Forest Pathology and Entomology at Fort Valley Experimental Forest

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Abstract—*Forest pathology and entomology have been researched at Fort Valley Experimental Forest throughout its history. The pathogens and insects of particular interest are mistletoes, decay and canker fungi, rusts, bark beetles, and various defoliators. Studies on life history, biotic interactions, impacts, and control have been published and incorporated into silvicultural programs. A brief review of select pathogens and insects illustrates the evolution of research problems, approaches, and applications. Southwestern dwarf mistletoe, a serious pathogen of ponderosa pine, provides a case history of research transitioning from eradication methods for a menacing pest to adaptive management for an ecological keystone species.*

Introduction

Research at Fort Valley Experimental Forest (Pearson 1918) began with studies to determine the best silvicultural practices for timber production of southwestern yellow pine (*Pinus ponderosa*). Besides issues of stocking levels and cutting cycles, this work sought economical methods for reducing losses from various physical factors and biotic agents. One of the most important of these agents was the southwestern dwarf mistletoe (*Arceuthobium vaginatum*). The early research in forest pathology and entomology was conducted by long-term monitoring on a series of silviculture plots (Table 1) and later by specific life history studies. As a consequence of virgin stand conditions, initial harvesting practices, and abundant natural regeneration circa 1919, the stands that developed on the silviculture plots consisted of a mistletoe-infected overstory and an understory showered with mistletoe seeds. Since mistletoe requires a living host and disperses a short distance, killing the infected overstory or pruning infected branches were logical controls for protecting the regeneration. Besides silviculture and control studies with infested plots, research included comparisons of stand growth and yield to plots with little or no mistletoe. After a half-century, a silviculture foundation for the Southwest was established (Egan 1954, Gaines and Shaw 1958). Soon after this, however, sentiment shifted to concern over forest health in general (Dahms and Geils 1997) and mistletoe control in particular as more damaging than the disease itself (Conklin 2000). This review briefly examines a century of forest pathology and entomology research at Fort Valley and by associated scientists in the Southwest (also see Appendix). This history illustrates the importance of Fort Valley research for a better understanding of the relevance of geography and evolution of ecosystems and societies.

The Southwest forests share many forest pathogens and insects with other western regions, yet the individual species and their behavior are regionally distinctive (Pearson 1943). Research at Fort Valley contributes to an understanding of forest pathogens and insects applicable both generally across the West and specifically within the Southwest. General research concepts developed in one region can be used widely, but many relationships need to be fit for a specific region. The Fort Valley Experimental Forest has filled the general and specific roles of research by serving as an individual experimental forest for long-term, plot-level research, by contributing to comparative, regional studies, and by its scientists integrating information from multiple regions and disciplines into useful management tools.

Southwestern Dwarf Mistletoe

Silviculture Plots

Of forest pathogens in the Southwest, the most common and damaging are clearly the mistletoes (Geils and others 2002, Hawksworth and others 1989). Dwarf mistletoes (*Arceuthobium* spp.) are long-lived, obligate, aerial parasites of conifers; they disperse locally by ballistic discharge of moderately large seeds. Trees infected by southwestern dwarf mistletoe form characteristic, large brooms clearly shown in many old Arizona photographs (see Moir and others 1997 for 1890 photograph by Gifford Pinchot). In the 1800s, dwarf mistletoe was common and already recognized as potentially damaging (MacDougal 1899). At Fort Valley, Burrall (1910) established the first known plot to quantify the effects of southwestern dwarf mistletoe on tree growth. Assistant Southwest Forester, T. S. Woolsey, Jr. well understood the general biology and pathology of this mistletoe and declared it a "serious menace" to ponderosa pine (Woolsey 1991). In 1911, William "Doc" Long was appointed as the first regional forest pathologist and given the assignment to study how to reduce losses in the Mountain West from mistletoe, decay, and rust. Although Doc Long and later other pathologists and

Table 1. Silviculture study plots at Fort Valley infested with dwarf mistletoe.

Reference	Silviculture plot				
	Burrall	S1[a]	S2[b]	S3[c]	S5
Burrall (1910)	establish study on effects to tree growth				
Pearson (1918)		reproduction and stand yield, 1909 to 1914	reproduction and stand yield, 1909 to 1914	reproduction and stand yield, 1909 to 1914	
Korstian and Long (1922)	effects on tree growth		effects on tree longevity	effects on tree longevity	
Krauch (1930)				20-yr tree mortality and causes	15-yr tree mortality and causes
Hatfield (1933)		establish mistletoe study			
Pearson (1933)				tree mortality, stand yield, and reproduction, 1901 to 1929	
Krauch (1937)				tree growth and stand yield	tree growth and stand yield
Pearson (1938)				tree mortality and stand yield	
Pearson (1939)				tree mortality	tree mortality
Pearson (1940)					yield, mortality by size-class
Pearson and Wadsworth (1941)					tree growth and mortality,1909 to 1939
Chapel (1942)				defect in 1939	
Pearson (1944a)				yield loss due long 1st cycle	yield loss due long 1st cycle
Pearson (1946)				tree growth in 2nd cycle	
Meagher and Herman (1951)		establish Mistletoe Reduction Study (MRS)			
Gill and Hawksworth (1954)		18-yr observation in Hatfield plots		10-yr observation in 2nd cycle trees	
Herman (1961)		MRS, 10-yr observation			
Myers and Martin (1963)				tree mortality in 2nd cycle	
Heidmann (1968)		MRS, 16-yr observation			
Heidmann (1983)		MRS, 27-yr observation			
Hawksworth and Geils (1985)				vertical spread of mistletoe in 2nd cycle trees	

[a] logged 1894.
[b] logged 1895.
[c] logged in 1909, second cut in 1939, new plots established in 1977.

eventually entomologists were stationed at an Albuquerque federal lab, they conducted much of their work in the Fort Valley area and associated themselves with its research.

G. A. "Gus" Pearson (1918) established a series of silviculture plots at Fort Valley (Table 1) and included observations on mistletoe as a principal cause of defect, growth loss, mortality, and vulnerability to bark beetles and windthrow. This first series of Fort Valley plots were in heavily harvested stands that were soon well stocked with regeneration under mistletoe-infested overstory trees. Since Gus Pearson knew mistletoe was lethal to small trees and pine reproduction was infrequent and subject to many losses, his first priority was protection of this regeneration. Control methods for mistletoe included cutting, poisoning, and pruning overstory trees. The research problems were: 1) the threat infected trees posed to neighbors and understory; 2) overstory losses due to growth reduction and mortality directly by mistletoe or by windthrow; and 3) stand productivity losses due to incomplete occupancy. The first important results from these plots were described by Korstian and Long (1922) who recommended management use silviculture to control mistletoe spread and intensification and thereby reduce host growth loss and mortality.

Additional silviculture plots (Table 1) established at Fort Valley represented uncut stands and stands on different soil types. Since several of these plots had little or no dwarf mistletoe, they provided baseline information on stand growth and yield. Other plots established by Hatfield (1933) and by Meagher and Herman (1951) investigated silvicultural prescriptions for controlling mistletoe with least cost and least reduction in forest productivity. Pearson (1946) concluded his initial efforts at mistletoe control had not been sufficiently "drastic" to reduce mistletoe to a negligible level. Determining the best level of sanitation (removal of mistletoe infections) in heavily infested stands, however, presented several problems. If the cut were too severe, the residuals might be lost to windthrow. If a stand were clear cut, expensive and risky planting would be required. Even if cutting left a well-stocked and wind-firm stand, mistletoe resurgence from missed or latent infections would require several re-cleanings to control mistletoe. Mistletoe generally occurred on larger trees, was distributed in patches, intensified slowly, and caused no apparent growth loss or mortality until the infestation was severe. The immediate goal of full site occupancy with the largest trees conflicted with a control objective of eradicating mistletoe from the stand.

