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EFFECT OF FOREST MANAGEMENT PRACTICES ON SOUTHERN FORESTED WETLAND PRODUCTIVITY

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Abstract: In the interest of increasing productivity of forested wetlands for timber production and/or wildlife value, management schemes that deal mainly with water-level control have been developed. The three forest types in the southeastern U.S. most commonly affected are cypress/tupelo forests, bottomland hardwood forests, and wet pine sites (including pocosins). In forested wetlands, hydrology is the most important factor influencing productivity. In bottomland and cypress/tupelo forests, water-level control can have mixed results. Alterations in natural hydrologic patterns leading to increased flooding or drainage can cause decreased growth rates or even death of the forest. Bottomland hardwoods respond favorably in the short term to water-level management, but the long-term response is currently under study. In wet pine sites, timber volume can be increased significantly by water-level management, but the impact upon other ecological functions is less understood. It is difficult to adequately describe productivity relations in wetland forests because of the great diversity in habitat types and the lack of data on how structure and function might be affected by forestry operations. There is a definite need for more long-term, regional studies involving multidisciplinary efforts.

Key Words: forested wetlands, cypress/tupelo, bottomland hardwoods, pine flatwoods, Atlantic white cedar, pocosins, productivity, hydrology, flooding, drainage, silvicultural practices

INTRODUCTION

Managing forested wetlands for timber production is a difficult job because of the periodic-to-continuously flooded nature of these areas. As a result, hundreds of thousands of hectares have been subjected to continual high-grading or harvesting of the better quality trees (Hanna 1981). During the late 1800s and early 1900s, logging methods in wet areas included construction of canals and railway lines for access and transport of logs as well as the construction of levees to keep forests flooded in order to float out logs (Davis 1975). These activities resulted in major changes to the natural hydrologic regime (Conner *et al.* 1981). While rubber-tired feller bunchers and skidders are commonly used for logging wet areas today (Jackson and Stokes 1991), the use of helicopters is being tried in some areas (Willingham 1989, Aust *et al.* 1990, DeCosmo *et al.* 1990). Impacts of these various logging techniques on forested wetland functions have only recently begun to be studied (Aust 1989, Mader 1990).

Other management techniques in use today include the construction of levees to flood large areas of forests during the winter dormant season to enhance winter waterfowl habitat (greentree reservoirs) and the ditching and draining of wet pine areas. Although increases in tree growth of as much as 25–90% (Broadfoot 1967, Broadfoot and Williston 1973) have been reported in greentree reservoirs (GTRs), long-term flooding problems are beginning to surface (Schlaegel 1984, Fredrickson and Batema 1992). Ditching and draining dramatically increase tree productivity in wet pine and pocosin areas (Campbell and Hughes 1981), but problems may arise when the links between pine areas and adjacent wetland systems are not taken into consideration (Richardson 1981).

Overall, there has been little research into optimum silvicultural practices for forested wetlands. This review will discuss the available data for forested wetlands and how primary productivity is affected by management, especially as related to water-level manipulations. Three specific forested wetland types—cypress/tupelo swamps, bottomland hardwoods, and wet pine forests—will be discussed, as these areas are the subjects of most of the research.

CYPRESS/TUPELO FORESTS

Cypress [*Taxodium distichum* (L.) Rich. and *T. distichum* var. *nutans* (Ait.) Sweet] and tupelo [*Nyssa aquatica* L. and *Nyssa sylvatica* var. *biflora* (Walt.) Sarg.] are found in southern swamps and floodplains where

Table 1. Growing stock volume of cypress and tupelo by state.[1]

State	Cypress[2]	Tupelo[3]
	million m^3	
Alabama	4.53	29.43
Arkansas	5.75	11.36
Florida	75.33	43.05
Georgia	24.36	63.52
Louisiana	41.43	32.48
Mississippi	3.06	19.12
North Carolina	11.95	50.04
South Carolina	14.81	43.50
Tennessee	2.29	7.79
Texas[4]	2.69	6.66
Virginia	1.19	11.95

[1] From the most recent published U.S. Forest Service survey data available at the time of study.
[2] Includes *Taxodium distichum* and *T. distichum* var. *nutans.*
[3] Includes both *Nyssa aquatica* and *N. sylvatica* var. *biflora.*
[4] East Texas only.

long-term flooding is common. Cypress has long been favored because of its decay resistance (Mattoon 1915, Brown and Montz 1986), although second-growth timber lacks the resistance of old-growth trees (Campbell and Clark 1960, Choong *et al.* 1986). Water tupelo is valued because of its white color, lack of odor or taste, and good staining quality (Kennedy 1982). The majority of the virgin cypress/tupelo forests were cut over during the late 1800s and early 1900s. Although there has been a general trend of land loss of these forested wetlands during the past 100 years (Frayer *et al.* 1983, Dahl *et al.* 1991), there are still vast areas of second-growth timber existing today (Williston *et al.* 1980, Kennedy 1982), and standing crop volumes continue to increase (Brandt and Ewel 1989, Conner and Toliver 1990). Over 75% of the cypress growing stock is located in Florida, Louisiana, and Georgia (Table 1). Tupelo growing stock is more widespread among the states, and there is nearly twice as much of it.

