韓國林學會誌 89(1) : 49 - 54. 2000
Jour. Korean For. Soc. 89(1) : 49 - 54. 2000

Effects of Hardwood Interspecific Competition on Stand Level Survival Prediction Model in Unthinned Loblolly Pine Plantations[1*]

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테에다소나무 造林地에서 闊葉樹와의 種間競爭이 林分水準 生存 豫測模型에 미치는 影響[1*]

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ABSTRACT

Stand level survival prediction model was developed that incorporated the incidence of fusiform rust(*Cronartium quercuum* [Berk.] Miyabe ex Shirai f. sp. *fusiforme*) and allowed the transition of trees from an uninfected stage to an infected stage.

The influence of hardwood interspecific competition on the survival of unthinned planted stands of loblolly pine (*Pinus taeda* L.) was analyzed by using of information from twelve years of tracking a set of permanent plots representing a broad range of plantation parameters. Significant interaction effects between site index and hardwood basal area per acre were revealed in the survival model. Survival of the planted pines decreased with increasing density of hardwood trees per acre and site index as the productivity rating of the forest land. The effects of hardwood trees interspecific competition on loblolly pine tended to show a negative effect on predicted future number of planted pine trees.

Key words : Pinus taeda, *interspecific competition, stand level survival prediction model*

要 約

林分水準의 生存豫測模型이 開發되었으며, 이 模型은 綠病(*Cronartium quercuum* [Berk.] Miyabe ex Shirai f. sp. *fusiforme*)의 發生率을 模型에 포함하였으며 그리고 綠病에 感染되지 않은 段階의 林木들이 感染되는 段階로의 轉移가 許容되는 特徵을 가지고 있다.

12年間 長期的으로 每年 測定된 永久的인 實驗plots의 多樣한 데이터베이스를 利用하였으며, 人工造林된 테에다소나무林分 내에서 自然的으로 發生된 闊葉樹들과의 種間競爭이 소나무林分의 生存豫測에 미치는 影響을 分析하였다.

本 硏究의 結果로서 林分水準의 生存豫測模型은 地位指數와 闊葉樹의 胸高斷面積 密度와의 有意한 影響이 生存豫測模型에서 나타났다. 地位指數와 闊葉樹의 密度가 增加함에 따라서 造林된 테에다소나무林分의 未來 生存 本 數는 뚜렷히 減少하는 경향을 나타내었다.

[1] 接受 1999年 9月 10日 Received on September 10, 1999.
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* 본 논문은 1999년도 경북대학교 Post-Doc. 연수지원에 의하여 연구되었음.

INTRODUCTION

Accurate predictions of timber growth and yield are necessary for forest managers to efficiently manage the resources. Since timber growth and yield are functionally related to the number of trees surviving at a given age, it is imperative that prediction systems contain reliable methods of predicting mortality.

A critical component in estimating future stand -level yields is the number of trees per unit area expected to survive and be available for harvest at rotation ages. The amount of wood expected to produced in a pine plantation is sensitive to the number of trees per unit area in conjunction with other useful predictors, such as plantation age, tree height, site index, basal area and diameter size.

Several modeling approaches to estimating the future number of trees in pine plantations have been developed. The probit transformation of percent survival was predicted as a function of age and initial stocking level by Lenhart (1972). The Weibull distribution was used as a model for survival of young natural loblolly pine stands in South Carolina by Somers et al. (1980).

Clutter and Jones (1980) developed a survival function based on a difference model, which implied that mortality represented a change in trees per acre with a change in time. This approach was utilized by Bailey et al. (1985) and Clutter et al. (1984) for southern pine plantations in the southeastern United States.

The idea that survival characteristics of fusiform rust infected trees and non-infected trees might be different was modeled by Devine and Clutter (1985) for slash pine plantations in the southeastern United States. One survival equation was computed for non-infected trees, and another survival equation was computed that included the additive effects of mortality associated with fusiform rust. Adams (1989) developed survival models for fusiform rust infected and uninfected trees that allowed for the transition of trees from an uninfected stage to an infected stage. Multinomial logistic regression models were developed by Arabatzis et al. (1991) to predict the possible transition paths of planted loblolly pine trees from live stems to dead stems. Stem infection with fusiform rust was one of the stages along the transition paths.