The research approach used by Hatfield (1933) and Meagher and Herman (1951) was to compare alternative control treatments in a few experimental plots. A later approach, including the work of Myers and others (1972), was to model stand growth and yield as a function of tree density, basal area, and mistletoe severity. Relationships were developed from numerous even-aged stands thinned (with sanitation) to represent a broad range of growing stock level and mistletoe severity. One study was established on a permanent sample plot S3 (Table 1) and monitored until 1989. Results from the Fort Valley silviculture, control, and growth and yield plots have been published (Table 1) and used to develop management guidelines and simulation models (e.g., Edminster 1978, Schubert 1974). The Fort Valley plots have not been remeasured recently, but their well-documented history of cutting, growth, and mortality provides an opportunity to examine the effects of silviculture and mistletoe on long-term stand development.

Frank Hawksworth

The silviculture and control plots at Fort Valley were complemented with a series of pathology studies directed by Lake Gill and conducted by Frank Hawksworth (Figure 1). Hawksworth (1961) investigated the crucial topics in mistletoe pathology—life history, seed flight, dispersal period, rate of spread, effects on host growth and fitness, types of witches' brooms, distribution, and control. Before 1950, the severity of mistletoe infection had been variously described in subjective terms and little attempt had been made to quantify the relation of mistletoe severity to either intensification or effects. Using southwestern dwarf mistletoe–ponderosa pine as a model, Hawksworth (1977) devised a rating system now used globally for quantifying mistletoe severity.

The Hawksworth studies and rating system provided the basis for developing several models of mistletoe spread, intensification, and effects on host growth and survival. Silviculturalists had traditionally used standardized tables of yield by age; computer programs allowed variable density tables to be calculated and to include mistletoe effects (Myers and others 1972). Growth and yield models soon progressed from computation tables of stand averages (Edminster and others 1991) to simulations of individual trees (Dixon 2002). Silviculture and pathology studies conducted at Fort Valley provided the fundamental relations used

Figure 1. Frank G. Hawksworth in 1961 inoculating seedlings with dwarf mistletoe. Photo by B. Schacht.

in the Southwest variant of the Forest Vegetation Simulator (FVS). Coincidentally, the primary architect of FVS, Albert Stage, (1973) was a Fort Valley scientist; and the present applications director, Gary Dixon, developed a mistletoe spread model (Dixon and Hawksworth 1976). The conceptual mistletoe model constructed by Hawksworth was adapted by Robinson and Geils (2006) for spatial simulation of mistletoe dynamics in complex stands. Frank Hawksworth's contributions in quantifying mistletoe were, however, only a part of his productive career.

Frank Hawksworth was a key investigator on mistletoe control projects at the South Rim of the Grand Canyon (Lightle and Hawksworth 1973) and on the Mescalero Apache Indian Reservation (Hawksworth and Lusher 1956). The Grand Canyon project was an important test of the Fort Valley control methods (killing and pruning) applied to improve tree health and longevity in an old-growth recreation forest. With a long-term record (1949 to 2003) of comparison plots, the Grand Canyon project (see Robinson and Geils 2006) well complemented the Fort Valley silviculture plots. Observations at the Grand Canyon demonstrated that reducing the mistletoe population could increase the longevity of residual old-growth trees (Geils and others 1991), stimulate pine regeneration, and retard mistletoe spread and intensification (Robinson and Geils 2006); but the long-term ecological effects and affects on fire hazard have not been assessed. The Mescalero project was a test of Fort Valley control methods for optimizing timber productivity through repeated cleanings aimed at mistletoe eradication. Early Fort Valley studies had substantiated that severe mistletoe infection greatly reduced tree growth and survival; the Grand Canyon and Mescalero projects demonstrated that significant mistletoe reduction was possible if a sufficient and sustained effort were implemented. Many forest managers, however, were unconvinced that the mistletoe was sufficiently widespread and serious to justify control (Gill 1960).

Frank Hawksworth participated in forest- to region-wide surveys (Andrews and Daniels 1960, Hawksworth 1959) to quantify the distribution and severity of dwarf mistletoes. These surveys served as prototypes for other regions and a Southwest re-survey to assess the 30-year trend in mistletoe distribution (Maffei and Beatty 1989). Approximately one-third of stands in the Southwest were infested in each survey (Andrews and Daniels 1960, Maffei and Beatty 1989). Although these surveys can be variously interpreted with regards to past success in mistletoe management, they nonetheless document that southwestern dwarf mistletoe remains a frequent and ecologically influential species in many Southwest forests.

Four additional Hawksworth projects illustrate the connection of Fort Valley research with topics of current interest—effects of climate change, high-elevation pines, prescribed burning, and wildlife habitat. Mark and Hawksworth (1976) related mistletoe distribution to geographic and altitudinal cli-mates. A warmer climate would allow southwestern dwarf mistletoe to migrate northward and up-slope. In resolving a question on the taxonomy of the dwarf mistletoe on bristlecone pine (*Pinus aristata*), Mathiasen and Hawksworth (1980), also mapped the distributions of the five-needled pines (subgenus *Strobus*) on the San Francisco Peaks. This provided a monitoring baseline for the potential effects of climate change and white pine blister rust (*Cronartium ribicola*) on these high-elevation pines. Alexander and Hawksworth (1975) reviewed the complex fire ecology of dwarf mistletoe; Harrington and Hawksworth (1990) conducted at the Grand Canyon one of the first studies on prescribed burning for mistletoe control. Data of that study corroborated a sanitation model developed by Conklin and Geils (2008). Many hours of scanning tree crowns for dwarf mistletoe at Fort Valley allowed Frank Hawksworth to observe the associated wildlife. Mistletoe-wildlife interactions include seed dispersal, mistletoe and infected branches as food, brooms for nesting and cover, and effects of mistletoe on habitat (Hawksworth and Geils 1996). Frank was an avid birder who didn't considered dwarf mistletoe as an insidious pest but as a member of a diverse biotic community with many, profound effects and interactions (i.e., a keystone species). As often the case in science, knowledge gained in one study eventually benefits greater understanding elsewhere. Frank Hawksworth was hired to improve pest control methods; he gave us a personal example of appreciating nature through humor and understanding an odd, little parasitic plant (see sidebar).

Mistletoe Power

Frank Hawksworth knew of the importance of applying research to crucial national needs. But he also had a dry sense of humor. In 1973, an oil embargo directed against the United States demonstrated the vital economic importance of a secure, domestic energy supply. From his distribution surveys and research on seed biology, Hawksworth (1973) estimated with a few simple calculations that the annual production and discharge of mistletoe seeds in the Southwest produced 67,000 kilowatts of energy! And this is a renewable resource that is basically solar power, produces water (like fuel-cells), has a low carbon-footprint (way better than clean coal), its "nuclear" activity does not produce radioactive wastes. He suggests "American ingenuity…and multi-billion dollar crash program" could solve the slight problem of collecting energy when seeds are expelled from billions of fruits over millions of acres discharged in thousandths of a second.

Other Pathogens and Forest Insects

In addition to dwarf mistletoe, numerous physical processes and other biotic agents known to damage or kill trees have been studied at Fort Valley. Krauch (1930) identifies lightning, fire, windthrow, frost heaving, drought, breakage, and animals as important mortality factors. The damages caused by many of these factors are often confounded by those of fungi and insects. For example, root disease and decay predisposes trees to windthrow and breakage, which increases vulnerability to attack by bark beetles and additional decay fungi. Pathogenic or saprophytic fungi cause needle cast, decay, canker, rust, and root disease (Ellis 1939, Lightle 1967). Phytophagous insects include bark and twig beetles, sap-sucking and shoot-feeding insects, and defoliators (Fairweather and others 2006). Many of these insects and some fungi typically display periods of outbreak and collapse; others are ubiquitous and persistent.

