

INTRODUCTION

Stresses to trees under a changing climate can lead to changes in forest tree survival, mortality, and distribution. For instance, a study examining the effects of human-induced climate change on forest biodiversity by Hansen and others (2001) predicted a 32-percent reduction in loblolly-shortleaf pine habitat across the Eastern United States. However, they also predicted an average increase in area of 34 percent for oak-hickory forests and a 290-percent increase in oak-pine forests. Drought is often a leading cause of stress and mortality in forest trees (Allen and others 2010, Choat and others 2012).

Drought, whether induced by climate change or other mechanisms, is considered a major inciting factor of forest decline (Leininger 1998, Manion 1981). For example a drought-induced oak decline event in Arkansas and Missouri that began in 2000 affected up to 120 000 ha in the Ozark National Forest of Arkansas alone (Starkey and others 2004). A study that examined 1991–2005 data across the Southeastern United States found that drought negatively impacted both growth and mortality of pines and mesophytic species, but not oaks (Klos and others 2009).

In that regard, three phases of research were addressed through this investigation. In the first phase, regional relationships of mortality and drought across the Ozark Highlands of

Arkansas and Missouri were examined. In the second phase, terrestrial vegetation response to climatological influences across 10 States in the Southeastern United States was investigated. In the third phase, probabilities were generated predicting future tree species distribution across the Southeastern United States.

Phase I: Mortality in the Ozark Highlands

For decades, oak decline has impacted Midwestern upland oak-hickory forests, particularly species in the red oak group (*Quercus* Section Lobatae) across the Ozark Highlands of Missouri, Arkansas, and Oklahoma. Drought is a common inciting factor of oak decline, and advanced tree age is considered a predisposing factor. Opportunistic organisms that take advantage of the already stressed trees such as armillaria root-rotting fungi and opportunistic wood-boring insects are believed to contribute to oak decline. An objective of this phase of research was to examine the relationship of drought and oak mortality.

Phase II: Mortality in Southeastern States

The objective of this phase of research was to expand our examination of the relationship between drought and red oak mortality across the following 10 Southeastern States: Alabama, Arkansas, Florida, Georgia, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, and Texas.

CHAPTER 13.

Tree Mortality Estimates and Species Distribution Probabilities in Southeastern United States Forests (Project SO-EM-F-10-01)

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Phase III: Future Distribution of Species in Southeastern States

This study area included the same 10 Southeastern States examined in Phase II. The objective of this phase of the research was to examine the likely spatial distribution of six major coastal species [loblolly pine (*Pinus taeda*), longleaf pine (*P. palustris*), red maple (*Acer rubrum*), water oak (*Quercus nigra*), southern red oak (*Q. falcata*), and post oak (*Q. stellata*)] through the year 2070.

METHODS

Mortality in the Ozark Highlands

To accomplish this phase of work, Forest Inventory and Analysis (FIA) annualized 1999–2010 data from plots in the Ozark Highlands of Arkansas and Missouri were used as well as corresponding cumulative monthly Palmer Drought Severity Indexes (PDSIs) and cumulative yearly PDSIs. The FIA data included 6,997 plots containing oaks. These plots were measured and remeasured from 1999 through 2010. Trees were divided into three species groups: red oak species group, white oak species group, and a non-oak species group. The percentage of standing dead trees was calculated by basal area and number of trees for each species group. This provided an indirect measure of oak decline and mortality. Cross-correlation analyses were used to examine the relationship between growing season PDSI and mortality. Detailed methods can be found in Fan and others (2012).

Mortality in Southeastern States

Mortality data were obtained from the 1991–2000 Forest Inventory and Analysis database for 10 Southeastern States (Alabama, Arkansas, Florida, Georgia, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, and Texas). To calculate percent mortality, basal area of standing dead trees was divided by total basal area (live and dead trees) of each FIA plot. Total annual precipitation, maximum temperature, minimum temperature, and temperature range were extracted from the PRISM (Parameter elevation Regression on Independent Slopes Model) climate database (Oregon State University 2012). Climate data (maximum and minimum temperatures and precipitation) were extracted from PRISM for 24 years prior to each inventory year. Potential spatial trends were examined through kernel smoothing. For detailed methods, see Crosby and others (2012).

