United States
Department of
Agriculture

**Forest
Service**

Southwestern
Region

Dwarf Mistletoe Management and Forest Health in the Southwest

David A. Conklin

Cover Photo: Effects of long-term dwarf mistletoe infection on mature ponderosa pine.

Printed on recycled paper • April 2000

Acknowledgments

Brian Geils, Bob Mathiasen, Mary Lou Fairweather, John Shafer, Reggie Fletcher, and Deb Allen Reid reviewed this report, and each provided many suggestions and comments that were used to improve both its content and readability. Brian's efforts, in particular, were especially helpful for providing clearer and more complete perspectives on many of these difficult topics. Thanks also to Mary Zabinski for editing.

Introduction

This report considers past approaches and more recent ideas for managing dwarf mistletoes in the Southwest. The impact of these parasitic plants on timber production has been known for decades, and considerable effort has focused on silvicultural control. With changing perspectives in recent years—particularly the increased attention on biodiversity and more public involvement in forest management—dwarf mistletoe control has become controversial. As a result, there is considerable uncertainty about how dwarf mistletoes should be addressed in our management scheme.

In many ways, dwarf mistletoes present a dilemma for forest managers (including pathologists). Probably anyone who has observed the effects of extensive infestation would agree that control is desirable, at least in many situations. On the other hand, aggressive control efforts have often been perceived as too extreme. To many people, some treatments have seemed worse than the disease itself.

A primary objective of this report is to help managers develop appropriate strategies for dwarf mistletoes, given the changes that have occurred—changes, not only in perspective, but also in the condition or "health" of the forest itself. Another goal is to increase awareness and understanding about dwarf mistletoes—both as natural parts of the forest ecosystem and as parasites and pathogens.

Developing a management strategy may seem relatively simple when dwarf mistletoe is viewed primarily as a pest, with its effects assessed solely as measurable losses in timber production. When additional factors are considered—especially wildlife resources and the visual impacts of treatment—it becomes more complex. As one pathologist has suggested recently, approaches to dwarf mistletoe control need to become more sophisticated (Worrall 1998).

Today's manager may ask: How much mistletoe can we tolerate and still have a reasonably productive forest? Will uneven-aged management be successful in infected stands? How should treatment priorities be set? Does dwarf mistletoe really provide ecological benefits, and, if so, how can these benefits be maintained or even enhanced? How does dwarf mistletoe—and our management of it—fit into the larger "forest health" picture? These are all difficult questions that need to be addressed.

Chapter 1 presents a brief overview of dwarf mistletoe infection. Additional concepts on mistletoe biology and ecology appear in succeeding chapters.

Chapter 2 provides an historical background on control efforts over the past century, leading to the present day controversies and uncertainties.

Chapter 3 examines the effects of these control efforts and considers various ecological factors which are relevant for management of dwarf mistletoes.

Chapter 4 presents suggestions for management in the Southwest and examines various treatment options.

Figure 1. Heavy "brooming" caused by severe Douglas-fir dwarf mistletoe infection.

Chapter 1: General Nature of Dwarf Mistletoe Infection

Dwarf mistletoes (*Arceuthobium* spp.) are parasitic flowering plants that depend almost entirely on their tree hosts for water and nutrients. They are considered to be pathogens (disease-causing agents) of trees because of their damaging effects, particularly growth reduction, branch distortions (most notably the characteristic witches' brooms), and decreased longevity. Essentially, they re-allocate growth to infected portions of the tree at the expense of the rest of the tree.

There are eight species of dwarf mistletoe in the Southwest, each with a different primary host (Table 1). Three species, those affecting ponderosa pine, piñon pine, and Douglas-fir, are found throughout most of the ranges of their respective hosts, while the others have more limited distributions. See Hawksworth and Wiens (1996) for distribution maps, taxonomic relations, and more detailed information on the biology and effects of these plants.

On both the stand and landscape levels, dwarf mistletoe distributions are usually patchy, with more or less discrete infection centers surrounded by areas without the disease. Infection centers vary in size from a few trees to many acres. Over one-third of the total ponderosa pine acreage in Arizona and New Mexico has some level of infection (Andrews and Daniels 1960, Maffei and Beatty 1988). Similar proportions of the mixed-conifer and woodland types appear to be infected. Dwarf mistletoe infestation is best described as a chronic situation rather than an "outbreak" or epidemic.

Dwarf mistletoes can occur on all ages and sizes of trees. Within infection centers, most of the larger trees (of the susceptible species) are usually infected, while significant but generally smaller proportions of the younger trees are infected. Within these areas, trees typically display an entire range of infection levels, some with very light infection (very few mistletoe plants), and others having mistletoe plants growing throughout their crowns.

Dwarf mistletoes spread by way of pressure-released seeds, with spread occurring both from tree to tree and within the crowns of individual trees. Plants tend to build up initially in the lower portion of the crown and gradually spread upward. Tree growth and vigor usually decline only when more than half the crown is parasitized. Most infected trees can survive for several decades; generally the smaller trees decline and die more quickly than the larger ones (Hawksworth and Geils 1990). Infection centers tend to expand at a rate of 1 to 2 feet per year (Hawksworth and Gill 1960), so over time a few scattered centers may coalesce and eventually cover an entire stand.

In terms of timber production, dwarf mistletoes are easily the most damaging pathogens in the Southwest, but as a natural part of the forest they do have an ecological role and benefit some other organisms.

Figure 2. Systemic infection produced by Douglas-fir dwarf mistletoe. Other dwarf mistletoes in the Southwest produce localized infection.

Figure 3. Apache dwarf mistletoe. Photo illustrates the localized nature of infection; shoots here originated from two different seeds.

Figure 4. Dwarf mistletoe seed expulsion (Rocky Mountain Research Station photo).

Table 1. Dwarf Mistletoes of Arizona and New Mexico

Southwestern (Ponderosa pine) dwarf mistletoe: *Arceuthobium vaginatum* subsp. *cryptopodum*

Hosts: ponderosa pine, also Arizona pine and Apache pine.

Distribution: Throughout most of the host range in Arizona and New Mexico, northward into Utah and Colorado, south into Mexico.

The most economically damaging dwarf mistletoe in the region. Andrews and Daniels (1960) found it on 36 percent of about 3,000 plots scattered throughout the range of ponderosa pine in Arizona and New Mexico. Its incidence is especially high in the Sacramento Mountains of southern New Mexico and portions of central Arizona.

Douglas-fir dwarf mistletoe: *A. douglasii*

Hosts: Douglas-fir, occasionally corkbark fir.

Distribution: Throughout most of the host range in Arizona and New Mexico, northward into Canada and south into Mexico.

The smallest species of dwarf mistletoe in western North America, but it induces some of the largest witches' brooms with its systemic mode of infection.

Piñon dwarf mistletoe: *A. divaricatum*

Hosts: Piñons.

Distribution: Throughout most of the range of piñon pine in Arizona, New Mexico, and adjoining states.

Often co-occurs with another mistletoe, *Phorodendron juniperinum*, in the piñon-juniper woodlands.

Western spruce dwarf mistletoe: *A. microcarpum*

Hosts: Engelmann and blue spruce, bristlecone pine (San Francisco Peaks).

Distribution: Smallest geographic range of any dwarf mistletoe in the U.S. Found only in very limited portions of the Southwest—North Rim of the Grand Canyon, San Francisco Peaks and nearby Kendrick Peak, White Mountains (probably the largest population), and the Pinaleno Mts. in Arizona; the Mogollon Mountains and a small portion of the Sacramento Mountains in New Mexico.

Induces small, very dense witches' brooms. Somewhat more damaging to blue than to Engelmann spruce.

Apache dwarf mistletoe: *A. apachecum*

Host: Southwestern white pine.

Distribution: Several ranges in southern Arizona and southern New Mexico, with an outlier in northern Mexico.

Interestingly, this mistletoe has not been found in the Sacramento Mountains of southern New Mexico, where the largest population of its host occurs.

White fir dwarf mistletoe: *A. abietinum* f. sp. *concoloris*

Host: White fir.

Distribution: Very limited in the Southwest; occurs on North and South Rims of the Grand Canyon, with small populations in the Chiricahua and Santa Catalina Mountains. More widespread in California and Oregon.

Chihuahua pine dwarf mistletoe: *A. gillii*

Host: Chihuahua pine.

Distribution: The Santa Catalina, Rincon, Santa Rita, Huachuca, and Chiricahua Mountains in southeastern Arizona, the Animas Mountains in southwestern New Mexico, and south into Mexico.

Blumer's dwarf mistletoe: *A. blumeri*

Hosts: Southwestern white pine and the closely related Mexican white pine.

Distribution: Primarily Mexico, but also the Huachuca Mountains of southern Arizona.

Chapter 2: Background on Dwarf Mistletoe Control in the Southwest

Early Work and Ideas

Dwarf mistletoes were observed and collected in the Southwest by botanists as early as the mid-1800's. They were clearly recognized as serious forest pathogens soon after the national forests were established around the turn of the century (Hedgcock 1915, Weir 1916). The Fort Valley Experimental Forest near Flagstaff was the site of early work on the effects of dwarf mistletoe on the growth of ponderosa pine (Burrall 1910, Korstian and Long 1922).

Strategies for controlling dwarf mistletoe by removing infected trees were described by Weir (1916) for the Northwest and by Korstian and Long (1922) for the Southwest. Korstian and Long's approach, outlined in their treatise "The Western Yellow Pine Mistletoe," is discussed here in some detail because the ideas still have some application in today's management and because they illustrate some of the difficulties inherent in managing the disease in the Southwest.

Korstian and Long had observed that "*mistletoe develops rapidly after cutting*," so they suggested that "*every effort should be made to free the stand entirely of mistletoe infection*" [during cutting operations]. However, they state that mistletoe "*cannot in all cases be eliminated in one cutting without too great a sacrifice of silvicultural requirements*." Weir's guidelines for the Northwest had basically called for removal of all infected trees; Korstian and Long may have been attempting a modification more suitable for conditions of the Southwest.

They clearly recommended leaving lightly (and even some moderately) infected trees as needed for stocking, as seed sources in areas lacking regeneration, for site protection, and to maintain forest continuity. They did say, however, that all infected trees should be cut in areas adequately stocked with advanced regeneration. They emphasized the importance of "*careful, intelligent*" selection and marking. They discussed the need to cut or prune infected trees in the smaller, non-commercial size classes. They saw a need to regenerate some infected areas, and recommended clearcutting stands "*too heavily infected with mistletoe to permit adequate sanitation measures*," although they stated that "*such a condition will seldom be encountered*."