From the utilitarian perspective of timber production (Kolb and others 1994), damaging irruptive species are characterized as *pests*. The general biology and destructive potential of these species were known when the Fort Valley station was established. Initial research focused on taxonomy, life history, effects, and epidemiology with the objectives of minimizing losses and preventing or reducing outbreaks. Over time, however, the Fort Valley forest has been seen less as a tree farm and more as a biotic community and natural ecosystem. From the ecological perspective, these pathogens and insects are not pests but *symbionts* at the host level (Combes 1996) and *transformers* at the ecosystem level (Richardson and others 2000). Gunderson and Holling (2002) describes cycles of forest ecosystem renewal to include stages of exploitation, conservation, release, and reorganization. A few but diverse pathogen and insect species play influential roles in that renewal cycle. Their influence on forest structure and dynamics depend on their specific effect (e.g., needle cast vs. root disease) and their particular epidemiology (e.g., outbreak typically short and showy vs. nearly permanent).

Wood decays are persistent, saprophytic fungi (Gilbertson 1974). The western red rot (*Dichomitus squalens*) is common in the Southwest as a saprophyte of ponderosa pine heartwood (Andrews and Gill 1943); cull in early defect studies determined losses at 10 to 15% but occasionally as high as 50%. Unlike the old-growth decays of other regions, western red rot enters through dead branches and attacks young ponderosa pine trees in open stands. Recommended silvicultural modifications are to delay thinning for the first 80 years, then thin the stand and prune the residuals. Fort Valley silviculture and utilization studies of the past contributed to reducing cull; new studies need to address decay of live ponderosa pine for it affects on soils, fuels and carbon sequestration.

The rust fungi cause several kinds of disease including foliage rust, broom rust, gall rust, limb rust, and stem rust. Hawksworth (1953) describes observations at Fort Valley that determined that limb rust has several taxonomic forms (*Cronartium* and *Peridermium*). He also reports a gall-forming rust on the San Francisco Peaks that is different from the common, damaging gall rust of other regions. This white-spored rust (*Peridermium* sp.) appears to be a genetically distinct, rare endemic with small disjunct populations from west Texas, to southern Nevada, to northern Colorado (Vogler and Bruns 1998). Generally, the native pine stem rusts have not caused severe economic or ecological impacts in the Southwest. Gilbertson (1985), however, describes a case wherein a rare stem rust native on ponderosa pine (*Cronartium comandrae*) unexpectedly and with serious damage appeared on an Asian pine species (*Pinus elderica*) introduced to Arizona. Combes (1996) provides numerous examples where a parasite plays a major but secretive role after a biotic system is disturbed. Although we have some knowledge on the pine rusts, we have much to learn before we understand their evolutionary history, genetic potential, and ecology.

Pine defoliators include both fungi and insects. Needle cast fungi belong to several taxonomic groups (e.g., molds) that infect live conifer foliage and cause early shedding (Ellis 1939, Gill 1940). Twig beetles (e.g., *Pitygenes*), Prescott scale (*Matsucoccus vexillorum*), sawflies (*Neodiprion*), pandora moth (*Coloradia pandora*) and other insect defoliators feed on shoots and foliage (McMillin and Wagner 1998, Wagner and Mathiasen 1985). These fungi and insects are usually eruptive with rapid and spectacular appearance related to favorable weather. Red foliage and defoliation can be alarming, especially when synchronous outbreaks occur over a large area. Although defoliation outbreaks in the Fort Valley area have several times prompted initiation of new, large investigations, these were short-lived when they determined the outbreak cause and its modest impact on host growth and survival. The most recent Fort Valley study on a defoliator is the now terminated laboratory work on the western spruce budworm (see Clancy 2002). University and Forest Service entomologists are now studying an eminent pandora moth outbreak in northern Arizona.

Canker fungi are pathogens that usually enter the stem through an injury and cause a perennially, enlarging wound; some are associated with decay (Hinds 1985). Aspen (*Populus tremuloides*) is easily susceptible to injury, canker disease, and decay. Although aspen can sprout prolifically after the clone is cut or burned, young stems are often so severely browsed that regeneration fails. Herman (1951) describes Fort Valley aspen regeneration studies and mentions fencing to prevent animal damage. The course of that and other experiments (see Martin 1965) have established the need for fencing to protect aspen, now principally from elk (Shepperd and Fairweather 1994, Rolf 2001). Aspen decline present now on the San Francisco Peaks is due to a complex of abiotic and biotic causes. Sustaining aspen communities requires cooperation among forest pathologists, forest and wildlife managers to ensure success of the aspen renewal cycle.

Most root disease fungi are also decay fungi, but these pathogens attack living roots and thereby cause host decline and vulnerability to windthrow or insect attack (Andrews

1957). Although root disease is found throughout the Southwest (Wood 1983), it has not been as important in the Fort Valley forest as elsewhere in the region. However, restoration and fuel treatments conducted recently here have greatly increased the food stock for root diseases (i.e., fresh stumps). Because root disease develops slowly but is very persistent, early detection and monitoring studies at Fort Valley would be prudent.

For pines of the Southwest, bark beetles are the insects of principal concern (DeGomez and Young 2002). These insects bore into and feed upon the inner bark of living trees. They usually form mass attacks on stressed trees or upper tree crowns, but when insect populations are sufficient they can successfully attack and kill healthy trees (Pearson 1943). The mountain pine beetle (*Dendroctonus ponderosae*) has been an aggressive cause of landscape-scale tree mortality on the North Kaibab plateau (Lang and Stewart 1909) but is uncommon elsewhere in the Southwest. On the Fort Valley plots, Krauch (1930) recognizes bark beetles as contributing to mortality (but minor compared to mistletoe). Hornibrook (1936) reports on a small, early study to reduce *Ips* populations by peeling the bark of infested trees (also see Vincent 1935 and Wadsworth 1939 for similar studies). Although *Ips* and other *Dendroctonus* beetles usually attack diseased trees in dense, blackjack stands, following a sustained drought as recently experienced, these bark beetles can kill thousands of trees in a forest-wide outbreak (Kenaley and others 2006). Recent work at Fort Valley conducted by university researchers has investigated the effects of forest thinning on the physiological defense of residual trees to bark beetle attack.

In the pine forest of the late 1800s, frequent, low-intensity fire had been an important natural disturbance for maintaining the system (Covington and others 1997, Moir and others 1997). Fire suppression for most of the past 100 years had disrupted that function, but a new fire policy is aimed at restoring it (Dahms and Geils 1997). Unfortunately, we know less about the natural disturbance regimes of bark beetles, other forest insects, fungal pathogens and mistletoes. Fort Valley studies have provided information valuable for developing guidelines and technologies for insect and disease management in a traditional forestry context. Additional research would be required, however, to determine the insect and disease regimes of a resilient, well-functioning ecosystem for providing various ecological services (Geils and others 1995).

Fort Valley, a Learning Experience

Historically, the Fort Valley scientists had the objective of learning and communicating practical information for managing productive timber stands and controlling pests (this proceedings). They developed information on pathogen and insect identity, distribution, life history, and epidemiology. They applied that knowledge to damage assessment, projection, and management. Beyond results of individual studies, however, also emerged an appreciation for the complexity of biotic systems and importance of symbiotic interactions of diverse form. For example, Jameson (1994) studied pinyon-juniper woodlands subjected to stress and disturbance. He recognized that succession was not just steady, species replacement to a single endpoint; succession could display rapid jumps to multiple, nearly irreversible endpoints in consequence to various stresses and insect or disease outbreaks. Among the authors he referenced for early development of ideas on complexity and interaction was C. S. Holling. Gunderson and Holling (2002) provide a conceptual framework in terms of adaptive management and cycles of ecosystem renewal that are useful for organizing our understanding of the ecology and management for forest pathogens and insects.

