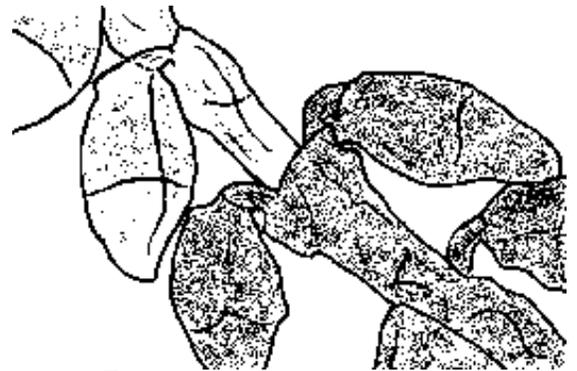


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# Chapter

# 7

## Management Strategies for Dwarf Mistletoes: Biological, Chemical, and Genetic Approaches



The opportunity and need for management of mistletoe populations with biological, chemical, and genetic approaches are greatest for application to the dwarf mistletoes. Although much information is available on these management strategies (see reviews by Hawksworth 1972, Knutson 1978), significant research and development are still required for these to become operational tools. In this chapter, we describe the potential for these tools and status of their research and development. Resource managers and practitioners interested in using these approaches can consult with forest pathologists and geneticists for specific applications.

## Biological Control

Many fungi and insects are pathogens or herbivores, respectively, of dwarf mistletoes (Hawksworth and Geils 1996, Hawksworth and others 1977b, Kuijt 1963, Stevens and Hawksworth 1970, 1984). None, however, are sufficiently studied and developed for operational use as biological control agents (Anonymous 1982, Hawksworth 1972). Some fungal pathogens and insect herbivores (particularly lepidopteran larvae) are highly destructive to dwarf mistletoes in some areas and years. The factors that induce or regulate these outbreaks result from complex and often indirect interactions of weather and a multitrophic community of organisms. Dwarf mistletoe pathogens and herbivores are indigenous organisms that have co-evolved with their hosts into relationships that are not readily amenable to human control. Nonetheless, given the potential number of agents and the advantages of the approach, development of biological control as a management option appears promising for the near future (Hawksworth 1972, Shamoun 1998).

### Integrating Biological Control with Silviculture

Development of an effective biocontrol program requires technologies for mass production of the agent, an efficient delivery system, and a deployment strategy. The biocontrol agent does not have to eradicate all the dwarf mistletoe from the entire stand. A satisfactory strategy is to reduce mistletoe spread from residual trees in a regeneration area by timely introduction of biocontrol agents that kill or deflower the parasite. The selection of a treatment area and schedule is a silvicultural decision based on an understanding of the epidemiology of the agent, the population dynamics of the mistletoe, and silvics of the host. The spatial-statistical model described by Robinson and others (2002) simulates mistletoe life cycles under various treatments and schedules and aids the selection of a preferred strategy. The objective is to protect new plantations from early mistletoe infestation where a significant number of infected residual trees are to be retained for various legacy values.

### Insects

Initial research identifies several destructive insect predators that are apparently endemic to Pakistan (Baloch and Ghani 1980, Mushtaque and Baloch 1979), but no steps have been taken to test their applicability for introduction into North America. Other Asian dwarf mistletoes also harbor candidates for biological control of New World dwarf mistletoes (Tong and Ren 1980).

