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Introduction

Many authors have investigated and written about dwarf mistletoe and its effect upon the host plant. With the combined knowledge in these articles and books, however, we actually know very little about this parasite and the magnitude of its damage to our forests. It is a pathogen with which we have been acquainted for years, but except for the concern of a few far sighted individuals, there has been little thought for the losses that it causes. Not until the increasing scarcity of timber supplies raised the value of wood products to their present level has financial backing been available for study of this disease.

As foresters our primary concern with dwarf mistletoe is in its effect upon the host. Observers have claimed varying amounts of growth losses but in all cases there have been no sound attempts made to prove or disprove these statements. This growth loss, while only one of several damaging effects of the parasite, should be of the most concern to woodland managers. The wide spread occurance of the disease on larch and Douglas fir in western Montana makes it most important to any plan of management if the venture is to prove profitable.

The study conducted and presented in this paper has measured the losses caused by dwarf mistletoe in individual trees and these measurements may be applied in any stand containing infected larch or Douglas fir if the infected trees are tallied during the cruise according to the infection categories described.

Recommendations are given on how mistletoe stands should be managed. These guides are based on observations made by the author and are not the result of experimental procedure. Their use should continue only until more knowledge becomes available and better methods are worked out.

FIGURE 1
Mistletoe in a cutover stand of Douglas Fir

CHAPTER II

Review of Literature

I. DESCRIPTION

Mistletoes are seed plants of the family *Loranthaceae.* Many generas of this parasite are found throughout the world, although most are found in the tropics. In Europe *Loranthus europaeus* Jacq. grows on oak, and *Viscum album* L., which is more widespread, can be observed on both hardwoods and conifers (Tubeuf 1923).

The *Loranthaceae* are mostly hemiparasitic. There are over twenty genera in the family which include 500 species. Most of these are tropical (Johnson 1931). Two genera are found in the United States. They are *Phoradendron*, sometimes called the "true mistletoes", and *Arceuthobium.* The latter genus was at first named *Razoumofskya* in honor of Alex Razoumofsky, a patron of a botanical garden near Moscow, Russia. Since another plant genus, *Razoumovia*, had already been named after him Von Bieberstein replaced the *Razoumofskya* with *Arceuthobium.* In 1930 the International Botanical Congress retained the one in use today.

Arceuthobium is derived from Greek words meaning "juniper living" because juniper is the most common host of mistletoe in the Mediterranean areas where this genus was first described (Gill and Bedwell 1949). The species of this genus are called dwarf mistletoes and are of far more importance to foresters than the true mistletoes. They are restricted to conifers and limited to the northern hemisphere with the greatest variety being found in North America (Boyce 1938). Junipers and their relatives are immune to these mistletoes (Gill and Bedwell 1949).

The five species of dwarf mistletoes recognized in North America are:

1. *Arceuthobium pusillum* Pk., found mainly on spruce from the Lake States east.
2. *A. americanum* Nutt., whose host is lodgepole and jack pine.
3. *A. douglasii* Engelm., found on Douglas fir.
4. *A. vaginatum* (Willd) Presl., which grows on the three needle pines.
5. *A. campylopodum* Engelm., occuring on pine, spruce, fir, hemlock, and larch from Alaska to Arizona.

In the Santa Catalina range of the Southwestern United States there is a form of *Phoradendron* growing on *Abies concolor.* This is the only known instance of leaf mistletoe growing on a needle plant (Blumer 1910).

Dwarf mistletoe has much smaller aerial branches than its true mistletoe relation and contains far less chlorophyll. Kuijt (1955) reports that cholorphyll has been found in several species but not all of them seem to be the same in this respect. This makes it a far more damaging parasite since it must obtain practically all of its necessities for life and growth from its host.

The aerial portions of the plant seem to be primarily for reproductive purposes and persist only short time (Parke 1951, Gill 1949, Thodday and Johnson 1930). Probably because dwarf mistletoe was smaller and less conspicuous than the true mistletoes, for years it was largely unnoticed. Attention was first called to it in North America in 1871 by Mrs. Lucy Millington (Schrenk 1900). Mrs. Millington found *A. pusillum* Peck growing on black spruce, *Picea mariana*, at Warrensburg, Warren County, New York.

The mistletoe *Arceuthobium* is dioecius and the staminate and pistillate flowers are cies (Kuijt 1955). *A. minutisimum* Hook is found on separate trees (Gill 1954, Wheeler 1901), but sometimes on different branches of the same tree (Jack 1900).

The aerial parts of the plant are perennial according to Boyce (1938), but the life of the shoots seems to differ for the different speannual according to Gorrie (1929), *A. pusil-*

lum is biennial (Jack 1900), and *A. Oxycedrii* (D. C.) Bieb. has aerial shoots that survive several years and produce several crops of flowers (Dowding 1929). Gill (1954) has stated that *A. campylopodum* may have several crops of flowers produced on one shoot while Hedgecock (1917) claimed the aerial parts of this species are annual.

The male flowers are spring flowering with *A. americanum, douglasii,* and *pusillum* and fall flowering with *A. campylopodum* (Kuijt 1955). With *A. oxycedrii* the male flower has shed its perianth by the middle of June, and the buds of the new male flowers are developed in the axils of the scales of the old plant (Dowding 1929). If there is any difference in the flowers between the species, it is in degree not in form. This applies to size, shape, and color (Kuijt 1955). They have only whorl, are usually three partite, occasionally four, rarely two or five, with each segment bearing a single sessil anther and joining below a slight elevation of the receptacle. The color of the floral leaves ranges from greenish to straw color and bright yellow. (Kuijt 1955).

For the female flowers the same uniformity prevails in all species as with the male flowers. It is a small elliptic structure the same color as the shoot to which it is attached. The perianth consists of 2, sometimes 3 lobes which are almost fused with one another and with the pistil, the style of which is slightly longer than the petal segments. The flower is not shed, but the entire arrangement develops into the fruit (Kuijt 1955).

It is believed that insects play the most important role in pollination (Gill 1953). Noticeable changes occur in all of the spring flowering species almost immediately after pollination, but in the fall flowering species there apparently is no development until the following spring (Kuijt 1955). Gill (1935) has found that fruit may develop without fertilization. In all species except *A. pusillum* the fruits mature the second season after pollination. They are about the size of a grain of wheat (Gill and Bedwell 1949). Late August of the year following pollination is about the time of maturity (Gill 1954).

The fruit is a fleshy, ovoid to oblong structure, attached to its shoot by a recurved pedicel. The upper and lower parts are of different color (Kuijt 1955). Each contain a single seed, only rarely two, covered with a mucilaginous pulp and a specialized pericarp (Boyce 1938). At maturity pressure builds up on the pericarp so that it breaks away at the base of the fruit and the seed is shot out through the base (Kuijt 1955). The pedicels curl downward in such a way that the seeds are shot upward (Gill and Bedwell 1949).

The sticky, gelatinous covering of the seed is absent on the end which is forward when expulsion takes place and is thickest on the back end (Peirce 1905). Because of this the seeds usually do not adhere to objects that are struck close to the parent plant. The expulsion of the seed takes place in the fall and when it clings to some object, germination may follow immediately but is usually delayed until spring (Kuijt 1955). Dowding (1929) claims that the seed of *A. americanum* commences germination the same fall but penetration of the bark of the host does not occur until late in June of the following summer. It will germinate anywhere with the proper moisture and temperature (Gill and Bedwell 1949). The seed of *A. campylopodum* f. *campylopodum* Engelm. that remains dormant for 2 months after ripening does not germinate (Gill 1954).

The part of the mistletoe within the tree has been given various names; rhizomes (Schrenk 1900), roots (Heil 1923), and endophytic system (Thoday and Johnson 1930). There are two types of endophytic systems - cortical strands in the tissues outside of the cambium and sinkers imbedded in the rays of the xylem (Kuijt 1955).

After penetration of the bark by the primary haustorium, the cortical haustoria develop, longitudinal extensions being more rapid than growth in other directions. The species *A. pusillum* and *A. douglasii* appear to be able to grow longitudinally only towards the tips of the host branches while the other species grow in both directions (Boyce 1938). Kuijt (1955) adds *A. americanum* to these two as growing towards the tips of the host branches while members of the *campylopodum* group are able to grow in both directions. These different growth habits are believed by Gill (1955) to be caused more by the host species than by inherited characteristics of the parasite.

Buds for the aerial portions of the parasite are formed from local thickening of the larger endophytic strands located nearest to the epidermis of the host (Cohen 1954). These buds erupt through the bark of the host plant. Usually the aerial shoots occur in tufts, but occasionally they are found scattered along the twigs. Boyce (1938) thinks that this variation may be caused by a reaction to the host.

He also states that *A. pusillum* shoots are always scattered but on tamarack the shoots are usually clustered. They have a tendency to scatter with *A. douglasii*, and *A. americanum* on lodgepole pine has both habits but they rarely occur on the same tree.

Buds do not appear on the surface of the host twigs until the mistletoe infection is two years old (Boyce 1938, Gill 1954, Thoday and Johnson 1930). Gill and Bedwell (1949) and Gill (1954) state that there is evidence that many infections can remain invisible or latent so far as surface growth goes much longer than 26 months. A few will not produce their first shoots for 10 years or longer. Whether the endophytic system is dependent upon the aerial parts for any length of time is a question of interest (Kuijt 1955).

II. EFFECTS OF MISTLETOE ON THE HOST

Branches. The initial effect of mistletoe infection is an increase in thickness and succulence of the inner bark and local acceleration of growth of the affected wood (Gill and Bedwell 1949). Mistletoe infected stems are characterized by distinct swellings in all species with the exception of Douglas fir when infected with *A. douglasii* (Parke 1951). According to Cohen (1954) this hypertrophy results because xylem is produced at a greater rate in areas where the mistletoe tissue is present. He also states that there are apparently adjustments made in the cortex and phloem of the host. The phloem parenchyma cells are enlarged and have enlarged nuclei. The increase in the tissue outside the cambium, however, is due mainly to the presence of the mistletoe tissue.

When *A. pusillum* grows on spruce the hypertrophy of the host twig is not localized so it is not so obvious. When *A. vaginatum* occurs on ponderosa pine, the first visible effect of the infection of a branch is fusiform swelling (Korstian 1922, Kuijt 1955). The first visible effect of infection in larch and Douglas fir is also fusiform swelling (Weir 1916b).

The rate of growth in diameter of limbs infected with mistletoe is faster than with the uninfected. This increased growth continues until the limb reaches the point where it starts to die. Swellings on the stem tend to become less noticeable as the tree grows. The hypertrophy of the tissues near the point of attack increases with repeated infections (Gaumann and Contesse 1951).

Korstian and Long (1922), Rankin (1929), Perry (1923), and Weir (1918) state that swellings in the branches are centers where abnormal amounts of food materials are stored. Korstian and Long (1922) go on to explain that the cortex is frequently eaten from these places by rodents such as porcupines and squirrels. The hypertrophy at the point of mistletoe infection is quite frequently accompanied by a flow of resin. The sapwood also becomes infiltrated with resin. This infiltration will continue until the fibrovascular tissue is so clogged with resin that the food supply is cut off to the limb. When enough of these resin flow areas occur on a tree it dies.

Kuijt (1955) writes that there is an excessive storage of starch in host tissues at the point of infection and that starch is even stored in the endophytic cells of the mistletoe. He considers this the result of the excessive flow of nutrients to the parasite. Eventually, however, a deficiency may develop at the infected area because of interference in the normal conduction of the host. Dufrenoy (1936) has stated that the cells of the infected rays are rich in oleo resins while the tissues of the mistletoe imbedded in them show an abundance of starch.

The flow of nutrients to the place of infection by mistletoe and its subsequent storage in this locality may cause the formation of buds and their development into branches (Kuijt 1955). Gorrie (1929) believes that the growth of dormant buds is stimulated. The result of these new branches grouped in the infection area is called "witches broom". Brooms follow soon after infection in Douglas fir (Weir 1916b). Kuijt (1955) states that these branches become negatively geotropic in all species in which they occur except those species infected by *A. douglasii* and that when infections involve the trunk, hypertrophies may develop without brooming. Young larch trees when infected by mistletoe develop such an extensive broom that by the time they become poles, the original crowns have disappeared, and heavily infected trees will develop a spiked top if they continue to live (Weir 1916a).

Brooms may reach several hundred pounds in weight and cause eccentricity in growth rings of the host when it attempts to provide support for them (Korstian and Long 1922). These writers also state that the tendency toward abnormal branching on the part of the host continues after aerial parts of the mistletoe have died in that locality.

Infection during the early life of the tree may cause the formation of a burl (Korstian and Long 1922). In older stems, where there is a continued formation of new sinkers within a small area, they may become so numerous that the cambium is pushed aside by the coalescing aberrant rays. When this occurs cankers may be formed (Cohen 1954). These cankers may be pitch-soaked and brashy (Gill 1954). Gill (1954) states that branches forming the brooms tend to live longer than normal branches and that direct infection of the leader is very likely to result in its death and make a spike top of the tree. Small brooms on larch and Douglas fir are frequently the last part of the tree to die (Weir 1916b).

Foliage. The leaves of infected branches and of the new branches formed in brooms are usually shorter and lighter in color than those of uninfected branches (Korstian and Long 1922, Kuijt 1955). In the case of *A. americanum* on the jack pines of central Canada leaves on the infected branches are retained several years longer than on uninfected branches (Dowding 1929). The brooms on an infected tree can make such a drain of nutrients upon the host that the uninfected parts may have their growth retarded to the point that the entire tree will be leafless with the exception of the broom (Kuijt 1954).

