DWARF MISTLETOES IN BRITISH COLUMBIA

AND RECOMMENDATIONS FOR THEIR CONTROL

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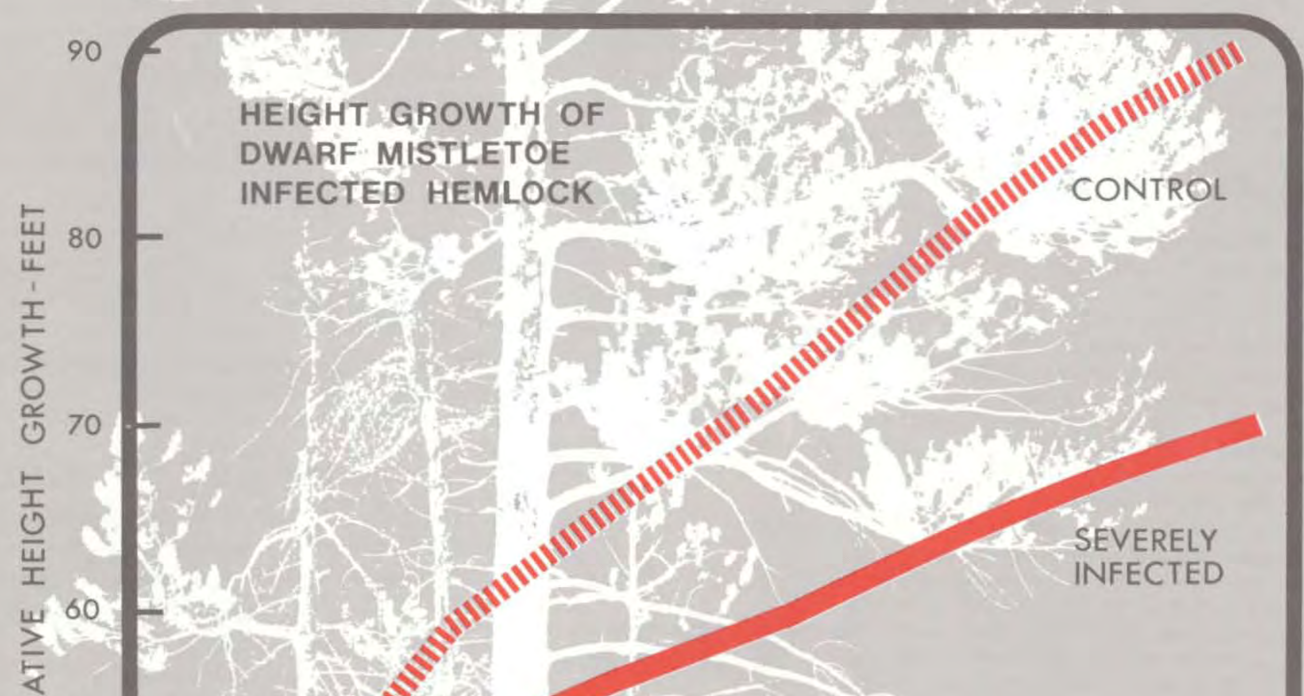

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AND RECOMMENDATIONS FOR THEIR CONTROL

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PACIFIC FOREST RESEARCH CENTRE

506 WEST BURNSIDE ROAD

VICTORIA, BRITISH COLUMBIA

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introduction

Dwarf mistletoes, *Arceuthobium* spp. (Viscaceae), a group of flowering plants parasitic on a wide variety of conifers, are found in Africa, Europe, Asia, North and Central America and the West Indies. Most of the 28 species cause extensive damage in wood production in North America, particularly in Mexico, western United States and in western Canada.

In British Columbia, the volume loss caused by this parasite annually is about 150 million cu ft of western hemlock and lodgepole pine, a quarter of the annual cut of these species. Only losses to decay fungi are greater; however, the gradual depletion of old growth forests is placing decay fungi second to dwarf mistletoes in economic importance.

There are four species of dwarf mistletoes in British Columbia:

- lodgepole pine dwarf mistletoe (*Arceuthobium americanum* Nutt. ex Engelm.)
- hemlock dwarf mistletoe (*A. tsugense* (Rosendahl) G. N. Jones)
- larch dwarf mistletoe (*A. laricis* (Piper) St. John)
- Douglas-fir dwarf mistletoe (*A. douglasii* Engelm.)

hosts and distribution

Tree species are classified as principal, secondary, occasional or rare hosts, based on their relative susceptibility to dwarf mistletoes. Most damage occurs on the principal hosts. Occasional and rare hosts are infrequently attacked and should be favored, along with resistant species, in areas where direct dwarf mistletoe control is not feasible. They are, however, capable of producing dwarf mistletoe seeds which can carry infection to principal and secondary hosts.

Table I shows the hosts of dwarf mistletoes in British Columbia.

Lodgepole pine dwarf mistletoe is broadly distributed in the central-western and northwestern United States and in western Canada. In Canada, it extends from the summit of the Coast Range in British Columbia (13) to Lac Seul, Ontario (on jack pine) (21). The most northerly occurrence is at Athabasca Lake, Alberta (13). The disease is widely distributed in British Columbia (15, 16) (Fig. 1). The area north of Clinton to Prince George, extending westward to Anahim Lake in the Chilcotin, and the region south of Spillimacheen in the Columbia River Valley to the border contains the most severely attacked lodgepole pine stands in western Canada. The high disease incidence is the result of a particular pattern of wildfires in which are left patches of infected trees.

Hemlock dwarf mistletoe occurs commonly from Haines, Alaska to central California. In British Columbia, its range is restricted to the west coast islands and to the seaward side of the Coast Range (Fig. 2). Stands on the Queen Charlotte Islands, northern Vancouver Island, Texada Island and on the mainland in the vicinity of Prince Rupert and Vancouver seem to be the most heavily infected, due to the paucity of wildfires and to early selective logging methods. For unknown reasons, **hemlock stands of the Interior Wet Belt are free of infection.**

The range of larch dwarf mistletoe is restricted to northwestern United States and to southeastern British Columbia. In British Columbia, it occurs in the Osoyoos, St. Leon (Upper Arrow Lake), Moyie triangle. Mixed larch and lodgepole pine stands are heavily infected around Trail, in the Valhalla Mountains and in the Creston-Kimberley area. The disease has not been detected in a 40 to 45-mile-wide strip on both sides of the above-mentioned area (Fig. 2).

Douglas-fir dwarf mistletoe ranges from southern British Columbia to central Mexico. It has the most restricted distribution of the species found in British Columbia (Fig. 3). Heavily infected stands are concentrated in the Okanagan and Similkameen valleys and in the Creston area. Isolated infected stands occur near Lytton, Sicamous and Rossland. **Douglas-fir mistletoe does not occur in our coastal forests.**

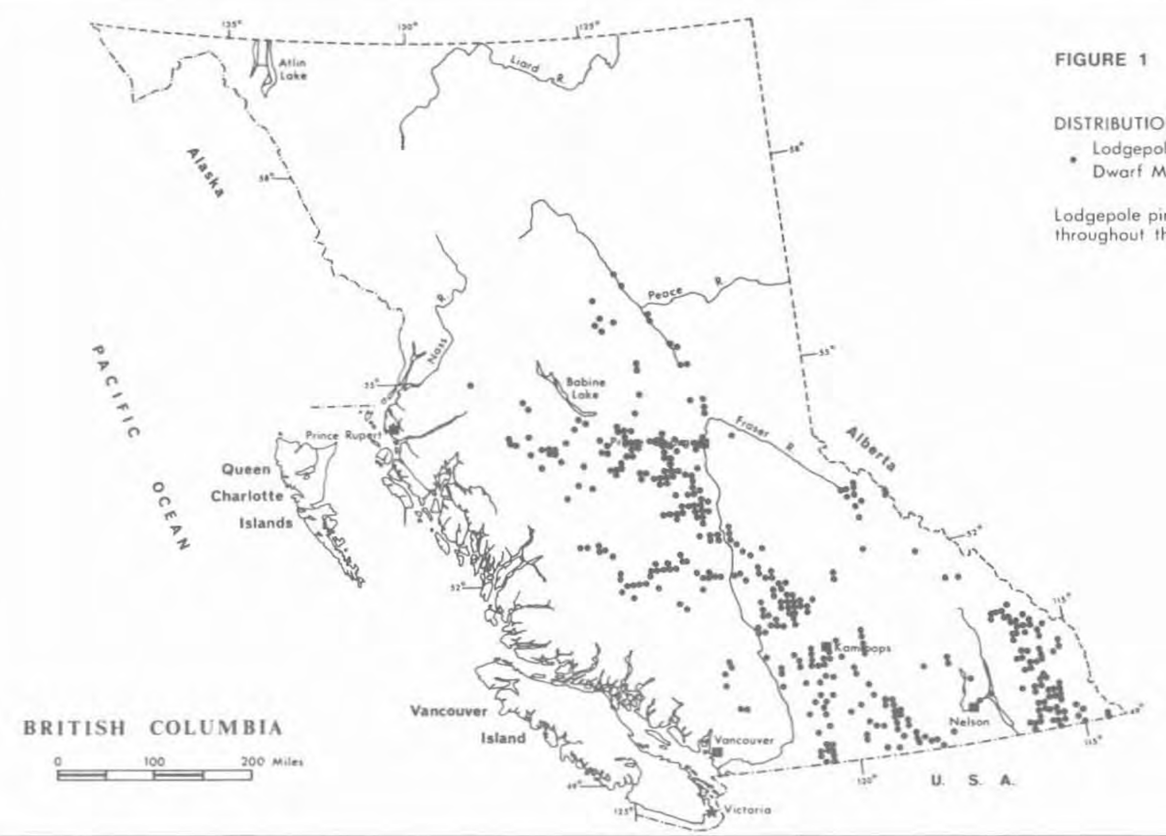


FIGURE 1

DISTRIBUTION OF • Lodgepole Pine Dwarf Mistletoe

Lodgepole pine is present throughout the province.