Future Distribution of Six Species across the Southeastern States

The likelihood of presence of six economically important southeastern tree species was projected through the year 2070 by using three climate envelope model simulation platforms. The six species were loblolly pine (*Pinus taeda*), longleaf pine (*Pinus palustris*), red maple (*Acer rubrum*), water oak (*Quercus nigra*), southern red oak (*Q. falcata*), and post oak (*Q. stellata*). The three simulation platforms compared were BIOCLIM, GLM, and MaxEnt, where BIOCLIM is a classic climate envelope model with percentile distributions (Hijmans and Graham 2006), GLM is a parametric method, and MaxEnt

is a maximum entropy model (Hijmans and others 2012). Detailed methods can be found in Sui (2015).

RESULTS

Mortality in the Ozark Highlands

Of the three species groups examined in this study, the red oak group consistently dominated dead basal area as a proportion of the total basal area from 1999 through 2010. The proportion of dead basal area and dead trees for the red oak group reached a peak in 2008 to 2009, 2 years after the end of the last drought event. In contrast, the white oak group and the non-oak group had comparable mortality rates that remained relatively stable over time (fig. 13.1).

Regionally, this mortality was significantly correlated with growing season PDSI with a

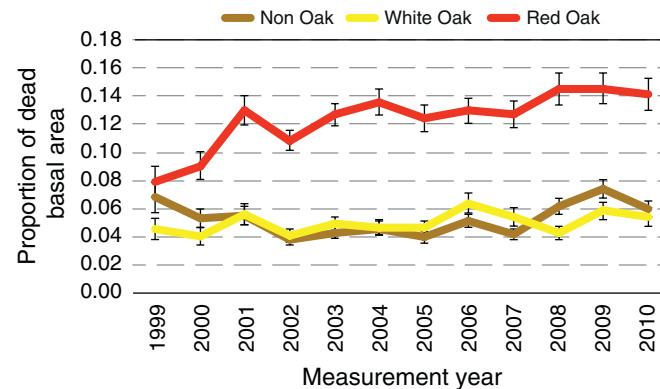


Figure 13.1—The 1999–2010 proportion of dead basal area for the non-oak group, white oak group, and the red oak group. Vertical lines are standard error for dead basal area of each species group and year. Based on 6,997 Forest Inventory and Analysis plots across the Ozark Highlands.

2- to 3-year time lag behind single drought events. Cumulative impacts of drought may last up to 9 years based on the previous 17 years of PDSI data. There were two droughts during the study period: a major drought from 1998 through 2000 and a somewhat milder drought in 2005–2006. These droughts triggered the oak decline events and associated mortality observed during the study period. Most of the red oak hot spots of mortality occurred toward the central part of the Ozarks and gradually increased in area over the Ozark Highlands. Small areas of white oak group mortality were more sporadic. See Fan and others (2012) for further details.

Mortality in Southeastern States

Levels of mortality varied between the upland red oak group and bottomland red oak group; mortality rate also varied within each of the two groups across the landscape. The highest mortality in upland red oak species extended from the coastal areas of southern Alabama northeastward through the Appalachian Mountains. Mortality rates in the coastal area of South Carolina ranged from 25 to 30 percent. Ozark Highland mortality was lower at 10 to 15 percent. For detailed results see Crosby and others (2012).

Future Distribution of Six Species across the Southeastern States

The three climate envelope models BIOCLIM, GLM, and MaxEnt were used to project the future distribution of six species during three time periods: 2010 through 2020, 2021 through 2050, and 2051 through 2070. Predicted distribution maps for southern red

oak (fig. 13.2), water oak (fig. 13.3), post oak (fig. 13.4), and red maple (fig. 13.5) show changes through time and the differences among the three models. Further details of this phase of the research as well as distribution maps for loblolly pine and longleaf pine can be found in Sui (2015).

