Spatial Distribution of the Nantucket Pine Tip Moth (Lepidoptera: Tortricidae) in Newly Established Loblolly Pine Plantations[1]

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ABSTRACT The spatial distribution of trees infested by the Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock), was examined using random 36 tree samples taken from contiguous quadrats in eight loblolly pine plantations in their first and second year of growth in southwestern Arkansas. Infestations were distributed throughout first-year plantations by the end of the second tip moth generation. The distribution of infested trees was generally random in the first generation, with increasing aggregation in subsequent generations. Factors such as vegetation level may alter this pattern.

KEY WORDS Nantucket pine tip moth, *Rhyacionia frustrana,* dispersion, spatial autocorrelation, Lepidoptera, Tortricidae.

The Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock), is a pest of young, intensively managed pine plantations in the southern and eastern United States. Shortleaf pine, *Pinus echinata* Mill., and loblolly pine, *P. taeda* L., are the major hosts in Arkansas, where there are three complete tip moth generations per year. Though distribution of tip moth immatures in the tips, whorls, and between trees has been examined (Waters and Henson 1959, Eikenbary and Fox 1968), the pattern in which infested trees are distributed within plantations has not. Tip moth dispersion in plantations is important because temporally changing spatial patterns may indicate behavioral changes in the population or shifts in the effects of density dependent and independent factors (Southwood 1978). Population dispersion information is also essential for devising sampling schemes and the analysis of data. The objectives of this study were: 1) to determine when initial infestations begin in loblolly pine plantations and how these spread, and 2) to determine what pattern initial infestations take and if changes in dispersion occur during the early stages of tip moth population growth within new plantations.

Materials and Methods

The study was conducted in southwestern Arkansas in the summer of 1981, utilizing four first-year loblolly pine plantations entering their first growing season, labelled 1A-1D, and four second-year plantations entering the second growing

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season, labelled 2A-2D. The plantations ranged in size from 32-88 ha, with tree spacing at 1.3 by 2.4 m.

Each plantation was divided into one-ha quadrats, with the tops of all quadrats to the north. Complete, rectangular grids were not possible due to irregular plantation borders and intervening ponds and hardwood areas, so the number of quadrats did not equal plantation size. Each quadrat was subdivided into 25 subplots, with one subplot per quadrat randomly selected for sampling. Sampling began at the southwest quadrat corner. Thirty-six trees per subplot were sampled, with six rows of six trees used when possible. Tree height and number of infested tips were recorded for each tree, with total tips counted for half of the trees in each subplot.

First-year plantations were examined in all three tip moth generations. The same 36 trees were checked each generation if possible. Second-year plantations were sampled only during the first tip moth generation. Non-destructive sampling was employed, with shoots considered infested based on external damage characteristics. Trees examination began when tip moth pupae were found in surrounding areas.

Total tips per tree, trees infested per 36-tree sample, and infested tips per quadrat sample were analyzed using PROC GLM (SAS 1982), with the 36-tree subplots as the experimental units. Means between generations were compared by Duncan's multiple range test (Duncan 1955), and each plantation was analyzed separately.

The variance/mean ratio was used to evaluate if the quadrat samples of infested trees were randomly or contagiously distributed. Random distributions would have a variance/mean ratio of approximately one, while aggregated distributions would have a ratio greater than one. The distributions were tested using the index of dispersion, $(x_j\text{-}x)^2/x$. This sum is approximately distributed as a chi-square variate (Pielou 1969), and the probability of obtaining the values of the indices of dispersion were determined from a chi-square table ($P \leq 0.05$), using the null hypothesis that the distribution was random.

The index of clumping (David and Moore 1954) was used as a measure of aggregation. This index was calculated by $I = (s^2/x)\text{-}1$, and increases with increasing aggregation. The degree of aggregation within plantations between generations was tested using $w = \text{-}0.5 \ln((V1/m1)/(V2/m2))$, where V1 and V2 are the variances and m1 and m2 are the means of the generations. If w was outside the range $\pm\ 2.5/\sqrt{(n\text{-}1)}$, the indices differed at the five percent level (David and Moore 1954).

The use of contiguous quadrats and the fact that quadrat counts in a plantation may not be independent suggested spatial autocorrelation for examining the dispersion of tip moths throughout plantations. Plantations with aggregated distributions of infested trees were tested for positive or negative spatial autocorrelation using the coefficients of Moran (1950) and Geary (1954). Under the null hypothesis of no correlation, Moran's $I = 0$, with $I > 0$ indicating positive spatial autocorrelation and $I < 0$ negative correlation. Geary's coefficient yields $C < 1$, $C = 1$, and $C > 1$ for positive, no, and negative autocorrelation, respectively. The coefficients were evaluated as standard normal deviates.

Numbers of infested trees and numbers of infested tips per quadrat sample were tested within each generation using neighbors with a common border or neighbors with a common border or vertex. Spatial autocorrelation was assumed even if only one test proved significant. Two weighting systems were used. In the first, each neighboring count received equal emphasis, while in the other the weights were scaled to a sum of one, so that higher counts received more emphasis. The weighting schemes used converted counts to percentages, and an arc-sine transformation was used to reduce inherent variation.

