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Ecology and Silviculture of Whitecedar and Associated Hardwoods in Southern New Jersey

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ECOLOGY AND SILVICULTURE OF WHITECEDAR AND ASSOCIATED HARDWOODS IN SOUTHERN NEW JERSEY

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ECOLOGY AND SILVICULTURE OF WHITECEDAR AND ASSOCIATED HARDWOODS IN SOUTHERN NEW JERSEY

INTRODUCTION

WHITECEDAR *(Chamaecyparis thyoides)** has been called the most important timber tree growing in the pine region of southern New Jersey (Moore and Waldron 1938). Ashe (1894) considered it the most valuable wood in eastern North Carolina and one of the most valuable woods of the eastern United States. In contrast, the associated hardwoods are generally of little or no value (Anon. 1896b, Gifford 1896). Yet information concerning the successful perpetuation of whitecedar stands is incomplete, and some of it is contradictory.

The purpose of this paper is to present additional information on the ecology and silviculture of the swamp forests of southern New Jersey.

Range of Whitecedar

Whitecedar occurs in a narrow coastal belt 50 to 100 miles wide from southern Maine to central Florida and westward to southeastern Mississippi (Harlow and Harrar 1937). Within this belt the distribution of the species is patchy, depending on the occurrence of suitable sites.

In Maine whitecedar is found southwest of Penobscot Bay, occupying in York County about 1,000 acres (Neal 1940). Whitecedar stands are relatively rare in New Hampshire and in Massachusetts north of Boston (Sargent 1933). However, they are more common in southeastern Massachusetts, western Rhode Island, and the two eastern counties of Connecticut. The whitecedar stands of Connecticut vary from very small patches to areas in excess of 300 acres, occupying in all not more than 2,000 acres (Noyes 1939). Today there are only a few stands of this species in New York, and Illick (1925) states that there are no natural stands in Pennsylvania,

* An index of scientific names, arranged alphabetically by common names, may be found in the appendix of this report. Scientific names of plants follow:
Kelsey, H. P., and W. A. Dayton. Standardized plant names.
2nd ed. 675 pp. 1942. Harrisburg, Pa.

although whitecedar swamps were once numerous in parts of those two states (Benson 1937).

In New Jersey the whitecedar stands are found principally in the coastal plain. These stands cover 100,000 acres, according to Cottrell's estimate in 1930. His estimate may be high. Vermeule (1900) estimated the area in whitecedar swamps at only 52,500 acres; however, he noted that 85,100 acres of pine and hardwood swamps contained some whitecedar.

Most of these whitecedar stands are in the pine region or "pine barrens" of southern New Jersey (Stone 1911). Generally they occur in narrow belts along streams. Most of these belts are not more than 1,000 feet wide, and some of them stretch from the source of the stream all the way to tide-water (Cottrell 1929). However, some of these swamps are quite large. One, the Great Cedar Swamp, was 17 miles long in 1867, but today it is only 6 miles long and 1 to 2 miles wide (Waksman *et al. 1943).*

Outside the pine region, some whitecedar stands are found in the Cape May peninsula and in the middle district of the state, particularly in the lower part of that district. Gifford (1896) and Waksman *et al.* (1943) noted the occurrence of whitecedar in several bogs in northern New Jersey. However, whitecedar stands in that part of the state are few and isolated; they are more of botanical interest than of economic importance.

In Maryland a similar situation prevails. There some whitecedar is found in the southern part of the Eastern Shore, mostly along the Wicomico and Nanticoke Rivers (Shreve *et al.* 1910). Many of the most important commercial stands occurred originally south of Maryland, especially in Virginia, North Carolina, Alabama, and northwestern Florida (Korstian and Brush 1931). Of these southern states, North Carolina probably had the greatest amount; but Pinchot and Ashe (1897) estimated that the total area in whitecedar stands there did not exceed 200,000 acres.

ASSOCIATED SPECIES

Three hardwood species are found growing with whitecedar through much of its range. They are red maple *(Acer ruhrum),* blackgum *(Nyssa sylvatica),* and sweetbay *(Magnolia virginiana).* Red maple occurs from Newfoundland south to southern Florida and west to Michigan and Texas, and its trident variety *(trilohum)* is found in the coastal districts from Massachusetts southward (Sargent 1933). Red maple is thus a common associate throughout the entire range of whitecedar (Hawley *et af.* 1932).

INTRODUCTION

Blackgum is found from southern Maine and Michigan south to central Florida and eastern Texas (Harlow and Harrar 1937). However, Korstian and Brush (1931) list swamp blackgum *(Nyssa sylvatica bi/lora)* as a more common associate of whitecedar south of Maryland than blackgum. Sweetbay grows in swamps near the coast in one locality in Massachusetts and from Long Island southward. It changes in the Carolinas to the variety *australis,* which is found as far south as southern Florida and west to Texas (Sargent 1933). Harper (1926) reported that sweetbay was even more numerous than whitecedar in one whitecedar swamp in Florida, and Ashe (1894) reported that in North Carolina whitecedar usually occurred mixed with sweetbay.

In the pine region of southern New Jersey red maple (trident variety), blackgum, and sweetbay are the principal associates of whitecedar. Pitch pine *(Pinus rigida)* and gray birch *(Betula populi/olia)* are less common associates. In one whitecedar swamp white pine *(Pinus strobus)* occurred (Gifford 1900). On Cape May and in the middle district of New Jersey whitecedar grows in some places with sweetgum *(Liquidambar styraci/lua)*, or more rarely adjoins or even mingles with yellowpoplar *(Liriodendron tulipi/era)*.

In northern New Jersey red maple is the predominant hardwood associate. There whitecedar may occur mixed with black spruce *(Picea mariana)* and tamarack *(Larix laricina),* as in the swamp near High Point, or with hemlock *(Tsuga canadensis),* as in the swamp north of Lake Wawayanda*. White pine has also been found growing with whitecedar in a bog in northern New Jersey (Waksman *et al.* 1943).

In other states there is a large number of associated species because of the great latitudinal range of whitecedar. In Connecticut the associates include red maple, yellow birch *(Betula lutea),* white pine, and hemlock (Noyes 1939). In contrast, the associates in North Carolina include - besides red maple, sweetbay, and swamp blackgum - pond pine *(Pinus rigida serotina),* cypress *(Taxodium distichum),* redbay *(Persea borbonia),* swampbay *(P. palustris),* and loblollybay *(Gordonia lasianthus)* (Korstian and Brush 1931, Buell and Cain 1943). Many other species have been found growing with whitecedar, but apparently no complete list has ever been compiled•

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* Personal communication from E. B. Moore, New Jersey Department of Conservation and **Economic Development.**

SITE

Whitecedar always grows in wet ground or swamps. Kalm recorded this fact in 1749 (Benson 1937). Geologists, such as Cook (1857, 1868) and Kerr (1875), noted that there are usually extensive deposits of peat where whitecedar stands occur.

The depth of the peat in these whitecedar swamps varies greatly. In some places there may be little or none. For example, Waksman *et al. (1943)* found peat only in spots under the whitecedar stands near Harrisville and along Ridgeway Branch, New Jersey. In other places the depth of the peat is greatly affected by topography. In the flat terrain of southern New Jersey the same authors noted that the average depth of the peat deposits is only 2 to 3 feet; and even though these deposits cover large areas, their maximum depths are usually less than 10 feet. In contrast, in the hilly terrain of northern New Jersey some peat deposits are 20 to 38 feet deep (Waksman *et al. 1943)*.

The peats of whitecedar swamps are generally acid (Harper 1910, Wherry 1922). Korstian (1924) gave the pH of the water, peat, and subsoil as 4.5 to 5.0. However, the data of Waksman *et al.* (1943) show a wide range in the acidity of peat deposits, from a pH of 2.0 in the peat deposit of Shoal Branch to 5.0 in the top foot of peat under a whitecedar stand near Ongs Hat. The peat deposits of southern New Jersey have an average pH of 4.0. The uppermost 7 feet of peat in whitecedar swamps of northern New Jersey are also acid, with a pH between 4.0 and 5.5 (Waksman *et al. 1943)*.

The peat soils where whitecedar stands are commonly found are generally in regions of sandy soils where erosion and deposition of mineral soils from surrounding uplands are not active. Akerman (1923) observed that in Virginia the whitecedar swamps are underlain by sand, but that a mixture of red maple, blackgum, and sweetgum prevails on the peat deposits that are underlain by clay. vVaksman *et al.* (1943) found that, in New Jersey too, nearly all of the peat deposits under whitecedar stands are underlain by sand.

In contrast, the peat deposits of the Delaware Valley section in southern New Jersey generally bear hardwood stands, but in this section the soils have appreciable amounts of silt and clay. Many of the peat deposits here contain varying amounts of these materials, largely alluvial in nature.

Harper (1914) reported that in northern Florida whitecedar seems to be confined to swamps where the water contains very little mineral matter in solution or suspension. However, the data of Waksman *et al.* (1943) show a wide range in the ash content of peat deposits under whitecedar stands, indicating that locally the deposition of mineral matter may be important. Where the alluvium is mostly sand, as would be true of any deposit by streams of the pine region in New Jersey, whitecedar should occur, and apparently does (*loc. cit.* p. 217, 233), as long as moisture conditions are suitable.

All three of the principal associates of whitecedar in southern New Jersey grow on a greater range of sites. Although the varieties of red maple are characteristic of swampy areas, they are often found in drier locations (Harlow and Harrar 1937). In New Jersey red maple occurs throughout the state on moist soils of all sections (Stone 1911). Blackgum is not so widely dispersed, but is common throughout the state except in Sussex and Warren Counties (Stone 1911). It generally occurs on moist sites or in swamps, and is rather common in certain areas of the middle district that probably never supported whitecedar. Sweetbay is less widely distributed than blackgum or red maple in New Jersey, and probably elsewhere, but does occur on a greater range of sites than whitecedar. Shreve *et al.* (1910) mention the statewide occurrence of red maple and blackgum in Maryland, but describe sweetbay as being confined to the coastal zone. There it occurs in swamps having either sandy or clay soils, although it is more abundant on the sandy sites.

VALUE AND USE OF WH1TECEDAR

History Of Utilization

The value of whitecedar was early recognized. It was among the first timber cut in the pine region of New Jersey. According to Hall and Maxwell (19II), cutting was "in full blast" in New Jersey early in the 18th century. Kalm, writing in 1749, stated that, besides being used in New Jersey for many purposes, whitecedar had been heavily cut for export. Nearly all the houses in Philadelphia were roofed with whitecedar shingles, and great quantities of shingles and other whitecedar products were then being exported to New York and the West Indies (Benson 1937). In 1758 whitecedar products formed about 20 per cent of the exports from Cape May County (Cook 1857:192).

The heavy use of whitecedar in colonial times was criticized, and fears of exhausting the supply were freely expressed (Hall and Maxwell 1911).

Kalm declared (in 1749) that the inhabitants of New Jersey were not only lessening the number of whitecedar trees, but even extirpating them entirely. He believed that most of the houses in New Jersey and Philadelphia would have to be rebuilt to support the weight of heavier shingles, because there would be no whitecedar timber available for replacements (Benson 1937). Possibly as a result of such prophecies, Charles Read sponsored an act in 1759 to prevent the waste of timber, specifically mentioning whitecedar trees (Woodward 1941 :139).

Although Smith, along with many others, considered in 1765 that there were hardly any merchantable stands of whitecedar left, the quantities removed from the swamps of southern New Jersey during the following (19th) century were immense. Much of the material cut during that period must have been second growth. By 1857 many of the swamps of Cape May County had been cut over twice, and some three times, and not a single acre of original growth was left. Still thousands of rails and sawed lumber were being annually exported, and these from two townships alone were valued in 1855 at $40,000 (Cook 1857). During the latter half of the 19th century the high demand for whitecedar continued, and stands of even smaller trees than those previously harvested were probably cut..In 1896 it was reported that whitecedar logs 3 inches in diameter were being sawed into lath, and 6-inch logs into shingles and siding (Anon. 1896a). It was during the 19th century that the mining of whitecedar logs buried under peat deposits flourished in parts of southern New Jersey. These logs were found to be relatively sound and were raised and split into rails and shingles (Cook 1868, Hall and Maxwell 1911).

Close utilization of the whitecedar swamps of southern New Jersey has continued into this century, and has even been intensified. Stone (1911) stated that the portable sawmills were sounding the doom of whitecedar swamps. Cottrell (1930) observed that whitecedar was of less importance in the annual cut of the state than it had been 25 or 50 years earlier, largely because merchantable stands had been so heavily cut. In this connection, it should be noted that continued lowering of the standards of merchantability has resulted in many stands being clear-cut today for round, rather than sawed, products.

The utilization of whitecedar stands in southern New England has been similar to that in New Jersey. In eastern Connecticut 50 to 100 years ago, landowners considered whitecedar such a valuable tree that practically every farmer owning land near a whitecedar swamp desired ownership of even fractions of acres of the swamp (Noyes 1939). Heavy utilization is still continuing in most sections of New England where whitecedar occurs, although in some places the small remaining quantities are not in great demand because both loggers and consumers are no longer familiar· with the wood. This is true in Maryland, also.

In Virginia and North Carolina, and farther south, the drain has probably not been so severe as in New Jersey. Hall and Maxwell (1911) mentioned that whitecedar was being used for various purposes in the Carolinas 200 years ago. However, Pinchot and Ashe could still say in 1897, that, although the *original* growth was being rapidly removed from the most accessible swamps of North Carolina, there still remained large quantities in the then inaccessible areas.

Uses Of Whitecedar

The light weight and durability of whitecedar wood has fitted it for a variety of uses. The earliest uses included canoes, fences, houses, and farm buildings; later uses were for floors, joists, doors, frames, rafters, and especially shingles. Tanks for whale oil and later for railroads were once made of whitecedar, and churns, pails, firkins, and washtubs of this wood were popular. Other uses included poles, paving blocks, fence posts, piling, boat boards, house and boat finish (Hall and Maxwell 1911). Korstian and Brush (1931) mention also the production of siding, lath, boxes and crates, and woodenware from whitecedar.

Today in New Jersey the wood is used for boat boards, shingles and lath, and in the round for beanpoles, shade-tree stakes, arbor poles, fence posts, poles, and cabin logs (Moore 1939). Some is also consumed in making rustic furniture, rustic fences, and interior finish. Relatively few boat boards are now produced because they are obtained from the large logs of high quality which, for the most part, are no longer available. The production of shingles is likewise limited by the small size of trees in the many stands that are harvested at an early age, primarily for round products.

Value Of Whitecedar Stands

The value of whitecedar stands has varied through the years, partly because of the fluctuating value of the dollar and partly because of the relative quality and availability of other woods. Gordon (1834) stated that in New Jersey the whitecedar swamps were in great demand and sold readily at from $100 to $300 an acre. Cook (1856) wrote that stands more than 60 years old had a value of $400 to $1,000 an acre, and he thought that some acres may have yielded a still larger sum. In 1885 Cook said that one stand 70 years old had sold for $800 an acre. More recently values have been somewhat less in New Jersey, where Korstian and Brush (1931) stated that good stands bring $150 an acre. That was about the usual price in 1938 for a good stand 50 years old.

Value and Use of Associated Species

The principal associates of whitecedar in New Jersey are of far less value. Although Sargent (1933) stated that red maple is used in large quantities in the manufacture of furniture, woodenware, turnery, and gun-stocks, the red maples of the pine region have seldom been harvested. On the poor sites prevailing there this species is usually defective, even though it is relatively sound on the good soils of the middle district. In the transitional areas the maple may also be sound enough to warrant cutting for lumber or pulpwood. However, on most of the sites where it grows associated with whitecedar in New Jersey, the generally defective maples are suitable only for firewood, temporary corduroy, and other uses that will hardly, or not at all, pay the cost of removal.

Blackgum is another species of low value that is harvested to some extent for certain specialized uses. Possibly the high cost of removal from the swamps of the pine region so lessens its value as to account for the usual lack of cutting of this species. Sweetbay, the third principal associate of whitecedar, is utilized to some extent in the South (Sargent 1933), but not in New Jersey.

From the preceding paragraphs it is evident that whitecedar is or could be of appreciable economic importance in several localities. On the other hand, the associated species are of little or no value — neither bringing the landowner a profit nor providing the many hours of profitable labor in harvesting, removing, and manufacturing wood products, as does whitecedar. The great difference in value makes knowledge of the ecology and silviculture of these species of prime importance in such areas as southeastern New Jersey.

SILVICAL HABITS

CERTAIN of the silvical habits of whitecedar and of the associated species can be best discussed before considering the interacting effect of the various species and their habits.

SILVICAL HABITS OF WHITECEDAR

Seed Production, Distribution, And Viability

Production

Whitecedar seedlings bear mature cones at an early age. Gifford (1895) noted that it is not uncommon to find a whitecedar 3 feet tall bearing cones. The youngest tree that Pinchot (1899) found bearing seed was 13 years old. Korstian (1924) reported seed production by seedlings 3 to 4 years old, although in 1931 he said that seed production began in open stands at 4 or 5 years and in dense stands at 10 to 20 years (Korstian and Brush 1931).

Some examples of the early production of cones have been observed recently in New Jersey by the author. The youngest natural seedling found bearing mature cones was 7 years old and 0.8 foot tall. Others ranged in age from 9 to 22 years and in height from 0.9 to 4.2 feet.

The age at which seed is first borne appears to vary greatly, depending on growing conditions, size and vigor of seedlings, and similar factors. Seedlings grown in the nursery and then planted in the field tend to produce seed earlier than natural reproduction. In one study involving the planting of 1,300 2-0 whitecedar seedlings in the spring of 1942,2 per cent of the trees bore mature cones at the end of the first growing season in the field. The maximum number of cones borne by a tree was 14. Similar stock planted in 1946 produced even more cones at the end of the first year in the field. In one plot 20 per cent of the seedlings bore one or more cones, and one tree had 64. However, these seedlings averaged 0.92 foot tall. Where the seedlings were only 0.35 foot tall they did not produce any cones.

The number of cones produced depends on the size of trees and growing conditions. Large trees produce more cones than small ones. Trees growing in the open tend to produce more cones than those in clumps, although dominant trees in clumps may be as prolific as open-grown trees of the same size. The data of Table 1 indicate the differences in cone production that may be expected because of size of trees and the competition they encounter.

TABLE I.— CONE PRODUCTION OF WHITECEDAR IN RELATION TO SIZE OF TREES AND THEIR COMPETITION*

Size of trees	Trees growing in open			Trees growing in clumps		
	Basis, number of trees	*Range in number of cones*	*Average number of cones*	*Basis, number of trees*	*Range in number of cones*	*Average number of cones*
By height (feet):						
1.6-2.5	9	0-2	0.2	1	—	0
2.6-3.5	10	0-3	0.3	0	—	—
3.6-4.5	3	0-4	1.7	0	—	—
4.6-0.5 in. d.b.h.	20	0-201	52.	7	0-17	4
By d.b.h. (inches):						
0.6-2.5	7	146-3,347	728.	30	0-2,198	218
2.6-4.5	9	326-7,825	2,891.	18	24-8,708	1,074
4.6-7.5	7	652-9,265	4,218.	13	351-26,176	4,540

* All trees growing in a dry swamp on Leon sand. All stems less than 0.6 inch d.b.h. had been injured by the browsing of deer.

The amount of seed produced varies somewhat from year to year. Most authors have been content to call whitecedar a prolific producer of seed (Ashe 1895, Gifford 1895) or to state that large crops of seed are borne nearly every year (Pinchot and Ashe 1897, Korstian and Brush 1931). Cottrell (1929) observed that some seed was produced annually, but large crops less frequently. N. T. Kessler, who for several years has supervised the collection of seed for use in the nurseries of the New Jersey Department of Conservation and Economic Development, states that a fair amount is borne each year, and that good or excellent crops occur at about 2- or 3-year intervals.**

The abundance of seed produced by whitecedar is indicated by data from an earlier study (Little 1940). Under a mature whitecedar stand the catch in four seed traps, each 4 feet square, was at the rate of 8 million seeds per acre from the 1937 crop and 9 million from the 1938 crop.

Period Of Seed Dispersal

Seed dispersal starts early in the fall, and most of the seed is released before the end of the winter. The dispersal begins about October 15 and continues during each month of the year, but 39 per cent of the crop falls by November 15 and more than 60 per cent by December 15. The peak of

** Personal communication.

seed fall in 1937 occurred between October 23 and November 2, and in 1938 between November 2 and 12. In both years 93 or 94 per cent of the seeds caught fell before March 1; the remainder were released during the remaining months before the next crop started to fall (Little 1940).

Within these broad periods, seed dispersal fluctuates greatly because of the influence of weather. Within a period of 10 days in November 1937, the number of seeds caught at 2-day intervals ranged from 637 to 61 and, within a similar period in December of the same year, from 437 to 6 (Wood 1938). Attempts to correlate seed fall with temperature or relative humidity were unsuccessful, but high winds did increase the quantity of seed that fell. However, in contrast to shortleaf pine *(Pinus echinata)* which sheds seed only on fair days, whitecedar dropped seeds, although at a reduced rate, during rainy weather (Little 1940). Observations showed that light rainfalls of 0.15 inch or less did not cause the complete closing of whitecedar cones, but that heavier rainfalls (0.45 inch) did.

Distribution Of Seed

The small, winged seeds of whitecedar may be widely distributed by the wind (Gifford 1895). In wet swamps some seed may also be scattered by floating (Akerman 1923).

The distance to which wind carries seed can be computed. The late H. W. Siggins of the California Forest Experiment Station determined that the average rate of fall of whitecedar seed in still air was 0.6 foot a second. On this basis Korstian and Brush (1931) estimated that *most* of the seed from a 50-foot tree will be carried about 600 feet by a 5-mile wind, and that seed from a 70-foot tree will be carried approximately a mile by a 30-mile wind.

However, other factors must be considered. The most important one is the density and height of surrounding vegetation. In dense stands of whitecedar most of the seed apparently falls directly under the stand. The extent to which seed is carried beyond these stands depends greatly on the density and height of surrounding vegetation.

Unless the whitecedar stands are bordered by open areas, very little seed is carried beyond the edges of the stands. In 1940, seed traps were installed under two whitecedar stands and at 1-chain intervals in three directions from these stands. Each trap was 1/16 milacre in size. The whitecedars of both stands were about 40 feet tall. The surrounding vegetation was typical of the pine swamps of southern New Jersey, grading into the oak-pine stands of upland sites. None of this vegetation was removed, except shrubs or small arborescent sprouts at the exact location of the traps. Although 1940 was a poor seed year, the catch under the edges of the stands was between 31 and 48 seeds per trap, or at the rate of 496,000 to 768,000 per acre. However, only three seeds were caught beyond the edges of the stands. Although the traps extended for 6 chains from the stands, these three seeds were all in traps located only 1 chain from the edges of the stands.

The distribution of whitecedar seed is also greatly affected by the direction of the prevailing winds. The three seeds caught beyond the edges of the stands in the 1940 study were all found in traps on the east side. This effect of wind direction is shown more clearly by the distribution of seed from the 1941 and 1942 crops. Then 1/16-milacre traps were located around two isolated whitecedar trees, one 20 feet tall and the other 30 feet tall. The traps were situated 5 feet from the bole on the north, east, south, and west sides, and at distances equal to half the height of the tree, its height, twice its height, and three times its height in the eight principal directions. The traps on the three easterly lines received 69 to 75 per cent of the total seed catch (Table 2). In fact, if the tree is considered as the center of a circle, 80 to 85 per cent of the seed catch was in the eastern half. Evidently westerly winds prevail during the distribution of whitecedar seed.

TABLE 2.—DISTRIBUTION OF SEED CATCH FROM ISOLATED TREES, BY DIRECTION FROM SOURCE*

Height of tree (feet)	*Seed crop*	*Direction from seed tree*							
		N	*NE*	*E*	*SE*	*S*	*SW*	*W*	*NW*
					Per cent of catch				
20	1941	8	21	28	26	5	2	6	4
	1942	18	18	25	26	4	2	3	4
30	1941	9	21	29	24	5	5	1	6
	1942	13	13	28	29	6	2	4	5
Approx. average		12	18	28	26	5	3	3	5

* Limited to seed falling 10 feet or farther from trees.

The importance of westerly winds apparently results from a combination of weather factors, including precipitation, drying conditions, wind velocity, and relative frequency of wind directions prevailing during periods of seed fall. This last factor may produce minor variations in seed distributions during different years; and it was perhaps the cause of more seed being caught on the north side of the trees in 1942 than in 1941 (Table 2).

However, precipitation and drying conditions are important. In southern New Jersey east and northeast winds are usually accompanied by high humidities and precipitation. Although the small cones of whitecedar are not so readily affected by high humidities and moistening as those of shortleaf pine and pitch pine, even whitecedar cones tend to open no farther or, under appreciable moistening, to close. Because the prevailing winds are from the west during fair weather, when opening of cones occurs, they direct the bulk of whitecedar seed to the eastern side of the source.

If there is no impeding vegetation, much of this seed may be carried to distances greater than the height of the tree. Although traps 5 feet from the isolated seed trees caught three to four times as many seeds as the traps located at a distance equal to the height of the trees (Table 3), these latter traps obviously sampled a much greater area. When area is considered, the data in Table 4 indicate that-despite the heavy seed catch close to the seed tree-at least 60 per cent of the seed falls at a distance beyond that equal to the height of the tree.

However, for practical purposes the important fact is that seed fall per unit of area decreases greatly as distance from the seed source increases. For example, 85 seeds of the 1942 crop were caught in the trap 5 feet east of the 3o-foot tree, 38 seeds at 30 feet, 9 seeds at 60 feet, but only 1 at 90 feet.

Viability Of Seed

The viability of whitecedar seed in New Jersey may be somewhat less than that of seed in other regions. Germination of 70 to 90 per cent was reported by Korstian and Brush (1931) for seed from North Carolina and Virginia. In 1940 the New Jersey Department of Conservation and Economic Development provided half a pound of seed for studies on germination and storage at the Boyce Thompson Institute. Miss Lela V. Barton of that Institute reported that, on the basis of cutting tests, only 8 per cent of the seeds contained embryos and that the desired tests on germination and storage would not be worth while*. These seeds were from the poor seed crop of 1940.

In contrast, cutting tests on seeds of the 1941 crop indicated that 31 to 53 per cent of the seeds, or an average of 40 per cent, contained embryos. These tests were made by the Northeastern Forest Experiment Station on

* Letter in the files of the Northeastern Forest Experiment Station.