Biomass and Biomass Production

Aboveground biomass and primary productivity values for cypress/tupelo forests are among the highest reported for forest ecosystems, due largely to the effects of fluctuating water levels and nutrient inflows (Brinson *et al.* 1981, Brown 1981, Conner and Day 1982). Average biomass is 227 t ha^{-1}, ranging from a low of 12 t ha^{-1} in thermally impacted forests in South Carolina to a high of 720 t ha^{-1} in a Florida floodplain forest (Table 2). Aboveground biomass production frequently exceeds 10 t ha^{-1} yr^{-1} in these forests, with a maximum of nearly 20 t ha^{-1} yr^{-1} being reported for an undisturbed cypress/tupelo forest in South Carolina. Litterfall accounts for an average of 43% of the aboveground primary production in wetland forests. Very little is known about belowground processes, although there is evidence that roots contribute as much as or more to the detrital pool than does litterfall (Symbula and Day 1988).

Brinson *et al.* (1981) suggest that the amount and frequency of water passing into and through a wetland are the most important determinants of potential primary productivity. Forests with unaltered seasonal water flow generally have aboveground net primary productivity in excess of 10 t ha^{-1} yr^{-1}. Periodic inundation subsidizes the forested wetland with nutrients and sediments that stimulate plant production (Gosselink *et al.* 1981). Forested wetlands with stagnant or sluggish waters are usually less productive, but not always (Brown and Peterson 1983). Communities in permanently impounded conditions or on sites with poor drainage leading to continuously high water tables and the accumulation of acidic peat soils have lower productivity, primarily because of low nutrient turnover due to the anoxic conditions, nitrogen limitations, and low pH (Brown *et al.* 1979). This change in productivity with respect to flooding has been discussed by several authors (e.g., Conner and Day 1976, 1982, Odum 1978).

Mature cypress and tupelo do well under flooded conditions (Kennedy 1970, Dickson *et al.* 1972). Cypress is well-known for its ability to grow in flooded areas (Wilhite and Toliver 1991). However, increased flooding can sometimes have serious consequences if the mean depth of flooding exceeds 60 cm (Brown and Lugo 1982). In Florida, Harms *et al.* (1980) found that 0–16% of the cypress trees died within seven years in water from 20- to 100-cm deep. In water over 120-cm deep, 50% of the cypress died after four years. A long-term study of cypress survival was conducted near Lake Chicot, Louisiana (Penfound 1949, Eggler and Moore 1961). After four years of flooding with water 60- to 300-cm deep, 97% of the cypress were still alive. Eighteen years after flooding, 50% of the cypress were still alive. However, most of the living trees in the deep water had dead tops (Eggler and Moore 1961). From the available data on flooding stress and cypress survival, it seems that cypress can adapt to shallow ($<$ 60 cm), permanent flooding, and even in deep water ($>$ 60 cm), death and decline is a gradual process (Eggler and Moore 1961, Harms *et al.* 1980).

Drainage of swamp forests can also affect primary productivity rates. Drainage of a cypress swamp in Florida led to a thinning of the overstory canopy and a reduction in biomass production of the trees, litterfall, and herbaceous plants (Carter *et al.* 1973). Productivity of a drained cypress stand in Florida was 3.87 t ha^{-1} yr^{-1} compared to 8.58 t ha^{-1} yr^{-1} for an undrained stand. Cypress dome systems are frequently part of the drainage system of surrounding industrial forest lands (Marois and Ewel 1983). As a result of decreased flooding, primary productivity of the trees in the cypress domes can be reduced (Mitsch 1975).

Natural Regeneration

While little silvicultural research has been conducted in cypress/tupelo forests, especially concerning the impacts of forestry management practices on productivity, there has been some research on regeneration and successional patterns following disturbance. Natural regeneration of cypress was poor to non-existent in Louisiana swamps following logging operations (Conner *et al.* 1986), mainly because the swamps remain flooded for much of the year. Cypress seeds cannot germinate in standing water (Demaree 1932) or do not grow tall enough to survive subsequent flooding. In the Okefenokee Swamp, Georgia, over 90% of the cypress has been removed by logging, and there has been a shift of large cypress areas to mixed or bay swamps because of poor cypress regeneration (Hamilton 1984). Limited regeneration of cypress occurred in logged swamp forests or burned swamp forests in south Florida, but no regeneration was found in logged and burned sites (Gunderson 1984). While surface fires may enhance cypress regeneration by reducing competition, severe or frequent fires generally result in conversion of cypress forests to prairie (Hamilton 1984) or willow stands (Gunderson 1984). Drainage of cypress wetland can also lead to changes in vegetative composition because of improved growth of many species that could not tolerate prolonged flooding (Marois and Ewel 1983).

Silvicultural Treatments

Cypress and tupelo stands should be managed on an even-aged basis because of the silvicultural characteristics of the species, the nature of the existing stands, and the sites they inhabit (Putnam *et al.* 1960, Stubbs 1973, Smith and Linnartz 1980). Because of the exacting requirements for germination and establishment (Stubbs 1973, Brandt and Ewel 1989) and the variable success of stump sprouting (Hook *et al.* 1967, Kennedy 1982, Conner 1988), planting of cypress and tupelo may be necessary to ensure adequate stocking of future stands (Bull 1949, Conner *et al.* 1986). While there has been little success in planting tupelo (Silker 1948, DeBell *et al.* 1982), much better results have been obtained with cypress. Planting of one-year-old cypress seedlings at least 1-m tall and larger than 1.25 cm at the root collar improves early survival and growth (Faulkner *et al.* 1985). A 2.4 × 2.4-m spacing is generally recommended, although regular spacing may not be possible unless the area was clearcut (Mattoon 1915, Williston *et al.* 1980). Even when planted in permanent standing water, height growth averages 20–30 cm per year when there are no herbivory problems (Conner 1988, Conner and Flynn 1989).

