FUEL CHARACTERISTICS AND FIRE BEHAVIOR PREDICTIONS IN NATIVE AND OLD-FIELD PINELANDS IN THE RED HILLS REGION, SOUTHWEST GEORGIA

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ABSTRACT

The study sought to determine how fire fuels and predicted fire behavior in upland pine forests vary according to land use history, fire regime, and timber stocking. Fuels at multiple sites were collected and measured by fuel type, and fuel loads were compared between native (longleaf/wiregrass) and old-field (shortleaf-loblolly) pinelands, 1- and 2-year roughs (years since burn), and levels of pine tree basal area per acre. Fire behavior predicted by BEHAVE software was similarly compared. Dead grass and live herb loads were greater in native (longleaf pine/wiregrass) pinelands than in old-field (shortleaf-loblolly) pinelands, presumably because of differences in soil disturbance history. Pine needle loads were also greater in native pinelands, attributable to dominance by longleaf pine. Needle loads increased with pine basal area, causing a corresponding increase in total fine fuel loads. In native pinelands, dead grass and live herb fuel loads decreased slightly with increasing pine basal area, but not enough to offset increasing needle loads. Standing fine fuel and needle loads remained relatively constant from year to year, while non-needle litter accumulated with time since previous burn. Using the fuel load measurements, the fire behavior model predicted that fire activity (flame length, rate of spread, fireline intensity) would be greater in native than in old-field pinelands, and that time since previous burn and pine basal area would have positive but smaller effects on fire. The results refine fire behavior predictions by providing fuel load assumptions that are specific to pineland cover types. Also, results demonstrate implications of native pineland conservation and pine timber management to prescribed fire behavior in southern pinelands.

Keywords: southeastern pine forest, prescribed fire, fire frequency, *Pinus palustris*, *Pinus echinata*, *Pinus taeda*, game bird management, fuel loads, fire modeling, timber management, *Aristida beyrichiana*.

INTRODUCTION

Improving management of the remaining natural pine forests in the southeastern United States will require refinement of models predicting prescribed fire behavior. In southeastern pinelands, it has long been known that management for native wildlife habitat requires prescription of frequent fire to suppress hardwood encroachment and maintain the open and herb-dominated understory characterizing the natural ecosystem (Stoddard 1935). However, upland pine forests vary in local fuel conditions which influence fire behavior and thus the ecological effects of fire. Factors potentially influencing fuel loads include land-use history (Hedman et al. 2000), time since last fire (McNab 1976), and timber volume (Harrington and Edwards 1999). Such influences may be relevant to land management decisions on properties where having effective prescribed fire is a key objective.

The Red Hills Region of southern Georgia and northern Florida (Fig. 1) provides an example of a pineland landscape where variation in cover characteristics may require special consideration in prescribing fire. Property in the region is largely composed of private land managed for bobwhite quail through the use of prescribed fire in late winter/early spring, timber management, and other wildlife-management practices (Moser and Palmer 1997). Pinelands within the region generally may be distinguished by land-use history as "native" (never plowed) versus "old-field" (post-agriculture). These two community types differ in certain vegetation characteristics (Hedman et al. 2000) the potentially influence fire. Also, fires generally are applied either one or two years following the previous burn, resulting in a mosaic of burn units that have either 1- or 2-year "rough". In addition, timber stands vary in basal area from a few scattered trees to excesses of 60 ft^2 basal area per acre (14 m^2/ha), depending on the particular timber management goals on a given property.

The effects of the above-listed factors on fire fuel loads and fire behavior within the region are not well documented and are largely based on casual observation. Native pinelands are thought to burn more readily and intensely, presumably because of relatively large and continuous 1 hr fuel loads provided by native bunch grasses and the abundant, pyrogenic needles of longleaf pine (*Pinus palustris* Mill.; McNab 1976, Platt et al. 1991, Harrington and Edwards 1999). Fires in 1-yr roughs (annual burns) are sometimes preferred for killing hardwood sprouts while they are relatively small and vulnerable, whereas 2-year roughs tend to burn more easily, presumably because of accumulated fine fuel loads. The influence of pine tree basal area is debated. Relatively open stands provide more light and potentially greater productivity of herbs and grasses in particular (Harrington and Edwards 1999, Dagley et al. 2002, Mulligan and Kirkman 2002), whereas pine trees provide a dependable source of needle litter fuel that presumably increases with pine tree basal area (McNab 1976, Harrington and Edwards 1999).

