CHARACTERISTICS OF SCOTCH PINE PROVENANCES RELATED TO EUROPEAN PINE SAWFLY ATTACK

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ABSTRACT

In 1958 seeds were requested from native Scotch pine (*Pinus sylvestris* L.) stands in several parts of Europe and Asia. Response was good and seedlots were obtained from 108 native stands plus a number of plantations. In 1961 the NC-51 series of test plantations was established. From 40 to 108 different seedlots were planted in each plantation; the planting following a randomized complete block design. In the years 1963 to 1965 four test plantations in southern Michigan suffered attack by the European pine sawfly (*Neodiprion sertifer* (Geoffrey)).

This study is part of a long-range Scotch pine improvement project. The objectives were: determine genetic differences in sawfly resistance in Scotch pine, and determine the factors responsible for possible resistance.

The damage estimates made in the years 1963 to 1965 consisted of counts of the number of infested trees. From each tree three 1-year-old needles were collected and measured in July 1965. The collections were made from centrally located branches on which feeding had occurred.

Slow growth was probably responsible for the limited attacks on the most northern origins -- the insects could not find the trees in

the weeds. However, it is doubtful whether growth rate was a major factor in resistance among the medium and fast-growing varieties. Also, there were instances in which a tall tree of var. uralensis was free of damage whereas a nearby smaller tree was heavily eaten.

Several factors were possibly correlated with sawfly resistance. Early onset of growth, wide needles, slow to medium growth rate, intense autumn coloration, and early needle maturity were characteristics of those seedlots with the fewest attacks. Those seedlots were mostly from northern latitudes. They also had lower concentration of foliar sodium, potassium, and magnesium than did susceptible provenances.

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by

William K. Randall

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INTRODUCTION

No farmer today would think of planting an orchard of wild apples, or a field of the inferior forms of corn from which the present very productive hybrid strains were developed. Increasingly, the forester is aware of the possibilities of improving forest trees and is trying to replace unimproved wild types with more productive strains.

There is genetic variation in all species. Certain individual trees are able to grow better on a particular site than are others. They grow faster than their neighbors and leave more seed. On another site other types of trees grow faster and produce more seed. Thus, in the course of time, natural selection results in the development of different races.

The racial variation pattern of Scotch pine (*Pinus sylvestris* L.) is well known through a series of studies going back to 1820. Most of the data pertains to growth characteristics. Some of the racial studies have been conducted in southern Michigan. Recently, some of the Michigan test plantations were infested by the European pine sawfly (*Neodiprion sertifer* (Geoffrey)). This provided an opportunity for the study of genetic differences in resistance to attack by this important pest.

My study is part of a long-range Scotch pine improvement project. My objectives were two: determine genetic differences in sawfly resistance in Scotch pine; and, determine the factors responsible for possible resistance. To this a third objective may be added as part of

the long-range project -- breed a resistant strain with satisfactory growth characters.

There are five commonly recognized methods of achieving insect control. They are:

1. Direct control by spraying with insecticides.
2. Biological control by the introduction of parasites or predators.
3. Ecological control by making the environment unfavorable for the insect.
4. Radiation control by the sterilization of males which are released in large numbers and cause females to lay sterile eggs.
5. Genetic control through the breeding of resistant tree varieties.

Insecticides have been sprayed over millions of acres as an insect control practice. Life is contaminated when the invisible insecticidal shroud settles on the earth's surface. Biological, ecological, and genetic control are methods for reducing insect populations without producing undesirable side effects which may accompany direct control. In the future we must always remember that our forest resource is not composed of timber alone and that other values must also be preserved.

A sound knowledge of the factors causing immunity or resistance and the conditions which influence these factors, is the basis for breeding plants for insect-resistance. However, it is not necessary to understand thoroughly these factors in order to make progress in a breeding program.

Genetic control through breeding has obvious advantages and disadvantages. In the case of this particular pest, it may cost many

thousands of dollars to produce a resistant strain of Scotch pine. But once produced, the strain would cost no more to plant than an ordinary one and would eliminate the need for periodic spraying of thousands of acres. Thus in the long run, genetic control might well be the most economical.

PAST WORK IN BREEDING FOR INSECT-RESISTANCE

Resistance and cause.--Painter (1951) defined insect-resistance as: "The relative amount of heritable qualities possessed by the plant which influence the ultimate degree of damage done by the insect." Søegaard (1964) defined resistance more simply: "Resistance refers to trees that are less damaged or less infested than others under comparable environmental conditions." Resistance results from the presence of a substance or structure in resistant plants and its absence in susceptible ones, or the reverse.

A knowledge of the cause of resistance is highly desirable, but it may or may not be of use in breeding programs. The agronomist does not demand a full knowledge of the cause of a high yield before breeding for this character in field crops. It is no more necessary to know the exact cause in breeding for insect resistance. In the majority of the breeding programs for insect resistance, the exact cause of resistance has remained unknown (Painter, 1951).

Breeding for forest tree insect-resistance is relatively new. Most of the literature cited for this study is by R. H. Painter, E. J. Schreiner, and various workers from the Institute of Forest Genetics, Placerville, California. Painter's interest is breeding for insect-resistance in agricultural plants. His methods, however, are applicable to breeding for insect-resistance in forest trees. Painter's recommended procedures were as follows:

1. A survey for possible sources of insect-resistant varieties and strains.

2. A determination of some of the basic properties of the plants responsible for resistance.
3. Hybridization to combine genes for resistance with desirable agronomic characters.
4. A study of genetics of resistance to the insect where possible.
5. Testing the resistance in advanced-generation hybrids.
6. The study of resistance of released varieties in plots and on farms to evaluate resistance as an insect-control method.

Examples of resistance.--Cherry fruit flies (*Rhagoletis cingulata* Loew) are unable to lay their eggs in cherries that have a certain degree of hardness (Snelling, 1941). This may be influenced by either the stage of maturity of the fruit or varietal characteristics.

Soft-wooded chrysanthemums have been reported to be more susceptible to *Paroxuna micella* Lw. than the hard-wooded varieties. Painter (1951) found that fiber hardness is a character which is associated with resistance in certain varieties of sugar cane to the sugar cane borer (*Diatraea saccharalis* Fab.).

A stiff-strawed Pawnee variety of wheat (*Triticum aestivum* L.) has been developed which is resistant to the hessian fly (*Phytopaga destructor* Say.). European grape (*Vitis vinifera* L.) is susceptible to the grape phylloxera (*Phylloxera vitifoliae* Fitch) while American varieties are resistant (Painter, 1951).

R. C. Hall (Forest Insect Laboratory, Columbus, Ohio) from 1930 to 1940 found two clones of black locust (*Robinia pseudoacacia* L.) resistant to the locust borer (*Magacyllene robiniae* Forster): (1) the resistant 'Shipmast' clone found on Long Island, New York; (2) the 'Higbee' clone of southern Indiana.

Schreiner (1949) conducted an experiment breeding poplar. He found differences in resistance to the Japanese beetle (*Popillia japonica* Newman). Four interspecific hybrid combinations demonstrated that there are wide differences between siblings of the same hybrid combination. The combinations in which this differential resistance occurred were:

Populus 'charkowiensis' X *P. balsamifera* var. *virginiana* Foug.
P. 'charkowiensis' X *P.* 'caudina'
P. 'charkowiensis' X *P. berolinensis* Dipp.
P. simonii Carr. X *P. berolinensis* Dipp.

In each case one parent was itself an interspecific hybrid.

The Institute of Forest Genetics, Placerville, California, has developed an insect-resistant variety of pine, by crossing Jeffrey pine (*Pinus jeffreyi* Grev. and Balf.) with Coulter pine (*P. coulteri* D. Don.) then using pollen from the hybrid and backcrossing to Jeffrey pine. The backcross hybrid was resistant to the resin midge (*Retinodiplosis* spp.) and the pine reproduction weevil (*Cylindrocopturus eatoni* Buch.). In resistant pines the cortical tissue became necrotic around the egg puncture made by the female pine reproduction weevil. In trees which were killed the larvae penetrated the necrotic tissue and reached the cambium. The larvae are unable to penetrate the necrotic tissue in resistant trees. Miller (1950) stated that resistance was possibly attributable either to this necrotic layer or to some property of the resin.

Yellow-green varieties of chick peas (*Cicer arietinum* L.) are more resistant to the pea aphid (*Macrosiphum pisi* Harris) than blue-green varieties (Painter, 1951). The European larch (*Larix decidua* Mill.) is susceptible to the larch gall aphid (*Chermes* spp.) which is not

found on the Japanese larch (Larix leptolepis Sieb. and Zucc.) (Søegaard, 1964).)

Permanence of resistance.--Insect-resistant varieties impose adverse effects on the insect's life cycle when used as host. These resistant characters act as control mechanisms in reducing the potential insect population, thus resulting in lesser host damage. However, with a resistant variety the factors of permanence and degree of resistance must be considered. Permanence of resistance depends upon several factors (Painter, 1941).

1. The proportion of acreage of a resistant to susceptible varieties in a given area.
2. The thoroughness with which other control measures are practiced.
3. The purity of the resistant variety as grown.
4. The number of genetic factors and resistance characters involved in the resistant variety.
5. Genetic relationships of the strain of insect to other insects.
6. The original proportion, if any, of the population capable of feeding on the resistant variety.
7. Ecological adaptation of the strain of insect feeding on the resistant variety.

Ninety years ago phylloxera-resistant grape vines were sent from the United States to France. These vines still are an important means of control of the grape phylloxera in Europe. Ordinary cotton (Gossypium spp.) could not be grown in South Africa because of the

cotton leafhopper (*Empoasca fascialis* Jac.). However, a hairy variety of (*Gossypium hirsutum* L.) has been found which is not attacked. This hairy variety of cotton has remained since 1925 (Painter, 1958).

Varieties of wheat (*Triticum aestivum* L.) resistant to the wheat rust (*Puccinia graminis* Pers.) have been developed (Shaw, 1964). However, new biological strains of the fungus appear and the formerly resistant wheat variety is rendered susceptible. Perhaps four years is the total maximum resistant period for any new wheat variety. This unfortunate situation results because the diploid stage of the life cycle occurs on the barberry (*Berberis canadensis* Mill.) while the haploid stage is confined to the wheat plant. The haploid stage is capable of rapid genetic change. In a diploid organism considerable more time is needed to produce a true-breeding new type. Most insects are diploid. Hence we do not expect the rapid evolution of damaging new types as has occurred in the wheat rusts.

MATERIALS AND METHODS

In 1958 seeds were requested by J. W. Wright from native Scotch pine stands in several parts of Europe and Asia. Response was good and seedlots were obtained from 108 native stands plus a number of plantations. The seeds were sown in the former Michigan State University Bogue Research Nursery in 1959 and the seedlings were grown there for two years and under the direction of W. I. Bull.

