Development of Hardwood Seed Zones for Tennessee Using a Geographic Information System

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ABSTRACT: *For species that have no or limited information on genetic variation and adaptability to nonnative sites, there is a need for seed collection guidelines based on biological, climatological, and/or geographical criteria. Twenty-eight hardwood species are currently grown for reforestation purposes at the East Tennessee State Nursery. The majority of these species have had no genetic testing to define guidelines for seed collection location and can be distributed to sites that have a very different environment than that of seed origin(s). Poor survival and/or growth may result if seedlings are not adapted to environmental conditions at the planting location. To address this problem, 30 yr of Tennessee county precipitation and minimum temperature data were analyzed and grouped using a centroid hierarchical cluster analysis. The weather data and elevational data were entered into a Geographic Information System (GIS) and separately layered over Bailey's Ecoregions to develop a seed zone system for Tennessee. The seed zones can be used as a practical guideline for collecting seeds to ensure that the resulting seedlings will be adapted to planting environments. South. J. Appl. For. 27(3):172–175.*

Key Words: Hardwood, seed zone, adaptation, geographic information system, Tennessee.

Forest tree nurseries often produce seedlings of many hardwood species from seed of unspecified origin. The resulting seedlings are distributed for planting to sites that can have a very different environment than that of the seed origin. If a seedling is not planted where it is most likely to survive and thrive, overall productivity will be reduced (Wakeley 1963, Schmidtling 2001). In addition, the adaptability and productivity of the next rotation of trees at that site also could be reduced by infiltration of nonlocal, undesirable genes, if poorly adapted trees survive and reproduce (Wilson 1990).

Nursery production of hardwood seedlings in Tennessee can be used to illustrate this problem. Tennessee has a wide range of ecological regions, corresponding to physiographic and climatic variation across the state (Bailey 1980). The western boundary of the state is comprised of bottomlands associated with the Mississippi River Basin, whereas eastern Tennessee is mountainous, with elevations reaching over 5,800 ft (1,768 m). Currently, 28 hardwood species are grown for reforestation purposes at the East Tennessee State Nursery. Many of these species are grown from bulked seedlots of unknown origin(s) and are distributed for planting throughout the state. The majority of hardwood species have had limited or no genetic testing to define guidelines for seed collection.

Genetic variation in the growth of numerous forest tree species has been demonstrated by planting seedlings that originated at different geographic locations within the natural range of the species at the same location (cf., Zobel and Talbert 1984). Studies have examined the interaction between site and genotype, in terms of adaptability and growth rates (Campbell 1986, Lantz and Kraus 1987, Campbell et al. 1989, Rehfeldt 1989, Monserud and Rehfeldt 1990, Parker 1992, Campbell 1992, Campbell and Sugano 1993, Ying and Liang 1994, Hamann et al. 2000). Based on biological, climatological, or geographical criteria, these studies demonstrate a need for seed collection guidelines for species in which there is no or

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limited information on genetic variation and adaptability to nonnative sites. A practical system is needed for collecting seeds and distributing the resulting seedlings back to sites with a similar environment to the seed origin (Schubert and Pitcher 1973) until genetic testing can provide guidance for seed transfer.

Some environmental factors that affect plant growth and reproduction include the length of the growing season, amount and seasonal pattern of precipitation, and minimum temperature. These factors can affect time of budbreak, rate of growth, cessation of growth, and species distribution. For example, precipitation and minimum temperature generally limit the distribution of southern pine species (Schmidtling 2001). A Geographic Information System (GIS) is a relatively new technique used to evaluate environmental information in relation to large land areas, such as states or regions. This technology can provide a basis for making management decisions by integrating information to understand spatial relationships. Applications for GIS exist in many fields, such as land use planning, ecological research, and demographic research. The objective of this study was to use a GIS system, in conjunction with climatic, elevational, and ecosystem data, to create a map of seed zones for Tennessee which could be readily used by resource managers to collect seed for reforestation of specific areas with locally adapted genotypes.

Materials and Methods

Weather, elevation, and ecological data were used to create four layers of data in a Geographic Information System (GIS) Arc/Info®. The GIS was used to create a seed zone map for Tennessee. A seed zone can be defined as homogeneous environments mapped across a region to indicate geographic variation (Campbell 1991). A layer consisted of attribute data, e.g., elevation, which was superimposed on the Tennessee land base. Time of budbreak (as indicated by elevation), temperature, and precipitation were considered the most important variables that could be quantitatively measured to represent critical adaptive limitations. Three analyses were conducted to create seed zone maps with a progressive reduction in number of zones. Each generation included GIS layers of temperature, precipitation, elevation, and ecological/physiographic data. The analyses were conducted using a digital elevation model, developed by the US Geological Survey for the conterminous United States that consisted of 1,035 m × 1,035 m grid cells. Thus, each cell represented elevation for an area slightly greater than 1 km^2. The 1:2,000,000-scale coverage of county boundaries also was acquired from the US Geological Survey. All GIS coverages were in Albers equal area projection. Arc/Info® (ESRI, Redlands, Calif.) version 7 was used for all GIS analyses (Environmental Systems Research Institute 1994).

