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# Forest Overstory–Understory Relationships in Alabama Forests

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ABSTRACT

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This study developed regional overstory-understory models for four forest types in southeastern Alabama and tested the ability of these models to predict understory vegetation using overstory data from southern and southwestern Alabama. Cross-sectional data from the USDA Forest Service Forest Inventory and Analysis Unit Multiresource Survey of Alabama was used to analyze the relationship between timber stand characteristics and herbaceous cover under planted pine, natural pine, mixed pine-hardwoods, and upland hardwoods. Herbaceous cover was significantly related to total growing stock volume of timber in all forest types. Stand characteristics and management activities that affected herbaceous cover varied by forest type. The models for planted pine, mixed pine-hardwoods, and upland hardwoods captured a significant amount of the variation in the original data. Extrapolation of southeastern Alabama overstory-understory relationships to southern and southwestern forests was not possible with these models.

## INTRODUCTION

Timber management activities and changing land use affect the quality and quantity of land available for forage production (Grelen, 1978). Regional timber models, such as the Timber Resource Inventory Model, TRIM, (Tedder, 1983), project the changes in timber volume as well as changes in forestland acres resulting from timber management. To assess the impact of timber management on the future supply of grazing in the South, the overstory–understory relationships in southern forests must be quantified and linked to timber projection models.

Herbaceous production decreases in a linear or nonlinear manner as timber volume or canopy cover increases. Previous overstory–understory models have been site-specific and have not included the effect of timber management (e.g., Gaines et al., 1954; Pearson and Whitaker, 1974; Wolters and Schmidtling, 1975; Meyers, 1977; Grelen and Lohrey, 1978; Clary, 1979; Wolters, 1982; Wolters et al., 1982). The ability of these models to predict understory vegetation for other similar areas has not been examined. The development of regional overstory–understory models has been hampered by lack of an adequate data base. Regional characteristics of timber have been periodically inventoried by USDA Forest Service (FS) Forest Inventory and Analysis (FIA) units across the United States, and these data have been used to develop regional timber growth and yield models (Tedder, 1983). The recent institution by the FIA of multiresource inventories, in which timber and other resources are measured at the same place and time (O'Brien and Van Hooser, 1983; McClure et al., 1979) provides the opportunity to analyze regional overstory and understory characteristics in southern forests and to test the ability of these models to predict understory characteristics in similar nearby regions.

The first objective of this study was to develop overstory–understory models for one multi-county region in southern Alabama using environmental and timber management variables. One model would be developed for each of four forest types: planted pine, natural pine, mixed pine-hardwoods, upland hardwoods. The analysis would include independent variables such as timber site class and stocking level and additional variables needed to link to the regional timber model, TRIM. The dependent variable would be herbaceous cover, an understory variable measured in the FIA inventory.

The second objective of this study was to test the ability of these overstory–understory models to predict understory dynamics in two nearby multi-county regions in southern Alabama. Most statistical models are not verified because of a limited number of data points available to build and test the model. The regional multiresource inventory provides the opportunity to test the overstory–understory model in nearby regions.

## METHODS

Data from even-aged plots within three survey units of the Alabama Multiresource Survey were used:

| Unit | Region (counties included) |
|---|---|
| 1 | Southwest-South Alabama (Baldwin, Covington, Escambia, Mobile, Washington) |
| 2 | Southwest-North Alabama (Choctaw, Clarke, Conecuh, Marengo, Monroe, Sumter, Wilcox) |
| 3 | Southeast Alabama (Autauga, Barbour Bullock, Butler, Chambers, Chilton, Coffee, Crenshaw, Dale, Dallas, Elmore, Geneva, Henry, Houston, Lee, Lowndes, Macon, Montgomery, Pike, Russell, Tallapoosa) |

