Southern Forested Wetlands

Ecology and Management

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LEWIS PUBLISHERS
Boca Raton Boston New York Washington London

Acquiring Editor: Joel Stein
Project Editor: Albert W. Starkweather, Jr
Cover design: Dawn Boyd

Library of Congress Cataloging-in-Publication Data

Catalog record is available from the Libary of Congress

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International Standard Book Number 1-56670-228-3
Printed in the United States of America 1 2 3 4 5 6 7 8 9 0
Printed on acid-free paper

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Southern Deepwater Swamps

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1-56670-228-3/97/$0.00+$.50

INTRODUCTION

GEOGRAPHICAL EXTENT

Deepwater swamps, primarily baldcypress-water tupelo (*Taxodium distichum-Nyssa aquatica*), pondcypress-swamp tupelo (*Taxodium distichum var. nutans-Nyssa sylvatica* var. *biflora*), or Atlantic white-cedar *(Chamaecyparis thyoides), are* freshwater systems with standing water for most or all of the year (Penfound 1952). Cypress-tupelo swamps are generally found along rivers and streams of the Atlantic Coastal Plain from Delaware to Florida, along the Gulf Coastal Plain to southeastern Texas, and up the Mississippi River to southern Illinois (Johnson 1990, Wilhite and Toliver 1990). Baldcypress was a very dominant tree in the coastal plain of the southern United States when settlers first arrived (Mattoon 1915), and this resource seemed inexhaustible to these early settlers, with more than 35 million m^3 (15 billion board feet) of timber estimated in the Louisiana delta swamps alone (Kerr 1981). Other deepwater swamp types include cypress domes (see Chapter 16) and depressional swamps like the Okefenokee and Dismal Swamps. Atlantic white-cedar swamps occur in a narrow band (80 to 210 km [50 to 130 mi] wide) from southern Maine to northern Florida and west to southern Mississippi (Little and Garrett 1990). For further information on deepwater swamps, the reader is referred to Lugo et al. (1990b), Ewel and Odum (1989), Kirk (1979), Cohen et al. (1984), Dennis (1988), Thomas (1976), and Laderman (1989).

CLASSIFICATION

Probably the first classification of deepwater swamp forests was Shaler (1890), who used both physical and vegetational characteristics to identify two types of forested wetlands: freshwater swamps and estuarine swamps. Freshwater swamps were located in lowlands where drainage was hindered by barriers made by the rivers, were composed of freshwater plants, and contained alluvium supplied by freshwater streams. Estuarine swamps occurred where water levels fluctuated from tidal action and were composed of grasses and river alluvium.

In the 1950s, the U.S. Fish and Wildlife Service (USFWS) recognized 20 types of wetlands in relation to wildlife habitat value (Shaw and Fredine 1956). Wooded swamps were characterized by waterlogged soil and frequent inundation with 30 cm (12 in) of water, and they were found along sluggish streams, flat uplands, and shallow lake basins. This was the most widely used classification system in the United States until the National Wetlands Inventory classification system (Cowardin et al. 1979) was adopted.

Other classification systems developed in the 1950s were based on vegetation, habitat, and the quantity, depth, and duration of water as diagnostic criteria (Putnam 1951, Penfound 1952). Penfound (1952) classified swamps of the Atlantic and Gulf Coastal Plains and the Mississippi River Alluvial Valley on the basis of water depth and duration of flooding. Deep swamps were identified as freshwater, woody areas with surface water throughout all or most of the growing season. Shallow swamps and peaty swamps were inundated for only part of the growing season. The terminology of Putnam (1951) has probably been the most widely accepted by the forestry profession. He recognized first bottoms as areas developed from recent deposits as a result of frequent flooding by the present drainage system. Secondary classifications within this site type included ridges, flats, sloughs, and swamps. These site types generally apply to the floodplain of all major streams (see Chapters 12 and 13).

Küchler (1964) compiled a map of the United States with 116 different plant community types. His system was based primarily on vegetation and unique in that he described the potential vegetation at one point in community succession if human influence were removed. Of the 10 types he identified as inland wetlands, only one pertains to deepwater swamps: southern floodplain forest. Unfortunately, this classification system is difficult to apply on the ground (Bailey et al. 1978), and the units are too large to be of practical value other than for broad land-use and resource planning (Mader 199 1).

Wharton et al. (1976) classified Florida freshwater swamps into four types based on hydrologic inputs. Stillwater cypress domes are poorly drained to permanently flooded depressions dominated by pondcypress. Lake edge swamps are found on the margins of many lakes and isolated sloughs of the southeastern United States. Both of these swamp &ems experience little water inflow except through precipitation and, in some cases, groundwater. Slow-flowing cypress strands are shallow forested depressions on a gently sloping plain, with seasonal wet and dry cycles, although deep peat deposits retain moisture even in extremely dry periods. Alluvial river swamps and floodplains are confined to permanently flooded depressions on floodplains such as abandoned river channels or elongated swamps paralleling the river.

The USFWS National Wetland Inventory includes deepwater swamps within the class of Palustrine Forested Wetlands (Cowardin et al. 1979), which is characterized by woody vegetation at least 6 m (20 ft) tall. This class is further subdivided into five subclasses, of which four are representative of southern deepwater swamps: (1) broad-leaved deciduous where water tupelo, swamp tupelo, and ash ***(Fruxinus*** spp.) are represented; (2) needle-leaved deciduous where baldcypress dominates; (3) broad-leaved evergreen where bays are prevalent; and (4) needle-leaved evergreen where Atlantic white-cedar is dominant.

A national system of forest cover types was developed by the Society of American Foresters (Eyre 1980) based solely on species dominance, with the name of each forest type usually limited to one or two species. Deepwater swamp types under this classification include baldcypress (Type 101), baldcypress-tupelo (Type 102), water tupelo-swamp tupelo (Type 103), Atlantic white-cedar (Type 97), and pondcypress (Type 100). This classification system is not intended for intensive land management.

The U.S. Forest Service (USFS) conducts periodic inventories of the nation's forests and uses a system of 20 forest type groups based on overstory species composition (USFS 1967). These type groups are further broken down into local groups but are seldom used when reporting the data. Wetland hardwoods are equivalent to the combined oak-gum-cypress and elm-ash-cottonwood type groups in the southern United States (Boyce and Cost 1974).

ECONOMIC IMPORTANCE

Both the Spanish in Florida and French in Louisiana found Indians using cypress, which the Seminoles called "hatch-in-e-haw," meaning everlasting (Neubrech 1939). The Europeans quickly recognized that cypress (refers to both baldcypress and pondcypress when used like this) wood was very rot resistant, strong, and easily worked, and efforts to establish a timber trade with Louisiana began around 1700 (Mancil 1980). 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 (Bums 1980), resulted in a logging boom during the period 1890 to 1925. Production of cypress lumber increased from 1.17 million m^3 (495 million board feet) in 1899 to more than 2.36 million m^3 (1 billion board feet) in 1913 (Mattoon 1915, Betts 1938), with the majority of the early commercial trade being baldcypress (Brown 1934). By 1925, nearly all of the virgin timber had been cut and most of the mills closed. In 1933, only about 10% 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.

Atlantic white-cedar logging began as early as 1700 in North and South Carolina (Frost 1987) and 1749 in New Jersey (Little 1950). Frost's (1987) analysis of Ashe's (1894) figures suggest that up to 50% 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). Another period of logging Atlantic white-cedar occurred during 1970-1980 (Baines 1990).

Although the majority of cypress/tupelo swamps were cut over during the late 1800s and early 1900s and there has been a general decline in land area of this forest type (Dahl et al. 1991), there are currently between 1.2 and 2 million ha (2.9 and 4.9 million acres) of second-growth timber (Williston et al. 1980, Kennedy 1982). Standing stock volumes continue to increase (Brandt and Ewel 1989, Conner and Toliver 1990), with the greatest concentration of baldcypress in Louisiana, pondcypress in Florida, and Atlantic white-cedar in Florida and North Carolina (Table 11.1). Tupelo growing stock is more widespread among the states.

Second-growth cypress is much less decay resistant than old-growth trees (Campbell and Clark 1960, Choong et al. 1986). Harvesting conditions, wetlands legislation, and confusion over the durability of cypress have resulted in an erratic market (Marsinko et al. 1991). Use of cypress wood remains popular, however. Baldcypress has many uses including fencing, boat planking, river pilings, furniture, interior trim, cabinetry, siding, flooring, and shingles (Brown and Montz 1986). Pondcypress is primarily used for fenceposts, mulch, and pulp (Terwilliger and Ewel 1986), although fence posts last less than five years (Applequist 1957). Second-growth Atlantic white-cedar has the same properties and durability of old-growth Atlantic white-cedar (Baines 1990, Earley 1987). There continues to be a high demand for all dimensions of Atlantic white-cedar for boat building, shingles, pilings, posts, furniture, and industrial millwork (Schroeder and Tams 1985, Little and

TABLE 11.1
Growing stock volume (million m^3) of major deepwater swamp species in the southern United States based on most recent U.S. Forest Service surveys.

