Survival and Growth *of* Individual Trees *in* Mixed-species Plantations *of Bottomland Hardwoods on 2 Mississippi Delta Soil Types*

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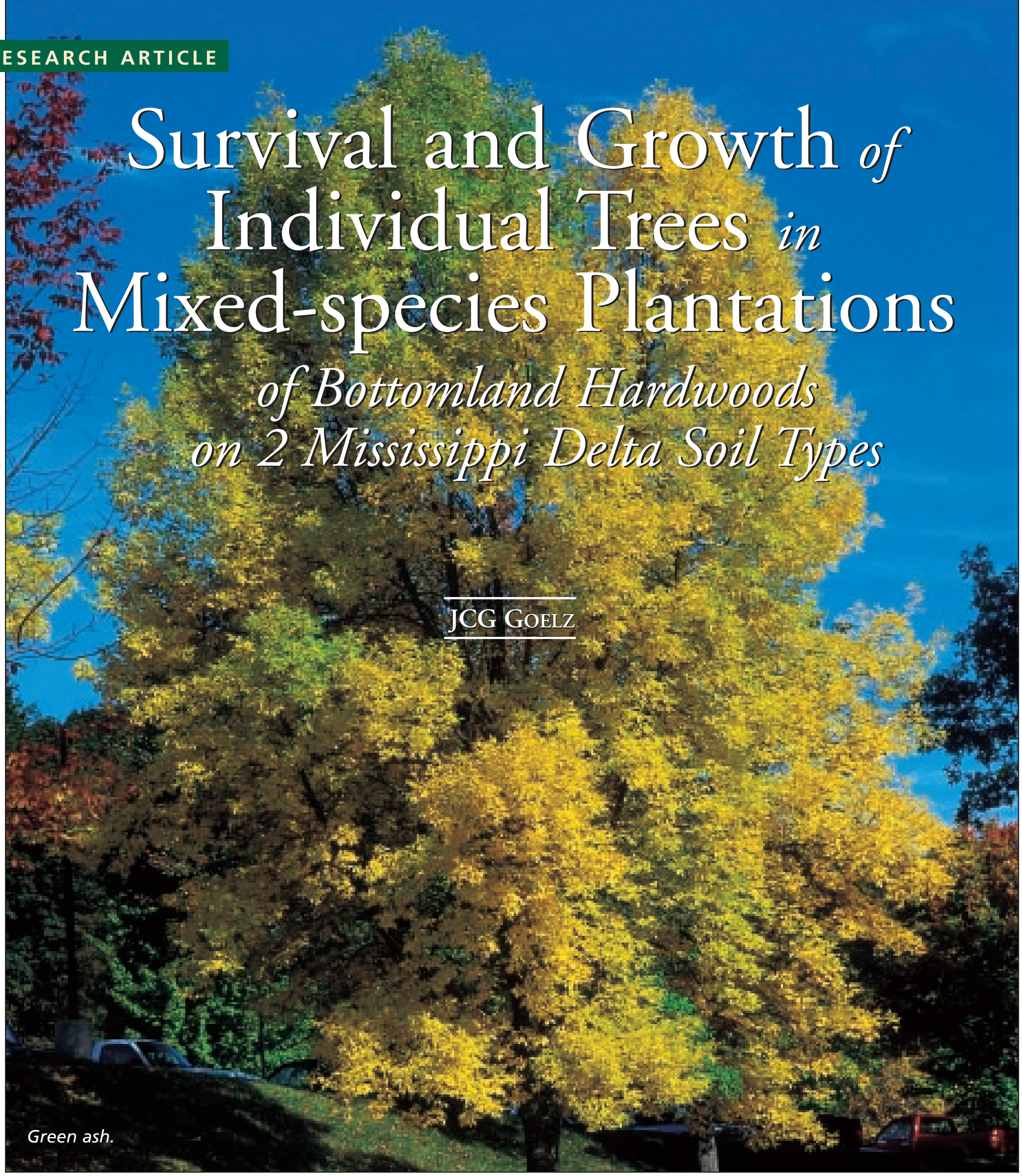

Green ash.

