United States
Department of
Agriculture

Forest
Service

**Southwestern
Region**

Forestry and
Forest Health

R3-FH-10-01

Dwarf Mistletoes and their Management in the Southwest

Conklin, D.A.; Fairweather, M.L. 2010. Dwarf mistletoes and their management in the Southwest. USDA Forest Service, Southwestern Region, R3-FH-10-01. 23p.
http://www.fs.fed.us/r3/resources/health

May 2010

Acknowledgments

Helpful reviews of this report were provided by Robert Mathiasen, Jim Youtz, and Jack Triepke. Thanks also to Brian Geils and Monica Boehning for encouragement and suggestions which led to several additional improvements. Dan Ryerson provided able and timely assistance in formatting the document. The dedication, enthusiasm, and wisdom of the late Frank Hawksworth have been continual sources of inspiration to the authors.

Cover: Mature Douglas-fir with heavy dwarf mistletoe infection.

Dwarf Mistletoes and their Management in the Southwest

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Preface

This report updates previous guidelines for managing dwarf mistletoes in the Southwest (Conklin 2000). It is intended to assist with current National Forest Plan revision efforts, as well as with project planning and implementation. This report should also be useful to land managers outside the Forest Service and of interest to those with more general interests in dwarf mistletoes.

Managing dwarf mistletoes may seem simple when they are viewed primarily as damaging pests that can be controlled by cutting infected trees. However, there are other factors to consider, including their potential ecological value, as well as the efficacy and costs of control efforts. Changes from historic forest conditions and the effects of past management have become important considerations for management of public lands. Finally, the effects—and use—of fire may need better integration into our management approach. These topics are discussed in initial sections of this report, and support recommendations presented in the final section.

Some of the information in this report applies specifically to dwarf mistletoe of ponderosa pine, often called southwestern dwarf mistletoe (*Arceuthobium vaginatum*). Because of its abundance and economic impact, that species has received the most attention from a research and management perspective. However, much of the information applies generally to the seven other dwarf mistletoes in Arizona and New Mexico (Table 1), which have similar biologies and effects.

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Contents

1. Overview of Dwarf Mistletoe Infection

Dwarf mistletoes (*Arceuthobium* spp.) are parasitic flowering plants which depend almost entirely on their host trees for water and nutrients. They are considered to be pathogens (disease-causing agents) of trees because of their damaging effects, which include growth reduction, deformities (notably the characteristic witches' brooms), and decreased longevity. Essentially, these plants 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 principal host (Table 1).

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, Phoradendron juniperinum, in the piñon-juniper woodlands.

Western spruce dwarf mistletoe: *A. microcarpum*

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

Distribution: Endemic to Arizona and New Mexico. Known distribution includes North Rim of Grand Canyon, San Francisco Peaks and nearby Kendrick Peak, White Mountains (its largest population), and Pinaleno Mountains 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.

Mature piñon with severe infection. Piñon dwarf mistletoe affects an estimated 10 to 15 % of the woodland type in the Southwest.

Severely infected blue spruce in Arizona's White Mountains.

Female Douglas-fir dwarf mistletoe plant with mature fruits.

Chihuahua pine dwarf mistletoe infection.

Dwarf mistletoes spread primarily by means of ballistic seed. Spread occurs both from tree to tree and within the crowns of previously infected trees. Plants tend to build up initially in the lower part of the crown and gradually spread upwards. Tree growth and vigor usually decline when more than half the crown is parasitized. A standard 6–class rating system (DMR, Hawksworth 1977) is often used to quantify infection severity; growth loss typically starts above DMR 3.

Most lightly infected trees (DMR 1–2) can survive for several decades; generally smaller infected trees decline and die more quickly than larger infected trees (Hawksworth and Geils 1990). Because it takes several years for new dwarf mistletoe plants to produce seed, spread is relatively slow, averaging 1 to 2 feet per year horizontally through a forest (Hawksworth and Gill 1960).

On both the stand and landscape level, dwarf mistletoe distribution is 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. More than one-third of the ponderosa pine acreage in Arizona and New Mexico has some level of infection, although incidence varies considerably across the Region (Andrews and Daniels 1960, Maffei and Beatty 1988). Roughly one- half of the mixed conifer acreage in the Southwest has some dwarf mistletoe. Infestation is best described as a chronic situation rather than an "outbreak" or epidemic. Historic (endemic) levels of dwarf mistletoes are discussed in Section 2.2.

In terms of timber production, dwarf mistletoes are easily the most damaging pathogens in the Southwest (Drummond 1982). Dwarf mistletoes are also a natural part of the forest and provide unique habitat for many insects, birds, and mammals. A wealth of information is available on dwarf mistletoes. Hawksworth and Wiens (1996) and Geils and others (2002) probably contain the most comprehensive information on the *biology* and *effects* of these plants. Fairweather and others (2006) provide a useful summary of these topics. Our *management* of dwarf mistletoes is still evolving.

