Proceedings of the

Symposium on Dwarf Mistletoe Control Through Forest Management

April 11-13, 1978, Berkeley, California

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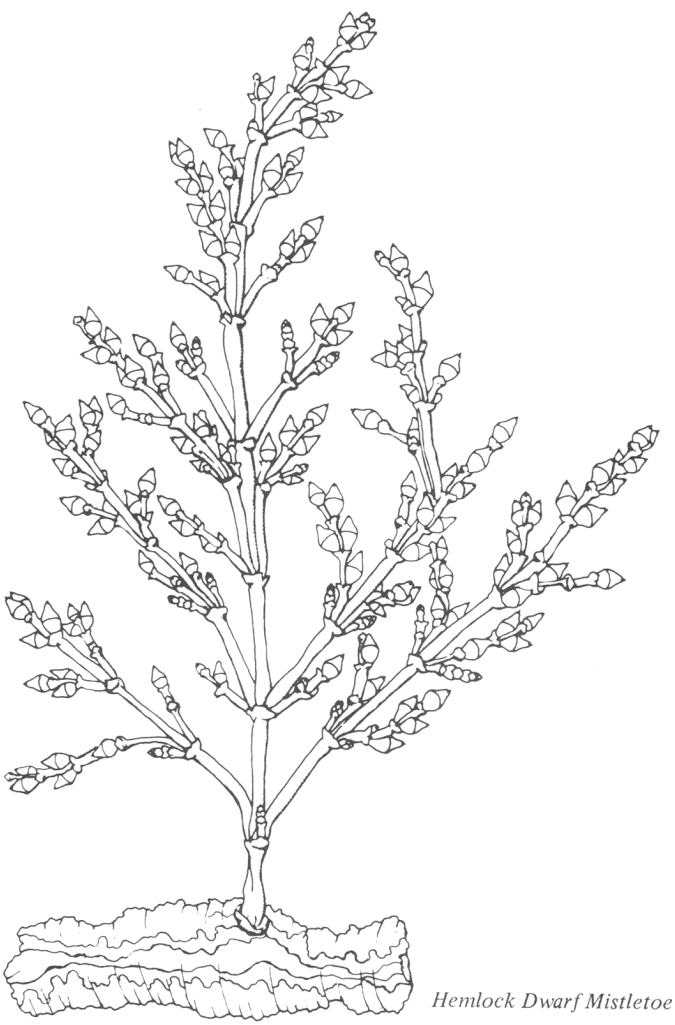

Hemlock Dwarf Mistletoe

GENERAL TECHNICAL
REPORT PSW-31

Proceedings of the Symposium on Dwarf Mistletoe Control Through Forest Management, April 11-13, 1978, Berkeley, California

Robert F. Scharpf John R. Parmeter, Jr.
Technical Coordinators

CONTENTS

	Page
Introduction	
Opening Remarks — *Robert F. Scharpf*	1
Overview of the Dwarf Mistletoe Problem — *James L. Stewart*	2
Bases for Control	
Biological Factors of Dwarf Mistletoe in Relation to Control — *Frank G. Hawksworth*	5
Forest Stand Dynamics and Ecological Factors in Relation to Dwarf Mistletoe Spread, Impact, and Control — *J. R. Parmeter, Jr.*	16
Control Planning and Decisionmaking	
Control Planning and Decisionmaking — *Wilfred L. Freeman, Jr.*	31
Survey Methods to Determine the Distribution and Intensity of Dwarf Mistletoes — *Oscar Dooling*	36
The Extent of Dwarf Mistletoe in Six Principal Softwoods in California, Oregon, and Washington, as Determined from Forest Survey Records — *Charles L. Bolsinger*	45
Approaches to Determining Volume Losses Due to Dwarf Mistletoe on a Westwide Basis — *David B. Drummond*	55
Impact Evaluation for Dwarf Mistletoe-Infested Ponderosa Pine in the Southwest — *James W. Walters*	62
Control Operations and Accomplishments	
Introduction to Dwarf Mistletoe Control — *Lewis F. Roth*	66
Genetic Control of Dwarf Mistletoe — *Lewis F. Roth*	69
Dwarf Mistletoe Management in the Pacific Northwest — *James S. Hadfield and Kenelm W. Russell*	73
Dwarf Mistletoe Control on the Rogue River National Forest in Oregon — *R. Duane Kingsley*	82
Intermediate Cuttings in Mistletoe-Infested Lodgepole Pine and Southwestern Ponderosa Pine Stands — *Frank G. Hawksworth*	86

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CONTENTS

Ecological Bases for Silvicultural Prescriptions for Control of Dwarf Mistletoe in Lodgepole Pine 93
Phil Guthrie
Dwarf Mistletoe Control in Residential Forests 100
John G. Laut
Dwarf Mistletoe Controls in British Columbia 106
G. A. Van Sickle and R. B. Smith
Evaluation and Success of Dwarf Mistletoe Control in California's East-Side Jeffrey Pine Type 113
Philip H. Intorf
Control of Dwarf Mistletoe on True Firs in the West 117
Robert F. Scharpf
Prescribed Fire–A Tool for the Control of Dwarf Mistletoe in Lodgepole Pine 124
S. J. Muraro
Loss Evaluations in Forest Recreation Areas 128
Richard S. Smith, Jr.

Refining and Improving Control Techniques

Cooperative Research and Management Efforts Leading to Better Control 132
Richard S. Smith, Jr.
Refinement and Quantification of Data for Regulating Dwarf Mistletoe Populations: An Ecosystems Approach 137
Ed F. Wicker
Improving Extension and Training Programs for Dwarf Mistletoe Control 143
Kenelm W. Russell
Biological and Chemical Control of Dwarf Mistletoe 151
Donald M. Knutson

Pest Damage and Integrated Control

Integrating Dwarf Mistletoe Control With Forest Management 156
William E. Waters
The Pest Damage Inventory in California 162
James W. Byler
Development of Growth and Yield Models for Dwarf Mistletoe-Infested Stands 172
Carleton B. Edminster

Program Summary

Needed Research and Development to Improve Dwarf Mistletoe Controls 178
J. R. Parmeter, Jr., F. G. Hawksworth, and R. F. Scharpf
Literature on the Dwarf Mistletoes: Damage and Control 180
F. G. Hawksworth and R. F. Scharpf

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These Symposium papers cover bases of control, control planning and decisionmaking, control operations and accomplishments, refining and improving control techniques, and pest damage and integrated control. A program summary and a list of literature references on the dwarf mistletoes are included.

Oxford: 412:442.1:176.1 *Arceuthobium campylopodum.*
Retrieval Terms: dwarf mistletoe; silvicultural control; disease control; control systems.

PREFACE

Dwarf mistletoes have long been recognized as among the most damaging diseases of conifers in western North America. Since the early 1900s, research and experimental management to control dwarf mistletoes have occupied the time of many workers in State, Provincial and Federal agencies of Canada and the United States. This effort has produced a voluminous literature and a fund of experience and observation of value to forest managers. Information, however, is scattered widely through the literature, stored in office archives, or carried in the heads of workers. In these forms, it is not always readily accessible or suitably organized for use by managers.

This Symposium, held in Berkeley, California, April 11-13, 1978, was designed to bring together current knowledge and experience in dwarf mistletoe control, with emphasis on forest management. The five sessions covered (a) the biological and silvicultural information on which control procedures are based; (b) the methods of collecting and applying information essential to control planning and decisionmaking; (c) the mechanics of control operations and assessment of accomplishments; (d) the needs for refining and improving control techniques; and (e) the integration of dwarf mistletoe control with other pest control and silvicultural requirements in stand management.

To speed up the publication of Symposium Proceedings, we decided to have each author assume full responsibility for submitting manuscripts in photoready format by the time the conference convened. The views expressed in each paper are those of the author and not necessarily those of the sponsoring organizations. Trade names are used solely for necessary information and do not imply endorsement by the sponsoring organizations.

We thank the many people who assisted in this Symposium. Julie Hart, Joan Green, Shirley Ramacher, and Johann and Nancy Bruhn helped in making local arrangements. Richard Clark, Marcia Wood, and illustrators from the Rocky Mountain Forest and Range Experiment Station and the Forest Service's Rocky Mountain and California Regions put together the visual aids. And finally we thank the speakers and panel moderators, who willingly gave their time and effort in the preparation and presentation of symposium papers, and the many participants whose questions and comments contributed much to the spirited discussion and exchange of ideas.

Robert F. Scharpf, Forest Service, U.S. Department of Agriculture
Co-chairman
J. R. Parmeter, Jr., University of California, Berkeley
Co-chairman
David B. Drummond, Forest Service, U.S. Department of Agriculture
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Arthur H. McCain, University of California, Berkeley
Local Arrangements Chairman

Speakers at the Symposium on Dwarf Mistletoe Control Through Forest Management held in Berkeley, California, April 11-13, 1978: **Front Row** *(Left to right):* Frank G. Hawksworth, Robert F. Scharpf, James S. Hadfield, Charles L. Bolsinger, Oscar J. Dooling, Donald M. Knutson, Kenelm W. Russell, James L. Stewart, David B. Drummond, James W. Walters. **Back Row** *(Left to right):* James W. Byler, J. R. Parmeter, Jr., Phil Guthrie, G. A. Van Sickle, Robert W. Harris, Carleton B. Edminster, R. Duane Kingsley, Richard S. Smith, Jr., Lewis F. Roth, John G. Laut, Wilfred L. Freeman, Jr., Philip H. Intorf, S. J. Muraro, Ed F. Wicker.

Introduction

OPENING REMARKS[1/]

Robert F. Scharpf[2/]

Ladies and gentlemen, welcome to Berkeley and to this first symposium on dwarf mistletoes, "Dwarf Mistletoe Control Through Forest Management." It gives me a great deal of pleasure to be here and to be a part of this program. As many of you already know, I have been involved in research aimed at the control of these parasitic plants for about two decades now, and it is a distinct honor and privilege for me to be co-chairing this symposium with my close friend and working colleague, Dr. J. R. Parmeter.

It gives me great pleasure to see the marvelous attendance we have received for this week's program. It shows to me that the forest manager and scientist, the teacher and administrator, or more simply put, the various people concerned with the management and well being of the forest are here to exchange knowledge and work in concert towards the solution of one of the West's most serious forest disease problems.

As the title of this symposium implies, the program is aimed at dwarf mistletoe control through forest management. This is not a research symposium on dwarf mistletoes--let me say again--this is not a research symposium on dwarf mistletoes; even though research scientists will play a prominent role in the program. This is a gathering not only of scientists but also of forest managers and practitioners who have valuable information, experience, and ideas to contribute to the topic of dwarf mistletoe control. I feel confident that they will take us further down the road towards a better understanding of these serious forest disease agents and how they can ultimately be brought under control.

For my final statement, let me point out that this is a symposium, which is a very special type of meeting. I think the term symposium as defined in Webster's Third New International Dictionary will describe what I judge will be the general tenor of this meeting. SYMPOSIUM: (1) "A drinking party; especially one following a banquet and providing music, singing and conversation, or a banquet or other social gathering at which there is a free interchange of ideas." (2) "A meeting at which several speakers deliver short addresses on related topics or on various aspects of the same topic or a collection of opinions on a subject especially one assembled and one published by a periodical."

Now I don't expect this group to adhere to the literal definition as just stated although I have a feeling, particularly among some of you I know quite well, that you won't deviate too far from at least one or two points of the before mentioned definition. What I do hope that you will keep in mind is that this symposium is to be an informal, open exchange of opinions, information, and ideas. We are not gathered here this week merely to receive information, but to share it.

[1/] Presented at the Symposium on Dwarf Mistletoe Control Through Forest Management, Berkeley, California, April 11-13, 1978.

[2/] Plant Pathologist, Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Berkeley, Calif.

OVERVIEW OF THE DWARF MISTLETOE PROBLEM[1/]

James L. Stewart[2/]

Abstract: Dwarf mistletoe is still the major disease problem in the Western United States. A simple approach to control based solely on pathology considerations is no longer compatible with the complexities of forest management. The development of simulated-yield models has been the most significant research during the past 15 years. This symposium is designed to present the most up-to-date knowledge and technology, and to indicate the needs for future research.

Why a symposium on dwarf mistletoe? Fifteen years ago, and much longer ago than that, when I started as a forest pathologist in Forest Pest Control, we knew how to control this pest. Research had provided the following information: Dwarf mistletoe was an obligate parasite, meaning that it could exist only on a living host. It was relatively host specific. Its spread into new stands was rapid near infected overstory trees but slow from tree to tree in an even-canopied stand. Mistletoe vigor improved when overdense stands were thinned, but from a practical standpoint, it was impossible to prune out 100 percent of the infections or otherwise completely sanitize an infested stand.

Based on this information the approach to control was quite simple: Infested stands at harvest were to be clearcut with complete destruction of residual whips. Younger infested stands could be thinned but only with complete discrimination against dwarf mistletoe, and the stocking was to be reduced just enough to improve tree growth but not stimulate the mistletoe. In mixed stands, those tree species that were immune or resistant to the dwarf mistletoe species were encouraged.

If we knew all these things that many years ago, why is there still so much confusion about how to deal with this pest. Why is dwarf mistletoe still the major disease problem in the West, causing an estimated annual loss of 3.2 billion board feet of timber? Why are we attending a symposium on dwarf mistletoe?

I think there are three main reasons:

One, the simplified approach to control is no longer compatible with the complexities of forest management. For example, in the past the approach was to clearcut large square or circular blocks and place sale boundaries in uninfested portions of adjacent stands or against natural barriers such as open fields or roads. In today's world, esthetics and other factors--not dwarf mistletoe--dictate location, shape, and size of clearcuts. If a pathologist recommended simply clearcutting today, the forest manager would likely come back and say, "I can't clearcut. Isn't there a way to satisfy both esthetics and reduction of mistletoe-caused impacts?"

Another example of increased complexities is the current role of economics in decision-making. Our approach to control was based primarily on silvicultural considerations. Now it is necessary to refine these considerations with economic evaluations. The forest manager must consider which treatment provides the best benefit-cost ratio. Should he thin a stand now or let it go until final harvest? To answer questions such as this, it is not enough to know that thinning will increase the vigor of dwarf mistletoe as well as tree vigor. The forest manager needs quantitative information on the interaction between increased tree growth and dwarf mistletoe intensification. Will the trees grow fast enough to compensate for the dwarf mistletoe impact and warrant the thinning investment?

Another situation might be this: A forester is faced with a mature infested stand and wants

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[1/] Presented at the Symposium on Dwarf Mistletoe Control Through Forest Management, Berkeley, Calif. April 11-13, 1978.

[2/] Director of Forest Insect and Disease Management Staff, State and Private Forestry, Forest Service, U.S. Dep. Agric., Washington, D.C.

to harvest it. Given the species and the site, he knows he can achieve natural regeneration at much less cost than for clearcutting and planting. Fifteen years ago, pathologists would have said "no" to natural regeneration because the new trees would become infected from the overstory. I think most of us still say that regeneration in the absence of any infected overstory is best. But economics now force the question of how long can infected seed trees be left before significant infection of the new trees occurs. Maybe natural regeneration with the chance of some dwarf mistletoe is more cost-effective in the long run than artificial regeneration and the assurance of no dwarf mistletoe.

The second major reason we are attending a dwarf mistletoe symposium is that over the past 15 years, spurred on by the need for refined information, research has produced significant new information and technology. The main purpose of this symposium is to present this new information to you. I want to highlight a few items. From a dwarf mistletoe standpoint, the most significant research over the past 15 years has been the progress in quantifying spread and intensification in managed stands, correlating levels of infection with growth impact, developing simulated stand yield programs, and incorporating mistletoe intensification and impact information into these simulations. The result is a simulated yield program or model for dwarf mistletoe infested stands. More research is needed to develop these models for additional host-parasite combinations and refine those now in existence. However, at least for ponderosa pine in the Southwest and lodgepole pine in the Central Rockies, the forest manager can use these computerized simulated-yield programs to compare the effects of dwarf mistletoe in a given stand under various management schemes. He can determine which scheme, varying from doing nothing to clearcutting and planting, will maximize yields and benefits or provide the best benefit-cost.

I am excited about this approach to pest management decisionmaking because it provides us with the needed tool to deal with the complexities in forest management in today's world. Dwarf mistletoe research personnel can be proud of this development. It is the outstanding operational example in pest management of a decisionmaking tool that integrates stand growth dynamics and pest population dynamics and impacts.

So the second major reason we are here is to receive an updating on new technology and control techniques, and maybe more importantly in evaluation and decisionmaking techniques.

The third reason we are here is because the job of transferring technology from the researcher to the user has not been receiving sufficient emphasis. Training forest managers in the rationale for dwarf mistletoe control and the technology for accomplishing it must be accelerated and this symposium is the beginning.

I would like to quote from a paper Duane Kingsley, whom you will hear later, presented to the Western International Forest Disease Work Conference in September 1976. Duane was talking about getting research into practice and he says, "I believe you will find the progress is more a crawl than a stampede and it will remain so until we can answer the following questions: Where should I do something and what is it that needs to be done? Why should it be done? What can I expect to happen if it doesn't get done? Where should I do nothing? Why?"

What I find disappointing is that we know the answers to these types of questions for many situations and have the technology to help the manager; we just haven't got the job done.

Duane goes on to say, "The managing forester needs to know the basic facts and how to design his own treatment prescription for each stand. With a few exceptions, I believe there are sufficient technical data on dwarf mistletoe for anyone who wants to dig them out. But there is a decided lack of state-of-the-art, practical guidelines on what to do about the problem. Salesmanship! Where is the pamphlet that I can hand to the District Ranger that tells him how to size up the problem, how to solve it and what will happen if he doesn't? Where is the group training package, the slide tape program, or self training aid designed for a group or a new forester to bring their skill level up to standard?"

So we are having this symposium because many of the simplistic approaches are now out of date with today's complex forest management, research has provided new information and new technology, and a symposium is a good way to start an accelerated effort to transfer this knowledge to you. But I would like to add that a symposium is only the beginning. You as forest managers are responsible for managing the forests under your jurisdiction in the most efficient and productive manner that you can, commensurate with your prescribed management objectives. This requires that you learn and apply new knowledge and technology as it becomes applicable to your situation. Research pathologists are responsible for providing new information and technology. Pest control specialists are responsible for training you in this new technology and helping you to apply it. But you and only you can actually apply new knowledge.

During this symposium you will be presented with the most up-to-date knowledge and technology, on the basis for control including biological factors of the parasite and forest stand dynamics, on decisionmaking, and on control planning and operations. There will be discussions on recent research and development activities in refining and improving control techniques, and finally on approaches to integrating dwarf mistletoe control into forest management. We expect this symposium to be followed by training sessions and updated guidelines for the control of dwarf mistletoe. Certainly there will be a continuing need for bringing you up to date as research aimed at your specific needs is accomplished. However I want to again stress one critical point. Symposiums, training sessions, and guidelines--although important--will not accomplish the reduction of dwarf mistletoe impacts on management objectives. Only the forest manager's application of the available technology can accomplish that.

The final topic in this symposium is "Needs for Further Research." I talked about the forest manager's obligation in applying new technology. He also has an obligation to identify and communicate his research needs. Unless he does this, there is no way we can have a viable, problem-solving research program designed to fill specific information gaps. This communication from the user to the researcher is especially critical in these times when funds for pathology research are few. If research administrators are to direct what few dollars there are to solving specific high-priority management problems, the forest manager must tell them what the specific problems are.

I think it is necessary for each of us to reflect every so often on what we may refer to as the total technology transfer system. In the case of dwarf mistletoe this involves the researcher, the pest management specialist, and the forest manager. If any one of these individuals does not do his part, the job does not get done. If the forest manager does not identify and communicate his research needs, then the researcher does not work on those needs. If the researcher is not responsive to the forest manager's needs, then the specific new knowledge is not provided. If the pest control specialist does not train and assist the forest manager, the new knowledge does not get transferred to the user, and if the forest manager does not apply the new knowledge, then the whole thing has been for naught and no improvements are made.

I hope each of you will keep this in mind during the symposium. Let your mental process dwell on practical situations and try to think through how you would handle them and apply what you are learning. If you come up against a question, let the question be known so that it can be answered or listed as a research need.

I look forward to these three days. Let us each learn and then go home and apply what we have learned.

Bases for Control

BIOLOGICAL FACTORS OF DWARF MISTLETOE IN RELATION TO CONTROL[1/]

Frank G. Hawksworth[2/]

Abstract: Dwarf mistletoes have been present in North American coniferous forests for essentially as long as their hosts. Most of the world's dwarf mistletoes occur in North America where they attack all six genera of the Pinaceae: Pinus, Picea, Abies, Larix, Tsuga, and Pseudotsuga. Dwarf mistletoes have many effects including: growth loss, mortality, reduction in seed crops, lowered wood quality, predisposition of infected trees to insects and fungi, and ecologic effects. Features that make the dwarf mistletoes amenable to silvicultural control measures are: they are obligate parasites so will live only as long as the host does; they are generally host specific; they have long life cycles, frequently 4 to 6 years; the rate of spread through stands is slow, generally on the order of 1 to 2 feet per year; and they are readily detected as they are non-microscopic organisms and cause distinctive symptoms.

INTRODUCTION

Dick Parmeter and I have been asked to help "set the stage" for this symposium by outlining some basics of dwarf mistletoe biology, stand dynamics, and ecological factors relating to control. I'll discuss the following items relating to biology and let Dick tackle the difficult topics of stand dynamics and ecological factors.

History
The genus Arceuthobium
Host relationships
Dwarf mistletoe effects
Dwarf mistletoe life cycles
Bases for control

[1/] Presented at Symposium on Dwarf Mistletoe Control through Forest Management, Berkeley, Calif. April 11-13, 1978.

[2/] Supervisory Forest Pathologist, Rocky Mountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Fort Collins, Colo.

HISTORY

The dwarf mistletoes are no newcomers to North America. We know from fossil evidence that these parasites have been here at least since the Miocene period, or about 25 million years. They presumably migrated across the Bering area from eastern Asia, along with their coniferous hosts. Thus, the dwarf mistletoes and Western conifers have co-evolved over the millenia. We must keep this in mind when we tend to regard mistletoes and other "pests" as something foreign to, and not an integral part of, forest ecosystems (Hawksworth 1975).

The earliest written record of dwarf mistletoe that I have found is from southern Europe (Clusius 1601). The first North American collection was by the famous explorer and naturalist Alexander von Humbolt, in Veracruz, Mexico, in 1804. David Douglas, the botanical explorer, was apparently the first to discover dwarf mistletoes in what is now the United States (Douglas 1914). In 1826 he found two dwarf mistletoes in eastern Washington, which we can now determine were Arceuthobium americanum on lodgepole pine, and A. campylopodum on ponderosa

pine (although he thought the latter was red pine).

Several early western botanists in the 1850's collected dwarf mistletoes which were sent to Dr. George Engelmann of the Missouri Botanical Garden, who described most of the species in the West. Dr. James R. Wier, pioneer forest pathologist in the Inland Empire from 1910 to 1923, was the first to point out the seriousness of the dwarf mistletoe problem in the coniferous forests of the West. Recognition of them as a serious problem in the West, however, was slow to develop. It took several early western Forest Pathologists--notably Lake S. Gill (who prepared a dwarf mistletoe monograph (Gill 1935)), Toby Childs, Willis W. Wagener, and J. S. Boyce--to bring about this awareness. These missionary pathologists helped show that not only were these parasites causing severe losses in the West, but more importantly, that the dwarf mistletoes could be controlled by silvicultural means. They, in fact, helped build the strong foundation on which this symposium was constructed.

THE GENUS ARCEUTHOBIUM

The dwarf mistletoes are unique as the only group of parasitic higher plants confined to conifers. They occur on conifer branches or stems, and their endophytic (or root) system is embedded in bark and wood tissues of the host (fig. 1).

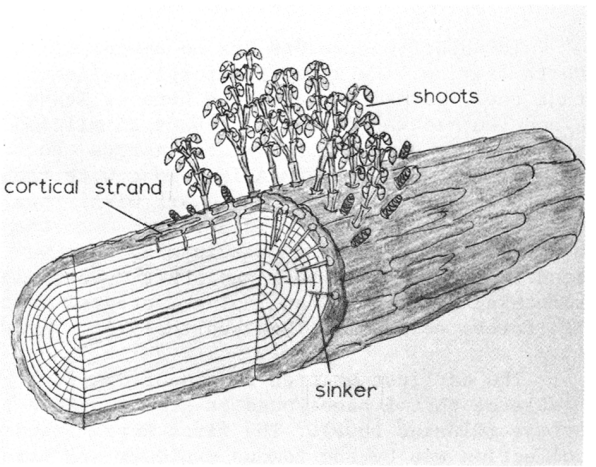

Figure 1--Dwarf mistletoe in a pine stem--showing shoots, cortical strands and sinkers.

