MULTI-SCALE MODELING OF RELATIONSHIPS BETWEEN FOREST HEALTH AND CLIMATIC FACTORS

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Abstract--Forest health and mortality trends are impacted by changes in climate. These trends can vary by species, plot location, forest type, and/or ecoregion. To assess the variation among these groups, Forest Inventory and Analysis (FIA) data were obtained for 10 states in the southeastern United States and combined with downscaled climate data from the Weather Research and Forecasting (WRF) model. A variable was created for analysis at the intersection of ecoregions, climate divisions, and forest type. Spatial autoregressive (SAR) modeling was employed to determine if mortality patterns over two inventory cycles were clustered and differed with climate variables. Models were developed showing the relationship between mortality and a series of climate indicators. This information could prove useful to forest managers if projected climate changes are verified.

INTRODUCTION

A variety of factors contribute to forest health and mortality. These factors can be biotic (e.g., insects, diseases, etc.), abiotic (e.g., drought, temperature, etc.), or a combination of the two (drought stress leading to insect infestation) (Crosby and others 2012, Fan and others 2012). However, the impacts of these factors may not be continuous across the landscape. Patterns of change in forest health and mortality can vary by species groups or forest type. Further, there may be a time lag effect between the onset of disturbance factors (e.g., drought) and the impacts on forested areas (Fan and others 2012). Analysis of relationships between climatic factors and forest health indicators will allow for model development to account for spatial clusters of mortality. In an effort to develop predictive models our objectives were to: (1) assess mortality (using percentages of dead basal area) trends for the southeastern United States; and (2) determine whether there is a relationship between mortality and climate variables during forest inventory cycles.

METHODS

Data for this study were obtained from a variety of sources. Forest Inventory and Analysis (FIA) data were obtained from the USDA Forest Service (http://apps.fs.fed.us/fiadb-downloads/datamart.html) for 10 southeastern states (Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, and Texas). Drought data, i.e. Palmer's Drought Severity Index (PDSI), were obtained from the National Climate Data Center (http://www7.ncdc.noaa.gov/CDO/CDODivisionalSelect.jsp). Average annual temperature and average annual temperature range were derived from downscaled Weather Research and Forecasting data. To effectively analyze the relationship between mortality and climatic factors, polygons were created by intersecting Bailey's ecoregions, a forest type map, and climate divisions in the southeastern United States (fig. 1).

Variables were extracted based upon the polygons in figure 1 (percent dead basal area, growing season PDSI, average annual temperature, and annual temperature range) for each of two FIA inventory cycles (cycle 1 from 2000-2004 and cycle 2 from 2005-2009). Variables for both inventory periods were divided into periods of drought/non-drought (based on PDSI values) prior to and during the inventory period (table 1). Spatial autoregressive (SAR) modeling was then utilized to determine the relationship between percent dead basal area and the climate variables. The SAR model is defined as:

$$Y = X\beta + \varepsilon \qquad (1)$$

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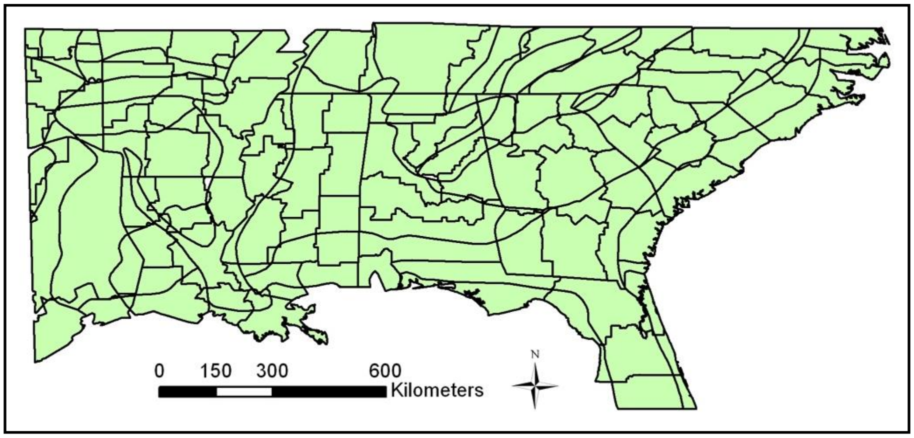

Figure 1--Study area depicting polygons created as a result of over-laying climate divisions, ecoregions, and forest type maps.

$$\varepsilon = \rho W \varepsilon + \upsilon \quad (2)$$

Where: Y = percentage of dead basal area; X = PDSI, average annual temperature, and annual temperature range; β_i = regression coefficients to be estimated; v = independent error vector (assumed normally distributed); ρ = SAR error coefficient; and W = spatial weight matrix. Akaike's Information Criteria (AIC) was used to select the "best" model and Nagelkerke's pseudo R^2 is used to assess goodness of fit for each SAR model.