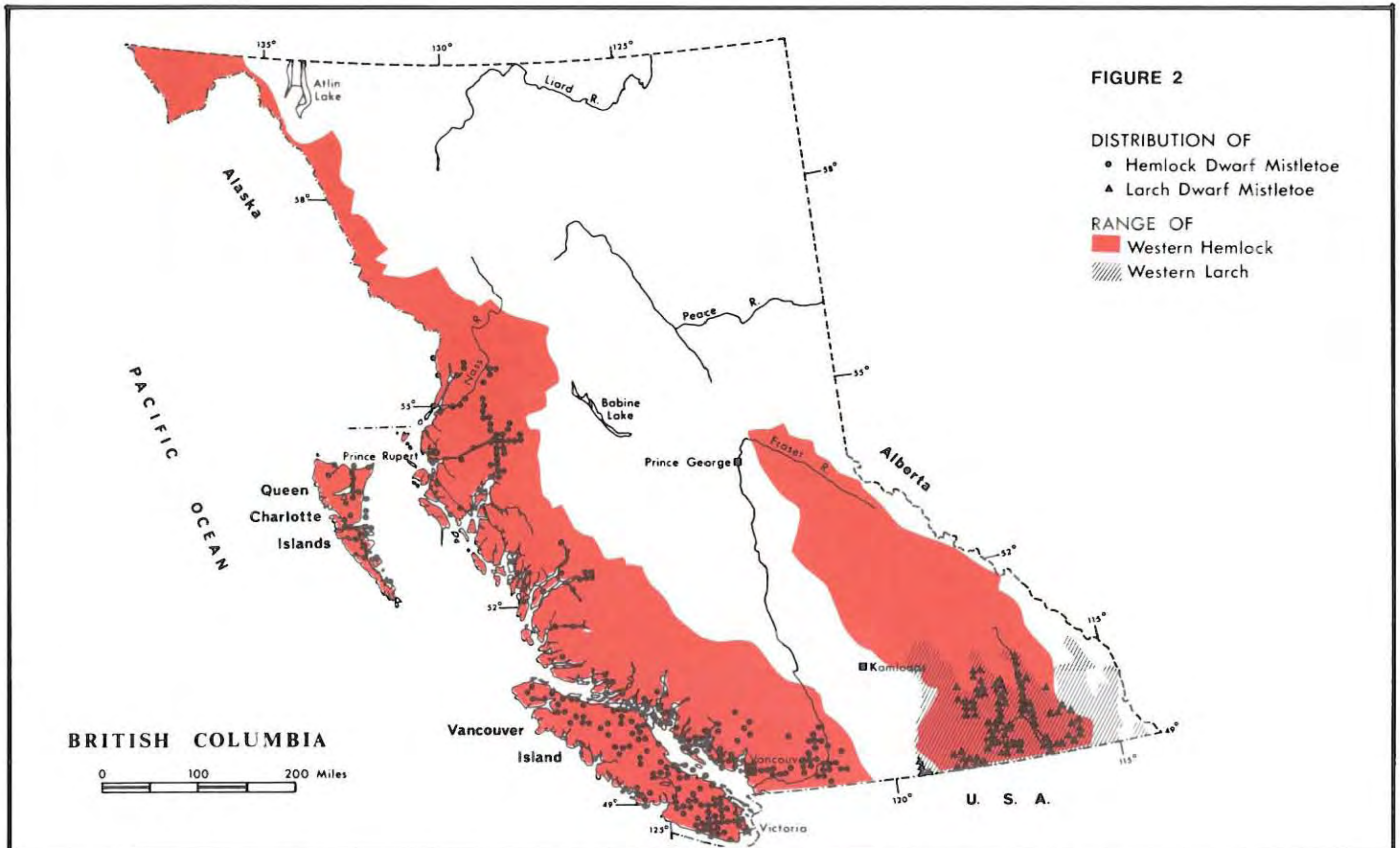


FIGURE 2
DISTRIBUTION OF
Hemlock Dwarf Mistletoe
Larch Dwarf Mistletoe
RANGE OF
Western Hemlock
Western Larch
Atlin Lake
Liard R.
Alaska
Peace R.
Nass R.
Babine Lake
Prince Rupert
Prince George
Fraser R.
Alberta
PACIFIC OCEAN
Queen Charlotte Islands
Kamloops
Vancouver Island
Vancouver
Victoria
U. S. A.
BRITISH COLUMBIA
0 100 200 Miles

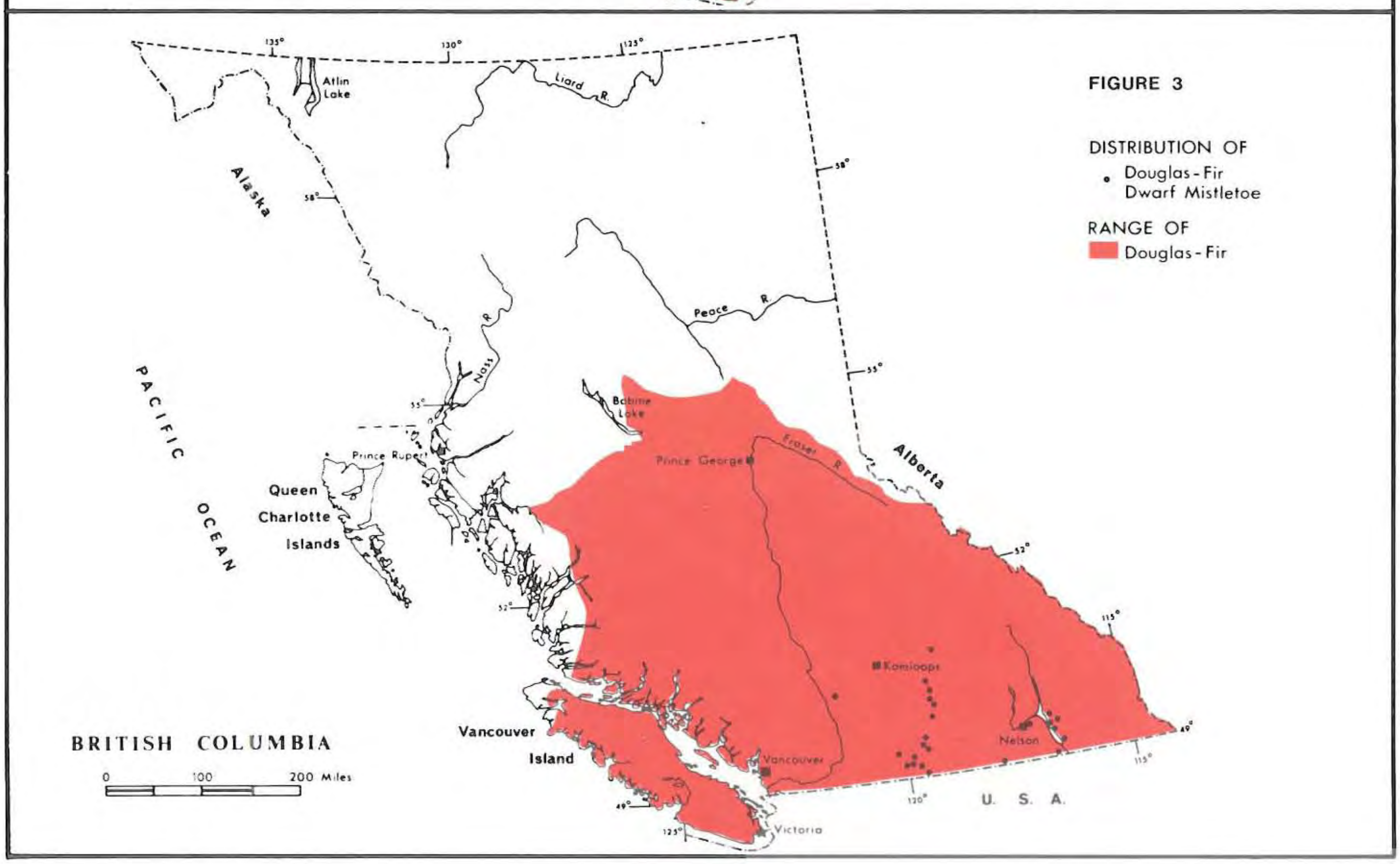


FIGURE 3
DISTRIBUTION OF
Douglas-Fir Dwarf Mistletoe
RANGE OF
Douglas-Fir
Atlin Lake
Liard R.
Alaska
Peace R.
Nass R.
Babine Lake
Prince Rupert
Prince George
Fraser R.
Alberta
PACIFIC OCEAN
Queen Charlotte Islands
Kamloops
Nelson
Vancouver Island
Vancouver
Victoria
U. S. A.
BRITISH COLUMBIA
0 100 200 Miles

