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PREDICTION OF LOBLOLLY PINE DEFOLIATION SEVERITY ASSOCIATED WITH CHANGES IN PATHOGEN PRESSURE IN RESPONSE TO CLIMATE CHANGE IN ALABAMA

by
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ABSTRACT
Loblolly pine defoliation was first noticed in 2013 and currently has been observed on more than 25,000 hectares of loblolly plantations in Alabama. *Lecanosticta acicola* is the predominant pathogen causing loblolly pine defoliation in combination with common needle cast pathogens in Alabama (see Chapter II). Understanding abiotic factors such as temperature, precipitation, and moisture influence on loblolly pine defoliation is important to predict defoliation severity in following years in Alabama. Weather data were collected from 14 land- based weather stations located within a 10 m radius of the infected stands. Forty years of long- term regional weather data indicates that there was an increase temperature and a decrease precipitation in this region from 1981 to 2019. Data confirmed that the previous year's Max.

February, Max. June and Min. May temperature and increasing July and decreasing fall precipitation are the best predictors of defoliation severity in Alabama. Increasing summer months precipitation and temperature are expected to favor loblolly pine defoliation the following years. Climatic models were developed to aid private landowners and forest managers to adjust their management strategies accordingly.

5.1. INTRODUCTION
Lecanosticta acicola is a predominant pathogen associated with brown spot needle blight in both natural and plantation loblolly pine stands in Alabama. From the first half of the 20th century, *L. acicola* has been a persistent problem for grass stage longleaf pine seedlings in the southeastern United States (Siggers, 1944). Later this disease was found to cause serious damage to scotch pine Christmas tree plantations in Wisconsin and Minnesota (Skilling & Nicholls, 1974).

Historically, this fungal pathogen was found to be associated with loblolly pine trees in its native range (Siggers, 1944; Hedgcock, 1929) but its impacts on tree health were never assessed as damage and tree mortality were not observed until recently. *Diplodia sapinea*, *Lophodermium* spp., and *Coleosporium* spp. pathogens have been found associated with loblolly pine defoliation. Two other fungi *Rhizosphaera kalkhoffii* and *Sydowia polyspora* have also been recovered in association with *L. acicola*. These fungi may affect disease severity in the infected stands. The understanding of abiotic factors such as temperature, precipitation and relative humidity is important as they may drive the emergence and spread of disease.

Needle disease and host susceptibility are correlated to climatic factors such as temperature and moisture (Wyka et al., 2017; Broders et al., 2015; Munck & Burns, 2012). Changing environmental conditions such as increasing temperature, precipitation, and humidity favors foliar fungal disease development by altering fungal virulence and behavior (Skilling and Nicholls, 1974). Moreover, temperature and moisture directly influence pathogen distribution and movement into area where regional climates are conducive for spore reproduction and survival (Sturrock et al., 2011).

Increasing overnight minimum temperature, summer and spring rainfall following needle wetness were found positively correlated to *Dothistroma septosporum* infection (Woods et al., 2005). Similarly, increasing winter mean temperature and spring precipitation was projected to increase Swiss needle cast disease in the Pacific Northwest (Manter et al., 2005). In the northern United States, white pine needle damage resulting from multi-fungi interactions were expected to become worsen with increasing spring and summer rainfall and winter temperature (Wyka et al., 2017). A study tested climatic influence on the distribution of *Fusarium* spp. and found that differences in *Fusarium* communities were resulted from differences in temperature which mimicked the natural communities of *Fusarium* spp. found in similar temperature gradients (Saremi et al., 1999).

Predictions of pathogen behavior to changing climate conditions are challenging and constitute a high degree of uncertainty. In forest settings, it is even more complex because of long-lasting tree life versus the short life span of pathogens (Burdon et al., 2021; Gray et al., 2013). The objectives of this study were to (a) determine if climatic patterns drive the recent emergence and spread of loblolly pine defoliation and (b) develop a climatic regression model to predict disease severity of loblolly pine to aid forest managers to adjust management strategies accordingly.

