METHODOLOGY FOR RATING *Pinus taeda* STANDS FOR PINE TIP MOTH, *Rhyacionia* spp. INFESTATION (LEPIDOPTERA; TORTRICIDAE)

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RESUMO

Metodologia para Prognose do Risco de Infestação de Talhões de *Pinus taeda* pelas Mariposas dos Ponteiros *Rhyacionia* spp. (Lepidoptera: Tortricidae)

Os danos causados nos ponteiros de mudas de *Pinus taeda* com 1 a 5 anos de idade pela mariposa dos ponteiros do pinos (MPP), *Rhyacionia frustrana* (Comstock), acarretam perdas de crescimento em altura, volume e forma das árvores. O objetivo deste estudo foi desenvolver modelos de regressão para prognose de infestação das MPP e desta forma classificar áreas já plantadas ou em fase de implantação em alto ou baixo risco. Quarenta parcelas medindo 25 x 20m foram instaladas em plantios de *P. taeda* na Região Costal da Georgia e Carolina do Sul. Em cada parcela quinze árvores alternadas em três linhas aleatorizadas foram marcadas e amostradas durante cada uma das gerações estudadas da praga. Todos os ponteiros foram examinados e classificados como sadios ou infestados em povoamentos com dois anos e 3 anos de idade. Em cada parcela foram medidas as variáveis da árvore, variáveis fisiográficas e variáveis vegetativas. A análise da variança detectou diferenças significativas entre as percentagens médias de infestação justificando o desenvolvimento de modelos individuais para cada geração das MPP. Análise de regressão foi utilizada para desenvolver modelos lineares e logarítmicos. Os modelos apresentaram coeficientes de determinação que variaram entre 59,0 e 68,1%. A validação dos modelos mostrou uma alta percentagem de acerto nas prognoses.

PALAVRAS-CHAVE: Insecta, mariposa dos ponteiros dos pinos, *Rhyacionia frustrana*, modelagem, análise de regressão.

ABSTRACT

Pine tip moths, *Rhyacionia* spp., damage to the shoot tip in one-to-five-year old loblolly pines (*Pinus taeda*) causes losses in tree height growth, form and volume. The purpose of this study was to develop models to predict pine tip moth infestation and thereby rate loblolly pine stands as high or low hazard. Forty plots of 25 by 20 meters were installed in loblolly pine stands in the Coastal Plain of Georgia and South Carolina. Fifteen alternate trees in three randomly selected lines where permanently sampled in each plot. All available and infested shoot tips were counted in each sample tree for third plus fourth *R. frustrana* (Comstock), (Nantucket pine tip moth) generation in 2-year-old seedling and in first, second and third plus fourth *R.*

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frustrana generation in 3-year-old seedlings. The independente variables measured included tree, physiographic and vegetative variables. Analysis of variance detected significant differences among mean percent infestations justifying the development of separate models for each generation of *R. frustrana*. Stepwise regression analysis was used to develop linear and logarithmic models. Developed models had R-squares that varied between 59.0% and 68.1%. Validation showed a high percentage of correct classification for all models.

KEY WORDS: Insecta, Nantucket pine tip moth, *Rhyacionia frustrana*, modeling, stepwise regression analysis.

INTRODUCTION

The identification of critical factors correlated to insect population outbreaks and quantification of the resulting damage are useful in developing hazard rating systems for predicting future incidence or damage severity. Indeed, risk-rating systems have become an important tool in the decision-making process for forest management (Hedden 1980). Pine tip moths, *Rhyacionia* spp. (Heinrich) (Lepidoptera: Tortricidae) are perhaps the most serious insect pest of young even-aged loblolly pine, *Pinus taeda* stands in the southeastern United States (Berisford 1988). The most common effects of the attack are the loss of the tree form and height growth (Berisford 1988, Berisford *et al.* 1989, Yates & Beal 1971). However, researchers have also related tip moth damage to losses in tree diameter and volume (Cade & Hedden 1987) wood quality (Hedden & Clason 1980) conelet production (Ebel *et al.* 1975) and increasing infections by fungal diseases (Powers Jr. & Stone 1988). The injury to conductive tissue often causes death to 15 cm of the shoot (Berisford & Ross 1990). The recovering tree usually develops a few to several lateral buds which compete for dominance resulting in a bushed, multiple stemmed tree (Berisford 1988). Tip moth injury to the shoots hampers the growth of new foliage, so less photosynthetic area is available resulting in loss of diameter growth . Larval damage may also create infection courts for the fusiform rust fungus *Cronartium quercuum* (Berk.) Miabe ex Shirai f. sp. *fusiforme*. (Powers Jr. & Stone 1988).