Temperature and Precipitation Data Source and Analyses

Temperature and precipitation data for 1961 to 1990 from 75 Tennessee weather stations were available from the National Oceanic and Atmospheric Administration (Owenby and Ezell 1992). The climatological normals were based on the monthly mean maximum and minimum temperature, and monthly total precipitation records and used to create graphs of temperature and precipitation over time. If a county had two weather stations, then one data set was randomly deleted. Both temperature and precipitation data were available for 66 of the 95 counties in Tennessee. For the counties without data, the temperature and precipitation means from surrounding counties were averaged and used.

To facilitate GIS analysis, the temperature and precipitation data were analyzed to produce a single standardized value to represent a county's weather history. The raw data were plotted with time as the x-axis, and temperature or precipitation as the y-axis for each county. The curves were grouped by use of a centroid hierarchical cluster analysis that revealed similar temperature or precipitation patterns over a 12 month period. The clusters were formed according to Equation (1) (below), which considered both pattern and amount to identify similar counties.

$$d_{ij} = 0.5*(1-r_{ij}) + 0.5*|(x_i - x_j)| / md$$

where

r_{ij} = correlation between county i and county j

x_i = mean temperature or precipitation for county i

md = maximum mean difference

i = county under consideration

j = county being compared

d_{ij} = climatic distance

The resulting distance values ranged from zero to one for both the temperature and precipitation variables. Counties with distance values near zero were highly correlated and had similar means, and were clustered together. Counties with distance values close to one had lower correlation values and different means, and were not clustered together.

The cluster analysis based on these distances formed seven temperature clusters and ten precipitation clusters. Each county was given a temperature and precipitation code according to the respective cluster in which the county was grouped. Overall, there was less land in the upper and lower elevations and more land in the middle elevation range.

The code associated with a particular county joined other counties with the same code into one cluster. Once the temperature and precipitation data were represented by a single value for each county, the data could be used as digital GIS layers.

Elevation Analysis

In Tennessee, elevation ranges from approximately 100 to 5,800 ft (30 to 1,768 m). The area occupying each 100 ft interval within the different elevation ranges was calculated and classified into groups. The groups were formed by a visual inspection of the map embedded with knowledge of the different forest types in the state. An additional consideration in grouping different elevation ranges was the need to distinguish localized differences between xeric, ridge top and lower, more mesic environments in eastern and middle Tennessee. Studies on root systems of different oak species suggest that there is a difference between dry and mesic site species (Kormanik et al. 1993). Those differences may be present in certain hardwood species, e.g., white oak, which occur on both sites and could affect survival if mesic ecotypes were planted in xeric conditions. The resulting elevation groups were assigned a value (1–5) (Table 2.1) and used as one of the GIS layers based on the area at each interval.

Ecoregion Analysis

Physiographic provinces, called "ecoregions" by Bailey (1980), were used to further delineate seed zones. Bailey's classification system reflects vegetation, soil, landform, fauna, and climate. Tennessee includes portions of nine regions: the Mississippi Alluvial Basin, the Coastal Plain, the Upper Gulf Coastal Plain, the Interior Low Plateau Highland Rim, the Northern Cumberland Plateau, the Southern Cumberland Mountains, the Central Ridge and Valley, the Northern Ridge and Valley, and the Blue Ridge Mountains.

Analysis One

Arc/Info® software was used to generate a Tennessee seed zone map using the precipitation layer (ten clusters), the temperature layer (seven clusters), the elevation layer (five classes) and Bailey's ecoregions (nine regions). The layers were combined into a single GIS coverage for Tennessee.

Analysis Two

The temperature and precipitation data layers were revised to reduce the total number of clusters. Temperature and precipitation layers remained separate in this analysis. The elevation data were reclassified to create fewer groupings by combining the fourth and fifth group (Table 1). To reduce the potential number of seed zones, Bailey's ecoregions were used in the analysis, but were not treated as a layer. Precipitation, temperature, and elevation layers were superimposed on the ecoregions within Tennessee to generate a seed zone map.

Analysis Three

The temperature and precipitation variables were combined into one layer by multiplying the temperature variable by 100 and then adding them together. This union created a single set of data, henceforth referred to as the weather data. The weather data were then plotted over the same 12 month period, previously used for temperature and precipitation data, and clustered together as described previously to form a weather layer. The elevation layer did not change from the second analysis. Weather and elevation layers were superimposed on each of Bailey's ecoregions as in the second analysis.

Table 1. Area comprising each assigned elevation group and the associated range of elevation used for the development of seed zones in Tennessee.

