A PRELIMINARY MODEL OF YELLOW-POPLAR SEEDLING ESTABLISHMENT TWO YEARS AFTER A GROWING SEASON PRESCRIBED FIRE IN SOUTHERN APPALACHIAN OAK STANDS

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Abstract—Factors affecting the density and distribution of yellow-poplar regeneration after a single growing season prescribed fire were studied in mature upland oak stands in the southern Appalachian Mountains. In burned and unburned stands, density of one and two year old yellow-poplar seedlings was inventoried within 50 m from isolated yellow-poplar canopy seed trees in response to distance from seed source, litter layer present and competition by other species. Yellow-poplar regeneration was absent on the forest floor in unburned stands, but averaged over 97 thousand seedlings/ha around seed trees in burned stands. Correlation analysis indicated yellow-poplar seedling density decreased with increasing leaf litter on the forest floor, increasing distance from the source seed tree and increasing competition by seedlings of other species. A parsimonious Poisson regression model using Akaike Information Criterion for variable selection included (in order of relative importance) percent forest floor covered by leaf litter and distance from the seed source. Results of this study suggest that prescribed fire may promote establishment of yellow-poplar regeneration where seed trees are a component of upland oak stands.

INTRODUCTION

Yellow-poplar (*Liriodendron tulipifera*) is a wind-disseminated, shade intolerant, highly productive pioneer species of mesic sites that typically dominates lower slopes and coves in the Southern Appalachian Piedmont and Mountains (Olsen 1969). Seed production by this species is abundant, dependable annually and accumulates in the forest floor for up to seven years (Carvell and Korstian 1955). Disturbance of the canopy and forest floor from silvicultural activities, such as harvesting, typically results in establishment of dense yellow-poplar regeneration that grows rapidly in height and typically excludes other, slower growing, desirable species (Beck and Hooper 1986).

Although yellow-poplar is typically classified as a mesophytic species (Olsen 1969) seedlings can become established following disturbance on dry sites with adequate soil moisture, such as during years of above average summer precipitation, and particularly on sites where soil temperature is high, up to 35°C. (Stephens 1965). In contrast, Whipple (1968) reported the combination of drought and high soil temperature (>38°C) on disked and bulldozed sites in north Alabama resulted in high mortality of new yellow-poplar seedlings. On some dry sites, yellow-poplar can become an unintended competitor with other desirable regeneration following harvests of mixed oak (*Quercus spp*) and hickory (*Carya spp*) stands (McGee 1975). Prescribed fire is an effective method for controlling competition from yellow-poplar saplings when regenerating oaks on Piedmont sites (Brose and others 1999). Other studies, however, suggest burning may promote yellow-poplar regeneration from stored seeds in the forest floor, particularly on moist sites (Shearin and others 1972, McNab and others 2013) in the southern Appalachians. With increasing use of prescribed burning for restoration of fire tolerant vegetative communities in the southern Appalachians (Brose and others 2001), information is lacking on its effects on establishment of yellow-poplar seedlings, particularly on dry sites dominated by oaks where codominant seed trees may be present as a result of past disturbances.

I utilized the design and several treatments of a large study on the effects of season of prescribed burning on vegetation in upland oak stands. My objectives were to determine if the density and distribution of yellow-poplar seedlings near seed trees were affected by (1) prescribed burning, (2) distance from a seed source, (3) amount of leaf litter on the forest floor and (4) competition from regeneration of other species. Although my study utilizes replicated treatment units, I characterize it as preliminary because my research questions were to determine if yellow-poplar regeneration differs significantly between unburned and burned upland oak stands, and to evaluate some of the important factors that should be examined in subsequent investigations of broader scope.