2. Dwarf Mistletoe Management and Ecology

2.1 Dwarf mistletoe management over the past century

Dwarf mistletoes have been recognized as major forest pathogens in the Southwest for nearly a century (Woolsey 1911, Hedgcock 1915). Until fairly recently, most attention has focused on the damage they cause, and on controlling them. Woolsey (1911) described mistletoe as a "serious menace" to ponderosa pine and recommended removal of infected trees during government timber sales. Somewhat later, Korstian and Long (1922) presented a more detailed mistletoe control strategy for the Southwest:

> *The most practical method of controlling mistletoe is to remove 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 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…*

This rather pragmatic approach influenced managers for decades—and to some extent, even to the present day. Research on dwarf mistletoe biology, damage, and control was conducted throughout much of the century, particularly at Fort Valley Experimental Forest near Flagstaff (Pearson 1950, Heidmann 1983). Korstian and Long's early recommendations were eventually considered inadequate from a disease control perspective. Studies concluded that, while dwarf mistletoes were amenable to silvicultural treatment, effective control required more intensive management than usually practiced. Hawksworth (1961) indicated that *removal of all infected trees, with follow-up treatments about 5 years later and possibly again 5 to 10 years after* was needed to keep mistletoe at low, non-damaging levels.

Eventually, a seemingly more practical solution—even-age management—became the standard approach for dwarf mistletoe control in the Southwest (Beatty 1982, USDA Forest Service 1985). Basically, the idea was that some mistletoe could be tolerated in a developing stand, once the infected overstory trees were removed. Mistletoe would be reduced (temporarily) at each entry, and then more or less eliminated (at least in theory) at rotation age when the stand was regenerated.

Fairly aggressive efforts to control dwarf mistletoes were made in the Southwest from the late 1970s through the early 1990s. Infested stands were given high priority for treatment and cut at a disproportionate rate in many areas. Overstory removal cuts and seed cuts were implemented in a large proportion of the infested (commercial) stands on several National Forests in Arizona and New Mexico. By 1990, these efforts had generated much controversy and opposition. Studies and reports appeared suggesting that dwarf mistletoes increased biodiversity (e.g. Tinnin 1984, Bennetts and Hawksworth 1991, Mathiasen 1996, Watson 2001).

Branch distortion and witches' broom formation from ponderosa pine dwarf mistletoe.

As the Forest Service moved toward more ecologically based management (Dahms and Geils 1997), it became apparent that potential beneficial aspects of dwarf mistletoe infection needed integration into an overall management scheme. Similarly, the effects of a century of management on **mistletoe dynamics** needed consideration within any valid restoration approach. These effects include not only changes in mistletoe abundance, but also changes in forest age and structure within infested areas (Conklin 2000).

2.2 Historical levels of dwarf mistletoe

Little quantitative information is available on mistletoe distribution and abundance in the mid to late 1800s; however, reasonable inferences can be made. Infected trees are frequently observed in historic photographs, and early reports by MacDougal (1899), Woolsey (1911), Korstian and Long (1922) each mention areas with extensive ponderosa pine dwarf mistletoe infestation. Woolsey (1911) reports large areas in northern Arizona with over 60% of trees infected. Korstian and Long (1922) mention stands where 75 to 90% of trees above 6" dbh are infected. Historic (or endemic) levels of dwarf mistletoe can be assumed to have been high in many locations in the Southwest[3].

[3] Woolsey (1911) also includes an estimated infection rate for all western yellow pine of only 1 to 2 percent, from George Hedgcock. This estimate seems best regarded as a casual observation, and may well include other western states. Objectively, the data in Woolsey of most significance here is his report of extensive infestation.

Evidence suggests that dwarf mistletoes have been present in western North America for tens of thousands of years or longer (Hawksworth and Wiens 1996). Given their slow rate of spread, their distribution in the historic period is probably well-reflected by their current distribution (Dahms and Geils 1997). In other words, the distributions we see today are probably similar to those 100 to 150 years ago.

Systemic infection on Douglas-fir.

Mistletoe *abundance* is probably greater today than in the 1800s, mostly because there are more trees now, especially in the ponderosa pine type. Much of the increase in tree density is due to major regeneration event(s) around 1920 (often linked with overgrazing), coupled with the exclusion of fire which had previously kept the forests more open. Natural openings filled in with young trees, facilitating the spread of mistletoe. While the number of infected trees has probably increased substantially, the actual proportion of the landscape with mistletoe has probably increased only modestly (if at all, *see next paragraph*) from historic levels, again, because of the relatively slow rate of spread. While mistletoe *has* undoubtedly spread into some previously uninfested stands, it can be assumed that *much* of its increase can be considered spread into *previously existing openings* within *already infested stands*.

There has been speculation that the era of heavy logging for railroad ties, mine props, and other timber products in the late 1800s and early 1900s contributed to the high levels of mistletoe seen in parts of the Southwest today. Certainly infected, non-merchantable trees left behind during that era would have infected stands as they regenerated. However, this seems more a perpetuation of existing conditions than the cause of a later mistletoe problem[4]. In fact, heavy logging during this period is thought to have *reduced* dwarf mistletoe distribution in some parts of northern New Mexico and central Arizona (Hawksworth 1961). Similarly, fires that consumed large areas of cut-over forest during the railroad logging era (Kaufmann and others 1998) probably reduced or even eliminated mistletoe in some areas.