Photo by Joseph G Strauch Jr

ABSTRACT

Water oak (*Quercus nigra* L.[Fagaceae]), Nuttall oak (*Q. nuttallii* Palmer), and green ash (*Fraxinus pennsylvanica* Marsh. [Oleaceae]) were planted in mixtures at 2 spacings, 1.8 and 2.7m (6 and 9 ft) triangular spacing, on 2 contrasting soil types: Sharkey and Dundee. Survival was high for green ash and Nuttall oak, but was poor for water oak. Green ash grew the fastest initially, but the oaks have caught up or exceeded the ash by age seven on the Dundee soil. On the Sharkey soil, Nuttall oak is nearly as tall as the ash, but the water oak is still shorter. Although green ash has been able to maintain height supremacy on each soil type, the oaks have exceeded them in crown diameter and stem diameter, and trends suggest that the oaks will soon surpass the ash. Both oak species appear to represent a viable mixture on the Dundee soil, but if growth trends continue, ash will eventually fall into inferior crown positions. Nuttall oak and green ash appear to mix well on the Sharkey soil, but most water oak will not attain codominance.

KEY WORDS: afforestation, competition, crown diameter, green ash, monoculture, Nuttall oak, species richness, water oak

NOMENCLATURE: (plants) Little (1979); (soil) SSD (2001)

Mixed-species plantations will have greater species richness in the overstory than monocultures; the associated plant and animal communities will also be more diverse. Mixed-species plantations may produce more biomass than single-species plantations (Harper 1977; Kelty 1992; DeBell and Harrington 1993). Conversely, Matthews (1989) believes timber yield of a pure stand of a fast-growing species will typically exceed that of a mixture. Kelty (1992) believes that proper selection of species can make it more likely, although still unlikely, for mixed-species stands to have greater growth than monocultures, and that there must be significant differences in the growth characteristics that will reduce competition. Assman (1970) believes that mixed-species stands will be more productive than single species stands when the mixture consists of a fast-growing intolerant species and a tolerant species that is relegated to the understory. Smith (1986) suggests that yield of a mixed stand may be greater than a monoculture when the mixed stand is vertically stratified. Mixed-species plantations may be more productive than monocultures when one of the species increases soil organic matter or nutrient concentration, typified by N-fixing species (Assman 1970; Matthews 1989; Smith 1986). Log quality is often better in mixed-species stands than in monocultures, as merchantable length and the length of the clear bole is increased in mixed stands (Clatterbuck and Hodges 1988), although Assman (1970) suggests that growth form will be poorer in mixed stands as phototropism will lead to stems that are more crooked. Mixed stands may more completely utilize the soil if the different species have different rooting patterns (Assman 1970), although this may only be important during the establishment phase of a forest, before the trees can completely exploit the soil to the ultimate rooting depth (Kelty 1992). Visitors to a forest may view mixed-species plantations as more pleasing than monocultures (DeBell and Harrington 1993), particularly when the species differ in size and form, bark texture and color, leaf shape, or leaf color.

Several types of mixed species stands may be planted (Goelz 1995a). Intercropping mixtures involve a mixture of species that differ greatly in growth rates, or in the product they produce. Thus, a mixture of a species planted for timber production with a species planted because it fixes nitrogen, produces desirable fruit, or attractive flowers would be an intercropping mixture. A plantation where 1 species with fast early growth is used as a nurse crop for a slower-growing species would also be an intercropping mixture. However, there are no environmental extremes that would suggest the need for a nurse crop for southern bottomland hardwoods; although initial growth of seedlings may be as good, or better, at 50% sunlight as in full sunlight, the additional insolation is not a detriment to growth after a few years. Relay intercropping (Vandermeer 1989) occurs when species are grown together for only part of the the rotation of either species, particularly when 1 species is several years old before the second species is planted, and the first species is harvested before the second.

