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GENETIC VARIATION IN RESISTANCE OF SCOTCH PINE TO ZIMMERMAN PINE MOTH[1]

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Scotch pine (*Pinus sylvestris* L.), a forest tree introduced from Eurasia, is commonly planted for Christmas tree and timber use in northeastern United States. In this country it has numerous insect enemies. Among the most important are European pine shoot moth, *Rhyacionia buoliana* (Schiffermüeller); pine root collar weevil, *Hylobius radicis* Buchanan; European pine sawfly, *Neodiprion sertifer* (Geoffroy); and eastern white-pine shoot borer, *Eucosma gloriola* Heinrich. Previous studies (Wright *et al.*, 1967; Wright and Wilson, 1972; Steiner, 1974) have revealed large genetic differences in resistance to some of these pests.

Another destructive pest is the Zimmerman pine moth, *Dioryctria zimmermani* (Grote). In 1968 this insect, native to the United States, was found attacking trees in a Scotch pine provenance test in southwestern Michigan. The attack rate was heavy and by 1973 it was obvious that some races or varieties were attacked more heavily than others. This is a report on those differences.

THE INSECT DAMAGE

Zimmerman pine moth larvae injure several native and exotic species of pine, but prefer open-grown, sapling-size Scotch pine. The larvae may attack lateral shoot tips, the base of the terminal shoot, or the main stem. After the adult females lay their eggs on the bark in late summer, the larvae hatch in a few days but do not start feeding until the following spring. In May or June of the next year they tunnel through the bark into the cambial region where they feed on wood and adjacent cambium. The injured tree exudes pitch or oleoresin which becomes coagulated and mixed with frass. This material accumulates outside the entrance holes. These pitch accumulations may be 1-3 inches in diameter and are the most visible signs of attack.

An injured lateral or terminal shoot usually dies rapidly and ultimately falls off. Many attacks are along the main stem, at the bases of branches (Fig. 1). An injured branch may die, or it may become weakened and break off during an ensuing storm. Lightly damaged trees may recover completely with little external evidence of injury.

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 within 2-3 years. Or, only the portion above the girdle may die, in which case a lateral branch assumes the place of the leader and the tree becomes misshaped. Heavily damaged trees are of no value commercially and may be esthetically undesirable.

TREE MATERIALS AND METHODS

The host materials in this study are part of a Scotch pine geographic origin study started in 1959 as part of the NC-99 (formerly NC-51) regional project, "Improvement of Forest Trees Through Selection and Breeding". They include trees grown from seed collected in 108 natural stands located in all parts of the species' natural range in Europe and Asia (Fig. 2). Test plantations were established in various parts of Michigan and other

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Fig. 1. Top of a young Scotch pine tree showing a branch (upper left) broken as the result of feeding by Zimmerman pine moth larvae and the pitch mass exudations (lower center) typical of larval feeding along the main stem. Such feeding along the main stem can result in branch breakage, death of the leader and subsequent stem deformity, or complete girdling and death of the entire tree.

north central states. Information on growth rate, foliage color, winter hardiness, etc. in those plantations is contained in a paper by Wright *et al.* (1966).

The Zimmerman pine moth outbreak occurred in plantation MSFGP 7-61 located on the Fred Russ Forest near Volinia, Cass County, southwestern Michigan. The plantation occupies a level site with a sandy loam soil favorable for the growth of Scotch pine. The 108 seedlots were planted as 2-year-old seedlings in 1961. A randomized complete block design with 10 replicates was used. Each replicate contains one 4-tree plot per seedlot. Original spacing was 8 × 8 ft. As of 1967, when the Zimmerman pine moth damage was first noticed, mortality in the plantation averaged 19%. Mean height in 1971 was 14.9 ft, about 10% lower than in the best of 12 similar plantations established in the state.

