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EPIDEMIOLOGY OF DWARF MISTLETOE

(*ARCEUTHOBIUM AMERICANUM*)

IN ALBERTA

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by

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John A. Muir[1]

INTRODUCTION

The dwarf mistletoe *Arceuthobium americanum* Nutt. is a widespread parasite of lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.) in Alberta and in other regions in western North America (4, 13). Recent studies (1, 10) have shown it to be particularly damaging to immature stands. Silvicultural methods for the control of dwarf mistletoe species have been suggested by several authors (5, 9, 11, 14).

A thorough knowledge of the development of dwarf mistletoe epidemics is a prerequisite for successful control of dwarf mistletoe. Development of dwarf mistletoe epidemics includes processes such as seed production and dispersal from residual trees, seed interception, establishment of infections, and intensification and subsequent spread in young stands. Since information on these processes was generally lacking for dwarf mistletoe in Alberta, several studies of intensification and extent of infection by dwarf mistletoe of young stands were undertaken. Because of the long life-cycle of dwarf mistletoe, these studies were generally based on examinations of dwarf mistletoe epidemics presently established in young stands.

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A preceding report (16) provides information on life cycle and growth habits of the dwarf mistletoe.

EXTENT OF MISTLETOE INFECTION IN A FOREST OF YOUNG LODGEPOLE PINE

A survey was made in 1967 and 1968 to determine the extent of dwarf mistletoe in a young forest of lodgepole pine. Data on the extent of infection by dwarf mistletoe is lacking for most lodgepole pine forests in Alberta. Such data would be useful to determine how much infection had developed in young stands in the absence of control measures, and to predict the amount of damage which would result from the infection.

Methods

The survey was conducted in a 4300 acre forest composed of mature and immature stands located in the Highwood District of the Bow River Provincial Forest (Lat. 50°20'N, long. 114°40'). The forest occupied a north-south oriented valley in the Subalpine Forest Region (17) at an elevation of approximately 5200 to 6500 ft. The immature stands were established after an extensive forest fire in the region in 1936. Scattered infected trees and stands of the mature forest, termed "residual" stands in this report, remained after the fire. They served as sources of infection for the spread of mistletoe into the young stands. In 1967 the average age of the young stands was 27 years, and average height of dominant and co-dominant trees ranged from 6 to 18 ft. in different stands.

The extent of dwarf mistletoe infection was determined on 25.5 acres (ac.) using 18 transects. Each transect was one-quarter chain (ch.) wide and 40 to 60 ch. long. Locations of the transects were randomly selected from a grid of east-west lines at 10 ch. intervals which was superimposed on a map of the area. Nine transects were run on each side of the valley due east or west from a forestry road which ran north-south along the valley bottom.

The extent of residual stands, young stands, and treeless open areas in each transect was recorded. Densities of young stands on the transects were estimated visually, and were used to calculate the net area of young stands. The extent of young infected stands on each transect was measured to the nearest 1 ft. The area within and around the periphery of infected young stands on the transects was examined thoroughly to locate residual infected trees. Areas of healthy young trees on the transects located within 30 ft. of residual infected stands were also recorded. It was assumed these areas of young stands would eventually become infected.

Results

Of the 25.5 ac. within the 18 transects, 72.4 per cent was occupied by young stands, 12.5 per cent by residual stands, and 15.1 per cent was unoccupied by trees. On the east side of the valley, young stands occupied 81.3 per cent and residual stands 9.9 per cent of the area. On the west side, 63.5 and 15.1 per cent of the area were occupied by young and residual stands, respectively.

Twenty-three separate areas of young infected stands were found on eight of the 18 transects, four on each side of the valley. The areas infected are summarized in Table 1. Of the total 13.20 ac. of young stands surveyed, 2 per cent was infected, and 0.80 per cent was potentially infected (i.e. exposed to infected residual trees but not at present infected). On the basis of area per transect, 1.76 per cent and

Table 1. Extent of dwarf mistletoe infection of a young lodgepole pine forest.