The purpose of this study was to interpret how various pineland cover types influence fire fuels and potential fire behavior. Specifically, we sought to 1) determine how fuel load and composition differs between native and old-field pinelands, 1- and 2-year roughs, and different levels of pine tree basal area, 2) demonstrate the influence of these factors on fire behavior predictions, and 3) evaluate the appropriateness of using of Standard Fuel Model Number 2 (Timber Grass and Understory; Rothermel 1983) to predict fire in natural southern pinelands using BEHAVE software (Andrews et al. 2001).

METHODS

Study Site and Field Sampling

The study was conducted on Pebble Hill Plantation in the southern Georgia portion of the Red Hills Region (Fig. 1). The region falls within the Coastal Plain and has very sandy soils with clayey subhorizons formed in marine-deposited sediments (Calhoun 1979). Pebble Hill Plantation covers approximately 3,020 acres (1,222 ha). It has been managed for quail (frequently burned) since ca. 1900 and is currently managed by Tall Timbers Research Station. Land management on Pebble Hill continues to follow traditions that are relatively uniform among quail hunting properties in the region. In particular, approximately 60-70 percent of the land is burned each year, including areas that were burned one and two years prior. Dirt roads traversing the property serve as firebreaks dividing the property into fire management units ranging in size from a few acres to approximately 80 acres (32 ha). Most of the upland portion of the property is managed for wildlife habitat, i.e., pinelands with open understory, naturally-seeded pines of multiple ages, few hardwood trees, and a layer dominated by herbaceous vegetation. About one third of these pinelands are considered native, dominated by longleaf pine and an herbaceous layer of varying densities of wiregrass (*Aristida beyrichiana* Trin. & Rupr.; Ambrose 2001) and a large number of indigenous herbs (A. Golsen, unpublished data). The old-field pinelands are typically dominated by shortleaf pine (*Pinus echinata* Mill.) and loblolly pine (*Pinus taeda* L.) and much smaller components of longleaf and slash pine (*Pinus elliottii* Engelm.), with an herbaceous layer dominated by widely common species typical of fallow fields (Billings 1938, McQuilkin 1940, Oosting 1942, Hedman et al. 2000). Resprouts from woody stump crowns that are top-killed during fires are common in both community types but are usually more dense in old-field pinelands. Timber stocking in most places is between 30-60 ft^2 basal area (BA) per acre (7-14 m^2/ha). When necessary, hardwood trees on uplands have been mechanically removed at intervals of several years.

Within the property, locations of study sites were randomly chosen. First, management units greater than approximately 5 acres (2 ha) were identified and categorized into cover types: 1) native 1-yr rough, 2) native 2-yr rough, 3) old-field 1-yr rough, and 4) old-field 2-yr rough. Three management units per land cover type were randomly selected (12 sites total) to serve as study sites. Native areas were identified using a map provided by a previous study that identified native forests based on the presence of wiregrass and other indigenous indicator species (Ambrose 2001). Remaining pinelands were considered to be old-field and were field-checked to determine that they were on or shared major characteristics with areas known to have been farmed prior to 1930. Age of rough was determined from records kept by the Pebble Hill land manager (C. Martin, unpublished data). Land cover information was stored and managed using GIS software (Arcview 3.2; ESRI 1999).

At each study site, five plot locations were randomly selected within the burn unit (60 plots total) using the Animal Movement Analysis extension (Hooge 2003) in Arcview 3.2 (ESRI 1999). Plots were navigated to in the field using a GPS unit. Each plot location was marked and a 6.5 ft (2 m) transect was run from it along a randomly selected azimuth. Available fuels were destructively sampled within a 4 in (10 cm) wide strip along one side of the transect, covering an area of 2.2 ft^2 (0.2 m^2) per plot.

