This is to certify that the

thesis entitled

GENETIC EFFECTS ON THE GROWTH RATE AND

STEM FORM OF SCOTCH PINE IN MICHIGAN

presented by

Stephen Raymond Homrich

has been accepted towards fulfillment
of the requirements for

M.S. degree in Forestry

Jonathan W. Wright
Major professor

Date Nov. 14, 1980

GENETIC EFFECTS ON THE GROWTH RATE AND STEM FORM OF SCOTCH PINE IN MICHIGAN

By

Stephen Raymond Homrich

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Forestry

1980

ABSTRACT

GENETIC EFFECTS ON THE GROWTH RATE AND STEM FORM OF SCOTCH PINE IN MICHIGAN

By

Stephen Raymond Homrich

Six 18-year-old Scotch pine (*Pinus sylvestris*) test plantations in Michigan containing 108 seedlots were measured. Between-seedlot and between-variety differences in height, diameter, frequency of crooks and frequency of pest attack were significant. The fastest growing varieties grew 3 times faster than the slowest growing varieties. All varieties had an inherent tendency to grow straight, growing crooked only when damaged. Damage was caused by insects, birds, porcupines or snow. At each plantation the varieties were exposed to potential damage by environmental agents. A variety's genetically inherited resistances to these agents determined its susceptibility to damage. At each location, varieties that were damaged least often grew the straightest. Planting sturdy seedlings of Central European varieties on sites where pest are not abundant will result in straight, fast growing Scotch pine useful as timber trees in Michigan.

ACKNOWLEDGEMENTS

My largest "Thank You" unquestionably goes to Dr. Wright. The time and patience he invested in my education is most deeply appreciated. His apparently endless sea of knowledge, great sense of humor, and unique personality made studying from him an irreplaceable experience. The concerned and helpful suggestions made by Dr. Rudolph and Dr. Lemme, as members of my guidance committee, were also very much appreciated. Much gratitude goes to Michigan State University for financial aid in the form of an assistantship in the Department of Forestry.

I am also very thankful to my parents and my good friend, Keith, for the needed encouragement they offered me throughout my stay in Michigan.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Scotch pine (*Pinus sylvestris*) is the principal timber tree in northern Eurasia, where it is native from Spain to Turkey and from Scotland to eastern Siberia (Harlow *et al*., 1969). It is the most common Christmas tree species in Michigan. Its ability to grow well on sandy sites too poor for other Christmas tree species has contributed to its popularity among growers.

In Michigan, thousands of acres of Scotch pine that have outgrown their intended use as Christmas trees have timber potential (Botti and Lemmien, 1974). The acreage planted to Scotch pine is not as large, however, as that planted to red pine (*Pinus resinosa*), Michigan's principal timber tree. Stands of this species occupy over one-half million acres in Michigan. Red pine stands in upper New York are being killed by Scleroderris canker (*Scleroderris lagerbergii*). The extreme susceptibility of red pine, coupled with the possibility of the disease spreading westward to Michigan, creates additional interest in other conifer species. Nicholls (1979) has located Scotch pine trees within the infected area that show complete resistance to the disease. Since the disease immigrated from Europe, it would seem possible to find Scotch pine that have developed resistances sufficiently enough to be used for timber purposes.

Scotch pine trees have a reputation in the United States for having crooked stems. In some instances a crooked tree may be desirable, possibly as an ornamental, but for timber purposes trees need to be grown straight. Scotch pine stands in Michigan that consist of straight trees cause us to question Scotch pine's reputation for being a crooked tree. The purposes of this study is to examine the causes of crooked Scotch pine. Understanding the factors affecting stem form could help us grow straight Scotch pine stands for timber production in the future.

METHODS

During the summer of 1958 Jonathan Wright contacted researchers throughout Europe and Asia. He requested seed from Scotch pine stands, asking that each stand be represented by 10 average trees. The response was good. He received seed from 106 natural stands and 16 plantations. The elevation and exact location of each seed source were recorded along with other detailed origin data.

The seeds were sown in Michigan State University's experimental nursery in East Lansing in the spring of 1959, using a randomized complete block design. The trees were grown at a density of 50 per ft^2 ($540/m^2$). This density was lower than usual in commercial nurseries. They were watered frequently, mulched over winter, and maintained weed free at a high fertility level. The result was a good quality stock, the seedlings being more uniform and 50-100% larger than those produced by most commercial nurseries. Periodic measurements were made on the seedlings.

Michigan State University crews lifted the 2+0 stock in the spring of 1961, and used the seedlings to establish six test plantations. "Seedlot" is used to describe the seedlings resulting from a source of seed. During the lifting operation the trees were tied into 4-tree bundles and labeled with a seedlot number for future reference. A 4-tree bundle of each seedlot was then placed into a replicate bundle. These replicate bundles were put into groups and transported to the six planting sites (Figure 1). The planting sites, located throughout the state, are as follows.

LAKE LINDEN School Forest: MSFGP-20-61, Houghton Co., northwestern Upper Peninsula. Heavy sod cover controlled by planting trees at the intersection of cross-plowed furrows. Munising fine sandy loam, 0-2% slopes (Alfic Fragiorthods, coarse-loamy, mixed, frigid), a well-drained, sandy loam. Replicates 8, seedlots 80, survival 83%.

DUNBAR FOREST Experiment Station: MSFGP-13-61, Chippewa Co., eastern Upper Peninsula. Medium sod controlled by spraying aminotriazole to strips before planting. Au Gres fine sand, 0-2% slopes (Entic Haplaquods, sand, mixed, frigid), a somewhat poorly drained, sandy loam. Replicates 10, seedlots 108, survival 93%.

HIGGINS LAKE State Forest: MSFGP-10-61, Crawford Co., north central Lower Peninsula. Heavy sod cover controlled by furrowing. Grayling, 0-2% slopes (Typic Udipsamments, mixed, frigid), a well-drained, loamy sand. Replicates 7, seedlots 72, survival 95%.