While data are limited, it seems that plantation-grown cypress grow better than natural stands and may even grow better than hardwood species (Krinard and Johnson 1987). Planted cypress grew over 2 m in height in 5 years in a Louisiana crayfish pond (Conner *et al.* 1993). In Mississippi, a plantation established on an abandoned agricultural field had cypress trees up to 21-m tall at age 41 years (Williston *et al.* 1980). Another Mississippi cypress plantation contained trees 21.6-m tall and 36 cm in diameter after 31 years (Krinard and Johnson 1987). In comparison, Mattoon (1915) reported height growth of 13–16 m by age 40 years for naturally established second-growth cypress in Maryland and Louisiana.

Cypress tends to grow well at high densities (Wilhite and Toliver 1991), but there is some evidence that thinning may enhance diameter growth in baldcypress (Table 3). Data for pondcypress are conflicting (Terwilliger and Ewel 1986, Ewel and Davis 1992). Crown thinning in baldcypress forests to 50% of original basal area increases diameter growth 2.5 to 2.75 times that of unthinned stands (McGarity 1977, Dicke and Toliver 1988). Thinning to that level, however, may produce an abundance of epicormic branches (increase from < 1% of trees in unthinned stand to 28% in thinned stand), which may lower timber value in the future. Dicke and Toliver (1988) recommended removing approximately 40% of the original basal area as the best alternative, since this level produced good growth with fewer epicormic branches.

The results of thinning in tupelo stands are mixed. While McGarity (1977) also reported that thinning increased growth of residual tupelo trees, Kennedy (1983) reported that thinning intensity had no significant effect on tupelo diameter and height growth. Defoliation of trees in the latter study by the forest tent caterpillar (*Malacosoma disstria* Hubner) may be one explanation of the difference in response. Many tupelo forests along the Gulf of Mexico are defoliated annually, and while the trees do not usually die, their growth is retarded (Morris 1975).

Logging Impacts

The impact of logging operations on productivity has only recently been studied. Clearcutting is probably the best method for harvesting these forests (Stubbs 1973, McKnight and Johnson 1975). Mader (1990) reported rapid recovery of aboveground primary production of tupelo, ash, and cypress following clearcut-

Table 2. Biomass and aboveground biomass production of forested wetlands in the southeastern United States.

Location/Forest Type	Biomass ($t\ ha^{-1}$)	Litterfall ($t\ ha^{-1}\ yr^{-1}$)	Stem Growth ($t\ ha^{-1}\ yr^{-1}$)	Above-ground Biomass Production ($t\ ha^{-1}\ yr^{-1}$)	Reference
Louisiana					
Bottomland hardwood	165	5.74	8.00	13.74	Conner & Day 1976
Cypress-tupelo	375	6.20	5.00	11.20	ibid
Managed hardwood	328	5.50	12.30	17.80	Conner et al. 1981
Impounded swamp	159	3.30	5.60	8.90	ibid
Cypress-tupelo	—	4.17	7.49	11.66	ibid
Tupelo swamp	362	3.79	—	—	Conner & Day 1982
Cypress swamp	278	5.62	—	—	ibid
North Carolina					
Tupelo swamp	—	6.09–6.77	—	—	Brinson 1977
Floodplain swamp	267	5.23	5.85	11.08	Mulholland 1979
Virginia					
Cedar swamp	220	5.06	—	—	Dabel & Day 1977, Gomez & Day 1982
Maple gum swamp	196	5.36	—	—	ibid
Cypress swamp	345	5.28	—	—	ibid
Mixed hardwood swamp	195	4.55	—	—	ibid
Tidal swamp	—	2.52	4.92	7.44	Fowler & Hershner 1989
Georgia					
Okefenokee swamp	307	3.28	3.53	6.81	Schlesinger 1978
Kentucky					
Floodplain forest	303	4.20	9.14	13.34	Taylor 1985
	184	4.68	8.12	12.80	ibid
Bottomland hardwood	303	4.20	9.14	13.34	Mitsch et al. 1991
Bottomland hardwood	184	4.68	8.12	12.80	ibid
Cypress, flooded					
Permanent, flowing	102	2.53	2.71	5.24	ibid
Semi-permanent, stagnant	94	0.63	1.42	2.05	ibid
Semi-permanent, flowing	312	1.36	4.98	6.34	ibid
Florida					
Cypress-tupelo	190	—	2.89	7.60	Mitsch & Ewel 1979
Cypress-hardwood	154	—	3.36	9.50	ibid
Pure cypress stand	95	—	1.54	—	ibid
Cypress-pine	101	—	1.17	—	ibid
Floodplain swamp	284	5.21	10.86	16.07	Brown 1981
Natural dome	266	5.41	4.15	9.56	ibid
Sewage dome	217	7.34	10.60	17.94	ibid
Scrub cypress	36	2.24	0.44	2.68	ibid
Cypress-large	608	7.00	1.96	8.96	Duever et al. 1984
Cypress-small	240	7.24	8.18	15.42	ibid
Cypress	192	3.45	7.72	11.17	Burns 1978
Cypress	286	6.50	6.40	12.90	Nessel 1978
Drained strand	89	1.20	2.67	3.87	Carter et al. 1973
Undrained strand	171	4.85	3.73	8.58	ibid
Floodplain swamp	720	—	—	—	Elder and Cairns 1982
Floodplain hardwood	280	4.79	—	—	ibid

Table 2. Continued.