TABLE 3.—RATIOS OF AMOUNT OF SEED CAUGHT AT VARYING DISTANCES FROM ISOLATED TREES

Height of tree (feet)	*Seed crop*	*Ratio of seed catch at the following distances from tree —* 5 feet	*One half tree height*	*Height of tree*	*Twice tree height*	*Thrice tree height*
20	1941	14	10	3	1	—
	1942	13	9	5	1	0.5
30	1941	16	11	6	1	—
	1942	12	7	3	1	0.2
	Average ratio	14	9	4	1	0.3

TABLE 4.—DISTRIBUTION OF SEED FROM ISOLATED TREES FOR DISTANCES INCLUDED IN THE STUDY, IN PER CENT

Height of tree (feet)	*Seed crop*	*Distribution of seed at the following distances —* Within 5 feet of tree	*Between 5 feet and half tree height*	*Between half tree height and tree height*	*Between tree height and twice tree height*	*Between twice and thrice tree height*
20	1941	6	16	34	44	—
	1942	4	10	25	44	17
30	1941	2	14	31	53	—
	1942	2	14	24	41	19

four lots of 100 seeds each. Actual germination of this 1941 seed in field and greenhouse varied, but showed higher viability than the cutting tests had indicated. Germination in the field reached about 50 per cent on the most favorable site, and in the greenhouse 76 per cent.

The viability of seed produced by very young whitecedars was also investigated. In 1943, 60 seeds were gathered from seedlings 4 years old; 25 per cent of these seeds germinated before August 1 of the following growing season. In the fall of 1946 five lots of 200 seeds each were collected from planted seedlings 3 years old. These lots of seed were placed in separate cloth bags, which were then buried under sphagnum moss in a swamp in southern New Jersey. On January 14, 1947, the seeds were sown in a sand flat in a greenhouse at Marsh Botanical Garden, Yale University. Germination prior to May 1 varied from 3.0 to 10.5 per cent, averaging 6.6 per cent.

Further evidence that some of the seed produced by very young whitecedar trees is viable is presented by the development of seedlings around planted stock in areas lacking other sources of seed, as in Neiserfield Branch, Belleplain State Forest.

Delayed Germination And Storage Of Seed In The Forest Floor

It appears that much of the whitecedar seed will germinate fairly promptly if (1) it has been stored for some time in a cool, moist medium such as the moss or peat of a swamp during the winter months, and (2) germination conditions are suitable. Usually neither of those requisites are wholly met, either in a nursery or on open swamp areas; even if they are, some seeds will not germinate before the second spring. This tendency to delayed germination of whitecedar seed was first mentioned by Emerson (1846).

Moore (1939) reported that the tendency of the seed to delay germination made the growing of nursery stock rather uncertain. To some extent this has been overcome in the Green Bank Nursery of the New Jersey Department of Conservation and Economic Development by sowing the seed in the fall; but even now about half of the germination does not occur until the second year. Thus present results-although considered satisfactory -are not good.*

Under natural conditions some of the tremendous amounts of seed produced by mature whitecedar stands remain viable, stored in the forest floor, for an unknown length of time. Moore (1939) stated that the seed remains viable there for many years. Korstian (1924) had seedlings start at the rate of 2,571,780 per acre when he sampled the top inch of peat from a mature whitecedar forest and spread the peat out under ideal conditions for germination; and from the underlying inch of peat germination was at the rate of more than 1,568,150 per acre. From an area cut clean the previous year and more than 100 yards from the nearest seed trees, he obtained seedlings from the upper inch of peat at the rate of over 3,575,840 per acre.

Similar tests were made by the author in New Jersey, and they also indicated large amounts of viable seed stored in the forest floor. For example, the top inch of forest floor under one mature whitecedar stand was sampled in the spring of 1941, and from this whitecedar seedlings germinated at the rate of more than 1 million per acre, even though 1940 had been a poor seed year. In addition, four spots 18 inches square were selected and marked under each of three mature whitecedar stands on October 4, 1940. Half of these spots were screened to keep out seed from the 1940 crop. The center 6-inch square of each spot was removed on September 18, 1941, and the peat was spread out on sand flats in a greenhouse at Marsh

* From information furnished by N. T. Kessler and C. F. Terry of the New Jersey Department of Conservation and Economic Development.

Botanical Garden, Yale University, for germination tests. Greater germination occurred in the samples from screened spots than in those from the unprotected spots. This is attributable to a combination of two factors. First, the screens apparently reduced germination in the screened spots during the summer of 1941; second, because the 1940 seed crop was poor and that of 1939 good, germination in the unprotected spots may not have been offset by addition of new seed. However, the important information from the test was that after two growing seasons without the addition of appreciable amounts of fresh seed, or 1 year of absolute exclusion of seed, the surface inch of forest floor may contain 260,000 to 1,100,000 viable seeds per acre, and the underlying 2 inches of peat may have 260,000 to 950,000 per acre.

Establishment Of Seedlings

Direction And Distance From Seed Source

Distance and direction from a seed source greatly affect the establishment of whitecedar seedlings in southern New Jersey (Fig. 5). Because of the prevailing westerly winds, whitecedar reproduction extends rather slowly to the westward of a stand and, for distances as small as 60 feet, fairly large trees are necessary as a seed source (Table 5). In contrast, on the eastern or leeward side of seed sources the establishment of whitecedar seedlings is favored. The data already presented on seed distribution indicate that this effect of direction on seedling establishment was to be expected.

Size Of Trees Forming Seed Source

The size of trees forming the seed source is another highly important factor affecting seedling establishment. Large trees not only produce more

TABLE 5.-AMOUNT AND EXTENT OF WHITECEDAR REPRODUCTION ON OPEN AREAS IN RELATION TO DIRECTION AND SIZE OF PARENT TREES*

Stream branch	*Direction of line*	*D.b.h. of dominant trees on edge of stand*		*Seedlings per acre at the following distances from edge of stand -*		
		Range	*Average*	0.1-0.5 *chain*	0.6-1.0 *chain*	1.1-1.5 *chainr*
		Inches	*Inches*	*Number*	*Number*	*Number*
McDonalds	NW	1-5	3	22,400	0	0
	W	3-6	5	64,000	0	0
Shinns	W	5-13	8	99,200	35,200	0
	W	4-15	11	198,400	48,000	0
Coopers	NE	1-8	4	51,200	46,400	12,800

* Data based on 1/16-milacre quadrats at intervals of 0.1 chain. All quadrats were on hummocks, and seedlings limited to those of current year.

seed than small trees (Table I), but their greater height aids in the wider distribution of seed. Hence, the size of trees forming the seed source greatly affects the rate of establishment of whitecedar reproduction in neighboring open areas of swamp (Table 5).

Moisture Relations

Akerman (1923) was probably the first person to describe in detail the importance of the microrelief of swamps in providing suitable seedbeds for whitecedar. He pointed out that only the moss-covered logs, stumps, or hummocks that are above the water level form favorable seedbeds during the periods of high water common during the spring and early summer, but that seedlings starting there may later die from lack of moisture during the dry periods of late summer or fall. On the other hand, seedlings starting in the low places are often drowned during subsequent periods of high water. Akerman concluded that seedlings originating midway between the top and base of stumps had better survival than those starting either on the top or near the base. He also reported that root development by the end of the first growing season began to make the seedlings resistant to damage by drought, but that they did not begin to be free from the danger of drowning until after the second growing season. Then many were more than a foot tall.

Excessive water in the swamps of New Jersey has often killed many whitecedar seedlings. One such case was reported in 1939 (Anon. 1939).

Water levels fluctuate more in some swamps than in others, and consequently the effect of microrelief on the establishment of whitecedar seedlings varies among swamps. For example, the hollows of one area had only 8 per cent as much reproduction as occurred on the hummocks, whereas in a similar area the hollows had 25 per cent (Table 6).

Pinchot (1899) observed that there is generally a more complete reproduction in dry swamps than in wet swamps, chiefly because of the amount of standing water in the latter. Harshberger (1916) made a similar observation; but he said the cause was that standing water prevented the germination of seed. The data of Table 6 indicate that Pinchot's statement is as valid today for the "true swamps" as when he wrote it. Hollows with standing water (as in areas 1 and 2, Table 6) usually have no reproduction. Hence, where these form a large part of the swamp there are a similar number of gaps in the stocking of reproduction.

On the other hand, relatively dry swamps, such as those commonly stocked with pitch pine, provide too little moisture for good germination of whitecedar seed and rapid growth of seedlings. In one experiment whitecedar seed was sown in the late fall in both hardwood and pine swamps. Germination by the following June was 49 per cent in open areas of the hardwood swamp, three times that on scalped spots in similar areas of the pine swamp.* Dominant seedlings at the end of the first growing season were also three times as tall in the hardwood swamp as in the pine swamp. During the first growing season planted seedlings grew an average of 1.1 feet in the open areas of the hardwood swamp, compared to 0.4 foot in similar areas of the pine swamp. Evidently the moister sites of the hardwood swamps favor the establishment and growth of whitecedar seedlings more than do the relatively dry, sandy sites of the pine swamps.

TABLE 6.—AMOUNT OF WHITECEDAR REPRODUCTION IN RELATION TO ELEVATION ABOVE WATER TABLE**

Area number	*Seedlings per acre* (1) *On hummocks*	(2) *In hollows*	*Relation of* (2) to (1)	*Average elevation above or below water table* *Hummocks*	*Hollows*
	Number	*Number*	*Per cent*	*Feet*	*Feet*
1	492,800	0	0	0.85	—0.49
2	41,600	0	0	0.66	—0.34
3	566,400	9,600	2	0.78	0.00
4	188,800	4,800	3	0.55	0.00
5	166,400	16,000	10	0.46	0.00
6	32,000	0	0	0.78	0.06
7	320,000	38,400	12	0.70	0.10
8	75,200	30,400	40	1.02	0.29
9	161,600	12,800	8	0.93	0.35
10	76,800	19,200	25	0.98	0.36

** From reproduction surveys.

Type Of Seedbed

Seedbed conditions, also, greatly affect the germination and establishment of whitecedar seedlings. Whitecedar, like pine, develops a rather short, weak taproot from the small amount of reserve food in the seed; thus, for successful establishment of seedlings there should be suitable moisture for germination of the seed and, within reach of the roots, for continued survival of the seedling.

* Detailed descriptions of this and other experiments, and of the areas studied, are given in the original manuscript, presented as a doctoral dissertation, on file in the Sterling Memorial Library and Library of the School of Forestry, Yale University.

Suitable seedbeds include rotten wood, peat, and sphagnum moss. These are usually present in the true swamps. Only under dense stands of hardwoods are there occasional patches of litter that might be considered an unfavorable seedbed. On the drier sites of the pine swamps far fewer favorable seedbeds occur, because in most places a thick litter of pine needles and leaves of shrubs and hardwood trees accumulates. This forest floor greatly reduces the germination of whitecedar seed. On untreated spots of one study the germination was less than 1 per cent (Table 7). Removal of the forest floor to expose the mineral soil raised the rate of germination to 13 per cent (Table 7), but even this was less than occurred on the moister sites of a nearby hardwood swamp.

TABLE 7.-GERMINATION IN JUNE OF WHITECEDAR SEED SOWN THE PREVIOUS FALL ON SCALPED AND UNSCALPED SPOTS IN A PINE SWAMP*

Stand treatment	*Germination on -*		*Stocking of-*	
	Scalped spots	*Unscalped spots*	*Scalped spots*	*Unsealped spots*
	Per cent	*Per cent*	*Per cent*	*Per cent*
Cutting of:				
Woody plants more than 2 feet tall	16	0.3	81	5
Trees more than 2 in. d.h.h.	17	0	96	0
Woody plants between 2 ft. tall and 2 in. d.b.h.	9	0.2	65	5
No cutting (controls)	10	0.04	81	2

* Each value based on 50 seeds sown on each of 100 spots.

The unfavorable effects of dense slash upon the establishment of an adequate amount of whitecedar reproduction have been described by Akerman (1923), Korstian (1924), and Korstian and Brush (1931). Korstian and Brush reported that whitecedar seedlings formed dense stands in cleared areas between masses of slash, but that few seeds germinated and still fewer seedlings survived under dense slash. In this connection they presented a table showing that on areas covered with dense slash after logging there were only 135 to 157 whitecedar seedlings per acre 1 to 8 years later, compared with 4,000 to more than 12,000 on areas cleared of slash.

Although Cottrell (1929) reported that slash did not interfere with reproducing whitecedar in New Jersey, recent surveys show that slash may be important there in limiting the establishment of whitecedar seedlings. Surveys of two cut-over areas showed that the stocking of whitecedar reproduction was excellent where they were not covered with slash after logging (Table 8). The spots relatively free of logging debris had 30 to 40 times as many seedlings, and there the tallest seedlings were 2 to 4 times as large as on the slash-covered portions. Furthermore, because slash was left on more than 40 per cent of one area and 50 per cent of the other, the effect of slash in reducing the establishment of whitecedar seedlings is highly important.

Corduroy roads also are unfavorable seedbeds, but are relatively unimportant because they cover only a small part of the cut-over areas. In these two swamps the corduroy occurred on only 2 to 5 per cent of the total area.

TABLE 8.-WHITECEDAR REPRODUCTION ON CUT-OVER AREAS IN RELATION TO SEEDBED CONDITIONS LEFT AFTER LOGGING*

Time since cutting	Type of seedbed left after cutting	Present condition of seedbed		Whitecedar reproduction		
		Area covered by slash or corduroy	Average depth of slash or corduroy	Stocking of quadrats	Number per acre	Average height of tallest seedlings
Years		Per cent	Feet	Per cent	Number	Feet
6	Mostly free of slash	5	0.1	98	94,720	1.7
	Covered with slash	95	.8	18	2,880	0·5
	Corduroy road	95	·4	18	6,080	·4
5	Mostly free of slash	4	.1	98	152,960	1.2
	Covered with slash	93	1.0	12	3,840	0·5
	Corduroy road	99	0·5	10	1,920	.2

* Each value is based on 50 quadrats. Each quadrat was 1/16-milacre in size, and all were so located as to exclude standing water.

Whether corduroy is a more favorable seedbed than the spots covered with slash apparently depends on its method of construction. For example, in the swamp logged 6 years ago there was more whitecedar reproduction on the corduroy road than in the spots covered with slash (Table 8). There smaller poles were used in constructing the road than in the area logged 5 years ago. In addition, in the latter area sawdust and other fine mill waste were spread on top of the corduroy. This waste has not decomposed enough nor does it remain moist enough to form a satisfactory seedbed. Hence, in that swamp the establishment of whitecedar reproduction has been less on the corduroy road than in the spots covered with slash (Table 8).

There is one interesting difference between the data recently obtained in New Jersey and those obtained in Virginia and North Carolina by Korstian and Brush (1931). In their study logs were removed from the swamp along rollways and tramways, in neither of which were logs or poles packed closely together as in the corduroy roads built for trucks. After the completion of logging, some logs used in the foundation of rollways or tramways might be left, but the number was not great. As these ways were kept free of slash, they formed a very suitable seedbed for the establishment of whitecedar seedlings. The old rollways and tramways could often be traced by the dense reproduction coming up in them (Akerman 1923). But in New Jersey, where corduroy roads are built to permit removal of logs by trucks, these ways do not offer the best seedbed for reproduction, but rather one of the worst.

Vegetative Reproduction

Whitecedar sometimes develops shoots from lateral branches or dormant buds when seedlings or saplings have been injured. Whitecedar seedlings that have been injured by animals may form new shoots from dormant buds either in the crown, as after severe browsing by deer, or at the base. One whitecedar seedling girdled by meadow mice subsequently produced 26 sprouts 1 to 4 inches long from its base. Sometimes whitecedar seedlings that have been repeatedly browsed by deer develop into multiple stems through layering. From one such seedling, only 3 feet tall, fourteen additional stems 0.5 to 3.3 feet tall had developed.

Maximum Size And Age

The maximum size and age that whitecedar attains are now mostly a matter of botanical interest and historical record. Cook, writing about New Jersey in 1868, noted that there was no first growth of whitecedar left and hence there were few trees known to be more than 100 years old. Most of the stands were then being cut when the trees were 60 years old. He did state that Charles Ludlam had counted 700 rings in one tree when it was cut, Dr. Beesley had counted 1,080 rings in a stump that was 6 feet in diameter, and J. Diverty had counted 1,000 rings in a log dug out of a swamp. Cook concluded that the average diameter of the old trees in the original forest was 2 to 3 feet; those 4 to 7 feet in diameter were rare.

Maximum size of whitecedar was apparently greater in the South and less in New England than in New Jersey. Schoepf, writing about 1784, mentioned that in North Carolina on the south side of Albemarle Sound whitecedar often developed trunks 60 to 100 feet long and 12 to 15 feet in circumference at the butt (Morrison 1911). Harlow and Harrar (1937) stated that whitecedar on good sites averages 80 to 85 feet in height and 10 to 14 inches in diameter, attaining a maximum size of 120 feet in height and 5 feet in diameter. In Alabama whitecedar attains heights of 80 to 90 feet with average diameters of 16 to 18 inches, diameters over 24 inches being rare (Mohr 1901). In the northern part of its range the maximum heights are undoubtedly less than in North Carolina and Virginia. The average height of mature trees in Connecticut is not much more than 40 feet, although occasional trees have reached 60 feet, and only a few trees have diameters exceeding 16 inches (Noyes 1939). However, some of the old trees in the original forest of southern New England had diameters of more than 2 feet. Bartlett (1909) mentioned buried logs and stumps of whitecedar exposed along the shore near Woods Hole, some of which were between 3 and 4 feet in diameter.

Trees of a similar size could apparently be produced again if cutting were prohibited. The intensive utilization—and not a change in climate as Raup (1937) implied—is undoubtedly the main reason why the whitecedars of today are generally smaller than the logs and stumps found buried in peat. Large, old stems are occasionally located today, their existence substantiating to some extent the view that the size of the trees in the original forest was chiefly due to their great age. J. C. MacDonald of the New Jersey Department of Conservation and Economic Development reports that there had been, until recently, one whitecedar tree 5 feet in diameter living in the Great Swamp of the Green Bank State Forest.* A tree of nearly the same diameter is still living on nearby private land.**

In New Jersey, and possibly in southern New England, it appears probable that some stands of whitecedar in the original forest lived to be about 200 years old and reached average diameters of 2 to 3 feet. The heights that these trees attained is questionable, but probably was between 50 and 70 feet, varying with locality and site.

Silvical Habits Of Associated Species

Seed Production, Distribution, And Viability

Red maple is a prolific producer of seed, although not so prolific as whitecedar. Sweetbay produces less seed than maple, but still bears seed in

* Personal communication.

** According to H. A. Somes, Northeastern Forest Experiment Station.

what would seem to be abundant amounts. Blackgum should apparently be classed among the poorer seed producers of the forest trees. In some years its low production of fruit may be due in part to killing of flowers by late frosts (Little 1941).

Both red maple and sweetbay bear seed at a rather early age, particularly when originating as sprouts in the open; but only under such conditions may these species produce seed at as early an age as whitecedar. Sprouts of both hardwoods have been observed bearing appreciable amounts of seed when the stems were only 1 inch in diameter. Sweetbay and red maple also tend to produce a fair amount of seed each year, while blackgum produces seed crops less regularly.

The seeds of red maple mature in the spring, usually in early May in southern New Jersey. During one 3-year period the dispersal of red maple seeds began about May 12 and ended May 21, although there was an occasional sheltered tree that retained a few seeds until June 8 (Little 1941). The seeds of red maple are distributed largely by wind and to a minor extent by water. There are about 18,420 to the pound compared with 2,840 drupes of blackgum (Tourney and Korstian 1942). The fleshy fruit or drupes of blackgum mature in late summer and their dispersal occurs mostly between September 19 and October 24 in southern New Jersey (Little 1941). However, some may persist until May (Van Dersal 1938). The fruits of blackguin either fall to the ground beneath the parent tree or are scattered by birds that pick them from the tree (Tourney and Korstian 1942).

Sweetbay seeds also mature in late summer, and most of them are dispersed in the fall, the seeds falling individually or still grouped together in the fleshy cone. Some distribution of sweetbay seeds by birds during the fall and winter seems probable; at least Stoddard (1931) mentioned that seeds of one of the species of magnolia were found in the analysis of stomach contents of adult quail. The seeds that are not eaten are, like those of blackgum, probably moved but short distances from the parent tree by either wind or water.

The seeds of red maple are reputedly short-lived. According to Harlow and Harrar (1937), these seeds germinate immediately; vitality is only transient. However, an occasional seedling of red maple will start from samples of the forest floor collected in the fall or winter from the swamps of southern New Jersey. The germination of red maple seed is given by Van Dersal (1938) as 70 per cent and by Tourney and Korstian (1942) as 72 per cent; but in one phase of this study seeds of red maple germinated at rates as high as 96 per cent.

The seeds of sweetbay and blackgum probably remain viable to some extent in the forest floor of a swamp for longer than 1 year, although no specific information is available. Tourney and Korstian (1942) have stated that the seeds of magnolias and blackgum, which are very slow to germinate, often lie over until the second year; but some germinate a few weeks after seeding. Their statement may partly account for the results obtained in a study started in 1941. Then cutting tests on 100 seeds of sweetbay indicated that about 90 per cent contained embryos; but actual germination in the greenhouse did not exceed 18 per cent. No data on the viability of blackgum seed have been noted.

Establishment Of Reproduction

Some information on the establishment of all three hardwood species, as influenced by moisture conditions and other factors, was obtained in studies that dealt with the relative requirements of these species and whitecedar. That information is given in a later section covering the relations among all species.

Red maple, blackgum, and sweetbay all sprout vigorously, far more vigorously than does whitecedar.

Maximum Size And Age

Red maple may attain a height of 100 feet or more, when growing in the forest, with a trunk 3 or 4 feet in diameter (Hough 1907). Red maples mature at 70 or 80 years, although some individuals may reach an age of ISO years (Harlow and Harrar 1937). Blackgum develops to about the same size as red maple (Hough 1907). The two species probably attain about the same age. The maximum sizes of both red maple and blackgum are far more than those commonly found in the pine region of New Jersey, where old stems are usually 40 to 50 feet tall and 8 to 20 inches in diameter.

Sweetbay varies greatly in size in different sections of its range. In New Jersey it is commonly between 10 and 30 feet tall and 1 to 7 inches in diameter, although slightly larger trees may occasionally occur. Its longevity is apparently about 20 years less than that of the other two hardwoods.

ECOLOGICAL RELATIONS

EVERY forest manager should know the ecological relations among the various species and the successional trends that occur within the different stands he is handling. Without such information he has scant basis for using specific treatments to favor certain species. With it he can estimate fairly accurately the conditions he must create to attain a given objective. Knowledge of the successional trends can be gained, at least partially, from long experience in managing a specific type, but can be substantiated and clarified only by studies designed to show the relations among the component species.

These studies can be divided into three broad groups: (1) field surveys to determine successional trends on the sites in question, (2) field studies of the reaction of the important species to various natural conditions and modifications thereof, and (3) studies in a greenhouse or other controlled environment of the effect of specific conditions on the different species. All three types of investigation have their advantages and limitations. For that reason all three approaches were used to some extent in attempting to provide a basis for the silvicultural management of swamp stands in southern New Jersey.

Methods Of Investigation

In 1940 temporary plots were established to determine the successional trends on lowland areas in the pine region of southern New Jersey. Most of these plots were located in the "true swamps" and in stands of whitecedar and associated hardwoods in or near the Lebanon State Forest in Burlington and Ocean Counties. All the areas supported stands that had been modified to a greater or lesser extent since colonial times by cutting, fire, or clearing for agricultural use. The plots were samples of 16 stands, 6 on old cranberry bogs that were reverting or already had reverted to forest, and 10 on areas that apparently had never been under cultivation. The data presented in this paper are separated on that basis, as well as by the approximate size of the components of the various stands. The size classification used in the summaries is as follows:

(1) Reproduction, i.e., stands in which the majority of the future dominants are still less than 15 feet tall,

(2) Sapling-pole, i.e., stands in which the overwood is composed of stems averaging between 2 and 5 inches d.b.h., and

(3) Mature, i.e., stands in which the overwood is composed of stems averaging more than 5 inches d.b.h.

Tallies were made of all vegetation, although the area sampled for plants of different sizes varied from 0.1 acre to 2.5 milacres. Water relations and light intensities were measured, and the ages of representative trees were determined.

The reaction of the different species to different field conditions was also studied by the use of reproduction surveys. Tallies of reproduction were made on areas that differed in site, amount and kind of overwood, direction from seed source, or similar factors.

The effect of varying field conditions on the establishment and early growth of whitecedar was studied also through planting seedlings and sowing seed in both hardwood and pine swamps. Fifty 2-0 seedlings and 50 seeded spots were included in each 0.1-acre plot. In the hardwood swamp there were two of these plots in each of the following treatments:

(1) Complete cutting of all woody vegetation more than 2 feet tall,
(2) Girdling of trees more than 3.6 inches d.b.h. and cutting of all smaller stems and shrubs more than 2 feet tall,
(3) Cutting of all trees 2.0 inches or more d.b.h., but leaving as undisturbed as possible all smaller trees and shrubs,
(4) Cutting of all woody vegetation more than 2 feet tall except trees 2.0 inches or more d.b.h., and
(5) Controls where the existing vegetation was left undisturbed.

Treatment (2) was not used in the area of pine swamp; there four plots of each of the other treatments were established. On two plots the litter and shrubby turf were scalped from all spots prior to seeding or planting; on the other two plots the spots were not treated before the seeding or planting.

To provide more information on the interaction of the three variables of light, moisture relations, and species, a study was started in 1942 in a greenhouse at Marsh Botanical Garden, Yale University. Three species were used in the study, whitecedar, sweetbay, and red maple, and also three degrees of shade and three positions of water table in the earthenware crocks. Light shade was merely the normal state inside the greenhouse. The light intensity was between 40 and 45 per cent of full sunlight until late June, when it decreased to 30 to 35 per cent, the decrease resulting from the addition of a new coat of whitewash to the greenhouse. Comparative light intensities for medium shade were 20 to 25 per cent and after June about 12 per cent of full sunlight, and for heavy shade, 12 to 16 per cent and later about 6 per cent. Medium and heavy shades were created by the use of screens, and the three positions of the water table, by overflow tubes inserted in holes near the bottoms of the crocks. Actual positions of the water table during the study are indicated below.

Relative position	*Position of water table after daily watering*	*Estimated maximum depth to water table during the study*
High water table	¼ inch below the surface of the sand	3 inches
Medium water table	3 inches below the surface of the sand	5 inches
Low water table	6 inches below the surface of the sand	7 to 8 inches

Fluctuations in the water levels varied with weather and shade conditions. There were practically no changes on rainy or dull days. In all weather conditions, greater fluctuations occurred in the blocks of light shade than in those of medium or heavy shade.