## Fungi

The extensive literature on biological control of unwanted higher plants (weeds) is reviewed by DeBach (1964), TeBeest and Templeton (1985), Shamoun (2000), Wall and others (1992), and Wilson (1969). Mycoherbicides are developed practical tools in agriculture. Example mycoherbicides include: *Phytophthora palmivora* (DeVine) for control of strangler vine in citrus (Ridings 1986), *Colletotrichum gloeosporioides* f. sp. *aeschynomene* (Collego) for control of northern jointvetch in rice and soybean (Daniel and others 1973), and *Colletotrichum gloeosporioides* f. sp. *malvae* (BioMal, and Mallet WP™) for round-leaved mallow in field crops (Jensen 2000, Makowski and Mortensen 1992). *Chondrostereum purpureum*, a well-known primary wood invader, is being developed for biological control of woody vegetation in forests and rights-of-way (de Jong and others 1990, Shamoun and others 1996, Wall 1994). *Chondrostereum purpureum* (Chontrol™) may become the first biological control agent in North America used for integrated forest vegetation management (Shamoun and Hintz 1998). In South Africa, *Cylindrobasidium laeve* (Stumpout) is used to clear Australian wattle tree (Morris and others 1998). Mortensen (1998) reviews a number of other products in development.

A particular challenge for application of mycoherbicides in controlling mistletoes is that death of the plant is not assured by destruction of the aerial shoots. The endophytic system of mistletoes within the host survives even when the shoots are killed back repeatedly; the endophytic system may persist for a century (Gill and Hawksworth 1961).

For a fungal parasite to be an effective biological control agent, it must possess a number of attributes (Mark and others 1976, Wicker and Shaw 1968):

1. It parasitizes only the target mistletoe, not the host or other vegetation.
2. Its activity seriously interferes with the life cycle of the mistletoe.
3. It produces abundant inoculum and significant infestations on the target mistletoe.
4. It has sufficient ecological amplitude to persistence throughout the range of the target mistletoe.
5. Its distribution coincides with that of the target mistletoe.
6. It exhibits high infectivity.
7. It shows high virulence.
8. It has an efficient mode of action for curtailing development of the target mistletoe.

Fungal parasites of dwarf mistletoe are of two general groups—those that attack aerial shoots and those that attack the endophytic system (canker fungi).

Although a large number of fungal parasites are associated with dwarf mistletoes (see Hawksworth and Geils 1996), there are no complete and comprehensive evaluations for most of these fungi, their hosts, and their interactions (Hawksworth and others 1977b).

**Aerial Shoot Fungi**—These fungi usually parasitize pistillate flowers, shoots, and fruits of certain spring-flowering species of mistletoe. Three of these fungi—*Colletotrichum gloeosporioides*, *Cylindrocarpon (Septogloeum) gillii*, and *Caliciopsis (Wallrothiella) arceuthobii*—are common and widespread in Western North America (Hawksworth and Geils 1996).

*Colletotrichum gloeosporioides* is commonly isolated from dwarf mistletoes in the United States and the Western Provinces of Canada (Kope and others 1997, Muir 1967, Wicker and Shaw 1968). Although different isolates of the fungus are distinct in mycelial growth, colony color, and sporulation, cross-inoculation experiments demonstrate that isolates are not host-specific (Scharpf 1964). *C. gloeosporioides* infections first appear as small, brown to black, necrotic lesions on the nodes of fruits and shoots (fig. 7-1 and 7-2). Lesions enlarge, coalesce, and cause dieback of the shoots (Parmeter and others 1959, Wicker and Shaw 1968). Parmeter and others (1959) observe that the fungus invades the endophytic system of *Arceuthobium abietinum*. Ramsfield (2002) did not detect the presence of the fungus in the endophytic system of *A. americanum*. Wicker (1967b) states that both sexes of *A. campylopodum* are attacked, and that from 35 to 67 percent of the plants or 24 percent of the shoots may be destroyed. Although the fungus may persist for years (Wicker and Shaw 1968), its occurrence is generally sporadic (Hawksworth and others 1977b). It can be destructive to *A. americanum* and *A. tsugense* subsp. *tsugense* in Western Canada (Muir



**Figure 7-1**—*Colletotrichum gloeosporioides* infecting shoots and fruits of *Arceuthobium tsugense*.



**Figure 7-2**—*Colletotrichum gloeosporioides* infecting shoots of *Arceuthobium americanum*.

1967, 1977, Ramsfield 2002, Kope and others 1997). Muir (1977) concludes that it can exert significant natural control of *A. americanum*.