ROSE LAKE Wildlife Research Station: MSFGP-12-61, Shiawassee Co., south central Lower Peninsula. Light herbaceous ground cover, no weed control used. Boyer loamy sand, 2-6% slopes (Typic Hapludalfs, coarse-loamy, mixed, mesic), a well-drained, sandy loam. Replicates 8, seedlots 75, survival 83%.

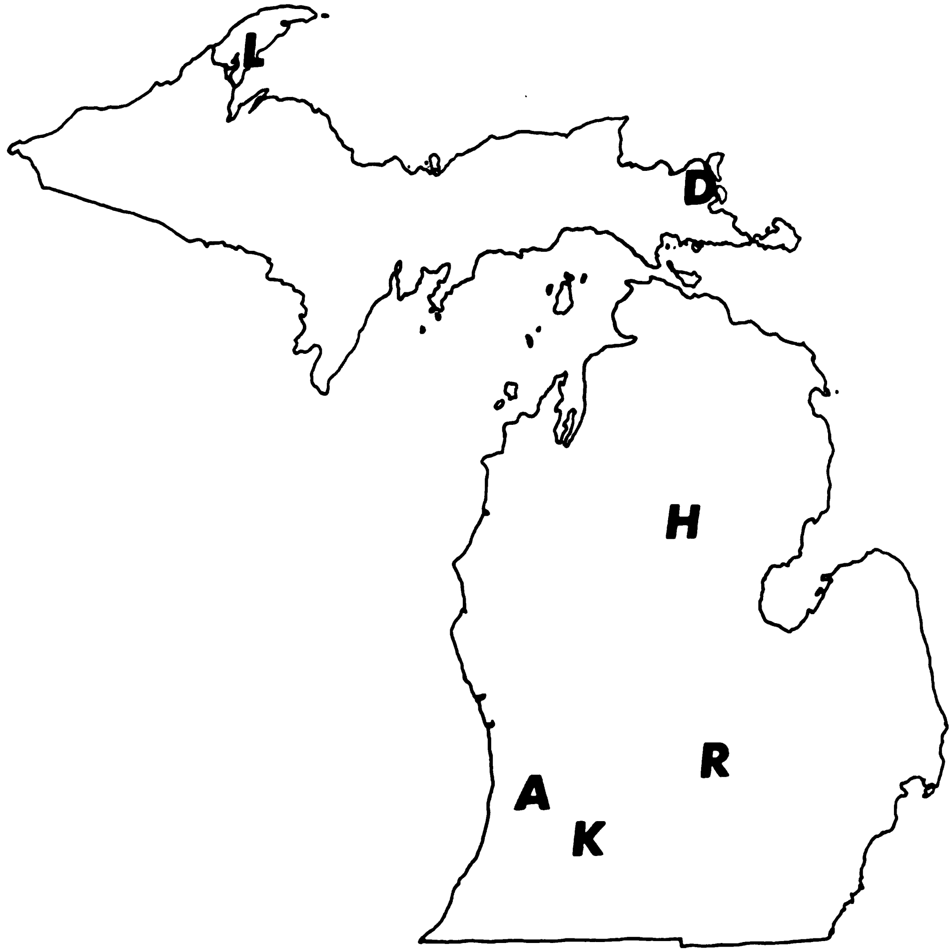

Figure 1.--Locations of the six Scotch pine test plantations in Michigan. L- Lake Linden School Forest, D- Dunbar Forest Experiment Station, H- Higgins Lake State Forest, R- Rose Lake Wildlife Research Station, A- Allegan State Forest, and K- W. K. Kellogg Experimental Forest.

ALLEGAN State Forest: MSFGP-11-61, Allegan Co., southwestern Lower Peninsula. Light sod cover, no weed control used. Oakville, 0-2% slopes (Typic Udipsamments, mixed, mesic), a well-drained, loamy sand. Replicates 10, seedlots 72, survival 91%.

W. K. KELLOGG Experimental Forest MSFGP-2,3,4-61, Kalamazoo Co., southwestern Lower Peninsula.

2,3-61, Light sod controlled by furrowing. Oshtemo sandy loam, 18-35% slopes (Typic Hapludalfs, coarse loamy, mixed, mesic), a well-drained sandy loam. Replicates 8, seedlots 108, survival 92%.

4-61, Heavy sod controlled by spraying amino-triazole to strips before planting, followed by simazine sprayed over trees. Kalamazoo loam, 0-2% slopes (Typic Hapludalfs, fine loamy, mixed, mesic), a well-drained sandy loam. Replicates 2, seedlots 108, survival 86%.

The plantations follow a randomized block design, with one 4-tree plot per seedlot per block. Spacing was 8 ft X 8 ft (2.7 m X 2.7 m). As of 1972, most trees had been pruned to 1/3 of their total height and the Kellogg and Rose Lake plantations had been thinned lightly.

Much data has been collected from these plantations since their planting. These stands were most recently measured during the summer of 1979 by Jonathan Wright and me. We recorded height and diameter of the two largest trees in each plot, crook data, mortality and, in some instances, pest damage. These measurements, along with earlier data, were used as a basis for this paper.

Analysis of variance or Chi-square analysis was used to detect differences between seedlots and varieties for each character measured. Height and diameter data were subjected to analysis of variance. Height data taken on a plantation having 10 replicates with 108 seedlots separated into 19 varieties would have degrees of freedom of 107, 18, 89, 9, 963 and 1079 for seedlot, between varieties, within varieties, replicate, error, and total respectively. The analysis pertaining to stem form and pest damage were accomplished using Chi-square analysis, with this procedure.

$$\text{Chi-square} = \frac{(\text{Observed-Expected})^2}{\text{Expected}}$$

The expected value is the average number when the hypothesis is true.