5.2. MATERIALS AND METHODS

5.2.1. Visual rating, and mapping of pathogen distribution

Total 32 brown spot needle blight infected loblolly plots were sampled from March to November. Needle samples were collected from the number of 212 symptomatic trees using a

0.22 mag caliber rifle. Samples were placed in a cooler and brought back to the laboratory in Auburn. Rating of the crown infection was scored as follows (a) less than one-third of the crown infected (<1/3) (b) one-third to two-thirds of the crown infected (1/3 to 2/3) and (c) more than two-thirds of the crown infected (>2/3). Tree and site information such as aspect, slope, recent silviculture were also collected (Wyka et al., 2017).

5.2.2. LPND infected sites and climatic records

Climate data available online in National Climatic Data Center were collected to obtain regional historical weather data and station history. Daily summary observations of temperature, precipitation and relative humidity around infected stands were collected. Since preceding year temperature, moisture and precipitation have been shown to be the best indicators of following years defoliation (Munck & Burns, 2012; Wyka et al., 2017), daily maximum and minimum temperature, the sum of seasonal precipitation in the year preceding scoring defoliation ratings of infected trees were obtained from NOAA online data. Counties with available weather stations were identified and measured the distance from the infected stands using an interactive mapping tool. Weather data were collected within 10 miles radius of infected stands except for two stations due to data availability. To collect relative humidity data, POWER Data Access Viewers were used. Data points were selected based on the longitude and latitude of infected stand.

Missing data were adjusted, maximum and minimum temperature were averaged, and the sum of precipitation was estimated.

5.2.3. Statistical analyses

To build climatic regression models, forty-nine climatic variables were included in the model. Average maximum and minimum temperature of the following: spring (March to May), summer (June to July), modified spring (May to August), and winter (December to February). Average relative humidity and cumulative precipitation were included as follows: spring, summer, modified spring and winter. Individual months within these seasons were also collected. To predict the best-fitted regression model, the stepwise selection was performed to choose variables in the model. Final linear regression models were performed with eleven variables in the model since they explained relationships with loblolly pine defoliation severity.

Several statistical analyses such as Akaike Information Criterion (AIC) were used to verify small sample correlation, Variation Inflation Factor (VIF) was used to check collinearity of the variables, adjusted R2, root-mean-square error, and model parsimony were tested to develop confidence on the models.

5.3. RESULTS

5.3.1. Long-term regional weather data

Forty years of regional long-term weather data revealed that increasing temperature and decreasing precipitation in the region during loblolly pine growing season. About 10C shifts of mean temperature from 1980 to 2019 (Figure 5.3). Rainfall patterns decreased in infected sites. Cumulative rainfall decreased from 1400 mm to 1300 mm from 1981 to 2019 (Figure 5.4). However, no changes in relative humidity from 1981 to 2019 (Figure 5.5).

5.3.2. Climatic regression model to predict loblolly pine defoliation severity in future

One factor model predicted that decreasing May minimum temperature was negatively correlated to loblolly pine defoliation severity in the coming year. May minimum temperature was added with February maximum temperature in the 2-factor model and model significance was improved from 37% to 66%. The 2-factor model found that May minimum temperature and February maximum temperature are the best predictors of loblolly pine defoliation severity.

The best 3-factor model included sum fall precipitation as well as other two predictors i.e., May minimum temperature and February maximum temperature in the model. Lowering cumulative fall precipitation in the preceding year predicted increasing loblolly pine defoliation severity in the following year. Following that, the best 4-factor model added cumulative July precipitation and improved the model significance by 4% and predicted loblolly pine defoliation severity related to the previous year's decreased cumulative fall precipitation. The best 5-factor model included May minimum temperature, February maximum temperature, June maximum temperature, cumulative July precipitation and cumulative fall precipitation to predict loblolly pine defoliation events in following year (Table 5.1). The final model revealed that increasing summer precipitation and temperature are the best climatic factors that would affect LPD in following years.

