Chapter 9

Characterizing the Site: Environment, Associated Vegetation, and Site Potential

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Abstract

"Site," in the context of this manual, can be defined as the totality of environmental factors - physical, chemical, and biological - influencing the survival and growth of planted southern pine seedlings. However, a host of additional constraints - economic, aesthetic, and legal - also affect management practices applied to a particular site. Environmental factors can be modified in many ways to affect regeneration, subject to these "additional constraints." In the climatically and ecologically diverse southern pine region, natural site conditions have been significantly modified over time through logging of presettlement virgin forests, conversion of sites from agriculture to forestry, drainage, and fire exclusion. Managers must be aware of the opportunities and limitations imposed by site over the wide variety of forest types to efficiently improve regeneration and stand growth.

9.1 Introduction

"Site" has been defined in many ways. In this manual, it is the totality of environmental factors that directly (e.g., nutrient availability) or indirectly (e.g., topography) influences the survival and growth of planted southern pine seedlings. Such factors can be broadly grouped into the physical, chemical, and biological aspects of the seedlings' aboveground and belowground environments (Table 9.1).

Many site factors can be manipulated after harvest but before regeneration, presenting foresters with myriad possible management alternatives for increasing performance of newly planted seedlings. At one extreme, manipulation may amount to nothing at all (i.e., natural regeneration with no site preparation). At the other extreme, it may alter many or all environmental factors (e.g., through plowing, fertilizing, applying pesticides, shading).

Many potential regeneration problems can be anticipated. For example, the likelihood of severe competition from noncrop species can largely be predicted by knowing the characteristics of the preharvest vegetation and the natural successional trends expected. Other problems, such as a "100-year drought," cannot really be predicted, although probabilities can and should be assessed by examining past records. Management must be prescribed based on careful analysis of site factors likely to be most important in each case.

However, other constraints to management activities may affect prescribed site manipulation (Table 9.1). These range from a concern for aesthetics in highly visible locations, to legal prohibitions, to limited cash flow of a particular landowner or manager. Although most environmental factors can be manipulated if money and labor are not limiting, these additional constraints may sometimes be insurmountable.

In this chapter, we examine how site potential is influenced by the environment and natural vegetation of forested sites in the southern U.S. Specifically, we describe the key features of the aboveground physical and chemical environments and associated natural vegetation, including successional trends, and some important social and legal constraints on site management.

9.2 Environment of the Southern Pine Region

9.2.1 Macroclimate

9.2.1.1 Weather patterns

The climate of the southern pine region is heavily influenced summer and winter by a warm surrounding ocean (and gulf), with the greatest effects farther south and nearer the coast. The 25° to 35° latitude belt worldwide is dominated by high pressure at the convergence of the temperate and tropical air masses and elsewhere supports many of the great deserts.

In summer, the "Bermuda High," a large semipermanent high-pressure system off the southeast coast, circulates mild breezes clockwise into the region, deflecting or blunting the effects of fronts moving in from the northwest.

M.L.Duryea & P.M. Dougherty (eds), Forest Regeneration Manual, pp. 163-182.

Table 9.1. Environmental factors and other constraints that can influence survival and growth of planted southern pine seedlings.

Factor[1] or constraint	Description or comment
Physical factors	
Aboveground	Direct: air temperature, relative humidity, solar radiation, wind speed and direction, fire
	Indirect: topography (convex vs. concave, degree of slope, aspect), slope position (ridge, bottom, flat)
Belowground	Surface properties (hydrophiticity, etc.), soil moisture availability, soil structure and texture, temperature, water-table depth, presence of impediments (rocks, discontinuities), aeration
Chemical factors	
Aboveground	Precipitation (wetfall) chemistry, dry air quality, pesticides
Belowground	Availability and balance of essential elements, accumulation of toxic substances, amount and quality of soil organic matter
Biological factors	Vegetation, soil microorganisms, insects and animals present or potentially present (may, in all cases, be positive, negative, or neutral factors)
Other potential constraints	
Presence of rare or endangered species	
Off-site impacts	Altered quantity and quality of runoff, increased sediment loading to streams through erosion, pesticide drift
Effects on wildlife on and near the site	Disruption of migration routes or foraging areas
Aesthetics	
Economics	
Other social concerns	Local community relations, hunting leases

[1] Variations and extremes in environmental factors are often of more interest than average conditions.

These breezes supply warm, moist air to the atmosphere which interacts with the hot land surface to generate regular afternoon convectional thunderstorms. Lightning from these storms was largely responsible for the frequent, low-intensity fires that historically swept the natural Coastal Plain and Piedmont forests.

In winter, the Bermuda High weakens, and fronts regularly penetrate as far as south Georgia or north Florida before they encounter warmer, more stable subtropical air masses. Spring and fall are transitional, their durations highly variable, and their weather patterns mild.

9.2.1.2 Temperature and precipitation patterns

Excellent long-term data on local and regional patterns of temperature and precipitation are available from over 5,000 weather stations in the continental U.S. that cooperate with the National Oceanic and Atmospheric Administration (NOAA), Environmental Data Center (EDC), whose national offices are in Asheville, North Carolina. These data can be obtained directly from NOAA or from the major libraries in each state.

The normal frost-free line in the South arcs across north Florida, dividing the state into subtropical and warm-temperate sections, and is demarcated at both coasts by the absence of mangrove (*Rhizophora* L. spp.) to the north. Virtually the rest of the southern pine region is classified as warm-temperate [57], with the incidence of freezing increasing inland and to the north (temperate). Mean annual air temperatures increase and seasonal variations decrease to the south. For example, the average number of days per year with air temperatures $< 0°C$ in Raleigh, North Carolina and Gainesville, Florida, is 88 and 12; in contrast, the average number of days per year $> 30°C$ is 28 and 85 at the same two locations. The average number of days from the last winter frost to the first fall frost is 237 for Raleigh and 295 for Gainesville [38].

Regional patterns for annual precipitation in the South are shown in Figure 9.1. Average annual precipitation generally exceeds 1,000 mm/year, ranging upward to 1,300+ mm/year along the coast and over 1,800 mm/year in some parts of the Appalachian Mountains. The driest area is in eastern Texas, where annual precipitation decreases to the south, although total amounts over the region generally decrease to the north and west. Corpus Christi, Texas, receives only 671 mm/year, whereas Tampa and Daytona Beach, at the same latitude, receive almost twice as much, highlighting the influence of the smaller land mass of peninsular Florida.

In the more inland parts, precipitation is more bimodal — summers generally receive less than spring and fall. Closer to the Gulf and Atlantic coasts, summers become the major period for rainfall, primarily in the form of local convective afternoon thunderstorms. Knoxville, Tennessee, and Cataloochee, North Carolina, are both influenced by the orographic effects of the nearby Appalachian Mountains, with abundant rainfall and little seasonal variation.

Although the frost line reaches into Florida, the South as a whole receives very little snow (Fig. 9.2a). Freezing weather is primarily a result of the penetration of dry, cold air masses from the north and high radiative cooling in the absence of cloud cover. Snow increases to the north and inland, reaching its regional maximum in the Appalachians. Glaze (frozen rain) likewise is uncommon (Fig. 9.2b).

Figure 9.1. Mean annual precipitation (mm) for the southern U.S. Based on long-term measurements from NOAA, and redrawn from Nelson and Zillgitt [41].

However, north of a line from Myrtle Beach, South Carolina, to Baton Rouge, Louisiana, severe ice storms occur regularly enough that damage to forests is an important consideration. Ice damage in pine stands throughout the Piedmont is fairly common, and was an important historical factor in limiting the natural ranges of longer needle pines.

9.2.1.3 Water available to plants

Amounts of water available to plants at various locations are not well represented by annual, or even seasonal, precipitation. First-order estimates of the relative wetness of a site can better be obtained with some sort of site water balance — for example, the difference between precipitation and evaporation (evaporation from a standard open pan is the most common measure and that which is recorded by NOAA stations). Unfortunately, < 5% of the NOAA stations measure evaporation, most records are for < 15 years and are spotty, and winter values are generally absent. This lack of data makes generating regional patterns difficult and uncertain.

Because evaporation is a function primarily of temperature and secondarily of relative humidity, it can reasonably be modeled with standard NOAA precipitation and temperature data, on the basis of some assumptions. For example, Thornthwaite et al. [511 used monthly NOAA data and a simple model to construct a map of potential evapotranspiration (PET) over the southern U.S., approximating the amount of water that could be used by a solid cover of vegetation with an unlimited supply of water to plant roots (Fig. 9.3). This figure clearly shows the combined effects of temperature and precipitation. The difference between these values and precipitation (see Fig. 9.1) — computed annual PET ranges from 50 to 90% of annual precipitation — indicates areas where water is relatively more or less abundant.

However, growing seasons vary so much that seasonal or shorter periods better reflect water availability for tree growth at specific sites. Using data from NOAA for 1977-86, the period with the most complete records, we have assembled monthly water balances (difference between precipitation and open-pan evaporation) for 16 representative locations in the South (dashed lines, Fig. 9.4). The integral of the area between zero and the water-balance curve when it is negative is a measure of the extent that water demand exceeds rainfall input. Because in almost all