SCOTCH PINE VARIETIES AND THEIR NAMES

Although a Scotch pine tree's performance will vary according to its place of origin, trees from any one region have very similar growth characteristics. This has made it possible to classify trees from particular regions into varieties. Each variety has developed many common names, making the use of these titles too vague and confusing. To make things simpler, we will use the Latin varietal names accepted as most proper by Ruby and Wright (1976). These names were given by taxonomists during the past 144 years according to a strict set of rules. Ruby and Wright applied this varietal nomenclature to the seedlots in this study utilizing measurements made while the seedlings were still in the nursery and additional measurements made until 1974. The varietal names, derivations and ranges are given in the following list. The ranges are also given in Figures 2 and 3.

lapponica--Lapland, the land of the Lapps in the northern parts of Norway, Sweden, Finland and Siberia.

septentrionalis--northern, referring to the range in central parts of Norway, Sweden, Finland and adjacent Russia.

rigensis--named after Riga, capital of the Latvian SSR, also growing in southern Sweden.

mongolica--Yakutsk ASSR in east-central Siberia.

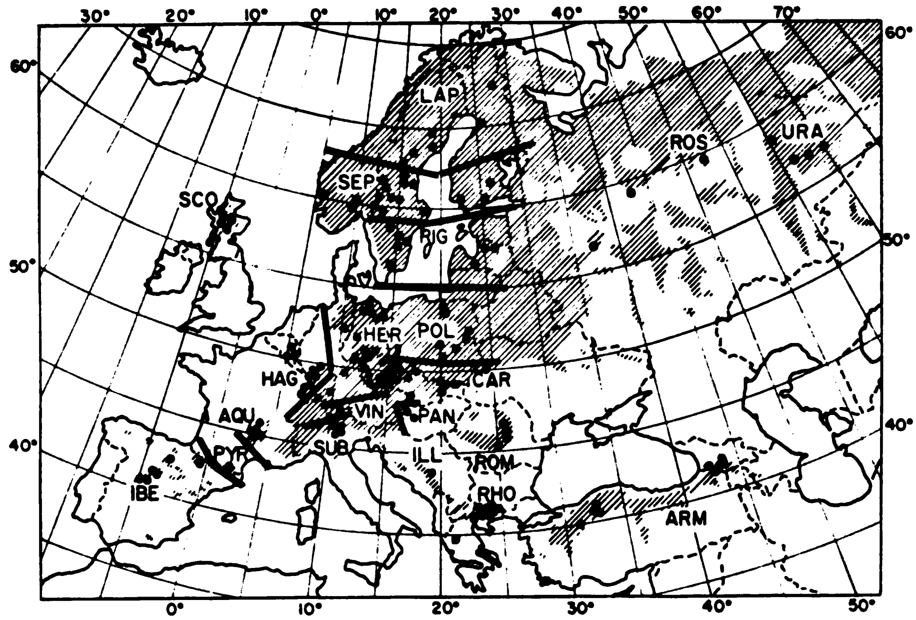

Figure 2.--Natural distribution (shaded), location of natural stands tested in the provenance studies (dots) and geographic varieties of Scotch pine in Europe and western Asia. The varietal abbreviations are as follows: AQUitana, ARMena, CARpatica, HAGuenensis, HERcynica, ILLyrica, LAPonica, PANonica, POLonica, PYReneica, RIGensis, RHOdopaea, ROManica, ROSsica, SCOtica, SEPtentrionalis, SUBillyrica, URAlensis, VINdelica (from Wright et al., 1976).

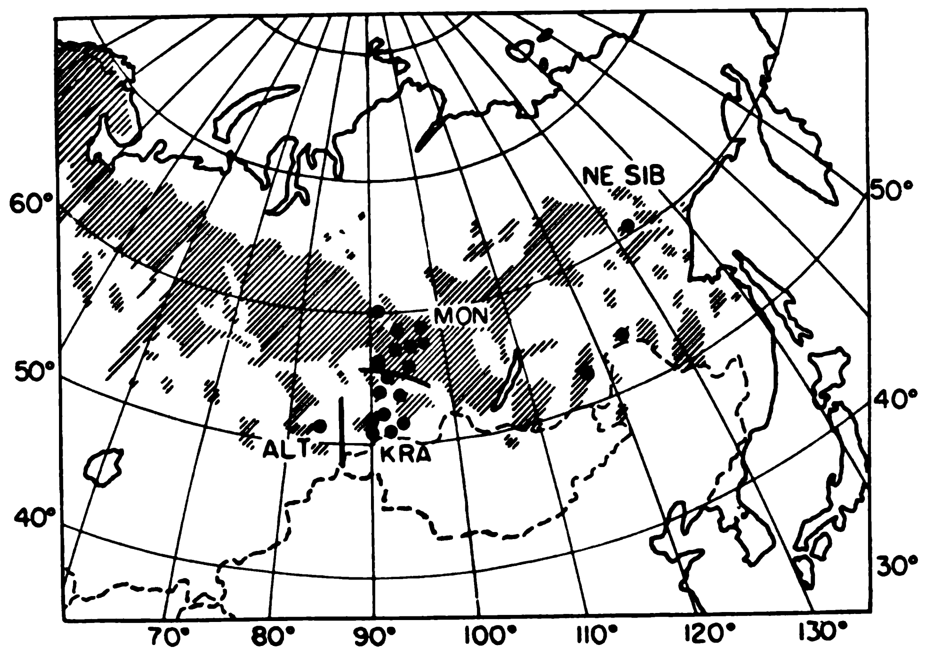

Figure 3.--Natural distribution, (shaded), location of natural stands tested in the provenance studies (dots) and geographic varieties of Scotch pine in central and eastern Asia. Abbreviations are as follows: NE SIBeria, MONgolica, KRAsnoyarsk, ALTaica. Other valid varieties may exist in unsampled areas. (From Wright _et al_., 1976).

uralensis--Ural Mountains separating European and Asiatic USSR.

polonica--Poland.

carpatica--Carpatian Mountains of NE Czechoslovakia and SE Poland.

