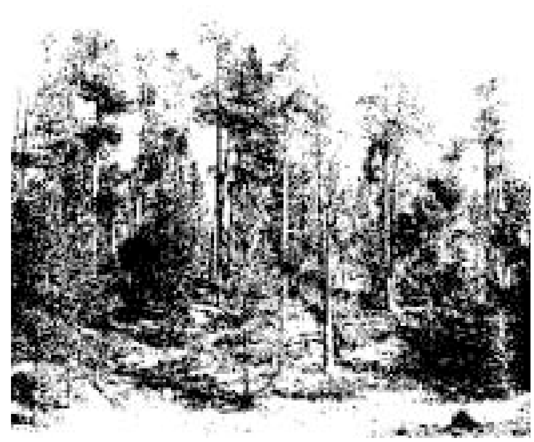
J. A. Muir
B. W. Geils

Chapter

8

Management Strategies for Dwarf Mistletoe: Silviculture



Although there are numerous sources for information on the practice of silviculture (Forest Service 2002), special considerations are required for control of dwarf mistletoe (Scharpf and Parmeter 1978). Mistletoe-infested forests, stands, and trees develop and respond to treatment differently than their uninfested counterparts (chapter 5). The spread, intensification, damage, and impacts of dwarf mistletoe can be reduced, maintained, or enhanced by silvicultural treatments alone or in combination with other control techniques (chapter 7). Silvicultural treatments discussed here include:

- Harvest, retention, and regeneration by clear-felling (even-aged silviculture), or selection harvesting to establish and maintain uneven or all-aged stand structures.

- Design and layout of harvest and treatment blocks.
- Site preparation and vegetation management by brushing, prescribed burning, and other methods.
- Planting or retaining residual and advanced regeneration.
- Thinning and sanitation.
- Pruning brooms and infected branches.

General guidelines for silvicultural treatment that integrate dwarf mistletoe information are presented in symposium proceedings (Scharpf and Parmeter 1978), regional directives (British Columbia Ministry of Forests 1995), and compendia (Alexander 1986). New strategies may be suggested and examined with simulation models (Robinson and others 2002), then tested and evaluated in practice at demonstration forests (Besse and others 2001, Edwards 2002, Nevill and Wood 1995).

The choice to initiate a silvicultural action, and the subsequent selection of techniques, timing, and location, are dictated by considerations in three major areas. First, each dwarf mistletoe species, forest type, and region present different situations. Some mistletoes have a wide distribution and cause serious damage; others are rare curiosities, spread slowly, cause little damage, or even enhance some aspect of the environment (chapter 5). Second, management objectives and constraints for individual stands (or sites), compartments (planning units), and whole forests determine the intended purpose of the treatment. Different objectives require different approaches. Objectives may be to produce timber and fiber (British Columbia Ministry of Forests 1995), enhance wildlife habitat (Reynolds and others 1992), or even promote wild mushroom production (Amaranthus and others 1998). Finally, any action must be consistent with an overall plan of forest regulation and a silvicultural system for regeneration. With even-aged silviculture, clear-felling, shelterwood, and seed tree harvests, planting, sanitation, and intermediate thinning all provide opportunities to direct stand and mistletoe development. With uneven-aged silviculture, tree and group selection determine forest character. Fuel management and prescribed burning may be used in both systems. Aesthetic values and economics may allow special cultural practices such as pruning to be used on high value trees such as found in recreation areas.

In this chapter, we describe silvicultural treatments that have been recommended or are used to prevent, mitigate, or encourage dwarf mistletoe development and effects. We provide examples of frequently encountered management situations. The discussion is organized into six topics. In *Designing Silvicultural Treatments*, we describe biological and ecological factors that apply to silvicultural decisions, especially the features that make mistletoes amenable to treatment. We also identify sources for species-specific guidelines. For *Management of Even-aged Stands*, we describe the strategies used primarily to prevent or reduce detrimental effects of dwarf mistletoes on timber and fiber production. The first and best opportunity is to prevent mistletoe spread into a clean, regenerated stand. Established stands with mistletoe present can still be treated with sanitation, thinning, harvesting, or be reestablished. In the discussion of *Uneven-aged Silviculture and Selection Cutting*, we recognize a shift in forestry to management for ecosystem structure and functions, retention of old-growth forest character, wildlife habitat, recreation, and other amenity values. Although we have less research and management experience for this kind of management, mistletoe can play a large role in determining whether those objectives are met. Techniques and tools are available for influencing the patterns and rates of mistletoe spread and intensification. *Prescribed Burning* is an especially useful tool for either even-aged or uneven-aged silvicultural systems. Regardless of the treatment considered, a manager needs to be aware of the likely responses to a proposed action. Because mistletoes add complexity and because the consequences of specific decisions may not be apparent for decades, managers can use *Models to Assess Treatment Opportunities*. Finally, in *Management for Recreation, Wildlife, and Ecosystem Values*, we describe some of the special requirements and techniques applicable to infested stands and trees managed with these objectives.

Designing Silvicultural Treatments

Dwarf mistletoes markedly affect the growth, form, and survival of infected trees and therefore how these trees and their stands develop and respond to silvicultural treatment (chapter 5). Effects to trees include: distorted growth from branch and stem infections, changes in wood quality, reduced overall tree growth, increased susceptibility to attack by secondary insects and fungi, and increased mortality. These damages aggregate over time, affecting forest health, sustainability, and productivity (DeNitto 2002, Hawksworth and Shaw 1984, Monning and Byler 1992). Consequently, mistletoes affect the basic ecological processes of primary productivity, biomass allocation, mortality, mineral recycling, and succession (Kipfmueller and Baker 1998, Mathiasen 1996, Tinnin and others 1982, Wanner and Tinnin 1989, Zimmermann and Laven 1984). Because significant infestations of dwarf mistletoe have profound, fundamental, and particular effects on stands, mistletoes need to be specifically considered in designing silvicultural treatments on infested sites (fig. 8-1).