The aerial parts of the dwarf mistletoe (the shoots) are essentially reproductive structures. The shoots range from as small as 1/4 inch high in Arceuthobium minutissimum of the Himalayas to as high as nearly 3 feet for A. globosum in Guatemala, but most species have shoots from 3 to 5 inches high. Dwarf mistletoe color ranges from black to red, purple, green, gray, brown, to yellow (Hawksworth and Wiens 1973). The root system consists of two main parts: (1) the cortical strands which occur primarily longitudinally in the inner bark, and (2) the sinkers, which extend from the cortical strands radially into ray tissues of the host xylem. The sinkers, which become imbedded in the xylem as the host tissues grow around them, provide the mechanism for water conduction from host to parasite tissues (Kuijt 1960).

The dwarf mistletoes contain chlorophyll so they can manufacture some of their carbohydrates, but they obtain most of their carbohydrates and all of their water and minerals directly from the host. In contrast to most mistletoes, carbohydrates manufactured by dwarf mistletoes are not translocated to the host (Leonard and Hull 1965).

Arceuthobium, the only genus that occurs in the eastern and western hemispheres, comprises some 31 known species. A few of these have recognizable subspecies on host forms so the grand total is now 38 dwarf mistletoes (table 1). This is six more than we knew of when we published our monograph 6 years ago (Hawksworth and Wiens 1972).

North America has the "lion's share" of the world's dwarf mistletoes--32 of the known 38. Most of these occur in Mexico and in the Western United States. The taxonomic status of the dwarf mistletoes, as indeed many of their host trees, is not yet "finalized." Several unsettled questions remain, e.g.; (1) the taxonomic status and host relationship of A. campylopodum and A. occidentale in California; (2) the status of dwarf mistletoes on white pines in northern California and southern Oregon, and (3) the status of "races" of the hemlock dwarf mistletoe--A. tsugense. It now seems fairly sure that A. tsugense has at least two "races" (Smith and Wass 1976) --one on shore pine in coastal British Columbia, Vancouver Island and Orcas Island, Washington, and one on western hemlock from Alaska to California. Possibly, the populations on mountain hemlock also are distinct.

Table 1--Synopsis of the genus *Arceuthobium*, with distribution and principal hosts of each taxon.

Dwarf Mistletoe	Distribution	Principal hosts
NEW WORLD TAXA		
1. *Arceuthobium abietinum*		
a. f. sp. *concoloris*	Western U.S.	*Abies concolor*
b. f. sp. *magnificae*	Calif., S. Oreg.	*Abies magnifica*
2. *Arceuthobium abietis-religiosae*	Mexico	*Abies spp.*
3. *Arceuthobium americanum*	West. U.S., West. Can.	*Pinus contorta*, *P. banksiana*
4. *Arceuthobium apachecum*	SW U.S.	*Pinus strobiformis*
5. *Arceuthobium aureum*		
a. Subspecies *aureum*	Guatemala, Belice	*Pinus* spp.
b. Subspecies *petersonii*	S. Mexico	*Pinus* spp.
6. *Arceuthobium bicarinatum*	Hispaniola	*Pinus occidentalis*
7. *Arceuthobium blumeri*	Ariz., Mexico	*Pinus strobiformis*
8. *Arceuthobium californicum*	Calif., Oreg.	*Pinus lambertiana*
9. *Arceuthobium campylopodum*	W. U.S., Mexico	*Pinus ponderosa*, *P. jeffreyi*
10. *Arceuthobium cyanocarpum*	W. U.S.	*Pinus flexilis*
11. *Arceuthobium divaricatum*	W. U.S., Mexico	Pinyons
12. *Arceuthobium douglasii*	B.C., W. U.S., Mexico	*Pseudotsuga menziesii*
13. *Arceuthobium gillii*		
a. Subspecies *gillii*	SW U.S., Mexico	*Pinus leiophylla*
b. Subspecies *nigrum*	Mexico	*Pinus* spp.
14. *Arceuthobium globosum*		
a. Subspecies *globosum*	Mexico	*Pinus* spp.
b. Subspecies *grandicaule*	Mexico, Guatemala	*Pinus* spp.
15. *Arceuthobium guatemalense*	Mexico, Guatemala	*Pinus ayacahuite*
16. *Arceuthobium hondurense*	Honduras	*Pinus oocarpa*
17. *Arceuthobium laricis*	B.C., NW U.S.	*Larix occidentalis*
18. *Arceuthobium microcarpum*	Ariz., N. Mex.	*Picea engelmannii*, *P. pungens*
19. *Arceuthobium occidentale*	Calif.	*Pinus sabiniana*, *P. radiata*
20. *Arceuthobium pusillum*	E. Can., E. U.S.	*Picea mariana*, *P. glauca*
21. *Arceuthobium rubrum*	Mexico	*Pinus* spp.
22. *Arceuthobium strictum*	Mexico	*Pinus* spp.
23. *Arceuthobium tsugense*		
a. Western hemlock race	Alaska to Calif.	*Tsuga heterophylla*
b. Shore pine race	B.C., NW Wash.	*Pinus contorta*
24. *Arceuthobium vaginatum*		
a. Subspecies *vaginatum*	Mexico	*Pinus* spp.
b. Subspecies *cryptopodum*	Colo., Utah to Mexico	*Pinus ponderosa*
c. Subspecies *durangense*	Mexico	*Pinus* spp.
25. *Arceuthobium verticilliflorum*	Mexico	*Pinus* spp.

OLD WORLD TAXA

26.	*Arceuthobium azoricum*	Azores	*Juniperus brevifolia*
27.	*Arceuthobium chinense*	SW China	*Abies* sp., *Keteleeria* sp.
28.	*Arceuthobium juniperi-procerae*	Central Africa	*Juniperus procera*
29.	*Arceuthobium minutissimum*	India, Pakistan	*Pinus wallichiana*
30.	*Arceuthobium oxycedri*	Spain to India	*Juniperus* spp.
31.	*Arceuthobium pini*	SW China	*Pinus tabulaeformis*

HOST RELATIONSHIPS

The dwarf mistletoes parasitize all six genera in the Pinaceae in North America: *Pinus*, *Picea*, *Abies*, *Larix*, *Pseudotsuga* and *Tsuga*. Most dwarf mistletoes parasitize pines as their principal hosts:

Principal Hosts	Number of Dwarf Mistletoes
Hard pines	18
White pines	6
True firs	3
Spruce	2
Hemlock	1
Larch	1
Douglas-fir	1

Junipers are the primary hosts in the Old World (3 of the 6 species) but this group is not parasitized by *Arceuthobium* in the New World, although the related genus *Phoradendron* is common on junipers here. Other conifers of the families Cupressaceae and Taxodiaceae (*Cupressus*, *Chamacyparis*, *Taxodium*, *Taxus*, *Thuja*, *Sequoia*, and *Sequoiadendron*) are not parasitized by the dwarf mistletoes. Perhaps that is why some of them are so long lived!

An important consideration for control is that dwarf mistletoes are generally host specific--that is, they are usually confined to a single host species or a group of closely related species. The dwarf mistletoes of the principal conifers of Western United States and Canada are listed in Table 2.

DWARF MISTLETOE EFFECTS

The effects of dwarf mistletoes on their hosts fall into six major kinds, which will be noted briefly here, but will be discussed in more detail by subsequent speakers.

I emphasize that we're talking about dwarf mistletoe "effects", which may or may not be causing an "impact" on the forest resource. This, too, will be discussed in more detail by the next speaker.

Growth Loss

The most common result of dwarf mistletoe infection is reduction of growth rates of infected trees. The degree of reduction depends on the intensity of infection. It ranges from essentially no measurable effect in lightly infected trees to severe reduction in heavily infected trees. In general, height growth is more seriously affected than diameter growth for a given degree of infection. In many forest types, growth loss is the primary mistletoe-loss factor (I'd place lodgepole pine, coastal ponderosa pine, western hemlock, etc., in this category.)

Mortality

Although it is often not realized by foresters, dwarf mistletoes can kill trees directly. The more common situation, however, is that dwarf mistletoes so seriously reduce the vigor of trees that they are "finished off" by secondary insects. The extent of mortality is very variable depending on the host/parasite combination, stand age, site factors, etc. For example, mortality accounts for a relatively small proportion of the total dwarf mistletoe-caused loss in coastal ponderosa pine but it is a much more significant loss factor in Southwestern ponderosa pine. Mortality is also particularly severe in infested Douglas-fir stands.

Table 2. Dwarf mistletoes of the principal conifers in the Western United States.

Host	Dwarf mistletoes common throughout most of the ranges of the host	Dwarf mistletoes locally common
Abies amabilis	A. tsugense	-
Abies concolor	A. abietinum f. sp. concoloris	-
Abies grandis		A. abietinum f. sp. concoloris
Abies magnifica	A. abietinum f. sp. magnificae	-
Larix occidentalis	A. laricis	-
Picea engelmanni		A. microcarpum
Picea pungens		A. microcarpum
Pinus aristata		A. microcarpum A. cyanocarpum
Pinus attenuata		A. campylopodum A. occidentale
Pinus contorta		
subsp. contorta		A. tsugense
subsp. murrayana	A. americanum	-
subsp. latifolia	A. americanum	-
Pinus coulteri		A. occidentale A. campylopodum
Pinus edulis	A. divaricatum	-
Pinus flexilis	A. cyanocarpum	-
Pinus jeffreyi	A. campylopodum	-
Pinus lambertiana	A. californicum	-
Pinus longaeva	A. cyanocarpum	-
Pinus monophylla	A. divaricatum	-
Pinus monticola		A. tsugense A. californicum
Pinus muricata		A. occidentale
Pinus ponderosa		
var. ponderosa	A. campylopodum	-
var. scopulorum	A. vaginatum subsp. cryptopodum	A. americanum
Pinus radiata	A. occidentale	-
Pinus sabiniana	A. occidentale	-
Pinus strobiformis	A. apachecum	A. blumeri
Pseudotsuga menziesii	A. douglasii	-
Tsuga heterophylla	A. tsugense	-
Tsuga mertensiana	A. tsugense	A. laricis

Seed Crops

Although we have little quantitative data, the evidence is that heavily infected trees produce both fewer seeds and seeds of lower viability (Korstian and Long 1922, Munns 1919). Because of this, heavily infected trees should not be left as seed trees.

Effects on Wood

The anatomy of host wood in dwarf mistletoe bole infections is markedly altered. Affected wood has shorter and distorted tracheids and a greatly increased proportion of ray tissue, so strength and pulping characteristics are reduced (Piirto et al. 1974, Hunt 1971). The practical significance of the strength reduction has not been determined, but it is presumably slight (Dobie and Britneff 1975, Wilcox et al. 1973). Most mistletoe-affected wood is near the outside of the bole and would tend to be removed in slabbing. Another marked, but again not quantified, effect of dwarf mistletoe is the increased size of knots in wood.

Predisposition to Insects and Fungi

Under "Mortality" I mentioned that dwarf mistletoes typically weaken trees so that they are more susceptible to attack by insects, particularly bark beetles. In some situations this may not only result in death of infected trees, but beetle populations may build up and spread out to adjacent non-mistletoe stands. The interaction between dwarf mistletoes and bark beetles is far from understood, and needs to be evaluated (Stevens and Hawksworth 1970, Parker and Stipe 1970, Johnson et al. 1976). In firs and hemlock, old bole infections, particularly those with exposed wood, may provide entrance points for decay fungi (Etheridge 1973). However, this is apparently not a factor in pines, spruce, or Douglas-fir--presumably because of the higher resin content of these trees.

Ecologic Effects

Dwarf mistletoes can have profound ecologic effects on forest stands. As will be discussed later in the symposium, wildfires have been the primary controlling factors of the dwarf mistletoes in the past. It is often not recognized that dwarf mistletoes may also affect fire hazard conditions in infested stands because the dead trees, lower limbs, etc., are more flammable. Also, dwarf mistletoes are intimately involved in forest succession and change of species composition in several types (see Wicker, these proceedings).

DWARF MISTLETOE LIFE CYCLES

I'll briefly outline the life cycles of dwarf mistletoes with emphasis on how they relate to control. I'll hope to pinpoint "weak links" to show the most susceptible points for interference with the life cycle.

Flowering

The male flowers in Arceuthobium are 2-3 mm across and typically 3- or 4-parted (fig. 2).

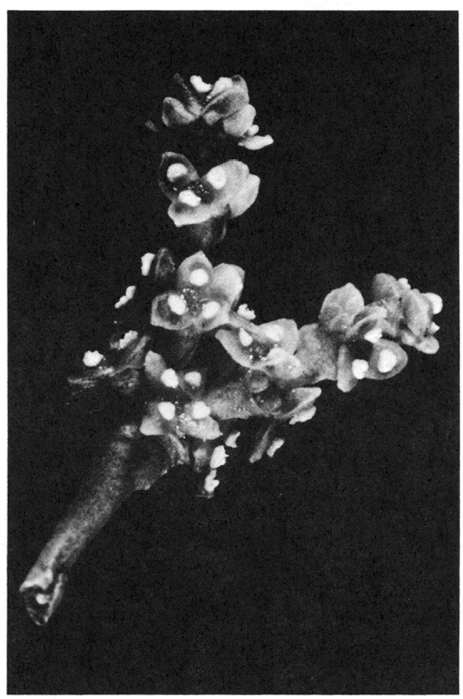

Figure 2--Male dwarf mistletoe flower.

Each segment has a single sessile anther, containing 1,000 to 4,000 yellow pollen grains. The center of each flower contains an organ which we interpret as a nectary. The female flowers are only 1-2 mm long and are very inconspicuous (fig. 3). They, too have a nectary which is attractive to insects.

Figure 3--Female dwarf mistletoe flower.

All the dwarf mistletoes are dioecious--that is, the male and female flowers occur on separate plants. All the Western United States and Canadian species studied to date show a sex ratio of approximately 1:1. However, some Mexican species seem to show a preponderance of female plants.

In general, the North American mistletoes fall into two main flowering groups--those that flower in the spring: A. americanum, A. pusillum, A. douglasii, A. vaginatum, and A. gillii--and those that flower in summer or fall: A. abietinum, A. apachecum, A. blumeri, A. californicum, A. campylopodum, A. cyanocarpum, A. divaricatum, A. laricis, A. microcarpum, A. occidentale, and A. tsugense.

Peak flowering in most species usually is confined to a 2- to 4-week period. The period is generally confined to a certain time of the year, depending on the species, but may vary somewhat from year to year due to climatic variation.

There is mounting evidence that the dwarf mistletoes are pollinated both by insects and by wind (Penfield et al. 1976). While both agents are probably involved to some extent in all species, either insects or wind seem to be the primary agent in particular species.

Seed Maturity and Dispersal

The length of the seed maturation period ranges from as little as 5 months in the eastern dwarf mistletoes, A. pusillum, to 18 months in some Mexican species. For most species, this period averages from 12 to 14 months. Seeds of the dwarf mistletoes mature in the late summer or fall (July to November) depending on the species.

The dwarf mistletoes have a unique, explosive seed dispersal mechanism. At maturity, the single seed is forcibly ejected from the fruit (figs. 4, 5) at initial velocities of 80 to 90 feet per second (60 miles per hour) (Hinds and Hawksworth 1965).

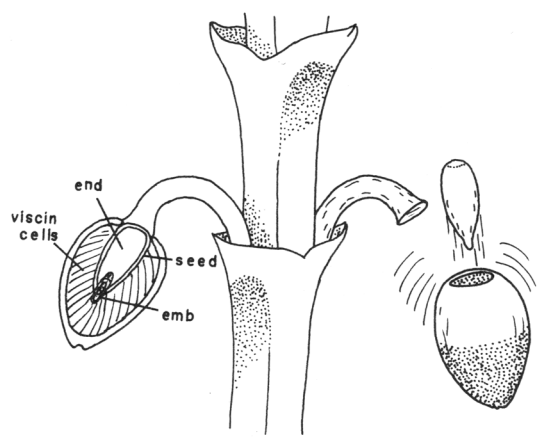

Figure 4--Diagrammatic view of the dwarf mistletoe seed expulsion mechanism. Left.--A mature fruit before the seed is expelled, showing how the pedicel of the fruit is elongated and recurved so that the original apex of the fruit is now pointed downward. The gross anatomy of the fruit showing the seed, embryo, endosperm, and viscin cells. Right.--A mature fruit immediately after the discharge of the seed. The fruit is severed from the pedicel and the seed is ejected from the fruit and propelled upwards.

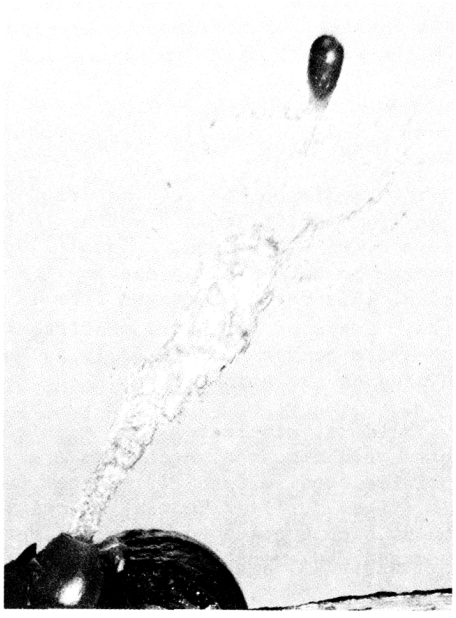

Figure 5--Seed discharge in Arceuthobium.

The distance of seed flight depends on several factors such as height of the source plant, angle of seed discharge, wind velocity, stand density, etc.

The seeds as they leave the fruit tend to be hurled upward (usually at angles of 30 to 40 degrees above the horizontal (Hawksworth 1961, Strand and Roth 1975)). Seeds that are expelled at lower angles fly further horizontally (fig. 6).

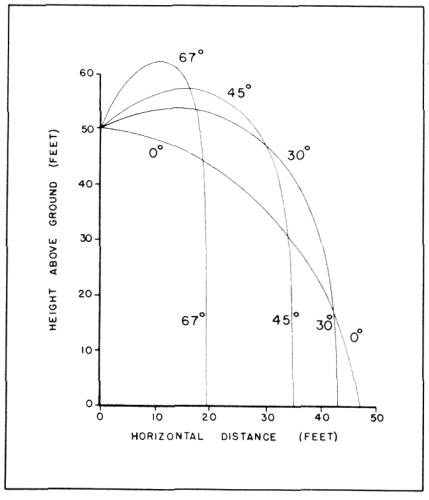

Figure 6--Trajectories of seeds expelled at various angles.

The relationship between number of seeds dispersed and distance from source plant is shown for Arceuthobium vaginatum in ponderosa pine (fig. 7).

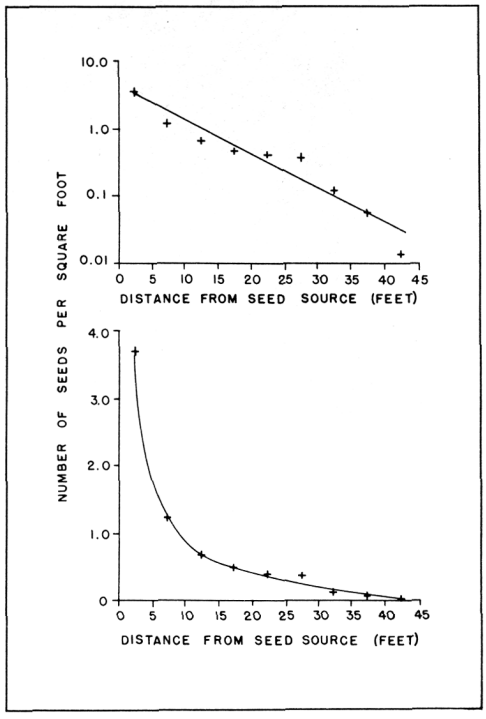

Figure 7--Relationship between seed density and distance from source. Arceuthobium vaginatum on ponderosa pine in Arizona (Hawksworth 1961).

The average horizontal distance of seed flight is between 15 and 20 feet, but seeds will sometimes fly as far as 100 feet.

Studies in Colorado for dwarf mistletoe in ponderosa pine and lodgepole pine showed that from 4 to 11 seeds per square foot fall through to the forest floor (Hawksworth 1965). When allowances are made for the seeds that stick to the trees, the total number of seeds produced range from about 300,000 to 800,000 per acre per year. In one ponderosa pine stand, we found an average of 160 seeds per square foot on the forest floor; this is over 7 million seeds per acre--and accounts for only the seeds that missed the trees!

Little is known of long-distance dispersal of dwarf mistletoe seeds. However, studies in the Lake States, the Rocky Mountains and in the Northwest implicate birds (Hudler et al. 1974, Zilka and Tinnin 1976, Hudler et al. 1978) and squirrels (Lemons 1978). In our studies with Arceuthobium vaginatum on ponderosa pine in Colorado, we found isolated infection

centers sometimes as far as 1/4 mile from the closest generally infested stands. Birds, mainly mountain chickadees and pygmy nuthatches, seem to be the primary vectors in this area. Long-distance dispersal, however, seems to be quite limited and, from a practical control standpoint, can probably be ignored.

Interception of Seeds by the Host

The seeds as hurled from the fruit are sticky and readily adhere to whatever they strike, providing their velocity is not too high. If they strike objects at close range at high velocity, they will rebound and perhaps land on another part of the potential host tree. Conifer needles, because of their high volume in the air space and their resilience, are very effective in intercepting seeds in flight.

Studies in a lodgepole pine and a ponderosa pine stand show that about 40 percent of the seeds produced are intercepted by the trees (Hawksworth 1965). Seeds usually remain on the needles until the fall rains, when the viscous coating swells and acts as a lubricant and the seeds slide down the needles toward the twigs (Roth 1959). If the particular needle does not form a high vertical angle with the twig then the seed may fall and be lost. In general, seeds must be transferred to within 0.5 cm of the twig for successful infection to take place.

Most infection takes place through the needle-bearing parts of the twig and the youngest growth is most susceptible. Needle-bearing twigs are usually 4-6 years old for pines but may be up to 20 years old for firs. Older tissues, generally, are not susceptible, except for A. americanum in lodgepole pine where infection can take place through trunk tissues up to 60 years old (Hawksworth 1954).

Germination and Infection

Most dwarf mistletoes germinate in the spring after overwintering on the needles or twigs. An exception is A. vaginatum on ponderosa pine which germinates in the fall soon after seed dispersal (Hawksworth 1961). The spring-germinating species contain a dormancy-inducing substance in the seed coat that slowly breaks down with time at temperatures near freezing (Beckman and Roth 1968). Germination rates are fairly high (often over 90 percent in the species that have been investigated).

In germination, the radicle of the seed grows along the host branch until it encounters an irregularity, such as the base of a needle, where a mound of tissue develops into the host cortex. This establishes the endophytic (or root) system of the mistletoe within the host.

Many seeds are lost due to various factors: insects, fungi, birds, washing off due to rain and snow, etc. (Wicker 1967). Studies are underway to determine the proportion of mistletoe seeds produced that produce new infections (Hawksworth 1965). We do not have firm figures yet, but the results to date indicate a success ratio of less than 5 percent, probably closer to 1 percent.

Incubation Period

The dwarf mistletoes have relatively long incubation periods--the time from germination to fruit maturity ranges from 4 to 6 years or more depending on the species (fig. 8).

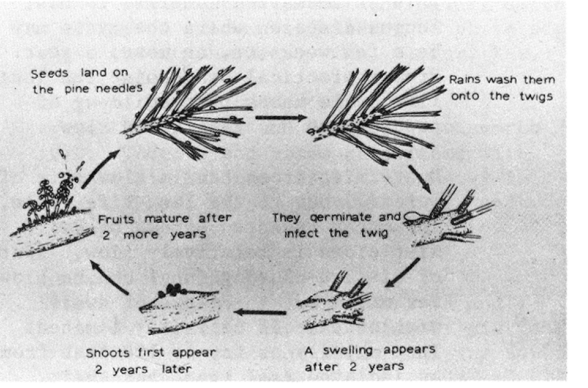

Figure 8--Life cycle diagram for a typical dwarf mistletoe.

Two to 3 years usually elapse before shoots emerge from the bark, making detection of incipient infections impossible.

Individual shoots live for 2 to 5 years although the endophytic system within the host lives for as long as the adjacent host tissues are alive and new shoots continue to arise. The endophytic system can live completely parasitically within the host without aerial shoots.

BASES FOR CONTROL

Several features of the dwarf mistletoes make them susceptible to cultural control

methods as we will hear about in subsequent papers. But these form the basis for control:

1. The dwarf mistletoes are obligate parasites; that is, they need a living host to survive. Hence, once an infected tree or branch is cut, dwarf mistletoe is no longer a threat. There is no need to burn the slash as it is harmless from the mistletoe standpoint.

2. The dwarf mistletoes are generally host specific. That is, they are usually confined to one host or a group of closely related species. It is frequently possible to favor an immune or lightly infected tree species to minimize dwarf mistletoe damage.

3. The dwarf mistletoes have a long life cycle. The time from infection to seed production is typically 4-6 years and sometimes even longer. This is in marked contrast to most fungus diseases where the cycle may be a few weeks or, at most, a year. From a practical standpoint the long life cycle means that build-up of populations is relatively slow.