TABLE I. Dwarf Mistletoes of British Columbia and Their Hosts

Dwarf mistletoe	Common name	Occurrence	Natural hosts			Useful resistant species
			Principal	Secondary	Occasional or rare	
Arceuthobium americanum	Lodgepole pine dwarf mistletoe	Interior	Lodgepole pine 1/	Ponderosa pine	White spruce Engelmann spruce	Douglas-fir Alpine fir Western larch
Arceuthobium tsugense	Hemlock dwarf mistletoe	Coast	Western hemlock Mountain hemlock	Lodgepole pine (Shore pine) Pacific silver fir	Sitka spruce Grand fir Alpine fir White pine Engelmann spruce	Douglas-fir Western red cedar
Arceuthobium laricis	Larch dwarf mistletoe	Southeastern interior	Western larch	Lodgepole pine Alpine larch	Ponderosa pine White pine Engelmann spruce Alpine fir Grand fir	Douglas-fir Western red cedar Western hemlock
Arceuthobium douglasii	Douglas-fir dwarf mistletoe	Extreme southern interior	Douglas-fir		Grand fir Engelmann spruce	Ponderosa pine Western larch Lodgepole pine

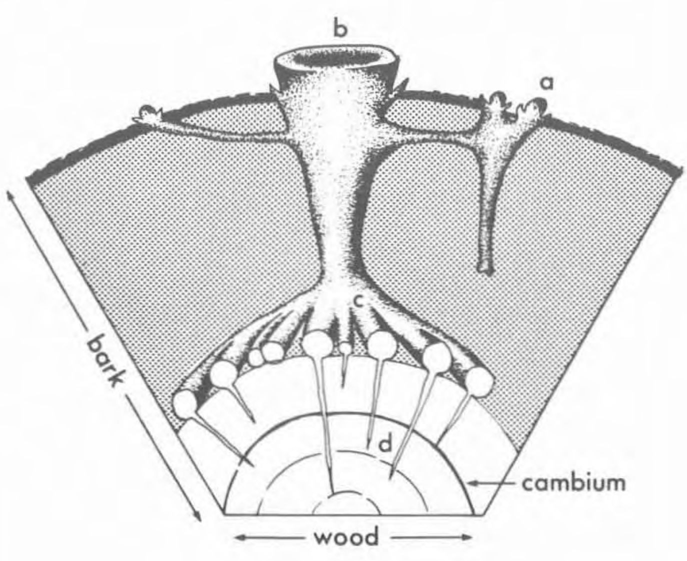
1/ Jack pine is a principal host in other parts of North America.

biology

Dwarf mistletoes are perennial plants which depend upon living hosts for support, water and most inorganic nutrients. Once established, they can survive as long as the host tissue remains alive. A dwarf mistletoe plant has an inner "root" (endophytic) system for absorption and transfer of food substances obtained from the host (Fig. 4), and an outer or reproductive aerial system made up of slender, segmented and leafless aerial shoots (Figs. 5, 9).

Fig. 4 Diagrammatic cross section of an infected branch showing the major structures of dwarf mistletoe: a. buds, b. basal cup, c. cortical strands, d. sinkers.

Fig. 5 Localized spindle-shaped branch infection of lodgepole pine dwarf mistletoe.



Life Cycle

a) Infection process

The life cycle is initiated by the **explosive discharge of a single seed from each mature fruit.** The seeds are covered with sticky viscin cells which enable them to adhere to foliage or, less commonly, to twigs and branches. During the first rain after dispersal, the viscin cells absorb water, swell and become very slippery, causing seeds attached to needles to slide downward. Depending on the angle of the needle, they reach the twig or drop to the ground (Fig. 7A). After wetting and drying several times, the seeds that have reached the twigs become tightly glued to the bark surface and overwinter in this condition. Germination occurs as early as February for hemlock dwarf mistletoe seed in mild coastal areas, and a few months later for other species in the Interior. Germination is indicated by the emergence from the seed of a reddish, root-like structure called a radicle. The radicle elongates until it reaches an obstruction such as a bark crack or base of a needle, needle bundle or bud, and a holdfast is formed (Fig. 7B). Infection then takes place through a mechanical wedging action of a penetrating structure, followed by the extension of fine, finger-like filaments into the host bark (cortex) (19). **Young bark up to 5 years of age is most commonly invaded,** though older bark may be successfully invaded on thin-barked hosts. With establishment of the dwarf mistletoe in the host, the seed and holdfast die and eventually disintegrate. By means of cortical strands, the dwarf mistletoe in the inner bark continues to grow longitudinally (up and down the twig) and circumferentially. Growth directly toward the cambium is accomplished by means of structures called sinkers (Fig. 4). As the twigs grow, the sinkers are embedded by successive layers of annual wood rings (xylem) and inner bark (phloem). By dissecting infections and determining the location of the deepest sinker, the year of infection can be established quite accurately. Dwarf mistletoe infection increases the number and size of host cells within the infected area, resulting in a swelling (Fig. 6). This is usually the first external symptom of infection (Fig. 7C).

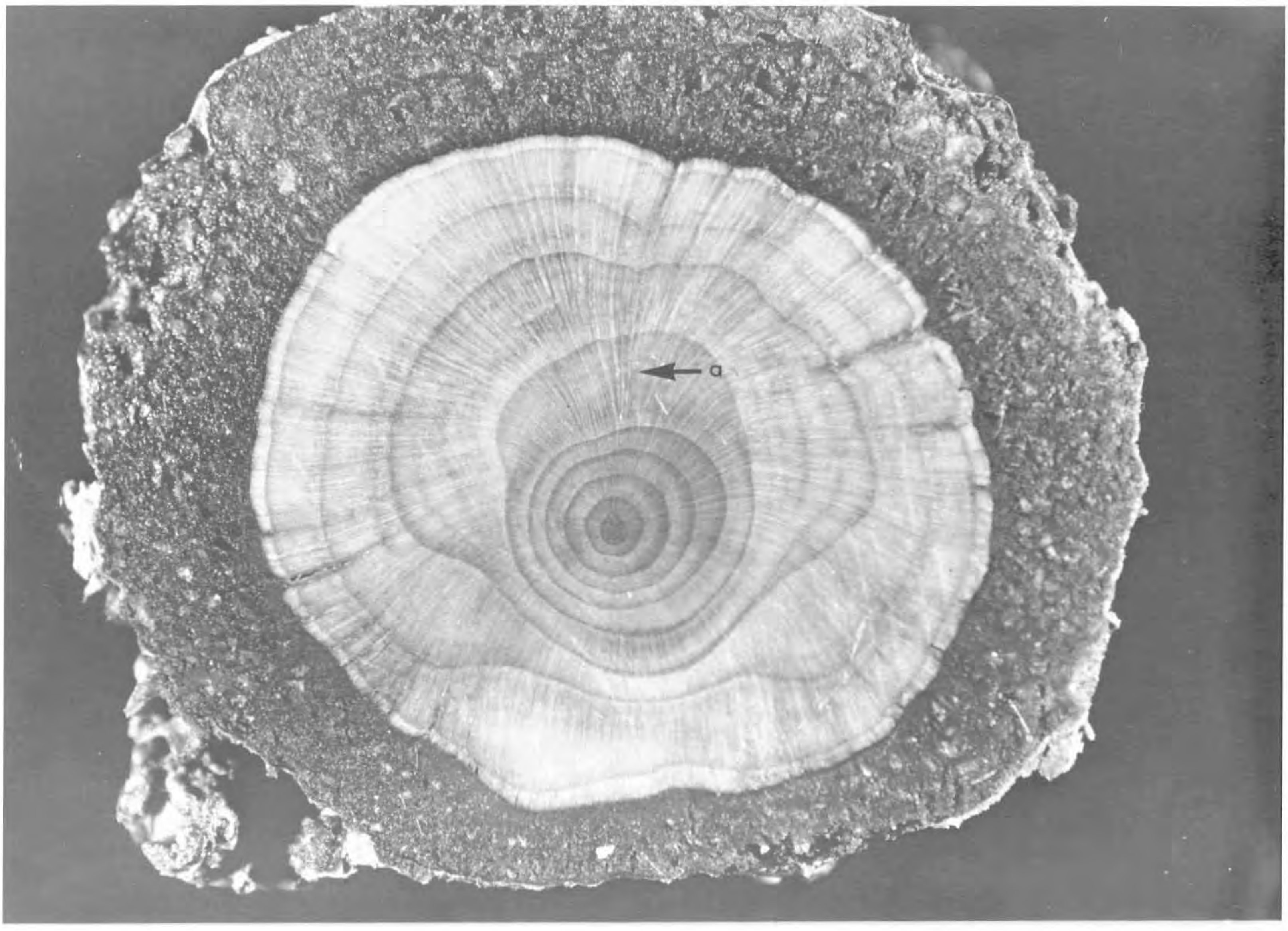


Fig. 6 Cross section of a dwarf mistletoe infected western hemlock branch showing: a. the first infected ring.