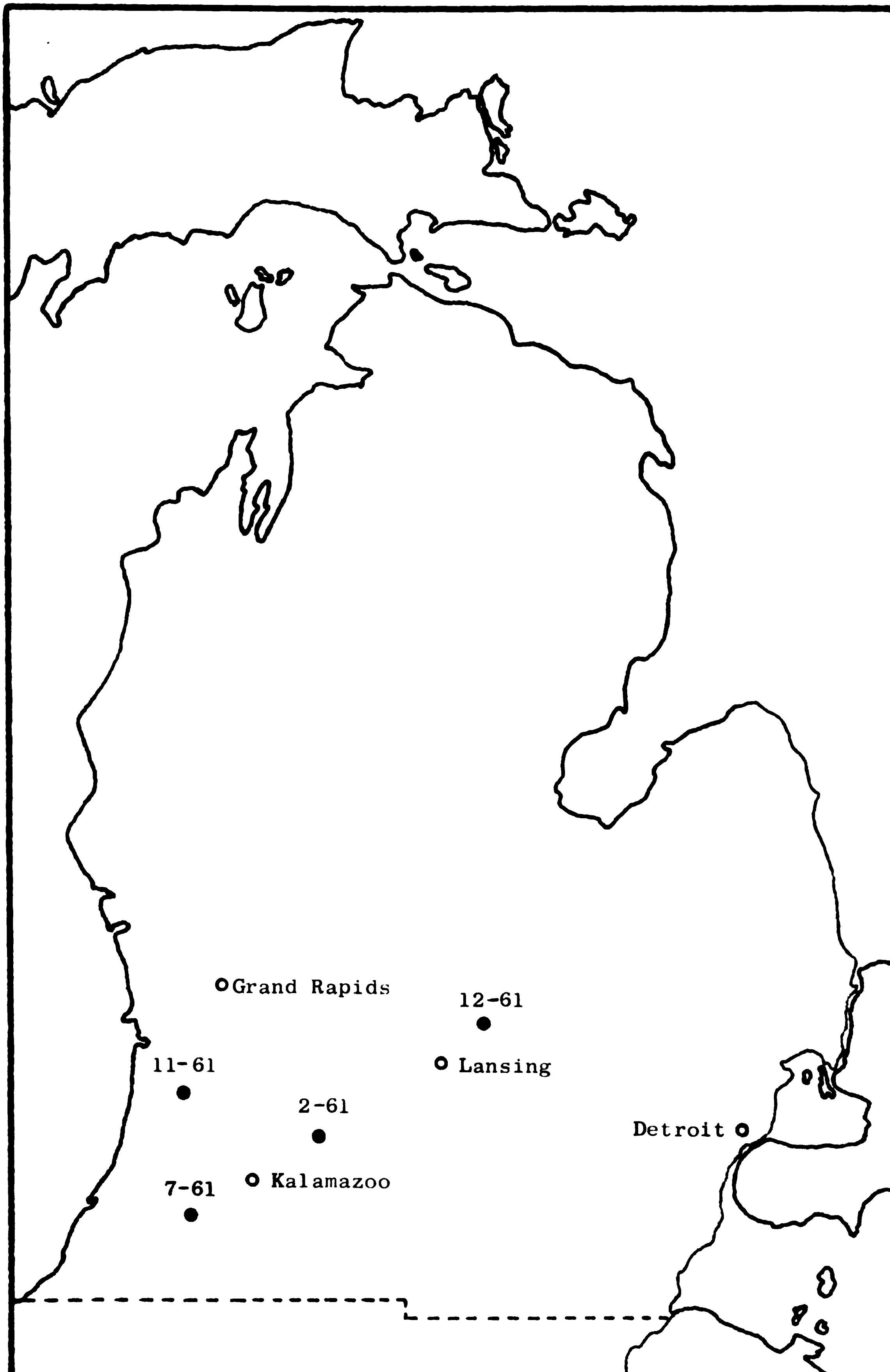
In 1961 the NC-51 series of test plantations was established. There were 10 such plantations in various parts of Michigan plus a number in other north central states. From 40 to 108 different seedlots were planted in each plantation; the planting followed a randomized complete block design. The number of replications varied from 7 to 10. An 8-by-8 foot spacing and 4-tree linear plots were used in each case.

In the ensuing years four of these test plantations suffered attack by the European pine sawfly and could be used in this study. These four were located in southwestern Michigan (Figure 1). More complete descriptions of these follow.

Kellogg Forest.--Plantation 2-61 is located on the W. K. Kellogg Forest, Kalamazoo County, 2 miles west of Augusta, Michigan. There are 108 Scotch pine origins represented in 10 replicates totalling about 4800 test trees. Planting strips were furrowed in October to remove the sod. Seedlings were hand planted in the furrows the following spring under the direction of W. L. Lemmien.

Two replicates are on level areas, the others are hilly with slopes to 40 percent. The soil is moderately fertile (Oshtemo loamy sand). The

Figure 1.--Locations of the outplantings in southern Michigan (solid dots) which were sampled for sawfly attack.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Detroit
7-61
Kalamazoo

level areas were cropped prior to planting. Survival as of 1964 was 93 percent. Average plantation height at that time was 34 inches. During the 1965 growing season many of the trees grew an additional 20 inches. Near the test area is a 30-year-old Scotch and red pine (*Pinus resinosa* Ait.) stand, the probable source of sawfly infestation.

Russ Forest.--Plantation 7-61 is located on the Fred Russ Forest, Cass County near Dowagiac, Michigan, and was planted under the direction of J. W. Wright and John Bright. It contains 105 Scotch pine origins replicated 10 times, a total of 4435 experimental and border trees. Chemical weed control was used to eliminate competing vegetation in the planting strips. Survival in 1965 was 83 percent. The area is level and the sandy loam is fertile. The plantation area was used as a nursery prior to planting. Average plantation height in 1964 was 34 inches.

Light sawfly infestations in 1963 and 1964 probably came from planted ponderosa (*Pinus ponderosa* Laws.) or Scotch pine a quarter mile distant. Nearby areas were sprayed by airplane for another insect pest in 1965. That apparently destroyed all sawflies.

Allegan Forest.--Plantation 11-61 is located on the Allegan State Forest, Allegan County near Allegan, Michigan. It was planted under the direction of J. W. Wright. There are 72 origins in 10 replications for a total of about 3000 experimental trees. It was machine planted with 2-0 seedlings. Scalping was unnecessary because of the slight amount of ground cover which consisted largely of lichens, poverty grass (*Danthonia spicata* (L.) Beauv.) and prickly pear cactus (*Opuntia humifusa* Raf.).

The planting site is level. Soil is coarse textured and relatively infertile. Survival as of 1965 was 88 percent. Average plantation

height in 1965 was 37 inches. Red pines (*Pinus resinosa* Ait.) 30 feet tall, a probable source of sawfly infestation, are located about 200 feet east of the test plantation.

Rose Lake.--Plantation 12-61 is located on the Rose Lake Wildlife Experiment Station, Shiawassee County near Lansing, Michigan. It contains 75 origins and 7 replications, or about 2100 test trees. It was established by machine with no weed control. John L. Ruby and J. W. Wright did the planting.

The plantation site is rolling with up to 10 percent slopes. The soil is well drained loamy sand with a sparse cover of lichens, poverty grass and dewberry (*Rubus* sp.). A clay layer at a depth of 2 to 3 feet provided good moisture relations once the trees were established. In 1964 the average height was 34 inches with some origins as tall as 45 inches. The taller origins grew an additional 2 feet in 1965. Survival as of 1964 was 90 percent.

There are two east-west rows of Scotch pine about 30 feet south of the test plantation. These trees average 15 feet in height. These trees have been severely attacked by the sawfly and undoubtedly provided the source of infestation for the test plantation.

The test trees suffered a moderate amount of sawfly damage in 1963. All infested test trees were sprayed so that new attacks would have to come from the neighboring rows of trees. This same practice was followed in 1964, when the attacks were heavier. The 1965 infestation was very severe.

Needle measurements.--I used previously gathered data on the percentage of first-year trees having mature needles and summer foliage

color of 2-year-old seedlings. In both instances the information was gathered from the nursery test. The data on foliar analysis were supplied by Klaus Steinbeck, based on samples collected at the Russ Forest plantation in the autumn of 1963.

The damage estimates made in 1963 and 1964 by Louis F. Wilson and J. W. Wright consisted of counts of the number of infested trees. Tree counts were also made in 1965. In addition the amount of damage per tree was determined. At Kellogg and Allegan the number of sawfly colonies was counted on each tree. At these two plantations the percentage of foliage eaten was rarely more than 5 percent. At Rose Lake the amount of damage was determined by estimating, to the nearest 5 percent, the amount of foliage eaten.

Needles for measurement were chosen from a branch on which feeding had occurred. Three 1-year-old needles were collected from each tree in July 1965. Each needle was from a different fascicle. The collections were made from centrally located branches on which feeding had occurred. In this way it was hoped that the measurements would apply to needles as the insect saw them.

The needle measurements were made in the laboratory with a dissecting microscope. The lengths were measured to the nearest millimeter and the widths to the nearest 40 microns.

Leaf hardness was estimated with the aid of a dissecting needle pressed against the epidermis by hand. It was hoped that this would duplicate the action of an ovipositor. Five grades of hardness were recognized. Possible observer bias was eliminated by hiding the identity of the leaf until the observation was recorded.

Each set of measurements for a single test plantation was subjected to analysis of variance. The degrees of freedom were as follows: S-1 for seedlot, R-1 for replicate, and (S-1)(R-1) for error, S and R being the numbers for seedlots and replicates in a plantation respectively. No transformations were used.

SCOTCH PINE

Distribution.--Scotch pine occurs naturally over an extensive area of Europe and Asia (Figures 2 and 3). The most northerly occurrence is near Alten, Norway (70° N. latitude). From there it ranges southward to the Sierra Nevada Mountains (37° N. latitude) of the Andalusia region of southern Spain. The Sierra Nevadas also mark the western boundary (50° W. longitude) of its range. The eastern extreme is delineated by the Aldan River (137° E. longitude) of northeastern Siberia. In its native range Scotch pine is one of the most important commercial timber species. It grows on varied sites, from the cold-climate pinetum-cladinosum cover type of northern Eurasia to the warmer mountain types of southern Europe. It is by preference a tree of siliceous soils, but occurs on almost all geological formations (Wilde, 1958).

Description.--Wright and Bull (1963) portrayed Scotch pine thus: "Needles 2 per cluster 1 to 3-1/2 inches (25 - 80 mm.) long, 1/25 to 1/12 inch (1-2 mm.) broad, stiff, sharp-pointed, twisted, gray-green, with persistent needle sheaths; cones 1-1/2 to 2-1/2 inches (4-6 cm.) long, 2 to 3 times as long as broad, conic with a rounded base, yellow to grayish brown, with long angular apophyses on the basal scales, opening in December or January and not long persistent after ripening; bark scaly, dark brown or black at first but changing to yellow or reddish on large branches or on the lower boles of large trees."

Figure 2.--Natural distribution of Scotch pine in Europe (shaded) and provenances included in Wright and Bull (1963) test (numbered dots).