Figure 8-1—A portion of lodgepole pine stand in the Bighorn Mountains, Wyoming. As evidenced by the numerous, large witches' brooms, most trees are severely infected with *Arceuthobium americanum.* If the management objective were timber-oriented, this stand is a good candidate for regeneration and a poor candidate for commercial thinning. Fuel distribution and canopy structure depart greatly from what would be expected in an uninfested stand with significant consequences to fire and wildlife objectives.

Dwarf mistletoes and the forest stands at risk of infestation develop at a pace that appears slow from a human perspective but not from that of the host trees. For example, a rule of thumb for spread of a mistletoe infestation is 10 m per decade (Dixon and Hawksworth 1979); intensification in trees is one DMR class per decade (Geils and Mathiasen 1990); half-life of DMR class-6 trees is one decade (Hawksworth and Geils 1990). [Note: many factors influence rates of spread, intensification, and mortality. These rules of thumb are meant only to suggest the magnitude of the rate of change and are not intended as specific management guidelines.] With stand replacement times of one to two centuries, mistletoes are able to produce tens of generations and increase unchecked at a low exponential rate. Noticeable effects are delayed until infection reaches a moderate level, but damage accumulates at an increasing rate after that point (Hawksworth 1961, Tinnin and others 1999).

The potential impacts of dwarf mistletoe infestation and their dynamics have several implications for designing silviculture treatments. First, over time a treated stand that remains infested will develop differently than an uninfested stand. Second, early and frequent interventions provide greater opportunities to affect stand and infestation dynamics and impacts than later or infrequent entries. The timing and number of entries are, of course, determined by other factors as well. Therefore, an early treatment assessment (such as immediately after completion) may not provide a satisfactory indication of its long-term consequences without an adequate model.

Several biological and ecological features make dwarf mistletoes especially amenable to silvicultural treatment (Hawksworth 1978a, Parmeter 1978). The epidemiological bases of these features are discussed in chapters 4 and 5; here we suggest their silvicultural implications:

- *Obligate parasitism*. Dwarf mistletoes require a living host to survive and reproduce. When an infested tree or branch dies (or is cut), the attached mistletoe plants die as well. There is no need to burn or destroy slash or pruned branches to kill and sterilize the pathogen.
- *Host specificity*. Dwarf mistletoes generally infect only a single, susceptible host species or group of related species. Retained immune and less susceptible hosts reduce spread and severity of damage.
- *Extended life cycles*. Life cycles of dwarf mistletoes are relatively long compared to other tree disease agents; a generation ranges from 2 to 10 or more years. Dwarf mistletoe spread from tree to tree, and increase within tree crowns is relatively slow. Because numerous infections are required to cause serious damage, the effects accumulate slowly. Time is available to plan and implement a treatment regime.
- *Limited seed dispersal*. Dwarf mistletoe seeds are dispersed a maximum horizontal distance of only 10 to 15 m; gravity and foliage limit effective spread in the vertical and horizontal planes; animal vectoring of dwarf mistletoe (with one or two exceptions) is rare enough to be ignored other than from ecological and evolutionary perspectives. Consequently, mistletoe tends to occur as pockets of infestation. Spatial variation in mistletoe abundance provides numerous patches in which different, appropriate treatments can be applied. Even with severe infestations, the amount of mistletoe seed produced is limited; small, young understory trees present a minimum target. There is an opportunity to regenerate a stand under an infected overstory before the young trees are infected.
- *Slow intensification within tree crowns*. Dwarf mistletoe infection typically begins in the lower tree crown, and vertical spread is slow enough that trees with rapid height growth can outgrow or at least keep pace with mistletoe intensifica-

tion (Hawksworth and Geils 1985, Roth 1971). Good sites for tree growth allow rapid height growth at higher stand densities, which has several effects on mistletoe. Greater crown closure reduces light within the canopy, reducing mistletoe reproduction and increasing the rate of crown lift; the distance of seed dispersal in a dense stand is also reduced (Shaw and Weiss 2000). At some point, however, for each stand, competitive effects impact tree growth, and eventually trees reach their height limit. Density management and pathological rotation allow silviculturalists to influence the balance between growth of the host and the pathogen (Alexander 1986, Barrett and Roth 1985, Muir 1970, Safranyik and others 1998).

The silvicultural guidelines and treatments we discuss here can only be of a general nature. The literature on damage and control is already summarized by Hawksworth and Scharpf (1978) and suggests that different mistletoes in different regions require different approaches. Recent silvicultural guides with recommendations for mistletoe-infected trees and infested stands are available for some of the principal conifers of North America (table 8-1). There are also regional guides: British Columbia Ministry of Forests (1995), Conklin (2000), Hadfield and Russell (1978), Knutson and Tinnin (1980), and Wicker and Hawksworth (1988). Numerous older publications emphasize methods for reducing dwarf mistletoe populations and damage including: Buckland and Marples (1953), French and others (1968), Gill and Hawksworth (1954), Hawksworth and Lusher (1956), Kimmey and Mielke (1959), Korstian and Long (1922), Wagener (1965), and Weir (1916b). Although dwarf mistletoes cause significant growth losses and mortality in Mexico, we know of only a few publications that discuss silvicultural treatment of Mexican conifers in general terms (Hernandez and others 1992, Reid and others 1987).

Where silviculture dwarf mistletoe management is conducted, treatments to mitigate mistletoe impacts can be integrated with other activities to reduce susceptibility to forest insects, other diseases, and fire. The complex interactions between mistletoes and bark beetles are reviewed by Stevens and Hawksworth (1970, 1984) and include situations where reduction of mistletoe also results in reduction of hazard to bark beetles. Thinning stands to reduce bark beetle hazard presents an opportunity for mistletoe sanitation. Although the effect on the mistletoe infestation was minimal, Vandygriff and others (2000) describe an attempt to relocate bark beetle attacks with aggregant baits to mistletoe-infected trees. Marsden and others (1993) explore the options for management in a stand infested with both root disease and mistletoe. This is

Table 8-1—Silviculture guides for management of North American conifers with dwarf mistletoe.