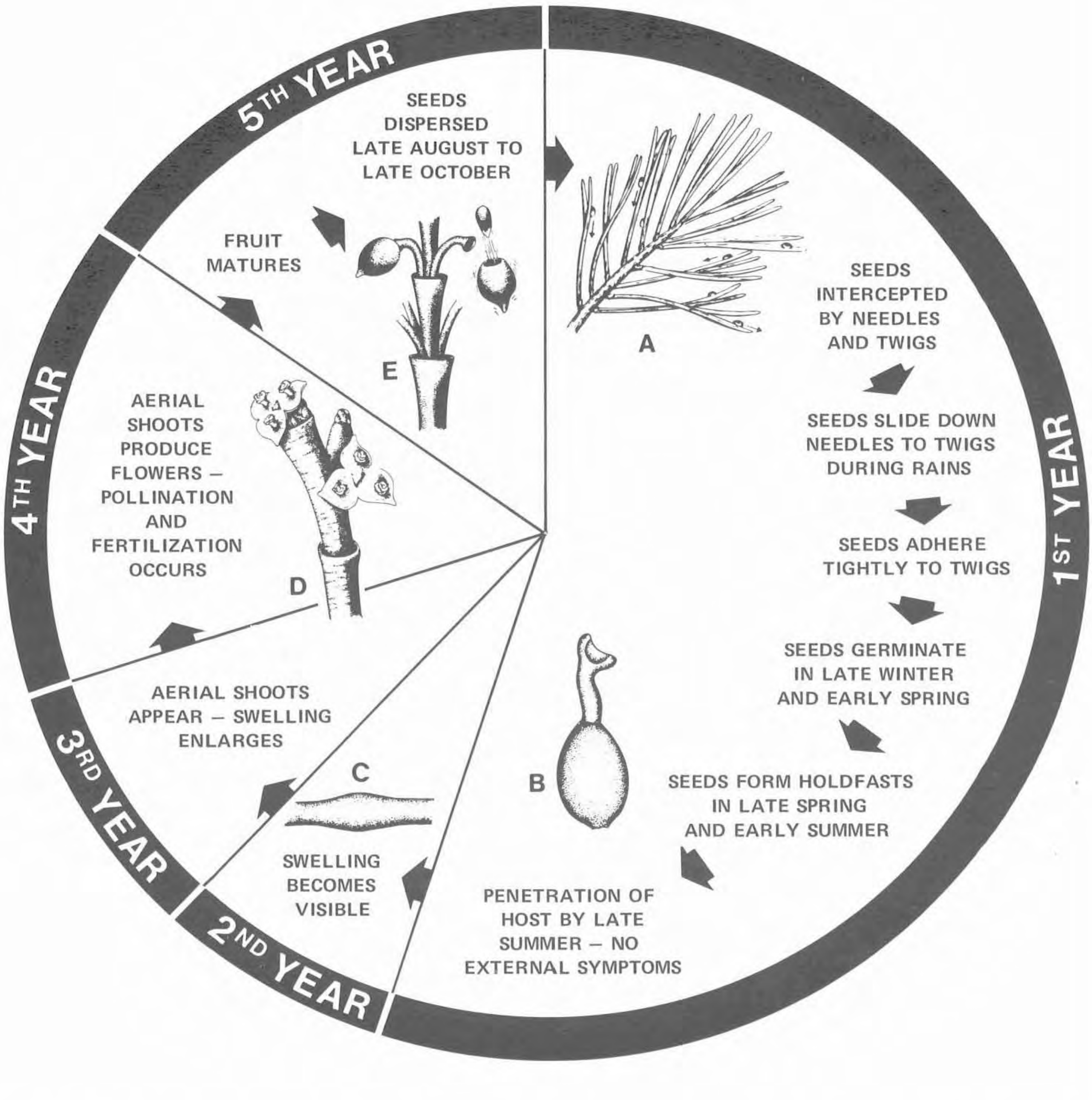


Fig. 7 Generalized life cycle of dwarf mistletoe:

A. Needle angles as they affect dwarf mistletoe seed movement.
B. A fully developed dwarf mistletoe seedling with holdfast.
C. Small branch swelling is the first indication of dwarf mistletoe infection.
D. Male (staminate) flowers of dwarf mistletoe.
E. Dwarf mistletoe seed discharge.

b) Aerial shoots

Aerial shoots do not usually emerge until the second or third year after seed deposition (Fig. 7). Thus, detection of infections is difficult until they have reached 3 or 4 years of age. Individual aerial shoots are known to live not much longer than 7 years (avg 2 - 3 years) (14, 24), but new shoots are continually emerging and replacing those that die. On vigorous infections, aerial shoots are present throughout the whole year and produce branches either in a whorled (verticillate) fashion as with lodgepole pine dwarf mistletoe, or in a fan-like (flabellate) fashion characteristic of the other three dwarf mistletoes in British Columbia (Fig. 8). **Branching pattern is an important diagnostic feature for identification when two species such as lodgepole pine and larch dwarf mistletoe occur together.**

c) Reproduction

Male or female flowers are usually produced in the second year after emergence of the shoots. As all dwarf mistletoes have staminate and pistillate flowers on separate infections, each infection is either male or female. The ratio of male to female is about 1:1. Male flowers have three or four petal-like parts which open, exposing the pollen sacs (Fig. 7D), while female flowers remain closed and relatively inconspicuous (Fig. 9). Nectar produced by both types of

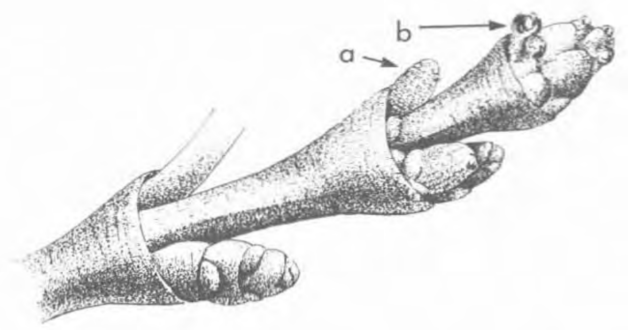


Fig. 9 Female (pistillate) flowers with a. pistils and b. droplets of nectar.

flowers attracts insects which, in turn, pollinate the female flowers, in spring or in late summer, depending on the species of dwarf mistletoe (Table II).

The period from pollination to production of mature fruit is about 1.5 years. As the berry-like fruit matures, an internal water pressure is built up to the point where the fruit breaks away from its base (pedicel), releasing the seed at a speed of about 50 mph (Fig. 7E) (12). **Seeds may travel distances up to 50 ft from the source** (avg 15 - 20 ft). With interception of seeds by a susceptible host, the life cycle begins again. **The time needed to complete the cycle** may be as short as the 4 years observed for some hemlock dwarf mistletoe infections, but **it is usually 5 or 6 years** (Fig. 7).

Fig. 8 Branching pattern of dwarf mistletoes: a. whorled (verticillate) branching, b. fan-shaped (flabellate) branching.