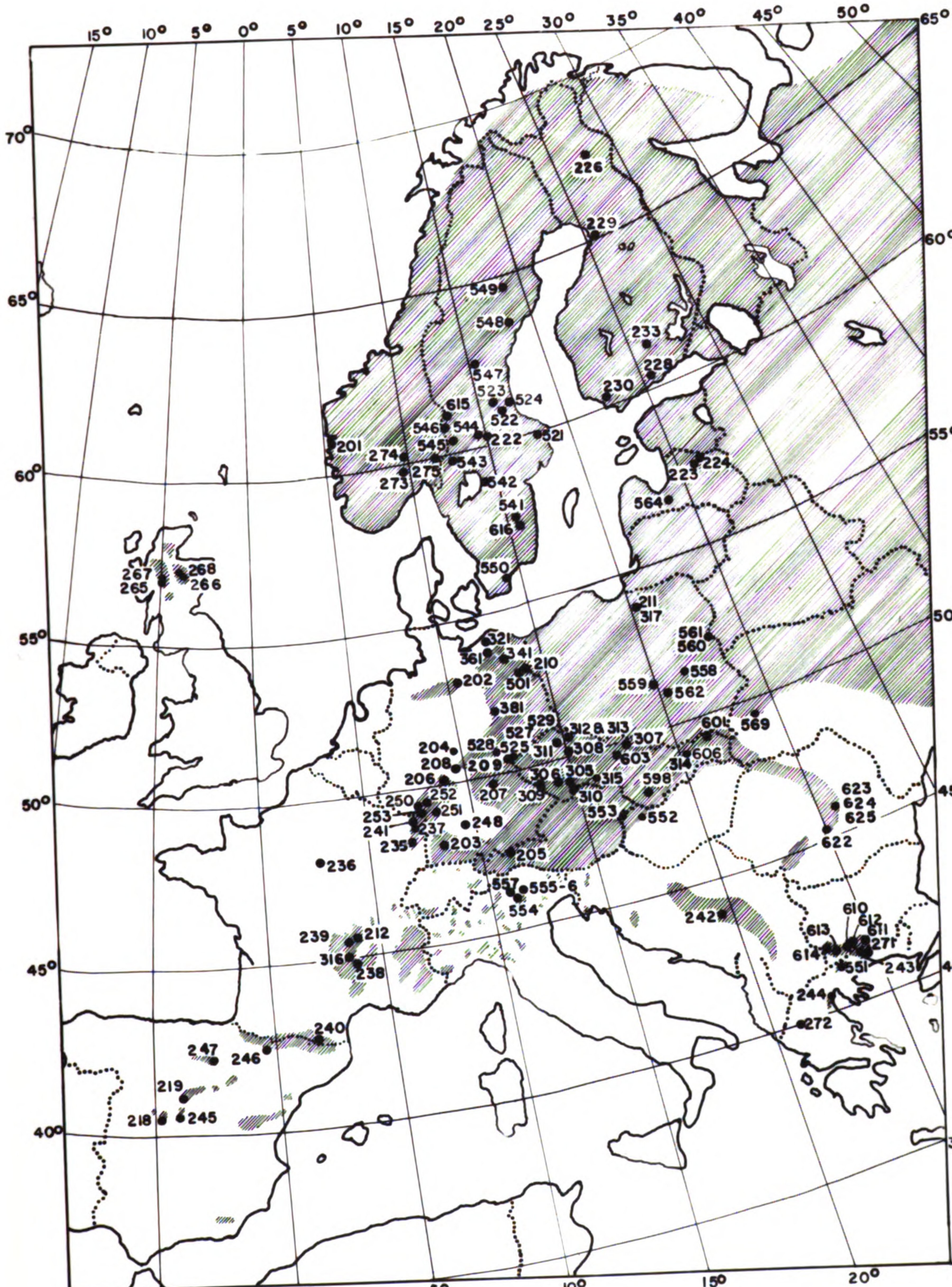
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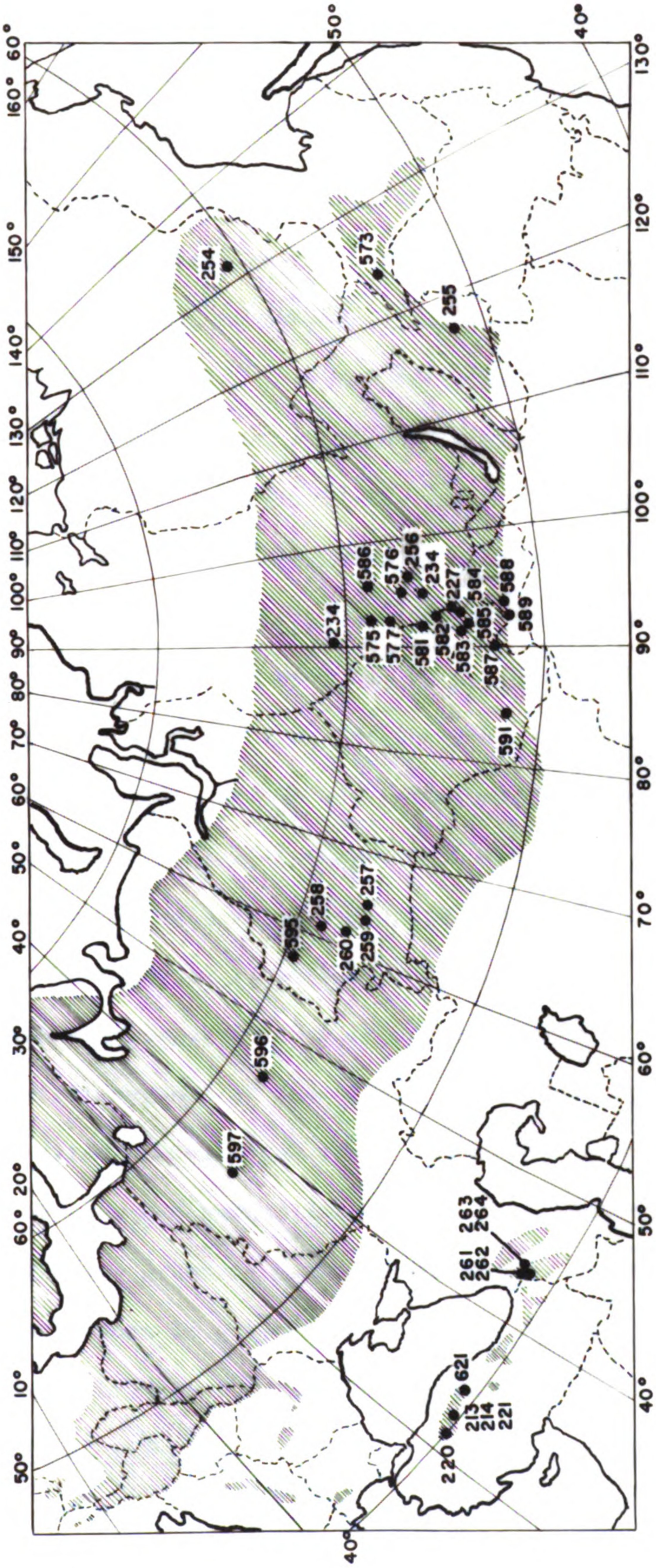
Figure 3. Natural distribution of Scotch pine in Asia (shaded) and provenances included in Wright and Bull (1963) test (numbered dots).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In the Scottish woods the Scotch pine is flat-topped and only 50 to 60 feet tall whereas spire-crowned trees 100 to 120 feet tall are common in old German and Scandinavian forests.

Fully stocked Scotch pine stands do not have as heavy a canopy as most other northern coniferous stands. Therefore, profuse ground vegetation occurs under 30- and 40-year-old stands.

Within any population that is transcontinental in distribution, there is apt to be a great amount of genetic differentiation. Scotch pine is transcontinental. Carlisle (1958) named 111 geographical and morphological variants. Those included many cultivars of limited importance, and there was some duplication among names. Ruby (1964) used genetic and taxonomic methods in arriving at his classification of the species. He used data from Michigan growth tests as well as measurements taken on cones, seeds, and leaves collected from wild trees. He recognized 21 geographic varieties (Table 1), each characterized by differences in growth as well as morphological characteristics.

Importance.--Scotch pine is an important species in the United States. It is the most important exotic planted today in the northeastern and north central regions of the country. Its use, for the most part, has been limited to Christmas trees. However, in the near future pulping of this species may become important. This importance is shown by the numbers of trees grown in Michigan nurseries. As of 1963 there were 28 million seedlings in private nurseries within the state. About 14 million seedlings are planted in Michigan each year.

Evolution within the species.--During the Pleistocene Epoch vast glaciers scoured the present geographic range of the Scotch pine. Northern Europe and northern Asia were subjected to glaciation which

Table 1. Varieties (and numbers of origins) of Scotch pine (*Pinus sylvestris* L.) included in the test and their natural ranges (from Ruby, 1964).

lapponica (5)	Northern Norway, Sweden, and northwestern USSR
mongolica (2)	Eastern Siberia
uralensis (4)	Ural Mountains in USSR
altaica (3)	Altai Mountains in USSR
septentrionalis (16)	Central and southern Norway, central Sweden, and central Finland
rigensis (5)	Southern Sweden and Baltic countries
armena (8)	Northeastern Turkey, Armena, Georgian SSR, and Iran
aquitana (6)	Massif Centrale of France
scotica (4)	Highlands of Scotland
iberica (5)	North-central Spain
nevadensis (0)	Sierra Nevada Mountains of southern Spain
rhodopaea (5)	Southern Bulgaria, northern Greece
illyrica (1)	Central Yugoslavia
pannonica (2)	Western Hungary
carpatica (1)	Northeastern and eastern Czechoslovakia
vindelica (0)	Southeast central France, Switzerland, and western Austria
engadinensis (0)	Engadine Alps, upper Inn Valley, and eastern Switzerland
borussica (2)	Northeast German lowlands
hercynica (20)	Southern and eastern Germany, central Austria
scotica X ? (2)	Plantations in England probably originating as hybrids between Scottish and south European trees
polonica (2)	Poland
haguenensis (10)	Western Germany, eastern France, and Belgium

eradicated most of the vegetation. However, there were a few isolated refuges where segments of the populations survived. Wright and Bull (1963) postulated that five such places existed --"the Ural Mountains of Russia, the Pyrenees of France and Spain, the Kjolen Mountains of Norway and Sweden, and the Alps or Carpathians of southeast Europe." In pre-Pleistocene times the pine was probably well differentiated so that these remnants formed distinct races. It is believed that the present varieties descended from these remnants.

When a barrier prevents the mingling of new characters as they arise, separated populations sooner or later evolve along divergent lines due to selection pressure. Thus there is an independent accumulation and loss of genes within each separated population. However, in the continuously forested areas of Germany and Czechoslovakia no barriers existed. Therefore, little differentiation resulted in such areas. Changes due to selection pressure are much slower than those due to environmental changes. Thus Scotch pine in some locations is not adapted to its modern environment. To a certain extent varieties of Scotch pine reflect their Pleistocene ancestry (Wright and Bull, 1963).

EUROPEAN PINE SAWFLY

Occurrence.--The European pine sawfly, a Hymenopterous leaf-eating insect, was introduced from Europe. It was first collected in North America in Somerset County, New Jersey, 1925. The present known range in the United States encompasses the northern states from New England to Michigan and southern Ontario. The sawfly also ranges to Iowa, southern Illinois, and southern Ohio. In Europe it is distributed in Sweden, Finland, Russia, Germany, Austria, Hungary, Czechoslovakia, and occurs in Japan.

According to Ross (1955) the original Neodiprion group, which spread across North America with its conifer host during the Mid-tertiary or early Miocene (40 to 50 million years ago) was later split into eastern "lecontei" and western "sertifer" groups by the formation of the Great Plains. European pine sawfly or its ancestral form later dispersed to the Eurasian continent via a Bering land bridge.

The European pine sawfly attacks Scotch pine, red pine (P. resinosa Ait.), Japanese red pine (P. densiflora Sieb. and Zucc.), jack pine (P. banksiana Lamb.), table-mountain pine (P. pungens Lamb.), and mugo pine (P. mugo Turra.). Also there is slight feeding on eastern white pine (P. strobus L.), Austrian pine (P. nigra var. austriaca (Hoess) Aschers and Graebn.), ponderosa pine (P. ponderosa Laws.), shortleaf pine (P. echinata Mill.), and pitch pine (P. rigida Mill.) (Lyons, 1964). Occasional larval feeding has been reported on black spruce (Picea mariana (Mill) B.S.P.) and white spruce (Picea glauca (Moench) Voss.) when these trees grow in close proximity to pines.

Although no one host species is consistently preferred by ovipositing females, Scotch pine is more suitable for the development and survival of the larvae (Lyons, 1964).

Description.--Full grown larvae are 3/4 to 1 inch (20 to 25 mm.) in length, with a black head and a gray-green body having a gray longitudinal stripe. The adult male is 1/4 inch (6 mm.) long, black in color with a feather-like antennae. The adult female is 3/8 inch (9 mm.) long, yellowish-brown in color with a thread-like antennae.

The oval egg is pale yellow-white, 0.05 inch (1.3 mm.) long by 0.01 inch (0.13 mm.) wide. The cocoon is a light tan or dark golden brown, cylindrical with rounded ends, 0.3 to 0.4 inch (8 to 10 mm.) long. A male cocoon is slightly smaller than a female cocoon.

Life History.--The European pine sawfly completes its life cycle in one year. Winter is passed in the egg stage on the needles. Hatching in mid-April or May, the larvae feed for a period of four or six weeks. In mid-June or July the cocoons are spun in the duff beneath the infested trees. The prepupae remain in their cocoons until August or early September at which time the adults emerge. After mating the female deposits her eggs in slits cut in the edge of the current year's needles.

