Site Quality in Relation to Damage by Locust Borer, *Megacyllene robiniae* Forster in Black Locust[1]

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Abstract Forty-three study sites within eight counties in Maryland were utilized in an investigation of Site Index in relation to attack by the locust borer, *Megacyllene robiniae* (Forster), on the black locus tree, *Robinia pseudoacacia* L. In addition, several other factors related to borer attack intensity were tested for relationship with Site Index of black locust. Site Index was found to be negatively correlated with borer tunnels per tree, i.e., sites with higher Site Indices had statistically fewer borer attacks per tree. Positive correlation was also inferred between Site Index, borer attacks, and (1) scarring from previous year's borer attacks, (2) herbaceous biomass within-site, (3) elevation above sea level, (4) soil factors, including pH, %sand, silt, and clay.

Key Words black locust tree, *Robinia pseudoacacia* L., locust borer, *Megacyllene robiniae,* tree vigor, site quality, Site Index.

The black locust tree, *Robinia pseudoacacia* L. (Family Leguminosae), is a high-value species, native originally to the Appalachian and Ozark highlands (Cuno 1930), but has been planted extensively throughout the United States and abroad. The wood is valued for its strength and resistance to rotting, and trees are planted as pioneer, nitrogen-fixing species for reclamation of barren, stressed, and depleted soils. It is severely damaged by the larval stage of the locust borer, *Megacyllene robiniae* Forster (Coleoptera: Cerambycidae), which mines sapwood and heartwood.

The locust borer is considered primary in habit, with ability to invade living trees, although a more common habit of the Cerambycidae is to be secondary, or capable of invading only dead, dying, or weakened trees (Nielsen 1981). Nonetheless, damage by the locust borer is more severe on unfavorable growing sites, i.e., off-range, nutrient-poor, depleted, or disturbed (Hopkins 1907, Hall 1942, Berry 1945, Harman et al. 1985). The locust borer is host-specific to black locust, has but one generation per year, and requires living host material for its development. Adults congregate on flowers of goldenrod (*Solidago* spp.), and may concentrate at woods-field fringes (Harman and Harman 1987).

For the forester, management and silvicultural decisions are often based upon best judgment using the tools at hand. One such tool, the Site Index (Wenger 1984),

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assumes that better sites will produce taller trees at a given age. The Site Index concept is used in evaluating woodland sites for particular tree species as discussed by Avery and Burkhart 1983. Mean height of dominant and co-dominant trees at a given site, in even-aged stands at some index age (usually 50 years), is used in the United States as the index of site quality, and is called Site Index. Growth in height of most commercial tree species has been found to be independent of stand density and strongly related to site quality, whereas trunk diameter at breast height (dbh) is related to stand density (Wenger 1984), in addition to other factors.

The objective of this study was to attempt to relate locust borer damage intensity to site quality, and particularly to Site Index, as a predictive tool. Also, several tree vigor measurements which have been used in the past to predict borer damage, were tested for correlation with site index, with the goal of more firmly evaluating their relation to borer attack rates. Whereas site quality was observable as a factor in growing black locust, it was presented as an unquantified observation in many early studies. Few, if any authors, have attempted to relate locust borer attack intensity to Site Index, nor could any references be found relating black locust vigor indices to Site Index.

Materials and Methods

Forty-three study sites composed predominantly of black locust, with representatives among the geographic provinces in the mid-Atlantic region (Coastal, Piedmont, Ridge and Valley, and Allegheny Plateau) were utilized. Stands of similar-sized, 7 to 13 m tall, medium-aged (15 to 40 yrs) trees, were selected and grids at 10 × 10 m were established in each stand. Two study plots, 10 × 10 m, were selected randomly from the grids. All black locusts within the study plots were mapped and tagged. The following variables were recorded for each tree: (1) height; (2) diameter (dbh); (3) tree age and periodic growth rate (radial stem growth past 10 years) using increment borings; (4) bark and sapwood thickness; (5) tree dominance class, i.e., dominant, co-dominant, intermediate, suppressed; (6) electrical resistance (kilohms) of cambium to pulsed electrical current using a Shigometer model OZ (Ozmose Wood Preserving Co. of America, Buffalo, NY). In applying the Shigometer, three readings/tree/visit were taken at breast height and at random compass direction on the trunks. Higher readings, indicating greater resistance to conductivity, indicate reduced tree thrift (Shigo 1982, Wargo and Skutt 1975).