The summary of their report includes the following statement:

> *The most practical method of controlling mistletoe is to remove the infected trees while cutting operations are in progress. All heavily infected trees should be marked for cutting. Moderately infected trees should be marked for cutting except where others are not available for seed trees. On areas of light to moderate infection, the marking rules should require the removal of all mistletoe-infected trees possible without breaking up the continuity of the stand or materially interfering with the silvicultural requirements of the forest.....*

Korstian and Long's strategy was largely intuitive, based on observations made in infected areas and a rather limited knowledge of the biology of dwarf mistletoes. Clearly they were attempting to integrate disease control with established management practices. They suggested that their approach could lead "*toward the eradication of the pest through a more or less gradual process of elimination*." This proved to be overly optimistic, at least from the standpoint of disease control. Perhaps they assumed that dwarf mistletoe could be successively reduced each cutting cycle until it was eliminated from a stand.

Mid-century Ideas and Research

Gill's monograph, "Arceuthobium in the United States" (1935), a major work on dwarf mistletoe taxonomy, also set the stage for new research on control. Gill's work in the Southwest, beginning in the 1930's, greatly increased regional awareness of the serious impact that dwarf mistletoes have on forest resources (Andrews 1957, Hawksworth and others 1967).

Gill (1958) described dwarf mistletoe infestation as a "*cancerous situation*." In many respects this was a good analogy, being that it spreads progressively from more or less distinct centers, can be very damaging, and is difficult to eliminate. Gill, his eminent successor Hawksworth (for most of his career), and many other pathologists and foresters who have worked in the Southwest (and other parts of the West) approached dwarf mistletoe control with enthusiasm and almost missionary zeal.

Experimental control areas were established at Fort Valley in the 1930's (Hatfield 1933, Pearson 1950, Gill and Hawksworth 1954). In the 1950's, more rigorous, long-term studies on silvicultural control were initiated at Fort Valley (Herman 1961, Heidmann 1968) and on the Mescalero Apache Indian Reservation (Hawksworth and Lusher 1956). In all, 51 study plots totaling 451 acres had been established in the Southwest by 1954 (Hawksworth and others 1967). Numerous studies on the biology of ponderosa pine dwarf mistletoe also took place in the 1950's and 1960's (Hawksworth 1961). A primary objective of this research was to determine the intensity and frequency of silvicultural treatments needed to keep the disease at low, non-damaging levels (Hawksworth and others 1967).

The steadily increasing demand for wood products during the 20th century provided a strong incentive to investigate ways to reduce the impacts of damaging agents, including dwarf mistletoes, in order to provide greater yields of sustainable timber. Since losses in productivity from dwarf mistletoes were so high in the Southwest and throughout the western United States (Andrews and Daniels 1960, Drummond 1982), it is not surprising that considerable research was conducted on control. Some studies have also been done on biological and chemical control, and on genetic resistance (see Hawksworth and Wiens 1996 for a review of these topics), but progress in these areas has been slow; currently these "alternative control methods" have very limited practical use.

Although timber production was the driving force behind control efforts, there have always been other, less tangible reasons (e.g., aesthetic values) for interest in controlling dwarf mistletoe. In the simplest of terms, people like forests and trees, and want to protect them from damaging agents like fire, insects, and disease. As a prime example, in 1949 a dwarf mistletoe control project was initiated in Grand Canyon National Park, an effort to preserve the ponderosa pine forest along a portion of the South Rim (Lightle and Hawksworth 1973).

Several characteristics of dwarf mistletoes make them amenable to silvicultural treatment (Hawksworth 1978a):

1. They are obligate parasites, so once an infected tree or branch is cut, the mistletoe dies.

2. They are usually host-specific, so on some sites their effects can be reduced by managing non-susceptible (or less susceptible) tree species.

3. They have relatively long life cycles, typically 6 years or longer, so the buildup of populations is relatively slow.

4. They spread primarily by means of forcibly ejected seeds. The vast majority of seeds travel less than 30-40 feet from the source. Horizontal spread through stands averages only 1 to 2 feet per year. [Long distance spread is discussed in Chapter 3].

5. Dwarf mistletoe infection is relatively easy to see. [Based on this fact, the 6-Class Dwarf Mistletoe Rating (DMR) System was introduced in the 1950's (Hawksworth 1977)].

These characteristics distinguish dwarf mistletoes from fungi, the cause of most tree diseases. Fungi typically reproduce rapidly, spread long distances, and can be hard to detect. While experience had demonstrated that many fungal diseases of trees were difficult to control, the prognosis for dwarf mistletoe control continued to be more favorable.

Nevertheless, the following statement by a pathologist in the 1950's indicates a significant change in thinking about dwarf mistletoe control:

> *Korstian and Long's recommendations for control work appear weak and ineffectual in the light of what is now known about dwarf mistletoe behavior. At the time, however, a compromise between pathological considerations and silvicultural and management objectives may have seemed possible.* (Andrews 1957).

Although it was apparent that dwarf mistletoes were amenable to silvicultural treatment, experience at Fort Valley, Mescalero, Grand Canyon, and elsewhere demonstrated that keeping them at low, non-damaging levels would require more intensive management than was generally practiced in the Southwest. Hawksworth's classic 1961 "Dwarf Mistletoe of Ponderosa Pine in the Southwest" recommended removal of all infected overstory trees, removal or pruning of all infected understory trees, and follow-up treatments in all size classes about 5 years later, and possibly again 5 to 10 years after that.

This rather sobering conclusion led to a seemingly more practical approach a decade or so later, involving even-aged management. Basically, the idea was that some infection could be tolerated in a developing stand, once the infected overstory trees were removed. Mistletoe would be reduced (temporarily) with each entry, and then more or less eliminated at rotation age when the stand was regenerated.

Operational Control Efforts

While a limited number of control areas were being experimentally monitored, most control work in the Southwest took place on an operational basis during timber sales and stand improvement work. Throughout the middle of the 20th century, most stands were harvested under “improvement-selection” or “sanitation-salvage” prescriptions, which involved relatively light cuts. Generally, only the more heavily infected overstory trees were removed from infected areas (Pearson 1950, Gill and Hawksworth 1954). In many parts of the Southwest, this remained a common practice throughout the 1960’s and into the 1970’s (Weiss and Loomis 1971; Frank Hawksworth, personal communication).

This practice, focusing on the removal of “high risk” trees, salvaged most of the merchantable infected trees that would die during the next 20-year cutting cycle, reducing the volume killed by the disease, but did little toward limiting the spread of mistletoe (Pearson 1950). Concern was expressed by pathologists (Gill and Hawksworth 1954, Hawksworth 1961) that the approach would not provide effective control and could even cause the disease to intensify. By now, numerous observations had indicated that dwarf mistletoe was stimulated in the remaining trees after harvest and thinning.

The standard practice—often referred to as “pick and pluck”—undoubtedly favored the build-up of mistletoe on many sites. On the other hand, it was a conservative approach that left a good proportion of the larger trees in most stands. Most foresters were reluctant to reduce stocking levels and residual volumes to the extent that cutting all of the visibly infected trees entailed. Economic considerations (particularly treatment costs) were also a factor. Initially, aggressive control efforts were implemented at only a few locations in the Southwest, most notably on a 13,000-acre portion of the Mescalero Apache Indian Reservation (Hawksworth and Lusher 1956).

The standard practice was undoubtedly influenced by the suggestions made by Korstian and Long. Almost certainly, however, more infected trees were being retained than these authors had envisioned. One thing in particular that may not have been foreseen was the reluctance to remove infected “seed trees” from areas that were already regenerated. This is still a dilemma for managers.

Beginning in the 1970’s and increasingly in the 1980’s, the Forest Service made more aggressive efforts to control dwarf mistletoes. Even-aged management was adopted in the national forest plans (originally developed during the 1970’s), at least in part to reduce the impacts of dwarf mistletoes and western spruce budworm. Computer-simulated growth and yield models were now available and being used in timber sale planning to demonstrate the impacts of dwarf mistletoes under various management strategies (Myers and others 1972, Edminster 1978).

Figure 5. Piñon dwarf mistletoe. This lesser-known species is widely distributed in the woodlands of Arizona and New Mexico.

Many timber sales now involved removal of all visibly infected merchantable trees in harvest areas. In some stands, all overstory trees were cut in order to provide better control, since not all infected trees could easily be detected. More effort also appears to have been made in reducing infection in the smaller, non-commercial component than previously. Overstory removals were considered to be a form of even-aged management, even though the remaining young stands often had two or more age/size classes.

An "Integrated Forest Protection Guide" (Beatty 1982) stated that dwarf mistletoe-infected stands should be given high priority when thinning and harvesting are scheduled. The highest priority, according to the Region 3 "Cutting Methods Handbook" (USDA 1985) were stands with an "infected mature overstory and an adequately stocked, healthy or lightly infected understory." Prior to the 1980's, there is little indication that infected stands were specifically targeted for cutting; rather, it appears that mistletoe was more or less treated as encountered during a regular schedule of harvest and thinning.

Another form of even-aged management that saw increased application for treatment of infected stands was the regeneration cut—shelterwood and seed-tree cuts. A common problem with using overstory removals to control dwarf mistletoe is that the level of infection in the understory is often already relatively high. Some infected stands are more or less single-storied and lack an understory. The basic concept behind the regeneration cut was to replace infected stands with uninfected regeneration (Beatty 1982). In some timber sales, seed-tree cuts were applied over large areas, had significant visual impacts, and generated much controversy.

By 1990, many individuals, both inside and outside the Forest Service, were saying that mistletoe was being used as an excuse to cut timber. This assertion may not be entirely fair to the Forest Service, which has been charged by law and policy to provide timber. Nonetheless, this perception developed in response to a large proportion of harvest units being placed in infected stands during the 1980's and early 1990's. The heavy cutting involved in these control efforts did mesh well with timber (target) objectives. The rationale was that without these aggressive control measures, serious losses in productivity would occur, which was generally true. However, the idea that heavily infected stands would "collapse" if not treated in a timely manner, which was used in the early models, is sometimes questionable and open to interpretation.

At the same time that dwarf mistletoe control was becoming controversial, a 2-year study conducted in Colorado found a positive correlation between infection levels and the abundance and diversity of birds (Bennetts and Hawksworth 1991). Also of considerable interest was information from the Pacific Northwest indicating that spotted owls often use Douglas-fir dwarf mistletoe witches' brooms for nesting sites. These reports helped precipitate a general shift in thinking about dwarf mistletoes, particularly among many wildlife biologists. Attention began to focus on the potential benefits of these plants as natural parts of the forest ecosystem.

It is interesting to note that beneficial aspects of dwarf mistletoe infection had been recognized by some forest pathologists several years earlier. For example, Tinnin and others (1982) discuss the use of dwarf mistletoe witches' brooms by animals, and state "*Without question, broomed trees represent a unique resource in forested ecosystems.*" It took several more years of heavy cutting in infected stands, an emerging biodiversity issue, and increased public involvement before significant controversy developed over control efforts.