*Colletotrichum gloeosporioides* is being developed as biocontrol agent of *Arceuthobium tsugense* and *A. americanum*. Successful projects to date include an *in vitro* bioassay system (Deeks and others 2001, 2002) and several laboratory and greenhouse experiments and field trials (Ramsfield 2002). The fungus is easily, inexpensively cultured and germinates over a wide temperature range (Parmeter and others 1959, Shamoun 1998). Its mode of action disrupts development of mistletoe shoots, thereby preventing reproduction. Because it attacks anytime after shoot emergence (Parmeter and others 1959), there is a broad window when the agent can be applied.

*Cylindrocarpon gillii* (formerly *Septogloeum gillii*) is a fungal parasite that causes anthracnose to staminate and pistillate shoots of dwarf mistletoes (Ellis 1946, Gill 1935, Muir 1973). The fungus and disease is recognized (fig. 7-3) by white eruptions at shoot nodes and conspicuous masses of hyaline, cylindrical to fusiform spores. The fungus parasitizes most dwarf mistletoes of Western North America (Hawksworth and others 1977b), including *A. americanum*, *A. douglasii*, and *A. tsugense* subsp. *tsugense* in Western Canada (Kope and Shamoun 2000, Shamoun 1998, Wood 1986). Mielke's (1959) inconclusive results from inoculating an isolate of a warm, dry climate to a cool, moist one suggest the need for proper climate matching when evaluating or using this fungus (Hawksworth and others 1977b).

*Caliciopsis arceuthobii* (formerly *Wallrothiella arceuthobii*) is the oldest known, fungal parasite of dwarf mistletoes. It attacks the spring-flowering mistletoes *Arceuthobium pusillum*, *A. americanum*,



**Figure 7-3**—*Cylindrocarpon gillii* infecting shoots and fruits of *Arceuthobium tsugense*.

*A. douglasii*, and *A. vaginatum* (Dowding 1931, Kuijt 1969b, Knutson and Hutchins 1979). Infection occurs at anthesis; stigmas are inoculated with ascospores carried by insects, wind, or rain. Within 2 months, hyphae penetrate the fruits to the ovary wall. Host cells deteriorate and are replaced by a black stromatic mass of hyphae (fig. 7-4). Normal fruit development and seed production are destroyed (Wicker and Shaw 1968). The fungus is widely distributed from Western Canada, United States, and Mexico (Hawksworth and others 1977b, Kuijt 1963). Parker (1970) demonstrates the fungus germinates and grows on artificial media. Its potential as a biocontrol agent, however, is limited by large, annual variations of infection. In a given location, natural infection will be high one year (80 percent of flowers infected) and fail (almost no



**Figure 7-4**—*Caliciopsis arceuthobii* infecting the pistillate flowers of *Arceuthobium americanum*.

infection) the next (Dowding 1931, Hawksworth and others 1977b, Weir 1915, Wicker and Shaw 1968).

Other fungal parasites associated with aerial shoots of dwarf mistletoes are: *Alternaria alternata*, *Aureobasidium pullulans*, *Coniothyrium* sp., *Metasphaeria wheeleri*, *Pestalotia maculiformans*, *Pestalotia heteroerconis*, and *Phomas* sp. (Gilbert 1984, Hawksworth and others 1977b, Hawksworth and Wiens 1996, Kope and Shamoun 2000, Shamoun 1998). The potential use of these species as biocontrol agents requires additional evaluation.

**Canker Fungi Associated with Endophytic System**—The canker fungi of dwarf mistletoe attack both the cortex and endophytic system (Hawksworth and Geils 1996). More than 20 species of canker fungi are identified for *Arceuthobium tsugense* in British Columbia (Baranyay 1966, Funk and Baranyay 1973, Funk and others 1973, Funk and Smith 1981, Kope and Shamoun 2000, Shamoun 1998). Their potential as biological control agents includes both advantages and disadvantages. Because they attack the endophytic system, effects are immediate, pronounced, and likely to kill the mistletoe. Because the host tree may be damaged as well, additional laboratory study is required before field inoculations are attempted. Three canker fungi are good candidates for biological control.