For each of the 27 combinations resulting from the three species, three water tables, and three degrees of shade, there were four samples or crocks. Whitecedar and sweetbay seeds were sown on March 20, 1942, and red maple seeds on May 16. The whitecedar seedlings that were allowed to grow in each crock for the duration of the study germinated before May 30; the sweetbay and red maple seedlings germinated before the end of June. All seedlings were removed between December 28, 1942, and January 5, 1943, and the height and length of taproot were measured. Seedlings typical of each condition were photographed. The total length of roots was measured on one seedling typical of those in each crock. Subsequently the tops and root systems of all seedlings from each crock were oven-dried and their weights determined.

Effect Of Light And Water Relations

Light

The light requirements of whitecedar have been the subject of many conflicting statements. The species has been described as very tolerant of shade by many authors (Baker 1922, Akerman 1923, Korstian and Brush 1931, Moore 1939, Noyes 1939). However, Pinchot (1899) stated that a certain amount of light is necessary for the germination of whitecedar seed and that after the crowns of a young stand closed no new seedlings start. Noyes (1939) expressed similar views and, in commenting on certain stands, remarked that most of the seedlings in the uncut plots did not extend more than 20 feet into the interior of the plot because light conditions were unfavorable. Buell and Cain (1943) stated that in North Carolina there is a complete absence of whitecedar seedlings in mature whitecedar stands.

The data from the studies described in this paper are more or less at odds with the above statements. The data of Table 9 indicate that a fair amount of light, probably to provide heat, is desirable for obtaining good germination of whitecedar seed, but that light intensities have to be less than 16 per cent of full sunlight before germination is greatly reduced. Even under a stand of swamp hardwoods where the light intensity in August was only 2 per cent of full sunlight, some germination occurred—although the amount was greatly reduced (Table 9). Some germination from a natural seed source was also observed in an area where the light intensity, measured during the summer, averaged only 1 per cent of full sunlight at 0.3 foot above the ground (data for plot 9 in Tables 14 and 17).

Statements cited above from various authors also imply that whitecedar seedlings are rare or absent under an overwood of that species. The data of Table 10 show that whitecedar seedlings may not only be present, but occur in large numbers under mature stands.

TABLE 9.—INITIAL ESTABLISHMENT OF WHITECEDAR SEEDLINGS IN A HARDWOOD SWAMP IN RELATION TO LIGHT INTENSITIES

Plot treatment	*Light intensity in terms of full sunlight**	*Germination in June*	*Stocking of spots in June*
	Per cent	*Per cent*	*Per cent*
(1) Cutting of all woody plants more than 2 feet tall	77	49	97
(2) Same as (1) except trees more than 3.6 inches d.b.h. were girdled	29	50	100
(3) Cutting of all trees more than 2.0 inches d.b.h.	32	32	98
(4) Cutting of woody plants between 2 feet tall and 2.0 inches d.b.h.	16	29	97
(5) Controls	2	8	89

* Measured at 0.3 foot above ground near 20 spots per plot on clear days in August 1942. Measurements made with a Weston illumination meter and compared with readings made in the open before and after those on each plot.

The relative light requirements of whitecedar seedlings and older trees have also been the subject of conflicting statements. Pinchot (1899) believed that, compared to seedlings, older trees are able to tolerate considerable shade, both from above and from the side. He cited, as evidence, the very long life of suppressed trees and the extremely crowded character of the woods. Harshberger (1916) also stated that a certain amount of light is necessary for the welfare of young whitecedars, but that, as they grow older, they become more tolerant of shade. On the other hand, Korstian and Brush (1931) reported both that whitecedar seedlings are very tolerant of shade and that light is necessary for seedling establishment. The same authors considered older trees less tolerant of shade than seedlings, offering as proof the death of suppressed trees and lower branches at an early age.

Recent observations and data support the view that whitecedar seedlings and older trees do not differ appreciably in their light requirements. The data of Table 10 have already shown that whitecedar seedlings can, and do, start in large numbers under mature whitecedar stands. However, their growth under heavy shade is greatly reduced, and their survival is limited to relatively short periods (Tables 11, 14, 15, and 16). With increasing light more seedlings and larger trees can survive for longer periods, as is the case on plot 2 of the successional study (Table 16). However, overtopped trees of whitecedar are rarely found unless they are receiving some light from the side. Apparently then there is no appreciable difference in the light requirements of whitecedar seedlings and older trees. Neither can apparently survive under a closed overwood for more than a few years.

Korstian and Brush (1931) stated that young whitecedars will stand about as much shade as most of the associated hardwoods and much more than white pine, pitch pine, pond pine, and cypress. In contrast, Cottrell (1929) said that on the better sites the more intolerant hardwood associ-

TABLE 10.-LIGHT INTENSITIES AND NUMBER OF WHITECEDAR SEEDLINGS UNDER CERTAIN SAPLING-POLE AND MATURE STANDS

Type of stand	*Plot number*	*Light intensity at 0.3 foot above ground in terms of full sunlight*	*Number of whitecedar seedlings per acre in 1940**
		Per cent	
Sapling-pole mixed	7	4.4	575,600
Mature whitecedar	3	4.7	283,600
	1	5.2	505,600
	4	6.0	995,600

* All less than 0.26 foot tall.

TABLE 11.—INITIAL ESTABLISHMENT AND GROWTH OF WHITECEDAR SEEDLINGS FROM SEEDING OR PLANTING IN A HARDWOOD SWAMP IN RELATION TO LIGHT INTENSITIES

Item	*Stand treatments**				
	1	2	3	4	5
Light intensity, per cent*	77	29	32	16	2
Seedlings on seeded spots:					
(a) Average number in June**	24.5	25.2	16.0	14.7	4.1
(b) Average number in September**	19.6	21.6	13.8	13.9	2.2
(c) Change in number between June and September, per cent	—20	—14	—14	— 5	—45
(d) Average height of tallest ones in September, feet***	0.34	0.32	0.23	0.14	0.10
Stocking of seeded spots:					
(a) In September, per cent**	93	100	97	99	66
(b) Change between June and September, per cent	— 4	0	— 1	+ 2	—23
Growth of planted seedlings during the first growing season, feet***	1.13	1.09	0.93	0.69	0.29

* For a description see Table 9.
** Of the first growing season.
*** Excluding spots where seedlings were injured by animals.

ates, such as red maple, sweetgum, sweetbay, and gray birch, are crowded out of whitecedar stands by the absence of light and moisture conditions necessary for their survival.

Results from the field study on successional stages indicate a relationship slightly different from that in either of the statements cited above. In this study eight arborescent species were encountered, namely, pitch pine, whitecedar, gray birch, red maple, sweetbay, blackgum, sassafras *(Sassafras albidum),* and holly *(Ilex opaca).* Evidently, whitecedar is more tolerant of shade than pitch pine, and both whitecedar and pitch pine are more tolerant than gray birch. Gray birch appeared only in areas in the reproduction stage (plots 8, 12, and 14) where most stems of this species had already reached a dominant position, or in areas having older stands where occasional birches occurred in the overwood (plots 1, 2, and 11). In the plots where pitch pine or whitecedar also occurred, these species tended to have a wider range in height classes and age than gray birch (Tables 12 and 13). Reproduction of pitch pine less than 6 feet tall was present in plots 12, 14, and 16 where the light intensities at a height of 0.3 foot varied from 19 to 38 percent of full sunlight, but this species occurred only in the overwood of plots 1, 5, 6, and 15 where light intensities measured at the same height were 5 to 18 per cent of full sunlight. In contrast, small whitecedar seed-

TABLE 12.—OCCURRENCE OF GRAY BIRCH, PITCH PINE, AND WHITECEDAR IN SPECIFIC HEIGHT CLASSES IN RELATION TO LIGHT INTENSITY AND THE HEIGHT OF ASSOCIATED TREE SPECIES*

Past history of area	*Plot number*	*Maximum height class occupied by any species*	*Light intensity at a height of 4.0 feet in terms of full sunlight*	*Extreme limits of height classes in which occur—*		
				Gray birch	*Pitch pine*	*Whitecedar*
		Feet	*Per cent*	*Feet*	*Feet*	*Feet*
Abandoned cranberry bog	16	2.6-6.0	97.7	—	1.1-6.0	0.0-6.0
	14	6.1-15.0	96.1	6-15	0.0-0.25; 2.6-15	0.0-15
	12	6.1-15.0	95.6	6-15	0.0-0.25; 2.6-6.0	0.0-15
	15	15.1-25.0	42.9	—	6-25	0.0-25
	5	over 25.0	8.9	—	over 15	0.0-0.25; over 6.0
Areas never cleared for cranberry bogs	8	15.1-25.0	47.3	1.1-25	—	0.0-2.5
	6	15.1-25.0	22.2	—	6-15	0.0-25
	11	over 25.0	15.3	over 25	—	—
	2	over 25.0	9.6	over 15	—	0.0-1.0; over 6.0
	1	over 25.0	8.6	over 25	over 25	0.0-0.25; over 15

* Height classes considered here are as follows: 0.0-0.25 foot; 0.26-1.0 foot; 1.1-2.5 feet; 2.6-6.0 feet; 6.1-15.0 feet; 15.1-25.0 feet; and 25.1 or more feet.

TABLE 13.—INDICATIVE AGES OF GRAY BIRCH, PITCH PINE, AND WHITECEDAR BY HEIGHT CLASSES ON DIFFERENT AREAS*

Past history of area	*Plot number*	*Range in age of —*								
		Gray birch			*Pitch pine*			*Whitecedar*		
		Over 15 feet	*6-15 feet tall*	*Less than 6 feet*	*Over 15 feet*	*6-15 feet tall*	*Less than 6 feet*	*Over 15 feet*	*6-15 feet tall*	*Less than 6 feet*
		Years								
Abandoned cranberry bog	16	—	—	—	—	—	5-10	—	—	1-19
	14	—	9	—	—	10	1-10	—	17	1-17
	12	—	13	—	—	—	1-10	—	17-19	1-16
	15	—	—	—	24-32	20-25	—	26-32	26-30	1-27
	5	—	—	—	25-46	—	—	30-59	26-35	1-2
Areas never cleared for cranberry bogs	8	11	7-9	5-6	—	—	—	—	—	1-11
	2	17-63	—	—	—	—	—	56-88	53-55	1-9
	1	63	—	—	62	—	—	55-109	—	1-2

* Ages given represent only those of sampled trees.

lings were found in places where similar measurements showed that the light intensities were less than 5 per cent (Table 10); and in the plots having both whitecedar and pitch pine, there was a pronounced tendency for the whitecedar to have a greater range in both size classes and age (Tables 12 and 13).

Usually gray birch and pitch pine are minor components of the stands in true swamps; whitecedar, red maple, blackgum, and sweetbay are far more common. The relative light requirements of whitecedar and hardwoods other than gray birch is again indicated by their occurrence under different light conditions and by their range in age. Information on these items is presented in Tables 14, 15, and 16. It is evident that whitecedar seedlings occur in large numbers under older stands having a high proportion of this species, but survive for only 1 to 3 years under closed canopies (plots 1,3, 4, and 5). In contrast, reproduction of red maple, blackgum, sweetbay, holly, and sassafras tend to survive for a longer period and to have a far more complete range in size and age. The differences between these hardwoods and whitecedar are well illustrated by the data from plots 3, 4, 9, and 10. Plots 3 and 4 are typical of many mature stands of whitecedar in southern New Jersey, and there the overwood of this species has a range in age of 10 to 20 years. Associated hardwoods occur in the overwood and, to a minor extent, as an understory. The hardwoods of the overstory have a range in age of 20 to 30 years and in the understory are in general less than 6 years old compared to 3 years or less in age for whitecedar seedlings. A few hardwoods of intermediate age do form a part of the understory (Fig. 7). In plots 9 and 10, where hardwoods predominate, light intensities at heights of 0.3 and 4.0 feet above the ground were less than those measured under mature whitecedar stands, but an almost complete range existed in size and age of the tolerant hardwoods. Thus, although whitecedar is less exacting in its light requirements than gray birch and pitch pine, it is more exacting than red maple, sweetbay, blackgum, holly, or sassafras.

The difference in tolerance between whitecedar and the associated hardwoods other than gray birch is most easily seen in the field in areas where the stand has been partially cut in thinning or harvesting whitecedar. The data for plot 2 (Tables 14, 15, and 16), as well as Figures 7 and 9, indicate the changes that occur on such areas. Although whitecedar reproduction is encouraged to live longer under the increased light, up to 9 years of age at least, the' hardwoods are able to show an even greater response. Consequently, hardwoods less than 6 feet tall dominate two to three times as many quadrats as whitecedars do. Moreover, in plot 2 there are 800 hardwood stems per acre between 1 and 6 feet tall, and none of whitecedar. There, too, the hardwoods are of all ages, while the partial cuttings have merely lengthened the normal spread in age of the whitecedar overstory and that of the reproduction.

TABLE 14.—REPRODUCTION OF WHITECEDAR AND ASSOCIATED HARDWOODS LESS THAN 1.1 FEET TALL IN RELATION TO LIGHT INTENSITIES AT A HEIGHT OF 0.3 FOOT

Type of area and stand	Plot number	Light intensity	Number of stems per acre in 1940			
			Whitecedar	Red maple	Sweetbay	Other hardwoods*
		Per cent				
Abandoned cranberry bog:						
Reproduction stand	16	38.3	12,000	3,200	400	—
	14	20.9	38,400	2,000	—	—
	12	19.0	98,800	800	—	—
	13	12.4	—	1,200	—	—
Sapling-pole stand	5	6.3	172,400**	—	—	—
	15	5.2	5,200	—	—	—
Areas never cleared for cranberry bogs:						
Reproduction stand	6	17.7	94,800	1,200	3,600	—
	8	8.0	15,200	67,600	1,600	4,400
Sapling-pole stand	2	7.1	34,000	94,800	—	400
	11	5.9	—X	7,200	1,600	—
Mature stand	7	4.4	575,600**	1,600	400	—
	4	6.0	995,600**	21,600	—	—
	1	5.2	505,600**	1,200	400	400
	3	4.7	283,600**	18,000	800	—
	10	1.3	—X	10,000	2,800	—
	9	0.9	—	4,800	400	400

* Includes blackgum, holly and sassafras, but not gray birch.
** All less than 0.26 foot tall.
X No seed source.

TABLE 15.—REPRODUCTION OF WHITECEDAR AND ASSOCIATED HARDWOODS MORE THAN 1 FOOT TALL IN RELATION TO LIGHT INTENSITIES AT A HEIGHT OF 4 FEET

Type of area and stand	*Plot number*	*Light intensity*	*Number of stems per acre*									
			Whitecedar		*Red maple*		*Sweetbay*		*Others**		*All hardwoods**	
			1.1-6.0 *feet tall*	6.1-15.0 *feet tall*	1.1-6.0 *feet tall*	6.1-15.0 *feet tall*	1.1-6.0 *feet tall*	6.1-15.0 *feet tall*	1.1-6.0 *feet tall*	6.1-15.0 *feet tall*	1.1-6.0 *feet tall*	6.1-15.0 *feet tall*
		Per cent										
Abandoned cranberry bog:												
Reproduction stand												
	16	97.7	12,800	—	18,000	—	—	—	—	—	18,000	—
	14	96.1	9,200	480	7,200	520	—	—	—	—	7,200	520
	12	95.6	57,600	1,280	6,000	360	—	—	—	—	6,000	360
	13	71.9	400	—	18,000	4,240	—	—	1,200	200	19,200	4,440
Sapling-pole stand	15	42.9	5,600	2,800	1,200	120	—	—	—	—	1,200	120
	5	8.9	—	3,840	—	40	—	—	—	—	—	40
Areas never cleared for cranberry bogs:												
Reproduction stand												
	8	47.3	800	—	800	—	—	240	4,400	200	5,200	440
	6	22.2	24,800	18,280	—	—	400	—	—	—	400	—
Sapling-pole stand	11	15.3	—X	—	—	—	800	400	—	—	800	400
	2	9.6	—	120	—	80	—	120	800	—	800	200
	7	5.7	—	120	—	40	—	200	—	40	—	280
Mature stand	4	9.3	—	—	—	80	—	—	—	—	—	80
	1	8.6	—	—	400	—	—	—	—	—	400	—
	3	7.1	—	—	—	80	—	—	—	—	—	80
	10	5.8	—X	—	—	—	—	160	—	—	—	160
	9	3.5	—	—	—	40	400	240	—	40	400	320

* Includes blackgum, holly and sassafras, but not gray birch.
X No seed source.

TABLE 16.—INDICATIVE AGES OF WHITECEDAR AND ASSOCIATED HARDWOODS BY HEIGHT CLASSES ON DIFFERENT AREAS

Type of area and stand	*Plot number*	*Range in age of —* *Whitecedar* *Over 15 feet tall*	*6-15 feet tall*	*Less than 6 feet*	*Hardwoods** *Over 15 feet*	*6-15 feet*	*Less than 6 feet*
				Years			
Abandoned cranberry bog:							
Reproduction stand	16	—	—	1-19	—	—	3-17
	14	—	17	1-17	—	8-11	6-12
	12	—	17-19	1-16	—	10	2-9
	13	—	—	—	—	8-12	1-14
Sapling-pole stand	15	26-32	26-30	1-27	—	32	1-26
	5	30-59	26-35	1-2	—	—	—
Areas never cleared for cranberry bogs:							
Reproduction stand	8	—	—	1-11	—	7-23	1-11
	6	30-32	26-31	1-27	—	—	1-6
Sapling-pole stand	2	56-88	53-55	1-9	26-107	13-47	1-9
	7	34-79	34	1-2	29-51	21-38	1-2
	11	—	—	—	25-121	6	1-6
Mature stand	1	55-109	—	1-2	23-45	—	1-4
	3	46-56	—	1-2	34-56	18	1-4
	4	36-55	—	1-3	27-56	—	1-6
	9	45-142	—	1	25-133	5-9	1-6
	10	—	—	—	16-185	5	1-6

* Excluding gray birch.

Small seedlings of the tolerant hardwoods do suffer high mortality when they are growing in heavy shade. The turnover is proportionately more rapid for whitecedar because of its lower tolerance, but even for the hardwoods the amount of reproduction less than 1 foot tall under closed canopies varies from year to year, depending on recent seed crops and the conditions affecting initial establishment and survival. The variability in this respect is indicated by the data of Table 17. Possibly it was in a year following favorable conditions for the production of red maple seed and the establishment of seedlings that, according to Kearney (1901), thousands of red maple seedlings covered the ground wherever there was no standing water in the hardwood stands of the Dismal Swamp.

Results from the greenhouse study corroborated those from the earlier field investigations. In general, light shade in the greenhouse approximated the light intensity found near the soil surface of abandoned cranberry bogs

TABLE 17.—VARYING AMOUNTS OF SMALL REPRODUCTION UNDER STANDS OF WHITECEDAR AND HARDWOODS, RESULTING FROM DIFFERENCES IN SEED YEARS AND CONDITIONS FOR ESTABLISHMENT

Type of stand	Plot number	Number of whitecedars per acre less than 0.26 foot tall		Number of red maples per acre less than 1.1 feet tall	
		In 1940*	Of 1941 origin	In 1940**	Of 1941 origin
Mature whitecedar	1	505,600	10,400	1,200	1,200
	3	283,600	44,800	18,000	5,200
	4	995,600	9,600	21,600	25,200
Sapling-pole hardwood	11	----	----	7,200	522,800
Mature hardwood	10	----	----	10,000	46,400
	9	0	1,200	4,800	57,200

* Practically all of 1940 origin from the 1939 seed crop.
** Very few of 1940 origin.

that are partially stocked with tree reproduction (plot 16 of the field successional study). Until the end of June 1942, the heavy shade of the greenhouse study permitted a somewhat greater light intensity than is commonly found near the ground under mature stands of whitecedar, but for the remainder of that experiment provided a comparable intensity. With the preceding comparisons in mind, it is interesting to note that:

(1) The decrease in light intensity from light to heavy shade resulted in a reduction of 28 per cent in the height of whitecedar compared to 10 per cent or less for the hardwoods, a decrease of 78 per cent in oven-dry weight of tops of the conifer contrasted to 55 per cent for the hardwoods, and a reduction of 90 per cent or more in length and weight of the root system of whitecedar compared to 70 to 80 per cent for the other species (Table 18).

(2) Under heavy shade even sweetbay had a significantly greater average height than whitecedar.

In addition, increasing the shade from light to medium caused about as great decreases in the growth of whitecedar seedlings as the change from light to heavy shade did on the development of the two hardwoods (Table 18). These results agree with those from the field studies in indicating that the associated hardwoods, other than gray birch, are more tolerant of shade than whitecedar.

In some respects red maple seemed to be less affected by increased shade than sweetbay was; but if the data for all items in Table 18 are compared, it is questionable if the light conditions used produced any appreciable differences in the two hardwoods. Oven-dry weights of the tops of all three species declined much more than their heights under increased shade, while length and weight of root systems were more uniformly affected.

The growth of the three species under different amounts of shade varied appreciably, because of the individual characteristics of each species. Red maple seedlings were always the tallest, but had a shallow root system with many small fibrous roots. Sweetbay stems, although decidedly shorter, occasionally weighed more than those of maple and were always stockier than those of the other species. The sweetbay seedlings had well-developed taproots with right-angled laterals, and the taproots penetrated deeply. Whitecedar was far more flexible than either of the hardwoods in both top and root development (Figs. 2, 3, and 4).

TABLE 18.-EFFECT OF INCREASED SHADE ON THE DEVELOPMENT OF SEEDLINGS OF THREE SPECIES, EXPRESSED AS A PROPORTION OF THE DEVELOPMENT UNDER LIGHT SHADE*

Item	*Relative development in terms of values under light shade*					
	Whitecedar		*Red maple*		*Sweetbay*	
	Medium shade	*Heavy shade*	*Medium shade*	*Heavy shade*	*Medium shade*	*Heavy shade*
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Height of seedlings	91	72	99	90	93	99
Oven-dry weight of top	47	22	84	46	49	45
Length of taproot	73	51	78	60	97	94
Total length of roots	28	10	68	30	51	27
Oven-dry weight of roots	25	8	62	26	33	21

* Limited to the "most favorable" water table for each species, i.e., high for whitecedar and medium for the two hardwoods.

Water Table

Pinchot (1899) stated that whitecedar seedlings develop a taproot, but that older trees have a flat root system with strong, superficial lateral roots. Akerman (1923) showed photographs of the root systems of seedlings 1, 2, and 3 years old, noting that the roots appear to go down at first in search of a supply of moisture and then later to spread laterally to give support in the unsteady soil. Similar statements and photographs were presented by Korstian and Brush (1931), who also noted that the depth to which roots penetrate varies with the depth to the water table.

Whitecedar seedlings grown in the greenhouse had a greater variability in root development than has so far been described. Where the water table was low, the taproot of whitecedar seedlings formed a large part (20 to over 50 per cent) of the root system; whereas in the cultures with high water tables the proportion in lateral roots increased. Under light shade lateral roots of seedlings in cultures with a high water table composed over 90 per cent of the total length of the root system. The flexibility of the root system formed by whitecedar seedlings 1 year old is shown by Figure 2 as well as by the data in Table 19.

These data indicate that the position of the water table under light shade tended to affect the form of the root system of whitecedar more than that of the other species. The initial root system developed by red maple in the greenhouse study did not have the great flexibility credited to it by Toumey and Korstian (1947). They stated that on wet sites its roots reach a depth of only 2 to 3 inches in the first year, but 10 to 13 inches on dry sites.

High water tables retard the downward growth of roots of most species because of the deficient aeration of saturated soils, only the roots of hydrophytes being able to penetrate very far into saturated soils (Meyer and Anderson 1939). McQuilkin (1935) found that pitch pine roots could develop extensively below the water table of saturated soils, and expressed the belief that whitecedar could do the same. The date of Table 19 indicate that whitecedar, sweetbay, and, to a far lesser extent, red maple can develop roots below the water table. For example, under light shade where the position of the high water table varied between 0.25 and 3 inches below the surface of the sand, the length of the average taproot formed by sweetbay was 10.4 inches, by whitecedar 8 inches, and by red maple 2.4 inches. From these values and additional data in Table 19, it is apparent that the downward penetration of sweetbay roots is affected less by high water tables than that of whitecedar or red maple.

Low levels of the water table encouraged deeper penetration of roots, particularly by whitecedar and red maple and, to a minor extent, by sweetbay. The taproots of sweetbay were frequently so long that they extended to the bottom of the crocks in all water tables (Fig. 4).

Sweetbay was the only species that tended to produce a heavier and larger root system with a lowering of the water table. Under light shade whitecedar produced its largest root system in the cultures with a high water table, but under medium or heavy shade, in those with a medium

TABLE 19.—EFFECT OF WATER-TABLE DEPTH ON GROWTH OF SEEDLINGS UNDER LIGHT SHADE

Item	*Whitecedar*			*Red maple*			*Sweetbay*		
	High water table	*Medium water table*	*Low water table*	*High water table*	*Medium water table*	*Low water table*	*High water table*	*Medium water table*	*Low water table*
Average height, inches	2.08	1.82	1.52	2.69	3.48	2.79	1.54	1.78	1.67
Oven-dry weight of average top, grams	0.059	0.054	0.040	0.045	0.067	0.040	0.039	0.051	0.047
Length of average taproot, inches	7.96	8.74	10.08	2.44	3.77	4.32	10.42	10.40	10.52
Average total length of roots, inches	103.8	75.7	48.9	94.6	152.6	86.4	94.5	109.7	146.4
Average oven-dry weight of roots, grams	0.071	0.072	0.057	0.095	0.159	0.087	0.133	0.190	0.231

water table. In all cases red maple developed a larger and heavier root system in cultures having a medium water table.

The whitecedar seedlings grown in containers with a high water table generally had the largest and heaviest tops, and with both high and medium water tables the tops excelled those produced in the crocks with low water levels. The relatively poor development of whitecedar in containers with a low water table substantiates the results already presented from seeding and planting whitecedar in hardwood and pine swamps. The results from both the field and greenhouse studies agree with earlier statements and data on the unfavorable effect of dry sites on the growth of whitecedar (Korstian and Brush 1931).

The occurrence of whitecedar may thus be limited by unfavorable moisture conditions. Pinchot (1899) wrote that whitecedar is strictly a swamp tree and the boundaries of its distribution usually coincide with the edges of swamps, although a few short and scrubby stragglers are found on dry ground. In cases where a whitecedar swamp grades into a pine swamp, the whitecedar mingles with the pine and finally disappears from the stand where the ground is too dry for it to grow (Pinchot 1899). Harshberger (1916) also reported that the amount of water in the soil determines the location of pine forest and that of whitecedar swamp.