Current-year tunnels were counted on each tree, as evidenced by emission of boring dust and/or sap, to height of 6 m on trunks. Previous year's borer attacks were also counted, using old scars, swellings, holes, and cankers. Survival of invading larvae to adult stage was assessed by trapping adults as they emerged from mines, using screen traps stapled over entrances. A random sample of mines, considered active by presence of boring dust, were trapped in this manner. If no adult emerged by December, the insect was assumed to have died in the tunnel.

Some additional data were recorded from each site, including the following: percent slope; elevation; understory plant biomass (oven-dried, from one plot, 1 m^2); plant diversity (identity and numbers) of woody and herbaceous plants, taken from a 2 × 10 m transect through study plots; and basic soil analysis (K, P, Mg, texture, and pH).

Results were analyzed using University of Maryland IBM system. The Statistical Analysis System, version 5 provided necessary applications. All variables were examined for normality by univariate tests and non-parametric analyses were conducted, as normality assumptions for parametric ANOVA were not satisfied. Data were analyzed using Pearson product-moment correlation coefficients, nonparametric ANOVA (Kruskal-Wallis test), and the Dunnett's multiple comparison procedure (Dunnett 1955). The Kruskal-Wallis method tests the null hypothesis that a group of independent samples are from an identical continuous population. To apply the Pearson test, product-moment correlation coefficients were calculated using all significant variables from the univariate test to determine independent relationships. Significant variables ($P = 0.05$) were examined further. Pearson correlation coefficients ranged from −1.0 to +1.0. A coefficient of zero suggests no linear relationship between the two variables, whereas a coefficient of +1.0 indicates a perfect positive relationship and a coefficient of −1.0 indicates a perfect negative relationship. Graphics were used to enhance examination of values and their respective patterns. Experimental data were also tested using the Kruskal-Wallis test to determine differences in Site Index means calculated by Dunnett's multiple comparison procedure. For the Dunnett procedure, critical difference values and significant values were calculated using the following formula: $/\bar{R} - \bar{R}/ \geq t - (z/2)\sqrt{\{(N)(N + 1)/N - k\}\{(1/n + 1/n)\}}$ where $\bar{R}$ and $\bar{R}$ are the rank sums of the two samples, t − (z/2) is the quantile obtained from a quantile distribution table with N − k degrees of freedom and N equals the ranked study sites and n equals the numbers of trees within a sample. If the absolute value of the difference between $\bar{R}$ and $\bar{R}$ is greater than or equal to the critical difference value, then the difference in the value in question is significant.

Results and Discussion

The study sample of 437 trees was subjected to Site Index curves prepared by Kellog (1936) for black locust in the central states. For each tree, height was plotted against age to obtain a Site Index reading. Readings from individual trees were averaged to obtain a mean Site Index value for each study site. To facilitate comparison, Site Index values for sites were divided into three classes as follows: (1) poorest, 9.1 to 11.9 m (mean age 17.6 yrs); (2) intermediate, 12.0 to 14.9 m (mean age 18.5 yrs); (3) best, above 14.9 m (mean age 16.5 yrs). Distribution of trees among site quality and Site Index classes is shown in Table 1.