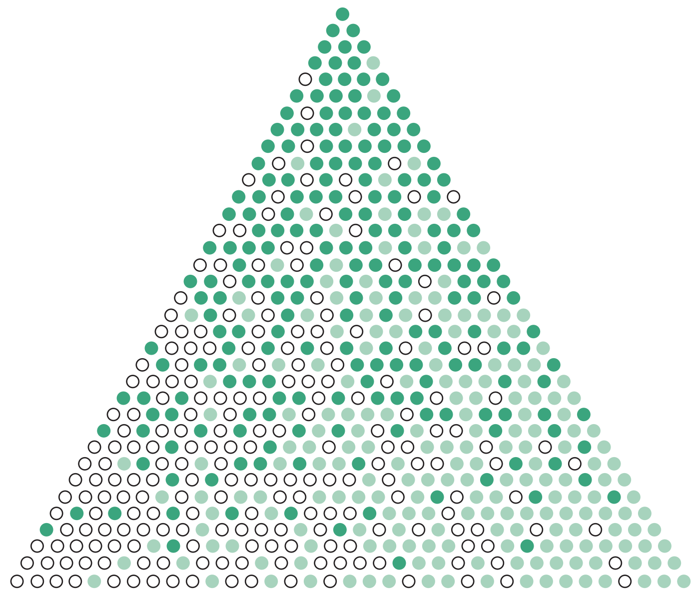

Figure 1 • The systematic mixed-species plot. There are 630 trees, 210 of each species represented by shading of the circle (from Goelz 1995b).

Mixed monotypes (or multi-species plantation) is where a mixed-species plantation is divided into patches of a single species. The patches may be rectangular (most commonly several rows of each species) or irregular. When information regarding the relative growth rates and competitive abilities of the species is lacking, mixed monotypes is the most sure way of establishing a mixed-species forest.

True mixtures represent an intimate mixture of species. It is the most difficult type of plantation to maintain, as success requires selection of compatible species. If the species are incompatible, 1 species may be subordinated and never produce the product that was desired, whether it be timber, fruit, or any other value. Thus the cost associated with planting that species is basically wasted.

All species of bottomland hardwoods desirable for timber production are moderately intolerant to intolerant of shade, except for the relatively minor species, persimmon (*Diospyros virginiana* L. [Ebenaceae]) (Putnam and others 1960). As relatively intolerant, they will not grow well or produce well-formed stems if they persist in an inferior crown position. Thus, species in a true mixture will not be compatible if 1 species is consistently subordinated by the other species and thus unable to produce the desired products.

One objective of this study was to describe survival and early growth of plantations of 3 species planted at 2 spacings on 2 contrasting soil types. My motivation was to determine whether the 3 species are compatible on both sites for the 2 spacings.

METHODS

Study Site

I installed the study at the Lake George reforestation project of the US Army Corps of Engineers. This area is between Holly Bluff and Satartia, Mississippi. I used 2 contrasting soil types, a poorly-drained clay soil (Sharkey, a Vertic Haplaquept), and a better-drained, loamy soil (Dundee, an Aeric Ochraqualf). The soil types are nearly adjacent, the Dundee soil is the remnant of the natural levee formed by a river that has since meandered to a different location. The Sharkey soil represents a flat, located further from the old watercourse. Both are common soil types of the Mississippi Delta.

I selected 2 initial spacings, 1.8 and 2.7 m (6 and 9 ft); the trees were planted on a triangular, rather than square, spacing. These spacings are somewhat closer than operational hardwood plantations, but I did did this to study competition among trees at an earlier age. I chose 3 species, Nuttall oak (*Quercus nuttallii* Palmer [Fagaceae]), water oak (*Quercus nigra* L. [Fagaceae]) and green ash (*Fraxinus pennsylvanica* Marsh. [Oleaceae]). These species are commonly planted in the area, and I believed they would all survive and grow well on my sites, although I expected that water oak might be most limited by the Sharkey soil, particularly if the area became flooded (Putnam and others 1960).

