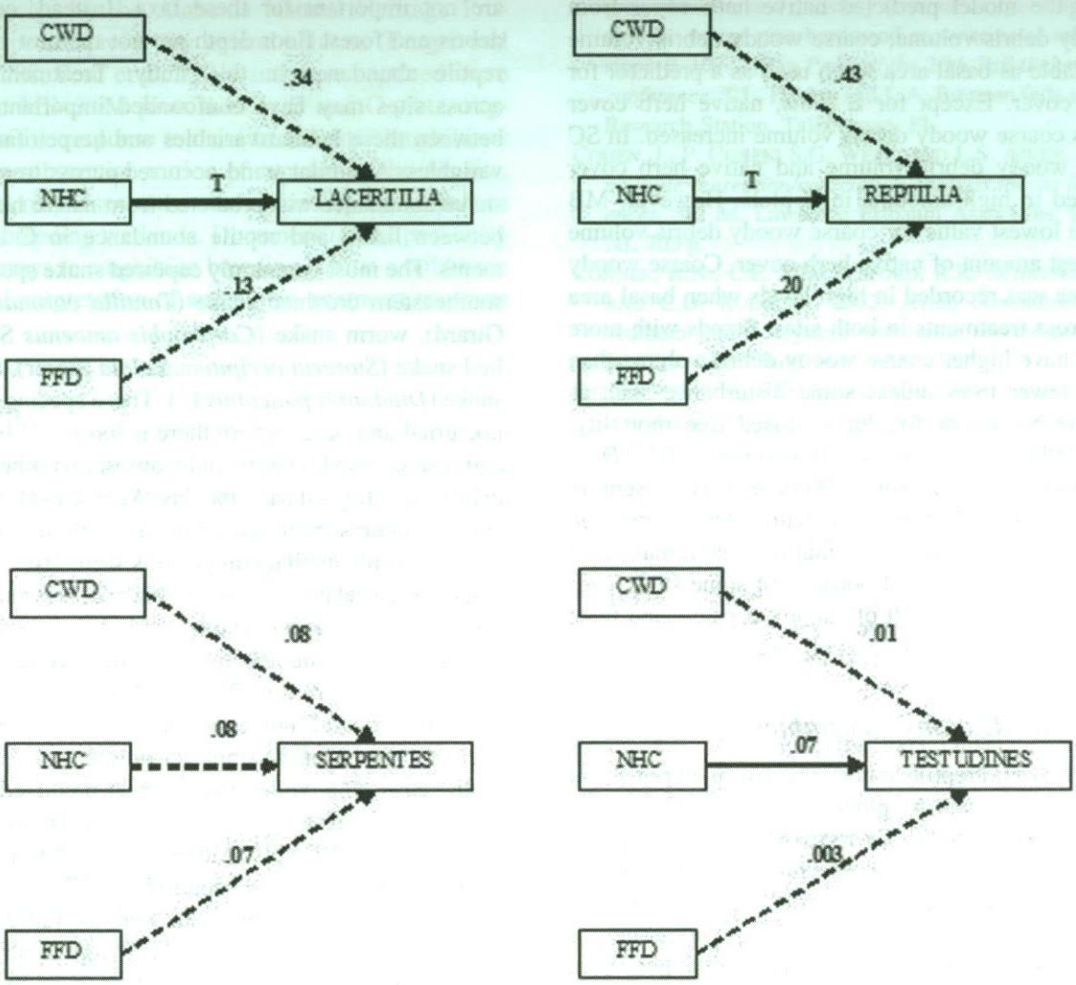


**Figure 2. Path diagrams for herpetofauna response variables. Solid lines denote positive effects; dashed lines denote negative effects. Values for path coefficients are above the direction of the effect (the line). Paths with a significant treatment interaction are indicated with a "T." Lacertilia, lizards; Serpentes, snakes; Testudines, turtles; Reptilia, reptiles; CWD, coarse woody debris volume ($m^3$/ha); BALT, basal area of live trees ($m^2$/ha); FFD, forest floor depth (mm); NHC, native herb cover (%).**

depth was predicted from basal area, the trend in NC was positive. In contrast, MB plots had the highest basal area, but lowest forest floor depth in SC. B plots had the lowest basal area and forest floor depth. MB plots influenced the overall negative trend predicting forest floor depth from basal area of live trees in SC by having high basal area but low forest floor depth. The total variance explained in the model predicting forest floor depth from basal area in SC was very low ($R^2 = 0.01$). Regression models including 1-h fuel, 10-h fuel, or tree density variables might better describe the relationship in C and MB plots.