Chapter 3: Dwarf Mistletoe Management and Ecology

The controversial nature of dwarf mistletoe control is exemplified in a statement by Bennetts and others (1996):

> *While dwarf mistletoe has traditionally been viewed as a forest pest because of reductions in timber volume, we suggest that in areas where management goals are not strictly focused on timber production, control of dwarf mistletoe may not be justified, practical, or even desirable. Our data suggest that dwarf mistletoes may have positive influences on wildlife habitat. Consequently, we suggest that eradication efforts be reconsidered given that dwarf mistletoes have been a part of these forest ecosystems for thousands, and possibly millions, of years.*

The documentation provided in this study about birds and dwarf mistletoe was timely, and the above statement expresses an important concern. However, the statement seems to imply that "eradication efforts" may be on the verge of eliminating these organisms from the forest ecosystem. As will be discussed in this chapter, this is hardly the case.

Moreover, the statement ultimately falls short of providing meaningful direction for management. The fact is that few (if any) areas in Southwestern forests are or have been managed strictly for timber production. While timber production has been an objective for a significant portion of the forest (what has been called the commercial base), there have always been other uses, values, and management goals in these areas. While these goals may at times appear to conflict, on a broad scale they are not necessarily incompatible.

Certainly a case can be made that timber production has been overemphasized in the past, however. While recent trends in harvest levels (Dahms and Geils 1997) suggest that this situation may be changing, the idea that dwarf mistletoes are natural components of the forest and provide certain ecological benefits may still need better integration into our overall management scheme. An adjustment in the way we prioritize stands for treatment (Conklin 1992, Dahms and Geils 1997) would help achieve this.

The real issue is not whether or not we should try to control dwarf mistletoe, but how we can best ***manage*** it, both ecologically and economically. Because of the widespread distribution of dwarf mistletoes in the Southwest, the majority of timber sales, thinning projects, restoration projects, etc., will encounter them.

Effects of Past Timber Management on Dwarf Mistletoes

Considerable insight into how dwarf mistletoe distributions and populations have been affected by past management can be gained from the results of research plots, project monitoring, and what we have learned about the structural changes that have occurred in forests of the Southwest over the past century.

Research plots at Fort Valley, Grand Canyon, and the Mescalero Apache Indian Reservation involved removal (or pruning) of all visibly infected trees, and one or more follow-up treatments at roughly 5-year intervals. This represents much more intensive management than has been conducted in most operational harvests and thinnings over the past century. Significantly, in none of the research plots was dwarf mistletoe eliminated. After treatments had reduced the parasite to undetectable levels, populations inevitably began to rise in these experimental areas.

Foresters are often surprised to see considerable infection in treated areas thought to be rid of dwarf mistletoe. Monitoring of several ponderosa pine stands in Arizona and New Mexico in which all, or at least most, of the visibly infected trees were cut indicates that stand infection levels return to pre-treatment levels in about 20 years (Geils, unpublished data).

A study on control of lodgepole pine dwarf mistletoe in Colorado (Hawksworth and others 1977) further illustrates both the effectiveness and limitations of "sanitation." Several plots were treated by removing an infected overstory and then cutting all visibly infected trees in the young (20- to 40-year-old) understories. A follow-up treatment 3 years later removed all additional visibly infected trees. Ten years after the initial treatment, 21 percent of the trees were visibly infected, compared to 31 percent before treatment. Infection on untreated plots increased from 28 percent to 42 percent over the same 10-year period.

A century of experience has demonstrated that it is virtually impossible to eliminate dwarf mistletoes through partial cutting. Latent infections—infections that have not yet produced visible mistletoe shoots—

are a major reason. Roughly speaking, for every 100 trees that are visibly infected, another 50 or so have latent (or very inconspicuous) infections in lightly to moderately infected stands (Hawksworth and others 1977, Knutson and Tinnin 1980, Merrill and others 1988).

As mentioned in Chapter 2, when stands are opened up by selective harvest or thinning, dwarf mistletoes are stimulated. Latent infections are more apt to develop shoots; existing shoots grow more rapidly and produce more seed. This is probably a result of both improved tree vigor—which provides more water and nutrients to the parasite—and increased light (Korstian and Long 1922, Hawksworth 1978a, Parameter 1978). Unlike many forest insects and pathogens that are often associated with weak or slow-growing trees, dwarf mistletoes actually do better on vigorous trees.

Figure 6. Western spruce dwarf mistletoe. This species has the smallest geographic range of any dwarf mistletoe in the United States. Note evidence of rodent feeding on infected bark.

The vast majority of stand entries made in the Southwest from the early 1900's to the present involved some type of selective or partial cut. The relatively light cuts made throughout the middle of the century were probably very favorable for dwarf mistletoes. The more aggressive treatments in the 1980's often resulted in better disease control, but for the most part, still only provided temporary reductions in infection levels. Overstory removal cuts eliminated major sources of infection, but stimulated infection already present in the understory. Final removal cuts following seed-tree or shelterwood cuts have seldom been implemented. Relatively few treatments in the Southwest have involved complete stand replacement.

Comparison of Regionwide roadside surveys done in the 1950's and repeated in the 1980's indicates an increase in the proportion of the ponderosa pine type containing dwarf mistletoe infection (Andrews and Daniels 1960, Maffei and Beatty 1988). However, interpretation of these data is unclear. Because of the slow lateral spread of dwarf mistletoe, the level of increase reported for some national forests over the 30-year period is unlikely. On the other hand, comparison of these survey data may indicate a trend.

There probably has been some increase in the area/ proportion of the ponderosa pine type (and perhaps other forest types) affected by dwarf mistletoe over the past century. Almost certainly there have been increases in the number of infected trees; this can be assumed simply because of evidence that today's forests contain many more trees (Covington and Moore 1994, Johnson 1994). Although direct evidence is limited, we can probably assume that increases in dwarf mistletoe populations have occurred simultaneously with changes in forest conditions since European settlement, especially in the ponderosa pine type.

Silvicultural treatments have periodically removed infected trees and reduced infection levels in managed areas, but have probably had less effect on disease ***spread*** than is often assumed. Even where attempts were made to remove all infected trees, those with latent infection along the edge of infection centers have enabled continued expansion of the centers. Foresters often think that "treating" a stand for dwarf mistletoe will prevent it from spreading to adjacent stands—this is usually not the case, although in some situations spread is temporarily slowed.

In portions of the western U.S. where clearcutting has been used more extensively, as in the lodgepole pine type, dwarf mistletoe distribution has probably been reduced. Relatively little clearcutting has been done in the Southwest. Overall, it is unlikely that past silvicultural treatments have had much effect on the distribution of dwarf mistletoes in the Southwest. (This is not to indicate "failure" on the part of past treatments, rather an attempt to be explicit about the results/effects. In fact treatments, by setting back mistletoe, have often allowed stands to develop with less disease impact.)

While probably having little effect on mistletoe distributions, silvicultural treatments over the past century have almost certainly reduced the number of large infected trees in the region. This situation has been a major concern among some environmental groups (Pollock and Suckling 1996), and has probably been the key issue in the controversy over dwarf mistletoe management.

The mid-century practice of removing only the more heavily infected overstory trees during timber sales retained many large infected trees, although it did result in fewer large snags. Later emphasis on complete overstory removals, with such treatments considered high priority, meant that infected areas were often cut heavily, and at a disproportional rate. In many areas, mature infected stands were replaced with young infected stands—even where attempts were made to "sanitize" the understories.

Today, mature infected stands are relatively uncommon in many parts of the Southwest. This is due more to cutting practices in recent decades than to the effects of dwarf mistletoe. This situation is certainly not irreversible, however.

Silvicultural control efforts have been, to a greater or lesser extent, an integral part of forest management in the Southwest for many decades. After objectively considering the limitations of these efforts and some of their negative consequences, it should be stated that they have contributed toward a steady flow of forest products and have increased future productivity in many areas.

Aggressive mistletoe treatments have generated some negative perceptions about control. For example, Kaufmann and others (1998) state that "*past attempts to control dwarf mistletoe have had undesirable effects,*" and as evidence mention a treatment that resulted in an outbreak of *Ips* bark beetles. In fact, *Ips* outbreaks can occur following any type of thinning in ponderosa pine, and have nothing to do, per se, with dwarf mistletoe control efforts.

There has been some speculation that the era of heavy logging for railroad ties, mine props, and other timber products in the late 1800's and early 1900's may have contributed to the high incidence of dwarf mistletoe found today in parts of the Southwest. Certainly in those days little attention was given to the quality of the remaining stand. In many areas, non-merchantable infected trees left behind after "high-grade" logging would have re-infected the areas as they regenerated. However, this seems more the perpetuation of an existing condition than the cause of a mistletoe problem, since the disease was already present.

It is known that fires consumed large areas of cut-over forest during the railroad-logging era (Kaufmann and others 1998), which probably reduced or even eliminated mistletoe in some areas. Heavy cutting during this period is thought to have reduced dwarf mistletoe distribution in some areas of northern New Mexico and central Arizona (Hawksworth 1961). Whether or not the heavy logging favored or reduced mistletoe clearly depended upon the forest structure and fire history within particular areas.

Fire History and Dwarf Mistletoe

Several investigators have stated that fire history is the most important factor governing the distribution and amount of dwarf mistletoes on the landscape (Alexander and Hawksworth 1975, Wicker and Leaphart 1976, Hawksworth and Wiens 1996.) Zimmerman and Laven (1984) demonstrated an inverse relationship between the abundance of dwarf mistletoe and fire frequency in several lodgepole pine stands in Colorado. Although their results do not necessarily apply to ponderosa pine and other forest types in Arizona and New Mexico, we can infer that several decades of fire suppression have probably been favorable to dwarf mistletoes in the Southwest.

Because of their branching patterns and the accumulation of resin, infected trees are often more flammable than uninfected trees. Similarly, fuel levels are often higher within infected areas than elsewhere, which would tend to cause more intense fires in those areas (Parmeter 1978, Koonce and Roth 1980). Because infections are usually more abundant in the lower crown, partial crown scorch often has a "sanitizing" effect on lightly to moderately infected trees. The survival rate of heavily infected trees with partial crown scorch may be lower than that of similarly scorched uninfected trees (Harrington and Hawksworth 1990).

Intense fires that kill all trees over large areas can reduce dwarf mistletoe distribution because trees often return to burned areas much faster than the parasite does (Alexander and Hawksworth 1975). On the other hand, intense but more spotty fires that leave scattered infected trees may contribute toward higher infection levels over time (Alexander and Hawksworth 1975, Parmeter 1978). However, the frequent low-intensity fires that occurred throughout much of the ponderosa pine type, and at least portions of the mixed conifer type, would have tended to provide periodic reductions in infection levels.