Forest type	Host species	*Arceuthobium* sp.	References
Black spruce	*Picea mariana*	*A. pusillum*	Johnson (1977) Ostry and Nicholls (1979)
California true fir	*Abies concolor* *Abies magnifica*	*A. abietinum*	Filip and others (2000) Scharpf (1969b)
Douglas-fir	*Pseudotsuga menziesii*	*A. douglasii*	Hadfield and others (2000) Schmitt (1997)
Lodgepole pine	*Pinus contorta* var. *latifolia*	*A. americanum*	Hawksworth and Johnson (1989a) van der Kamp and Hawksworth (1985)
Pinyon pine	*Pinus edulis* *P. monophylla*	*A. divaricatum*	Mathiasen and others (2002a)
Sugar pine	*Pinus lambertiana*	*A. californicum*	Scharpf and Hawksworth (1968)
Western hemlock	*Tsuga heterophylla*	*A. tsugense*	Hennon and others (2001) Muir (1993)
Western larch	*Larix occidentalis*	*A. laricis*	Beatty and others (1997) Taylor (1995)
Western pines	*Pinus jeffreyi* *Pinus ponderosa*	*A. campylopodum*	Schmitt (1996) Smith (1983)
Rocky Mountain ponderosa pine	*Pinus ponderosa* var. *scopulorum*	*A. vaginatum* subsp. *cryptopodum*	Conklin (2000) Lightle and Weiss (1974)

an especially complex situation because trees killed by mistletoe or cut for mistletoe reduction provide stumps, which are the food base for root disease; simulation models are especially useful in such cases. We later discuss prescribed burning as a tool for mistletoe management, but it can be noted here that fuel reduction by cutting or burning can also reduce mistletoe. Applications of direct mistletoe control by chemical and biological means and genetic selection (see chapter 7) can be considered an adjunct to traditional silviculture treatments with the chain saw, planting bar, and drip torch.

An important consideration in the design of a silvicultural entry is whether dwarf mistletoe treatment is necessary. In many cases the presence of dwarf mistletoe poses no threat to stand objectives. The mistletoe may be infrequent and have a low potential for increase and damage. Mistletoes may not be a concern at their altitudinal or geographic range limits (Trummer and others 1998) or where conditions permit rapid tree growth (such as with ponderosa pine in southern Colorado). Where wildlife objectives take precedence, retention of some dwarf mistletoe may even be desired to generate snags (Bennetts and others 1996) or mistletoe brooms (Parks and others 1999a).

Management of Even-Aged Stands

Even-aged, single-storied stands composed of one or two tree species are the simplest to treat for mistletoe. Prevention of dwarf mistletoe infestation in a regenerated stand is essentially guaranteed where all susceptible host trees are harvested or killed soon after harvest.

Most early guidelines assume the objective of management is timber production, and the purpose of treatment is the timely and economical eradication of dwarf mistletoe (Korstian and Long 1922, Weir 1916a). The traditional recommendation for dwarf mistletoe has been clear-cut harvesting with relatively large blocks, followed, if necessary, by intermediate thinning and sanitation to create even-aged stands free of mistletoe (Wicker and Hawksworth 1988). This method has been used extensively and successfully for many Western and Northern species (but see Johnson 1994, Stewart 1978). Treatment before or after harvest removes or kills infected and suspect trees to prevent the young stand becoming infested.

Prevention of Spread Into Cut Blocks

One of the primary issues of dwarf mistletoe treatment in even-aged silviculture is the design and layout of cut blocks (treatment units) to prevent or reduce invasion of dwarf mistletoe from adjacent infested areas. Preventative measures recommended by previous authors and some agencies include:

- Wherever possible, locate cutting boundaries in noninfested stands, nonsusceptible timber types, and natural or created openings, and take advantage of natural or constructed barriers such as roads, streams, openings, or meadows.
- Design cut blocks within infested stands to create large ratios of area to perimeter and minimize the length of infested border; avoid long, narrow blocks and units of less than 8 ha, but compromise where required for natural regeneration of heavy-seeded trees (Alexander 1986).
- Unless local, long-term, successful plantings have been demonstrated, do not plant barriers of nonsusceptible tree species around the cut block perimeter. In the majority of cases, this strategy fails because of rapid natural regeneration and fast growth of the susceptible tree species; however, in a few exceptions, a mixture of nonsusceptible tree species has retarded mistletoe spread.
- If infected trees are to be left on the boundary, avoid leaving fringes or narrow strips but rather maintain dense blocks of trees and leave a relatively uniform, abrupt (nonfeathered) margin. In British Columbia and Alberta, mistletoe spread into an adjacent young stand appears retarded from dense stands with abrupt edges (Muir 1970). Where spread and infection of young trees occurs, remove or kill infected trees at the next treatment entry.
- Avoid leaving single trees or small clumps of residual infected trees scattered throughout the harvested area. Scattered overstory trees are a significant inoculum source for young, understory regeneration, because improved light or growing conditions favor production and dispersal of dwarf mistletoe seeds (Muir 1970, 2002). Remove or destroy these trees.
- When regenerating stands with seed tree or shelterwood systems, select residual trees that are mistletoe-free or only lightly infected (DMR 2 or less). If infected trees are left, remove them before regeneration reaches 1 m in height or about 10 years of age, or prune residual seed trees to remove infected branches. Because of its deciduous habit and ability to produce epicormic, adventitious branches, larch can be severely pruned.

Silvicultural Treatments of Young Stands

When an even-aged, immature stand is already infested by dwarf mistletoe, management options are available to reduce mistletoe at one or more stages of early stand development. Factors involved in evaluating the need, kind, and timing of treatment include stocking level, growth rate, and disease level. Although mistletoe may kill some small trees in young stands, infections are usually too recent and too light to cause much growth loss; damage is a poor management indicator. More important is the potential for future, unavoidable damage as indicated by the areal extent of the infestation, the percent of trees infected, and the rate of spread. In general, treatment options for mistletoe control are to remove infected overstories, favor nonsusceptible tree species, sanitation, and thinning.

