2000

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Abstract—Planting in deepwater swamp areas is difficult and time consuming, and nursery-grown seedlings are often not suited for such conditions. Baldcypress [*Taxodium distichum* (L.) Rich.], water tupelo (*Nyssa aquatica* L.), swamp blackgum [*N. sylvatica* var. *biflora* (Walt.) Sarg.], and green ash (*Fraxinus pennsylvanica* Marsh.) have been planted at various flooded sites in South Carolina and Louisiana. One of the most effective means of planting these species in flooded situations was to heavily prune the lateral roots, grasp the seedling at the root collar, and push it into the soil. Excellent results have been obtained with baldcypress, whereas green ash was most sensitive to root pruning and water depth. Water tupelo and swamp blackgum were intermediate in response. Tree shelters are commonly used to reduce herbivory problems, and height growth inside the shelters is increased. Additional research is needed to compare operational performance of various techniques under conditions of interacting stresses such as herbivory and flooding.

INTRODUCTION

Deepwater swamps are found along rivers and streams of the Atlantic and Gulf Coastal Plains, and baldcypress [*Taxodium distichum* (L.) Rich.], pondcypress (*T. distichum* var. *nutans*), water tupelo (*Nyssa aquatica* L.), and Atlantic white-cedar (*Chamaecyparis thyoides*) are common tree species found in these areas. Both the Spanish in Florida and French in Louisiana found Indians using cypress (when used this way can be either baldcypress or pondcypress), which the Seminoles called "hatch-in-e-haw," meaning everlasting (Neubreck 1939). Europeans quickly recognized that cypress wood was very rot resistant, strong, and easily worked, and efforts to establish a timber trade with Louisiana began around 1700 (Mancil 1980). Cypress was the staple commodity of the colonial lumber industry in Louisiana and the principal cash product for most colonists of the Lower Mississippi Valley until the 1790s, when sugar products became profitable.

The timber resource in the swamps seemed inexhaustible to early settlers with over 35.5 million m^3 (15 billion fbm) of cypress estimated in the Louisiana delta swamps alone (Kerr 1981). Harvesting in these wet swamps was seasonal in nature until the invention of the pullboat in 1889. Pullboats and the expansion of the railroad system (Sternitzke 1972), combined with a massive national campaign by cypress dealers (Burns 1980), resulted in a logging boom during the period from 1890 to 1925. Production of cypress lumber increased from 1.17 million m^3 (495 million fbm) in 1899 to over 2.36 million m^3 (1 billion fbm) in 1913 (Betts 1938, Mattoon 1915). By 1925, nearly all of the virgin timber had been cut and most of the mills closed. In 1933, only about 10 percent of the original standing stock of cypress remained (Brandt and Ewel 1989), but some cypress harvesting continued throughout the Southern United States on a smaller scale (Conner 1988).

Atlantic white-cedar logging began as early as 1700 in North and South Carolina (Frost 1987) and 1749 in New Jersey (Little 1950). Up to 50 percent of the Atlantic white-cedar area in North Carolina was cut between 1870 and 1890. As in other parts of the Southern United States, the rate at which Atlantic white-cedar swamps were logged greatly increased following the introduction of railroads, steam logging technology, portable sawmills, and dredging technology (Earley 1987, Frost 1987).

Unfortunately, the early exploitation of these swamplands occurred with little regard for sustainability. According to one logger, "We just use the old method of going in and cutting down the swamp and tearing it up and bringing the cypress out. When a man's in here with all the heavy equipment, he might as well cut everything he can make a board foot out of; we're not ever coming back in here again" (Van Holmes 1954). Nearly all of the virgin swamplands in the Southern United States were logged (Conner and Buford 1998).

Compared to other forest ecosystems, little silvicultural information is available for deepwater swamp forests, and management of these areas has been largely limited to clearcutting and highgrading (Johnson 1979, Williston and others 1980). Only recently have studies begun to investigate the response and recovery of these forests to harvesting practices, e.g., Aust and others 1989, 1997.