2.3 Effects of past timber management

Timber sales and other silvicultural treatments over the past century have routinely removed infected trees, but (with few exceptions) these activities can be assumed to have had little effect on the distribution of dwarf mistletoes on the landscape (Conklin 2000). The vast majority of stand entries have involved some type of selective or partial cut, which, over the long run, tends to favor mistletoe. Even on research plots that have received multiple "sanitation" treatments, mistletoe has seldom, if ever, been eliminated through partial cutting. Monitoring of several ponderosa pine stands in Arizona and New Mexico where all, or at least most, of the visibly-

[4] Despite the "high grading", it is evident—based on the behavior of dwarf mistletoe—that many of the trees *harvested* in these areas would also have been infected. At the same time, where disturbance from these activities contributed to higher tree densities later, it may have eventually led (indirectly) to more mistletoe on some sites.

infected trees were cut indicates that stand infection levels return to pre-treatment levels in about 20 years (Geils, unpublished data).

The effectiveness of aggressive mistletoe control efforts on National Forests lands during the 1980s varied considerably. However, in most cases, only temporary reductions in mistletoe were achieved. Overstory removal cuts eliminated sources of infection "from above", but typically left substantial amounts of infection in the understories—despite routine sanitation efforts. Final removal cuts following seed-tree or shelterwood seed cuts were seldom implemented. One net effect of mistletoe treatments in the 1980s (and to a lesser extend throughout the century) was replacement of older infested stands with younger infested stands. Relatively few treatments in the Southwest in the 1980s (or previously) involved complete stand replacement.

Besides persisting, mistletoe tends to increase faster following harvests and thinning (Conklin 2003, Bickford and others 2005). Latent infections (new infections not yet visible) are more apt to develop visible 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, Parmeter 1978). Unlike many forest insects and diseases associated with weak or slow-growing trees, dwarf mistletoes actually do better on vigorous trees.

Although silvicultural treatments over the past century have probably had little effect on mistletoe distribution, they have contributed towards a steady flow of forest products and increased long-term productivity in many areas. However, over time, these treatments have clearly reduced the number of large infected trees in the Southwest, compared with historic conditions. Today, *mature* infested stands are relatively uncommon in many parts of the Southwest.

2.4 Fire and dwarf mistletoe

Fire has long been recognized as an important natural control of dwarf mistletoe (Hawksworth 1961). Over time, stand replacement fires help limit mistletoe distribution on the landscape, since trees typically return to burned sites well before the mistletoe (Hawksworth 1961, Alexander and Hawksworth 1975). However, these early reports suggested that less intense, "incomplete" fires might actually lead to more severe mistletoe over time. Certainly surviving infected trees within burned areas can *perpetuate* mistletoe, not unlike what occurs in partially cut stands. Nonetheless, a better understanding of natural fire regimes has broadened our perspectives on fire–mistletoe relations. We now recognize that historic, frequent low intensity fires also served as an important natural control of mistletoe.

Crown scorch has a strong tendency to reduce infection on surviving trees.

Attempts to quantify the effects of low intensity fire on dwarf mistletoe include Harrington and Hawksworth (1990), Conklin and Armstrong (2001), and Conklin and Geils (2008). Direct controlling effects include 1) higher mortality rates among heavily infected, scorched trees compared to other scorched trees and 2) scorch pruning among surviving infected trees. Data from six prescribed underburns in New Mexico indicates that a relatively uniform burn generating 50% average crown (needle) scorch sets mistletoe back about 10 years (Conklin and Geils 2008).[5] In addition to these direct effects, an historic fire regime of frequent low intensity fire would have kept forests more open, often limiting tree-to-tree spread of mistletoe.

A century or more of fire suppression/exclusion has undoubtedly been favorable to dwarf mistletoes in most situations (Parker and others 2006). For example, the number of infected ponderosa pines on the landscape—and the abundance of its mistletoe—have probably increased considerably in many areas. Again, these increases are largely a result of increased tree densities. However, given its slow rate of spread, any increase in the distribution of dwarf mistletoe and the proportion of the landscape affected have probably been relatively minor (*see section 2.3 above*).

Dwarf mistletoe itself can affect fire behavior in some situations. Fuel loading is often greater in infested areas than in uninfested areas (Koonce and Roth 1985, Hoffman and others 2007). The branching patterns and accumulation of resin on infected trees, as well as increased tree mortality within infested areas, all tend to increase flammability. The potential for mistletoe to influence fire behavior should not be overstated, however. Under extreme fire conditions, these effects may become insignificant, compared to other factors, across much of the landscape. Under less extreme conditions, the effects might often be localized. Any enhancement of fire intensity within infested areas would essentially represent a feedback loop reducing mistletoe on the landscape.

The past 20 years have seen a higher frequency and increasing average size of wildfires in the Southwest. Clearly this has reduced the abundance and distribution of dwarf mistletoes in some areas. Because of the influence of mistletoe on fire behavior, it may not be unreasonable to assume that these recent fires have also reduced the percentage of trees and proportion of the forested landscape with mistletoe; however, no data on this is currently available.

2.5 Other factors in the distribution and abundance of dwarf mistletoes

Other factors besides fire history influence the distribution of dwarf mistletoes on the landscape. Observations over more than a century indicate that dwarf mistletoes tend to do better on some sites than others (MacDougal 1899). Perhaps the most notable example in the Southwest is the strong tendency of ponderosa pine mistletoe to be more common on ridgetops and upper slopes than on lower slopes and in canyon bottoms (Hawksworth 1961); the reason is poorly understood, but may involve microclimate differences. Ponderosa pine mistletoe is more abundant within the mid-elevational range of its host, while Douglas-fir mistletoe has an upper-elevational limit slightly below that of its host (Hawksworth and Wiens 1996). Both these relations, especially the latter, suggest the importance of climate in determining dwarf mistletoe distribution. In general, dwarf mistletoes occur over a broad range of site quality, aspect, soil type, and habitat type. However, inoculation experiments with ponderosa pine mistletoe seed supports the idea that establishment and spread *is* limited by ecological factors, and that some areas are more susceptible to infection than others (Hawksworth 1961). Anecdotal observations suggest that the

[5] These results should apply generally to both management ignited burns and wildland fire use. Note that heat and smoke alone, in the absence of crown scorch, appears to have relatively little effect on dwarf mistletoe.