State	Year of Survey	Baldcypress	Pondcypress	Tupelo	Atlantic white-cedar
Alabama	1990	4.53	14.40	0.30	
Arkansas	1988	5.43	2.58		
Florida	1987	16.81	58.50	42.74	2.21
Georgia	1989	6.53	17.82	63.50	
Louisiana	1991	42.46	22.23		
Mississippi	1994	5.74	2.72	0.04	
North Carolina	1990	9.20	3.14	54.83	2.08
South Carolina	1993	9.34	3.41	40.64	0.04
Tennessee	1989	2.30	0.35		
Texas[a]	1992	2.60	0.99		
Virginia	1992	1.13	0.29	12.99	2.55[b]

[a] East Texas only

[b] Value calculated from information provided by D. Brownlie, U.S. Department of interior, Fish and Wildlife Service, Great Dismal Swamp National Wildlife Refuge, Suffolk, VA.

Garret 1990). With reasonable management, these forests may once again become significant sources of wood products (Stemitzke 1972, Williston et al. 1980).

PHYSICAL ENVIRONMENT

CLIMATE

Although cypress and tupelo species are found across a wide climatic range, they grow best in the southern United States. Average annual precipitation ranges from 1120 to 1630 mm (44 to 64 in) across this range, although southeast Texas receives only 760 mm/year (30 in). The growing season ranges from 190 days in southern Illinois to 365 days in southern Florida. Temperatures average 27°C (81°F) in summer and 7°C (45°F) in winter across the range of these species. Baldcypress has been planted in the northern U.S. and southern Canada, where it survives minimum winter temperatures of -29 to -34°C (-20 to -29°F) (Harlow and **Harrar 1979),** but few seeds mature in these extreme conditions (Fowells 1965).

Atlantic white-cedar also grows in a humid climate with average annual precipitation ranging from 1020 to 1630 mm (40 to 64 in). The frost-free season for this species ranges from 140 days at its northern limit to 305 days at its southern-most location. Temperatures can range from extremes of -38°C (-36°F) in the winter to 38°C (100°F) in the summer (Fowells 1965).

GEOLOGY, GEOMORPHOLOGY, AND SOILS

Deepwater swamps occur in a wide variety of geomorphic situations ranging from broad, flat floodplains to isolated basins. Major features of these floodplain systems include meandering river channels, natural levees adjacent to the rivers, meander scrolls created as the rivers change course (ridge and swale topography), oxbow lakes created as meanders become separated from the main channel, and sloughs which represent areas of ponded water in meander scrolls and backwater swamps (Leopold et al. 1964, Bedinger 1981, Brinson et al. 1981b, Mitsch and Gosselink 1986). In the Mississippi River drainage, large loads of meltwater and soil material were carried by the river during glacial intrusions and recessions. Soil from the western plains, the midwest, and the Allegheny and Appalachian mountains was worked and reworked in the Mississippi floodplain, creating isolated backwater swamps and bayous and building ridges and natural levees (McKnight et al. 1981). On the Atlantic Coastal Plain, development occurred through cycles of continental submergence and emergence. Soils are generally of Appalachian and coastal origin, and rivers have modified the landscape to a lesser degree than in the Mississippi drainage (Sharitz and Mitsch 1993). Backwater swamps are less extensive and the bottoms are less dissected on the Atlantic Coastal Plain (Braun 1950).

Even though these swamps are areas of very low topographic relief, slight changes in elevation (a few cm) produce quite different hydrologic conditions, soils, and plant communities (Brown 1972). Peat deposition is characteristic of these systems because of slow decofnposition rates, and the thickness of the peat decreases towards the shallow edges of the swamps (Dennison and Berry 1993). Baldcypress and water tupelo commonly grow on soils ranging from mucks and clays to silts and sands (Alfisols, Entisols, Histosols, and Inceptisols). These soils are moderately to strongly acidic with a subsoil that is rather pervious (Johnson 1990, Wilhite and Toliver 1990). Although Atlantic white-cedar sometimes grows on sandy soils, it mainly grows on muck (peat) soils of the orders Spodosols and Histosols. The muck ranges in depth from a few centimeters to 12 m (39 ft) and is generally acid with a pH between 3.5 to 5.5 (Little and Garrett 1990). Atlantic white-cedar is not normally found in areas where the muck is underlain by clay or contains appreciable amounts of silt or clay (Fowells 1965). It also occurs sporadically along blackwater streams from the Sandhills region in North and South Carolina to blackwater streams in Florida and Alabama. Small stands occur along these streams where organic matter overlays or is layered with clay or stream bed alluvium (Moore and Carter 1987, Laderman 1989).

Soil oxygen content is one of the most important characteristics in these flooded soils. Anaerobic conditions are created rapidly upon flooding and can persist for long periods in deepwater swamps, especially during low flow or stagnant conditions. Soils high in clay content (small pore size) hinder drainage more than do sandy or loamy soils, and are thus more likely to be poorly aerated. High organic matter content can both increase and deplete soil oxygen. Organic matter can improve soil structure in clayey soils, increasing soil aeration, but decomposing organic matter creates an oxygen demand (Sharitz and Mitsch 1993). While the organic matter content of upland soils is low (0.4–1.5%), organic levels in deepwater swamps can reach 36% (Wharton et al. 1982).

HYDROLOGY

Hydrologic inflows are dominated by runoff from surrounding uplands and by overflow from flooding rivers (Mitsch and Gosselink 1993). Topographic features may impound water and cause flooding from rainfall rather than from stream overflow. Examples where this type of flooding is common are oxbows, backswamp depressions, and swales between relict levees where drainage patterns are poorly developed (Brinson 1990). Even though deepwater swamps are usually flooded, water levels vary seasonally and annually. High water levels coincide with winter-spring rains and melting snow runoff. Low levels occur in the summer from high evapotranspiration and low rainfall (Wharton and Brinson 1979). During extreme droughts, like those of 1924 and 1960, even deepwater forests may lack surface water for extended periods (Mancil 1969).

BIOGEOCHEMISTRY

Soils of deepwater swamps generally have ample nutrients. High clay content results in higher concentrations of phosphorus, and the relatively high organic matter content results in higher concentrations of nitrogen (Sharitz and Mitsch 1993). Soils tend to be highly reduced, thereby increasing mobilization of minerals such as phosphorus (P), nitrogen (N), magnesium (Mg), sulfur (S), iron (Fe), manganese (Mn), boron (B), copper (Cu), and zinc (Zn) (Mitsch and Gosselink 1986). In addition, low oxygen may foster accumulation of potentially toxic soil compounds (Sharitz and Mitsch 1993). Low oxygen also causes a shift in the redox state of several nutrients to more reduced states, making them unavailable to plants (Wharton et al. 1982).

Biogeochemical processes are strongly linked to hydrologic characteristics. The depth and duration of flooding, as well as whether floodwaters are flowing or stagnant, affect whether these wetlands serve as sources, sinks, or transformers of nutrients. Flooding in these swamps causes a lateral transport of elements. Dissolved and particulate forms are carried into the wetland from upstream or are transported downstream (Brinson 1990). Phosphorus inputs, based on sedimentation rates, range from 0.17 g $P/m^2/yr$ (6×10^{-4} $oz/ft^2/yr$) in North Carolina swamps (Yarbro 1979) to 3.6 g $P/m^2/yr$ (1×10^{-2} $oz/ft^2/yr$) in southern Illinois swamps (Mitsch et al. 1979a). Deepwater swamps can also serve as sinks for nutrients. Kitchens et al. (1975) reported a 50% reduction in P as overflow waters passed through a South Carolina swamp. Day et al. (1977) found a 48% reduction in N and a 45% reduction in P as water passed through a swamp/lake complex in Louisiana.

Some wetlands serve as sinks for nutrients for a number of years. A Florida cypress strand was found to be an effective sink even after 50 years of enrichment with partially treated wastewater (Nessel 1978a, b, Nessel and Bayley 1984, DeBusk and Reddy 1987). Floodplain forests along the Apalachicola River in Florida are nutrient transformers rather than sinks (Elder and Mattraw 1982, Elder 1985). While inputs and outputs of total N and P are similar, there are net increases in particulate organic N, dissolved organic N, particulate P, and dissolved P along with decreases in dissolved inorganic P and soluble reactive P. These transformations of inorganic forms to organic forms may be important for secondary productivity in downstream ecosystems (Sharitz and Mitsch 1993).