hercynica--the variety inhabiting most of West Germany, East Germany and eastern Czechoslovakia, named after the ancient Hercynian Mountains, raised in the Carboniferous and now mostly eroded.

haguenensis--the variety inhabiting the Bosges Mountains of E. France and the Hardt Mountains of W. Germany and most commonly planted in Belgium, named after the city of Hagenau in France.

pannonica--Pannonia, a Roman province, now western Hungary.

illyrica--Illyria, a Roman Province, now part of Yugoslavia.

scotica--Scotland.

aquitana--Aquitaine, a medieval kingdom including the district around Auvergne in the Central Massif of France.

subillyrica--a misnomer, occurring in northern Italy.

iberica--the Spanish variety, named after the Iberican Peninsula.

rhodopaea--Rhodope Mountains of NE Greece and SE Bulgaria.

armena--Armenia, an ancient kingdom now part of southern USSR and Turkey.

In addition, two other types of Scotch pine are distinct enough to be considered separately, but have not yet been described as varieties in the botanical literature. They are:

'E. Anglia'--a region of eastern England

'Krasnoyarsk'--city and region of south-central Siberia.

GROWTH RATE

The overall average height of the plantations at age eighteen was 27 feet. The heights of the plantations varied from 16 feet at Higgins Lake to 35 feet at Kellogg Forest. Some fast growing seedlots exceeded these averages by up to 10 feet. By the early 1970s the crowns of these stands had closed enough to eliminate most herbaceous understory vegetation.

Soil differences seemed to be the primary cause of variation in growth rates between the different plantations. Scotch pine's performance was best on the well-drained sandy loam soils with high moisture holding capacities. Higgins Lake, where growth was slowest, had the most excessively drained soil with the lowest water holding capacity of any of the plantations. The dry sandy soils there contributed to a slow growing, unhealthy stand, which was susceptible to numerous attacks by insects. Although the growing season is shorter in the Upper Peninsula, the plantations at Lake Linden and the Dunbar Forest averaged faster growth than the Higgins Lake plantation. The faster growth at these two plantations can be attributed to better soil conditions. The soils at Dunbar Forest and Lake Linden had higher moisture retention capabilities than did the soil at Higgins Lake. When two plantations were grown on similar soils, the plantation that was further south grew fastest.

Scotch pine is variable genetically, especially regarding growth rate. Within the plantations the fast growing seedlots outgrew the slowest ones by as much as a 3 to 1 ratio. The difference in height between seedlots is often 2-3 times greater than the difference within a seedlot, making it possible to recognize neighboring seedlots while walking through a stand. Analysis showed the variation in growth rate to be significant as shown in Figure 4.

Scotch pine's adaptation to the many climatic differences within its native range has created a wide variety of growth rates which fluctuate according to the origin of the seed. Adaptation to the cold climate of the northern parts of Sweden, Norway, Finland and Siberia, has caused the variety lapponica to become slow growing. There seems to be a physiological association such that trees that can withstand very cold temperatures are not the fastest growing. Moving southward, toward the warmer climate of Central Europe, the growth rates gradually increase. Natural selection in this central region is not regulated by temperatures that are as low as those found in Northern Europe. More selection is made for fast growing trees than can effectively compete for light and space in the forest canopy. This selection process has caused the trees originating from the area of eastern Czechoslovakia, southern West Germany, southern Belgium and northeast France to be the fastest growing. Seed collected south of this Central European area resulted in trees that had slower growth rates. These slower growth rates can be explained as an adaptation to the dry climate of Southern Europe.

```
0   10   20   30   40   50   60   70   80   90   100   110   120   130
----------------------------------------------------------------------
                Varieties from Northern Europe and Asia
----------------------------------------------------------------------
lapponica            xxxxxxx
septentrionalis                      xxxxxx
rigensis                                       xxxxxxx
mongolica                        xxxxxxxxxxxxxxx
'Kransnoyarsk'                             xxx
uralensis                                      xxxxxx
----------------------------------------------------------------------
                     Varieties from Central Europe
----------------------------------------------------------------------
polonica                                                 xxxx
hercynica                                                 xxxxx
carpatica                                                  xxxxx
haguenensis                                                xxxx
pannonica                                             xxxxxxx
----------------------------------------------------------------------
          Varieties from Western and Southern Europe and Asia
----------------------------------------------------------------------
'E. Anglia'                                             xxxx
scotica                                      xxxxxx
iberica                                xxxxxxx
aquitana                                          xxx
subillyrica                                         xx
illyrica                                             xxx
rhodopaea                                     xxxxxxxxx
armena                                       xxxxxx
----------------------------------------------------------------------
0   10   20   30   40   50   60   70   80   90   100   110   120   130
----------------------------------------------------------------------
```

[1]The bar shows variation within a variety represented by the varietal mean ± one standard deviation unit. The plantation average = 100%.

Figure 4.--Relative growth rate of Scotch pine varieties by age 18.[1]

Sacrifices in growth rate had to be made in order for southern varieties to develop genetic resistance to water stress. The fastest growing varieties, therefore, developed in Central Europe where few trade-offs between fast growth and drought resistance, or cold tolerance, were needed.

It is interesting to see how Scotch pine's natural genetic differences affected its performance at plantations throughout the state. Cold conditions at the Dunbar Forest severely hampered the height growth of variety iberica (Table 1). This variety was injured by low winter temperatures, which killed the portion of the trees not covered by snow. This winter damage was not surprising since iberica originates from the warm growing conditions in Spain where there has been little selection for cold resistance. The Central European varieties, on the other hand, did not seem to be affected by the cooler temperatures of the Upper Peninsula. Apparently these varieties have developed enough resistance to withstand the Upper Peninsula winters. These Central European varieties maintained the highest relative growth rate. On good Scotch pine sites, the varieties hercynica, carpatica and haguenensis grew 2.7 feet per year for the period 1974-1979. Unexpectedly, the performance of the north European varieties did not improve in the Upper Peninsula. They still grew more slowly than any of the other varieties. Their relative performance in this colder part of the state did increase in relation to the growth rate of the southern varieties. This increased relative performance was due, however, to slower growth of southern varieties rather than the increased growth rate of northern varieties.