However, moisture conditions that limit the distribution of whitecedar today are not sharply defined, particularly in certain sections. There most of the whitecedar stands are found on sites where the water table is usually no more than 5 inches below the mean elevation, although during long dry periods it may drop to as much as 30 inches. Yet whitecedar or pine-whitecedar stands can also be found on drier sites, even on sites that are drier than some of those having pine-hardwood stands typical of the pine swamps (Table 20). Consequently, in some sections the present distribution of whitecedar stands and of pine swamps tends to overlap, probably because it has been modified by past fires, cutting, and the creation and abandonment of cranberry bogs. In other sections having a more uneven topography the boundaries of whitecedar swamps are usually still sharp, because the wet swamp changes to dry upland within a distance of a few feet without an intervening zone of pine swamp.

TABLE 20.—POSITION OF THE WATER TABLE AND ITS FLUCTUATIONS DURING A YEAR IN RELATION TO TYPE OF FOREST*

Type of forest	*Range in depth from mean elevation to water table, in inches*				*Range in maximum fluctuation between May 1 and Sept. 1, 1941, in inches*
	On Oct. 3, 1941	*Between Nov. 1, 1940, and Sept. 1, 1941*			
		Maximum	*Average*	*Minimum*	
Whitecedar	6 to 36	1 to 17	-1 to 8	-9 to 4	1 to 11
Whitecedar-hardwood	10 to 33	4 to 17	0 to 8	-5 to 5	2 to 10
Hardwood	13 to 41	4 to 12	0 to 5	-6 to 3	2 to 14
Pine-whitecedar	32 to 35	21 to 24	11 to 14	4 to 6	11 to 13
Pine-hardwood	23	14	7	5	8

* Based on monthly measurements in 1 to 7 areas of each type of forest.

The relative growth of whitecedar on the different water tables in the greenhouse differs to some extent from that observed in the field. For example, Korstian and Brush (1931) noted that growth of whitecedar on continuously flooded areas or on old cranberry bogs in New Jersey is as slow, or slower than that on the edge of the upland sites. In contrast, the growth of whitecedar seedlings in the greenhouse was greater in the crocks with high water tables than in the others, possibly because it was favored by diurnal fluctuations, arising from evaporation, more than it would be in the continuously flooded areas described in the table prepared by Korstian and Brush. Observations in southern New Jersey indicate that there is relatively poor growth of whitecedar on extremely wet sites, possibly because of insufficient aeration. Best growth seems to occur in swamps that have a relatively dry surface, but with a water table usually at a depth no greater than 4 or 5 inches and sufficiently supplied so that ordinary fluctuations in water level are limited to a relatively few inches. As Pinchot (1899) observed, the timber is less dense, attains smaller dimensions and is poorer in quality in wet swamps than in drier ones where interlacing whitecedar roots cover the peat with a complete network.

The relative development of whitecedar, red maple, and sweetbay in the greenhouse indicated that on high water tables whitecedar might be expected to compete most successfully with the hardwoods. On the other hand, Cottrell (1929) claimed that the hardwood associates are crowded out of whitecedar stands on sites that usually do not have standing water, but are always present on extremely wet sites. However, the data on water levels (Table 20) show that the location of whitecedar and hardwood stands is not closely related to either position of the water table or fluctuations therein. In contrast, in the greenhouse, red maple and sweetbay developed better in the cultures having relatively low water tables than in those having high water tables. Whitecedar gave an opposite response. The difference might indicate that red maple and sweetbay belong to a higher successional stage than whitecedar, because, according to Weaver and Clements (1938), moisture conditions become less extreme with advance toward the regional climax.

Water Table And Light

In the greenhouse study whitecedar had an initial development comparable to that of red maple and sweetbayonly under light shade and on the high water table. Under these conditions the coniferous seedlings were taller than those of sweetbay and approached the height of the red maple seedlings. The tops of whitecedar were heavier and their root systems were larger than those of either hardwood. With increasing shade the differences due to water table tended to decrease among all species, but especially in the case of whitecedar.

Results obtained in the greenhouse indicate the importance of relatively open, moist conditions for the development of whitecedar. Only on such sites does this species have initial growth rates that favor its chances for competing successfully with the hardwoods. The development of the hardwoods in the heavily shaded crocks, on either moist or rather dry soil, was appreciably better than that of whitecedar. Both hardwoods had taller stems and larger root systems than the conifer. With a lowering of the water table differences arising from the three degrees of shade tended to decrease appreciably in the case of whitecedar, decidedly more so than for red maple or sweetbay that were not similarly affected.

The relative effect of light and moisture observed in the greenhouse study was also noticed in the field study involving the seeding and planting of whitecedar in hardwood and pine swamps. On the relatively moist sites of the hardwood swamp light intensity appeared to be the important factor in affecting the germination of whitecedar seed and growth and mortality of seedlings (Tables 9 and II). On the drier and more open sites of the pine swamp, position of the water table had a more important effect than stand treatments in modifying the stocking of seeded spots and the number and growth of seedlings thereon. For example, in the plots of all treatments where the water table was 18 to 22 inches below the soil surface, 92 to 100 per cent of the scalped and seeded spots were stocked at the end of the second growing season, compared to 58 to 76 per cent of the spots on plots of the same treatments, but having a water table at least 26 inches below the surface.

The relatively low importance of stand treatments in the pine swamp was probably due to two factors. In the first place, even on the unscalped controls light intensity near the ground was 14 per cent of full sunlight; and, in the second place, the relative dryness of the site doubtless acted, as did a lowering of water tables in the greenhouse, to reduce the relative importance of light intensity.

The interacting effect of shade and water table on the growth of whitecedar, observed in the greenhouse, is quite important. Under heavy shade the growth was so retarded that differences due to water table became relatively slight, but development was still poorest on the low water table. On that moisture condition, growth was again retarded with increasing shade, and the poorest development was under heavy shade. In other words, on the very sites where drought and competition might require the largest tops and root systems for survival of seedlings, total development of each was the poorest. Similar observations have of course been previously made for different species, one of the more recent papers discussing this interacting effect of light and moisture being that by Romell and Malmstrom (1945).

SUCCESSIONAL STAGES

Primary succession is of little or no importance in the present investigation; consequently no attempt was made to determine the various stages in the development of bogs to the point where they provide suitable conditions for the growth of trees. These stages have already been investigated and described by Rigg (1940). The literature thereon was reviewed by Waksman (1942). On the other hand, secondary succession, that is, succession occurring on land that previously supported or is now supporting tree growth, is of prime importance to forestry.

If woody vegetation on a swamp site in southern New Jersey is completely killed or removed, one or more tree species may be among the new invaders. As would be expected, these invaders are usually species that produce good crops of seed at frequent intervals and that have seed that is distributed by the wind. Species with these characteristics include whitecedar, red maple, gray birch, and pitch pine. Gifford in 1900 wrote that whitecedar is constantly invading cranberry bogs. Shreve *et at.* (1910) stated that in Maryland red maple was the first tree to become established on marshes that had been built up by deposits of silt. Wickenheiser (1922) noted that in New York City the first invaders of an area were gray birches, for which the nearest seed source was half a mile away. In his discussion of bogs along the Atlantic Coast, Rigg (1940) stated that the earliest and most successful invader is whitecedar, although red maple and pitch pine also occur.

All the species mentioned above were found on the abandoned cranberry bogs of the author's study, and in addition blackgum and sweetbay. The last two are usually quite unimportant; each occurred on only one of six plots. Sweetbay was, moreover, limited to one individual, and blackgum to eight, all about 40 feet from the edge of the parent stand.

The prevalence of whitecedar, red maple, gray birch, and pitch pine among the invaders of abandoned cranberry bogs depends to a large extent on the relative amounts of seed available, and also on the competition of other vegetation. Probably because of the competition of cranberry vines, small trees, and shrubs, gray birch and pitch pine normally form a relatively small proportion of the stand, but under certain conditions these species become more important as invaders. The lower view of Figure 5 shows an area that had no tree growth in 1940, but by 1946 it was densely stocked with gray birch and pitch pine.

Red maple may form most of the pioneer stand on an abandoned cranberry bog (as in plot 13), or be present in minor amounts, or even be lacking, depending on nearby seed sources. Whitecedar, when the seed source is good, establishes itself in great abundance and evidently forms the first stage of forest growth on many areas (as in plots 5 and 12; also

Fig. 6). When nearby seed sources are composed of several species, mixed stands should be expected on the abandoned cranberry bogs (as in plot 16).

Relatively dry sites favor the occurrence of higher proportions of pitch pine in the pioneer stands on abandoned cranberry bogs. These stands also tend to be rather open and to contain much more of a shrubby understory than is found under dense stands of whitecedar on moist sites (Fig. 6).

The scattered pines and gray birches, with their lower tolerance of shade, are doubtless the first species to be excluded from the pioneer stands on swamp sites. Pitch pine can grow among whitecedars only by overtopping them; and the occasional pine in whitecedar stands indicates that it is not the site, but competition, which generally excludes the pines (McQuilkin 1935). The gray birches and pitch pines that gain and retain dominance survive; but these species, especially gray birch, are relatively short-lived. In the absence of catastrophes, such as fire, extensive windthrow, or flooding, they will die before the associated whitecedars.

The pure whitecedar stands that develop under favorable conditions are rather dense and contain many stems (Fig. 6). The whitecedar trees require little growing space, because even trees that occur in the open have a very narrow crown compared with that of pitch pine, red maple, or blackgum (Fig. I). Some investigators, such as Korstian and Brush (193I), apparently considered the dense stands and, forgetting that nearly all crowns were exposed to some full sunlight (Fig. I), designated whitecedar as being very tolerant of shade. In reality, this species should be considered as having only a medium tolerance. Hawley *et al.* (1932) were correct in stating that the whitecedar type tends to be replaced by swamp hardwoods.

The economically more important whitecedar stands are considered subclimax to the hardwoods because:

(I) Whitecedar stands present an even-aged aspect, even though overwood members may differ by several years in age (Figs. I, 6, and 7; also data in Table 16).

(2) Associated hardwoods, other than gray birch, tend to be all-aged, regardless of stand density. Furthermore, whitecedar reproduction, although starting in great quantities, fails to survive as long as hardwood seedlings.

(3) In hardwood swamps the deciduous members other than birch are all-aged and give every indication of perpetuating themselves. In contrast, even when an occasional whitecedar is present in the over-

story, coniferous reproduction older than 1 year is lacking.

(4) Reproduction of whitecedar dominates that of hardwoods only on relatively open areas. Under stands that have been partially cut, hardwood reproduction attains a larger size and greater age than whitecedar.

The change from whitecedar to hardwoods is rather gradual, even if not checked by catastrophes as flooding and windthrow. Buell and Cain (1943) found that in one mature whitecedar stand in North Carolina the establishment of hardwoods was apparently favored by the maturation of the overstory. They implied that, when 65 years old, the overwood became less dense as the crown canopy was thinned through mortality, and the establishment and growth of a hardwood understory were then encouraged under the increased light. No data were obtained in the present study to substantiate the statements made by Buell and Cain on the time the natural thinning of the overwood occurs. From the data previously presented, it is apparent that some hardwoods may be as old as the whitecedars and may also occur in the upper story. In undisturbed stands dominant whitecedars may survive longer than hardwoods of the same age because of their greater longevity; but the gradual replacement of any dying members of the overwood would be from the hardwood understory. Elimination of the veteran whitecedars would probably be prolonged, in the absence of disturbances, until the last surviving conifer was more than 200, or possibly 500 years old. As the whitecedar overstory began to thin, the density of the shrubby understory as well as of the arborescent hardwoods would undoubtedly increase.

The resulting forest would probably resemble that shown in Figure 8. Red maple would usually predominate in the upper story, although locally blackgum might be more important. On most areas there would be a mixture of these two species with occasional individuals of holly and sassafras. Sweetbay would doubtless form most of the second story and, with red maple, the bulk of the reproduction. These stands would tend to be all-aged and would have a dense shrubby understory as shown in Figure 8.

In sections south of New Jersey most of the hardwood species forming the climax forest community would be different from those in New Jersey. Buell and Cain (1943) stated that in North Carolina the climax would be composed of swampbay and several associated hardwoods. Of these only sweetbay occurs in New Jersey. On the drier sites now largely stocked with pond pine in North Carolina and pitch pine in New Jersey, the climax community would also be composed of hardwoods (Buell 1946, Little 1946).

Recent Influences on Succession

Cutting

The harvesting of whitecedar has had two different effects. In some places it has favored perpetuation of the whitecedar type; in others it has hastened the succession to the hardwood climax. Consequently the literature contains many statements that are seemingly in conflict.

In 1895 one author stated that, when whitecedar stands are cut, the following stands are composed of several species, most of which are not valuable. He recommended cutting all undesirable species for a few years after the harvest cutting, so that the quality of the stand could be completely changed at slight expense (Anon. 1895). In spite of that early recommendation, liberation cuttings and cleanings have been so rarely applied in swamp stands that they have had little effect in favoring the perpetuation of the whitecedar type.

Nearly all the cutting has been limited to the harvesting of whitecedar because usually that species alone has been commercially valuable. Usually most of the whitecedar stems have been felled on the cutting area. The size of the cut-over areas has varied. Under the diversified ownership of swamps in the Northeast it is probable that most cut-over areas have been small, and rarely has a stand covering an entire swamp been clear-cut at one time. The cutting has generally been confined to a small area each time, resembling a clear-cutting in patches or strips (Cottrell 1929).

On such clear-cut areas in pure whitecedar swamps another pure whitecedar stand may result under favorable conditions. Gifford (1895) implied that if advance reproduction of blackgum, red maple, and similar species was present, the next stand would contain relatively little whitecedar; but if these species were not already established, whitecedar might restock the cut-over area. Usually if the whitecedar stands have not been thinned or partially cut, they are densely stocked, and a well-established hardwood understory is not prominent at the time the overwood is cut (Figs. 7 and 9). Larger members of the scattered hardwood understory may be cut or broken in removing the whitecedar, and small reproduction of the deciduous species will suffer appreciable mortality due to drought, mechanical injury, and similar factors. Almost pure whitecedar stands may again develop from seed stored in the peat, from small seedlings that survive the logging, and possibly from seed blowing in from uncut stands. Low stocking or gaps in the whitecedar reproduction may be expected on the portions of the area covered with slash or corduroy (Table 8).

As the proportion of hardwoods increases, the detrimental effects of slash become more noticeable, even on the areas where the hardwoods are cut. Korstian and Brush (1931) stated that hardwood sprouts come up through dense slash, and in 5 to 10 years, when the slash has decayed sufficiently to form a seedbed suitable for whitecedar, the hardwoods have become so tall that they form the main part of the stand. However, Joranson and Kuenzel (1940) found that slash reduced the number of sprouts from white oak stumps. The data obtained by the author in reproduction surveys of cut-over areas indicate that a similar reduction occurs in the sprouts of swamp hardwoods, but, more important, that the proportional reduction in whitecedar seedlings tends to be two to three times that of hardwood reproduction. As a result, as Korstian and Brush (1931) observed, unburned cut-over areas that have spots covered with dense slash and other spots free of logging debris tend to restock to mixed stands of whitecedar and swamp hardwoods.

The rapid growth of hardwood sprouts enables them to gain an initial advantage over the whitecedar reproduction starting from seed. This factor alone might be considered the primary reason for the fact that hardwoods restock many whitecedar swamps following cutting.

However, the conversion has been hastened on many areas through another practice common in the harvesting of whitecedar stands. This practice has been to leave standing many of the larger stems of undesirable species, as well as occasional whitecedars of low value. Usually the conifers, having very slender stems, are snapped off by the first severe storm or are bent over and finally blown down (Pinchot and Ashe 1897, Akerman 1923). Some of the spindling hardwoods may suffer the same fate. Occasional hardwoods with large crowns may be overturned; but as the proportion of deciduous trees in the stand increases, the residual stems offer more mutual protection and the loss from windthrow and breakage lessens.

"Selective logging" of whitecedar and leaving of less desirable species has apparently been chiefly responsible for the conversion of many whitecedar stands to pure hardwoods, although conflicting opinions have been expressed. Pinchot and Ashe (1897) thought that, while the hardwoods left after logging made more rapid growth at first than whitecedar, the small coniferous seedlings later grew more rapidly in height and were able to break through the hardwood canopy. On the other hand, Harshberger (1916) claimed that many hardwood swamps represent the natural succession where whitecedar has been removed in lumbering operations and where no other attempt was made to clear the ground. Akerman (1923) and Korstian and Brush (1931) implied that the main effect of large residual stems of undesirable species is in their production of seed.

Although an increase in the amount of hardwood seed can be expected with more deciduous hold-overs, these trees have an even more important effect, that of increased shade on whitecedar reproduction. As the data on relative tolerance have already shown, increasing shade from a residual overstory favors hardwood reproduction rather than whitecedar. In fact, the conversion of whitecedar swamps to hardwoods may proceed at an increasing rate as more hardwoods reach the overstory and are left after logging. The increasing rate appears due to the composite effect of increases in (1) the amount of seed produced by hardwoods, (2) the amount of advance reproduction of hardwoods present before logging, and (3) the relative rate of growth of deciduous reproduction compared to that of whitecedar seedlings.

Plot 8 of the successional study furnishes an illustration of the end result from heavy "selective logging" of whitecedar. This plot was located in an area of about 2/10 of an acre from which whitecedar had been cut in 1930. The remaining stand for some distance was chiefly hardwoods, although there were two whitecedar culls near the edge of the cut-over area. In 1940 whitecedar reproduction occurred on 80 per cent of the quadrats of plot 8 at the rate of 16,000 seedlings per acre. Few of these seedlings were of 1940 origin, and none were more than 2.5 feet tall. In contrast, there were 80,000 hardwood seedlings and sprouts to the acre, of which 760 were more than 6 feet tall. The small whitecedar seedlings could not compete with the deciduous reproduction. By 1946 whitecedar seedlings had been reduced to the rate of 800 per acre, all less than 1 foot tall. The next stand on this cut-over area will be composed only of hardwoods.

Less frequently a lighter "selective logging" has been practiced, one that involved removing from whitecedar stands the largest and best trees or the trees suitable for certain products. This type of cutting may create uneven-aged stands, according to Cottrell (1929). He mentioned one stand that ranged in age from 30 to 130 years. More frequently the whitecedar components would form the two-aged stands that, Korstian and Brush (1931) stated, occurred occasionally. One or two of these light "selective" cuts may result in stands composed largely of whitecedar, provided that hardwood seed sources are lacking; but even one or two light cuts will be sufficient to encourage a dense understory of shrubs. Hardwood reproduction will usually also be encouraged and will withstand more successfully than whitecedar seedlings the competition of the remaining overstory and the shrubs (data for plot 2 in Tables 14, 15, and 16; also Fig. 9). Korstian and Brush (1931) stated that there has been an increase in mixed stands in the South as the result of culling of pure stands for poles. However, mixed stands are only the intermediate result. In the long run the whitecedaris entirely superseded and a pure hardwood stand is established (Hawes and Hawley 1909).

Sometimes when whitecedar stands are cut there develops an association of tall shrubs that prevents the formation of another whitecedar stand. This is usually not true in the Northeast. In New Jersey, for example, dense shrubby understories are not common under pure, fully stocked, even-aged stands of whitecedar in moist swamps. Where these stands are clear-cut and good restocking to whitecedar is obtained within a few years, no permanent increase in the shrubby understory has been observed. If stands are understocked or partially cut, the shrubby understory builds up as Moore and Waldron (1938) observed on their thinning plots (Figs. 7 and 9). However, when whitecedar stands are cut in the South, an association of tall shrubs may be greatly encouraged (Kearney 1901, Korstian and Brush 1931). These shrubs may develop into a thicket in which whitecedar seedlings become established with great difficulty (Korstian and Brush 1931). Buell and Cain (1943) found no whitecedar seedlings in the well-developed pocosin shrub of North Carolina. However, even in the South improper management of whitecedar stands, particularly "selective logging" and no disposal of slash, may have been largely responsible for the increase in shrubs. Kearney (1901) stated that the association of tall shrubs is said to have been once almost unknown in the interior of the Dismal Swamp. On areas with dense understories of shrubs, the more tolerant hardwoods thrive better than the whitecedar seedlings and may form the next stand when the existing overstory is removed.

Largely because of "selective logging", cutting in general has tended to reduce the area occupied by whitecedar. Small narrow swamps have suffered the most heavily, for two reasons. First, light from the side has tended to encourage an understory of hardwood trees and shrubs under their stands. Second, no nearby sources of whitecedar seed were available after heavy cutting to supply any lack of seed in the peat or to restock the area if extensive flooding or other factors caused heavy mortality of reproduction. In Connecticut many narrow swamps along creeks, once continuous stands of whitecedar, have been so heavily cut that now there are only patches or clumps of this species (Noyes 1939). Harshberger (1916) stressed the fact that many hardwood swamps arose solely from cutting of the whitecedar, but mentioned only one specific case, the Dennisville swamp in which whitecedar has been replaced in part by hardwoods. Waksman *et al.* (1943) recorded that deciduous vegetation is dominant on cut-over land along the Tuckahoe River.

Even though the area in whitecedar has been reduced, the species can hardly be called an evanescent type as Bromley (1935) did in describing the forests of southern New England. Nor was the same author correct in stating that clear-cutting completely destroys the whitecedar type, red maple and yellow birch succeeding it. Clear-cutting of nearly pure stands, particularly in the larger swamps, has undoubtedly been a major factor in maintaining the whitecedar type.

Draining

Whitecedar swamps cannot be drained and made into profitable farm land for most agricultural crops (Kearney 19°1, Akerman 1923), although some swamps have been cleared for the profitable production of cranberries, chiefly in Massachusetts and New Jersey (Korstian and Brush 1931). The culture of cranberries requires relatively moist sites so, for the most part, the attendant draining and damming have had their major effect upon the cranberry bogs and reservoirs. In a few places ditches have been dug to divert or modify in some way the natural drainage of forested swamps. Flooding the cranberry bogs or reservoirs diverts water from the forested swamps downstream and may lower their water table, while release of impounded water may raise their water level; but both changes are temporary effects, although at times increasing the influence of dry or moist periods. Appreciable changes in water levels over periods as long as a season seem to be limited mostly to forested areas immediately adjoining the cranberry bog or reservoir on the upstream side.

In part of the Dismal Swamp ditches have lowered the water table and adversely affected the establishment and growth of whitecedar seedlings, as well as increased the fire risk (Akerman 1923). The undergrowth of tall shrubs has been greatly encouraged along the ditches, possibly because of the increased light (Kearney 1901). In the Lake States LeBarron and Neetzel (1942) found that draining favored the ecologically higher hardwood forest over the coniferous stage, and favored also the production of a much greater volume of wood, although of less merchantable value. A similar encouragement of hardwoods might be expected from drainage work in whitecedar swamps of the Atlantic Coast.

Fire

Fires have been common through much of the coastal region where whitecedar grows, ever since the first settlements were established by Europeans. For example, Kalm wrote in 1748 that fire breaks out often in the woods of southern New Jersey (Benson 1937). Many of these fires, of course, burned only on the uplands. As early as 1755, however, one fire occurred in the whitecedar swamps near Barnegat and within a few days had covered a distance of nearly 30 miles, consuming many shingles and other whitecedar products that had not been removed from the swamps (Beck 1945). Wright (1895) and Gifford (1896b) described other large fires that had burned in the whitecedar swamps of southern New Jersey. In 1895 it was also reported that at least one fire a year burned through the whitecedar swamps of North Carolina, and that fires had ruined thousands of acres of timbered swamplands in the eastern part of the state (Ashe 1895). More recent fires in the whitecedar swamps of Virginia and North Carolina have also been described (Korstian and Brush 1931, Anon. 1945).

Fires, however, seldom start and spread on the wet sites of the true swamps (Little 1946). Usually the peat is so wet and the air within the forest is so humid and still that fires spread there only during unusually dry periods or at times when a large, extremely hot fire is driven into the swamp by a strong wind. Most of the fires that have damaged whitecedar stands have originated on drier sites, and fires that started in the true swamps have usually occurred within a few years after heavy cuttings that left dense slash covering the ground (see Ashe 1894, Gifford 1896b, Pinchot and Ashe 1897, Korstian and Brush 1931). Some of the severe fires have favored the development of an inflammable shrubby or herbaceous cover that increases the risk of subsequent fires, but this effect has been more common in dry swamps than in wet swamps (Kearney 1901, Little 1946).

Whitecedars of all ages are very susceptible to injury by fire because of their thin bark and inflammable foliage. Fire scars on living trees are not common, because most of the affected trees are killed (Korstian and Brush 1931). The type of damage varies, of course, with the kind of fire; surface, crown, and ground fires have all occurred in whitecedar swamps.

Dry, and usually sandy, swamps burn more readily and have suffered from more fires than wet ones. In the sandy swamps fires are of the surface or crown types. These may not kill pitch or pond pines, but usually would cause the death of whitecedars. Moore (1939) expressed the view that in New Jersey considerable areas of pine swamps, which separate the true swamps from adjoining uplands, may have had at one time stands of whitecedar that were converted to their present condition by cutting and fire. Possibly Kearney (1901) was referring to similar sites when he stated that frequent fires prevent a material increase in the area occupied by whitecedar. In the dry sandy swamps fires have been largely responsible for maintaining the subclimax stage of pond pine in North Carolina and of pitch pine in New Jersey (Buell 1946, Little 1946).

Wet swamps have frequently served as firebreaks, but usually the whitecedars on the edges, at least, have been killed by the large, hot fires burning into the swamp from drier sites (Fig. 5). When driven by a strong wind, a large, hot fire may cross a wet swamp by crowning in the whitecedars and thus kill the stand (Gifford 1896b, Pinchot 1899, Cottrell 1929, Korstian and Brush 1931, Noyes 1939, Little 1946). If the swamp is wet, the fire may burn little or none of the organic debris at the surface of the forest floor. At the other extreme, during unusually dry seasons the peat may be consumed down to the water table or even to the underlying mineral substratum (Gifford 1896b, Korstian and Brush 1931). The deeply burning fires, as in the peat soils of Florida, cause the greatest damage, whereas surface fires may have beneficial effects (Davis 1943).

The variable effects of fires in the true swamps have been the cause of many seemingly conflicting statements. For example, Ashe (1894) thought that if an area was not burned after logging, whitecedar would probably form the next stand, whereas if the area was burned, sweetbay would succeed and usually retain possession. Gifford (1895) expressed just the opposite view. Certain authors have thought that fires played a major role in perpetuating the whitecedar type (Moore and Waldron 1940, Buell and Cain 1943). When some whitecedar stands are burned, however, the hardwoods restock the area in spite of nearby sources of whitecedar seed (Little 1946).

