Species Suitability on a Lowland Site Altered by Drainage

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ABSTRACT. Surface drainage created adequate conditions for survival and growth of loblolly pine (Pinus taeda *L.*) *on most sites within a wet lowland area. Successful pine establishment occurred on soils having loamy or sandy surface horizons and where original forest cover had been pine-hardwood or hardwood. On a lesser but significant number of sites, however, loblolly pine had unsatisfactory survival. Such problems were common where clay content of surface soil was high and the water table remained near the surface after ditch installation. In most cases, these conditions occurred on sites formerly occupied by cypress-hardwood timber. Planted sweetgum* (Liquid ambar styraciflua *L.*) *and baldcypress* (Taxodium distichum *(L.) Rich.*) *had better survival than loblolly pine on these sites. Guidelines for delineating such problem sites are given and management alternatives discussed.*

Drainage of wet forestland is a common practice in lowlands of the southeastern coastal plain. At least two million acres have been drained to date (Klawitter 1978), and additional efforts are anticipated in attempts to meet worldwide demands for softwood fiber and timber. In typical drainage projects, wet areas are ditched to remove surface water and provide access roads. Sites are then logged, site prepared, planted with pine and fertilized. On some large drainage projects, significant portions of the area are not successfully converted to pine plantations because drainage remains inadequate due to local topography and soil conditions. Forest managers face problems associated with recognition and delineation of these areas which may remain unsuitable for pine production. Questions arise about regeneration and management of such areas once they have been delineated. To help resolve these difficulties, the Southeastern Forest Experiment Station and Westvaco Corporation established a species-site study more than 20 years ago. Recently we revisited many of the study plots to assess 20-year performance of five planted species and examined previously collected data by discriminant analysis. The paper presents guidelines and suggestions for selecting among species for planting on similarly drained lowlands. Other alternatives available to managers of such lands are also discussed.

THE STUDY

The study was established in 1961 on lands of Westvaco Corporation near Summerville, South Carolina. A primary drainage system had been installed a few years earlier to provide logging access, and subsequent regeneration was considered inadequate in sizeable portions of the area. The land is typical of thousands of acres of wet flats, hardwood stream margins, and baldcypress stands occurring in the lower coastal plain of South Carolina. Forest cover prior to logging was quite diverse and was mapped by Westvaco primarily as pine-hardwood, hardwood, or cypress-hardwood timber types. Soils within the area are also variable; major soil series represented include Cape Fear, Ogeechee, Coosaw, Bladen, and Argent. Precipitation averages about 50 inches per year, with 60 to 70 percent occurring during the growing season. Drainage ditches are 5 or more feet deep and 10- to 15-feet wide and occur at irregular spacings that generally follow the natural drainage. The primary ditches have a slope of approximately 1 foot per mile.

The drainage project area sampled in this study encompassed several thousand acres of land. Fifty plots were established which were representative of a wide range of soil and water table characteristics as well as prior forest cover types. Many of the plots were still poorly drained. Each plot was 34 feet wide and 60 feet long with an isolation strip surrounding the plot to eliminate shading. Plots were cleared of vegetation by chain saw, machete, and brush-hook; no other site preparation was done prior to establishment nor was there any attempt to control subsequent competition from volunteer vegetation. Fifty one-year-old seedlings of each of five species—loblolly pine, baldcypress, sweetgum, swamp tupelo (*Nyssa sylvatica* var. *biflora* (Walt.) Sarg.), and water tupelo (*Nyssa aquatica* L.)—were planted at 2- by 2-foot spacing in 12- by 22-foot portions of each plot. The remaining 12- by 60-foot portion of the plot was cleared in the same manner and planted/replanted with 25 trees of each species in the second, third, and fourth years of study; these temporary subplots were established to assess year-to-year variation in initial survival and growth. Except for a sweetgum seed source from Georgia planted on temporary subplots in the second year, all seed were of coastal plain origin. Seedlings were grown in Westvaco's nursery near Summerville.

Survival and seedling height were measured on the plots after each growing season for 5 years. Similar data were collected on the temporary subplots prior to clearing and replanting. Water table depths were measured biweekly for five years on two nonrecording water wells installed near the center of each plot. These measurements were used to calculate annual averages and standard deviations of the water table levels; the latter parameter was used to characterize fluctuation of the water table level. Soil depth to the least permeable layer was measured at three points on each plot; samples of soils in horizons above the least permeable layer (hereafter referred to as surface soil) were collected at each point and composited for subsequent textural analyses by the hydrometer method. Information on forest cover before logging was determined from Westvaco's forest type maps of the area.