*Neonectria neomacrospora* (formerly *Nectria macrospora*, *Nectria neomacrospora*) is characterized by a stroma with dark red perithecia containing eight-spored asci (Booth and Samuels 1981, Mantiri and others 2001). The conidial sporodochia (*Cylindrocarpon*) appear white and are found most commonly on freshly cankered swellings (fig. 7-5 and 7-6) caused by *Arceuthobium tsugense* (Funk and others 1973, Kope and Shamoun 2000, Shamoun 1998). Byler and Cobb (1972) report *N. neomacrospora* (as *N. fuckeliana*) is a virulent pathogen of *A. occidentalis* on *Pinus muricata*. The fungus is only weakly parasitic on pine and is secondarily parasitic on western gall rust cankers caused by *Peridermium harknessii*. *Cylindrocarpon cylindroides* is more virulent than *Colletotrichum gloeosporioides* on germinating seeds and callus of *Arceuthobium tsugense* (Deeks and others 2002).

The characteristics that recommend *Neonectria neomacrospora* as a biocontrol agent are its selectivity for dwarf mistletoe-infected host tissue, pathogenicity, ability to invade, rapid canker production, abundant spore production, reduction of shoot growth, girdling, and branch mortality. Further development involves improvements of formulation and delivery technologies (Funk and others 1973, Shamoun 1998, Smith and Funk 1980).

*Cytospora abietis* is the best known fungus associated with dwarf mistletoe cankers and is common (20 percent) on *Abies magnifica* and *A. concolor* parasit-



**Figure 7-5**—*Neonectria* canker of *Arceuthobium tsugense*. Note: symptoms of the disease are resinosis and necrosis of mistletoe shoots.

ized by *Arceuthobium abietinum* (Scharpf 1969a, Scharpf and Bynum 1975, Wright 1942). The fungus occasionally parasitizes nonmistletoe-infected branches. The overall interactions of the fungus, the mistletoe, and the host tree need to be evaluated. Although the fungus kills mistletoe-infected branches, it is not known how much the mistletoe population is reduced (Hawksworth 1972).

**Resin Disease Syndrome**—Resin disease syndrome is common on *Arceuthobium americanum* infecting *Pinus contorta* in the Rocky Mountains (Mark and others 1976). The symptoms include excessive



**Figure 7-6**—*Neonectria neomacrospora* (anamorph: *Cylindrocarpon cylindroides*) infecting the basal cup and the swelling (endophytic system) of *Arceuthobium tsugense*.

resinosis of the mistletoe canker, necrotic lesions and discoloration of the host bark, and retention of dead needles, necrophylactic periderms, and dead mistletoe shoots. Numerous fungi are isolated from resin disease cankers. *Alternaria alternata* is the most consistent (recovered from 89 percent of cankers), but the syndrome appears to be a disease complex caused by *Alternaria alternata*, *Aureobasidium pullulans*, and *Epicoccum nigrum* (Mark and others 1976). However, Gilbert (1984) isolated these fungi from nonsymptomatic mistletoe cankers and host wood; these fungi alone may not be the sole cause of the syndrome. Additional studies needed include: effects on reproductive potential of the mistletoe, comparisons for systematic and nonsystematic mistletoe infections, and assessments of environmental factors and each fungal component in disease development (Mark and others 1976).

**Summary**—Numerous studies of the mycobiotic associates of dwarf mistletoes are complete. The fungal parasites *Colletotrichum gloeosporioides*, *Cylindrocarpon gillii*, *Caliciopsis arceuthobii*, and *Neonectria neomacrospora* are effective in destroying aerial shoots or the endophytic system. They can disrupt the mistletoe life cycle and reduce dwarf mistletoe spread, intensification, and damage. Canker fungi are attractive biological control agents because they attack the mistletoe over a long period and infect the endophytic system. These canker fungi have the potential of killing the mistletoe in addition to reducing reproduction. The most promising biocontrol agents are *Colletotrichum gloeosporioides* and *Neonectria neomacrospora*.