Area surveyed and basis	Side of Valley: east	west	Total
Total young tree area	7.28	5.92	13.20
1. infected - acre	0.18	0.085	0.265
" - %	(2.47)[1]	(1.35)[1]	(2.00)[1]
2. potentially[2] infected - acre	0.055	0.051	0.106
" " - %	(0.75)	(0.86)	(0.80)
3. total infected and potentially[2] infected - acre	0.235	0.136	0.371
potentially[2] infected - %	(3.22)	(2.21)	(2.80)
Average area per transect - %			Mean
1. infected	2.06	1.46	1.76
2. potentially[2] infected	0.78	0.91	0.84
3. total infected and potentially infected	2.84	2.37	2.60

[1] Percentages of the respective column totals.

[2] Healthy young tree area on transects within 30 ft. of infected residual trees.

0.84 per cent of the total area were infected and potentially infected respectively. Proportions of infected area per transect ranged from zero to 8.7 per cent. Although the total infected and potentially infected area on the east side of the valley appeared higher than on the west side, differences were not statistically significant on the basis of the average areas per transect.

Of the 23 areas of young infected stands, 19 were located close to infected residual stands. The remaining four areas were located 130 ft. or more from any re-infected residual tree standing or recently fallen. The occurrence of only a few small infections in each of these four areas indicated that the infection occurred recently.

Conclusions

The survey revealed an average 1.76 per cent of the area of young stands is presently infected by dwarf mistletoe and an additional 0.84 per cent is immediately exposed. Substantial damage from dwarf mistletoe infection can be expected on this area (1, 10). Ninety-seven per cent of the infected area of young stands was located close to infected residual trees. Apparently most of the infection of young stands could have been prevented by destroying the infected residual trees (5, 9, 11, 14).

Further enlargment of the infected area can be expected by local spread of dwarf mistletoe, and by long distance spread and establishment of new infection centres. Of the twenty-three infection centres found on the transects, three, amounting to 3 per cent of the total infected area, were located 130 ft. or more distant from any standing or recently fallen infected residual tree. Only a few small infections were found in these centres, indicating their recent establishment. Evidence and possible means of long-distance spread of dwarf mistletoe were discussed by Kuijt (12). Infection centres on the transects were separated by distances of 3 to 30 ch., indicating a high potential for further infection by local or long-distance spread. The area of these exposed but healthy young stands was relatively large in comparison to the presently infected area of young stands. Apparently spread of dwarf mistletoe into a large proportion of young stands was delayed by unknown factors. Other instances of delays of spread of dwarf mistletoe into young stands of jack pine (P. banksiana Lamb.) stands in central Alberta have been observed (2).

SPREAD OF INFECTION FROM RESIDUAL INFECTED TREES

Information was required on the spread and distribution of dwarf mistletoe infections in young stands with respect to infection sources. Previous studies of seed dispersal revealed no finite limit to the distance of seed dispersal from an infection source (16), the average maximum spread was approximately 25 ft. (9), and in stands 8 to 28 years of age there was no correlation between stand age and maximum distance of spread.

Our studies on infection and spread were carried out in the same stands of lodgepole pine previously described.

Methods

Studies were made in three 27 year old stands, two located adjacent to residual stands and one adjacent to a single residual tree.

In these stands all the young trees, to a distance of 60 ft. from the infection sources, were examined thoroughly for dwarf mistletoe infections. Numbers of infections per tree, distances from infected trees to the sources, and ages of infections were determined. Maximum distance of dwarf mistletoe spread was also measured in 21 additional young stands, 19 adjacent to single residual trees and 7 adjacent to residual stands. Direction and distance of spread was measured from single residuals, and from the uniform margins of stands. Spread was not measured from margins of any stands occupying an area less than 200 sq. ft.

Results

The frequency distributions of infections with distance from sources are summarized in Figure 1. All of the frequency distributions resembled "normal" distributions. The distances from infection source at which the greatest number of new infections occurred ranged from 15 to 30 ft., and the maximum distance was 45 ft. In the two stands adjacent to residual infected stands, the maximum distance was 30 ft. and the modes were from 15 to 25 ft. In the young stand adjacent to the single residual tree, the maximum distance was 45 ft. and the mode 26 to 30 ft. The oldest infection was located in the 15 to 20 ft. interval from the residual stands, and in the 35 to 40 ft. interval adjacent to the single residual tree.