Opposite trends between sites were also observed for the path predicting native herb cover from basal area. The highest values for native herb cover in SC were in B and MB plots and the lowest were in M and C plots. Although basal area of live trees was high in MB plots, it was lowest in B plots. C and M plots also had high values for basal area. This results in an overall negative trend when basal area is used to predict native herb cover. In contrast, NC had a net positive trend when native herb cover was predicted from basal area. Herbaceous cover in NC may not have fully responded to the treatments because prescribed burning was conducted in spring 2003 and vegetation was sampled the following summer. Basal area predicting native herb cover was more completely defined by treatments than by site. Native herb cover was highest in B and MB plots where basal area was lowest overall. The positive relationship between native herb cover and basal area in C plots may have been influenced more by the sampling time than treatment. C plots in SC had the expected trend of high basal area and low native herb cover.

Forest floor depth was a better predictor for native herb cover than basal area and followed an expected trend in SC. Forest floor depth was expected to be lowest in B and MB plots, whereas native herb cover was expected to be highest in B and MB plots. The lowest forest floor depths in NC were also recorded in B and MB plots, but native herb cover remained about the same in all plots except for M. The positive trend for forest floor depth predicting native herb cover was only marginal ($R^2 = 0.19$) in NC. Native herb cover in B, C, and M plots increased at a similar rate as forest floor depth increased. In contrast, native herb cover decreased in MB plots as forest floor depth increased. This may have resulted from the different mechanical treatment so the herbaceous response was more detectable in SC than NC.

Although the model predicted native herb cover from coarse woody debris volume, coarse woody debris volume is not as reliable as basal area when used as a predictor for native herb cover. Except for B plots, native herb cover decreased as coarse woody debris volume increased. In SC both coarse woody debris volume and native herb cover were recorded in high amounts in B plots. However, MB plots had the lowest value for coarse woody debris volume but the highest amount of native herb cover. Coarse woody debris volume was recorded in high levels when basal area was high across treatments in both sites. Stands with more trees should have higher coarse woody debris volume than stands with fewer trees unless some disturbance such as southern pine beetles or fire have caused tree mortality. During the 2000 growing season, southern pine beetle (*Dendroctonus frontalis* Zimmerman) damage was present in various levels across SC plots. Plots with extensive damage were replaced, but plots with minimal damage remained in the study. From 2002 to 2004 portions of some study sites became more open as a result of canopy gaps created from southern pine beetle damage in 2000 and 2001.

## *Herpetofauna Response Variables*

Lizard and overall reptile abundance was higher in B and MB plots than in C and M plots in NC and SC. Similar trends have been reported in Georgia (Moseley et al. 2003) and Florida (Mushinsky 1985). Mechanical treatment followed by burning removed a portion of the overstory and resulted in an increase in temperature and exposure of sunlight to forest floor materials. Reptiles use the heat from sunlight for thermoregulation and obtain this energy by basking (Zug 1993). Thinning also provides habitat for ground dwelling and arboreal lizards. The most commonly captured lizard species in SC plots were the fence lizard, green anole, and five-lined skink. Similarly, the green anole, broadhead skink, and fence lizard dominated lizard captures in AL, whereas the five-lined skink and fence lizard were most abundant in NC plots. The fence lizard, green anole, and skink species seem to benefit from conditions created by overstory removal. It is likely that these species were more abundant because of increased activity within the study site due to faster attainment of active temperatures (Phelps and Lancia 1995, Perison et al. 1997). Warm areas often attract reptiles and the acquired energy can lead to longer activity periods and increased performance (Grant and Dunham 1988, Zug 1993). Green anoles and fence lizards are often associated with disturbed areas with abundant sunlight (Martof et al. 1980). The five-lined skink and broadhead skink characteristically occur in mesic areas (Gibbons and Semlitsch 1991), and it appears that these species used B and MB plots for thermoregulation as did the green anole and fence lizard. The less open canopy condition of C and M plots does not allow much light to reach the forest floor, resulting in a lower number of attractive basking sites for lizards.