I used mechanical and chemical weed control to nearly eliminate any herbaceous or woody competitors for the first 3 seasons. I used mowers, cultivators, grass-selective herbicide, and patch spraying of non-selective herbicides; for the narrow spacing I used implements moved by an all-terrain-vehicle. I did complete cultivation, which was preceded by mowing and, possibly, herbicide application. Mowing was used to reduce vegetation height; if johnsongrass (*Sorghum halepense* L.(Pers.) [Poaceae]) was abundant I used a grass-selective herbicide; after mowing, or after the grass had died, I cultivated with a disc or a rototiller. Hoeing was conducted around individual seedlings. Spot spraying was conducted to kill vines or patches of johnson grass. For the next 2 seasons I did a more limited weed control consisting of mowing the competing vegetation one or more times per year, with some spot spraying around seedlings that had not yet grown above the herbaceous vegetation.

A Systematic Triangular Plot

I chose to create a systematic design to study mixed-species plantations. Systematic designs are useful for fitting response functions, particularly at the early stages of a research program, although they are not well-suited to test for differences between 2 levels of a factor (Mead 1988). See Goelz (2001) for a more complete description of methodology and motivation for using a systematic design. My design is based on a large triangular plot in which species composition varies gradually (Figure 1). In an attempt to maintain the desired species proportions, I replanted 1 y after planting at each planting spot where mortality occurred, using extra trees that had been planted adjacent to the study plots (essentially 1+1 seedlings). For water oak replacements, I used some 2+0 stock obtained from a nursery. Survival of replants was negligible, except for the 2.7 m spacing on the Dundee soil.

Plot Layout

I installed 2 replicates of each density on each soil type, thus providing a total of 8 main triangular plots. The 2 plots for a given soil-by-spacing combination were adjacent to each other. The buffer area between the 2 triangular plots is 4 rows, with a buffer of 11 m (4 rows) around the 2.7 m spacing plots, and 9 m (5 rows) around the 1.8 m spacing plots. The 2 triangular plots and surrounding buffer rows comprise a parallelogram. Species were allocated to the buffer areas proportional to the species composition of the adjacent plot—with triangular spacing there are 2 trees of the adjacent row that are closest to any tree in the buffer row. Thus species in a given location of the buffer row was randomly selected based on the species of the 2 closest trees.

Measurements

Diameter at breast height (dbh) of all trees was measured annually for 7 y; before trees attained 2.5 cm (1 in) dbh, diameter at 0.15 cm (0.5 ft) was also measured. Height was measured on every tree within the measurement plots. Crown diameter was measured on every tenth tree, in both the measurement plot and the border rows. I report crown diameter measurements that are the average of the largest crown diameter and the crown diameter perpendicular to the largest diameter. My averages are based upon the 420 planting spots of each species for each spacing-by-soil combination within the measurement plots, except the crown diameter measurements, which are based on all measurements taken, including trees planted as buffer rows.

Data Presentation

My emphasis is to describe survival and trends in dbh, height, and crown diameter over time. I show average dbh, height, crown diameter, and survival for the 12 treatment combinations (3 species, 2 spacings, and 2 soils) for 7 y of measurements. I calculated averages and plotted them with their corresponding 95% confidence intervals; I do not present confidence intervals for the crown diameters as they are largely overlapping and thus produce a confusing figure. The confidence regions for dbh and height are very small as they reflect 420 planting spots per species for each soil-by-spacing combination. I analyzed initial survival by fitting loglinear models to the contingency table data (Fienburg 1980); I partitioned G^2 to test for significance of terms.

RESULTS AND DISCUSSION

Survival

Survival at 1992, 1 y after planting, was significantly different among species, spacings, and soil types (Figure 2). Mortality was negligible among the green ash for any spacing or soil type. Survival was also high for Nuttall oak, but was low for water oak. This was particularly true of the 2.7 m (9 ft) spacing on the Sharkey soil; I noticed large cracks in the soil during mid-summer and I attribute mortality to dessication of the roots exposed by cracks in the soil. Cracks in soil for 1.8 m spacing on the Sharkey were less abundant and more shallow; this might reflect minor soil differences. At planting, water oak seedlings had root systems that were basically a taproot with few or no lateral roots. I suggest this type of root system is more sensitive to exposure due to cracking of the soil. It also seemed that cracks were more common near a water oak than the other species. The more extensive root systems of the other species may have partially resisted soil cracking. Also, many of the water oak seedlings still had green leaves, and may not have been fully dormant when lifted, and thus dessication of the plants may have followed outplanting.