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METHODS

Study Area

The study is in the Bent Creek Experimental Forest, located in the Pisgah Ranger District of the Pisgah National Forest, in the Southern Appalachian Mountains of western North Carolina (35.5°N, 82.6°W). The study area occupies 47.5 ha on the southerly exposure of a low, east-west trending ridge with elevations ranging from 700 - 730 m. Soils are primarily Ultisols that formed from gneisses and schists in the Late Proterozoic Ashe Metamorphic Suite. Soils in the study area consist predominantly of two map units: a complex of Evard-Cowee series (Typic Hapludults) on ridges and middle slopes and Tate series (Typic Hapludults) on lower slopes and in coves. Soils in both map units are deep (>80 cm), acidic (pH<5.5) and relatively infertile. Annual precipitation averages 125 cm and is uniformly distributed, although brief soil moisture deficits may occur during the late growing season. Mean daily temperature ranges from 2.3° C in January to 22.5° C in July.

Composition of the present timber stand is an overstory mixture of dry-site oaks (*Quercus spp.*) and hickories (*Carya spp.*). Oaks include scarlet (*Q. coccinea*), chestnut (*Q. prinus*), southern red (*Q. falcata*), white (*Q. alba*) and black (*Q. velutina*); hickories are mockernut (C. tomentosa) and pignut (C. glabra). A shade tolerant midstory consists of red maple (*Acer rubrum*), black gum (*Nyssa sylvatica*), sassafras (*Sassafras albidum*) and sourwood (*Oxydendron arboreum*). The shrub layer consists of tall (2-4 m) evergreen mountain laurel (*Kalmia latifolia*) and short (<0.5 m) deciduous hillside blueberry (*Vaccinium vacilians*). Yellow-poplar is a minor and variable canopy component throughout the stand, occurring with an estimated mean stem density of about 1 ha^{-1} with greater frequency on lower slopes and in drainages. The presence of scattered, shade-intolerant, shortleaf pines (*Pinus echinata*) in the canopy suggests the area was used as a woodlot and pasture for livestock when farming ceased and old-field succession began (Nesbitt 1941). There is no record or evidence of fire in the study area. Arborescent vegetation on the study area likely became established around 1900, when the land was acquired by the Biltmore Estate following approximately 50 years of subsistence farming.

Study Design and Sampling

The 47.5 ha study area was subdivided into nine treatment units of approximately uniform size, each of which extended from ridge top to lower slope position. The core prescribed burning study was a completely randomized design consisting of three replications of three treatments: (1) no burning (control), (2) growing season burn and (3) dormant season burn; the latter treatment was not utilized in this investigation (fig. 1). The growing season burn treatment was applied to the three replication units sequentially on the same day in late April 2013, using a strip head fire ignition method beginning on the ridge and extending down the slope at about 10 m intervals along the contour. The fire consumed the entire upper layer of the 1 to 2 year old, generally non-decomposed leaf litter (the O_1 - horizon) and varying amounts of the compact, decomposed duff (the O_2 horizon above the mineral soil) depending on local variation of fuel loading, fuel moisture content, wind velocity and convergence of flame zones between two fire types consisting of heading and backing flame zones. Fire intensity ranged from 19 to 80 kcal/sec/m as estimated from crown scorch of eastern white pine (*Pinus strobus*) foliage, which averaged about 3 m and ranged from 2 m to 7 m (VanWagner 1973).

In October 2014, two growing seasons after the burn treatment in April 2013, I located all codominant yellow-poplar trees in the six unburned and burned treatment