Fifth-year survival and height measurements were the basis for identifying the best-performing or superior species on each plot, *i.e.*, a survival × height index (SHI) was calculated as the summed total heights of all living trees. The species having the highest SHI on a given plot was considered the best species to plant on that plot, and all 50 plots were thereby categorized by their best species. Data from temporary subplots indicated that year-to-year variation in initial survival would have little or no effect on "superior species" designations. Moreover, selected plots were visually examined after 20 years to assess whether or not species identified as superior at 5 years had maintained that superiority.

Soil depth to the least permeable layer, percent sand and percent clay of the surface soil as well as 5-year averages for depth and fluctuation (standard deviation) of the water table were used in a series of discriminant analyses to determine which combination of these characteristics was the most efficacious in classifying the 50 plots as to species suitability. Classification was based on the sample Mahalanobis distance (Morrison 1976) as follows:

Set $D_i^2 = (x - \bar{x}_i)'S^{-1}(x - \bar{x}_i)$;

Where

Di^2 is the sample Mahalanobis distance of the unknown plot from the i^{th} group; i = loblolly pine (LP), baldcypress (BC), or sweetgum (SG).

x is the vector of measurements on the soil and water table characteristics.

$\bar{x}_i$ is the vector of plot characteristic means for species i.

S is the variance-covariance matrix of the plot characteristics.

A plot is classified as species 'i' if D_i^2 is minimum of D^2_{LP}, D^2_{BC}, D^2_{SG}. In other words, each species has a typical site defined by the average soil and water table characteristics of plots on which it has been the best performing species. Discriminant analysis determines the superior species for a plot to be that species whose typical site characteristics most closely match the characteristics of the plot in question. Analyses were performed for several combinations of the five plot characteristics.

RESULTS AND DISCUSSION

General

Information on species performance (means and ranges for survival, height, and SHI) on all plots and on those plots where the species was the best performer are presented in Table 1. Loblolly pine had the highest SHI on 32 plots, baldcypress was best on 9 plots, and sweetgum and swamp tupelo were best on 7 and 2 plots, respectively. Water tupelo was not superior on any of the 50 plots. Because two observations were judged inadequate to establish a separate class for swamp tupelo, those plots were reclassified on the basis of the second-best species, which was baldcypress in both cases.

Table 1. Means and ranges for survival, height, and survival x height index (SHI) for each species at age 5.

Species	Characteristic	Performance on all plots		Performance on plots where species is superior	
		Mean	*Range*	*Mean*	*Range*
Loblolly Pine	Survival (%)	60	0–96	80	52–96
	Height (ft)	9.6	0–15.5	11.0	8.5–15.5
	SHI (ft)	314	0–666	439	273–666
Bald-cypress	Survival (%)	83	4–100	89	64–100
	Height (ft)	4.7	2.4–8.2	5.7	4.4–8.2
	SHI (ft)	196	8–394	253	179–394
Sweet-gum	Survival (%)	64	6–94	77	68–86
	Height (ft)	6.1	1.4–13.2	10.6	9.3–13.2
	SHI (ft)	203	6–515	404	350–515
Swamp Tupelo	Survival (%)	74	22–96	—	—
	Height (ft)	3.8	2.0–8.6	—	—
	SHI (ft)	143	39–285	—	—
Water Tupelo	Survival (%)	56	0–90	—	—
	Height (ft)	2.7	0–7.5	—	—
	SHI (ft)	86	0–322	—	—

Flooded hardwood area before drainage deep in the Wassamassaw Swamp. Photo courtesy Westvaco Corporation.

Relative Importance of Survival And Growth in Superior Ratings

On plots where loblolly pine was the best-performing species, its superior SHI could generally be attributed to a rapid growth rate for surviving trees, rather than to superior survival as compared to other species. Total height of loblolly pine was surpassed by other species on only 13 of the 50 plots. Best performance of baldcypress could be attributed to high or at least acceptable survival (76 to 100 percent) in the presence of very poor survival of loblolly pine. On plots where sweetgum was the best species, its success could usually be attributed to superior growth as well as good survival.