"aggressiveness" of this mistletoe, including its rate of spread, may also vary considerably between sites.

Notable landscape scale differences occur in the incidence and severity of ponderosa pine dwarf mistletoe across the Southwest. For example, forests in southern New Mexico—especially in the Sacramento Mountains—have a much higher rate of infection than in northern New Mexico. Both climatic differences—especially in summer rainfall—and genetic differences are suggested as possible reasons. Similarly, ponderosa pine forests along the Mogollon Rim in central Arizona are severely infested with dwarf mistletoe.

Over tens of thousands of years, medium and long-distance dispersal of dwarf mistletoe seeds by birds and mammals has probably contributed to their widespread and patchy distributions across the landscape. The sticky seeds of dwarf mistletoe have been found on birds, and less commonly on mammals, and can be rubbed off or deposited on susceptible host foliage (Hudler and others 1979, Nicholls and others 1984). Studies in Colorado have documented young "satellite" infection centers that appear to have originated from vector-disseminated seed. (Hawksworth and Wiens 1996).

Female with mature fruits (top) and male (bottom) ponderosa pine dwarf mistletoe plants.

Initiation of new infection centers from long-distance spread is probably rare, because dwarf mistletoes are dioecious, that is, there are separate male and female plants. Plants of both sexes must be in fairly close proximity for reproduction to occur; a single isolated plant would not result in spread (Nicholls and others 1984). However, medium range dispersal (that is, beyond the range of ballistic seed, but within a few hundred feet of existing infection centers/pollen sources) could have facilitated spread among relatively isolated groups of trees in historic conditions.

2.6 Effects of dwarf mistletoe on forest structure and productivity

Without question, the damaging effects of dwarf mistletoes to individual trees and timber resources are substantial (Drummond 1982, Hawksworth and Wiens 1996). Nonetheless, dwarf mistletoes have evolved with their hosts for many thousands, perhaps millions, of years. As in many other host–parasite relations, a certain balance has been attained. Although infested areas clearly have higher rates of tree mortality than uninfested areas (Hawkworth 1961, Maffei 1989, Mathiasen and others 1990), the host is seldom eliminated from these areas. (Exceptions may occur in mixed-species stands, where infection can accelerate the loss of a particular host species, at least at fine scales.) Mistletoe rarely "kills all the trees" in a stand or results in sizable deforested areas.

Over time, infection centers generally become more open, with lower crown cover and basal area than the surrounding forest. Productivity (tree growth) declines markedly within these centers, and they may become dominated by stunted, deformed trees. Individual trees typically begin to experience measurable growth loss at DMR 4 (Hawksworth and Wiens 1996). Most infected trees survive for several decades, with larger infected trees usually surviving longer than smaller ones (Hawksworth and Geils 1990). As a general rule of thumb, DMRs of infected trees increase by 1 about every 10 years, and most DMR 6 trees die within 10 to 20 years. The rate of intensification usually decreases with increasing tree size. Infected seedlings and saplings rarely become large trees.

Although heavy infection can reduce host seed production (Korstian and Long 1922), host regeneration still occurs and may be naturally abundant within infested areas (Wanner and Tinnin 1989). Much of the regeneration may eventually become infected, but usually some of it will escape infection long enough to reproduce and continue the cycle. Some infection centers are probably thousands of years old. Depending upon the dynamics of the situation, productivity may eventually *increase*, at least temporarily, within infested areas (Robinson and Geils 2006). This could occur following mortality of older infected trees, allowing a younger, lightly infected cohort to develop with less infection from above.

Mature ponderosa pine with top-kill from long-term infection.

Thus, over extended periods of time, mistletoe severity and forest productivity can be expected to fluctuate within any given area (in the absence of management). This can be hard to visualize when observing an infested stand at a single point in time (or sometimes even over decades). The primary focus of research and management over the past century has been on measuring damage (which *is* easily visualized) and reducing it. This is hardly surprising, given the impacts of dwarf mistletoe on timber resources throughout western North America. However, a broader perspective seems warranted, especially given the persistent nature of mistletoe—it *can* be difficult and costly to control—and the unique characteristics and potential ecological benefits of infected trees—especially the larger ones.