Fuels were collected separately into the following categories: dead grass, dead forbs + woody stems = 0.25 in diameter, undecomposed pine needles, other litter = 0.25 in, dead fuels

0.25-1 in, live herbs, and live woody plant material = 0.25 in. Standing fuels were collected if their bases were within the plot, needles were collected if their fascicle was within the plot, and the portion of fuels on the ground that fell within the plot was collected. Categories were chosen in part to be compatible with fuel input categories in BEHAVE software (Andrews et al. 2001) used to run the Rothermel-Albini fire behavior model (Rothermel 1972, Albini 1976). The "one hour" fuel types (dead grass, dead forbs + woody, pine needles, litter) were sampled separately to interpret their individual responses to land cover types. Sampling of live woody material was restricted to fuels = 0.25 in to include only those likely to burn in typical fires on the property (K. Robertson, pers. obs.). Fuel samples were dried for 48 hrs and weighed to determine fuel load. Average fuel bed height was estimated at each plot. Fuel bed was considered to be the matrix of fine fuels having a continuous distribution likely carry fire.

To interpret the influence of pine tree basal area on fuel loads, trees were measured around each plot. All trees = 0.8 in (2 cm) diameter breast height (DBH) within 65 ft (20 m) of each plot were identified to species and measured for DBH. This distance from the plot was used to approximate the range of pine needle dispersal and shading by trees. Although all tree species were measured, > 95 % of trees measured were pine species. Thus, pine tree BA was used as an independent variable in analyses.

Fuel Analysis and Estimates

Fuel loads were analyzed to determine if they differed significantly between community types (native/old-field) and age of rough (1 or 2 years). A MANOVA was run using community and age of rough as factors, each of the measured fuel categories as response variables, and plot means for each site as replicates. Univariate analyses were used to interpret the specific responses of fuel load types to the community and age of rough factors and their interaction effects.

Because of the continuous nature of pine tree BA, its effects on certain fuel types were tested separately in linear regression analyses. Specifically, pine needle and standing 1-hr fuel loads were tested for their response to pine stocking, based on results of studies cited above. Community type and age of rough were included in analyses to correct for and test their effects. Thus, pine tree BA, community type, and year of rough were independent variables in each analysis and dead grass, dead forbs + woody, pine needles, and live herbaceous fuel loads were dependent variables in separate analyses for each fuel type. Plots were used as replicates to capture the large amount of variance in pine BA among plots within sites. Exploratory data analyses showed pine tree basal area to vary independently of community type and age of rough. Community type in effect represented both soil disturbance history (post-agriculture/never plowed) and pine species, given that native sites were almost invariably covered with longleaf pine and old-field sites with a mixture of shortleaf and loblolly pine. Community type and year of rough were entered as binary "dummy variables". In the cases where the categorical independent variables had significant effects, regression coefficients were estimated separately for each level of the variable and graphically displayed.

To provide input for fire behavior models, mean fuel loads and fuel bed depths were calculated for the different fuel types and land cover categories, based on differences identified in statistical tests. Mean fuel loads were reported for each community type (native/old-field) and age of rough (1 or 2 yr) combination for most of the measured fuel categories. Means were calculated from plot means for each site. Pine needle loads were reported separately to demonstrate their dependence on pine tree BA. Mean pine needle loads were reported for two pine tree BA classes (± 50 ft^2 / acre), community type (corresponding to tree species), and age of rough. Means of pine needle loads were calculated from all plots without regard to site, with the assumption that tree cover effects were greater than site effects.

Fire Behavior Predictions

To assess the potential influence of land cover on fire behavior, the collected data were used to predict fire behavior with BEHAVE 1.0 software (Andrews et al. 2001). BEHAVE runs were conducted for each possible combination of native vs. old-field cover, age of rough, and pine tree basal area class (± 50 ft^2 / acre) to predict fire line intensity (Btu/ft/s), rate of spread (chains/hr), and flame length (ft). Required model parameters that were not measured in this study (1000 hr fuel load, surface area/volume ratios, dead fuel moisture of extinction, fuel heat contents) were borrowed from Standard Fuel Model 2 (provided by BEHAVE software). Live herbaceous, woody, and 10 hr moisture contents were estimated (121, 113, and 11, respectively) based on measurements in local pinelands in early May of the same year (R. Masters, unpublished data). Weather parameters used were the means of measurements taken during burns on the study sites within 1-3 weeks following fuel sampling (March-early April; 75º F, 41 % relative humidity (RH), 3 mph mid-flame windspeed, 3 % slope). Based on RH, 1 hr fuel moistures were estimated to be 8 % (Rothermel 1983) and 100 hr fuel moistures were estimated to be 12 %.