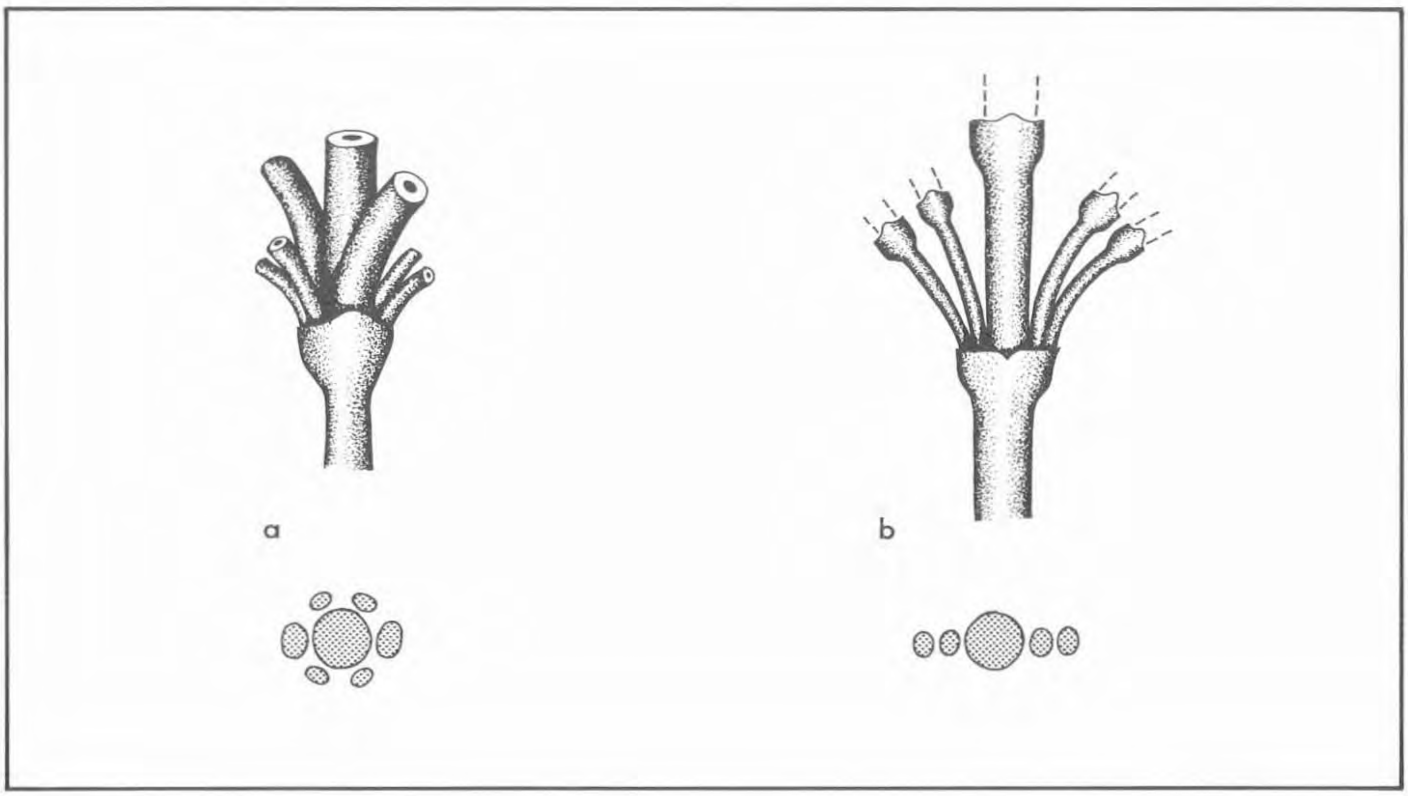


Table II. Some Important Characteristics of the Four Dwarf Mistletoe Species in British Columbia

Dwarf mistletoe	Types of infection	Aerial shoots		Time of	
		Branching	Average max height (cm)	Flowering	Seed dispersal
A. americanum (lodgepole pine)	Localized and systemic	Whorled	6 - 10	April - May	Late August and early September
A. tsugense (hemlock)	Localized	Fan-like	8 - 12	July - August	Late September and October
A. laricis (larch)	Localized	Fan-like	4 - 6	July - August	Early to mid-September
A. douglasii (Douglas-fir)	Localized and systemic	Fan-like	2 - 4	March - May	Early September

Types of Infection

Two types of infection may develop, localized and systemic. All begin as localized infections in which the inner system of the dwarf mistletoe is restricted to the swollen portion of the host. Systemic infection occurs when the inner system invades a dormant bud, stimulating it to grow into a branch. It then grows systemically by keeping pace with all terminal buds of the new branch. This type of infection results in the large brooms characteristic of lodgepole pine and Douglas-fir dwarf mistletoe infections. There is no obvious swelling in systemically infected branches, but aerial shoots are produced in a regular fashion along the branches. With larch and hemlock dwarf mistletoe, the infections remain localized throughout their life. However, even in these species there is stimulation of dormant buds and a proliferation of branches that produces witches' brooms.

Development of Infections

Where moisture and light conditions are optimal for host-branch growth, local swellings caused by dwarf mistletoe will enlarge rapidly (2 - 4 cm/year), and aerial shoots will be abundant. As infections become older and host branches become shaded, the rates of swelling enlargement and aerial shoot production decrease. This effect is most noticeable in dense stands. As indicated by the continued enlargement of swellings, **dwarf mistletoe infections may remain alive under shaded conditions, but often do not produce aerial shoots.** Though they still withdraw nutrients from the host, these "vegetative" infections **are no longer able to function reproductively and thus fail to spread and intensify the parasite.** However, if, for instance, **light intensity increases as a result of thinning, aerial shoots will develop and the infection can again become reproductively active.**

Rate of Spread within Stands

The rate of spread is greatest from infected overstory trees to understory, amounting immediately to 30 to 50 ft. Studies on hemlock dwarf mistletoe have shown that a single infected overstory tree dispersed seeds over an area of nearly 6,000 sq ft (22). Thus, if distributed evenly, less than 10 infected trees per acre could cause infection of all intervening susceptible regeneration. The rate of subsequent **spread through even-aged stands** of fairly uniform height **is slower, generally less than 2 ft/year** (5) (Fig. 14). **Spread through open stands is about 1.5 times faster than through closed stands** because of more vigorous dwarf mistletoe plants and longer seed flights in the former (5).

Intensification within Crowns

Intensification within a tree proceeds quickly, the number of infections doubling as frequently as every two years (6). Disease intensity in individual trees is often rated by a 6-point system (see Damage p. 13). It is estimated that dwarf mistletoe increases in intensity in trees one rating point every 10 to 20 years. Assuming no overstory seed source, **vertical intensification** or advance upward in the crown of a tree **proceeds at a rate of about 2 ft/year,** the rate being greater in open than in closed stands (18).

recognition

Dwarf mistletoe infected trees and stands can be readily recognized by their definite symptoms.

Witches' Brooms

The most conspicuous symptom of infection is a proliferation of distorted branches called witches' broom. The size and shape of brooms vary considerably, depending on the species of dwarf mistletoe. The systemic old brooms on lodgepole pine and Douglas-fir are open, sometimes pendulous, and reach large sizes (Fig. 10). In contrast, the localized infections on larch form small spherical but very dense brooms (Fig. 11). On hemlock, the brooms are flat, palm-shaped, and reach large sizes with age (Fig. 12). Careful inspection of brooms will usually reveal the presence of dwarf mistletoe aerial shoots. **Because brooms are caused by factors other than dwarf mistletoes** (e.g., rusts, stimulation, genetic), **the presence of shoots is an important diagnostic sign.**

Branch and Stem Swellings

A less obvious symptom is the spindle-shaped swellings on branches and stems which is similar for all dwarf mistletoes (Fig. 5). Aerial shoots usually appear on the whole swelling of a young infection; on old infections, they are produced only at the margins of the advancing mistletoe. When an aerial shoot dies it disintegrates, leaving the **basal segment or cup** in the bark of the host (Fig. 4), which persists as an **important diagnostic feature where no living aerial shoots are present.** Stem infections usually originate from nearby branch infections and remain active as long as the host lives. The cambium is killed at the center of old lodgepole pine stem infections and a sunken canker-like deformity is common. On hemlock and, less commonly, on larch, stem infections develop into large swellings (Fig. 13).

Fig. 10 Large pendulous witches' brooms caused by lodgepole pine dwarf mistletoe on lodgepole pine.