Borer tunnels/tree/site decreased significantly as site quality (expressed as Site Index) improved (Table 1). Active larval tunnels decreased from 4.69 per tree in class 1 (poorest sites) to 0.90 in class 3 (best sites). The Kruskal-Wallis test, and Dunnett's multiple comparison procedure indicated significant differences in tunnels/tree/site

Table 1. Borer tunnels for current season per tree and site by Site Index class

Site Index class	Value range (m)	Average tree age (yrs)	Mean site index value (m)	Number of sites	Number of trees	Borer tunnels/tree		
						Mean	Std. error	Range
1-poorest	9.1-11.9	17.6	10.5	16	176	4.69	1.77	0-49
2-intermed	12.2-14.9	18.5	13.3	20	206	1.66	0.64	0-18
3-best	>14.9	16.5	15.9	7	55	0.9	0.85	0-12

between classes 1 and 2, 1 and 3, and 2 and 3 (Table 2). Correlation analysis inferred a significant negative relationship between Site Index values for the 43 study sites and borer tunnels/tree/site ($P = 0.031$). A low R value (0.108) was obtained, indicating that only a low percentage of variability in the data was explained in the analysis.

Several other variables which have been used in prediction of locust borer damage were tested for correlation with Site Index. Soil factors measured herein, i.e., pH, phosphorus, magnesium, and potassium were significantly related to Site Index, as shown in Table 3. Means for each of the soil chemistry factors (pH, Mg, P, K) were considered low in agricultural terms (personal communication, Southern States, Inc., soil testing service, Cumberland, MD). Soil texture (%sand, silt, clay), however, did not vary substantially among Site Index classes, and were not correlated with it. Elevation of study sites, which varied from 60 to 820 m, was correlated (inversely) with Site Index class ($P = 0.048$; $R = 0.09$). Again, variability was high, as reflected by the R value. Herbaceous biomass (dry wt) was also inversely correlated with Site Index. As expected, better sites produce more herbaceous biomass possibly enhanced by nitrogen-fixing activities of black locust. Mean dry weights of herbaceous biomass for Site Index classes (poorest, intermediate, and best) were 242, 229, and 118 gm, respectively. As with current year's borer attacks, scars from previous year's attacks were correlated with Site Index. Three types of scars on tree trunks, as previously described by Harman and Dixon (1984), i.e., stellate (star-shaped) scars, holes (unhealed), and swellings, were tested. Among the several scar types, only stellate scars and holes were correlated with Site Index; swellings were not significantly different among Site Index classes.

Resistance to pulsed electrical current in the cambium layer did not prove to be correlated (95% level) with Site Index. However, as a generality, lower numerical means in Shigometer readings accompanied higher Site Index values. For Site Index classes (poorest, intermediate, and best) mean Shigometer readings were: 8.79, 8.23, and 8.06 kilohms, respectively. Cambial electrical resistance was correlated with periodic growth rate, which in turn was correlated with Site Index class ($P = 0.04$).

Current borer tunnels/tree/site were compared against site and vigor factors listed above, and tested for correlation using the Pearson correlation coefficient analysis. Results are shown in Table 4. Correlation (95% level) was indicated between borer tunnels/tree/site and (1) cambial electrical resistance (inverse), (2) sapwood thickness (inverse), (3) periodic growth rate for past 10 years (inverse), (4) numbers of

Table 2. Numbers of current borer attacks per tree per site by Site Index class, compared statistically

	ANOVA, Kruskal-Wallis		
Site Index class comparison	Mean scores	Mean score differences	Critical difference values
1 vs 2	265.46	68.97	>31.04*
1 vs 3	196.49	110.8	>46.72*
2 vs 3	154.65	111.84	>45.90*

* Significantly different, utilizing Dunnett's multiple comparison procedure (Dunnett 1955).

Table 3. Average measurements of various soil factors by Site Index class

Site Index class	pH Mean	pH Range	Mg (ppm) Mean	Mg (ppm) Range	P (ppm) Mean	P (ppm) Range	K (ppm) Mean	K (ppm) Range
	Soil pH and macronutrient values and ranges*							
1-poorest	5.49	4.3-7.20	125.65	25-580	3.78	1.0-25.90	108.93	25-270
2-inter	5.97	4.5-7.30	148.30	10-255	2.98	1.0-11.10	90.93	30-185
3-best	5.83	4.7-6.50	151.45	30-275	2.77	1.0-07.80	117.09	30-215