The BEHAVE predictions were subjectively compared among land cover types to infer the relative influence of those factors on fire behavior. Also, predictions generated from measured data were compared with those from the Standard Fire Model 2 to assess its appropriateness for use in the studied habitat types.

RESULTS

Overall, fuel loads differed among land cover types. Results from the MANOVA showed community type (native/old-field) to have a significant effect on fuel loads in the measured categories taken together (Table 1). Univariate tests showed community type to effect dead grass, needle, and live herb loads in particular (Table 1). Each of these fuel types had higher loads in native than in old-field pinelands (Table 2). Although age of rough did not have an overall significant effect in the MANOVA, univariate tests showed significant effects for litter and live herb loads. Litter loads were highest in 2-year roughs, and live herb loads were highest in 1-year roughs (Table 2). There was no significant interaction effect shown by the MANOVA. In univariate tests, the only significant interaction effect was between live herb load and community type (Table 1), because differences were greater in the native than in the old-field community (Table 2).

Multiple regression analyses reflected results of the MANOVA for community type and age of rough. Dead grass and live herbaceous fuels responded significantly to community type (P = 0.018, P <0.0001, respectively) but not to pine BA or age of rough. However, both of these fuel types showed a trend of decreasing fuel loads with increasing pine BA in native sites, with opposite but weaker trends in old-field sites (Fig. 2a,b). The 1 hr forb + woody fuel category showed no significant responses to land cover. Pine needle load responded significantly to pine BA (P = 0.034) and nearly significantly to community type (P = 0.082), but did not vary with age of rough. Pine needle loads increased with increasing pine BA in both native and old-field pinelands (Fig. 2c).

In general, 1-hr fuels in the studied pinelands were most heavily composed of litter, followed in order by pine needles and standing fuels (forbs + woody, grass). Litter composed approximately half of 1-hr fuel loads and needles approximately on quarter of 1-hr loads in each community type and age of rough combination (Table 2).

Predicted fire behavior varied according to land cover type. Community type (native/old-field) was most predictive of fire activity, followed in order by age of rough and pine tree BA (Table 3). In a given age of rough and BA, predictions for native pinelands showed approximately twice the rate of spread and fireline intensity and one-third longer flame lengths than old-field pinelands. Predicted fire activity showed more subtle increases with year of rough and pine tree BA. For example, average predicted flame length and rate of spread were approximately 20 % higher in 2- than in 1-year roughs and 10 % higher in 50-80 than in 20-30 ft^2/acre BA pines (Table 3).

Fire behavior predictions generated by Fuel Model 2 were within the range of predictions made with the measured fuel load inputs. Model 2 predictions were closer to those for old-field than for native pinelands (Table 3).

DISCUSSION

Fuel loads and expected fire behavior varied according to land-use history and current cover conditions in the studied upland pine forests. Specifically, 1-hr fuel loads were greater in native than in old-field pinelands, reflecting greater quantities of dead grass, live herbs, and pine needles. Also, 1-hr fuel loads were greater in 2-year than in 1-year roughs because of litter accumulation. Community type had a greater influence on fuel loads than year since burn. The effects of these two factors appeared to be additive and independent of one another, given their lack of interaction in statistical analyses and their respective influences on different fuel types.

The greater quantities of dead grass and live herbs in native pinelands than in old-fields is attributable to differences in soil-disturbance history. In native pineland communities, much of the herbaceous biomass is made up of persistent perennial grasses that are slow to re-invade following elimination by intensive plowing (Clewell and Hilty 1976). In particular, wiregrass, which often dominates the herb layer of native pinelands, produces viable seeds only when burned later than the traditional early-spring period and has very limited seed dispersal (Van Eerden 1988, Seamon et al. 1989, McGee 1996).

The pattern of fuel loads with respect to age of rough suggests a fairly thorough annual turnover in herbaceous vegetation. Given the relatively consistent levels of dead grass and live herbs from year to year, it appears that most herbaceous vegetation dies back during the winter and, if not burned, contributes to litter accumulation during the following year. Meanwhile, live herb fuel loads are replenished by new growth in the spring. Thus, differences in fire behavior between 1- and 2-year roughs reflect litter abundance and/or continuity rather than changes in standing vegetation.

The larger pine needle loads in native versus old-field pinelands (corrected for by pine tree BA) may be explained by the dominance of longleaf instead of shortleaf and loblolly pines. Longleaf pine has been noted for its particularly abundant provision needle litter per BA (McNab 1976, Platt et al. 1981, Harrington and Edwards 1999) as was observed in this study.