Griffiths (1959) noted that most pupae emerge as adults in late summer or early fall; a few overwinter in the cocoon for one or more years. This survival of overwintering pupae serves to buffer the population against the catastrophic elimination of a single class-year.

Damage.--Defoliation causes a reduction of height growth. Wilson (1964) found that 10 larval colonies per tree feeding on 5-foot-tall

Scotch pines in southern Michigan reduced height growth by 14 percent during the following year. Under those same conditions 25 larval colonies per tree reduced height growth by 23 percent. Seldom does a 5-foot-tall tree support more than 25 larval colonies on the average.

Oviposition.--Egg laying occurs in late August or early September. A female flies to a tree and selects a needle, usually above the level of adjacent weeds. She uses her thread-like antennae to determine the presence of eggs already laid. Then the female backs down the entire length of the needle before any egg laying is done. However, Ghent (1959) stated that females may lay eggs along any portion of the needle.

Visualizing a needle from its flat surface, apex upward, a female cutting egg pockets on the right edge of the needle extends her left legs only a short distance across the flat surface. The right legs must reach the greater distance around the curved surface, to grasp the same edge. In this position she cuts the egg pocket and deposits a single egg. The female then advances and the process of cutting an egg pocket and depositing an egg is repeated until 6 to 8 eggs are laid per needle. Egg laying ceases when the female's antennae detect the narrowing of the needle at its tip.

Egg laying proceeds while the legs are fully extended across the needle. In the case of a wide needle the leg movement is restricted and closer egg spacing results. Thus there is an inverse relationship between needle width and the egg spacing. A female may find that an exceptionally wide needle is difficult to grasp so she abandons it and seeks a narrower one.

An inverted position is adopted by the female in 76 percent of the cases (Ghent, 1959). This is due to the greater stability offered by having its weight slung below the needle.

Females of all sizes can oviposit on narrow needles, but only the largest females are able to utilize wide needles, that is, needles over 1.5 mm. (Lyons, 1964).

The female deposits her eggs on several needles, thus forming an egg cluster. Griffiths (1959) determined that on Scotch pine an egg cluster contains 90 eggs.

Many Scotch pine in southern Ontario, during the 1958 growing season, produced exceptionally wide needles (Ghent, 1959). In areas of heavy infestation these needles were shunned.

RESULTS

Date of onset of growth.--Table 2 gives the day of year that growth started in 1960 for different origins of Scotch pine. Onset of growth was determined when the terminal bud opened and elongation was apparent. The less attacked trees started growth two days earlier than the heavily attacked origins; the difference was significant (5 percent level). The two-day spread in the start of growth is a character that has continued and this difference was apparent in 1965.

Table 2 also shows the percentage of trees with mature needles on October 1, 1959. The wide difference in percent of needle maturity cannot be accounted for alone by the two-day spread in the onset of growth. The difference is apparently due to a timing mechanism that has developed in certain trees, since after the first year the character of needle maturity was the same for all trees.

Sawfly attack was less on trees with a high percentage of mature needles at the end of the first year's growth than trees with a low percentage of mature needles in the years 1963 to 1965. This character of needle maturity related to insect attack was merely observed and may be only incidental to resistance.

Needle hardness.--The mean and range of needle hardness for the resistant and susceptible trees was respectively 5.4, 3 to 12; and 6.1, 4 to 9. The lower number signifies the harder needles (Table 3).

When the resistant and susceptible origins are grown in mixture, the slight difference in needle hardness may be detected by the female

Table 2. Date of onset of Scotch pine growth and the percent of mature needles per tree, related to European pine sawfly resistance.

MSFG No. and country	Variety	North latitude	Started growth 1960*	Mature needles per tree 1959**
		Degrees	Day of year	Percent
		Resistant origins		
546 SWE[a]	lapponica	60.9	113	87
255 SIB	mongolica	52.3	113	84
257 URAL	uralensis	56.8	113	59
258 URAL	uralensis	58.7	114	80
260 URAL	uralensis	57.0	114	43
256 SIB	altaica	56.7	113	90
230 FIN	septentrionalis	60.5	113	52
273 NOR	septentrionalis	59.7	113	84
523 SWE	septentrionalis	61.2	113	82
		Susceptible origins		
207 GER	hercynica	49.7	115	16
210 GER	hercynica	53.1	115	16
308 CZE	hercynica	50.2	115	13
312 CZE	hercynica	50.9	115	21
525 GER	hercynica	50.3	115	11
211 GER	polonica	53.8	115	13
252 GER	haguenensis	49.3	115	11
318 BEL	haguenensis	51.2	115	10
235 FRA	haguenensis	48.2	115	10

[a]BELgium, CZEchoslovakia, FINland, FRAnce, GERmany, NORway, SIBeria, SWEden, URAL Mountains.

*, ** Differences between groups of origins are significant at the 5 and 1 percent levels, respectively.

Table 3. Scotch pine tree height and foliage characteristics possibly related to resistance to the European pine sawfly.

MSFG No. and country	Variety	Tree height 1965	Needle Length 1965	Needle Width 1965	Needle Hardness[b] 1965	Needle August color[c] 1961
		Inches	Mm.	Microns	Grade	Grade
		Resistant origins				
546 SWE[a]	lapponica	22	40	1530	5	3
255 SIB	mongolica	27	50	1580	4	6
257 URAL	uralensis	54	58	1600	8	7
258 URAL	uralensis	42	52	1650	1	6
260 URAL	uralensis	42	63	1750	12	8
256 SIB	altaica	31	55	1550	7	7
230 FIN	septentrionalis	21	38	1500	5	3
273 NOR	septentrionalis	33	47	1640	3	3
523 SWE	septentrionalis	36	45	1600	4	5
		Susceptible origins				
207 GER	hercynica	59	67	1480	7	12
210 GER	hercynica	58	70	1500	9	12
308 CZE	hercynica	58	64	1520	4	12
312 CZE	hercynica	55	73	1330	7	12
525 GER	hercynica	57	61	1440	0	12
211 GER	polonica	54	67	1500	5	12
252 GER	haguenensis	56	73	1440	6	12
318 BEL	haguenensis	62	79	1580	8	12
235 FRA	haguenensis	52	56	1490	9	9

[a]BELgium, CZEchoslovakia, FINland, FRAnce, GERmany, NORway, SIBeria, SWEden, URAL Mountains.

[b] 0 = hardest, 20 = softest

[c] 0 = yellowest, 12 = greenest

sawfly. If hardness differences are detectable she probably selects the softer needle.

The hardness of plant tissue may be a cause of resistance (Painter, 1951). This relationship is a mechanical prevention to feeding or egg laying. Painter (1951) further stated that it is during the ovipositing stage that mechanical obstructions are most likely to be a factor of resistance.

Ghent (personal letter, 1965) posed the theory that slight differences of needle hardness between Scotch pine provenances should prove no deterrent to the ovipositing female European pine sawfly. The possibility exists that if a hard, wide needle is encountered by the female sawfly, she may find it relatively awkward to wield the chitinized saw while her legs are in an unnatural over-extended position. Then possibly the combination of a hard, wide needle might prove resistant. Ghent (1960) proposed tree selection for needle width and hardness as an indirect approach to sawfly resistance.

Results of this study indicate that selection for needle hardness is not justifiable for the selection of resistant trees.

Needle width.--Significant between-origin differences were found in needle width. As a group the resistant origins had wider needles than the susceptible origins. The mean widths for the resistant and susceptible origins were 1.60 mm. and 1.48 mm., respectively (Table 3).

There were two susceptible origins with wide needles (MSFG 211 and MSFG 318. Two resistant origins (MSFG 546 and MSFG 230) had narrow needles.

Recent studies (Ghent, 1959 and 1960) have indicated that needles of 2.0 mm. or more in width are virtually immune to the European pine sawfly. The female sawfly encountering a wide needle that is also hard may find it awkward to oviposit. She seeks a soft, narrow needle on which to deposit her eggs. However, if such a needle is not available, oviposition may take place on the hard, wide needle. The result may be fewer eggs per needle and fewer clusters per tree. Thus the resulting damage from the feeding larvae will be less.

Needle color.--There were parallel trends in late summer foliage color and amount of sawfly attack. Resistant origins had yellower foliage than susceptible ones (Table 3). The color was scored on August 10 which slightly precedes the onset of the egg laying period. At that there was a moderately wide range of needle color.

Although color sensitivity of the sawfly is not known, some insects respond positively to a segment of the color spectrum (Painter, 1951). Peak sensitivity seems to be to wavelengths in the ultraviolet and the violet range. While the blue and blue-green portion causes less response, the yellow-yellow-red portion causes even less (Painter, 1951).

Tree height.--Resistant origins of Scotch pine are found in northern latitudes. Their growth is generally slower than in origins from more southerly latitudes. The mean height for the resistant group in 1965 was 34.2 inches and the mean for the susceptible group was 56.8 inches (Table 4, Figures 4 and 5).

Provenances MSFG 229 (var. lapponica) and MSFG 245 (var. mongolica) are resistant to the European pine sawfly, but their growth is extremely slow. They should not be included in a breeding program

Table 4. Relation between sawfly attack and height of Scotch pine varieties in southern Michigan, 1965.

Variety	Country of origin	Trees attacked at Kellogg	Allegan	Rose Lake	Mean	Mean Height
		--- Percent of trees ----				Inches
lapponica	SWE FIN[a]	0	0	0	0	19
mongolica	SIB	0	0	0	0	21
uralensis	URAL	4	1	1	2	43
altaica	SIB	5	2	0	2	32
septentrionalis	FIN SWE NOR	3	3	12	6	32
rigensis	SWE LAT	7	4	38	16	41
armena	GEO TUR	6	6	36	16	39
aquitana	FRA	11	16	38	22	40
scotica	SCO	14	--	25	--	36
iberica	SPA	20	22	46	29	38
rhodopaea	GRE	7	25	29	30	41
illyrica	YUG	25	26	56	36	48
pannonica	HUN	25	17	69	37	50
carpatica	CZE	10	--	--	--	54
borussica	GER	38	19	67	41	53
hercynica	GER CZE	33	22	70	42	53
scotica X ?	ENG	26	--	72	--	56
polonica	POL	28	28	73	43	51
haguenensis	GER FRA BEL	36	27	79	47	63
Average		19	15	45	26	48

[a]BELgium, CZEchoslovakia, ENGland, FINland, FRAnce, GEOrgian SSR, GERmany, GREece, HUNgary, LATvian SSR, NORway, POLand, SCOtland, SIBeria, SPAin, SWEden, TURkey, YUGoslavia, URAL Mountains.

Figure 4a.--*Pinus sylvestris* var. *mongolica* (Yakutskaya, Siberia 60° 45' N. Lat. 131° 40' E. Long.) 6 years from seed, Rose Lake Wildlife Experiment Station, Shiawassee County, Michigan. Trees this small were rarely attacked.

Figure 4b.--*Pinus sylvestris* var. *haguenensis* (Moselle, France 49° 36' N. Lat. 2° 06' E. Long.) 6 years from seed, Rose Lake Wildlife Experiment Station, Shiawassee County, Michigan. This and other seedlots of the same variety were heavily attacked by the sawfly.


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Figure 5. Pinus sylvestris var. hercynica (Bohemia, Czechoslovakia 50° 12' N. Lat. 15° 3' E. Long.). A susceptible provenance defoliated by the European pine sawfly. Photo taken at the Rose Lake Wildlife Experiment Station, Shiawassee County, Michigan. Age: 6 years from seed.


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for a desirable insect-resistant strain. Rudolf stated (1960): "Superior trees should be free, or nearly so, of damage from insects or disease." "Superior" also refers to growth rate and other desirable tree characters. A slow growing variety even though insect resistant is not compatible with the program of selection of a superior variety for the future.