Data from Unit 3, the largest unit, were used to build the models and data from Units 1 and 2 were used to test the models. Class data for forest type, stocking level, site index, burning history and harvesting were aggregated into management variables based on the mid-South adaptation of TRIM (Table 1). Only a small number of plots were available in the low stocking level and in the low site class categories; to reduce the complications of missing cells in the analysis, only high- and medium-level plots were included in the analysis. Browse cover, that part of leaf and twig growth of shrubs, woody vines and trees available for animal consumption, was included in this analysis. Herbage cover included the cover of forbs, grasses and grasslikes. The FIA inventoried timber harvest activities by recording one of ten harvest activities, including no evidence of harvesting (Quick, 1981). The frequency of each type of timber harvest activity varied widely across forest types; some activities were recorded on less than 1% of the total plots and others, such as clearcuts, on more than 30%. This variability resulted in an insufficient number of plots for examining the effects of specific harvesting techniques on herbaceous cover. In loblolly pine-hardwoods, Schuster (1967) reported significant differences in herbaceous production between harvested (selection, shelterwood, clearcut) and an uncut site. Therefore, for this analysis, plots were grouped into two categories of harvesting: (1) no harvesting, and (2) harvesting activities noted. While thinning activities also impact the forest overstory, there were an insufficient number of thinned plots available for this analysis.

The dependent variables, herbaceous cover and the logarithm of herbaceous cover, were tested for normality within the categories of site class, stocking level, burning history and harvesting. Variables which violate the normality assumptions of regression analysis are often transformed using logarithms to stabilize the variances (Snedecor and Cochran, 1967).

Analysis of variance was used as a screening tool to determine the significant factors associated with varying herbaceous cover in Unit 3 (Table 1). A regression model was developed using these factors as independent variables. In using inventory data, neither the sample frequency nor the sample design are controlled for use in any subsequent analysis. This poses problems of uneven cell frequencies and of missing cells. These problems were minimized using Type III and Type IV partial sums of squares of the general linear model of SAS (Freund and Liddle, 1981; SAS Institute, 1982). Overstory data from Units 1 and 2 was used to test the model's ability to predict herbaceous cover within nearby geographic regions.

## RESULTS AND DISCUSSION

Herbaceous cover was not normally distributed within the categories of site class, stocking level, burn history, and harvesting activity. Thus, the logarithm

TABLE 1

Forest stand variables used in model development

| Factor | Level | Definition |
|---|---|---|
| Forest type | Planted pine<br>Natural pine<br>Mixed pine-hardwoods<br>Upland hardwood | |
| Stocking level | High<br>Medium | Greater than 100% stocked<br>Between 50 and 99% stocked |
| Site index | High<br>Medium | Site index > 3.5 $m^3$/ha<br>Site index 3.5–6 $m^3$/ha |
| Burning history | None<br>Recent<br>Old | No evidence of burning<br>Burn within the last 3 years<br>Burn older than 3 years |
| Harvesting | None<br>Present | No evidence of harvesting<br>Evidence of harvesting |
| Timber volume | | Total growing stock volume |
| Browse cover | | Percent cover of shrubs |

of herbaceous cover was used as the dependent variable in all models. Models developed on a transformed scale, such as the log–linear model, suffer from a retransformation bias (Duan, 1983). In the case of the log–linear model, model predictions when retransformed underestimate the expected value. The naive adjustment as discussed by Duan (1983) was used to correct this bias in the models developed here. The adjusted prediction is:

$$z_i = \exp(\hat{y}_i + \mathrm{ADJ})$$

where $z_i$ is the adjusted $i$th prediction, $\hat{y}_i$ is the $i$th estimate from the model, and:

$$\mathrm{ADJ} = \frac{(y_i - \hat{y}_i)^2}{N} \qquad \text{for } i = 1, 2, ...., N$$

where $y_i$ is the $i$th observation and $N$ is the total number of observations. For a log–linear model, the retransformation function is the exponential function (exp above).