2.7 Dwarf mistletoe and animal interactions

Abert squirrels frequently feed on the nutrient-rich phloem in infected branches and utilize witches' brooms on infected ponderosa pines. *Photo courtesy of Sylvester Allred.*

As dwarf mistletoes are an inherent component of forest ecosystems, consequential interactions with animals are common (Hawksworth and Weins 1996, Shaw and others 2004). Dwarf mistletoes affect insects, birds, and mammals by generating food, storage sites, resting areas, and changes in forest structure. Dwarf mistletoe is a direct food source for many diverse species of in insects, including the thicket hairstreak butterflies (genus *Mitoura*), whose larvae are dependent on dwarf mistletoe shoots (Stevens and Hawksworth 1984). Many bird species have been observed feeding on mistletoe berries and shoots, although consumption may be inconsequential except for blue grouse, which increases use of Douglas-fir dwarf mistletoe shoots in the fall (LeCount 1970, Severson 1986). Of seemingly greater importance, dwarf mistletoe provides an indirect food source for birds that feed on insects that feed on mistletoe, and those that feed on bark beetles which often attack weakened infected trees. Porcupines feed selectively on southwestern dwarf mistletoe (Johnson and Carey 1979), and deer and elk feed on dwarf mistletoe shoots whenever it is accessible. Red squirrels selectively feed on small mistletoe-infected twigs over uninfected twigs, while abert squirrels will also feed on the inner bark of large dwarf mistletoe-infected host branches (and not on large uninfected branches) (Allred and Gaud 1994).

Accipiter (probably Cooper's hawk) and nest in witches' broom on ponderosa pine.

Dwarf mistletoe-induced witches' brooms provide nesting, foraging, and caching sites for birds and mammals (Garnett and others 2006, Hedwall and others 2006, Tinnin and others 1982). Several raptors are known to use dwarf-mistletoe brooms as nesting sites in the Southwest, especially in Douglas-fir. Species observed in witches' brooms include Mexican spotted owls (Pederson 1989, Fletcher 1990, Seamans and Gutiérrez 1995), great-horned owl (Fairweather personal observation 1993), goshawk, Cooper's hawk (Reynolds and others 1982), and sharp-shinned hawk (Hedwall 2000). Several passerine birds have also been observed nesting in witches' brooms of either ponderosa pine or Douglas-fir (Hawksworth and Weins 1996, Hedwall 2000).

Small mammal use of witches' brooms in Douglas-fir (Hedwall 2000) and ponderosa pine (Garnett and others 2006) is common in the Southwest. Sixty-seven percent of surveyed Douglas-fir dm witches' brooms in Arizona and New Mexico were used for foraging, caching, or nesting by red squirrels (Hedwall and others 2006). Red squirrels showed a preference for large platform brooms located closer to the bole and 15-30 feet high. Abert squirrel witches' broom utilization in ponderosa pine (Garnett and others 2006) is also associated with denser brooms located higher in trees. Several mammals have been observed using large witches' brooms in the lower crowns for cover (Hedwall 2000).

Dwarf mistletoe infestations at the stand level create structural changes that include more compact crowns due to witches' brooms, and increases in openings, snags, and downed woody debris (Mathiasen 1996). These changes may influence, directly or indirectly, positively or negatively, animal abundance and diversity. Positive, negative, and null correlations have been observed between southwestern dwarf mistletoe related variables (e.g., the amount of mistletoe on a site and snag density) and bird species abundance in ponderosa pine sites (Bennetts 1996, Parker 2001). Avian species positively correlated with dwarf mistletoe infestation are typically cavity-nesting birds likely benefitting from increased mortality rates. In one study, some foliage nesting and foliage gleaning bird species were negatively associated with higher stand average dwarf mistletoe ratings (Parker 2001).

3. Management Recommendations

This section addresses both current Forest Planning efforts and more general recommendations for project-level work on National Forests and other forested lands in the Southwest.

Information provided here for National Forest planning is limited to **ponderosa pine** and **mixed conifer** forest types. We suggest that Forest Plans need not include specific information for management of dwarf mistletoes in other forest types in the Southwest, including piñon-juniper and spruce-fir.

3a. National Forest plans

Under these plans, management activities are expected to achieve, or at least move toward, what are termed Desired Forest Conditions (DFCs). As currently drafted by the Southwestern Regional Planning Team, DFCs are patterned on historic conditions of the mid to late 1800s. DFCs for ponderosa pine and dry mixed conifer forests include relatively open, clumpy, uneven-aged forests across most of the landscape, with occasional areas of even-aged forest. DFCs for wet mixed conifer forests also involve a mosaic of tree groups of various ages, but with higher overall canopy closure than dry mixed conifer. Dwarf mistletoes, like other native insects and diseases, would occur at endemic or historic levels in all forest types. Presumably this would include not only the distribution and abundance of mistletoe on the landscape, but also forest age and structure within infested areas.

Historic levels of mistletoe, effects of past management, and changes from historic conditions are discussed in earlier sections of this report. Briefly: 1) the overall incidence of dwarf mistletoes (including their distribution, the proportion of the landscape affected, and the percentage of trees infected) is thought to have increased (but only modestly) from historic levels; 2) the abundance of mistletoe, especially the number of infected trees, has probably increased considerably; 3) mature infected stands, and large, older infected trees in general, have decreased considerably in many portions of the Region.

Several approaches for managing dwarf mistletoes to achieve DFCs could be envisioned. It might be noted that, over time, dwarf mistletoe infection itself can lead to a relatively open, uneven-aged forest —albeit with substantial loss in productivity (section 2.6). Our recommendations are intended to maintain/achieve reasonably productive forests (at the landscape scale) which also provide high ecological values, at a reasonable cost to the public.

Management is discussed below in terms of *even-aged* and *uneven-aged* cutting prescriptions, consistent with Forest Plans. However, both cutting and prescribed fire should be used to manage mistletoe, especially in ponderosa pine forests. Any plan for controlling mistletoe or maintaining it at or below a certain level need not, and generally should not, be based solely on cutting prescriptions. The effects of wildfires—unplanned but expected--should also be noted in any plan for dwarf mistletoe (see section 2.4). Given recent trends of increasing fire size and severity, along with projections of climate change, future wildfires can be expected to have a significant controlling effect on dwarf mistletoes.