Average distance of spread of dwarf mistletoe from residual stands was 27.9 ft., range 14 to 52 ft. This distance of spread was comparable to that found to occur in Montana, Wyoming and Colorado (9). Average spread from single residual trees in the study area was 45.1 ft. with a range of 20 to 74 ft. A "t-test" analysis of the data

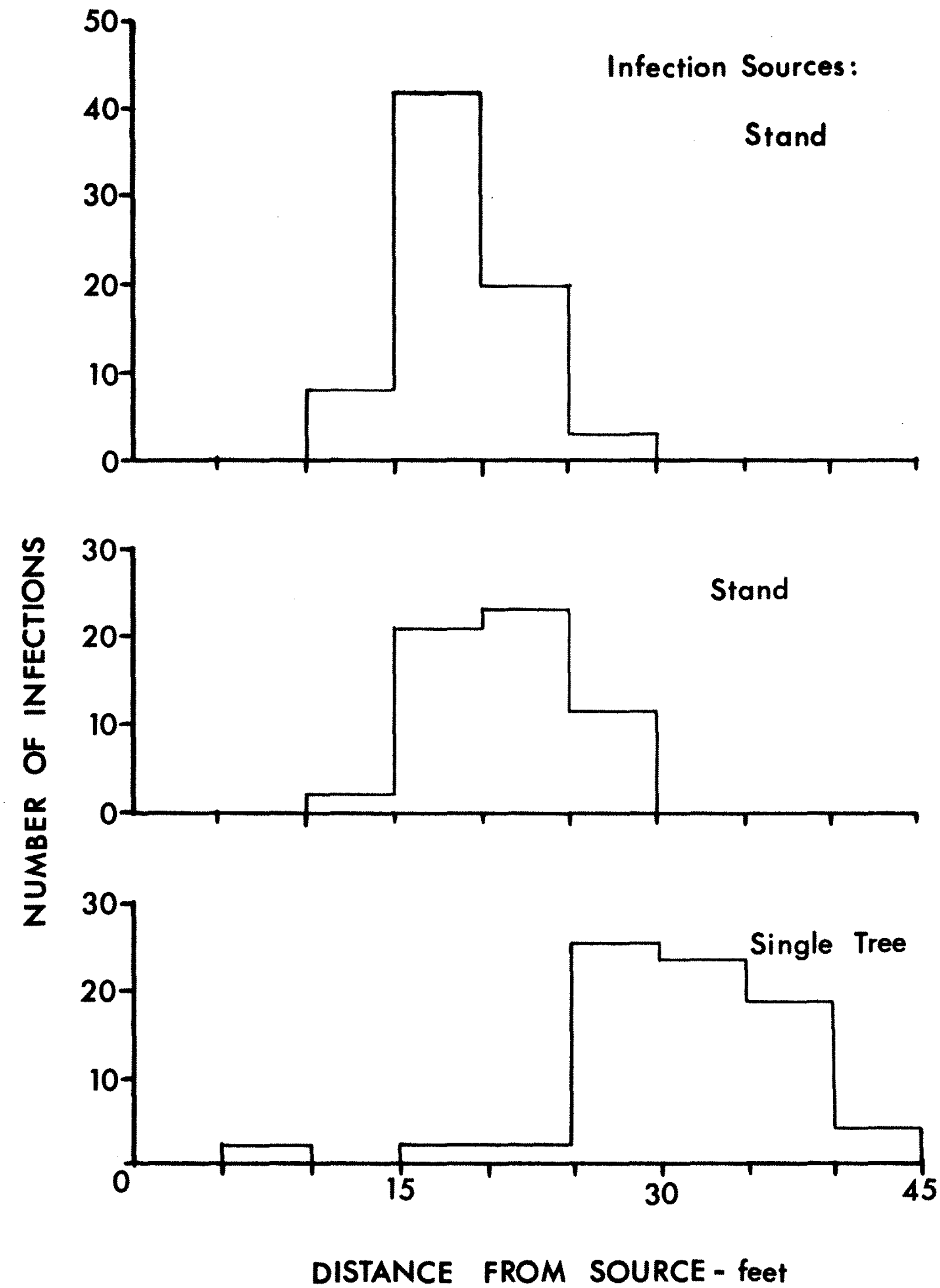

Fig. 1. Distributions of dwarf mistletoe infections in young stands adjacent to residual infected stands and a single residual infected tree.

showed that this distance of spread was significantly greater, at a probability of 0.01, than spread from residual stands.