*Planted pine forest type*

Harvest activity, the harvest-burn interaction, and growing stock volume, were significantly ($P < 0.001$) associated with the response of herbaceous cover

TABLE 2

Overstory-understory models of four forest types in Alabama

| Forest Type | Model | $R^2$ |
|---|---|---|
| Planted pine | LN(HC) = 4.58 − 0.00005*VOL − 0.899*HN − 1.83*BH − 1.205*B1*HN | 0.39 |
| Natural pine | LN(HC) = 3.26 − 0.00003*VOL − 0.657*FOR − 0.53*S1 | 0.29 |
| Mixed pine-hardwoods | LN(HC) = 3.234 − 0.00008*VOL − 1.012*HN | 0.57 |
| Upland hardwoods | LN(HC) = 2.701 − 0.00007*VOL − 0.024*BC − 0.86*S1 + 0.64*B1 + 1.61*B2 | 0.54 |

[1]Model parameter definitions

| | |
|---|---|
| LN(HC) | = natural logarithm of herbaceous cover |
| VOL | = Total growing stock volume ($m^3$/ha) |
| HN | = 1 if site had not been harvested; 0 if otherwise |
| HA | = 1 if site was harvested; 0 if otherwise |
| B1 | = 1 if no burning on site; 0 if otherwise |
| B2 | = 1 if burned within the last 3 years; 0 if otherwise |
| BH | = 1 if site not burned and harvested or if site burned less than 3 years ago and not harvested or if site burned more than 3 years ago; 0 otherwise |
| S1 | = 1 if site class was high; 0 if medium |
| FOR | = 1 if type was loblolly pine: 0 if shortleaf pine |
| BC | = Browse cover (%). |

under planted pine (Table 2). Previous research indicated the positive effect of prescribed burning on the herbaceous biomass (Thill and Wolters, 1979). In this study, the response of herbaceous cover to harvest activity differed on burned and unburned plots. On unburned plots, herbaceous cover was not significantly different between harvested and unharvested plots. On plots with evidence of burning, herbaceous cover was significantly greater on plots with harvest activity. This resulted in two nonsignificant coefficients of the four coefficients in the burn-harvest interaction. Thus, the final model was developed with only two dummy variables for the burn history-harvest interaction (Table 2). The standard error of the estimate (SEE) was less than the standard deviation (SD) of the logarithm of herbaceous cover data, suggesting the model captured some of the variability of herbaceous cover (Table 3). When the predicted estimates were transformed back to percent herbaceous cover, the model underestimated herbaceous cover. The average of all transformed predictions was less than 70% of the actual untransformed values. Using the naive estimate, the adjusted prediction was within 5% of the actual average (Table 3).

When tested in Units 1 and 2, the model overestimated the logarithm of herbaceous cover and the adjustment factor further skewed the prediction (Table 3). The lack of fit for Unit 1 was related to the distribution of forest type and volume across the plots in Unit 3 versus Unit 1. In Unit 2 and 3, most of the plots were dominated by loblolly pine, whereas in Unit 1, most of the

TABLE 3

Comparison of actual estimates, predicted estimates, and adjusted estimates of herbaceous cover (percent) with Unit 3 regression model and test cases, Unit 1 and Unit 2, Alabama