3a.1 Ponderosa pine forest type

Uneven-aged prescriptions are recommended when treating lightly infested stands, where less than 20% of the host trees (excluding seedlings and saplings) are infected or less than 25% of the acreage is affected (that is, at least 75% of the area is essentially free of mistletoe). These stands can be treated basically the same way as stands without mistletoe, to achieve/maintain a relatively open, groupy, uneven-aged forest. (Prescriptions currently envisioned by the Regional Planning Team more closely resemble *group selection* [similar to existing guidelines for northern goshawk] than *individual tree selection*, although the latter may be appropriate in stands that already have the desired structure.)

Uneven-age prescriptions will create small openings that will encourage tree regeneration. Some of these openings will often be created by removing groups of infected trees. However, wholesale targeting of these groups for removal is discouraged. In most situations, some groups of intermediate size (VSS 3 and/or VSS 4)[6] and larger infected trees should be retained for their diversity and potential ecological value. At least to some extent, infected groups would be buffered from the rest of the stand under these prescriptions because of inter-group spacing (with 50 to 80 feet between groups). It is important to realize that even if efforts are made to remove all visibly infected trees and groups, significant amounts of mistletoe will likely remain because of missed and latent infections.

Small openings that regenerate provide ideal conditions for the development of dwarf mistletoe over time. Although uneven-aged prescriptions have traditionally *not* been recommended for mistletoe-infected stands, they can be applied with modest success (from a control perspective) in lightly infested stands, where the majority of the area is free of mistletoe. Periodic use of fire can help keep the mistletoe in check.

Even-aged prescriptions are recommended when treating moderately to heavily infected stands, where greater than 20% of the host trees or 25% of the area is infected.[7] These prescriptions

[6] Even where VSS 3 and/or VSS 4 are in excess (which is the norm throughout much of the Region), it usually makes sense to retain some infected VSS 3 and/or VSS 4 groups. This avoids unnecessary sacrifice of accumulated and potential growth and excessively large openings.

[7] The "% of trees" criterion is best-suited for large-scale analyses, especially in Forest Planning. Either criterion might be used for stand-level decisions.

should provide an irregular spacing of leave trees, and can also tend toward clumpy, groupy stand structures. However, regeneration is not an objective until maturity or beyond.

Even-aged prescriptions (intermediate thinnings) should generally focus on retaining the best dominant and codominant trees with the least amount of mistletoe. Improved growth and vigor of the best trees is a primary objective. Across most of the Region, a majority of infested stands are predominantly pole to small sawtimber size (VSS class 3 and 4). Intermediate thinnings would hasten the development of larger trees—including larger infected trees often now deficient on the landscape. Eventually, some proportion of these stands could be regenerated and replaced (section 3b.3) and then, over time, converted to an uneven-age condition. Some moderately to heavily infested stands could be managed primarily with fire.

Silvicultural prescriptions for moderately infested stands should be flexible. For example, for stands where infection is patchy and does not greatly exceed our suggested "break point" (i.e. 20% infection rate, see above), any existing *uneven-age structure* could be maintained within uninfested portions. The terms *even-aged* and *uneven age* are scale-dependent, and are often not ideal descriptions of stands/areas (Bradford 1992).

Intermediate (sanitation) thinnings are usually not recommended for severely infested stands, that is, where more than about 80% of the host trees or 90% of the area is infected. These stands are often best replaced or deferred from mechanical treatment. However, a third option for some stands is to thin from below, which (to some extent) mimics the effect of low-intensity fire and does not greatly stimulate the mistletoe in the remaining trees.

We encourage **underburning** in mistletoe-infested ponderosa pine forests. Fire (of sufficient intensity) will help keep the disease in check, and is usually much less costly to implement than mechanical treatment. In many areas, fire might be used as frequently, or more frequently, than mechanical treatment. Although mechanical treatment is warranted in many areas before fire is re-introduced, there are currently many opportunities for increased use of fire on the landscape.

3a.2 Mixed conifer (both dry and wet) forest type

Because of the variety of situations and host-parasite combinations in mixed conifer forests, *specific* management guidelines for dwarf mistletoes are difficult to develop. However, the following information might be included in Forest Plans:

Flexible **uneven-aged prescriptions** can be used in most areas where treatments are planned. Substantial mistletoe reduction should be applied in most project areas; however, wholesale targeting of infected trees/groups for removal is discouraged. In most situations, some groups of intermediate size and larger infected trees should be retained for their diversity and potential ecological value; at least to some extent these would be buffered from the rest of the stand under these prescriptions because of inter-group spacing. Available trees with large witches' brooms (especially Douglas-firs) should be intentionally retained within most project areas because of their potential value to wildlife.

Even-age prescriptions should be considered when treating some heavily infested mixed conifer stands, especially where these are abundant at a landscape scale (e.g., within a large analysis area). Often because of previous entries, many of these stands currently have a more or less even-age structure. Continuation of this silvicultural trajectory, including eventual stand replacement, is a reasonable approach for some of these stands and may contribute to a more diverse landscape (as opposed to using the same uneven-age prescription everywhere). We suggest that some proportion of mixed conifer stands with more than 50 % of all conifer trees infected (excluding white fir) be managed under an even-age system. Some proportion of heavily infested mixed conifer stands should probably be deferred from treatment. Section 3b.4 below provides additional recommendations for management of dwarf mistletoes in this forest type.