4. Dwarf mistletoes have a slow rate of spread. Due to the long life cycle, and other factors, spread of dwarf mistletoes is relatively slow. Spores of disease-causing fungi can be blown for miles but the range of dwarf mistletoe seeds is fairly limited. They may fly as far as 100 feet from an isolated tall tree, but their flight in even-aged stands is short. On the average, dwarf mistletoes progress through stands at about 1-2 feet per year, and occurrence is characteristically spotty.

5. Effects of dwarf mistletoes are readily visible. This may seem obvious, but it is important to keep in mind that we are working with a disease caused by a non-microscopic organism and one that is associated with distinct symptoms. Dwarf mistletoes are not like many forest diseases--e.g., root rots, foliage diseases, abiotic disorders--where the cause of the problem may be obscure. In dwarf mistletoe stands it is generally easy to detect diseased and healthy areas.

Thus, several features of the dwarf mistletoes render them amenable to control. We'll hope to show during the rest of the symposium how we can take advantage of these features to develop control strategies.

LITERATURE CITED

Beckman, K. M., and L. F. Roth
1968. The influence of temperature on longevity and germination of seed of western dwarf mistletoe. Phytopathology 58:147-150.

Clusius, Charles
1601. Caroli clusi at rebatis..rariorum plantarum historia. 364 p. Antwerp, Belgium.

Dobie, J., and A. A. Britneff
1975. Lumber grades and volumes from lodgepole pine infected with dwarf mistletoe. Wood and Fiber 7:104-109.

Douglas, David
1914. Journal kept by David Douglas during his travels in North America, 1823-1827. 364 p. Antiq. Press Ltd., New York.

Etheridge, D. E.
1973. Wound parasites causing tree decay in British Columbia. Can. Dep. Environ. For. Serv., Pacific For. Res. Cent. For. Pest Leaf1. 62, 15 p.

Gill, L. S.
1935. Arceuthobium in the United States. Conn. Acad. Arts and Sci. Trans. 32:111-245.

Hawksworth, F. G.
1954. Observations on the age of lodgepole pine tissues susceptible to infection by Arceuthobium americanum. Phytopathology 44:552.

Hawksworth, Frank G.
1961. Dwarfmistletoe of ponderosa pine in the Southwest. U.S. Dep. Agric. Tech. Bull. 1246, 112 p.

Hawksworth, Frank G.
1965. Life tables for two species of dwarfmistletoe. I. Seed dispersal, interception, and movement. For. Sci. 11:142-151.

Hawksworth, Frank G.
1975. Dwarf mistletoe and its role in lodgepole pine ecosystems. In Management of lodgepole pine ecosystems. Symp. Proc. Wash. State Univ., D. A. Baumgartner, editor. Vol. 1:342-358.

Hawksworth, F. G., and D. Wiens
1972. Biology and classification of dwarf mistletoes (Arceuthobium). U.S. Dep. Agric., Agric. Handb. 401, 234 p.

Hinds, T. E., and F. G. Hawksworth
1965. Seed dispersal velocity in four dwarfmistletoes. Science 148:517-519.

Hudler, G. W., F. G. Hawksworth, and N. Oshima.
1978. Bird dispersal of southwestern dwarf mistletoe in Colorado. Am. Midl. Nat. [In press]

Hudler, G., T. Nicholls, D. W. French, and G. Warner.
1974. Dissemination of seeds of the eastern dwarf mistletoe by birds. Can. J. For. Res. 4:409-412.

Hunt, K.
1971. A comparison of Kraft pulping of sound and dwarf mistletoe-infected western hemlock wood. Can. Dep. Fish. and For., For. Products Lab., Vancouver, Inf. Rep. VP-X-78, 7 p.

Johnson, D. W., L. C. Yarger, C. D. Minnemeyer, and V. E. Pace
1976. Dwarf mistletoe as a predisposing factor for mountain pine beetle attack of ponderosa pine in the Colorado front range. U.S. For. Serv., Rocky Mt. Reg., For. Insect and Dis. Manage. Tech.Rep. R2-4, 7 p.

Korstian, C. F., and W. H. Long
1922. The western yellow pine mistletoe: effect on growth and suggestions for control. U.S. Dep. Agric. Bull. 1112, 35 p.

Kuijt, Job.
1960. Morphological aspects of parasitism in the dwarf mistletoes (Arceuthobium). Univ. Calif. Publ. Bot. 30:337-436.

Lemons, Daniel E.
1978. Small mammal dissemination of dwarf mistletoe seeds. M.S. thesis, Portland State Univ., Portland, Oregon, 38 p.

Leonard, O. A., and R. J. Hull
1965. Translocation relationships in and between mistletoes and their hosts. Hilgardia 37:115-153.

Munns, E. N.
1919. Effect of fertilization on the seed of Jeffrey pine. Plant World 22:138-144.

Parker, Douglas L., and Lawrence E. Stipe.
1974. Does the mountain pine beetle select and kill dwarf mistletoe-infected lodgepole pine? Insect and Dis. Control. State and Priv. For. Reg. 4, For. Serv., U.S. Dep. Agric., Ogden, Utah. 12 p.

Penfield, F. B., R. E. Stevens, and F. G. Hawksworth.
1976. Pollination ecology of three Rocky Mountain dwarf mistletoes. For. Sci. 22:473-484.

Piirto, Douglas D., Donald L. Crews, and Harry E. Troxell.
1974. The effects of dwarf mistletoes on the wood properties of lodgepole pine. Wood and Fiber 6:26-35.

Roth, Lewis F.
1959. Natural emplacement of dwarfmistletoe seed on ponderosa pine. For. Sci. 5:365-369.

Smith, R. B., and E. F. Wass
1976. Field evaluation of ecological differentiation of dwarf mistletoe on shore pine and western hemlock. Can. J. For. Res. 6:225-228.

Stevens, Robert E., and Frank G. Hawksworth
1970. Insects and mites associated with dwarf mistletoes. USDA For. Serv. Res. Pap. RM-59, 12 p., Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Strand, M. A., and L. F. Roth
1976. Simulation model for spread and intensification of western dwarf mistletoe in thinned stands of ponderosa pine saplings. Phytopathology 66:888-895.

Wicker, Ed F.
1967. Seed destiny as a klendusic factor of infection and its impact upon propagation of Arceuthobium spp. Phytopathology 57:1164-1168.

Wilcox, W. Wayne, W. Y. Pong, and J. R. Parmeter
1973. Effects of mistletoe and other defects on lumber quality in white fir. Wood and Fiber 4:272-277.

Zilka, Paul J., and Robert O. Tinnin
1976. Potential avian influences in the distribution of dwarf mistletoe. Northwest Sci. 50:8-16.

FOREST STAND DYNAMICS AND ECOLOGICAL FACTORS IN RELATION TO DWARF MISTLETOE SPREAD, IMPACT, AND CONTROL[1]

J. R. Parmeter, Jr.[2]

Abstract: Dwarf mistletoes are markedly host specific, perennial, obligate parasites. The success of mistletoe populations is tied not only to the suitability of the environment, but also to the availability and conditions of the hosts they infect. Thus, the dynamics of forest stand development and change exert major influences on the capacity of dwarf mistletoes to spread, intensify, and cause damage to host trees. Silvicultural control of dwarf mistletoe damage rests mainly with manipulation of stand dynamics to minimize spread and intensification. Thorough understanding of dwarf mistletoe/forest stand interactions is therefore crucial to the development and application of controls.

In North America there are some two dozen species of dwarf mistletoes associated with numerous host species growing in a variety of forest and habitat types distributed over different terrains under widely divergent climatic conditions. Detailed treatment of stand dynamics in each of these associations is beyond the scope of this discussion. Rather, I have attempted to highlight some stand and ecological relationships that appear to be general to dwarf mistletoes, to indicate how these relationships provide bases for dwarf mistletoe control, and to suggest where increased information could improve control application. The literature on dwarf mistletoes is voluminous (Scharpf, et al. 1976). Citations were selected to confirm or to illustrate principles, but no attempt was made to cite all papers dealing with the material discussed here.

DAMAGE, IMPACT, AND DWARF MISTLETOE POPULATIONS

Land managers are concerned about dwarf mistletoes because mistletoes can reduce the number, size, quality, or longevity of trees, and such reductions can affect the productivity and value of trees or stands. Unfortunately, a standard terminology to express disease effects has not evolved. Such terms as effect, damage, loss, and impact are often used interchangeably to designate mistletoe-induced changes in trees or stands. It has been suggested that the term impact be restricted to "...the cumulative net effects of a given pest or pest complex on the productivity, usefulness and value of a tree species or forest type with respect to different resource uses and values (timber production, watershed protection, wildlife cover, recreation, etc.) and the management objectives..." (Waters, 1976). By this definition, various types of damage (growth reduction, quality reduction, mortality, etc.) may or may not have impact, depending upon whether such damage reduces the productivity or value of a stand.

Investigators have seldom dealt with impact. Most available data involve various measures of damage either to individual trees or to stands. The following discussion therefore deals mainly with damage, with the recognition that land managers must ultimately convert damage data to impact data and that this conversion is dependent on the amount of damage to individual trees and the numbers and distribution of damaged trees in a stand. These data in turn are dependent on the rates at which mistletoes spread through stands and

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[1] Presented at Symposium on Dwarf Mistletoe Control Through Forest Management, Berkeley, Calif. April 11-13, 1978.

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intensify within trees.

Generally, the amount of damage is related to the numbers of infections and their distribution within tree crowns (Baranyay 1970; Baranyay and Safranyik 1970; Childs and Wilcox 1966; Dooling 1974; Dooling and Brown 1976; Hawksworth 1961a; Hawksworth and Lusher 1956; Korstian and Long 1922; Pierce 1960; Shea 1963; Shea and Orr 1963; Shea and Belluschi 1965; Smith 1969). A number of systems have been devised to rate intensities of dwarf mistletoe infection (Hawksworth 1977; Dooling, this vol.) and to correlate damage with intensities in individual trees or with general conditions of stands.

Damage on a stand basis is usually estimated by comparing volumes, basal areas, or mortality rates in stands without mistletoe to that in stands with various amounts of mistletoe. While absolute volume, basal area or mortality may differ with different host/mistletoe combinations and with a variety of site and stand factors, the association of increasing loss with increasing mistletoe intensity is well established (Andrews and Daniels 1960; Baranyay 1970; Graham 1960a; Graham and Frazier 1962; Haglund and Dooling 1972; Hawksworth 1958a, 1968a; Hawksworth and Hinds 1964; Hawksworth and Lusher 1956; Lightle 1966; Richardson and van der Kamp 1972; Wagener 1961). In general, stand losses below some critical level of mistletoe intensity are negligible (Baranyay 1970; Baranyay and Safranyik 1970; Dooling 1974; Richardson and van der Kamp 1972; Shea and Orr 1963). This level is a function of numbers of infected trees in a stand, the intensities of infection in these trees, and the amount of damage resulting from different intensities.

Whether damage is expressed as decreased radial, height, or volume growth or as increased mortality, significant damage is seldom observed until at least the lower 1/3-1/2 of a tree crown is heavily infected (Baranyay 1970; Baranyay and Safranyik 1970; Dooling 1974; Dooling and Brown 1976; Hawksworth 1961a; Hawksworth and Lusher 1956; Pierce 1960; Shea 1963; Shea and Orr 1963; Shea and Belluschi 1965; Smith 1969). Light infection throughout the crown or heavy infection in the lower crown usually cause little or no damage, except where stem infections may lead to heartrot (Etheridge 1973), where stem infections occur in seedlings and small saplings (Knutson and Toevs 1972; Roth 1971; Weir 1918), or perhaps where large brooms are produced.

The effects of brooms on host growth has not been investigated thoroughly. Pierce (1960) suggested that the growth of trees with brooms in the lower crown was comparable to trees with healthy crowns of a length equal to the unbroomed portion of infected trees. Hawksworth (1961a), however, showed that growth reduction was greater in broomed trees than in non-broomed trees of the same infection class. Further, Lightle and Hawksworth (1973) illustrate dramatic improvement in host vigor following pruning of brooms from the lower crown. Since the numbers of brooms increase with increasing intensities of infection (Hawskworth 1961a), the amount of damage to trees can be expected to increase with increasing levels of infection.

Rates of increase in dwarf mistletoe population levels undoubtedly are affected by a number of host, stand, and environmental factors. Few data are available on measured rates of increase. Hawksworth (1969) found that the numbers of infections on inoculated digger pines increased from 4 to 240 per tree within 16 years after inoculation, indicating a population doubling rate of about 2.5 years. Doubling rates were estimated to be 1.25 years in lodgepole pine (Muir 1972) and 4 years in hemlock (Richardson and van der Kamp 1972). Scharpf and Parmeter (1976) found that population increases in inoculated red and white firs were highly variable. In two groups of trees, populations doubled within 12-15 years from inoculation; in a third group the population tripled; in a fourth group the population increased 35 times (a doubling rate of about 3 years), and in one group the population scarcely increased. These extreme variations are presently unexplained, but they suggest that the collection of population data in one area may have limited relevance to other areas.

Generalized estimates of population increase rates have been made by rating the mistletoe intensity according to the system of Hawksworth (1977) in stands of different ages or in stands infected for different periods of time. Hawksworth and Hinds (1964) estimated that the average rating (on a 0-6 scale) in lodgepole pine stands increased 0.8-0.9 per decade for the first 4 decades of infection, with increases of 0.6 and 0.3 for the next 2 decades. This indicates an average increase of 1 class each 14 years. Flora (1966) indicated that it takes about 70 years for ponderosa pines to go from a 1.5 to a 5.5 rating, an increase of 1 class each 17.5 years. Wass (1976) suggests that shore pine infection intensities increased by 1 class each 15 years. Myers, et al. (1976) developed an equation for calculating increases in infection intensity for mistletoe in southwestern

ponderosa pine. By this equation, rates of increase vary according to time of infection, stand density, and site index.

It is obvious that equations or estimates for population or rating increases can apply only to specified time periods, host/mistletoe combinations, and stand/site conditions. With estimated doubling times of 1.25-4 years, dwarf mistletoe populations would reach impossible numbers within normal rotation periods for most host species. On a stand basis, if infection ratings increased by 1 every 15 years (allowing 10 years for establishment), young infected stands would reach damaging 3-4 levels of infection within 55-70 years, and we would be hard pressed to justify rotations beyond this time. However, for each 5-year increase in the number of years it takes for ratings to increase by 1, the rotation is extended by 30 years (Fig. 1). Whether increase rates are straight-line functions or whether they change with stand age and duration of infection (as the data of Hawksworth and Hinds, 1964, suggest), reduction in the rate of increase may be critical to sound management.

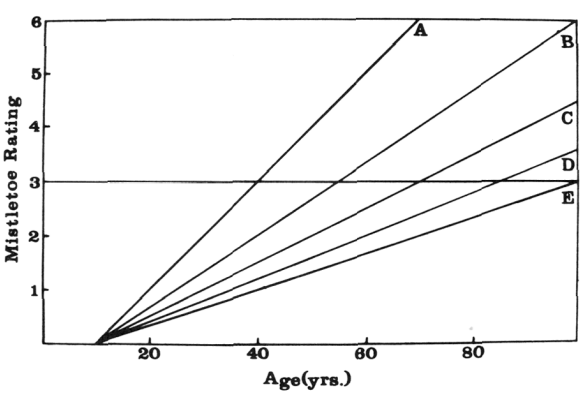

Figure 1--Ages at which stand dwarf mistletoe ratings would reach levels of 3 or more with infection ratings increasing by 1 every 10 yr (A), 15 yr (B), 20 yr (C), 25 yr (D), or 30 yr (E), assuming infection is established at about 10 yr.

Fortunately, rates of dwarf mistletoe spread and increase are subject to a variety of limitations that can be manipulated by land managers or that he can take advantage of. These involve the influences of: (1) site quality and host vigor, (2) stand density, (3) host age, (4) stand structure, and (5) stand composition. These various elements of stand dynamics are inextricably interwoven and difficult to discuss in isolation. For convenience, however, they will be discussed individually.

ELEMENTS OF STAND DYNAMICS AFFECTING SPREAD, INTENSIFICATION, AND DAMAGE

Site Quality and Host Vigor

Reports of the relationship of dwarf mistletoe prevalence, intensity or damage to site quality are difficult to interpret. In ponderosa pine, increased mistletoe has been associated with poor site quality (Daubenmire 1961, 1969; Korstian and Long 1922), with intermediate site quality (Larson et al. 1970), or showed no significant relationship to site (Childs and Edgren 1967; Hawksworth 1961a, 1961b, 1968a). In lodgepole pine, Alexander (1975) reported heavier infection on poor sites, Hawksworth and Graham (1963) found a higher percentage of infected trees in reproduction on good sites, and Hadfield (1977) found no relationship of site quality to percent of trees infected. Baranyay and Safranyik (1970) found greater growth loss on dry than on wet sites. It has been suggested that because mistletoes affect host growth, heavily infected stands may give the appearance of low site quality (Childs and Edgren 1967; Hawksworth 1961a).

Since site quality is measured by tree growth, and growth may be affected by a number of factors (soil type and depth, nutrients, available water, drainage, length of growing season, etc.), it is not surprising that data are difficult to interpret. While site quality per se might have some direct effects on dwarf mistletoe activity, it is likely that fundamental host/stand/parasite interactions affected by site factors are more important in determining mistletoe spread and intensification.

Host vigor, which is in part a reflection of site quality, affects mistletoes in several important ways. Vigorous trees are generally larger, have fuller crowns, greater needle complements, and longer needles than do unthrifty or suppressed trees. It has long been recognized (Weir 1916) and repeatedly confirmed (Childs 1963; Childs and Edgren 1967; Gill 1957; Hawksworth 1961a, 1965; Hawksworth and Graham 1963; Roth 1959; Wicker 1967; Wicker and Shaw 1967) that vigorous, full-crowned trees intercept more seeds and are therefore more liable to infection. It

appears well established that for a given level of inoculum, the rate of infection increases with host vigor.

Host vigor also promotes dwarf mistletoe vigor. The endophytic system invades vigorous host tissues more rapidly (Hawskworth 1960a; Scharpf 1962; Parmeter unpubl.), and more robust shoots and larger amounts of seed develop on vigorous hosts (Baranyay and Smith 1972; Childs 1963; Dooling 1974; Hawksworth 1961a; Roth 1953).

It has also been reported that vigorous lodgepole pines are more liable to damage. Statements regarding the effects of host vigor on mistletoe development are not apt to have much significance unless the stand and site characteristics are specified. While a vigorous tree in one stand may be more liable to damage, a similar tree in another stand may be less liable to damage.

Since trees of most species seldom show significant growth losses when mistletoes are confined to the lower crown, factors that affect the rate of vertical spread through tree crowns are important. Alexander (1975) indicated that where the site index exceeded 70, usually only the middle and lower crowns of dominant and codominant lodgepole pines were infected. Below index 70, all crown classes were susceptible to heavy infection throughout the crown. Graham (1967) suggested that vertical spread in ponderosa pine was about 4 inches per year, and Strand (1973) estimated 3 inches per year. Hawksworth (1969) found that vertical spread in digger pines averaged 2 feet per year. Richardson and van der Kamp (1972) estimated vertical spread to be 65 cm (about 2 feet) per year in open grown hemlock and 30 cm (about 1 foot) per year in dense hemlock. Scharpf and Parmeter (1976) found the average vertical spread in red and white firs was about 3 inches per year. Childs (1964), Richardson and van der Kamp (1972), and Scharpf and Parmeter (1976) have suggested that most trees will escape serious damage if the rate of height growth exceeds the rate of vertical spread sufficiently to confine mistletoe to the lower crown and that, in the absence of overstory seed sources, damaging invasion of upper crowns will not occur until host growth slows with age.

The rate of vertical spread is probably governed mainly by crown characteristics. Species with open crowns, such as digger pine, permit rapid vertical spread, whereas species with dense crowns, such as true firs, greatly impede vertical spread. Among trees within a species, crown characteristics can change with host vigor. Vigorous crowns, because of their fullness, will impede vertical spread, even though the rate of population increase in the lower crown may be high. In contrast, unthrifty or suppressed trees, because of thin crowns, may provide less barrier to vertical spread. For each mistletoe/host combination, it may be possible to construct height-growth/vertical-spread curves that will allow prediction of probable damage for any set of vigor and site conditions (Fig. 2).

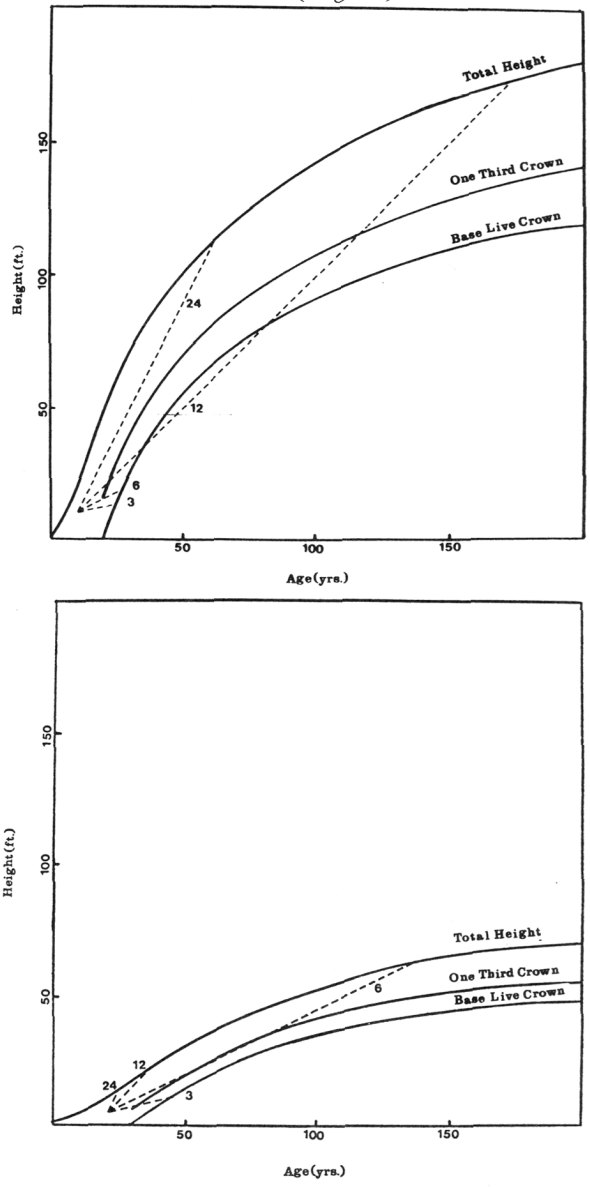

Figure 2--Hypothetical relationship of vertical spread rates of 3, 6, 12, or 24 inches per year to position of dwarf mistletoe in crowns of trees at different ages on high and low sites. Infection of young trees is estimated to occur slightly earlier on high sites.

In addition to rates of population buildup within crowns, site and vigor might also affect rate of tree-to-tree spread through a stand. Trees of low vigor on poor sites have thin crowns and might therefore provide less "screening" for lateral spread. Such effects, if any, would likely be small in comparison to the effects of stand density, structure, and composition.

Stand Density

Stand density can affect spread and intensification either directly or through changes in host vigor and growth. In general, mistletoes spread more rapidly in open stands than in dense stands (Hawksworth 1958a, 1961a). Hawksworth (1961a) found that average spread in open stands of ponderosa pine reproduction was 1.5 times as fast (1.7 feet/year) in open stands as in dense stands (1.2 feet/year). Data on spread in lodgepole pine were similar (Hawskworth 1958a) but spread rates were slightly less (average 1.2 feet/year vs. 1.5 feet/year). Density may affect spread in several ways. Beyond some critical distance that varies with tree size and mistletoe species, the chances of seed shooting from one tree to another decrease until trees are so far apart that ballistic spread is very unlikely (Fig. 3). As spacing decreases, the likelihood of seed reaching adjacent trees increases until densities are sufficiently high that trees interfere with spread by "screening" out seeds, thus "protecting" the trees beyond. Where densities are sufficiently high as to reduce host growth and vigor, seed production may be reduced, thus decreasing the opportunities for spread. The generalized relationship of density to spread presented by Hawksworth (1961a) undoubtedly can be applied to most mistletoe/host combinations, but the curve would have to be adjusted according to species and to the sizes of trees involved.

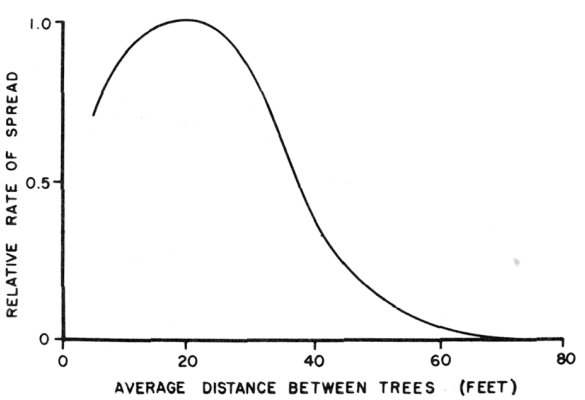

Figure 3--Rate of dwarf mistletoe spread in relation to stand density (after Hawksworth 1961a).