* Means per site class for all values, pH and macronutrient, were considered low (pers. comm., Southern States, Inc., soil testing service). Suggested intermediate values (ppm) for these factors were: Magnesium, 175-180; Phosphorus, 180; Potassium, 125-200; pH, near 7. Nonparametric ANOVA (Kruskal-Wallis test) and Dunnett's multiple comparison procedures inferred the following significant differences: pH, Site Index 1 vs 2, 1 vs 3; Mg, Site Index 1 vs 2, 1 vs 3; Phosphorus, Site Index 1 vs 3, 2 vs 3; Potassium, Site Index 2 vs 3.

unhealed holes of past attacks (direct), (5) herbaceous biomass (dry wt) (direct), and (6) elevation of site above sea level (direct).

More accurate predictability of the amount of borer damage on a given site, based on a measurable quantity, the Site Index, can improve black locust management. Sets of Site Index curves for restricted localities within the range of black locust, as for other species, are desirable (Wenger 1984), but the task is large.

Ranking of sites into three classes, based on Site Index values, facilitated statistical comparison somewhat, but overall results differed little from comparison of unsegregated values.

The tests for correlation between Site Index and several additional factors associated with borer attack intensity in prior studies were also promising, although unanswered questions remained. Resistance in cambium layer to pulsed electric current failed to correlate with Site Index, possibly because Site Index is based upon readings from only dominant and co-dominant trees, which may have been too similar physiologically to show a difference in conductivity. Site Index is also a long term measurement of growth whereas electrical resistance in the cambium relates only to a brief point in time. The Shigometer has validity in evaluating vigor of individual trees, reported from some species (Blanchard et al. 1983). Correlation of cambial electrical resistance with periodic growth rate, which was in turn correlated with Site Index, indicated some type of association, if not a significant one.

Three additional factors of elevation, herbaceous plant biomass, and soil factors have a probable interrelationship. Sites from higher elevations had lower Site Index values and was possibly associated with soil factors. The impact of strip-mined soils on borer attack intensity has been shown in past studies (Harman et al. 1985), and the implication of soil effects on locust tree vigor is suggested by others (Hopkins 1907, Hall 1942, Berry 1945). Higher pH accompanied improved Site Indices in this study, supporting the observation that locust grows better on limestone soils.

The data further supported an inverse relationship between locust borer attack and tree vigor, using various factors to measure vigor, and pointed to multiple interacting factors. Borer attacks per tree were correlated with most tree factors tested. A larger database is probably required for improvement in predictability.

Table 4. Pearson correlation coefficient analysis showing association of borer attack intensity with several variables in relation to Site Index classes, and a continuum of all 437 trees

		Number of attacks per tree Site Index categories			
Variables		Poorest (176 trees)	Intermediate (206 trees)	Best (55 trees)	Continuum (437 trees)
E.R. reading	r:	−0.184	0.040	−0.041	−0.098
	p:	0.014*	0.561	0.765	0.034
Bark thickness	r:	−0.043	−0.170	−0.452	−0.023
	p:	0.056	0.014*	0.0005*	0.623
Sapwood thickness	r:	0.223	−0.093	−0.082	0.094
	p:	0.002*	0.182	0.550	0.042
DBH	r:	−0.093	0.199	−0.406	−0.056
	p:	0.217	0.004*	0.002*	0.227
Periodic growth	r:	0.144	−0.111	−0.186	−0.041
	p:	0.055	0.109	0.171	0.373
Stellate scars	r:	0.204	−0.021	−0.029	0.186
	p:	0.006*	0.763	0.831	0.0001
Hole scars	r:	0.117	−0.090	0.206	0.193
	p:	0.119	0.195	0.129	0.0001*
Swell scars	r:	−0.055	0.049	−0.055	0.001
	p:	0.466	0.480	0.689	0.970
Dry biomass	r:	0.240	0.191	0.590	0.228
	p:	0.0007*	0.005*	0.0001*	0.0001*
Elevation	r:	0.351	0.295	0.522	0.384
	p:	0.0001*	0.0001*	0.0001*	0.0001*

* Significant value at the 0.95 confidence.

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