Major flows of nutrients most frequently measured in these swamps include decomposition, wood accumulation, sedimentation, and return of nutrients from the forest canopy as litterfall (Brinson 1990). Nutrient return from the canopy to the forest floor is high in riverine forests compared to upland forests, suggesting that fluvial processes are important in maintaining the relative high fertility of these systems (Brinson et al. 1980). When floodplain soils are nutrient poor, resorption from leaves prior to abscission may be important in conserving nutrients (Adis et al. 1979). Decomposition rates of leaf litter vary greatly (Duever et al. 1975, Brinson 1977, Bums 1978, Nessel 1978b, Brinson et al. 1981a, Kemp et al. 1985, Conner and Day 1991), with peat accumulation occun-ing in areas with long hydroperiods (Brinson 1990). Flowing water alters litter through transport, concentration, sorting, physical destruction, siltation, and increased moisture regime (Bell and Sipp 1975). Debris piles accumulate on the, upstream side of trees (Hardin and Wistendahl 1983). Decomposing litter in slowly flowing situations, however, may immobilize N and P, providing a mechanism for nutrient conservation during the dormant season (Brinson 1977). Annual P accumulations in the wood of trees is quite low when compared with recycling in litterfall. Uptake of P by stem wood does respond to supply, however. The rate of P accumulation in the stem wood increased three-fold when nutrient rich sewage effluent was released into a cypress strand in Florida (Nessel 1978a). Sedimentation rates vary greatly in deepwater swamps, and only a few studies have reported P deposition rates (Mitsch et al. 1979a, Yarbro 1983). The proportion of the sediment P that is available for plant uptake has not been determined (Brinson 1990).

In Atlantic white-cedar stands, acid conditions generally occur with soil and water pH ranging from 2.5 to 6.7 (Day 1984, Golet and Lowry 1987, Schneider and Ehrenfeld 1987, Whigham and Richardson 1988, Laderman 1989). Available information indicates that Histosols under Atlantic white-cedar stands are generally high in organic matter content (20 to 30%) and cation exchange capacity. They have relatively high levels of Ca, Mg, and Al and relatively low levels of P (Bandle and Day 1985, Whigham and Richardson 1988, Laderman 1989). Day (1984, 1987b) determined that litter accumulation rates in Atlantic white-cedar stands exceeded those of associated cypress and mixed hardwood communities, and that decomposition rates were generally lower in cedar-dominated communities than in associated cypress or mixed hardwood-dominated communities in the Great Dismal Swamp.

FIRE

Fire is generally infrequent in natural deepwater forests of the southern United States because of the continuously moist conditions. During droughts, or after drainage, however, fire can have a significant effect on these forests. Mature cypress trees are seldom killed by fire, although tree vigor may be reduced (Duever et al. 1986). Broad-leaved species, on the other hand, are killed, thereby helping maintain cypress dominance (Ewe1 and Mitsch 1978, Schlesinger 1978). Even-aged cypress stands developed after fire in Georgia's Okefenokee Swamp (Duever and Riopelle 1984). Although cypress returned to most sites in the Florida Everglades after a series of fires in 1937, there was little regeneration after a 1962 fire (Craighead 1971); this was probably due to the lowering of the water table in the area by drainage (Brandt and Ewel 1989). Atlantic white-cedar has thin bark and flammable foliage, making it extremely susceptible to injury and death by fire. Living trees with fire scars are rare, as most of the impacted trees are killed (Akerman 1923, Korstian and Brush 1931, Little 1950).

WIND

In deepwater swamp forests, hurricanes are capable of defoliating, topping, and overturning trees, but it is usually the defective and hollow trees that break, and windthrow of these wetland species is generally rare (Craighead and Gilbert 1962, Duever et al. 1984a, Hook et al. 1991a). Windthrow of bottomland species is more common and may be related td shallow rooting in moist, soft soil (Hedlund 1969, Gunter and Eleuteris 1973). In south Florida, new leaf growth was unusually rapid for several species of trees, and many species flowered a second time immediately following Hurricane Donna in 1960 (Vogel 1980). The major short-term effect to bottomland and swamp species during Hurricane Hugo was the loss of foliage and small branches (Gresham et al. 1991, Putz and Sharitz 1991). Putz and Sharitz (1991) also reported that trees that had previously suffered wind damage were more susceptible to new damage.

VEGETATIONAL COMMUNITIES

TYPES

Based on field observations and study in four southern states, Wharton et al. (1982) described 30 dominance types in deepwater swamps. These dominance types can be broken down into four broad categories: cypress/tupelo gum forests, bay swamps and shrub bogs, tidal forests, and Atlantic white-cedar forests. In the cypress/tupelo gum forests, subtle differences determine the relative dominance of baldcypress, water tupelo, swamp tupelo, and Ogeechee tupelo (*Nyssa ogeche*). Water tupelo occurs primarily in alluvial floodplains of the coastal plain and tolerates deeper and longer flooding than swamp tupelo. Swamp tupelo is also common in coastal plain floodplains as well as in upland swamps and ponds and in brackish water fringing coastal estuaries (Penfound 1952). Ogeechee tupelo occurs only in Florida and Georgia hut is found in both alluvial and blackwater systems. Baldcypress is found throughout the southern United States, but is often replaced by water tupelo because of erratic reproduction, slower growth rates, and poor stump and root sprouting (Wharton et al. 1982). Frequent disturbance, such as logging, also favors water tupelo dominance (Penfound 1952, Putnam et al. 1960, Eyre 1980). Pondcypress is codominant with water tupelo and swamp tupelo on some Florida blackwater floodplains and depressional wetlands (Wharton et al. 1982).

Bay swamps and shrub bogs are comparatively rare in the floodplain environment (Wharton et al. 1982). For more information on these upland counterparts, see Chapter 14.

Tidal forest types can be found within the zone of tidal influence of all of our coastal floodplains and may extend a considerable distance inland. Soils are peaty and tightly bound by interwoven root mats. The water table is continuously high and the forest floor covered up to twice a day as a result of tidal action (Wharton et al. 1982, Rheinhardt and Herschner 1992).

Atlantic white-cedar seems to be a disturbance-adapted successional species and is found in bog stream swamps on peat overlying sandy soils or in acid backswamps (Wharton et al. 1982). Fire is a common precursor to Atlantic white-cedar forests developing, although logging, flooding, or windthrow can yield similar results (Korstian and Brush 1931, Little 1950, Frost 1987).

DOMINANT SPECIES WITHIN TYPES

Southern deepwater swamps have unique plant communities that either depend on or adapt to the almost continuously wet conditions. The dominant canopy species found in these swamps include baldcypress, water tupelo, swamp tupelo, and Atlantic white-cedar. These species grow together or in pure stands. Other species include red maple (*Acer rubrum*), black willow (*Salix nigra*), swamp cottonwood (*Populus heterophylla),* green and pumpkin ash *(Fraxinus pennsylvanica* and *F. profunda*), pondcypress, Atlantic white-cedar, pond pine (*Pinus serotina*), and loblolly pine (*Pinus taeda*) (Barry 1980, Eyre 1980, Wharton et al. 1982, Sharitz and Mitsch 1993). Along the shallow margins of deepwater swamps, species diversity is greater and may include overcup oak *(Quercus lyrata),* water hickory *(Carya aquatica),* waterlocust *(Gleditsia aquatica), American* elm (*Ulmus americana*), persimmon *(Diospyros virginiana),* sweetbay *(Magnolia virginiana),* and redbay (*Persea borboniu).* Ogeechee tupelo occurs in southwest Georgia and northern Florida. The understory in deepwater swamps is generally sparse because of low light conditions and long periods of flooding. Small tree and shrub associates include buttonbush *(Cephalanthus occident&is),* redbay, swamp-privet *(Forestieru acuminata*), waterelm (*Planera aquatica),* sweetbay, swamp dogwood (*Cornus* spp.), poison sumac (*Rhus vet-nix),* Virginia willow (*Itea virginica*), swamp cyrilla (*Cyrilla racemiflora*), fetterbush *(Lyonia* spp.), swamp leucothoe (*Leucothoe racemosa*), hollies (*Ilex* spp.), swamp rose (*Rosa palustris*), Carolina ash (*Fraxinus caroliniana*), southern bayberry (*Myrica cerifera*), and viburnums *(Viburnum* spp.) (Eyre 1980, Johnson 1990, Wilhite and Toliver 1990).