Slow growth was probably responsible for the limited attacks on the most northern origins -- the insects could not find the trees in the weeds. However, it is doubtful whether growth rate was a major factor in resistance among the medium and fast-growing varieties. To test this one need only compare the large differences in susceptibility between the equally fast growing varieties _uralensis_, _regensis_, _armena_, and _rhodopaea_ (Table 4). Variety _uralensis_ and var. _iberica_ are very similar in growth rate, however, only 2 percent of the trees of var. _uralensis_ were attacked while 29 percent of the trees of var. _iberica_ were damaged. Also, there were instances in which a tall tree of var. _uralensis_ was free of damage whereas a nearby smaller tree was heavily eaten. Thus var. _uralensis_ was best in the respect that it alone exhibited unique resistant qualities (Figures 6 and 7).

Other possible resistance factors.--The susceptible origins have longer needles than the resistant ones. The mean for the susceptible group was 68 mm. and the mean for the resistant group was 50 mm. (Table 3).

There were significant differences between the resistant origins and the susceptible ones in their relative amount of sodium, potassium,

Figure 6.--*Pinus sylvestris* var. *uralensis* (Ural Mountains of Russia 56° 51' N. Lat. 61° 23' E. Long.). A resistant provenance planted at the Rose Lake Wildlife Experiment Station, Shiawassee County, Michigan. Age: 6 years from seed.

Figure 7.--Relationship between height and trees attacked for the northern, central, and southern groups of Scotch pine varieties.

<u>Northern varieties</u>

lapponica
mongolica
altaica
septentrionalis
rigensis
uralensis

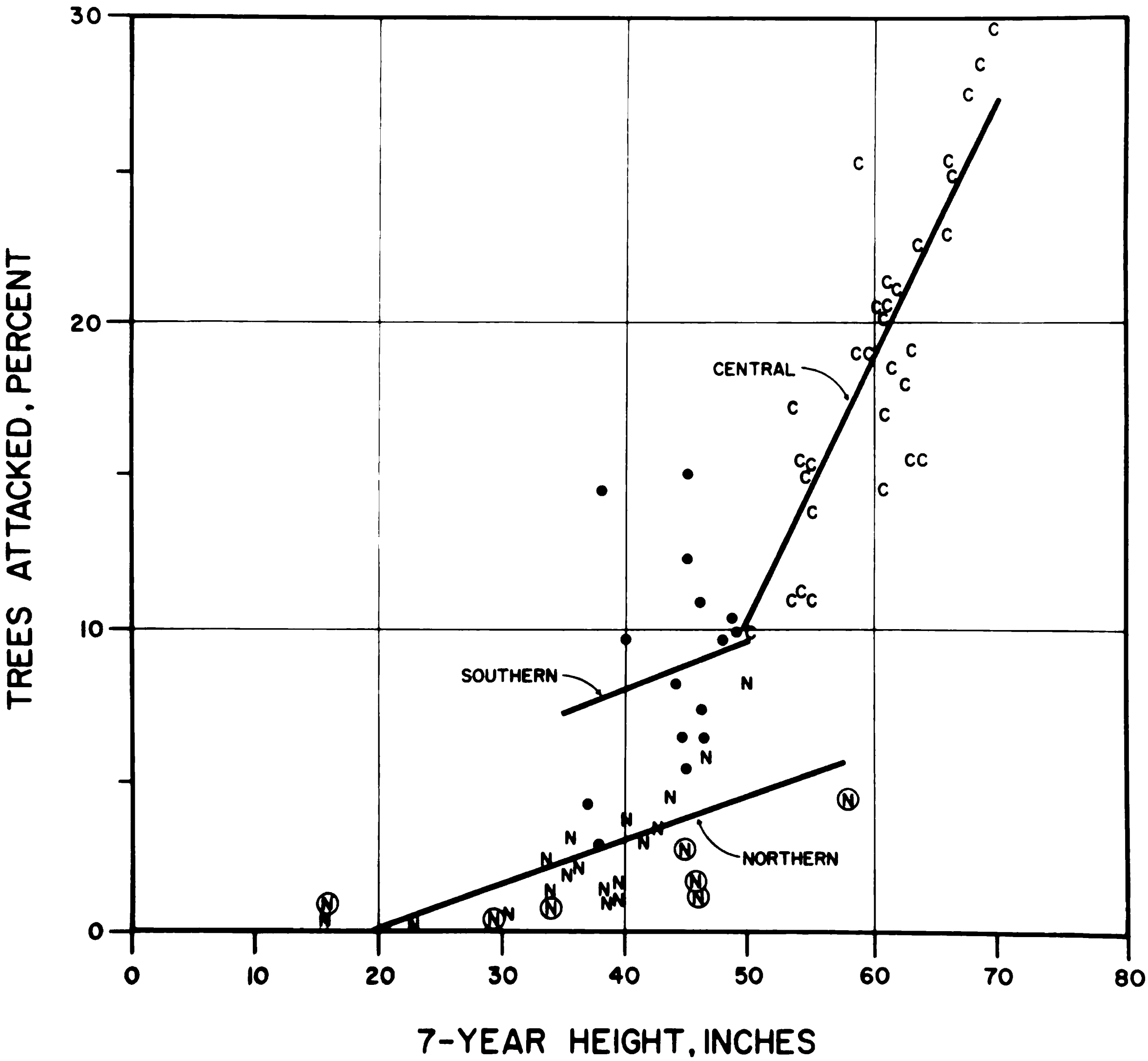
<u>Central varieties</u>

polonica
borussica
hercynica
haguenensis
scotica X ?
pannonica
illyrica

<u>West and South varieties</u>

scotica
iberica
aquitana
rhodopaea
armena

(Siberian and Ural Mountain seedlots circled N's)



TREES ATTACKED, PERCENT
7-YEAR HEIGHT, INCHES
CENTRAL
SOUTHERN
NORTHERN
0
10
20
30
40
50
60
70
80

and magnesium. The susceptible origins had higher amounts of sodium, potassium, and magnesium (Table 5).

Table 5. Scotch pine foliar potassium, sodium, and magnesium as related to attack by the European pine sawfly.

MSFG No. and country	Variety	Potassium**	Sodium*	Magnesium*
		Percent	Ppm	Percent
		Resistant origins		
546 SWE[a]	lapponica	.48	32	.10
255 SIB	mongolica	.46	48	.06
257 URAL	uralensis	.54	29	.07
258 URAL	uralensis	.52	69	.08
260 URAL	uralensis	.48	32	.07
256 SIB	altaica	.52	56	.07
273 NOR	septentrionalis	.52	52	.07
523 SWE	septentrionalis	.52	56	.07
		Susceptible origins		
207 GER	hercynica	.56	60	.08
210 GER	hercynica	.50	134	.08
308 CZE	hercynica	.56	64	.10
525 GER	hercynica	.56	48	.09
211 GER	polonica	.52	79	.13
252 GER	haguenensis	.58	60	.10
318 BEL	haguenensis	.56	56	.09
235 FRA	haguenensis	.58	93	.07

[a]BELgium, CZEchoslovakia, FRAnce, GERmany, NORway, SIBeria, SWEden, URAL Mountains

*, ** Differences between resistant and susceptible groups are significant at the 5 and 1 percent levels, respectively.

DISCUSSION

The resistant factors determined in this screening procedure are related to the adult sawfly. The adult sawfly flies to new areas and selects the individual trees in which to deposit her eggs. The odor, or other characters of a tree which attract the adults for oviposition, does not always correspond with the suitability of the attractive plant for larval food or survival.

A tree may possess a component of resistance called antibiosis, and may affect the biology of the insect (Painter, 1958). Lyons (1964) stated that although no one host species is consistently preferred by the female European pine sawfly, Scotch pine is more suitable for the development and survival of the larvae. Insect development on varieties of Scotch pine was determined by Wilson (Personal communication, 1966). L. F. Wilson compared European pine sawfly larvae on a resistant origin var. *uralensis* with a susceptible origin var. *haguenensis*. All larvae found on the resistant varieties were one feeding instar behind those larvae found on the resistant varieties.

The response of insects to chemical attractions and repellents in plants generally is thought to constitute a major factor in resistance to insect attack. Insects apparently orient to the odorous substance (Smith, 1960). This is apparent in the hybrids ponderosa X Jeffrey pine and Jeffrey X Coulter pine. Each produces resins which are toxic to the western pine beetle (*Dendroctonous brevicomis* Le Conte) but are non-toxic to the mountain pine beetle (*D. monticolae* Hopkins).

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Future tests are needed.--Future experimentation is needed to learn more about the factors causing resistance. A future test relating potassium content to insect attack can be conducted by adding potassium to resistant trees. The addition of potassium would raise content of potassium in resistant trees to the level of the susceptible ones. During the following years if there are differences in the relative amount of attack between the fertilized and the control trees (of the same origin) then the foliar potassium level is a contributor to sawfly resistance. Similarly the addition of other chemicals and their effect upon the European pine sawfly can be tested.

If an occasional single resistant tree of a heavily attacked origin is found, the needles from that tree can be compared to needles from the three other trees of the same plot and also to needles from other trees of the same origin. If the needles of the resistant tree are significantly wider than all other needles, needle width may be suggestive as being a resistant character.

Shading prevents the needle color change from green to yellow. If var. uralensis is shaded and there are differences in the amount of attack then yellow foliage can be considered a resistant factor.

Tree height can be held constant by controlling or limiting the height of the taller trees. The faster growing trees can be pruned to the height of the slower growing trees. An alternate method of controlling height is planting the faster growing trees one or two years after the slower growing ones were planted.

Future breeding program.--The future breeding program is the transfer of one character (resistance) from one parent and several

characters (growth and form) from another parent into the genetic component of the progeny. The F_1's (progeny from the original cross) are back-crossed to the recurrent parent (the parent contributing several characters). The F_2's are likewise back-crossed and the program continues until a desirable sibling is attained.

SUMMARY

Scotch pine varieties lapponica (Norway, Sweden, and northwest Russia) and mongolica (Siberia) were not attacked by the European pine sawfly. Varieties uralensis (Ural Mountains of Russia) and altaica (Altai Mountains of Mongolian Republic) are also resistant. Of these four resistant varieties, uralensis is the most rapid growing and has the best form. Incidence of sawfly attack was greatest on variety haguenensis (Germany, east France, and Belgium).

The combination of needle width, needle hardness, foliage color, number of mature needles, and post-Pleistocene evolution all interacting are correlated with sawfly resistance. The factors that show possible resistance are short, mature, hard, wide, yellow-green needles. Conversely, those factors possibly related to susceptibility are long, immature, soft, narrow, blue-green needles. Susceptible origins contained higher concentrations of foliar sodium, potassium, and magnesium.

One inescapable silvicultural requirement is the need to develop resistant trees that are also well adapted to the climate and the soil of potential planting sites. A second highly desirable objective is the development of resistant trees that are also superior in growth and in timber quality (Austin, 1927; Rudolf, 1956; Meager, 1957). The resistant varieties themselves cannot be called "superior trees." There is much regular breeding work remaining; crossing resistant X rapid growing varieties. Perhaps, the result then approaches the superior tree classification, a desirable, fast growing, and insect-resistant tree.

Future work includes the evaluation of the female sawfly preference and deterrent factors. Also included in this study should be the determination of the oleoresin content of the foliage. Are certain origins resistant only because there is an assortment of origins in all test plantations? That question is readily answered by caging female sawflies and determining their egg laying response. Planting the resistant origins in solid blocks is an alternate experiment. The latter method, even though time and land consuming, is desirable before recommendations and the release of planting stock are made.

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APPENDIX

Appendix 1. Scotch pine foliar concentrations of nitrogen, potassium, phosphorus, calcium, magnesium, and sodium sampled at Russ plantation.