Increasing coarse woody debris volume and forest floor depth were correlated to decreases in lizard, snake, turtle, and reptile abundance across all treatments. These results do not imply that coarse woody debris and forest floor material are not important for these taxa. Instead, coarse woody debris and forest floor depth are not the best predictors for reptile abundance in this study. Treatment differences across sites may have confounded important correlations between these habitat variables and herpetofauna response variables. A similar trend occurred across treatments when snake abundance was predicted from native herb cover and between lizard and reptile abundance in C and M treatments. The most commonly captured snake species were the southeastern crowned snake (*Tantilla coronata* Baird and Girard), worm snake (*Carphophis amoenus* Say), red-bellied snake (*Storeria occipitomaculata* Storer), and ringneck snake (*Diadophis punctatus* L.). These species are primarily nocturnal and occur where there is loose soil for borrowing and coarse woody debris, old stumps, and other forest floor debris for refugia during the day (Martof et al. 1980). Fewer snake captures occurred in areas with more herb cover where suitable habitat components were less abundant. The negative correlation between herb cover and lizard and reptile abundance in C and M could have resulted from the shading of basking locations by herbaceous growth. Although this occurred in B and MB, the open canopy condition still provided numerous basking locations where herbaceous vegetation was not yet present.

Increasing native herb cover best predicted turtle abundance across treatments and lizard and reptile abundance within B and MB plots. Although more box turtles (*Terrapene carolina* L.) were captured in MB plots, the sample size was low in SC, and there were no turtles captured in NC. Native herb cover, lizard, and reptile abundance was highest in B and MB plots, and each of these variables responded positively to B and MB treatments. Burning and thinning southern pine forests usually lowers the basal area and increases the amount of herbaceous cover in the understory. The increase in native herb cover in B, M, and MB plots with decreasing basal area is the expected trend. Many southern forests that are burned and thinned develop dense understory herbaceous plant communities over time (Wilson et al. 1995, Conner et al. 2002, Wood et al. 2004). Herbaceous understory species respond positively to the increase in light and reduction in basal area. Prey items may have been in higher abundance in B and MB plots, which could have increased the foraging activity and capture of insectivorous reptiles.

Coastal plain longleaf pine ecosystems are known to support a number of herpetofauna species in need of conservation (Dodd 1997). The gopher tortoise, a species with state and federal conservation status (US Fish and Wildlife Service 1990), comprised a majority of captures in the FL site, but represented only one capture in the AL site. Gopher tortoises occur locally in the southeastern coastal plain and require open upland habitats with deep sandy soil (Auffenberg and Franz 1982) where they feed on a variety of herbaceous understory plants (Mushinsky et al. 2003). The gopher tortoise is considered to be a keystone species (Eisenberg 1983) and an indicator of habitat condition for a number of fire-adapted species. The coachwhip (*Masticophis flagellum* Shaw) and pine snake (*Pituophis melanoleucus* Daudin) were captured in the AL site and are listed as protected species by the Alabama Natural Heritage Program. Both species prefer dry upland habitats (Burger and Zappalorti 1988, Ford et al. 1991) and were captured more frequently in MB or M plots than in B and C plots, suggesting a positive response to these treatments. Amphibians represented a substantial portion of captures in the AL site, but treatment responses were confounded by the influence of proximal breeding wetlands. Documenting the proximity of existing arrays to amphibian breeding habitat would have aided in the interpretation of amphibian treatment response in this site.

## Conclusion

Fuel reduction treatments had a direct effect on basal area of live trees, forest floor depth, native herb cover, and coarse woody debris volume in two southeastern FFS study sites. Native herb cover was found to be the best predictor of lizard and reptile abundance in the NC and SC FFS study sites. Mechanical fuel reduction followed by prescribed burning resulted in a positive response from the reptile community in the NC and SC sites. It is likely that these treatments have a similar influence on reptiles in the AL and FL sites. Both coastal plain sites support pine communities that are adapted to frequent fire, and it is well documented that understory vegetation responds positively to prescribed fire in these ecosystems (Lucas 1993, Burger et al. 1998).

In future studies, consistent sampling techniques, consistent sampling effort, and attention to plot location are essential if a regional assessment of fuel reduction treatments on herpetofauna is to be accurately done. Trends could exist across the four southeastern sites, but it may be more efficient to assess the effects of fuel reduction on herpetofauna at each site using a long-term study. It is evident that vegetation and fuels change in response to prescribed burning and thinning. Other natural disturbances such as southern pine beetle can also influence basal area, coarse woody debris volume, and fuel loading. Fire suppression is contradictory to the frequent disturbance that historically occurred in many southeastern ecosystems (Nelson 1957, Frost 1996, Pyne et al. 1996, Johnson and Hale 2000). Fuel reduction treatments should continue to be implemented to restore these ecosystems and continue to improve habitat for fire-adapted species.

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