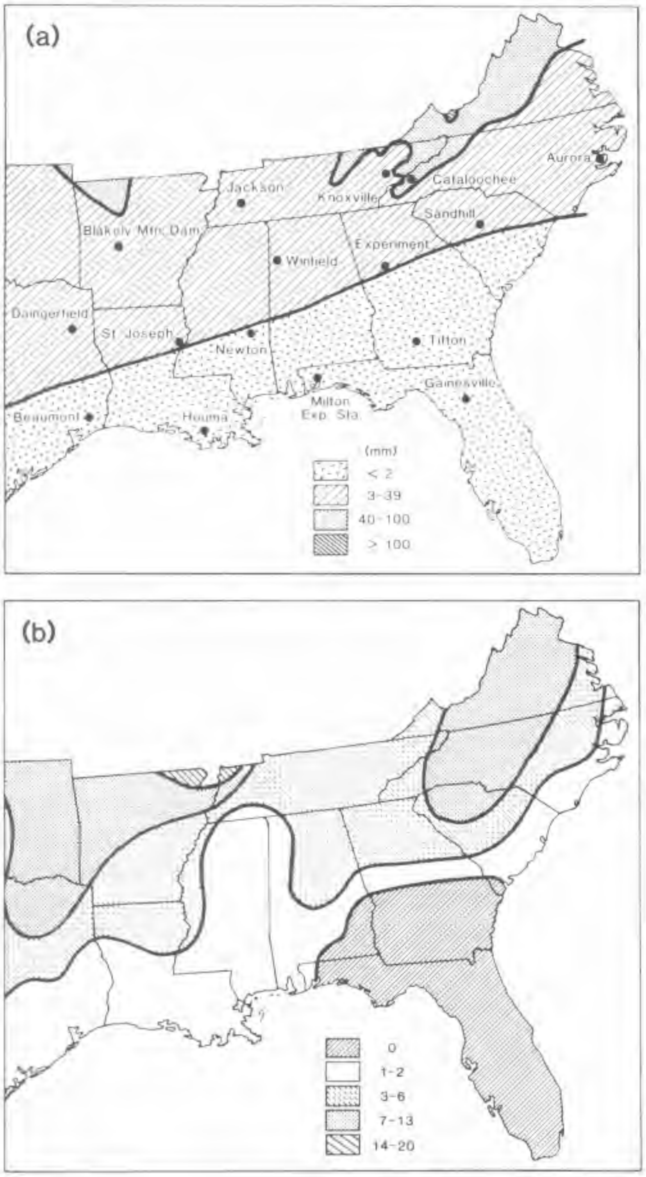

Figure 9.2. (a) Annual snowfall for the southeast U.S. Snowfall increases further north and inland, with maxima in the Appalachian Mountains (adapted from [15]). (b) Total number of glaze (frozen rain) storms between 1925 and 1953 (adapted from [53]). Note that freezes are common into central Florida, but occur under clear skies not conducive to ice formation.

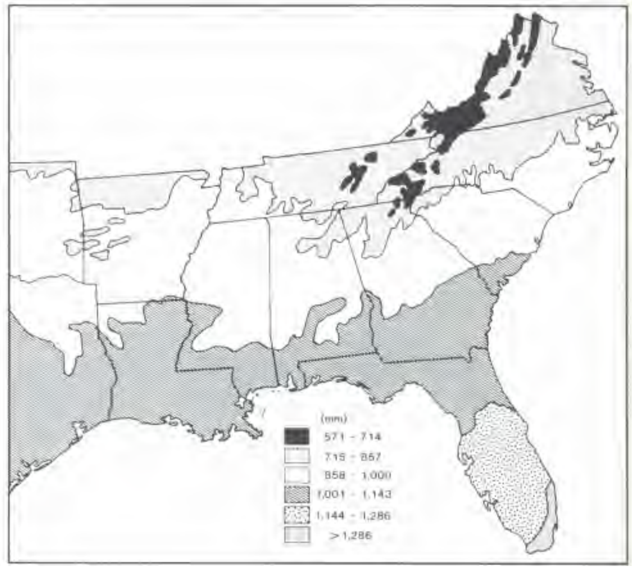

Figure 9.3. Mean annual potential evapotranspiration (PET) for the southern U.S. (after [51], and redrawn from [41]). Seasonal water deficits are more likely where PET is closer to mean annual precipitation (see Fig. 9.1).

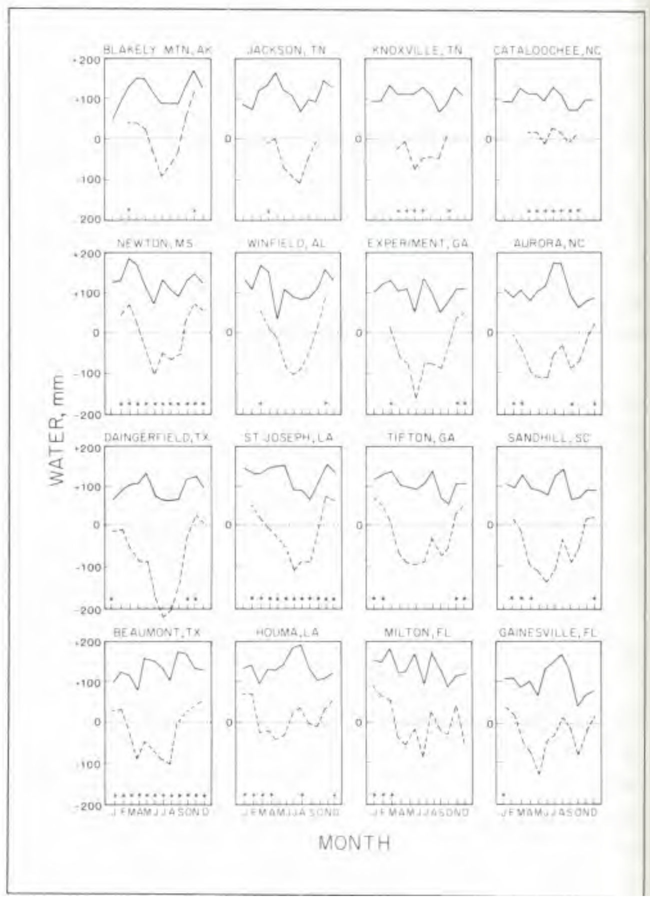

Figure 9.4. Monthly precipitation averages (solid lines) and water balances (dashed lines) for 1977-86 for representative sites in the southern U.S. (see Fig. 9.2a for site locations). Water balances were calculated as the difference between precipitation and open-pan evaporation for the same period (month). Data are from annual climatological summaries published for each state by NOAA. Asterisks indicate months for which data were available for < 10 years.

areas the soil is completely recharged over winter, a part of this deficit in water supply may be offset by soil-water storage. Even where soil storage can offset rainfall deficits, however, growth can still be reduced by high evaporative demand.

In most years, precipitation exceeds evapotranspiration in winter and late summer and fall, but spring and summer water deficits are frequent and often severe, occurring earlier to the south (Fig. 9.4). Summer droughts are most pronounced inland. Though fall can also be dry, temperatures are usually cooler, dry periods shorter, and plant growth and development generally not much affected.

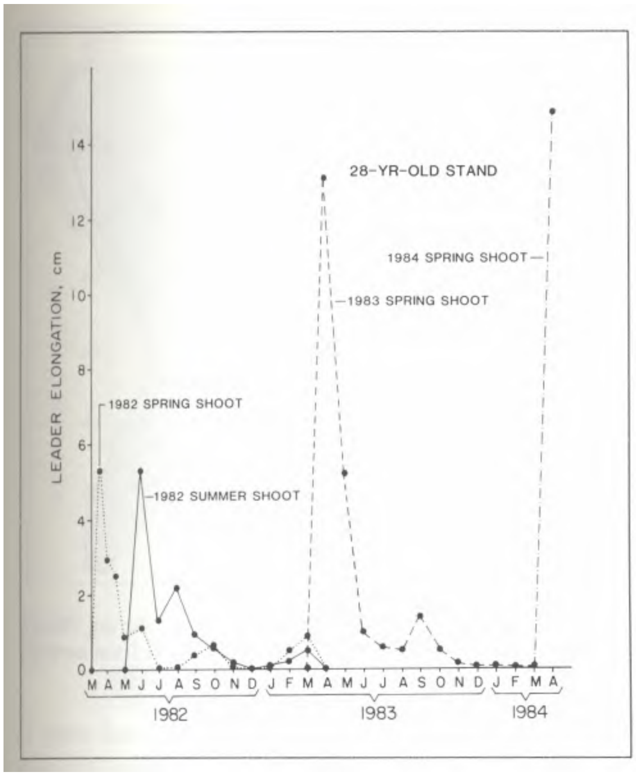

Figure 9.5. Leaders of mature slash pine trees in north Florida have largely elongated by midsummer, although some growth continues into fall (adapted from [24]). Here, 1980 and 1981 were dry years whereas 1982 and 1983 were wetter than normal. Needle and lateral growth followed patterns similar to those of leaders.

It should be noted that the patterns in Figures 9.1 through 9.4 are based on long-term averages and indicate expected environmental conditions for forest sites in the South. Local geographic variation has little impact on average conditions except in the mountains, where elevation and orographic influences have major effects, or near the coast, where fluctuations are damped compared to areas only 10 to 20 km inland. However, these average patterns may mask considerable annual variations. Particularly strong or long-duration northern fronts penetrate into the region in winter, major tropical storms can be frequent visitors spring through fall, and thunderstorms can be fast-moving and spotty in summer. In making management decisions about species selection, family allocation, and stand densities, foresters must consider the extremes and their frequencies of occurrence, along with the average trends.

9.2.2 Important Deviations from Average Conditions

9.2.2.1 Droughts

Annual precipitation varies dramatically from year to year as illustrated by 30 years of records for a single location, Gainesville, Florida (Table 9.2; [39]). Years with 1,075 mm precipitation (one standard deviation below average for the 38 years) are surprisingly frequent, about 1 in every 5. As previously mentioned (see 9.2.1.3), droughts occur primarily in late spring and early summer in this area. This is a major concern because spring is normally low in precipitation. Severe spring droughts recur about once every 15 years throughout the region; a recent analysis by Biasing et al. [5] indicates a 15- to 25-year frequency for severe droughts in the south-central U.S. since 1750. As surfaces dry, maximum temperatures often rise to values well above average. Indeed, this positive feedback may be responsible for the fact that a drought is often associated with an adjacent year that is drier than average (e.g., 1954-55, 1980-81, in Table 9.2), intensifying impacts.

Dry periods after March can have major effects on tree growth and development because April, May, and June constitute the normal growth period for height and lateral twigs (Fig. 9.5). Diameter growth over much of the inland South is halted by early July [4, 34] in droughty years, partly because of low soil moisture but also because of high evaporative demand from the higher than average temperatures normally associated with drought years.

9.2.2.2 Temperature extremes

Both extreme high and low temperatures concern farmers and foresters because both can cause significant damage. However, "extreme" is a relative term, often depending more on timing and other prevailing conditions than on absolute temperature.

High temperatures accompanied by dry, clear conditions early in the growing season, or very cold temperatures earlier than usual in fall, are of primary concern in regeneration. Indirectly, persistent high temperatures associated with droughts are a major problem for seedlings, which depend on *in situ* carbon production. In this case,

Table 9.2. Annual precipitation for Gainesville, Florida, 1948-86 (from annual NOAA data). Mean annual precipitation over this period (38 records) is 1,348 mm; one standard deviation is 273 mm.