TABLE 1.--Relative size of Scotch pine varieties in six Michigan plantations established in 1961 and measured in 1978 or 1979

Variety	Kellogg Forest	Allegan	Rose Lake	Higgins Lake	Dunbar Forest	Lake Linden
Relative height or diameter expressed as a percentage of the plantation mean (100 = plantation average).						
Varieties from Northern Europe and Asia						
lapponica	49	28	71	52	35	48
septentrionalis	83	73	81	71	83	80
rigensis	98	88	100	91	111	104
mongolica	85	62	77	65	84	80
'Krasnoyarsk'	86	70	--	71	68	96
uralensis	95	83	100	78	102	96
Varieties from Central Europe						
polonica	107	117	119	117	119	120
hercynica	114	128	113	123	123	120
carpatica	110	124	116	123	133	120
haguenensis	118	130	116	129	123	124
pannonica	105	120	116	123	98	116
Varieties from Western and Southern Europe and Asia						
'E. Anglia'	116	--	103	--	121	--
scotica	97	--	97	--	88	96
iberica	94	101	94	84	54	84
aquitana	99	98	100	117	93	100
subillyrica	103	--	97	--	97	--
illyrica	109	96	113	110	102	100
rhodopaea	101	105	100	97	95	108
armena	99	101	97	97	87	96
Average size at date of last measurement						
Height (feet)	35	--	31	16	19	25
Diameter (inches)	--	5.2	--	--	--	--
Age (years)	19	19	19	19	18	19
Year	1979	1979	1979	1979	1978	1979

Thus, as far as growth rate is concerned, the Central European varieties carpatica, hercynica and haguenensis are superior at all plantations throughout the state.

Although red pine is the most commonly planted timber tree in Michigan, Scotch pine may be a faster growing and a more appropriate tree to plant on some sites. Experience at Kellogg Forest has shown that red pine can be expected to produce more wood volume than Scotch pine on a per acre basis, but on an individual tree basis Scotch pine may grow faster than red pine. There is a stand of red pine at Kellogg Forest that is adjacent to our Scotch pine stand. Over a 12-year period, the average growth of the red pine has been 2.2 feet per year, while Scotch pine varieites carpatica, hercynica and haguenensis have averaged 2.7 feet per year. This individual tree growth is important when considering which species to plant for sawlog production

Earlier relative height data published by Wright and Bull (1963), based on 2-year old nursery data, showed a high correlation with the results on this study. The varieties that were tallest in 1961 remained the tallest in 1979. The relative height of the other varieties were nearly the same as in 1961 (correlation of r = .92). A study in Belgium based on 50 year-old Scotch pine plantations by Alolphe Nanson (1968) showed early height data to be a good indicator of later height. Therefore, we expect the tallest seedlots now to maintain their height superiority.

VARIETAL DIFFERENCES IN SUSCEPTIBILITY TO PEST ATTACK

Wright et al. (1976) collected and analyzed Scotch pine pest resistance data for previous studies. These studies occurred before two of the plantations had many of their pest damaged trees removed during thinnings. Thus, an accurate assessment of pest resistance is best obtained from these earlier studies. The sections on insect and bird attack were obtained from them.

Although no varieties appeared completely pest resistant, some differences were striking. Generally, the largest differences were among groups of varieties. The northern, central and southern groups tending to have distinct levels of resistance to each pest. One thing is for certain, resistance seems to be specific for each pest. Those seedlots which were least attacked by one pest might be most heavily attacked by another.

The following are pests that have an influence on stem form. The summary of varietal differences can be seen in Table 2.

Zimmerman Pine Moth

Zimmerman pine moth (Diorycrtria zimmermani) is one of the most important pests of Scotch pine. The females are attracted to fresh pitch and lay their eggs on the bark of the stem in late summer. The larvae feed in the cambial region and exude masses of coagulated

TABLE 2.--Percentage of trees attacked by various pests of Scotch pine

Variety	Percentage of trees attacked by				
	Zimmerman moth	White Pine Weevel	Eastern pine shoot borer	Pine Grosbeak	Porcupine
Varieties from Northern Europe and Asia					
lapponica	15	5	7	77	0
septentrionalis	38	30	21	64	2
rigensis	47	39	31	30	7
mongolica	50	22	18	32	0
'Krasnoyarsk'	50	22	18	33	0
uralensis	61	50	19	25	0
Varieties from Central Europe					
polonica	62	38	37	5	19
hercynica	57	23	34	10	17
carpatica	62	44	42	7	18
haguenensis	74	38	38	7	20
pannonica	62	48	47	0	14
Varieties from Western and Southern Europe and Asia					
'E. Anglia'	75	--	36	28	--
scotica	57	--	41	46	12
iberica	33	7	58	7	15
aquitana	29	38	49	11	21
subillyrica	48	--	44	21	--
illyrica	43	38	56	20	19
rhodopaea	41	38	53	21	28
armena	29	25	51	20	21

pitch and frass. Damage varies with the intensity and position of attack. An injured lateral or terminal shoot usually dies rapidly and ultimately falls off. If several larvae feed at the same level on the main stem the tree may be completely girdled. If this happens the tree may die or only the portion above the girdle may die. The latter case causes a lateral branch to assume the place of the leader and the tree becomes crooked (Wilson, 1977 and Wright et al., 1975).

An experimental plantation at Fred Russ Forest in Cass County, Michigan, was pruned in midsummer. Fresh pitch from the pruning wounds probably acted as an attactant and resulted in an extremely heavy infestation of Zimmerman pine moth. Unpruned plantations 1/4 mile away suffered only minor damage, as did plantations in other nearby areas. Fast growing varieties from central Europe were attacked most heavily and suffered 19-37% mortality. Much less attack was observed on the varieties from southern Europe (Table 2).