| Forest type Unit | Logarithm of Herbaceous Cover | | | | | Herbaceous Cover | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Actual | | Model Prediction | | | Actual | | Retransformed Prediction | | | Adjusted Retransformed Prediction | | | |
| | $\bar{y}$ | SD | $\bar{y}$ | SEE | $r$ | $\hat{y}$ | SD | $\hat{y}$ | SEE | $r$ | ADJ | $\bar{z}$ | SEE | $N$ |
| Planted pine | | | | | | | | | | | | | | |
| Unit 3 | 1.79 | 1.26 | 1.77 | 1.00 | 0.62 | 11.88 | 17.3 | 7.58 | 16.1 | 0.41 | 0.50 | 12.5 | 15.5 | 72 |
| Unit 1 | 1.53 | 1.15 | 2.13 | 1.38 | 0.20 | 8.15 | 12.7 | 13.06 | 23.7 | 0.01 | 0.50 | 21.5 | 37.1 | 41 |
| Unit 2 | 1.39 | 1.15 | 2.02 | 1.19 | 0.51 | 8.33 | 16.6 | 10.95 | 19.9 | 0.17 | 0.50 | 18.1 | 27.8 | 45 |
| Natural pine | | | | | | | | | | | | | | |
| Unit 3 | 1.85 | 1.23 | 1.85 | 1.06 | 0.27 | 12.27 | 16.6 | 7.95 | 14.9 | 0.36 | 0.53 | 13.5 | 14.0 | 60 |
| Unit 1 | 1.31 | 1.15 | 1.71 | 0.90 | 0.78 | 2.60 | 2.9 | 5.68 | 3.4 | 0.88 | 0.53 | 9.6 | 7.1 | 5 |
| Unit 2 | 1.31 | 0.79 | 1.16 | 0.80 | 0.32 | 4.31 | 6.8 | 4.31 | 5.1 | 0.72 | 0.53 | 7.7 | 5.7 | 16 |
| Mixed pine-hardwoods | | | | | | | | | | | | | | |
| Unit 3 | 2.28 | 1.19 | 2.26 | 0.81 | 0.75 | 16.53 | 19.0 | 13.65 | 15.5 | 0.58 | 0.40 | 20.4 | 16.0 | 32 |
| Unit 1 | 1.47 | 1.23 | 2.04 | 1.33 | 0.37 | 7.70 | 10.3 | 10.65 | 11.9 | 0.21 | 0.40 | 15.9 | 16.1 | 27 |
| Unit 2 | 1.97 | 1.27 | 2.65 | 1.37 | 0.36 | 13.46 | 16.2 | 17.2 | 16.2 | 0.29 | 0.40 | 25.7 | 21.1 | 26 |
| Upland hardwoods | | | | | | | | | | | | | | |
| Unit 3 | 2.11 | 1.30 | 2.11 | 0.95 | 0.73 | 16.69 | 23.2 | 13.00 | 20.7 | 0.48 | 0.47 | 19.2 | 22.7 | 39 |
| Unit 1 | 1.75 | 0.97 | 2.52 | 1.43 | 0.12 | 7.64 | 8.1 | 18.00 | 20.9 | 0.00 | 0.47 | 28.7 | 34.5 | 14 |
| Unit 2 | 1.69 | 1.33 | 1.92 | 1.29 | 0.29 | 11.82 | 18.0 | 8.43 | 17.1 | 0.28 | 0.47 | 15.5 | 17.3 | 17 |

$\bar{y}$ = mean of variable, $\hat{y}$ = mean of model predictions, SD = standard deviation of variable, SEE = standard error of the estimate, ADJ = value of adjustment factor

ADJ $= \frac{(y_i - \hat{y}_i)^2}{n}$ for $i = 1, 2, \ldots, N$ where $y_i$ = $i$th observation and $\hat{y}_i$ = ith estimate for model $N$ = total number of observations, $r$ = correlation coefficient, $z$ = mean of adjusted model predictions.

plots were dominated by slash pine. Total growing stock volume ranged from 0.6 to 224 $m^3$/ha in Unit 3 and from 0 to 105 $m^3$/ha in Unit 1. Timber stands were generally younger, and no plots with volumes greater than 42 $m^3$/ha had yet been harvested. Rapid crown closure, common to slash pine sites (Wolters, 1973), may be affecting these results.

Overestimation of herbaceous cover in the log model for Units 1 and 2 suggests a different overstory–understory relationship than that developed for Unit 3, and extrapolation of the southeastern model to the southwestern parts of Alabama would not be feasible. Within the southeastern portion of Alabama, the model for understory cover on planted pine sites would provide predictions with large estimation errors.

*Natural pine forest type*

In natural pine, harvest activity occurred on only 20% of the plots and included single tree selection, group selection, and diameter-limit harvesting activities only. No clearcuts were recorded for natural pine in Unit 3. Even with the aggregation of harvest activity into two categories, the small number of observations representing the response of harvesting with the other factors precluded analyzing the impact of harvesting on herbaceous cover. Preliminary analyses indicated that forest type within natural pine – loblolly and shortleaf pine – was a significant factor.

Forest type, site class, and total growing stock volume were found to vary significantly ($P < 0.001$) with herbaceous cover (Table 2). The retransformed average of all predictions from logarithm model for natural pine underestimated the actual average of herbaceous cover by 40% (Table 3). When the naive adjustment was used, the prediction was within 10% of the expected value of herbaceous cover (Table 3).