After the first year, mortality was negligible for all species. Occasionally a tree would die-back to the ground, then resprout the following year; thus apparent survival would increase. A number of water oak replants survived in the 2.7 m spacing on the Dundee soil, thus the increase in survival from 1992 to 1993. Almost all other replants died.

Height

Initially, average heights are greater for the 1.8 m (6 ft) spacing than the 2.7 m (9 ft) spacing for all species and both soils. However, by the seventh year, height on the 2.7 m (9 ft) spacing is equal to or taller than height on the 1.8 m (6 ft) spacing. Trees are taller on the better Dundee soil for all species and spacings. I suggest that trees with close neighbors will be straighter and grow faster in height than trees that lack close neighbors. "Closeness" is relative to tree size, and as the trees grew, neighboring trees at the 2.7 m (9 ft) spacing became large enough to influence adjacent trees. I

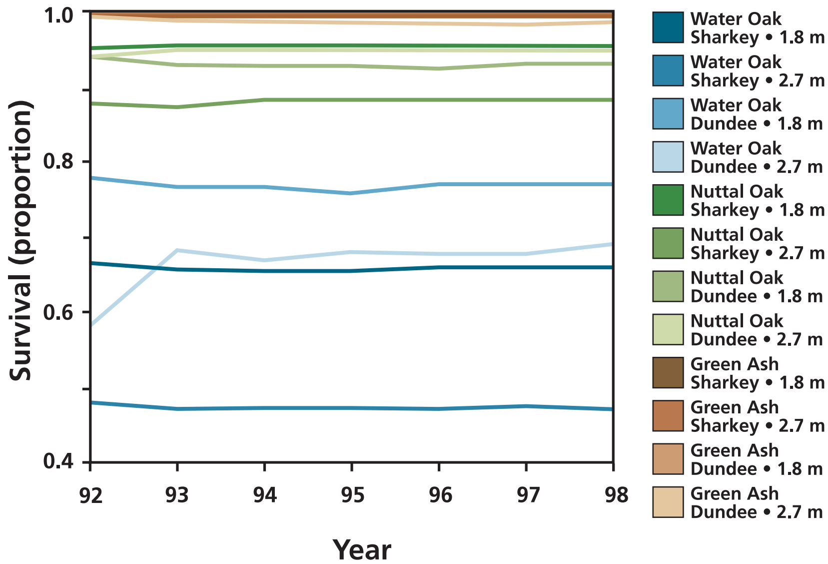

Figure 2 • Seven-year survival for 3 species (water oak, Nuttall oak, and green ash) on 2 soil types (Sharkey and Dundee), with 2 spacings, 1.8 and 2.7 m (6 and 9 ft).