Two modeling efforts with loblolly pine stands did include the hardwood competition effects in estimating the future number of planted pines (Burkhart and Sprinz 1984; Burkhart et al. 1987). The objective of this study was to develop model to estimate future number of planted loblolly pines subject to the effects of hardwood interspecific competition plus consider the productivity of the site and the incidence of fusiform rust on the survival of unthinned planted stands of loblolly pine.

MATERIALS AND METHODS

1. Plantation measurements

The study area consists of 22 counties in East Texas, USA. Generally, the counties are located within the rectangle from 30° - 35′ north latitude and 93° - 96° west longitude.

Long-term data from East Texas Pine Plantation Research Project (ETPPRP) permanent plots located in pine plantations throughout the region were analyzed in this study. Each plot consists of two adjacent subplots separated by a 60 ft (18 m) buffer. Within a subplot, for this study, the life of each planted loblolly pine tree had been tracked for 15 yrs. In addition, the non-planted hardwood trees within two embedded circular 8.9 ft radius sampling areas in each subplot were tracked for twelve years or four measurement cycles.

For this study, at a plot, one subplot was randomly selected for model fitting, and the other subplot was utilized for model evaluation. Due to inconsistent determination of stem fusiform rust incidence in young plantations, minimum plantation age was 5 yrs. As a result, number of loblolly pine observations was 519 and 516 for model fitting and model evaluation.

The nature and character of the variables are depicted in Table 1 for loblolly pine plantations.

Age and site index values (base age 25 yrs, Lee 1998) for both subplots are similar. On the average, about 9% of the loblolly pines had a stem cankers due to fusiform rust incidence.

Table 1. Observed stand characteristics for unthinned loblolly pine plantations data sets.

	Model development subplots (n = 519)				Model evaluation subplots (n = 516)			
	Mean	Std Dev.	Min.	Max.	Mean	Std Dev.	Min.	Max.
A	12	4.6	5	27	12	4.5	5	27
S	69.9	12.6	24	114	69.7	12.8	24	116
T	463	144	87	998	457	149	131	935
N_u	423	142	61	978	416	147	105	898
N_i	40	42	0	253	41	40	0	255
HBA	8	10.9	0	102.6	14	78	0	154

Where : A= plantation age (yrs), S= site index (ft), T= total trees per acre, N_u= number of trees per acre without a fusiform rust stem gall, N_i= number of trees per acre with a fusiform rust stem gall and HBA= non-planted hardwood basal area per acre (ft^2).

2. Survival Models

Adams (1989) developed survival models for fusiform rust infected and uninfected trees that allow for the transition of trees from an uninfected stage to an infected stage. His work was based on Shapiro's (1946) differential equations, which are used to describe the growth of two different bacteria types (X, Y). These two populations increases not only by cell divisions resulting in the same type (e.g., X dividing to yield X), but also by mutation (e.g., X mutation to Y). The equations are :

$$\frac{dx}{dt} = ax + by$$

$$\frac{dy}{dt} = mx + cy, \qquad (1)$$

where : a, c = population growth rates,

b, m = mutation rates.

Shapiro (1946) presented the solutions for these differential equations and discussed methods for estimating the parameters.

In this study, loblolly pine plantations in the southern Unites States were considered as consisting of two components : trees infected with fusiform rust (N_i) and those uninfected (N_u). After a period of time (dA), the numbers in each group will have changed (dN_i and dN_u). The number of trees in the infected group will have decreased due to mortality, but will have gained the number of uninfected trees that become infected during this time. Mortality and a change in uninfected status will both decreased the number in the uninfected component.