Location/Forest Type	Biomass (t ha^{-1})	Litterfall (t ha^{-1} yr^{-1})	Stem Growth (t ha^{-1} yr^{-1})	Above-ground Biomass Production (t ha^{-1} yr^{-1})	Reference
South Carolina					
Scrub/shrub	56	3.90	9.09	12.99	Bates 1989
Thermally affected swamp					
Least disturbed	229	4.15	3.73	7.88	Scott et al. 1985
Intermediate	167	1.51	4.13	5.64	ibid
Most	12	0	0.14	0.14	ibid
Cypress-maple	348	6.14	13.43	19.57	Muzika et al. 1987

ting of an Alabama forest (Table 4). In addition, Mader found no significant difference in the response of the forest to helicopter or skidder logging operations, and he predicted that it would take only a few years for the disturbed sites to be as productive as the undisturbed forest. An important factor to remember when considering these two studies is that both were conducted in areas with rapid natural reproduction and no major change had occurred in site conditions. If natural hydrologic conditions have been changed, natural regeneration may be hampered and recovery rates may be much slower or nonexistent (Sharitz and Lee 1985, Conner *et al.* 1986).

Atlantic White Cedar Forests

Another habitat type that deserves mention when considering swamps is the Atlantic white cedar (*Chamaecyparis thyoides* (L.) B.S.P.) ecosystem. Although the range for this species stretches along the Atlantic and Gulf coasts from Maine to Mississippi, most of the forests have disappeared as a result of logging, conversion, changes in water-level regimes, and wildfire suppression (Laderman 1989). It is still considered a commercially important species in southeastern Virginia, eastern North Carolina, and northwestern Florida (Little and Garrett 1991).

Most of the available literature on Atlantic white cedar is qualitative in nature, representing mainly descriptions of remnant stands. The only area that has been studied to any extent is the Great Dismal Swamp (Dabel and Day 1977, Day 1979, McKinley and Day 1979, Montague and Day 1980, Day 1982, Gomez and Day 1982, Tupacz and Day 1990). Litterfall in an Atlantic white cedar stand was 5.06 t ha^{-1} yr^{-1}, making it as productive as many of the other swamps listed in Table 2. Planting of rooted cuttings in South Carolina resulted in nearly 90% survival rates after 16 months with average heights of 38 cm, indicating that the species could be planted for wetlands restoration and as a wet site crop (Buford *et al.* 1991). Unfortunately, there are few other reliable data, making it difficult to understand basic ecological processes that would aid in the development of management strategies for this community type (Laderman 1989).

Since 1988, Weyerhaeuser has placed considerable effort into preserving Atlantic white cedar forest lands. Most of the company's natural cedar groves have been set aside for gene conservation. In addition, they have developed rooted-cutting technology to avoid the

Table 3. Effect of thinning on diameter growth of baldcypress. Thinning treatment represents percent reduction in basal area.

Location	Thinning Treatment	Diameter Growth (mm/yr)	Reference
Louisiana	unthinned	1.6	Dicke and Toliver 1990
	18%	2.2	ibid
	36%	2.6	ibid
	54%	3.9	ibid
Florida	unthinned	1.5	McGarity 1977
	38%	3.8	ibid
	57%	4.1	ibid
	76%	6.1	ibid

Table 4. Aboveground net primary productivity (t ha^{-1} yr^{-1}) in a tupelo/cypress forest in Alabama following logging in 1986 (Mader 1990).

Treatment	1987	1988
Control (no logging)	11.79	13.26
Helicopter logged	5.25	9.24
Skidder logged	7.64	9.41

Table 5. Average annual diameter growth rates (cm yr^{-1}) for trees in unmanaged stands on average bottomland sites (adapted from Putnam *et al.* 1960).

Species	Diameter Class 15–30 cm	36–46 cm	50–71 cm	>75 cm
Liquidambar styraciflua L.	0.7	0.7	0.8	0.6
Quercus spp. (red oaks)	0.9	1.1	1.1	0.8
Quercus spp. (white oaks)	0.6	0.6	0.7	0.7
Fraxinus spp.	0.5	0.6	0.7	0.7
Nyssa spp.	0.7	0.8	0.8	0.8
Carya illinoensis (Wang.) Koch.	0.7	0.9	0.9	0.8
Populus deltoides Bartr.	1.6	1.5	1.6	1.2
Salix spp.	1.0	1.4	1.4	1.1
Quercus lyrata Walt.	0.5	0.6	0.5	0.5
Carya aquatica (Michx.) Nutt.	0.5	0.5	0.6	0.6
Taxodium distichum (L.) Rich. (2nd growth)	0.6	0.7	0.8	0.7
Misc. rapid growers[1]	0.8	0.8	1.0	0.9
Misc. slow growers[2]	0.5	0.5	0.6	0.6
Average	0.6	0.7	0.8	0.7