DISCUSSION

Mortality in the Ozark Highlands

This analysis of mortality and of PDSI as it correlated with mortality between 1999 and 2010 corroborated the important function of

drought in this oak decline and mortality event in the Ozark Highlands. The regionwide droughts that began in 1998 and again in 2005 were followed by an escalation in relative mortality in the red oak group. Decline sites appear to be in areas where during the preceding century red oak established on dry, rocky, shallow soils. Much of this red oak establishment took place after the extensive harvesting and agricultural clearing that occurred during the early part of the 20th century and was facilitated by a period with relatively cool and moist climate.

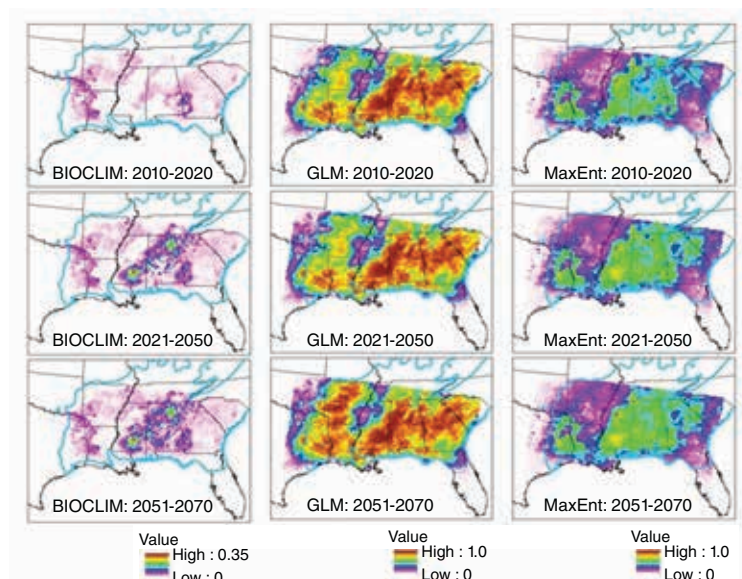


Figure 13.2—Distribution probabilities for southern red oak for the three climate envelope models: BIOCLIM, GLM, and MaxEnt.

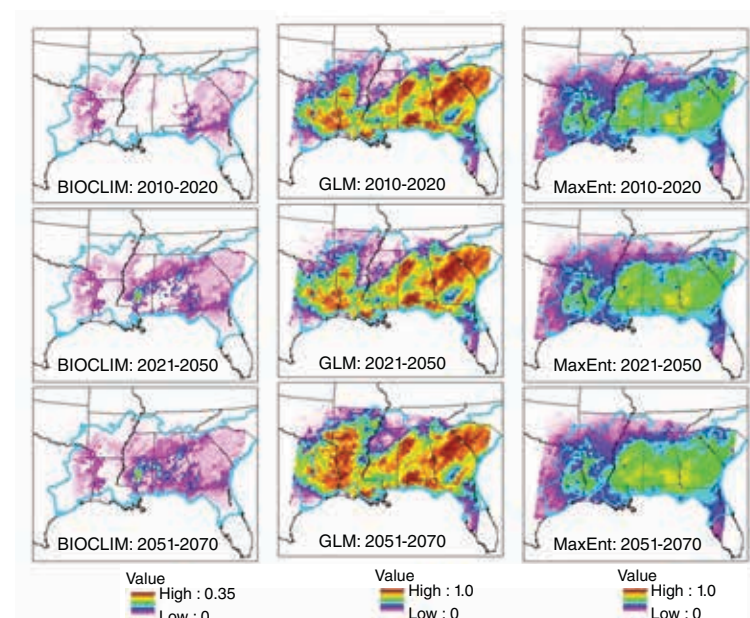


Figure 13.3—Distribution probabilities for water oak for the three climate envelope models: BIOCLIM, GLM, and MaxEnt.