Because Atlantic white-cedar grows over such a broad latitudinal range, a variety of species are associated with it. In the southern United States, these include red maple, swamp tupelo, baldcypress, loblolly bay *(Gordoniu lasianthus*), redbay, sweetbay, pond pine, and slash pine (*Pinus elliottii).* Common fetterbush *(Lyonia lucida*), greenbriar (*Smilax* spp.), and southern bayberry are the most common associated shrubs (Korstian and Brush 1931, Buell and Cain 1943, Laderman 1989).

ADAPTATIONS

In order to survive standing water for most of the year, plants have developed many morphological and physiological adaptations. For a detailed description of these features, see Chapter 8 or Kozlowski (1984). Common features in deepwater swamps are knees and buttressed tree trunks. Knees are produced by baldcypress, pondcypress, water tupelo, and swamp tupelo, and represent extensions of the root systems to well above the average water level. On baldcypress, the knees are conical in shape and typically less than a meter in height, although some knees reach 3 to 4 m (10 to 13 ft) (Hook and Scholtens 1978, Brown and Montz 1986). Water tupelo produce fewer knees than baldcypress (Hall and Penfound 1939a), and the knees of swamp tupelo are actually arching roots that approximate the appearance of cypress knees (Mitsch and Gosselink 1993). Atlantic white-cedar possesses neither knees nor arching roots (Keamey 1901).

The exact function of these knees has not been resolved. It is commonly believed that they function in gas exchange for the root systems, but Kraemer et al. (1952) concluded that they do not provide aeration for the rest of the tree. Even though some CO, evolves from knees (Cowles 1975, Brown 1981), this does not prove that oxygen transport is occurring through the knees (Mitsch and Gosselink 1993). Another possible function is an adaptation for anchoring trees in unstable soils. Under each knee, there is a secondary root system similar to and smaller than the main root system (Mattoon 1915, Brown 1984).

Another adaptation in flooded swamps is buttressing of the lower part of the tree trunk. The height of the buttress varies depending on the water depth. Swelling generally occurs along the part of the tree where there is a frequent wetting and soaking of the tree trunk but where the trunk is also above the normal water level (Kurz and Demaree 1934). The value of this swelling to survivability is also unknown (Mitsch and Gosselink 1993) but has been proposed as an aid in support.

Atlantic white-cedar has developed reproductive strategies that are likely an adaptation to the hydrologic and fire disturbance regimes in cedar habitats. Cones and viable seeds are produced at a very early age (Little 1950, C. G. Williams, pers. comm.). Seeds are generally wind or water disseminated. Poor seed years are rare, and seeds can germinate at rates exceeding 2.5 million seedlings/ha (1 million/acre) (Korstian and Brush 1931). Seedlings and saplings can produce shoots from lateral branches or dormant buds when injured (Little 1950).

SUCCESSIONAL PATTERNS

On permanently flooded sites with little sediment deposition, succession tends to be stalled, and changes in composition may not occur for hundreds of years without disturbance. Cypress-tupelo forests may be 200-300 years old before canopy trees begin to die (Hodges 1994a). In some poorly drained areas, deposition of fine-textured material on the floodplain eventually creates better drained conditions. The pioneer tree species on such sites is generally black willow, a short-lived species. Black willow stands start to deteriorate as early as age 30 and few survive to age

60 (Johnson and Shropshire 1983). Further compositional changes depend on the degree of sedimentation. Low sedimentation rates usually result in an association of swamp privet, water-elm, and buttonbush which may eventually be replaced by baldcypress. High rates of sedimentation (or drainage) may foster a replacement of the cypress-tupelo forest with species like water hickory-overcup oak association (Hodges 1994a).

According to Korstian and Brush (1931), the best conditions for establishing Atlantic white-cedar stands are open, warm conditions following recent burns in wet swamps, recently cut-over lands, and clearings. The species aggressively regenerates from seed under favorable conditions, often developing in dense, pure stands. In the South, it appears to be naturally limited to those sites where return intervals for catastrophic fires vary from 25 to 250 years and that occupy the relatively narrow moisture gradient bounded by high and stable water tables of deep swamps and the seasonally variable water table of pocosins. Alterations in the fire/hydrology regime shift regenerating stand composition toward a cedar-hardwood mixture and ultimately to a mixed hardwood stand (Frost 1987).

PRODUCTIVITY

Aboveground primary productivity values for cypress/tupelo forests are among the highest reported for forest ecosystems, due largely to fluctuating water levels and nutrient inflows (Brinson et al. 198 la, Brown 198 1, Conner and Day 1982, Brinson 1990, Lugo et al. 1990c, Conner 1994). Aboveground biomass production of forests with unaltered seasonal water flow frequently exceeds 10 t/ha/yr (8,900 lbs/acre) in these forests, with a maximum of nearly 20 t/ha/yr (17,800 lbs/acre) being reported for an undisturbed cypress/tupelo forest in South Carolina (Table 11.2). Litterfall accounts-for an average of 39% of the aboveground primary production in wetland forests. Very little is known about belowground processes, although there is evidence that roots contribute as much or more to the detrital pool than does litterfall (Symbula and Day 1988). Powell and Day (1991) reported that belowground productivity in a frequently flooded Atlantic white-cedar swamp (3.66 t/ha/yr or 3,266 lbs/acre) and a cypress swamp (3.08 t/ha/yr or 2,748 lbs/acre) was much lower than in a mixed hardwood swamp (9.89 t/ha/yr or 8,906 lbs/acre), suggesting that the allocation of carbon to the root system decreases with increased flooding.

Brinson et al. (1981a) suggest that the amount and frequency of water passing into and through a wetland are the most important determinants of potential primary productivity. 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 with 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 under anoxic conditions, N 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) and is illustrated in Figure 11.1.

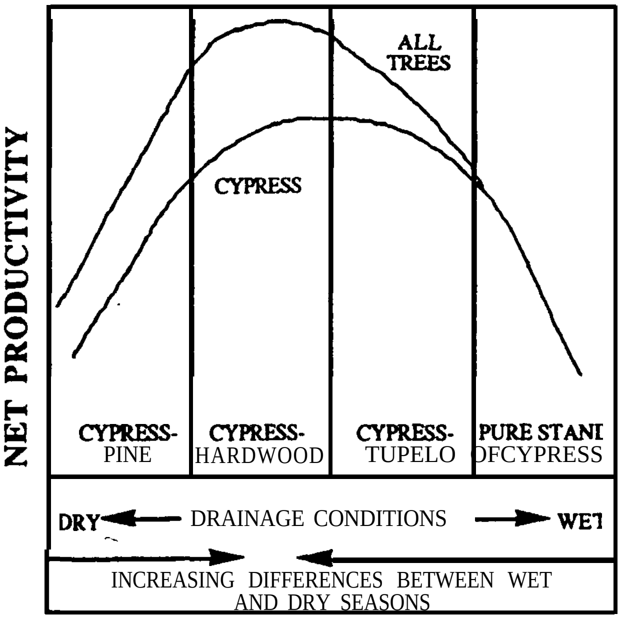

FIGURE ***11.1 The*** relationship between productivity and hydrologic conditions for deepwater swamps (from Mitsch and Ewel 1979, copyright © by American Midland Naturalist, reprinted with permission).

Mature cypress and tupelo prosper under flooded conditions (Kennedy 1970, Dickson et al. 1972), but when changes in the natural regime occur, tree growth can be affected. Cypress has tolerated flood depths of 3 m (10 ft) or more (Wilhite and Toliver 1990). In Florida, Harms et al. (1980) found that 0 to 16% of the cypress trees died within seven years in water from 20 to 100 cm (8 to 39 in) deep. In water more than 120 cm (47 in) 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 (24 to 118 in) deep, 97% of the cypress survived. 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). Conner and Day (1992a) found that growth of both baldcypress and water tupelo was greater in a permanently flooded swamp than in a natural cypress-tupelo forest. Keeland and Sharitz (1995) found that water tupelo and swamp tupelo achieved best growth under deep periodic flooding while maximum growth of baldcypress occurred with shallow permanent flooding. Stahle et al. (1992) and Young et al. (1995b) reported that increased flooding resulted in a short-term increase in baldcypress growth rate followed by a long-term decline in both South Carolina and Tennessee. Although Atlantic white-cedar is found in a variety of hydrologic regimes from nontidal coastal wetlands to permanently flooded areas, it generally grows on slightly elevated hummocks surrounded by water up to 1 m (3.3 ft) deep. When the boles are under water, cedars are stressed, and while surviving, they do not grow well (Laderman 1989).