[1] *Ulmus americana* L., *Acer* spp., *Platanus occidentalis* L., *Gleditsia triacanthos* L., *Gleditsia aquatica* Marsh.
[2] *Ulmus crassifolia* Nutt., *Ulmus alata* Michx., *Nyssa sylvatica* var. *sylvatica*, *Carya* spp., *Celtis laevigata* Willd.

problems of relying on uncertain seedling production (Hughes 1991b). A cooperative effort between Weyerhaeuser, the North Carolina Forest Service, North Carolina State University Forestry Extension, and several landowners was begun in 1988 to provide demonstration areas across a variety of soil types and with various cultural treatments (Hughes 1991b). Data from these projects will be useful in developing management guidelines.

BOTTOMLAND HARDWOOD FORESTS

Bottomland hardwood forests are common along most major and minor streams in all southeastern states (Smith and Linnartz 1980, Wharton *et al.* 1982) and cover approximately 12.9 million ha of the Atlantic and Gulf Coastal Plain (Megalos *et al.* 1987). In general, these forests have greater basal area, biomass, and biomass production rates than nearby uplands (Brinson 1990). Periodic flooding usually contributes to the high productivity of these areas by providing an adequate water supply during the summer months, by supplying new nutrients, and by creating a more oxygenated root zone (Brinson *et al.* 1981). Some values for biomass and productivity are presented in Table 2. Overall, there has been very little research on this forest type. Although growth data for common species are scanty, diameter growth tends to vary by species, by size, and by site depending upon hydrologic and chemical factors, as well as stand density (Table 5). Mixed bottomland stands should average 10 cm of diameter growth per decade with good management on a good site (Smith and Linnartz 1980).

Diversity

Bottomland forests are very diverse, with more than 70 commercially important species (Smith and Linnartz 1980) and a large array of community types (Brinson 1990). Vegetation varies from those species adapted to long hydroperiods in the low-lying reaches of the floodplain to less flood tolerant species growing higher on the floodplain. A typical cross-section of a river floodplain in the southeastern United States is shown in Figure 1. Zonation of tree communities seldom occurs as depicted, but the figure illustrates the complex nature of this community type. Because of the large plant and habitat diversity, bottomland forests can support two to five times as many animals as nearby pine forests (Harris *et al.* 1984). Twice the number of whitetail deer can be found in bottomland forests as in an equivalent amount of upland forest (Zwank *et al.* 1979). Bird density in these forests has been reported to be double that of many upland areas (Brinson *et al.* 1981). During flooding, numerous waterfowl species use the forests, and up to 53 species of fish have been reported to feed and/or spawn in these areas during flooding (Taylor *et al.* 1990).

Silvicultural Treatments

Many areas of bottomland hardwood forest have been drained and cleared for agriculture (Abernethy and Turner 1987). Most of the remaining bottomland forests contain many inferior and less desirable tree species than the original forests because of past cutting practices, past agricultural use, indiscriminate cattle grazing, uncontrolled fires, and lack of attention to regeneration (Smith and Linnartz 1980, Nix 1989). As more and more of this habitat is converted to other uses, the remaining forests become that much more important. Management practices are needed that provide renewable sources of timber while maintaining value to the overall ecosystem (Harris *et al.* 1984). Forest management practices range from selective removal of mature trees to clearcutting (Brinson 1990). Selective cutting (high-grading) has reduced the quality of timber in many areas (Maki *et al.* 1980). It is estimated that 90% of the South's hardwood forests would require some silvicultural treatment to approach potential site productivity (USDA Forest Service 1974). Although clearcutting seems to be the preferred prac-