Mortality in Southeastern States

During the 1991–2000 study period, mortality was higher in the eastern portion of the study area than in the Ozark Highlands in the west. The most important climate variables associated with mortality were average annual temperature for bottomland species and average annual precipitation for upland species. This difference in influential climate variables between bottomland and upland sites could inform future management strategies.

Future Distribution of Six Species across the Southeastern States

For all species, the BIOCLIM model produced the lowest species distribution probabilities, and the GLM model produced the highest species distribution probabilities. In all three models southern red oak, water oak, and post oak distribution probabilities increased with time, with post oak displaying the highest distribution probabilities. Other studies support a future increase in oak species (Hansen and others 2001,

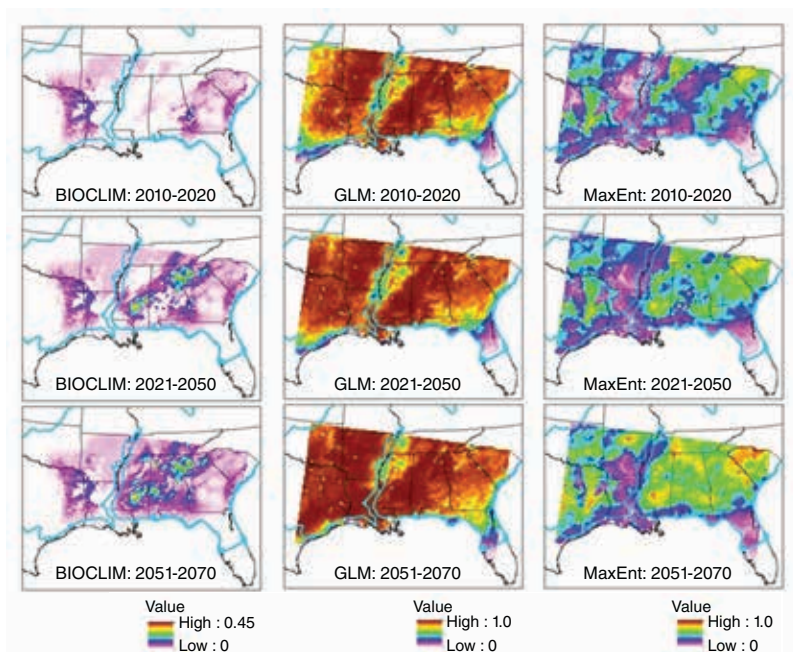


Figure 13.4—Distribution probabilities for post oak for the three climate envelope models: BIOCLIM, GLM, and MaxEnt.