No consistent differences were found in the spread north, south, east or west from individual residual trees. Spread of dwarf mistletoe from some margins of the residual stands was affected by topographic features such as streams, rock outcrops, or swamps. In several instances where young trees were present adjacent to residual infected stands, no spread of dwarf mistletoe into the young stands had occurred. In other instances where scattered residual trees were located close to the margin of residual stands or where the margin of the stand had been partially logged, distance of spread into the young stands was comparable to that from single residual trees. Spread from these irregular margins was not included in the calculation of average spread from residual stands.

Conclusions

The distributions of infections in the stands were very different from distributions of dwarf mistletoe seed fall previously described (16). Dwarf mistletoe seed fall is characteristically distributed logarithmically with distance; whereas the infections were distributed almost normally. The simplest possible explanation is that the target area (22), composed of young trees, was sparse near the infection sources. Hawksworth and Graham (9) observed that height growth of young trees immediately adjacent to residual stands is suppressed. Observations in the study area also indicated that few young trees were established within 10 ft. of residual trees.

Maximum spread of dwarf mistletoe from the single tree sources was much greater than from the infected residual stands. Because little secondary spread apparently occurs in stands of these ages (9), it was concluded that the distances of spread were the result of seed dispersal from the primary infection sources. Although the causes of differences in spread distance are not known, the greater spread from single trees than from stands likely was caused by a greater number of seed dispersed from the single trees. It has been observed (12) that dwarf mistletoe seed production is greatly stimulated on isolated single trees.

These results indicate control treatments to prevent spread of dwarf mistletoe into young stands should first be applied to widely spaced infected residual trees, and then to dense residual stands. During harvesting of a mature infected stand of lodgepole pine, care should be taken to destroy all residual trees in the clearcut area, and to leave only dense residual stands with straight margins (5). Partial logging of infected residual stands should be avoided, since this breaks up stand margins, isolates trees, and apparently increases spread into adjacent young stands.

INTENSIFICATION OF DWARF MISTLETOE INFECTION IN YOUNG STANDS

The study reported here was carried out in 1965 and 1966 to determine the rate at which dwarf mistletoe infections had increased in occurrence (intensification) in a typical young forest of infected lodgepole pine.

Methods

Ten infected stands were sampled to investigate possible variations of intensification between stands, and between two levels of dwarf mistletoe incidence or intensity. Intensification was estimated by determining the ages of randomly selected dwarf mistletoe infections from each stand. Nine of the ten infected stands were situated 72 miles southwest, and one 50 miles west, of Calgary, Alberta. The stands were located in the Subalpine Forest Region of the Rocky Mountains (17). Fungous parasites of the dwarf mistletoe (13, 15), which could affect the intensification of the dwarf mistletoe, were not found in or near the infected stands. The immature stands were established following an extensive forest fire in 1939. Infected mature trees not destroyed by the fire were sources of dwarf mistletoe spread into the immature stands. The maximum distance of spread from the residual trees was usually about 50 ft. or less. Discrete areas of young infected trees are called "infected stands" in this report.

Seven moderately infected stands were selected for representation of different geographic exposures and infection sources; four were located adjacent to single infected residual trees, and three adjacent to infected residual stands. Two stands had a north exposure, two a west, two a south, and one had an east. Three additional stands having low incidence of dwarf mistletoe (50 to 70 infections per stand) were also utilized. Two of these were located adjacent to residual infected stands, the other adjacent to a single infected residual tree. Geographic exposures were east or west for the two adjacent to residual stands, and level or no exposure for the stand adjacent to the single residual tree.

In the stands with a low incidence of dwarf mistletoe, all infections were tabulated and collected. In the moderately infected stands a 10 ft. by 10 ft. square grid was extended over the total area of each stand. Sampling points were selected randomly at the corners of square grids and approximately 450 infections were collected. At each selected point, all trees within a 5 ft. radius were examined thoroughly for dwarf mistletoe infections. Infections were identified by the occurrence of buds or aerial shoots of the dwarf mistletoe. Dead infections were also tabulated in four of the infected stands to estimate the mortality of infections. All living infections found were labelled, and stored at 35 to 40^{o} F. for a period of 3 weeks or less.