Growth. The effect of the parasite upon the growth rate of the host seems to vary. Korstian and Long (1922) report that an accelerated growth has been noted in lightly infected trees. The current increment, however, is directly dependent upon the degree of infection and this continually increases with the length of time that a tree has been infected. The decrease in growth rate was evident in each age and crown class in which sufficient trees could be secured. This reduction of growth appears to be caused by replacement of the crown and not to any toxic effect of the mistletoe. The decreased growth rises sharply with heavy infection (Nicholson 1955).

Lanternier (1946), working with silver fir, concluded that there is a slowing down, and, in some cases, a stoppage of both height and diameter increment. Weir (1915a) writes that the parasite causes serious retardation of growth and exposes the tree to attack by fungus and insect.

Wellwood (1956) made a study of the effect of mistletoe on the growth of western hemlock. Through stem analysis he calculated the volumes for time of cutting and for each decade over the past 100 years. He separated his trees into large and small diameters and then averaged the results. Moderate to light infection appeared to have no serious effect on the tree vigor while severe infection did.

Weir (1916c), writing about mistletoe in the forests of the Northwest, states that when the younger age classes are infected in the main stem, the increment will drop off very soon and that these trees seldom if ever attain a merchantable size. The space occupied by these trees is wasted and the possibility for maximum yield is lost. He considered a more direct adverse influence resulted in the future of the next stand of trees because of the small size and poor quality of seed produced by the infected trees.

As a rule the height of infected trees is less than that of healthy trees of the same age, growing under the same conditions, and the diameter growth is even more markedly decreased (Weir 1916b). This author in arriving at these conclusions measured 80 larch trees growing under similar circumstances and averaged these measurements with the following results: Infected trees, average height 63 feet and average diameter 11.5 inches. Healthy trees, average height 115 feet and average diameter 19.5 inches. All trees were 144 years of age.

Following the same procedure with 40 Douglas fir trees the results were: Infected trees, average height 62 feet and average diameter 17.3 inches. Uninfected trees, average height 73 feet and average diameter 22.2 inches. These trees were 97 years old. He goes on to state a middle aged Douglas fir increased its radial growth after removal of an immense broom.

Hawley (1937) writes that the effect upon the host by mistletoe is the reduction in growth and a decrease in stocking of the stand. In merchantable stands of lodgepole pine *A. americanum* causes a reduction of about ⅓ of the growth (Gill 1957). Dowding (1929) does not believe that the rate of growth of the infected trees varied with the amount of infection. This same author found that only the extremely deformed trees showed a marked decrease in growth rate. The female of the parasite makes a greater demand on the host for nutrients than does the male, so it has more effect and results in a yellowish color in the host's foliage.

The slower growth increment of infected trees is believed by Gauman and Contesse (1951) to be caused in part by the generally greater age of the host.

Mistletoe is not considered by Wellwood (1956) to be the direct cause of the death of the western hemlock. But it reduces the tree's resistance and may cause die back of the top. Spike top is an almost universal condition in infected larch (Weir 1916b). Wheeler (1901) claimed that when a black spruce had a number of branches infected with mistletoe the tree would die. Infected ponderosa pine stands in the Southwest have a greatly increased mortality (Andrews 1957).

Larch and Douglas fir seedlings that become infected with mistletoe usually die, but trees of pole size may linger indefinitely if secondary agents do not appear to kill them (Weir 1916b). When heavily infected, the greater part of a stand may never reach sawlog size (Perry 1923). The extent and nature of the injury done by the mistletoe to its host varies with the forest type, topography, and climate (Weir 1916a). This investigator goes on to state that the amount of damage to larch by mistletoe because of limb breakage is much greater than is realized. The younger portion of the crown remaining above, which also probably contains mistletoe, is not able to supply the deficiency in food materials and the tree merely exists. The radial dimensions of the last annual rings of trees in the final stages of mistletoe suppression are so fine and narrow that they cannot be counted by the unaided eye. Boe (1958) writes that all mistletoe infections interfere with the normal functions of the tree. Slight infections may reduce growth as much as 25 per cent and severe infections can increase this reduction to 50 per cent in young trees.

Secondary effects. The endophytic strands sometimes penetrate the foliar spurs, causing them to enlarge with the result that fewer needles are produced (Weir 1916a). The same author also states that burl tissue can start to be formed within 2 years after infection begins, and that these burls sometimes take up the entire merchantable part of a tree, causing pitch streaks and checks. Two types of burls are listed. One of these results from limb infections. It occurs at the base of the limb and gives rise to a large broom which later dies, leaving the burl. The second type, which results from stem infection, ruins the most lumber. Douglas fir seems to have fewer of these burls than do the other species. Burls cause a decrease in the proportion of sawtimber to the total volume of the tree or stand, and there is also a decrease in the quality of this sawtimber (Lanternier 1946).

Out of 600 mistletoed larch examined by Weir (1916b), 278 had wood destroying fungi established, and each infection had, to all indications, started in a burl. Besides providing a place of access for fungi, the mistletoe weakens the tree and makes it more susceptible to the fungus attack. Rankin (1929) lists wounds left where brooms break off as one of the sources of damage by mistletoe. Suppression by the parasite causes more rapid and earlier formation of heartwood in the younger age classes (Weir 1916a). Thinning of the foliage of heavily mistletoed trees and the appropriation by brooms of much of the food materials results in an unbalanced relation between the crown and the root system, causing a lack of food material for the roots. This results in the suppression and dying off of the more extended members. Trees so affected become more susceptible to windfall (Weir 1916a).

Mistletoed trees have a weak flow of sap, lowering their resistance against insect attack. *Dendroctonus pseudostuga* is usually very abundant in mistletoe areas (Weir 1916b, Perry, 1923).

Korstian and Long (1922) and Gill (1957) say that mistletoe results in increased size and number of knots which lowers the grade of the lumber. It also produces a curly or abnormally grained wood and this results in a weaker product. The wood invaded by the sinkers is spongy and discolored. They go on to say that a mistletoed tree is more susceptible to wind breakage, and a seedling or sapling whose stem is infected will seldom yield a bole large enough to have any economic value.

Seed production. Infected trees are poor seed producers according to Boyce (1938) and Lanternier (1946). As the infection becomes more severe, fewer cones are produced, and there is a marked decrease in the viability and yield per cone (Korstian and Long 1922, Weir 1916b). Witches' brooms are usually less important as seed sources than thrifty, younger infections (Kimmey 1957). This same author claims that the seed crops of ponderosa pine can be reduced as much as 75 per cent.

Extent of damage. Pearson (1950) wrote that dwarf mistletoe can be classed along with lightning and wind as one of the three major causes of mortality in merchantable timber. Heavy infections may reduce increment as much as ⅓ under what it normally would be, and this loss will probably exceed those associated with mortality. The first effect of damage is reduced growth. This is followed by excessive mortality in the merchantable size trees. The reproduction that comes in after the death of these trees is infected at an early age and the area becomes completely unproductive (Anon. 1955b).

Ellis (1946) and Kimmey (1957) rate mistletoe next to heart rots in the losses caused in western forests, and they also believe that in the future, if past cutting practices are continued, it will probably be more damaging than the fungi. Gill (1954) states that the losses from mistletoe have never been accurately evaluated, but he believes they are exceeded only by the damage done by heart rots. An anonymous author (1955), writing in the "Timber Resource Review", claims that mistletoes lead the diseases in the amount of damage caused in the Southern Rocky Mountain Region.

Weir (1916b) found mistletoe to be so abundant in the Northwest that it was bound to have some economic significance. He also singles out the Bitterroot National Forest, where the Douglas fir is so heavily infected that this species is sometimes omitted altogether from the estimate of the prospective cut. The Roosevelt and Medicine Bow National Forests have 67 per cent of their commercial area infected with mistletoe (Anon. 1954a).

Gill (1935) sums up the effect of mistletoe on the coniferous forests of the United States by saying that those areas heavily infected do not produce top yields, there is premature death of many trees, the growth rate is reduced, seed production is decreased, the form of individual trees is poorer and the quality of wood products obtained from these trees is lower. All infected trees have increased susceptability to attack by insects and disease.

III. FACTORS AFFECTING THE GROWTH AND ESTABLISHMENT OF MISTLETOE

Korstian and Long (1922) report that *R. crytopoda (A. vaginatum)* is one of the most serious enemies of western yellow pine, especially on southern exposures and near the lower limit of the type. They believe that low atmospheric humidity has only a very limited influence on the mistletoe, but that large amounts of sunshine are favorable to it. According to them a very definite relation exists between the unfavorableness of the site and the degree of infection.

When mistletoe occurs on silver fir, the even age stands are more vulnerable than selection forests in which only the dominants are attacked. Infection is most severe on permeable soils, in dry climate and at low altitudes. It is found on all sites with a northeast aspect (Lanternier 1946).

Gill (1935, 1957) stated that the dwarf mistletoes are most abundant on dry or poorer sites such as dry ridges and south slopes. The shoots seem to respond directly in vigor and number to the amount of light and one-storied stands result in a very slow rate of spread. Mistletoe does not develop well except on the warmer slopes, where it is exposed to ample light (Anon. 1955b).

A. campylopodum f. *laricis* (Piper) Gill is most abundant in open stands and causes little damage in dense forests. Nearly all species are most abundant on dry sites and there seems to be an inverse relation between severity of site and attack (Boyce 1938). On the best sites the trees are not deformed (Rankin 1929). Weir (1916a) states that mistletoe is found on the poorer sites and that suppressed trees do not become infected as easily as trees standing in the open. He believes this may result because suppressed trees have less young growth and so fewer vulnerable points of easy infection exist. The mistletoe if started may become suppressed and die. Infection may run as high as 90 per cent on dry slopes, but the per cent of infection is very low on favorable sites. It thrives best in uneven stands; thinning favors its development, and it spreads more rapidly in the crowns of the remaining young trees.

Buckland and Marples (1952) found in eastern hemlock that selective cutting resulted in spread of mistletoe throughout the new stand, while clear cutting on extensive areas resulted in mistletoe only in widely scattered locations. Where occasional trees or scattered blocks were left, the mistletoe rarely spread far into the reproduction, but well established centers of infection were left. Opening up a stand seems to stimulate growth of mistletoe on the trees remaining (Boyce 1938, Gill 1957).

Gaumann and Contesse (1951) believe that altitudinal limits of mistletoe may be explained by hypersensitivity of the hosts fostered by unfavorable growing conditions. The result is a point of complete intolerance. Sensitivity on the part of the host may be caused by repeated infection with mistletoe.

In the lodgepole pine stands of the Roosevelt and Medicine Bow National Forests, mistletoe is most extensive in cut over stands and is lightest in pole stands, most of which are regenerated burns. It is most common on ridges and least common in valley bottoms. Volumes in virgin stands on the average are 7,590 board feet per acre for those with mistletoe and 10,950 board feet per acre for stands that do not contain any of the parasite. The damage is not confined to the poorer sites. Cutting without regard for it intensifies the damage (Anon. 1954).

The upper altitudinal limits of *A. americanum* are a few hundred feet below the upper limits of commercial lodgepole pine. The highest elevation of infection in Colorado is 10,700 feet and in Wyoming 9,200 feet. It is believed that the dwarf mistletoes are more susceptible to extreme or unseasonable cold than are their hosts. The upper limits of infection coincide with about the 30 degree Fahrenheit mean annual temperature isotherm. The minimum temperature at this point is about a minus 55 degrees (Hawksworth 1956).

Plagnat (1950b) states that aspect has no direct influence on the degree of infection, that the influence of altitude is temperature, and the determining factors are warmth and illumination, which are essential to the growth and spread of mistletoe. In dense stands the parasite is confined to the tops of the crown, where it does but little damage. Any opening due to thinning gives it an opportunity to spread.

Gill (1954) observing mistletoe on ponderosa pine in the Southwest found that it is most abundant on ridges or level sites, is common on slopes, less common in bottoms, and is extremely rare on sub-marginal sites outside the commercial range of the host. It is characteristic of open, but merchantable stands yielding up to 10,000 board feet per acre. Increased light and the stimulating effects of release tend to favor the production or growth of mistletoe aerial shoots (Gill and Bedwell 1949). Weir (1916b) thought that the infections were more severe on the poorer sites.

In the western sandhills of Canada *A. americanum*, which is found on the pines, gains a foothold only on the eastern, more barren types of hills (Dowding 1929). It is Dowding's opinion that the chief reason for the limitation in the distribution of the parasite is fire. The dry sunny slopes have so little vegetation that fire is unable to gain a headway. The thick stands of timber on the other slopes are burned over before the timber can reach any great age. The spread of the mistletoe is so slow that the trees are burned before infection becomes heavy. An anonymous observer (1955b) and Gill (1949) believe that in the past uncontrolled fires held the parasites in check.

Severely diseased stands of ponderosa pine are the result of a continuous intensification of the parasite over a long period of time. Eventually the mistletoe is depleted, either from lack of a suitable host or from natural control factors such as fire. Partial burns favor the plant, but total burns result in new stands completely free of the pest (Andrews 1957).

Dowding (1929) wrote that the slow rate of spread of mistletoe in stands on the better sites is caused by the natural resistance of the host. On good sites a tree may outgrow the parasite, cast the diseased branches, and still make a fair growth. Gill (1957) has stated, however, in lodgepole pine the vigorous trees favor the best development of the parasite.