The objective of this study was to develop a hazard-rating system to predict pine tip moth infestation level in loblolly pine plantation. The models presented here can provide pine growers with a tool to help identify the relative susceptibility of a site to pine tip moth infestation guiding forest managers in establishing realistic control strategies.

MATERIAL AND METHODS

Sampling procedure. The study areas were established in the Coastal Plain region in the middle and flatland provinces of Georgia and South Carolina. Site preparation consisted of shearing, raking, chopping, burning, harrowing, and bedding. Stands in South Carolina were abandoned pastures and had no site preparation. Stands receiving chemical site preparation were not included in the study. All the areas had been machine planted with genetically improved loblolly pine seedlings on a 1.80 by 3.10 m spacing during the winter of 1988-89. Thirty-two sample plots were established in Georgia, and eight sample plots were located in South Carolina. Each plot measured 20 by 25 m. Fifteen permanent sample trees on each plot were chosen alternately in 3 randomly selected rows. The experiment began in the winter 1990-91 with all the trees entering their third growing season.

Variables Used to Develop the Models. Dependent Variable. The total number of available shoot tips and the number of infested shoot tips were counted for combined third and fourth generations of *Ryacionia frustrana* (Comstock), the Nantucket Pine Tip Moth (NPTM) in 1990 and for first, second and third plus fourth generations in 1991. The third and fourth NPTM generations were sampled together due to extensive lifestage overlap; thus, they were regarded as the fourth generation. The percentage of infested shoots for each sample tree was calculated and the mean percentage of infestation per plot was the average per tree percentages. **Independent Variables.** The whole methodology presented below was conducted for each plot: Tree Variables - Height and Diameter = The total height and diameter at 15 cm above groundline of the sampled trees were taken every time NPTM damage was assessed. The final height and diameter were the average of the sampled trees; Root depth = The mean vertical length of the complete root system of two randomly chosen trees was measured. Physiographic Variables - Slope = The slope was the average of three slope measurements taken from the first plot corner to the opposite corners using and optical clinometer and expressed as percent of slope; Soil texture = Soil samples were taken from the bedding at 10 and 20 cm deep in three random points and analyzed by the hydrometer method; Soil bulk density = Two random samples were taken in the beds at 0-5 cm deep using the core method (Blake 1965); Available water = It was estimated on a volume basis from the formula by Peele *et al.* (1970) without considering runoff or evaporation: cc/cc = (Field Capacity - Wilting Percentage) x Bulk Density; Soil "A" horizon = It was the average depth of the "A" horizon measured in two random soil pits excavated in the bed; Soil nutrients = One soil sample was extracted from the mixture of three random soil samples collected from the bedding at 10 cm. The determination of phosphorus, potassium, calcium, and magnesium followed the Mehlich I extraction method (University of Georgia 1983); Soil pH = The soil pH was determined in the same soil samples used for nutrient analysis in a 1:1 water/soil solution using a pH meter (University of Georgia 1983); Organic matter = Plot soil samples were collected at 0-3 cm depth at three random points, mixed and reduced to one sample; and Site index = The site indexes were taken from the forest inventory records of the local companies. Vegetative Variables - Grass vegetation = Four vegetative plots measuring 1.0 x 1.0 m were established at random (Zutter *et al.* 1986). All the vegetation was clipped at groundline, separated into the classes grass or woody, bagged and dried to a constant weight at 70°C (Zutter *et al.* 1986). Total grass biomass was the average dried weight of the four vegetative plots; and Woody vegetation = The sampling and laboratory procedures were the same as described for grass vegetation. Woody vegetation was defined as non-pine trees, shrubs, vines, herbs, and canes.

Data Analysis. General Analysis = The mean percent infestation for each NPTM generation was subjected to analysis of variance F-test ($P < 0.05$ ANOVA), compared and separated by Tukey's Studentized Range Test (Tukey 195385xsw2) (SAS Institute Inc. 1985). **Analysis of Each NPTM Generation**. Prior to analysis, a qualitative variable (TYPE) was introduced to discriminate between Georgia and South Carolina plots in case of possible differences. A logarithmic transformation of the data set was used in some analyses because there was the possibility that some of the independent variables were not linearly correlated to the percentage of infestation. For each NPTM generation the forward stepwise method was employed separately for the linear and logarithm models using the maximum R-square and the significance of partial F-statistics as criteria for variable selection. In this procedure a probability level equal to 0.15 was used to allow a greater number of variables to be included in the predictor model. The final empirical model for each NPTM generation was the result of the stepwise regression analysis (SAS Institute Inc. 1985) ($P < 0.05$) starting with the best variables selected in the previous linear and logarithm stepwise analyses.