TABLE 11.2

Aboveground biomass production of deepwdter swamps in the southern United States.

location/type	Flood periodicity	Water	leaf litterfall (t/ha/yr)	Stem growth (t/ha/yr)	Reference
Florida					
baldcypress-pop ash	seasonal”	Rowing	4.76	6.10	Brown 1981
tupelo[b]-cypress[c]-ash	semi-permanent	poor drainage	4.81	—	Elder & Cairns 1982
water tupelo-baldcypress	semi-permanent	poor drainage	4.76	—	ibid
baldcypress	seasonal	undrained	3.45	7.72	Bums 1978
cypress	permanent	stagnant	—	1.54	Mitsch and Ewel 1979
Georgia					
pondcypress	permanent	stagnant	3.28	3.53	Schlesinger 1978
baldcypress-sweetgum-oak-blackgum-tupelo	seasonal, 36 mo.	Rowing	6.50–8.50		Cuffney 1988
Illinois					
baldcypress-water tupelo	permanent	stagnant	2.35	—	Middleton 1994
Kentucky					
green ash-baldcypress	semi-permanent	slowly flowing	1.36	4.98	Mitsch et al. 1991
baldcypress	permanent	slowly Rowing	2.53	2.71	ibid
baldcypress	semi-permanent	stagnant	0.63	1.42	ibid
Louisiana					
baldcypress-water tupelo	semi-permanent	slowly flowing	6.20	5.00	Conner and Day 1976
baldcypress-water tupelo	semi-permanent	slowly flowing	4.17	7.49	Conner et al. 1981
baldcypress-water tupelo	permanent	stagnant	3.30	5.60	ibid
baldcypress-water tupelo	semi-permanent	slowly flowing	4.88	3.38	Megonigal et al. 1997
baldcypress-water tupelo	seasonal	slowly flowing	7.25	4.30	ibid
baldcypress	permanent	slowly flowing	3.33	3.30	ibid

North Carolina					
water tupelo	seasonal	flowing	5.52-6.77	—	Brinson 1977 Brinson et al. 1980
South Carolina					
baldcypress-water tupelo	frequent flooding	flowing	4.66	2.93	Muzika et al. 1987
baldcypress-red maple	frequent flooding	flowing	5.44	13.43	ibid
black willow-red maple-baldcypress (recovering)	seasonal	flowing	4.35	9.09	Bates 1989
water tupelo-baldcypress	permanent	flowing	4.38	2.16	Megonigal et al. 1997
Virginia					
Atlantic white-cedar	seasonal, 4 mo.	stagnant	5.69	—	Gomez and Day 1982
Atlantic white-cedar	seasonal		9.06	1.68[d]	Day 1984
baldcypress-red maple-blackgum	seasonal, 6 mo.	stagnant	5.68		ibid
green ash-blackgum-bluebeech-red maple	daily tidal	flowing	2.52	4.92	Fowler & Hershner 1989

[a] Prior to dam construction, flooding was year-round

[b] Includes water tupelo, swamp tupelo, and Ogeechee tupelo

[c] No distinction made as to whether baldcypress or pondcypress

[d] Average value over 57 years

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/yr (3,453 lbs/acre) compared to 8.58 t/ha/yr (7,656 lbs/acre) for an undrained stand.

ANIMAL COMMUNITIES

MAMMALS

The most common mammals found in permanently-flooded swamps include American beaver (*Castor cunadensis)* and northern river otter (*Lutra canadensis*). Beavers often change local hydrologic conditions through their dam building activities and cause tree mortality through removal as well as flooding. Baldcypress distribution along small drainages in Missouri appears to be related to beaver activity. In Louisiana swamps, nutria (*Myocastor coypus)* imported into the state during the 1930s have severely limited cypress regeneration attempts by feeding on planted seedlings (Blair and Langlinais 5960, Conner and Toliver 1990). Mink (*Mustela vison*) concentrate their activities adjacent to permanent water while raccoons *(Procyon lotor*) utilize both wetland and upland areas. Occasionally, white-tailed deer (*Odocoileus virginianus),* bobcats (Lynx *rufus*), and swamp rabbits (*Sylvilagus aquaticus)* can be found in these swampy areas. Eastern gray squirrels *(Sciurus carolinensis*) and southern flying squirrels (*Glaucomys volans*) are common throughout the floodplain forests (Sharitz and Mitsch 1993).

Few studies have quantified mammal use of Atlantic white-cedar swamps. White-tailed deer can be a significant damaging agent in regenerating stands (Little 1950, Laderman 1989, Little and Garret 1990). Some mammals known to use Atlantic white-cedar on the Atlantic Coastal Plain are gray squirrel, eastern red bat (*Lasiurus borealis),* common muskrat (*Ondatra zibethicus*), red fox (*Vulpes vulpes*), black bear (*Ursus americanus),* and bobcat (Laderman 1989).

REPTILES AND AMPHIBIANS

Wharton et al. (1982) report that only a few reptiles and amphibians are locally abundant in deepwater swamps. Major species include mud turtles (*Kinosternon subrubrum subrubrum* and *K. buurii),* glossy crayfish snakes *(Regina rigida*), mud snakes *(Furunciu ubucuru),* plainbelly water snakes *(Nerodiu erythroguster),* and eastern cottonmouth snakes *(Agkistrodon piscivorus).* Water snakes are more common in swamps, in both numbers and biomass, and are commonly misidentified as cottonmouths. Another reptile of deepwater swamps is the American alligator *(Alligator mississippiensis*), found from North Carolina to Louisiana and making a tremendous comeback after being hunted almost to extinction.

Dominant amphibia of deepwater swamps include the lesser siren *(Siren intermedia)* and two-towed amphiuma (*Amphiuma means).* Amphibious salamanders include the dusky *(Desmognuthus* spp.), the many-lined (*Stereochilus murginutus),* and the dwarf (*Eurycea quadridigitata*). *The* rusty mud salamander *(Pseudotriton montanus floridanus*) and the northern two-lined salamander (*E. bislineutu)* occur on the edge of the permanently flooded zone (Wharton et al. 1982). Frogs are less specific in this forest type, but include the green frog *(Rana clamituns melunotu),* southern leopard frog (*Rana utricularia*), southern cricket frog (*Acris gryllus gryllus*), and the bird-voiced treefrog (*Hyla uvivocu)* (Wharton et al. 1982).

Detailed information on reptiles and amphibians associated with Atlantic white-cedar swamps in the South is limited. Reports from the Great Dismal Swamp and from Dare County, NC, include the five-lined skink *(Eumeces inexpectutus),* redback salamander *(Plethodon cinereus),* carpenter frog (*Rana virgutipes),* southern copperhead snake *(Agkistrodon contortrix contortrix),* and timber rattlesnake (*Crotalus horridus)* (Laderman 1989).

BIRDS

Deepwater swamps are used by birds for nesting and summer and winter foraging (Fredrickson 1979). In open areas within the forest, shorebirds are attracted to areas that are muddy or of shallow depth. Dabbling ducks are attracted best when water depths are 30 cm (12 *in)* or, less (Taylor 1977), while wading birds and other deepwater foragers exploit deeper waters (Fredrickson 1979). Characteristic passerine birds include the prothonotary warbler (*Protonotaria citreu),* tufted titmouse (*Parus bicolor),* northern parula warbler (*Parula americana*), and common grackle *(Quisculus quiscula*) (Wharton et al. 1982). Prothonotary warblers nest in cavities within the swamp and forage in the vicinity of their nests. Parula warblers nest in Spanish moss (Bent 1953). Yellow-crowned night-heron (*Nyctanassa violucea),* green heron *(Butorides virescens),* great blue heron *(Ardeu herodias*), great egret *(Cusmerodius albus*), and white ibis *(Eudocimus albus*) usually nest in colonies, and nest sites may be immediately adjacent to the water or a considerable distance from foraging sites (Palmer 1961). Wood storks (*Mycteria americana*) nest in cypress stands and once occurred from South Carolina to Texas. Their range is now largely restricted to Florida with some rookeries in Georgia and South Carolina (Ernst and Brown 1989). Permanently flooded sites are excellent foraging areas for anhingas *(Anhingu anhingu).* Hooded mergansers *(Lophodytes cucullatus*) always nest in tree cavities over or immediately adjacent to water (Morse et al. 1969). Wood ducks (*Aix sponsu)* and mallards *(Anus plutyrhynchos) are* common wintering waterfowl. Wood ducks commonly nest in cavities over water (Sharitz and Mitsch 1993). The red-shouldered hawk *(Buteo lineatus*) is a characteristic raptor in this forest. American swallow-tailed kites (*Elanoides forficatus*) feed and nest in these forests (Wharton et al. 1982). Terwilliger (1987) reported that prairie warblers *(Dendroica discolor),* prothonotary warblers, hooded warblers (*Wilsonia citrina),* worm-eating warblers *(Helmitheros vermivorus),* and common yellowthroats *(Geothlypis trichus)* account for a majority of birds found in a study of Atlantic white-cedar stands in the Great Dismal Swamp. Numerous other migratory birds use these forests seasonally and temporarily, taking advantage of enhanced foraging opportunities because of the fluctuating water levels.