If the disease is in the bole such trees will never entirely resume normal growth (Perry 1923). Seventy per cent of the infections observed on ponderosa pine occurred on the main stem and will eventually cause deformity or serious reduction in growth (Gill and Andrews 1942). If trees are infected before they reach pole size, they will be culls. If the tree is infected after this age, it may furnish some merchantable material (Weir 1916b).

Gill (1949) believes that some trees have a natural resistance to mistletoe. Jack pine occurs in extensive stands from British Columbia to the Atlantic Coast, but mistletoe is not known to occur on jack pine in the East. There is no known reason why this parasite should not occur throughout the range of its host (Riley 1948).

Significant variations were observed by Roth (1953) in the resistance of young trees to mistletoe infection. Only very few trees appeared highly resistant. On the other hand Weir (1916a) wrote that no trees of any age are safe from infection.

IV. SEED DISSEMINATION

The maximum distance of spread of dwarf mistletoe from an overstory of trees whose average height is 120 feet is 130 feet in the direction of the prevailing wind. Heavy infections were concentrated within approximately 33 feet of the overstory and beyond this distance infections were moderate to light (Roth 1953). Gill (1949, 1957) believes that it may be carried long distances by birds and mammals.

Kuijt (1955) believes the role of wind and animals in the dissemination of the seed is of minor importance. Weir (1916b) states that birds and animals play a minor role in distributing the seed. In India Kippiker (1948) believes that the main means of spreading the seed is by birds.

Gill and Andrews (1942) observed that reproduction was slow to become established after the logging of a heavily infected ponderosa pine stand in which the old non-merchantable trees were left standing. In the new trees the infection was low and limited to stands within a radius of 50 feet of infected overstory trees.

V. CONTROL

Disease. Three fungi have been found parasitic on various species of dwarf mistletoe. One of these is an *Ascomycete*, *Wallrothiella arceuthobii* (*Peck*) Sacc. It lives on *A. pusillum, A. americanum, A. douglasii,* and *A. campylopodum f. abietinum* Engelm. The pistillate flowers only are attacked and all except the inner tissues develop normally (Dowding 1931, Kuijt 1955). The parasitized flowers never produce viable seed. Damp low lying localities near water are most favorable for the growth of the fungus (Dowding 1931). This fungus has been found on *A. americanum* on both lodgepole pine and white spruce in Alberta (Bourcheir 1955). Wheeler (1901) found this fungus on *A. pusillum* in Michigan.

The spores of the fungus are beginning to ripen and to be expelled in North Idaho about the end of November and are capable of germinating immediately. The part of the mistletoe tissue that forms the seed is completely destroyed by the mycellium of this fungus. The drain on vigor of the mistletoe if all the flowers are infected, is such that it may be killed (Weir 1915b). The same author believes that the ease with which the fungus seems to infect its host may make it of some economic importance in the control of certain species of mistletoe, at least for small areas.

A second fungus is *Septogloem gillii* Ellis (Fungi Imperfecti). This species effects primarily the stems of the mistletoe although infections have been seen on the fruits. It forms in the early stages small yellowish-white lessions concentrated near the nodes (Ellis 1946, Kuijt 1955). These lessions are most common in the summer and fall (Kuijt 1955). They gradually enlarge, coalesce, and erupt disclosing conspicuous white spore masses from June through Sept. (Ellis 1946).

Shoots of all ages may be attacked but there seems to be a preference for the pistillate plants (Ellis 1946, Kuijt 1955). Pistillate plants are not favored as much with *A. douglasii* and the fungus does not seem to be so severe on this species. The first indication of the disease visible in the field is usually the death of a large number of aerial shoots of the mistletoe, and in areas where it is well established, the low ratio of pistillate to staminate plants (Ellis 1946).

It is found on all species of mistletoe previously listed for *W. arceuthobii* (Kuijt 1955). Spores may be found on both living and dead stems. Mistletoe mortality may occur at any season of the year but is most common during the summer and fall. In the fall it can usually be found only on plants already dead (Ellis 1946).

It has been found in Arizona, California, New Mexico, Oregon, Utah, and Washington (Ellis 1946). Because of its virulent nature this fungus is believed to have possibilities (Kuijt 1955). Ellis (1946) wrote that this fungus is responsible for considerable control of dwarf mistletoe under natural conditions. Its growth is favored by low temperatures.

A fungus was found on mistletoes at Point Lobos Reserve, California that has been called *Metashpaeria Wheeleri* Linder. It attacks the stems which it girdles, killing that portion of the plant which is beyond the infected area. The stems of the host become yellowish and stand out in contrast to the brownish-green stems of the healthy plants (Linder 1938).

Insects. Insects destroy a large proportion of the seeds in some areas (Anon. 1954b). Several are known to feed upon more than one species of the parasite, but most are considered of little value in control (Kuijt 1955). Spittle bugs (*Cercopidae)* are the most common (Gill 1949). They are most destructive on *A. vaginatum* f. *cryptopodum* and *A. campylopodum* f. *campylopodum* causing the deaths of entire shoots (Kuijt 1955). Korstian and Long (1922) observed a spittle insect (*Clostoptera obtusa*) on mistletoe but did not believe it to be of much practical importance.

Birds and mammals. Grouse and sparrows eat the berries and some rodents, squirrels and porcupines are known to prefer the swelling on mistletoe infection (Kuijt 1955). Dufrenoy (1936) believes that their preference for this spongy cortical material may be caused by the abundance of starch available in such areas. Several rodents eat the bark around the infected area (Ellis 1946, Boyce 1938). Porcupines eat the shoots in large quantities during the winter months (Gill 1949).

Poisons and growth hormones. Spraying with 2-4-D kills the shoots but the endophytic system is not harmed (Gill 1949). Good results in killing the aerial portion of the plant are also obtained with Endothal and M.C.P. sodium salt. Both of these poisons killed 90 to 100 per cent of the mistletoe sprayed but no harm was done to the portion of the parasite within the tree (Bourchier 1956). M-C-P-3 mixed with water at 1 to 5 and 1 to 10 caused the plant to wither and die quickly without any apparent injury to the host (Bouchier 1954).

Many of the 2-4-D and 2-4-5-T derivatives are too harmful for general application. However, some sprays do not seem to damage ponderosa pine seriously and are effective against the aerial portions of the mistletoe (Anon. 1955a). This same investigator stated that some means of getting dilute solutions into the sap stream is needed so that there will be a greater chance of destroying the endophytic system.

Experiments for mistletoe control by injection of poisons into the sap stream of the tree were started in Australia in 1948 on *Eucalyptus polyanthemos* and the *Loranthus* parasitic on it. For trunk infections one ¾ inch hole per inch of diameter of the tree was bored through the cambium. The dose was proportional to the square of the diameter at breast height (Greenham 1952). Shallow holes as prescribed are more effective than a few deep holes (Anon. 1954c). Ax cuts to replace the holes shows some promise as an application technique (Anon. 1955).

When using 2-4-D the optimum dosage varied throughout the year, the maximum being in April, requiring 4 to 6 times as much as in November. Fall treatment gives the best results. Injections of a 10 percent 2-4-D solution gave the best results throughout the year (Anon 1952).

The treatment prescribed above has resulted in an increased rate of diameter growth of the host (Anon. 1952, Nicholson 1955). The effect does not appear to last longer than 12 months (Anon. 1952). The stimulated growth of the tree occurs mainly in the bark and seems to be confined to a small length of the trunk in the vicinity of the point of injection (Anon. 1952, Nicholson 1955). In addition to the stimulated bark growth some abnormal wood elements are also formed (Nicholson 1955). Most of the mistletoes are killed by the infections (Anon. 1952).

Mistletoe surviving the first treatment was largely killed by a second treatment. The parasite surviving a treatment is able to recover and neither susceptibility nor immunity was acquired by uninfected trees treated (Anon. 1954c, 1955).

While the 2-4-Ds have slow results, they were the most effective. Of the inorganic poisons, copper sulphate at the rate of 20 grams for a 9 inch tree gave the best results (Greenham 1952).

CHAPTER III

Material and Methods

I. VARIABLES

The growth losses resulting from mistletoe infections are believed to be the most damaging of all the adverse effects resulting from this disease. Controlled laboratory experiments to measure these losses are time consuming and as such were not feasible for this study. Instead, the use of past growth, determined by increment cores, was selected as a means of measuring the effect of the parasite upon the growth of trees.

To correct for the effect of diameter, the growth was expressed in terms of basal area. Square foot increase in the cross sectional area was used instead of per cent increase because it presents a truer picture of the effect of mistletoe. The infected trees were smaller than the control trees because of the presence of the parasite and the experiment was designed on this premise. To ignore the smaller size of the trees, if this decrease in size is caused by the infection, would result in values indicating losses lower than actually occur.

Factors affecting growth, other than the four variables measured, can reduce the size of a tree. However, such factors that were apparent in trees being selected cause that tree to be excluded. Trees of all levels of infection with hidden elements that might have adverse or favorable influences on growth rates had equal chance of selection with those of normal growth.

Three borings spaced at approximately equal distances apart around the tree were taken and averaged. This was to correct for the eccentricity that exists in many trees. Ten consecutive rings were counted in from the cambium and their accumulative width measured.

Boggess (1955) states that basal area when used alone is not an adequate way of expressing growth and yield. Volume, which is an expression of diameter, height and form, is far more accurate. Calculations by the author on information from growth studies in Douglas fir on sites IV and V at the Pack Forest of the University of Washington indicate that cubic foot volume growth in Douglas fir will exceed basal area growth by about ten per cent.

While basal area growth over the past ten years was relatively easy to measure, height growth for such a period was not, and it was not within the scope of this study to do so. Form will undoubtedly be affected by mistletoe and result in a further reduction of volume growth, but this also was not measured. It would be highly variable and the results would depend upon whether the bulk of the infection was above or below the height at which the measurement was taken to determine form.

Investigations have shown that following logging, which removed the overmature and decadent trees, the growth is described satisfactorily by the diameter of the trees even though there is wide disparity in the ages of individuals in the same diameter group (Orr 1956).

The basal area increment in a tree is more closely related to the area of crown surface than any other dimension of the crown (Holsoe 1948). Any interruption in the development of the crown can therefore change the growth rate of the tree. Mistletoe is believed to interrupt the development of the effective crown of a tree (Nicholson 1955). If the effective live crown is reduced below a certain size then a loss in diameter growth will occur. Hawley and Smith (1954) state that a crown smaller than thirty to forty per cent of the total height results in a reduction of growth.

This study is designed on the premise that the mistletoe infected portion of a tree contributes little or nothing to the growth rate of a tree. In comparing trees of equal crown length height ratio, those with a portion of their crown infected with mistletoe should have a slower growth rate than those whose entire crown is uninfected.

The total losses in growth caused by mistletoe in western Montana are unknown, and one can only guess at their magnitude. It is not the purpose of this study to estimate these losses, but it is the intent to determine and present growth loss figures that can be applied to any mistletoe infected area of larch or Douglas fir. If, during cruising, the trees of these species can be tallied as healthy or infected, upon compilation of the field work an estimate can be made of the growth being lost in a stand if the effect of the mistletoe is known. Accuracy in this estimate can be increased if the infected trees are further separated into degrees of infection. The number of divisions, however, should be kept practical for field application.

Identification of mistletoe infection for application during cruising should be rapid and easy. Because the visible portion of the parasite itself is small and inconspicuous its presence requires a more positive means of identification. New infections are not included in this study. Not until the mistletoe has been present in the tree long enough to produce brooming is that tree recognized as being infected. It is the presense of these brooms that becomes the guide to the degree or per cent of the crown that contains mistletoe.

Does the effect of the mistletoe extend over all conditions of growth? Toumey and Korstain (1957) listed seven factors that influence the rapidity of growth of trees. These factors are species, soil, climate, degrees of competition, age of tree, individual variation and normal development. Cox (1958) has written that the wider the range of conditions investigated in the experiment, the greater is the confidence in the interpretation of the results. There are so many variables in forestry, however, that it becomes necessary to select the more important of these and ignore the rest (Bruce and Schumacker 1950).

The effect of variations in soil productivity are taken care of by determining five levels of site. Climate changes with elevation, but accurate measurements of the amount of this variation are not available from past records. Since it is one of the factors that determines site, at least part of its effect is considered. Growth variation between species is eliminated by making a separate study on larch and on Douglas fir.

The degree of competition is variable, and its effect is measured by including the factor of stocking. To eliminate variable competition within a stand of determined density only dominant trees were selected. Age is included as a variable, and trees selected for each plot were as close to the same age as possible.

It was not thought that any of these factors, either singly or in combination, would change the effect of mistletoe on the host. When there is a possibility that this condition exists, replication can be dispensed with (Fisher 1937). In addition, an experiment containing enough factors to make one replicate suffice enables the experimental labor and materials to be used more advantageously (Finney 1955).

With only one observation on each treatment combination there are no sets of units receiving the same treatment on which to base the error estimate (Cox 1958). While there will be no variation due to error or residual, there will be numerous interactions, the apparent effects of which are principally due to error, and these may be used to provide a measure of the precision of the more important comparisons (Fisher 1937).

Fisher (1937) states that tests may be applied to any of the interactions which may seem to be significant. If none of these results are very important compared with the average of the remainder, we have a confirmation of the ideas upon which the experiment was designed, that the main factors are not strongly related.