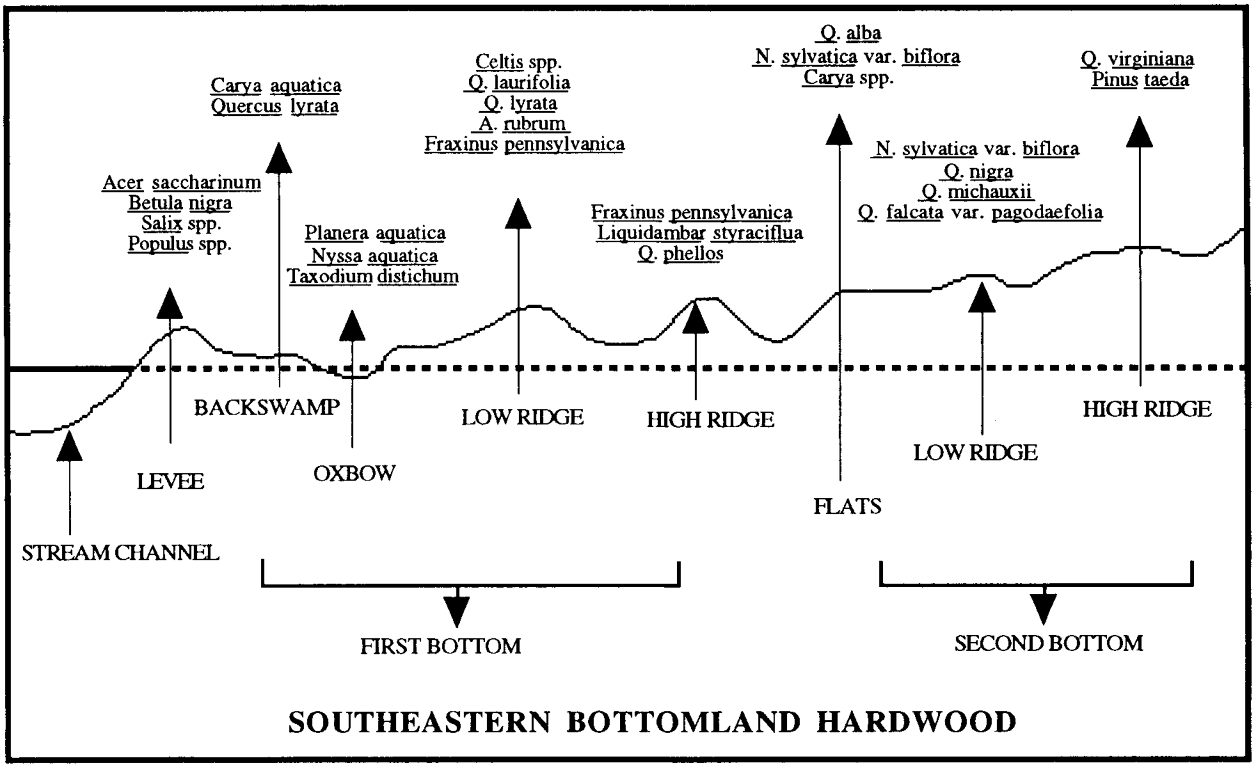

Figure 1. Idealized profile of species associations in southeastern bottomland forests (after Wharton 1978).

tice for logging (Putnam *et al.* 1960) and is the most effective method of natural regeneration for many species, this method is aesthetically unacceptable to many people (Toliver and Jackson 1989).

While southern bottomland forests have the potential to be one of the most productive areas in the United States (Smith and Linnartz 1980), actual productivity is often lower because of past management practices (Dicke *et al.* 1989). Since clearcutting may not always be feasible in established stands, other methods have to be used to improve productivity. The most common silvicultural practice used in established stands to increase tree growth is improvement cutting (Smith 1986). However, there are few data on how bottomland forests respond to this type of treatment. Dicke *et al.* (1989) performed a series of improvement cuttings in a minor stream bottomland forest in Louisiana. Diameter growth in the thinned stands was greater during the first 1.5 years following cutting than in the control stands. Cutting increased diameter growth for all size classes by 0.13 cm/year. Although this was still below the expected growth rate of 1 cm/year (Putnam *et al.* 1960), diameter growth was expected to respond more with time (Dicke *et al.* 1989).

Another way to increase the quality and quantity of valuable trees in a stand is by planting. This is especially important in areas where natural regeneration following cutting is not sufficient to ensure a mixture of desired species (Gresham 1985). A considerable amount of research in bottomland hardwood plantings has been conducted at the U.S. Forest Service's Southern Hardwoods Laboratory, Stoneville, Mississippi (e.g., Kennedy 1984, Johnson and Krinard 1988, 1989). Specific planting recommendations for hardwood seedlings can be found in Allen and Kennedy (1989). Overall, planting of seedlings on cleared bottomland sites is a good method for quickly establishing bottomland species (Allen 1990). When planted on old-field sites, at least one year of weed control seems to increase growth of seedlings (Kennedy 1984, Krinard and Kennedy 1987), as does fertilization (Francis 1985).

Productivity will recover rapidly in many cutover stands. Francis (1987) found standing woody biomass increased steadily during the first four years following cutting. The four-year average annual increase in woody biomass was 3.68 t ha^{-1} yr^{-1}, greater than the 3.25 t ha^{-1} yr^{-1} in the original stand (Francis 1984). Krinard and Johnson (1986) reported 7.85 t ha^{-1} yr^{-1} from coppice regrowth in an oak stand four years after harvesting. Bates (1989) found that net aboveground primary productivity of the scrub/shrub community on a Santee River, South Carolina clearcut (high-lead skidding operation) was 15.75 t ha^{-1} yr^{-1} only 6 years after harvesting. A majority of the productivity in the South Carolina study was from black willow (*Salix* *nigra* Marsh.) and red maple (*Acer rubrum* L.), although a number of other bottomland species were also found, and these latter species should become dominant as the forest matures.

Flooding Effects

While flooding does introduce nutrients into bottomland hardwoods, the resulting submergence can be deleterious to individual tree species depending upon the season flooded, the depth of flooding, and the duration of the flood event (Teskey and Hinckley 1977, Whitlow and Harris 1979, McKnight *et al.* 1981, Kozlowski 1982). Short-term flooding events during the growing season seem to have little effect on mature trees. Mitsch and Rust (1984) found little correlation between growth of water-tolerant trees and flooding in Illinois. However, they did find that years with a high percentage of flooding during the growing season were years of low tree growth. Johnson and Bell (1976), in a similar study in Illinois, found no relationship between frequency of flooding and growth of trees with diameters exceeding 4 cm.