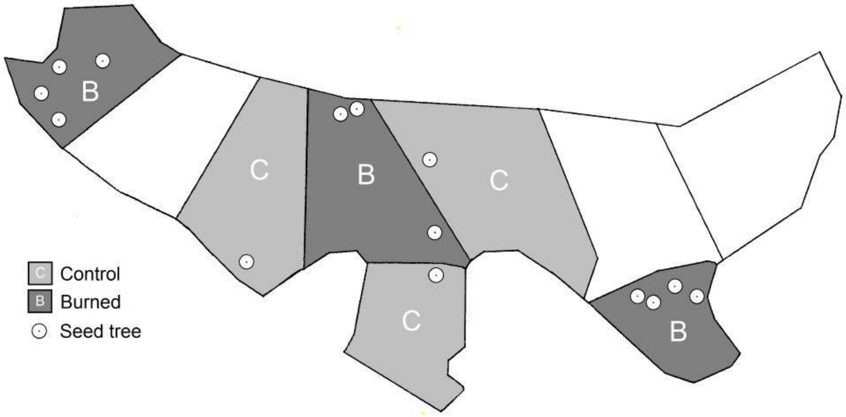

Figure 1—Study area in Bent Creek Experimental Forest showing unburned control and prescribed burned treatment units and approximate locations of yellow-poplar seed trees mentioned in the text.

units and evaluated them as candidate sample sites for my study. Ideally, seed trees would have been widely separated (>200 m) but the scarcity of suitable trees in some units resulted in some being separated by only 100 m. Although the seed shadow of yellow-poplar trees can extend 100 m or more (Engle 1960), 90% of seed fall occurs within 50 m of the seed tree (Carvell and Korstian 1955). Whipple (1968) found that yellow-poplar seed dispersal was strongly affected by wind direction and most seeds fell within 2 to 5 times the height of seed trees. I measured diameter breast height (dbh), total height, and basal area of the surrounding stand for each suitable seed tree in the six treatment units.

I counted live yellow-poplar seedlings at 30 randomly located sample plots (0.44 m^2) within 50 m radius of each seed tree. Sample plots were excluded that were located outside of the treatment unit (if the tree was near a unit boundary) or in disturbed areas such as a fire line or a trail. The number of sample plots was reduced around several seed trees because of their proximity to other seed trees or location near the edge of a treatment. Data were collected for the following variables at each sample plot: (1) density (n/ha) of yellow-poplar seedlings (designated hereafter as DEN), (2) distance (m) from the seed tree (DIS), (3) density (n/ha) of competition (COM) consisting of the pooled number of seedlings and sprouts of all species excluding yellow-poplar and (4) estimated percent of the pre-burn (O_1 and O_2) litter layer (LIT) present on the forest floor.

Data Analysis

I used two-tailed t-tests with assumed unequal variances to compare size and competition (i.e. surrounding stand basal area) characteristics of the yellow-poplar seed trees in the two treatments. For testing treatment effects on the four response variables (e.g. DEN, LIT, DIS and COM) I pooled sample plot data by unit and seed tree and used the nonparametric Kolmogorov-Smirnov test to compare means. Observations during field data collection suggested non-normal distribution of regeneration DEN for sample plots in the unburned control treatment (i.e. seedling counts on nearly all plots were zero). Levenes test indicated inequality of sample population variances for DEN between the control and burned treatments. Spearman rank correlation was used to determine the relationship of yellow-poplar seedling density with each of the three independent variables of DIS, LIT and COM. I used multiple Poisson regression to model the individual and collective relationships of the count of yellow-poplar seedlings on each sample plot in response to variation of LIT, DIS and COM on burned treatment units. For the Poisson analysis of DEN as a function of LIT, DIS, and COM, I considered the random sample sites around the seed trees as independent observations that responded to variation of fuel loading, fire intensity and other factors, and therefore did not pool my data. Akaike's Information Criterion (AIC) was used as a guide for ranking model formulations consisting of each variable and combinations of variables. Because AIC is not a measure of significant improvement of one Poisson model compared to another, the reduction of deviance between two competing models was evaluated for significance using the chi-square test statistic. Finally, a measure of goodness of fit of various model formulations was calculated using deviance of regression (i.e. $R^2 = 1 - (SS\ model / SS\ total)$). R statistical software was used for analysis (R Core Team 2014). Statistically significant differences were tested at the alpha = 0.05 level.