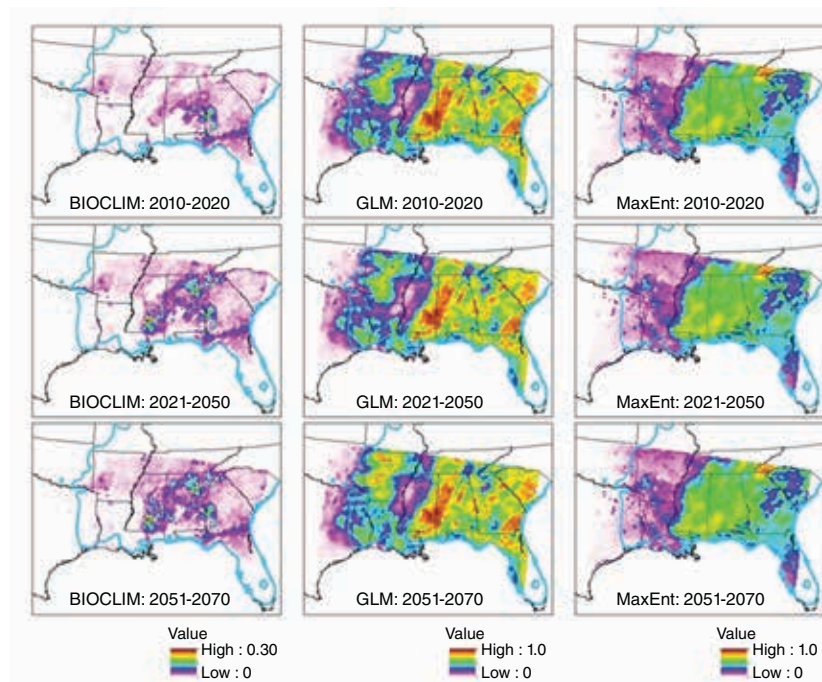


Figure 13.5—Distribution probabilities for red maple for the three climate envelope models; BIOCLIM, GLM and MaxEnt.

Vose and Elliott 2016). For red maple there was a small increase in distribution with time in the BIOCLIM and GLM models at the core of the region; the MaxEnt model indicated relatively little change.

Overall Summary

These combined results point to a future in which impacts of climate change on drought, temperature, and precipitation may well lead to changes in forest species composition, structure, and spatial distribution across the Southeastern United States. Support continues to grow for the idea of climate-influenced forest change. For instance, a study published in *Nature* that examined global vulnerability of forests to drought predicted extensive forest decline in areas where droughts are predicted to increase in length and severity (Choat and others 2012). An assessment of global tree mortality indicated the prospect for expanded tree mortality as influenced by drought and heat (Allen and others 2010). A recent review article looking at large-scale “mega-disturbances” on temperate forests suggests future large-scale transformations in forest composition and structure (Miller and Stephenson 2015). A more recent paper that examined the influence of changes in fire, climate change, and other disturbances in the Eastern United States suggests that these disturbances will favor oak in the long run (Vose and Elliott 2016). All of this points to a future in which past methods of forest management may require novel

implementation to mitigate unfavorable changes in forest species diversity, composition, structure, and function.

CONCLUSIONS

In the Ozarks, proactive management will be necessary to reduce the impacts of future oak decline events. However, it may be necessary for management intervention to be taken in young stands before they mature and become more susceptible to decline (Spetich and others 2016).

The complexity of predicting future distributions of tree species is compounded by an unknown degree of influence from future disturbance and climate. In the analyses of future species distributions, the three alternative models predicted different future tree species distributions. There are no currently available models that completely reflect the dynamic ecology of these forests as trees compete with one another and interact with climate, site conditions, and disturbance factors. Continued monitoring of forest health and tree mortality across the region will be important so that management intervention can be applied in an appropriate and timely way. Well-informed managers will be prepared to guide these forests in a way that maintains structure, function, diversity, and health to the benefit of both the environment and society.

CONTACT INFORMATION

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The annual national report of the Forest Health Monitoring (FHM) Program of the Forest Service, U.S. Department of Agriculture, presents forest health status and trends from a national or multi-State regional perspective using a variety of sources, introduces new techniques for analyzing forest health data, and summarizes results of recently completed Evaluation Monitoring projects funded through the FHM national program. In this 16th edition in a series of annual reports, survey data are used to identify geographic patterns of insect and disease activity. Satellite data are employed to detect geographic patterns of forest fire occurrence. Recent drought and moisture surplus conditions are compared across the conterminous United States. Data collected by the Forest Inventory and Analysis (FIA) Program are employed to detect regional differences in tree mortality. Change over time in the understory Vegetation Diversity and Structure Indicator is assessed on more than 500 FIA plots in the North Central and Northeastern States. Remeasured vegetation data across several Northern States are used to assess change over time in plant species diversity, occupancy and constancy. A new Regeneration Indicator, which includes a suite of tree-seedling and browse impact measurements, is described. The general magnitude of tree mortality predicted by the National Insect and Disease Risk Map was compared to FIA estimates of mortality. Six recently completed Evaluation Monitoring projects are summarized, addressing forest health concerns at smaller scales.

Keywords—Change detection, drought, fire, forest health, forest insects and disease, regeneration, tree mortality.