Flooding continuing into the growing season or for extended periods can have serious effects on the survival of bottomland trees as was found by Bell and Johnson in Illinois (1974). Even though flooding may have no visible effect the first growing year, the trees usually start dying the second year, and only a few species have been reported to survive three years of continuous flooding (Green 1947). Most species cannot survive two years of continuous flooding (Broadfoot and Williston 1973). Hall and Smith (1955) reported that in Tennessee, none of the 39 common deciduous tree species could survive flooding if the root system was covered for more than 54% of the growing season during an eight-year period.

Flooding and submersion during the growing season can have a substantial impact on tree growth. Studies at the Southeastern Forest Experiment Station (1958) have shown that yellow-poplar (*Liriodendron tulipifera* L.) seedlings submerged during the dormant season were relatively unaffected, while those submerged for only three days during the growing season were adversely affected. After 14 days of submersion during the growing season, only 5% of the seedlings survived. Baker (1977) studied the influence of spring submersion on the growth and survival of several bottomland tree species and noted, as others have, that seedlings of most species lose their leaves during submersion. Intolerant species died, and the growth of cottonwood and water tupelo occurred in the form of sprouts from the root collar; green ash was the only species studied where new growth was from the original stem.

Most of the investigations involving flooding impacts have come from studies of forests inundated after construction of reservoirs or other flood-control structures (Hall *et al.* 1946, Green 1947, Silker 1948, Hall and Smith 1955, Broadfoot and Williston 1973, Bell and Johnson 1974, Harris 1975, Harms *et al.* 1980) in which existing stands of trees have been subjected to a sudden shock of continuous inundation. According to McKnight *et al.* (1981) this may not always indicate how a species will perform if it has to start as a seed and progress through the various stages of its life cycle under the influence of intermittent flooding.

Many bottomland hardwood sites in the Mississippi River Alluvial Valley have been impounded and flooded during the winter dormant season since the 1930s. Greentree reservoir (GTR) management was originally developed to create habitat for waterfowl. An important secondary goal of this type of management could be to increase tree growth (Rogers and Sander 1989). This type of flooding does not mimic natural flooding since flooding occurs earlier and to a greater depth than would normally occur under natural conditions. These alterations in hydrology may impact the ecological structure and function of these forests (Fredrickson and Batema 1992). The use of silvicultural methods to promote growth, quality, and regeneration of bottomland hardwoods would be invaluable to greentree reservoir managers (Moorhead *et al.* 1991). The challenge for successful greentree reservoir management is to simulate a natural flooding regime while continuing to provide a healthy, functional wetland forest.

Flooding during the dormant season, as is common in greentree reservoir systems, seems to have no effect on tree growth (Broadfoot 1967, Broadfoot and Williston 1973), while seedlings of several species are very susceptible to flood damage after leaf emergence (Broadfoot and Williston 1973). Positive responses in tree growth to dormant season flooding have been attributed to increased soil moisture during the summer months following flooding (Broadfoot 1958). Green ash (*Fraxinus pennsylvanica* Marsh.), cottonwood (*Populus deltoides* Bartr.), and sweetgum (*Liquidambar styraciflua* L.) responded best to four years of winter flooding (Table 6). Long-term studies, however, have shown that tree growth may be adversely affected by this type of management (Francis 1983, Schlaegel 1984, Rogers and Sander 1989). Current management recommendations to maintain or enhance productivity in GTRs include clearcut harvests in blocks or patches to create openings to promote regeneration and thinnings in the mid- and understory to increase desirable species (Rogers and Sander 1989, Moorhead *et al.* 1991). There is a definite need for more research in this type of management, however, as little has been conducted outside of the Mississippi River Valley.

Table 6. Effect of spring and early summer shallow water impoundment on four year radial growth of bottomland hardwoods (adapted from Broadfoot 1967).

Species	4-year Radial Growth (mm) Unimpounded	Impoundment	Growth Increase (%)
Fraxinus pennsylvanica Marsh.	8.0	15.1	89
Populus deltoides Bartr.	8.4	16.0	90
Ulmus americana L.	10.6	14.4	35
Celtis occidentalis L.	9.0	13.1	45
Carya aquatica (Michx.) Nutt.	5.9	8.6	45
Gleditsia triacanthos L.	8.1	12.4	53
Acer rubrum L.	7.2	13.3	85
Quercus nuttallii Palmer	15.7	21.6	38
Quercus lyrata Walt.	8.6	10.3	20
Quercus phellos L.	17.5	19.3	10
Diospyros virginiana L.	6.6	10.0	51
Liquidambar styraciflua L.	8.9	16.5	86

WET PINE FORESTS

The Atlantic and Gulf Coastal Plain regions are characterized by a series of terraces oriented nearly parallel to the present coastline. Near the coast, these terraces tend to be very flat and poorly drained. Except for permanent swamp areas, these low terraces are called "flatwoods" (Walker 1980). Also located in this area are other poorly drained systems known as Carolina bays and pocosins. Bays are generally shallow, elliptical depressions with well-defined sandy rims. Bays were named by European pioneers who observed the evergreen shrubs and bay trees growing in them (Sharitz and Gibbons 1982). Pocosins are swampy areas that developed where dunes along the shoreline impeded drainage (Walker 1980), and they typically support scattered pond pines (*Pinus serotina* L.) and a dense growth of mostly evergreen shrubs (Sharitz and Gibbons 1982).