The relationship within three of the factors or variables is not linear. Proof of this is indicated with site curves, age on volume curves and the effect of stocking on individual trees as illustrated in Chapman and Meyer (1949). When the relationship is not linear, at least three levels are needed in each factor. The ideal number of levels depends largely on the reliability of existing information on the quantity sought. If reasonably good predictions can be made in advance, three levels will be adequate and there should be equal intervals between successive values (Finney 1955).

Degree of infection. Infection was divided into four units, the intensity being judged by the per cent of crown that was represented by mistletoe caused brooms. Trees with no visible infection were classed as "none" and were used as a control. Trees with less than one third of their crown broomed were "light", and when one third to two thirds of the crown was infected, they were "medium". When over two thirds of the crown was made up of brooms, the infection was "heavy".

Site. Five levels of site, as described by Cummings (1937), were recognized and determined by measuring the height and age of at least two dominant trees on the plots. The site curves were made for western larch but were used for the Douglas fir as well since nothing else is available for this species. Before applying these tables to Douglas fir stands, the height axis was reduced by five feet. The fallacy of accurately determining the soil productive capacity for Douglas fir by such methods is recognized but for the purpose of site comparison it proved to be adequate.

Stocking. Three degrees of stocking were recognized and based on a normal as indicated by Cummings (1937). Light stocking was thirty three per cent of normal or less, medium stocking was from thirty three to sixty six per cent, and heavy stocking included all stands over sixty six per cent stocked. Stands of such dense stocking as to cause stagnation were not included.

Stocking was usually determined by visual inspection of the stand, but border line areas were checked against the yield tables by taking the volume on a one fifth acre plot. Since stems per acre or basal area per acre are not given in the tables as a means of determining stocking, such methods of measurement could not be used with young stands which had not grown to board foot size. In these stands, stocking was looked for that would result in crowns that were less than forty per cent of the total height in the dominant trees for heavy stocking. Crowns on the dominant trees that were between forty and sixty per cent of the total height were used as an indicator of medium stocking, and trees with crowns extending over more than sixty per cent of their total length were found in lightly stocked stands.

Age. The age of each tree used was determined and the trees were grouped in ages 0 to 80, 80 to 160, and over 160 years old. In no case were trees used in the study that were over 220 years of age.

II. SELECTION OF PLOTS

The selection of plots for the experiment was not random. Trees containing the four levels of infection were located as close to each other as possible to reduce soil variations within a site. The host plants used were never more than 300 feet apart. Plots with the different levels of the other three variables were located by extensive searching. If the experiment had been conducted by making random selection of the units, the information would not have been complete. Many replications would have been taken in some categories to the complete exclusion of others.

A reduction of randomization can be accepted only with reluctance but is often preferable to abandonment of the problem (Finney 1955). The occasions on which randomization is required vary with the type of experiment and must be left to the judgement of the experimenter according to Cochran and Cox (1957). These authors go on to say that in some experiments the application of randomization to every operation becomes time consuming, and the experimenter should use his judgement in omitting it. The failure to randomize may produce bias, unless either the variation introduced from bias is negligible or the experiment randomizes itself.

This experiment randomizes itself. As the areas for location of the plots were being selected, at no time was there a choice of selection for any one set of factors. The main difficulty lay in finding the level of factors wanted. If, as did happen on occasion, combinations were found later that matched a plot already taken, the original was retained.

III. MEASUREMENTS

The heights of all trees tallied were measured with an abney level to the nearest five feet when they were in the two older age classes, and to the nearest foot on the younger samples. Diameters of the trees were measured at breast height, four and one half feet from the ground, with a steel diameter tape graduated to read diameters in inches and tenths. These values were recorded to the nearest tenth of an inch. Trees with hypertrophy at breast height were not used.

Bark thickness to the nearest 0.05 of an inch was measured with a Swedish bark gauge at one location on the tree, four and one half feet from the ground.

The age of each tree was determined with an increment borer by taking one core at breast height. The age to the nearest year was counted on this core, and the age of a seedling at breast height, as given by Cummings (1937) for that site, was then added to obtain the total age of the tree.

The radial growth, to the nearest 0.01 of an inch, for the past ten years was determined for each tree by taking three cores equally spaced around the tree at breast height. These values were averaged, and the resulting value doubled for diameter growth. The diameter increase was then converted to basal area increase.

IV. LOCATION

Measurements in Douglas fir were taken during the summer of 1957. The trees were located in the Lolo and Bitterroot National Forests of western Montana, with the Bitterroot Valley providing nearly all of the infected areas.

The measurements for larch were made during the summer of 1958. The Kootenai National Forest provided all of the plots except one that was located in the lower Thompson River drainage of the Lolo National Forest.

Many of the sites used in the study had been selectively logged. None of these were used, however, unless logging had been completed for fifteen years. In these areas, all trees were avoided which were beside roads or skid trials or above high cuts where subsoil drainage could have been altered.

Stands were sought that would give all four levels of infected trees in close proximity. Only dominant trees were selected, and the degrees of infection were determined by visual inspection. Each group of four trees had approximately the same crown length to total height ratio. Trees that contained visible defects or dead tops were not used.

V. ANALYSIS OF DATA

An analysis of variance has been applied to the data collected. In this procedure, first introduced by Fisher (1937), the size of the effect of the main factors are analyzed; first alone and then in combinations with each other. The results of the field work have been arranged for this purpose and presented in Tables I through VIII. The individual values for diameters at the begining of the growth period and ten year basal area growth from which the sum squares are calculated, are listed in the tables of the appendix. Each of the sum squares has been divided by its number of degrees of freedom in order to obtain the figures listed in the column headed "variance".

The "Null Hypothesis" is made that all the effects named in the table for the analysis of variance have no real difference. The variance estimates listed for each factor and the first and second order interactions are independent estimates of the same quantity given by the error term or the variance of the third order interaction. The "F" test, as described by Snedecor (1946), is used to tell whether the variance estimates based on the named sources of variation are significantly greater than the variance estimate of the error term.

The analyses resulted in most of the secondary interactions showing no significant size over the variance of the third order interactions. Those second order interactions that were not significant are estimates of error, so their sum squares and degrees of freedom can be added to those of the third order interaction to form the error term (Moroney 1956). The pooled error term is used to test the main effects and the primary interactions. This procedure was used with Douglas fir, but the third order interaction for larch contained forty eight degrees of freedom so there is no advantage gained by pooling.

Variation not controlled in the conduct of an experiment is often associated with some measurable variate. A possible fifth factor that could have influenced basal area growth of the trees sampled is a diameter difference that existed prior to mistletoe infection. Measurement of the effect of this variate, if it existed, would enable the investigator to use regression for increasing the accuracy of the information available.

To test for the possibility of a fifth variate, scatter diagrams of basal area increment over diameter were prepared for both species. Little or no correlation was evident. A mathematical check on the relationship was performed by calculating a coefficient of correlation for both Douglas fir and larch and conducting an analysis of variance upon the regression. No significance was indicated. The possibility of a variation in diameters of the sample trees affecting the accuracy of the results was rejected.

The regression of growth on infection level is linear so the regression coefficient is used to obtain the average effect of the mistletoe on both basal area and height growth. The standard error of the estimate will tell us how much variation the growth reduction effect of mistletoe may have for any level of infection. Limits are determined within two standard deviations.

The difference in growth in basal area, as found by regression, is calculated and expressed as a percentage of the growth rates determined for the control and listed with the allowable variation in Table VII.

CHAPTER IV

Results and Conclusions

I. RESULTS

Diameter of Douglas fir. All four of the main factors had "F" ratios that were highly significant. An increase in stocking results in smaller diameters but the difference between average diameters for medium and for heavy stocking is not significant.

TABLE I

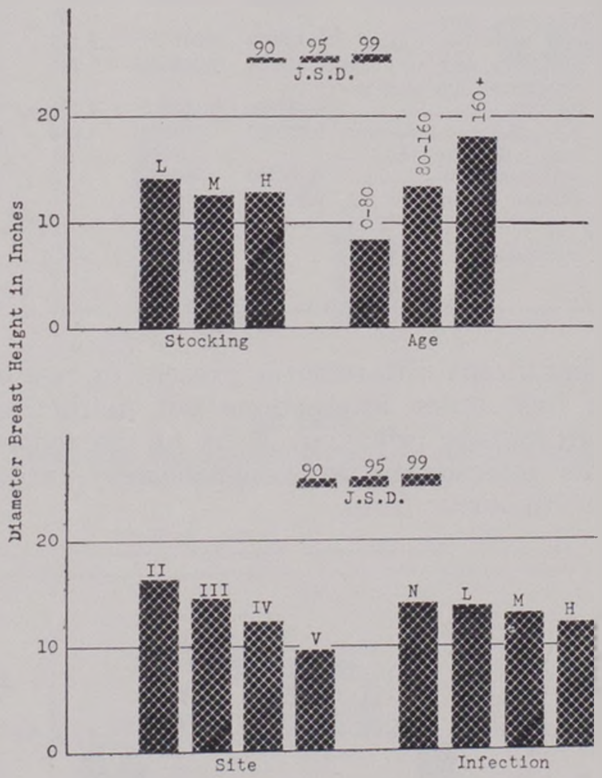
ANALYSIS OF VARIANCE FOR THE DIAMETER OF DOUGLAS FIR

Degrees of Freedom	Source of Variation	Net Sum Squares	Variance	F Ratio	Sig. %
143	All factors	4,585.12			
2	Stocking	65.00	32.50	7.59	99
2	Age	2,286.58	1,143.29	267.12	99
3	Infection	82.04	27.35	6.39	99
3	Site	916.36	305.45	71.37	99
6	Stocking and site	213.76	35.63	8.32	99
4	Stocking and age	66.88	16.72	3.91	95
6	Stocking and infection	35.51	5.92	1.38	†
6	Site and age	169.32	28.22	6.59	99
9	Site and infection	36.91	4.10	0.96	†
6	Age and infection	14.44	2.41	0.56	†
18	Stocking, site and infection	92.01	5.11	1.00	†
12	Stocking, site and age	338.68	28.22	5.53	99
12	Stocking, age and infection	35.53	2.96	0.69	†
18	Age, site and infection	48.68	2.70	0.63	†
36	Stocking, age, site and infection	183.42	5.10		
84	Pooled variance[1]	359.64	4.28		

†No significance.
[1]Four-way interaction plus non-significant three-way interaction.

The effect of infection upon diameters is not large. The difference between the average diameter of trees with no infection and those with light infection is not even significant when a "t" test is applied. Average diameters for the other levels of infection are significantly different.

For three of the first order interactions the "Null Hypothesis" breaks down but none of these involves infection. One secondary interaction has a significant "F" ratio but again infection is not involved.



GRAPH 1
Effect of the four main factors upon the diameter of Douglas Fir

Basal area growth of Douglas fir. The variance of each of the four main factors are significant; age at the 95 per cent level of confidence and the other three at 99 per cent. All of the trees selected were vigorous so within the limits used an increase in age resulted in greater growth. The difference between the average basal area growth for the different ages is not significant.

An increase in stocking results in slower basal area growth. A decrease in site quality causes less growth as well, but a reversal occurs with site III. There is no explanation for this variation. Increasing infection results in a large and steady decrease in basal area growth.

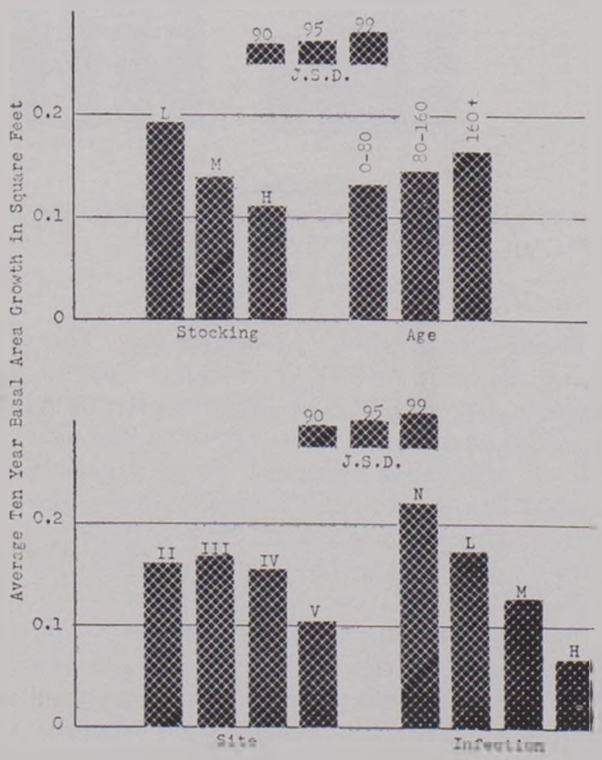
TABLE II

ANALYSIS OF VARIANCE FOR THE TEN-YEAR BASAL AREA GROWTH OF DOUGLAS FIR

Degrees of Freedom	Source of Variation	Net Sum Squares	Variance	F Ratio	Sig. %
143	All factors	1.304776			
2	Stocking	0.170434	0.085217	27.150	99
2	Age	0.024837	0.012418	3.950	95
3	Infection	0.457601	0.152534	48.580	99
3	Site	0.094268	0.031423	10.000	99
6	Stocking and site	0.106238	0.017706	5.639	99
4	Stocking and age	0.025780	0.006445	2.052	†
6	Stocking and infection	0.021678	0.003613	1.151	†
6	Site and age	0.043879	0.007313	2.390	95
9	Site and infection	0.053000	0.005889	1.875	†
6	Age and infection	0.005620	0.000937	0.298	†
18	Stocking, site and infection	0.025872	0.001437	0.473	†
12	Stocking, site and age	0.063597	0.005300	1.746	†
12	Stocking, age and infection	0.043384	0.003615	1.191	†
18	Age, site and infection	0.059307	0.003295	1.085	†
36	Age, stocking, site and infection	0.109281	0.003036		
96	Pooled variance[2]	0.301441	0.003140		

[2]Ibid., p. 21.
†No significance.