Results

First-year plantations had very few infested trees during the first tip moth generation, and numbers of infested trees increased in the second generation (Table 1). Plantation 1D had the highest number of total tips, mean infested trees and mean infested tips per quadrat sample in the second generation. The number of infested trees increased significantly during the third generation in plantation 1D while remaining fairly stable in the other three. Infested trees per quadrat sample, infested tips per quadrat sample, and total tips were again highest in plantation 1D. Mean total tips increased significantly each generation in all four plantations.

Among second year plantations, all 36 tree quadrat samples contained at least 1 infested tree (Table 1). Means of infested tips and trees per quadrat sample were all lower than that found for plantation 1D in the third generation, though means of total tips per tree were higher.

Low populations in the first tip moth generation in first-year plantations precluded testing the distribution of infested trees, though the few infested trees encountered appeared randomly distributed. Chi-square tests for the variance/mean ratio were significant for all four plantations in generations two and three (Table 2), indicating contagious distributions. Plantations 1A and 1C retained ca. the same number of infested trees from generation two to three, but the distribution became slightly more aggregated as indicated by increased indices of clumping. Plantation 1B exhibited opposite results, the distribution becoming slightly less aggregated. However, none of the changes in the indices of clumping between generations for these three plantations were significant. The distribution of infested trees in plantation 1D became significantly more aggregated from generation two to three as the range of the number of trees infested per 36-tree sample increased substantially.

Plantation 2A was the only second-year plantation with an aggregated distribution of infested trees (Table 2). The other three plantations had random distributions with low indices of clumping.

Spatial Autocorrelation. Excluding plantation 1D, first-year plantations generally exhibited little or no spatial autocorrelation for numbers of infested trees per quadrat sample in the second generation (Table 3). Plantation 1B had significant positive autocorrelation when neighbors with a common vertex were included. Results for plantation 1C were inconsistent, with three of eight calculated coefficients significant. All tests were significant for plantation 1D.

In the third generation, significant positive spatial autocorrelation of infested trees was obtained for all plantations except 1C (Table 3). The degree of significance of spatial autocorrelation also increased or remained unchanged from generation two to three. Significant positive spatial autocorrelation was also found for first generation counts of infested trees in plantation 2A in every test.

Table 1. Mean total tips per tree, mean infested trees and infested tips per quadrat sample, and range of infested trees per 36-tree sample from 4 first-year and 4 second-year loblolly pine plantations in southwestern Arkansas in 1981.

Plantation	Number of quadrats	Generation	Mean* total tips per tree	Mean trees*† infested per 36-tree sample	Mean tips*† infested per 36-tree sample	Infested trees* per 36-tree sample (range)
		1	2.4 c	0.09	0.09	0-1
1A	33	2	3.6 b	5.2 a	8.3 a	0-17
		3	4.3 a	5.3 a	9.5 a	0-21
		1	2.2 c	0.03	0.03	0-1
1B	39	2	3.0 b	4.9 a	7.6 a	0-21
		3	3.9 a	5.5 a	9.7 a	0-17
		1	2.4 c	0.42	0.54	0-6
1C	24	2	2.8 b	2.9 a	4.1 a	0-14
		3	3.5 a	2.4 a	3.5 a	0-15
		1	3.2 c	0.03	0.03	0-1
1D	62	2	4.8 b	6.7 b	9.3 b	0-14
		3	6.2 a	14.2 a	35.8 a	0-21
2A	41	1	11.1	9.2	19.9	1-20
2B	61	1	11.2	9.0	15.9	4-18
2C	31	1	9.3	11.3	19.0	5-19
2D	28	1	11.2	7.9	14.8	1-14

* Means in a column and plantation followed by the same letter are not significantly different ($P \leq 0.05$; Duncan's [1955] multiple range test).

† Generation 1 of first-year plantations not included in analyses due to low number of infested trees.

Table 2. Indices of clumping and dispersion for numbers of infested trees per quadrat sample in loblolly pine plantations in southwestern Arkansas, 1981.

Plantation	Generation	Index of* Clumping	Index of Dispersion
1A	2	2.0a	95.5†
	3	2.8a	123.1†
1B	2	4.1a	194.1†
	3	3.8a	181.2†
1C	2	2.7a	85.6†
	3	5.8a	156.1†
1D	2	0.4b	87.2†
	3	2.0a	183.3†
2A	1	1.2	88.1†
2B	1	0.3	75.8
2C	1	0.3	39.3
2D	1	0.3	35.8

* Means within a plantation followed by the same letter are not significantly different ($P \leq 0.05$).

† Hypothesis of random dispersion rejected based on chi-square test ($P \leq 0.05$).

Table 3. Moran's and Geary's coefficients of spatial autocorrelation for first- and second-year loblolly pine plantations in southwestern Arkansas.