Ages of dwarf mistletoe infections were determined using methods previously described (7, 9, 18). Each infection was cut transversely through the point of initial penetration, judged by the occurrence of seeds with holdfasts, or through the point of maximum swelling. Cross sections thus exposed were dipped briefly into a solution of methylene violet (6), and examined under a binocular dissecting microscope. The age of each infection was determined by counting the number of annual wood rings in which the longest multiseriate rays (sinkers) induced by the dwarf mistletoe (20) were embedded. A period of one or more years lapses between the time of initial penetration and initiation of sinkers (9), but this period was not known for infections in Alberta. Hence ages of infections could not be adjusted.

Results

Age distributions of dwarf mistletoe infections from the stands are shown in Figures 2 and 3. The distributions resembled Poisson distributions with a peak in number of infections at 3 years infection age, and a rapid decrease in numbers at ages greater or less than 3 years.

The data (Figs. 2 and 3) suggest a great reduction occurred in new infections, i.e. few infections were younger than 3 years of age. This apparent infection pattern was constant in stands sampled in 1965, 1966, and in two stands not included in this study, sampled in 1967.

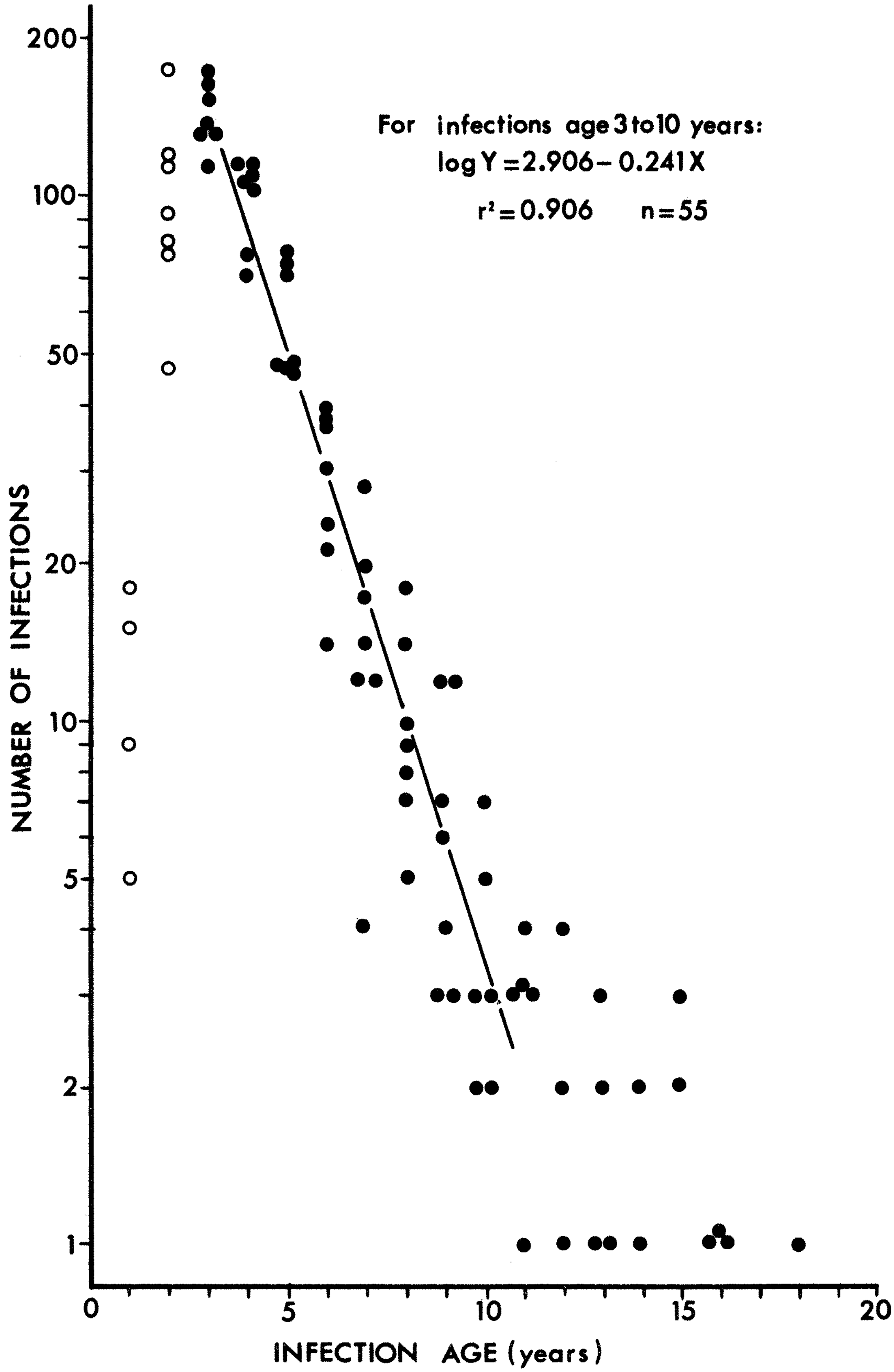

Fig. 2. Age distribution and intensification of dwarf mistletoe infections in seven moderately infected stands.