The major reason for the confusion is the number of variables, only some of which Korstian and Brush (1931) and Garren (1943) included in their discussion. The variables that should be considered are (1) composition of original stand, i. e., whether hardwoods are present in overstory or understory, (2) amounts of viable seed, by species, stored in the forest floor at varying depths, (3) the composition of nearby stands that survive the fire and will disperse seed over the burn, (4) the depth to which the fire burns in the forest floor, and (5) the position of the water table after the burn.

The lowering of the forest floor by burning is equivalent to raising the water table (Akerman 1923). During unusually dry periods it is possible for fires to burn sufficiently in the peat so that thereafter water normally stands on the area. This may throw the stage of succession back to leatherleaf *(Chamaedaphne calyculata)* which, in both New Jersey and Rhode Island, is usually the first shrub to invade quaking bogs (Rigg 1940, Wright 1941). In one dense stand of leatherleaf, where the water level was measured monthly for a year, there was normally 2 inches of standing water and, at times, 6 inches. The lack of hummocks on such areas is probably the reason for the absence of tree growth, which may not become re-established for a long time (Little 1946). However, occasional surface fires may impede the establishment of trees even when moisture conditions become favorable, as Kearney (1901) noted in the Dismal Swamp and Penfound and Hathaway (1938) observed on the marshes of Louisiana.

Where hardwoods occur, their ability to sprout may be an important factor affecting the composition of the stand that arises following a fire. Conceivably the forest floor may be burned just enough so that whitecedar seedlings either will not start or will not survive because of excessive moisture, although hardwood sprouts will do both. However, it is questionable if hardwood sprouts will come up through a foot or more of water as Korstian and Brush (1931) stated, particularly if that depth of water is normal.

Where moisture conditions are suitable for tree growth after a fire, species occurring outside of the burn may restock the area under certain conditions. These conditions are (1) where pure whitecedar reproduction has not borne sufficient seed to build up a supply of viable seed in the forest floor of the burn, or (2) where the seed borne by older stands of pure whitecedar is not effective in restocking a burn because of destruction in the fire or the killing of subsequent seedlings by such factors as temporary flooding, or (3) where in stands composed partly or wholly of other species the fire burned deeply enough into the peat both to destroy any viable seed and to prevent' sprouting. Thus the resulting stand may be composed of anyone or any combination of several species, depending on available seed sources. Whitecedar may predominate in the next stand under favorable conditions (Fig. 5) ; or whitecedar may be replaced by gray birch and pitch pine.

Of course, if more resistant pines occur mixed with whitecedar and survive the fire, their seed and sprouts may largely restock the burn (Figure 9 of Korstian and Brush 1931).

Under certain conditions pure whitecedar stands may restock a burn, chiefly from seed stored in the peat at the time of the fire. These stands would have to follow pure stands, but may originate either following a crown fire in uncut stands or a slash fire in a cut-over area, in both alternatives the swamp being so wet that the peat will not burn. According to Korstian and Brush (1931), the Dismal Swamp fire of Easter Sunday, 1913, burned only the slash and resulted in prompt restocking with whitecedar.

Usually some hardwoods would be present, and hardwood sprouts would occur with the whitecedar seedlings starting from seed stored in the peat. For example, in 1936 a crown fire killed the stand on the western half of the swamp in the Heronry tract of the Penn State Forest. The new stand on the burn contains a high amount of whitecedar reproduction, mixed with some hardwoods*.

Pure stands of hardwood sprouts may be expected to restock some burns. These may follow stands containing whitecedar in some cases, as where the whitecedars were in the reproduction stage and little or no viable seed of this species was consequently stored in the forest floor, or where older trees occurred, but the stored seed was consumed in the fire or the subsequent seedlings were killed by flooding or other factors.

Frequently burns are restocked partly by hardwood sprouts and partly by seedlings arising both from seed borne by the neighboring stands and

*Personal communication from J. C. MacDonald of the New Jersey Department of Conservation and Economic Development.

from seed stored in the forest floor. Such a combination apparently formed the origin of the reproduction starting in both Merrygold Branch and East Branch after a 1930 fire, because it is composed of both hardwood and whitecedar seedlings as well as hardwood sprouts. Furthermore, according to reproduction surveys, the number of whitecedar seedlings per acre varies from 16,000 to 48,000 in Merrygold Branch and from 35,000 to 96,000 in East Branch; and the varying amounts appear to be affected directly by the distance and direction from a seed source.

Although both original stands were classed as mature whitecedar, the one in Merrygold Branch had a greater admixture of hardwood trees and shrubs, as does its successor. In the present reproduction more than 90 per cent of the hardwoods are sprouts, compared to about 50 per cent in East Branch. Futhermore, in Merrygold Branch there are about 5,000 hardwoods per acre and, although there are six times as many whitecedars, the dominant hardwoods are more than twice as tall as dominant whitecedars. In contrast, in East Branch there are fewer than 2,000 hardwoods per acre, with 30 times as many whitecedars, and dominant whitecedars are twice as tall as the hardwoods. Consequently, the next mature stand in Merrygold Branch will probably be predominantly hardwood, but in East Branch predominantly whitecedar.

The effect of fires on the whitecedar type since 1700 has evidently not been so favorable as Buell and Cain (1943) implied. In contrast, fire and cutting have usually worked together in reducing the proportion of whitecedar in favor of the associated species. The conversion has, of course, been most complete in the narrow swamps, although the edges of wide ones have suffered. In the hearts of the larger swamps some recent fires have aided in reproducing whitecedar stands, while other fires have hastened the succession to hardwoods.

Animals

Wild animals influence to some extent the occurrence of woody species or their development. In recent years deer have had a more noticeable effect on the establishment and growth of whitecedar in southern New Jersey than other wild animals.

There were great numbers of deer in New Jersey at the time of the first settlements by Europeans, and even then the deer frequented the whitecedar swamps (Thomas 1698, Benson 1937). However, the population of deer in pre-settlement days was kept at relatively low levels because of the killing both by Indians and by predatory animals. Then there were excessive numbers of wolves (Benson 1937). Panthers and wild cats were also common. These three predators killed great numbers of deer (Smith 1765). However, by 1700 these predators were greatly reduced in number by the colonists and by 1840 had been eliminated (Thomas 1698, Rhoads 1903).

With the destruction of the predators, deer doubtless increased in numbers for a short time, but extensive hunting soon caused an even greater reduction. The first law regulating the season for hunting deer was passed in 1771; yet by the latter part of the 19th century deer were confined mostly to Cape May and Atlantic Counties. Estimates then of the total number were as low as 50 deer in Cape May and Cumberland Counties (Rhoads 1903).

Efforts of the Division of Fish and Game, New Jersey Department of Conservation and Economic Development, have greatly changed the status of deer since 1900. Although there are some sections, as in the vicinity of the Belleplain State Forest in Cape May County, where there are still relatively few deer, the center of the pine region probably has a far heavier stocking than ever before. A census made on 3,500 acres of the Lebanon State Forest in 1938 indicated about 1 deer to every 17 acres (Anon. 1938). Some sections have 1 deer to every 10 acres. These areas are overstocked. As in Pennsylvania, a desirable stocking would be about 1 deer to every 40 acres (Clepper 1931).

Woody species furnish the main food for deer in winter and are usually browsed only during the dormant season (Burnham 1928, Pearce 1937). Several writers have reported that northern white-cedar *(Thuja occidentalis)* is favorite browse (as Burnham 1928, Aldous 1941), but the whitecedar of the Atlantic Coast has hardly been mentioned. Noyes (1939) did report that deer browsed whitecedar reproduction in Connecticut, and Clepper (1931) indicated that whitecedars planted in Pennsylvania were only lightly damaged by deer. Van Dersal (1938) did not mention any deer browsing on this species, although he did say that red maple formed the fifth most important winter food of deer in Massachusetts and that blackgum was also browsed by deer. In southern New Jersey observations and tallies made in connection with the present study indicate that whitecedar is the favorite browse for deer during the dormant stage of vegetation. Although reproduction of pitch pine on upland sites in southern New Jersey may be injured appreciably by deer (Little 1937), much of that on lowland areas where whitecedar reproduction is heavily damaged is not injured.

In wet swamps the extent of damage by browsing varies greatly. In many areas the browsing tends to be concentrated along roads or trails. For example, reproduction along the edge of the gravel road through Great Swamp, Green Bank State Forest, has been heavily browsed, although seedlings in the swamp are usually uninjured. For dense natural stands of whitecedar reproduction in wet swamps, Noyes (1939) was probably correct in concluding that it is questionable whether deer are a serious menace. Even there, however, initial growth may sometimes be retarded, and on areas with little reproduction the damage becomes still more important.

The greatest injury on wet sites probably occurs in hardwood areas where whitecedars are introduced through seeding or planting. In one case of this kind the planted stock had a survival of about 100 per cent at the end of the first growing season, but were browsed so heavily during the following winter that many died. Even on the control plots 97 per cent of the seedlings were injured during the first winter and mortality on the open areas approached 50 per cent at the end of the second growing season. On all treatments, surviving seedlings were then 0.3 to 0.45 foot shorter than at the end of the first growing season. One striking example was a seedling 0.5 foot tall when planted and 1.8 feet tall at the end of the first growing season, but only 0.3 foot tall at the end of the second summer. Most of the reproduction could not survive under the severe browsing, and by the end of the second winter mortality was nearly complete.

Damage by deer is usually more important in dry sandy swamps, where the footing is better, than in wet swamps of peat. In one area of dry lowland where natural reproduction of whitecedars between 0.5 and 2.5 feet tall was at the rate of more than 27,000 per acre, a tally was made of the extent of browsing on the tallest seedling of each I/4-milacre quadrat. On 119 stocked quadrats out of 120, only 8 per cent of the tallest seedlings had not been injured, 47 per cent had been lightly browsed, and 45 per cent had been heavily damaged. Similar conditions prevail in many areas.

The rate of growth of whitecedars is slow in the dry swamps, and browsing can check the development of the reproduction for a long period. Where there is dense reproduction the browsing is usually not severe enough to cause high mortality within a short time, but it has caused the development of multiple stems in a few observed areas and probably in many similar ones. Of course, this development greatly increases the competition and further reduces the growth rate. Although in southern New Jersey, as a whole, the main effect from deer browsing has apparently been in retarding growth, locally the proportion of pitch pine on dry sites or of hardwoods on wet sites has at the same time been encouraged.

Occasional whitecedars of sapling size suffer injuries from antler rubbing by deer, similar to those described by Lutz and Chapman (1944), but the amount of such damage is very slight compared to that from browsing.

Locally rabbits or mice may cause appreciable damage to whitecedar reproduction, although they are generally less destructive than deer. Damage by rabbits may be expected in brushy swamps of the pine region, particularly in areas where efforts are being made to convert from swamp hardwoods to whitecedar and where relatively few conifers are introduced through seeding or planting. In one study damage chiefly by rabbits occurred on 70 per cent of the seeded spots of one treatment during the first winter after seedlings had started.

Damage by meadow mice, *Microtus pennsylvanicus*, should be expected along with that by rabbits whenever whitecedar is introduced on abandoned farm land of West Jersey. In one place rabbits and meadow mice injured 192 out of 200 planted seedlings during the first 2 years and were a large factor in the death of 185 during that period. Thus, while less destructive than deer, rabbits and mice may also form a deciding factor in checking the extension of whitecedar stands in certain areas. However, their important effect, like that of cutting and draining, has been confined to the period since the first settlements by Europeans.

Perpetuation of Whitecedar Stands in the Original Forest

The perpetuation of whitecedar stands in the original forest doubtless required the recurrence of some catastrophe or combination of catastrophes. As already shown, whitecedar is less tolerant of shade than several species of swamp hardwoods, and these hardwoods would gradually replace it unless other factors were operating to check the trend.

Effect Of Wind

Extensive damage by strong winds has been considered by some authors to have played an important role in maintaining intolerant species in the forest stands of certain areas (for example, Cline and Spurr 1942). Whitecedar has long been regarded as rather susceptible to damage, because of its shallow root system and the spongy character of the peat soil in wet swamps. Many mature whitecedars are thrown by storms, and those that have grown in dense stands on peat soils never become wind-firm (Korstian and Brush 1931).

Strong winds such as hurricanes are needed to produce extensive windthrow, but even hurricanes are not unusual within the range of whitecedar. For example, the average number of storms of hurricane intensity in 100 years for each 100 miles of coastline has been 21 in Alabama, 6 in Florida (10 in the Pensacola region), 13 in Georgia, 11 in South Carolina, and 8 in North Carolina (Tannehill 1942). The more northern states have, of course, had fewer hurricanes. Some of the storms that may have brought winds of hurricane force to New Jersey were those of Sept. 8-9, 18°4, Sept. 3, 1821, August 1879, Sept. 16, 1903, Sept. 15, 1904, and Sept. 8-16, 1944 (Tannehill 1942, Sumner 1944). For New England Brooks (1938) stated that 5 times in 50 years the storms (originally West Indian hurricanes) are strong enough when they reach New England to cause great damage over a belt 20 miles wide, and that once in a century or two a hurricane of considerable size strikes on a wide front. Perley (1891) mentioned that extensive damage to New England forests occurred in the storms of August 1635, August 19, 1788, October 9, 1804, and September 23, 1815. The hurricanes of 1788, 1815, and 1821 had paths in southern New England similar to that of the 1938 storm; hurricanes of 1635 and 1869 had paths similar to that of the 1944 storm (Smith 1946).

Hurricanes were apparently as common at the time of the first settlements by Europeans, and in pre-colonial days, as they have been more recently. Bartram (1791) described damage by hurricanes to forest and buildings in the South. Kalm wrote that hurricanes were frequent in New Jersey and that high winds caused great devastation in the forests by felling many trees (Benson 1937).

Evidence that whitecedar stands in the original forest were damaged by high winds is provided by Cook (1857). He noted that some of the trees buried in the peat, and mined for lumber, had been blown down and their upturned roots could still be seen.

Extensive blow-downs in whitecedar stands had apparently not been reported prior to the 1938 storm, although Denison (1878) stated that in the hurricane of 1815 all the forests along the coast of southern New England were blown down. In 1938 the extensive stands of whitecedar in the swamps near Voluntown, Connecticut, were heavily damaged. In places the wind pushed over whole acres of these trees, leveling everything, while in other places the trees were pushed only part way over and were left leaning at a sharp angle (Hawes 1939).

The usual lack of extensive damage in recent storms does not preclude the possibility that it was common in the original forest. Whitecedar stands then were not cut when 50 to 80 years old, and many probably reached an age of 150 years or more. The old-growth forests would be quite susceptible to windthrow because of:

(1) Their greater heights than trees of today. About 1784 Schoepf wrote that on the best sites in North Carolina trees reached heights of 60 to 100 feet, but only where protected by other trees against violent winds (Morrison 1911).

(2) The gaps that may have developed in preceding storms. As Gifford (19°°) stated, when a few whitecedars are felled by a storm, the neighboring trees are deprived of their support and fall in every direction.

(3) The greater irregularity in crown canopy that accompanies increasing age. This would increase local turbulence of air which, combined with greater exposure of individual stems, would cause far more windthrow in old even-aged stands than in younger, more uniform ones (Jensen 1941).

Extensive blow-downs similar to the 1938 damage described by Hawes (1939) may therefore have been rather common. Certainly the frequency of hurricanes in the different parts of the range of whitecedar appears to be sufficient to cause extensive damage in old stands. Probably too, as stands reached old age, scattered stems went down and then windthrow gradually spread out from these holes until the original stand was completely overthrown, even without the occurrence of hurricanes. Local storms with wind velocities over 45 miles per hour would be sufficient, and are common enough to have caused appreciable damage in individual swamps or those of a section.

Where extensive windfall occurred, nearly pure stands of whitecedar may usually have developed, even though hardwood reproduction had been present. In the leveling of a whitecedar overwood, large mounds of peat would be turned up. Many of the hardwood seedlings would be involved in the disturbance of the peat and may have later died. Sudden and extensive windthrow might also block the drainage channels and cause a general rise in the water levels throughout the swamp for a few months. The effect then might be to kill outright much or all of the existing vegetation. Under these circumstances whitecedar seedlings starting from seed stored in the peat or shed by wind-thrown trees would have a good chance of restocking the area, possibly even starting on the boles or upturned roots of their parents. Pure stands of whitecedar, almost lacking in other species, might result. Even if damage by flooding did not occur, the large openings created by extensive blow-downs would favor the perpetuation of practically pure stands of whitecedar because of the large amount of seed available on the trees and in the forest floor and the favorable growth of this species under open conditions. Under more gradual or incomplete windfall a slight increase in the proportion of hardwoods might be favored.

On the few areas that were stocked by old hardwoods in the original forest, some damage by strong winds doubtless occurred, as it does today. Red maple was damaged in the 1938 hurricane (Hawes 1939, Jensen 1941). Van Dersal (1938) stated that blackgum is not wind-firm. However, observations made in New Jersey indicate that extensive blow-downs in hardwood swamps would not be common, although damage to single trees would be. The small holes created by individual windfalls would doubtless be restocked by hardwoods, even if seed sources of whitecedar were available. Mixed stands of hardwoods and whitecedar, if even-aged, might be expected to suffer damage similar to that in whitecedar forests and possibly to restock largely to whitecedar, while uneven-aged stands of mixed composition might react in both respects more like the hardwood areas.

In dry swamps where whitecedar may have occurred mixed with pitch pine and swamp hardwoods in the original forest, damage by strong winds was probably of a different nature. Old trees of all species would usually be infected with wood-rotting fungi that had entered through fire scars or branch stubs. When strong winds occurred, windfall might be common when the soil was saturated, but at other times breakage may have been the principal form of damage. The composition of the succeeding stand would probably be determined to a great extent by the preceding and subsequent fire history of the area.

Influence Of Fire

Forest fires have been considered an important factor in perpetuating whitecedar in the original forest (Moore and Waldron 1940, Buell and Cain 1943, Buell 1946) ; and they were evidently common on upland sites, at least, in the original forest throughout the range of whitecedar. Early travelers in the South,. for example Bartram (1791), noted the frequency of fires and described the original forest of the upland. Later writers, such as Heyward (r939), have concluded that frequent fires were the only natural agent that could have perpetuated the pure stands of pine that Bartram described. Similar conditions prevailed farther north. In New Jersey Smith (1765) wrote that before the European settlements the Indians burned the woods regularly to make easier the hunting of deer. The description by Budd (1865) of the lack of undergrowth in the original forest tends to substantiate Smith's statement. Writing of southern New England, Wood reported in 1634 that the Indians frequently burned the woods to improve hunting conditions and that consequently there was scarcely a bush or a bramble under the stands (Hawes 1923).

On the other hand, Raup (1937) claimed that fire was not prevalent in the original forest and was not the cause for the park-like appearance of the stands, but his views are considered fallacious. Raup apparently erred in not appreciating the wide range in type of fire due to differences in seasonal danger and in amounts of fuel, and also in not properly evaluating the effect that cutting since settlement has had on inflammability and damage. The principal points to consider seem to be as follows:

(1) Season. Possibly the Indians used fire chiefly in the fall and winter, as Pritts (1841) and Wood (Hawes 1923) implied. If so, fires would have had far lower intensities than those of today, which are concentrated in dry periods of late spring.

(2) Frequency of burning. Relatively frequent fires, even if not every year, tend to be far lighter in intensity than those at less frequent intervals because a smaller amount of fuel accumulates between burns.

(3) Effect of cutting. Cutting has not only created younger stands more susceptible to damage, but also, through periodic removal of the competing overstory, has encouraged shrubby understories. These understories would be largely absent under closed canopies, particularly when repeatedly killed back by light fires, but when present they tend to add greatly to the intensity of a fire.

Thus frequent burns in the original forest did maintain park-like stands of species relatively resistant to fire and able to grow into the overwood when gaps in the canopy occurred. On upland sites in much of the coastal plain of the South these forests were principally longleaf pine (Wahlenberg 1946). In the pine region of New Jersey they were pitch and shortleaf pines (Moore 1939, Little 1946). In the coastal sections of southern New England they may have been pitch pine or, under less frequent burns, possibly white pine and some of the oaks.

The frequency and type of fire occurring in swamps were probably quite different from those of today. Since 1700 the combination of cutting and less frequent, but hotter, fires have created far more hazardous conditions on upland sites than occurred in the original forest, particularly in certain areas such as the pine region of southern New Jersey (Little 1946). The greater hazard on upland sites and the likelihood of more frequent occurrence of fires in the late spring have doubtless affected the frequency and type of fire occurring in the swamps. In 1634 Wood observed that the only underbrush was in swamps where the wetness of the site protected the area from fires (Hawes 1923). The frequent fires of relatively low intensity in pre-settlement days probably seldom provided hot head-fires that would run through the crowns of whitecedar stands, or even cause appreciable damage to the edges of whitecedar swamps. Furthermore, in the absence of cuttings, slash fires would not occur in the swamp.

Following extensive blow-down, fire might be expected to occur in the swamps as Cline and Spurr (1942) found it occurring under similar conditions on upland sites in New England. However, fire did not always follow wind damage in swamps. Reporting on observations made on whitecedar logs buried in the peat in southern New Jersey and mined for lumber, Cook (1857) stated that some of the trees that had been blown down continued to grow for a long time afterwards, as was known by the heart being very much above the center and by the wood on the under side being hard and "boxy". If a fire had occurred soon after the blow-down, the trees would not have continued to grow.

Evidence that fires did occur in wet swamps in pre-colonial times is provided by charcoal found at various depths by some investigators. Under one whitecedar stand in North Carolina Buell and Cain (1943) found scattered fragments of charcoal at a depth of 2 to 3 feet and abundant charcoal below that level, indicating the occurrence of severe and frequent fires at an earlier date. Waksman *et al.* (1943) apparently discovered little charcoal in the peats of New Jersey, although they do mention its occurrence at various depths in one bog in the southern part of the state. Charcoal of course indicates relatively hot fires that perhaps burned into the peat or fed on the great amount of woody fuel that would be present on an extensive blow-down. Fires that consumed only the foliage of standing or wind-thrown trees would create no charcoal.

At rare intervals fires during unusually dry periods may have traveled from the upland into wet swamps where they burned in the peat, but only where there was a large intervening area of dry swamp unburned for several years is it probable that the fires could have developed sufficient intensity so that they might have been driven by a high wind into or through a whitecedar stand, consuming chiefly its crowns. Dry sandy swamps are uncommon in New England and in some sections of New Jersey because of the topography, but are common in other parts of New Jersey and farther south, as in eastern North Carolina. Most of these areas probably burned at frequent enough intervals to prevent the development of hot fires capable of spreading through the crowns of whitecedar alone when the fires ran into the true swamps.

The effect of fire was doubtless greater in dry swamps than in wet ones, even as it is today. On the frequently burned portions of a dry swamp, pine stands with relatively little underbrush undoubtedly occurred (Little 1946). Understories of swamp hardwoods and whitecedar developed on areas less frequently burned, the hardwoods being largely sprouts and the whitecedar from seed borne by the neighboring stands. On occasional tracts that were frequently burned over a long period and then by chance were not burned for many years, stands of whitecedar and pitch pine may have developed. When these stands were again burned, however, most of the whitecedars would be killed, leaving pine the predominant species. The interspersion of areas having a different past history of burning was doubtless not only by large tracts, but, as occurs to some extent today, also within a large tract due to differences in moisture and fuel that affected fire occurrence and intensity.

The occurrence of whitecedar in both dry and wet swamps of the original forest was apparently favored more by fire than it is today, because of several factors. First, there were far greater supplies of whitecedar seed. In the wet swamps the stands of this species were then relatively old and large, and hence good producers of seed. The larger production meant more seed stored in the peat and more distributed to adjoining areas, and for greater distances than the younger, shorter trees permit today. Second, a wider variance in fire intensity and occurrence than has been true in recent years probably favored whitecedar in dry swamps of the original forest. Most of these sites now undergo periods of fire exclusion broken only by severe burns that cover spots that would not be burned by many lighter fires. Third, the type and frequency of fires in wet swamps also probably favored whitecedar more in the original forest than today. Then there were probably very few fires in young stands of whitecedar, and hence far less chance that they would be replaced by other species. Of the infrequent fires that did burn in wet swamps, most may have burned during very dry periods and thus consumed sufficient peat to prevent sprouting by any associated hardwoods. Following such a burn, whitecedar with its large amounts of wind-distributed seed would have an excellent chance of restocking the area when moisture conditions became suitable. At rare intervals fires may have occurred following an extensive blow-down with results similar to those following slash fires of today, except that the greater supply of whitecedar seed in the peat or shed by neighboring stands would have increased the chances of another pure stand of this species.

Influence Of Salt Water

Salt water may be driven inland during major storms and injure coastal forests in two ways: through spray carried by the wind, and through inundation by storm waves or tides. In New Jersey sufficient spray was carried by the wind in the storm of September 3, 1821, so that 3 miles inland from the shore the leaves of forest trees were killed (Cook 1881). Spray was carried over the entire land area of Cape Cod by the gale of September 8, 1932, but not in amounts necessary to kill the trees.

White pine suffers greater damage than the other conifers; some killing of its foliage has been observed at distances as great as 5 miles from the shore (Hall 1933). Whitecedar is badly injured, although not so severely as white pine (Wallace and Moss 1939). Pitch pine is quite resistant (Hall 1933, Wallace and Moss 1939). Injury to hardwoods depends to a great extent on whether it occurs during the growing season; but even the 1938 storm, coming late in the season, caused severe damage to certain hardwoods. Blackgum was heavily injured, more so than any other species, and some were killed (Moss 1940). In a few localities salt spray may modify the composition of coastal swamps, favoring pitch pine and any hardwoods that are less susceptible to damage than are white pine, whitecedar, blackgum, and sassafras.

However, inundation has apparently had a far more important effect on the composition of coastal forests than have injuries from salt spray. Most of the high storm tides have occurred during hurricanes, although some have developed during northeast gales. Tides 15 to 20 feet above mean sea level have occurred in some places along the South Atlantic and Gulf Coasts and in the future will certainly occur at other places (Tannehill 1942). A similar statement is justified for the North Atlantic Coast, particularly for the coast of New England. For example, the tide was 20 feet higher than usual at Boston in 1635, 17 feet higher at Stonington in 1815 (Perley 1891), and 10 to 15 higher from Falmouth to Stonington in 1938 (Brooks 1938).