The rate of mistletoe increase and subsequent host damage is also related to stand density, but the relationship is not entirely clear. Some workers have reported an inverse relationship of density to prevalence or damage (Graham 1960b; Richardson and van der Kamp 1972; Williams et al. 1972). Williams et al. (1972) suggested, however, that infection in limber pine was directly related to density. Since density relationships are relative and may vary according to a variety of site and stand factors, generalizations are feasible only within specific contexts; e.g., similar densities on high and low sites may not have similar effects on dwarf mistletoes.

Density can affect host vigor, as has already been discussed. Where the relationship of height growth to vertical spread of mistletoe is changed by crowding and suppression, the rate of crown involvement might be expected to change, but the nature of the change may depend on specific densities. Childs (1964) has discussed in some detail the relationship of crown closure to mistletoe population increase and vertical spread. Baranyay and Smith (1972), Childs (1963), Richardson and van der Kamp (1972) and Scharpf and Parmeter (1976) have also suggested that crown closure and subsequent "pruning" of lower branches may stabilize or reduce population increases in tree crowns. If the rate of crown closure and branch pruning is greater than the rate of vertical spread, populations of dwarf mistletoes might virtually disappear from trees not exposed to overstory seed sources (Fig. 2).

The above observations suggest that for each site/host/mistletoe combination there is an optimum density that promotes good height growth and rapid crown closure to minimize population buildup and vertical spread of mistletoe. At densities above optimum, crown thinning and reduced height growth might lead to increased vertical spread, or with densities below optimum, increased branch longevity, increased mistletoe inoculum, and increased opportunities for "stepwise" vertical spread between trees might also lead to increase damage. The relation of site and density to vertical spread and population buildup warrants research emphasis.

Stand Age and Size Structure

Trees of any age or size are susceptible to dwarf mistletoe infections. Seedlings one-year-old or less are readily infected under greenhouse conditions (Knutson and Toevs 1972; Knutson 1974), and infection of trees 2.5 inches tall have been observed in nature (Hawksworth and Graham 1963). Infection of very

young or very small trees is, however, relatively rare. Data from many sources indicate that numbers of trees infected, intensity of infection, and degree of damage consistently increase with the age of trees or stands and, in the case of reproduction exposed to overstory seed sources, with size of trees (Baranyay 1970; Childs 1963; Graham 1960a, 1964; Hadfield 1977; Hawksworth 1958a, 1961a; Hawksworth and Graham 1963; Hawksworth and Hinds 1964; Muir 1972; Scharpf 1969a; Stewart 1976). The escape of or reduced infection in young trees involves the relatively small target area, the short duration of exposure to inoculum, and the short period for inoculum production and spread within crowns. Loss of seeds under snow may also reduce infection of small trees (Wicker 1967).

Because young trees tend to escape infection, reproduction following opening of infested stands by logging, fire, insects or other agencies is ordinarily lightly infected until it reaches some critical age or size. Jones (1974), Shea and Stewart (1972), and Scharpf (1969a) have provided guidelines for timing of overstory removal. If overstory sources of mistletoe seed are removed, subsequent buildup and damage in the released stand depend upon the site and density factors already discussed and upon silvicultural manipulation of the young stand, as will be discussed in later sections of this symposium.

At the opposite end of stand development, all trees eventually cease appreciable height growth. In such trees, vertical spread can be expected to involve the entire crown, and the intensity of infection can be expected to increase because of the long duration of exposure to inoculum. Mortality rates are apt to be high in old stands in which heavy infection levels have been reached.

Roth (1953) suggested that less mistletoe seed is produced in old, declining trees than in young trees. Although seed production may be reduced, appreciable numbers of seeds have been trapped under old, heavily infected and broomed trees (Parmeter and Scharpf 1972). It is probably safest to consider all such trees as potential sources of inoculum.

Perhaps the most firmly established of all stand influences on dwarf mistletoes is that of stand structure (Gill and Hawksworth 1954; Graham and Frazier 1962; Graham 1959a; Hawksworth 1961a; Kimmey and Graham 1960; Kuiyt 1955; Roth 1953; Scharpf and Hawksworth 1968, Shea 1963; Shea and Stewart 1972; and many others). In stands comprised of susceptible trees of different sizes, the crowns of smaller trees are continually exposed to inoculum from larger trees. Under these circumstances, the upper crowns of understory trees can rarely remain free of increasing mistletoe populations, and reductions in growth with further increase in mistletoe is almost certain. The impact of mistletoe in such stands can render them virtually non-productive.

The rate of spread through two-storied or multistoried stands is more rapid than through single-storied stands. Small trees provide little "screening" of mistletoe seeds, therefore tall seed sources provide for greater unimpeded seed trajectories. Hawksworth (1961a) calculated trajectories for mistletoe seeds discharged at different angles (Fig. 4). From these calculations, it is evident that, in the example shown, a nearby tree less than 40 feet tall would not impede flight from the 50 foot seed source at most discharge angles above the horizontal. A nearby 60 foot tree would, however, intercept seeds and markedly reduce the distance of flight.

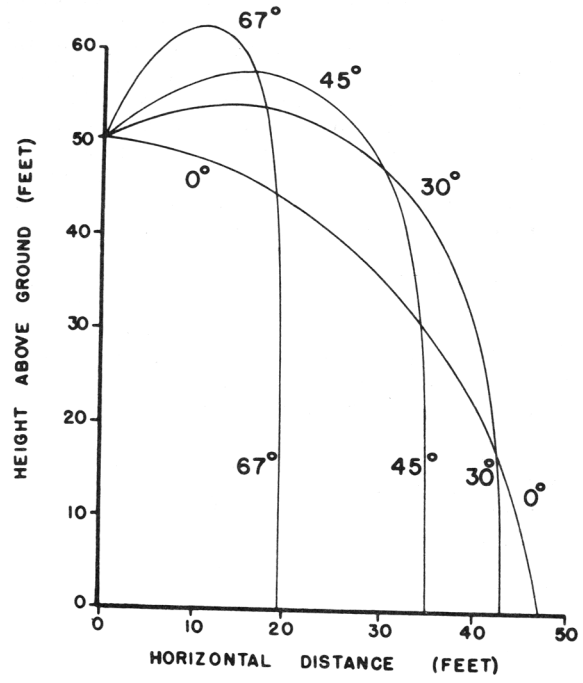

Figure 4--Calculated trajectories of dwarf mistletoe seeds expelled at four vertical angles from a point 50 feet above ground level (after Hawksworth 1961a).

Average distances of maximum spread, based on seed trapping or on infection of reproduction, range from about 40-60 feet in southwestern ponderosa pine (Gill 1954; Gill and Hawksworth 1954; Hawksworth 1961a, 1961b), 25-60 feet in lodgepole pine (Gill and Hawksworth 1964; Hawksworth and Graham 1963; Hawksworth

1973; Muir 1970), and 15-50 feet for western hemlock (Shea and Stewart 1972; Smith 1973). These data correspond well with trajectories calculated by Hawksworth.

Wind may, however, increase the distance of spread. Seed from tall overstory ponderosa or Jeffrey pines can be deposited on smaller trees over distances of 100 feet or more (Roth 1953; Scharpf and Parmeter 1967, 1971; Parmeter and Scharpf 1972) and could infect nearly an acre of reproduction if so dispersed in all directions. Muir found that spread from isolated overstory trees was greater (avg. 45 feet) than from stand margins (avg. 28 feet). The above data indicate that greatest distances of spread are associated with tall, isolated overstory trees exposed to wind. Least distances of spread are associated with relatively even-aged stands.

Stand Composition

The geographic ranges of many species of dwarf mistletoes overlap (Hawksworth and Wiens 1972); however, the occurrence of two species of mistletoe in the same place is not common. While a variety of "crossovers" among host species have been observed (Gill and Hawksworth 1961; Hawksworth 1974; Hawksworth and Wiens 1972; Muir 1973; Smith 1974), in general, one or more species in a mixed stand will be free of mistletoe (Kjuit 1955).

The effects of stand composition on any one host species have not been well documented. In some areas, mistletoe is more frequent in stands where the host species predominates (Graham 1964). In other areas, mistletoe is as abundant or more so in stands where the host species is a lesser component (Acciavatti and Weiss 1974; Graham 1959b, 1960b). In stands undergoing conversion, mistletoe damage is often reduced (Baranyay and Smith 1972; Jones 1974; Hawksworth 1973), and selective pressure on one host may promote stand conversion (Parmeter and Scharpf 1963).

While quantitative data are limited, it can be argued a priori that mistletoe impact will be reduced in mixed stands because a percentage of the trees will not be damaged. Spread through mixed stands may also be reduced if nonsusceptible trees are sufficiently large and sufficiently numerous as to impede flight of mistletoe seeds between susceptible trees. Manipulation of stand composition to reduce damage has been recommended (Baranyay and Smith 1972; Jones 1974; Kimmey 1957; Kimmey and Graham 1960; Parmeter and Scharpf 1963; Scharpf 1964, 1969a; Schwandt 1977).

Stand History

Discussion of dwarf mistletoes and stand dynamics would not be complete without consideration of special events in the history of stand development that affect the characteristics of stands and the incidence of dwarf mistletoes. Chief among these are logging, fire, forest succession, insect activity, and possibly the evolution of resistance mechanisms. These past events probably have had major influences on the mistletoe situations we observe today.

Logging and other stand manipulations will be discussed in following sections of this symposium and will not be dealt with in detail here. Obviously, past cutting practices that have modified vigor, density, age, structure, and composition of stands have influenced mistletoe activity as previously indicated. In a sense we have inherited many of our mistletoe problems from past forest practices. High-grading, selective cutting, and preferential removal of certain species have left many stands open, multistoried, reduced in species complexity, and in a condition to favor rapid buildup and damage by mistletoe. Conversely, extensive clearcutting in some timber types has resulted in large areas of essentially mistletoe-free second growth.

Along with logging, fire has undoubtedly had a major influence on present mistletoe conditions in many areas. The relationship of fire to mistletoe activity has been thoroughly discussed in the excellent reviews of Alexander and Hawksworth (1975) and Wicker and Leaphart (1976) and will be discussed by Muraro in a later section of this symposium. Fires may have positive or negative effects on dwarf mistletoes, depending on the extent and intensity of the burn and on the characteristics of the stand and the terrain. Where large areas of forest have been completely destroyed by intense wildfire, the replacement stand will be mistletoe free except at the margins. Since dwarf mistletoes reinvade such new stands at an average of only 1-2 feet per year following initial infection from the margins (Hawksworth 1958a, 1960b, 1961a; Shea and Stewart 1972; Wagener 1965), large areas of replacement stands remain mistletoe free.

Owing to patchy fuel accumulations, rock outcrops, and other irregularities, even large fires often leave groups or individual live trees within burned areas. When infected, these can serve as sources of inoculum to

reinfest the replacement stand. In some regions, the prevalence of dwarf mistletoes is markedly associated with areas where large, complete burns are rare because of terrain or fuel conditions (Baranyay 1970).

Available evidence suggests that frequent low-intensity ground fires were characteristic of many forest types (Biswell 1967; Weaver 1974). Because heavy dwarf mistletoe infection leads to accumulation of dead trees, witches' brooms, resinous stems and branches, and other fuels, low intensity fires may flare up and consume most of the trees in localized infection centers. In addition, heavy brooming provides concentrated fuel for "torching" and destruction of infected trees, where normal tree crowns are too open to carry fire up the tree. Low intensity fires may also kill infected lower branches, thus reducing mistletoe populations in lower crowns (Roth 1974). These fire effects have probably reduced mistletoes in many areas, but not all fire effects have been beneficial.

In the long view, fires have also served to perpetuate seral fire types in which dwarf mistletoes may be a perpetual problem. In addition, owing to accumulation of fuels in stands with mistletoe levels sufficient to apply selection pressures for resistance, locally intense fires may have greatly reduced opportunities for the evolution of resistance, since any resistant trees within such stands would be consumed along with infected trees (Roth 1966).

Resistance to dwarf mistletoes is infrequently observed and poorly understood. Some trees within stands are essentially free of mistletoe, even when exposed to abundant inoculum (Hawksworth 1961a, Roth 1953, 1971; Wagener 1965). In other cases, stands over large areas may show differing susceptibilities. Hawksworth (1961b) found that inoculation of trees in infested stands produced 10 times the rate of infection obtained from inoculations in uninfested stands, apparently because of differences in the survival of germinated seed. Infection of ponderosa pine by A. americanum is uncommon in stands infested by A. vaginatum and vice versa (Hawksworth 1968b). Scharpf and Parmeter (1967) provided limited evidence that Jeffrey pines from high elevation seed sources were more susceptible than trees from low elevation sources. Smith and Wass (1976) found that A. tsugensis includes forms that preferentially attack shore pine in some areas and hemlock in others. Hawksworth and Wiens (1972) discussed the "exclusion principle", a frequently observed phenomenon in which other species of mistletoes seldom infect trees in stands infested by a principal dwarf mistletoe of the host.

While genetic interactions among hosts and parasites undoubtedly account for some of the above observations and some bases for resistance have been suggested (Roth 1966; Smith 1974), environmental limitations and evolution of ecotypes might also account for different host/parasite interactions in different stands. These phenomena deserve further investigation, since prediction of mistletoe damage in different stands may rest with understanding of the bases for differing host/parasite interactions.

Forest succession has also influenced the present distribution and intensity of dwarf mistletoes. As has been pointed out by Hawksworth (1973), mistletoe damage is often reduced when stands of seral species are replaced by "climax" species. It can be argued that in stands where succession from one species to another is possible, dwarf mistletoe will apply pressure against the susceptible host, thus hastening stand succession (Parmeter and Scharpf 1963). However, if mistletoe species attacking the "climax" species are present in stands, reduction of mistletoe damage by succession may be only temporary.

Wass (1976) indicated that hemlock mistletoe on shore pine is mainly a problem where shore pine tends to be climax. In California, it appears that heavy mistletoe damage is often associated with such timber types as eastside Jeffrey pine, upper elevation red fir, and poor-site lodgepole pine in which the host species are self perpetuating and opportunities for succession to other species or to mixtures are minimal. Perpetuation of "climax" types may eventually lead to heavy mistletoe damage because such types tend, in the absence of catastrophic removal, to develop uneven-aged structures, a condition favoring dwarf mistletoe intensification.

It is difficult to reconstruct past successional changes that have affected present mistletoe conditions. It seems safe to assume, however, that frequent changes in timber type resulting from the interplay of catastrophe and succession have helped to reduce mistletoe incidence. And conversely, perpetuation of the same type, either seral fire types or "climax" types has tended to increase mistletoe damage. Knowledge of such trends can aid land managers in long-range planning.

While logging, fire, and succession are probably the main factors that have shaped the character of stands and the distribution

of mistletoes within stands, other events have likely had significant influence. Epidemic insect activity can change the composition and structure of forest stands (Schmid and Hinds 1974). Few data are available to assess possible effects of insect activity on dwarf mistletoe populations, and both plus and minus effects can be postulated. Infected trees are often attacked by bark beetles (Hawksworth 1973), and each killed, infected tree represents a temporary reduction in inoculum. However, random killing of individual trees may lead to open, uneven-aged stands in which mistletoes are ultimately more damaging. Extensive killing, as can result from repeated defoliation of lodgepole pine by needle miners (Koerber and Struble 1971), might have effects similar to fire in that replacement stands would tend to be even-aged and surviving overstory trees would provide inoculum for infection of reproduction.

Dwarf mistletoes may also influence insect activity. Trees weakened by dwarf mistletoes are often susceptible to bark beetle attack (Hawksworth 1973; Miller and Keen 1960; Struble 1965), although heavily infected trees may provide poor substrate for brood development (Roe and Amman 1970). Details of possible relationships between dwarf mistletoes and population dynamics of destructive forest insects are poorly understood and should provide a fruitful area for further study.

OTHER ECOLOGICAL INFLUENCES

Available evidence suggests that a variety of factors other than stand dynamics per se affect the occurrence and intensity of dwarf mistletoe populations. Many of these factors are not well understood and evidence for their influences is often circumstantial. Mistletoes are higher plants and we can expect that they are subject to many of the same environmental limitations that govern the distribution of other higher plants. Detailed discussion of these ecological factors is beyond the scope of this paper, but mention should be made of their existence and possible implications in land management.

The distribution of dwarf mistletoes is not continuous over the ranges of their host species. These discontinuities have been discussed by a number of workers (Baranyay and Smith 1972; Baranyay 1970; Hawksworth and Wiens 1972; Smith and Baranyay 1970; Wicker 1974b). They include the absence of mistletoes over large geographic areas (Hawksworth and Wiens 1972); the absence from certain habitat types (Acciavatti and Weiss 1974; Hadfield 1977; Hawksworth 1973; Hawksworth and Wiens 1972), and absence or reduced activity in relation to slope, aspect, and other topographic features (Andrews and Daniels 1960; Baranyay 1970; Gill 1957; Gill and Hawksworth 1961, 1964; Hawksworth 1958b, 1961a, 1968a; Larson et al. 1970; Roth 1954; Williams et al. 1972).

The absence of dwarf mistletoes on some hosts over major portions of the host range may involve large scale shifts in ranges associated with advance and retreat of ice sheets during glacial epochs (Hawksworth and Wiens 1972). Other large-scale discontinuities may be due to geographical barriers or discontinuities in the distribution of host species (Wicker 1974b). On a smaller scale, absence of mistletoe can involve such catastrophes as volcanic devastation (Hawskworth 1960b).

Environmental limitations may also be responsible for some of the observed patterns of dwarf mistletoe distribution. Seed survival, germination, and radicle development are sensitive to both high and low temperature extremes (Beckman and Roth 1968; Knutson 1971; Scharpf 1969b, Wicker 1974a). Gill (1957) recognized that the upper elevational limit of A. americanum in the Rocky Mountains coincides with the 30 F mean annual isotherm. Baranyay and Smith (1974) showed that freezing temperatures before or during seed dispersal permanently damaged fruits and greatly reduced seed discharge of A. americanum and A. tsugense.

In some regions, mistletoes may be restricted by inadequate moisture during the period of germination and infection (Bonga 1969, Hawksworth 1967). Moisture is required for seed germination, and unsuitable moisture conditions may reduce viability, germination, or survival (Bonga 1969; Knutson 1971; Wicker 1974a).

Our present state of knowledge about requirements and limitations is inadequate to permit firm correlation of distribution patterns with environmental limitations in most cases, but it seems reasonably certain that such limitations exist. Future studies may help to distinguish between areas that are mistletoe free because mistletoes haven't successfully spread into them and areas that are mistletoe free because mistletoes can't successfully spread into them. In either case, today's land managers must deal with mistletoes where they are, and prudent land managers will take steps to minimize the possibility of their spread or introduction into areas presently free of mistletoes on important hosts.

CONCLUSIONS

Mistletoe damage and impact in forest stands are mainly functions of the numbers of infected trees and the distribution and numbers of infections within tree crowns. These parameters are in turn functions of the rates at which mistletoes spread through stands, the rates at which they spread vertically within crowns, and the rates at which populations increase. These rates are governed in large part by stand characteristics that can be manipulated by land managers.

Basic principles of tree/stand/mistletoe interactions are well established and provide broad guidelines for stand management. Many refinements of our information base will be necessary to develop precision in the management of the many timber types and host/mistletoe combinations under different geographic, topographic, climatic, and site conditions. Ultimately, predictive models of varying precision, as have been explored by Myers, et al. (1976), Strand and Roth (1976), and Edminster (this vol.), should become available to managers. We need not wait for such models, however. The broad principles already developed can and should be applied to the management of stands in which dwarf mistletoes are an actual or potential problem. Ideally, as these principles are applied, post-treatment research and monitoring on a long-term basis will: (1) provide needed refinement of our data base, (2) confirm or dismiss presently uncertain but suspected relationships, and (3) lead to the development of new concepts and approaches to the control of dwarf mistletoe impact.

LITERATURE CITED

Acciavatti, R. E., and M. J. Weiss.
1974. Evaluation of dwarf mistletoe on Engelmann spruce, Fort Apache Indian Reservation, Arizona. Plant Dis. Rep. 58:34-35.

Alexander, R. R.
1975. Partial cutting in old-growth lodgepole pine. USDA For. Serv. Res. Pap. RM-136. 17 p.

Alexander, M. E. and F. G. Hawksworth.
1975. Wildlands fires and dwarf mistletoes: a literature review of ecology and prescribed burning. USDA For. Serv. Gen. Tech. Rep. RM-14. 12 p.

Andrews, S. R. and J. P. Daniels.
1960. A survey of dwarfmistletoes in Arizona and New Mexico. USDA For. Serv., Rocky Mtn. For. Range Exp. Stn. Pap. 49. 17 p.

Baranyay, J. A.
1970. Lodgepole pine dwarf mistletoe in Alberta. Can. For. Serv. Publ. 1286. 22 p.

Baranyay, J. A., and L. Safranyik.
1970. Effect of dwarf mistletoe on growth and mortality of lodgepole pine in Alberta. Can. For. Serv. Publ. 1285. 19 p.

Baranyay, J. A., and R. B. Smith
1972. Dwarf mistletoes in British Columbia and recommendations for their control. Can. For. Serv. BC-X-72. 18 p.

Baranyay, J. A., and R. B. Smith
1974. Low temperature damage to dwarf mistletoe fruit. Can. J. For. Res. 4:361-365.

Beckman, K. M., and L. F. Roth
1968. The influence of temperature on longevity and germination of seed of western dwarf mistletoe. Phytopathology 58:147-150.

Biswell, H. H.
1967. Forest fire in perspective. Proc. Tall Timbers Fire Ecology Conf.:43-64.

Bonga, J. M.
1969. Growth potential of seeds and site requirements of eastern dwarf mistletoe. Can. Dep. Fish and For., Bi-monthly Res. Notes 25(2):10-11.

Childs, T. W.
1963. Dwarfmistletoe control opportunities in ponderosa pine reproduction. USDA For. Serv., Pac. Northw. For. Range Exp. Stn. Ofc. Rep. 20 p.

Childs, T. W., and J. W. Edgren
1967. Dwarfmistletoe effects on ponderosa pine growth and trunk form. For. Sci. 13: 167-174.

Childs, T. W., and E. R. Wilcox
1966. Dwarfmistletoe effects in mature ponderosa pine forests in south-central Oregon. J. For. 64:246-250.

Daubenmire, R.
1961. Vegetative indicators of rate of height growth in ponderosa pine. For. Sci. 7:24-34.

Daubenmire, R.
1969. Ecological plant geography of the Pacific Northwest. Madroño 20:111-128.

Dooling, O. J.
1974. Dwarf mistletoe control--why and what?

USDA For. Serv. - Northern Reg. Rep. 74-16. 11 p.

Dooling, O. J., and D. H. Brown
1976. Guidelines for dwarf mistletoe control in lodgepole pine in the northern and central Rocky Mountains. USDA For. Serv., Northern Reg., For. Environ. Prof. Rep. 76-14. 10 p.

Etheridge, D. E.
1973. Wound parasites causing tree decay in British Columbia. Can. Dep. Environ. For. Serv., Pac. For. Res. Cent. For. Pest Leafl. 62. 15 p.

Flora, D. F.
1966. A method of forecasting returns from ponderosa pine dwarfmistletoe control. USDA For. Serv. Res. Pap. PNW-32. 17 p.

Gill, L. S.
1954. Dwarfmistletoe of ponderosa pine in the Southwest. USDA For. Serv., Rocky Mtn. For. Range Exp. Stn., Stn. Paper 14. 9 p.

Gill, L. S.
1957. Dwarfmistletoe of lodgepole pine. USDA For. Serv., For. Pest Leafl. 18. 7 p.

Gill, L. S., and F. G. Hawksworth
1954. Dwarfmistletoe control in southwestern ponderosa pine forests under management. J. Forestry 52:347-353.

Gill, L. S. and F. G. Hawksworth
1961. The mistletoes, a literature review. USDA Tech. Bull. 1242. 87 p.

Gill, L. S., and F. G. Hawksworth
1964. Dwarfmistletoe of lodgepole pine. USDA For. Serv. For. Pest Leafl. 18. 7 p.

Graham, D. P.
1959a. Dwarfmistletoe survey in Kootenai National Forest. USDA For. Serv. Interm. For. Range Exp. Stn. Res. Note 67. 5 p.

Graham, D. P.
1959b. Dwarfmistletoe survey in Coeur D' Alene National Forest. USDA For. Serv., Interm. For. Range Exp. Stn. Res. Note 68. 5 p.

Graham, D. P.
1960a. Dwarfmistletoe survey in Nezperce National Forest. USDA For. Serv., Interm. For. Range Exp. Stn. Res. Note 75. 7 p.

Graham, D. P.
1960b. Dwarfmistletoe survey in Kaniksu National Forest. USDA For. Serv., Interm. For. Range Exp. Stn. Res. Note 74. 6 p.

Graham, D. P.
1964. Dwarfmistletoe survey in western Montana. USDA For. Serv. Res. Note INT-14. 7 p.

Graham, D. P.
1967. A training aid on dwarf mistletoe and its control. USDA For. Serv., Pac. Northw. Reg., Portland, Oregon. 40 p.

Graham, D. P., and W. E. Frazier
1962. Dwarfmistletoe survey in northeastern Washington. USDA For. Serv., Interm. For. Range Exp. Stn. Res. Note 103. 8 p.