Magnitude of Species Differences

Because a major objective of most forest drainage projects is to enhance pine production, one might ask whether the superiority of performance of other species on some plots is important enough to justify the delineation of areas having similar characteristics and managing them for those species. The data illustrated in Figure 1 help to answer that question. On sites where baldcypress was the superior species, its SHI averaged more than four times that of loblolly pine on those sites. Where sweetgum was the best species, its SHI was nearly three times more than that of loblolly pine planted there. We believe such differences warrant attention and the development of specific management prescriptions for areas where loblolly pine is not the best performer.

Classifying Sites for Superior Species via Soil and Water Table Characteristics

The purpose of the discriminant analyses was to determine if the 32 loblolly pine plots, 11 baldcypress plots, and 7 sweetgum plots could be classified on the basis of soil and water table characteristics. The best classification (Table 2) was obtained by using all five characteristics (water table depth and fluctuation, depth to the least permeable layer, percent sand, and percent clay). These characteristics appeared sufficient for classifying loblolly pine and baldcypress plots, but were less satisfactory for sweetgum plots. The superior species was assigned correctly on 43 of the 50 plots (86 percent).

If the data are examined in terms of the over-all

Clearing prior to construction of drainage ditch. Photo courtesy Westvaco Corporation.

matching of species to site, there are two kinds of errors. These errors can be illustrated by using loblolly pine as an example: (1) planting another species on sites where loblolly pine was the superior species, and (2) planting loblolly pine on sites where another species would make superior growth. Judged in this manner, the discriminant analysis was most effective for identifying sites where loblolly pine should and should *not* be planted.

General Relationships of Soil And Water Table Characteristics To Superior Species

Means and ranges of five discriminating characteristics for plots classified by best-performing species are listed in Table 3. Plots on which loblolly pine was the best-performing species were characterized by high sand and low clay contents and deep water tables. The surface soils were generally loamy sands and sandy loams, and water tables averaged more than one and one-half feet below the soil surface. Most baldcypress plots had soils with high clay content and water table levels were usually within one foot of the soil surface; on two plots, water table levels were somewhat deeper but had a larger fluctuation. On those plots where sweetgum performed best, clay contents were generally high and on the high clay soils (>25 percent clay), soil depth to the least permeable layer was substantially greater than in baldcypress plots having similarly high clay content. Water table depths on the sweetgum plots, however, ranged from the shallowest to nearly the deepest of all plots.

Species Performance after 20 Years

Can 5-year performance data provide an adequate index of relative production of these species

Table 2. Comparison of plot classifications based on 5-year survival x height indices (SHI) with results of discriminant analysis.

5-year SHI		Discriminant analysis		
		Superior species		
Superior species	Number of plots	Loblolly pine	Baldcypress	Sweetgum
		Number of plots		
Loblolly pine	32	28	1	3
Baldcypress	11	0	10	1
Sweetgum	7	1	1	5
Total	50	29	12	9