Wet pine forests comprise an extensive and productive forest site type in the southeastern United States (Aust *et al.* 1991). Clearcutting and planting are common practices in these forests because of regeneration problems associated with selection and shelterwood cutting (Walker 1980). Loblolly pine (*Pinus taeda* L.) accounts for 90% of all pine planted in this area (Boyer and South 1984) and grows well under a variety of conditions. Extensive and intensive water management is also practiced in these poorly drained forests to enhance tree productivity (Allen and Campbell 1988, McCarthy and Skaggs 1992). Approximately 1 million ha of plantation pine are currently drained to improve soil moisture conditions and soil trafficability (McCarthy and Skaggs 1992). Water management ranges from infrequent use of drainage to well-engineered ditching systems on a grid system. Some drainage systems are used throughout the rotation, while others are used only for 4–5 years during harvest, site preparation, and plantation establishment (Olszewski 1989). The use of water-control structures in the drainage system allows for some regulation of water-table depth and discharge rates (McCarthy and Skaggs 1992).

Intensive management consisting of water management, bedding, phosphate fertilization, and weed control can dramatically increase loblolly and slash pine growth (Terry and Hughes 1975). Although pine growth is very varied across the region, increases in growth of 80–1,300% have been reported for drained pine stands compared to undrained stands (Table 7). Drainage also improves logging access and reduces soil disturbance. This is important as soil damage can reduce site index (base age 25) by 3 m or more (Terry and Campbell 1981). Overall, growth rates on intensively managed sites ranges from 10–14 m^3/ha compared to 2.1–3.5 m^3/ha for natural pine or hardwood sites (Hughes 1991a).

The Weyerhaeuser Company has had an extensive research effort in the pocosin wetlands of the lower coastal plain of North Carolina since 1969 (Campbell and Hughes 1981). Pocosins have several physical and economic factors that have made them highly attractive for forestry. They are found in large, uniform, and easy-to-manage tracts. Timber rotations of 25–35 years are common for these forests as pocosin soils, with

Table 7. Growth response of southern pine to drainage.

Study/Species	Mean Annual Growth (m^3 ha^{-1}) Drained	Undrained	% Increase Over Undrained
Miller and Maki 1957/*P. taeda* L.	17.90	1.28	1,298
Klawitter and Young 1965/*P. elliottii* Engelm.	9.00	4.90	84
White and Pritchett 1970/*P. elliottii* Engelm.	14.60	5.70	156
Ibid/*P. elliottii* Engelm.	13.30	5.70	133
Ibid/*P. taeda* L.	7.60	1.30	585
Ibid/*P. taeda* L.	4.90	1.30	277
Terry and Hughes 1975/*P. taeda* L.	4.30	0.54	696

drainage, continue to produce good height, volume, and growth even at advanced tree ages (Campbell and Hughes 1981).

Although timber production in pocosins seems to be viable, there are definite concerns surrounding its continued development, including (from Richardson 1991):

1) loss of unique plant and animal habitat,
2) subsidence and oxidation of peat due to drainage,
3) intrusion of salt water into regional water supplies because of freshwater drainage,
4) increased trace metal output from drained areas,
5) loss of biological diversity,
6) loss of biological gene pools from one of the least studied systems in the United States.

CONCLUSIONS AND RECOMMENDATIONS

In the past, forested wetlands were generally considered as waste areas whose only value lay in being drained and converted to more productive uses. Today, however, we recognize this view is wrong, these wetlands are very productive ecosystems, and this high productivity is related to hydrologic conditions. One of the problems in developing silvicultural management practices for forested wetlands lies in the fact that all sorts of moisture regimes and hydrologic conditions combined with great soil diversity have resulted in a number of forest types (e.g., cypress/tupelo, cypress domes, bottomland hardwoods, pocosins, Carolina bays, pine flatwoods, etc.). It is difficult, therefore, to adequately describe productivity (plant and animal) relations in these forests and to predict how the structure and function might be affected by forestry operations.

Despite the large number of publications cited in this review, there remains much to be understood about forested wetlands. One of the most important aspects that needs to be understood is the role of altered hydrology patterns on productivity and regeneration patterns. Some forest types benefit more from drainage than others, and some forest types may be harmed by drainage. Changes in duration and timing of flooding affect productivity and also alter the course of succession, which determines the composition of the forest. There is a definite need to understand how logging and site-preparation activities affect productivity of wetlands. Research has been initiated at a few sites, and the data should prove beneficial in understanding these processes. Best Management Practices (BMPs) have been developed for forested wetlands in most states. These BMPs need to be adopted on a wider basis and followed if they are to be effective. As new research is completed, BMPs need to be updated and the information relayed to the people conducting field operations. Tree response to environmental change often occurs over a period of years, thus there is a need for more long-term studies in wetland forests such as those conducted in upland forests at the Coweeta or Hubbard Brook forests. Short-term studies are important by providing site and time-specific conditions, but the data may be very misleading if viewed without all of the facts. Species-site requirements are another important area of study. We need to know more about the site requirements of individual species for each forest type. Site requirements vary greatly, and it is difficult to generalize with data from different regions. All of these suggestions point to the need for more long-term, regional studies involving multidisciplinary efforts. It is only through this type of research that we will have any hope of understanding the complex interrelationships among forest production, ecosystem function, and forestry practices.

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