Hadfield, J. S.
1977. A disease survey of lodgepole pine stands in Oregon and Washington. USDA For. Serv., Pac. Northw. Region, For. Insect Disease Management. 13 p.

Haglund, S. A., and O. J. Dooling
1972. Observations on the impact of dwarf mistletoe on Douglas-fir in western Montana. USDA For. Serv., Northwest Reg. Rep. D-72-1.

Hawksworth, F. G.
1958a. Rate of spread and intensification of dwarfmistletoe in young lodgepole pine stands. J. For. 56:404-407.

Hawksworth, F. G.
1958b. Survey of lodgepole pine dwarfmistletoe on the Roosevelt, Medicine Bow, and Bighorn National Forests. USDA For. Serv., Rocky Mtn. For. Range Exp. Stn. Pap. 35. 13 p.

Hawksworth, F. G.
1960a. Growth rate of dwarfmistletoe infections in relation to the crown class of the host. USDA For. Serv. Rocky Mtn. For. Range Exp. Stn. Res. Note 41. 4 p.

Hawksworth, F. G.
1960b. Distribution of ponderosa pine dwarfmistletoe in the vicinity of an Arizona volcano. Ecology 41:799-800.

Hawksworth, F. G.
1961a. Dwarfmistletoe of ponderosa pine in the Southwest. USDA For. Serv. Tech. Bull. 1246. 112 p.

Hawksworth, F. G.
1961b. Dwarfmistletoes of ponderosa pine. Pages 1537-1541 in Recent Advances in Botany. Univ. Toronto Press, Toronto, Can.

Hawksworth, F. G.
1965. Life tables for two species of dwarf mistletoe. 1. Seed dispersal, intercep-

tion and movement. For. Sci. 11:142-151.

Hawksworth, F. G.
1967. Distribution of ponderosa pine dwarf mistletoe on the south rim of Grand Canyon, Arizona. Plant Dis. Rep. 12:1049-1051.

Hawksworth, F. G.
1968a. Ponderosa pine dwarf mistletoe in relation to topography and soils on the Manitou Experimental Forest, Colorado. USDA For. Serv. Res. Note RM-107. 4 p.

Hawksworth, F. G.
1968b. Lodgepole pine dwarf mistletoe on ponderosa pine. Plant Dis. Rep. 52:125-127.

Hawksworth, F. G.
1969. Rapid intensification and upward spread of dwarf mistletoe in inoculated digger pines. Plant Dis. Rep. 53:615-616.

Hawksworth, F. G.
1973. Dwarf mistletoe and its role in lodgepole pine ecosystems. Pages 342-358 In Proc. Manage. Lodgepole Pine Ecosystems Symp. D. M. Baumgartner, ed. Wash. State Univ., Pullman.

Hawksworth, F. G.
1974. Mistletoes on introduced trees of the world. USDA For. Serv. Agric. Handb. 469. 49 p.

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

Hawksworth, F. G., and D. P. Graham
1963. Spread and intensification of dwarf-mistletoe in lodgepole pine reproduction. J. For. 61:587-591.

Hawksworth, F. G. and T. E. Hinds
1964. Effects of dwarfmistletoe on immature lodgepole pine stands in Colorado. J. For. 54:384-390.

Hawksworth, F. G., and A. A. Lusher.
1956. Dwarfmistletoe survey and control on the Mescalero Apache Reservation, New Mexico. J. For. 54:384-390.

Hawksworth, F. G., and D. Wiens
1972. Biology and classification of dwarf mistletoes (Arceuthobium). USDA For. Serv. Agric. Handb. 401. 234 p.

Jones, J. R.
1974. Silviculture of southwestern mixed conifers and aspen: the status of our knowledge. USDA For. Serv. Res. Pap. RM-122. 44 p.

Kimmey, J. W.
1957. Dwarfmistletoes of California and their control. USDA Calif. For. Range Exp. Stn. Tech. Pap. 19. 12 p.

Kimmey, J. W., and D. P. Graham
1960. Dwarfmistletoes of the Intermountain and northern Rocky Mountain regions and suggestions for control. USDA For. Serv., Interm. For. Range Exp. Stn. Res. Pap. 60. 19 p.

Knutson, D. M.
1971. Dwarf mistletoe seed storage best at low temperature and high relative humidity. USDA For. Serv. Res. Note PNW-145. 8 p.

Knutson, D. M.
1974. Infection techniques and seedling response to dwarf mistletoe. Plant Dis. Rep. 58:235-238.

Knutson, D. M., and W. J. Toevs
1972. Dwarf mistletoe reduces root growth of ponderosa pine seedlings. For. Sci. 18:323-324.

Koerber, T. W., and G. R. Struble
1971. Lodgepole needle miner. USDA For. Serv., For. Pest Leafl. 22. 8 p.

Korstian, C. F., and W. H. Long
1922. The western yellow pine mistletoe. U.S. Dep. Agric., Agric. Bull. 1112. 35 p.

Kuijt, J.
1955. Dwarf mistletoes. Botan. Rev. 21:569-620.

Larson, F. R., P. F. Folliott, and W. P. Clary
1970. Distribution of dwarf mistletoe in ponderosa pine stands on the Beaver Creek watershed, Arizona. USDA For. Serv. Res. Note RM-175. 4 p.

Lightle, P. C.
1966. Dwarf mistletoe reduces basal area growth in ponderosa pine in the Southwest. (Abstr.) Phytopathology 56:886-887.

Lightle, P. C., and F. G. Hawksworth
1973. Control of dwarf mistletoe in a heavily used ponderosa pine recreation forest: Grand Canyon, Arizona. USDA For. Serv. Res. Pap. RM-106. 22 p.

Miller, J. M., and F. P. Keen
1960. Biology and control of the western

pine beetle. USDA Misc. Publ. 800. 381 p.

Muir, J. A.
1970. Dwarf mistletoe spread in young lodgepole pine stands in relation to density of infection sources. Dep. Fish For. Bi-mon. Res. Notes 26:49.

Muir, J. A.
1972. Increase of dwarf mistletoe infections on young lodgepole pines. Can. J. For. Res. 2:413-416.

Muir, J. A.
1973. Lodgepole pine dwarf mistletoe on Douglas fir in Alberta. Can. For. Serv. Bi-mon. Res. Notes 29:25-26.

Myers, C. A., C. B. Edminster, and F. G. Hawksworth
1976. SWYLD2: Yield tables for even-aged and two storied stands of Southwestern ponderosa pine, including effects of dwarf mistletoes. USDA For. Serv. Res. Pap. RM-163. 25 p.

Parmeter, J. R., Jr., and R. F. Scharpf
1963. Dwarf mistletoe on red fir and white fir in California. J. For. 61:371-374.

Parmeter, J. R., Jr., and R. F. Scharpf
1972. Spread of dwarf mistletoe from discrete seed sources into young stands of ponderosa and Jeffrey pines. USDA For. Serv. Res. Note PSW-269. 5 p.

Pierce, W. R.
1960. Dwarf mistletoe and its effect upon the larch and Douglas fir of western Montana. Mont. St. Univ. Sch. For. Bull. 10. 38 p.

Richardson, K. S., and B. J. van der Kamp
1972. The rate of upward advance and intensification of dwarf mistletoe on immature western hemlock. Can. J. For. Res. 2:313-316.

Roe, A. L., and G. D. Amman
1970. The mountain pine beetle in lodgepole pine forests. USDA For. Serv. Interm. For. Range Exp. Stn. Res. Pap. INT-71. 23 p.

Roth, L. F.
1953. Pine dwarf mistletoe on the Pringle Falls Experimental Forest. USDA For. Serv., Pac. Northw. For. Range Exp. Stn. Note 91. 3 p.

Roth, L. F.
1954. Distribution, spread and intensity of dwarf mistletoe on ponderosa pine. Phytopathology 44:504.

Roth, L. F.
1959. Natural emplacement of dwarf mistletoe seed on ponderosa pine. For. Sci. 5: 365-369.

Roth, L. F.
1966. Foliar habit of ponderosa pine as a heritable basis for resistance to dwarf mistletoe. Pages 221-228 in Breeding Pest-Resistant Trees (H. D. Gerold, R. E. McDermott, E. J. Schreiner, and J. A. Winieski, eds.). Pergamon Press, New York. 505 p.

Roth, L. F.
1971. Dwarf mistletoe damage to small ponderosa pines. For. Sci. 17:373-380.

Roth, L. F.
1974. Juvenile susceptibility of ponderosa pine to dwarf mistletoe. Phytopathology 64:689-692.

Scharpf, R. F.
1962. Growth rate of the endophytic system of the dwarf mistletoe on digger pine. USDA For. Serv., PSW Res. Note 193. 5 p.

Scharpf, R. F.
1964. Dwarf mistletoe on true firs in California. USDA For. Pest Leafl. 89. 7 p.

Scharpf, R. F.
1969a. Dwarf misteltoe on red fir, infection and control in understory stands. USDA For. Serv. Res. Pap. PSW-50. 8 p.

Scharpf, R. F.
1969b. Temperature affects penetration and infection of pines by dwarf mistletoes. For. Sci. 15:149-151.

Scharpf, R. F. and F. G. Hawksworth
1968. Dwarf mistletoe on sugar pine. USDA For. Serv., For. Pest Leafl. 113. 4 p.

Scharpf, R. F., F. G. Hawksworth, and B. J. Erickson
1976. Mistletoe literature of the world: a user's guide to a FAMULUS retrieval system. USDA For. Serv. Gen. Tech. Rep. RM-30. 5 p.

Scharpf, R. F., and J. R. Parmeter
1967. Spread of dwarfmistletoe into Jeffrey pine plantation. USDA For. Serv. Res. Note PSW-141. 6 p.

Scharpf, R. F. and J. R. Parmeter, Jr.
1971. Seed production and dispersal by dwarf mistletoe in overstory Jeffrey pines

in California. USDA For. Serv. Res. Note PSW-247. 5 p.

Scharpf, R. F., and J. R. Parmeter, Jr.
1976. Population buildup and vertical spread of dwarf mistletoe on young red and white firs in California. USDA For. Serv. Res. Pap. PSW-122. 9 p.

Schmid, J. M., and T. E. Hinds
1974. Development of spruce-fir stands following spruce beetle outbreaks. USDA For. Serv. Res. Pap. RM-131. 16 p.

Schwandt, J. W.
1977. Dwarf mistletoe control guidelines for Idaho forests, Idaho Dept. of Lands, Div. For. Res., Bur. Private For., Rep. 77-2. 13 p.

Shea, K. R.
1963. Diameter increment in old-growth Douglas fir infected by dwarf mistletoe. Weyerhauser Co. For. Res. Note 50. 11 p.

Shea, K. R., and P. G. Belluschi
1965. Effects of dwarfmistletoe on diameter increment of immature ponderosa pine before and after partial logging. Weyerhauser For. Res. Center Pap. 4. 7 p.

Shea, K. R., and T. J. Orr
1963. A survey of dwarfmistletoe of ponderosa pine in south-central Oregon. J. For. 61:138-141.

Shea, K. R., and J. L. Stewart
1972. Hemlock dwarf mistletoe. USDA For. Serv., For. Pest Leafl. 135. 6 p.

Smith, R. B.
1969. Assessing dwarf mistletoe on western hemlock. For. Sci. 15:277-285.

Smith, R. B., and J. A. Baranyay
1970. Dwarf mistletoes in British Columbia. Canad. For. Serv., For. Res. Lab., Misc. Publ. BC-M3-71. 8 p.

Smith, R. B.
1973. Factors affecting dispersal of dwarf mistletoes on plantation grown trees in British Columbia. Can. For. Serv. Rep. BC-X-97. 21 p.

Smith, R. B., and E. F. Wass
1976. Field evaluation of ecological differentiation of dwarf mistletoe on shore pine and western hemlock. Can. J. For. Res. 6:225-228.

Stewart, J. L.
1976. Dwarf mistletoe infection from residual hemlock on cutover stands. USDA For. Serv. Res. Note PNW-278. 3 p.

Strand, M. A.
1973. Simulation of population changes of western dwarf mistletoe on ponderosa pine. Ph.D. Thesis, Oregon State University, Corvallis.

Strand, M. A., and L. F. Roth
1976. Simulation model for spread and intensification of western dwarf mistletoe in thinned stands of ponderosa pine saplings. Phytopathology 66:888-895.

Struble, G. R.
1965. Attack pattern of mountain pine beetle in sugar pine stands. USDA For. Serv. Res. Note PSW-60. 7 p.

Wagener, W. W.
1961. Forty years of dwarfmistletoe on a ponderosa pine plot near Quincy, California. USDA For. Serv., PSW For. Dis. Res. 4600 (file). 15 p.

Wagener, W. W.
1965. Dwarfmistletoe removal and reinvasion in Jeffrey and ponderosa pine, northeastern California. USDA For. Serv. Res. Note PSW-73. 8 p.

Wass, E. F.
1976. Ecology of shore pine stands infested with dwarf mistletoe. Can. For. Serv. BC-X-142. 33 p.

Waters, W. E.
1976. Evaluation of insect impacts on forest productivity and values. In The Bases for Integrated Pest Management. Proc. XVI IUFRO World Congr., Group 6, Oslo, Norway. 28 p.

Weaver, H.
1974. Effects of fire on temperate forests: Western United States, p. 279-319. In Fire and Ecosystems. Kozlowski, T. T. and C. E. Ahlgren, eds. Academic Press, New York. 542 p.

Weir, J. R.
1916. Larch mistletoe:some economic considerations of its injurious effects. USDA Bull. 317. 25 p.

Weir, J. R.
1918. Effects of mistletoe on young conifers J. Agric. Res. 12:715-718.

Wicker, E. F.
1967. Seed density as a klendusic factor of infection and its impact upon propagation of Arceuthobium spp. Phytopathology 57: 1164-1168.

Wicker, E. F.
1974a. Ecology of dwarf mistletoe seed. USDA For. Serv. Res. Pap. INT-154. 28 p.

Wicker, E. F.
1974b. Arceuthobium douglasii: its absence from the flora of the Puget-Willamette lowlands. Northw. Sci. 48:239-244.

Wicker, E. F., and C. D. Leaphart
1976. Fire and dwarf mistletoe (Arceuthobium spp.) relationships in the northern Rocky Mountains. Proc. Montant Tall Timbers Fire Ecology Conference and Fire and Land Management Symposium, No. 14, Missoula, Montana. 1974. p. 279-298.

Wicker, E. F., and C. G. Shaw
1967. Target area as a klendusic factor in dwarf mistletoe infections. Phytopathology 57:1161-1163.

Williams, W. T., F. Fortier, and J. Osborn
1972. Distribution of three species of dwarf mistletoe on their principal pine hosts in the Colorado Front Range. Plant Dis. Rep. 46:223-226.

Control Planning and Decisionmaking

CONTROL PLANNING AND DECISIONMAKING[1/]

WILFRED L. FREEMAN, JR.[2/]

Abstract: Decisions about dwarf mistletoe control are made by a process common in forest pest management and, indeed, common in forest resource management. The decision-making process is examined in detail, to show its logic, to demonstrate that landowners or resource managers are the decisionmakers, to review what inputs and decisions have to be made in the process, and to clarify the responsibilities of forest pest management (and other) specialists in the process. The point is made that today's landowners and resource managers typically need information that only specialists can provide, and that specialists are not informed enough to make sound land management decisions.

INTRODUCTION

In this panel we are to discuss the topic "Control Planning and Decisionmaking" -- or the how, when, and where of control decisions and the information base needed to make sound decisions. The essential steps of the control decision process will be outlined, with the objectives of 1) indicating that there is a logical sequence of events leading to control decisions, and 2) providing a reference framework into which the remarks and contributions from others in the field may be placed.

The control-decision process is made up of a logical sequence of steps leading to answers to the questions, "Do I control?" and, "How do I control?" The answers to these questions should be based on information about the stands, pest-caused losses, management goals, environmental and social considerations, and control options. As I briefly go through the steps in the control-decision process, I will indicate which steps are information gathering -- and what information is needed and where you might best get it -- and those steps that are decisionmaking. I will indicate who should make the decision, and what kinds of decisions might be made.

What I am describing -- the processes of informed decisionmaking which are used by forest landowners and resource managers -- is not unique to dwarf mistletoe work. Whether and how a landowner or resource manager reacts to dwarf mistletoe is determined by processes used in deciding what to do about many other things affecting him and his forest resources. Those who provide technical advice and assistance to landowners and resource managers, therefore, should know the kinds of information needed and the value of this information to the decision-making process.

PATHWAY TO CONTROL DECISIONS

The steps in the decision process are arranged into a flowchart (fig. 1) and will be discussed in the logical order in which they occur in the process.

Step 1: "Detection of Pest Activity." -- A pest activity on the forest is detected. I say "pest activity" because, at this point, it is yet to be determined if it is a problem. Pest detection takes place in several ways. For example, it may occur as a casual observation, as in the course of a forest management inventory: or, it may be the result of a pest survey. Indications of pest activity include the appearance of the pest, signs of tree damage, loss of growth, or tree death.

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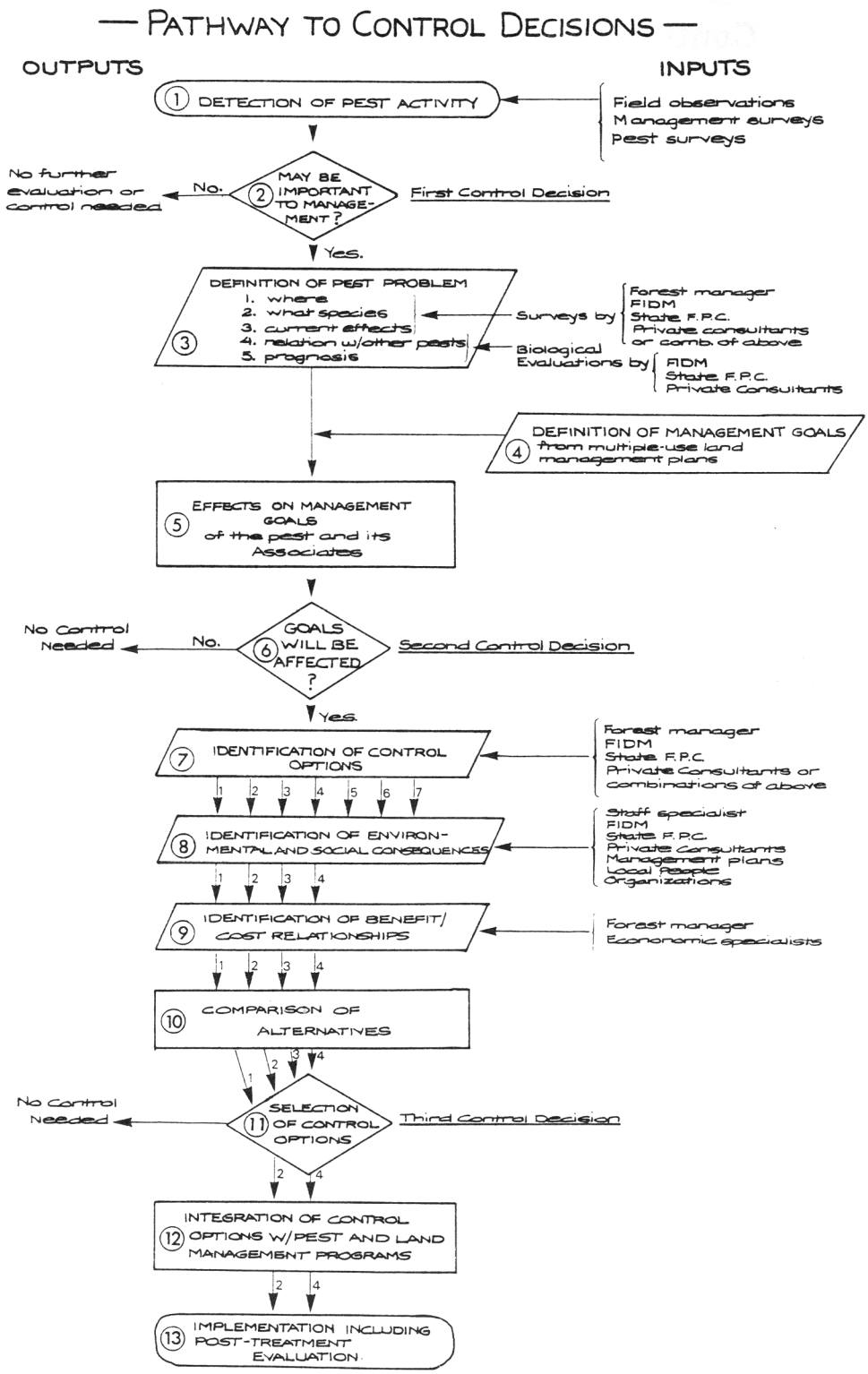

Figure 1--The pathway to control decisions is a logical step-wise progression in 13 steps.

Step 2: "First Control Decision." -- At the time the pest activity is detected, or shortly thereafter, someone is required to make the first control decision, and this decision begins the process. Essentially, this first decision is based on the question, "Might this pest activity be important in the management or ownership of this forest or stand?" If the answer is "no" -- that in the owner or manager's estimation the pest does not pose a problem to his ownership or management objectives -- the process ends and no further action is required. A "no" answer can result from such things as low damage levels, damage to noncommercial species, and management constraints. If the answer is "yes," we proceed to Step 3.

Step 3: "Definition of the Pest Problem." -- At this Step the biological information needed for decisionmaking is assembled. Because so much else depends on it, this information must be sound. It is not necessary, however, for the total biological information package to be prepared only by pest management specialists. To clarify, the work of getting the biological information falls in two categories. Learning where the problem is, what host trees are affected, and the current losses are jobs that can be done by the forest resource manager or landowner, as well as by specialists in Forest Insect and Disease Management (in the Forest Service), State forest pest control units, and private industry (consulting forest entomologists and pathologists). The expertise of pest management specialists should be used, however, to get the other biological information needed: the interrelationships of insects and diseases with forest conditions that have caused the situation, and the prediction of what will happen if no action is taken -- that is, expected pest-caused losses and stand development.[3/]

Step 4: "Definition of Management Goals."-- The determination of management goals is one of the most frequently overlooked steps in the control-decision process. In many single-purpose management units, the goals may be easy to define, but in multiple-use forest management units, they may be quite varied. The land and resource management plans at various administrative levels should be a good source of information for defining the objectives of the particular unit.

Step 5: "Pest Effects on Management Goals."-- Now that the landowner or resource manager has information on the effects of the pest or pests from Step 3 and has assembled the management goals for the unit (Step 4), he examines them together here. His purpose is to learn if the pest-caused damage is affecting his current management goals adversely to any significant degree, and whether it may prevent the achievement of future goals. He has enough information to make some first estimates of how serious the losses are and will be. When losses are not serious, they are referred to as having "no negative effect." Examples of no negative effect from pest damage might be scattered mortality in wilderness or roadless areas, growth loss in recreation areas, and scattered mortality in unthinned, overstocked, young nonmerchantable timber stands.

Step 6: "Second Control Decision." -- In this Step the landowner or resource manager can now make the second control decision by answering the question "Is the pest problem keeping me from reaching my management goals?" The answer to this question was developed in Step 5 Again, if the answer to this question is "No, the pest is not affecting the attainment of management goals," then no control efforts are needed and the process ends. If the answer is "yes," we proceed to Step 7.

Step 7: "Identification of Control Options." -- After a decision that goals are adversely affected, the landowner or resource manager needs to identify the control options available. They may include mechanical, biological, chemical, or cultural approaches to control. Assistance to the forest manager in identifying the options is available from FIDM, State forest pest control staffs, private consultants, or combinations of the above.

Step 8: "Identification of Environmental and Social Consequences." -- This is another input step, but it can have the effect of eliminating certain control options from further consideration. Here the environmental and social consequences of taking no action at all are identified and arrayed with the consequences associated with each alternative control option. A control option calling for clearcutting on a steep slope with unstable soil could be eliminated here. Also, one calling for removal of all overstory trees in a heavily used recreation area could be eliminated. Assistance in identifying environmental and social considerations, is available from management plans and specialists in wildlife, archeology, hydrology, recreation and other disciplines. Input may be needed from local people who could be affected or interested, organizations, governmental agencies, politicians, and others. Some insights

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[3/] When pest management specialists undertake all the work described in this step, they refer to it as "biological evaluation."

are available from forest pest management specialists (Forest Service, State, and private industry) in identifying the environmental and social effects of control options.

Step 9: "Identification of Benefit/Cost Relationship." -- In this final input step, the economic effects of taking no action at all and of taking each of the alternative control options are determined. Economic values are applied to information from Steps 3 and 5: current and predicted effects of the pest on management goals. Assigning realistic economic values to resources is a job familiar to the landowner or resource manager. He may do it himself or he may have specialists who assist him with it. Sometimes the job of economic evaluation is very difficult, because in fact the process requires the assignment of human values to damaged or undamaged forest resources, and human values are more than just monetary, measurable in dollars. Examples of things that have difficult-to-measure human values include: seeing wildlife, experiencing peace, feeling solitude, having a forest setting for recreation, identifying with the living force of a forest environment, feeling the great ages represented in forests, and witnessing the cycle of life and death in forest ecology. Complicated and controversial or not, human values involved in a pest situation must be identified and weighed by the decisionmaker in any benefit/cost relationship.