5.4. DISCUSSION

Lecanosticta acicola was the primary pathogen causing loblolly pine defoliation in Alabama. This pathogen wasn't recovered from other infected sites of Louisiana, Georgia, and South Carolina and Mississippi (except one site in Greene). Infected loblolly pine trees in Louisiana, Georgia, Mississippi and South Carolina didn't mimic the symptomology of diseased loblolly trees in Alabama. Therefore, those sites were not included in the model to predict loblolly pine defoliation severity. Temperature has increased and precipitation has decreased in infected sites in Alabama. The results indicate that changing climatic conditions in Alabama are likely to have an impact on loblolly pine defoliation in Alabama since fungal growth, reproduction and spread are associated with increasing temperature (Wyka et al., 2017; Tainter and Baker, 1976). The study developed a model and identified that February, May and June temperature and July and fall months precipitation are the best predictors of loblolly pine defoliation severity in following years. Wyka et al., (2017) reported that increasing temperature and rainfall have been shown to drive emergence of white pine needle disease in the northeastern United States. Similarly, a local increase in spring precipitation and winter mean temperature are the best predictors to determine increase Swiss needle cast severity in western North America (Manter et al., 2005). Moreover, increasing overnight temperature and summer and spring rainfall are identified as the driving factors to increase *D. septosporum* severity to lodgepole pine plantations across its native range in northeastern British Columbia, Canada (Woods et al., 2005). All these findings supported the study findings and emphasized that increasing summer months temperature and precipitation provide favorable environmental conditions for *L. acicola* pathogen to cause loblolly pine defoliation disease emergence and outbreak.

Changing climatic conditions i.e., temperature and precipitation favored the spore development, dispersal, and infection potential of needle pathogens (Sturrock et al., 2011). Although it is difficult to establish a causal relationship between local biological trends and climate change, a mechanistic relationship exists between an observed climate trend and host- pathogen interactions (Woods et al., 2005). Wet moist site conditions and poor drainage might have posed stress to the trees and increased temperature might have facilitated increased fungal disease by increasing fungal growth and reproduction eventually leading to increased pathogen pressure to loblolly trees (Hansen, 1999). Since fungal loads, dispersal are correlated to changing temperature and precipitation (Manter et al., 2005; Woods et al., 2005; Wyka et al., 2017), temperature and precipitation may modulate *L. acicola* spore development, virulence, and infection potential which might have resulted in a recent emergence and outbreak of loblolly pine defoliation. Inoculum pressure is the most basic requirement to overcome the host defense (Agrios, 2005). Presence of abundant loblolly pine might have allowed the increasing number of

L. acicola spore development which may have helped the fungus to overcome the defense of host tree. A wide geographic distribution of host species favored the potential distribution of fungi through air-currents and rain-splash spores (Siggers, 1944). The study concluded that the high occurrence of loblolly pine trees coupled with changing seasonal temperature and precipitation has driven the current loblolly pine defoliation emergence and outbreak.

This disease is expected to increase in a broader geographic region and cause tree mortality if there are favorable environmental conditions. The uncertainty related to climate change associated with loblolly pine defoliation requires regular monitoring, planning, and mitigation strategies as well as linking them in forest management policies, and decision making.

5.5. CONCLUSION

The study identified the role of temperature and precipitation influence on loblolly pine defoliation in Alabama. Warmer and wetter summer and drier spring and fall are likely to favor loblolly pine defoliation severity in following years. The high occurrence of loblolly pine coupled with increasing temperature and precipitation are at the greatest risks in this region.

Short-term and long-term changes in climatic conditions can result in a disease outbreak. However, it is established that climate change can make trees more vulnerable to damage by insects, pests, and pathogens and especially, from those which have not been considered a threat due to unfavorable climate. The study requires incorporation of host layer mapping to better predict the disease patterns in Alabama. Southern forest managements are based on an implicit assumption that management will increase yield. However, this could be contributed to high disease occurrence.