The lack of response of live woody and 10-hr fuels to cover categories may be due in part to the scale of sampling. Generally, woody stem densities are lower in native than old-field areas (K. Robertson, pers. obs.), and it is expected that 10-hr fuels accumulate with time since burn. However, both woody stems and 10-hr fuels were observed to be dispersed more widely than the other fuel categories, such that the plots used may not have captured variance among sites.

The influence of pine tree BA on needle loads resulted in a positive effect of BA on total 1-hr fuel loads and corresponding levels of predicted fire behavior. The expected trend of decreasing dead grass and live herb loads with increasing BA was evident in native pinelands, but it was not strong enough to offset the influence of needle fall on total 1-hr fuel loads. The fact that this trend was only evident in native pinelands suggests that a certain abundance of perennial grasses, which have relatively low densities in old-field pinelands, must be present for there to be a perceivable response of standing fuels to light levels.

The fire behavior predictions generated by BEHAVE suggest that the Standard Fuel Model 2 uses fuel load assumptions that are a reasonable approximation of those in the studied pinelands, especially for old-field pinelands. How well these fuel estimates predict fire behavior in local pinelands remains to be measured. In slight contrast to the reported fire predictions, it has been observed by the authors that Fuel Model 2 typically under-predicts fire behavior in old-field pinelands and more accurately predicts behavior in native pinelands. A likely source of error is the estimate of fuel bed depth, which is assumed for the purpose of the model to be continuous (Rothermel 1983). In reality, our estimates of bed depth were averages of varying, discontinuous fuel beds, especially in old-field pinelands, where there are fewer bunch grasses. Thus, fires in the studied pinelands likely alternate between being carried by standing fuels (assumed by Model 2) and litter (Models 8, 9, and 10) during a burn, resulting in overall lower fire dynamics (Rothermel 1983).

In conclusion, the results from this study provide a greater understanding of how certain land cover characteristics predict fuel conditions and expected fire behavior in a natural pineland landscape. The findings shed light on how certain land management decisions will likely effect prescribed fire in the Red Hills Region and comparable southeastern pinelands. In particular, conservation of native pinelands or restoration of key vegetation components (longleaf pine, perennial bunch grasses) will provide higher fire intensities and presumably better woody stem kill than burning in old-field pinelands. Also, timber thinning within the studied basal area range will not guarantee an increase in total 1-hr fuel loads, especially if there is low grass density initially. Future studies should use the provided fuel estimates to test and refine predictions of prescribed fire behavior in southern upland pine forests.

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Table 1. Results from MANOVA testing influence of community type (native vs. old-field) and age of rough (1 or 2 years) on measured fuel load categories, with pine tree BA as a covariate. Multivariate statistic used was Pilai's Trace. Univariate test results are given for each fuel category. Significant results are in bold type.

Multivariate Tests

	Comm.		Rough		Comm. x Rough	
	F	*P*	*F*	*P*	*F*	*P*
	6631.3	**0.010**	34.17	0.131	159.52	0.061

Univariate Tests

	Comm.		Rough		Comm. x Rough	
	F	*P*	*F*	*P*	*F*	*P*
1 HR						
Litter	0.43	0.533	**7.46**	**0.029**	1.03	0.345
Forbs + Woody	0.17	0.696	2.94	0.130	0.00	0.975
Grass	**7.07**	**0.033**	0.00	0.978	4.51	0.071
Needles	**7.55**	**0.029**	0.15	0.706	3.11	0.121
10 HR	0.29	0.605	0.26	0.625	0.16	0.700
Live Herbs	**81.92**	**<0.001**	**7.91**	**0.026**	**7.51**	**0.029**
Live Woody	0.22	0.652	0.48	0.510	0.05	0.837

Table 2. Estimated fuel loads (tons/acre) in fuel type categories. A. Mean of three sites per land cover type (plots averaged within each site) and standard error. B. Mean of all plots and s.e. for pine needle loads in each cover type and BA category.

A.