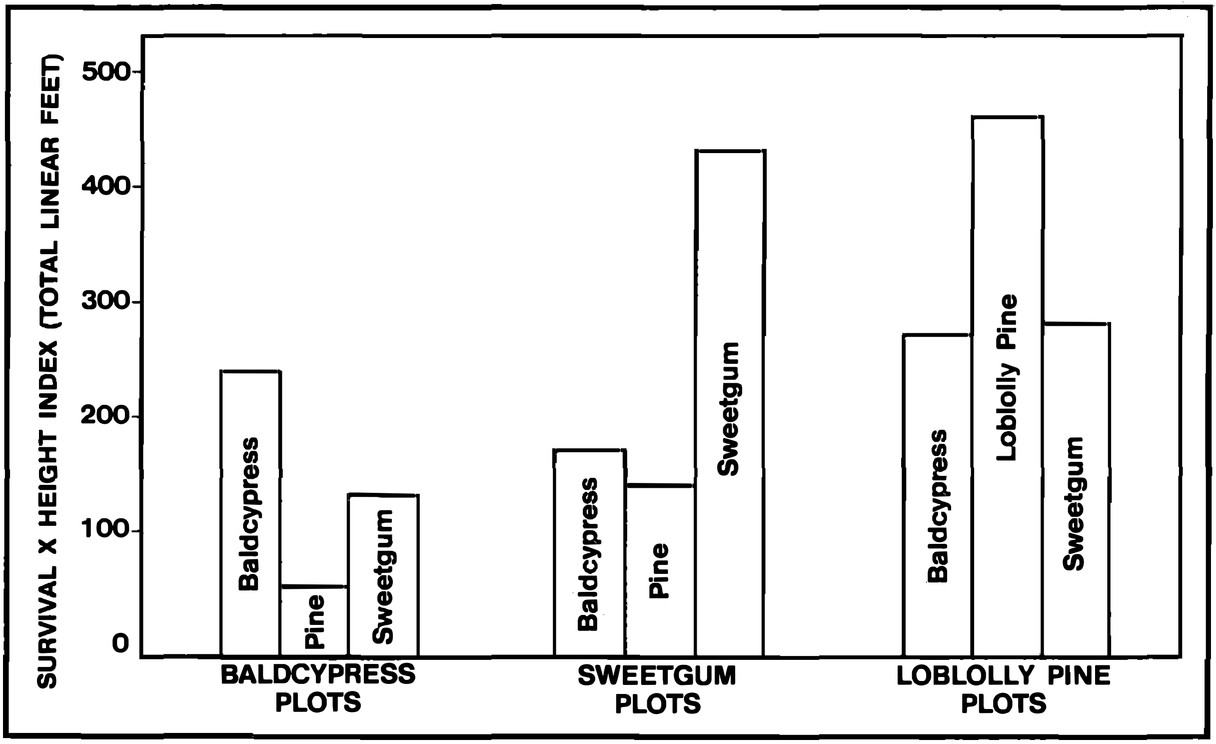

Figure 1. Performance at 5 years of baldcypress, loblolly pine, and sweetgum on plots classified by superior species.

over longer time periods? To help answer this question, we visited several of the plots at age 20. Although the trees were planted much too close for good growth beyond 5 years, observations on 20-year height and survival may be indicative of changes in ranking among species with respect to relative suitability for planting on the plots. Twenty plots were selected to represent the range in soil and water table characteristics as well as species

Table 3. Means and ranges of soil and water table characteristics for plots classified by superior species.[1]

Characteristics		Superior species Loblolly Pine	Bald-cypress	Sweet-gum
Percent sand	mean	71	48	49
	(range)	(38–39)	(24–71)	(26–85)
Percent clay	mean	11	28	29
	(range)	(4–26)	(15–47)	(6–46)
Soil depth to least permeable layer (inches)	mean (range)	18 (7–35)	10 (3–28)	15 (4–26)
Average annual water table level (feet)	mean (range)	1.6 (0.7–2.5)	0.6 (0–1.9)	0.9 (0–2.3)
Standard deviation of water table level (feet)	mean (range)	1.1 (0.8–1.4)	1.0 (0.6–1.9)	1.0 (0.8–1.2)

[1] *Classification by 5-year survival x height index.*

performance on the study area. All intact and readily accessible plots on which baldcypress or sweetgum had outperformed loblolly pine were examined.

Loblolly pine's superiority was maintained through age 20 on all 7 plots on which it was originally the best performer, and future change in relative species performance on these loblolly pine plots is extremely unlikely. This was also true for 4 of the 5 plots on which sweetgum was the best performer. On the other plot, loblolly pine had become the best species by age 20. Superior early performance was not maintained by baldcypress. This species remained superior on only one of eight plots; loblolly pine had become best by age 20 on one plot, and sweetgum was better than or equal to baldcypress on the remaining six plots

There are several possible reasons why baldcypress did not continue in superiority. In most cases, good survival was maintained and tree growth appeared to stagnate in the dense 2- by 2-foot plantings. Perhaps natural thinning processes do not occur as rapidly in baldcypress as in most species, and its growth is much reduced in very dense stands. Another possible cause of the shift in performance is a gradual lowering of water table level over the past 15 years, due to increased transpiration of the developing forest canopy.

Observations made at 20 years indicated that the 5-year assessment did very well in distinguishing loblolly pine sites from nonloblolly pine sites, *i.e.*, those on which other species grew better. Sweetgum sites could also be identified at 5 years, but baldcypress performance was usually surpassed at age 20 by sweetgum on sites where the former species had the best 5-year performance.

A FIELD APPLICATION EXAMPLE

In the previous section, we showed that the relative performance of loblolly pine, baldcypress, and sweetgum on a given site could be predicted from information on water table level (average as well as fluctuation) and physical soil properties (depth and texture of the surface horizon). Specific data on average annual water table depth and fluctuation, however, are unlikely to be available for most areas. Thus, some other index of "wetness" after drainage and logging is needed which can be substituted for the water table data in our analysis. Foresters with considerable experience in such areas should have little difficulty developing such an index; it might be based on topography, soils, and prior vegetation cover. As an example, we developed a species selection framework for this study area (Figure 2) based on forest cover types before logging, soil depth to the least permeable layer, and clay content of surface soils.