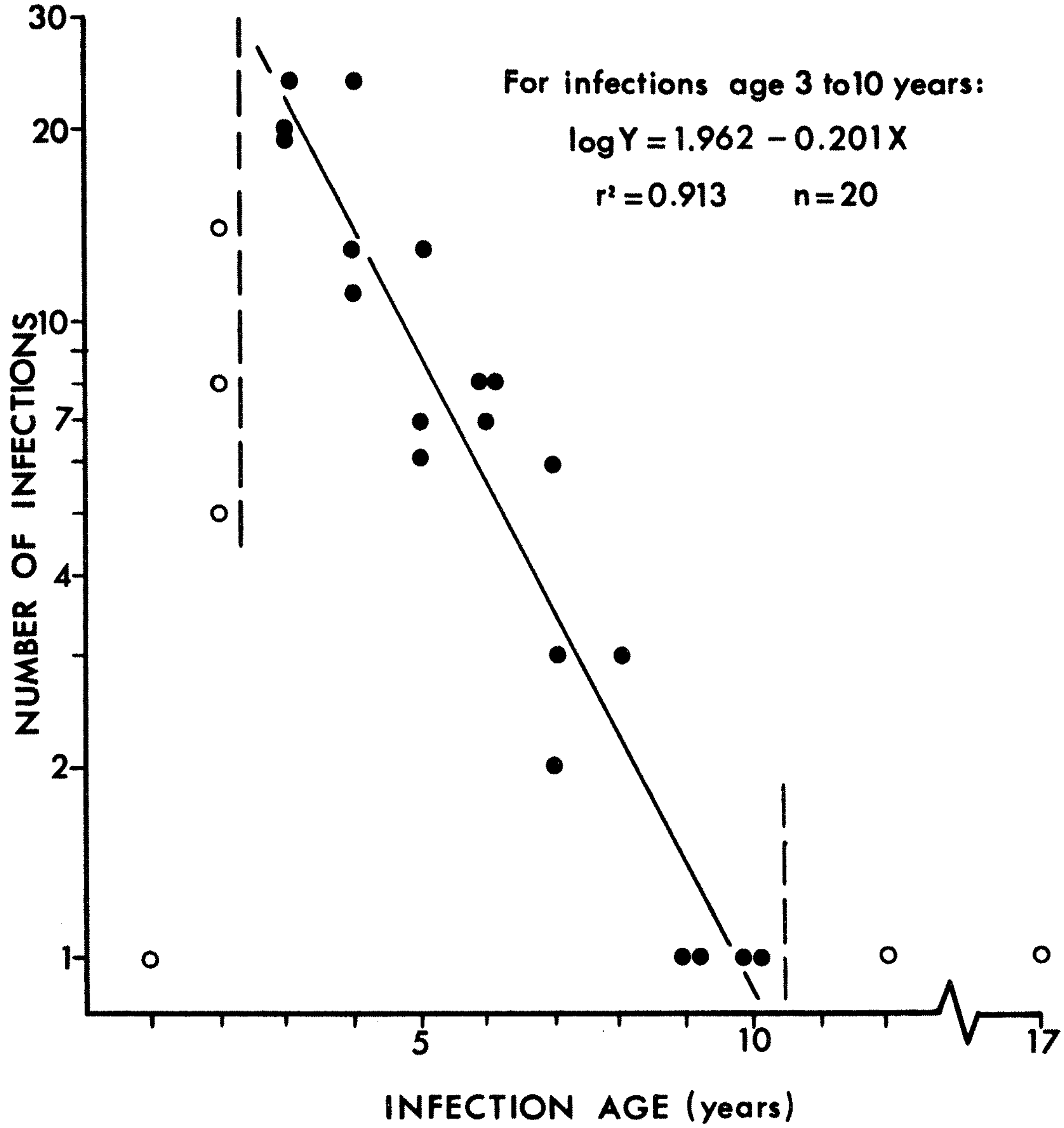

Fig. 3. Age distribution and intensification of dwarf mistletoe infections in three lightly infected stands.

The apparent scarcity of infections less than three years in age, however, was believed the result of the incubation period. Observations (8) in Colorado indicated that the minimum incubation period for the dwarf mistletoe is two years, and other observations (19, 21) indicated that the incubation period could range from two to six years. Infections less than 3 years of age were present but were not recognized and counted.

The observed distributions of infections older than three years were assumed to have resulted primarily from intensification or multiplication of dwarf mistletoe infections. In four of the stands only 2 to 3 per cent of the infections counted were dead, and mortality appeared similarly low in the other stands. To determine the intensification in the stands, distributions of infections between the ages of 3 and 10 years were analyzed. Highly significant linear relationships, at a probability of 0.01, were found between the logarithms of the number of infections and infection age for all of the stands and for the combined observations (Fig. 2 and 3). In other words the number of infections in each stand had increased at a logarithmic or exponential rate.

The logarithmic rates of intensification (slopes of the regressions) of dwarf mistletoe in the seven moderately infected stands ranged from 0.189 to 0.285 with an average rate of 0.241. Analyses of covariance (3), comparing rates in pairs and as a group, showed that there were significant differences between some rates, but there was no significant difference among all the rates considered as a group. Possibly some differences had been obscured by the residual variations of the regressions. Differences in rates were not consistently correlated with any of the geographic or stand conditions recorded.

Rates of intensification in the three lightly infected stands were 0.199, 0.206 and 0.215 with an average rate of 0.205. Covariance analyses showed that the differences between the three rates were not statistically significant, but the average rate, 0.205, was significantly less in the lightly infected stands than in the moderately infected stands.

Discussions and Conclusions