		1 HR			10 HR	Live		Bed Depth
Community	Rough	Litter	Forbs/Woody	Grass		Herbs	Woody	
Native	1	0.53 ± 0.20	0.14 ± 0.03	0.31 ± 0.08	0.42 ± 0.02	0.30 ± 0.07	0.33 ± 0.03	1.62 ± 0.44
	2	0.92 ± 0.38	0.11 ± 0.05	0.14 ± 0.15	0.24 ± 0.19	0.27 ± 0.08	0.32 ± 0.15	1.42 ± 0.21
Old-field	1	0.64 ± 0.27	0.11 ± 0.02	0.23 ± 0.11	0.60 ± 0.21	0.06 ± 0.02	0.29 ± 0.17	0.86 ± 0.11
	2	1.03 ± 0.10	0.17 ± 0.04	0.07 ± 0.02	0.40 ± 0.17	0.06 ± 0.05	0.56 ± 0.35	1.09 ± 0.10

B.

Community	Rough	Pine BA	Needles	n (plots)
Native	1	20-50	0.45 ± 0.16	7
		50-80	0.59 ± 0.17	6
	2	20-50	0.31 ± 0.09	9
		50-80	0.85 ± 0.30	4
Old-field	1	20-50	0.34 ± 0.14	9
		50-80	0.46 ± 0.06	6
	2	20-50	0.24 ± 0.14	10
		50-80	0.31 ± 0.01	2

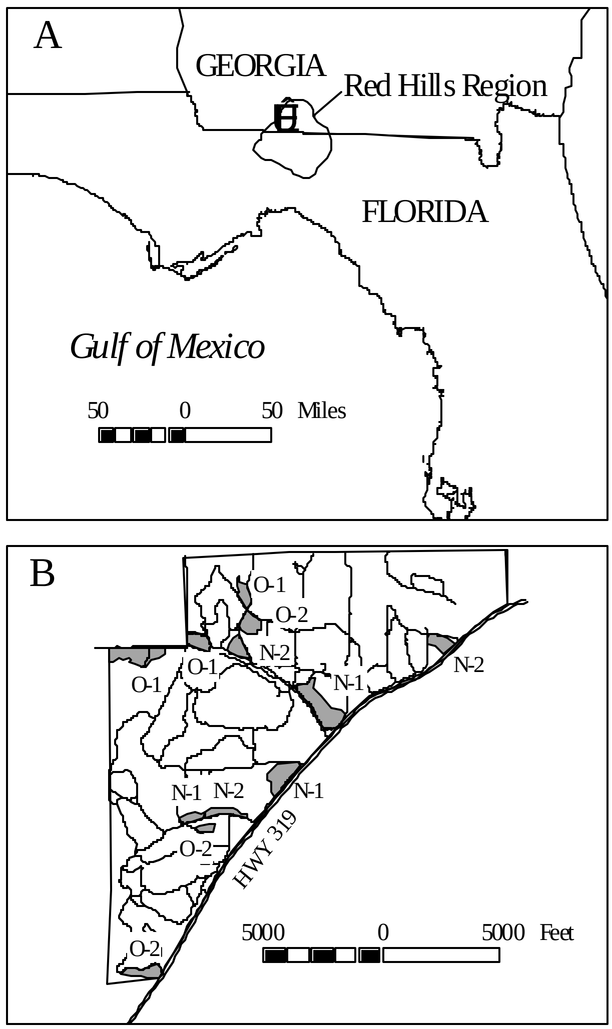
Table 3. BEHAVE inputs and outputs for each land cover category and fuel class. Fuel loads are in tons/acre and bed depth is in ft. Outputs: FI = fireline intensity (btu/ft/s), FL = flame length (ft), ROS = rate of spread (chains/hr).

			Inputs					Outputs		
Comm.	Rough	BA	1-HR	10-HR	Live Herb	Live Woody	Bed Depth	FI	FL	ROS
Native	1	20-50	1.43	0.42	0.30	0.33	1.62	88	3.5	13.9
		50-80	1.57	0.42	0.30	0.33	1.62	101	3.8	14.8
	2	20-50	1.48	0.24	0.27	0.32	1.42	110	3.9	16.8
		50-80	2.02	0.24	0.27	0.32	1.42	167	4.7	19.7
Old-field	1	20-50	1.32	0.60	0.06	0.29	0.86	46	2.6	8.6
		50-80	1.44	0.60	0.06	0.29	0.86	52	2.8	9.2
	2	20-50	1.51	0.40	0.06	0.56	1.09	71	3.2	10.4
		50-80	1.58	0.40	0.06	0.56	1.09	75	3.3	10.7
Model # 2			2.00	1.00	0.50	0.00	1.00	84	3.5	10.6

FIGURE LEGENDS

Figure 1. A. Red Hills Region in southern Georgia. Study location (Pebble Hill Plantation) is indicated by a star. B. Pebble Hill Plantation. Thin lines indicate roads and study sites are shaded. Sites are labeled by community type (native = N, old-field = O) and age of rough (1, 2).