MSFG No. and Country	Variety	N	K	P	Ca	Mg	Na
		- - - - - -		Percent	- - - - -		Ppm
546 SWE[a]	lapponica	2.20	.48	.235	.41	.10	32
255 SIB	mongolica	2.10	.46	.245	.41	.06	48
257 URAL	uralensis	1.92	.54	.210	.41	.07	29
258 URAL	uralensis	1.88	.52	.210	.32	.08	69
260 URAL	uralensis	2.04	.48	.227	.41	.07	32
256 SIB	altaica	1.96	.52	.218	.32	.08	29
273 NOR	septentrionalis	2.22	.52	.245	.32	.07	52
523 SWE	septentrionalis	2.02	.52	.235	.41	.07	56
207 GER	hercynica	1.98	.56	.193	.41	.08	60
210 GER	hercynica	1.98	.50	.235	.43	.08	134
308 GER	hercynica	1.96	.56	.227	.30	.10	64
525 GER	hercynica	1.96	.56	.227	.27	.09	48
211 GER	polonica	1.84	.52	.193	.46	.13	79
252 GER	haguenensis	1.93	.58	.218	.35	.10	60
318 BEL	haguenensis	2.06	.56	.235	.30	.09	56
235 FRA	haguenensis	1.92	.58	.227	.43	.07	93

[a]BELgium, FINland, FRAnce, GERmany, NORway, SIBeria, SWEden, URAL Mountains.

Appendix 2. Scotch pine foliar concentrations of manganese, iron, copper, boron, zinc, aluminum, and molybdenum, samples taken at Russ plantation.

MSFG No. and Country	Variety	Mn	Fe	Cu	B	Zn	Al	Mo
					ppm			
546 SWE[a]	lapponica	1050	98	12.0	33	57	1030	1.8
255 SIB	mongolica	1200	102	7.6	31	67	1230	1.9
257 URAL	uralensis	1020	85	11.0	31	71	960	1.9
258 URAL	uralensis	840	82	9.3	29	50	1200	1.4
260 URAL	uralensis	1200	98	7.6	30	60	1320	1.8
256 SIB	altaica	1030	121	10.2	34	64	1070	1.4
273 NOR	septentrionalis	1200	124	9.3	38	44	980	1.4
523 SWE	septentrionalis	1180	121	10.2	39	54	1210	1.9
207 GER	hercynica	680	111	9.3	39	83	730	2.1
210 GER	hercynica	780	82	8.4	39	60	940	2.2
308 CZE	hercynica	1100	118	8.4	40	44	1090	1.3
525 GER	hercynica	1070	98	7.6	29	44	1050	1.2
211 GER	polonica	300	66	8.4	23	75	1300	2.2
252 GER	haguenensis	1080	91	9.3	41	64	1130	1.6
318 BEL	haguenensis	1160	111	9.3	35	47	1070	1.3
235 FRA	haguenensis	700	91	8.4	33	64	1010	2.1

[a]BELgium, CZEchoslovakia, GERmany, NORway, SIBeria, SWEden, URAL Mountains.

Appendix 3. Number of Scotch pine trees attacked by the European pine sawfly in 1963 and 1964.

MSFG No. and Variety	Kellogg 1963	Kellogg 1964	Russ 1963	Russ 1964	Allegan 1963	Allegan 1964	Rose Lake 1963	Rose Lake 1964	Sum
	Number								
lapponica									
229	0	0	0	0	0	0	-	-	0
546	0	2	0	0	0	0	0	0	2
547	0	0	0	0	-	-	-	-	0
548	0	0	0	0	-	-	-	-	0
549	0	0	0	0	-	-	-	-	0
Total	0	2	0	0	0	0	0	0	2
mongolica									
254	0	0	1	2	0	0	0	0	3
255	0	0	0	0	0	0	2	0	2
Total	0	0	1	2	0	0	2	0	5
uralensis									
257	0	2	0	0	0	0	1	2	5
258	0	0	0	0	0	0	2	0	2
259	0	1	0	1	1	0	2	0	5
260	0	3	1	0	-	-	1	0	5
Total	0	6	1	1	1	0	6	2	17
altaica									
227	0	2	0	0	0	0	-	-	2
234	0	1	0	1	-	-	-	-	2
256	1	1	0	0	0	0	1	0	3
Total	1	4	0	1	0	0	1	0	7
septentrionalis									
228	0	0	0	0	-	-	-	-	0
230	0	2	0	0	0	0	0	0	2
232	0	2	0	1	-	-	-	-	2
233	0	1	0	0	-	-	-	-	1
222	0	1	0	0	0	0	0	0	1
521	0	1	0	1	0	0	1	1	4
522	0	1	1	0	1	0	0	0	3
523	0	1	0	0	0	0	2	1	4
524	0	0	0	0	0	0	6	0	6
543	0	1	0	0	0	0	0	0	1
544	0	1	0	0	0	0	0	0	1
545	0	0	0	0	0	0	0	0	0
273	1	0	0	0	0	0	4	0	4
274	0	0	2	0	0	0	1	1	4
201	0	0	1	0	0	0	1	1	3
Total	1	11	4	2	1	1	15	4	39

Appendix 3. (continued) Number of Scotch pine trees attacked by the European pine sawfly in 1963 and 1964.

MSFG No. and variety	Kellogg 1963	Kellogg 1964	Russ 1963	Russ 1964	Allegan 1963	Allegan 1964	Rose Lake 1963	Rose Lake 1964	Sum
	- - - -	- - - -	- - - -	- - - -	Number	- - - -	- - - -	- - - -	- - - -
rigensis									
542	-	6	-	-	-	-	1	-	7
541	0	3	1	0	0	0	3	4	11
550	1	3	0	0	1	0	-	-	5
223	0	2	0	0	0	0	2	2	6
224	1	2	0	0	0	0	0	1	4
Total	2	16	1	0	1	0	6	7	33
armena									
213	0	3	0	0	1	0	5	2	11
214	0	0	0	0	-	-	-	-	0
220	0	3	0	0	1	0	2	2	8
221	0	3	0	0	0	0	2	2	7
261	0	1	1	0	-	-	1	1	4
262	0	2	0	1	-	-	-	-	3
263	0	0	0	0	-	-	-	-	0
264	0	0	0	0	-	-	-	-	0
Total	0	12	1	1	2	0	10	7	33
aquitana									
212	1	4	0	0	-	-	-	-	5
238	2	0	0	0	2	1	1	0	6
239	0	3	2	0	3	0	7	4	19
240	0	0	0	0	-	-	-	-	0
249	-	-	-	-	0	0	4	2	6
316	0	0	0	0	-	-	-	-	0
320	3	2	1	0	-	-	11	4	21
Total	6	9	3	0	5	1	23	10	57
scotica									
265	0	3	-	-	-	-	-	-	3
266	0	3	0	0	-	-	-	-	3
267	0	2	0	0	-	-	1	0	3
268	1	4	0	2	-	-	-	-	7
Total	1	12	0	2	-	-	1	0	16
iberica									
218	0	7	0	2	0	0	11	4	24
219	0	7	2	2	0	0	3	1	15
245	0	1	0	0	2	1	1	1	6
246	1	1	0	0	2	0	2	2	8
247	1	4	0	0	0	2	1	1	9
Total	2	20	2	4	4	3	18	9	62

Appendix 3. (continued) Number of Scotch pine trees attacked by the European pine sawfly in 1963 and 1964.

MSFG No. and variety	Kellogg 1963	Kellogg 1964	Russ 1963	Russ 1964	Allegan 1963	Allegan 1964	Rose Lake 1963	Rose Lake 1964	Sum
	Number								
rhodapaea									
243	1	1	1	0	1	0	1	1	6
244	0	0	0	1	0	1	6	6	14
271	0	4	0	1	3	4	-	-	12
272	0	2	0	1	-	-	2	2	7
551	0	6	0	0	0	0	-	-	6
Total	1	13	1	3	4	5	9	9	45
illyrica									
242	1	6	0	2	2	4	11	6	32
pannonica									
552	3	2	1	2	-	-	9	4	21
553	0	8	1	5	1	2	15	8	40
Total	3	10	2	7	1	2	24	12	61
carpatica									
314	0	1	-	-	-	-	-	-	1
borussica									
202	0	6	3	1	1	1	6	6	24
210	0	9	0	2	3	2	14	17	47
Total	0	15	3	3	4	3	20	23	71
hercynica									
203	1	4	0	2	1	0	0	2	10
204	0	5	0	1	1	1	-	-	8
207	1	7	0	4	3	0	9	12	36
208	1	4	0	1	2	1	9	6	24
248	-	-	-	-	-	-	13	11	24
525	1	6	1	2	3	0	13	11	37
526	2	8	0	0	-	-	-	-	10
527	0	6	0	1	2	0	11	5	25
528	2	6	0	0	1	0	-	-	9
529	5	12	1	1	-	-	-	-	19
305	1	9	0	0	2	1	11	18	42
306	1	6	3	1	5	0	9	9	34
307	2	9	0	4	1	3	-	-	19
308	2	5	1	4	1	2	8	6	29
309	0	6	0	2	1	0	7	4	20
310	4	7	0	2	1	1	13	13	41
311	0	6	0	2	1	0	10	14	33

Appendix 3. (continued) Number of Scotch pine trees attacked by the European pine sawfly in 1963 and 1964.

MSFG No. and variety	Kellogg 1963	Kellogg 1964	Russ 1963	Russ 1964	Allegan 1963	Allegan 1964	Rose Lake 1963	Rose Lake 1964	Sum
	Number								
hercynica (con't)									
312	1	8	2	2	3	0	12	13	41
313	0	1	-	-	-	-	-	-	1
315	1	9	-	-	-	-	-	-	10
319	-	-	2	3	2	0	9	13	29
Total	25	124	10	32	30	9	134	137	501
scotica X ?									
269	2	13	0	2	-	-	17	15	49
270	1	9	1	3	-	-	-	-	14
Total	3	22	1	5	-	-	17	15	63
polonica									
211	0	8	0	5	1	1	9	10	34
317	1	2	0	1	0	1	10	6	21
Total	1	10	0	6	1	2	19	16	55
haguenensis									
206	1	5	1	1	0	2	10	3	23
250	2	8	4	2	-	-	16	17	49
251	2	12	0	7	0	0	15	19	55
252	2	3	2	8	1	3	8	12	49
253	4	8	2	3	2	2	14	14	49
235	1	5	2	0	1	1	9	6	25
236	0	8	0	2	0	2	-	-	12
237	1	13	8	8	-	-	-	-	30
241	2	10	1	5	0	1	17	15	51
318	0	11	0	0	0	2	24	19	56
530	2	13	3	3	3	0	18	21	63
Total	17	96	23	39	7	13	131	126	452
no described variety									
554	3	3	1	2	-	-	6	2	17
555	0	2	3	0	-	-	-	-	5
556	2	1	2	0	-	-	7	7	19
557	0	2	1	0	-	-	7	3	13
225	0	5	0	2	1	0	7	12	27
205	1	4	-	-	-	-	-	-	5
209	0	6	0	1	-	-	-	-	7
Total	6	23	7	5	1	0	27	24	93

Appendix 4. Number of Scotch pine trees attacked by the European pine sawfly and the amount of attack per tree, June 1965.