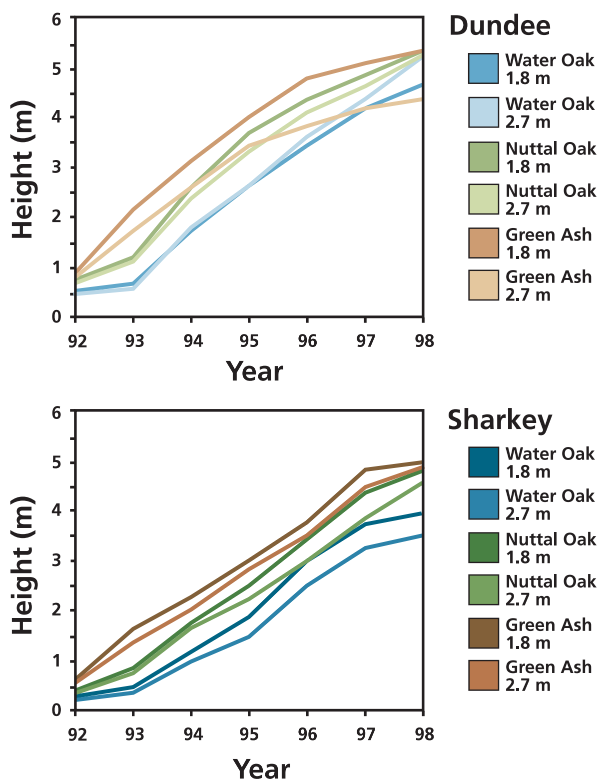

Figure 3 • Seven-year heights for 3 species (water oak, Nuttall oak, and green ash) on 2 soil types (Sharkey and Dundee) with 2 spacings, 1.8 and 2.7 m (6 and 9 ft).

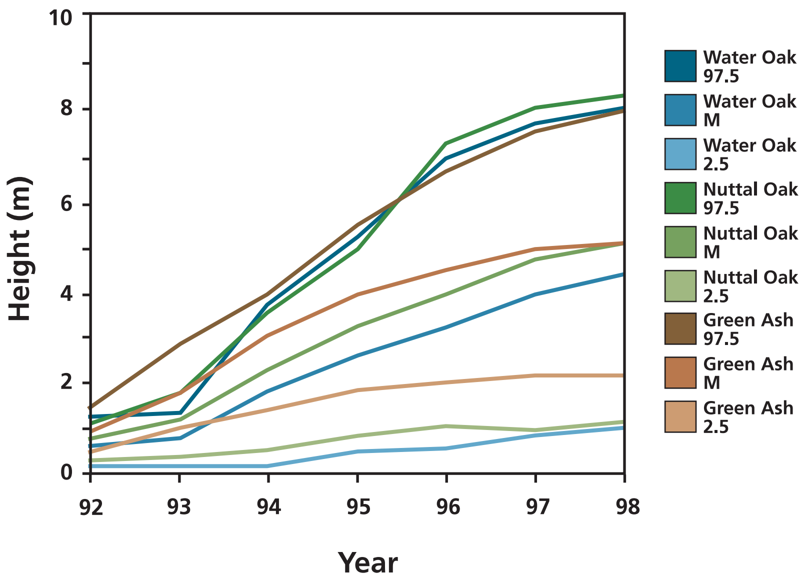

Figure 4 • For the 1.8 m (6 ft) spacing on the Dundee soil, mean (M), 97.5 percentiles and 2.5 percentiles of the height measurements are plotted for 7 y.

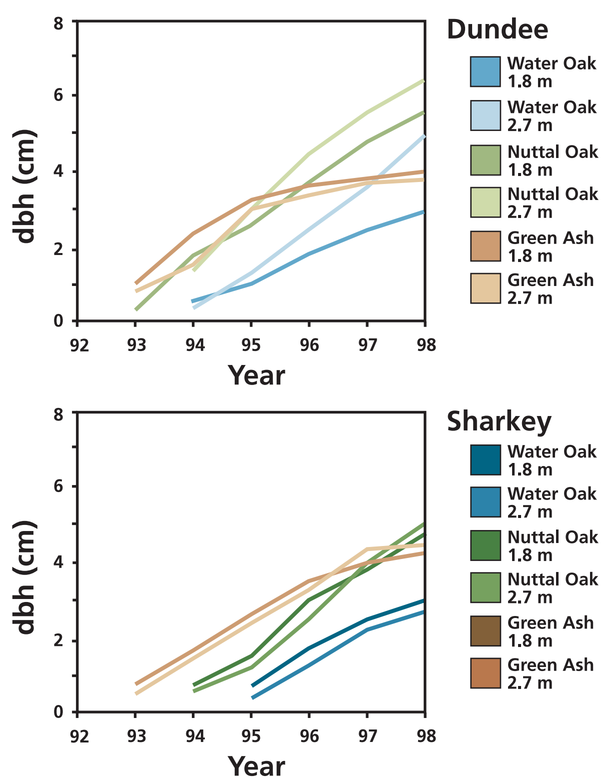

Figure 5 • Diameter breast height (dbh) for 7 -y survival for 3 species (water oak, Nuttall oak, and green ash) on 2 soil types (Sharkey and Dundee) with 2 spacings, 1.8 and 2.7 m (6 and 9 ft).