Table 1--Variable definitions for the inventory cycles used in analysis where D represents periods of drought and ND represents periods of non-drought

Cycle 1 (2000-2004)	Cycle 2 (2005-2009)
D1=1999	D1=2006-2008
D2=2000-2002	D2=1999-2002
ND1=1994-1998	ND1=2005
ND2=2003-2004	ND2=2003-2004
	ND3=1994-1998
	ND4=2009

RESULTS AND DISCUSSION

Cycle 1 (2000-2004)

The percentages of dead basal area for the created polygons show values that are high across vast portions of the southeastern United States [fig. 2(a)]. The relationship between mortality and climate variables are clustered in portions of eastern Texas and western Louisiana and across portions of central South Carolina [fig. 2(b)]. Results from the SAR model show that the most significant variables for selecting the best model for cycle 1 are diameter at breast height (d.b.h.), PDSI in 1999, and PDSI from 2000-2002 (table 2). This model indicates that drought periods prior to and during the inventory cycle and d.b.h. are related to mortality. The D1 drought period (table 1) only considers 1 year of drought conditions prior to measurement, which could lead to the confounding result of higher PDSI values (i.e., non-drought conditions) being related to more mortality. The D2 period (table 1) indicates a negative relationship, where a lower PDSI (i.e., more severe drought) would be related to higher mortality as has been found by previous studies (Fan and others 2012).

Cycle 2 (2005-2009)

The percent dead basal area for inventory cycle 2 shows an altogether different pattern from that in cycle 1. The greatest values found in cycle 2 occurred across eastern Texas, central Arkansas, Tennessee, northern Georgia, and western portions of North and South Carolina [fig. 3(a)]. The Moran's I result [fig. 3(b)] indicates clusters in western Louisiana, eastern Arkansas/western Texas, and across portions of Florida, North Carolina, and South Carolina. Accounting for these clusters, the SAR model for cycle 2 had more significant variables than cycle 1 (table 3). D.b.h., height, PDSI, average annual temperature, and average temperature range all proved significant. While the model selected had

Table 2--Variables and coefficients from the best SAR model for inventory cycle 1[a]

	Estimate	Std. Error	z value	Pr(>lzl)
(Intercept)	0.045778	0.024856	1.842	0.065511
DIA	0.015508	0.004459	3.478	0.000505
PDSI(D1)	0.022962	0.009414	2.439	0.014722
PDSI(D2)	-0.032851	0.010241	-3.208	0.001337

[a]AIC: -228.47; R^2 = 0.511.

Table 3--Variables and coefficients from the best SAR model for inventory cycle 2[a]

	Estimate	Std. error	z value	Pr(>|z|)
(Intercept)	-0.352817	0.087946	-4.0117	0.000060
DIA	0.030346	0.002287	13.267	< 2.2e-16
HT	0.000945	0.000446	2.1185	0.034129
PDSI(D1)	0.010183	0.002528	4.0277	0.000056
PDSI(D2)	-0.006817	0.002919	-2.3352	0.019531
PDSI(ND3)	0.006016	0.003453	1.7426	0.081411
Avg temp(ND2)	0.010114	0.002677	3.7788	0.000158
Temp range (D1)	0.034717	0.007482	4.6401	0.000003
Temp range (D2)	-0.039571	0.006700	-5.9058	0.000000
Temp range (ND4)	0.010769	0.004680	2.3012	0.021380

[a]AIC: -513.55; R^2= 0.824

the best fit, the individual variables proved somewhat confounding. For example, greater PDSI values indicate non-drought conditions but the relationship would indicate that this condition led to increased mortality. Further analysis and model refinement will be necessary to critically analyze such relationships. Of note, however, are the PDSI and annual temperature range relationships with mortality in the drought period prior to inventory measurement. These relationships indicate that a larger temperature range (increased high temperatures or decreased low temperatures) and more severe drought conditions (lower PDSI values) are related to increased mortality. These conditions indicate that extreme temperatures (higher temperature ranges) and drought could act to stress trees, which may not succumb for a period of several years, indicating a lag effect previously discussed (Fan and others 2012), although further analysis is required.

It is difficult to compare cycle 1 and cycle 2 aside from the general trend that greater mortality levels were detected in northern portions of the region in cycle 2. In-growth was not accounted for in the analysis which could, at least partially, explain the lower percent dead basal area results for cycle 2. Drought was indicated to have played a role in greater mortality in both inventory cycles, and the relationship between mortality and the selected climate variables seem to be clustered in certain areas. These areas could be selected for further study to provide insight into local stand/site factors that could be contributing to these relationships although more intense data collection would be required. These preliminary results could indicate areas that should be monitored as drought conditions become apparent. Future research will seek to refine the analysis presented here to present more detailed information (e.g., models for species groups). Also, this study only utilized data from trees that were found to have died from competition; such conditions as drought and high temperature ranges could act to stress trees and lead to the infestation by insects and increase fuel loads for forest fires.