A system of differential equations based on Shapiro's equation reflects this scenario as :

$$\frac{dN_i}{dA} = -\rho_i N_i + \lambda N_u$$

$$\frac{dN_u}{dA} = -(\rho_u + \lambda) N_u \qquad (2)$$

where :

N_i =number of surviving infected trees,

N_u =number of surviving uninfected trees,

ρ_i =instantaneous mortality rate for infected trees,

ρ_u =instantaneous mortality rate for uninfected trees and,

λ =instantaneous rate of uninfected trees becoming infected.

After integration of equation (2), a model to estimate future number of trees was :

$$N_{u2} = N_{u1} \exp(-\alpha(A_2 - A_1))$$

$$N_{i2} = (N_{i1} - \beta N_{u1}) \exp(-\rho(A_2 - A_1)) + \beta N_{u1} \exp(-\alpha(A_2 - A_1)) \qquad (3)$$

where :

A_2 = projection age (yr),

A_1 = initial age (yr),

N_{u2} = number of surviving uninfected trees per unit (acre) at A_2,

N_{u1} = number of surviving uninfected trees per unit (acre) at A_1,

N_{i2} = number of surviving infected trees per unit (acre) at A_2,

N_{i1} = number of surviving infected trees per unit (acre) at A_1,

α, β & ρ = parameters.

This survival modeling idea provided for separate estimates of mortality rates for infected and uninfected, as well as the possible transition of uninfected to infected. The parameter α is the rate at which trees are lost from the uninfected class. The parameter β allocates the number of uninfected tree to be affected by a different mortality rate in the model. Behavior of this model is consistent with the desired properties of path invariance, convergence, and surviving trees converges to zero with extreme age values.

For planted pines in the southeastern United States, the two studies found that as site index increased, survival tended to decrease (Adams 1989; Adams et al. 1996). In addition to the productivity of an area, another plantation parameter that may play a role in survival is the non-planted hardwood trees component. These hardwood trees are probably competing with the planted pines for sunlight and soil nutrients. The influence of non-planted hardwood trees interspecific competitions on the survival of planted loblolly pines was investigated in this study.

RESULTS AND DISCUSSION

1. Survival prediction models

After extensive examination of the survival trends exhibited by the 519 development subplot values, it showed that an interaction effects between site index and non-planted hardwood density existed. A fitting procedure described in details by Borders (1989) was used to account for the presence of cross equation error correlation. As a result, the 519 observations were used to fit the model in a simultaneous manner using the SYSNLIN procedure in SAS (1985) to produce two survival models as :

$$N_{u2}=N_{u1}\ \exp(-0.101567(S*HBA)(A_2-A_1))$$
$$N_{i2}=(N_{i1}-0.060039N_{u1})\ \exp(-0.761073(S*HBA)(A_2-A_1))+0.060039N_{u1}\ \exp(-0.101567(S*HBA)(A_2-A_1)) \quad (4)$$

where : S = site index (base age = 25 yrs.),
HBA = non-planted hardwood basal area per acre (ft^2).

The asymptotic standard errors for coefficients $\hat{\rho}$, $\hat{\alpha}$, and $\hat{\beta}$ are 0.00123, 0.00015, and 0.06004, respectively. None of the 95% confidence intervals for the parameters contained zero, and all parameters were significantly different from zero at the 0.05 level of probability ($P<0.05$). It was estimated that the uninfected component in the above model explained about 95% of the variation in the average values. But infected component in the survival model explained about 60% of the variation. Therefore, the uninfected component was more accurately predicted than the number of surviving infected trees. Plottings of standardized residuals against predicted and independent variables indicated that a random pattern around zero with no detectable trends.

Fit statistics based on the data from 516 evaluation subplots are presented in Table 2.

Table 2. Fit statistics for performance evaluation of survival model.

Equation	R^2	RMSE	Residual Mean	Absolute Residual Mean
N_{u2}	0.95	30.04	2.92	23.6
N_{i2}	0.60	26.29	-2.47	22.0

Data from the 516 evaluation subplots were utilized to compare predicted and observed values. All residual mean differences were nonsignificant from zero ($P>0.05$), and graphical residual analyses for the fitted models showed no biases.