The Russ Forest plantation was pruned during the summer of 1966, to one-third of total height. Other observers have noted that adult Zimmerman pine moth females are attracted to fresh pitch. That appeared to be true at the Russ Forest. During 1966 and 1967 a heavy infestation started to develop. By 1968, up to 50% of the trees of some seedlots had fresh pitch masses. By the next year, the attack rate had risen to 80% in some seedlots, and 2% of all trees had died as a result of girdling by the larvae. Many new attacks were visible again in 1970 although by then the infestation had begun to decline. By 1973, 49% of all trees had been attacked and 20% were dead as the result of girdling or were girdled so badly that they seemed destined to die. However, by 1973 the new attack rate had decreased to a low level and some trees which had been injured in 1968 or 1969 were completely recovered. Thus it appears that the infestation has run its course and that additional damage will be slight.

Two other Scotch pine experimental plantations were established at the Russ Forest in 1961 and 1963. They were left unpruned until the winter of 1974-75. They were

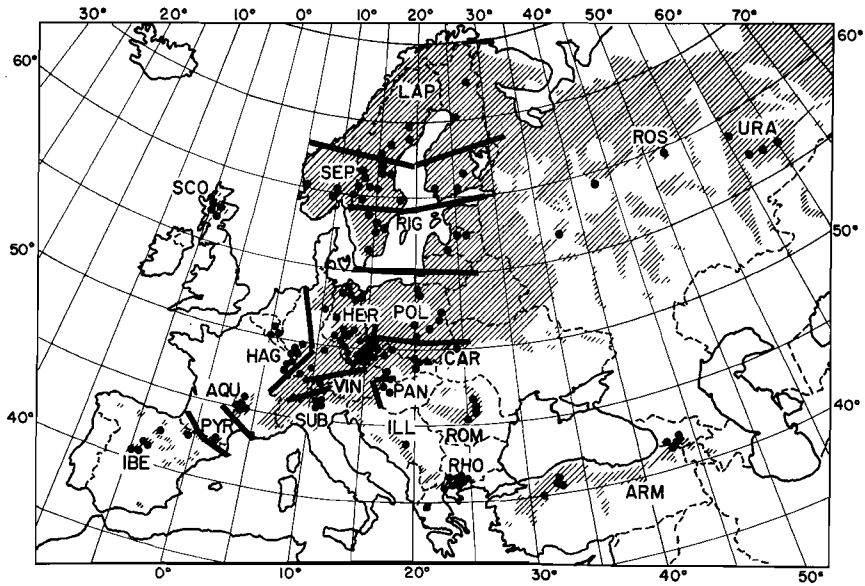

Fig. 2. Natural range (shaded), points of seed collection for the Russ Forest plantation (black dots) and varieties of Scotch pine. The varieties mentioned in this paper are *AQUitana, ARMena, CARpatica, HAGuenensis, HERcynica, IBErica, ILLyrica, LAPponica, PANnonica, POLonica, RIGensis, PHOdopaea, SCOtica, SUBillyrica* and *URAlensis.* The Siberian range of var. *MONgolica* is not shown. Varieties *PYRenaica* (probably resistant), *ROManica, ROSsica* and *VINdelica* (all probably susceptible) were not represented in the plantation.

situated one-fourth to one-half mile distant from plantation 7-61 and have contained some Zimmerman pine moth damage since 1967. However, the infestations have never reached epidemic proportions and less than 1% of the trees have died or been seriously deformed as the result of attack. Light infestations have also occurred in similar experimental plantations in other parts of the state.

Plantation 7-61, last measured in 1971, has been measured several times previously for height, foliage color, cone production, and other characters. Zimmerman moth damage was assessed in 1968, 1969 and 1973. Each time number of trees attacked, number of trees dead, and number of trees with larvae-caused bole crooks larger than 2 inches were counted. Each set of measurement data was subjected to analysis of variance.