## Chemical Control

The development of a selective herbicide to control dwarf mistletoes has been a primary but elusive goal for decades. The fundamental challenge is to find a chemical that is easy to apply and kills the mistletoe without toxic effects to the host or other nontarget species. If the mistletoe cannot be killed, a second strategy is to cause abscission of shoots, thereby reducing and delaying spread and intensification.

Numerous lethal herbicides have been tested for control of dwarf mistletoes (Gill 1956, Quick 1963, 1964, Scharpf 1972). The most common chemicals investigated in early studies are various formulations of 2,4-D and 2,4,5-T. Typically, these chemicals are not effective at killing the mistletoe without also injuring the host. At low rates that do not damage the host, the endophytic system is not killed, and resprouting occurs. The most promising herbicide from a large study by Quick (1964) is an isooctyl ester of 2,4,5-T; but it is now banned for concerns over adverse, nontarget effects.

Hawksworth and Wiens (1996) review a series of tests from 1970 to the early 1990s with a number of herbicides and growth regulators including Dacamine, MCPA, Butyrac, Goal, Thistrol, D-40, Weedone, Emulsamine, DPX, Prime, and Florel. Although these chemicals cause high shoot mortality with minimal host injury, they also do not kill the endophytic system. Experiments to date with systemic chemical are inconclusive.

The most promising chemical for inducing shoot abscission is ethephon (Florel, active ingredient 2-chloroethyl phosphoric acid). The mode of action of ethephon releases ethylene, a natural growth-regulating chemical that causes early abscission of flowers, fruits, and shoots (Hawksworth and Johnson 1989b). Ethylene is a natural substance that dissipates quickly and shows few nontarget effects. It has been evaluated for numerous mistletoe–host combinations (Frankel and Adams 1989, Hawksworth and Johnson 1989b, Livingston and Brenner 1983, Livingston and others 1985):

- *Arceuthobium americanum* on *Pinus banksiana* in Manitoba
- *Arceuthobium americanum* on *Pinus contorta* in Colorado and California
- *Arceuthobium campylopodum* on *Pinus ponderosa* in California and Idaho
- *Arceuthobium campylopodum* on *Pinus jeffreyi* in California
- *Arceuthobium divaricatum* on *Pinus edulis* in New Mexico
- *Arceuthobium douglasii* on *Pseudotsuga menziesii* in Oregon
- *Arceuthobium laricis* on *Larix occidentalis* in Oregon
- *Arceuthobium pusillum* on *Picea mariana* in Minnesota
- *Arceuthobium vaginatum* on *Pinus ponderosa* in Colorado and New Mexico

An important consideration is achieving adequate coverage. Ground application can be effective (Johnson 1992, Johnson and others 1989, Nicholls and others 1987a, 1987b). Robbins and others (1989) and Baker and others (1989), however, report aerial applications by helicopter are not effective due to poor penetration. Most mistletoe infections are in the lower crown and protected from the spray by overhead host foliage.

With good coverage, shoot abscission rates of 90 to 100 percent are achieved (Johnson 1992). Limited, premature browning of older host needles may occur, but serious side effects on the nontarget host are few (Nicholls and others 1987a). Resprouting from the endophytic system, however, limits effectiveness (Parks and Hoffman 1991). When resprouting is rapid and extensive, long-term protection from mistletoe spread

and intensification is not provided. With good control, mistletoe seed production is delayed 2 to 4 years; but it is not a permanent cure. Ethephon may be used to protect understory trees beneath an infested overstory in high-value areas (Adams and others 1993).