MSFG No. and variety	Trees attacked				Attack per tree		
	Kellogg	Allegan	Rose Lake	Sum	Kellogg	Allegan	Rose Lake
	---- Number ----				-- Colonies --		Percent
lapponica							
229	0	-	-	0	0	-	-
546	0	0	0	0	0	0	0
547	0	-	-	0	0	-	-
548	0	-	-	0	0	-	-
549	2	-	-	2	6	-	-
Total	2	0	0	2	6	0	0
mongolica							
254	0	0	0	0	0	0	0
255	0	0	0	0	0	0	0
Total	0	0	0	0	0	0	0
uralensis							
257	4	-	7	11	4	-	15
258	0	1	2	3	0	1	20
259	0	0	3	3	0	0	24
260	1	-	5	6	2	-	25
Total	5	1	17	23	6	1	84
altaica							
227	0	0	-	0	0	0	-
234	2	-	-	2	4	-	-
256	1	1	0	2	2	1	0
Total	3	1	0	4	6	1	0
septentrionalis							
228	0	-	-	0	0	-	-
230	0	0	2	2	0	0	5
232	0	0	0	0	0	-	-
233	1	-	-	1	1	-	-
222	1	0	3	4	1	0	115
521	6	2	7	15	14	7	97
522	0	1	1	2	5	5	78
523	1	1	2	4	1	1	21
524	1	0	6	7	2	0	52
543	1	1	8	10	1	1	124
544	1	0	5	6	2	0	51
545	1	1	1	3	1	1	114
273	0	2	3	5	0	7	5
274	1	0	5	6	1	0	39
201	0	5	5	10	0	8	92
Total	14	13	48	85	33	30	793

Appendix 4. (continued) Number of Scotch pine trees attacked by the European pine sawfly and the amount of attack per tree, June 1965.

MSFG No. and variety	Trees attacked				Attack per tree		
	Kellogg	Allegan	Rose Lake	Sum	Kellogg	Allegan	Rose Lake
	- - - - Number - - - -				- - Colonies - -		Per-cent
rigensis							
542	1	3	9	13	4	8	91
541	5	1	17	23	16	2	122
550	7	3	-	10	15	6	-
223	2	2	14	18	3	8	218
224	1	0	9	10	1	0	76
Total	16	9	49	74	39	24	507
armena							
213	3	2	18	23	6	4	78
214	2	-	-	2	6	-	-
220	4	4	9	17	9	13	92
221	8	1	14	23	15	3	112
261	1	-	4	5	1	-	70
262	5	-	-	5	7	-	-
263	9	-	-	9	18	-	-
264	6	-	-	6	12	-	-
Total	38	7	45	90	74	20	352
aquitana							
212	5	-	-	5	11	-	-
238	5	7	11	23	18	22	98
239	2	6	13	21	5	18	104
240	4	-	-	4	2	-	-
249	-	-	7	7	-	-	70
316	5	-	-	5	12	-	-
320	3	-	11	14	11	-	93
Total	24	13	42	79	59	40	365
scotica							
265	6	-	-	6	20	-	-
266	1	-	-	1	8	-	-
267	7	-	10	17	10	-	159
268	4	-	-	4	5	-	-
Total	18	-	10	28	43	-	159
iberica							
218	6	12	20	38	21	29	194
219	7	7	11	25	13	11	57
245	7	12	25	44	21	35	106
246	3	0	8	11	5	0	121
247	9	12	9	30	20	17	68
Total	32	43	73	148	80	92	546

Appendix 4. (continued) Number of Scotch pine trees attacked by the European pine sawfly and the amount of attack per tree, June 1965.

MSFG No. and variety	Trees attacked Kellogg	Allegan	Rose Lake	Sum	Attack per tree Kellogg	Allegan	Rose Lake
	- - - - Number - - - -				- - Colonies - -		Percent
rhodopaea							
243	2	8	9	19	4	24	44
244	7	8	13	28	18	21	106
271	3	4	-	7	5	10	-
272	2	-	19	21	4	-	95
551	9	-	-	9	12	-	-
Total	23	20	41	84	43	55	245
illyrica							
242	12	9	17	38	25	24	134
pannonica							
552	7	-	20	27	40	-	140
553	8	7	22	37	32	15	108
Total	15	7	42	64	72	15	248
carpatica							
314	3	-	-	3	8	-	-
borussica							
202	5	4	18	27	20	12	89
210	19	11	25	55	53	24	279
Total	24	15	43	82	73	36	368
hercynica							
203	6	7	19	32	18	20	115
204	7	8	-	15	25	20	-
207	14	14	27	55	31	43	247
208	8	13	22	43	23	34	129
248	-	-	18	18	-	-	176
525	4	13	23	40	10	28	234
526	10	-	-	10	24	-	-
527	14	3	20	37	36	8	105
528	13	13	-	26	41	33	-
529	13	-	-	13	39	-	-
305	13	7	23	43	31	14	196
306	13	8	22	43	24	10	90
307	7	11	-	18	29	39	-
308	9	8	23	40	29	18	223
309	11	6	26	43	28	11	192
310	11	4	16	31	47	8	123
311	8	16	25	49	37	33	281

Appendix 4. (continued) Number of Scotch pine trees attacked by the European pine sawfly and the amount of attack per tree, June 1965.

MSFG No. and variety	Trees attacked Kellogg	Trees attacked Allegan	Trees attacked Rose Lake	Sum	Attack per tree Kellogg	Attack per tree Allegan	Attack per tree Rose Lake
	Number				Colonies		Per-cent
312	12	8	22	42	27	21	227
313	7	-	-	7	15	-	-
315	15	-	-	15	53	-	-
319	-	7	23	30	-	10	154
Total	195	146	309	650	567	350	2392
scotica X ?							
269	12	-	29	41	62	-	260
270	7	-	-	7	25	-	-
Total	19	-	29	48	87	-	260
polonica							
211	10	14	25	49	31	32	246
317	8	8	22	38	22	22	123
Total	18	22	47	87	53	54	369
haguenensis							
206	6	14	19	39	14	38	106
250	10	-	27	37	29	-	242
251	19	11	26	56	42	25	163
252	8	14	25	47	11	58	256
253	12	11	23	46	27	32	204
235	4	12	19	35	9	27	217
236	18	-	-	18	88	-	-
237	10	-	-	10	31	-	-
241	14	8	29	51	40	21	193
318	17	12	30	59	44	28	226
530	17	12	29	58	50	30	162
Total	135	94	227	456	385	259	1769
no described variety							
554	4	-	9	13	9	-	69
555	4	-	-	4	9	-	-
556	6	-	17	23	23	-	62
557	6	-	12	18	17	-	38
225	4	7	25	36	26	16	200
205	4	-	-	4	11	-	-
209	9	-	-	9	28	-	-
Total	37	7	63	107	123	16	189

Appendix 5. Trees with European pine sawfly damage.

Analysis of variance -- plantation 2-61

ecotype	source	df	SSQ	MSQ	F statistic
A	variety				
	replicate				
	error				
	total				

ecotype	source	df	SSQ	MSQ	F statistic
B	variety				
	replicate				
	error				
	total				

ecotype	source	df	SSQ	MSQ	F statistic
C	variety	11	3.62	.329	1.87
	replicate	7	1.82	.260	1.45
	error	77	13.80	.179	
	total	95	19.24		

ecotype	source	df	SSQ	MSQ	F statistic
D	variety	3	1.34	.447	2.76
	replicate	7	1.72	.246	1.52
	error	21	3.41	.162	
	total	31	6.47		

ecotype	source	df	SSQ	MSQ	F statistic
E	variety	3	.12	.04	.13
	replicate	7	.22	.03	.10
	error	21	.63	.30	
	total	31	.97		

ecotype	source	df	SSQ	MSQ	F statistic
F	variety	1	.25	.25	.47
	replicate	7	19.75	2.82	5.32*
	error	7	3.75	.53	
	total	15	23.75		

Appendix 5. (continued) **Trees with European pine sawfly damage.**

Analysis of variance -- plantation 2-61

ecotype	source	df	SSQ	MSQ	F statistic
G	variety	13	27.44	2.11	1.51
	replicate	7	15.56	2.22	1.58
	error	91	127.06	1.40	
	total	111	170.06		

ecotype	source	df	SSQ	MSQ	F statistic
H	variety	8	29.26	3.66	2.00
	replicate	7	7.21	1.03	.56
	error	56	102.41	1.83	
	total	71	137.88		

ecotype	source	df	SSQ	MSQ	F statistic
J	variety	1	4.00	4.00	5.49
	replicate	7	1.00	.14	.19
	error	7	5.00	.71	
	total	15	10.00		

ecotype	source	df	SSQ	MSQ	F statistic
K	variety	4	3.35	.84	1.02
	replicate	7	5.20	.74	.90
	error	28	23.05	.82	
	total	39	31.60		

ecotype	source	df	SSQ	MSQ	F statistic
M	variety	1	.56	.56	.65
	replicate	7	3.44	.49	.58
	error	7	5.94	.85	
	total	15	9.94		

ecotype	source	df	SSQ	MSQ	F statistic
N	variety	4	3.40	.85	.95
	replicate	7	8.00	1.14	1.28
	error	28	25.00	.89	
	total	39	36.40		

Appendix 5. (continued) Trees with European pine sawfly damage.

Analysis of variance -- plantation 11-61

ecotype	source	df	SSQ	MSQ	F statistic
A	variety				
	replicate				
	error				
	total				

ecotype	source	df	SSQ	MSQ	F statistic
B	variety				
	replicate				
	error				
	total				

ecotype	source	df	SSQ	MSQ	F statistic
C	variety	11	2.29	.21	1.48
	replicate	9	1.17	.13	.09
	error	99	14.13	.14	
	total	119	17.59		

ecotype	source	df	SSQ	MSQ	F statistic
D	variety	3	.50	.17	1.00
	replicate	9	2.10	.23	1.39
	error	27	4.50	.17	
	total	39	7.10		

ecotype	source	df	SSQ	MSQ	F statistic
E	variety	3	.10	.03	1.00
	replicate	9	.90	.10	3.03*
	error	27	.90	.03	
	total	39	1.90		

ecotype	source	df	SSQ	MSQ	F statistic
F	variety	1	1.80	1.80	1.97
	replicate	9	5.80	.64	.70
	error	9	8.20	.91	
	total	19	15.80		

Appendix 5. (continued) Trees with European pine sawfly damage.

Analysis of variance -- plantation 11-61

ecotype	source	df	SSQ	MSQ	F statistic
G	variety	13	23.22	1.79	2.63**
	replicate	9	9.99	1.11	1.63
	error	117	80.21	.68	
	total	139	113.42		

ecotype	source	df	SSQ	MSQ	F statistic
H	variety	8	6.00	.75	.73
	replicate	9	8.93	.99	.96
	error	72	74.67	1.03	
	total	89	89.60		

ecotype	source	df	SSQ	MSQ	F statistic
J	variety	1	.45	.45	1.97
	replicate	9	8.45	.94	4.12*
	error	9	2.05	.23	
	total	19	10.95		

ecotype	source	df	SSQ	MSQ	F statistic
K	variety	4	2.92	.73	1.46
	replicate	9	3.62	.40	.80
	error	36	17.88	.50	
	total	49	24.42		

ecotype	source	df	SSQ	MSQ	F statistic
M	variety	1	.05	.05	.04
	replicate	9	8.05	.89	.77
	error	9	10.45	1.16	
	total	19	18.55		

ecotype	source	df	SSQ	MSQ	F statistic
N	variety	4	11.03	2.78	3.35*
	replicate	9	10.82	1.20	1.44
	error	36	30.17	.83	
	total	49	52.02		

Appendix 5. (continued) Trees with European pine sawfly damage.

Analysis of variance -- plantation 12-61

ecotype	source	df	SSQ	MSQ	F statistic
A	variety				
	replicate				
	error				
	total				

ecotype	source	df	SSQ	MSQ	F statistic
B	variety				
	replicate				
	error				
	total				

ecotype	source	df	SSQ	MSQ	F statistic
C	variety	11	11.50	1.04	2.26*
	replicate	7	9.00	1.28	2.78*
	error	77	35.50	.46	
	total	95	56.00		

ecotype	source	df	SSQ	MSQ	F statistic
D	variety	3	5.84	1.95	1.19
	replicate	7	7.72	1.10	.67
	error	21	34.41	1.64	
	total	31	47.97		

ecotype	source	df	SSQ	MSQ	F statistic
E	variety	3	.68	.23	2.29
	replicate	7	1.63	.23	2.35
	error	21	2.07	.09	
	total	31	4.38		

ecotype	source	df	SSQ	MSQ	F statistic
F	variety	1	.56	.56	.30
	replicate	7	5.44	.78	.42
	error	7	12.94	1.85	
	total	15	18.94		

Appendix 5. (continued) Trees with European pine sawfly damage.