Year	Annual precipitation, mm	Year	Annual precipitation, mm
1948	1,485	1968	1,266
49	1,605	69	1,360
50	1,187	70	1,538
51	1,422	71	1,279
52	1,070	72	1,722
53	1,862	73	1,285
54	895	74	1,283
55	1,085	75	1,814
56	1,219	76	1,222
57	1,477	77	852
58	1,520	78	1,250
59	1,553	79	1,519
60	N/A	80	1,056
61	1,213	81	895
62	1,226	82	1,553
63	947	83	1,660
64	1,955	84	997
65	1,626	85	1,226
66	1,389	86	1,329
67	1,335		

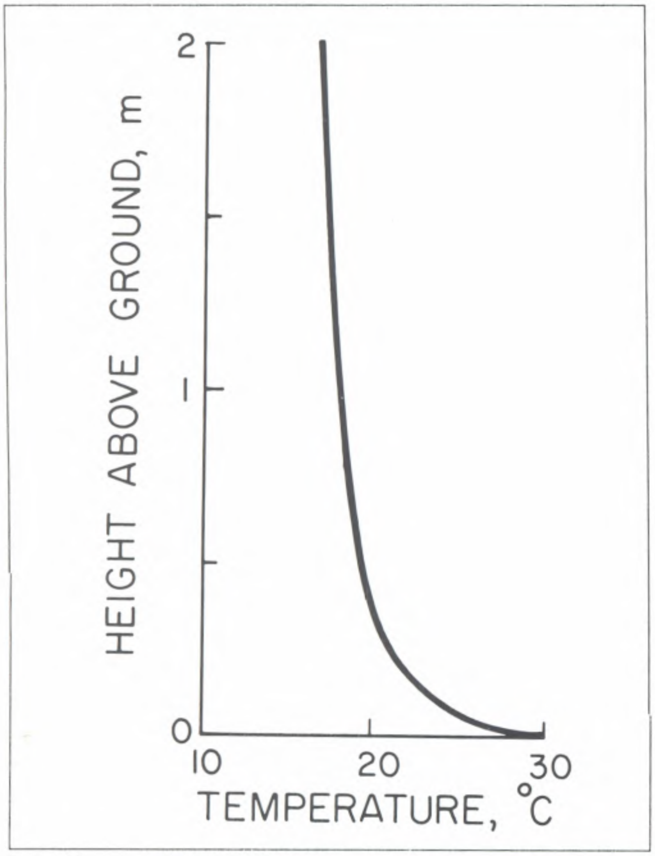

Figure 9.6. Air-temperature profile above a dry soil in early summer, north Florida [unpubl. data, 19]. Note that temperatures at the ground surface can be quite elevated over temperatures a few centimeters above the surface. Most climate data are collected in shaded shelters elevated about 1.5 m above the ground.

respiration is accelerated at a time when assimilation is limited by water stress. The main direct effect of high temperatures is damage to the cambium low on the stem where temperature extremes are exacerbated by radiation reflected from the ground surface (Fig. 9.6). At the other extreme, freezing can rupture cells and cause plant tissues to die.

Other indirect effects of temperature extremes include damage from ice or snow loads and desiccation. Desiccation in spring is usually due to poorly developed root systems and inadequate root-soil contact of the newly planted seedlings. Desiccation can also occur under dry winter conditions because cold soils decrease root permeability and increase the viscosity of soil water [30]. Species from warmer environments seem generally more sensitive than those adapted to colder environments, with both loblolly *(Pinus taeda* L.) and slash *(Pinus elliottii* Engelm.) pine seedlings being ranked as relatively sensitive [29].

9.2.2.3 Hurricanes and tornadoes

Interestingly, the frequency of hurricanes (> 119 kph winds) that have hit the southern coastline is almost equal to the frequency of major droughts, about one every 15 years (one every 10 years on the Gulf Coast and one every 20 years on the Atlantic Coast). The frequency of landfalling tropical cyclones (> 63 but < 119 kph winds) is about one every 7 years for areas on the Gulf Coast and Florida, and one every 10 years for the rest of the eastern seaboard [38]. In addition to intense rainfall and flooding, high winds have the most impact, especially on older stands. However, strong winds across beds can uproot 3- to 5-year-old trees because their crowns create substantial resistance while their root systems are still not fully developed.

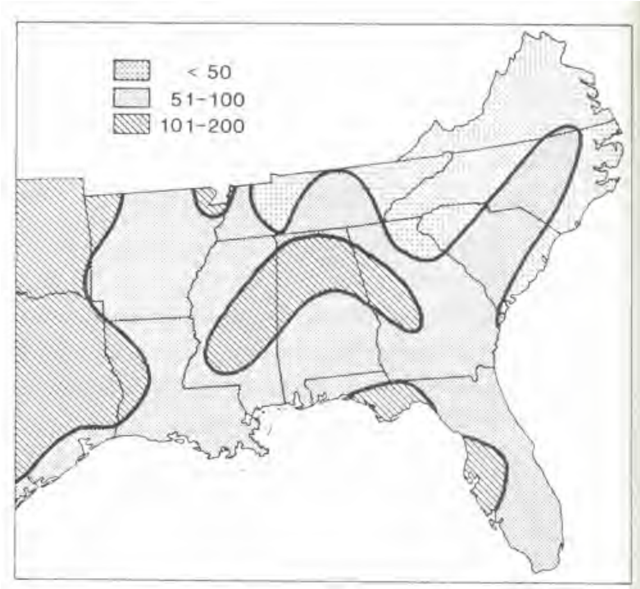

Figure 9.7. Tornado activity in the Southeast during 1955-67. Most tornadoes in the U.S. tend to concentrate from northern Texas into northern Missouri (adapted from [15]).

Tornadoes are often spawned by hurricanes along the coasts, whereas they primarily result from the clash of major continental air masses to the northwest. These storms are highly erratic and can be locally destructive. Tornado frequency is spotty over the Southeast, but there are definite locations with higher incidence (Fig. 9.7), including the Tampa and Tallahassee areas of Florida, central Mississippi through northern Alabama, the Atlantic coast north of Georgia, and the Appalachian Mountains.

Strong winds do not seem to be considered in the design of most plantation stand layouts in the South, and few research results from which to develop such guidelines are available. However, considerable information and silvicultural recommendations may be drawn from the radiata pine *(Pinus radiata* D. Don) growing regions in New Zealand (e.g., [50]).

9.2.2.4 Air pollution

The southern U.S. is characterized by relatively pollution-free atmospheric conditions, except in some local urban areas, although there is also evidence that forest sites in the southern Appalachian Mountains are being subject to air pollution severe enough to affect growth [47].

Ozone and sulfur oxides seem to have the greatest

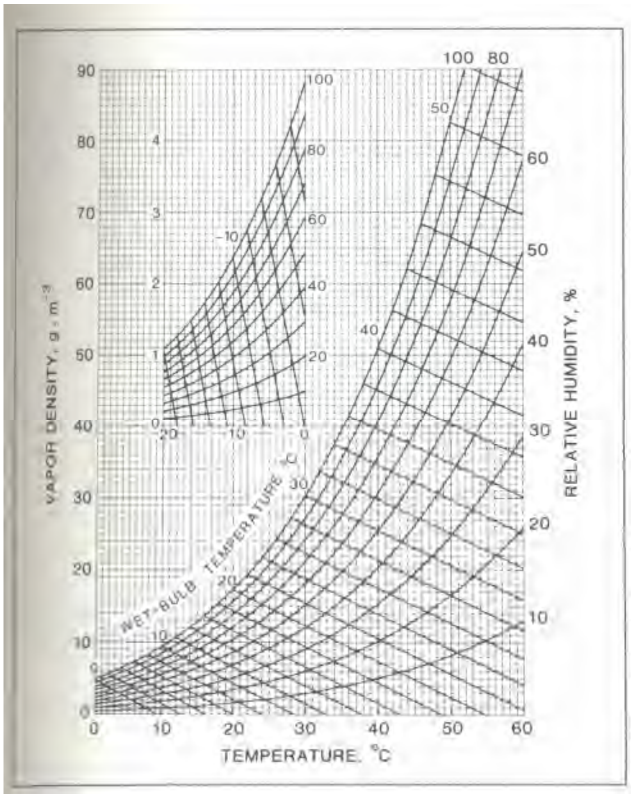

Figure 9.8. The relationship at sea level of vapor density to temperature is exponential both above and below (inset) 0°C (adapted from [81). Diagonal lines are used with psychrometric (wet bulb/dry bulb) data. With this figure, data for vapor density, air temperature, relative humidity, dewpoint temperature, and wet-bulb temperature can be related to one another. Vapor pressure can be computed from vapor density and air temperature (see [8]).

potential as regional pollutants and tree growth in the Piedmont, and the Appalachians may already be impacted. A series of ongoing studies, coordinated by the Southern Commercial Forest Research Cooperative through the U.S.D.A. Forest Service [9], is determining the sensitivity of a range of southern pine genotypes to simulated "acid rain" and ozone exposure. In 3 to 5 years, more resistant families should be identified for outplanting in more polluted areas. A concomitant study in regional ambient air quality [1] should provide the best data yet for assessing pollution levels in forested areas of the Southeast.

Although it remains a highly debated subject, there is no question that air-pollution effects, in conjunction with climate change induced by carbon dioxide and other "greenhouse" gases, must be a primary concern for forest managers and researchers now and into the future. To maintain site productivity, it may be necessary to select genotypes most resistant to the pollutant of greatest concern.

9.2.3 Microclimate

In addition to fluctuations in annual climate, seedling growth depends on specific local environmental conditions. With little internal buffering capacity, seedlings are particularly vulnerable to short-term changes in their

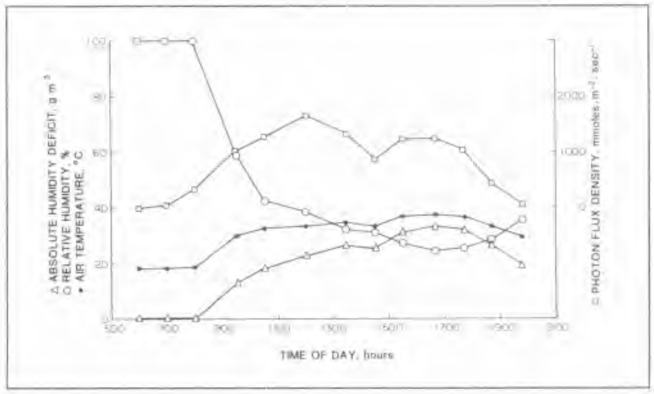

Figure 9.9. Microclimate of the canopy of a 21-year-old slash pine plantation in early summer (June 10, 1987), north Florida [unpubl. data, 19]. The day was clear, except for brief clouds around 1430.

environment. If severe enough, even a few hours of certain conditions can be damaging or fatal, particularly immediately following outplanting.