Recently Harvested and Regenerated Stands—The best opportunity for preventing reinfestation of an area by dwarf mistletoe is through complete harvest, removal, or killing of infected trees of the previous stand. This opportunity may be exercised during or soon after the harvest and regeneration period. Although the length of time and size of seedlings before which they are at serious risk of infection vary by species and site, few are infected before they are 5 to 15 years old or about 1 m tall (Wicker 1967a). The decisions to be made on the basis of management objectives and specific situation are the number of infected residual trees to be retained and the length of time they remain.

The most important means by which a regenerated stand becomes infested is through infected residual trees left on site. In decreasing order of importance, infected advanced regeneration, spread from adjacent stands (see above), and long-distance animal vectoring play lesser roles. Trees are intentionally retained for a number of reasons, even though some of these trees may happen to be infected. For example, visual quality, screening, and wildlife objectives may call for the retention of "legacy" trees. The potential for these trees to survive and fill their role must be weighted against their possible contribution to the infestation of the new stand. Total eradication of mistletoe-infected trees is neither realistic nor necessary; a sufficient goal of sanitation can be to allow for effective mistletoe management. A new stand with some infested legacy trees can still be treated with periodic sanitation thinning (see below) to selectively remove more severely infected trees and by pruning infected branches.

Some residual trees are left not for legacy objectives but because they have no merchantable value. Many timber contracts and silviculture prescriptions stipulate the felling of diseased, nonmerchantable trees for safety and forest health reasons. If undesired residual trees remain after harvest, remedial work may be appropriate. For mistletoe control purposes alone, only residuals over 3 m in height with branch infections need to be felled; shorter trees and those with only bole infections have limited potential for spreading the pathogen (Mark and Hawksworth 1974).

Another option for controlling mistletoe infestation in a new stand is to regenerate with a mixture of species including trees less susceptible to mistletoe. Robinson and others (2002) report on simulations of stands infested by *Arceuthobium tsugense* and regenerated under three different scenarios including a 20 percent mixture of an immune species (cedar). Their simulations suggest that over time, mistletoe incidence (percent infected) and severity (DMR) are less for the 20 percent mixture compared to the other scenarios. Different mixtures may be better in other situations.

Sanitation Thinning—The purpose of sanitation thinning is to reduce mistletoe incidence. As trees increase in size, stands can benefit from silvicultural thinning to select crop trees and distribute growth to those individuals. Sanitation is conducted in young stands; silviculture thinning with sanitation is practiced in precommercial and commercial stands. Sanitation is most practical in young stands after initial infection appears but before subsequent spread occurs. A postregeneration survey is useful to determine stocking and the distribution and incidence of infection (see chapter 6). A decision is required as to whether there is sufficient stocking of noninfected, potential crop trees. The options are for sanitation or for destruction and reestablishment of the stand. A third option is, of course, to redefine management objectives that reset the decision criteria for selecting a treatment. Each situation requires appropriate assessment because of the ecological and economic constraints of different management objectives, different hosts, and mistletoes with different potentials for growth and damage. Numerous sanitation and thinning studies and computer simulations suggest a few general guidelines where the manager wishes to minimize mistletoe damage and maximize tree growth.

Sanitation is most effective in lightly infested stands younger than 15 to 30 years old. At early ages, infection percentages are less; at later ages potential crop trees can be selected. In the past, most timber stands less than 30 years old were sufficiently stocked (over 1,200 stems per ha) and infested at a low enough percentage (10 to 20 percent) that sanitation was feasible. A sanitation treatment that removes all visibly infected trees can significantly reduce an infestation (Hawksworth and Graham 1963b); but due to latent infections, missed trees, and spacing requirements, complete elimination of mistletoe is unlikely (Conklin 2002). A sanitation treatment usually retains the best, apparently mistletoe-free trees and whatever additional lightly infected trees are required to meet stocking and spacing standards. Mistletoe is sometimes found as a light or moderate infection (DMR 2 or 3) in the larger of the young trees. Given the potential for future spread and growth loss, these initially larger trees may not be as desirable for retention as smaller healthy trees. For stands about 40 years old and with few patches of infected trees, approximately 1,200 healthy stems per hectare on good sites are sufficient to retard mistletoe spread.

The effectiveness of sanitation is doubtful in heavily infested young stands. Although stands about 20 years old with half or more of the stems infected may sometimes be encountered, they are poor candidates for sanitation (Scharpf and Vogler 1986). These stands generally do not have a sufficient number of healthy trees to stock the site. Severely infected trees (DMR 3 to 6) do not sufficiently respond to spacing, and reducing stand density may increase mistletoe spread and intensification. Generally, the degree of infestation in the stand, not strictly stand age, is the best criterion to decide whether sanitation is practical. For example, a general rule for lodgepole pine is that stands with more than 40 percent of the trees infected (average stand rating greater than DMR 0.5) are too heavily infested for sanitation. In these stands, removing all infected trees reduces stocking below minimal standards and depresses yields (Hawksworth 1978b). An alternative is stand replacement by clear-cutting, roller chopping, or prescribed burning.

Thinning Precommercial Stands—Whether or not an early sanitation treatment was conducted, the standard practice of precommercial thinning conducted in some forests—even for healthy stands—provides an opportunity to promote tree growth and reduce mistletoe spread and intensification. For infested stands, the usual criteria for scheduling and marking thinning treatments are supplemented with several mistletoe-related considerations. The silvicultural evaluation that precedes the drafting of a prescription can include an assessment of the size and location of patches of infected trees within a stand, approximate number and location of infected residual trees, and number of potential crop trees. An intensive, systematic survey can provide these data (see chapter 6).