Validation of the Empirical Models. The prediction sum of squares (PRESS) selection was used as validation procedure for the best-fitted equations. This criterion was defined by Allen (1971):

$$PRESS = \sum_{i=1}^{n} [Y(i) - \hat{Y}(i)]^2$$

where Y(i) is the observed value for observation "i" , and $\hat{Y}_{(i)}$ is the presss predicted value for the observation "i" excluding the i-th observation. First of all, one observation was left out of the data set either for the response or predictor variables and the appropriate model was fitted to the remaining n - 1 data points. The model was then used to predict the deleted observation resulting in the PRESS predicted value. The procedure was repeated until all the observation had been predicted by the model and so to obtain the difference between the observed value and the predicted value for infestation (SAS Institute Inc. 1985). The median value of percent infestation was calculated for the generation corresponding to each model and used as a discriminant value between low and high infestation levels. Each plot was analysed simultaneously for the observed percent infestation and PRESS-predicted value for infestation and classified as high hazard or low hazard when it had respectively both values larger or smaller than the median. The percent of correct classification for each model was the ratio between the number of plots classified as high hazard plus the number of plots classified as low hazard divided by the total number of plots.

RESULTS AND DISCUSSION

General Analysis. Table 1 shows a summary statistics of percent infestation per NPTM generation and stand age. The analysis of variance F-test ($P < 0.05$ ANOVA) detected a highly

Table 1. Summary statistic for percent infestation per Nantucket pine tip moth generation, ANOVA test and median values for hazard rating classification.

Generation/ Stand Age	Mean % infest.	Std. Dev.	Range	Median
4/2	30.77 b	10.16	13.95 - 54.90	28.40
1/3	21.81 a	8.16	6.20 - 38.86	20.13
2/3	32.43 b	13.06	11.09 - 68.26	30.62
4/3	58.93 c	13.91	18.77 - 75.56	62.46

significant F-value indicating differences among the mean percent infestations ($F = 74.94$; df = 3, 156; $P = 1.0$ E-4). The highest mean NPTM infestations were observed in the fourth generation in 3-year-old stands. The results are consistent with normal NPTM population growth trends, increasing from the second year, growing rapidly during the third year after planting (Berisford 1988). This fact is related to the insect population build up in the previous generations and/or may be it is related to increasing nitrogen levels in the shoots by the end of the autumn (Smith *et al.* 1971). The highly significant differences among infestation means necessitated development of separate models for each one of the NPTM generations. In fact, environmental factors such as soil fertility, soil moisture, and concurrent vegetation acting upon developing seedlings may vary in their influence seasonally as the tree grows, thereby influencing foliar concentration of macro and micronutrients and carbohidrates mediating its relationship with its insect guild (Edwards & Wratten 1980). The separate analysis for each

Table 2. Definition, units of measure and summary statistics of variables used to develop hazard rating models for pine tip moth in Coastal Planin of Georgia and South Carolina.

Variable	Definition	Unit	Mean	Std.Dev.	Range
		Tree Variables			
H	total tree height	m	1.56	0.63	0.58 - 3.28
D	stem diameter at 15 cm	cm	3.08	0.92	0.90 - 6.10
RS	mean total length root system	m	0.70	0.22	0.39 - 1.17
		Physiographic variables			
SLOPE	average incline	%	2.05	2.15	0.17 - 9.95
SND10	sand content at 10 cm	%	85.09	5.51	65.67- 93.01
SLT10	silt content at 10 cm	%	7.10	3.88	2.59 - 21.71
CLY10	clay content at 10 cm	%	7.81	3.46	4.34 - 24.01
SND20	sand content at 10 cm	%	84.88	5.68	67.17-93.57
SLT20	silt content at 20 cm	%	7.10	4.46	1.60 - 20.64
CLY20	clay content at 20 cm	%	8.03	2.44	4.83 - 14.31
BLKDS	bulk density	g/cc	1.15	0.28	0.47 - 1.67
AWxRS	available water capacity X root depth	cc/cc	12.40	5.98	2.13 - 25.62

Table 2. Cont.

Variable	Definition	Unit	Mean	Std.Dev.	Range
DAHOR	depth "A" horizon	cm	19.83	11.56	0.00 - 61.00
P	phosphorus	kg/ha	21.64	30.01	3.98 - 99.78
K	potassium	kg/ha	37.49	34.71	1.12 - 179.76
CA	calcium	kg/ha	348.64	201.52	102.01 - 850.53
MG	magnesium	kg/ha	56.09	47.00	13.45 - 262.86
PH	soil pH	moles/1	5.00	0.60	3.80 - 6.20
ORGAN	organic matter content	%	1.86	1.80	0.62 - 9.76
SI	site index at 50 years	m	64.40	11.65	50.00 - 90.00
Vegetative Variables					
GR	grass veg. biomass	g/m^2	207.54	143.96	0.0 - 647.50
WD	woody veg. biomass	g/m^2	195.30	135.26	15.75 - 505.75
Qualitative Variables					
TYPE	zero for GA plots one for SC plots				

NPTM generation allowed focusing on important periods of sapling development yielding the high R^2 values observed. The separate analysis reduced variability and increased precision and model fitness.