In the South, most of the environmental stresses on seedlings relate to water — nutrients are relatively abundant after site preparation unless competition is severe. The one exception is on poorly to very poorly drained soils where the presence of a water table may limit nitrogen and phosphorus availability and uptake. Water stress can result from low available soil water, high atmospheric water-vapor deficits, or soil and seedling conditions that limit root development or activity. In much of the Lower Coastal Plain and on some flooded soils throughout the pine range,

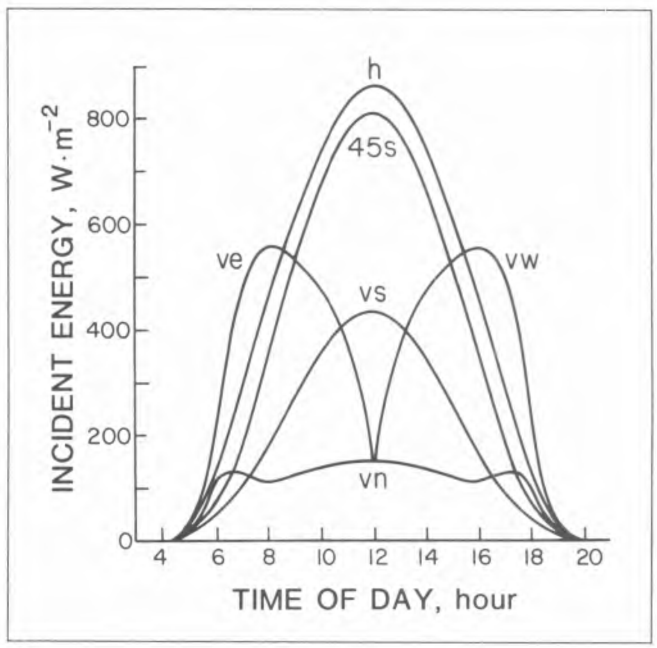

Figure 9.10. Incident irradiation of various slopes and aspects at 40° north latitude on June 22 with an atmospheric transmittance of 0.6 and a ground reflectance of 0.2. Subscripts: h = horizontal, vn = vertical north-facing, vs = vertical south-facing, ye = vertical east-facing, vw = vertical west-facing, 45s = 45° south-facing (adapted from [17]).

too much water can be as much a problem as too little.

Simple water balances, as illustrated previously (see 9.2.1.3), which integrate the effects of rainfall, evapotranspiration, and soil-water storage, can be used to characterize site water conditions. However, many more sophisticated measurements can be made or indexes constructed [18]. The most complex consist of computer simulations of actual water use by trees. The key variable in all cases, however, is the relative dryness of the atmosphere, which drives the evapotranspiration process and can also directly affect stomatal conductance [20]. Atmospheric water "vapor deficits" occur when the air is less than saturated by water vapor (the condition of 100% relative humidity). The absolute amount of water that can be held at saturation in a volume of air increases exponentially with temperature (Fig. 9.8). As relative humidity decreases below 100%, a vapor deficit occurs. Because of the exponential nature of the relationship, as temperatures increase the same drop in humidity creates an increasingly larger deficit. For example, a drop from 100 to 80% relative humidity at 10°C induces a deficit of 2 g/m^3, whereas the same humidity drop at 40°C induces a deficit of 10 g/m^3 (Fig. 9.8). At 30°C, a relative humidity of 20% creates a 25 g/m^3 deficit, sufficient to drive the evapotranspiration process at a maximum. If soil water is not sufficiently available or newly planted seedlings have not established good root-soil contact, water transport from the roots to the stomata will not be fast enough to meet this demand, and an internal water stress will develop.

Even though we think of the South as "humid" in summer, large atmospheric vapor deficits are common. Because evaporation of water from within the soil is very slow, the air can drop from saturated at dawn to 20% relative humidity in a short time on a sunny summer day, and absolute humidity deficits can exceed 35 g/m^3 (Fig. 9.9). Moveover, the situation is exacerbated for a seedling because temperatures near the ground may be much higher than those just a few centimeters above the ground (see Fig. 9.6). Where soil is dry, this can greatly increase vapor deficits and thus seedling water stress.

Topography can also have a large influence on the temperature regimes that seedlings experience through the combined effects of slope and aspect on the amount of solar radiation received (Fig. 9.10). The influences of topography on incoming radiation (under cloud-free conditions) can actually be predicted with straightforward models for any hour by knowing the latitude, slope, and aspect of a given site (e.g., [16]). In the Northern Hemisphere, south- and southwest-facing slopes reach higher temperatures than north- and northeast-facing slopes; thus, seedlings planted on the former undergo more water stress. Seedlings conditioned for survival on droughty sites may need to be used on south and southwest aspects.

Effects of wind on transpiration are small. It only takes a slight breeze to break down the boundary-layer resistance to water vapor exchange around a leaf; thereafter, more wind does not lead to more transpiration. With no wind, high boundary-layer resistance can greatly slow both the movement of water vapor and thermal energy transfer (sensible heat) from a leaf, especially for broadleaves. The result of high boundary-layer resistance is increased leaf temperature and, perhaps, damage. There is an uneasy balance between transpiration sufficient to assist in cooling and to permit the concomitant and necessary influx of carbon dioxide into the leaf for photosynthesis, and the resultant loss of water and development of a damaging water stress.

Figure 9.11. Broad forest associations found within the southern pine region closely approximate the physiographic provinces shown in Figure 10.1, this volume.

The important microclimatic facets of a site that should be considered in developing a regeneration plan can be identified by examining soil topographic maps and vegetation characteristics. Vegetation associations often integrate the effects of slope, drainage, and wind patterns better than do indexes derived from physical site properties and regional climate data.

9.3 Vegetation of the Southern Pine Region

General vegetation patterns of the Southeast are strongly influenced by two major factors, the high degree of physiographic and environmental diversity in such a large forested region, and the drastic alteration of dominant Precolumbian forest communities by agricultural and forestry practices. The boundaries of the broad forest associations of the Southeast, adapted from the forest classification systems of Braun [6] and Greller [21], and illustrated in Figure 9.11, approximate the boundaries of the major physiographic provinces (see chapter 10, Fig. 10.1, this volume). Although most of the southern pine commercial range is included within the Piedmont Oak-Pine and coastal Southeastern Evergreen forest associa-

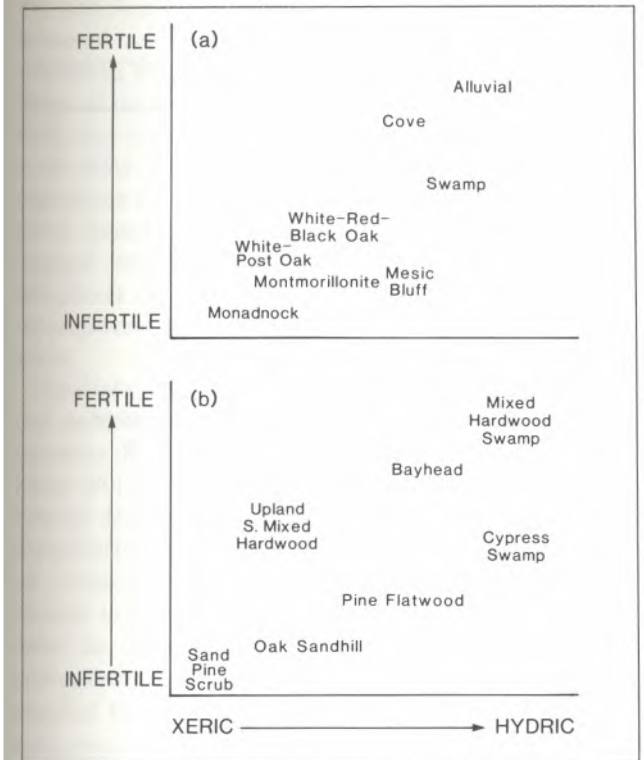

Figure 9.12. Major forest types and their relative distribution along site moisture and fertility gradients: (a) North Carolina Piedmont, Oak-Pine association (drawn from data presented in [42, 44]; (b) north-central Florida, Southeastern Evergreen association (adapted from [36]).

tions, the northern limits extend into the Mesophytic and Appalachian Oak associations, the western limits into the Oak-Hickory association of the central interior highlands.

Pine species were historically significant components of most of these forest associations, and especially dominated less fertile, frequently burned, or otherwise disturbed sites. However, agricultural and forestry activities in the region have drastically altered original forest patterns by land conversion and suppression of normal burning intervals and intensities. In some areas, this has facilitated the establishment of competing hardwood species or the replacement of one dominant pine species by another; elsewhere, the original hardwood forests have been superseded by plantations of southern pines. The magnitude of human impacts was perhaps greatest in the Oak-Pine association, where past cotton farming and land abandonment allowed early successional, naturally regenerated pine forests and pine plantations to dominate. Most of the original longleaf pine *(Pinus palustris* Mill.) forests in the Southeastern Evergreen association have been replaced by either slash or loblolly pine plantations, or by some phase of mixed hardwood forest as a result of harvesting and fire suppression.

Although Braun [6] and Kuchler [31] have examined the general distribution of vegetation within North America, and numerous studies of specific locations have been conducted (perhaps best exemplified by sites such as the north Florida Coastal Plain or North Carolina Piedmont), few studies have synthesized regional information. Accordingly, here we characterize vegetation and ecological responses of dominant species to environment and disturbance within each of the broad forest associations of the southern pine growing region. Some examples have been extracted from the relatively few intensive studies which, though somewhat site specific, effectively illustrate the dynamics of competing pine and hardwood species. Forest managers must thoroughly understand the history and distribution patterns of these associations, based upon landform and species characteristics, to (1) determine areas suitable for pine regeneration, (2) anticipate the type, intensity, and cost of controlling hardwood competition on a given site, and (3) assess potential site quality for pine growth. This rather complex indicator system should help predict relative degrees of productivity and economic returns.