Cypress and water tupelo regenerate well in swamps where the seedbed is moist and competitors are unable to cope with flooding, but extended dry periods are necessary for the seedlings to grow tall enough to survive future flooding (Keeland and Conner 1999). Early height growth is important because seedlings can be killed in as little as 10 to 12 days of total submergence during the growing season (Demaree 1932). Although natural regeneration has also been the preferred method of regenerating Atlantic white-cedar

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Citation for proceedings: Holland, Marjorie M.; Warren, Melvin L.; Stanturf, John A., eds. 2002. Proceedings of a conference on sustainability of wetlands and water resources: how well can riverine wetlands continue to support society into the 21st century? Gen. Tech. Rep. SRS-50. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 191 p.

(Laderman 1989), many projects now rely on artificial means to recreate Atlantic white-cedar habitat (Guidry 1999, Phillips and others 1993), and much research has been initiated to identify nursery practices to produce the best seedlings (Summerville and others 1999). Lack of seed source and herbivory problems are commonly reported as causing failure of natural regeneration projects for Atlantic white-cedar.

Coppice regeneration is also a possibility in cutover areas of cypress and water tupelo. Stumps of vigorous stock up to 60 years old can generally be counted on to send up healthy sprouts. Although many stumps sprout during the first growing season after logging, few of these sprouts survive, although results are often contradictory.

PROBLEMS LIMITING SWAMP REGENERATION

Flooding and Salinity

Human activities have inextricably altered the hydrology of almost all major alluvial floodplains in the United States within the last two centuries through the construction of dams, levees, and causeways and by channelization. Dams reduce the frequency and magnitude of downstream flooding, often extend the length of time the floodplain is inundated, and reduce the rates of erosion and sedimentation. Channelization and canal building, with associated levees or spoil banks, represent major modifications to natural hydrological patterns and often result in permanent impoundment of large areas of swamplands (Conner and Day 1989). Floodplain communities are adapted to a fairly predictable flood pulse, and alteration of the timing, duration, or magnitude of this flooding reduces diversity and productivity (Junk and others 1989). Because many swamp areas are permanently to nearly permanently flooded, natural regeneration is negligible (Conner and others 1986), and planting is difficult.

Another aspect of flooding that should be considered for vast coastal swamp areas is sea level rise and resulting increases in salinity (Conner and Brody 1989, Conner and Day 1988). While baldcypress and water tupelo can survive extended and even deep flooding (Hook 1984, Keeland and Sharitz 1995), they do not seem capable of enduring sustained flooding by water with salinity levels > 8 ppt (Conner and others 1997, McLeod and others 1996), and Atlantic white-cedar is very intolerant of salinity (Little 1950).

Hurricanes

Coastal Plain swamps have developed with windstorms as a normal, episodic part of the climatic regime (Conner and others 1989). Recent hurricanes such as Hugo (1989) in the southeast Atlantic Coastal Plain and Andrew (1992) in the northern Gulf caused extensive damage to forests in their paths. Such damage may be especially severe to the shallow-rooted hardwoods with large crowns that are common on alluvial floodplains. In the Congaree Swamp in South Carolina, 61 percent of the bottomland oaks (*Quercus* spp.) and 45 percent of the sweetgums were severely damaged by Hurricane Hugo, but only 3 percent of the baldcypress trees were affected (Sharitz and others 1993). Regeneration in hurricane-damaged areas may be limited if natural hydrological patterns have been altered.

Animals

Nutria were introduced from South America in the 1930s, and early plantings of baldcypress in Louisiana were destroyed (Blair and Langlinais 1960). The problem has not been solved (Brantley and Platt 1992, Conner 1988), and nutria have been reported to damage even mature trees (Hesse and others 1996). Beaver, deer, and feral hogs can also present a problem and can be fairly numerous in some areas. Conner and others (2000) found that clipped seedlings usually die, but baldcypress tends to resprout in many cases. Even such a small creature as the crayfish can become a problem to planted seedlings when food sources are low. Scraping of algae at the waterline can girdle a seedling and cause tip die-back (Conner 1988). Deer, field mice, and rabbits have deterimental effects on Atlantic white-cedar seedlings (Guidry 1999, Zimmerman and others 1999).