White Pine Weevil

The white pine weevil (Pissodes strobi) burrows into the terminal shoot causing it to die. Any elongating portion of the new growth usually curls into a "shepherd's crook" before it dies. The larvae may burrow back into one or more years worth of growth before they emerge at the base of their feeding areas (Wilson, 1977). The resulting dead portion of the stem often remains on the tree for several years. The dead leader is replaced by a lateral branch, resulting in slight to severe stem crook. These insects were present in all the test plantations, but caused serious damage only at

Higgins Lake. The site conditions at this plantation are considered the poorest.

Although there are differences in resistance to attack between varieties, the differences are not so great as to warrant recommendation of any one variety. Scotch pine is just one of the pines this insect feeds on. Injury that is not too severe may be corrected for and minimized with additional stem growth.

Eastern Pineshoot Borer

The Eastern pineshoot borer (*Eucosma gloriola*) also burrows into the pith of new growth. The larvae attack small twigs, large twigs and leaders with equal frequency. This attack normally causes only a few inches of dieback. Death often occurs early enough in the growing season that new buds can be formed at the top of the live portion of the twig. Thus damage may be of little consequence unless there are more than 10 attacks per tree (Steiner, 1974 and Wilson, 1977). There are differences in resistance to this pest, northern varieties being more resistant than southern one.

Pine Grosbeak

Pine grosbeaks (*Pinicola enucleator*) are birds that feed on pine buds during the winter. Within a bud cluster they prefer the small lateral buds. By eating lateral buds they reduce the number of branches or twigs the following year. They occasionally eat terminal buds as well, thus causing stem crooks. These birds were abundant at the Dunbar Forest plantation for several years, eating some buds on almost every tree. Counts were confined to trees in which 5% or more of the buds had been eaten.

The varieties that were usually resistant to pest problems were the ones most susceptible in this instance. The fast growing central European varieties were the trees resistant to attack (Table 2).

Porcupine

Within the last several years porcupines (*Erethizon dorsatum*) attacked the Lake Linden plantation located in the western Upper Peninsula. The overall percentage of crooked trees increased from 26% in 1972 to 43% in 1979, primarily as a result of porcupine damage. Porcupines climb the trees and feed on the phloem, essentially girdling the tree in many instances. Feeding can result in low quality timber, crooked stems or the death of the tree if it is girdled low on the bole.

Although porcupines feed on other hardwoods and conifers, red pine stands adjacent to the Scotch pine test plantation appeared much less damaged. Thus, in the Lake Linden vicinity, Scotch pine was the preferred host. Porcupines have a history of showing preference for trees with high vigor and a diameter larger than seven inches (Krefting *et al*., 1962). At Lake Linden the fast growing central and western European varieties have both of these characteristics and were attacked significantly more often than were the slower growing varieties (Table 2). It is very likely that future plantings of these varieties will also be attacked by porcupine.

Thus, unless practical control programs can be implemented, Scotch pine should not be grown in porcupine country.

STEM FORM

Stem Form and Pest Damage

The major problem with Scotch pine in the United States is its reputation for having poor stem form. Part of this reputation can be attributed to plantations in the northeastern United States and misconceptions taught in many forestry schools. That reputation is not warranted in many parts of Michigan. Many of the stands within Michigan have good form (Botti and Lemmien, 1974). Some people believe that crooked stands result from planting an inherently crooked variety. Their solution would be to identify and plant an inherently straight type of Scotch pine. Unfortunately, the data do not support this notion of some varieties being inherently more crooked than others.

The experimental plantation at Higgins Lake consists of 108 seed sources. All are crooked. The identical seed sources grown at Allegan produced straight trees. Since these plantations represented the same seed sources, the difference in form must relate to something more than the variety planted. This example and similar observations have led to the conclusion that all Scotch pine varieties are inherently straight but become crooked when damaged.

It is known that environmental agents, such as the pests described earlier, can cause Scotch pine to grow crooked. The frequency of crooks found within a variety at any plantation is controlled by the relative susceptibility of that variety to pests present there. Since varietal resistance is specific for each pest, differences in frequency of crooks can be expected among the varieties. Furthermore, because environmental agents that affect stem form change from site to site, varieties that are most crooked at one site may be least crooked at another. An example of this variation in attack, and the resulting crook, can be drawn from Tables 2 and 3. At the Lake Linden plantation porcupines attacked the central European varieties most often. As a result these varieties became the most crooked. At the Dunbar Forest no porcupines are present, instead pine grosbeaks were the major problem. The central European varieties were least affected by pine grosbeak. These factors contributed to a 33% reduction in the frequency of crooks among central European varieties at Dunbar Forest as compared with the Lake Linden plantation. Thus, the ability of a variety to grow straight does not depend solely upon seed source. It depends upon the ability of the variety to resist attack by pests present in the environment in which it is planted.

Although these pest problems need special consideration, they should not exclude the use of Scotch pine for future timber plantations. In some instances crooks may be minimized or eliminated with additional stem growth. Trees with minor crooks often can be utilized during pulp thinnings. Sites with extremely poor conditions and areas were pests are abundant, such as Higgins Lake and Lake Linden respectively, should be avoided.

The fast growing varieties hercynica, carpatica and haguenensis also tend to be the most crooked in all the plantations (Table 3). This becomes the most important problem when considering the use of Scotch pine as a timber tree. At some plantations, such as Dunbar Forest, these varieties were attacked less often than the other varieties. Why then are these central European varieties always the most crooked? A possible explanation and solution for their poor stem form is provided in the next section.

Planting Stock and Snow Damage

Scotch pine often has difficulty recovering from disturbances to its terminal leader. When planting stock is spindly, it can be bent over by wet snow during the first winter, in which case a basal crook results. Once this basal crook has been established, the tree's future height growth may develop a winding pattern that continues years later.