The variation in rates of intensification found in this study could produce large differences in incidence (numbers of infections) of dwarf mistletoe in young stands. For example, if equal numbers of infections were initially present in two stands but the rate of increase in one was 0.201 and in the other 0.241, then after twenty years intensification the number of infections in the stand with a rate of increase of 0.201 would be about 10 per cent of the number of infections in the other stand. Another factor affecting incidence is the length of time that a young stand has been infected. Dowding (2) observed that spread of dwarf mistletoe from residual stands into adjacent young stands of jack pine had occasionally been delayed by unknown factors. Similar delays of spread were also observed in some young stands of lodgepole pine during this study.

The logarithmic increase of dwarf mistletoe infections revealed by this study should be considered if young infected stands are treated to eradicate dwarf mistletoe. The logarithmic intensification rate and a long incubation period of dwarf mistletoe infections result in a large proportion of invisible infections, i.e. infections established but currently without symptoms. For example, assume that infections are established at a rate of 175 per cent per year, which corresponds to a logarithmic rate of 0.242, and that the incubation period of infections is two years. Then the number of infections present but without symptoms would be slightly more than double the number present with symptoms.

It is evident present techniques of pruning or thinning young infected stands to eradicate dwarf mistletoe must be re-examined. Because of the large proportion of invisible infections and the difficulties in detecting small infections with visible infections, it seemd probable that a large proportion of infections will be missed during first treatment. Treatments must be repeated at frequent intervals to eradicate new or overlooked infections before they produce seed. Although the repeated treatments are costly and their effectiveness is uncertain at present, this method of eradication may be needed under certain conditions. Trials of several control methods have recently begun in Alberta and elsewhere, and they should provide much useful information. Another method of dwarf mistletoe eradication in young stands, which might be practicable on good sites, would be to destroy all young trees located within the range of seed dispersal, approximately 33 ft. (2, 5), from presently infected trees, and to restock the area by planting new trees.

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