Significant difference is present in two of the first order interactions but neither of them include infection. None of the second order interactions were significantly larger than the error term.



GRAPH 2

Effect of the four main factors upon the basal area growth of Douglas Fir

The coefficient of correlation for the average growth resulting from the four levels of infection is -0.99 and the regression coefficient is - 0.00175. When Student's "t", with two degrees of freedom is applied to the latter value, significance is indicated at the 99 per cent level of confidence.

Using this "β" to determine what growth can be expected for each level of infection, it was found that a light infection resulted in a value which is 13.7 per cent lower than that for control. Medium infection gave a 41.0 per cent reduction, and a heavy level of infection resulted in 68.5 per cent less basal area growth. The standard error of the estimate is $\pm$ 0.0098 square feet, so growth at any level of infection will not vary over 0.0197 square feet either side of its mean 95 times out of 100. Expressed in per cent of basal area growth of trees without infection the variation will not be over 9.2 per cent either side of the mean infected growth at the 95 per cent level of confidence.

Height growth of Douglas fir. The analysis of the average yearly height growth of Douglast fir resulted in significant "F" ratios for all of the four main factors. Stocking, however, was significant at the 95 per cent level of confidence and the trend is not consistant as is illustrated in Graph 10. Stocking did not effect height growth in the stands that were selected for this study.

Average height growth drops off rapidly

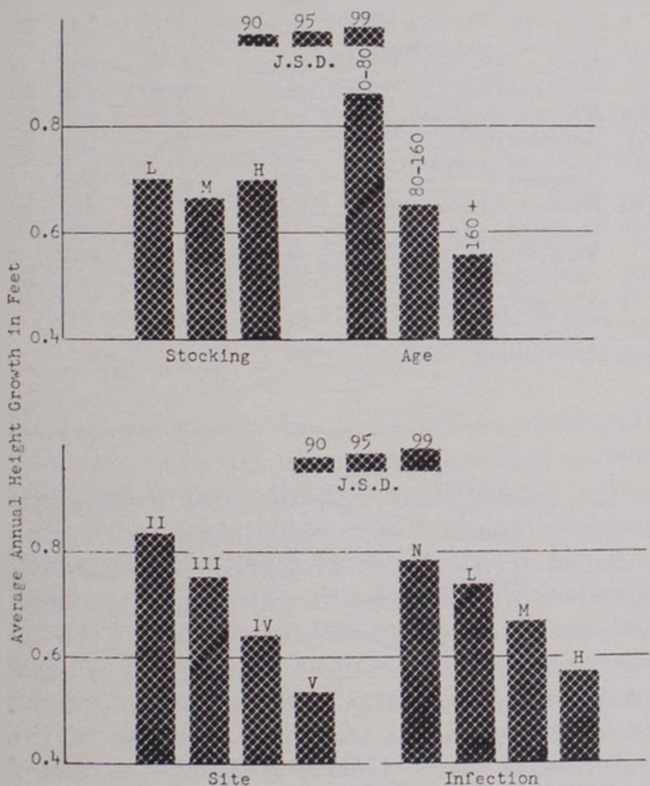
TABLE III

ANALYSIS OF VARIANCE FOR THE AVERAGE YEARLY HEIGHT GROWTH OF DOUGLAS FIR

Degrees of Freedom	Source of Variation	Net Sum Squares	Variance	F Ratio	Sig. %
143	All factors	6.920113			
2	Stocking	0.039110	0.019555	4.063	95
2	Age	1.278500	0.639250	236.713	99
3	Infection	0.904530	0.301510	62.645	99
3	Site	1.823190	0.607730	126.268	99
6	Stocking and site	0.144502	0.024084	5.004	99
4	Stocking and age	0.010540	0.002635	0.547	†
6	Stocking and infection	0.017014	0.002836	0.589	†
6	Site and age	1.474060	0.079010	16.416	99
9	Site and infection	0.094569	0.010508	2.183	95
6	Age and infection	0.308730	0.051455	10.691	99
18	Stocking, site and infection	0.116210	0.006456	1.772	†
12	Stocking, site and age	0.420930	0.035077	9.629	99
12	Stocking, age and infection	0.031960	0.002663	0.731	†
18	Age, site and infection	0.125020	0.006945	1.906	†
36	Age, site, stocking and infection	0.131150	0.036430		
84	Pooled variances[3]	0.404340	0.004813		

[3]Ibid., p. 21.
†No significance.

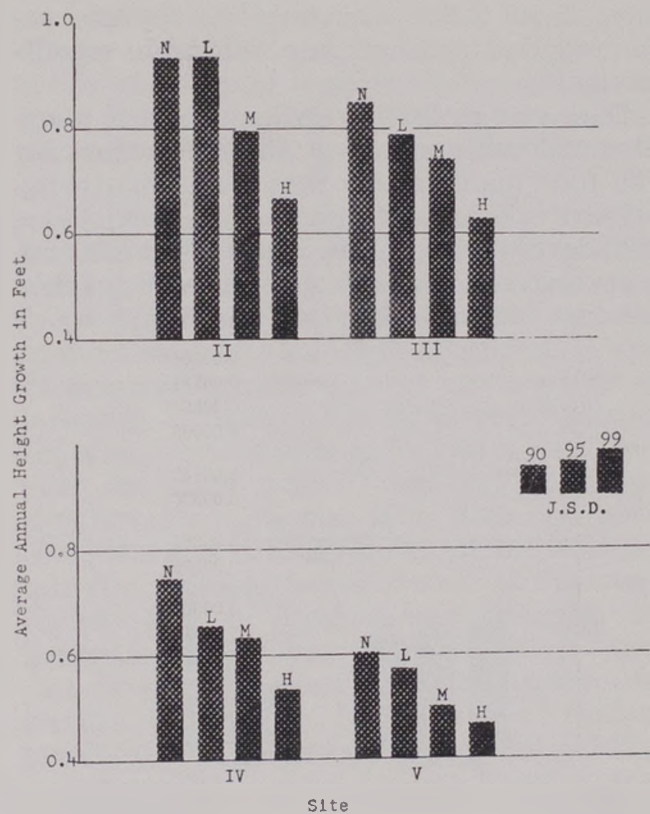
with an increase in age and with a decrease in the productive capacity of the soil. An increase in infection also results in decreased growth and the difference between the average height growth for each level of infection is highly significant.



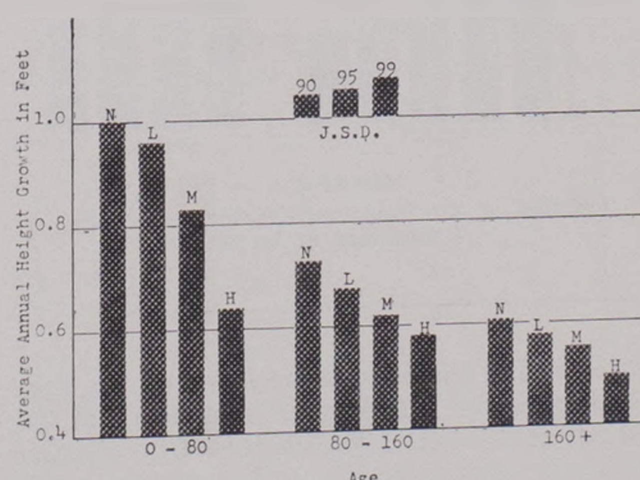
GRAPH 3
Effect of the four main factors upon the height growth of Douglas Fir

Significant differences are present in four of the primary interactions including that of age and infection and site and infection. A separate "F" test between each of these interactions and the main factor of infection indicates a significant difference in the variances at the 99 per cent level of confidence for site and infection but the "Null Hypothesis" does not break down for the first combination. Graph 5 shows that the effect of infection is always the same regardless of the age class, but in the 160 year plus age group the annual growth between adjacent levels of infection is not significant when the "t" test is applied. Graph 4 illustrates that, with the exception of the two lower levels of infection on site I, increased infection results in progressively less height growth.

If the average yearly height growth were



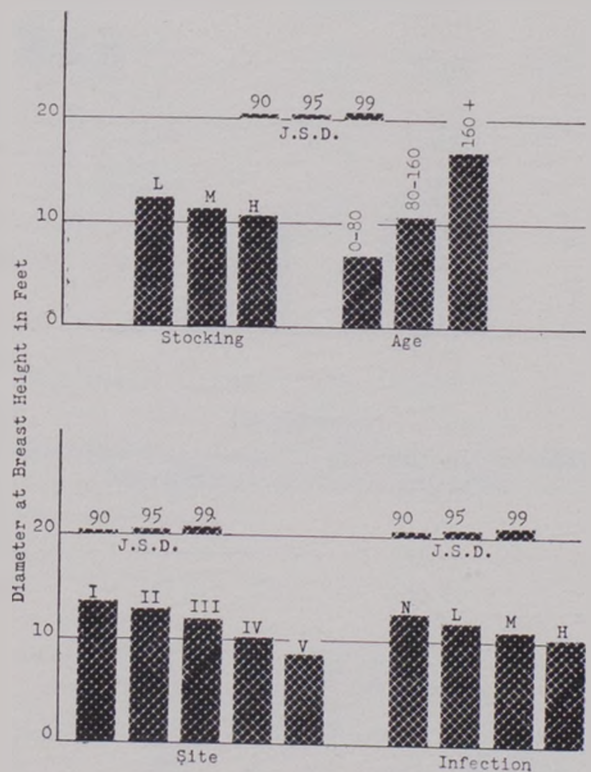
GRAPH 4
Effect of the interaction of site and infection upon the height of Douglas Fir



GRAPH 5
Effect of the interaction of age and infection upon the height growth of Douglas Fir

not spread over the entire life of the tree and determined for the infection period only, this significance probably would not occur. Nothing can be gained by breaking the analysis down into the different levels of age and site. None of the secondary interactions containing the factor of infection were significant.

Diameter of larch. The analysis of diameter of larch resulted in variance values for the four main factors that were highly significant. Increased infection from mistletoe reduces the size of the trees. The relationship between the averages for each level in all four factors is illustrated in Graph 6.



GRAPH 6
Effect of the four main factors upon the diameter of larch

In testing the first order interactions, four of them were found to be significant at the 99 per cent level of confidence. One of these was age and infection and a separate "F" test between the variance of this unit and that of the main factor of infection does not show significance. Graph 7 indicates that a reversal in the trend of the average diameters occurs with heavy infection in the older age class. The difference in ages of trees selected within any of the four levels of infection can be the cause of this significant interaction. No additional information will result from a breakdown of the variance analysis into the three age levels. One second order interaction, that did not include infection, resulted in a significant "F" ratio.

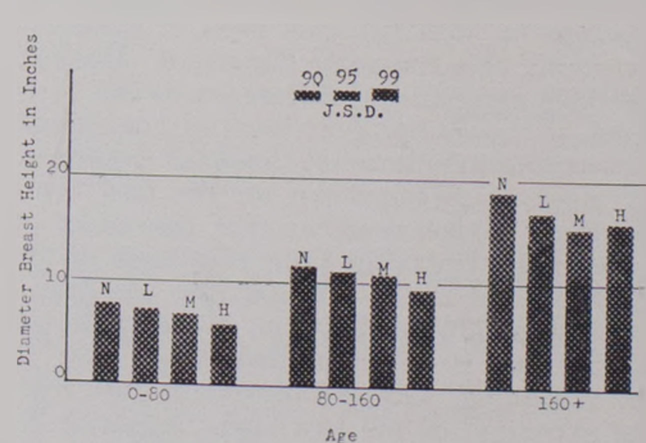
TABLE IV
ANALYSIS OF VARIANCE FOR THE DIAMETER OF LARCH

Degrees of Freedom	Source of Variation	Net Sum Squares	Variance	F Ratio	Sig. %
179	All factors	4,564.66			
2	Stocking	83.68	41.84	24.61	99
2	Age	2,976.78	1,488.39	875.52	99
3	Infection	137.04	45.68	26.87	99
4	Site	576.23	144.06	84.74	99
8	Stocking and site	167.89	20.99	12.35	99
4	Stocking and age	36.46	9.12	5.36	99
6	Stocking and infection	5.79	0.96	0.56	†
8	Site and age	124.99	15.62	9.22	99
12	Site and infection	26.59	2.22	1.31	†
6	Age and infection	33.72	5.62	3.31	99
24	Stocking, site and infection	60.01	2.50	1.47	†
16	Stocking, site and age	210.43	13.15	7.74	99
12	Stocking, age and infection	6.22	0.52	0.31	†
24	Age, site and infection	37.29	1.55	0.91	†
48	Age, site, stocking and infection	81.54	1.70		

†No significance

Basal area growth of larch. The analysis resulted in "F" ratios for all four of the main factors that were highly significant. An increase in stocking caused a reduction in basal area growth. As the trees became older the amount of growth increased because of the increase in size. Graph 20 indicates that a reversal occurs with trees over 160 years old. It is not known whether this is caused by the reduced vigor of the trees because of age or by sampling error.