Plantation	Generation	Weighting System	Neighboring quadrats with a common edge		Neighboring quadrats with common edge or vertex	
			Moran's I	Geary's C	Moran's I	Geary's C
1A	2	Equal	0.14	0.89	0.09	0.96
		Scaled	0.13	0.95	0.10	1.0
	3	Equal	0.27*	0.76	0.24†	0.83
		Scaled	0.29*	0.90	0.27†	0.98
1B	2	Equal	0.17	0.76	0.18*	0.77
		Scaled	0.16	0.84	0.24*	0.84
	3	Equal	0.34†	0.62†	0.28†	0.66†
		Scaled	0.36†	0.73	0.30†	0.78
1C	2	Equal	0.21	0.45†	0.11	0.68*
		Scaled	0.26	0.58	0.23*	0.72
	3	Equal	-0.06	0.83	0.04	0.83
		Scaled	-0.19	1.1	0.20	1.3
1D	2	Equal	0.23†	0.78*	0.17†	0.78*
		Scaled	0.18*	0.67‡	0.16*	0.67‡
	3	Equal	0.24†	0.69†	0.25‡	0.69‡
		Scaled	0.21*	0.65‡	0.23†	0.65‡
2A	1	Equal	0.29†	0.68*	0.17*	0.78*
		Scaled	0.33†	0.64†	0.18*	0.75*

* Significant autocorrelation ($P \leq 0.05$).
† Significant autocorrelation ($P \leq 0.01$).
‡ Significant autocorrelation ($P \leq 0.001$).

Repeating all tests using numbers of infested tips per quadrat sample did not change the significance or non-significance of spatial autocorrelation for any plantation in any generation.

The weighting systems used generally did not affect significance/non-significance of spatial autocorrelation, with differences only in plantation 1B, third generation and plantation 1C, second generation.

Discussion

Our results show that Nantucket pine tip moths can invade and colonize first-year plantations in substantial numbers, and that aggregated infestations are spread throughout the plantation by the second tip moth generation. Heavy infestations generally do not occur until the end of the second growing season (Henry and Hepting 1957, Nord 1978).

The few infested trees ecountered in the first-year plantations in the first tip moth generation were scattered, perhaps due to tip moth oviposition behavior or low survivorship in the small trees, though healthy pupae were observed in very small trees. The aggregations of infested trees found in the second generation may be the result of female moths laying eggs on clusters of trees. The stable number of infested trees in plantations 1A, 1B, and 1C in generations two and three suggests that mortality factors are increasing or many emerging moths are emigrating out of the plantations to nearby plantations where populations are larger and tree size is perhaps more favorable. The increasing spatial autocorrelation from generation two to three in plantations 1A and 1B indicates that the remaining females aggregate. Quadrat and sample size together with the small area and low population level in plantation 1C may have masked this redistribution, causing scattered aggregations to appear clumped in generation two, and the reverse in generation three if the clumps were aggregated within quadrats.

Sample size did not appear to affect the determination of the dispersion pattern for the range of population densities encountered in this study, except perhaps for plantation 1C as explained above. The random distributions observed in the second-year plantations were not a function of sample size, as plantation 1D in generation three had fewer total tips, a higher mean number of infested trees, and an aggregated distribution. However, sample size may have affected the calculated degree of clumping or spatial autocorrelation.

In our tests, Moran's coefficient was more likely to indicate significance, and Cliff and Ord (1975) considered Moran's coefficient to be slightly more efficient than Geary's.

The large number of infested trees in plantation 1D is counter to the suggestions of Warren (1963) and Miller and Stephen (1983) that high vegetation impedes tip moth attack. This plantation had high levels of vegetation by late spring (> 2m), as compared with levels in the other plantations (generally < 1m). However, the low vegetation level in the early spring following site preparation and planting would not have inhibited infestation, while the increased number of tips and high vegetation later in the year may have induced emerging females to remain in the plantation. Most of the vegetation in this plantation was between the rows and did not obscure the shoot tips.

The random distribution of infested trees in second-year plantations in the first tip moth generation may in part be a result of density dependent mortality factors or a behavioral change in the oviposition pattern of females. Females emerging from overwintered pupae may make long flights between oviposition stops for physiological or other reasons, creating random distributions of infested trees. Green (1962) proposed two distinct types of oviposition behavior for the European pine shoot moth, *R. buoliana* (Schiffermüeller). One type spreads the infestation locally while the other, a pioneer type, is responsible for long-range colonization. The shoot moth is univoltine, so the two types are needed. The Nantucket pine tip moth could use different generations to accomplish its local and long range spread.

The aggregation found in plantation 2A may have resulted from limited immigration routes into the plantation. It was surrounded on all sides by mixed conifer-hardwood forest, and only one road led into the plantation, entering at the west where much of the infestation was located. The other second-year plantations had multiple access points.

The trend in dispersion patterns in newly established loblolly pine plantations appears therefore to be initially a random distribution of infested trees in the first generation, with increasing aggregation in the following two generations. How long this pattern continues remains to be determined.

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