Hawksworth (1961) originally presented his work on the life history and spread of southwestern dwarf mistletoe in the silvicultural context of the time (Figure 2, from observations at Fort Valley). Like Jameson (1994), he developed an appreciation for the complexity of the mistletoe–pine pathosystem—multiple impacts and alternative outcomes occur as result of differences in initial conditions and interactions of various factors. Spread of dwarf mistletoe is more than an increasing area removed from timber production. Although Pearson (1944b) recognized he knew little about host resistance, he suspected that regenerating a stand from mistletoe-free trees would improve its genetics. Mistletoe's first effect by disease or by control may be on host fitness, but we have much to learn on this topic. Regardless of the genetic consequences, infected trees are often retained as a seed source and left long enough that the regeneration becomes infected (e.g., Fort Valley plot S3). Mistletoe in a residual, overstory tree continues to intensify until the host dies (Figure 2). Early Fort Valley studies sought to identify which trees would be "lost" before the next cutting cycle; but later studies recognized these snags as valuable for wildlife habitat (a second effect). The first infected sapling dies rapidly, leaving a persistent and later increasing canopy gap (a third effect). Bickford and others (2005) determined that reducing competition around an infected tree at least temporally improves its growth, but mistletoe growth is also enhanced. Although poles survive infection longer than seedlings, they develop mistletoe brooms of various types (a fourth effect). Brooms reduce host vigor, yet they also provide special habitat for wildlife (Hawksworth and Geils 1976). By itself or in combination with other factors (Krauch 1930), mistletoe eventually kills the host and may lead to additional mortality by fire or bark beetles (a fifth effect, Kenaley and others 2006). But released of competition from the ponderosa pine, many other plant species thrive to create a different biotic community than one of pine only (a sixth effect). More than just reducing timber volume, mistletoe affects biodiversity, vegetation pattern, and ecosystem functions. Although individual trees can be killed or pruned, we've learned that eradication may be undesirable (Conklin 2000). We've learned how to model the effects of mistletoe on infected trees; we have yet to learn how to manage forest stands for optimizing the benefits of mistletoe to forest health.

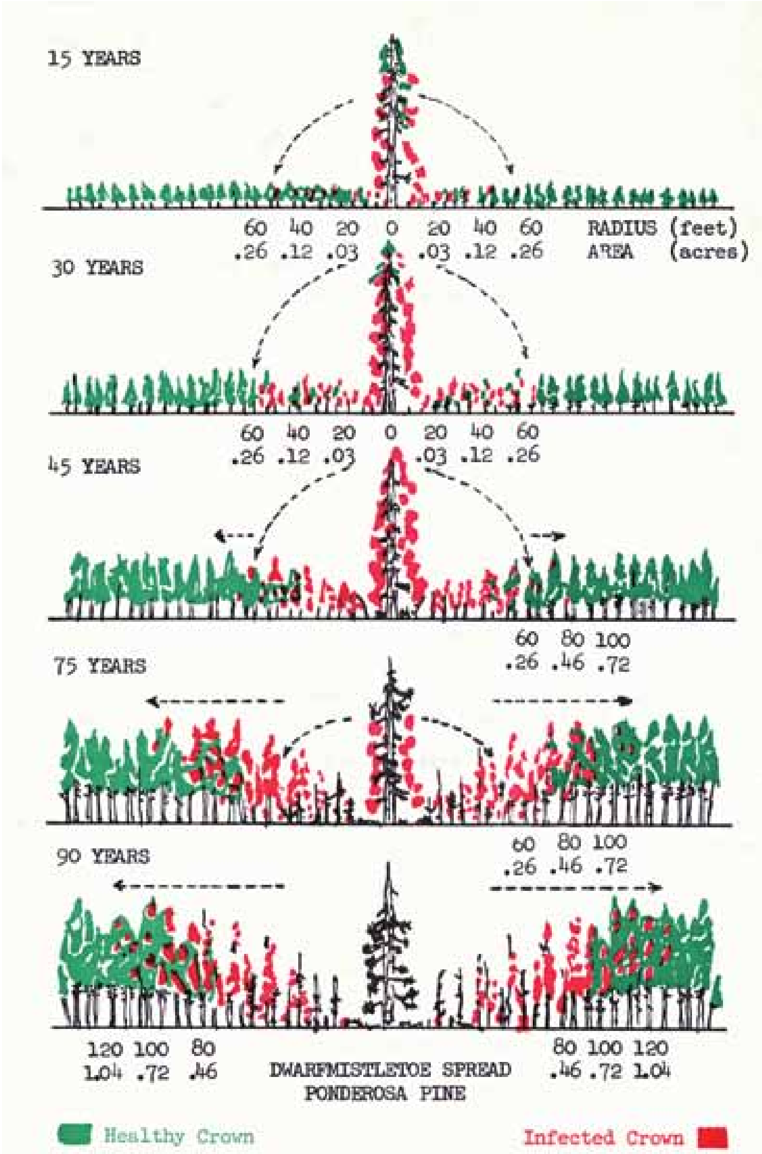

Figure 2. Spread of dwarf mistletoe as a phenomena of overstory to understory spread followed by expansion of the infestation. Reprinted from Hawksworth and Gill 1960.

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References

Alexander, M. E.; Hawksworth, F. G. 1975. Wildland fires and dwarf mistletoes: a literature review of ecology and prescribed burning. Gen. Tech. Rep. RM-14. Fort Collins, CO: U.S. Department of Agriculture, Rocky Mountain Forest and Range Experiment Station. 12 p.

Andrews, S. R. 1957. Forest disease research at Albuquerque Forest Insect and Disease Laboratory. May 1, 1957. Problem analysis. Albuquerque, New Mexico: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 94 p. Unpub. Pap. on file at Flagstaff, AZ: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Forest Pathology archives.

Andrews, S. R.; Daniels, J. P. 1960. A survey of dwarfmistletoes in Arizona and New Mexico. Sta. Pap. 49. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 17 p.

Andrews, S. R.; Gill, L. S. 1943. Western red rot in immature ponderosa pine in the Southwest. Journal of Forestry. 41(8):565–573.

Bickford, C. P.; Kolb, T. E.; Geils, B. W. 2005. Host physiological condition regulates parasitic plant performance: *Arceuthobium vaginatum* subsp. *cryptopodum* on *Pinus ponderosa*. Oecologia. 146(2):179–189. [Online]. doi: 10.1007/s00442-005-0215-0

Burrall, H. D. 1910. Report on measurements taken on western yellow pine to ascertain the effects of mistletoe on its growth. Typed report. Albuquerque, NM: U.S. Department of Agriculture, Forest Service, Coconino National Forest and Albuquerque Lab. 50 p. Unpub. Pap. on file at Flagstaff, AZ: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Valley Experimental Forest archives.

Chapel, W. L. 1942. Unmerchantability in second cut ponderosa pine. Journal of Forestry. 40(1):45–48.

Clancy, K. M. 2002. Mechanisms of resistance in trees to defoliators. In: Wagner, M. R.; Clancy, K. M; Lieutier, F.; Paine, T. D., eds. Mechanisms and deployment of resistance in trees to insects. Dordrecht, the Netherlands: Kluwer Academic Publishers: 79–103.

Combes, C. 1996. Parasites, biodiversity and ecosystem stability. Biodiversity and Conservation. 5:953–962.

Conklin, D. A. 2000. Dwarf mistletoe management and forest health in the Southwest. Albuquerque, NM: U.S. Department of Agriculture, Forest Service, Southwest Region. 30 p. [Online]. Available: http://www.fs.fed.us/r3/publications/documents/dwarfmistletoe.pdf

Conklin, D. A.; Geils, B. W. 2008. Survival and sanitation of dwarf mistletoe-infested ponderosa pine following prescribed underburning. Western Journal of Applied Forestry. [accepted August 7, 2007].

Covington, W. W.; Fulé, P. Z.; Moore, M. M.; Hart, S. C.; Kolb, T. E.; Mast, J. N.; Sackett, S. S.; Wagner, M. R. 1997. Restoring ecosystem health in ponderosa pine forests of the Southwest. Journal of Forestry. 95(4):23–29.