Moreover, the historic fire regime, by keeping the forest more open and park-like, would have limited tree-to-tree spread of the parasite. Over the past century, many forest openings (natural buffers) have filled in with trees, facilitating spread. This phenomenon is related to grazing history as well as to fire suppression. Present forest conditions are probably more favorable for increases in dwarf mistletoe populations than past conditions. It should be noted, however, that the lateral spread of dwarf mistletoe is relatively slow in a dense forest, due to the screening effects of the crowns (Hawksworth 1961, Parmeter 1978, Knutson and Tinnin 1985).

Other Factors Affecting the Distribution of Dwarf Mistletoes

While fire history is undoubtedly important, other ecological factors influence the distribution of dwarf mistletoes on the landscape. Although our knowledge of these factors is limited, from a management perspective we should at least be aware they exist. Like other plants, mistletoes are subject to certain environmental limitations—particularly temperature and moisture regimes—that affect their distribution (beyond the obvious fact that they can only grow where their hosts grow!).

It can be difficult to distinguish between areas that are mistletoe-free because mistletoe simply hasn't gotten there yet and areas that are mistletoe free because mistletoes ***can't*** successfully spread into them (Parmeter 1978). In inoculation experiments with ponderosa pine dwarf mistletoe seeds, Hawksworth (1961) had a success rate over 10 times higher in an infected stand than in a nearby uninfected stand. This suggests that spread is limited by ecological or climatic factors, and that some parts of the forest may be more susceptible to infestation than others.

Ponderosa pine and Douglas-fir dwarf mistletoes are both found throughout most of the elevation ranges of their hosts in the Southwest. However, ponderosa pine mistletoe is more abundant in the mid-elevation range of its host, while Douglas-fir mistletoe has an upper elevation limit slightly below that of its host (Hawksworth and Wiens 1996). Both these relations, especially the latter, suggest the importance of climate as a determinant of dwarf mistletoe distribution. The fact that ponderosa pine dwarf mistletoe occurs most frequently on ridge and mesa tops and least frequently on bottom sites (Hawksworth 1961) seems more likely a result of microclimatic differences than fire history.

Notable differences are found between the incidence and severity of ponderosa pine dwarf mistletoe in different parts of the Southwest. A striking example is the high level in the Sacramento Mountains of southern New Mexico compared to most areas in northern New Mexico. These differences could be a result of climate—the Sacramentos have an unusually strong summer monsoon pattern which usually provides ample moisture for germination of dwarf mistletoe seeds—or they might involve the genetics of the host/pathogen relationship. (Note that differences in incidence could simply be a result of chance, but my impression is that pathogenicity also somehow differs. These differences may mean that ponderosa pine dwarf mistletoe is more difficult to manage in some parts of the Southwest than others.)

No definitive relationships have been found between dwarf mistletoe distribution and site quality, aspect, or soil type. Relationships between dwarf mistletoes and habitat types/plant associations are also hard to discern; it is clear that both ponderosa pine and Douglas-fir dwarf mistletoes occur across a wide range of habitat types containing their respective hosts. Merrill and Hawksworth (1987) did report some differences in the incidence and severity of ponderosa pine dwarf mistletoe among habitat types in southwestern Colorado, while Mathiasen and Blake (1984) found that the effects of Douglas-fir dwarf mistletoe on host growth varied by habitat type in Arizona and New Mexico.

While the distributions of other species of dwarf mistletoe in the Southwest are well documented (Hawksworth and Wiens 1996), little is known about the factors that affect these distributions. Why, for instance, is Apache dwarf mistletoe common in several mountain ranges of central and southern New Mexico, but entirely absent from the nearby Sacramento Mountains, which contain the largest population of its host—Southwestern white pine (*Pinus strobiformis*)—in the region?

Although its significance is unknown, another factor governing dwarf mistletoe distribution may be dispersal by animals, especially birds. This is suspected because the sticky seeds of several dwarf mistletoe species have been found on the feathers of birds, and, less commonly, in the fur of mammals; the seeds can be rubbed off or deposited on susceptible host foliage (Nicholls and others 1984, Hudler and others 1979). Recent studies in Colorado and elsewhere have documented young "satellite" infection centers that appear to have originated from vector-disseminated seed (Hawksworth and Wiens 1996).

Initiation of new infection centers by long distance dispersal is probably rare, because dwarf mistletoes are dioecious, that is, they have separate male and female plants. Plants of both sexes must be in fairly close proximity for pollination and seed production to occur (Nicholls and others 1984); a single isolated plant would not result in spread. Over extended periods of time, however, medium and occasional long distance spread could help account for the patchy distribution of dwarf mistletoes on the landscape.

Note that unlike true mistletoes (*Phorodendron* spp.), dwarf mistletoes are not spread by birds eating the fruits or seeds. Most birds do not eat dwarf mistletoe seeds, or if they do, the seeds are rendered inviable by the digestive process (Zilka and Tinnin 1976, Hudler and others 1979, Nicholls and others 1984).

Dwarf Mistletoes and the Ecosystem

Recently some managers have been asking what the ***endemic*** or natural level of dwarf mistletoe is for a stand or particular area. A question like this really cannot be answered. Infection is a dynamic process—infected areas tend to become more heavily infected over time; occasionally natural processes, especially fire, reduce infection levels. Some areas are more prone to infection than others, but we really have no basis to say how much mistletoe "should be" in any particular area.

Dwarf mistletoes and their hosts have evolved together for many thousands, perhaps millions of years; as in many other host/parasite relations, a certain balance has been attained. The parasite seldom eliminates its host over large areas—this would be a disadvantage to an obligate parasite. (Exceptions may occur in mixed-species stands, where infection can accelerate the loss of a particular host species.) Although heavy infection can reduce host seed production (Korstian and Long 1922), it does not necessarily limit host regeneration (Wanner and Tinnin 1989).

Most infected trees survive for several decades (Hawksworth and Geils 1990, Geils and Mathiasen 1990), ample time to infect nearby regeneration. Eventually, most of the regeneration within a center becomes infected, but usually some of it will live long enough to reproduce and continue the cycle. Some infection centers are probably several hundred years old.

Over time, infection centers usually become more open, with lower crown cover and basal area than the surrounding forest. Productivity (tree growth) eventually becomes markedly reduced within these centers, and they may become dominated by stunted, deformed trees. As noted by Tinnin (1984), any effect on community dominants (trees) will result in marked changes in the rest of the community. For example, understory vegetation (grasses, forbs, shrubs) often benefit as trees die.

Tree mortality rates are often several times higher in infected than in uninfected areas (Hawksworth 1961, Maffei 1989, Mathiasen and others 1990). Most of this mortality occurs in severely infected trees, which have a "half-life" of roughly 7 to 10 years, depending on their size (Hawksworth and Geils 1990). Although bark beetles, drought, and other agents often hasten the death of these trees, dwarf mistletoe can usually be considered the "primary mortality agent."

The witches' brooms and higher snag densities in infected areas enhance habitat values for birds and other wildlife (Tinnin and others 1984, Bennetts and others 1996, Mathiasen 1996). In considering the beneficial aspects of dwarf mistletoe infection, it seems reasonable to assume that it is the large infected trees—particularly those with large witches' brooms—which have the greatest ecological value.

Because there are numerous insects associated with dwarf mistletoes, insect-feeding birds find increased foraging opportunities in infected areas. Some birds have been known to eat dwarf mistletoe shoots and fruits; the best example is the blue grouse, whose diet consists mostly of Douglas-fir needles but includes a significant amount (2-8 percent) of Douglas-fir dwarf mistletoe (Severson 1986). In general, however, feeding on dwarf mistletoe shoots and fruits by birds is thought to be uncommon in the western U.S. (Hawksworth and Wiens 1996). Various mammals, including squirrels, porcupines, and deer eat dwarf mistletoe shoots or infected bark, although none are dependent on it as a primary food source. See Hawksworth and Wiens (1996) for a more complete discussion on “biotic associates” of dwarf mistletoes.

There is little doubt that dwarf mistletoes have beneficial as well as damaging effects. Although many managers may still regard it as “*an insidious forest pest*” (Wicker 1984), the idea that the “*presence of dwarf mistletoe in a stand means that a portion of the stand is not healthy*” (Smith 1978) is changing. Moreover, due to their widespread distribution and persistent nature, there will always be a lot of dwarf mistletoe in the forests of the Southwest, regardless of our values and perspectives.

It may be better for us to think in terms of ***managing*** dwarf mistletoes rather than simply ***controlling*** them, given what we know about the disease, our previous management, and the overall condition or “health” of forests in the Southwest. While control should remain an integral part of our management, a singular focus on control is inappropriate, considering the unique and beneficial aspects of infection, as well as the difficulties and limitations of control.

In one sense, dwarf mistletoes should be relatively easy to control, since they require a living host. Removing infected trees destroys the mistletoe. However, dwarf mistletoes are well-adapted for survival and are remarkably persistent. They infect all ages and sizes of trees; moreover, a very significant proportion of infected trees have no visible shoots. Although these parasites spread slowly, trees grow slowly. Dwarf mistletoe populations can double several times during the length of a rotation (Parmeter 1978).

Dwarf mistletoes tend to do better on vigorous trees. Since a primary goal of silviculture is to promote vigorous trees, it can indirectly promote the parasite (Mathiasen 1990). While dwarf mistletoes are certainly amenable to silvicultural treatment, it is probably fair to say that they are harder to control—especially over the long run—than has often been assumed by managers (including many pathologists), or implied in some reports and publications.

Johnson and Hawksworth (1985) and Hawksworth and Wiens (1996) state that *“if a stand were properly treated, dwarf mistletoe would not be a serious problem in subsequent rotations.”* For this to be true, the “proper treatment” would essentially have to be a large clearcut or stand-replacing fire, at least for stands where the disease is a “serious problem” to begin with. With partial cutting, the disease will rebound between each entry, let alone in subsequent rotations.

Hessburg and others (1985), Maffei and others (1987), and Beatty and others (1987) state that the solution to the mistletoe problem is to *“treat infected stands first, thereby reducing mistletoe incidence in stands, one stand at a time . . . Prescriptions need to reflect a major emphasis on reducing stand DMR, while trying to reflect stocking, spacing, and tree diameter objectives . . . [Dwarf mistletoe] impact can be reduced with proper management so that the effects are negligible.”*

Except for the idea that infected stands should receive high priority for treatment, this is very similar to what Korstian and Long suggested 75 years ago. The effects of dwarf mistletoe on productivity are still significant under this scenario, however, unless one assumes a true even-aged condition and complete stand replacement at rotation age. This assumption is unrealistic, given both the natural ecology of our forests and today’s social and political climate. Perhaps, through frequent entries (say every 10-15 years), the effects of dwarf mistletoe could be kept negligible in some areas, but such a strategy could be uneconomical and might easily detract from management of other areas.