VARIETAL DIFFERENCES IN SUSCEPTIBILITY

Scotch pine is a genetically variable species. It has been subdivided by taxonomists into a number of geographic varieties (Ruby and Wright, in press), whose ranges are shown in Fig. 2. In Michigan plantations as a whole, differences among these varieties account for 75-90% of the total genetic variation in traits such as growth rate, foliage color, and oleoresin composition. The same is true with regard to the data presented here. Differences among seedlots belonging to the same variety were not statistically significant although there were large and important differences among varieties. Thus, for convenience, the data are summarized in terms of the geographic varieties (Table 1).

Fast growing timber-type varieties from England and central Europe suffered most. That is true no matter what the criterion–per cent attack, per cent mortality or per cent

Table 1. Differences among Scotch pine varieties in growth rate, susceptibility to Zimmerman moth attack and larval-caused bole crooks.

Variety	Country of origin*	Average height in 1971 at age 11	Trees attacked by Zimmerman pine moth: Total trees attacked 1969	Total trees attacked 1973	Trees dead 1973	Trees dead or with crooked boles 1973
		feet	per cent of trees living in 1966			
		Varieties from northern Eurasia				
lapponica	FIN SWE SIB	7.5	11	15	7	8
septentrionalis	SWE NOR	12.1	30	38	18	32
rigensis	SWE LAT	14.3	46	47	22	40
mongolica	SIB	12.9	50	55	29	46
uralensis	SIB	14.4	58	61	31	49
		Varieties from England and Central Europe				
polonica	POL	17.4	55	62	25	55
hercynica	GER CZE	17.1	56	57	22	48
carpatica	CZE	18.0	66	62	26	49
haguenensis	BEL FRA GER	18.0	71	74	35	70
pannonica	HUN	16.5	55	62	19	57
'E. Anglia'	ENG	16.4	63	75	37	69
		Varieties from Scotland, S. Europe and Asia Minor				
scotica	SCO	14.8	41	57	26	49
iberica	SPA	14.3	43	33	3	18
aquitana	FRA	16.1	33	29	7	22
subillyrica	ITA	15.1	46	48	7	38
illyrica	YUG	15.4	48	43	9	20
rhodopaea	GRE	16.1	42	41	6	31
armena	TUR GEO	14.7	37	29	3	18

*BELgium, CZEchoslovakia, ENGland, FINland, FRAnce, GEOrgian S.S.R., GERmany (East and West), GREece, HUNgary, ITAly, LATvian S.S.R., NORway, POLand, SCOtland, SIBeria, SPAin, SWEden, TURkey, YUGoslavia.

crooked trees. In most of these varieties the attack rates were above 60% and more than 50% of the trees died or became severely misshaped.

Next most heavily attacked were the slower growing varieties from Scotland or northern Eurasia. They are also regarded as timber varieties because in many situations they grow straight and have relatively fine branches. However, all except var. *lapponica* suffered almost as much mortality as did those from central Europe and had a high proportion of misshaped trees.

One northern variety, *lapponica,* was exceptional. Its native range is close to the Arctic Circle and trees of this variety grow very slowly. At the height of the epidemic they were only 2-4 ft tall, so small as to present little attraction to a flying insect. Probably because of its small size, this variety also has been relatively free from damage by other types of insects at other tests plantations.

The least damaged varieties were from southern Europe and Asia Minor. They are characterized by moderate growth rates and foliage which remains nearly as green during the winter as during the summer. Accordingly they are most in demand by Christmas tree growers. Among the southern seedlots, 30-50% of the trees were attacked, but there

were usually only one or two pitch masses per tree. Several trees with visible signs of attack in 1968 or 1969 had completely recovered by 1973. The mortality rate was low, averaging only 3-9%. For the southern varieties as a whole, only 23% experienced severe stem crooks or mortality, as compared with 32-70% for trees of more northern origin. If the plantation had been composed entirely of southern trees, the Zimmerman moth infestation would probably have amounted to no more than a light thinning.