Growing spindly seedling stock is a nursery problem. When seedlings are overcrowded in the nursery bed they develop thin stems. Since different varieties of Scotch pine grow at various rates, it is necessary to sow faster growing varieties at a wider spacing in order to avoid growing spindly stock. All the varieties in this experiment were planted at a density of 50 seedlings per ft^2. That caused the faster growing seedlots to develop more spindly stems than the more slowly growing varieties. The faster growing seedlings, therefore, were probably more susceptible to being bent over by wet snow. During the first winter this apparently was the case, since

TABLE 3.--Percentage of trees with crooks in the basal 17 ft. in five Scotch pine plantations

Variety	Percentage of trees with crooks				
	Kellogg Forest	Allegan	Rose Lake	Dunbar Forest	Lake Linden
Varieties from Northern Europe and Asia					
lapponica	6	3	14	17	24
septentrionalis	14	5	7	14	24
rigensis	11	7	11	19	39
mongolica	10	5	3	10	35
'Krasnoyarsk'	21	17	--	5	31
uralensis	28	10	10	16	57
Varieties from Central Europe					
polonica	20	7	32	8	32
carpatica	20	10	20	19	59
hercynica	21	13	30	25	56
haguenensis	32	24	41	28	61
pannonica	25	17	30	25	61
Varieties from Western and Southern Europe and Asia					
'E. Anglia'	18	--	14	12	--
scotica	11	--	24	11	25
iberica	12	9	12	70	54
aquitana	11	7	19	22	45
subillyrica	22	--	5	17	--
illyrica	9	9	5	0	44
rhodopaea	13	6	11	17	43
armena	14	8	22	13	45

many of the taller seedlings were observed weighted down by snow. Unfortunately, no data keeping track of the later growth of these seedlings were taken. Therefore, we have assumed that the trees in our plantations having a winding pattern are the ones originally bent over by snow. Unlike the pest damaged trees, these trees do not appear to have lost their leading shoot. Instead, they tend to have a crook at their base followed by a winding motion in later growth, never fully compensating for the original crook.

Adjacent to the experimental plantations and at many locations throughout the state, Scotch pine established by natural regeneration can be found. These trees, reproduced naturally, do not have crooks resulting from snow damage. These open grown seedlings would have developed sturdier stems less susceptible to being bent over by wet snow. This supports the possibility that spindly seedlings caused by crowded nursery conditions are responsible for many crooks found in fast growing varieties.

During the summer of 1980, I went to the Allegan plantation to collect data on the frequency of occurrence of this winding type of crook within the different varieties. This crook, which starts at the base of the tree and follows an alternating sweeping motion upwards, is easy to distinguish from the sharp crook that results from insect attack. In Figure 5 the relationship between height and frequency of basal crooks at the Allegan plantation is graphically displayed. The general trend indicates that the faster growing varieties had this type of crook more often than more slowly growing

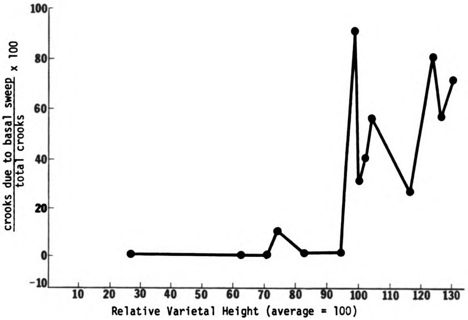

Figure 5.--The relationship between the percentage of crooks which begin with a basal sweep and relative tree height.

varieties. This severe type of crook, which is never fully compensated for by additional growth, may possibly be avoided by using good, sturdy planting stock.

Further studies that record the progress of snow damaged trees are recommended before we rely heavily on this information. The use of sturdy planting stock is still suggested, however, since there is a good possibility that its use will reduce the frequency of crooks found among the faster growing varieties of Scotch pine.

Transplanting and Stem Form

The transplanting of large trees is a major cause of crook among Scotch pine used for landscape purposes. The disturbances to the root system of Scotch pine, due to transplanting, may cause a tree that was previously straight and fast growing to grow crookedly and slowly. Examples of this effect are commonly found in landscape settings.

Behind the Natural Resource building at Michigan State University there are eight Scotch pine planted as ornamentals. They were moved to the building when they were 9 years old in the spring of 1967. All eight had grown straight and at a rate of 2 feet per year prior to transplating. Their growth pattern since the time of their planting has changed dramatically. In most cases the terminal buds stopped growing and were replaced by lateral branches. In the trees where the terminal buds did not die, the new growth is quite crooked. The growth rate of all the trees is much slower now than it was before they were transplanted. Usually the leaders, or the branches replacing the leaders, grew only 4 inches per year since the time of transplanting.

This immediate change from fast straight growth to slow crooked growth can be seen in many Scotch pine that were transplanted at a late age. Observers should be aware that the crooked growth pattern of these landscape trees is a misleading representation of Scotch pine's ability to grow straight and fast in a forest setting.

SUMMARY

Scotch pine, the principal timber tree of northern Eurasia, has the potential of being an important timber tree in Michigan. The constant need for diversity in our forest, and the threat of Scleroderris canker to red pine, has created an interest in this species. The major problem with Scotch pine in the United States is its reputation for having crooked stem form. The purpose for this study was to understand the causes of crooked Scotch pine and examine solutions enabling us to grow straight stands of Scotch pine in the future.

During the summer of 1958 Jonathan Wright obtained seed from sources throughout Europe and Asia. In 1961 the seedlings grown from this seed were used to establish six test plantations throughout the state. The number of seed sources represented at each plantation ranged from 72 to 108. These stands were most recently measured in the summer of 1979 by Jonathan Wright and me. We recorded data on height, diameter, crook, mortality and, in some cases, pest damage. These measurements, along with earlier data, were statistically analyzed and used as a basis for this paper.