Dahms, C. W.; Geils, B. W., tech. eds. 1997. An assessment of forest ecosystem health in the Southwest. Gen. Tech. Rep. RM-GTR-295. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 97 p. [Online]. Available: http://www.rms.nau.edu/publications/rm_gtr_295/

DeGomez, T.; Young, D. 2002. Pine bark beetles. AZ1300. Tucson, AZ: University of Arizona, Cooperative Extension. 3 p. [Online]. Available: http://www.ag.arizona.edu/pubs/natresources/az1300.pdf

Dixon, G. E., comp. 2002. Essential FVS: a user's guide to the Forest Vegetation Simulator. (Revision January, 2006). Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Forest Management Service Center. [Online]. Available: http://www.fs.fed.us/fmsc/ftp/fvs/docs/gtr/Essent

Dixon, G. E.; Hawksworth, F. G. 1979. A spread and intensification model for southwestern dwarf mistletoe in ponderosa pine. Forest Science. 24(1):43–52.

Edminster, C. B. 1978. Development of growth and yield models for dwarf mistletoe-infested stands. *In:* Scharpf, R. F.; Parmeter, J. R., Jr., tech. coords. Symposium on Dwarf Mistletoe Control through Forest Management. 1978 April 11–13; Berkeley, CA. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station: 172–177.

Edminster, C. B.; Mowrer, H. T.; Mathiasen, R. L.; Schuler, T. M.; Olsen, W. K.; Hawksworth, F. G. 1991. GENGYM: A variable density stand table projection system calibrated for mixed conifer and ponderosa pine stands in the Southwest. Res. Pap. RM-297. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 32 p.

Egan, J. E. 1954. Silvicultural foundations for National Forest cutting practice in the ponderosa pine stands of the Southwest. Journal of Forestry. 52(10):756–766.

Ellis, D. E. 1939. Conifer diseases hitherto unreported from the Southwest. Plant Disease Reporter. 23(21):341.

Fairweather, M. L.; McMillin, J.; Rogers, T.; Conklin, D. A.; Fitzgibbon, B. 2006. Field guide to insects and diseases of Arizona and New Mexico. MR-R3-16-3. Albuquerque, NM: U.S. Department of Agriculture, Forest Service, Southwestern Region. 271 p. [Online]. Available: http://www.fs.fed.us/r3/resources/health.

Gaines, E. M.; Shaw, E. W. 1958. Half a century of research, Fort Valley Experimental Forest 1908–1958. Sta. Pap. RM-38. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 17 p.

Geils, B. W.; Cibrian Tovar, J.; Moody, B., tech coords. 2002. Mistletoes of North American conifers. Gen. Tech. Rep. RMRS-GTR-98. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 123 p. [Online]. Available: http://www.fs.fed.us/rm/pubs/rmrs_gtr098.pdf

Geils, B. W.; Hawksworth, F. G.; Janssen, J. E. 1991. Longevity of ponderosa pine parasitized by southwestern dwarf mistletoe. Bulletin of the Ecological Society of America. 72 (Suppl 2): 122.

Geils, B. W.; Lundquist, J. E.; Negron, J. F.; Beatty, J. S. 1995. Disturbance regimes and their relationships to forest health. In: Eskew, L. G., comp.; Forest health through silviculture: Proceedings of the 1995 National Silviculture Workshop; 1995 May 8–11; Mescalero, NM. Gen. Tech. Rep. RM-GTR-267. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 67–72. [Online]. Available: http://www.fs.fed.us/rm/pubs_rm/rm_gtr267/rm_gtr267_067_073.pdf

Gilbertson, R. L. 1974. Fungi that decay ponderosa pine. Tucson, AZ: University of Arizona Press. 197 p.

Gilbertson, R. L. 1985. Comandra blister rust on Mondell pine in Arizona. Arizona Plant Pathology. Tucson, AZ: University of Arizona, Cooperative Extension Service. 3 p.

Gill, L. S. 1940. Activities of Albuquerque Branch, Division of Forest Pathology, March 8, 1939 to February 26, 1940. February 16, 1940. Annual report for 1940. Albuquerque, NM: U.S. Department of Agriculture, Division of Forest Pathology. 33 p. Unpub. Pap. on file at Flagstaff, AZ: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Forest Pathology archives.

Gill, L. S. 1960. Principles and practice of dwarfmistletoe control. 7th Western International Forest Disease Work Conference. 1959 December 1–4; Pullman, WA: 94–98.

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

Gunderson, L. H.; Holling, C. S., eds. 2002. Panarchy, Understanding transformations in human and natural systems. Washington, DC: Island Press. 507 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 management of southwestern natural resources; 1988 November 15–17; Tucson, AZ. Gen. Tech. Rep. RM-191. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 234–240.

Hatfield, I. J. 1933. The establishment of an experimental control plots at the Fort Valley Experimental Forest, Flagstaff, Arizona. September 29, 1933. Mimeographed report. Albuquerque, NM: U.S. Department of Agriculture, Forest Service. 17 p. Unpub. Pap. on file at Flagstaff, AZ: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Valley Experimental Forest archives.

Hawksworth, F. G. 1953. The pycnial stage of *Cronartium filamentosum*. Plant Disease Reporter. 37(4): 246.

Hawksworth, F. G. 1959. Distribution of dwarfmistletoes in relation to topography on the Mescalero Apache Reservation, New Mexico. Journal of Forestry. 57(12): 919–922.

Hawksworth, F. G. 1961. Dwarfmistletoe of ponderosa pine in the Southwest. Tech. Bull. 1246. Washington, DC: U.S. Department of Agriculture, Forest Service. 112 p.

Hawksworth, F. G. 1973. On a new power source. Journal of Irreproducible Results. 20(1): 20.

Hawksworth, F. G. 1977. The 6-class dwarf mistletoe rating system. Gen. Tech. Rep. RM-48. Fort Collin, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 7 p.

Hawksworth, F. G.; Geils, B. W. 1985. Vertical spread of dwarf mistletoe in thinned ponderosa pine in Arizona. Res. Note RM-460. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 3 p.

Hawksworth, F. G.; Geils, B. W. 1976. Biotic associates. In: Hawksworth, F. G.; Wiens, D. Dwarf mistletoes: Biology, pathology, and systematics. Agric. Handbk. 709. Washington, DC: U.S. Department of Agriculture, Forest Service: 73–89. [Online]. Available: http://www.rmrs.nau.edu/publications/ah_709/

Hawksworth, F. G.; Gill, L. S. 1960. Rate of spread of dwarfmistletoe in ponderosa pine in the Southwest. Res. Note RM-42. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 2 p.

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

Hawksworth, F. G.; Shaw, C. G., III; Tkacz, B. M. 1989. Damage and control of diseases of southwest ponderosa pine. In: Tecle, A.; Covington, W. W.; Hamre, R. H., tech. coords.; Multiresource Management of Ponderosa Pine Forests; 1989 November 14–16; Flagstaff, AZ. Gen. Tech. Rep. RM–185. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 116–129.

Heidmann, L. J. 1968. Silvicultural control of dwarf mistletoe in heavily infected stands of ponderosa pine in the Southwest. Res. Pap. RM-36. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 11 p.

Heidmann, L. J. 1983. Silvicultural control of dwarf mistletoe in southwestern ponderosa pine. Res. Note RM-433. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 4 p.

Herman, F. R. 1951. Hockderfer [sic] aspen reproduction study. November 30, 1951. Establishment report. 3 p. Unpub. Pap. on file at Flagstaff, AZ: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Forest Pathology archives.

Herman, F. R. 1961. Silvicultural control of dwarfmistletoe on southwestern ponderosa pine. Sta. Pap. 62. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 20 p.

Hinds, T. E. 1985. Diseases. Aspen: Ecology and management in the western United States. Gen. Tech. Rep. RM-119. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 87–106.