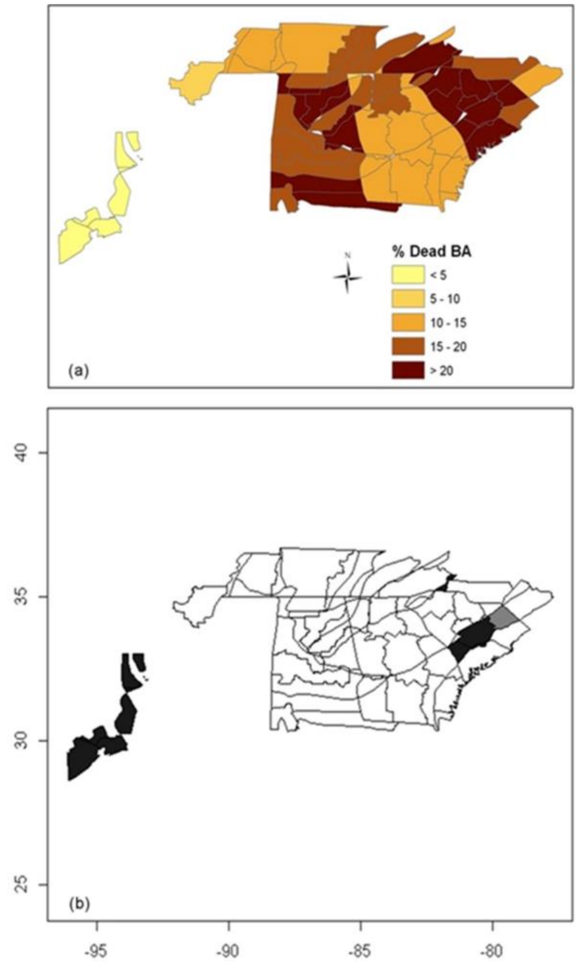

Figure 2--Pattern of percent dead basal area (a) and Moran's I results showing spatial clusters of mortality (b) for inventory cycle 1.

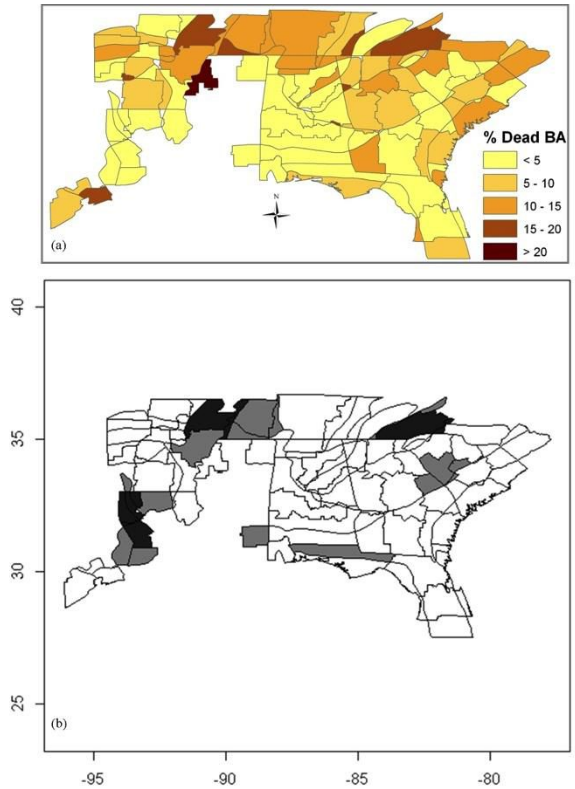

Figure 3--Pattern of percent dead basal area (a) and Moran's I results showing spatial clusters of mortality (b) for inventory cycle 2.

CONCLUSIONS

While the two inventory cycles had different values for mortality (percent dead basal area), there were significant clusters of mortality. Both cycles exhibited significant clusters across portions of Texas, Louisiana, and South Carolina. The spatial autoregressive model proved useful for accounting for spatial relationships among variables (clusters) in model development. The models developed show a relationship between mortality and biometric (e.g., d.b.h.) and climatic factors (drought and temperature range). While this is not a novel discovery, it is interesting that the polygons analyzed were similarly clustered for both inventory cycles. This suggests that these variables are interacting in a similar manner though a more thorough analysis and treatment of the variables is warranted. This study provides a good basis for the further examination of spatial clusters which could yield more robust models for the prediction of the relationship between mortality and climate across the region.

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