The role of pest management specialists in this Step is to identify the resources affected by the insect or disease and to help quantify the damage to those resources of concern to the landowner or resource manager. When the benefit/cost relationships have been clarified, the decisionmaker is ready to take the next step.

Step 10: "Comparison of Alternatives." -- In this Step the landowner or resource manager compares the control options available to him. He examines and contrasts the biological, environmental, social, and economic consequences of taking no action at all, and of taking each of the alternative control actions that were identified for him.

In the Forest Service it is at this step in the decisionmaking process that the Environmental Analysis Report is written. Missing from the completed report, of course, is a statement of what the decision is, and why; that comes at the next Step. At this step, the job is to assemble all of the information that will be considered in making that decision. This documentation of the information considered in making decisions that affect the environment is a requirement of the National Environmental Policy Act.

Step 11: "Selection of Control Options." -- After comparing the various alternative actions he might take and the consequences of each, the landowner or resource manager makes his decision at this Step. He may decide on no control action at all. Or he may select more than one option -- he might select a chemical control for immediate suppression and a cultural control for long-term prevention.

Step 12: "Integration of Control Options with Land and Pest Management Programs." -- In this Step, the landowner or resource manager plans the meshing of the control activities into his program of work in order to reach his objectives effectively, efficiently, and with as little disruption of his other resource management activities as possible. The investment of manpower, equipment, and dollars for control must be timed and given whatever priority is appropriate. The planned action could clash with other pest management programs in the same forested area. For example, a thinning operation for pine dwarf mistletoe control would produce slash in which Ips beetles could build up, later attacking the residual stand. Timing the thinning operation would be one of several possible ways to prevent that problem. In general, a pest management specialist should assist the landowner or resource manager in planning the implementation of the control action.

Step 13: "Implementation, Including Post-Treatment Evaluation." -- The planning and decisionmaking processes should lead to action. It has been argued that sound business and sound management result, as a matter of course, in an examination of whether or not the objectives of any particular action are met. Nevertheless, that does not happen often enough. Yet a pest management specialist must invest resources where there are pay-offs, and must document them. Therefore, the pest management specialist needs to work with resource managers who will use his expert knowledge, and needs to make sure that results of control actions are evaluated.

Post-treatment evaluation is achieved by planning, for each project, how to determine whether control objectives were met, and then making that determination. The work involved may be very simple in some projects; in others it may be complex enough to require the assistance of specialists, both in planning and in field work.

The post-treatment evaluation includes the results of any monitoring activities that were part of a project. Many projects today include monitoring as a result of the decisionmaking process. That is to say, the decisionmaker has examined the information available to him and

decided on a particular action that is to have either no adverse environmental impact or else an acceptable level of impact. Without monitoring the project, he cannot demonstrate that any environmental impact was within the limits that he decided were acceptable. In the Forest Service, the Environmental Analysis Report or Environmental Impact Statement prepared for a project often states that monitoring will take place. In such projects, post-treatment evaluation is even more important.

CONCLUSIONS

This, then, is a view of the control-decision process in detail. Some of the steps described can be taken almost automatically, and others may be combined with one another in actual practice. Any process looks complicated and even artificial until it is examined in detail. Knowing what the process is, however, is essential for identifying who is responsible for doing what, and when. Too often, the roles of pest management specialists are confused with the responsibilities or prerogatives of landowners or resource managers. We do better work when we each do our own job.

SURVEY METHODS TO DETERMINE THE DISTRIBUTION AND INTENSITY OF DWARF MISTLETOES [1/]

Oscar J. Dooling [2/]

Abstract: Dwarf mistletoe distribution and intensity must be known to determine feasibility and priority of control measures. Surveys range from a quick estimate included in a general stand examination to a thorough investigation with large-scale maps. Accuracy and precision needed for management decisions will dictate which method to use. The 6-class system for rating dwarf mistletoe intensity is currently the best available for general use.

INTRODUCTION

The theme of this symposium is dwarf mistletoe control through forest management. Before something can be managed, you must know where it is. Because dwarf mistletoes are seed-producing plants with a limited spread potential, their occurrence tends to be spotty and concentrated, not random. It is not only important to know where dwarf mistletoes are, but also where they are not. If a significant portion of a stand is dwarf mistletoe-free, your options are broader. Conversely, if the stand is heavily infested, your options may be limited to either doing nothing or destroying the stand and starting over. Knowing the distribution of dwarf mistletoe will help you determine the feasibility or priority of a proposed action.

Knowing the infection intensity is also important. A light infection does not have a measurable impact on tree or stand growth, but a heavy infection can reduce potential volume to as little as one-seventh, or 14 percent, that of a healthy stand (On and Dooling 1969). [3/]

Intensity rating systems are used to quantify degree of infection for management priority determinations, to quantify growth loss and mortality, to help define suitable seed trees, and to help quantify infection hazard of overstory trees to understory stands (Hawksworth 1977). Infection intensities are also required as inputs for yield simulation models (Myers and others 1976, Myers and others 1971).

DISTRIBUTION SURVEYS

The simplest and least expensive survey is one included as part of stand examinations. The number of sample points is necessarily limited, and may give neither the accuracy nor precision required for good management planning. At the other end of the scale is a complete cruise with accurate mapping of all infected trees and infection centers. Either method may be necessary in specific circumstances, but normally something in between these extremes will provide the desired accuracy and precision at a reasonable cost.

Extensive surveys, designed to give the overall distribution over large areas can be either random or systematic. Graham (1964) determined the distribution of *Arceuthobium douglasii* in Douglas-fir, *A. americanum* in lodgepole pine, and *A. laricis* in western larch in western Montana by sampling townships at 10 locations. He predetermined the start of a line from a point on the road nearest the center of each township and spaced his plots at 10-chain intervals along the line. At each plot, he gathered data on infection from three concentric circular areas: 1/5-

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[1/] Presented at Symposium on Dwarf Mistletoe Control Through Forest Management, Berkeley, Calif. April 11-13, 1978.

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[3/] On, D., and O.J. Dooling. 1969. A study of the effect of dwarf mistletoe infection on the growth of western larch. USDA Forest Serv., 7 p. Northern Region, Missoula, Mont.

acre for sawtimber, 1/50-acre for pole sized, and 1/500-acre for saplings.

In a smaller area, Brown (1976) gathered data on distribution of A. americanum in lodgepole pine with a sampling technique that gave an intensity of one plot for every 10 acres. He took a stratified sample consisting of a prism plot for the overstory and a 1/100-acre circular plot for the understory at each sample point. He examined trees only for presence or absence of dwarf mistletoe.

In conjunction with a roadside strip survey of A. americanum in lodgepole pine, Hawksworth (1958) established starting points mechanically along roads and designated two parallel lines at least one mile long for sampling. Distance between lines was random, but was not less than 20 or more than 40 chains. He examined eight circular 1/10-acre plots per mile for presence and intensity of dwarf mistletoe infection.

In a survey of A. vaginatum subsp. cryptopodum in ponderosa pine, Hawksworth (1956) gathered data on presence and intensity of dwarf mistletoe from six random plots per mile along parallel lines spaced at 1/2-mile intervals.

Cahill (1973) recorded presence or absence of A. americanum in lodgepole pine on plots at five-chain intervals along lines spaced one mile apart. He also rated trees for infection intensity.

Bourchier (1956) cruised strips one chain wide spaced at 10-chain intervals for presence or absence of A. americanum in lodgepole pine.

A survey designed originally for determining white pine blister rust incidence (Clutter 1966) [4/] was modified by Toko and Carlson (1968) to determine presence and intensity of Arceuthobium spp. The design is a tree cluster double-sampling technique; the first part is a "hasty" examination, the second is a "detail" examination. The hasty examination consists of inspecting trees only for presence of infection from which the proportion of infected stems is estimated. The authors selected and examined three detail trees per cluster to determine number and location of infections.

Walters and Brown (1973) and Brown (1973) compared three sampling techniques for determining presence and infection intensity of A. americanum in lodgepole pine: the Stage II compartment examination used in the Rocky Mountain Region, a one-percent fixed plot sample, and third nearest tree sample on two- and four-chain grids. An analysis of their data compared to a complete cruise showed that a modified third nearest tree sample using a four-chain spacing will give acceptable precision at a reasonable cost. The sample point is a variable size plot with a maximum radius of 33 feet. Each plot is divided into four quadrants by the intersection of a base line through the plot center at right angles to the compass line. Quadrants are examined in a clockwise direction around plot center. The modified third nearest tree consists of an examination of only the third nearest host tree from the plot center in each quadrant for a maximum of only four trees per sample point.

Walters and Geils (1977) have modified the four-chain grid to an eight-chain grid for determining distribution of A. vaginatum subsp. cryptopodum in ponderosa pine. All other details are identical.

Hawksworth (1956, 1958) traversed all passable roads through several Ranger Districts by motor vehicle at less than 10 miles per hour. He recorded type of stand, size class, and intensity of dwarf mistletoe for a strip on the right side of the road. Strip width varied with the type of stand: one chain in old-growth and cutover stands, and 1/2-chain in pole stands. He recorded distances to the nearest 0.05 mile whenever changes occurred in type of stand or degree of infection. He has used this technique for A. douglasii in Douglas-fir, A. vaginatum subsp. cryptopodum in ponderosa pine, A. microcarpum in spruce, and A. americanum in lodgepole pine.

Similar roadside surveys were used in other localities for determining distribution and intensity of A. douglasii in Douglas-fir, A. laricis in western larch, and A. americanum in lodgepole pine (Graham 1959, 1960; Graham and Frazier 1962; Doidge 1973a, 1973b).

Several types of dwarf mistletoe/host infections are easily recognized from the air: A. campylopodum in ponderosa pine (Anon. 1958, 1976); A. douglasii in Douglas-fir (Anon. 1958, 1976; Aho and Anderson 1959; Hopkins 1959); A. vaginatum subsp. cryptopodum in ponderosa pine (Anon. 1976); and A. americanum in lodgepole pine (Anon. 1976, Baranyay and Bourchier 1961). Both airplanes and helicopters can be used. Locations of visible infections are sketched onto maps of suitable scale.

[4/] Clutter, J.L. 1966. A preliminary sampling design for a white pine blister rust incidence survey. 17 p. Univ. Ga., Athens, Ga.

The Canadian Forestry Service designed an integrated tape/event recorder for aerial distribution surveys of A. pusillum in jack pine (Robins 1972, Anon. 1973a, Ives and others 1973). The equipment consists of a four channel event recorder, a tape recorder, control boxes, and headsets for two observers, a navigator, and the pilot. They use an airplane at 500 feet above ground and 100 miles per hour. Observers record dwarf mistletoe infections at right angles to the airplane on the event recorder and make comments on the tape recorder. The navigator insures proper course, altitude, and speed, and indicates start, intermediate, and finish flight line check points on the event recorder, base map, and tape recorder. Infection occurrence is transferred from event recorder to map by a Map-O-Graph [5/] adjusted to match event tape scale to map scale. Relevant verbal comments are also transferred to the map.

In some parasite/host combinations, dwarf mistletoe-caused mortality results in circular openings in the canopy easily visible on conventional vertical aerial photographs: A. pusillum in black spruce (Anderson 1949, Meyer and French 1966, Murtha 1972) and A. americanum in jack pine (Murtha 1972, Anon. 1973b, Muir and Robins 1973). The appearance of these openings on the photographs have been described as "moth-eaten" (Anderson 1949) or "ringworm-like" (Murtha 1972). Scales of 1:15,840 to 1:31,680 are usable (Muir and Robins 1973).

On western pines, large-scale photography taken at a low oblique angle has shown promise for detecting brooming within crowns in open-grown stands (Heller and Bega 1973).

Infra-red (false color) film for aerial detection of dwarf mistletoe was used at least as early as 1963 when Baranyay (1963) showed that A. americanum in lodgepole pine appeared as darkened areas in oblique, across valley photographs. He could not illustrate adequate shade differences between healthy and infected patches of trees on vertical photography (Baranyay 1968).

Infra-red aerial photography has been successfully used to detect mortality in black spruce caused by A. pusillum (Meyer and French 1967, Douglas 1973, [7/] Douglas and others 1972, French and others 1975). In addition to old infection centers with mortality, young infection centers in which only brooming has occurred are also detectable (Meyer and French 1967, Douglas and others 1972).

Photography scales from 1:30,000 (French and others 1975) to 1:118,000 (Douglas 1973) [7/] are useful for detecting A. pusillum-caused openings as small as 0.1 acre in black spruce. Openings of 0.25 acre are visible at a scale of 1:462,000 (Douglas 1973).

Dooling and others (1977) used a 3-person crew to examine and map the complete distribution of A. americanum in lodgepole pine in two sale areas in Montana. The survey crew consisted of a leader and two observers. The crew leader recorded presence of dwarf mistletoe as determined by the observers (based on presence of plants, swellings, or brooms). Each observer covered a strip two chains wide.

Distribution surveys range from simple to complex in design, and from reasonable to nearly prohibitive in cost. All these methods have valid uses. Tree species, stand structure, and proposed management action, along with accuracy and precision needed, will dictate which method to use.

INFECTION INTENSITY RATING SYSTEMS

There have been many attempts to quantify dwarf mistletoe infection on a tree basis (table 1) (Hawksworth 1977). Some systems have as few as four classes and one as many as 18. The terms "light," "medium," and "heavy" have been used in many rating systems, but have not been very well defined.

The 6-class dwarf mistletoe rating system, introduced by Hawksworth and Lusher (1956) is now the accepted standard in the Western United States and Western Canada. Hawksworth (1977) has recently discussed the 6-class system in detail and described its uses and limitations.

For the 6-class system, the live crown is divided into thirds, and each third is rated as: 0, no mistletoe; 1, light mistletoe (less than half of the branches infected); and 2,

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[5/] A special projector used in mapmaking when changing scale.

[6/] Anderson, R.L. 1949. Black spruce dwarf mistletoe in Minnesota. Masters Thesis, 139 p. Univ. Minn., Minneapolis, Minn.

[7/] Douglas, R.W. 1973. Use of high altitude photography for forest disease detection and vegetation classification within the sub-boreal forest region. PhD Thesis, 141 p. Univ. Minn., Minneapolis, Minn.

Table 1--Rating systems used for dwarf mistletoe-infected trees (Hawksworth 1977).

Arceuthobium species (and host)	Number of Classes (including healthy)	Description	Reference
A. laricis (western larch)	5	0, healthy trees; infected rated X, XX, XXX, or XXXX based on degree of infection (not defined).	Weir 1916
A. vaginatum subsp. *cryptopodum* (ponderosa pine)	4	0, healthy trees without mistletoe; X, light mistletoe infection; XX, medium mistletoe infection; XXX, heavy mistletoe infection.	Korstian and Long 1922
A. americanum (jack pine)	4	0, healthy tree; X, slightly infected tree; XX, severely infected tree; XXX, very badly broomed tree.	Dowding 1929
A. douglasii (Douglas-fir) and *A. vaginatum* subsp. *cryptopodum* (ponderosa pine).	7	Six-class system. Each third of live crown rated as 0, no mistletoe; 1, less than half the branches infected; or 2, more than half the branches infected. Ratings of each third totaled. Ratings range from 0 (uninfected tree) to 6 (heavily infected).	Hawksworth and Lusher 1956, Hawksworth 1961
A. douglasii (Douglas-fir and *A. laricis* (western larch).	4	"None" - no visible infection; "Light" - less than one-third of crown broomed; "Medium" - one to two thirds of crown broomed; "Heavy" - more than two-thirds of crown broomed.	Pierce 1960
A. douglasii (Douglas-fir)	4	Class I - no evidence of brooming; Class II - brooming confined to lower third of crown; Class III - brooming for at least two-thirds of live crown; Class IV - brooming for at least two-thirds of live crown, and spike top developing.	Shea 1963
Arceuthobium spp. (several hosts in western Montana)	5	Live crown divided into 2 equal parts, each half was rated as 0, no infection; 1, less than one-third of branches infected; or 2, more than one-third of branches infected. Total for each half of crown added for three totals which range from 0 (no infection) to 4 (very heavy infection).	Graham 1964

Table 1--Rating systems used for dwarf mistletoe-infected trees (Hawksworth 1977) (continued).

Arceuthobium species (and host)	Number of Classes (including healthy)	Description	Reference
Arceuthobium spp. (several hosts in NE Washington)	6	Same as above, but with 1 additional class for trees killed within the previous 5 years and showing symptoms or signs of having had dwarf mistletoe.	Graham and Frazier 1962
A. tsugense (western hemlock)	18	Each third of crown rated from 0.0 (no visible infections) to 3.0 (numerous large branch infections in the form of witches' brooms and at least 1 trunk swelling) by 0.5 class intervals. Rating in each third totaled for tree ratings.	Smith 1969
A. tsugense (western hemlock)	6	Middle-third rating system. Because the lower third of the tree often had numerous dead, broken, and missing branches and because the top third was often partially hidden, an analysis of growth loss in relation to the middle-third rating only was made. The results suggest that middle-third rating is superior to whole-tree rating.	Smith 1969
A. americanum (lodgepole pine)	4	0, healthy; 1, light branch infection, less than 50% of crown infected; 2, heavy branch and stem infection, more than 50% of the crown infected; 3, witches' brooms, branch and stem infections, more than 50% of the crown infected.	Baranyay and Safranyik 1970
A. abietinum (true firs)	10	Each third of crown rated as 0, no mistletoe; 1, 1-10% of branches infected; 2, 11-50% of branches infected; and 3, over 50% of branches infected. Totals added for tree rating. Note that by combining classes 1 and 2 in each third, ratings are the same as in the 6-class system.	Scharpf 1977

heavy mistletoe (more than half of the branches infected). The ratings of each third are added to obtain a total for the tree. For example, a tree heavily infected in the lower third of the crown, lightly infected in the middle third, and not infected in the upper third, would be Class 3 (fig. 1). A tree heavily infected in each third would be Class 6. The system is simple to use, and different observers tend to rate an infected tree similarly. A tree with an infection on the bole, but not the branches, is rated as Class 1. Otherwise, bole infections are not considered in the rating system.

The 6-class system was originally used for A. vaginatum subsp. cryptopodum in ponderosa pine and for A. douglasii in Douglas-fir in the Southwest (Hawksworth and Lusher 1956, Andrews and Daniels 1960, Hawksworth 1961). It was later found to be applicable to A. americanum in lodgepole pine in the Central Rockies (Hawksworth and Hinds 1964, Myers and others 1971). The system has also been applied to A. campylopodum in ponderosa pine in the Pacific Northwest (Shea 1964, Flora 1966), A. occidentale in digger pine in California (Hawksworth 1969), and A. cyanocarpum on limber pine in Colorado (Hawksworth and others 1975).

The 6-class system is also being widely used in Western Canada: A. americanum in lodgepole pine (Dobie and Britneff 1975), A. tsugense in western hemlock and shore pine (Smith and Wass 1976), and Arceuthobium spp. (Baranyay and Smith 1972).

Of the 12 rating systems proposed, the 6-class system is most widely used. It is being used for several host/parasite combinations in the Western United States and Canada. The 6-class system has been used for many purposes: to quantify height and diameter-growth loss in infected trees, to quantify infection in stands, and to select seed trees. The system does have limitations and may not be applicable to all host/parasite combinations, but it does have the strong attribute of comparability and seems to be the best currently available system for general use.

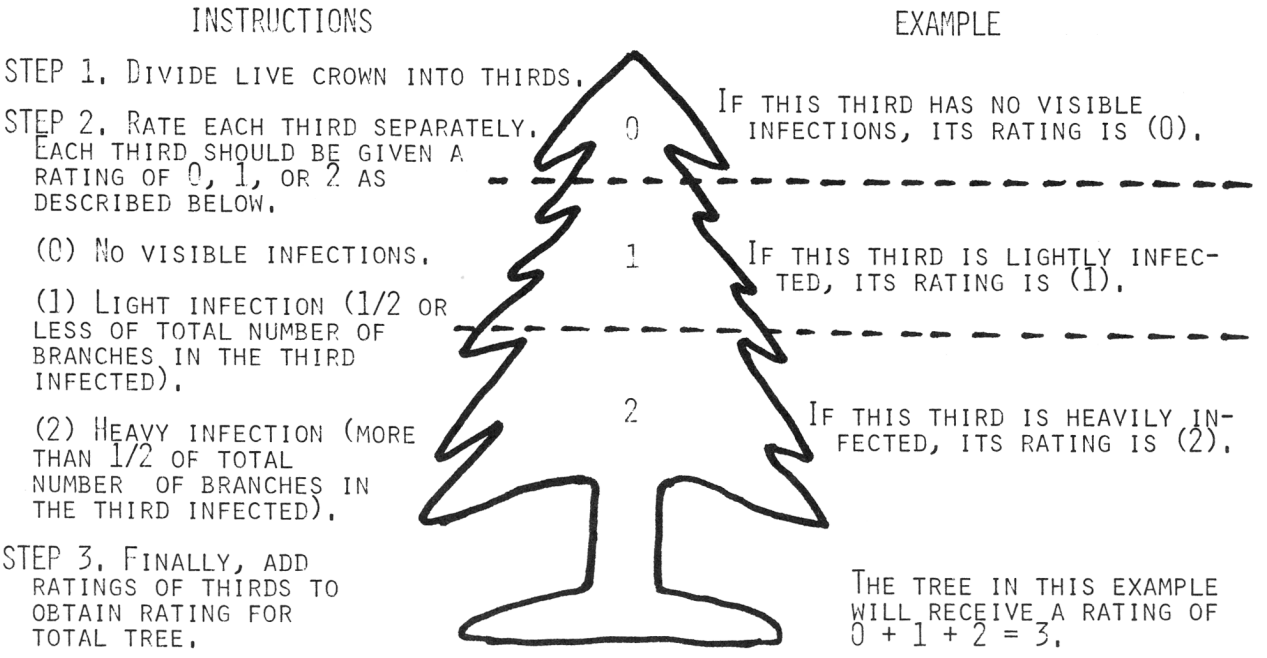

Figure 1--Instructions and example of the use of the 6-class mistletoe rating system (Hawksworth 1961, 1977).

LITERATURE CITED

Aho, P.E., and L.N. Anderson
1959. Douglas-fir dwarf mistletoe aerial survey, Rouge River National Forest 1958. USDA Forest Serv., Pacific Northwest Forest and Range Exp. Stn., Portland, Oreg. 12 p.

Andrews, S.R., and J.P. Daniels
1960. A survey of dwarf mistletoes in Arizona and New Mexico. USDA Forest Serv., Rocky Mountain Forest and Range Exp. Stn., Stn. Pap. 49, 17 p., Fort Collins, Colo.

Anonymous
1958. Annual Report 1957. USDA Forest Serv., Pacific Northwest Forest and Range Exp. Stn., Portland Oreg., p.62-63.

Anonymous
1973a. A dwarf mistletoe survey technique. Can. Forest Serv., Northern Forest Res. Centre, Alberta, Can., For. Rept. 3(2):7.

Anonymous
1973b. Dwarf mistletoe damage. Can. Forest Serv., Northern Forest Res. Centre, Alberta, Can., For. Rept. 3(3):8.

Anonymous
1976. Forest insect and disease conditions in the Intermountain States during 1975. USDA Forest Serv., Intermountain Region, Ogden, Utah, 12 p.

Baranyay, J.A.
1963. Detection of dwarf mistletoe-infected stands by aerial photography. Ann. Rept., For. Entomol. and Pathol. Branch, Can. Dep. For., Calgary, Alberta, Can., 138 p.

Baranyay, J.A.
1968. Experiment with aerial color photography for detecting dwarf mistletoe infested lodgepole pine stands in the Alberta Territories Region. Forest Res. Lab., Calgary, Alberta, Can., Internal Report. A-12, 35 p.

Baranyay, J.A., and R.J. Bourchier
1961. Province of Alberta forest disease survey. 1960 Annu. Rept. For. Ins. and Dis. Survey. Can. Forest Serv., p. 88-92.

Baranyay, J.A., and L. Safranyik
1970. Effect of dwarf mistletoe on growth and mortality of lodgepole pine stands in Alberta. Can. Dep. Fish and For. Publ. 1285, 19 p.

Baranyay, J.A., and R.B. Smith
1972. Dwarf mistletoes in British Columbia and recommendations for their control. Can. Forest Serv. Rept. BC-X-72, 18 p.

Bourchier, R.J.
1956. Province of Alberta, forest disease survey. Div. of For. Bio. Ins. and Dis. Survey Annu. Rept. 1955, p. 89-91 Calgary, Alberta, Can.

Brown, D.H.
1973. An evaluation survey procedure for dwarf mistletoe in proposed thinning projects. USDA Forest Serv., Rocky Mountain Region, 6 p. Lakewood, Colo.

Brown, D.H.
1976. Biological evaluation, dwarf mistletoe - Arapaho and Roosevelt National Forests, Redfeather Ranger District, 1974. USDA Forest Serv., Rocky Mountain Region Rept. R2-76-1, 7 p. Lakewood, Colo.