Analysis of variance -- plantation 12-61

ecotype	source	df	SSQ	MSQ	F statistic
G	variety	13	15.79	1.21	1.34
	replicate	7	47.49	6.78	7.53**
	error	91	82.14	.90	
	total	111	145.42		

ecotype	source	df	SSQ	MSQ	F statistic
H	variety	8	13.52	1.69	2.58*
	replicate	7	31.78	4.54	6.93**
	error	56	36.70	.65	
	total	71	82.00		

ecotype	source	df	SSQ	MSQ	F statistic
J	variety	1	.25	.25	.36
	replicate	7	18.00	2.57	3.63
	error	7	4.75	.69	
	total	15	23.00		

ecotype	source	df	SSQ	MSQ	F statistic
K	variety	4	7.15	1.79	1.57
	replicate	7	14.98	2.14	1.89
	error	28	31.65	1.13	
	total	39	53.78		

ecotype	source	df	SSQ	MSQ	F statistic
M	variety	1	.25	.25	.15
	replicate	7	14.00	2.00	1.19
	error	7	11.75	1.68	
	total	15	26.00		

ecotype	source	df	SSQ	MSQ	F statistic
N	variety	4	28.15	7.04	9.14**
	replicate	7	20.18	2.88	3.74**
	error	28	21.45	.77	
	total	39	69.78		

Appendix 6. Branches defoliated by the European pine sawfly.

Analysis of variance -- plantation 2-61

ecotype	source	df	SSQ	MSQ	F statistic
A	variety				
	replicate				
	error				
	total				

ecotype	source	df	SSQ	MSQ	F statistic
B	variety				
	replicate				
	error				
	total				

ecotype	source	df	SSQ	MSQ	F statistic
C	variety	11	21.08	1.92	1.38
	replicate	7	26.50	3.78	2.72*
	error	77	107.25	1.39	
	total	95	154.83		

ecotype	source	df	SSQ	MSQ	F statistic
D	variety	3	17.25	5.75	2.70
	replicate	7	22.00	3.14	1.47
	error	21	44.75	2.13	
	total	31	84.00		

ecotype	source	df	SSQ	MSQ	F statistic
E	variety	3	.38	.13	1.02
	replicate	7	.88	.13	1.02
	error	21	2.62	.12	
	total	31	3.88		

ecotype	source	df	SSQ	MSQ	F statistic
F	variety	1	5.60	5.60	.91
	replicate	7	238.94	34.13	5.57**
	error	7	42.90	6.13	
	total	15	287.44		

Appendix 6. (continued) Branches defoliated by the European pine sawfly.

Analysis of variance -- plantation 2-61

ecotype	source	df	SSQ	MSQ	F statistic
G	variety	13	205.68	15.82	.90
	replicate	7	375.54	53.65	3.05**
	error	91	1600.46	17.59	
	total	111	2181.68		

ecotype	source	df	SSQ	MSQ	F statistic
H	variety	8	182.76	22.84	1.22
	replicate	7	259.27	37.04	1.99
	error	56	1037.91	18.53	
	total	71	1479.94		

ecotype	source	df	SSQ	MSQ	F statistic
J	variety	1	16.00	16.00	5.59*
	replicate	7	25.75	3.68	1.29
	error	7	20.00	2.86	
	total	15	61.75		

ecotype	source	df	SSQ	MSQ	F statistic
K	variety	4	17.65	4.41	.96
	replicate	7	18.80	2.69	.61
	error	28	123.95	4.43	
	total	39	160.40		

ecotype	source	df	SSQ	MSQ	F statistic
M	variety	1	10.44	10.44	.50
	replicate	7	124.44	17.78	.85
	error	7	147.06	21.01	
	total	15	281.94		

ecotype	source	df	SSQ	MSQ	F statistic
N	variety	4	24.50	6.15	.83
	replicate	7	45.20	6.46	.87
	error	28	206.30	7.37	
	total	39	276.00		

Appendix 6. (continued) Branches defoliated by the European pine sawfly.

Analysis of variance -- plantation 11-61

ecotype	source	df	SSQ	MSQ	F statistic
A	variety				
	replicate				
	error				
	total				

ecotype	source	df	SSQ	MSQ	F statistic
B	variety				
	replicate				
	error				
	total				

ecotype	source	df	SSQ	MSQ	F statistic
C	variety	11	11.50	1.04	1.18
	replicate	9	9.50	1.05	1.18
	error	99	87.50	.88	
	total	119	108.50		

ecotype	source	df	SSQ	MSQ	F statistic
D	variety	3	5.10	1.70	.76
	replicate	9	20.40	2.27	1.01
	error	27	60.40	2.24	
	total	39	85.90		

ecotype	source	df	SSQ	MSQ	F statistic
E	variety	3	.10	.03	1.00
	replicate	9	.90	.10	3.12*
	error	27	.90	.03	
	total	39	1.90		

ecotype	source	df	SSQ	MSQ	F statistic
F	variety	1	5.00	5.00	.37
	replicate	9	52.20	5.80	.43
	error	9	121.00	13.44	
	total	19	178.20		

Appendix 6. (continued) Branches defoliated by the European pine sawfly.

Analysis of variance -- plantation 11-61

ecotype	source	df	SSQ	MSQ	F statistic
G	variety	13	154.66	11.90	2.24*
	replicate	9	62.57	6.95	1.31
	error	117	621.63	5.31	
	total	139	838.86		

ecotype	source	df	SSQ	MSQ	F statistic
H	variety	8	137.76	17.22	1.85
	replicate	9	84.46	9.38	1.01
	error	72	670.24	9.31	
	total	89	892.46		

ecotype	source	df	SSQ	MSQ	F statistic
J	variety	1	.45	.45	.14
	replicate	9	64.45	7.16	2.22
	error	9	29.05	3.23	
	total	19	92.95		

ecotype	source	df	SSQ	MSQ	F statistic
K	variety	4	36.60	9.15	1.82
	replicate	9	30.90	3.43	.68
	error	36	181.00	5.03	
	total	49	248.50		

ecotype	source	df	SSQ	MSQ	F statistic
M	variety	1	.80	.80	.00
	replicate	9	87.00	9.67	.95
	error	9	90.20	10.02	
	total	19	178.00		

ecotype	source	df	SSQ	MSQ	F statistic
N	variety	4	78.32	19.58	9.28**
	replicate	9	60.32	6.70	3.17**
	error	36	76.09	2.11	
	total	49	214.72		

Appendix 6. (continued) Branches defoliated by the European pine sawfly.

Analysis of variance -- plantation 12-61

ecotype	source	df	SSQ	MSQ	F statistic
A	variety				
	replicate				
	error				
	total				

ecotype	source	df	SSQ	MSQ	F statistic
B	variety				
	replicate				
	error				
	total				

ecotype	source	df	SSQ	MSQ	F statistic
C	variety	11	8453.83	768.53	3.56**
	replicate	7	8188.03	1169.72	5.14**
	error	77	16638.10	216.08	
	total	95	33279.95		

ecotype	source	df	SSQ	MSQ	F statistic
D	variety	3	1775.34	5917.80	16.95**
	replicate	7	2918.97	416.99	1.19
	error	21	7329.91	349.04	
	total	31	12024.22		

ecotype	source	df	SSQ	MSQ	F statistic
E	variety	3	49.20	16.40	.43
	replicate	7	73.10	10.44	.27
	error	21	805.30	38.35	
	total	31	927.60		

ecotype	source	df	SSQ	MSQ	F statistic
F	variety	1	945.00	945.00	1.34
	replicate	7	2346.88	335.27	.47
	error	7	4940.50	705.78	
	total	15	8232.38		

Appendix 6. (continued) Branches defoliated by the European pine sawfly.

Analysis of variance -- plantation 12-61

ecotype	source	df	SSQ	MSQ	F statistic
G	variety	13	7784.23	598.79	2.14*
	replicate	7	13842.97	1977.57	7.08**
	error	91	25427.91	279.42	
	total	111	47055.11		
ecotype	source	df	SSQ	MSQ	F statistic
H	variety	8	2538.69	317.34	1.02
	replicate	7	10157.72	1451.10	4.69**
	error	56	17337.53	309.60	
	total	71	30033.94		
ecotype	source	df	SSQ	MSQ	F statistic
J	variety	1	430.56	430.56	5.04
	replicate	7	3455.90	493.70	5.77*
	error	7	598.48	85.50	
	total	15	4484.94		
ecotype	source	df	SSQ	MSQ	F statistic
K	variety	4	367.44	91.86	.48
	replicate	7	2534.84	360.69	1.88
	error	28	5366.16	191.65	
	total	39	8258.44		
ecotype	source	df	SSQ	MSQ	F statistic
M	variety	1	2.00	2.00	.00
	replicate	7	1380.75	197.25	1.14
	error	7	1215.00	173.57	
	total	15	2597.75		
ecotype	source	df	SSQ	MSQ	F statistic
N	variety	4	1470.35	367.59	1.18
	replicate	7	1958.30	279.76	.90
	error	28	8738.45	312.08	
	total	39	12167.10		

Appendix 7. **Origin of Scotch pine seedlots used in the NC-51 plantations.** The taxonomic varieties follow Ruby's (1964) classification.

Ecotype	Variety	Seedlot	Country
A	lapponica	229	Finland
	mongolica	254	Siberia
B	lapponica	546	Sweden
	"	547	"
	"	548	"
	"	549	"
C	septentrionalis	228	Finland
	"	230	"
	"	232	"
	"	233	"
	"	222	Sweden
	"	521	"
	"	522	"
	"	523	"
	"	524	"
	"	543	"
	"	544	"
	"	545	"
	"	201	Norway
	"	273	"
	"	274	"
	"	275	"
D	rigensis	541	Sweden
	"	542	"
	"	550	"
	"	223	Latvia
	"	222	"

Ecotype	Variety	Seedlot	Country
E	mongolica	255	Siberia
	altaica	227	"
	"	234	"
	"	256	"
	uralensis	257	Ural Mountains
	"	258	"
	"	259	"
	"	260	"
F	polonica	211	Poland
	"	317	"
G	borussica	202	Germany
	"	210	"
	carpatica	314	Czechoslovakia
	hercynica	203	Germany
	"	204	"
	"	207	"
	"	208	"
	"	248	"
	"	525	"
	"	526	"
	"	527	"
	"	528	"
	"	529	"
	"	305	Czechoslovakia
	"	306	"
	"	307	"
	"	308	"
	"	309	"

Ecotype	Variety	Seedlot	Country
G (con't)	hercynica	310	Czechoslovakia
	"	311	"
	"	312	"
	"	313	"
	"	315	"
	"	319	Austria
H_1	haguenensis	206	Germany
	"	250	"
	"	251	"
	"	252	"
	"	253	"
	"	236	France
	"	237	"
	"	241	"
	"	318	Belgium
	"	530	"
H_2	not identified	554	Italy
	"	555	"
	"	556	"
	"	557	"
	pannonica	552	Hungary
	"	553	"
I	scotica X ?	269	England
	"	270	"
J	illyrica	242	Yugoslavia
	not identified	209	Germany
		205	Austria
		235	France
		225	New York

Ecotype	Variety	Seedlot	Country
K	rhodopaea	243	Greece
	"	244	"
	"	271	"
	"	272	"
	"	551	"
	armena	213	Turkey
	"	214	"
	"	220	"
	"	221	"
	"	261	Georgia
	"	262	"
	"	263	"
	"	264	"
L	scotica	265	Scotland
	"	266	"
	"	267	"
	"	268	"
M	aquatina	212	France
	"	238	"
N	iberica	218	Spain
	"	219	"
	"	245	"
	"	246	"
	"	247	"

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