A reduction in site results in less basal area growth and an increase in mistletoe in-



GRAPH 7
Effect of the interaction of age and infection upon the diameter of larch

TABLE V

ANALYSIS OF VARIANCE FOR THE TEN-YEAR BASAL AREA GROWTH OF LARCH

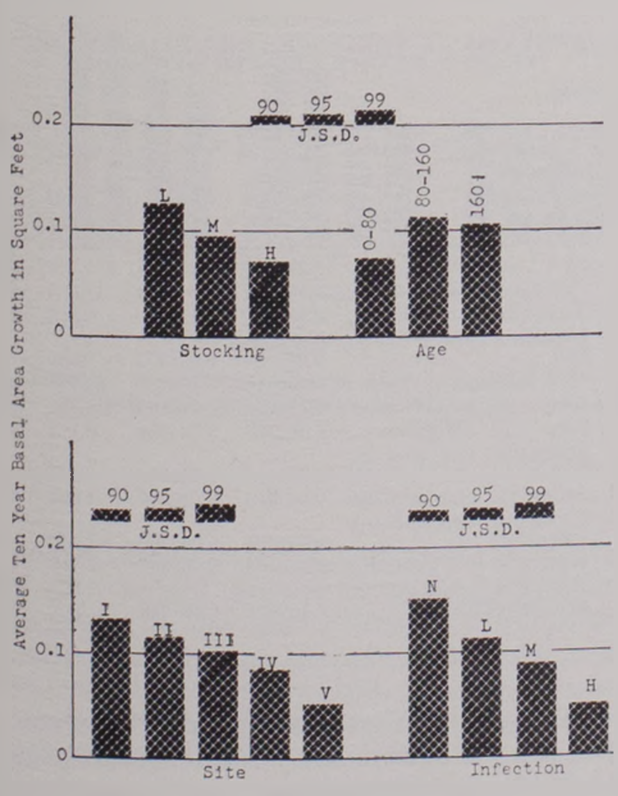
Degrees of Freedom	Source of Variation	Net Sum Squares	Variance	F Ratio	Sig. %
179	All factors	0.814965			
2	Stocking	0.091049	0.045524	62.530	99
2	Age	0.049881	0.024940	34.260	99
3	Infection	0.257601	0.085967	117.950	99
4	Site	0.134256	0.033564	46.100	99
8	Stocking and site	0.027820	0.003478	4.675	99
4	Stocking and age	0.003842	0.000960	1.290	†
6	Stocking and infection	0.011976	0.001996	2.683	95
8	Site and age	0.032408	0.004051	5.445	99
12	Site and infection	0.040771	0.003398	4.567	99
6	Age and infection	0.008158	0.001360	1.868	†
24	Stocking, site and infection	0.020336	0.000847	1.163	†
16	Stocking, site and age	0.069166	0.004323	5.938	99
12	Stocking, age and infection	0.008080	0.000673	0.924	†
24	Age, site and infection	0.024657	0.001027	1.411	†
48	Age, stocking, site and infection	0.034964	0.000728		

fection produces the same effect. The differences between averages for the various levels of each factor are significant.

The first order interaction of stocking and infection is just significant at the 95 per cent level of confidence. A separate "F" test with the main factor of infection gives a confidence level of over 99 per cent. Graph 9 indicates a similar relationship between all levels of infection regardless of stocking and these differences are significant at the 95 per cent, or higher, level of confidence in all cases.

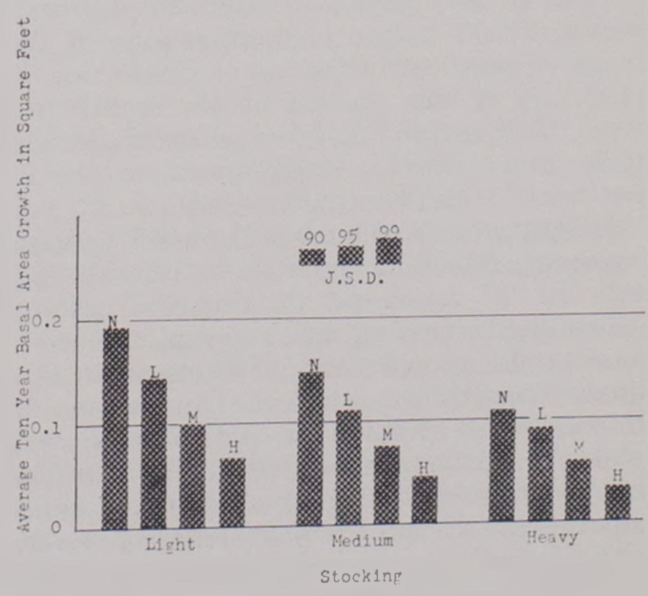
The first order interaction of site and infection is highly significant. A separate "F" test between this interaction and the main factor of infection indicates that the variance of the main factor is highly significant. Graph 10 illustrates that the trend of the effect of infection is always the same regardless of the site, but that in sites IV and V a "t" test does not show that all adjacent levels are significantly different. This does not, however, warrant a break down of the analysis into the different levels of site. If the trend for any level of site had been reversed, the analysis should have been carried further. The very strong effect of site comes into the picture here and can be the cause of this interaction. With the second order interactions, one group that did not contain infection was significant.

Using the average growth rate for each level of infection, a correlation coefficient of —0.98 is obtained. A "t" test applied to the regression coefficient with two degrees of freedom results in significance at the 98 per cent level of confidence. Using the "β" value of — 0.00116 to calculate what basal area growth can be expected for each level of infection, resulted in a growth reduction of



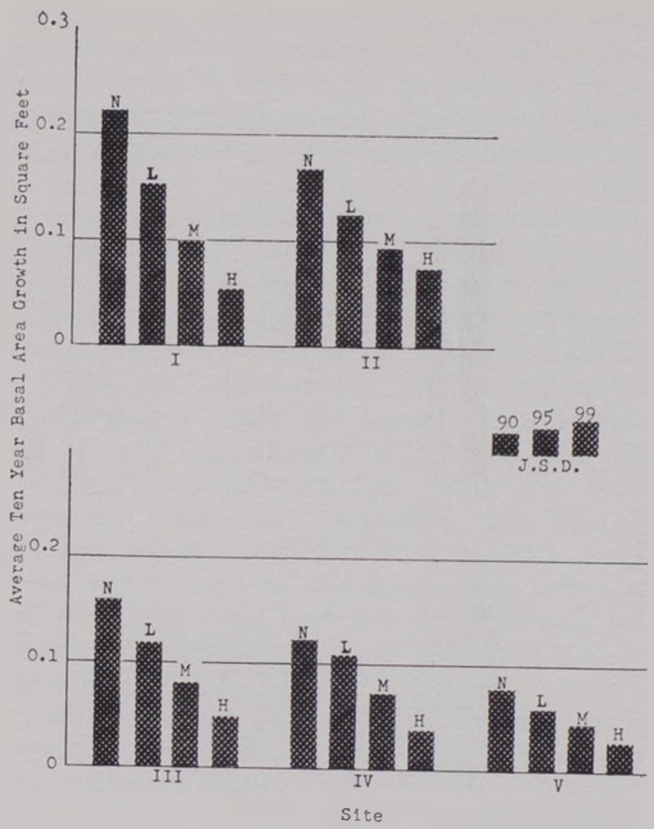
GRAPH 8

Effect of the four main factors upon the basal area growth of larch

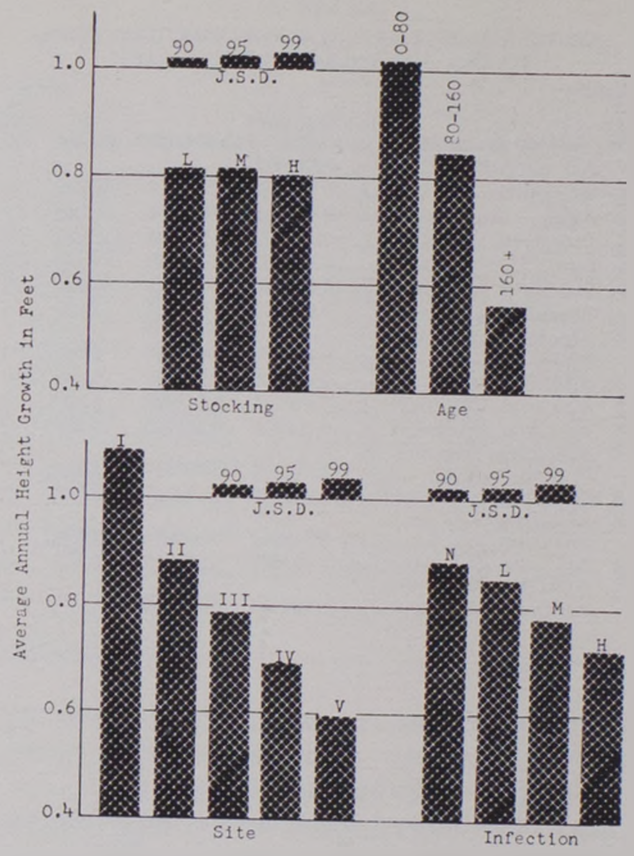


GRAPH 9

Effect of the interaction of stocking and infection upon the basal area growth of larch



GRAPH 10
Effect of the interaction of site and infection upon the basal area growth of larch



GRAPH 11
Effect of the four main factors upon the height growth of larch

14.2 per cent for the low infection level and a reduction of 41.1 per cent and 68.8 per cent respectively for infection levels of medium and heavy.

The standard error of the estimate is ± 0.0103 square feet. The variation in the growth at any level of infection will fall within 0.0206 square feet either side of the mean 95 per cent of the time. Expressed in per cent of the growth of the uninfected trees, this variation of the infected growth will not be over ± 14.6 per cent at the 95 per cent level of confidence.

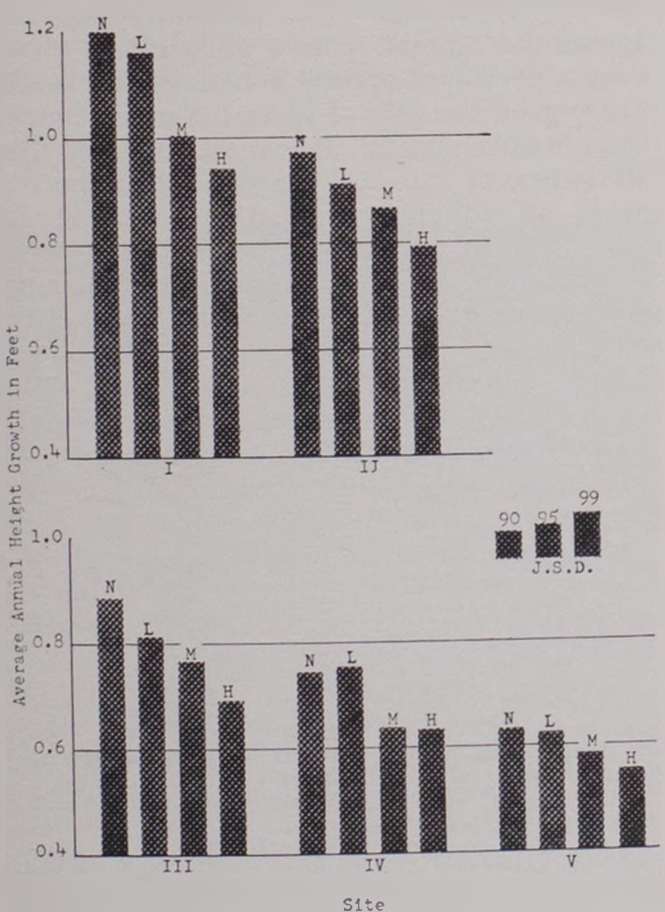
Height growth of larch. Three of the variates, age, infection and site, had highly significant "F" ratios but stocking was not significant. Increasing age reduced the average height growth and a decrease in site quality had the same effect. An increase in infection also resulted in less height growth and the differences between the average height growth for each level of infection are significant. Graph 11 illustrates the relationships for all the main factors.