The persistence and resurgence of dwarf mistletoes in managed (treated) areas suggest that we should periodically treat infected stands to help keep the disease in check. On the other hand, it indicates that infected areas will consistently underperform comparable uninfected areas in terms of productivity. For this reason, and because infected stands have

[illegible] infected stanoes in

For this reas000delayed infecease iss is ver0detracbhoul1 Tw 0 -1.2

has, in some cases, negated thinning of other, often more productive areas. Uninfected stands can also benefit from treatment and are much easier to manage, especially over the long run, than infected stands.

Nevertheless, because of the widespread distribution of dwarf mistletoes, most projects will encounter them, and they will need to be addressed accordingly. Cutting in infected areas without regard to the presence of mistletoe can have serious long-term impacts on productivity. Prudent treatment of dwarf mistletoe can increase long-term productivity.

The discussions that follow are often a compromise between generality and precision. Every stand/area is different. Management decisions should be based on the specific needs and objectives for each area, but within a framework that considers the overall landscape and forest condition.

Even-aged vs. Uneven-aged Management

Because dwarf mistletoes spread readily from overstory to understory trees, previous guidelines have stressed the use of even-aged systems for managing the disease (for example, see Beatty 1982, Hawksworth and others 1989, Lightle and Weiss 1974; and Chapter 2). With increased emphasis being placed on uneven-aged systems in recent years, many foresters have expressed concerns about their ability to effectively manage dwarf mistletoes.

In theory, it is relatively easy to control dwarf mistletoes using even-aged management because it involves: 1) single-storied stands, which eliminates the problem of the mistletoe spreading from the older to younger trees; and 2) stand replacement at rotation age. However, with a few exceptions, even-aged management has really been more myth than reality in the Southwest. It is one thing to manage a more or less single-storied stand or a "featured" age class, but quite another to "replace" the stand.

While shelterwood and seed-tree cuts have been implemented in many harvest units during the last few decades, final removal cuts have seldom been done. In many of these treatment areas, some of the existing advanced regeneration has been retained, providing one or more additional age classes. Most stand replacement occurring in the Southwest has been a result of wildfire; this is even more likely to be the case in the future.

Most stands in the Southwest, including most that have received silvicultural treatments in the last 20 or so years, contain two or more age/size classes. Although regeneration events are infrequent, there are usually several during the length of a rotation, making an uneven-aged condition the norm in most (though not all) pine and mixed-conifer stands.

The usual perception of an uneven-aged stand is one with several sizes and ages of trees growing together on every acre. To actively manage for such conditions—for example, by removing trees of various size classes in an attempt to achieve balanced or regulated stand structures—would not be sustainable or economically prudent within most dwarf mistletoe-infected areas. Mixed-conifer stands containing sufficient numbers of non-host (or less susceptible) trees probably offer the best opportunity for this type of management (Mathiasen 1989).

However, there are many infected ponderosa pine stands where it appears that multiple age-classes ***can*** be successfully managed for extended periods of time. Provided that infection is not too severe, and, depending upon the spatial arrangements of both the mistletoe and the various cohorts (age classes), many of these stands can be kept reasonably productive for many decades. Periodic entry, with emphasis on good selection and marking, is a key. Some losses to mistletoe will have to be accepted, however, and more aggressive measures may eventually need to be considered. This is basically the type of management Korstian and Long envisioned (although they were more optimistic about the results), and more or less describes how infected stands have been managed for decades in many parts of the Southwest.

The terms "even-aged" and "uneven-aged" are scale-dependent, relative to the size of the area (Bradshaw 1992), and may not be the best terms for describing our forests or our management of them. Generally a better approach is to work with and improve existing stand conditions rather than rigidly adhere to an idealized system, provided that we maintain reasonable levels of growth and get regeneration when needed.

Thinning in Dwarf Mistletoe Infected Stands

The term thinning is used here in a rather broad sense to include most types of selective tree removal. Treatment of very young stands, group selection, and regeneration cuts (shelterwood and seed-tree) are discussed in later sections.

The main reasons/objectives for thinning any stand—whether or not it has mistletoe—are usually to improve the growth of the remaining trees and other vegetation, to reduce densities and associated fire hazards, and to provide forest products. Unless these (or other) needs/objectives have been identified, efforts to control dwarf mistletoe are usually not justified. Basically, if a stand doesn't need to be thinned yet, then "sanitation" can wait until it does. An exception might be in areas where a good cohort of young regeneration has become established since the last entry, and the removal of relatively few infected trees (especially small, low-value trees) can protect it from infection. This can be considered "spot treatment" rather than thinning, however.

Should Visibly Infected Trees be Left when Stands are Thinned?

This question has long been a dilemma for pathologists and foresters in the Southwest (Korstian and Long 1922), and recommendations have varied over the years. Because of the relatively rapid intensification of the parasite in thinned ponderosa pine stands, Hawksworth (1961) originally recommended removal of all visibly infected trees during stand entries, as well as follow-up treatments to remove missed and latent infections (see chapter 2). A similar approach was advocated by Heidmann (1983), who concluded that *"complete removal of infected overstory and understory trees is the only effective silvicultural method of controlling dwarf mistletoe in mature stands of southwestern ponderosa pine."*

Because of the typical patchy, concentrated distribution of the parasite, the removal of all visibly infected trees usually results in stands having understocked areas that contain mostly small trees. Except in very lightly infected stands, this type of treatment can greatly alter stand structure and have significant visual impact. Moreover, even when attempts are made to remove all infected trees, considerable infection remains in most treated areas, due to latent infection. Follow-up treatments (before the next scheduled entry) are often difficult to justify economically, except in very young stands.

While cutting all visibly infected trees can provide better disease control than a less vigorous approach, the practice can fall short when other factors—especially aesthetic and ecological ones—are considered. In terms of production, it often represents a significant sacrifice of both accumulated and potential growth. The "cut all infected trees" recommendation was eventually tempered by most pathologists, at least for most precommercial and intermediate cuts (for example, see Hawksworth 1978b, Hawksworth and Wiens 1996).

Thinning Guidelines

As Korstian and Long stressed 75 years ago, there is no substitute for good selection and marking. As a rule, the most vigorous dominant and codominant trees should be retained. Selection of "leave trees" should be based on overall tree qualities rather than just mistletoe. A lightly infected dominant or codominant tree is usually a better choice for retention than an intermediate or suppressed tree without visible infection. Some past efforts to eliminate all mistletoe have been described as "silvicultural abominations" (Hadfield and Russell 1978). Spacing should vary, not only to retain the best trees, but also to provide a more irregular structure.

Hawksworth's 6-class dwarf mistletoe rating (DMR) system is briefly described here for readers unfamiliar with it since it is widely used by managers and serves as a reference in these guidelines: Tree ratings are determined by visually dividing the live crown into thirds (top, middle, bottom) and rating each third as 0 (no mistletoe), 1 (1/2 or less of branches infected), or 2 (more than half of branches infected). The ratings for each third are totaled to give a tree rating of 0 to 6. Stand ratings are the average rating for all (sampled) trees in the stand (including the 0's). Note that a tree with a rating of 3 is moderately infected while a stand with a rating of 3 is heavily infected.

This leave tree guideline may be useful for many commercial and non-commercial entries:

DBH Class	Maximum Allowable DMR
0-4"	0
4-6"	1
6-9"	2
9"+	3

Note that these DMR's are individual tree ratings, not stand ratings!

The amount of infection a tree can have and still be retained depends on its size. Most lightly infected trees over 4" dbh can grow at a good rate long enough to become sizable trees. Most infected trees less than 4" dbh will not; since they take up growing space and are infection sources, they should be cut.

This guideline does not mean, for example, that only the more heavily infected trees (DMR 4, 5, and 6) over

9" dbh should be removed, but rather that some lightly to moderately infected trees of merchantable size can often be left. Entering a stand to remove only the more heavily infected trees is usually not an effective way to manage dwarf mistletoe or to improve forest conditions. In most cases, stand infection levels would rebound to even higher levels before the next entry and become progressively more severe over time. Infection should generally be reduced as much as possible without sacrificing the best trees in the stand.

An alternate guide based on these same basic principles is:

DBH Class	Maximum Allowable DMR
0-4"	0
4-9"	1
9"+	2

This guideline may be easier to implement, depending on the skill and experience of the marking or thinning crew, and should insure a lower stand DMR after treatment. It would also be appropriate for relatively dense or lightly infected stands that have more good trees to work with.

Both of these guidelines are intended for stands managed for multiple objectives, including, but not limited to, timber production. In stands managed primarily for timber production, it may be preferable to remove all the larger infected trees, but not necessarily. Removal of all infected overstory trees clearly results in better disease control for stands that are distinctly two-storied. However, in many ponderosa pine and mixed conifer stands, there is really no clear distinction between overstory and understory. In such cases, removing all infected trees above a given diameter provides only marginally better mistletoe control than leaving some of the lightly infected, larger trees.

Occasionally, larger trees or small groups with heavier infection might be left for wildlife and for future snags, especially where they are not a direct threat to surrounding regeneration. Very dense, pole-sized thickets with more than about 50 percent of the trees visibly infected are seldom good candidates for thinning. They can be seriously impacted by mistletoe after they are “opened up,” and are often best left unthinned to meet wildlife objectives.

These thinning guidelines are intended for areas with light to moderate infection. Stands with ratings of 3 or higher are usually considered too heavily infected for thinning (Hawksworth 1978a). In these stands, roughly 90 percent of the trees are infected, and there are usually not enough uninfected and lightly infected trees to work with. Actually, stands with ratings between 2 and 3 are often better treated using shelterwood cuts rather than normal thinning.

No treatment prescription should be written without a thorough walk-through examination of the stand. Inventory data is helpful, but can significantly overestimate or underestimate infection levels and does not always adequately describe stand structure. During walk-throughs, estimates can be made of the proportion of the stand that is infested and/or the percentage of host trees infected. These estimates can supplement existing stand data and lead to better prescriptions and marking guidelines.

Group Selection

This method has seen increased use in the Southwest in recent years, in part due to its inclusion in management guidelines for the Northern goshawk (Reynolds and others 1992) and the Mexican spotted owl (USDI Fish and Wildlife Service 1995). Group selection has a great deal of appeal because it has less visual impact than some other cutting practices, seems “ecologically friendly,” and can replicate a natural pattern of tree reproduction. Group selection has also been perceived and used recently as a tool for treating dwarf mistletoe. However, its efficacy for control of mistletoe is largely untested, and opinions and perspectives vary.

Because the disease usually has a patchy distribution, group selection (or at least management of specific groups) seems to provide good opportunities for mistletoe control (Anon. 1992). Removal of entire groups of trees can eliminate (or greatly reduce) the problems with latent infections and the stimulation of the parasite on remaining trees. As a regeneration method in uneven-aged management, group selection intuitively provides better mistletoe control than single-tree selection, since the regeneration occurs in openings rather than directly beside infected trees.