3b. General recommendations

In general, the presence of dwarf mistletoe in a stand should not influence treatment priorities. Efforts to improve forest conditions (health) should focus on areas that can benefit the most from treatment—at a reasonable cost—rather than on specific "problem areas" like mistletoe-infested stands. While dwarf mistletoes are certainly amenable to silvicultural control (Hawksworth 1978b), effective long-term control can be more difficult than often assumed. Uninfested stands are usually easier to manage, especially over the long-run, than infested stands; similarly, their treatment often provides a greater benefit/cost. Vast forested areas in the Southwest are in need of treatment and financial resources are limited.

Nevertheless, because of the widespread distribution of dwarf mistletoes, most projects will encounter them, sometimes over extensive areas. Cutting in infested areas without regard to the presence of mistletoe can have serious impacts on productivity. Prudent treatment can increase long-term productivity. At the same time, most projects can be designed, where desired, to maintain or promote beneficial aspects of mistletoe infection.

The information provided below is often a compromise between generality and precision. Every stand/area/situation is different. Management decisions should be based on specific needs and objectives for each area, but within a framework that considers the overall condition of the surrounding landscape.

3b.1 Thinning in dwarf mistletoe infested stands

Although thinning within infested areas tends to stimulate the remaining mistletoe (see section 2. 3), thinning of lightly to moderately infected stands is often beneficial from a number of perspectives. Thinning is usually not recommended for stands with average dwarf mistletoe ratings (DMR) of 3 or higher (Hawksworth 1978a).

Usually the best approach is to remove as much mistletoe as possible without sacrificing the best trees. In most situations this will involve retaining some lightly infected dominant and codominant trees. These are usually better choices for retention than intermediate or suppressed trees that appear to be uninfected. Spacing of leave trees should vary, not only to retain the best trees, but also to provide a more irregular structure. Pre-marking of leave-trees usually improves results and is recommended in most situations.

These leave-tree guidelines are useful in many situations:

DBH Class	Maximum Allowable DMR
0–5"	0
5-9"	1 or 2
>9"	2 or 3

This approach is appropriate for most lightly to moderately infested stands, of any forest type. Similar guidelines have been recommended in the past for even-age stands. However, the above guidelines can also be used in some uneven-age situations, particularly where groups of infected trees are retained and are at least somewhat isolated from the rest of the stand.

The above guidelines are based largely on expected growth and longevity of infected trees. Most lightly infected dominant and codominant trees can grow at a good rate and survive for at least a few decades. *On average*, the larger they are, the slower the mistletoe will intensify (increase to the next DMR class) and the longer they can be expected to survive. As a general rule, all visibly infected trees less than 4 to 5" dbh should be cut, since few of these have potential to become sizable, mature trees.

In *some* situations, deviation from these guidelines is appropriate for managing *isolated groups* of infected trees. Because mistletoe intensifies more rapidly following thinning, it is usually best to leave these groups relatively dense. Therefore, it is appropriate to retain larger, more severely infected trees (DMR 4–6) within some groups. Although it is commonly believed that removing these trees slows disease spread and intensification, usually the reverse is true.

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 hazard, to modify wildlife habitat, and/or to provide forest products. Unless these (or other) needs 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 usually wait until it does. Exceptions may occur in areas where substantial amounts of young regeneration can be protected from infection by the removal of scattered infected residual trees. Similarly, very young regeneration itself—in an even-age situation—may warrant periodic sanitation. However, these examples are not "thinning" in the usual sense.

Sanitation and Latent Infections

A study on control of lodgepole pine dwarf mistletoe in Colorado (Hawkworth and others 1977) well-illustrates the efficacy of mistletoe "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) understory. 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 to 42 percent over the same 10–year period.

As mentioned earlier (section 2.3), monitoring of ponderosa pine stands in Arizona and New Mexico indicates that infection levels typically return to pre-treatment levels about 20 years after removal of all, or at least most, visibly infected trees (Geils unpublished data). Similar patterns have been observed via other post-treatment monitoring in the Southwest (Conklin 2003; *unpublished data*).

Latent infections—infections that have not yet produced visible shoots—help account for the resurgence of dwarf mistletoe in most treated areas. Roughly speaking, for every 100 visibly infected trees there are another 50 or so with only latent infection, in most lightly to moderately infected stands (Hawksworth 1978a, Knutson and Tinnin 1980, Merrill and others 1988). Monitoring on the Mescalero Apache Reservation in New Mexico has demonstrated that even young pine regeneration (2–3 feet tall) can have can have significant amounts (5 to 10 % rate) of latent infection (Conklin 2002). Most latent infections produce visible shoots within 5 or 6 years of germination (Hawksworth 1961) ; however, longer latency is not uncommon and can extend for up to 10 years in southwestern ponderosa pine.

Clearly latent (and "missed") infections are why follow-up treatments have sometimes been recommended for control of dwarf mistletoe. However, in *most* situations, it can be demonstrated that these are uneconomical. Much of the benefit from thinning an infested area is associated with improved growth of selected leave trees. Coming back to remove additional infected trees before the next scheduled entry usually provides little of this benefit, and often represents an unnecessary sacrifice of accumulated and potential growth. And it rarely, if ever eliminates the disease.