Analysis of Each Generation. The variable notation, definition, units of measure and summary statistics are presented on Table 2. The estimated coefficients, the best predictor variables and the fitted equation from final stepwise analysis for each NPTM generation is shown in Table 3. For two-year-old stands, fourth NPTM generation the fitted model accounted for 60.4% of variation in percent infestation observed in the field. For three-year-old stands, first NPTM generation, model 2 explained 61.8% of the total variation in the observed percent infestation. For second NPTM generation, all predictors together explained 62.2% of the observed variation in percent infestation. For fourth NPTM generation the multiple R^2 calculated for model 4 indicated that this model is the best-fitting of all accounting for 68.1% of variation in percent infestation.

Validation of the Empirical Models. Table 3 shows the values for percent correct classification for the best-fitting models. Values for percent correct classification express the usefulness of the equations in correctly classifying stands as high or low hazard to pine tip moth

Table 3. Best predicting equations along with percent of correct classification per generation for predicting pine tip moth infestation in two-(*) and three-year-old (**) loblolly pine in the Georgia and South Carolina Coastal Plains.

Model/Generation	Predicting Equation	Multiple-R^2	%Correct Classific.
1/4*	INF = 19.59280 + 8.65692D + 0.15572MG + 0.02243WD - 5.62369ORGAN - 1.57917 L DAHOR - 1.41653L GR	0.604	82.5
1/1**	INF = 21.10519 + 7.41222TYPE - 1.52310SLOPE - 0.0625lMG - 4.37019L SLT10 - 14.49140L H + 3.54604 L WD	0.618	85.0
3/2**	INF = 77.61884 - 13.22409 H - 1.64855SLT20 - 3.0884SLOPE - 0.12753 MG + 0.14664 P	0.622	80.0
4/4**	INF = 44.94496 - 30.58556TYPE + 1.35146SLT20 + 5.22889 H	0.681	82.5

attack. The good fit of the models is confirmed by the high percent of correct classification of stand as high or low hazard for pine up moth. Though the estimates obtained by least square regression are data-dependent, the values of percent for correct classification indicate that the models are correct at least 80% of the time. Hood *et al.* (1988) in developing a hazard rating system for pine tip moths in the Piedmont of South Carolina considered 75% as an acceptable level of accuracy. In this study all equations are useful for predicting percent infestation based on the observed significance values for the predictors, coefficient of determination and percent of correct classification. The results indicated that a strong relationship of cause and effect among predictors and response variable is present in all models. In general, loblolly pine plantations in the Coastal Plains incur high hazard to the pine tip moths when seedlings have large diameter and low height. Site factors relating to high hazard include reduced grass and higher woody vegetation biomass, lower percentage of silt, thinner "A" horizons, lower percent slope and higher phosphorus content. Experimentation and further research is advised to explore the causes for the observed statistical reationships and to improve the models.

Model Use and Applications. The use of the prediction equations presented here should be restricted to conditions similar to those observed in this study. Extrapolation beyond the areas where the evaluations were made may reduce prediction accuracy. Foresters have to obtain the necessary information on independent variables according to the age of the pine plantation and according to the NPTM generation under consideration. If the objective is to predict likely pine tip moth infestation levels in planted areas, height and diameter should be measured in random plots installed on the site following the described methodology. If the objective is to predict future infestations in areas not yet harvested, tree variables can be obtained from available forest inventories. Data on physiographic variables are obtained on soil inventories, otherwise field measurements and soil tests are necessary. Vegetation variables have to be measured at the site by the end of the summer following the described methodology. If the area is not planted, these variables could be measured on the nearest pine plantation of the same age and site index, and similar site preparation to proposed regeneration. In order to hazard rate plantations, the median percent infestation given in Table 3 can be used as a discriminant value to compare with the predicted infestation obtained from the appropriate equation. A stand is classified as high or low hazard to pine tip moth, respectively if the predicted value is higher or lower than the median.

The models presented here can be used to make relative estimates of future infestation or to rate existing plantations. Forecasting models can help the forest manager in the decision making process before regeneration by indicating need for gnetically improved seedlings or in choosing less susceptible pine species in high-risk areas. These models may also help the forest manager after stand establishment in assessing pine tip moth populations and in establishing control priorities.

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