When the model was tested using data from Units 1 and 2, the model performed poorly in both cases (Table 3). While the model reduced some of the variation associated with herbaceous cover in Unit 1, the prediction was larger than the actual value. In Unit 2, the model underestimated herbaceous cover and did not reduce the variability of the estimate. In Unit 3, all natural pine plots consisted entirely of the loblolly-shortleaf pine type. In Unit 1, there were only five loblolly-shortleaf pine plots and these were mainly in the high site classes. In Unit 2, the poor fit for the 16 loblolly-shortleaf plots reflects the small amount of variation of variation captured by the original model as measured by the low correlation coefficient (Table 2).

The original design factors were focused on the commercial aspect of timber (Table 1). One criteria for the selection of plots for this study was even-aged plots. Natural pine types tend to mixed-aged plots. Factors associated with the development of even-aged plots in the natural pine type may be artificial.

Gaines et al. (1954) reported that much of the variation in herbage production under longleaf pine could be related to the distribution of trees in a stand; that is, whether trees were clumped or evenly distributed. The poor prediction in natural pine in contrast to the highly significant model for planted pine could reflect increased variability associated with differences in the spatial patterns of trees on natural pine sites.

Overstory–understory relationships reported in the literature for loblolly-shortleaf sites focus on loblolly-shortleaf pine-hardwood sites. While hardwoods are present on the plots analyzed here, hardwood stocking was always less than 25%. Average values for herbaceous cover on these natural pine sites were similar to herbaceous cover averages on planted pine sites (Table 3). Halls and Schuster (1965) reported significant relationships for herbaceous production as a function of tree cover or basal area. The amount of variation explained was greater when tree cover was used (71%) than when basal area was used as the independent variable (46%). Total growing stock volume was the variable used in this analysis to capture the continuous changes in the forest stand. The relationship between this estimate of merchantable volume and total tree volume may be weaker in the natural pine type than in planted pine where management is directed towards maximizing the commercial yield. Within the southeastern area of Alabama, additional variables need to be explored to adequately predict herbaceous cover under the natural pine type; the poor fit here limits the utility of this model for this area and other areas.

*Mixed pine-hardwood forest type*

Total growing stock volume and harvest activity were significantly ($P<0.0001$) associated with the response of herbaceous cover (Table 2). Transforming the estimates back to percent herbaceous cover provided the expected underestimate of actual herbaceous cover; however, using the adjustment factor overcorrected the underestimate (Table 3).

The model performed poorly in predicting herbaceous cover for Units 1 and 2 (Table 3). While the distribution of volume was similar for mixed pine-hardwood across the three units, the effects of management activities differed at lower levels of volume between Units 2 and 3. In Unit 3, if the site showed no signs of harvesting or any other management activity such as thinning, total growing stock volume averaged 51 m$^3$/ha. This contrasted with an average volume of 15 m$^3$/ha on similar plots in Unit 2. The low volume in Unit 2 was the result of several plots with a merchantable volume of zero. These low volume plots in Unit 2 averaged only 12% herbaceous cover in contrast to similar plots in Unit 3 that averaged 66% herbaceous cover. If the plots were harvested and volume was zero, herbaceous cover averaged 17% in Unit 2 and 33% in Unit 3. Herbaceous cover on these sites in Unit 3 was higher than similar in Unit 2 when factors such as site class, stocking level, and burn history were held constant. Sites with low or zero merchantable volume may have a nonzero timber volume of trees not commercially harvested. This timber volume related to non-commercial species could be the cause of much lower herbaceous cover on these plots in Unit 2 and the reason why the model did so poorly in Unit 2.

Schuster (1967) reported separate coefficients for mid-story and dominant story cover effects on grass production in mixed pine-hardwoods, but reported as significant only the sum of mid-story and dominant story cover on total herbaceous production. The mid-story hardwood cover effect on herbaceous production may be different than the pine overstory effect. The growing stock volume variable does not capture the variability associated with multiple-story forests.