suggest that the greater height of the 2.7 m (9 ft) spacing of the water oak on the Dundee soil, compared to the closer spacing, might suggest some water oaks are becoming suppressed by neighboring trees, thus reducing the average height growth for water oaks on the closer spacing.

Green ash was tallest throughout the experiment, except for the 2.7 m spacing on the Dundee, although Nuttall oak has nearly equalled green ash by year seven. Average height of water oak has caught up to the Nuttall on the 2.7 m spacing on the Dundee, but is lagging elsewhere. Water oak grew very little during the first 2 y, but appears to be catching up to the other species, at least in relative terms.

Average heights are somewhat misleading because the oaks have much higher variability than green ash; water oaks represent both the tallest and shortest of the trees. Some oaks have grown very little during the seven years. In Figure 4, we display the mean, 97.5 percentile, and 2.5 percentiles of heights for each species on the 1.8 m spacing on the Dundee soil. For the 2.5 percentile, the green ash is twice that of the oaks. For the tallest trees of each species (97.5 percentile) little difference in height was apparent after the third growing season.

These height growth patterns suggest that if the 3 species were grown in an intimate mixture, all three would maintain a component among the dominant and codominant trees. However, the water oak, and to some extent the Nuttall oak, would include many trees that would become subordinate. The trends suggest that average height of the oaks may soon be overtaking the green ash. However, most ash have grown well enough that they would be in an intermediate crown position, at worst, by the time the stands would be dense enough to warrant a thinning operation.

Diameter

Green ash had the largest dbh for several years for each soil-by-spacing combination (Figure 5). However, by age seven, Nuttall oak is larger on both soil types, and water oak is larger for the 2.7 m spacing on the Dundee soil. For all species, dbh was slightly greater for the 1.8 m spacing for the first few years, but the 2.7 m spacing has equal or greater diameter by age seven. I believe this reflects the influence of competition. Thus, neighboring trees are interfering with each other at least at the 1.8 m spacing on both soils. On the Dundee soil, it appears the oaks are overtaking green ash. This is much more evident than was the case for the height data. Although the ash have not lost their primacy in height, it is clear that they have lost the lead in dbh. On the Sharkey soil, the Nuttall oak has overtaken the ash, but water oak is nearly paralleling the ash.

Crown Diameter

Nuttall oak had consistently larger crown diameters for each spacing and soil type (Figure 6). Although green ash had relatively large crown diameter at the younger ages, it had the most narrow crowns for each soil-by-spacing combination by age seven. For most soil-by-spacing combinations, green ash crowns have expanded little, or shrunk, during the last 2 y. Holsoe (1948) observed that northern red oak (*Quercus rubra* L. [Fagaceae]) tends to crowd out white ash (*Fraxinus americana* L. [Oleaceae]). Water oak had the narrowest crowns for the first few years, coincident with their ranking for other measurements, but had larger crowns than green ash by age seven. On the 2.7 m spacing on the Dundee soil, water oak has crowns as large as Nuttall oak. Qualitative differences exist between the shapes of water oak and Nuttall oak crowns. In a vertical cross-section, the water oak crowns approach the shape of a neiloid, with a very wide crown at the base, but with only a 0.6-to-1.5 m leader with few or no lateral branches at the tip of the tree. Viewed another way, it might be considered analogous to a herbaceous plant that has a basal rosette subtending the main stalk. In contrast, Nuttall oak has a much more spreading crown. I postulate that Nuttall oak is exerting much greater influence on neighbors than is water oak. However, the shape of the water oak crowns might provide benefit in shading out herbaceous vegetation, and may promote natural pruning of the lower branches of the other species.