Silviculturalists need to balance two results of thinning that work in opposition to one another. First, spacing reduces tree-to-tree competition and over a density range stimulates height growth and crown lift. Second, opening a canopy also stimulates mistletoe shoot growth, seed production, spread, and intensification (Hodge and others 1994). In practice, thinning is most likely to favor the host where trees are no more than moderately infected (less than DMR 3) and growing in height faster than the vertical spread of the mistletoes (Barrett and Roth 1985, Parmeter 1978, Roth and Barrett 1985). In a similar finding, Hawksworth (1978b) found that thinning in stands less than moderately infested (40 percent incidence) and on better quality sites can produce satisfactory volumes, but not on more severely infested stands or on poor quality sites. As with sanitation, replacement and acceptance are options for stands that cannot be satisfactorily thinned. The sale of merchantable timber may be available to help offset cleaning and reforestation of immature, severely infested stands. Simulation models are useful for particular situations (Hawksworth 1978b, Strand and Roth 1976) and help managers to better understand the range of outcomes that are likely to follow from specific activities.

Sanitation—removing as many infected trees as practical—is usually an integral part of precommercial thinning. For stands where average tree diameter exceeds 5 cm, the prethinning evaluation can include an assessment of potential crop trees. The priority for crop trees depends on species but is often set as:

1. Noninfected dominant and codominant trees.
2. Dominant and codominant trees with mistletoe confined to branches in the lower one-third of live crown (DMR 2 or less).
3. Dominant and codominant trees with mistletoe confined to less than one-half of the branches in the lower two-thirds of the live crown (DMR 3 or less).
4. Intermediate trees with no visible infection.

In mixed species stands where immune or less-susceptible species are available, their priority for retention can be determined by their intrinsic value plus their disease-mitigation value. If acceptable stocking cannot be obtained, alternative objectives and treatments can be considered. Thinning crews must be able to recognize mistletoe infections if a sanitation objective is to be realized. Economics may permit a single precommercial treatment but are unlikely to support additional entries until there is a commercial opportunity. Although usually considered in the context of uneven-aged management, forest health and fuel reduction treatments may be justified as well in young or old even-aged stands.

Commercial Thinning Treatments

As trees reach commercial size and the stand approaches harvest (rotation) age, a different set of concerns and opportunities are presented to the manager. As before, information on mistletoe distribution is useful, but as the infestation develops, disease level as average DMR becomes more relevant than percent of trees infected. Trees rated with a DMR of 3 or greater exhibit growth loss, greater mortality, reduced reproductive capability, and increased potential for mistletoe spread. Trees may be harvested at intermediate thinnings, shelterwood cuts, or at rotation. Simulation programs that project final, cumulative yields can be used to assess the number, timing, and severity of thinnings, to select the kinds of trees to harvest at various entries, and to set the regeneration schedule. Mistletoe factors can be integrated into these simulations to address specific situations.

Thinning trials and simulations suggest three general guidelines for management at this stage (Filip and others 1989, Hawksworth 1978b, Hawksworth and others 1977a, Knutson and Tinnin 1986, Tinnin and others 1999). Intermediate thinning in stands with an average DMR rating of 3 or greater is not practical. As most trees are infected, stocking requirements cannot be met with healthy trees; many trees are so severely infected that growth responses are poor. These stands can be considered for early harvest and regeneration. Because severely infected trees of DMR 5 or 6 show little growth and have a high risk of mortality, they can be removed at any opportunity. Within 10 to 20 years of harvest, however, other sanitation and thinning treatments may be deferred. An important consideration is the early selection of potential seed trees for regeneration; uninfected host trees and nonsusceptible species are usually preferred.

Uneven-Aged Silviculture and Selection Cutting

Because the spread and intensification of dwarf mistletoe in uneven-aged, multistory strands can be quite rapid, management of these stands is a serious challenge. But they also present opportunities. Dwarf mistletoe spread is greatest when seeds rain down from an infested overstory to a susceptible understory. With greater crown closure and competition, understory trees do not increase rapidly in height and are less likely to outgrow the mistletoe. Managers, however, do have several factors to work with. Uneven-aged, multistory stands are usually a mosaic of different size and density of trees and mistletoes. These patches can be used to isolate pockets of mistletoe. Such stands are also often composed of several tree species with a range of susceptibility to the prevalent mistletoe. Nonhost species provide not only immune stocking but also screening, which reduces mistletoe spread. Selection for greater species diversity has numerous, ecological benefits.

Management in uneven-aged stands consists of frequent entries for harvest or improvement thinning. If these entries are timely and removals sufficient, sanitation can check mistletoe spread, intensification, and damage. Several cautions are warranted, however. Mistletoe spread can be several times faster than managers expect from their experience in even-aged strands. Overtopped or severely infected trees (DMR 3 or greater) grow at reduced rates and do not outgrow mistletoe. Periodic entries at 10- to 20-year intervals with modest sanitation may be adequate to check mistletoe; but in 30 to 40 years without control, it can spread throughout the stand. Writing a prescription and marking trees in these stands requires a high skill level to detect mistletoe, recognize its potential, and select the proper action.

Guidelines for uneven-aged management are available (Mathiasen 1989, Conklin 2000). In principle, many of the suggestions described in previous sections for even-aged stands are applicable here also. The goals are to maintain individual tree ratings at DMR 3 or less and prevent infection in the top of the crown. Diligence and thoroughness can be major obstacles in applying treatments, and monitoring is important (Merrill and others 1998). One of the key considerations in uneven-aged management is whether silvicultural treatment (cutting trees) maintains the height growth of remaining trees at a rate that exceeds mistletoe vertical spread. Where trees outgrow the mistletoe and infections remain in the lower crown, impacts on tree growth are generally insignificant (Hawksworth 1978b, Parmeter 1978). For coastal hemlock, Richardson and van der Kamp (1972) suggest that trees growing 36 cm per year outgrow the mistletoe. Parmeter (1978) suggests a rate of 20 cm per year for lodgepole pine. For ponderosa pine in the Pacific Northwest, Barrett and Roth (1985) and Roth and Barrett (1985) report that infected ponderosa pine saplings outgrew the effects of dwarf mistletoe for 20 years at 25 cm annual height growth. Similarly, Wicker and Hawksworth (1991) state that after thinning, western larch grew 37 cm per year, while the larch dwarf mistletoe spread upward only 9 cm per year. Because mistletoe spread and effects vary with stand density, site quality, and other factors, these are only approximate rates (Bloomberg and Smith 1982).