9.3.1 Oak-Pine Association

This association includes the southeastern Piedmont in a broad crescent from Virginia to eastern Texas. The forests are dominated by the species which provide its name, but hardwoods historically prevailed over pines except on infertile, dry sites and on burned or otherwise disturbed, secondary successional sites. Braun [6] distinguishes this association from the southern division of the more western Oak-Hickory association by its relatively greater species diversity, including more pines and hardwood species such as yellow-poplar *(Liriodendron tulipifera* L.), sweetgum *(Liquidambar styraciflua* L.), and sourwood *[Oxydendrum arboreum* (L.) DC.].

Our most complete understanding of the forest types in the Oak-Pine association comes from studies in the North Carolina Piedmont. These diverse types range from alluvial and swamp hardwoods on the hydric extreme to varied oak forests in the uplands (Fig. 9.12a). Table 9.3 lists species composition for the nine forest types, based upon a synthesis of studies by Oosting [42] and Peet and Christensen [44]. The alluvial and swamp types share numerous species along the bottomlands, and the cove type is transitional on optimal sites to the upland oaks (white-post oak, white-red-black oak, and montmorillonite types) which occupy diverse sites with intermediate nutrient and water availability. The mesic bluff type may occur along river bluffs with unique microclimates and maintains a more northern species composition. The white-post oak and monadnock types occupy the most infertile, dry sites where species such as white *(Quercus alba* L.), chestnut *(Q. prinus* L.), and post *(0. stellata* Wangenh.) oaks mix with sourwood and hickories *(Carya* spp.). The soils underlying these latter two forest types are sandy and shallow, derived from crystalline (e.g., quartzite) and granitic parent material, respectively.

9.3.1.1 Uplands

In Georgia, Nelson [40] categorized most of the

Table 9.3. Dominant species of each forest type in the Oak-Pine association (adapted from [42, 44]).

Forest type	Scientific name
Alluvial	*Liquidambar styraciflua*
	Liriodendron tulipifera
	Platanus occidentalis
	Fraxinus pennsylvanica
	Acer rubrum
	A. negundo
	Betula nigra
	Ulmus rubra
	Fagus grandifolia
	Quercus lyrata
	Q. michauxii
	Q. falcata var. pagodaefolia
	Carya cordiformis
Swamp	*Liquidambar styraciflua*
	Liriodendron tulipifera
	Fraxinus pennsylvanica
	Ulmus rubra
	U. alata
	Quercus phellos
	Q. michauxii
	Carya cordiformis
Montmorillonite	*Ulmus alata*
	Fraxinus spp.
	Carya ovata
	Quercus phellos
	Q. stellata
	Q. marilandica
	Diospyros virginiana
	Pinus taeda
	P. echinata
Cove	*Liriodendron tulipifera*
	Fagus grandifolia
	Quercus alba
	Q. rubra
	Faxinus americana
	Cornus florida
	Cercis canadensis
	Ostrya virginiana
	Carpinus caroliniana
Mesic bluff	*Oxydendrum arboreum*
	Acer rubrum
	Fagus grandifolia
	Quercus prinus
	Q. alba
	Q. coccinea
	Vaccinium spp.
	Kalmia latifolia
	Rhododendron spp.
Monadnock	*Quercus prinus*
	Q. alba
	Q. coccinea
	Carya tomentosa
	Acer rubrum
	Oxydendrum arboreum

Table 9.3 (continued)

Forest type	Scientific name
White-red-black oak	*Quercus alba*
	Q. rubra
	Q. stellata
	Q. velutina
	Carya ovata
	C. ovalis
	C. glabra
	C. tomentosa
	Cornus florida
	Acer rubrum
	Nyssa sylvatica
	Liriodendron tulipifera
	Fraxinus americana
	Cercis canadensis
White-post oak	*Quercus stellata*
	Q. velutina
	Q. alba
	Carya ovata
	C. ovalis
	C. glabra
	Oxydendrum arboreum
	Acer rubrum
	Vaccinium spp.

Piedmont upland "red lands" soils (primarily sites with eroded Cecil, Davidson, and Lloyd soils) as originally supporting diverse oak-mixed hardwood forests, and most of the gray-sandy (sites with uneroded Cecil, Appling, and Durham soils) and granitic soils as supporting mixed pine-oak forests. These forests correspond roughly to Oosting's [42] intermediate oak, white oak, and monadnock types, respectively. An interesting difference, however, is that apparently more loblolly and shortleaf pine *(P. echinata* Mill.) were present in the xeric, infertile sites in Georgia than corresponding sites in North Carolina.

The Oak-Pine forests have been drastically altered by agricultural cycles since settlement by Europeans. In middle Georgia from 1793 to 1825, two early periods of intensive cotton cropping apparently occupied most of the Piedmont east of the Chattahoochee River. As a result, considerable amounts of topsoil were lost and soils severely eroded by gullies. Piedmont agricultural land was abandoned in three phases: (1) during the Civil War, (2) with the 1880s agricultural depression, and (3) following the introduction of the boll weevil in the 1920s [7]. Approximately 75% of this eroded agricultural land was abandoned by the 1930s and developed extensive secondary forest dominated by loblolly and shortleaf pines which have been repeatedly harvested since. In spite of intensive removal of competing hardwoods to maintain pine plantations, there has been a long-term successional trend toward hardwood dominance on private, nonindustrially owned land [40].

The relatively fertile, mesic Cecil and Davidson soils of the Piedmont "red lands" favor loblolly pine growth. However, Nelson [40] predicted that maintaining producfive pine forests on these uplands would be difficult because of ever-increasing hardwood competition and the successional tendency of these sites to return to hardwood forests. At the same time, he predicted that the sandy, less fertile, and drier sites, such as those on Appling soils, would likely be easier to maintain in their presumed original state as pine forests. These predictions have largely proven correct. Hardwood forest area has substantially increased over the past 3 decades, and intensive forest management today focuses upon mechanical and chemical site-preparation techniques to control these hardwood species.

Historically, the Indians and early settlers used fire to clear lands, opening forest understories and increasing the importance of fire-resistant tree species [10, 28]. Although Nelson [40] did not discuss fire in his soils-oriented historical description of the Georgia Piedmont, this was unquestionably an important influence upon the pine and oak composition of the region [3]. Fire suppression, practiced in earnest since the turn of the century, has shifted the composition of many forests from pine to hardwood dominance, while the concurrent use of prescribed fire on other sites is an essential tool for the management of Piedmont pine forests.

The more frequent use of prescribed fire to manage pine and pine-mixed hardwood forests on upland Piedmont sites is a renewed challenge and an opportunity for the forest manager. Numerous questions remain which relate to control of understory vegetation and impacts on nutrient cycling, but many of these are already being addressed by regional research organizations. Contemporary problems with smoke management near roads and urban areas present real constraints, but the increasing costs of using other methods to suppress dominant hardwoods on good pine sites, and the restrictions on and public resistance to the expanded use of herbicides, make prescribed burning a viable, economical option that should be examined more widely in the Piedmont [55].

9.3.1.2 River bottoms and terraces

Alluvial and Swamp types occur on fertile, periodically flooded bottomlands along Piedmont streams and rivers (Fig. 9.12a). A typical floodplain forest contains several major features — including a river or stream channel meandering through the area, natural levees adjacent to the channel, and areas farther away differing in topography — which result from the combination of varying deposition of alluvial materials and erosion of surface geology from many years of floods [33]. The prolonged soil saturation characteristic of such bottomlands produces chemical changes which lead to diagnostic soil coloration and other physical features usually indicative of hydric soils (see chapter 10, this volume). The low oxygen content and physical action of floodwaters, as well as their maximum depth and the period and frequency of inundation, all strongly influence species composition of any particular site.

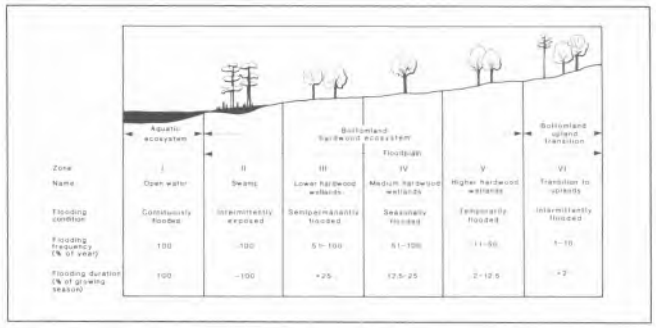

Figure 9.13. Zonal classification of bottomland forests (adapted from [12]).

An ecological classification scheme for bottomland forests, based on flooding regimes and focusing on dominant tree species along a wet to dry gradient, has been developed by the Society of American Foresters [12] (Fig. 9.13). [The wetlands delineation procedures used by the U.S. Army Corps of Engineers (see 9.4.3.1) are not a hierarchical classification system, but a technique for affirming or rejecting the presence of a wetland.] Sites not continuously flooded are highly productive and generally dominated by mixed hardwood species, although large loblolly pines are common in zones V and VI in natural stands with a recent history of disturbance (Fig. 9.13). However, the flooding during regeneration, intense hardwood competition, increasing value of merchantable bottomland hardwood species, and value of bottomlands for hunting leases usually make zones I through IV undesirable for pine management. Under some circumstances, management activities in wetlands may be legally restricted (see 9.4.3).

9.3.2 Southeastern Evergreen Association

This forest type includes a broad arc of the southeastern Coastal Plain from the New Jersey pine barrens across the Carolinas, Georgia, and Gulf states to eastern Texas, and northward along the Mississippi alluvial plain (see Fig. 9.11). As with the Oak-Pine association, forest types vary considerably within the latitudinal range and, because of the profound effects of soil moisture and fire regime, even in a given location (Fig. 12b). Within the association, upland southern mixed hardwood, mixed hardwood swamp, and bayhead forest types may be considered stable climax communities (Table 9.4). Sand pine [*P. clausa* (Chap. ex Engelm.) vasey ex Sarg.] scrub, oak sandhill, pine flatwood, and cypress swamp communities may be considered successional in that fire maintains the first three and deep flooding the fourth [36].