Several writers have reported damage by these high storm tides to vegetation. In one section of New Jersey, about 1878, the tide rose higher than it had done in former years and killed maples, other species of hardwood trees and shrubs, as well as whitecedars (Cook 1881). Cook (1868, 1881) mentioned other specific areas which salt water, brought in by storm tides, had flooded and where whitecedar stands were killed. Damage in New England from the 1635 storm tide was not mentioned by Perley, although it doubtless occurred. In 1815 around Buzzards Bay the tide was 8 feet higher than usual, and salt water was driven in on the land so far and in such quantities that it killed corn, potatoes, and trees in the whitecedar swamps (Perley 1891). The 1938 storm tide also flooded farm land, as well as forested swamps (Bergman 1940, Moss 1940).

Moss (1940) reported that damage to the forests varied with the duration of the flooding by salt water. Where the water had been impounded all trees died. Where drainage was better and the water receded with the storm wave, the trees put out new growth similar to that on the unflooded areas, but almost as soon as the foliage reached full size, it began to die, and then new leaves would develop. This process continued throughout the growing season. Such damage varied in occurrence both in locality and on individual trees (Moss 1940).

Although Sumner (1944) stated that tide heights during the 1944 hurricane did not approach those of the 1938 storm, a sufficient storm wave was created in 1944 so that salt water inundated some of the forested swamps on Cape Cod, killing all or nearly all of the vegetation on the flooded areas. The author visited a few of the affected areas in the summer of 1946, with District Forester C. L. Cherry of the Massachusetts Department of Conservation. Whitecedars had been killed outright, as were most of the hardwood trees and shrubs. An occasional large red maple had sprouted from the base or along the bole, but the new growth appeared unhealthy. In one area where whitecedars 6 inches or larger in diameter had formed an appreciable part of the stand, there was excellent reproduction of whitecedar, either from seed stored in the forest floor or shed in the fall of 1944 by the dying trees. In another area where the dead whitecedars were mostly 2 to 4 inches in diameter, the amount of reproduction was less, but there were still several thousand seedlings 1 and 2 years old per acre. Possibly any whitecedar stands in the reproduction stage that were flooded may have few or no new seedlings of this species unless there are older trees nearby.

In the original forest similar damage from inundation doubtless occurred, but the older stands of larger whitecedars then present would favor restocking by this species more than do the younger ones of today. In some places, inundation by salt water probably caused the replacement of mixed stands of swamp hardwoods and mature whitecedars by pure stands of whitecedar.

In many areas, however, the killing of forest growth by a storm tide is due in large part to what has been called "coastal subsidence" or the rise in sea level in relation to the land surface. The killing of forest growth may there represent the first step in the further encroachment by salt marsh on fresh-water sites (Cook 1881). An appreciable amount of forest land has been involved in many of the states along the Atlantic Coast. On Cape Cod whitecedar stumps have been found more than 3 miles out in Barnstable Bay (Hitchcock 1833). Cook (1856) estimated that within the previous 50 years salt water had killed 1,000 acres of forest growth just between Maurice River and West Creek in Cumberland County, New Jersey. Great Cedar Swamp, which is now some 6 miles long and 1 to 2 miles wide, apparently constitutes a remnant of the huge whitecedar forests that may once have bordered New Jersey, and of which many are now buried under several feet of tidal marsh peat and sand (Waksman *et al.* 1943).

The present relation between tidal marsh and whitecedar swamp has been described by Waksman *et al.* (1943). According to them, the marsh vegetation changes abruptly in most places to that of the whitecedar swamp, although in a few areas scattered whitecedars are found in the marsh. The whitecedar trees that border the marsh or tidal streams are smaller and appear poorer in vigor than those farther from the influence of salt water. Because the flow of fresh water through the swamp is largely responsible for checking the extent of brackish water, the balance between fresh and salt water is delicate. Any flooding by salt water may kill the present stand. If the shallow water becomes fresh again, a new whitecedar stand will develop. If this water remains saline, vegetation of the tidal marsh will prevail, at least until sufficient peat has accumulated so that conditions are again suitable for whitecedar. Gifford (1900) noted that there were areas where the forest was encroaching on the marsh as well as areas where the opposite was true.

Although other factors may locally affect the balance between fresh-water vegetation and that of the tidal marsh, the coastwise relation in level between sea and land is usually the most important factor. The rise in sea level in relation to the land has, without any serious break, been steady and slow, perhaps not exceeding a foot a century for the last 2,000 to 3,000 years (Raup 1937). However, whole regions in New Jersey, as in Cape May County, have undergone two or more periods of submergence (Waksman *et al.* 1943).

The ecological effects of changes in sea level are believed to be confined for the most part to the swamps bordering the coast. Recent changes in sea level even during a century would cause far less fluctuation in the water relations of a swamp 20 miles inland than occur seasonally, and the same may be true of fresh-water swamps only a mile from tidewater. Along the coast itself the effect generally has been to favor the perpetuation of pure stands of whitecedar. Temporary flooding may eliminate for many years most of the competition by hardwood associates and provide open areas that may be restocked by whitecedar from seed stored in the peat or shed by neighboring stands. Other open areas are at times available when the peat of a tidal marsh has accumulated sufficiently, or during a period when the sea level is becoming lower.

Effect Of Inundation By Fresh Water

Excessive water in swamps, even when not saline, may be Injurious to vegetation, but the extent of damage is variable. Observations made by Klose (1927) indicate that standing water may cause higher mortality than flowing water. Submerged trees have suffered more than those in which the aerial portions were only partly or not at all covered (Lentz 1928). Thus size of trees has affected the amount of damage from inundation in some cases (Lentz 1928, Hall *et ai. 1946).*

Vigor of trees prior to flooding has also had an effect on mortality (Lentz 1928). Flooding during the growing season was found to be more injurious to woody plants than during the dormant season (Hall *et al. 1946).*

The length **of** time **an** area is inundated is extremely important. For example, Eiffert (1933) observed that most of the hardwoods in one area in Ohio were able to recover after being submerged for a week. However, Lentz (1928) reported that where flood waters remained for 3 months along the lower Mississippi River all the trees that had been submerged were killed.

Little information is available on the relative tolerance to flooding of the species in the whitecedar-hardwood forests. Waksman *et at.* (1943) stated that temporary flooding by fresh water does not injure whitecedar, although if long continued it results in the killing of mature trees. Red maple was more seriously affected by inundation than were black ash *(Fraxinus nigra)* and elm *(Ulmus americana)* in the area studied by Gates and Woollett (1926). On the other hand, Hall *et at.* (1946) reported that red maple was tolerant of flooding, although less so than cypress and water tupelo *(Nyssa aquatica).*

Observations in New Jersey indicate that relatively brief periods of flooding, such as occur when the impounded water in an upstream cranberry bog is released, do not cause any apparent damage to whitecedar and hardwood stands even though water levels may be temporarily raised by about a foot. Flooding to a similar depth, but more prolonged as a result of excessive precipitation, may cause some mortality in whitecedar stands, but usually only scattered stems are apparently affected among those not submerged. Damage to reproduction, the crowns of which are partly or wholly covered, may of course be heavy.

That apparently happened in Great Swamp, Green Bank State Forest, in 1938. There, as a result of removing the hardwoods from a mixed mature stand, crews of the Civilian Conservation Corps had favored the establishment of many whitecedar seedlings, 4 to 12 inches tall in 1938. Preceding and during the hurricane of that year, about 10 inches of precipitation fell in a period of 5 days, and because of the presence of storm waves brought by the hurricane, the flow of fresh water seaward was doubtless impeded.* At high tide the water stood 2 feet deep on the section of the Green Bank-Wading River Road through Great Swamp. The small whitecedar seedlings were submerged and most of them died, although larger whitecedars, hardwood sprouts, and mature trees were apparently not affected.**

*The precipitation at Atlantic City was 10.04 inches, at Tuckerton 9.78 inches, according to the "Climatological Data, New Jersey Section, September 1938" published by the U. S. Weather Bureau.

**Information was supplied by J. C. MacDonald of the New Jersey Department of Conservation and Economic Development who thought that saline water may have been the cause for the damage. In the absence of injury to the large whitecedars and to hardwood sprouts, an excessive amount of fresh water appears to be the more probable cause.

During relatively dry years whitecedar or other invaders may become established in bogs normally too wet for tree growth, and subsequently in years of heavy precipitation the newly established seedlings may be killed by excessive water. Occasional areas having such a history have been described by Wright (1941) and Parker (1945).

On the whole, however, fluctuations or excessive amounts of precipitation have probably had relatively little effect on the composition of forested swamps unless aided by other factors, particularly those that favor the retention of water. As mentioned previously, extensive windthrow may have clogged drainage channels and raised water levels so that temporary flooding killed all vegetation and created open sites favorable for the subsequent establishment of pure stands of whitecedar. Beaver dams were probably far more common in the original forest than extensive blow-downs and doubtless were responsible for much of the damage from flooding that occurred then.

Effect Of Animals

Unlike deer, rabbits, and mice, the influence of which has apparently been at its maximum in recent years, beavers appear to have had their greatest ecological effect before the settlements by Europeans were established. Then beavers occupied the streams and lake shores of most of the continent, from northern Florida north to Labrador (Bailey 1927). Southward they were less numerous than in New England (Morgan 1868). Bailey (1922) indicated that the original range of beaver did not include Cape Cod, Long Island, the eastern half of southern New Jersey, or the Dismal Swamp; but the accuracy of his map is questionable. Thomas (1698) stated that beaver skins formed a part of the "peltage", then one of the principal exports from Burlington County, New Jersey. In 1749 Kalm wrote that beavers were formerly abundant in New Jersey, and the early settlers saw one dam after another raised in the rivers and brooks by beavers (Benson 1937). By 1765 there were few beavers in New Jersey (Smith 1765).

The decline in number of beavers was rapid in all the states of the East Coast, and probably had been appreciable in coastal sections before many of the settlements were established. Although as many as 66,000 beaver skins were exported annually from New York City in the 1600'S, this trade had practically ceased shortly after 1700. The trade in beaver pelts from New England, Pennsylvania, Delaware, Maryland, and Virginia had a similar history (Morgan 1868).

Beavers were still to be found in the swamps of the New Jersey pine region long after those in southeastern Pennsylvania had been exterminated. In southern New Jersey they lived along Wading River, along Toms River, and near Dennisville, as well as at other places where swamp stands would be composed of whitecedar and associated hardwoods, but they were possibly exterminated by 1820 (Rhoads 1903). Mostly because of restocking by the Division of Fish and Game, New Jersey Department of Conservation and Economic Development, beavers occur occasionally today in southern New Jersey, as along the Rancocas Creek near New Lisbon and Wading River near Speedwell.

The feeding habits of beavers are chiefly responsible for the importance of these animals as an ecological factor. They rarely feed on conifers. Usually when coniferous trees are cut they are used only as building material (Bailey 1922, 1927). Birch, maple, and other deciduous trees and shrubs, particularly aspen and cottonwood, have been considered the favorite food of beavers (Morgan 1868). However, Bailey (1922) emphasized the importance of aspen and other members of the genus *Populus* and stated that birch, maple, and oak are used only under the stress of necessity. Sweetbay has not been mentioned by recent authors; but Kalm wrote in 1749 that this species formed the chief food of beavers in New Jersey, so much so that early settlers called it the beaver tree and used its branches as bait in trapping beavers (Benson 1937).

Recent observations at Speedwell, New Jersey, indicate that the beavers there today also prefer sweetbay as a source of food. All trees of this species have apparently been cut in the area where the beavers have been feeding. Possibly the boles and larger branches were cut into shorter lengths and stored for food, because a few sticks about 3 feet long and with the bark gnawed off were found on the bank. The bark had also been stripped from all stumps. Nearly all the stems of blackgum, a common species in this area, had also been felled or partly cut, but the bark had been stripped only from the stumps. There was no evidence that any feeding had occurred on the felled boles. Although red maple and whitecedar were also common, no evidence of feeding thereon was observed. However, in excavating Lake Nummy on the Belleplain State Forest, T. W. Haigh of the New Jersey Department of Conservation and Economic Development found branches of whitecedar that had been cut by beavers.*

***Personal communication.**

At Speedwell, dams have been constructed by beavers, and several acres flooded. The beavers have also dug canals that permit them, while under water most of the way, to reach individual sweetbays and blackgums in almost any part of the swamp. Many whitecedars are dying or dead from the standing water impounded by the beaver dams.

In the original forest beavers were common, and apparently had a great effect on the composition of swamp forests. Although the beavers were particularly common in the Northeast, they probably occurred to some extent through most of the range of whitecedar. As Hawes (1923) stated for New England, in all of the original forests there were swamps and meadows made by beaver dams. The beavers doubtless lived in areas where the stands had a high proportion of hardwoods, even as they do today*. Dams may not have been constructed on the larger streams, but from these the beavers probably built and used canals to reach different sections of a swamp. There the activities of beavers had an effect opposite to that of the "selective logging" today, because then hardwoods were removed and the whitecedars left. On smaller streams dams were built and whitecedars, as well as hardwoods, were killed by the impounded water. The rise in water level near each dam may usually have been only 1 to 2 feet, but this would be sufficient to flood several acres and the aggregate damage caused by a large population of beavers was probably important.

Although whitecedars on the flooded areas usually died, the perpetuation of whitecedar stands was favored in the original forest by beavers because (1) these animals worked chiefly in areas with a high proportion of hardwoods and (2), when dams were abandoned, open areas became available for restocking to whitecedar. Beavers may, therefore, have played a major role in holding natural succession in check and in perpetuating whitecedar stands.

*Besides occurring in the mixed stand at Speedwell and in the hardwood swamp near New Lisbon, beavers recently lived near Francis Mills, according to E. B. Moore of the New Jersey Department of Conservation and Economic Development, and on Ballanger Creek, Bass River State Forest, according to H. A. Somes of the Northeastern Forest Experiment Station. Both of the last two areas had hardwood stands. Dams were built in all areas except along the Rancocas Creek near New Lisbon.

SILVICULTURE

WITHIN its range whitecedar is usually the most valuable tree that can be grown on wet peat soils. Pure crops of this species are the most profitable product of such sites (Ashe 1895, Baker 1922, Noyes 1939). The following pages summarize present knowledge of methods that provide these crops, and that are applicable to conditions in New Jersey and possibly elsewhere in the Northeast.

MANAGEMENT OF PURE WHITECEDAR STANDS

Harvest Cuttings

Several types of harvest cuttings have been recommended for whitecedar stands. Ashe thought that a selection system involving the removal of only the largest trees gave the best results, but if that was not economically feasible, a shelterwood system should be used (Pinchot and Ashe 1897). Akerman (1923) recommended leaving two medium-sized trees with a fair amount of crown on each acre to ensure a supply of seed. Korstian (1924) disagreed, stating that the reservation of seed trees is impractical because of the great susceptibility of the species to windthrow when the surrounding stand is cut. In 1931 he recommended clear-cutting in strips not more than 1,000 feet wide, and located approximately at right angles to the direction of storm winds, so that seed from intervening uncut strips would be effectively distributed over the clear-cut area (Korstian and Brush 1931).

All other authors have also advocated clear-cutting, although the type of clear-cutting recommended has varied. Cottrell (1929) and Noyes (1939) thought that it should be in patches or strips. Strips were also advocated by Jemison *et al.* (1945) and Moore *et al.* (1946). The width of strips recommended was 100 to 150 feet by Moore *et al.* (1946), less than 500 feet by Noyes (1939), and 250 to 1,000 feet by Jemison *et al.* (1945). The strips should be at right angles to the prevailing winds (Jemison *et al.* 1945, Moore *et al.* 1946). Moore *et al.* (1946) recommended progressive strips. On the other hand, Jemison *et al.* (1945) recommended the use of intervening uncut strips not less than 150 feet wide. Adjoining stands may be cut when adequate reproduction of whitecedar on the cut-over area has attained a height of 1 foot (Moore *et al.* 1946). In contrast, Jemison *et al.* (1945) recommended that there should be at least 1,000 seedlings per acre, 3 feet or taller, on the clear-cut strips or that the reproduction on the strips first cut should have grown to sufficient size so that it will seed the original seed strips when they are cut.

In both New Jersey and Connecticut most of the past cuttings have been clear-cuttings of small areas, and not of an entire swamp (Cottrell 1929, Noyes 1939). Consequently, seed from adjoining stands is nearly always distributed over the cut-over area (Cottrell 1929). Both Cottrell and Noyes implied that these past cuttings have usually resulted in satisfactory restocking by whitecedar. In eastern Connecticut, the Connecticut Forest Service has clear-cut blocks of 1 acre on a checkerboard pattern, leaving alternate blocks uncut (Noyes 1939). Some very fine stands of reproduction have resulted from this method.*

Data obtained in the author's study show the importance of even-aged management and of clear-cutting as the method of harvesting the timber crop, but there is less definite information on the proper size of cutting areas. If all conditions necessary for germination and growth through the sapling stage could be assured, there would be little need for seed trees; but conditions may be unfavorable and there is some risk of the supply of viable seed becoming exhausted (Akerman 1923). Seedlings may start in great quantities from seed stored in the peat, and subsequently die from drought, flooding, damage by animals, or other causes. The frequency with which these seedlings are eliminated, so that seed from standing trees is necessary for restocking, is unknown; but apparently the frequency is sufficient to warrant consideration. Therefore, the cuttings should be made in such a manner that outside sources provide seed, or seed trees should be left-and the first alternative seems preferable in view of wind damage. Thus, distance and direction of seed distribution by the wind have to be considered in planning the cuttings. As has been mentioned previously, the bulk of the seed is distributed by the prevailing westerly winds in southern New Jersey, and the distances at which a large amount of seed falls on a unit of area are not great. On the other hand, the clear-cutting of small areas, particularly at long intervals, is not advisable because partial shade from adjoining stands will encourage hardwoods rather than whitecedar, and under adjoining uncut stands hardwood understories will also be favored.

For practical purposes in most swamps of the Northeast two alternatives are possible. For relatively small holdings, particularly those of less than 5

"Letter from former Connecticut State Forester A. F. Hawes, dated March 15, 1943, in the files of the Northeastern Forest Experiment Station.

or 6 acres, a complete clear-cutting of an individual property is apparently desirable, as long as pole or mature whitecedars form the adjoining stands, especially on the west side. If large trees are lacking on neighboring land, a few clumps or a small fringe of whitecedar seed trees might be left, possibly near a road or the edge of the swamp so that they could be removed when reproduction 1 to 3 feet tall is established on the cut-over area. For larger holdings in one swamp a system of strip cuttings progressing from east to west, or southeast to northwest, might be employed.

The strips should usually be as short as possible, because exposure and windthrow frequently cause appreciable losses in the residual stand along the edge of clear-cut areas. Thus, in relatively narrow swamps the strips should extend across the swamp, possibly at an angle so as to be properly oriented.

Width of the strips might ideally be the distance of effective seeding, that which will stock an area with several thousand seedlings per acre within a period of 5 years. In New Jersey this distance is usually limited to less than 200 feet on the east side of pole or mature stands. Thus, the strips might ideally be only 100 to 150 feet wide, as recommended by Moore *et al.* (1946).

However, seed from standing trees usually is only a supplement to the seed stored in the peat. Consequently, most of the strips 300 to 400 feet wide appear to reproduce satisfactorily, although wider strips may be understocked in the center. Adjoining seed sources to the west of the cut-over area should not be removed until adequate reproduction 1 to 3 feet tall is established, and seed trees should be left on the west edge of the last strip if they are not available on adjoining property.

The proper size of the cutting area is affected somewhat by the size of trees harvested and the size of those left in adjoining stands. Once stands are 45 years old or more there is usually enough seed stored in the peat to restock the area, but in stands 30 years old the amount may be so much less that the amount of reproduction is affected. The low production of seed by relatively young stands, and the short distances to which it may be distributed, are factors that sometimes warrant consideration in planning harvest cuttings. Fortunately most stands are not cut until they are more than 45 years old.

Rotations recommended by foresters vary greatly. However, only Korstian and Brush (1931) have indicated that rotations as short as 35 years may be financially desirable on the best sites. Both Cottrell (1929) and

Korstian and Brush (1931) have discussed the desirable rotation in view of type of products desired, growth in cubic and board feet, and financial factors such as taxes, stumpage and land values, and administrative charges. For New Jersey Cottrell (1929) stated that the rotation based on the culmination of growth in cubic feet would be 50 years, and in board feet more than 100 years, but that the best financial rotation was between 50 and 60 years. Moore (1939), however, thought the rotation in New Jersey should be 70 to 80 years. Noyes (1939) stated that in Connecticut it should be between 80 and 100 years. The actual rotation in New Jersey today is usually 40 to 70 years, with many stands being cut between 50 and 60 years.

Hardly any of the authors who have discussed the harvesting of whitecedar have stressed the importance of also removing or killing any associated hardwoods. Moore *et al.* (1946) did state that all hardwoods in the stand should be girdled or cut. Possibly some of these can be used in constructing the temporary corduroy roads. In any case they should not be left standing unless they have been girdled or poisoned. Treatment of the associated hardwoods and proper slash disposal are rarely accomplished and, consequently, seem usually to have a decisive effect on the composition of the resulting stand.

Akerman (1923) suggested controlled burning or browsing by cattle and goats to clear the ground of underbrush and slash. Korstian and Brush (1931) favored burning the slash in the first winter following logging, and, if that was impossible, rigidly protecting the cut-over areas from fire for 5 to 10 years. Although Cottrell (1929) thought slash disposal was unnecessary in New Jersey, Moore (1939) recommended burning slash in the first winter following logging. Noyes (1939) made a similar recommendation, but qualified it by saying that when stands were not dense the slash could be scattered without interfering with seedling establishment. Jemison *et al.* (1945) presented the same alternatives as Noyes, but included also piling the slash without burning.

In most areas slash should be burned during the winter following logging (Moore *et al.* 1946). The burning should be done when the peat is too wet to ignite, and it is not necessary that all woody material in the slash be consumed. Burning the foliage and smaller branches would usually be sufficient, and most of this can be done without repiling the slash. There is also no need for attempting to burn any material in hollows where water normally stands. The objective in slash disposal is to prepare a suitable seedbed for the establishment of whitecedar on the hummocks.

Although some disposal of the underbrush may also be necessary in the South, in the Northeast it will rarely be needed in the true swamps except where stands have been previously thinned or partially cut. There the cutting or breaking of shrubs in the logging, and possibly burning some in disposing of the slash, will favor the establishment of whitecedar.

Cleanings

Cleanings should be an important part of the silviculture of whitecedar. This species should be grown in dense pure stands, and hence a major problem both in southern New Jersey and elsewhere is obtaining regeneration that is adequate in amount and purity. Consequently, in many reproduction stands cleanings are needed, but the pure stands thus created will usually need no further attention until they are harvested.

The need and cost of cleanings varies greatly, depending on the stand composition. Where the harvested stands are pure whitecedar, no subsequent cleanings may be necessary in obtaining a new stand of similar composition. Cleanings become more important as the proportion of hardwoods increases, and are necessary on areas where a heavy understory of shrubs and small hardwoods was established prior to the removal of the overwood. In these areas three cleanings, each taking about 3 to 5 man-days per acre, may be needed to ensure a high proportion of whitecedar in the subsequent stand. In contrast, in areas where the harvested stand was relatively pure whitecedar and there were few shrubs and small hardwoods in the understory, the desired cleanings may require a total of only 2 man-days per acre.

Thinnings

Thinnings have long been advocated for whitecedar stands. Emerson (1846) thought that when stands were only a few years old highly profitable thinnings could be made. He recommended removing 80 to 90 per cent of the trees present in dense sapling stands. Pinchot (1899) stated that thinnings would pay in stands 40 to 60 years old. Gifford (1900) believed that regular thinnings are necessary almost throughout the whole life of a whitecedar stand. Akerman (1923) thought that thinnings would save 20 per cent of the necessary time, as well as improve the quality, in growing trees for saw timber.

The New Jersey Department of Conservation and Economic Development has so far done most of the thinning in whitecedar stands, and the information available therefrom has been given in various publications (Baker 1922, Cottrell 1930, Korstian and Brush 1931, Moore and Waldron 1938 and 1940). The first thinnings were very light, but later ones rather heavy. All were in the form of low thinnings. The general practice was to leave about the same number of trees after thinning as would be found in the dominant stand at maturity (Cottrell 1930). However, two degrees of thinning were used on sample plots; in one about a third of the basal area was removed, in the other slightly more than a half (Moore and Waldron 1940).

Thinnings have been tried in stands ranging from 25 to 65 years old. Thinnings in stands 25 years old do not pay either silviculturally or financially (Cottrell 1930). Stands 65 years old are too old to thin advantageously. The thinnings are justified only on 45-foot sites, or better, and in stands where there are at least 200 square feet of basal area per acre. This amount will not often occur in stands younger than 45 years old (Moore and Waldron 1940).

Thinnings of course remove many of the trees that would die before harvest cuttings are made, thereby affecting growth and yields. For example, Moore and Waldron (1940) stated that a mortality of 50 per cent occurred in the trees of one unthinned stand between its 36th and 46th year. Comparable mortality on the thinned areas was only 2 to 6 per cent, the 6 per cent occurring in a heavily thinned stand 65 years old and being mostly due to windthrow along the edges. Differences in height growth in thinned and unthinned stands have been negligible, and differences in diameter growth are obscured by the effect of mortality. Losses due to mortality have also affected the volume data for periodic annual growth and growth per cent presented by Moore and Waldron (1940). Even though their data showed far higher values in these measurements on the thinned areas than on the control plots, it is questionable what effect the thinnings really have on (1) the growth of dominant stems comprising the final crop, (2) final yields in volume and value, and (3) net returns over a rotation.

The thinning of whitecedar stands has been an expensive, although profitable, proposition. It has been expensive because of the cost of logging equipment, the difficulties of working in a swamp, and the boggy condition of the swamp approaches. Thus the cost, even before 1930, ran from $200 to $300 per acre, excluding overhead and marketing costs (Cottrell 1930). However, the dense stands of whitecedar contain much material that can be removed in a thinning. In one stand 50 years old a medium thinning removed 930 bean poles, 1,127 shade-tree stakes, 312 arbor poles, and 296 fence posts per acre (Moore and Waldron 1940). On the first 26 acres thinned a net profit of $37 an acre was obtained (Cottrell 1930). Later profits ran as high as $120 per acre, and the average net profit over a period of 5 years (1927-1932) was $56 an acre (Moore and Waldron 1938).