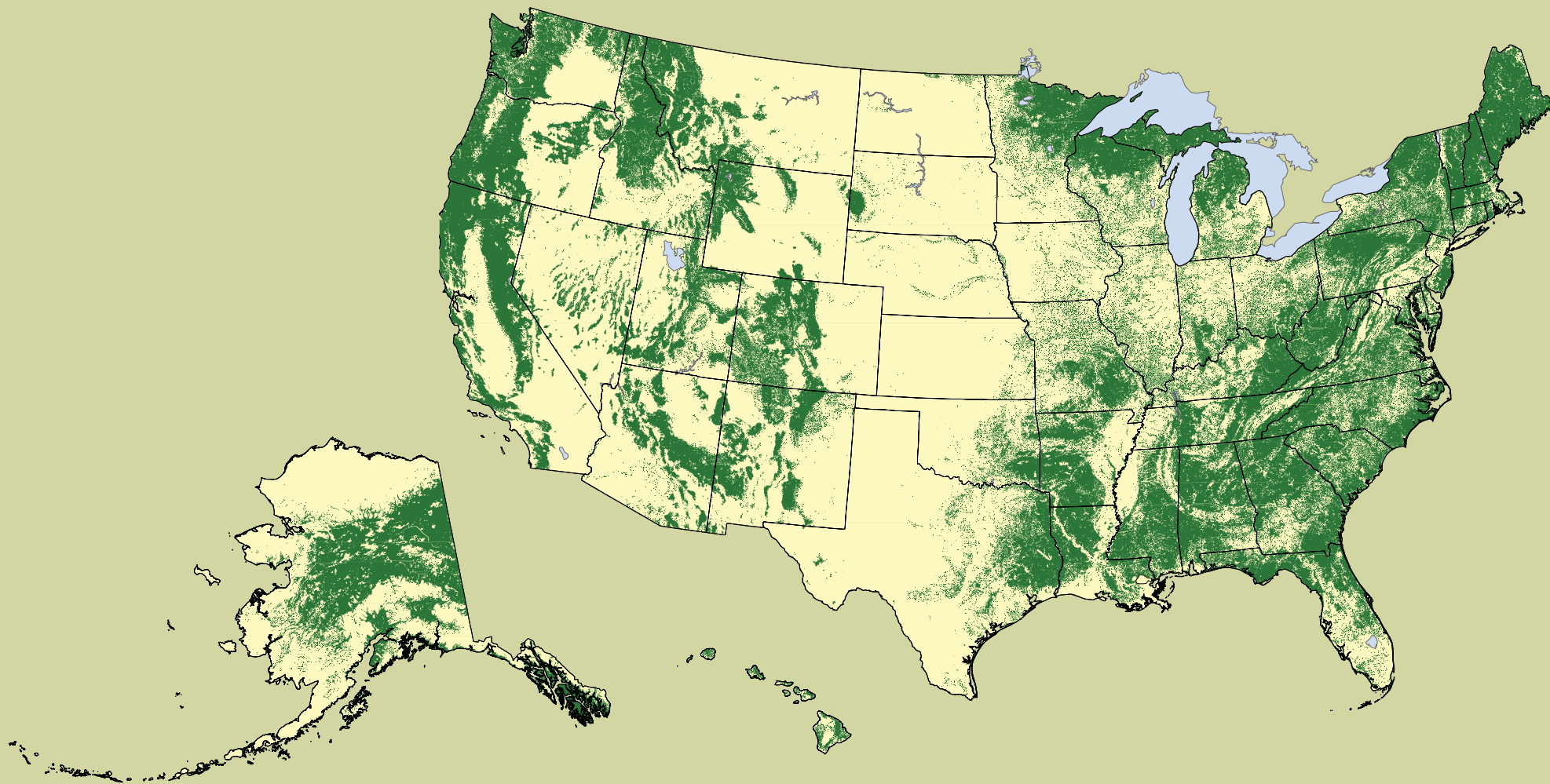


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