Human- and lightning-generated fires were the primary historical factors controlling forest distribution and composition of the entire Coastal Plain. Florida provides the most obvious illustration of the high storm activity prevalent, averaging about 80 days/year with thunder, 3 times the national average [32], and 10 to 15 lightning strikes/km^2 annually [52]. This very high lightning

Table 9.4. Presence of tree species (potential to reach 10 cm dbh) in six forest types in north-central Florida (adapted from (361)).

Species[1]	Upland southern mixed hardwood (n = 60)[2]	Mixed hardwood swamp (n = 24)	Bayhead (n = 9)	Cypress swamp (n = 15)	Pine flatwood (n = 32)	Oak sandhill (n = 16)
	% of stands					
Acer barbatum	21	–	–	–	3	–
A. negundo	8	4	–	–	–	–
A. rubrum	33	100	22	53	53	–
Aesculus pavia	13	–	–	–	–	–
Aralia spinosa	4	–	11	–	–	–
Alnus serrulata	–	4	–	–	–	–
Aronia melanocarpa	–	29	–	–	–	–
Betula nigra	2	4	–	–	–	–
**Bumelia lanuginosa*	23	–	–	–	–	–
**B. tenax*	3	–	–	–	–	–
Carpinus caroliniana	52	38	–	–	–	–
Carya aquatica	3	21	–	–	–	–
C. glabra (inc. *tomentosa*)	77	8	–	–	3	19
Celtis laevigata	33	–	–	–	3	–
Cephalanthus occidentalis	7	83	33	67	3	–
Cercis canadensis	23	–	–	–	–	–
Chionanthus virginicus	7	–	–	–	3	–
**Cinnamomum camphora*	2	–	–	–	12	–
Cornus florida	38	–	–	–	3	6
Crataegus marshallii	11	–	–	–	–	–
C. uniflora	15	–	–	–	–	25
**Cyrilla racemiflora*	2	–	11	–	–	–
Diospyros virginiana	41	4	–	–	34	69
Fraxinus profunda	34	–	–	–	3	–
F. caroliniana	–	92	–	–	–	–
Gleditsia aquatica	2	29	–	–	–	–
**Gordonia lasianthus*	2	–	78	20	28	6
Ilex ambigua	23	–	–	–	–	–
**I. cassine*	10	88	44	53	28	–
I. decidua	3	–	11	–	–	–
**I. opaca*	79	4	–	–	9	–
**Illicium floridanum*	–	–	22	–	–	–
**Juniperus virginiana*	38	8	–	–	–	–
**Leucothoe spp.*	–	–	22	–	–	–
Liquidambar styraciflua	77	71	33	20	34	6
Liriodendron tulipifera	–	–	11	–	3	–
**Lyonia ferruginea*	28	–	–	–	56	19
**Magnolia grandiflora*	85	–	22	13	25	6
**M. virginiana*	13	21	100	60	37	–
Morus rubra	51	–	–	–	–	6
**Myrica cerifera*	39	75	56	93	84	31
Nyssa aquatica	2	–	–	–	–	–
N. sylvatica	41	88	56	100	47	–
**Osmathus americanus*	52	–	11	–	–	–
Ostrya virginiana	48	–	–	–	–	–
**Persea borbonia*	79	–	–	–	–	12
**P. palustris*	13	63	100	53	47	–
**Pinus clausa*	2	–	–	–	6	19
**P. elliottii*	18	–	44	93	72	50
**P. glabra*	25	–	–	–	–	–
**P. palustris*	2	–	–	–	59	100
**P. taeda*	26	17	11	–	12	31
**P. serotina*	–	–	11	–	3	–
Prunus angustifolia	15	–	–	–	–	–
**P. caroliniana*	50	–	11	–	3	–
P. serotina	48	–	–	13	9	25
Ptelea trifoliata	5	–	–	–	–	–
Quercus chapmanii	8	–	–	–	22	19

Table 9.4 (continued)

Species[1]	Upland southern mixed hardwood (n = 60)[2]	Mixed hardwood swamp (n = 24)	Bayhead (n = 9)	Cypress swamp (n = 15)	Pine flatwood (n = 32)	Oak sandhill (n = 16)
	% of stands					
Q. durandii	30	–	–	–	–	–
Q. falcata	7	–	–	–	3	37
Q. incana	–	–	–	–	22	37
Q. laevis	2	–	–	–	19	100
**Q. laurifolia*	100	38	22	13	50	6
Q. lyrata	5	–	–	–	–	–
Q. michauxii	33	–	–	–	–	–
**Q. myrtifolia*	8	–	–	–	12	19
Q. nigra	72	83	33	–	50	–
Q. shumardii	10	–	–	–	–	–
Q. margaretta	2	–	–	–	–	56
**Q. virginiana*	92	–	–	–	53	69
Rhamnus caroliniana	8	–	–	–	–	–
**Sabal palmetto*	52	88	–	7	19	–
Salix caroliniana	–	13	–	20	3	–
Sambucus simpsonii	–	41	11	–	–	–
Sapindus marginatus	8	–	–	–	–	–
Sassafras albidum	–	–	–	–	–	6
Taxodium distichum	8	88	11	–	–	–
T. ascendens	–	–	–	100	19	–
Tilia floridana	48	–	–	–	–	–
Ulmus alata	36	–	–	7	–	–
U. floridana	33	83	–	–	6	–
**Vaccinium arboreum*	61	25	44	13	22	–
Viburnum obovatum	–	17	11	–	–	–
Zanthoxylum clava-herculis	–	25	–	–	–	36
Number of tree species	71	30	27	18	42	26
Number of species/stands	20	14	10	8	10	8
Percent evergreen/stand	56	11	76	18	91	44

[1] designates evergreen species.
[2] n = number of stands sampled.

frequency and density were central to the maintenance of the fire-dependent longleaf pine-wiregrass *(Aristida sticta)* forests that historically dominated this association.

In recent decades, the longleaf pine-wiregrass forests (on sandhill and flatwood sites) have diminished in importance throughout the Coastal Plain uplands due to logging, intensive forest management of loblolly and slash pine, decreased fire frequency, and increased seed dispersal from competing pine species. Loblolly pine in particular has replaced longleaf on most xeric sites, the uplands are now dominated by plantations of other pine species and successional mixed hardwood stands, and slash pine is now the most widely planted species on the wetter sites [11].

9.3.2.1 Upland southern mixed hardwoods

Numerous ecologists contend that upland fire exclusion results in successional changes in the stable climax community called the southern mixed hardwood type [22, 45, 60], eventually to be dominated by American beech *(Fagus grandifolia* Ehrh.), southern magnolia *(Magnolia grandiflora* L.), and diverse other hardwood species. Upland southern mixed hardwood stands are best developed on fertile soils derived from limestone, phosphatic deposits, or finer textured sediments, but may also occur on less fertile sites if fire has been excluded for long periods [35]. The currently limited extent of this type is attributed to conversion of these fertile sites to agriculture, which has a 350-year history in some parts of the Coastal Plain [58, 59].

9.3.2.2 Pine flatwoods and savannahs

Pine flatwoods occur on variable sites at the middle of the moisture and fertility gradients, intergrading with some sandhill communities. The mesic extreme is much wetter than the sandhills, and many of these sites are poorly drained. Pine flatwoods may be dominated by longleaf, slash, loblolly, or pond *(P. serotina* Michx.) pines and may shift toward southern mixed hardwood, bayhead, or mixed hardwood swamp types [36], which makes the flatwoods difficult to interpret successionally. They generally have diverse understories and are analogous to successional pine forests in the Oak-Pine association (see 9.3.1; [11]).

Longleaf pine savannahs occur as local variations on seasonally wet sites; Christensen [11] considers them to be transitional between xeric pine communities and wetland pocosins (shrub - dominated wetlands). They may be dominated by longleaf pine and wiregrass, or may have small boggy microsites with rare and endangered insectivorous plants and other wetland species. Surface fires are more frequent than in the flatwoods, and fire suppression results in the establishment of understory shrubs and hardwoods.

9.3.2.3 Oak sandhills and sand pine scrub

Oak sandhill forests occur on dry, infertile sites along coastal sand ridges, the southeastern fall-line southward from North Carolina to parts of Alabama, and the highlands of central Florida. These forests are frequently burned and are characterized by longleaf pine with a wiregrass understory when the fire regime is maintained; they may shift toward southern mixed hardwood types when fire is suppressed. Less frequent fire and logging directly lead to a greater oak component, typically sand post oak *[Q. stellata* var. *margaretta* (Ache) Sarg.], turkey oak *(Q. laevis* Walt), or southern red oak *(Q. falcata* Michx.) [36, 56].

In areas with deep sands and historically protected from frequently fires, sand pine scrub forests develop. These dense forests stagnate in 60 to 80 years, after which, historically, they catastrophically burned; today, they are clearcut. Fire management in the scrub continues to be a highly risky venture. Kalisz and Stone [26] discuss the factors differentiating scrub from sandhill forests in central Florida.

9.3.2.4 Wetland forests

Wetland forests are more numerous in the Coastal Plain provinces than in the Piedmont because there is less of a topographic gradient in the former. Most of the environmental descriptors of Piedmont river bottoms and terraces (see 9.3.1.2) are also valid for Coastal Plain wetland forests, but the latter are greater in area and are flooded longer and more frequently.