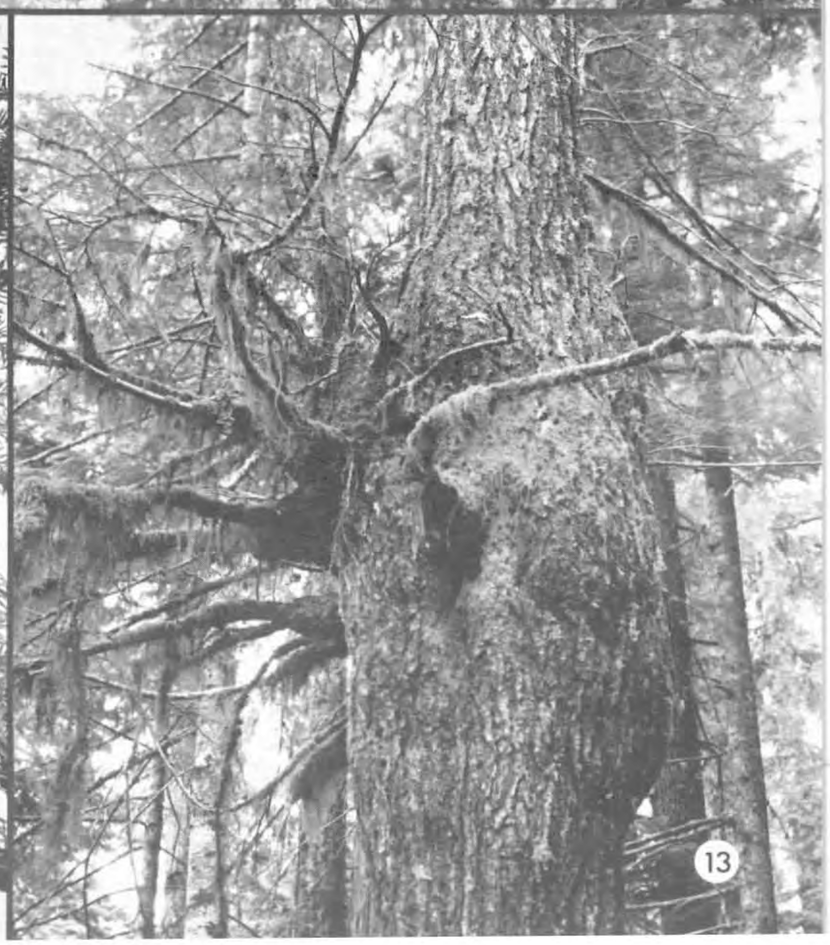
Fig. 11 Spherical witches' broom caused by larch dwarf mistletoe on western larch. Compare the size of healthy crown on right.

Fig. 12 Palm-shaped witches' broom caused by hemlock dwarf mistletoe on western hemlock.

Fig. 13 Large stem swelling on hemlock caused by hemlock dwarf mistletoe.

11

12



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Stand Symptoms

Symptoms of dwarf mistletoe infections in a stand are most evident with shade intolerant hosts (lodgepole pine, western larch and Douglas-fir). Infection centers in young stands usually occur around larger living or dead infected residual trees (Fig. 14). Squirrels often feed on and girdle dwarf mistletoe infected lodgepole pine branches. These freshly killed branches appear as conspicuous "red flagging". In stands 50 to 100 years of age, height growth of severely infected trees is reduced, dead tops and mortality are evident and infection centers are thinned. **In stands over 100 years of age, heavily broomed dead or dying trees mark the infection centers;** these centers can be detected from the air. **In hemlock stands, recognition of infection centers is difficult.** "Red flagging" is not evident. Dead tops and **heavily broomed dead wolf trees indicate infection centers.**

damage

Dwarf mistletoes attack their hosts in all age classes, causing mortality or loss of vigor, growth and wood quality.

Damage appraisal studies are based on disease intensity ratings. Most commonly used is the 6-class system (10), in which the crown is divided into thirds and each third is rated independently as follows:

0 - no visible infection.

1 - light infection, less than half of the branches infected.

2 - heavy infection, more than half of the branches infected.

The ratings of each third are then added and the sum gives the intensity rating for the tree (0 = healthy; 1 - 2 = lightly infected; 3 - 4 = moderately infected; 5 - 6 = severely infected). A stand infection index can be obtained by averaging individual tree ratings.

Growth losses of 18.1 to 31.5% were determined for five lodgepole pine stands ranging in age from 37 to 117 years (2). Merchantable volumes in 100-year-old stands of lodgepole pines, severely infected for 70 years, averaged only 300 cu ft per acre compared with 2,350 cu ft in healthy stands (8).

Severe infection by hemlock dwarf mistletoe affected wood density and impaired tree vigor (25). Growth reduction of up to 60 cu ft per acre a year occurred in a heavily infected mature western hemlock stand in British Columbia, about 40% of the actual volume growth (23). In the same stand, **severely infected trees at 15 inches in diameter were 14 ft shorter than the control trees of the same diameter.** Branches on the lower two-thirds of severely infected trees were larger than on healthy trees, thereby reducing the quality of products.

One comparison indicated that in 90 years, a healthy managed mixed western larch stand on a good site produced about 7 times the volume of an unmanaged infected stand (17). Similar results were obtained for Douglas-fir dwarf mistletoe - "during the past ten decades, average dbh increment of trees with moderate and severe infection was 79 and 43%, respectively, of that in otherwise similar but lightly infected trees" (20).

In addition to a direct effect, **dead tissues produced by dwarf mistletoes provide entry points for stain and decay fungi.** Mistletoe-infected branches and stem infections were found to be the most important entry points for infection by decay fungi in western hemlock (4, 11).

control

Dwarf mistletoes are responsive to control for several biological reasons: they are confined to the above-ground parts of their hosts; their distance of seed dispersal is limited; they require specific living hosts, and infection centers can be detected.

Biological and Chemical Control

Biological control agents have been extensively investigated but have not led to practical control possibilities. Three fungal parasites, (*Wallrothiella arceuthobii, Septogloeum gillii* and *Colletotrichum gloeosporioides*), occur on aerial shoots of dwarf mistletoes in British Columbia and occasionally restrict their development. Several canker-producing fungi which parasitize dwarf mistletoe infections are being studied. Birds, rodents and insects also act as biological control agents but cannot be considered to be effective (2). Considerable work has been directed to the development of chemicals for controlling dwarf mistletoes, but no material has been found that warrants widespread application.

Silvicultural Control

Dwarf mistletoe is destroyed by killing infected host parts or infected trees. This can be accomplished, in most instances, with normal forest management practices, thus obtaining control at little extra cost. The effectiveness of silvicultural control depends on existing disease patterns.

Even infection. Even infection results when infected residual trees are evenly distributed throughout susceptible regeneration. **This condition develops from selective logging, e.g., diameter-limit and species selection** (Fig. 15). If the distance between these trees is about 80 ft or less, the new stand becomes uniformly infected within 25 to 30 years, at which time incidence could be severe enough to warrant the replacement of the whole stand. In mixed stands, where the susceptible host is evenly infected, sanitation is governed by the presence and distribution pattern of resistant species. If they can form the basis of the future stand, the mistletoe problem