3b.2 Use of fire

Periodic underburning is recommended in most dwarf mistletoe infested ponderosa pine stands. Although mistletoe control is usually not the primary objective of prescribed burning, it is certainly one of the potential benefits. Fires generating 30 to 60 percent average crown (needle) scorch[8] will set back mistletoe (average DMR) for several years, while providing a modest amount of tree thinning (mostly thinning from below). Fires generating little or no crown scorch will have little or no effect on dwarf mistletoe, and may also have relatively little effect on fuels, fire hazard, or other forest conditions.

Underburns of sufficient intensity have a significant controlling effect on ponderosa pine dwarf mistletoe.

Increased application of wildland fire use could also have a significant controlling effect on dwarf mistletoe on the landscape. Conversely, mistletoe infestation is one of several reasons why increased application of wildland fire use might be appropriate.

3b.3 Heavily infested stands

Because of the behavior of dwarf mistletoes after partial cutting, sound management options for heavily infested stands are usually limited. Stand replacement is the best option for areas managed primarily for timber production. Low thinning and/or underburning can often be beneficial in areas where fire hazard is a concern—including the wildland-urban interface.

Shelterwood seed cuts are a good option for management of some heavily infested stands in the Southwest. These treatments generally retain the largest, most vigorous trees as a seed source for natural regeneration. Spacing of seed trees can be highly irregular, and groups of larger trees can be retained. Once the site has regenerated, the standard recommendation has been to remove all infected seed trees before the regeneration is three feet tall, or 10 years old, whichever comes first (Hawksworth and Wiens 1996).

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.

[8] In a typical underburn, most scorch is a result of convective heating, rather than direct combustion. Moreover, because of bud survival, usually about half the scorched portion of a crown survives.

An aggressive dwarf mistletoe control project area. Treatment of this (formerly) severely infested ponderosa pine stand involved removal of all host trees greater than two feet tall. The ample young natural regeneration here provided for a successful result.

In severely infested ponderosa pine stands lacking enough potential seed trees, the only option may be to clearcut and replant, if these sites are to produce timber in the future. Occasionally these sites have enough young natural regeneration present to avoid the need for planting. However, in such cases the regeneration will require periodic sanitation.

In National Forest areas where aggressive mistletoe control efforts (overstory removals, etc.) were widespread in the past, we suggest that most remaining *mature*, heavily infested stands be deferred from mechanical treatment. From an ecological perspective, healthy forests in the Southwest do include some of these stands, with their unique characteristics.

3b.4 Mixed conifer forests

Non-host or less susceptible tree species in mixed conifer 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 non-host species has often been recommended for managing dwarf mistletoes, and this idea is useful in many situations. On the other hand, as a general rule we recommend retaining the best non-host and host trees. This usually provides greater stand diversity, avoids unnecessary sacrifice of accumulated growth, and may increase options for future management.

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, it is usually better to leave a pine seed source.

Large witches' brooms on infected Douglas-fir.

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 controlling mistletoe. In fact, intentionally retaining larger infected Douglas-firs can be recommended from a wildlife perspective.

Stands with two or more species of dwarf mistletoe present special challenges and are often difficult to manage. Low thinning can be beneficial in some situations, and provides a more even-age structure. An uneven-age structure (with some sacrifice in productivity) can usually be maintained where infection is variable and patchy in one or more or more host species. Stands with extensive infestation in two or more species are often best deferred from cutting operations, except where timber production is a primary objective.

To be most meaningful, the stand rating (average 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.

3b.5 Planting

As a general rule, susceptible host seedlings should not be planted within at least 50 to 60 feet of dwarf mistletoe infection sources. This guideline has particular application for restoration efforts within burned areas containing scattered infection sources.

Planting non-host species within mistletoe-infected areas can increase future productivity. Planting pines in areas with Douglas-fir dwarf mistletoe can be a good strategy, provided there is evidence that pines will do well on the site. Planting shade tolerant species on sites with pine mistletoe seems more questionable, given the overall trend toward replacement of high-elevation pines with shade tolerant species.

4. Summary

The dynamics of dwarf mistletoe infestation in the Southwest appear to have changed substantially since the mid to late 1800s. Management efforts to restore (or at least approach) historic conditions on public lands should address these changes.

We can infer that dwarf mistletoes were common and widespread in historic conditions. Their abundance has probably increased in many areas over the past century, largely a result of increased tree densities. A century or more of fire exclusion and decades of selective cutting have generally been favorable for dwarf mistletoes. At the same time, past control efforts appear to have greatly reduced the number of large infected trees in many parts of the Southwest, compared to historic conditions.

Because of their behavior following selective cutting, efforts should be made to reduce dwarf mistletoes substantially in most project areas. However, any credible restoration strategy for southwestern forests should include retention of some groups of intermediate size and larger infected trees (as well as individual trees with large witches' brooms) for their unique characteristics and presumed ecological values. In general, strategies to achieve more open, "groupy" forest structures should be compatible with historic mistletoe dynamics. Even-age management, with eventual stand replacement may be an appropriate strategy for some heavily infested areas.

Prescribed fire can be, and probably should be, an important management tool for this disease, especially on public lands. If recent history is any guide, future wildfires will have an increasing controlling effect on dwarf mistletoes, and will essentially "replace" many infested areas on the landscape.

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