Cahill, D.B.
1973. Impact evaluation, mountain pine beetle and dwarf mistletoe, Dillon Reservoir. USDA Forest Serv., Rocky Mountain Region Timber Manage. Rept. R2-73-19,24p. Lakewood, Colo.

Dobie, J., and A.A. Britneff
1975. Lumber grades and volumes from lodgepole pine infected with dwarf mistletoe. Wood and Fiber 7:104-109.

Doidge, D.F.
1973a. Annual district report forest insect and disease survey, British Columbia, 1972, Part VI, Caribou Forest District. Can. Forest Serv., Pacific Forest Res. Centre Info. Rept. BC-X-77, 22 p. Victoria, B.C., Can.

Doidge, D.F.
1973b. Forest insect and disease conditions, 1973, Caribou District. Can. Forest Serv. Pacific Forest Res. Centre Info. Rept. BC-X-96, 10 p. Victoria, B.C., Can.

Dooling, O.J., J.D. Bortz, and M.W. Maxwell
1977. Dwarf mistletoe survey, Hebgen Lake Ranger District, Gallatin National Forest, Montana. USDA Forest Serv., Northern Region Rept. 77-13, 5 p. Missoula, Mont.

Douglas, R.W., M.P. Meyer, and D.W. French
1972. Remote sensing applications to forest vegetation classification and conifer vigor loss due to dwarf mistletoe.

NASA Earth Resources Survey Program, Final Rept., 91 p. Univ. Calif., Berkeley, Calif.

Dowding, E.S.
1929. The vegetation of Alberta III. The sandhill areas of central Alberta with particular reference to the ecology of Arceuthobium americanum Nutt. J. Ecol. 17:82-105.

Flora, D.F.
1966. A method of forecasting returns from ponderosa pine dwarf mistletoe control. USDA Forest Serv., Pacific Northwest Forest and Range Exp. Stn. Res. Pap. PNW-32, 17 p. Portland, Oreg.

French, D., M. Meyer, and F. Irving
1975. Application of remote sensing to detection and contol of dwarf mistletoe in black spruce stands. Univ. Minn., Remote Sensing Lab. Res. Rept. 75-4, 11 p. Minneapolis, Minn.

Graham, D.P.
1959. Dwarf mistletoe survey in Kootenai National Forest. USDA Forest Serv., Intermountain Forest and Range Exp. Stn. Res. Note 67, 5 p. Ogden, Utah.

Graham, D.P.
1960. Dwarf mistletoe survey in Kaniksu National Forest. USDA Forest Serv., Intermountain Forest and Range Exp. Stn. Res. Note 74, 6 p. Ogden, Utah.

Graham, D.P.
1964. Dwarf mistletoe survey in western Montana. USDA Forest Serv., Intermountain Forest and Range Exp. Stn. Res. Note INT-4, 7 p. Ogden, Utah.

Graham, D.P., and W.E. Frazier
1962. Dwarf mistletoe survey in northeastern Washington. USDA Forest Serv., Intermountain Forest and Range Exp. Stn. Res. Note 103, 8 p. Ogden, Utah.

Hawksworth, F.G.
1956. Region 3 dwarf mistletoe survey, progress report of the 1954-55 field work. USDA Forest Serv., Rocky Mountain Forest and Range Exp. Stn. Spec. Rept., 5 p. Fort Collins, Colo.

Hawksworth, F.G.
1958. Survey of lodgepole pine dwarf mistletoe on the Roosevelt, Medicine Bow, and Bighorn National Forests. USDA Forest Serv., Rocky Mountain Forest and Range Exp. Stn. Pap. 35, 13 p. Fort Collins, Colo.

Hawksworth, F.G.
1961. Dwarf mistletoe of ponderosa pine in the Southwest. U.S. Dep. Agric. Tech. Bull. 1246, 112 p.

Hawksworth, F.G.
1969. Rapid intensification and upward spread of dwarf mistletoe in inoculated digger pines. Plant Dis. Rept. 53:615-617.

Hawksworth, F.G.
1977. The 6-class dwarf mistletoe rating system. USDA Forest Serv., Rocky Mountain Forest and Range Exp. Stn. Gen. Tech. Rept. RM-48, 7 p. Fort Collins, Colo.

Hawksworth, F.G., J.T. Fisher, and R.L. Mathiasen
1975. An unusual occurrence of Arceuthobium cyanocarpum on ponderosa pine near Boulder, Colorado. Plant Dis. Rept. 59:758-759.

Hawksworth, F.G., and T.E. Hinds
1964. Effects of dwarf mistletoe on immature lodgepole pine stands in Colorado. J. For. 62:27-32.

Hawksworth, F.G., and A.A. Lusher
1956. Dwarf mistletoe survey and control on the Mescalero Apache Reservation, New Mexico. J. For. 54:384-390.

Heller, R.C., and R.V. Gega
1973. Detection of forest diseases by remote sensing. J. For. 71:18-21.

Hopkins, H.G.
1959. Salvaging mistletoe damaged timber. Proceedings, West. For. Conf., 1958, p. 36-39.

Ives, W.G., J.J. Lawrence, and J.K. Robins
1973. Prairies Region forest insect and disease survey Annu. Rept., 1972, p. 74-81. Can. Dep. Environ.

Korstian, C.F., and W.H. Long
1922. The western yellow pine mistletoe: effect on growth and suggestions for control. U.S. Dep. Agric. Tech. Bull. 1112, 35 p.

Meyer, M.P., and D.W. French
1966. Dwarf mistletoe in black spruce forests can be assessed through sequential aerial photography. Photogramm. Eng. 32:812-814.

Meyer, M.P., and D.W. French
1967. Detection of diseased trees. Photogramm. Eng. 33:1035-1040

Muir, J.A., and J.K. Robins
1973. Detection of dwarf mistletoe of jack pine on aerial photographs. Plant Dis. Rept. 57:951-954.

Murtha, P.A.
1972. A guide to air photo interpretation of forest damage in Canada. Can. Forest Serv. Publ. 1292, 62 p.

Myers, C.A., F.G. Hawksworth, and J.L. Stewart
1971. Simulating yields of managed, dwarf mistletoe-infected lodgepole pine stands. USDA Forest Serv., Rocky Mountain Forest and Range Exp. Stn. Res. Pap. RM-72, 15 p. Fort Collins, Colo.

Myers, C.A., C.B. Edminster, and F.G. Hawksworth
1976. SWYLD2: Yield tables for even-aged and two-storied stands of southwestern ponderosa pine, including effects of dwarf mistletoe. USDA Forest Serv., Rocky Mountain Forest and Range Exp. Stn. Res. Pap. RM-163, 25 p. Fort Collins, Colo.

Pierce, W.R.
1960. Dwarf mistletoe and its effect upon the larch and Douglas-fir of western Montana. Mont. State Univ. School of For. Bull. 10, 38 p. Missoula, Mont.

Robins, J.K.
1972. Dwarf mistletoe aerial surveying method: results of preliminary trials in the Athabasca Forest, Alberta, March 1972. Can. Forest Serv., Northern Forest Res. Centre Misc. Rept. NOR-Y-10, 4 p. Calgary, Alberta, Can.

Scharpf, R.F.
1977. Dwarf mistletoe does not increase trunk taper in released red firs in California. USDA Forest Serv., Pacific Southwest Forest and Range Exp. Stn. Res. Note PSW-326, 3 p. Berkeley, Calif.

Shea, K.R.
1963. Marking guide evolved for mistletoe-hit Douglas-fir. For. Indus. 90:58-59.

Shea, K.R.
1964. Diameter increment of ponderosa pine infected with dwarf mistletoe in south-central Oregon. J. For. 62:743, 746-748.

Smith, R.B.
1969. Assessing dwarf mistletoe on western hemlock. For. Sci. 15:277-285.

Smith, R.B., and E.F. Wass
1976. Field evaluation of ecological differentiation of dwarf mistletoe on shore pine and western hemlock. Can. J. For. Res. 6:225-228.

Toko, H.V., and C.E. Carlson
1968. Dwarf mistletoe survey procedure. USDA Forest Serv., Northern Region Ins. and Dis. Rept., 11 p. Missoula, Mont.

Walters, J.W., and D.H. Brown
1973. An administrative study of sampling techniques in dwarf mistletoe-infested stands. USDA Forest Serv., Rocky Mountain Region Timber Manage. Rept., 11 p. Lakewood, Colo.

Walters, J.W., and B.W. Geils
1977. Technical report - simulated yield tables for dwarf mistletoe management in ponderosa pine stands (SWYLD2 program). Phase I - two storied stands, Chalender Ranger District, Kaibab National Forest, Arizona. USDA Forest Serv., Southwestern Region Rept. R-3 77-11, 25 p. Albuquerque, N.M.

Weir, J.R.
1916. Larch mistletoe: some economic considerations of its injurious effects. U.S. Dep. Agric. Bull. 317, 25 p.

THE EXTENT OF DWARF MISTLETOE IN SIX PRINCIPAL SOFTWOODS IN CALIFORNIA, OREGON, AND WASHINGTON, AS DETERMINED FROM FOREST SURVEY RECORDS[1/]

Charles L. Bolsinger[2/]

Abstract: Forest inventory records show dwarf mistletoe infection in six principal softwoods (14 species) on 23 percent of the commercial forest land in California, Oregon, and Washington. Infection was most widespread in Douglas-fir (3.6 million acres), ponderosa and Jeffrey pines (3.2 million acres), and true firs (1.9 million acres). Western larch and lodgepole pine were the most seriously infected species.

INTRODUCTION

Dwarf mistletoe information recorded from 1966 to 1976 on 16,904 commercial forest inventory plots in Oregon, Washington, and California was summarized for six principal softwood groups (see table 8, appendix), by forest type, geographic area, and ownership group. The area sampled by these plots is 49,706,000 acres, about 84 percent of the total commercial forest in the three States.

Inventory plots on National Forests were established by Regions 5 and 6 of the U.S. Forest Service. The Bureau of Land Management Districts established plots on BLM land in western Oregon. Plots on other lands were established by the Renewable Resources Evaluation Research Unit of the Pacific Northwest Forest and Range Experiment Station. (See table 8, appendix, for dates of inventory and numbers of plots.)

Oregon and Washington plots were located on a systematic grid. California plots were randomly located within prestratified volume classes; each plot in a sampling unit represented about the same area. Plots on the three National Forests examined in Washington were circular and 1/5-acre in size. All trees with 5.0-inch and larger d.b.h. in the first quadrant were tallied, and all trees 11.0 inches and larger in all quadrants were tallied. In all other inventories, plots consisted of 10 points distributed over an acre. At each point, trees 5.0-inch d.b.h. and larger were tallied by prism; and trees from 6-inch height to 4.9-inch d.b.h. were tallied on fixed-radius plots, usually 1/300-acre in size. All trees were examined for the presence of dwarf mistletoe. Trees on the first three points were bored to determine growth, except on some remeasurement plots, where diameter growth was determined from successive diameter measurements.

In most areas inventoried, infections were recorded by severity classes; in National Forests in Washington, infections were not classified by severity. Before 1968 or 1969, dwarf mistletoe infections were recorded if nothing more serious affected tally trees, as judged by inventory crews. Infections were classified as light, medium, or heavy. After 1968 or 1969 a six-point rating system (Hawksworth and Lusher 1956) was used for all trees tallied.

The three-class system was equated to the six-point system and average stand dwarf mistletoe rating (DMR) was calculated for each plot (table 7, fig. 3, appendix).

Three-class system	Equivalent six-point rating system
Light infection	1
Medium infection	3
Heavy infection	5

Percent of trees 5.0-inch d.b.h. and larger infected by dwarf mistletoe also was calculated for each plot.

[1/] Presented at the Symposium on Dwarf Mistletoe Control Through Forest Management, Berkeley, California, April 11-13, 1978.

[2/] Research Forester, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Forest type was computed from tree tally data on each plot.[3/] Dwarf mistletoe infections were recorded by tree species and data were summarized by species infected and by forest type.

RESULTS

Area of Infestation

Dwarf mistletoe (*Arceuthobium* spp.)-infected trees were found on about 23 percent of 16,904 commercial forest inventory plots in Oregon, Washington, and California (table 1). The area represented by the plots with dwarf mistletoe present is 11,270,000 acres.

Commercial forests west of the Cascade crest in Oregon and Washington were relatively free of dwarf mistletoe; in western Oregon and western Washington 10 percent were infected. In both eastern Oregon and eastern Washington, 41 percent of the commercial forest was infested. In California, 21 percent was infested (fig. 1 and table 1).

[3/] Resources Evaluation Research Work Unit. Forest Survey field instructions for eastern Oregon, 1977. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg. (Unpublished).

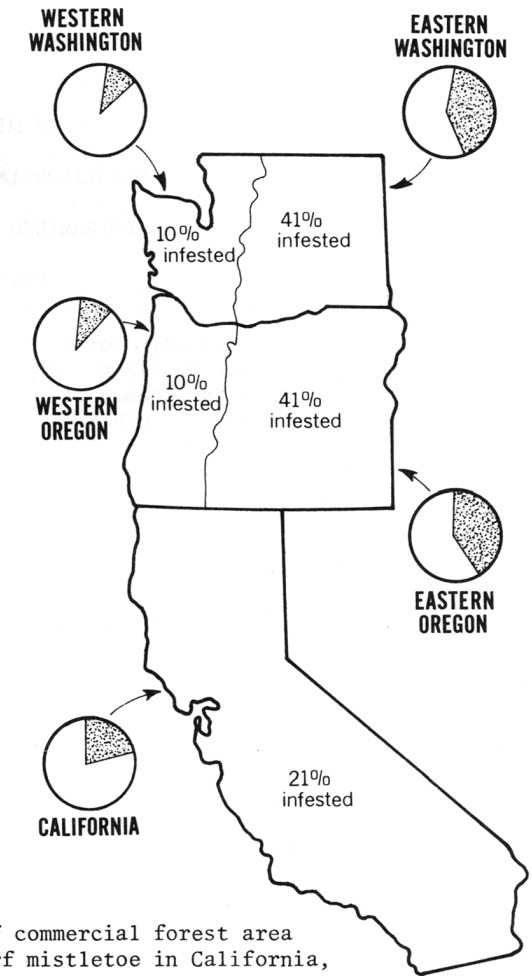

Figure 1--Percent of commercial forest area infested with dwarf mistletoe in California, Oregon, and Washington, circa 1972.

Table 1--Area of commercial forest examined for dwarf mistletoe and area infested, by State and half-State and ownership group, California, Oregon, and Washington, circa 1972

State and half-State	National Forests			All other ownerships			All ownerships		
	Total area examined	Area infested	Percent of area infested	Total area examined	Area infested	Percent of area infested	Total area examined	Area infested	Percent of area infested
	- Thousand acres - -			- Thousand acres - -			- Thousand acres - -		
California	5,911	889	15	7,658	1,779	25	13,569	2,811	21
Western Oregon	3,604	629	17	9,158	685	7	12,762	1,314	10
Eastern Oregon	5,068	1,942	38	3,556	1,629	46	8,624	3,571	41
Total or Percent	8,672	2,571	30	12,714	2,314	18	21,386	4,885	23
Western Washington	[1/] 184	34	18	7,774	778	10	7,958	812	10
Eastern Washington	[2/] 1,593	574	36	5,200	2,188	42	6,793	2,762	41
Total or Percent	1,777	608	34	12,974	2,966	23	14,751	3,574	24
Three-State Total or Percent	16,360	4,068	25	33,346	7,202	22	49,706	11,270	23

[1/] Data developed only for north Mt. Baker National Forest.

[2/] Data developed only for Okanogan and Wenatchee National Forests.

Douglas-fir dwarf mistletoe infections in Douglas-fir were found over 3.6 million acres (table 2). Second in area infested was ponderosa pine - 3.2 million acres. True firs infected by dwarf mistletoe were third in area - 1.9 million acres; included were grand, white, noble, California red, Shasta red, Pacific silver, and subalpine firs. Other tree species examined, in order of area infested, were lodgepole pine, western and mountain hemlocks, and western larch.

Western larch was the most heavily infested (table 3); 47 percent of the forest-type acreage had dwarf mistletoe infected trees. Lodgepole pine was second--42 percent of the forest-type was infested; other forest types: ponderosa and Jeffrey pines--26 percent of the area infested, true firs--21 percent, hemlocks--21 percent, and Douglas-fir--13 percent.

Only 12 percent of the total area infested had a dwarf mistletoe rating (DMR) greater than 2.4. At least 41 percent of all trees were infected in 29 percent of the infested stands. Tables 4 and 5 show these degrees of infestation by species and forest type.

An examination of dwarf mistletoe incidence by stand size showed a definite increase in the proportion of area infested with an increase in stand size for hemlocks, western larch, and true firs. For Douglas-fir a slight trend of increasing infection with increasing stand size was shown. No trend at all was apparent for lodgepole pine, possibly because of the large area in seedlings, saplings, and poletimber. Ponderosa pine showed a weak reverse trend (fig. 2 and table 6).

Site Relationship

All areas were classified by site index. To what degree dwarf mistletoe infections influenced the site classification is not known. Field crews were instructed to select trees free of disease or damage. Sometimes this was difficult. The data show that the distribution of dwarf mistletoe is generally proportional to site distribution for most species in most regions. Weak site preferences did appear for Douglas-fir and true firs: No Douglas-fir dwarf mistletoe was found on high sites in California, eastern Oregon, or eastern Washington; and only 1 percent of the high sites in western Oregon was infested, compared with 5 percent for medium and low sites. True fir dwarf mistletoe seemed to favor high and medium sites in all areas, but the differences shown by the sample are not conclusive. True fir infestations were distributed by site as follows:

	All areas examined	Outside National Forests in California
	- - - Percent infested - - -	
High sites	25	40
Medium sites	22	42
Low sites	20	33

Table 2--Area of commercial forest examined for dwarf mistletoe, and area infested, by species and forest type, in California, Oregon, and Washington, circa 1972[1/]

Tree species and forest type[2/]	Total area in type	Area in the type with type species infected[3/]	Percent of type infested	Species infected in other forest types[3/]	Total area in which the species is infected[3/]
	- - - Thousand acres - - - -			- - - - - Thousand acres - - - - -	
Ponderosa and Jeffrey pines	8,346	2,158	26	995	3,153
Douglas-fir	16,526	2,160	13	1,415	3,575
Lodgepole pine	2,578	1,090	42	375	1,465
Western and mountain hemlocks	3,250	668	21	596	1,264
Western larch	360	168	47	869	1,037
True firs	5,710	1,219	21	718	1,937
Total or percent	36,770	7,463	20	4/	4/
All other species and forest types	12,936	3,807			
Total area examined	49,706	11,270	23		

1/ See table 8, appendix, for actual dates of data collection.

2/ See list of tree species and dwarf mistletoe species (table 9, appendix).

3/ Included are areas in which two or more tree species are infected.

4/ Not summable.

Table 3--Percent of commercial forest land infested by dwarf mistletoe with a dwarf mistletoe rating (DMR) of 2.41 and greater, and with infections in 41 percent or more of all trees tallied

Species and forest type	DMR 2.41+	Infections in 41 percent or more of all trees tallied
	Percent of total infested area	
Ponderosa and Jeffrey pines	11	32
Douglas-fir	7	19
Lodgepole pine	20	52
Hemlocks	14	29
Western larch	37	50
True firs	8	20

Table 4--Area of commercial forest land infested by dwarf mistletoe, by species and forest type, and by average stand dwarf mistletoe rating, California, Oregon, and Washington, circa 1972

Species and forest type	Infection only in trees less than 5.0" d.b.h.	Average stand dwarf mistletoe rating in trees 5.0"+			Total area infested[1/]
		0.01-1.00	1.01-2.40	2.41+	
	Thousand acres				
Ponderosa and Jeffrey pines	141	1,363	378	245	2,127
Douglas-fir	73	1,419	219	122	1,833
Lodgepole pine	117	489	246	213	1,065
Hemlocks	25	426	100	93	644
Western larch	0	66	24	52	142
True firs	74	914	112	99	1,199
Total	430	4,677	1,079	824	7,010
Percent	Percent				
	6	67	15	12	100

Table 5--Area of commercial forest land infested by dwarf mistletoe, by species and forest type and by percent of trees infected, California, Oregon, and Washington, circa 1972

Species and forest type	Percent of trees 5.0" d.b.h. and larger infected				Total area infested[1/]
	1-20	21-40	41-60	61+	
	Thousand acres				
Ponderosa and Jeffrey pines	975	354	189	478	1,986
Douglas-fir	1,114	325	124	197	1,760
Lodgepole pine	312	139	153	344	948
Hemlocks	328	111	57	123	619
Western larch	14	57	19	52	142
True firs	745	162	73	145	1,125
Total	3,488	1,148	615	1,329	6,580
Percent	Percent				
	53	18	9	20	100

[1/] These totals are less than shown in table 2 because severity of dwarf mistletoe infections are not rated in all areas. Excludes stands in which infection was only in trees less than 5-in. d.b.h.

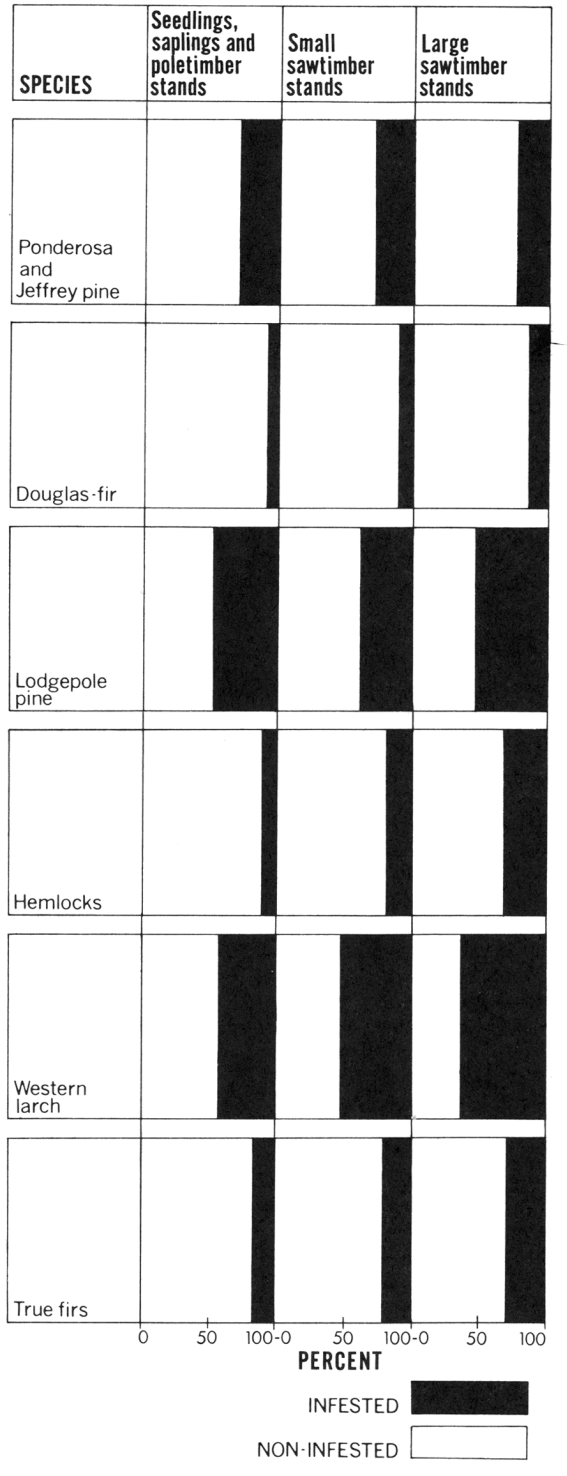

Figure 2--Proportion of area infested with dwarf mistletoe by forest-type species and stand size class, California, Oregon, and Washington

Infestation by Species

Ponderosa and Jeffrey pines

Ponderosa pine dwarf mistletoe was most plentiful and infections were most severe in eastern Oregon, though this disease was found throughout most of the range of ponderosa and Jeffrey pines in the three States. About 32 percent of the total area of ponderosa and Jeffrey pine infections in the three States was in forest types other than ponderosa or Jeffrey pine. In California almost half of the dwarf mistletoe infected ponderosa and Jeffrey pines occurred in other forest types, mainly incense-cedar and hardwoods. In Oregon and Washington about 25 percent was in other forest types, mostly Douglas-fir and true firs.

Douglas-fir

Most of the Douglas-fir region--the area west of the Cascades in Oregon and Washington and northwestern California--is free of Douglas-fir dwarf mistletoe. Most of the dwarf mistletoe found in the Douglas-fir region was in the Klamath Mountains of southwestern Oregon and northwestern California. Douglas-fir forests east of the Cascades were heavily infested--42 percent of the Douglas-fir type in eastern Oregon and 43 percent in eastern Washington.

In all three States combined, about 40 percent of the area infested with Douglas-fir dwarf mistletoe was in types other than Douglas-fir, most commonly true fir. In California, 52 percent of the area infested with Douglas-fir dwarf mistletoe was in other types.