Hornibrook, E. M. 1936. The effectiveness of partial bark peeling in the control of *Ips*. Journal of Forestry. 34(6): 620–622.

Jameson, D. A. 1994. Continuous and discontinuous change in a southwestern woodland. In: Covington W. S.; DeBano L. F.; Sustainable ecological systems: Implementing an ecological approach to land management; 1993 July 12–15; Flagstaff, AZ. Gen. Tech. Rep. RM-247. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 137–142.

Kenaley, S. C.; Mathiasen, R. L.; Daugherty, C. M. 2006. Selection of dwarf mistletoe-infected ponderosa pines by *Ips* species (Coleoptera: Scolytidae) in northern Arizona. Western North American Naturalist. 66(3): 279–284.

Kolb, T. E.; Wagner, M. R.; Covington, W. W. 1994. Concepts of forest health: Utilitarian and ecosystem perspectives. Journal of Forestry. 92(7): 10–15.

Korstian, C. F.; Long, W. H. 1922. The western yellow pine mistletoe, Effect on growth and suggestions for control. Bull. 1112. Washington, DC: U.S. Department of Agriculture. 35 p.

Krauch, H. 1930. Mortality in cut-over stands of western yellow pine in the Southwest. Journal of Forestry. 28(12): 1085–1097.

Krauch, H. 1937. Growth and yield of cut-over stands of ponderosa pine in Arizona under different methods of cutting. Journal of Forestry. 35(12): 1134–1147.

Lang, D. M.; Stewart, S. S. 1909. Reconnaissance of the Kaibab National Forest. 37 p. Unpub. Pap. on file at Flagstaff, AZ: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Forest Pathology archives.

Lightle, P. C. 1967. Major disease problems and status of disease research in the southwestern United States. In: 15th Western International Forest Disease Work Conference. 1967 September 11–15. Santa Fe, NM: 7–11.

Lightle, P. C.; Hawksworth, F. G. 1973. Control of dwarf mistletoe in a heavily used ponderosa pine recreation forest, Grand Canyon, Arizona. RP-RM-106. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 22 p.

MacDougal, D. T. 1899. Seed dissemination and distribution of *Razoumofskya robusta* (Engelm.) Kuntze. Minnesota Botany Studies. 2 (12): 169–173.

Maffei, H. M.; Beatty, J. S. 1989. Changes in the incidence of dwarf mistletoe over 30 years in the Southwest. In: van der Kamp, B. J., comp. 36th Western International Forest Disease Work Conference. 1988 September 19–23. Park City, UT. Vancouver, BC: University of British Columbia: 88–90.

Mark, W. R.; Hawksworth, F. G. 1976. Distribution of ponderosa pine dwarf mistletoe (*Arceuthobium vaginatum* subsp. *cryptopodum*) in relation to climatic factors. In: 4th National Conference on Fire and Forest Meteorology. 1976 November 16–18; St. Louis, MO. Society of American Foresters and American Meteorological Society.

Martin, E. C. 1965. Growth and change in structure of an aspen stand after a harvest cutting. Res. Note RM-45. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 2 p.

Mathiasen, R. L.; Hawksworth, F. G. 1980. Taxonomy and effects of dwarf mistletoe on bristlecone pine on the San Francisco Peaks, Arizona. Res. Pap. RM-224. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 10 p.

McMillin, J. D.; Wagner, M.R. 1998. Influence of host plant versus natural enemies on the spatial distribution of a pine sawfly, *Neodiprion autumnalis* (Hymenoptera: Diprionidea). Ecological Entomology. 23(4): 397–408.

Meagher, G. S.; Herman, F. R. 1951. Working plan for study of management of ponderosa pine stands heavily infected with mistletoe. February 7, 1951. Study plan. Tucson, AZ: Southwestern Forest and Range Experiment Station. 37 p. Unpub. Pap. on file at Flagstaff, AZ: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Forest Pathology archives.

Moir, W. H.; Geils, B. W.; Benoit, M. A.; Scurlock, D. 1997. Ecology of southwestern ponderosa pine forests. In: Block, W. M.; Finch, D. M. Songbird ecology in southwestern ponderosa pine forests: a literature review. Gen. Tech. Rep. RM-GTR-292. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 3–27. [Online]. Available: http://www.fs.fed.us/rm/pubs_rm/rm_gtr292/rm_gtr292_003_027.pdf

Myers, C. A.; Hawksworth, F. G.; Lightle, P. C. 1972. Simulating yields of southwestern ponderosa pine stands, including effects of dwarf mistletoe. Res. Pap. RM-87. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 16 p.

Myers, C. A.; Martin, E. C. 1963. Mortality of southwestern ponderosa pine sawtimber after second partial harvest. Journal of Forestry. 61(2): 128–130.

Pearson, G. A. 1918. Studies of yield and reproduction of western yellow pine in Arizona and New Mexico. Journal of Forestry. 16(3): 273–293.

Pearson, G. A. 1933. A twenty-year record of changes in an Arizona pine forest. Ecology. 14(3): 272–285.

Pearson, G. A. 1938. Lighter cuts and larger yields in ponderosa pine. Journal of Forestry. 36(8): 779–789.

Pearson, G. A. 1939. Mortality in cutover stands of ponderosa pine. Journal of Forestry. 37(5): 383–387.

Pearson, G. A. 1940. Growth and mortality of ponderosa pine in relation to size of trees and method of cutting. Journal of Forestry. 38(4): 323–327.

Pearson, G. A. 1943. How local is silviculture? Journal of Forestry. 41(12): 917–919.

Pearson, G. A. 1944a. Growth, mortality, and cutting cycles in New Mexico ponderosa pine. Journal of Forestry. 42(12): 901–905.

Pearson, G. A. 1944b. Applied genetics in forestry. Scientific Monthly. 58: 444–453.

Pearson, G. A. 1946. Ponderosa pine in the second cutting cycle. Journal of Forestry. 44(5): 354–368.

Pearson, G. A.; Wadsworth, F. H. 1941. An example of timber management in the Southwest. Journal of Forestry. 39(5): 434–452.

Richardson, D. M.; Pysek, P.; Rejmanek, M.; Barbour, M. G.; Panetta, F. D.; West, C. J. 2000. Naturalization and invasion of alien plants: Concepts and definitions. Diversity and Distributions. 6(2): 93–107. [Online]. doi: 10.1046/j.1472-4642.2000.00083.x

Robinson, D. C. E.; Geils, B. W. 2006. Modelling dwarf mistletoe at three scales: life history, ballistics and contagion. Ecological Modelling. 119:23–38. [Online]. doi:10.1016/j.ecolmodel.2006.06.007

Rolf, J. A. 2001. Aspen fencing in northern Arizona: A 15-year perspective. In: Shepperd, W. D.; Binkley, D.; Bartos, D. L.; Stohlgren, T. J.; Eskew, L. G., comps.; Sustaining aspen in western landscapes; 2000 June 13–15; Grand Junction, CO. Proceedings RMRS-P-18. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 193–196. [Online]. http://www.fs.fed.us/rm/pubs/rmrs_p018/rmrs_p018_193_196.pdf

Schubert, G. H. 1974. Silviculture of southwestern ponderosa pine: the status of our knowledge. Res. Pap. RM-123. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 71 p.

Shepperd, W. D.; Fairweather, M. L. 1994. Impact of large ungulates in restoration of aspen communities in a southwestern ponderosa pine ecosystem. In: Covington W. S.; DeBano L. F. Sustainable ecological systems: Implementing an ecological approach to land management. 1993 July 12–15. Flagstaff, AZ. Gen. Tech. Rep. RM-247. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 344–347.

Stage, A. R. 1973. Prognosis model for stand development. Res. Pap. INT-137. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 32 p.

Vincent, P. Y. 1935. *Ips* (*Tomicus*) *confusus* and the effect of stripping on pole stands after a thinning and improvement cutting in ponderosa pine. 6 p. Unpub. Pap. on file at Flagstaff, AZ: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Valley Experimental Forest archives.