Monk [36] and Monk and Brown [37] classified swamplands in north-central Florida as mixed swamps (deciduous hardwood swamps), bayheads (evergreen hardwood swamps), and cypress swamps. The mixed swamps, found along creeks, rivers, sloughs, and basins that are seasonally flooded, are characterized by a greater depth of maximum flooding, higher soil pH, and higher soil-cation availability. The bayheads, in contrast, developed from bogs, marshes, or low pine flatwoods, are more shallowly flooded and acidic, and accumulate a surface layer of peat. Water hickory *[Carya aquatica* (Michx. f.) Nutt.], cabbage palm *[Saba! palmetto* (Walt.) Lodd.], Carolina ash *(Fraxinus caroliniana* Mill.), Florida elm *(Ulmus floridana* Chapm.), and baldcypress *[Taxodium distichum* (L.) Rich.] are more restricted to the mixed

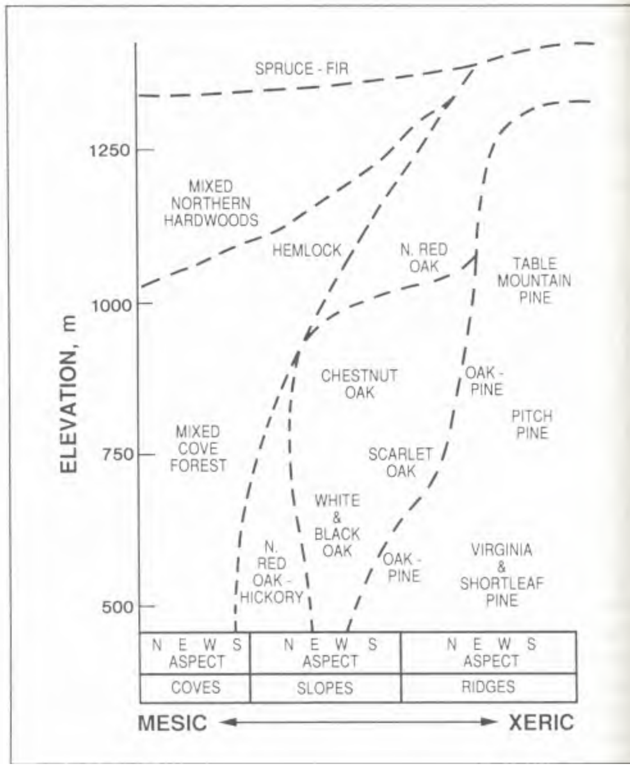

Figure 9.14. Major forest types of the Appalachian Oak association and their relative patterns along complex environmental gradients (adapted from [14, 61]).

swamps, loblolly-bay *[Gordonia lasianthus* (L.) Ellis], swampbay *[Persea palustris* (Raf.) Sarg.], and sweet bay *(Magnolia virginiana* L.) to the bayheads. Water oak *(Q. nigra* L.), red maple *(Acer ruhrum* L.), sweetgum, and swamp tupelo *[Nyssa sylvatica* var. *biflora* (Walt.) Sarg.] occupy both forest types. The cypress swamps, with pondcypress *[T. distichum* var. *nutans* (Ait.) Sweet] and baldcypress, are found around sloughs, inland lagoons, ponds, lakes, and small depressions in pine flatwoods. Pondcypress is characteristic of flatwood depressions with infertile, acid soils, whereas baldcypress is more important on fertile, alluvial sites. There are also several local variants of nonalluvial wetlands, including the pocosins of the Carolinas and Atlantic white-cedar *[Chamaecyparis thyoides* (L.) B.S.P.] swamps [11]; these are of relatively limited distribution and will not be addressed here.

Many of the sites occupied by these forest types have been drained for various reasons, including conversion to pine plantations. However, many also have major problems with rising water levels when harvested, and the expense of bedding and intense hardwood control mitigates against conversion to pine. As with Piedmont bottomlands, there are also other potential legal constraints to wetland management (see 9.4.3).

9.3.3 Appalachian Oak and Mesophytic Associations

These associations occupy the broad central region of the eastern deciduous forest. Mixed oak forests dominate the lower elevation slopes of the southern Appalachian Mountains and the Valley and Ridge provinces, and mesophytic forests dominate the Interior Appalachian Plateau provinces (subsections of the Appalachian Highlands region). Oak forests are also locally important throughout the Appalachian and Interior Low Plateau regions, as are diverse mesophytic forests on cove sites in the mountains. The complex physiography and soil relationships of these regions (detailed in chapter 10, this volume) are reflected in Figure 9.14.

The most favorable sites within these regions (coves, gorges, and other sites with well-drained loam soils) are dominated by a large diverse group of mesophytic hardwoods including American beech, sugar maple *(Ater saccharum* Marsh.), American basswood *(Tilia americana* L.), painted buckeye *(Aesculus sylvatica* Bartr.), yellow birch *(Betula alleghaniensis* Britton), and numerous oak and ash species. On upper slopes and well-drained soils within the mountains and plateaus, oak species dominate and intergrade with pine species on ridges, rock outcrops, and sandy plains [6]. Most of the forests in these regions had at least a small component of American chestnut *[Castanea dentata* (Marsh.) Borkh.] before the 1930s, and the chestnut blight and subsequent demise of the species caused restructuring of most mixed oak-chestnut stands to oak-mixed hardwood [27]. On slopes and ridges with a fire history, shortleaf and pitch *(P. rigida* Mill.) pines may be dominant components of the stand. Barden and Woods [2] reported that severe crown fires which removed more than 85% of the hardwood basal area and canopy cover encouraged pines to re-establish.

The western Mesophytic association is a transition zone in which forests dominated by a mixture of species in the east shift to forests dominated by oak and hickory species in the west. Braun [6] classified much of central Tennessee as a mosaic of oak-dominated stands reflecting widespread human influence over the last 200 years. Most forest tracts that remain here are small, isolated, and so disturbed by logging, grazing, and fire that past variations in composition are difficult to interpret [49]. Former pockets of prairie barrens that once existed in this area have mostly been converted to pasture or row crops, and some have successionally advanced to mixed oaks [49].

Although most of the sites within these two associations are unquestionably best suited for hardwood silviculture, there are considerable opportunities for the use of prescribed fire to regenerate and maintain mixed pine-hardwood stands on upland sandy plateaus, ridges, and slopes. At lower elevations of the southern Appalachians, Hooper [25] successfully controlled dense, highly competitive evergreen shrubs with a prescribed burn, regenerating a mixed stand with planted eastern white pine *(P. strobus* L.). However, burning in such complex topography requires a high degree of experience and knowledge. As previously discussed for the Piedmont region, the more frequent use of prescribed fire to manage pine-mixed hardwood forests is both a challenge and an opportunity for the forest manager, and future research should provide new guidelines for burning in the Appalachian region [55].

9.3.4 Oak-Hickory Association

The Oak-Hickory association of the region west of the Mississippi River is a transition zone from dense, closed, relatively tallgrass prairie. Decreasing precipitation is directly correlated with this transition. Braun [6] considered the best development of the Oak-Hickory association to be in the Ozark and Ouachita Mountains, but it also occupies extensive areas in the plains, rolling hills, and drift-flats regions. Oak species are often accompanied by hickory species, and unusually favorable mesic sites in the mountains also have American basswood, magnolia and ash species, and black walnut *(Juglans nigra* L.) [6].

Throughout the Ozark Plateau and the Boston Mountains, oak-hickory predominates, although pine and pine-hardwood (historically shortleaf pine) mixtures are extensively distributed. In the Ouachitas, pine forest is much more prevalent and usually carries greater significance in forest-type classification [43]. Increases in the importance of pine forest over recent years have largely been due to more intensive management, including hardwood control and large-scale site conversion, increasingly with loblolly pine.

Throughout the association, forest composition and parent material formations are closely related. Soils derived from limestone, sandstone, shale, and residual chert provide a highly variable landscape and strongly influence species composition [43]. Read [46] classified oak forest types in relation to geology and soils, and made recommendations for species-site selections. Along with several hardwood species, pines were recommended on most dry, south-facing sites. The economically important hardwood and pine species develop best on sites with deep, well-drained soils; however, competition there also is greatest. Historically, economic controls have often outweighed biological aspects and dictated generally less intensive management. Shortleaf pine grows well on better, north-facing slopes but cannot be maintained without intensive control of hardwood competitors. As a result, the species has been primarily grown in less competitive hardwood mixtures on drier sites [43].

Although fire has been historically important in the region, it has not been as widely used as a management tool as in more southern regions because of the complex topography, and lack of information about its proper application [43].

9.4 Social and Legal Environment

9.4.1 Public Perceptions and Concerns

The public is sensitive to management decisions that may have perceived negative sociological or environmental impacts, and this factor should be increasingly considered relative to harvesting and regeneration practices. Two prime examples are the smoke generated from slash fires, and the chemical quality or sediment load of runoff water; in these cases, there may already be strict regulations at the federal or state levels, or both. Legally protected plants or animals, as well as common game and nongame wildlife, also are important public concerns. Some species, such as the white-tailed deer *(Odocoileus virginianus),* may actually be severe pests to young seedlings under some circumstances. No fool-proof formula can easily be derived for dealing with all of these potential conflicts of interest, but ignoring any of them in management could be legally or politically disastrous.

The public has extensive feedback mechanisms available through local and national legislative processes that may ultimately have negative impacts (e.g., extremely stringent regulations) upon timber management on both publicly and privately owned forestland. Therefore, forest managers of all ownerships must be sensitive to the public's changing perceptions of forestry. Major demographic changes in the South are underway — this once predominantly rural society is rapidly becoming urbanized. Reoriented public perceptions and the potential for political feedback are new elements with which southern foresters must cope. Effective public relations must address these new political and environmental concerns, as well as endeavor to better educate the public about forestry and its importance to the region.

9.4.2 Endangered Species

The Endangered Species Act of 1973 is the strongest legislation to date protecting "endangered" and "threatened" plants and animals. The act gives the Department of Interior regulatory and statutory authority on issues that potentially affect forest management in the United States. It calls for participation, where appropriate, by all federal agencies and directs that no federal funds can be utilized for any activity that would be detrimental to an "endangered" or "threatened" species. The program, of course, has its greatest impact on the management of public lands, but compliance on large private holdings is advisable if only from the standpoint of maintaining positive public relations. Private landowners can be prosecuted for "willful disturbance of endangered species" or for destruction of federally designated "critical habitat." Additionally, "404" dredge-and-fill permits issued by the U.S. Army Corps of Engineers (see 9.4.3) may be denied to applicants who have not first completed a required endangered-species survey of the site.

The Act also has provisions for state participation, and most states in the region currently have cooperative Natural Heritage programs with The Nature Conservancy, usually administered through departments of natural resources or environmental protection. For information on species and habitat protection, managers should contact their state program and refer to supplemental information in Appendix A9.1, this chapter.

Although implementation of these programs to date has dealt largely with designation of species status and critical habitats, there may be broader impacts on forest management in the future. Recent revisions to the 1977 Clean Water Act may halt drainage and/or site conversion of wetlands containing endangered species, especially if the landowner has no previous silvicultural exemption for forest management. Also, new U.S. Environmental Protection Agency (EPA) requirements for labeling herbicide containers to indicate the susceptibility of endangered plant species suggest that more restrictions on altering endangered species' habitats are likely to be implemented.