CONCLUSIONS AND IMPLICATIONS

Although height measurements suggested that all 3 species could coexist in upper canopy positions on each soil type if they were planted in an intimate mixture, other measurements suggest that might not be the case. On the Dundee soil, green ash is clearly being subordinated by the oaks, as evidenced by dbh and crown diameter. However, as green ash is still the tallest species on the 1.8 m spacing, it will not be displaced soon. If spacing were wider, or if thinning will be conducted within a few years, green ash could persist in competition with the oaks on this soil; however, based upon the growth trends, I feel a similar pattern would be evidenced if a more-typical spacing of 3.6 m (12 ft) was used. Otherwise, most of the ash will drop into the intermediate crown class, and if no thinning is done, will eventually become suppressed. Alternatively, if green ash were the predominant species in the mixture (75% or more), it would maintain a considerable component in the upper crown classes, and those that became subordinate to the oak could be removed in the first thinning. Recent growth suggests that water oak will be a viable component of a species mixture with Nuttall oak, although many individuals will be in inferior crown positions. However, low water oak survival makes the species much less attractive. Dundee soils are suitable for many bottomland species and leading candidates for inclusion in mixed-species plantations might be cherrybark oak (*Quercus falcata* var. *pagodifolia* Ell. [Fagaceae]), Shumard oak (*Quercus shumardii* Buckl. [Fagaceae]), sweetgum (*Liquidambar styraciflua* L. [Hamamelidaceae]), and possibly sycamore (*Platanus occidentalis* L. [Platanaceae]) (Broadfoot 1976), although sycamore has much faster early growth and may not be compatible with the other species (Oliver and others 1990).

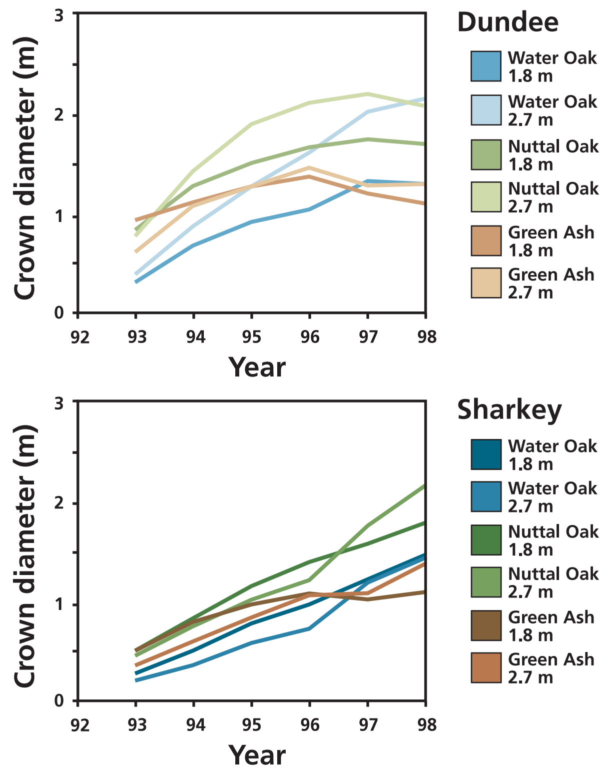

Figure 6 • Average crown diameters for 7-y survival for 3 species (water oak, Nuttall oak, and green ash) on 2 soil types (Sharkey and Dundee) with 2 spacings, 1.8 and 2.7 m (6 and 9 ft).

On the Sharkey soil, water oak does not appear to be closing the gap between itself and the other 2 species. Thus, in an intimate mixture, many water oaks will be relegated to an inferior crown position. Green ash does not seem to be at risk of being dominated by the other species in the near future, at least not at the 2.7 m spacing. Thus green ash and Nuttall oak are likely to be compatible on Sharkey soils. Other species that might be suitable in mixed species plantations on the Sharkey soil are sweetgum and willow oak (*Quercus phellos* L. [Fagaceae]) (Broadfoot 1976).

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