2. Illustrations of Survival Projections

1) Survival projections

Illustrations of survival projections for planted loblolly pines were presented in Table 3 by utilizing equations (4). In this scenario, plantation parameters were defined as :

- Site index = 70 feet (the average value for loblolly pine species).
- Plantation age ranged from 5 to 30 years, and extrapolation is minimized.
- The non-planted hardwood basal area per acre = 10 ft^2/ac (the average value for loblolly pine species).

· Total surviving trees per acre at 5 years = 500, for loblolly, stem fusiform rust = 10% infected at age 5 years.

Table 3. Survival projections for loblolly pine stands infected with fusiform rust.

Plantation age	No. of uninfected trees/ac.	No. of infected trees/ac.	Total surviving no. of trees/ac.
5	450	50	500
10	434	44	478
15	419	39	458
20	404	35	439
25	390	31	421
30	377	29	406

This stand level survival model could enable foresters to make better decisions concerning pine plantations especially infected with fusiform rust as shown in Table 3.

2) Role of non-planted hardwood basal area per acre

In some plantation management situations, the density of non-planted hardwood tree component might be measured in basal area per acre. Using the same scenario described above, square feet basal area per acre ranged from 5 to 30 by 5 foot classes, which includes the majority of observed values. Based on equations (4), Fig. 3 was developed for loblolly pines.

The survival of the planted loblolly pines is definitely influenced by the density of non-planted tree component. For a given age, as non-planted basal area increases, expected planted pine survival decreases.

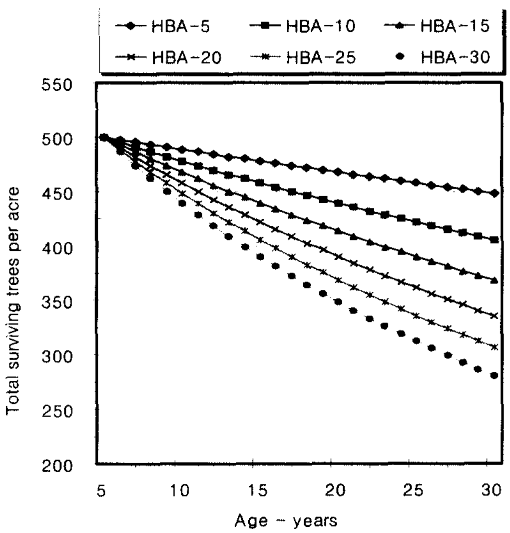

Fig. 1. Predicted surviving planted loblolly pine trees by non-planted hardwood basal area per acre classes (site index = 70 feet (21m) and stem fusiform rust incidence = 10% at 5 yrs).

3) Role of site productivity considerations

Additional calculations and plottings provided insight on the site productivity on forest land. As site index ranged from 50 feet to 90 feet and non-planted trees varied across their ranges, the surviving planted loblolly pine trees were computed using equations (4).

According to the results (Lee 1998), as non-planted hardwood density increased and site index increased, the survival of planted loblolly pine trees decreased. Realizing this can be a complicated operational situation with many factors to consider, a conclusion might be to attempt to reduce the number of competing non-planted trees as soon as possible during a rotation period. And the reduction is probably most important on the sites with higher productivity potential.

CONCLUSIONS

The non-planted hardwood tree component in loblolly pine plantations is a strong competitor for soil moisture and nutrients plus the available sunlight.

This study did not include economic analyses, but from a biological perspective, it appears that management activities that reduce the number of non-planted hardwood trees are beneficial in increasing survival of the planted loblolly pines. And the earlier in the rotation that the reduction can occur, the more likely the beneficial effects are enhanced.

ACKNOWLEDGEMENTS

This project was supported by industrial companies in the East Texas Pine Plantation Research Project - Champion International Corporation, International Paper Company, Louisiana-Pacific Corp., Resource Management Services, Inc. and Temple-Inland Forest Products Corp. - and Arthur Temple College of Forestry, Stephen F. Austin State University are appreciated.

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