*Upland hardwoods forest type*

Herbaceous cover was significantly ($P < 0.0001$) associated with the factors of browse cover, total growing stock volume, site index, and burning history (Table 2). Herbaceous cover on plots burned less than 3 years ago was significantly greater than herbaceous cover on unburned plots or plots burned more than 3 years ago. The transformed estimates underestimated the actual herbaceous cover, as would be expected with the log model (Table 3). The adjustment factor, however, increased the average estimate to a value higher than the actual.

The model performed poorly in Unit 1 and Unit 2 (Table 3). In Unit 3, the plots were distributed across merchantable volume ranging from 0 to 112 $m^3$/ha. Twenty percent of the plots occurred on sites with volume greater than 42 $m^3$/ha. In Unit 1 only two plots out of 14 occurred on sites with total volume greater than 42 $m^3$/ha and in Unit 2 only one plot out of 17 fell into this range. Even with an average lower timber volume, Units 1 and 2 had an average herbaceous cover less than Unit 3. The limitations of merchantable timber volume as a surrogate for the forest's impact on herbaceous cover appear to be the cause of the model's inadequacy here.

Herbaceous cover on harvested and on unharvested plots in Unit 3 were not significantly different. Harvest activity on the upland hardwood types occurred on a greater number of plots than planted pine: 60% of the upland hardwood plots were harvested in contrast to only 28% in planted pine. In planted pine, 50% of the plots harvested were clearcut, usually in association with a stand regeneration of pine, and occasionally a stand conversion to pine. In upland hardwoods, only 37% of the plots were clearcut. The remaining types of harvesting activity on upland hardwoods included selective harvesting methods such as diameter-limit cuts, group selection, and clearcut of merchantable trees only. These selective harvest methods appear to have less of an impact on the understory vegetation, because the harvesting treatment was not significant in the regression model.

## CONCLUSIONS

The exponential form and the statistical variation captured in these regional overstory–understory models are similar to the forms and variation of the site-specific models. Overstory–understory dynamics for the original area were significantly ($P < 0.001$) captured in the regional logarithmic models for planted pine, mixed pine-hardwoods and upland hardwoods. This study showed the need to include an adjustment factor for logarithmic models, such as the naive estimate (Duan, 1983). The understory variation responding to changing timber stand dynamics in southeastern Alabama can be examined in response to the timber projections from TRIM using models developed within the southeastern area. However, it should be noted that the error estimate, while less than the original data, is still quite large.

The applicability of site-specific models outside of the area where they were developed has not been explored. Results from this study suggest that even though the original models appear to capture a significant amount of variation (as in the case of the planted pine, mixed pine-hardwoods, and upland hardwoods models), the range of applicability is very limited. Models developed for southeastern Alabama did not extend well into the southwestern parts of the state, most likely because of individual model dynamics discussed above, the regional inventory data base, and the required linkages to the timber model.

The cross-sectional inventory data used in this analysis sampled the site-specific variation as well as the regional variation. These inventory designs were constructed to minimize the variation associated with sampling timber volume on commercial forestland. Only plots with high and medium site or stocking levels were analyzed because of the small number of low-level plots. Herbaceous cover was not significantly different between the high and medium levels of site class or stocking level for planted pine, natural pine, and mixed pine-hardwoods. The significance of site class and stocking level on herbaceous cover may only be apparent when plots at the low levels are available for analysis.

The variable used to capture the impact of trees was merchantable timber volume, the variable projected in the timber model. This variable represents the volume per unit area that can be harvested for commercial wood products. Any part of a single tree unusable because of decay or roughness is omitted from this volume estimation. In addition, only commercial timber species are included in the volume estimate. A zero merchantable timber volume does not imply a zero total volume. Methods to link merchantable volume with total volume or biomass might improve these overstory–understory models. Regional forage models are limited to using growing stock volume as a surrogate of the impact of trees on the understory until further improvements are made in the extant timber growth and yield models.

The inability to extend the original model beyond the southeastern unit speaks for the need of an adequate regional sample of overstory–understory characteristics. Multiresource data are needed at a larger scale than was used here in order to develop an adequate regional model. The inventory data should contain an adequate number of observations within the overstory categories that significantly affect herbaceous cover. Based on this study, those categories should minimally include site class, burning history, harvesting activity, and forest type.

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