RESULTS AND DISCUSSION

Yellow-poplar Seed Trees

Fourteen yellow-poplar seed trees were suitable for data collection; 3 in control treatments and 11 in the prescribed fire treatments (fig. 1). Seed trees were significantly smaller in dbh in the control stand compared to the burned stand (37.5 cm vs 52.0 cm), however there was no difference in total height (31.2 m vs 30.8 m) (table 1). Mean basal area of the predominantly oak stand around the yellow-poplar seed trees was significantly higher in the control treatment (26.8 m^2/ha) compared to the burn treatment (19.1 m^2/ha). None of the seed trees in the burned units showed evidence of heat damage to the crown or bole.

Table 1—Mean (SD) of yellow-poplar seed tree dbh, height and surrounding stand basal area by treatment

Parameter	Treatment Control (n=3)	Burn (n=11)
Dbh (cm)	37.5 (4.5)	52.0 (17.1)[a]
Height (m)	31.2 (2.3)	30.8 (6.4)
Basal area (m^2/ha)	26.8 (1.6)	19.1 (3.4)[a]

[a] Significantly different from control at $p < 0.05$ level by two-tailed t-test with unequal variances.

Table 2—Mean (SD) density of yellow-poplar regeneration, leaf litter cover on forest floor, distance sampled from seed tree and competition from other species by prescribed burn treatment

Variable	Treatment Control (n=82)	Burn (n=179)
Yellow-poplar density (n/ ha)	244.7 (423.8)	97,181.8 (56,447.2)[a]
Litter cover (%)	99.9 (0.2)	54.2 (13.8)[a]
Distance (m)	22.3 (4.0)	21.8 (3.2)
Competition (n/ ha)	59,266.7 (11,249.1)	39,118.2 (12,235.9)

[a]Significant treatment difference at $p < 0.05$ by Kolmogorov-Smirnov test.

Seed production, as a prerequisite for seedling establishment, by the sample trees was not quantified, but was estimated from a relationship with dbh developed by Carvell and Korstian (1955) in the Piedmont of North Carolina. Estimated mean annual production of sound yellow-poplar seeds was 43,500 /ha and 75,600 /ha in the control and burned treatments respectively. Because yellow-poplar seeds can remain viable up to 7 years in leaf litter on the forest floor (Carvell and Korstian 1955), the potential total supply of sound seeds available for regeneration was approximately 283,000 seeds/ha in the control treatment and 492,000 seeds /ha in the burned treatment, assuming a conservative viability period of 5 years. Although potential seed production was less in the control units than in the burned units that fact alone does not appear to be a plausible explanation for the nearly complete lack of yellow-poplar regeneration.

Control vs Burn Treatments Effects

Histograms of density distributions of the two populations of yellow-poplar seedlings suggested different variances for the control vs burn treatments. Levene's test indicated significant heteroscedasticity of population variances for yellow-poplar DEN, between the two treatments. The non-parametric Kolmogorov-Smirnov test indicated a significant difference of mean yellow-poplar DEN on the control treatment (245 seedlings/ha) compared to the burn (97,182 seedlings/ha) (table 2). The leaf litter on the forest floor was greater for the control treatment (99.9 percent) than for the burn treatment (54.2 percent). I found no difference between the control and burn treatments for DIS (22.3 m vs 21.8 m) and COM (59,267 seedlings/ha vs 39,118 seedlings/ha).

The almost complete lack of yellow-poplar DEN of any size in the control treatment was unexpected, but not surprising considering silvical characteristics of the species. Olsen (1969) reported that light and adequate moisture enhance seed germination and development of seedlings. On the 82 sample plots examined in the three units of the control treatment, only one seedling was found; it was on bare soil of an upturned root system of a wind thrown tree. Apparently the combination of thick, undisturbed leaf litter in combination with reduced light on the forest floor was sufficient to retard seed germination. Observations elsewhere in the control treatments outside of sample plots were similar, except that seedlings were occasionally observed on exposed soil in the pit of recently wind thrown trees. Clark and Boyce (1964) reported that yellow-poplar seeds can germinate on an undisturbed forest floor but seldom survive beyond one year.