9.4.3 Wetlands

Throughout the southeastern U.S., many wetland habitats have been drained, bedded, and planted with intensively managed pines. Amendments to the 1972 Federal Water Pollution Control Act (FWPCA) and the 1977 Clean Water Act potentially restrict many such activities by regulations implemented through the U.S. Army Corps of Engineers requiring a "404" dredge-and-fill permit (Federal Register 41206-41260, November 13, 1986). The objectives of this legislation are to protect multiple wetland resources by protecting the wetland ecosystems themselves. Additionally, the EPA has increased involvement, through a new Office of Wetland Protection, for setting policies for protecting wetlands and overseeing "404" permitting (administered by the Corps of Engineers). More stringent requirements will likely apply to new permits, and the Corps now has the authority to assess fines for violators.

In addition, several states have enacted their own comprehensive wetlands laws, some of which may be stricter than their federal counterparts [13]. Florida was one of the first to enact comprehensive legislation in 1984 with the passing of the Warren S. Henderson Act. South Carolina had a wetlands law introduced to the legislature in 1987, and Georgia had a study bill introduced in 1988. Almost all coastal states have legislation that directly or indirectly addresses use of coastal wetlands. Given these considerations, the legal definition and delineation of wetlands in accordance with federal and, in some cases, state laws are discussed (9.4.3.1), as are the potential impacts on forestry operations and management (9.4.3.2).

9.4.3.1 Legal delineation

Defining wetlands has proven difficult in terms of both legal jurisdiction and ecological classification used by scientists and resource managers [33]. Because wetlands are areas that are periodically or continuously inundated by water, they fall along a transition zone between permanently wet aquatic ecosystems and dry terrestrial ecosystems. From one end to the other, this zone varies considerably in the associated hydrologic conditions and area. Consequently, wetland boundaries are not easily identified. A definition that is both practical and legally precise and that accurately reflects ecological reality is problematic.

The legal definition of wetlands, as enacted by Section 404 of the Clean Water Act, is stated as:

> ... those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas.

However, to identify consistent criteria for delineating wetlands that fall within their jurisdiction, the Corps of Engineers has recently released a wetlands manual in which three key parameters — vegetation, soils, and hydrology — are the bases for characterizing a wetland and its boundaries [54].

Plant indicator species are listed and categorized in the manual according to their affinity for wetlands. These categories, prepared by a national interagency panel, include obligate wetland, facultative wetland, facultative upland, and obligate upland species [54]. Regional lists of plants have been developed because some species vary in their likelihood of occurrence in a particular habitat throughout geographical regions.

Soils are categorized in the manual according to how well each meets the definition and following criteria for hydric soils: (1) soil consists predominantly of decomposed plant material (peats and mucks); (2) soil has a thick layer (20 cm or more) of decomposing plant material on the surface; (3) soil has a bluish gray or gray color at 25 to 30 cm below the surface, or most of the soil at this depth is dark (brownish black or black) and dull; (4) soil has the odor of rotten eggs; (5) soil is sandy and has a layer of 8 cm or more of decomposing plant material at the soil surface, due to slow decomposing conditions; and (6) soil is sandy and has dark stains or dark streaks of organic material in the upper layer 8 to 30 cm below the soil surface — streaks are decomposed plant material attached to soil particles and when soil from streaks is rubbed between the fingers, a dark stain is left on them [54].

Hydrologic features (periodic presence of flooding or saturation) in the manual include: (1) standing or flowing water observed on the area for 7 or more consecutive days during the growing season; (2) waterlogged soil, as determined by standing water appearing in a hole 30 cm deep or the ability to squeeze water from the soil; (3) water marks present on trees or other erect objects; (4) drift lines (small piles of debris oriented in the direction of water movement through an area) along contours; (5) debris lodged in trees or piled against other objects; and (6) thin layer of sediments deposited on leaves or other objects [54].

According to the current Corps of Engineers delineation methods, indicators of all three parameters — vegetation, soils, and hydrology — must be present for an area to be called a wetland and reside under their Section 404 permitting authority. There is some debate, however, among EPA, the Corps, and some interest groups about whether presence of all three parameters is required.

9.4.3.2 Implications for forest management

The preceding sections described federal law and wetlands delineation methods in some detail. But what does all this mean for forest management?

Except for several explicitly enumerated exceptions, "404" permits issued by the Corps are required for deposit of dredged or fill material in the nation's waters. Section 323.4 of the final Corps Section 404 regulations continues to exempt normal silviculture activities from permit requirements. But it states that "Activities which bring an area into farming, silviculture, or ranching use are not part of an established operation." Thus, these activities are not exempt from permit requirements if they have not been practiced on the site previously [13]. Additionally, while normal harvesting is exempt, this "... does not include the construction of farm, forest, or ranch roads."

Roads and skid trails which meet best management practice **(BMP)** guidelines established under state Section 208 Planning may be exempt if they meet several additional Section 404 criteria: they must be minimized in number, width, and length; located sufficiently far from streams or other water bodies; bridged or culverted so as not to impede expected flood flows; properly maintained and stabilized to prevent erosion; and fulfill other specified requirements [13].

The silvicultural exemption section explicitly states that any of the preceding exempt activities would still require a permit if its purpose were "to convert an area of other waters of the United States into a use to which it was not previously subject, where the flow or circulation of waters of the United States may be impaired or the reach of such waters reduced." Discernible alteration to flow or circulation is presumed to be impairment. The regulations continue: "For example, a permit will be required for the conversion of a cypress swamp to some other use or the conversion of a wetland from silvicultural or agricultural use when there is a discharge of dredge or fill material into waters of the United States in conjunction with construction of dikes, drainage ditches, or other works or structures used to effect such conversion."

BMP guidelines will begin to be scrutinized and monitored for their effectiveness much more in future years. In fact, some environmental groups feel that voluntary BMPs will not adequately protect wetlands and would prefer that wetland regulations be administered by an environmental agency.

To date, most ongoing forest operations have not been seriously affected by the dredge-and-fill permit requirements [13]. Indeed, much commercial forestland, even in the southern Coastal Plain, would not be classed as wetlands under the Corps' delineation methods and would not be subject to Section 404 regulations. Some bottomland hardwoods, cypress swamps, and pocosins — about 10 to 20% of the total forest area in the South — would fall within the wetlands definition, but much of that land is not viable for commercial timber production. For example in Georgia, the 1982 forest survey reported that, of a total of forested area of 9.6 million ha [48], over 1.2 million ha of oak-gum-cypress forest types and about 243,000 ha of elm-ash-cottonwood and pond pine types might not be suitable for forestry operations. However, not all of these areas would be classed as wetlands, and many are not managed intensively, if at all.

Even in designated wetlands, most conventional forest-management practices, including site preparation and planting, timber stand improvement, timber harvesting, road building, and minor drainage have been considered exempt from the permit requirements in the 1977 law, although this has recently been subject to some re-interpretation. For example, very large drainage projects — even in pine stands — that are designed to improve site quality by facilitating more rapid runoff may soon require permits, whereas they have not in the past. Additionally, even minor drainage projects near large swamps, such as the Okefenokee, probably will need permits before operations can begin. The Corps may deny such permits on ecological grounds. Furthermore, EPA is reconsidering its prior general exemption for minor drainage and may tighten the qualifications [13].

In most southern states, federal wetlands regulations have affected only a fraction of the commercial timber-growing operations. Several areas, including much of the Mississippi delta, southern Louisiana, Florida, Carolina pocosins, and other large swamps, may however ultimately be affected. If the pervasive national sentiment for preserving wetlands and for vigorous enforcement by the Corps and EPA prevails, many of these lands may have to be managed for alternative objectives such as hardwood production or wildlife.

In all, federal water-quality laws have had considerable success at reducing pollution and improving water quality, largely attributable to the reduction of point-source discharges via other federal permitting programs. The Section 404 dredge-and-fill regulations have also helped improve water quality and preserve wetland habitat. However, these regulations were initiated largely to control filling of wetlands resulting from high-impact development, road construction, and alteration for agriculture, not forestry operations. Therefore, the full ramifications for forestry are yet to be determined.

Because of the problems in defining wetlands and the rapid changes in state and federal policies affecting forestry in these areas, forest managers are strongly advised to contact the responsible Corps of Engineers permitting sections before implementing new activities on potential wetland sites. Several states also have individual wetlands-protection legislation on wetland issues. In some cases, professional environmental consultants may be helpful in clarifying technical and legal definitions that may apply to specific sites.

9.5 Conclusions

Extensive logging of native forests and land clearing for agriculture through the early part of this century have changed the face of the southeastern U.S., obscuring many clues to the original patterns of the natural vegetation there. Fire suppression also has effected change, creating large, uncharacteristically dense thickets of second-growth forest that dominate many areas and that, ironically, add to the danger of reintroducing uncontrolled wildfire. Other important, but often less obvious, disturbances have included drainage of large areas of wetlands, fertilization of current forest sites and former agricultural fields, accidental or purposeful introduction of non-tree species (e.g., kudzu [*Pueraria lobata* (Willd.) Ohwi]), planting of various species out of their natural ranges, and large-scale manipulation of the genetic base of the managed pine forest.

In planning for regeneration, foresters should consider these historical modifications. Even where historical patterns are difficult to ascertain, vegetation may still reveal clues to the physical environment of the site and to its potential productivity. Prime examples include the presence of pitcher plants (*Sarracenia* spp.) on frequently saturated and nutrient-poor sites, and turkey oak on drier sites. In the Piedmont, hardwood "invasion" of pine forests is often more a recolonization of former hardwood sites on fertile soils, an inevitability in most old fields.

Site-preparation plans must account for potential competition from a range of species and be tailored to site conditions; the characteristics of the former forest's understory and the species present on other disturbed, nearby sites offer the best clues to possible vegetation problems. Site environment can be substantially altered through burning, drainage, fertilization, bedding, subsoiling, or the application of a suite of herbicides. But unless the objectives are specific, the methods well thought out, and the environmental and legal ramifications of the prescribed action adequately considered, the economic and/or social costs could easily become excessive.

Finally, there is the less tangible concept of ecological connectedness among all the sites in a larger landscape. For example, most wildlife managers now consider appropriate sizes and shapes of forestry openings, juxtaposition of different types of stands ("edge effects"; e.g., a recent clearcut next to an older stand containing a wetland), and possible corridors for animal movements in devising their management plans (see, for example, [23]). Such considerations will become increasingly mandated as the southern forested landscape becomes even more fragmented by future urban and agricultural development.

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