Vogler, D. R.; Bruns, T. D. 1998. Phylogenetic relationships among the pine stem rust fungi (*Cronartium* and *Peridermium* spp.). Mycologia. 90(2): 244–257. [Online]. Available: http://www.jstor.org/stable/3761300

Wadsworth, F. H. 1939. Control of *Ips* beetles by the trap tree method. 13 p. Unpub. Pap. on file at Flagstaff, AZ: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Valley Experimental Forest archives.

Wagner, M. R.; Mathiasen, R. L. 1985. Dwarf mistletoe–pandora moth interaction and its contribution to ponderosa pine mortality in Arizona. Great Basin Naturalist. 45(3): 423–426.

Wood, R. E. 1983. Mortality caused by root diseases and associated pests on six national forests in Arizona and New Mexico. Rep. R3 83-13. Albuquerque, NM: U.S. Department of Agriculture, Forest Service, Southwestern Region. 31 p.

Woolsey, T. S., Jr. 1911. Western yellow pine in Arizona and New Mexico. Bull. 101. Washington, DC: U.S. Department of Agriculture, Forest Service. 64 p.

Appendix

A timeline for selected events in the history of forest pathology and entomology related to research associated with the Fort Valley Experimental Forest.

1908–1917, G.G. Hedgcock makes nearly annual pathology collecting trips to the West; these specimens become the core of the USFS Forest Pathology–Fort Collins herbarium.

1910, U.S. Forest Service and Bureau of Plant Industry agree to cooperate on forest pathology research; this collaboration continues until 1954 when the Division of Forest Pathology is incorporated into Forest Service research organization.

1910, H.D. Burrall reports measurements taken on western yellow pine to ascertain the effects of mistletoe on host growth.

1910, D.M. Lang and S.S. Stewart survey north Kaibab forest and observe 'mistletoe quit prominent…but insect infestation [bark beetles] has attained enormous proportions of scattered trees or whole acres'.

1911, W.H. Long is assigned as first regional pathologist and stationed in Albuquerque.

1911, T.S. Woolsey claims dwarf mistletoe is a serious menace to ponderosa pine and report large areas occur on Coconino and Tusayan Forests with over 60% of trees infected.

1912, G.A. Pearson reports seed from mistletoe-infected ponderosa pine had 17% lower germination.

1914, T.S. Woolsey advocates shelterwood cutting even within infested areas and removal of only those infected trees expected to die soon.

1917, E.P. Meineke observes that American forestry is in transition for virgin to regulated forests and proposes that purpose of forestry is good economic utilization and that sanitation and hygiene are required to achieve that end.

1918, G.A. Pearson regrets that in previous cutting, mistletoe was not given sufficient attention and now advocates greater discrimination of heavily infected trees.

1922, W.J. Perry admits pruning and cutting could decrease mistletoe but questions if it can be economically justified.

1922, C.F. Korstian and W.H. Long issue a comprehensive report on southwestern dwarf mistletoe; they note effects on growth vary by severity of infection (for example, on heavily infected trees this is a 14% reduction in radial and 30% reduction in volume).

1923, G.A. Pearson advises cutting all heavily infected trees, leaving moderately diseased trees only where no other seed source present and recognizes several cleanings are necessary.

1923, W.J. Perry describes mistletoe distribution is more common on ridges and dry slopes, notes that dispersal is usually only 10 to 15 ft but occasionally farther if carried by birds; indicates control can be effected with repeated pruning; observes mistletoe is also often associated with red rot (to 20% loss) and that heavily infected trees may ultimately killed by bark beetles.

1925, E.P. Meineke reviews the history of forest pathology in America and states the primary interests are cull, sanitation (especially for mistletoe), disease interactions in stands ('not just concerned with sick trees'), impacts on productivity ('not dead tree count'), and a national forest disease survey.

1926/30, H. Krauch records pine losses due to mistletoe (50% of killed, especially larger trees), wind, suppression, and insects.

1930, E.E. Hubert places responsibility on foresters for keeping future timber stands 'healthy', that is 'producing a maximum rate of yield of sound timber.'

1933, G.A. Pearson in a 20-year summary of Plot S3 notes mistletoe is the most common mortality agent but that mistletoe is even more important for its impact on growth of young and middle-age trees.

1933, I.J. Hatfield establishes an experimental control plots at the Fort Valley.

1934, D.E. McHenry questions if mistletoe kills trees or just predisposes them to other agents.

1935, L.S. Gill revises mistletoe taxonomy.

1937, H. Krauch declares that on Plot S3, mistletoe accounts for more deaths and greater loss in volume that any other agent.

1938, D.E. Ellis studies ponderosa pine twig blight associated with scale insects, fungi, and climate.

1940, L.S. Gill describes several major projects at the Division of Forest Pathology, Albuquerque Lab as 1) twig blight (noticed in 1917 at Prescott, epidemic in 1933 epidemic at Prescott and several other valleys, determined to be a scale insect, severity varies over a irregular, several year period); 2) mistletoe (plots at Fort Valley and elsewhere); 3) pathological survey (needle cast on Douglas-fir, parasites of dwarf mistletoe, miscellaneous diseases, Armillaria root disease, herbarium), and 4) western red rot (survey finds decay is serious in young timber stands).

1940/1941, G.A. Pearson and F. Wadsworth provide update on Plot S3 where mistletoe has intensified and pine growth has declined on severely infected trees (amount varies); they write that trees with infections throughout crown maintained growth for a while but eventually declined and died.

1941, W.G. Thomson affirms that western red rot can cause from 70% to 80% of total defect and 20% to 30% of volume loss.

1942, L.S. Gill and S.R. Andrews warn mistletoe readily spreads to regeneration under infected overstory.

1942, W.L. Chapel and others report on the second cut at Fort Valley. They observe that un-merchantability totaled 10.8% compared to 25% to 50% in first cut and that 2.5% is due to miscellaneous causes including crooks, forks, mistletoe, porcupine damage, rough tops. They also note that mistletoe is mostly controlled except one block and that small crown trees can be release and produce.

1943, S.R. Andrews and L.S. Gill summarize the western red rot survey; they note decay is important in immature trees and conclude fungus enters thorough dead branches.

1944, G.A. Pearson (3 papers) summarizes conclusions from experiments at Fort Valley and operational harvests in New Mexico. He notes that in the Southwest, silviculture and protection different from other regions but that intensive management can still produce an economic return if a 20-year cutting cycle were employed.

1946, G.A. Pearson summarizes the 2nd cutting cycle at Fort Valley Plot S3 and observes that 'errors of the past now stand out clearly. Mistletoe control should have been more drastic'.

1949 and 1951, F.R. Herman begins an aspen study at Hart Prairie after partial cutting and installs fencing.

1949, F.G. Hawksworth develops a plan to study the effect of mistletoe on cone and seed production.

1950, C. Hartley divides forest pathology history into three stages: 1899–1912, primarily reconnaissance; 1912–1930, evaluation of damage with an emphasis on introduced epidemics and in the West on silviculture and diseases; and 1930–1950, continued work on introduced epidemics but with more effort on forest management and on deterioration of forest products.

1951, G.S. Meagher and F.R. Herman draft study plan for management of ponderosa pine stands heavily infected with dwarf mistletoe at Fort Valley Unit 1.

1952, Division of Forest Pathology identifies its major projects to include 1) mistletoe control in the Southwest, 2) western red rot–pruning, 3) limb rust survey, 4) sanitation and fertilization of aspen (North Rim), 5) mistletoe seed germination, and 6) trunk cankers of aspen.

1953, F.G. Hawksworth observes limb rust pycnial stage.

1954, L.S. Gill and F.G. Hawksworth study mistletoe incubation and dispersal; they note that most infected reproduction occurs within 60 feet of infected overstory trees.