## Summary

Investigations for chemical control of dwarf mistletoes have considered numerous herbicides intended to selectively kill the parasite or cause shoot abscission. No material tested warrants widespread application. Although the growth-regulating chemical ethephon is approved by the U.S. Environmental Protection Agency for control of dwarf mistletoes, it has limited use. Because the chemical does not affect the endophytic system, new shoots and fruits develop 3 to 5 years after application (or sooner). This chemical is most useful for high value trees at homes, offices, and parks, where frequent applications are possible, but pruning is not acceptable. A chemical treatment regime can be supplemented with various other cultural techniques such as underplanting immune species.

## Management Through Selection for Genetic Resistance

Hanover (1966) describes the need for identification of heritable resistance and development of a controlled breeding program for genetic resistance to mistletoes. In the past, the relative low cost and ease with which mistletoes were controlled silviculturally delayed the development of these programs (Hawksworth and Wiens 1996). In general, trees suspected to be resistant to mistletoe are identified in the process of other management activities rather than through a deliberate search (Roth 1974a). A few scientists such as Frank G. Hawksworth, Lewis F. Roth, and Robert F. Scharpf have made consistent efforts to identify genetically resistance trees.

Native mistletoes can be relatively destructive in natural forests, and because tree species have been coevolving with mistletoes for 25 million years (Hawksworth 1978a), we can expect trees to have developed genetic resistance (Roth 1978). The existence of host-specific mistletoes and variation in host preference suggests a genetic basis of resistance, at least at the species level. *Arceuthobium douglasii* does not infect *Pinus ponderosa* (Hawksworth and Wiens 1996). Scharpf (1984) notes that two-thirds of dwarf mistletoes parasitize hosts in addition to a principal species; the levels of infection in these hosts are highly variable from secondary to rare for factors other than escape. *Arceuthobium pusillum* exhibits variation in ability to infect *Larix laricina*, *Picea glauca*, *Picea rubens*, *Pinus resinosa*, and *Pinus strobus* — all

species naturally exposed to the mistletoe (Tainter and French 1971).

In contrast to our knowledge of species-specific susceptibility, within-species susceptibility to mistletoe has been less rigorously examined. Field observations of mistletoe-free trees in areas with high levels of mistletoe infection are reported for several host–mistletoe combinations. In Western North America, these reports include healthy *P. ponderosa* in areas heavily infected with *A. vaginatum* subsp. *cryptopodum* (Arizona and New Mexico, Hawksworth 1961); *P. ponderosa* and *P. jeffreyi* free of *A. campylopodum* (Oregon, Roth 1953; California, Scharpf 1984, 1987, Scharpf and Parameter 1967, Wagener 1965); *Pseudotsuga menziesii* var. *glauca* free of *A. douglasii* (Arizona, Nowicki and others, unpublished research); *A. americanum*-free *P. contorta* (Colorado, Hawksworth and Wiens 1996); healthy *Tsuga heterophylla* in areas heavily infected with *A. tsugense* (Vancouver Island, Smith and others 1993); and *Pinus hartwegii* free of mistletoe in heavily infected areas of Mexico (De la Puente 1966). Although the progeny of these “resistant” trees have not generally been tested for resistance, these field observations suggest variation of genetic resistance within host populations exists.

When trees suspected to be resistant to mistletoe are identified in the field, they may be tested by artificially inoculating grafts and out-planting grafted scions in a mistletoe-infested area. Scharpf and Roth (1992) report high correlation between resistant *Pinus ponderosa* parents and their scions grafted and out-planted in areas with heavy mistletoe infection. Artificially inoculated grafted *Tsuga heterophylla* trees from resistant and susceptible parents also show resistance correlations (Smith and others 1993). Although results of these studies using grafted material do not prove heritable resistance, they do verify resistance is being controlled genetically rather than environmentally. These sources represent good candidate trees for progeny tests of heritable resistance.