Significant "F" ratios resulted in four of the first order interactions, and two of these involved infection. The first, site and infection, is just significant. For the second, age and infection, the "Null Hypothesis" breaks down at the 99 per cent level of confidence. A separate "F" test between the variance of both of these interactions and the

TABLE VI
ANALYSIS OF VARIANCE FOR THE AVERAGE YEARLY HEIGHT GROWTH OF LARCH

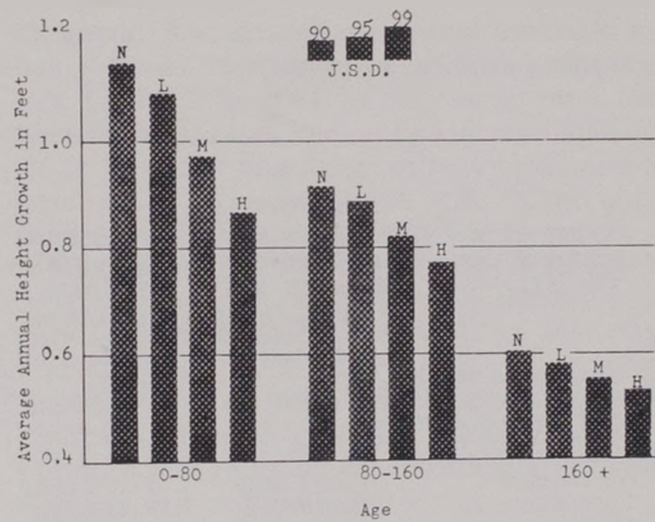
Degrees of Freedom	Source of Variation	Net Sum Squares	Variance	F Ratio	Sig. %
179	All factors	14.27432			
2	Stocking	0.003186	0.001593	0.387	†
2	Age	6.234146	3.117013	756.924	99
3	Infection	0.742371	0.237457	60.092	99
4	Site	5.131827	1.282957	311.548	99
8	Stocking and site	0.392051	0.049006	11.900	99
4	Stocking and age	0.102321	0.025580	6.212	99
6	Stocking and infection	0.009430	0.001572	0.382	†
8	Site and age	0.638129	0.079766	19.370	99
12	Site and infection	0.125454	0.010454	2.539	95
6	Age and infection	0.202082	0.033680	8.179	99
24	Stocking, site and infection	0.041964	0.001748	0.424	†
16	Stocking, site and age	0.307295	0.019206	4.664	99
12	Stocking, age and infection	0.075709	0.006309	1.532	†
24	Age, site and infection	0.070703	0.002946	0.715	†
48	Age, site, stocking and infection	0.197651	0.004118		

variance of infection results in significance in both cases. Graphs 12 and 13 illustrate the relationship between the average height growths for the various levels of infection under different sites and ages. In applying the "t" test to the differences between these averages, they are not found to be significant in all cases. Between none and light infection for site IV a reversal of the trend occurs.



GRAPH 12
Effect of the interaction of site and infection upon the height growth of larch

As with Douglas fir, the effect of the mistletoe upon height growth is spread over the entire life of the trees, greatly minimizing its effect. It is not thought that these significant interactions would occur with the greater growth variations resulting if the average height growth had been determined for the past ten years. With the second order interactions only that of stocking, site and age is significant.



GRAPH 13
Effect of the interaction of age and infection upon the height growth of larch

II. CONCLUSIONS

The analyses of the diameters of the sample trees, both Douglas fir and larch, has proven that the smaller size of the trees is caused by the parasite. This reduction occurs regardless of the age of the tree, stocking of the stand, or the growth capacity of the soil.

Mistletoe is slow to spread within a stand and each infection point in a tree does not have a rapid growth. Because of this, the levels of infection used in the study have been a long time in developing. Once a tree became infected, its growth slowly reduced as the parasite grew and spread, resulting in a tree today that is smaller than the uninfected neighbor. Variation in the sizes of the trees caused by age, site, or stocking has been accounted for in the analyses.

The analyses of the basal area growth rates have proven that mistletoe causes a reduction and that this adverse effect results regardless of the conditions under which the tree is growing.

A reduction occurs in the height growth of the trees that are infected with mistletoe but the amount of this loss has not been measured. All that has been proven is, that a reduction does result and that it can be expected under any condition of growth, so the volume losses caused by this parasite will equal or exceed the basal area growth loss. The growth reduction per centages can be used to determine losses for any infected stands, providing the volumes of infected trees falling within each of the three levels of infection have been determined during the volume sampling procedure.

TABLE VII

EXPECTED TEN YEAR BASAL AREA GROWTH FOR DIFFERENT LEVELS OF MISTLETOE INFECTION AND THE STANDARD ERROR OF THESE ESTIMATES

	10 Year Basal Area Growth in Square Feet	
	Douglas fir	Larch
Standard Error of the Estimate	0.0096	0.0103
Growth with the Allowable Variation at the 95% Level of Confidence		
No Infection	0.213 ± 0.020	0.141 ± 0.021
Light Infection	0.184 ± 0.020	0.121 ± 0.021
Medium Infection	0.126 ± 0.020	0.083 ± 0.021
Heavy Infection	0.067 ± 0.020	0.044 ± 0.021
Growth Reduction in Per Cent		
Light Infection	13.66	14.18
Medium Infection	40.96	41.13
Heavy Infection	68.54	68.79

The growth losses resulting from mistletoe, and it is only one of the adverse effects of this parasite on its host, makes it incompatible with profitable management of timber stands composed of Douglas fir and larch. Under normal conditions, per acre growth rates in the forests covered by this study are lower than those found on most of the other commercial forest lands of the nation. The parasite must be eliminated from the present young stands and be completely controlled in all new reproduction that is to form the future crops.

Most of the loss of growth capacity in both species appears to be caused by the brooming from the mistletoe infection. These brooms take up effective crown space. Brooms, regardless of size and density, contribute little or nothing to the tree and use the food produced by this mass of foliage in maintaining the mistletoe and for further expansion of the broom. A tree with a full healthy crown, in addition to several mistletoe brooms, will have a growth rate comparable to that of uninfected trees with crowns similar in size to the healthy portion of the infected tree.

Mistletoe infection in larch, unless near the base of the limb, results in severe pruning. This pruning action robs the tree of part of its crown while at the same time removing the mistletoe in that limb. When such self pruning becomes severe, epicormic branching will result, and in many cases trees made up entirely of this secondary foliage in their lower crowns may be the result of just such action even though they are now mistletoe free. These epicormic branches never reach the size of the original branches, and so the tree never fully regains its capacity for growth. Secondary branches and accumulations of moss can easily be mistaken for mistletoe brooms. Careful observation in mature trees is needed to distinguish the difference.

No satisfactory method of chemical control has been devised so it must come from cutting practices. The parasite does not spread far from a source of infection, even over a period of several years. When stocking is good the rate of spread is much slower than in open stands. It is most desirable that all source of infection be removed from cut areas on which reproduction is being established. If this cannot be done, it is most important to keep the perimeter of the reproduction exposed to mistletoe to a minimum.

Cut over stands. Infected stands of larch or Douglas fir that have been logged without regard to this parasite are now in very poor condition. Mistletoe is growing and spreading rapidly and any chance of these areas regenerating with the infected species is gone unless man steps in and helps. The trees are putting on little growth and are very susceptible to disease and insect attacks.

All remaining timber of the mistletoe infected species must be removed. If any uninfected trees are available and are left as a source of seed they should be checked for the presence of mistletoe at intervals not to exceed five years and this inspection should be repeated over a period of fifteen years or until the trees are removed. If infections are discovered, the entire tree or the infected portion should be removed. Planting will normally be required to restock these areas since many of them are extensive.

The permitter of the treated area should contain a buffer strip free of mistletoe 100 feet wide. If on a slope, the width of this strip across the top should be increased to as much as 300 feet, the width varying with the gradient.

Uncut stands containing mistletoe. If the mistletoe infection in either larch or Douglas fir is light a shelterwood or seed tree cut may be used if all infected trees are removed. The overstory should be logged as soon as reproduction becomes established or checked every five years for infections if left for longer periods. A shelterwood cut with intolerant larch should have the overstory removed as soon as the new crop becomes established. On many sites this species is not wind firm. In such areas clear cutting is the recommended practice.

In logging heavily infected stands, all mistletoed trees should be removed. If the smaller infected trees are not large enough to be merchantable an investment should be made to have them cut and disposed of with the slash. With the younger stands it may be more profitable or even necessary to hold them until a pulp market develops and more of this small timber can be sold.

Regardless of the severity of the infection, the stand should not be touched until all infected trees can be removed. A mistletoe free buffer zone will be needed around the area to be reproduced unless a tree species other than the one infected is desired as reproduction. The mistletoe will infect only the host species upon which it is found.

Maximum disturbance of the duff layer covering the soil, accomplished during logging and slash disposal, will aid in securing reproduction. On severe south and west slopes, where summer soil temperatures can become critical to seedling survival, maintaining an even distribution of slash without disposal can reduce mortality.

FIGURE 2
Larch with no infection

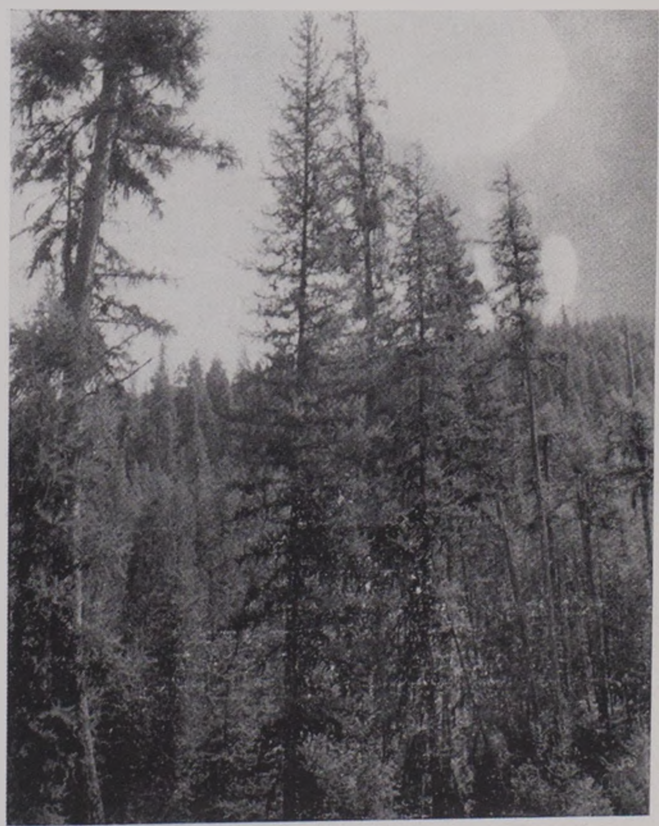


FIGURE 3
Larch with light infection

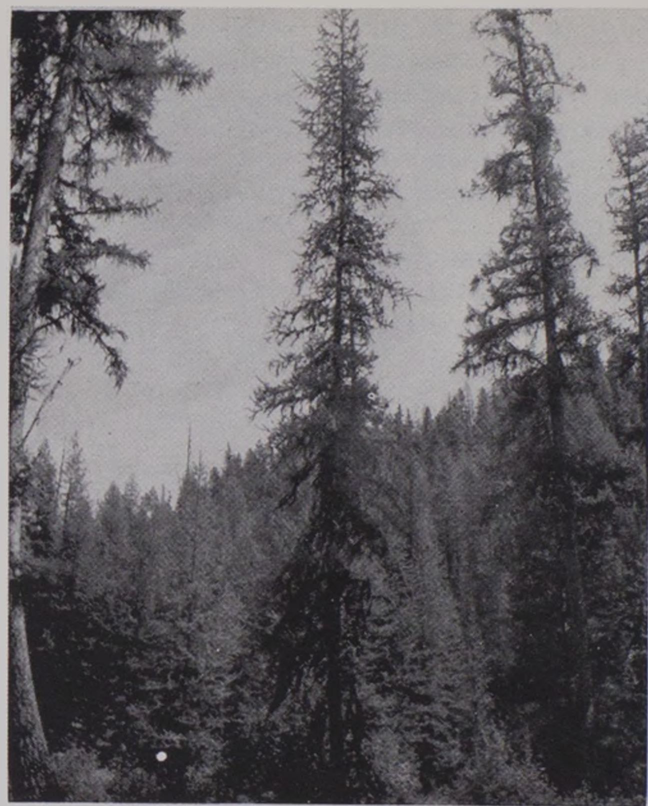


FIGURE 4
Larch with medium infection

FIGURE 5
Larch with heavy infection

FIGURE 6

Larch sections taken 4.5 feet above the ground

Section 1. Cut from the tree in FIGURE 2. Basal area growth during the preceding 10 years was 0.217 square feet.

Section 2. Cut from the tree in FIGURE 3. Basal area growth during the preceding 10 years was 0.152 square feet, 30 per cent less than the growth of the tree without any infection.

Section 3. Cut from the tree in FIGURE 4. Basal area growth during the preceding 10 years was 0.125 square feet, 42 per cent less than the growth of the tree without any infection.

Section 4. Cut from the tree in FIGURE 5. Basal area growth during the preceding 10 years was 0.76 square feet, 65 per cent less than the growth of the tree without any infection.

All four trees were located within 200 feet of each other, in light stocking, on site II and were 65 years of age.