FISH

Sloughs and backwater swamps serve as spawning and feeding sites for fish and shellfish during the flooding season (Lambou 1963, 1990, Patrick et al. 1967, Bryan et al. 1976, Wharton et al. 1982). Deepwater swamps also serve as a reservoir for fish when floodwaters recede, even though conditions are less than optimal for aquatic life because of fluctuating water levels and low oxygen conditions (Mitsch and Gosselink 1993). Fish adapted to low oxygen conditions include bowfin (*Amia* sp.), gar (*Lepisosteus* sp.), and certain top minnows (e.g., *Fundulus* spp. and *Gambusia affinis*).

INVERTEBRATES

Macroinvertebrates dominate deepwater swamp invertebrate communities. A wide diversity and high number of invertebrates have been reported in permanently flooded areas (Mitsch and Gosselink 1993, Sharitz and Mitsch 1993). The types of invertebrates found in these forests depend on water depth, duration of flooding, current, substrate, food availability, and oxygen level (Sklar 1983). Characteristic species include crayfish, clams, oligochaete worms, snails, freshwater shrimp, midges, amphipods, and various immature insects (Mitsch and Gosselink 1993). In the Atchafalaya swamp of Louisiana, cypress-tupelo forests contain more invertebrates than do bayous, lakes, canals, and rivers, likely due to the abundance of detritus in the forest (Beck 1977). High densities of invertebrates in natural cypress-tupelo forests in Louisiana (Sklar and Conner 1979) and stream floodplains of Virginia (Gladden and Smock 1990) indicate that periodic flooding also contributes to the density and diversity of invertebrate communities. The Hessel's hair-streak butterfly (*Mitoura hesseli*), the larva of which feed exclusively on Atlantic white-cedar, has been reported in the Great Dismal Swamp and in Dare County, North Carolina (Beck and Gamett 1983, Laderman 1989).

MANAGEMENT ISSUES

PAST PRACTICES

During the 1700s, French settlers along the lower Mississippi River paid for imported goods mainly with shipments of lumber. Although oak and pine were exported in small quantities, 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 (Moore 1967).

Early loggers coming from the drier pine forests of the North had to devise new harvesting methods for the wet swamplands where cypress grew. Axemen preferred working in the swamps during low river stages in order to have comparatively firm ground. Log planks were cut on the spot with simple two-man handsaws because of the difficulty of moving the heavy green logs. During periods of high water, the axemen cut the trees while standing in boats, dropping the trees as close to shore as possible. Trees were dragged onto dry ground where handsaws could be used. When large timbers were required, green logs were lashed to rafts constructed of buoyant woods. Unfortunately, many logs broke free during transportation and sank (Moore 1967).

By 1725, loggers realized that by simply girdling the trees during the late summer and winter, the trees dried sufficiently enough to float out of the swamp during spring high water (Moore 1967, Burns 1980). Loggers working from boats or scaffolding were able to fell the trees, trim the branches from the floating logs, cut the boles to log lengths, and bind the logs into rafts without setting foot on dry land (Moore 1967). The May Brothers Company of Garden City, Louisiana, erected a levee approximately 1.8 m (6 ft) in height around sections of swamp 400 ha (1,000 acre) or more in size and flooded it to a depth of 1 m (3.3 ft) after girdling the trees. Later, they returned and cut the dried logs and floated them out of the constructed pond (Anonymous 1959, Davis 1975, Prophit 1982).

Many of the early sawmills along the lower Mississippi River were powered by water. Settlers dug ditches from the swamp through their land and the river levee into the river. Swamp water flowing through the ditch carried the logs from the swamp to the mill and supplied power to turn the water wheel attached to the sawmill (Moore 1967, Eisterhold 1972). Because of the relatively short time between the river cresting and the emptying of the swamps, the mills could operate no more than five months of the year. Thus, operations were generally small, and the owners were planters first and lumbermen second (Prophit 1982).

Large-scale commercial logging of cypress did not begin until the Homestead Act of 1866 was repealed by the Timber Act of 1876. The Homestead Act declared swamp lands unfit for cultivation and unavailable to private individuals. When the act was repealed, large tracts of swamp lands were sold for 60 cents to $1.25 per hectare (25 to 50 cents/acre) (Davis 1975). During the 1890s, tbe pullboat, and later the overhead-cableway skidder, increased the range of the logger and the amount of timber that could be brought out of the forest. By the close of the 19th century, 7.08 million m^3 (3 billion board ft) of baldcypress had been logged in Louisiana (Kerr 1981). Nationwide, the production of cypress sawtimber rose from 68.4 thousand m^3 (29 million board ft) in 1869 to slightly more than 2.36 million m^3 (1 billion board ft) in 1913, with the majority of the timber coming from Louisiana (Mattoon 1915).

Many of the logging operations maintained their own dredges to prevent delays in digging access canals (Davis 1975). The average size of the canals was 3 to 12 m (10 to 40 ft) wide and 2.4 to 3 m (8 to 10 ft) deep, resulting in partial drainage of many swamps (Mancil 1969, 1980). In other areas, railway lines were constructed. The mileage of railroads in Louisiana between 1880 and 1910 increased from 1,050 km (650 mi) to 8,942 km (5,557 mi). By 1920, however, the mileage began to decrease because of the abandonment of the logging operations (Mancil 1969). With the use of pullboat barges, trees could be pulled in from as far as 1,524 m (5,000 ft) from the canal through runs spaced about 46 m (150 ft) apart in a fan-shaped pattern. The runs were cleared of all trees and stumps and the logs pulled to the canal This skidding of timber across the swamp floor damaged and destroyed much young growth, and the continual use of a run resulted in a mud-and-water-filled ditch 1.8 to 2.4 m (6 to 8 ft) deep for the length of the run (Mancil 1980). This operation left distinctive wagon wheel-shaped patterns that can still be seen on current aerial photographs.

The earliest settlements in North and South Carolina occurred in 1655 and 1670, respectively, and Atlantic white-cedar was used for cabins, shingles, and boats. Population levels were low and extraction methods primitive, so little impact was made on the resource prior to 1732. The introduction of the water-powered sawmill in 1732 hastened the harvest of most readily accessible timber. The introduction of steam dredging and logging railroad technology in the 1850s foreshadowed the harvest of essentially every known stand of Atlantic white-cedar in the Carolinas. Many stands regenerated following harvesting, however, the area regenerating to white-cedar forests was apparently smaller than the area of cedar harvested initially (Frost 1987). Drainage occurred on only a minor scale by the early 1900s, and it is speculated that the reduction in area regenerating to Atlantic white-cedar was due primarily to the fact that logging created a different, and less favorable, regeneration environment than did natural fire disturbances (Little 1950, Frost 1987).

Unfortunately, the early exploitation of these swamp lands 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 swamp lands were logged of cypress and Atlantic white-cedar. In some cases, landowners were encouraged to drain their cut-over lands and convert them to agriculture or to plant fast-growing black willow and tupelo trees (Norgress 1947).

PRESENT MANAGEMENT PRACTICES

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 et al. 1980). Only recently have studies begun to investigate the response and recovery of these forests to harvesting practices (Aust 1989, Mader et al. 1989, Mader 1990, Aust et al. 1989, 1991, 1997, Aust and Lea 1991, 1992). Most stands today are second-growth, are fairly dense, and support high basal areas (Table 11.3). Timber volumes can exceed 170 m^3/ha (2,429 $ft^3/acre$) (McGarity 1977). Deepwater stands should be managed on an even-aged basis because of the species' silvical characteristics, the nature of the existing stands, and the sites they inhabit (Korstian and Brush 1931, Putnam et al. 1960, Stubbs 1973, Smith and Linnartz 1980). Baldcypress 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. Naturally seeded baldcypress seedlings often reach heights of 20 to 36 cm (8 to 14 in) the first growing season and 40 to 60 cm (16 to 24 in) the second season (Mattoon 1915). Early height growth is important because seedlings can be killed by four to five weeks of total submergence during the growing season (Mattoon 1916, Johnson and Shropshire 1983). Baldcypress seedlings can endure partial shading but require overhead light for normal growth (Williston et al. 1980). Coppice regeneration is also a possibility in cut-over areas. Mattoon (1915) reported that stumps of vigorous stock up to 60 years old can generally be counted on to send

TABLE 11.3
Density and basal area (BA) of deepwater swamps of the southern United States.