Management of mistletoe-infested uneven-aged stands is discussed in detail by Mathiasen (1989) and Conklin (2000). At each entry they recommend that: more severely infected trees (DMR 5 and 6) are cut; healthy trees and those with a DMR of 1 and 2 are retained; moderately infected (DMR 3 and 4) trees are retained only where height growth is expected to exceed 30 cm per year or where the next cutting entry is scheduled within 20 years. Pruning infected branches or large witches' brooms from moderately to severely infected trees reduces spread, intensification, and damage. Pruning, however, is expensive (see section on Management for Recreation Values).

The practice in the Southwestern United States for management of pine stands with dwarf mistletoe is to consider uneven-aged management where 25 percent or fewer of the stems are infected. Individual tree selection is used where fewer than 15 percent of stems are infected; and group selection of trees in patches of less than 1 ha where 15 to 25 percent of stems are infected. Where more than 25 percent of trees are infected, even-aged management is used. Because larger trees tolerate more dwarf mistletoe infection without deleterious effects, Conklin (2000) proposes cutting and selection guidelines based on tree size and infection severity (table 8-2).

One of the major challenges for management of infested uneven-aged stands is the dispersal of dwarf mistletoe seed from infected overstory trees to the understory (Mathiasen 1989, Bloomberg and Smith 1982). Although the predominant opinion has been that dwarf mistletoe intensifies rapidly after a partial cutting or disturbance such as windthrow, there are exceptions. Shaw and Hennon (1991) and Trummer and others (1998) describe the relatively slow spread and intensification of hemlock mistletoe in Alaska. Situations such as these are good candidates for uneven-aged management. Geils and Mathiasen (1990) provide equations for the increase in DMR for Douglas-fir in uneven-aged, multistory stands. Maffei and others (1999) describe an exercise to develop similar equations for other species and incorporate the results in the Dwarf Mistletoe Model (Forest Health Technology Enterprise Team 2002). Because spatial relations are paramount in uneven-aged, multistory stands, the spatial-statistical model (Robinson and others 2002) provides another means for determining expected mistletoe spread.

In view of the uncertainties and potential adverse effects from selection and partial cutting in infected stands, use of the appropriate criteria for selecting and retaining trees is especially important. Overcutting reduces growing stock and possibly accelerates spread of dwarf mistletoe; undercutting and leaving more infected trees allows severe damage and unacceptable impacts. Cutting cycles and intensity of cutting can be adjusted to maintain healthy stands. Monitoring stand and infestation characteristics is especially important, as is the employment of well trained and highly skilled individuals who can recognize and evaluate dwarf mistletoe infection and apply complex marking guides. Although it is a challenge, management of infested, uneven-aged stands is possible (Hawksworth 1978a, Roth and Barrett 1985).

Table 8-2—Dwarf mistletoe ratings for leave trees in selection cuttings in Southwestern ponderosa pine.

Tree dbh (cm)	Maximum DMR per tree
<10	0
10-15	1
16-20	2
>21+	3

Based on Conklin (2000), acceptable rating of leave trees assumes a 20-year cutting cycle; a maximum of rating of 3 is allowed for trees that are intended for timber purposes.

Prescribed Burning

Prescribed burning is a potential silvicultural treatment applicable to even-aged and uneven-aged stands or forests. Historically, wildfire is an important ecological factor in many Western forest ecosystems and a strong determinant of mistletoe distribution and abundance (chapter 5 and Zimmerman and Leven 1984). In recent years, burning has been prescribed to maintain or reestablish desired stand conditions. Prescribed burning for treatment in dwarf mistletoe-infested stands can be used for stand replacement or mistletoe reduction.

Muraro (1978) and Zimmermann and others (1990) describe the use of fire as an economical method for replacing lodgepole pine stands that are overstocked and severely infested. Lodgepole pine, however, has a number of unusual silvicultural and fire ecology characteristics that make this species suitable for such treatment but that are not shared by all forest types.

Prescribed burning is usually a silvicultural tool for reduction of fuels where forest type and condition permit. Moderately to severely infected trees may be more vulnerable to fire because of lower crowns, witches' brooms, and accumulation of debris and resin. A goal of prescribed burning can be the differential killing of infected trees with discrimination of more severely infected trees and consequently a reduction in average stand infestation (Conklin and Armstrong 2001). Fire intensity and distribution can be directed at specific trees or groups of trees using techniques such as removing or piling duff and selecting upslope/upwind or down slope/downwind ignition points. In some stands, dwarf mistletoe infestation generates openings or gaps where infected trees survive fire (Wanner and Tinnin 1989). An approach for infected lodgepole pine or Douglas-fir stands is to replace these with more fire-resistant species such as ponderosa pine by a series of light fires over a period of several years. In any case, prescribed burning requires careful design and execution by experts (Muraro 1978). Numerous variables such as fuel loading and condition, stand structure, objectives for burn, weather, and other factors must be considered. Although prescribed fire will remain primarily a treatment for other forest management purposes, additional research and development (for example, on fire behavior, fuel distribution, and brooms) can enhance its potential as a tool in dwarf mistletoe infested stands.

Models to Assess Treatment Opportunities

When considering more complex or controversial silvicultural treatments such as sanitation and selection cuttings in uneven-aged stands or thinning of immature, even-aged stands, it is helpful to undertake a detailed, site-specific analysis of potential impacts and benefits. Such evaluations typically include a summary of current conditions, potential growth of an infested stand, costs and effects of treatments, and projected outcome with treatment. A variety of factors are important to consider, such as tree age, stand structure, stand density, species composition, site index, and years to next treatment. Useful mistletoe data are incidence (percent of stems infected), severity (DMR), area and pattern of infestation, and length of time the stand has been infested. The most feasible approach for summarizing information, making projections, and displaying results is with a forest growth and yield simulation model that includes the dynamics and effects of dwarf mistletoe infestation.