If thinnings are to be profitable, only the best stands should be treated. Products of high value cannot be cut from poorly stocked stands on inferior sites containing a large number of short trees (Cottrell 1930). Thinnings have to be delayed until even the best stands in New Jersey are about 45 years old, because only these have enough material for shade-tree stakes, arbor poles, and fence posts to make the operation profitable. Bean poles are not profitable and should not be removed. Even in the good stands care must be taken not to remove too much in an effort to show profit, and so invite windthrow and the development of underbrush (Moore and Waldron 1940). There is danger, too, in making the thinnings relatively late in the life of a stand, that too much growing stock will be removed, lowering the volume and value of the stand at maturity (Cottrell 1930).

The development of underbrush and a hardwood understory forms a serious obstacle to the use of thinnings. Moore and Waldron (1938) reported that the crowns have not closed on the thinned plots and in one plot, for example, where 50 per cent of the basal area had been removed, a dense understory averaging 6 feet in height developed in the 10 years since thinning. In contrast to their control plots that remained relatively free of undergrowth, the dense understory on the thinned plots included many shrubs as well as reproduction of red maple, blackgum, and sweetbay. Moore and Waldron rightly concluded that this understory is apt to cause considerable trouble in the satisfactory regeneration of the area to whitecedar.

The Northeastern Forest Experiment Station has made a preliminary investigation of thinning whitecedar in southern Maine. There, although the site index was only 30 to 35, the initial results indicated that thinnings could be profitably made in stands between 35 and 40 years old.*

*Personal communication from G. R. Trimble, Northeastern Forest Experiment Station.

In the South, Jemison *et al.* (1945) recommended that only light thinnings should be made in immature stands so as to avoid the danger of windthrow, but later stated that intermediate cuttings could remove all trees in excess of 300 whitecedars per acre, 6 inches or larger d.b.h. The two statements by Jemison *et al.* seem decidedly incompatible because, according to Korstian and Brush (1931), a stand 80 years old with a site index of 60 has 500 stems per acre, and one of the same age but with a site index of 50 has 790 trees. Furthermore, after a medium thinning in New Jersey a stand 50 years old had 1,050 stems per acre with an average diameter of 5.3 inches, and a stand 65 years old had 550 trees with an average diameter of 7.6 inches (Moore and Waldron 1940).

The advisability of thinning whitecedar stands still seems questionable. There are probably some overstocked stands where a thinning would benefit the stand. Baker (1922) described one stand 65 years old that had 7,296 trees per acre, the largest of which were only 4 inches in diameter. On the other hand, more careful consideration needs to be given to the effect of thinning on the growth of the trees forming the mature stand. In many areas the natural differentiation in height (Fig. I) may be sufficient so that the growth of the dominants is not appreciably stimulated by thinning. There are also economic limitations that should be considered. If the thinning cannot be profitably made and still be quite light, the treatment probably should not be attempted in most areas. Medium thinnings, and heavy ones in particular, may yield early profits, but more than the present gain may have to be expended later in obtaining a new stand of whitecedar. A profit of $37 or even $56 an acre from thinning does not meet the extra costs for disposing of the underbrush at the time of harvest cuttings and for the additional cleanings that will apparently be necessary in obtaining another stand of whitecedar (Fig. 7).

MANAGEMENT OF MIXED STANDS

Whitecedar-Hardwood Stands

There is relatively little information available on the proper management of whitecedar-hardwood stands. Pinchot and Ashe (1897) did state that the proportion of whitecedar could be increased in mixed stands by removing the competing hardwoods and permitting the whitecedar to take their place by natural seeding. Gifford (1900) made about the same recommendation, although he also suggested planting or seeding to hasten the development of the new stand.

The procedure for favoring whitecedar appears more complicated than the early authors implied, because it probably should vary with the amount of whitecedar in the present stand. Where whitecedar usually forms a stem-wise mixture with the hardwoods and constitutes 50 per cent or more of the trees in the overstory, harvest cutting should be made in the same manner as in pure whitecedar stands. There should be sufficient seed stored in the peat throughout the area, and with enough cleanings, probably three in many areas, the resulting stand can be formed largely of whitecedar.

Where this species forms only 25 to 50 per cent of the stand, and particularly where it occurs largely in clumps, clear-cut strips should be only 100 to 200 feet wide and the edge of the uncut stand should be composed of as many whitecedars as possible. After sufficient whitecedar seedlings have started and reached 1 to 3 feet in height, another strip should be cut.

In stands containing relatively few whitecedars there will be little seed stored in the peat and that will be near the parent trees, because the associated hardwoods obstruct, of course, any greater distribution. These hardwoods should be removed, and spindling whitecedars, subject to breakage or bending, may also be cut, but at least 10 to 20 whitecedars having crowns of fair size should be left on the average acre, either as individuals or in clumps. Some of these may be overthrown by the wind, but sufficient trees will frequently survive for a long enough period to furnish the desired seed. Removal of the seed trees, if undertaken at all, should be delayed until adequate reproduction 1 to 3 feet tall has developed.

Proper slash disposal is, of course, a necessity, and cleanings are absolutely necessary after harvest cuttings in mixed stands if the next crop is to contain a high proportion of whitecedar. Even if all hardwoods are cut Or girdled at the time of harvest cuttings, vigorous sprouting can generally be expected. Without cleanings the small whitecedar seedlings cannot compete successfully with the sprouts, and the resulting stand will usually contain a higher proportion of hardwoods than the one recently harvested. On areas recently burned, cleanings are also desirable to permit the whitecedar seedlings to overtake hardwood sprouts. The last cleaning that is apparently necessary should be made when a well-stocked stand of whitecedar reproduction 3 to 4 feet tall covers most of the area.

In all cleanings in the swamps, cutting of all hardwood stems of arborescent species—and sometimes, too, of some of the taller shrubs—is a desirable practice. Partial removal on the theory that certain clumps of sprouts are not at present hindering the growth of any whitecedars is generally not satisfactory. Before the stand is mature, many of these hardwoods, if left, will have developed spreading crowns that may overtop and kill, through shading, whitecedars 10 to 15 feet away.

Improvement cuttings, involving removal of hardwoods from stands past the sapling stage, are apparently not advisable. Most of the whitecedars either become dominant or soon die, and hence there are few stands where improvement cuttings or girdling of competing hardwoods would favor whitecedar to any great extent.

On the other hand, liberation of young whitecedars from overtopping hardwood hold-overs should be done and can perhaps be best accomplished through girdling, although poisoning may be a satisfactory alternative. Liberation work would, of course, be largely confined to areas cut-over within the last 15 years.

Actual examples of success from the above proposals, as well as indications of the costs, are rare. In the Great Swamp tract of the Green Bank State Forest crews of the Civilian Conservation Corps did cut all hardwoods from a mixed stand of about 300 acres between 1933 and 1935. All whitecedars, comprising generally less than 25 per cent of the stand, were left. The hardwoods ranged in size from 2 to 10 inches in diameter, averaging about 7, and produced 10 to 30 cords of wood an acre*. The work was done at a loss, probably exceeding $50 an acre. Surveys of subsequent reproduction by whitecedar in this area showed 519,235 seedlings per acre in 1935 and 20,000 seedlings per acre in 1936. In 1937 a cleaning was made and at that time there was an excellent stand of whitecedar reproduction covering the area (Anon. 1935, 1936, 1937). Unfortunately most of these seedlings were killed by flooding at the time of the 1938 hurricane. The risk of similar damage by flooding, drought, or animals warrants serious consideration in attempting to increase the proportion of whitecedar on most areas having mixed stands. However, the method outlined was successful in converting at least one small area of the Belleplain State Forest from a predominantly hardwood stand to whitecedar through natural reproduction.

These proposed methods for managing mixed stands vary greatly in cost.

*Preceding information on the Great Swamp tract was furnished by J. C. MacDonald of the New Jersey Department of Conservation and Economic Development.

Disposal of slash and cleanings on areas where 60 per cent of the preceding stand was composed of whitecedar may at times require only 7 man-days per acre in obtaining a new crop predominantly of whitecedar. In all probability no great improvement in method and costs can be expected on those areas. At the other extreme are the stands now containing relatively little whitecedar. There, if reliance is placed on felling and removing large hardwoods, disposal of slash and underbrush, and cleanings, the cost will be extremely high. Even large hardwoods generally cannot be removed without an appreciable loss. In some of the attempts made by crews both of local labor and of the Civilian Conservation Corps to improve the composition of stands having little whitecedar, charges of $100 or more per acre were incurred. Although costs may always be rather high, investigation may provide cheaper methods of attaining satisfactory results.

Pitch Pine-Whitecedar Stands

Desirable silvicultural practices in mixed stands of pitch pine and whitecedar are even more problematical than are those on the wetter sites. Possibly pitch pine should be favored, not whitecedar. If the latter is to be encouraged, seedbed preparation may be necessary, possibly through a broadcast burn of slash on a small clear-cut area. Competition from shrubs may be a factor even where seedbeds are suitable, and in many areas of southern New Jersey adequate establishment and growth of whitecedar reproduction would be dependent on temporary reductions in animal populations.

On similar sites in the South where pond pine forms a large part of the stand, Jemison *et al.* (1945) recommended partial cutting by removing trees as individuals or small groups. That practice and the lack of any treatment of seedbeds or shrubby understories would hasten the succession to swamp hardwoods.

Conversion of Hardwood Swamps

Hardwood swamps are a definite liability in the pine region of southern New Jersey. Trees in these swamps start, reach large size, and die, usually without ever being worth the cost of felling and removal. Their lack of value is due to the high cost of operating in a swamp, the low technical value of the wood, and the rot generally present in the larger trees, particularly of red maple. Conversion of these swamps to whitecedar would be highly desirable. Gifford (1895) stated that there were thousands of acres in southern New Jersey where whitecedar would grow with a little care, but because of the competition of less valuable trees and shrubs it was unable to establish itself.

In some swamps the area of whitecedar can be extended by natural seeding into stands now composed of hardwoods. There all the hardwood growth has to be felled, slash burned, and cleanings made until the dominance of whitecedar reproduction is secured. This method of increasing the area of whitecedar has to be decidedly limited in application. As the data from the study on seed distribution and from the surveys of natural reproduction have indicated, adequate amounts of seed for the establishment of a satisfactory number of seedlings are limited to areas near the parent stand. Probably a safe rule to follow would be to rely on natural regeneration only in areas within a distance equal to the height of the whitecedars on the west side of the seed source, and to a distance equal to three times that height on the east side. Natural seeding can, of course, be relied on for greater distances where seed distribution is not obstructed by large hardwoods; but the additional costs of controlling hardwood growth over a longer period, and of removing large trees, probably should limit reliance on natural reproduction to areas close to the seed source.

The extension of whitecedar stands through natural seeding has been tried in the state forests of southern New Jersey with a fair degree of success. This method is particularly applicable along the edges of swamps where severe fires have killed the whitecedar and, although trees of this species in the center of the swamp escaped damage, the burn has been restocked largely by hardwood sprouts. On one area of the Penn State Forest a fire burned into the swamp about 1923, creating the conditions just described. Crews of the Civilian Conservation Corps cut all hardwood sprouts in 1933-34, and again in 1936 and in 1939, at a total cost of 15 man-days per acre. Although there was little reproduction of whitecedar in 1933, there is plenty now*.

Ashe stated that in North Carolina the area of whitecedar could be greatly increased by introducing it artificially in localities having a suitable soil, but having stands of large hardwoods that had naturally been able to exclude whitecedar. He said that the artificial propagation should be done by sowing seed broadcast in the spring under the hardwoods (Pinchot and

*From information furnished by J. C. MacDonald of the New Jersey Department of Conservation and Economic Development.

Ashe 1897). In mixed deciduous swamps Gifford (1900) suggested that the proper method of converting was to cut and keep down all the deciduous growth and to introduce whitecedar through seeding or planting.

In areas where whitecedar has to be introduced by artificial means, complete removal of the present growth is not necessary if it is killed back so that whitecedar seedlings can overtop it. In some areas the hardwoods of the overstory may be worth logging, but in most of the swamps in the pine region of southern New Jersey even large hardwoods will not pay their way. In one study felling these trees and the additional slash disposal necessary increased the man-hours about six times over the labor required in girdling them. Girdling was found to be reasonably effective; 92 per cent of the sweetbays were dead at the end of the second growing season, along with 50 per cent of the blackgums and 22 per cent of the red maples. At the end of 5 years nearly all trees were dead. Although an occasional blackgum and 5 to 10 per cent of the red maples were still living, none were healthy and apparently all will eventually die back to below the girdle. Poisoning is an alternative method that has not been tried in southern New Jersey. However, red maple is also quite resistant to poisoning (Cook 1944).

Even if girdling is used to kill the overstory, treatments preparing the site for whitecedar are very expensive. These treatments apparently require 9 to 20 man-days per acre by local labor. Including subsequent cleanings, the total effort necessary would take between 13 and 30 man-days per acre, and that does not include the time necessary for introducing whitecedar through seeding or planting. Relief labor, such as crews of the Civilian Conservation Corps, would require even more time.

These initial costs are excessively high and can be reduced only by a method requiring little labor to treat an area of some size. Consideration should be given to such schemes as burning or flooding a swamp, and the use of salt or some other killing agent. Each of these schemes appears to have serious limitations, but to warrant an investigation of the possibilities and costs.

The introduction of whitecedar can be accomplished through seeding or planting. The New Jersey Department of Conservation and Economic Development grows and sells 2-0 whitecedar seedlings for planting on forestry projects. Seed may be collected and then sown the same fall. Satisfactory germination will usually occur so that from about 50 seeds sown at each spot approximately 25 seedlings on the average will have started by the following June and nearly all spots will then be stocked.

Whitecedar seeds can also be introduced through gathering the upper part of the forest floor from a mature stand of this species and then distributing this debris on the desired areas. This method was tried on 780 spots in early April 1946, a bushel of debris being sufficient for about 20 spots. In June 90 to 98 per cent of the spots were stocked with one or more seedlings, the average number per spot being six.

In the hardwood swamps planting requires considerably more time than sowing seed and has other disadvantages. Proper planting is difficult on these sites because the hummocks usually consist of a thin mat of roots and peat, below which there is only a very loose mixture of water and peat. Thus there is little material, other than sphagnum moss, to pack around the seedling. Consequently, most seedlings are rather poorly planted and may later suffer from too much water or air.

Seedlings starting in place from seed have the advantage that, from the beginning, their root systems are modified to fit local conditions. Their mortality will be greater than among planted seedlings, but because many start at each spot, their later stocking may be as good as that of planted seedlings. In the use of both seed alone and of peat containing seed there may be some delayed germination, which might be advantageous if the first season was unfavorable. Seeding is also more flexible than growing seedlings in a nursery for 2 years. The collection of cones for sowing seed alone is limited to a relatively short period in the early fall and the seed should be sown, or stratified, that same fall if germination in the following spring is desired. However, the collection and sowing of surface debris from a mature whitecedar stand can apparently be done any time between November and May with fair results.

On the other hand, the use of planted stock may be advantageous where some losses from animals or from the competition of hardwood sprouts are expected. Of course, any of the methods of introducing whitecedar will fail if populations of deer, rabbits, or mice are high; and failures are also possible if needed cleanings are not made. However, planted seedlings tend to have an advantage in that they are larger and, in a shorter time than seedlings starting from seed, might overtop the hardwood sprouts or outgrow the period of susceptibility to damage by animals. Possibly planting should be the chief method used in areas where vigorous sprouting is to be expected, and the sowing of seed or peat containing seed might be limited to areas where the deciduous vegetation had been completely killed through previous flooding or other treatment.

One attempt to convert a hardwood swamp to whitecedar by artificial means was initially successful in the Lebanon State Forest, but soon failed because of excessive damage by animals. However, there are examples of the successful conversion of a hardwood swamp to whitecedar through planting in the Belleplain and Green Bank State Forests. In 1934 a hardwood stand in the Green Bank State Forest was clear-cut and planted with wild whitecedar seedlings 6 to 15 inches tall. In 1938 these were 2 to 5 feet tall (Anon. 1938). Also in 1934, the swamp hardwoods on 5 acres in the Neiserfield Branch, Belleplain State Forest, were heavily thinned and underplanted with wild whitecedar seedlings. Portions of the area were replanted in 1939 and 1940. Several cleanings have been made, and the residual overstory of hardwoods has been gradually removed, leaving whitecedars 5 to 18 feet tall dominant on most of the area*.

Use of Whitecedar in Reforestation

On the edge of the pine region and in the Delaware Valley section of southern New Jersey there are some abandoned fields or pastures on wet sites that the owner may not wish to retain in tillage and might wish to reforest. On the wet sites in the sandier sections whitecedar is a logical tree to use, because it probably occurred there originally. In the Delaware Valley, where the soils are heavier and yellowpoplar or sweetgum might be a more logical species to use, whitecedar may be preferred because the owner desires a crop of fence posts, or possibly for other reasons. The same situation probably prevails in other parts of the range of whitecedar.

The role of whitecedar in reforestation of such sites is not well defined at the present time, largely because there is insufficient knowledge and experience in using both hardwoods and whitecedar. Certainly the reforestation is not so easy as Emerson (1846) indicated. He stated that all one had to do was to gather the seed and then sow it in abundant amounts in the fall on the chosen site. Although Moore (1939) reported that whitecedar seedlings have been planted on wet lands in both North and South Jersey with a fair degree of success, much more information is necessary before the successful introduction of whitecedar can be achieved.

*From information furnished by H. A. Scribner of the New Jersey Department of Conservation and Economic Development.

To obtain further information, a study was started in 1946, testing the success of planting and seeding on representative sites in the Delaware Valley. Planting stock was furnished by the New Jersey Department of Conservation and Economic Development. Employees of the Soil Conservation Service and Forest Service of the U. S. Department of Agriculture cooperated in establishing the plots and making the treatments. The study included areas of abandoned farm land that had (I) alders *(Alnus rugosa)* and heavy sod, or in spots chiefly cat-tails, and (2) a dense cover of tall herbs, although tussocks of marsh grasses were also common. For comparative purposes the same treatments were made in a rather dry forested swamp stocked with red maples. Both these trees and the alders were cut. The soil in the second area, that having tall herbs, was classed as muck by K. Craver of the Soil Conservation Service, who called the soils on the other two areas Johnston silt loams.

In this study planting proved to be the more successful method, although both seeding and planting required about the same amount of labor. This was true, even though the charges against seeding included the gathering of material from the forest floor of a mature whitecedar stand and somewhat more scalping of spots than was done in planting. This method of seeding gave initially favorable results, with an average of six seedlings starting per spot, but such heavy mortality subsequently occurred that few, if any, seedlings will develop into saplings. Most of this mortality was attributed to competition and unsuitable moisture conditions, both drought and flooding.

Planted seedlings have also suffered from unsuitable moisture conditions, and from damage by animals. Some of these seedlings have drowned, and many more have died back in all areas. In one area flood waters even washed out some of the planted seedlings or covered them with alluvium. Rabbits and meadow mice have damaged seedlings in all areas, but the damage has been most important in the area of abandoned farm land that had tall herbs. There 96 percent of 200 unprotected seedlings were injured during the first 2 years, compared with 75 per cent of the 200 seedlings that were protected from rabbits by a fence. In both groups damage by animals will evidently prevent the establishment of whitecedar saplings. Survival of planted seedlings in the other areas has been better, but was still only about 50 per cent at the end of 2 years.

The poor results from this small study should be a warning of the difficulties that may be encountered in attempting to reforest wet sites.

Many areas—if they have been tilled-will be relatively level, and damage from standing water will occur. There the creation of hummocks may be necessary. Ryle (1933) recommended that in England the planting of bogs should be made on upturned sod that had been allowed to stand for a period. Competition by herbaceous and woody vegetation, usually great on wet sites, is another factor. Even the herbs may reach heights of 3 to 6 feet and heavily shade the soil surface during the summer months. Damage by meadow mice and rabbits, although not usually by deer, may be another decisive factor. With all these handicaps the planting of large, vigorous stock, while initially more expensive, may give the most satisfactory results, but still produce a low percentage of successful attempts unless measures are·taken to remove the handicaps.

GROWTH OF WHITECEDAR

Kalm, writing in 1749, was probably one of the first authors to describe the relatively slow growth of a whitecedar tree. He determined the ages of several trees, noted that a tree 108 years old was only 18 inches in diameter, and correctly observed that, for the production of stands of saw timber in southern New Jersey, the whitecedar trees would have to be about 80 years old (Benson 1937).

Even though the growth of individual trees may be relatively slow, the large number of trees per acre produces high volume and good growth in volume. For example, a typical unthinned stand 60 years old had 83 cords per acre, its growth during the last 10 years having been at the rate of 2.5 cords annually and its mean annual growth, 1.4 cords per acre (Moore 1939). Further information on the growth and yield of whitecedar may be found in publications by Pinchot (1899), Akerman (1923), Korstian and Brush (1931), Moore and Waldron (1938, 1940).

However, the information on growth and yield does not appear to be complete. Probably the majority of swamps in southern New Jersey do belong in the 40 to 45-foot sites, as the available information indicates (Moore 1939, Moore and Waldron 1940). On the other hand, Cook (1885) stated that the value of whitecedar stands 50 years old ranged from $75 to $400 per acre, depending largely on the location and size of the timber. Recent information indicates that sites near the edge of the pine region, as near Medford or in Cumberland County, may be appreciably better than those farther east, and that in many swamps local differences due to changes in water relations have an appreciable effect on amount and quality of growth. Furthermore, although relative growth in volume and value, as well as the relative silvicultural charges, should determine the boundary between pitch pine stands on dry sites and whitecedar stands on wet ones, not enough information is now available on the growth of these species in relation to moisture conditions to indicate accurately which one should be favored on a specific area.

However, site is not the only factor affecting growth and yield during a period of 50 or 60 years, and quick and adequate restocking following a harvest cutting seems to be particularly important. This appears to be greatly affected by silvicultural measures such as slash disposal and cleanings, as well as by such environmental factors as drought, flooding, and damage by animals. Now there is great variability in the rate of restocking and growth of seedlings. Some occurring on open areas reach 0.8 foot in height when only 1 year old, and yet dominant individuals on apparently similar areas logged 5 years ago may average only 1.2 feet in height. The amount and size of reproduction on some areas cut-over 10 years ago are as great as in certain other swamps logged 25 years ago. Evidently more information is needed on the proper methods to use in obtaining the best growth possible on a site.

The effect of site on quality of growth is also still questionable. For example, Cottrell (1929) reported that in the wet portions of true swamps the trees produced a hard, tough wood with a glassy appearance, locally called "brazelly". Cook (1868) claimed that when whitecedar grows where the peat is shallow, so that its roots reach the underlying mineral substratum, its wood is unfit for timber because the fibers are so interlocked that it will not split freely. Where the trees rest on gravel it is said that shake is apt to be present (Pinchot 1899). According to M. Kauflin, a sawmill owner in Burlington County, the wood of whitecedars grown in the dry, sandy swamps is harder and more brashy than that from the true swamps, although not generally containing shake. Apparently there is no specific information available that would verify any of the preceding statements describing the effect of site on quality of wood produced.

PROTECTION OF WHITECEDAR STANDS

Fungi

Relatively few fungi attack whitecedar, and their damage is usually not serious. *Keithia chamaecyparissi* Adams and *Lophodermium juniperinum*

(Fr.) de Not. attack whitecedar foliage, but usually only the first may locally cause sufficient damage to kill young trees. A broom-forming rust, *Gymnosporangium ellisii* (Berk.) Farl., causes a spherical or oblong swelling on a bole or branch, frequently accompanied by a broom-like development of the branches. As the mycelium of the fungus is perennial, the affected parts increase in size from year to year; but the fungus, while deforming certain trees, has not occurred in sufficient amounts to warrant much attention (Korstian and Brush 1931). Of less importance is *Gymnosporangium biseptatum* Ellis, which stimulates the cambium so that a spindle-shaped burl develops. If the burl encircles the stem, the trunk or branch above the burl dies (Boyce 1948).

Trametes subrosea Weir is the most important fungus that destroys the heartwood of whitecedar, and is one of the many that attack cut timbers, particularly the sapwood, when stored or used in the forest (Korstian and Brush 1931). However, rot is seldom found in living trees less than 80 years old, although Korstian and Brush (1931) report one infection by *Trametes subrosea* in trees 40 to 50 years old. Recently a stand of similar age in Ocean County, New Jersey, was found to be likewise infected, here after basal wounding by a surface fire.

In general, although native fungal diseases may slightly reduce the growth and yield of whitecedar stands, they apparently do not form an important factor in stands under management and will seldom, if ever, require control measures.

Insects

Whitecedar has no serious insect enemies. The larvae of the common bagworm (*Thyridopteryx ephemraeformis* Haw.) may feed on the foliage and completely defoliate a few small trees (Korstian and Brush 1931). However, control measures are apparently never necessary.

Fire

On the wet sites to which, seemingly, whitecedar should be usually confined, the risk is very low. Proper management of the swamp forests, especially adequate disposal of slash after logging, will lower the risk still further. In recent years many whitecedar stands have suffered from fires that started on dry sites and burned into the swamp. Proper management of the dry sites would maintain stands with small amounts of fuel, provide access roads, and in general favor the elimination of the large, intense fires that have been so damaging to whitecedar stands.

Wind, Snow, And Ice

Wind and wet snow or ice may, alone or together, cause bending or breakage of whitecedar trees, and wind also causes shake and blow-down. Shake is not common (Korstian and Brush 1931).

The extent of bending, breaking, or uprooting of whitecedars depends (1) on the infrequent occurrence of heavy, wet snows, sleet storms, or high winds, and (2) on the type of forest and condition of component trees. In general, defective trees are subject to breakage; exposed spindling whitecedars, to bending; and recently exposed trees with crowns of fair size, to windthrow. Uneven-aged mixed stands have been described as less susceptible to damage by wind than are even-aged pure stands (Luncz 1932). However, uneven-aged mixed stands of whitecedars and hardwoods are ecologically, silviculturally, and economically undesirable if the swamp forests are to produce commercial crops of wood.

Pure, even-aged whitecedar stands are desired and will rarely suffer appreciable damage from wind, snow, and ice if properly managed. Any thinnings made should be light, removing no more than 35 per cent of the basal area and leaving many trees of the intermediate crown class as well as most of the dominants and codominants. In addition, an unthinned zone, 20 to 25 feet wide, should be left along the edges of the stand (Moore and Waldron 1938). If new roads are developed through pole or mature whitecedar stands, gradual windthrow of the newly exposed trees can be expected. However, the windfalls can be salvaged, and doubtless all adjoining areas of large timber can be properly harvested and converted to relatively wind-firm young stands within an adequate period. Some windthrow or bending should be expected along the edge of a pole or mature stand adjoining a clear-cut area, but many of the affected trees may be salvaged in the next cut.