FIGURE 7
Staminate and Pisilate mistletoe in Larch

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Appendix

TABLE VIII

DIAMETERS INSIDE BARK IN INCHES FOR DOUGLAS FIR

Site	Infection	Stocking: Light, Age 1	2	3	Medium, Age 1	2	3	Heavy, Age 1	2	3
II	None	10.8	13.0	25.6	10.6	18.4	21.0	11.1	19.5	19.8
	Light	10.6	18.4	27.0	9.4	16.7	17.9	12.4	18.2	25.1
	Medium	8.4	13.6	20.9	9.5	13.8	26.1	12.4	24.2	23.7
	Heavy	7.3	11.3	21.9	5.8	12.4	20.8	10.2	22.9	19.9
III	None	13.8	13.6	28.3	10.6	16.2	16.3	6.5	15.8	24.6
	Light	14.4	13.5	20.4	9.3	16.5	17.0	9.9	16.5	23.5
	Medium	9.5	11.9	23.7	6.8	14.1	14.2	7.7	15.4	17.7
	Heavy	9.4	9.7	17.1	6.5	16.4	13.4	5.6	17.3	23.6
IV	None	6.0	17.7	19.5	9.3	11.1	19.1	6.1	11.1	15.1
	Light	8.7	12.0	27.2	7.8	11.3	18.8	5.9	10.0	12.5
	Medium	9.0	15.0	18.4	10.6	10.8	16.6	5.2	9.6	15.1
	Heavy	6.2	14.5	19.0	8.4	11.6	13.6	5.2	10.9	14.9
V	None	5.8	16.9	14.7	9.0	5.4	14.4	6.3	9.1	14.1
	Light	6.3	14.2	13.3	7.7	7.2	12.5	6.0	7.5	11.6
	Medium	7.4	13.9	12.7	7.4	7.3	15.1	7.3	7.0	7.7
	Heavy	5.5	10.7	12.7	9.5	8.4	14.4	5.9	6.6	7.0

TABLE IX

TEN YEAR BASAL AREA GROWTH OF DOUGLAS FIR IN SQUARE FEET

Site	Infection	Stocking: Light, Age 1	2	3	Medium, Age 1	2	3	Heavy, Age 1	2	3
II	None	.266	.187	.277	.244	.148	.330	.238	.214	.193
	Light	.225	.260	.130	.224	.288	.062	.226	.103	.221
	Medium	.170	.120	.204	.119	.074	.303	.221	.103	.093
	Heavy	.075	.032	.057	.035	.045	.041	.066	.048	.152
III	None	.405	.291	.477	.254	.210	.195	.136	.219	.386
	Light	.205	.267	.337	.116	.088	.119	.190	.133	.251
	Medium	.101	.189	.161	.091	.089	.139	.090	.135	.123
	Heavy	.089	.114	.156	.016	.079	.045	.013	.099	.085
IV	None	.184	.423	.263	.221	.238	.334	.091	.144	.108
	Light	.236	.221	.193	.113	.298	.257	.055	.101	.165
	Medium	.154	.344	.129	.096	.141	.209	.055	.054	.067
	Heavy	.081	.167	.058	.119	.079	.100	.044	.010	.027
V	None	.132	.333	.201	.170	.066	.158	.079	.053	.090
	Light	.131	.269	.199	.120	.086	.146	.046	.051	.085
	Medium	.086	.197	.179	.101	.051	.041	.070	.019	.042
	Heavy	.033	.066	.191	.081	.023	.052	.029	.013	.048

TABLE X

TEN YEAR BASAL AREA GROWTH OF DOUGLAS FIR AS DETERMINED BY CORRELATION AND THE STANDARD ERROR OF THIS ESTIMATE

Average Infection Levels in Per Cent	Average Basal Area Growth in Square Feet	Calculated Growth in Square Feet	Growth Reduction in Per Cent
0	0.221	0.213	
16.7	0.173	0.184	13.7
50.0	0.127	0.126	41.0
83.3	0.069	0.067	68.5

Gross sum squares of infection	9,717.78
Gross sum squares of growth	0.0997
Gross sum products	14,986.80
Mean of infection	37.50
Mean of growth	0.1475
Standard deviation of infection	36.93
Standard deviation of growth	0.065
Coefficient of correlation	-0.99
Coefficient of regression	-0.00175
Student's "t" for the coefficient of regression	11.49
Level of significance of the coefficient of regression in per cent	99
Standard error of the estimate	0.00975

TABLE XI

AVERAGE YEARLY HEIGHT GROWTH OF DOUGLAS FIR IN FEET

Site	Infection	Stocking: Light, Age 1	2	3	Medium, Age 1	2	3	Heavy, Age 1	2	3
II	None	1.300	.600	.758	1.200	.857	.750	1.364	.800	.765
	Light	1.300	.630	.735	1.260	.815	.722	1.308	.767	.875
	Medium	1.222	.367	.727	.846	.704	.675	1.167	.700	.765
	Heavy	.818	.448	.658	.615	.704	.575	.800	.733	.647
III	None	1.250	.938	.711	1.000	.700	.688	1.000	.724	.625
	Light	1.000	.778	.553	1.000	.700	.618	1.091	.733	.625
	Medium	.929	.812	.650	.786	.633	.571	.909	.815	.575
	Heavy	.800	.706	.583	.533.	633	.406	.727	.679	.575
IV	None	.810	.773	.618	.846	.882	.559	.917	.800	.512
	Light	.800	.789	.618	.667	.636	.529	.750	.700	.419
	Medium	.600	.636	.588	.867	.591	.500	.750	.722	.432
	Heavy	.407	.591	.486	.692	.625	.529	.583	.500	.372
V	None	.800	.667	.469	.917	.500	.351	.714	.500	.500
	Light	.800	.667	.438	.833	.368	.351	.714	.500	.469
	Medium	.550	.611	.406	.692	.412	.333	.643	.450	.406
	Heavy	.417	.588	.438	.667	.368	.316	.615	.400	.375

TABLE XII

DIAMETERS INSIDE BARK IN INCHES FOR LARCH

Site	Infection	Light Age 1	Light Age 2	Light Age 3	Stocking Medium Age 1	Stocking Medium Age 2	Stocking Medium Age 3	Heavy Age 1	Heavy Age 2	Heavy Age 3
I	None	9.3	13.7	23.8	9.5	12.5	24.0	9.8	10.9	24.5
	Light	10.4	13.4	21.4	8.5	11.8	20.4	8.9	10.6	19.5
	Medium	9.8	10.3	17.3	8.0	11.3	19.4	9.6	13.5	19.2
	Heavy	6.3	9.6	13.4	6.0	12.0	22.3	9.2	9.4	18.6
II	None	10.5	14.3	20.5	6.4	16.4	21.9	8.5	10.1	16.0
	Light	10.0	12.8	16.8	7.2	19.2	22.3	7.0	10.5	15.6
	Medium	8.9	15.8	14.2	6.3	12.1	19.1	6.8	8.0	13.3
	Heavy	7.8	11.6	21.6	5.9	14.2	23.3	5.2	9.9	14.0
III	None	7.2	13.4	21.6	10.0	12.5	16.9	7.4	14.3	19.3
	Light	7.6	13.7	18.7	8.4	10.0	14.4	5.1	11.3	18.1
	Medium	7.2	14.6	19.7	7.8	10.7	13.9	5.4	12.4	15.0
	Heavy	5.8	12.3	17.9	6.3	8.2	14.5	5.0	9.7	15.5
IV	None	6.5	12.5	23.2	5.4	12.0	15.1	6.1	7.9	13.8
	Light	5.9	11.3	17.7	4.6	11.7	14.5	6.9	8.3	13.3
	Medium	5.8	10.6	18.4	4.8	13.3	13.4	5.0	7.2	10.4
	Heavy	4.6	10.3	17.2	4.1	8.8	12.1	5.6	7.3	12.8
V	None	7.5	10.4	12.9	5.6	6.2	13.8	7.2	6.3	15.6
	Light	5.3	11.1	13.2	5.3	5.4	12.2	7.6	5.3	15.0
	Medium	6.1	9.3	13.5	4.5	5.6	10.4	6.0	6.7	14.6
	Heavy	4.1	8.5	12.6	4.1	5.5	8.4	6.7	4.8	14.9

TABLE XIII

TEN YEAR BASAL AREA GROWTH OF LARCH IN SQUARE FEET

Site	Infection	Light Age 1	Light Age 2	Light Age 3	Stocking Medium Age 1	Stocking Medium Age 2	Stocking Medium Age 3	Heavy Age 1	Heavy Age 2	Heavy Age 3
I	None	.192	.231	.382	.174	.332	.247	.091	.111	.242
	Light	.185	.159	.228	.130	.139	.188	.075	.123	.146
	Medium	.115	.072	.136	.107	.079.	097	.057	.097	.136
	Heavy	.058	.025	.096	.049	.059	.077	.034	.030	.060
II	None	.274	.176	.302	.081	.190	.128	.119	.130	.112
	Light	.178	.135	.245	.091	.168	.106	.081	.057	.067
	Medium	.144	.151	.106	.075	.127	.079	.062	.050	.054
	Heavy	.049	.079	.172	.033	.147	.061	.026	.077	.024
III	None	.137	.197	.131	.196	.237	.136	.077	.199	.133
	Light	.113	.217	.072	.123	.117	.128	.027	.145	.121
	Medium	.060	.130	.051	.084	.152	.072	.021	.090	.067
	Heavy	.046	.094	.035	.037	.058	.069	.016	.025	.063
IV	None	.083	.211	.214	.053	.191	.074	.081	.109	.086
	Light	.065	.113	.206	.042	.162	.129	.090	.087	.077
	Medium	.066	.119	.143	.030	.057	.068	.049	.076	.043
	Heavy	.041	.083	.075	.011	.017	.017	.034	.046	.025
V	None	.080	.206	.077	.041	.050	.097	.037	.061	.050
	Light	.045	.135	.070	.027	.028	.093	.030	.051	.048
	Medium	.042	.114	.052	.023	.027	.071	.018	.038	.022
	Heavy	.013	.103	.030	.015	.010	.025	.019	.025	.013

TABLE XIV

TEN YEAR BASAL AREA GROWTH OF LARCH AS DETERMINED BY CORRELATION AND THE STANDARD ERROR OF THIS ESTIMATE

Average Infection Levels in Percent	Average Basil Area Growth in Square Feet	Calculated Growth in Square Feet	Growth Reduction in Percent
0	0.150	0.041	
16.7	0.112	0.121	14.2
83.3	0.049	0.044	68.8
50.0	0.078	0.083	41.1

Gross sum squares of infection	9,717.78
Gross sum squares of growth	0.0435
Gross sum products	9.852
Mean of infection	37.50
Mean of growth	0.0972
Standard deviation of infection	36.93
Standard deviation of growth	0.044
Coefficient of correlation	-0.97
Coefficient of regression	-0.00116
Student's "t" for the coefficient of regression	7.183
Level of significance of the coefficient of regression in per cent	98
Standard error of the estimate	0.0103

TABLE XV

AVERAGE YEARLY HEIGHT GROWTH OF LARCH IN FEET

Site	Infection	Light Age 1	Light Age 2	Light Age 3	Stocking Medium Age 1	Stocking Medium Age 2	Stocking Medium Age 3	Heavy Age 1	Heavy Age 2	Heavy Age 3
I	None	1.600	1.222	.838	1.700	1.294	.738	1.492	1.235	.727
	Light	1.600	1.235	.811	1.700	1.167	.714	1.338	1.176	.705
	Medium	1.500	1.059	.800	1.300	1.167	.690	1.333	1.176	.636
	Heavy	1.300	.941	.743	1.000	1.167	.643	1.133	.947	.591
II	None	1.400	.923	.788	1.190	.917	.652	1.277	1.050	.538
	Light	1.349	.846	.794	1.083	.962	.630	1.154	.864	.520
	Medium	1.321	.793	.765	1.050	.826	.587	1.000	1.000	.462
	Heavy	1.071	.769	.743	.857	.840	.587	.917	.905	.442
III	None	1.222	.792	.595	1.167	1.000	.556	1.045	1.000	.595
	Light	1.000	1.864	.476	1.077	.842	.545	.923	1.000	.568
	Medium	.900	.760	.512	1.077	.842	.523	.857	.826	.595
	Heavy	.700	.682	.465	.923	.842	.545	.846	.704	.523
IV	None	.867	.654	.479	.909	.773	.552	1.000	.889	.600
	Light	.857	.621	.500	1.000	.818	.548	1.000	.889	.571
	Medium	.733	.552	.417	.855	.607	.476	.818	.778	.514
	Heavy	.600	.621	.409	.800	.615	.455	.909	.722	.571
V	None	.818	.615	.409	.702	.684	.576	.800	.667	.417
	Light	.760	.789	.409	.702	.632	.500	.800	.611	.420
	Medium	.655	.700	.432	.649	.600	.469	.733	.611	.400
	Heavy	.640	.700	.386	.526	.550	.469	.750	.556	.385

TABLE XVI

FORMULAS

Standard Deviation

$$\sigma = \frac{\sqrt{\Sigma X^2 - (\Sigma X)^2/N}}{\sqrt{N - 1}}$$

σ = Standard deviation
X = Individual values of the variable
N = Number of units of the variable
Σ = Summation

Coefficient of Correlation

$$r = \frac{\Sigma XY - N(M_x M_y)}{(N - 1)\ (\sigma_x \sigma_y)}$$

r = Coefficient of correlation
X = Independent variable; average per cent of infected crown for each level of infection
Y = Dependent variable; average growth for each level of infection
N = Number of pairs of variables
M_x = Mean of the values of X
M_y = Mean of the values of Y
σ_x = Standard deviation of the values of X
σ_y = Standard deviation of the values of Y

Coefficient of regression

$$\beta = r\frac{\sigma_y}{\sigma_x}$$

β = Coefficient of regression

Calculated growth

$$Y' = M_y - \beta(M_x - X)$$

Y′ = Calculated growth

Standard Error of the Estimate

$$\sigma_{xy} = \frac{\sqrt{\Sigma(M_y - Y')^2}}{\sqrt{N - 2}}$$

Σ_{xy} = Standard error of the estimate
N = Number of pairs of variables

Test of significance of "β"

$$t = \frac{\beta\sqrt{\Sigma(X - M_x)^2}}{\sigma_{xy}}$$

t = Student's "t"

Least Significant Difference

$$L.S.D. = t\sqrt{\text{Error Variance}\ (1/N + 1/N)}$$

L.S.D. = Least significance difference
t = Student's "t" for a given level of significance with the degrees of freedom in the error variance
N = Number of units comprising the averages being tested