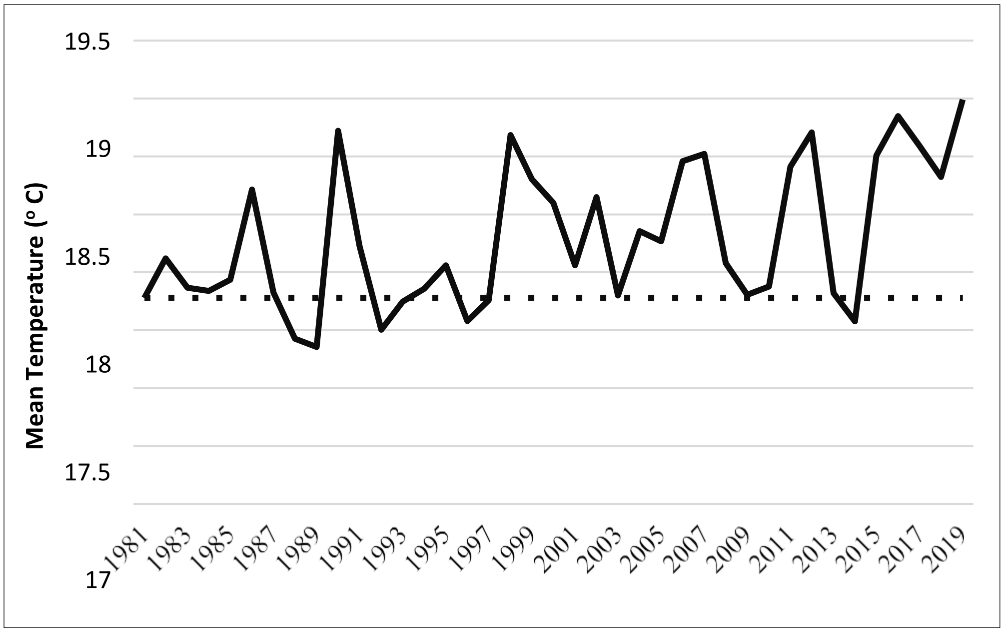

Figure 5.1. Average temperature during loblolly pine growing seasonat 11 infected sites in Alabama

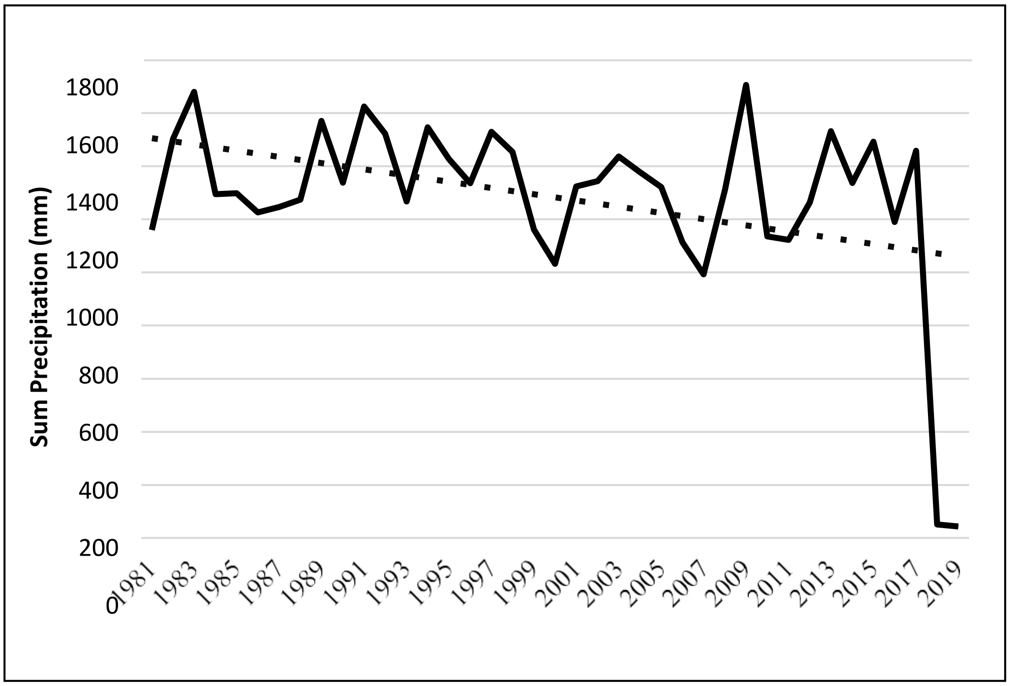

Figure 5.2. Cumulative precipitation during loblolly pine growing seasonat 11 infected sites in Alabama