In areas formerly mapped as pine-hardwood, loblolly pine was the best-performing species at 5 years on 26 plots and baldcypress was superior on 2 plots. None of the loblolly pine plots had more than 26-percent clay in the surface horizon. The two baldcypress plots had high clay content (27 and 40 percent) as well as shallow surface soil depths (5 and 3 inches). In areas formerly mapped as hardwoods, five plots were best suited to loblolly pine after drainage. On the two hardwood plots with the highest clay content (15 percent), however, baldcypress grew best. As surface soils were rather deep on the latter two plots (17 and 28 inches), it is surprising that sweetgum did not outperform baldcypress. Within both pine-hardwood and hardwood areas, it is quite likely that the few sites with high clay soils represent minor inclusions or variants within the general mapping units and, perhaps, may have originally supported vegetation other than that shown on the general forest type map.

Areas that previously contained cypress-hardwood stands usually had clay contents exceeding 15 percent. On these areas, baldcypress tended to be the superior species where the surface soil depths were 12 inches or less whereas sweetgum was usually best where surface horizons were thicker. Actual 5-year performances (SHI) on cypress-hardwood areas indicated that loblolly pine was best on one plot, and baldcypress and sweetgum were each best on seven plots.

In summary, the scheme depicted in Figure 2 enabled us to predict the species with the highest

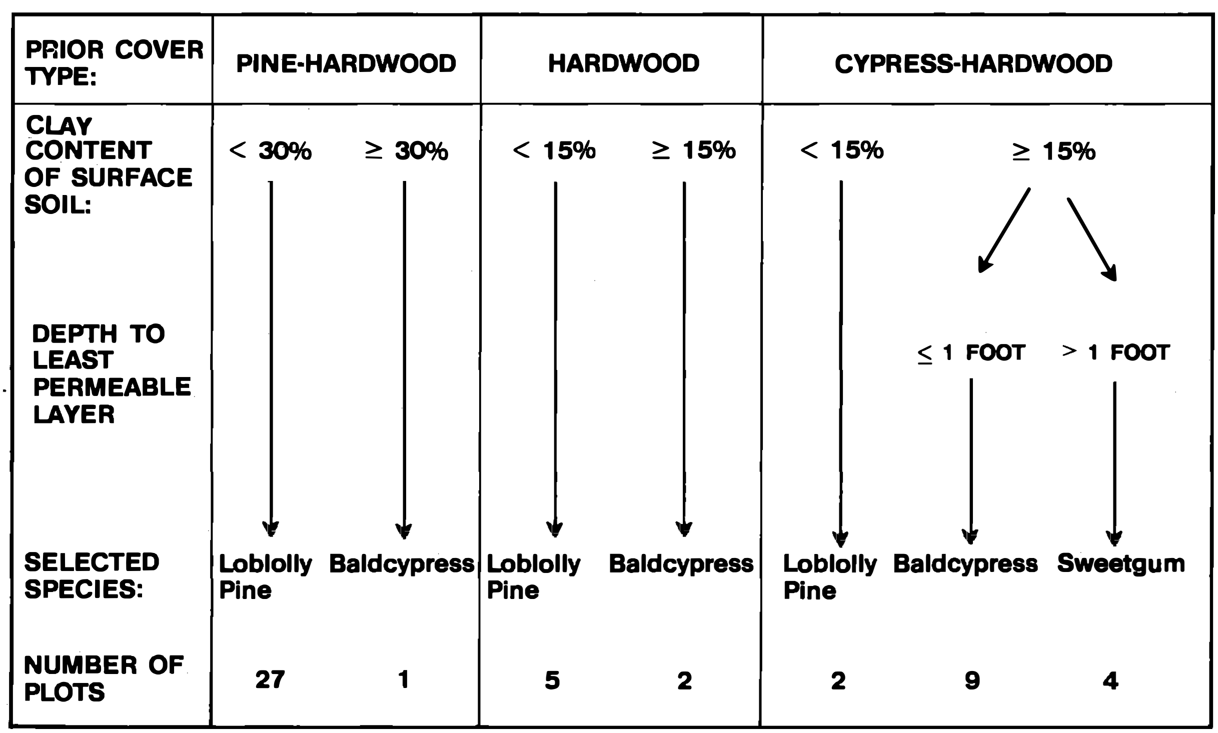

Figure 2. Species selection based on forest cover before logging and surface soil characteristics.