Forest Type	Density (stems/ha)	BA (m^2/ha)	Reference
water tupelo	2730	69.0	Brinson et al. 1980
water tupelo	916	52.4	Applequist 1959
water tupelo/ogeechee gum	2210	32.8	Leitman et al. 1983
water tupelo/swamp tupelo	2050	66.1	ibid
swamp tupelo	746	251.4	Hall and Penfound 1939b
swamp tupelo	988	51.7	Applequist 1959
tupelo/cypress	703-1484	77.4-77.6	Good and Whipple 1982
tupelo/cypress	830-1423	77.1-93.9	Hall and Penfound 1943
tupelo/cypress	1588	55.0	White 1983
tupelo/cypress	3558	46.6	Hall and Penfound 1939a
tupelo/cypress	1120	59.2	Leitman et al. 1983
tupelo/cypress	900	46.0	Megonigal et al. 1997
cypress	1644	32.5	Brown 1981
cypress	856	80.2	Duever et al. 1984a
cypress	1560	59.3	Dabel and Day 1977
cypress	—	138.1	Marks and Harcombe 1981
cypress	2186	80.4	Schlesinger 1976
cypress	272	52.3	Schmelz and Lindsey 1965
cypress	530	26.6	Megonigal et al. 1997
cypress/tupelo	372-535	33.7–41.9	Robertson et al. 1978
cypress/tupelo	325–449	55.5-62.7	Anderson and White 1970
cypress/tupelo	1235	56.2	Conner and Day 1976
cypress/tupelo	930	54.5	Megonigal et al. 1997
cypress/tupelo	560	46.7	ibid

up healthy sprouts. Although many stumps sprout during the first growing season after logging, few of these sprouts survive in either baldcypress (Prenger 1985, Conner et al. 1986) or water tupelo (DeBell 1971, Kennedy 1982), although results from a study in the Mobile-Tensaw delta disagree (Goelz et al. 1993).

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) and natural regeneration (Hamilton 1984, Gunderson 1984, Conner et al. 1986), planting of seedlings in these flooded environments may be necessary to ensure regeneration success (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 baldcypress. Rathbome Lumber Company planted nearly 1 million baldcypress seedlings on cutover land in Louisiana. Ninety percent of the seedlings planted in 1949 and 1950 survived into 1951 and grew 30 to 46 cm (12 to 18 in) in height by the end of the 1950 growing season. An additional 141,000 seedlings were planted in early 1951, with

80 to 95 percent survival (Rathbome 1951). In another Louisiana project, 8,500 seedlings were planted during January to March 1951 in water 15 to 50 cm (6 to 20 in) deep. In April 1951, nearly 95% of them were growing vigorously and had increased in height by an average of 7.5 cm (3 in) (Peters and Holcombe 1951). Unfortunately, both projects were abandoned and no further records maintained.

Planting of one-year-old baldcypress seedlings at least 1 m (3.3 ft) tall and larger than 1.25 cm (0.5 in) at the root collar improves early survival and growth (Faulkner et al. 1985). Planting is recommended in the late fall and winter so that seedlings become established during low water periods (Mattoon 1915). A 2.4 X 2.4 m (8 × 8 ft) 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 (8-12 in) per year for baldcypress when there are no herbivory problems (Conner 1988, Conner and Flynn 1989). A simple planting technique has been successfully tested for planting seedlings in standing water areas (Conner and Flynn 1989, Conner 1995, Funderburk 1995, McLeod et al. 1996). Root pruning, or trimming off the lateral roots and cutting the taproot to approximately 20 cm (8 in), allows the planter to grasp the seedling at the root collar and push it into the sediment until his hand hits the sediment. This method has worked well in trials with baldcypress and water tupelo, but not as well with green ash and swamp tupelo.

While data are limited, it appears that plantation-grown baldcypress grow better than natural stands and may even grow better than hardwood species (Krinard and Johnson 1987). Planted baldcypress grew more than 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 baldcypress trees up to 21 m (69 ft) tall at age 41 years (Williston et al. 1980). Another Mississippi baldcypress plantation contained trees 21.6 m (71 ft) tall and 36 cm (14 in) in diameter after 31 years (Krinard and Johnson 1987). In comparison, Mattoon (1915) reported height growth of 13-16 m (43-52 ft) by age 40 years for naturally established second-growth baldcypress in Maryland and Louisiana.

Cypress tends to grow well at high densities (Wilhite and Toliver 1990), but there is some evidence that thinning may enhance diameter growth in baldcypress. Data for pondcypress are conflicting (Terwilliger and Ewel 1986, Ewel and Davis 1992), but 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, Toliver et al. 1987, Dicke and Toliver 1988). Thinning to that level, however, may produce an abundance of epicormic branches (increase from <1% of trees in untbinned stand to 28% in thinned stand) which may lower future timber value. 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) found that thinning intensity had no significant effect on diameter and height growth. Defoliation of trees in the latter study by the forest tent caterpillar *(Mulacosoma disstria)* may explain 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, Conner et al. 1981).

The most commonly used regeneration method in deepwater swamps is usually clearcutting (Stubbs 1973, McKnight and Johnson 1975). In shallow swamps less than 1 m (3 ft) deep, bombadiers and wide-tracked tractors can be used. In deeper swamps, pullboats or some type of floatation logging may be required. Logging with helicopters has had some acceptance although it can be very costly (Jackson and Morris 1986, Willingham 1989, DeCosmo et al. 1990). One study in Louisiana investigated the use of hot air balloons to extract timber from the Atchafalaya Basin, but this method has not gained acceptance (Trewolla and McDermid 1969).

In an intensive study in Alabama, changes to a water tupelo/baldcypress site caused by helicopter vs. rubber-tired skidder clearcut logging operations were investigated. During the first two years following logging, vegetative growth was best in the helicopter logged area (Mader 1990). Seven years following treatment, average densities, total heights, diameters, and aboveground biomass of the skidder treatment was equal to or greater than in the helicopter treatment area (Aust et al. 1997). An important factor affecting results is that both treatments were conducted in areas with rapid natural reproduction and where no major changes 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 1985b, Conner et al. 1986).

Where Atlantic white-cedar is managed using natural regeneration, the guidelines developed by Little (1950) are still appropriate; i.e., manage in even-aged stands harvested by clearcutting, reduce slash, and control competing species and deer browse. The successful application of these simple guidelines is dependent upon many factors including hydrology and the availability of a suitable seed source. Yield tables for natural stands of Atlantic white-cedar were produced by Korstian and Brush (1931), with no significant improvements made to date. Attempts to develop ***nursery*** methods for Atlantic white-cedar seedlings have met with limited success, due in part to the large variability in seedling size. Techniques for rooting Atlantic white-cedar cuttings are becoming more widely used to produce a consistently uniform and healthy plant for regeneration purposes (Crutchfield, pers. comm., Hughes, pers. comm., and C. G. Williams, pers. comm.). Rooted cuttings are being used to examine the relationships between tree and stand development and density, and the growth and dynamics of Atlantic white-cedar stands created and maintained with intensive silviculture methods similar to those used for loblolly pine (Buford et al. 1991, Phillips et al. 1993). Conclusive results are not yet available from these studies.

The first consideration in choosing from the numerous silvicultural and management options available is determining clearly: 1) the objective to be achieved and 2) the existing land and forest condition. The objective may be as simple as maximizing one particular output (e.g., timber) or as complex as optimizing for a suite of objectives (e.g., songbird habitat, timber production, and wastewater application).

The desired objective, or condition, can often be described in terms of species composition and tree size distribution. These are determined by many factors such as monetary goals, habitat requirements for specific faunal species, nutrient uptake capability, and owner preference, singly or in combination.

As stated earlier, the silvical characteristics of the deepwater swamp species indicate that they should be managed in an even-aged system. If an uneven-aged condition is desired, it must be maintained by clearcutting groups of at least 1.2-2 ha (3-5 acres) in size to ensure appropriate light conditions for the regenerating stand (Williston et al. 1980, Toliver and Jackson 1989). The desire to maintain the uneven-aged forest condition must be weighed against potential impacts of the multiple entries required to maintain the condition (Toliver and Jackson 1989). Clearcutting with subsequent control of competing vegetation, coupled with planting or reliance on natural regeneration, is the preferred reproduction method for deepwater swamp species. Where a reliable seed source is not available, planting is the preferred method for both baldcypress and Atlantic white-cedar (Williston et al. 1980, Phillips et al. 1993). Results with coppice and planting water tupelo have been conflicting, and the optimum method for consistently regenerating this species without reliance on natural seed or direct seeding is currently unclear (Hook et al. 1967, Kennedy 1982). The control of competing vegetation that is crucial to regeneration success of deepwater species can be achieved through mechanical, chemical, or hydrologic means.