Numerous computer models are available that simulate various aspects of tree or stand development for dwarf mistletoe infected trees or infested stands. Strand and Roth (1976) describe a population model for young pine with *Arceuthobium campylopodum*. Baker and others (1982) predict stand impacts on spruce from *A. pusillum*. For hemlock forests with *A. tsugense*, Bloomberg and Smith (1982) model second-growth stands and Trummer and others (1998) model old-age stands. Myers and others (1971) introduce a growth and yield program of mistletoe-infested pine that, through many iterations and updates, has become the Dwarf Mistletoe [Impact] Model (DMIM) described by Hawksworth and others (1995). The DMIM is an operational tool supported by the U.S. Department of Agriculture, Forest Service and available on the Internet (Forest Health Technology Enterprise Team 2002). The DMIM functions with the Forest Vegetation Simulator (FVS) to model tree and stand dynamics and provide a number of presimulation and postprocessor features for data preparation, simulation control, and display (Forest Management Service Center 2001). Development currently under way for the DMIM includes improvement of overstory to understory spread (Maffei and others 1999). Robinson and others (2002) describe a process-oriented simulation model derived from the same origin as the DMIM but with additional capabilities to represent features of the mistletoe life cycle and crown canopy. This spatial-statistical model has a potential for examining such integrated mistletoe treatments as the silvicultural deployment of biological control agents.

The conversion of mistletoe control from eradication with large clear-cuts for timber production to sustained, uneven-aged management for ecological services has greatly increased the complexity of silvicultural assessments. Dwarf mistletoe simulation models are most useful to silviculturalists for addressing these complex situations, in which numerous factors interact over a long period. In chapter 5, we identify some of these interacting factors and effects; in chapter 6, we describe some procedures for acquiring data; in chapter 7 and earlier in this chapter, we outline treatments available to silviculturalists for managing infested stands. Simulation models permit planners to evaluate a number of treatment alternatives and to compare the long-term results before committing on the ground to a single, "experiment" in the sense of adaptive management (Holling 1978). Elaborate simulation models such as the DMIM–FVS incorporate a huge volume of research and experience. These models simplify an analysis by conducting the tedious bookkeeping and arithmetic required for such processes as computing statistics and applying growth functions. Because these processes are coded in the program, they are documented and can be reexecuted numerous times. The analyst is able to focus on formulating the problem, generating possible solutions, evaluating results, and documenting the overall activity.

Models are a simplification of a reality that is more or less "correct" and hopefully at least insightful. Although models are especially useful for novel situations, confidence in their predictions is supported by comparisons to the actual performance of benchmark stands. A useful set of benchmark stands represents the range of conditions and treatments silviculturalists are likely to consider (Taylor and Marsden 1997). Models are usually evaluated for sensitivity to a number of factors (Chen and others 1993). Knowledge of which factors a system is sensitive or insensitive to is useful to the planner, as these suggest what data are required to achieve high levels of accuracy or precision, and what treatments may be effective. The DMIM has numerous stochastic functions and is apparently sensitive to mistletoe incidence (percent of infected trees) at low levels (Chen and others 1993). This may well reflect real situations where a small infestation of only several trees could either spread throughout the stand or be isolated in one packet and eventually expire. A single simulation represents one likely outcome. Gregg and Hummel (2002) describes a bootstrapping facility for FVS that simplifies execution of multiple simulations to obtain information on the distribution (mean and dispersion) of outcomes. It is not necessary to simulate every infested stand to be managed. Most stands can be clustered into groups with similar conditions and treatment regimes. An analysis of these typical situations provides local guidelines that can be applied to all similar stands. Special analyses are then conducted for unusual cases and may contribute to the portfolio of guidelines.

Although the scope, availability, and applicability of current models for dwarf mistletoes are limited, their chief value is in the ability to determine quantitative effects and impacts of dwarf mistletoes under various stand conditions and treatment regimes. In so doing, models provide forest managers with a rational framework for decisionmaking.

Management for Recreation, Wildlife Habitat, and Other Ecosystem Values

It is becoming increasingly evident that active forest management by silvicultural treatment is necessary to sustain or enhance desirable stand conditions where trees or stands are infested by dwarf mistletoe. The particular conditions desired for different objectives vary: for recreation sites, live trees that are not a hazard; for some wildlife species, dense tree cover for screening; for other wildlife species, large openings with a few big trees and mistletoe brooms for nesting and roosting. Forests are not static, and trees, especially mistletoe-infected trees, have short lives. Forest management, working with the opportunity and capability provided by a site or stand, can influence vegetation development, including mistletoe, to meet a variety of objectives.

Management of dwarf mistletoe in recreation, administration, and home sites has the fundamental objective to maintain a safe and pleasant environment (Scharpf and others 1988). Although in these areas there is a low tolerance for mistletoe damage, trees are sufficiently valuable to justify repeated, individual treatment such as pruning branches. Methods are outlined as *Treatments in Developed Recreation Sites*.

Where wildlife habitat is an important consideration, it may be desirable to maintain or encourage features resulting from mistletoe infections, such as snags and witches' brooms. The same factors that can be manipulated to reduce mistletoe spread, intensification, and effects can also be used to enhance these processes and produce a continuing supply of dead and diseased trees. Examples are outlined in the section *Treatments for Wildlife Habitat and Other Ecosystem Values*.

Treatments in Developed Recreation Sites

In developed, intensively managed sites, treatments of dwarf mistletoe are needed to protect human life and property, and aesthetic and recreational values. Scharpf and others (1988) outline general principles and strategies for managing infested recreation sites and for maintaining individual trees or stands. They emphasize that specific management objectives and constraints for each site should be carefully considered and incorporated in the action plan.