Table 4. Comparison of plot classification based on 5-year species x height indices (SHI) with results of empirical procedure.

5-year SHI		Empirical procedure		
		Superior species		
Superior species	Number of plots	Loblolly pine	Baldcypress	Sweetgum
		.... *Number of plots*		
Loblolly pine	32	32	0	0
Baldcypress	11	1	9	1
Sweetgum	7	1	3	3
Total	50	34	12	4

5-year SHI on 88 percent of the plots (Table 4). It was successful in delineating areas best suited for loblolly pine from those where other species had better survival and growth. We were only marginally successful in distinguishing between areas on which baldcypress and sweetgum were the best species. As sweetgum growth surpassed that of baldcypress by age 20 on essentially all nonpine plots, this shortcoming is not too serious from a practical standpoint. Most landowners involved in large drainage projects would probably prefer sweetgum. Based on our results, it seems possible to develop site-specific species selection schemes from easily determined site and soil characteristics.

OTHER IMPLICATIONS

General Effects and Success of Drainage

In the lowlands of this study, drainage generally resulted in the conversion of pine-hardwood and hardwood areas to loblolly pine. Most cypress-hardwood types, however, were converted to conditions favoring either baldcypress or sweetgum during the first 5 years; by age 20, sweetgum was the superior of these two species on most sites. Although swamp tupelo and water tupelo were commonly dominant species in the original forest cover, conditions following drainage—even on the wettest sites—rarely provided a satisfactory environment for good growth. Both tupelo species were browsed heavily and this may have contributed to their lack of success. It is also possible that species (other pines and hardwoods) not tested in this experiment would outproduce loblolly pine, baldcypress or sweetgum on some of the study plots.

The study was limited to one geographic area, but we believe the results may provide a means of predicting the success of similar drainage systems in converting wet sites to loblolly pine production By knowing the proportion of various cover types and soil characteristics in a planned project area, managers may be able to estimate the percentage of land that can be successfully converted to loblolly pine.

Options for Wetter, Clayey Sites

Planting a species more suitable than pine on the wetter, clayey sites is only one of several options available to forest managers, and it may not be the most attractive from the standpoint of economic and biological effectiveness. Other options should also be considered:

(1) *Increased drainage* by secondary and tertiary ditching may make some sites suitable for pine production. Subsurface drainage, however, is difficult to achieve in many soils with high clay content in the surface horizons. Also, in this drainage study, some plots with high clay content in the surface soils remained unsuitable for pine growth despite lower water table levels.

(2) *Applications of phosphorus fertilizer* have improved pine growth on many wet sites (Pritchett 1979) and, in some instances, have produced growth increases comparable to those associated with improved drainage (Pritchett and Smith 1974). Although survival might be enhanced to some degree with improved nutrition and vigor, phosphorus fertilization by itself seems unlikely to remedy the very poor survival encountered on the wet, clayey sites.

(3) *Bedding* can improve drainage of the seedling root zone, and thereby increase survival and growth of pines on wet sites (Haines et al. 1975, Haines and Haines 1978). Once stands are established and crowns close, evapotranspiration would lower water tables to levels more favorable for tree growth (cf Langdon and Trousdell 1978). Soils with high clay content, however, may be difficult to bed.

(4) *Selection, breeding, and propagation of pine genotypes for wet environments* may also provide a solution to acceptable pine production on these problem areas. Adapted strains of loblolly and pond pine (*P. serotina* Michx.) have been selected for the wet, deep peat soils of eastern North Carolina by the Cooperative Tree Improvement Program at North Carolina State University (Zobel 1979).

(5) *Natural regeneration might be accepted and managed within the delineated problem areas.* All the nonpine sites that we visited in the 20-year examination were adequately stocked with young timber. Sweetgum, red oaks (*Quercus* spp.), and red maple (*Acer rubrum* L.) were the predominant species; baldcypress and swamp cottonwood (*Populus heterophylla* L.) were common in some areas as well as an occasional loblolly or spruce pine (*P. glabra* Walt.) In the past, this option may have been taken

largely by default, but there are some excellent points in its favor. In contrast to most other options which involve large expenditures for site preparation and plantation establishment, it is the least costly and poses few potential problems and risks. Species composition could be controlled in an early cleaning or precommercial thinning. In addition, regeneration of portions of the drainage project with nonpine species provides increased natural diversity and benefits associated therewith.

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