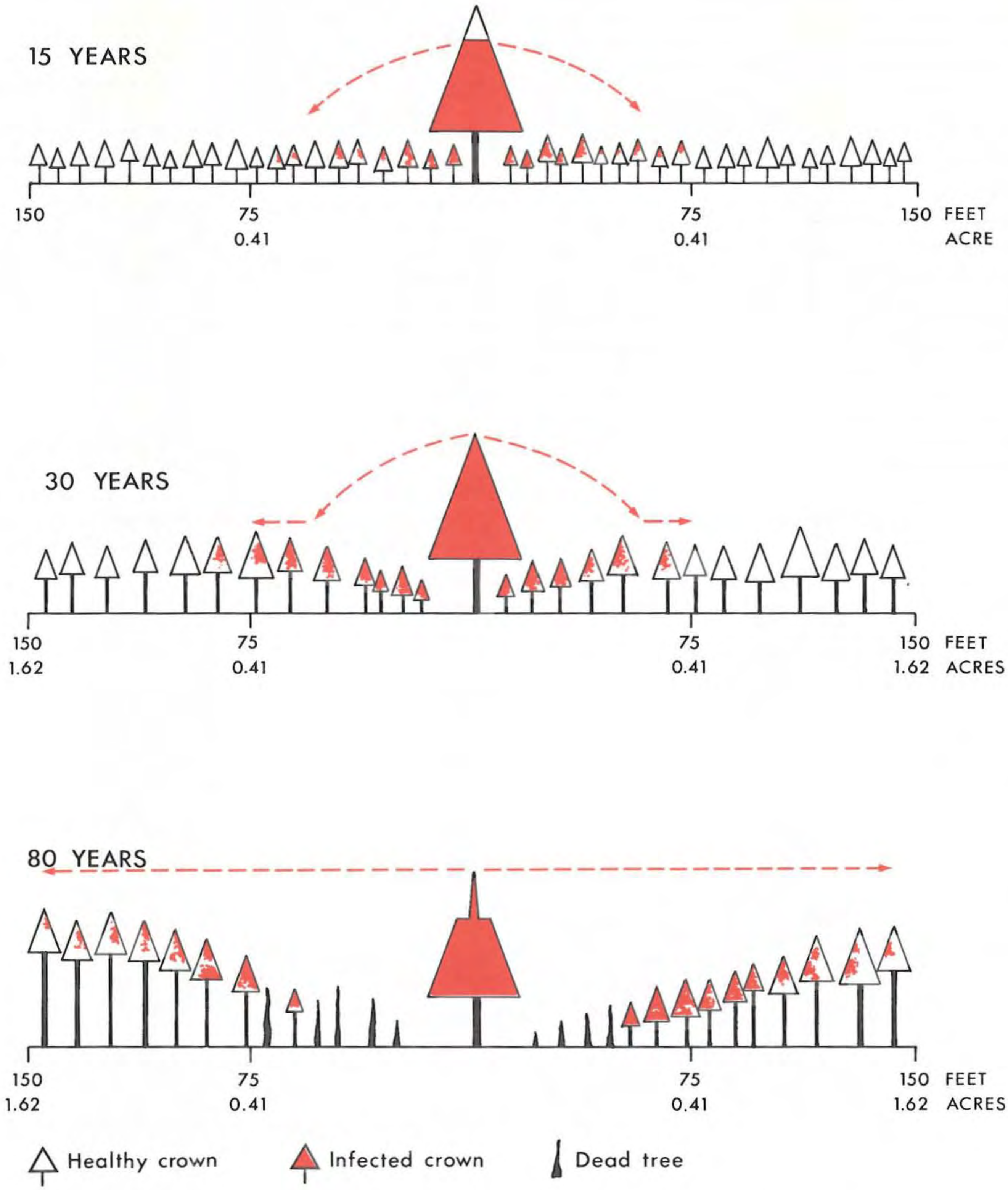

Fig. 14 Infection center as it develops during the years around a single infected tree in dense lodgepole pine stands.

can be solved by cutting the infected species.

Uneven infection. **Uneven infection is common in mixed stands after logging or in pure stands developed after wildfires.** Infected residuals survive fire in unevenly, widely spaced patches of few or many trees. Infection centers develop around these residuals and disease incidence in a new stand depends on the abundance and distance between residuals. Another form of uneven infection develops when no residuals survive logging or fire, and dwarf mistletoe invades the regeneration from adjacent infected stands.

a) Prevention

Cut layout. **The initial and most feasible opportunities for control are those that prevent the establishment of dwarf mistletoe in regeneration.** As the first opportunity for prevention comes during the preparation of cutting plans, **a good knowledge of the location of infected stands is necessary. Partial cutting should not be allowed in these stands.** To avoid re-invasion of the disease, clear-cut borders should be located along man-made barriers to mistletoe, such as road and power-line rights-of-way, and in healthy stands, including stands of resistant coniferous and immune broadleaf species. The latter often form an effective barrier along rivers and around lakes and bogs. If clear-cut boundaries can not be located in healthy stands, they should be located in valley bottoms rather than on ridges. Conditions for spread and intensification of the disease are more favorable on the latter.

In dwarf mistletoe infected stands, large clear-cut areas (over 200 acres) will reduce the ratio of perimeter to area and the rate of re-invasion. Narrow strips are ineffective in dwarf mistletoe control since too much of the cutover area will be within the infection range of the bordering infected stand. Strip cutting or small clear-cuts are justified only if the regeneration of a resistant species is ensured.

Elimination of infected residuals. Infected residual trees or advanced regeneration are important infection sources in new stands. **During or shortly after clear-cutting, infected residuals and susceptible advanced regeneration should be removed.** Residual trees left after logging of infected stands are generally from the suppressed and intermediate crown classes. Due to favorable light conditions in stands of shade-intolerant host species (lodgepole pine, western larch and Douglas-fir), dwarf mistletoe infections on these small trees are reproductively active and able to produce seed and infect regeneration as soon as it becomes established; therefore, elimination of dwarf mistletoe seed sources should be practiced during or immediately following logging. In hemlock stands, because of poor light conditions before logging, shaded infections have low vigor and low capacity to produce seed. After logging, several

Fig. 15 Infected residual lodgepole pine stand after "clear" cutting in the Interior.

years are required before substantial numbers of seeds are produced; therefore, removal of dwarf mistletoe seed source might be extended up to 5 years after logging without significant infection of new regeneration.

Fire effectively removes non–merchantable infected material. Broadcast slash burning is recommended, if possible, and silviculturally and locally acceptable. Areas with dwarf mistletoe infected original stands should have priority for slash burning. After burning, however, the area should be checked for living infected residuals and these should be cut or poisoned.

Where terrain permits, a drag scarifier or drum chopper can be effectively used to destroy infected residuals and advanced regeneration. Where terrain is unfavorable or where wet conditions prevail (Queen Charlotte Islands, Prince Rupert area), none of the aforementioned methods may be applicable, and manual elimination of dwarf mistletoe seed sources after logging may be necessary.

After the cutover area is cleared of infected residuals, the establishment of a 120-ft-wide barrier strip along bordering infected stands is recommended to prevent or reduce the rate of re-invasion. This can be done by planting resistant species (Table I) before the susceptible regeneration becomes established.

Species manipulation. **An effective means of reducing future disease incidence is to promote higher participation of the mistletoe resistant species in the future stand.** This is possible in the following mixed stands:

lodgepole pine* - Douglas-fir

lodgepole pine* - spruce (e.g., Central Douglas-fir section, Montane Forest Region) (Fig. 16)

western larch * - Douglas-fir - hemlock (e.g., Southern Columbia Section, Columbia Forest Region)

Douglas-fir* - ponderosa pine (e.g., Ponderosa pine and Douglas-fir section, Montane Forest Region)

Species manipulation can be achieved by logging the infected overstory with care to preserve the existing immune regeneration. Where immune regeneration is sparse or lacking, seed trees of immune tree species should be left after harvesting. In infected coastal western hemlock stands, the practice of planting Douglas-fir is an example of effective species manipulation.

b) Sanitation

Dwarf mistletoe is particularly damaging to immature stands (1, 5, 7). If acceptable yields are to be obtained from heavily infected stands, they must be treated. The method of sanitation depends on existing disease conditions. Some gen-

Fig. 16 Dense understory of spruce in a dwarf mistletoe infected lodgepole pine stand in the Interior.

*denotes the infected species.

eral observations on mistletoe behavior are offered as guidelines for sanitation. As stated previously, initial spread from a single infected tree is up to 50 ft and lateral spread is about 2 ft per year (5). Initial spread from a bordering stand is less (30 ft) (2). Rate of spread can be estimated by using the formula:

$Spread_{ft}$ = initial spread + (yr since logging - 5 yr) X 2.

On this basis, the expected distance of infection at various ages of regeneration around infected residuals or along infected bordering stands can be calculated and the area to be sanitized determined.

During sanitation, old-infected residual trees, groups of trees or infected bordering stands should be cut first (Fig. 17). Young trees with stem infections should be killed; those with branch infections can be killed or, if practical, pruned. Dwarf mistletoe can be eliminated by pruning branches less than 2 inches in diameter if aerial shoots do not occur within 4 inches of the stem (9).

Sanitation is most effective when trees are small; therefore, the age at which fast-growing trees can be effectively sanitized is lower than for slow-growing trees.

In planning sanitation, age classes up to 15 years in infected hemlock stands and up to 25 years in infected lodgepole pine, Douglas-fir and larch stands should have priority treatment. In these age classes, disease intensity is the lowest. Infected residual trees are usually taller than new regeneration, and infection centers are thus detectable. Tree height is approximately 15 - 30 ft, and infections with aerial shoots, usually restricted to the lower half of the crown, can be spotted from the ground. **Sanitation of infected stands can be combined with juvenile spacing at little extra cost. The proper training of spacing crew members for dwarf mistletoe detection is the key to success. If the presence of the disease is disregarded and infected trees are left, disease incidence and intensity will become greater than would occur without spacing.** This results from increased mistletoe seed production due to improved light conditions, and increased seed dissemination due to the wider spacing. Since there is a lag period between infection and production of visible symptoms of the disease (e.g., swellings and aerial shoots), trees with latent infections are unlikely to be recognized. One or two retreatments at 3-year intervals are generally necessary to achieve success.

Preliminary results indicate (3) that in heavily infected stands older than 25 years, sanitation is justified only if less than 50% of the dominant and codominant trees are infected. In dense stands of western hemlock, heavily shaded infections do not produce aerial shoots. If crown closure is maintained, infected branches gradually self-prune and disease incidence declines. Opening up the stand would stimulate dwarf mistletoe seed production on previously shaded infections.

c) Salvage

In stands over 40 years old, sanitation is difficult and unreliable because dense crowns obscure branch infection. Lightly infected stands are best held for logging to rotation age as growth loss will be light. **Intermediate cuttings in these stands should be avoided as they increase disease intensity in the overstory and promote the establishment of regeneration, which becomes infected.** As the period since infection increases and the disease intensifies, losses increase. Stands with a history of heavy infection will suffer large growth losses by the time rotation age is attained. Early removal of such stands is recommended to get the land back into maximum production.