1954, J.E. Egan writing on silviculture in Southwest suggests that with frequent selection cuts, losses from lightning, insects, blister rust, red rot, and mistletoe (except in extreme cases) can be held to a minimum.

1954, Rocky Mountain Forest and Range Experiment Station report states that mistletoe has little effect on ability of poles to accept decay retardants.

1955, F.G. Hawksworth and S.R. Andrews provide early results of Region 3 survey that has completed work in northern Arizona and Mescalero, NM; they find that 50% of stands have mistletoe and greater mortality occurs in heavily infested stands.

1956, S.R. Andrews warns that in spite of detailed, plot-level observation over many years, there remains a need for range-wide appraisal of mistletoe impacts before mistletoe control will be supported.

1956, F.G. Hawksworth reports on the Mescalero survey of ponderosa pine that 53% of stands are infested, losses are three times greater in cut-over stands than virgin stands, and a control program is in progress.

1957, S.R. Andrews drafts a problem analysis for Albuquerque Lab with a good review of the history and present situation. He describes the natural and social environment of the region and identifies chief forest disease problems as dwarf mistletoes; heart rots; rusts and foliage diseases; root rots; physiological, climatic, and environmental diseases.

1958, G.H. Hepting and G.M. Jameson provide a national timber resources review on forest protection, growth loss and mortality and note that diseases being persistent and ubiquitous have large impact.

1958, F.G. Hawksworth completes Ph.D. work, which serves as a basis for several 1961 papers.

1959, F.R. Larsen continues aspen study at Hart Prairie and reaffirms the need to protect aspen from browsing to get and keep good regeneration.

1960, S.R. Andrews and J.P. Daniels complete a Southwest-wide survey; they report 36% of ponderosa stands infested, mostly in virgin stands and ridges, increasing with elevation (Hawksworth finds most of infested stands at mid-elevations). They also report 47% of Douglas-fir is infested and mortality is several-folder greater within infested stands.

1960, F.G. Hawksworth and L.S. Gill diagram mistletoe spread and report spread averaged 1.2 feet per year in dense stands and 1.7 feet per year in open.

1961, F.G. Hawksworth and S.R. Andrews issue pruning guides that branches 1 inch in diameter can be effectively pruned if mistletoe shoots not closer than 6 inches from the bole and that for each 1-inch increase in diameter, the safe distance should be increased by 2 inches.

1961, F. Herman reviews silvicultural control of mistletoe based on work from Fort Valley.

1961, L.S. Gill and F.G. Hawksworth review of world literature on mistletoes.

1962, F.G. Hawksworth takes lead for west-wide studies on mistletoe taxonomy, hosts, and distribution and assembles mistletoe collection.

1963, C.A. Myers and E.C. Martin observe that at Plot S3, dwarf mistletoe caused 24.4% of tree mortality and 15.7 percent of the volume loss.

1965, F.G. Hawksworth studies mistletoe on bristlecone pine on San Francisco Peaks.

1965, F.G. Hawksworth and T.E. Hinds photograph mistletoe seed discharge.

1967, F.G. Hawksworth reviews a program for mistletoe research, history of dwarf mistletoe research in Rocky Mountain and Southwest Regions since 1910 and specifies what information is most needed to develop controls.

1967, P.C. Lightle and others describe re-cleaning at Mescalero.

1968, L.J. Heidmann writes on mistletoe control at Fort Valley that limited control appeared impractical but that silvicultural control of heavy infections required almost complete stand destruction and opened stands to serious risk of windthrow.

1972, C.E. Myers and others simulate yields of southwestern ponderosa pine stands, including effects of dwarf mistletoe (later, C.B. Edminster authors several papers continuing this series).

1973, P.C. Lightle and F.G. Hawksworth review program for control of dwarf mistletoe in a heavily used ponderosa pine recreation forest, Grand Canyon, Arizona.

1973, G.H. Schubert issues a silviculture review (additional reviews by other authors follow over several years).

1976, W.R. Mark and F.G. Hawksworth relate distribution of southwestern dwarf mistletoe to climate, as January and June temperature means and note absence of mistletoe where January temp <6 ºC.

1977, J.W. Walters and B.W. Geils demonstrate use of simulations to develop management plans for mistletoe-infested ponderosa pine.

1977, F.G. Hawksworth publishes the already well-established 6-class rating system for dwarf mistletoe severity.

1977, G.E. Dixon completes Ph.D. on a mistletoe spread using a regression modeling approach.

1980, R.L. Mathiasen and F.G. Hawksworth determine the mistletoe on bristlecone on San Francisco Peak is *A. microcarpum,* which is also found on spruce and rarely on white pine.

1983, L.J. Heidmann suggests that for mature, heavily infested stands of ponderosa the only effective silvicultural treatment is 1) eliminate the source of infection in the overstory by cutting,

2) remove infection in pole and sapling stands by cutting or pruning, 3) re-treat periodically and 4) regenerate if needed. Similar recommendations are made in 1984 by F. Ronco, G. Gottfried, and R. Alexander.

1985, F.G. Hawksworth and B.W. Geils observe vertical spread at an average of 10 cm/yr or 2/3 host height growth for 343 trees over 6 years at Fort Valley.

1985, T.E. Hinds reviews diseases of aspen.

1989, H.M. Maffei and J.S. Beatty speculate on causes for apparent, regional increase from the 1960 to 1980s survey. They suggest the increase from 30% to 38% may be due to single tree selection, incomplete or inappropriate prescriptions to control mistletoe, and lack of priorities for treating mistletoe infected stands.

1990, R.L. Mathiasen and others survey mistletoe on Douglas-fir. They note that volume growth reduction increases with mistletoe class: 3, 10%; class 4, 23%; class 5, 45%; and class 6, 65%. and that mortality in severely infested stands is three to four times that of healthy stands.

1990, M.G. Harrington and F.G. Hawksworth report reduction in dwarf mistletoe at Grand Canyon due to prescribed burning (first such research in the Southwest).

1991, C.B. Edminster and others release GENGYM with mistletoe effects (later incorporated into Forest Vegetation Simulator).

1992, R.T. Reynolds and others issue management guidelines for goshawk that considers mistletoe effects. They recognize there are some wildlife benefits from mistletoe but also caution that the pathogen over time has detrimental effect retarding or regressing stand stage to detriment of prey species.

1994, W.S. Allred and W.S. Gaud report that the Albert squirrel shows selective preference for certain trees and feeds upon mistletoe and within mistletoe-infected trees. But since selection was not correlated with physical appearance, conclude that removing diseased, deformed trees should not impact the squirrel.

1994, W.D. Sheppard and M.L. Fairweather indicate fencing to protect aspen for elk browsing is required to protect saplings and given the high animal numbers and grazing pressure, admonish that fencing must remain indefinitely.

1997, C.W. Dahms and B.W. Geils edit an assessment of forest ecosystem health in the Southwest.

1997, W.H. Moir and others review the ecology of ponderosa pine in Southwest.

2000, D.A. Conklin presents a history of dwarf mistletoe control in the Southwest, discusses ecological factors relevant to management and presents guidelines based on his review of research, management, and public involvement.

2001, J.A. Rolf writes more on fencing aspen to protect from elk browsing.

2005, C.P. Bickford and others conduct an experiment to assess how much host physiological condition may regulate parasitic plant performance.

2006, G.N. Garnett and others find Abert squirrel uses mistletoe brooms for caching, foraging, and nesting; they recommends retaining larger, broomed trees.

2006, D.E. Robinson and B.W. Geils construct and evaluate an epidemiology model for mistletoe spread.

2006, S.C. Kenaley and others conclude the probability of ponderosa pine mortality due to *Ips* is greater in stands severely infested with southwestern dwarf mistletoe.

2008, D.A. Conklin and B.W. Geils present results on effects of fire on dwarf mistletoe. Relatively uniform burns generating 50% average crown scorch set back mistletoe intensification by 10 years.