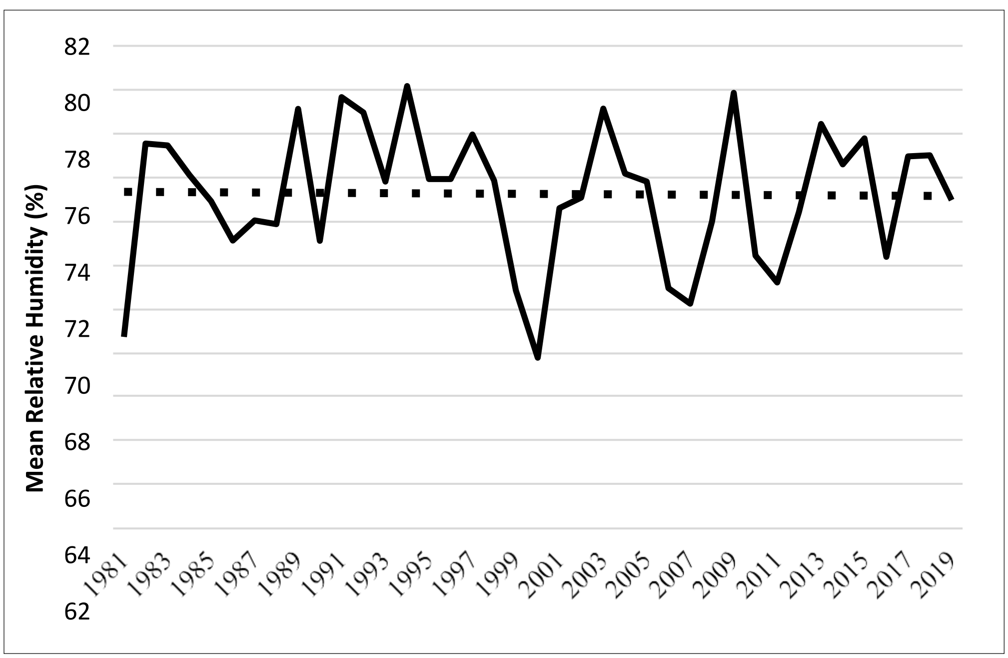

Figure 5.3. Mean relative humidity during loblolly pine growing seasonat 11 infected sites in Alabama

Table 5.1 Best-fit regression models to predict loblolly pine defoliation severity.

Model, variables	Parameter estimate	SE£	Prob. > t	VIF¥	Model Prob. > F	Adj. R^2	RMSE ¢	AIC€
5-Factor								
Intercept	0.45597	1.31881	0.7355					
Max February T	0.01921	0.00500	0.0023	4.21				
Max June T	0.03203	0.01507	0.0550	3.76				
Min May T	-0.06964	0.00802	<.0001	3.10				
Sum July P	0.03583	0.00941	0.0025	4.64				
Sum Fall P	-0.00838	0.00557	0.1579	4.27				
Total model					<.0001	0.8874	0.00113	-62.6345
4-Factor								
Intercept	3.14165	0.42606	<.0001					
Max February T	0.02228	0.00539	0.0012	4.21				
Min May T	-0.06716	0.00894	<.0001	3.10				
Sum July P	0.02585	0.00920	0.0147	4.64				
Sum Fall P	-0.01535	0.00507	0.0097	4.27				
Total model					<.0001	0.8450	0.00224	-74.789
3-Factor								
Intercept	3.07400	0.51974	<.0001					
Max February T	0.02529	0.00646	0.0016	4.21				
Min May T	-0.06785	0.01092	<.0001	3.10				
Sum Fall P	-0.01305	0.00612	0.0511	4.27				
Total model					0.0002	0.7508	0.00845	-66.5523
2-Factor								

Intercept	2.81150	0.56158	0.0002					
Max February T	0.02623	0.00717	0.0023	4.21				
Min May T	-0.06697	0.01214	<.0001	3.10				
Total model					0.0002	0.6698	0.01132	-57.6458
1-Factor								
Intercept	2.75236	0.74780	0.0020					
Min May T	-0.03746	0.01209	0.0069	3.10				
Total model					0.0069	0.3749	0.01852	-42.4364

P=sum precipitation, T=average temperature; £SE=Standard error; ¢RMSE=Root Mean Square Error; ¥VIF=variance inflation factor; €AICc=Akaike information criterion. (Seasonal temperatures were averaged and precipitation was summed up in the year before defoliation ratings of the trees were conducted such as winter (December, January, February); spring (March, April, May); mod. spring (May, June, July); summer (June, July, August).