The hydrologic regime necessary to regenerate and maintain the stand must exist on the site. If the hydrologic regime has been significantly altered through impoundment, dredging or soil loss, for example, then it must be controllable to create conditions fostering regeneration, establishment, and growth of the desired species. This is crucial when restoration or creation of a deepwater habitat is necessary. Drayton and Hook (1989) gave a detailed description of a project designed to create a water management system to restore the hydroperiods of a baldcypress-water tupelo swamp. The objective of the project was to favor regeneration and growth of the deepwater species, thereby enhancing the habitat values associated with the forest type and to control the water level to facilitate access at harvest. Restoring or constructing the necessary infrastructure to control the hydrologic regime of a site can involve obtaining the appropriate permits under Section 404 of the Clean Water Act. Any project that involves construction or alteration of the site hydrologic regime may require federal, state, and/or local permits.

Each project will require access, usually a road system used for tending and extraction and for owner and tenant access. Road construction for silvicultural purposes in jurisdictional wetlands does not require a permit. However, to qualify, the road system must comply with the Best Management Practices (BMPs) outlined in Section 404 of the Clean Water Act. The primary factors governing road construction are protecting water quality, wildlife habitat, and the hydrologic regime of areas traversed. All southern states have established BMP guidelines which should be followed in developing access systems for deepwater swamps

RESEARCH NEEDS

Even though data exist on the biota and productivity of deepwater swamps, many aspects of their ecology and management are still poorly understood. Some basic management principles have been devised for these wetlands, but we must improve our long-term predictive capabilities and knowledge of the fine structure of these systems in order to produce a realistic, flexible, and permanent framework for planning and management (Livingston and Loucks 1979). Major areas of research identified in the late 1970s and 1980s, including hydrology, biogeochemistry, effects of perturbations, biological productivity, spatial patterns, and coupling with other ecosystems (Clark and Benforado 1981, Gosselink et al. 1990), require further attention to allow us to accurately forecast long-term management consequences. In addition, new needs have recently arisen as researchers and managers have attempted to determine the functions and values of these wetlands, the factors contributing to their loss, and appropriate techniques for creating and restoring these wetlands (Mitsch and Gosselink 1993).

Hydrology is one of the most important driving forces in forested wetlands, and the length, depth, and timing of flooding determines the diversity and productivity of these systems. Changes in normal hydrology patterns due to stream channelization or construction of roads, canals,) levees, or dams affect the establishment and growth of forest species (Conner et al. 1981, Sharitz et al. 1990). Even species adapted to flooding are severely impacted by increased flooding (Harms et al. 1980, Megonigal et al. 1997). The long-term impacts of changes in hydrology should be a major area of research.

Another aspect of hydrology that needs consideration, especially in coastal areas, is eustatic sea level rise (Gornitz et al. 1982) and subsidence (Gosselink 1984). Recent projections by the Environmental Protection Agency suggest that there will be a rise of 30 cm (12 in) by the year 2100. Penland and Ramsey (1990) have shown that there is already a significant increase in water level along the entire Louisiana coast primarily due to subsidence. Flood control levees along the Mississippi and Atchafalaya Rivers prevent the flooding of these wetlands by sediment-laden waters, and subsidence generally exceeds sedimentation in many areas. Most of coastal Louisiana is presently experiencing an apparent water level rise of about 1 m (3 ft)/century (Salinas et al. 1986), impacting forested wetland species composition and growth (Conner and Day 1988, Conner and Brody 1989). More data are needed on stand level responses to refine forest growth models to better predict the impacts of changes in these systems.

Biogeochemical cycling in deepwater swamps is difficult to study because of the complex hydrologic linkages with associated streams and adjacent uplands (see Chapter 7). Additional quantitative work on the mass flow of nutrients and carbon within these wetlands is needed (Livingston and Loucks 1979, Laderman 1989). In addition, it is important to understand the role of these wetlands in mediating the form and timing of nutrient export to downstream ecosystems and what role these exports play in maintaining secondary production levels.

Deepwater swamps are sometimes considered to be "subclimax" forests. Tree species composition remains fairly constant because few species other than baldcypress and the tupelos can tolerate extended flooding. Wetland management goals based on the concepts of this stability, however, may be highly disruptive to the productivity of wetlands. There is growing evidence that periodic physical disruption (by man or nature) is necessary to maintain continued high productivity and species composition in these wetlands and associated systems (Livingston and Loucks 1979), and many of these coastal forests have developed through time as a result of this disturbance (Little 1950, Frost 1987, Conner et al. 1989). In the case of Atlantic white-cedar, we must understand the intricate balance among fire, hydrologic regime, inter-species competition, and stand establishment and growth.

Nutria herbivory is a growing problem in Gulf coastal deepwater swamps. Although nutria are a recent import from South America, they have made a distinct impression on Louisiana wetlands. During the 1950s, the Soil Conservation Service recommended that planting of baldcypress be suspended until some means of nutria control were developed (Blair and Langlinais 1960). The problem has not been solved (Conner 1988, Brantley and Platt 1992), and nutria have been reported to damage even mature trees (Hesse et al. 1996). Animal control or seedling protection must be developed if successful regeneration of forest species is expected in cutover swamps.

Long-term, multidisciplinary studies must be conducted on representative plants and animals as well as whole communities if development of reliable management regimes is desired. These long-term studies are desirable and necessary, but often are difficult to maintain because of funding uncertainty, shifts in personnel, complexity of data analysis, and the pressure to produce frequent publications. However, only long-term research can consider both the short- and long-term fluctuations of key driving forces. In conjunction with long-term studies, we should examine processes across the entire southern United States to determine if all wetlands function similarly. Although deepwater swamps can be fairly similar in species composition across their range (Sharitz and Mitsch 1993), their response to hydrology and nutrients may vary (Mitsch et al. 1991, Keeland 1994, Megonigal et al. 1997).

There has been relatively little research on the creation and restoration of deepwater swamp forests, and techniques for evaluating the success or failure of these projects have not been developed (Sharitz and Mitsch 1993). Regeneration successes have occurred, but failures are common. Success can be improved by paying attention to hydrology and matching species to site conditions (Hodges 1997).

Deepwater swamps have been used as sites for treatment of secondarily treated wastewater in order to avoid the construction of expensive tertiary treatment plants (Brandt and Ewel 1989, Breaux and Day 1994). While the application of wastewater to swamp forests has enhanced tree growth in some areas (Nessel and Bayley 1984, Hesse 1994), this is not always the case (Kuenzler 1987). The reasons for these different responses needs to be elucidated. Other unknowns to be considered include how long these forests can assimilate additional nutrients, the impact of wastewater on animal populations, the effects on wood quality, and the impacts of timber management activities on the water quality function of the system.

Because of the nearly constant to permanent flooding of these forests, traditional timber harvesting methods do not work well. As a result, research needs to be conducted on wood extraction activities and the impacts of these activities on wetland functions and values. Because of the expansive clays found in swamps and continued sediment deposition, these sites are generally not as sensitive to harvesting perturbations as upland sites (Hodges 1997). When ground-based operations are not feasible, alternatives such as helicopters or balloons may prove beneficial, although more research is needed to determine how effective these methods are and whether or not they can be cost-effective (Jackson and Stokes 1991). Another method that may have application in deepwater swamps involves the use of water level management. By controlling water levels, harvesting can theoretically be done without significantly altering the character of the wetland and allows for natural regeneration to occur before flooding is reintroduced (Drayton and Hook 1989). The long-term impacts of this type of management needs study.

SUMMARY

Southern deepwater swamps are freshwater systems characterized by standing water for most or all of the year. Stands of baldcypress, pondcypress, water tupelo, swamp tupelo, and Atlantic white-cedar (either in pure stands or intermixed) occur throughout the southern United States in a wide variety of geomorphic situations ranging from broad, flat floodplains to ,isolated basins. Slight changes in elevation produce quite different hydrologic conditions, soils, and plant communities. Since many deepwater swamps are-found along the floodplains of rivers, their soils generally have ample nutrients, and these forests are highly productive. Primary productivity in these forests is closely tied to hydrologic conditions, with highest productivity occurring in forests that receive high inputs of water, sediments, and nutrients. These swamps once provided large amounts of timber and have the potential to do so again. Once thought to be useless areas, recent research has demonstrated that these wetlands perform many functions beneficial to man. Little silvicultural information is available for deepwater swamp forests, and management of these areas is generally restricted to clearcutting and natural regeneration. In order to produce a realistic, flexible, and permanent framework for planning and management of these lands, we need to better understand the impacts of logging activities, hydrologic modifications, and wastewater additions on these forests.