The primary interests in developed, intensively used sites are to reduce the negative effects of dwarf mistletoe on tree vigor, longevity, and hazard, and to prevent mistletoe spread into healthy trees (Wood and others 1979). The first opportunity to do this is at the time of site selection and establishment. Spread from adjacent infested areas is slow and easy to control. Site planning and layout can achieve eradication by sanitation of light or patchy mistletoe infestations; hardy, immune species can be planted. The value of early control is appreciated when long-term costs of treatment and site replacement are recognized. Recreation sites range in size and level of intensity from campgrounds to National Parks (Hansen 1997, Lightle and Hawksworth 1973, Maffei 1984). Various techniques and concepts of even-aged or uneven-aged silviculture can be adapted for special uses. For example, a site may be laid out to remove an infested block of trees; or a portion of the infected trees may be removed on a periodic schedule to encourage establishment of healthy trees (Johnson 1998, Pronos 1995). A common feature of recreation sites is inspection and treatment of potentially hazardous trees on a relatively frequent schedule. Although branch pruning is rarely done in commercial forests to produce clear bole wood, pruning infected branches and brooms in high value sites is a common practice.

Pruning mistletoe-infected and broomed branches is used to maintain and improve tree vigor and to reduce hazard (Hawksworth and Johnson 1993, Maffei 1992). The most suitable candidates for branch pruning are trees having: infections in the lower half of the crown only; a DMR of 3 or less, and if smaller than 13 cm in diameter, with no bole infections or branch infections closer than 10 cm from the bole. Mark and Hawksworth (1974) have concluded that infections on tree boles larger than 13 cm have little effect on growth and produced few seeds, and they are therefore not a management concern. Aerial shoots on a branch but within 10 cm of the bole probably emerge from an endophytic system that has already reached the bole. Because most trees can tolerate removal of up to half the live crown, general practice is to prune all live branches to two whorls above the highest visibly infected branch. Mistletoe infestations in a tree usually include a number of latent (invisible, incubating infections) and other easily overlooked infections. Most of the missed infections appear in 3 to 5 years; reinspection and repeated pruning are appropriate. Such treated trees often show dramatic recovery in crown vigor. Trees with severe infections, however, such as those with infections throughout the lower crown or in the upper crown, are not likely to respond but likely to soon die. The proper consideration for these trees is whether the value of retaining them for a few more years is greater than the risk they pose for infecting other trees.

Broom pruning can also prolong the life and crown vigor of individual pine trees (Lightle and Hawksworth 1973, Scharpf and others 1988). In this method, the emphasis is on removing branches with witches' brooms rather than removing all visibly infected branches. Hadfield (1999) describes the hazard in high traffic areas from breakage of brooms in species with large or brittle witches' brooms. Pruning these may also be justified.

Treatments for Wildlife Habitat and Other Ecosystem Values

From certain perspectives and in some situations, dwarf mistletoe infestations have beneficial impacts for associated species and communities (Mathiasen 1996, Monning and Byler 1992, Tinnin and others 1982). In old-growth forests, dwarf mistletoes may exert a different set of effects on infected trees and display different dynamics (Hawksworth and others 1992a, Trummer and others 1998). Special management strategies and silvicultural treatments for infested stands are required where the objectives are to maintain and enhance wildlife habitat, old-growth character, and other ecosystem values.

As described in chapter 5, dwarf mistletoe infection produces mistletoe shoots, fruits, diseased branches, brooms, distorted crowns and boles, detritus, diseased and insect-infested trees, snags, and eventually logs. Infestations alter succession, disturbance regimes, and vegetation pattern of the landscape. Within limits, these features favor some species (or groups), inhibit other species, and are essentially neutral to most (Watson 2001). By influencing the spread and intensification of mistletoe and the environment around infected trees, managers are able to affect mistletoe infestations and ecological effects. The specific goals of a treatment depend on specific management objectives such as identification of featured species. For example, Reynolds and others (1992) describe guidelines for the northern goshawk that include consideration of mistletoe and other forest disturbance agents (also see Steeger and Hitchcock 1998).

Most of the recent interest in research and development of management recommendations has focused on snags, brooms, birds, and mammals. Bennetts and others (1996) describe a study of passerine bird diversity in a Colorado Front Range ponderosa pine forest. They suggest greater bird diversity is associated with increased mistletoe infestation (24 of 28 species positively associated); the key limiting resource for the birds in this situation may be snags. Parker (2001) reports a similar study in a northern Arizona ponderosa pine forest. He finds, however, a more complex situation with four species positively associated with mistletoe (cavity-nesting birds), five species with a negative association (avoiding infested areas), and seven with no relation (indifferent). Fairweather (1995) and Parks and others (1999b) describe mistletoe control treatments in which infected trees were killed but left standing for woodpeckers and other cavity-nesting animals. Although these snags are used, they remained standing for only a few years. Studies of broom use by wildlife include work by Parks and others (1999a), Hedwall (2000), and Garnett (2002). These studies identify which birds and mammals use witches' brooms, how they use it (for nesting and roosting), and what kinds of brooms are preferred. This information is useful to determine if retaining certain brooms is a potential benefit for a favored species. Information still lacking is knowledge of how the number and distribution of snags and brooms relates to levels of mistletoe infestation and to wildlife populations and the dynamics (rates of generation and loss) of these features.

Marshall (1996) discusses management lessons, implications, and research needs from a project to manage infested stands for northern spotted owl in southwestern Oregon. Maffei (2002) presents results of an analysis for a similar situation also in Oregon, and for maintaining owl habitat. Although owls use mistletoe brooms for nesting, vegetation changes and disturbance stimulated by the mistletoe (such as fire) lead to loss of critical owl habitat. The analyses demonstrate use of an infection index that represents desired condition (relative to owls and mistletoe) and application of the FVS-DMIM in a landscape planning exercise. These projects illustrate how mistletoe information can be integrated with wildlife criteria to design treatment regimes that benefit long-term survival of a featured species. Complex situations involving numerous ecological relationships are not amenable to simple guidelines defining which trees to cut and which to retain; rather, they require an adaptive management process of analysis, simulation, experimenting, monitoring, and revision (Holling 1978).