The overall height of the plantations at age 18 was 27 feet, varying from 16 feet at Higgins Lake to 35 feet at Kellogg Forest. Soil differences appeared responsible for this variation. Scotch pine performed best on well-drained sandy loam soils with high moisture

retention capabilities. The soil at Higgins Lake, where growth was slowest, had the lowest water holding capacity of any of the plantations. There was much variation in growth rates between the varieties. The varieties _hercynica_, _carpatica_ and _haguenensis_ were the fastest growing under all conditions. On good sites these varieties averaged a growth rate of 2.7 feet per year for the period 1974-1979. These varieties have maintained their superiority in growth rate since the seedling stage and are expected to continue to do so.

Damage by pests, which results in crooked stems, is an important problem with Scotch pine. There are large varietal differences in susceptibility to attack, yet no variety is completely resistant. One thing is for certain, resistance is specific for each pest. Those varieties least attacked by one pest might be most heavily attacked by another. In most cases a pest damaged tree is still useful. Small crooks resulting from minor damage can be minimized or eliminated with additional stem growth. Trees with minor crooks often can be utilized during pulp thinnings.

Scotch pine, unfortunately, has a widespread reputation of having poor stem form. In many parts of Michigan this reputation is unwarranted. It is also commonly believed that crooked stands of Scotch pine result from planting inherently crooked varieties. The data do not support this notion of some varieties being inherently more crooked than others. Research on different varieties of Scotch pine planted throughout the state has led to the conclusion that all varieties are inherently straight but become crooked when damaged.

At particular locations, some varieties will tend to grow straighter than others because of their inherent resistances to pests present there. Since the types of pest problems change from place to place, the relative frequency of crooks occurring within any variety changes with location. By planting on good sites in areas that are not high in pest problems, we can grow straight Scotch pine.

The major problem with the fast growing varieties *hercynica*, *carpatica* and *haguenensis* is their tendency to be the most crooked. There is a good possibility that the higher frequency of crooks found within these varieties is related to their fast growth rate. Since all seedlings grew at the same spacing, the faster growing varieties developed more spindly stems than did the slower growing varieties. These spindly stems were bent over by wet snow during the first winter, which probably resulted in large basal sweeps that were never fully compensated for with additional growth. The solutions to the crook problem in this case is simple, plant sturdier seedling stock. Future studies that record the later growth pattern of snow damaged trees is needed, however, before we can rely heavily on this information. Based on present data, there is a good chance that the use of sturdy planting stock will decrease the frequency of crooks in these fast growing varieties.

Scotch pine should not be thought of as a replacement for any species presently planted, but rather as an additional pine species that can be used for timber production. Understanding the environmental agents responsible for poor stem form, and taking steps to correct these problems, can insure growing straight, useful Scotch pine in the future.

REFERENCES

REFERENCES

Anonymous. Soil Survey Staff. (1979). Classification of Soil Series of the United States. Puerto Rico and the Virgin Islands. USOA-SCS.

Botti, William and W. A. Lemmein. (1974). Scotch pine for timber production in northwest lower Michigan. Mich. Agric. Expt. Sta. Res. Rpt. 230. 4pp.

Harlow, William and E. S. Harrar. (1969). Textbook of Dendrology. Fifth ed., McGraw-Hill Book Company.

Krefting, L. W., J. H. Stoeckeler, B. J. Bradle and W. D. Fitzwater. (1962). Porcupine-Timber relationships in the Lake States. Jour. For. 60: 325-330.

Nanson, Adolpe. (1969). La valeur des tests precoces dans la selection des arbres forestiers, en particulier au point de vue de la croissance. Faculte des Sci. Agron. de l'Etat. Gembloux, Belgium. 242pp.

Nicholls, Thomas. (1979). Scleroderris Canker in Conifers. Amer. Christmas Tree Jour. Vol. 23(1): 23-26.

Ruby, John L. and J. W. Wright. (1976). A revised classification of geographic varieties in Scotch pine. Silvae Genetica.

Steiner, K. (1974). Genetic variation in resistance of Scotch pine to eastern pineshoot borer. Great Lakes Entomologist 7: 103-107.

Wilson, L. F. (1977). A guide to insect injury of conifers in the Lake States. U.S. Dept. of Agric. For. Serv. Agr. Handbook No. 501.

Wright, J. W. and W. I. Bull. (1963). Geographic variation in Scotch pine, results of a 3-year Michigan study. Silvae Genetica 12: 1-25.

Wright, J. W., W. A. Lemmien, J. N. Bright, M. W. Day and R. L. Sajdak. (1976). Scotch pine varieties for Christmas planting in Michigan. Mich. Agric. Exper. Sta. Res. Rpt. 293, 14pp.

Wright, J. W., L. F. Wilson and J. W. Bright. (1975). Genetic variation in resistance of Scotch pine to zimmerman pine moth. Great Lakes Entomologist. Vol. 8, No. 4: 231-236.

VITA

Stephen R. Homrich

Candidate for the Degree of

MASTER OF SCIENCE

Final Examination: November 5, 1980

Guidance Committee: J. W. Wright (Major Professor)
V. J. Rudolph
G. D. Lemme

Biographical Items:

Born August 30, 1957 in Royal Oak, Michigan. From 1959-1975 lived in Boca Raton, Florida, until attending Michigan State University in the Fall of 1975.

Education:

Diploma from Cardinal Gibbons High School, Fort Lauderdale Florida, 1975.

B.S. in Forestry from Michigan State University, 1979.

M.S. in Forestry from Michigan State University, 1980.

Professional Experience:

1978--Worked the summer as a Forestry Aide for the United States Forest Service in Munising, Michigan.

1979-1980--Research and teaching assistant in the Department of Forestry, Michigan State University. Teaching assistant in Forest hydrology, Quantitative methods for natural resources, and Dendrology

Professional Organizations and Honoraries:

Society of American Foresters and Xi Sigma Pi.