Elevation group	Range of elevation (ft)	Area (thousands of acres)
1	100–200	1,271
2	300–1000	17,022
3	1100–1900	5,751
4	2000–3600	1,022
5	3700–5800	181

Results and Discussion

The precipitation and temperature layers combined in the first analysis generated more than 60 weather zones. These data, coupled with the five elevation groups and Bailey's nine ecoregions, resulted in over 300 seed zones. In the second analysis, the cluster program produced five temperature zones and six precipitation zones, yielding a possibility of 30 zones when combined. The GIS analysis again produced a large number of seed zones (175), despite reductions in the number of temperature, precipitation, and elevation zones, and eliminating Bailey's ecoregions as a variable. In the third analysis, the layering of weather and elevation zones over each of Bailey's ecoregions distinguished 21 general seed zones across the Tennessee land base (Figure 1). Zones of the same color divided by an ecoregion boundary are not considered to be exactly the same seed zone, but have similar attributes. Although distinguishing similar seed zones as different zones subdivides the state into more seed zones, the total number is less than in the first and second analyses. Additionally, guidance is provided for making collections to provide seedlings for areas with a seed crop failure. Seeds from a neighboring ecoregion with the same color may be used, as suggested by Schubert and Pitcher (1973), in the event that trees in a particular seed zone do not produce seeds. Moreover, the third analysis distinguished ridges in middle and eastern Tennessee from lower, more mesic sites within a seed zone at the county level (not shown), that will allow for separation of ecotypes if warranted.

The progressive reduction of layers and clusters within layers in the three analyses caused a corresponding reduction in seed zone numbers. The first two approaches generated too many seed zones to implement seed collections for practical application in nursery management and seedling distribution. The number of zones generated in the third analysis is small enough to allow Tennessee land managers to collect seed by zone to generate locally adapted seedlings for reforestation purposes.

The Tennessee seed zone map (Figure 1) is an initial step in a sequential process to develop data to construct a final map in the future. This system can be used until genetic testing is conducted and corresponding specific guidelines for seed transfer are developed. It is hoped that the genetic testing will reduce the number of seed zones, which is quite large when compared to certain coniferous species. Redefining seed zones can be an incentive to managers in that fewer resources on collection, processing, growing, and shipping processes will be expended.

Collecting seed according to the seed zone map can be an initial first step toward the genetic improvement of a species. Genetic testing could be readily conducted by keeping seed separate by provenance or mother tree for experimental plantings. Establishment of provenance/progeny tests to assess growth potential and other characteristics will not only provide data to refine the seed zones, but will also generate genetically improved materials for seed orchards and advanced generation breeding.

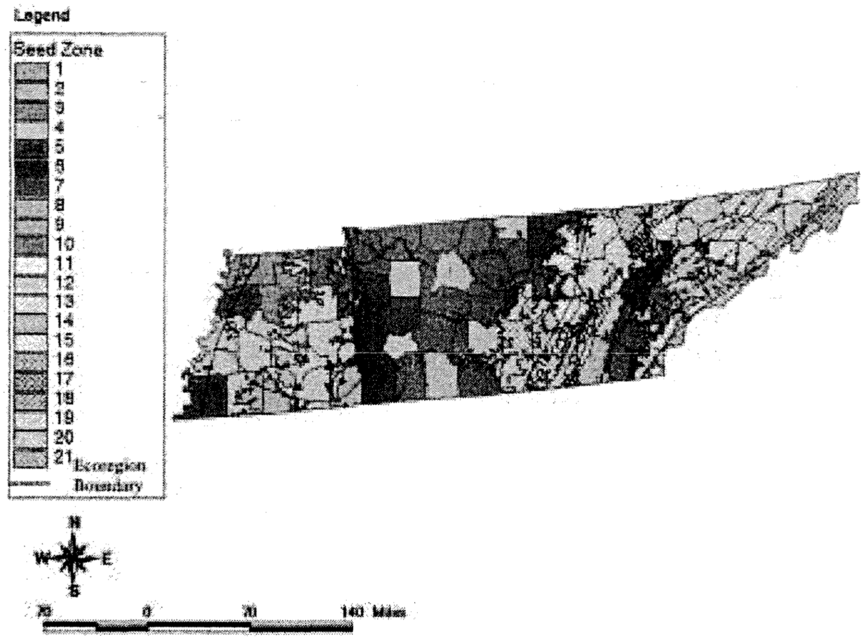

Figure 1. Seed zone map for the State of Tennessee based on a Geographic Information System analysis. Bailey's Ecoregions (1980) are indicated by the solid black lines.

When seed zone guidelines are not followed in artificial regeneration, overall yields can be reduced (Schmidtling 2001) and local ecotypes will be contaminated with nonlocal genes (Wilson 1990) that can reduce the overall productivity and fitness of the surrounding forests of similar species. Hardwood species, especially oaks (*Quercus* spp.), have not been regenerated artificially with the same success as coniferous species (McElwee 1970, Schlarbaum 2002), so gene contamination is probably minimal. Recent improvement of artificial regeneration techniques for hardwood seedlings may increase planting success (Kormanik et al. 2002), and thereby augment gene contamination of local populations. Prompt implementation of a seed zone system should assure the survival and productivity of Tennessee forests for future generations.

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