On the other hand, the creation of small openings can be very favorable to dwarf mistletoes over the long run, leading to heavy losses (Kliejunas 1995, Mason and others 1989). In many cases, the regeneration that develops within the openings will be exposed to infected trees on the edges—and, in some cases—from infected trees within the openings. The parasite can penetrate small (1- to 4-acre) openings relatively quickly. If there are infected trees along a good proportion of the perimeter, it will be difficult and costly to maintain productivity over the long-term.

Disease-free regeneration can develop in group openings if their margins are cut beyond the edge of visible infection—perhaps 30 to 40 feet—to account for missed and latent infections. In practice, this is often difficult due to the irregular shape of infection centers and their tendency to coalesce. Moreover, limitations on group size and shape, as well as "reserve tree" requirements, compromise control opportunities. Infected edges have occurred in most of the groups I've seen to date where attempts were made to remove entire infection centers.

Edminster and Olsen (1996) discuss the use of group selection as a way to increase structural diversity in the relatively homogeneous, second-growth pine stands common in the Southwest. However, they mention that the group selection method will likely not meet management objectives in dwarf mistletoe-infected stands. In fairness to the group selection method, it should again be noted that other methods for treating infected stands have certain limitations and difficulties.

Sometimes groups can be located to protect existing young regeneration from infection. Another perspective is that groups could be managed as more or less as permanent openings, a means to restore some of the meadows that have been lost to trees over the century (Reggie Fletcher, personal communication). Under this scenario, the openings could be used to isolate infection and serve as buffers to the spread of mistletoe. Although past efforts to "buffer" mistletoe have often been ineffective or seemed impractical, creating (and maintaining) more openings on the landscape would tend to reduce overall spread.

Used in moderation and with sufficient attention to layout, group selection may be an appropriate tool for managing dwarf mistletoes in **lightly** infected areas. My opinion is that it should not be the only method used, or even the preferred method, for treating these areas, however. A general disadvantage of group harvest is that it allows little opportunity for selecting superior trees for retention or for improving growth. Where it is used, thinning **outside** the groups should be considered as a way to improve overall forest conditions. An additional consideration is that widespread use of group selection in infected areas could further reduce the number of large infected trees in some parts of the Southwest (see previous chapter).

Prescribed Fire

Ideas about the use of prescribed fire for managing dwarf mistletoes have changed considerably over the past few decades. In a comprehensive literature review on the subject, Alexander and Hawksworth (1975) concluded that prescribed burning could be used 1) to eliminate infected residuals in cut-over areas and 2) to destroy heavily infected stands. Essentially, these applications were limited to intense, "complete" fires that eliminate the parasite prior to regeneration of a site. Only more recently has attention been given to use of less intense "underburning" as a potential management tool (Koonce and Roth 1980, Harrington and Hawksworth 1990).

Underburning may well be a good ecological approach for managing dwarf mistletoes on many ponderosa pine and mixed conifer sites. Often a combination of mechanical thinning and burning can be used to reduce infection levels and improve overall stand conditions. Fire can be used to help maintain infection at or below a desired level, perhaps allowing longer intervals between mechanical treatments.

Significant amounts of crown scorch are probably needed to provide a controlling effect (this effect is discussed in Chapter 3, under "Fire History.") Koonce and Roth (1980) indicated that scorch of 30-60 percent of the live crown is needed to significantly reduce infection. Our work in northern New Mexico indicates that an average crown scorch of around 50 percent provides partial "sanitation" of stands as well as a modest amount of thinning.

A concern that has been expressed about this level of crown scorch is that it would reduce live crown ratios too much, affecting tree growth and vigor. We have found, however, that a given amount of visible crown scorch usually does not reduce the crown ratio by that full amount, since many branches with scorched needles actually survive. For example, a tree with a live crown ratio of 50 percent receiving 50 percent crown scorch will typically end up with a crown ratio of 30 to 40 percent, rather than 25 percent.

Ground fires resulting in little or no crown scorch will probably have little or no effect on infection levels, although they may accomplish other objectives such as fuels reduction. The effects of heat and smoke on dwarf mistletoe plants themselves (in the absence of branch or tree mortality) are not well understood. Our observations suggest that shoots are fairly heat tolerant, but additional studies would be helpful. Zimmerman and Laven (1987) found that seed germination was inhibited by exposure to smoke for

60 minutes or longer under laboratory conditions, but the significance of this to field conditions is unknown.

Prescribed fire will be more effective in reducing infection levels when crews can "shape" the fire (increase intensity) within infected areas. Fires covering relatively small areas (certainly no more than a few hundred acres at a time) should provide better results than larger fires, since crews generally have more control over coverage and intensity.

Prescribed burning certainly has promise as a tool for managing dwarf mistletoes and improving long-term forest conditions (health), but should not be regarded as a panacea. There are a number of good reasons to selectively thin many portions of our forests with commercial and non-commercial cuttings.

Figure 7. Crown scorch from prescribed fire tends to reduce tree and stand infection levels.

Newly Regenerated Areas

Given its persistent nature, the best way to control dwarf mistletoe is to ***prevent*** infection by protecting young tree regeneration. Unfortunately, this is where dwarf mistletoe control can become most controversial. "Prevention" can essentially mean stand replacement or clearcut (Beatty 1982, Hawksworth and Wiens 1996). However, there are some opportunities for protecting regeneration without greatly impacting a site.

The idea of "spot treatment" for protecting regeneration in irregular, uneven-aged stands was included in the previous section on thinning. Although spot treatment is not always practical, on some sites it can help provide a more sustainable condition by reducing or delaying infection. Similarly, young trees can sometimes be protected from infection through good selection and marking during normal thinning operations, or when designating groups of trees for removal.

Some of the best opportunities to protect regeneration occur in previously logged or burned areas that were either planted or have regenerated naturally. Often these areas contain infected, "residual" trees that were left, either because they were non-merchantable, or more commonly, because they previously appeared to be uninfected. Removal of infected residual trees, especially the smaller, low-value ones, should be a high priority in newly regenerated areas. Small sales or snag recruitment are options for larger infected trees in these areas.

The regeneration itself should be thoroughly "sanitized," with a follow-up treatment scheduled about 5 years later. In areas that had high levels of infection prior to logging, considerable amounts of latent infection can be expected in advanced natural regeneration. Because of this, it is usually best to delay thinning (i.e., spacing) of overstocked groups of young trees, and focus initially on removing only the infected trees. Otherwise many young "crop trees" may turn out to be infected, after potential replacements have already been cut.

Other than through "final harvest," Hawksworth and Wiens (1996) agree that young (5- to 15-year-old) stands present the best opportunity to control dwarf mistletoe. However, they suggest that infected trees less than 3 meters tall can be left, since mistletoe seed dispersal from these trees is minimal and because these small trees will not live very long. Although these smaller infected trees are certainly not as much a “threat” as larger ones, many of them ***can*** live for many years and infect neighboring regeneration. In most situations, these small infected trees should be cut. Infection should be reduced as much as possible in very young stands, especially if long rotations are anticipated.

Many young, lightly infected trees can be successfully “sanitized” by branch pruning. However, significant numbers of apparently “pruneable” young trees will develop new infections, and will need to be pruned again or cut later.

Figure 8. Shelterwood cut in heavily infested ponderosa pine stand. Over 75 percent of the stems were cut, leaving only dominant and codominant trees with little or no infection. Down material was sold for firewood.

As a general rule, removal of infection sources ***within*** a newly regenerated stand is more beneficial, and usually more practical, than cutting infected trees along the boundary.

Heavily Infected Stands

Heavily infected stands have always presented a difficult management problem in the Southwest (Hawksworth 1961), certainly in areas managed for timber production. Because of the behavior of dwarf mistletoes after partial cutting, sound management options are often limited. As discussed in Chapters 2 and 3, following decades of selective logging, the Forest Service took a more aggressive approach toward mistletoe from the mid-1970’s through the early 1990’s. Efforts were made to “replace” a large proportion of the accessible, heavily infected stands in the Southwest with either overstory removals or regeneration cuts.

Seed-tree cutting for replacement of heavily infected stands was an essential element in previous management guidelines for the Southwest (Beatty 1982, Heidmann 1983). Where feasible, the seed-tree cut seemed preferable to clearcutting and replanting. It retained some large trees to provide for natural regeneration, which seemed more economical, and perhaps more likely to succeed, than planting. However, extensive use of this prescription in some timber sales in the 1980’s proved extremely controversial, at least in stands where the existing understories were destroyed.

Moreover, in most cases only the first step in this strategy—the seed-cut itself—was completed. To be successful, infected seed trees need to be removed before the new regeneration sustains significant infection. The standard recommendation has been to remove them before the regeneration is 3 feet tall or 10 years old, whichever comes first (Hawksworth and Wiens 1996).

Note that while ideally only uninfected seed trees would be retained in regeneration cuts, in nearly all infected stands where they have been implemented, some infected trees have been needed to provide an adequate seed source. For example, in several seed-tree cuts we have been monitoring in northern New Mexico, 14 to 47 percent of the surviving seed trees were visibly infected 10 years after treatment.

Because seed-tree cuts were so controversial, some heavily infected stands have been treated more recently with ***shelterwood*** cuts, which retain a higher density of seed trees. This prescription has less visual impact than the seed-tree cut, and may be more conducive to natural regeneration since it doesn't change site conditions as much. However, the "final removal" cut remains a predicament for managers, since it can resemble a clearcut.

In today's sociopolitical climate, it is unrealistic to recommend final removal cuts for all the stands that have received seed-tree or shelterwood cuts in recent years, once they have regenerated. However, these sites should be monitored for regeneration, and final removals considered for some of them. From the perspective of long-term sustainability, it would be remiss to ignore these stand conditions.

Rather than removing all remaining overstory trees in these areas, a good option will be to locate and remove (or kill) only the visibly infected ones. Although some infected trees will inevitably be missed, this will be much more effective (for disease control) than doing nothing. In portions of a stand where regeneration is still lacking, infected seed trees can be retained.

An alternative for some of these previously treated areas would be to maintain their open, park-like condition using periodic prescribed fire. This would not preclude the possibility of removing infected seed trees at some point in the future, following a major regeneration event.

Shelterwood cuts are still a good option for management of some heavily infected stands in the Southwest. These treatments retain the best trees in the stand, and are implemented before infection becomes so severe that other management options are lost. In the future, they may be especially appropriate in areas of extensive second-growth forest, where they can provide some heterogeneity. Spacing of leave trees can be highly irregular, and groups of larger trees can be retained.

Advanced regeneration often presents a dilemma when implementing a regeneration cut, because it invariably contains some infection, and will have even more infection by the time a final removal cut can be considered. Whether or not advanced regeneration should be completely destroyed needs to be carefully evaluated for each particular site.