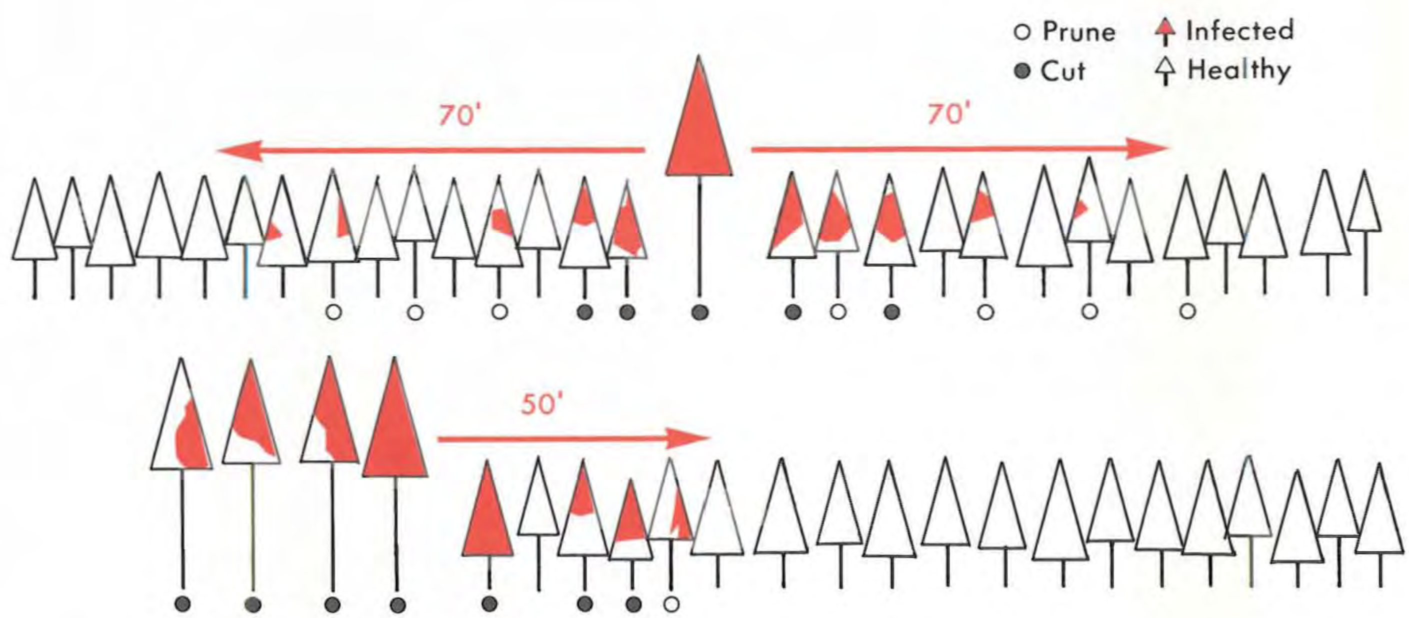

Fig. 17 Sanitation in a 15-year-old dwarf mistletoe infected stand.

conclusions

Dwarf mistletoes are widespread in British Columbia and cause considerable reduction in yield and quality of lodgepole pine, western hemlock, western larch and Douglas-fir. However, owing to several biological limitations, including slow spread, restriction to a limited number of hosts and dependence on living trees for survival, **they are the most amenable to control of all agents causing disease in forest stands.** Losses caused by them can be greatly reduced through proper forest management techniques.

Due to variability of disease incidence, it is not possible to provide overall control recommendations for all conditions. **The most suitable decision for each case depends on stand composition, stand age, number of years to harvest, disease incidence and pattern and length of time the stand has been infected.** Complete eradication of the disease is possible if effective preventative measures are applied during or shortly after clear-cut logging. Where preventative measures are not applied successfully, the disease can be reduced in young stands by sanitation to a level at which there is little growth loss, i.e., by maintaining only uninfected and lightly infected trees in the stand. In weighing the economic feasibility of sanitation, it is reasonable to assign treatment costs to the protected rather than only the treated acreage. If properly controlled during the first rotation, dwarf mistletoe should not be a serious problem in subsequent rotations.

literature cited

1. Baranyay, J.A. and L. Safranyik. 1970. Effect of dwarf mistletoe on growth and mortality of lodgepole pine stands in Alberta. Can. Dep. Fish. Forest., Can. Forest. Serv. Publ. 1285.
2. Baranyay, J.A. 1970. Lodgepole pine dwarf mistletoe in Alberta. Can. Dep. Fish. Forest., Can. Forest. Serv. Publ. 1286.
3. Baranyay, J.A. 1972. Silvicultural control of dwarf mistletoe in young lodgepole pine stands in Alberta and British Columbia. Can. Forest Serv., Pacific Forest. Res. Centre, Int. Rept. B.C.-29.
4. Englerth, G.H. 1942. Decay of western hemlock in Western Oregon and Washington. Yale Univ.: School of Forest. Bull. 50, 53 p.
5. Hawksworth, F.G. 1958. Rate of spread and intensification of dwarf mistletoe in young lodgepole pine stands. J. Forest. 56: 404-407.
6. Hawksworth, F.G. 1969. Rapid intensification and upward spread of dwarf mistletoe in inoculated digger pines. Plant Dis. Reptr. 53: 615-616.
7. Hawksworth, F.G. and D.P. Graham. 1963. Spread and intensification of dwarf mistletoe in lodgepole pine reproduction. J. Forest. 61: 587-591.
8. Hawksworth, F.G. and T.E. Hinds. 1964. Effects of dwarf mistletoe on immature lodgepole pine stands in Colorado. J. Forest. 62: 27-32.
9. Hawksworth, F.G. and N.E. Johnson. 1961. Guides for pruning dwarf mistletoe-infected lodgepole pine branches. U.S. Forest Serv., Rocky Mount. Forest Range Exp. Sta. Res. Note 65, 4 p.
10. Hawksworth, F.G. and A.A. Lusher. 1956. Dwarf mistletoe survey and control on the Mescalero-Apache Reservation, New Mexico. J. Forest. 54: 384-390.
11. Hepting, G.H. and J.W. Kimmey. 1949. Heart rot. USDA. Year Book of Agric. 462-465.
12. Hinds, T.E. and F.G. Hawksworth. 1965. Seed dispersal velocity in four dwarf mistletoes. Sci. 148(3669): 517-519.
13. Kuijt, J. 1963. Distribution of dwarf mistletoes and their fungus hyperparasites in western Canada. Can. Nat. Mus. Bull. 186: 134-148.
14. Kuijt, Job. 1970. A systematic study of branching patterns in dwarf mistletoe (*Arceuthobium*). Memoirs Torr. Bot. Club 22(4): 1-38.
15. Molnar, A.C., J.W.E. Harris, D.A. Ross and J.A. Baranyay. 1969. Dwarf mistletoes. *In:* Can. Dept. Fish. and Forest., Ann. Rep., Forest Ins. Dis. Surv. 1969: 105-106.
16. Molnar, A.C., D.A. Ross and R.L. Fiddick. 1970. Dwarf mistletoes. *In:* Can. Dep. Fish. and Forest., Ann. Rep., Forest Ins. Dis. Surv. 1970: 82-83.
17. On, D. and O. Dooling. 1969. A study of the effect of dwarf mistletoe infection on the growth of western larch. Special Rept., State and Private Forest., U.S. Forest Serv., Missoula, Mont. No. 2470.
18. Richardson, K.S. and B.J. van der Kamp. 1972. Vertical spread rate and intensification of dwarf mistletoe on western hemlock. Can. J. Forest Research (In press).
19. Scharpf, R.F. and J.R. Parmeter. 1967. The biology and pathology of dwarf mistletoe (*Arceuthobium campylopodum* f. *abietinum*) parasitizing true firs (*Abies* spp.) in California. USDA, For. Serv., Tech. Bull. 1362, 42 p.
20. Shea, K.R. 1963. Diameter increment in old-growth Douglas-fir infected by dwarf mistletoe. Weyerhaeuser Co. Timberland Div., Forest Res. Note. 50, 11 p.
21. Sippell, W.L., H.L. Gross and A.H. Rose. 1970. Dwarf mistletoes. *In:* Can. Dep. Fish. and Forest., Ann. Rep., Forest Ins. Dis. Surv. p. 61.
22. Smith, R.B. 1966. Hemlock and larch dwarf mistletoe seed dispersal. Forest. Chron. 42: 395-401.
23. Smith, R.B. 1969. Assessing dwarf mistletoe on western hemlock. Forest Sci. 15: 277-285.
24. Smith, R.B. 1971. Development of dwarf mistletoe (*Arceuthobium*) infections on western hemlock, shore pine and western larch. Can. J. For. Res. 1: 35-42.
25. Wellwood, R.W. 1956. Some effects of dwarf mistletoe on western hemlock. Forest. Chron. 32: 282-296.