Figure 2. Scatter plots and regression lines showing effect of pine tree basal area on fuel load (A. dead grass, B. live herbs, C. pine needles). Symbols represent individual plots. Solid circles = native pinelands, empty circles = old-field pinelands.


A
GEORGIA
Red Hills Region
FLORIDA
Gulf of Mexico
50 0 50 Miles
B
O-1
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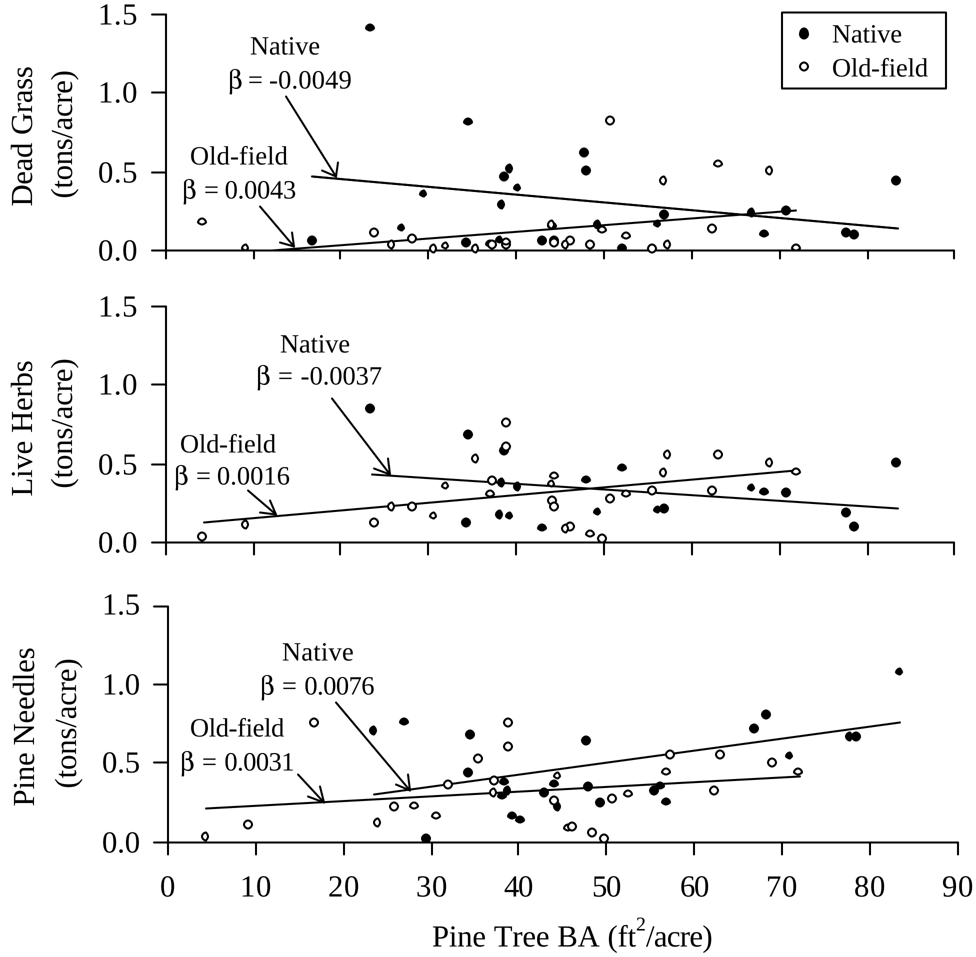

Native
Old-field
Native
β = -0.0049
Old-field
β = 0.0043
Dead Grass (tons/acre)
Native
β = -0.0037
Old-field
β = 0.0016
Live Herbs (tons/acre)
Native
β = 0.0076
Old-field
β = 0.0031
Pine Needles (tons/acre)
1.5
1.0
0.5
0.0
0
10
20
30
40
50
60
70
80
90
Pine Tree BA (ft²/acre)