RESTORATION OF WETLAND SITES

Because of loose, unconsolidated muck commonly found in deepwater swamps, an easier method of planting seedlings was needed. The method adopted in our studies involves pruning the lateral root systems and clipping the tap root so we end up with a spear. Root systems of seedlings grown in unsaturated soils in the nursery are not appropriate to saturated soils, and large portions of this system will be lost once planted. A new root system appropriate for saturated soils will be produced. Since much of the original root system would normally be lost anyway, pruning it prior to planting generally does not cause problems.

Seedlings are bundled in plastic with damp peat moss around the tap root and either stored in coolers or transported to the field. Planting can be done along precisely laid out lines or by walking and estimating distances. By holding the seedling at the root collar, one pushes the seedling into the ground until the hand hits the soil surface. There are no tools to carry for digging holes, and one does not have to worry about filling in completely around the root. In very loose soils, the seedlings will need to be staked to keep vertical.

Root pruning does not work well with all species. While baldcypress and tupelo success rates have been high, green ash (*Fraxinus pennsylvanica* Marsh.) and swamp blackgum [*N. sylvatica* var. *biflora* (Walt.) Sarg.] success has been poor. Green ash seemed to do well in the first 1 to 2 years after planting but died in succeeding years (Conner and others 2000). One reason is that root systems never redeveloped on the seedlings when planted in wet areas.

Hand-bagged seedlings and balled and burlap seedlings have also been tried (Conner and others 1999). Balled seedlings planted on the sediment surface produced sufficient rooting down into the sediment to withstand complete drying of the surface water. However, there was no real benefit to using the hand-bagged or balled and burlapped seedlings since root-pruned baldcypress and water tupelo seedlings are less costly and easier to plant and survive just as well.

If the site is subject to drying out, a seedling with a large lateral root component is desirable. Increased root branching allows for more water and nutrient absorption, which results in more root growth and a healthier seedling. One such way to accomplish this is by way of specialized containers such as RootMaker. The pots have openings in the corners and at various levels in the sides and bottom. Roots are air-pruned and the design is such to prevent the secondary roots from becoming congested at the bottom of the pot. Seedlings are generally grown on a wire bench 20 cm above the moist soil to allow for good air circulation. Otherwise the roots of species like baldcypress and some oaks grow out of the openings, swell, and removal is awkward. The roots and secondary roots are well distributed within the pot.

Atlantic white-cedar is generally done using the same planting tools and techniques used in planting southern pines, and there is no apparent need to develop other techniques. Work by Weyerhauser has shown that rooted cuttings are more reliable and easier to grow than bare-root seedlings (Phillips and others 1998).

Tree shelters work well, especially in early years before seedlings emerge from the tube. After emerging from shelters, height growth is not as great, but the initial growth spurt keeps them above nonsheltered seedlings. Overall, baldcypress and water tupelo have grown well (Conner and others 2000). Tree shelters are generally advertised to breakdown within a few years due to ultraviolet light in the field. This has not been our experience, but the diameter growth of the seedlings has been strong enough to rip the shelters longitudinally and not girdle the trees.

CONCLUSIONS

Tree species composition in deepwater swamps remains fairly constant because so few species can tolerate extended flooding. With changes in hydrology, many of these forests are now flooded more than in the past. Regenerating swamp forests is not a simple matter of overcoming past disturbances, but is complicated by continuing disturbances and impacts, both natural and manmade. Successful regeneration is limited by flooding, and planting may be required to ensure that populations of these trees are established in areas impacted by manmade (logging) or natural (herbivory, hurricanes, salt-water intrusion) disturbances. Not all adverse site conditions can be overcome, and some solutions may not be cost effective in meeting landowner objectives. Simple root-pruning techniques allow easy planting of these areas, and survival and growth have been shown to be excellent in many areas if animal herbivory can be controlled.

ACKNOWLEDGMENTS

Many field volunteers including L. Wayne Inabinette, Michael R. Reed, and Keith T. Barnett have aided the research that has been conducted through the years on regeneration. Funding for this research has come from a variety of sources including McIntire-Stennis funds from Clemson University, the Savannah River Technology Center (Westinghouse Savannah River Company), and Financial Assistance Award Number DE–FC09–96SR18546 from the Department of Energy to the University of Georgia Research Foundation.

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