POSSIBLE NATURE OF THE RESISTANCE

This is the fourth insect for which resistance data have been obtained from plantings similar to plantation 7-61. One of our first concerns was to learn whether the resistance is general for all insects or specific for particular insects. This can be done by comparing attack patterns, as follows:

Insect	Varieties which are	
	Most resistant	Most susceptible
European pine sawfly	*uralensis*	*iberica*
Pine root collar weevil	*scotica* & southern	central & northern
Eastern white-pine shoot borer	northern	southern
Zimmerman pine moth	southern	central & northern

There was a general similarity between the attack patterns for the pine root collar weevil and the Zimmerman pine moth. However, even in that case there were important differences. Variety *scotica* was resistant to the pine root collar weevil but not to the Zimmerman pine moth whereas trees from one place in Greece succumbed to the pine root collar weevil but not to Zimmerman pine moth. The attack pattern is totally different for the other insects, indicating that the resistance mechanism of the trees to each insect is probably different.

The six southern varieties resistant to Zimmerman pine moth larvae have two morphological features in common. They have shorter needles (45-57 mm) than more northern trees (60-75 mm), and have greener winter foliage (less green in var. *subillyrica* than in var. *scotica*) than more northern trees. It is doubtful whether either of these foliage characteristics explains the relative freedom from damage from an insect which feeds on the cambium. Certain features of the oleoresin content of the cortex (inner bark) seem to offer a more probable explanation. The cortical oleoresin composition was studied by Tobolski *et al* (1971). According to their data there are striking differences in concentration of two monoterpenes, as follows:

Monoterpene	Concentration in cortical oleoresin of	
	6 resistant southern varieties	Other, non-resistant varieties
3-carene	1-6%*	26-58%
terpinolene	0.3-0.9%*	2.4-4.6%

*The single seedlot representing resistant var. *illyrica* had 20% and 1.8% concentrations of 3-carene and terpinolene, respectively, higher than in other southern trees but still below that found in non-resistant trees.

These monoterpenes are volatile substances present in the fresh pitch. They have characteristic odors recognizable to humans and some insects. One or both may be attractants to female moths seeking oviposition sites, or may contribute to the nutrition of the larvae. The possible importance of 3-carene was indicated by the study of Renwick

and Vité (1970). Working with western pines, they observed that 3-carene combined with beetle pheromones was a potent attactant during the initial attack phase of the western pine beetle (*Dendroctonus brevicomis* LeConte).

PRACTICAL APPLICATION

Zimmerman pine moth is one of the most important pests of Scotch pine, especially in the western part of the lower Peninsula of Michigan where Christmas tree plantations are abundant. It may be that Christmas tree plantations are more prone to attack than others because of the practice of annual shearing which creates many small wounds and fresh oleoresin which can act as an attractant to female Zimmerman pine moths. Two decades ago, much of the Christmas tree planting stock was of central European origin. Because they are among the most susceptible, their use helps to explain why the moth has been such a pest in some of the early plantations. Now, most growers plant the winter-green varieties, most of which are resistant to Zimmerman pine moth and the pine root collar weevil. However, two susceptible varieties, *scotica* and 'East Anglia' are still planted on a large scale. Their further use should probably be restricted in areas where either of these pests has been important.

For timber production it is necessary to use a fast growing, susceptible variety, otherwise growth rate is too slow. That being the case, any pruning or mechanical thinning should be done during the winter if Zimmerman moth damage is to be avoided.

SUMMARY

A heavy infestation of Zimmerman pine moth started in 1966 in an experimental plantation established in 1961 at the Fred Russ Forest, Cass County, Michigan. The plantation consists of 108 seedlots of Scotch pine, representing the species' entire natural range. The plantation consists of 10 replicates, each containing one 4-tree plot per seedlot. The infestation abated in 1972. As of 1973, six southern varieties suffered an attack rate of 29-48% and a mortality rate of 3-9%; northern and central varieties suffered an attack rate of 38-75% and a mortality rate of 18-37%. Resistance may be owing to low levels of 3-carene and terpinolene in the cortical oleoresin of the varieties from southern Europe and Asia Minor.

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