Yellow-poplar Regeneration

Yellow-poplar DEN in the burn treatment was strongly correlated with LIT ($r = -0.45$, $p < 0.01$, $n = 179$) and DIS ($r = -0.26$, $p < 0.01$, $n = 179$), and weakly correlated with COM ($r = -0.15$, $p < 0.05$, $n = 179$) (table 3). The negative relationship indicated seedling numbers decreased with increasing LIT, DIS, and COM. There were no significant correlations among the three independent variables in the burn treatment. In the control treatment the almost perfect and highly significant correlation of DEN with LIT ($r = -0.99$, $p < 0.01$, $n = 82$) is an artifact of the field data, where a single seedling was recorded on a microsite with reduced leaf litter. Because of the spurious relationship of yellow-poplar regeneration with the control treatment, I omitted it from further investigation in this study.

I used Poisson multiple regression to assess interrelationships of yellow-poplar DEN in the burn treatment with the three significant independent variables (table 4). I began model development for prediction of DEN with trial formulations using each of the three factors. Yellow-poplar DEN was significantly affected by each factor, ranging from the weakest relationship for COM, which explained about 4 percent of variation, to LIT, which accounted for 24 percent. Including either COM or DIS with LIT resulted in significantly better prediction models. The decrease of AIC for the three variable model suggested it was an appropriate parsimonious formulation. However, the chi-square test of deviance reduction indicated the three

Table 3—Spearman rank correlation coefficients among study variables measured on sample plots within 50 m of yellow-poplar seed trees on control treatment (upper diagonal, n = 82) and the burned treatment (lower diagonal, n = 179)

Variable	Seedling density	Litter cover	Distance	Competition
	n/ha	%	m	n/ha
Seedling density (n/ha)	–	-0.99[a]	-0.02	0.17
Litter cover (%)	-0.45[a]	–	0.02	-0.17
Distance (m)	-0.26[a]	-0.06	–	-0.14
Competition (n/ha)	-0.15[a]	0.10	0.11	–

[a] $p < 0.05$ (two-tailed)

Table 4—Comparison of sequential Poisson models based on Akaike's Information Criterion (AIC), deviance explained and pseudo R^2 for yellow-poplar seedling density two-years after a growing season prescribed burn in upland oak forests of the southern Appalachian Mountains (n=179)

Model formulation	df	AIC[a]	Deviance	R^{2b}
Null	178	—[c]	11903.5	—
COM[d]	177	12353.7	11484.1[e]	0.04
DIS	177	11738.6	10869.0[e]	0.09
LIT	177	9937.4	9067.7[e]	0.24
LIT+COM	176	9731.2	8859.6[e]	0.26
LIT+DIS	176	8624.6	7753.0[e]	0.35
LIT+DIS+COM	175	8517.9	7644.3	0.36

[a] Akaike Information Criterion; smaller values indicate a preferred model with fewest variables that provides an adequate fit to the data; models are ordered by decreasing AIC.

[b] Pseudo R^2 calculated as 1-(SS model/SS total).

[c] Not applicable.

[d] COM, competition from regeneration of species other than yellow-poplar; DIS, distance from the seed tree to a maximum of 50 m; LIT, leaf litter remaining on the forest floor post burn.

[e] Deviance explained by this model formulation differs significantly from the model above; chi-square $p < 0.05$.

variable model was not significantly better ($p = 0.0502$) than the best two-variable model, which included only LIT and DIS, and accounted for approximately 35 percent of the variation of DEN.

The relationship of yellow-poplar seedling density with DIS and LIT is shown in Figure 2. The model trend lines suggest that yellow-poplar seedlings could be established at distances farther than 50 m from seed trees, which agrees with my field observations. The best model also supports my field observations that competition from seedlings and sprouts of other species was a variable minimal influence of DEN on some sample sites, but was not a consistent significant source of variation at the end of the second growing season. However, because of the likely rapid growth rate of competition from sprouts, particularly red maple and oaks, coupled with canopy shade on the forest floor and intolerant yellow-poplar seedlings, COM will probably be a factor of subsequent greater importance.