On the whole, pure even-aged stands of whitecedar, grown rather densely for silvicultural and ecological reasons and harvested when 50 to 80 years old, appear relatively resistant to damage from ice, snow, and wind. As Baker (1922) observed, the whitecedar stands are naturally protected by their great density.

SUMMARY

ALTHOUGH it occupies only a small proportion of the forest area, whitecedar is one of the most important timber trees of southern New Jersey and of certain other sections along the Atlantic Coast. It occurs

on poorly drained peat or sandy soils in which the organic matter may range in depth from only a few inches to over 30 feet. The soils are acid, the pH ranging from 2.0 to 5.5.

Whitecedar stands have been heavily cut. Even before 1760 many men thought that the supply of this species in New Jersey was exhausted, yet large amounts of timber were removed in the 19th century. Clear-cutting of stands 50 to 60 years old is a common practice today. The heavy utilization has been stimulated by the high technical value of the wood for purposes requiring durability and light weight. The excellent qualities of the wood have given whitecedar stands a high stumpage value in spite of the high costs of operating in a swamp. Sales of pure whitecedar stumpage have brought up to $1,000 an acre. In recent years the value of good stands has been about $3 to $5 an acre for each year of growth.

Associated hardwoods in southern New Jersey are principally red maple, blackgum, and sweetbay; all are common associates in many parts of the range of whitecedar. The hardwoods are of little or no value. Commercially valuable stands of hardwoods, principally of sweetgum and yellowpoplar, occur only on the moist sites underlain by silt or clay, or having these fine materials directly mixed with the organic matter. These species are not normally associated with whitecedar in swamp habitats. Evidently in the sections of sandy soils swamp sites should be managed for pure whitecedar.

Whitecedar has several characteristics favoring successful management. Seed is first borne at an early age and later fair crops are produced annually, with heavy crops at intervals of 2 to 3 years. Viability of the seed varies greatly, but a large amount of seed may remain viable in the forest floor for at least 1 to 2 years. Although the seed falls throughout the year, 60 per cent is disseminated between October 15 and December 15, and 93 per cent by March 1. Whitecedar seed is distributed by the wind, and the distance to which it is carried depends greatly on the extent of obstructions by surrounding vegetation. The amount of seed falling on a unit of area decreases greatly with increased distance from a seed source, even from an isolated tree, although 60 per cent may be carried to distances greater than the height of the tree. As a result of the influence of weather conditions, 80 to 85 per cent of the seeds borne by isolated trees fall on the east side of the source. Because of this distribution of seed, natural reproduction is obtained most easily, and to greater distances, on the east side of seed sources than on the west side. Large trees are better seed sources than small ones.

The establishment of natural reproduction is greatly affected by mOisture and light relations. Excessive water prevents the germination of white-cedar seeds or kills seedlings; too little moisture, because of site, seedbed, or drought, also has unfavorable effects. Unfavorable seedbeds include a thick litter, and the slash and corduroy left after logging. Although large numbers of seedlings start under mature stands, many survive only 1 year and none older than 3 years are found under a closed canopy. For continued survival and growth whitecedars of all ages need a fair amount of light.

Pitch pine and gray birch are less tolerant of shade than whitecedar; but red maple, blackgum, and sweetbay are more tolerant. The relative tolerance of these species was determined from comparative ages, heights, and occurrence under different conditions. Furthermore, in a controlled environment the growth of whitecedar decreased more rapidly with increased shade than did that of either red maple or sweetbay.

Seedlings of sweetbay and whitecedar, grown in a greenhouse, developed more roots below the water table than did red maple, but only whitecedar developed better on the high water tables than on lower ones. In the field whitecedar had far better growth in the wet peat of a hardwood swamp than in the relatively dry, sandy soil of a pine swamp. Growth and development of whitecedar is apparently slow on excessively wet sites, relatively high on organic soils with little standing water but with a water table usually within 6 inches of the surface, and slow again in the drier, sandy soils of the pine swamps. The initial growth of whitecedar seedlings is comparable to that of the hardwoods only on open, relatively moist sites. However, the distribution of pine, hardwood, and whitecedar stands is not determined entirely by the position of the water table, but to a great extent by the influence of previous fires and cuttings.

Whitecedar, pitch pine, gray birch, and red maple are all common invaders of open areas. In the true swamps pitch pine and gray birch usually form only a small proportion of the pioneer stands. Where sources of whitecedar seed are adequate, this species may form nearly pure stands. The proportion of pitch pine tends to increase on dry sites.

Whitecedar is subclimax to the hardwoods other than gray birch. In southeastern New Jersey the physiographic climax on swamp sites is an all-aged stand composed predominantly of red maple and sweetbay, but locally containing a high proportion of blackgum and occasional trees of holly and sassafras. The development of the climax is very gradual. If whitecedar stands are not disturbed, a hardwood understory develops as the overstory thins out and gradually replaces the veteran whitecedars as they die.

Clear-cuttings have tended to favor the perpetuation of whitecedar stands, but partial cuttings of whitecedar alone and the lack of slash disposal have aided the succession to hardwoods. Fires in recent years have had a dual role, favoring in some places the perpetuation of whitecedar, although more usually conversion to hardwoods. To a minor extent, damage to whitecedars by deer, rabbits, and mice may have locally favored the proportion of pitch pine and swamp hardwoods.

There were extensive whitecedar stands in the original forest. They probably grew to be 100 years or more old when some at least may have been overthrown by the wind. Any hardwood understory that had started may have been killed as a consequence of the windthrow, and another whitecedar stand permitted to develop. Along the coast, stands were occasionally killed by salt water brought in by storm tides. Even if these stands were largely hardwoods, those following were probably of pure whitecedar in many cases. Changes in the level of the sea in relation to the land has at times reduced the area in whitecedar and at other times provided extensive, open areas which this conifer doubtless invaded. Where hardwood stands did develop, beavers probably set back the stage of succession through their selective cutting of certain hardwoods, flooding of the whole area, and subsequent abandonment of dams when the food was exhausted. Fires were probably common on upland sites in pre-settlement days and may have had a different effect than in recent years. Possibly a higher proportion of whitecedar was permitted to developed in the dry, sandy swamps than occurs today.

Whitecedar should be grown in pure, even-aged stands. Proper methods of harvest cuttings, thinnings, and other treatments should permit the perpetuation of such stands with little difficulty and expense. Mixed stands of whitecedar and hardwoods can, and should, be converted to pure whitecedar. There the difficulties and costs seem to vary inversely with the amount of whitecedar in the present stand. Conversion of hardwood stands to whitecedar is desirable; yet in many cases it may not only be expensive, but may not be successful unless the population of deer, rabbits, or mice is reduced. Protection of whitecedar stands from damage by fire, fungi, insects, snow, ice, or wind apparently offers no serious problem as long as both swamp and adjacent upland sites are properly managed.

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APPENDIX

INDEX OF COMMON AND SCIENTIFIC NAMES OF PLANTS USED IN THE TEXT

Common name	*Scientific name*
Alder	*Alnus rugosa*
Ash, black	*Fraxinus nigra*
Birch, gray	*Betula populi/olia*
Birch, yellow	*B. lutea*
Blackgum	*Nyssa sylvatica*
Blackgum, swamp	*N. sylvatica biflora*
Cypress	*Taxodium distichum*
Elm	*Ulmus americana*
Hemlock	*Tsuga canadensis*
Holly	*Ilex opaca*
Leatherleaf	*Chamaedaphne calyculata*
Loblollybay	*Gordonia lasianthus*
Maple, red	*Acer rubrum*
Maple, trident red	*A. rubrum trilobum*
Pine, pitch	*Pinus rigida*
Pine, pond	*P. rigida serotina*
Pine, shortleaf	*P. echinata*
Pine, white	*P. strobus*
Redbay	*Persea borbonia*
Sassafras	*Sassafras albidum*
Spruce, black	*Picea mariana*
Swampbay	*Persea palustris*
Sweetbay	*Magnolia virginiana*
Sweetgum	*Liquidambar styraciflua*
Tamarack	*Larix laricina*
Tupelo, water	*Nyssa aquatica*
Yellowpoplar	*Liriodendron tulipi/era*
Whitecedar	*Chamaecyparis thyoides*
White-cedar, northern	*Thuja occidentalis*

ILLUSTRATIONS

FIGURE 1

Harvesting a mature stand of whitecedar. This photograph also illustrates several characteristics of swamp forests—(1) the even-aged appearance of most whitecedar stands, (2) the long, clear bole, with little taper, formed by a mature whitecedar in a dense stand, (3) the differentiation in height of whitecedars in the overstory, (4) the lack of living, overtopped whitecedars, and (5) the comparative size of crowns formed by hardwoods and whitecedars. Note the narrow crowns of dominant whitecedars, and compare with the spreading crown of the red maple in the left foreground.

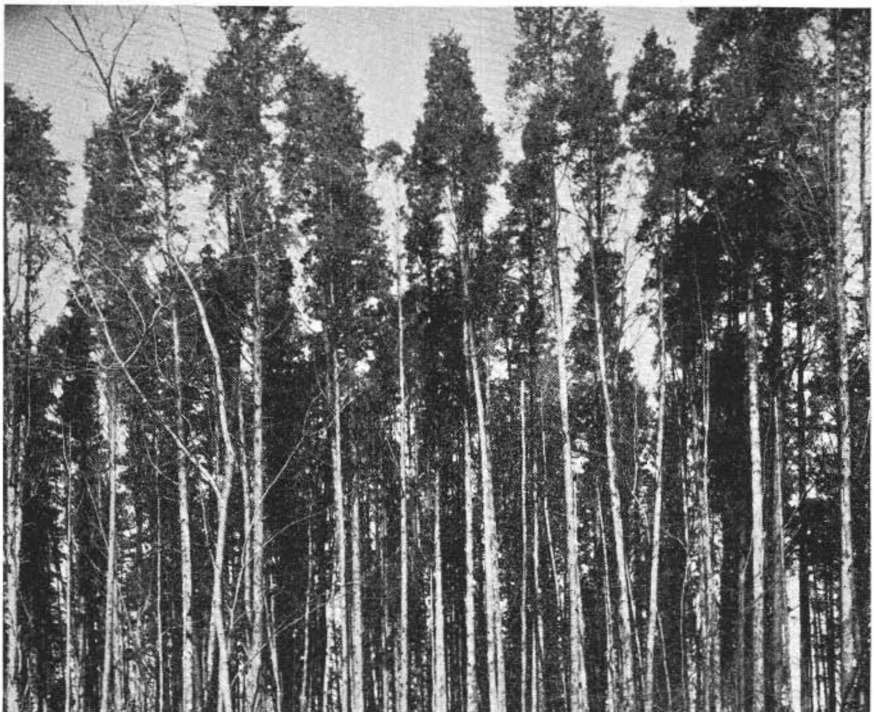
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FIGURE 2

Typical whitecedar seedlings 1 year old grown in a greenhouse under varying conditions of shade and water table.

Top: low water table; center: medium water table; bottom: high water table.

Left to right in all views: heavy shade, medium shade, light shade. (The black lines form 6-inch squares. These photographs were made of tracings of the original photographs.)

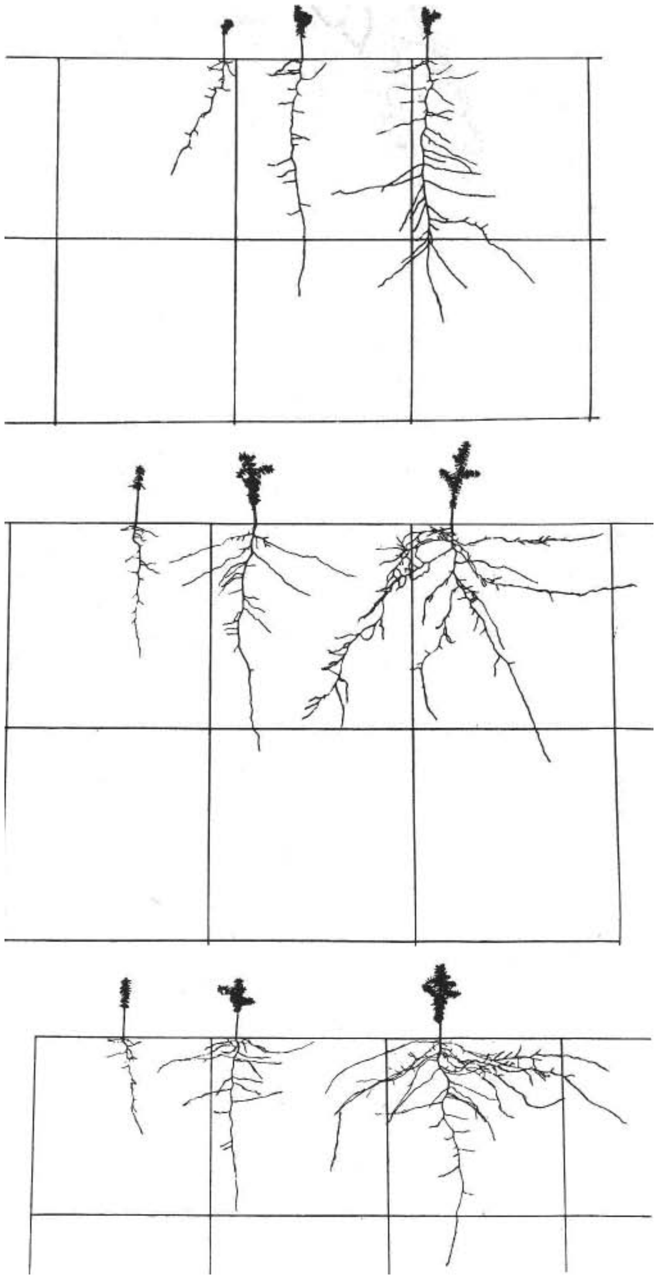


FIGURE 3

Typical red maple seedlings 1 year old grown in a greenhouse under varying conditions of shade and water table.

Top: low water table; center: medium water table; bottom: high water table.

Left to right in all views: heavy shade, medium shade, light shade. (The black lines form 6-inch squares. These photographs were made of tracings of the original photographs.)

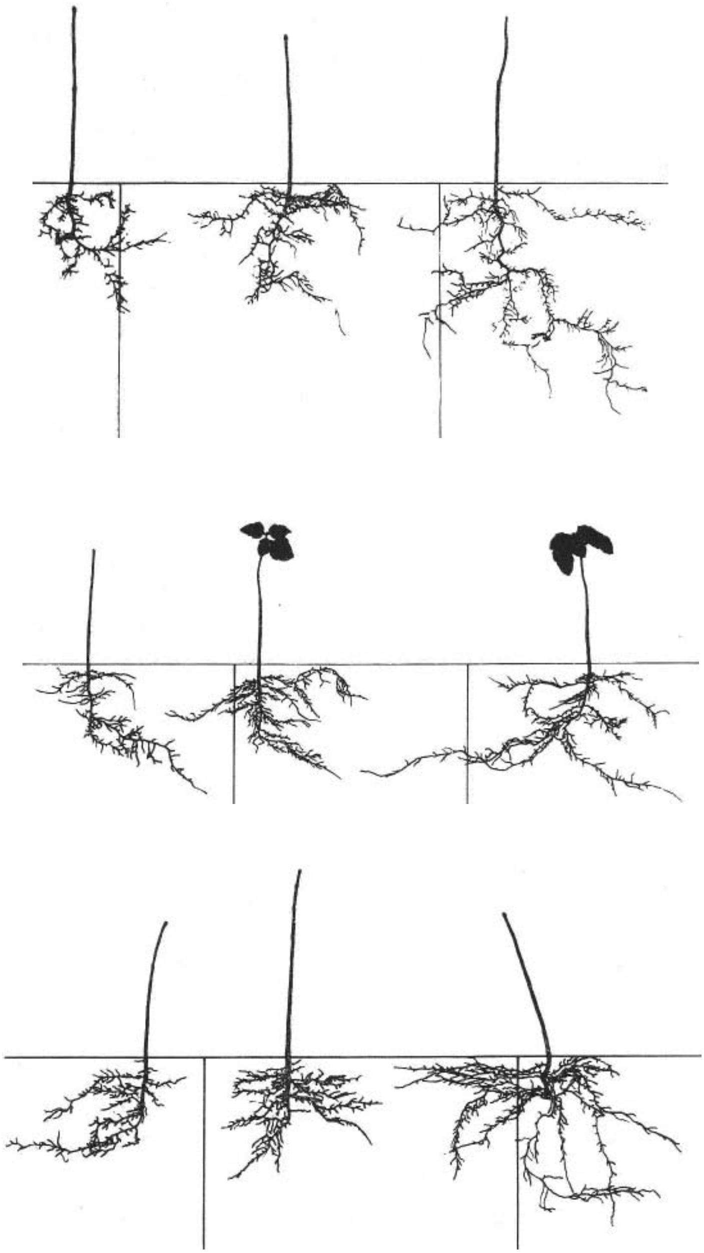


FIGURE 4

Typical sweetbay seedlings 1 year old grown in a greenhouse under varying conditions of shade and water table.

Top: low water table; center: medium water table; bottom: high water table.

Left to right in all views: heavy shade, medium shade, light shade. (The black lines form 6-inch squares. These photographs were made of tracings of the original photographs.)

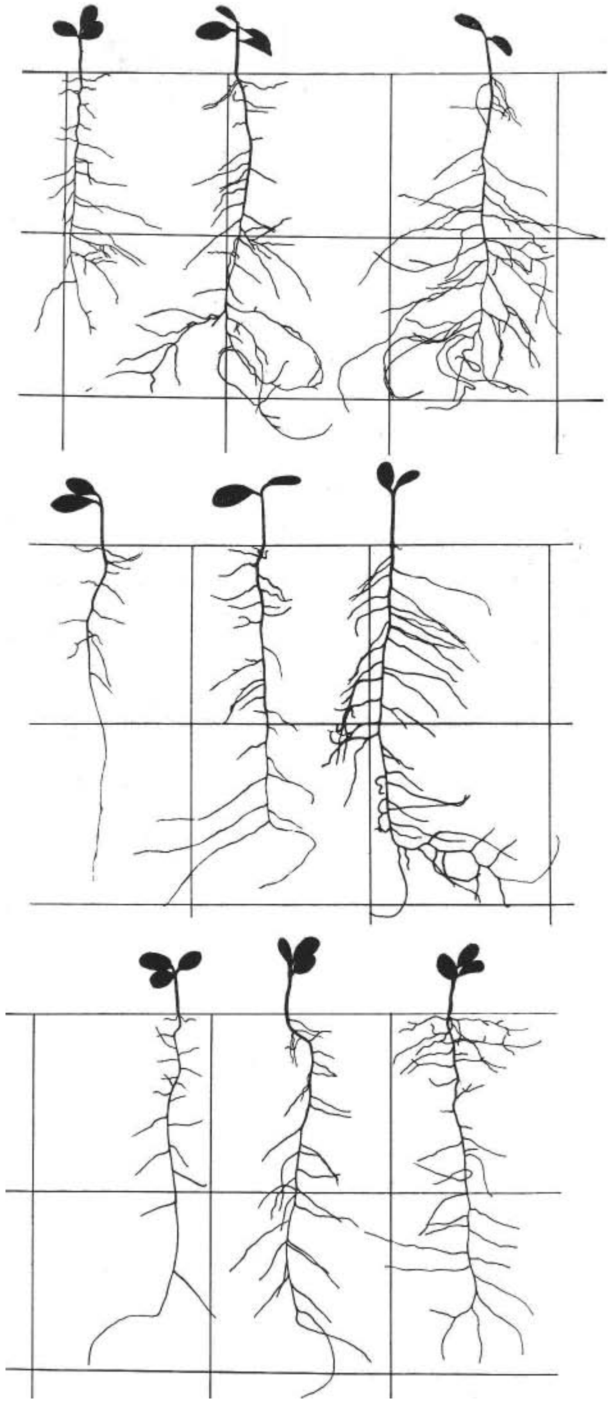


FIGURE 5

The influence of wind direction on natural establishment of whitecedar reproduction. The upper photograph was taken on the southeast side; the lower, on the northwest side of the same swamp. On both sides whitecedars had been killed by fires, although the trees in the heart of the swamp had escaped damage. The top view shows that new reproduction has become established as far as the edge of the upland; the lower view illustrates the absence of whitecedar seedlings on the windward side.

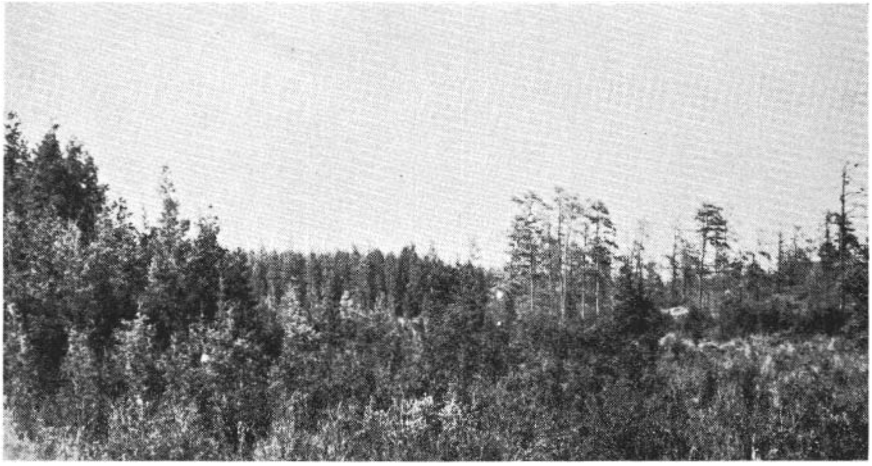
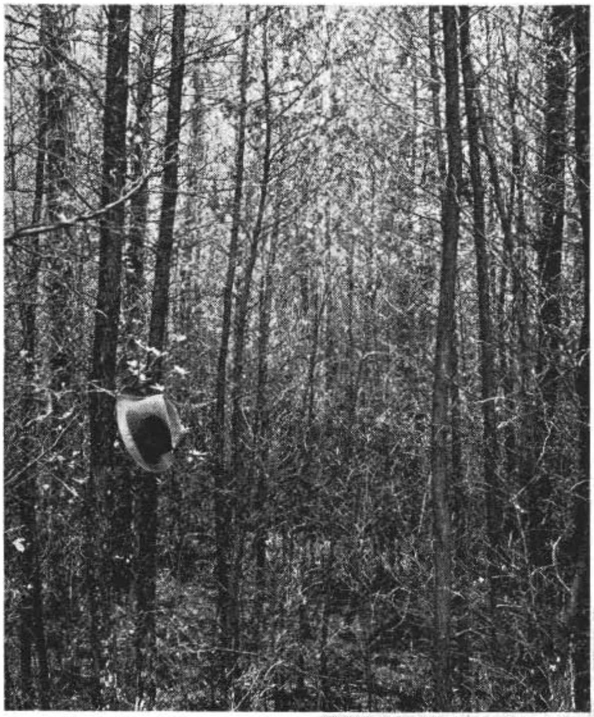


FIGURE 6

Two sapling-pole stands on abandoned cranberry bogs.

Above: dense pure stand of whitecedar on plot 5. Note the lack of shrubs.

Below: open stand of whitecedar and pitch pine on plot 15, a rather dry site. Note the density of the shrubby understory.



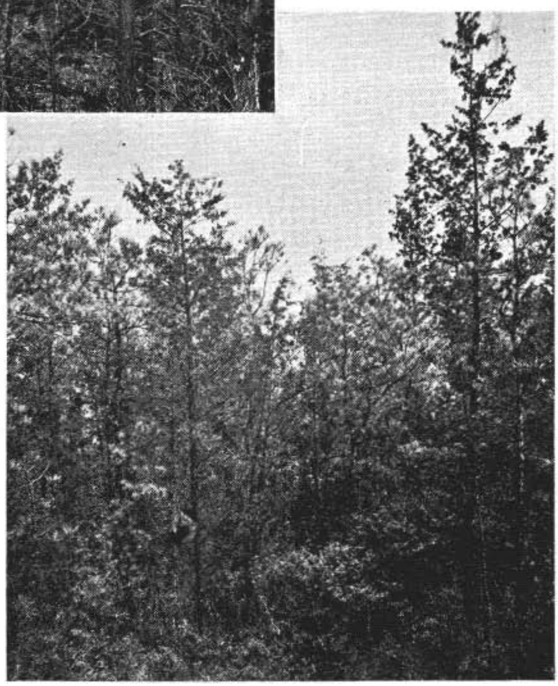


FIGURE 7

Mature whitecedar stands.

Above: unthinned stand on plot 4, typical of many stands of similar age in southern New Jersey. Note the large maple in the foreground and smaller ones in the background, also the small number of shrubs.

Below: stand thinned 14 years ago. Note the great increase in the understory of shrubs and small hardwoods compared to that normally occurring under an unthinned stand of similar age.

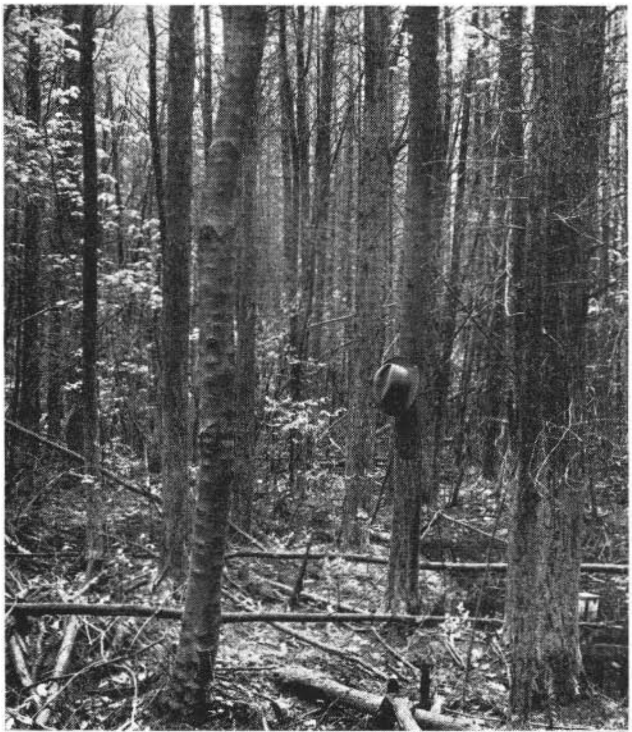


FIGURE 8

Hardwood stand, probably typical of the climax community on swamp sites in the pine region of southeastern New Jersey. Note the dense shrubby understory.


2

FIGURE 9

Mixed stand of whitecedars and hardwoods on plot 2. This area received a light "selective cutting" about 1920 and a heavier one about 1877. Note the dense shrubby understory; compare with Figure 7.

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