Progeny tests for inherited genetic resistance to mistletoes show mixed results. Some cases of field resistance represent escapes or other nonheritable mechanisms of resistance. The work of Roeser (1926) and Bates (1927) represents one of the first attempts to breed forest trees for disease resistance in the United States. Regrettably, there are no differences after 50 years in the incidence of infection between slow-growing, susceptible and fast-growing, resistant selections (Hawksworth and Edminster 1981). These results suggest that growth rate is not a reliable indicator of mistletoe resistance. Hawksworth and Wiens (1996) discuss the early results of an unpublished study by G. Fechner examining putative resistance of selected *P. contorta* seedlings. The infection rates 10 years after inoculation for putatively resistant families and susceptible families are similar

(Geils, personal communication). Other progeny tests for mistletoe resistance show more positive results. Roth (1971, 1974a, 1974b) demonstrates that *Pinus ponderosa* seedlings from resistant parents have fewer infections and faster growth rates than those from more susceptible parents. Examination of these progeny tests 20 years later shows the same result (Scharpf and Roth 1992). Scharpf (1987) identifies *P. jeffreyi* trees with variation in field resistance; artificial inoculations on 7-year-old progeny from these parents indicate the resistance is heritable (Scharpf and others 1992). Finally, *Pseudotsuga menziesii* var. *glauca* progeny from healthy parents in heavily infested areas had fewer infections than progeny from infected parents. Subsequent genetic laboratory analysis using allozymes support a heritable basis for this apparent resistance (Nowicki and others, unpublished research).

Attempts to identify inherited mechanisms controlling resistance to mistletoe are few. Genetic resistance to pathogens and insects in general is classified as “vertical,” where specific resistant genes have developed, or as “horizontal,” where aggregate combinations of genes have developed to create a phenotypic response. Roth (1974a and 1974b) suggests that horizontal resistance is more likely controlling resistance to mistletoe in Western conifers. Age-related changes may confer some resistance to mistletoe in pines (Roth 1974b, Scharpf and Roth 1992), but younger true fir trees appear to be more resistant to mistletoe than older individuals (Scharpf 1984). Anatomical changes associated with age are under a high degree of genetic control and may serve as a clue for locating genetically controlled resistance mechanisms. In *Larix laricina*, the formation of a wound periderm that restricts endophytic growth of *Arceuthobium pusillum* is identified as a resistance mechanism (Tainter and French 1971); however, inheritance of the wound periderm response has not been demonstrated. Atsatt (1983a) suggests resistant hosts may produce chemicals that inhibit mistletoe or lack chemicals needed by the mistletoe to initiate and/or develop haustoria formation. In general, production of secondary chemicals is a common, genetically controlled, defense strategy used by plants; secondary chemicals may play a role in genetic resistance to mistletoe.

## Summary

Despite the relatively limited investigation, there are field observations, progeny tests, and graft studies that all point to the presence of some degree of resistance to mistletoe in North American conifers. The recent need to develop options to traditional, even-aged silvicultural treatments has led to the renewed interest in developing genetic and breeding programs for resistance to dwarf mistletoe. Field identification

of resistant sources, progeny testing to confirm heritability, plus screening and breeding programs such as exists for blister rust (*Cronartium ribicola*) are critically needed for a genetic strategy to become a viable. A screening program is being developed by Ringnes and others (1996). The objectives of this program are to identify trees exhibiting resistance to dwarf mistletoe, to evaluate testing methods for screening candidates, to identify resistance levels of candidates and their progeny, and to determine the mode and strength of inheritance for resistance mechanisms. Additional mistletoe resistance screening programs for *Pseudotsuga menziesii* var. *glauca* (DeWald and

Nowicki Northern Arizona University, Flagstaff, AZ), and *Tsuga heterophylla* (Shamoun, Canadian Forest Service, Pacific Forestry Centre, Victoria BC, Canada) have been initiated. Finally, biotechnology approaches (including tissue culture, see Deeks and others 2001, Marler and others 1999) can be used to supplement traditional resistance screening and breeding programs. Trees whose resistance to mistletoe has been confirmed can be searched for molecular DNA markers. These markers can then be used in marker-aided selection for mistletoe resistance to eliminate the long generation times currently needed to confirm genetic resistance.