In severely infected ponderosa pine stands lacking enough potential seed trees to provide natural regeneration, the only option may be to clearcut and replant, if these sites are to produce timber in the future. Sometimes these sites have enough young natural regeneration present that a clearcut (technically a final removal or release cut) can protect it from infection and avoid the need for planting. However, in such cases the regeneration will require periodic sanitation. Where feasible, this approach seems preferable for sites that are difficult to plant successfully.

Given the past emphasis on aggressive treatment of infested areas, perhaps a majority of the remaining mature, relatively undisturbed, heavily infected stands in some parts of the Southwest (i.e., in areas where they are uncommon) could be managed passively as wildlife habitat (deferred from cutting). From an ecological perspective, healthy forests in the Southwest do include some of these stands, with their unique characteristics. For heavily infected stands where fire hazard is a concern (particularly in the wildland-urban interface), low thinning and/or underburning should be beneficial.

Mixed Conifer Forests

The complexity and variety of conditions in mixed conifer forests merit some special considerations. An important but often overlooked "forest health" concern involves the conversion of high-elevation ponderosa pine forests to mixed conifer, and similarly, the gradual loss of the pine component from mixed conifer forests. While this is to some extent a natural process, it has been accelerated by decades of fire suppression, as well as by past logging of the more valuable pine. Because of this, as a general rule, silvicultural treatments should be designed to promote pine whenever possible.

The resistant (or less susceptible) tree species in mixed forests often provide a screening effect that slows the spread of dwarf mistletoe. They also provide flexibility when selecting "leave trees" in thinnings or other cuttings. Favoring "alternate species" has often been recommended for control of dwarf mistletoes. However, as a general rule, I recommend retaining the best non-host ***and*** host trees.

Some past cuttings in mixed conifer stands with ponderosa pine dwarf mistletoe removed all (or most) of the pine, greatly accelerating the conversion to fir. Unless there is a significant amount of pine regeneration present—which is often not the case—it is usually better to leave a pine seed source. If the remaining pine is severely infected, an option might be to remove the pine and replant pine. In some stands, pine can be planted without removing the infected trees if plantings are kept at least 50 feet from the infection sources.

In stands with infected Douglas-fir and a healthy pine component, the disease will tend to favor the pine, essentially setting back succession. In these situations, there should be less need to focus on control. In fact, retaining some of the larger infected Douglas-fir may provide good nesting habitat.

Douglas-fir dwarf mistletoe can be a serious problem in areas managed primarily for timber production, however, especially when the host makes up a major proportion of the stand. This parasite is greatly stimulated when stands are selectively cut. Removing all host trees from heavily infected areas may be the only effective solution (Graham 1961). If there are enough potential seed-trees, a shelterwood cut may be a good option. Mathiasen (1986) reported a very low rate of infection in Douglas-fir saplings less than 20 years old, which indicates that infected seed trees might be retained over developing regeneration longer than in the case of ponderosa pine dwarf mistletoe.

Stands with both these species of dwarf mistletoe are often very difficult to manage. Unless timber production is the primary objective, these areas might best be deferred from cutting operations. If infection is not too severe in one or both species, however, prudent thinning may be beneficial.

To be most meaningful, the stand rating (DMR) for a mixed conifer stand should pertain only to the infected host species. Inventory data from non-host trees should not be included when calculating stand DMR. A stand with two or more species of dwarf mistletoe will have two or more DMR's.

Planting

As a general rule, susceptible host seedlings should not be planted within about 50 feet of dwarf mistletoe infection sources. Although this should be fairly obvious, too often it has been done in the past.

Planting non-host species in infected areas has often been recommended, and can be a sound approach for increasing future productivity. However, given the trend toward replacement of high-elevation ponderosa pine with more shade-tolerant species, I seldom recommend planting Douglas-fir or other species where it would accelerate this process. Planting pine in areas with Douglas-fir dwarf mistletoe can be an excellent strategy, provided there is evidence that pine can do well on the site.

There are many opportunities to interplant site-compatible pine seedlings on previously logged mixed conifer sites that formerly supported more pine. This would increase stand diversity, and would reduce long-term impacts from defoliating insects and possibly root disease. Such efforts should be included in a long-term forest health restoration strategy for the Southwest.

Computer Models

Computer models can be powerful tools for predicting the long-term effects of dwarf mistletoe and for comparing treatment alternatives. Validated models developed from good research can provide credible, scientific support to professional judgment. However, at the present time, available models can adequately represent only simple, single and 2-storied stands under even-aged management. Models dealing with more complex stand structures, multi-age cohorts, irregular stem distributions, etc., are much more difficult to develop and validate. Moreover, previous models have focused on projecting timber yields, rather than less easily quantified objectives and benefits (ecological, aesthetic, etc.). For making sound silvicultural decisions, it is this author's opinion that models cannot replace the need for careful, on-the-ground observations and experience.

Literature Cited

Alexander, M.E.; Hawksworth, F.G. 1975. Wildland fires and dwarf mistletoe: a literature review of ecology and prescribed burning. USDA Forest Service Gen. Tech. Rep. RM-14. 12 p.

Andrews, S.R. 1957. Forest disease research (dwarf mistletoes) at Albuquerque forest insect and disease laboratory (a project analysis and working plan). Typewritten Report. 50 p.

Andrews, S.R.; Daniels, J.P. 1960. A survey of dwarf mistletoes in Arizona and New Mexico. USDA Forest Service, RM Station Paper No. 49. 17 p.

Anonymous. 1992? Goshawk implementation guidelines and the effects on the management of dwarf mistletoes. USDA typewritten report. 12 p.

Beatty, J.S. 1982. Integrated forest protection guide, southwestern dwarf mistletoe, *Arceuthobium vaginatum* subsp. *cryptopodum* (Engelm.) Hawks. and Wiens, in ponderosa pine. USDA Forest Service R3-82-13. 12 p.

Beatty, J.S.; Hessburg, P.F.; Maffei, H.M. 1987. Incidence, severity, and growth losses associated with ponderosa pine dwarf mistletoe on the Carson National Forest, New Mexico. USDA Forest Service, R3 87-5. 29 p.

Bennetts, R.E.; Hawksworth, F.G. 1991. The indirect effects of dwarf mistletoe on bird communities in Colorado ponderosa pine forests. In: Proceedings of the 39th Western International Forest Disease Work Conference. pp. 14-17.

Bennetts, R.E.; White, G.C.; Hawksworth, F.G.; Severs, S.E. 1996. The influence of dwarf mistletoe on bird communities in Colorado ponderosa pine forests. Ecological Applications. 6(3):899-909.

Burrall, H.D. 1910. Report on measurements taken on western yellow pine to ascertain the effects of mistletoe on its growth. Coconino National Forest. Albuquerque Lab (USDA Forest Service), Typewritten report. 50 p.

Conklin, D.A. 1992. Managing dwarf mistletoe to enhance biological and landscape diversity. In: Proceedings of the 40th Western International Forest Disease Work Conference. pp. 40-42.

Covington, W.W.; Moore, M.M. 1994. Southwestern ponderosa pine forest structure: changes since Euro-American settlement. Journal of Forestry. 92(1):39-47.

Dahms, C.W.; Geils, B.W., tech. eds. 1997. An assessment of forest ecosystem health in the Southwest. USDA Forest Service, RM-GTR-295. 97 p.

Drummond, D.B. 1982. Timber loss estimates for the coniferous forests in the United States due to dwarf mistletoes. USDA Forest Service, Forest Pest Management, Methods Application Group, Fort Collins, CO. Report 83-2. 24 p.

Edminster, C.B. 1978. RMYLD: computation of yield tables for even-aged and 2-storied stands. USDA Forest Service Res. Pap. RM-199. 26 p.

Edminster, C.B.; Olsen, W.K. 1996. Thinning as a tool in restoring and maintaining diverse structure in stands of southwestern ponderosa pine. In: Conference on adaptive ecosystem restoration and management: restoration of Cordilleran conifer landscapes of North America, Flagstaff, Arizona. USDA Forest Service, RM-GTR-278, pp. 62-68.

Geils, B.W.; Mathiasen, R.L. 1990. Intensification of dwarf mistletoe on southwestern Douglas-fir. Forest Science 36: 955-969.

Gill, L.S. 1935. *Arceuthobium* in the United States. Connecticut Academy of Arts and Sciences Transactions. 32:111-245.

Gill, L.S.; Hawksworth, F.G. 1954. Dwarf mistletoe control in southwestern ponderosa pine forests under management. Journal of Forestry, 52(5): 347-353.

Graham, D.P. 1961. Dwarf mistletoe of Douglas-fir. USDA Forest Service, Forest Pest Leaflet 54. 4 p.

Harrington, M.G.; Hawksworth, F.G. 1990. Interactions of fire and dwarf mistletoe on mortality of southwestern ponderosa pine. In: Krammes, J.S., tech. coord. Effects of fire in management of southwestern natural resources: Proceedings of Symposium. Gen. Tech. Rep. RM-191. USDA Forest Service: 234-240.

Hatfield, I. 1933. The establishment of an experimental control plot at the Fort Valley Experimental Forest, Flagstaff, Arizona. Albuquerque Lab, USDA Forest Service. Mimeo Report, 17 p.

Hawksworth, F.G. 1961. Dwarf mistletoe of ponderosa pine in the Southwest. USDA Forest Service Tech. Bul. No. 1246. 112 p.

Hawksworth, F.G. 1977. The 6-class dwarf mistletoe rating system. USDA Forest Service Gen. Tech. Rep. RM-48. 7 p.

Hawksworth, F.G. 1978a. Biological factors of dwarf mistletoe in relation to control. In: Proceedings of the Symposium on dwarf mistletoe control through forest management, USDA Forest Service Gen. Tech. Rep. PSW-31, pp. 5-15.

Hawksworth, F.G. 1978b. Intermediate cuttings in mistletoe-infested lodgepole pine and Southwestern ponderosa pine stands. In: Proceedings of the Symposium on dwarf mistletoe control through forest management, USDA Forest Service Gen. Tech. Rep. PSW-31, pp. 86-92.

Hawksworth, F.G; Andrews, S.R.; Hayes, G.L.; Hinds, T.E.; Lightle, P.C.; Stewart, J.L.; Hester, D.A.; Yasinski, F.M.; Weiss, M.E. 1967. Proposed program for dwarf mistletoe research and control in the central Rocky Mountains and the Southwest. USDA Forest Service. Typewritten Report. 79 p.

Hawksworth, F.G.; Geils, B.W. 1990. How long do mistletoe-infected ponderosa pines live? Western Journal of Applied Forestry 5(2): 47-48.

Hawksworth, F.G.; Gill, L.S. 1960. Rate of spread of dwarf mistletoe in ponderosa pine in the Southwest. USDA Forest Service, Research Note RM-42. 2 p.

Hawksworth, F.G.; Hinds, T.E.; Johnson, D.W.; Landis, T.D. 1977. Silvicultural control of dwarf mistletoe in young lodgepole pine stands. Technical Report R2-10. USDA Forest Service, Rocky Mountain Region. 13 p.