SUMMARY AND CONCLUSIONS

Results of this study supplement the sparse information available on the effects of prescribed burning on regeneration of yellow-poplar. Shearin and others (1972) and McNab and others (2013) reported that prescribed burning can increase regeneration of yellow-poplar on mesic sites, apparently by promoting germination of

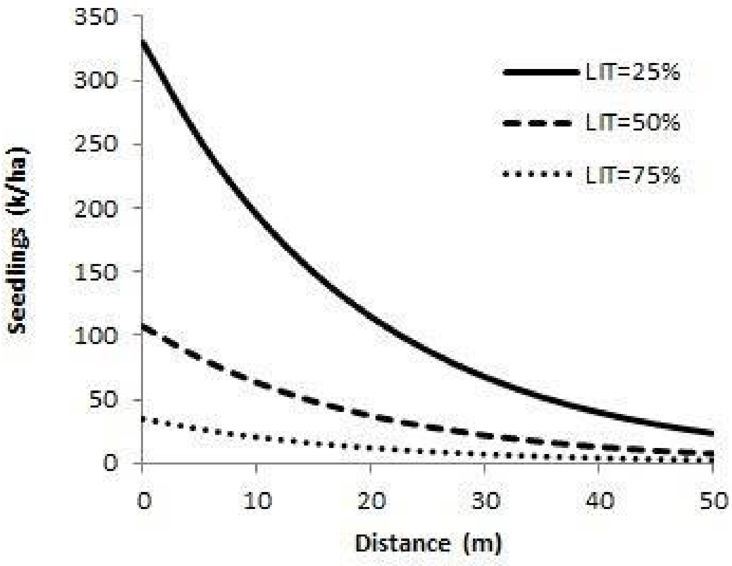

Figure 2—Estimated density of yellow-poplar regeneration following a single growing season prescribed burn in relation to distance from seed trees and three levels of litter cover (LIT25%, LIT50%, LIT75%) on the forest floor.

stored seeds in the forest floor. Although much research has been directed toward description of yellow-poplar seed shadows and quantification of seed production, this study is among the first to use a designed study with replicated treatments to identify factors affecting establishment of regeneration, particularly in relation to prescribed burning. Of the three variables investigated in this study affecting the density of one and two year old yellow-poplar regeneration after a single prescribed fire, the amount of leaf litter on the forest floor was found to be the most important explanatory factor.

It is doubtful that yellow-poplar regeneration will be competitive on this dry site, particularly because shade from the over story and sprout competition will likely retard height growth of this intolerant species. This study does demonstrate the potential for establishment of yellow-poplar regeneration from scattered seed trees in a predominantly oak stand, particularly if silvicultural activities were planned following burning, such as thinning or harvest. If yellow-poplar regeneration is not desirable on dry sites such as this, then a series of prescribed burns will be needed to control the currently established seedlings, exhaust remaining seeds that might be stored in litter on the forest floor and prevent accumulation of seeds in the forest floor resulting from annual production.

Results from my preliminary study leaves many questions unanswered. For example, will the one and two year old yellow-poplar seedlings have high mortality rate during beneath the closed oak canopy in following years? Is the observed regeneration of yellow-poplar seeds typical or the result of a fortuitous combination of above average seed production followed by above average precipitation, which allowed unusually high seedling germination? Was the buried seed bank exhausted by a single burn, or is a series of closely spaced repeat burns needed to accomplish that? What is the rate of seedling establishment on burned seedbeds from annual yellow-poplar seed fall? Also, because so little of the variation of yellow-poplar regeneration was explained by the variables examined in this study (about 35 percent), future study should include other variables potentially influencing regeneration of yellow-poplar. Follow up study is particularly desirable at other locations distant from Bent Creek Experimental Forest, with different soils and weather conditions during the growing season.

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