Hawksworth, F.G.; Lusher, A.A. 1956. Dwarf mistletoe survey and control on the Mescalero-Apache Reservation, New Mexico. Journal of Forestry 54(6): 384-390.

Hawksworth, F.G.; Shaw C.G.; Tkacz, B. 1989. Damage and control of diseases of Southwestern ponderosa pine. In: Multiresource management of ponderosa pine forests. USDA Forest Service GTR RM-185, pp. 116-129.

Hawksworth, F.G.; Wiens, D. 1996. Dwarf mistletoes: biology, pathology, and systematics. USDA Forest Service Ag. Handbook 709. 410 p.

Hedgcock, G.G. 1915. Notes on some diseases of trees in our national forests. Phytopathology 5: 175-181.

Heidmann, L.J. 1968. Silvicultural control of dwarf mistletoe in heavily infected stands of ponderosa pine in the Southwest. USDA Forest Service, Research Paper RM-36, 11 p.

Heidmann, L.J. 1983. Silvicultural control of dwarf mistletoe in southwestern ponderosa pine. USDA Forest Service, Research Note RM-433, 4 p.

Herman, F.R. 1961. Silvicultural control of dwarf mistletoe on Southwestern ponderosa pine. USDA Forest Service, RM Station Paper No. 62, 20 p.

Hessburg, P.F.; Beatty, J.S.; Wood, R.E. 1985. Incidence, severity, and growth losses associated with ponderosa pine dwarf mistletoe on the Apache-Sitgreaves National Forests, Arizona. USDA Forest Service, R3 85-10. 32 p.

Hudler, G.; Oshima, N.; Hawksworth, F.G. 1979. Bird dissemination of dwarf mistletoe on ponderosa pine in Colorado. American Midland Naturalist. 102(2): 273-280.

Johnson, D.W.; Hawksworth, F.G. 1985. Dwarf mistletoes: candidates for control through cultural management. In: Insect and disease conditions in the United States, 1979-1983. USDA Forest Service, GTR WO-46: 48-55.

Johnson, M. 1994. Changes in southwestern forests: stewardship implications. Journal of Forestry. 92(12):16-19.

Kaufman, M.R.; Huckaby, L.S.; Regan, C.M.; Popp, J. 1998. Forest reference conditions for ecosystem management in the Sacramento Mountains, New Mexico. USDA Forest Service, RMRS-GTR-19. 87 p.

Koonce, A.L.; Roth, L.F. 1980. The effects of prescribed burning on dwarf mistletoe in ponderosa pine. In: Proceedings of the Sixth Conference on Fire and Forest Meteorology, Seattle WA. Society of American Foresters, Washington DC. p. 197-203.

Korstian, C.F.; Long, W.H. 1922. The western yellow pine dwarf mistletoe: effect on growth and suggestions for control. U.S. Dept. Agr. Bul. 1112, 35 p.

Knutson, D.M.; Tinnin R. 1980. Dwarf mistletoe and host tree interactions in managed forests of the Pacific Northwest. USDA Forest Service, PNW-GTR-111. 19 p.

Lightle, P.C.; Hawksworth, F.G. 1973. Control of dwarf mistletoe in a heavily used ponderosa pine recreation forest: Grand Canyon, Arizona. USDA Forest Service Research Paper RM-106. 22 p.

Lightle, P.C; Weiss, M.J. 1974. Dwarf mistletoe of ponderosa pine in the Southwest. Forest Pest Leaflet 19. USDA Forest Service, Forest Pest Management. 8 p.

Maffei, H. 1989. Southwestern dwarf mistletoe damage to multi-aged ponderosa pine stands of the Colorado Front Range. Fort Collins, CO: Colorado State University. 112 p. Ph.D. Dissertation.

Maffei, H.; Beatty, J. 1988. Changes in the incidence of dwarf mistletoe over 30 years in the Southwest. In: Proceedings 36th Western International Forest Disease Work Conference, Park City, Utah. pp. 88-90.

Maffei, H.M.; Beatty, J.S.; Hessburg, P.F. 1987. Incidence, severity and growth losses associated with ponderosa pine dwarf mistletoe on the Gila National Forest, New Mexico. USDA Forest Service, R-3 87-10. 28 p.

Mason, G.N.; Gottschalk, K.W.; Hadfield, J.S. 1989. Effects of timber management practices on insects and diseases. In: The scientific basis for silvicultural and management decisions in the National Forest System, USDA Forest Service Gen. Tech. Rep. WO-55, pp. 152-169.

Mathiasen, R.L. 1996. Dwarf mistletoes in forest canopies. Northwest Science, Vol. 70, Special Issue, 1996. pp. 61-71.

Mathiasen, R.L. 1989. Management of dwarf mistletoes using uneven-aged cutting methods. In: Proceedings of the 9th Intermountain Region Silviculture Workshop, Jackson Hole Wyoming. pp. 186-194.

Mathiasen, R.L.; Blake, E.A. 1984. Relationships between dwarf mistletoes and habitat types in western coniferous forests. In: Biology of dwarf mistletoes: Proceedings of the Symposium, USDA Forest Service Gen. Tech. Rep. RM-111. pp. 111-116.

Mathiasen, R.L.; Edminster, C.B.; Hawksworth, F.G. 1990. Infection of young Douglas-firs by dwarf mistletoe in the Southwest. Great Basin Naturalist 50(1): 67-72.

Mathiasen, R.L.; Hawksworth, F.G.; Edminster, C.B. 1990. Effects of dwarf mistletoe on growth and mortality of Douglas-fir in the Southwest. Great Basin Naturalist 50(2): 173-179.

Merrill, L.M.; Byler, J.W.; Corse, T.; Reedy, T.; Hall, L.D. 1988. An evaluation of the effectiveness of dwarf mistletoe suppression in uneven-aged stands on the Flathead Indian Reservation. USDA Forest Service, R-10, Report 89-6. 9 p.

Merrill, L.M.; Hawksworth, F.G. 1987. Frequency and severity of ponderosa pine dwarf mistletoe in relation to habitat type and topography in Colorado. Plant Disease 71: 342-344.

Myers, C.A; Hawksworth, F.G.; Lightle, P.C. 1972. Simulating yields of southwestern ponderosa pine stands, including the effects of dwarf mistletoe. USDA Forest Service Res. Pap. RM-87. 16 p.

Nicholls, T.H.; Hawksworth, F.G.; Merrill, L.M. 1984. Animal vectors of dwarf mistletoe, with special reference to *Arceuthobium americanum* on lodgepole pine. In: Biology of dwarf mistletoes: Proceedings of the Symposium, USDA Forest Service Gen. Tech. Rep. RM-111. pp. 102-110.

Parmeter, J.R. 1978. Forest stand dynamics and ecological factors in relation to dwarf mistletoe spread, impact, and control. In: Proceedings of the Symposium on dwarf mistletoe control through forest management. USDA Forest Service Gen. Tech. Rep. PSW-31. pp. 16-30.

Pearson, G.A. 1950. Management of ponderosa pine in the Southwest. U.S. Dept. Agr., Agr. Monog. 6. 218 p.

Pollack, M.M.; Suckling, K. 1996. An ecologically integrated approach to management of dwarf mistletoe (*Arceuthobium*) in southwestern forests. Southwest Center for Biological Diversity. 22 p.

Reynolds, R.T.; Graham, R.T; Reiser, M.H.; Bassett, R.L.; Boyce, D.A.; Goodwin, G.; Smith, R.; Fisher, E.L. 1992. Management recommendations for the northern goshawk in the southwestern United States. USDA Forest Service Gen. Tech. Rep. RM-217. 90 p.

Russell, K.W. 1978. Improving extension and training programs for dwarf mistletoe control. In: Proceedings of the Symposium on dwarf mistletoe control through forest management. USDA Forest Service Gen. Tech. Rep. PSW-31, pp. 143-150.

Severson, K.E. 1986. Spring and early summer habitats and food of male blue grouse in Arizona. Journal of the Arizona-Nevada Academy of Science. 21: 13-18.

Smith, R.S. 1978. Loss evaluations in forest recreation areas. In: Proceedings of the Symposium on dwarf mistletoe control through forest management. USDA Forest Service Gen. Tech. Rep. PSW-31, pp. 128-131.

Tinnin, R.O. 1984. The effects of dwarf mistletoe on forest community ecology. In: Biology of dwarf mistletoes: Proceedings of the Symposium. USDA Forest Service Gen. Tech. Rep. RM-111. pp. 117-122.

Tinnin, R.O.; Hawksworth, F.G.; Knutson, D.M. 1982. Witches' broom formation in conifers infected by *Arceuthobium* spp.: an example of parasitic impact upon community dynamics. American Midland Naturalist 107(2): 351-359.

USDA Forest Service. 1985. Cutting methods handbook. Southwestern Region, Albuquerque, NM.

USDI Fish and Wildlife Service. 1995. Recovery plan for the Mexican spotted owl, volume 1. Albuquerque, NM. 172 pp.

Wanner, J.L.; Tinnin, R.O. 1989. Some effects of infection by *Arceuthobium americanum* on the population dynamics of *Pinus contorta* in Oregon. Canadian Journal of Forest Research 19: 736-742.

Weir, J.R. 1916. Mistletoe injury to conifers in the Northwest. U.S. Dept. Agr. Bul. No. 360. 39 p.

Weiss, M.J.; Loomis, R.C. 1971. Status of disease, southwestern states. USDA Forest Service, Albuquerque, NM. Typewritten Report. 6 p.

Wicker, E.F. 1984. Dwarf mistletoes: insidious pests of North American conifers. In: Biology of dwarf mistletoes: Proceedings of the Symposium, USDA Forest Service Gen. Tech. Rep. RM-111. 1 p.

Wicker, E.F.; Leaphart, C.D. 1976. Fire and dwarf mistletoe (*Arceuthobium* spp.) relationships in the northern Rocky Mountains. In: Proceedings of the Tall Timbers Fire Ecology and Land Management Symposium, No. 14, Missoula MT., pp. 279-298.

Worrall, J. 1998. Forest pathology, parasitic plants, mistletoes. SUNY College of Environmental Science and Forestry. http://149.119.6.124/course/jworrall/mistle.htm

Zilka, P.J.; Tinnin, R.O. 1976. Potential avian influence in the distribution of dwarf mistletoe. Northwest Science. 50(1): 8-16.

Zimmerman, G.T.; Laven, R.D. 1984. Ecological interrelationships of dwarf mistletoe and fire in lodgepole pine forests. In: Biology of dwarf mistletoes: Proceedings of the Symposium. USDA Forest Service Gen. Tech. Rep. RM-111. pp. 123-131.

Zimmerman, G.T.; Laven R.D. 1987. Effects of forest fuels smoke on dwarf mistletoe seed germination. Great Basin Naturalist. 47: 652-659.