Lodgepole Pine

Dwarf mistletoe was not found in the few widely scattered stands of lodgepole pine in western Oregon and western Washington but was common in other areas. In eastern Oregon, outside National Forests, 55 percent of the lodgepole pine type was infested. In the pumice region of central Oregon, the author has observed that dwarf mistletoe in lodgepole pine is typically associated with infections of gall rust (*Endocronartium harknessii* [Moore]).

Western and Mountain Hemlocks

The only serious dwarf mistletoe threat in the Douglas-fir region seems to be in hemlock but occurrence is scattered. Extensive areas are entirely free of this disease. Three locations in which the author has noted severe hemlock dwarf mistletoe damage are Larch Mountain in Oregon's Cascades, the westside of the Olympic Peninsula in Washington, and the Nooksak River drainage in northern Washington. Nearly half of

Table 6--Area of commercial forest land examined for dwarf mistletoe and area infested by species and forest type and by stand size class, California, Oregon, and Washington, circa 1972

Species and Forest type[1/]	Seedling-sapling and poletimber			Small sawtimber			Large sawtimber		
	Total area	Infested area		Total area	Infested area		Total area	Infested area	
	Thousand acres		Percent	Thousand acres		Percent	Thousand acres		Percent
Ponderosa and Jeffrey pines	2,421	740	30.6	3,064	788	25.7	2,538	603	23.7
Douglas-fir	4,487	320	7.1	5,197	533	10.2	6,087	637	10.5
Lodgepole pine	1,615	752	46.6	636	235	36.9	151	77	51.0
Hemlocks	1,008	101	10.0	941	169	18.0	1,158	375	32.4
Western larch	162	63	38.9	112	61	54.5	29	19	65.5
True firs	1,164	197	16.9	1,968	381	19.4	2,378	620	26.0

[1/]This table includes only infections in the tree species for which type was named.

the hemlock dwarf mistletoe infestations are in other forest types; included are Douglas-fir, true fir and red alder.

Western Larch

Western larch is found on the east slopes of the Cascades from near Bend, Oregon, north to Canada and in the Blue Mountains, the Okanogan Highlands, and the Selkirk Mountains. Only in the Selkirks are there extensive areas of larch type. Most of the larch occurs in other types; therefore, most of the area infested with larch dwarf mistletoe--84 percent--was in other types, usually Douglas-fir or true firs. Also included were Engelmann spruce, lodgepole pine, and ponderosa pine. In many areas, it is difficult to find larch trees 21.0-inch d.b.h. or larger that are not infected. Forest managers and planners consider dwarf mistletoe to be a significant factor related to the high mortality in larch measured in recent inventories in eastern Oregon and eastern Washington.

True Firs

California has 46 percent of the true fir type examined in the study but 53 percent of the area infested with true fir dwarf mistletoe. Outside National Forests in California, 38 percent of the true fir types were found to be infected. In the Klamath Mountains in the southwest corner of Oregon, true fir dwarf mistletoe was usually found in the same stands as Douglas-fir dwarf mistletoe. In all areas, 37 percent of true fir dwarf mistletoe infections were in other types.

LITERATURE CITED

Hawksworth, Frank G., and Lusher, Arthur A.
1956. Dwarf mistletoe survey and control on the Mescalero-Apache Reservation, New Mexico. J. For. 54:384-390, illus.

Kimmey, James W.
1957. Dwarf mistletoes of California and their control, USDA Forest Serv. Tech. Pap. No. 19, Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif. 12 p.

APPENDIX

Table 7--Dwarf mistletoe infestation

3-class rating system

Infection	Seedlings or saplings	Poletimber or sawtimber
	(Trees 6 inches high to 4.9 inch d.b.h.)	(Poletimber 5.0- to 8.9-inch d.b.h.; sawtimber 9.0-inch + d.b.h.)
Light	No more than two separate infections per tree. All infections more than 12 inches from bole.	Infections confined to lower third of crown. May have few developing witches broom in lower third of crown.
Medium	Three to six separate infections per tree with all infections at least 12 inches from bole.	Lower two-thirds of crown infected.
Heavy	More than six separate infections or fewer if within 12 inches of bole, or one infection on bole.	Infection through entire crown or in upper third. Spike tops may may be developing.

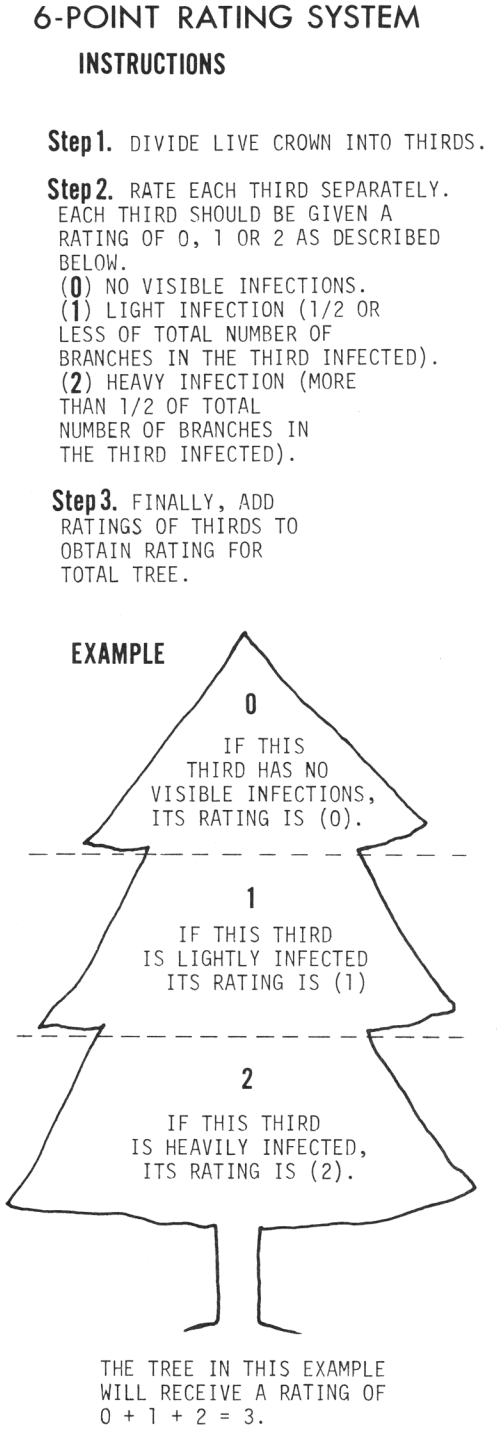

Figure 3--Six-point dwarf mistletoe rating system

Table 8--Number of inventory plots examined for dwarf mistletoe by date, State, and unit and dwarf mistletoe rating system, California, Oregon, and Washington

State and Unit	Inventory Date	Dwarf Mistletoe Rating System	Number of Plots
California			
National Forests			
Klamath	1967	3-class	571
Lassen	1970	6-point	224
Mendocino	1971	6-point	236
Modoc	1970	6-point	240
Plumas	1969	3-class	260
Shasta	1968	3-class	212
Six Rivers	1966	3-class	398
Tahoe	1972	6-point	261
Trinity	1969	3-class	182
			2,584
Outside National Forests			
Humboldt County	1966	3-class	262
Mendocino County	1967	3-class	257
Siskiyou County	1968	3-class	135
Rest of State exclusive of Southern California	1970-1972	6-point	993
			1,647
Total for California			4,231
Western Oregon			
National Forests			
Mount Hood	1971	6-point	421
Rogue River	1967	3-class	300
Siskiyou	1968	3-class	400
Siuslaw	1973	6-point	487
Umpqua	1969	6-point	749
Willamette	1971	6-point	589
			2,946
Bureau of Land Management	1967-1969	3-class	1,828
Outside National Forests	1973-1976	6-point	953

(continued)

Table 8--Number of inventory plots examined for dwarf mistletoe by data, State, and unit and dwarf mistletoe rating system, California, Oregon, and Washington

State and Unit	Inventory Date	Dwarf Mistletoe Rating System	Number of Plots
Eastern Oregon			
National Forests			
Deschutes	1971	6-point	712
Fremont	1973	6-point	430
Ochoco	1972	6-point	291
Umatilla	1968	3-class	749
Wallowa-Whitman	1968	3-class	639
Winema	1972	6-point	383
			3,204
Outside National Forests			
Central Oregon	1964	3-class	334
Blue Mts.	1969	6-point	246
			580
Total for Oregon			9,511
Western Washington			
North Mt. Baker National Forest	1965	Not rated	102
Outside National Forests			
Southwest Washington	1963	3-class	461
Olympic Peninsula	1965	3-class	487
Puget Sound	1966	3-class	546
			1,494
Eastern Washington			
National Forests			
Okanagan and Wenatchee	1964-1965	Not rated	885
Outside National Forests			
Central Washington	1967	3-class	369
Inland Empire	1968	3-class	414
			783
Total for Washington			3,162
Total for all three States			16,904

Table 9--List of tree species and most commonly associated dwarf mistletoe species[1/]

Common name	Scientific name	Dwarf mistletoe[2/]
Ponderosa pine	*Pinus ponderosa* Laws.	*Arceuthobium campylopodum* Engelm.
Jeffery pine	*Pinus jeffreyi* Grev. and Balf.	*Arceuthobium campylopodum* Engelm.
Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco	*A. douglasii* Engelm.
Lodgepole pine	*Pinus contorta* Dougl.	*A. americanum* Nutt.
Western hemlock	*Tsuga heterophylla* (Raf.) Sarg.	*A. tsugense* (Rosend.) G. N. Jones
Mountain hemlock	*Tsuga mertensiana* (Bong.) Carr.	*A. tsugense* (Rosend.) G. N. Jones
Western larch	*Larix occidentalis* Nutt.	*A. laricis* (Piper) St. John
Pacific silver fir	*Abies amabilis* (Dougl.) Forbes	*A. tsugense* (Rosend.) G. N. Jones
White fir	*A. concolor* (Gord. & Glend.) Lindl.	*A. abietinum* (Engelm.) Gill
Grand fir	*A. grandis* (Dougl.) Lindl.	*A. douglasii* (Engelm.)
Subalpine fir	*A. lasiocarpa* (Hook.) Nutt	*A. laricis* (Piper) St. John
California red fir	*A. magnifica* A. Murr.	*A. abietinum* (Engelm.) Gill
Shasta red fir	*A. magnifica* var *shastensis* Lemm.	*A. abietinum* (Engelm.) Gill
Noble fir	*A. procera* Rehd.	*A. tsugense* (Rosend.) G. N. Jones

[1/] See footnote 3 in text, Kimmey 1957, and Graham, Donald P. 1964, The dwarf mistletoes, their characteristics and identification. USDA For. Serv. Reg. 6, Portland, Oreg. 7 p. (Unpublished).

[2/] Listed are the species of *Arceuthobium* most commonly infecting the tree species listed. No attempt was made to identify the species of *Arceuthobium*, though more than one may infect some tree species. The area of lodgepole pine shown in this report to be infected with dwarf mistletoe, for example, may include infections of *A. americanum*, *A. laricis*, *A. campylopodum*, or *A. tsugense*.

APPROACHES TO DETERMINING VOLUME LOSSES DUE TO DWARF MISTLETOE ON A WESTWIDE BASIS[1/]

David B. Drummond[2/]

Abstract: Timber inventory data from three National Forests were evaluated to determine their suitability as a source of data which could be used to compute cubic-foot volume loss. These data indicate that while timber inventory and forest survey represent the logical approach to the collection and storage of such information, existing data are not adequate to provide cubic-foot volume loss estimates at this time. Results from a road-plot survey indicate that the system can be used to estimate dwarf mistletoe incidence and intensity in areas where all topographic aspects contain adequate roads.

INTRODUCTION

Information on forest insect- and disease-caused losses over large areas has usually been available only by extrapolating timber stand data initially collected for other purposes. Few attempts have been made to relate disease incidence to volume loss at a statewide level. In the past, confidence limits could not be placed on national estimates of insect- and disease-related losses, and they were often disregarded. To rectify this, we are attempting to assess loss from dwarf mistletoe and other forest pests over a statewide area. To help in planning and carrying out this attempt, the U.S. Forest Service organized a Loss Assessment Working Group composed of forest pathologists.

At first glance, statewide estimates of forest insect- and disease-caused loss would appear to be of little benefit to the timber manager at the district level. Indirect values to the timber manager, however, include (1) the determination of long-term effects of a pest or pest complex on growth which will help establish priorities in management; (2) the documentation of the success or failure of silvicultural and/or direct control measures applied by the timber manager (these estimates will assure that research support is provided for problems of greatest concern to the timber manager); and (3) the reduction in the amount of management by crisis--a syndrome often displayed by the Forest Service in its dealings with pests. Furthermore, data of this nature will aid in allocating funds when needed.

The estimates per se, if made for an entire forest, state, or region, will be of little direct value to the timber manager in dealing with specific stands. However, data from which such estimates were drawn would be of use to him if they were located in a common data base.

TIMBER INVENTORY AS A FUTURE SOURCE OF LOSS DATA

Remote sensing techniques are coming into wide use, but dwarf mistletoes do not lend themselves well to detection using such techniques. In most areas, greatest losses are attributed to reduced growth, not mortality; consequently, these losses are often ignored.

To measure the effects of dwarf mistletoes and other pathogens, data need to be collected over large areas, and data collection should be

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[1/] Presented at the Symposium on Dwarf Mistletoe Control Through Forest Management, Berkeley, Calif. April 11-13, 1978.

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repeated at specified intervals. This reevaluation is most important. Growth loss caused by forest pests must be studied during the endemic phase so that host-pathogen interactions at that level can be documented. In this way, it can be determined if a particular pest causes sufficient loss at normal population levels to alter existing management strategy.

Research has documented the effects of mistletoes on a stand-by-stand basis (Baranyay and Safranyik 1970; Hawksworth and Hinds 1964; Weir 1916), and these results have been incorporated into simulation models for lodgepole pine and southwestern ponderosa pine (Edminster 1977). These tools can aid in estimating loss on a state or regional basis.

The Loss Assessment Working Group agreed that the timber inventory would provide the best way to fulfill these data collection requirements; however, existing timber inventory data are not adequate to provide reliable disease and insect information. Generally, information concerning pests available in the inventory is not adequate to assess insect or disease presence at the stand level, nor is it sufficiently consistent for estimates of disease loss over large areas. Insect and disease information in many regional inventories consists of a subjective evaluation of only the "most damaging agent" observed on each plot tree. This does not permit accurate determination of specific pest organisms involved in complexes or the relative importance of other organisms endemic in the area. We hope eventually to alter slightly the various timber inventory methods to improve the quality and quantity of pest data collected; in the meantime, we hope to generate loss estimates by using several approaches.

In the interim, we are evaluating existing dwarf mistletoe incidence data, and where possible, use those data that appear adequate to provide an interim volume loss estimate. We are also investigating methods of rapidly acquiring accurate data for areas where either timber inventory and/or dwarf mistletoe incidence data are not available, i.e., private and state ownerships.

This paper describes approaches used to estimate losses due to dwarf mistletoes on three National Forests: the Medicine Bow in Wyoming, the Prescott in Arizona, and the Deschutes in Oregon.

GATHERING LOSS ASSESSMENT INFORMATION

Medicine Bow National Forest, Wyoming

During 1977, a pilot project was conducted on the Medicine Bow National Forest in Wyoming. The purpose of this survey was to evaluate an existing timber inventory system that included a dwarf mistletoe rating (Hawksworth 1956), in addition to the "most damaging agent" evaluation of plot trees. These timber inventory data were compared with results of a road-plot survey, carried out by forest pathologists during the summer. The survey was intended to test our ability to estimate green stand parameters and, at the same time, determine if timber inventory crews accurately evaluated the presence of dwarf mistletoe.

Road Plot Survey

The survey was similar in design to one conducted by Hawksworth (1958), but with some modifications. The study consisted of two parts. The first part was a road reconnaissance where the distance was recorded at any point where a detectable change in forest type, size class, or dwarf mistletoe infection level occurred along the right-hand side of the road. Type maps were used to exclude obvious areas of non-lodgepole pine type. Lodgepole pine stands above 3,000 m elevation were also excluded because lodgepole pine dwarf mistletoe does not occur above this elevation in the Medicine Bow National Forest (Hawksworth 1956). Inventory data were used to provide acreage estimates for lodgepole pine type on the forest.

Dwarf mistletoe infection was recorded as none, light, moderate, or heavy. "Light" indicated less than one-third of the trees in the stand's predominant size class were infected; "moderate" indicated one-third to two-thirds were infected; and "heavy" indicated that greater than two-thirds of the trees were infected. The stands were evaluated to a depth of 1 chain from the road for mature stands, and one-half chain in pole, and seedling stands. The percent area of lodgepole pine type affected by mistletoe was estimated by determing the ratio of miles of lodgepole pine type with infected trees present to the total number of miles of lodgepole pine type traversed.

The second part of the survey consisted of establishing variable-radius plots at three-mile intervals along the road. Plots were located 2 chains into the forest at right-angles to the road being traveled.

Plots were established on the right-hand side of the road; however, if the plot was non-type, then the left side of the road was used. If both sides were non-type, the plot location was rejected without replacement.

Basal area was determined for 107 variable plots. Diameter at breast height (DBH), and a dwarf mistletoe rating (DMR), were recorded for each tree 5 inches or more in diameter. A one-one hundredth-acre (1/100) fixed plot was also established to evaluate reproduction. Trees greater than 6 feet in height and less than 5 inches DBH were recorded and evaluated for dwarf mistletoe. Plot data were combined to represent approximately 70 hypothetical stands.

The RMYLD simulation model (Edminster 1977) was then used to estimate cubic-foot volume loss for each stand, based on the average dwarf mistletoe rating from the plots combined to make up the stand. This loss estimate was derived by making two consecutive computer runs using the model, the first with average DMR's derived from the data, and the second with all DMR's converted to zero to represent non-infected stands. The latter simulates growth over the next ten-year period as if no dwarf mistletoe infection existed in the forest.

Timber Inventory

Ninety-two Stage I timber inventory plots had been established within the lodgepole pine type in the Medicine Bow National Forest. Region 2 timber inventory personnel provided a summary of the green stand data for these plots. From printouts, data for the following parameters were transposed to a summary sheet and were segregated by computer into the following categories:

Site index (five categories)

a. 40-49
b. 50-59
c. 60-69
d. 70-79
e. $\geq$ 80

Dwarf mistletoe infection level (four categories)

a. no infection (0)
b. light (L) 1-60 percent of trees infected
c. moderate (M) 61-81 percent of trees infected
d. heavy (H) greater than 81 percent of trees infected

Basal area (five categories)

a. 0-50 $ft.^2$
b. 51-100 $ft.^2$
c. 101-150 $ft.^2$
d. 151-200 $ft.^2$
e. greater than 200 $ft.^2$

On the basis of these categories, similar plot data were segregated into 65 hypothetical stands. The RMYLD simulator was used to estimate growth loss in the same way as it was used for the survey.

Volume Loss Estimates

Incidence, as used in this paper, refers to the presence or absence of the pathogen on the timber inventory or survey plot, and does not reflect an evaluation of disease severity. Table 1 compares incidence data for the Medicine Bow National Forest acquired from several sources, revealing that 47% of the Stage I timber inventory plots contained one or more mistletoe infected trees. Fifty-five percent of the lodgepole pine acreage represented by those plots contained mistletoe infected trees. The road survey conducted in 1977 revealed that 60.5 percent of the miles traversed were adjacent to mistletoe infested stands. Sixty percent of the plots established in conjunction with the road survey contained mistletoe infected trees. Hawksworth's survey conducted in the mid-1950's reported that 59 percent of the plots on the Medicine Bow National Forest contained mistletoe infected trees.

The average volume derived from the Stage I timber inventory was 2302 cubic feet per acre (table 1). The 1977 road survey estimate was 2213 cubic feet per acre. These two estimates are not significantly different.

All data sources produced similar estimates of dwarf mistletoe incidence, and the plot portion of the road survey and the Stage I timber inventory produced comparable estimates of average total cubic foot volume per acre.

A large discrepancy occurred in the acreage and corresponding volume loss estimates for the different dwarf mistletoe severity categories (table 2). The survey conducted by trained forest pathologists resulted in a larger number of acres within the higher severity categories of infection and a concomitant increase in volume loss.

These results indicate that while timber inventory crews may be able to recognize dwarf mistletoe incidence on inventory plots, as

Table 1--Incidence of dwarf mistletoe on the Medicine Bow National Forest.

Source	Parameter	Percent
Timber Inv.	plots with mistletoe	47.0
Timber Inv.	acres with mistletoe	55.0
1977 Survey	miles with mistletoe	60.5
1977 Survey	plots with mistletoe	60.0
Hawksworth's 1958 Survey	plots with mistletoe	59.0

Per Acre Volume Estimates:

T.I. Stage I	2302.6 cu. ft.
Road Survey Plots	2213.3 cu. ft.

revealed by the consistency of the results shown in table 1, they significantly underestimate the intensity of the infection. This is further illustrated by the fact that 34 percent of the acreage was represented by average dwarf mistletoe ratings of 3.1 or greater for the 1977 survey plot data, while, according to the timber inventory data, only 3 percent of the acreage contained stands that had average dwarf mistletoe ratings greater than 3.1.

Prescott National Forest, Arizona

Other approaches to the generation of loss data were attempted for the Prescott National Forest, Arizona, by using timber inventory files and a 1970 dwarf mistletoe survey conducted by the forest. The survey was conducted in areas shown by an earlier compartment examination to contain dwarf mistletoe infected trees.

Timber Inventory Data

Dwarf mistletoe presence on plot trees was not recorded separately in the Forest Service Region 3 timber inventory as it was in Region 2; however, it was given precedence over all other damaging agents in the evaluation. If a tree displayed symptoms or signs of more than one damaging agent, one of which was dwarf mistletoe, it was recorded as mistletoe infected in the "most damaging agent" column of the inventory.

Therefore, all individual tree entries for ponderosa pine on the Prescott National Forest that did not display a dwarf mistletoe infection rating (1-6) indicated either no mistletoe or some other damaging agent category.

Dwarf mistletoe infection rating, net volume and net growth per acre in cubic feet for each plot tree, and the plot basal area and site index for approximately 130 plots were summarized for the entire forest. Total volume per acre for the average plot tree was averaged by site class for all plots with infected trees present. The same calculation was made by site class for all plots without infected trees present. The difference between these two figures (table 3) should represent the net difference in volume or growth of the average plot tree for that particular site class. Our assumption was that volume difference resulted primarily from mistletoe presence.

Data acquired from the Prescott National Forest timber inventory show that the only significant difference occurred in the volume of the average Site 1 plot tree (table 3). Net volume was significantly lower for Site 1 plots containing infected trees. Significant differences were expected for Sites II and III, but were not detected. No significant differences were observed when all plots, irrespective of site, were combined; again, significant differences were expected but did not occur.

Although significance was noted for the one category, our confidence in the results is low and will remain so until they are verified. It is possible that site evaluation was compromised in the inventory as a result of using the height of dwarf mistletoe infected trees to establish site. The most we could possibly infer from these data is that dwarf mistletoe seems to be lowering the productivity of those areas with good growth potential.

Table 2--Annual cubic-foot volume loss estimates for the Medicine Bow National Forest, derived from Stage I Timber Inventory and 1977 plot surveys using RMYLD model.

Dwarf Mistletoe Severity Category	M's of Acres Represented		Annual Cubic Foot Volume Loss	
	Stage I Tim. I.	1977 Plot Survey	Stage I Tim. I.	1977 Plot Survey
0	158	182	0	0
0.1-1.0	138	38	0	0
1.1-2.0	37	17	20,780	7,015
2.1-3.0	12	10	72,857	56,087
3.1-4.0	4	47	49,776	871,891
4.1-5.0	4	60	17,880	2,879,211
5.1-6.0	-	21	-	194,044
TOTAL	353	375	161,300	4,008,250

Dwarf Mistletoe Survey

A second source of information on dwarf mistletoe-caused loss for the ponderosa pine type on the Prescott National Forest was available from a dwarf mistletoe survey conducted during 1969 and 1970. The original data from this survey were furnished to Forest Insect and Disease Management (FI&DM) personnel by the Forest. Region 3 FI&DM personnel summarized these data, extracting the following parameters:

A. Dwarf Mistletoe Level (DMR)

1. (0) = no infection
2. (1-2) = low
3. (3-4) = moderate
4. (5-6) = heavy

B. Size Class (As defined in the original dwarf mistletoe survey, 1972)

1. 1 to 7 in.
2. 7.1 to 11.6 in.
3. Greater than 11.6 in.

C. Site Class (Region 3 uses three categories, as follows)

1. Site 1: greater than 75
2. Site 2: 55-74
3. Site 3: 54 or less

D. Basal Area

Basal areas were used to describe stand density and calculate the DBH of the tree of average basal area, parameters necessary to use with the RMYLD simulator.

Height was not available from the dwarf mistletoe survey data; however, the RMYLD simulator will insert a standard value for height if site is given.

The combined results of two separate complete runs using the RMYLD simulation model show that the annual cubic-foot volume loss estimates generated for the overstory and understory were 37,000 and 46,200, respectively (table 4). These losses occurred on approximately 6000 of 9300 infested acres. Dwarf mistletoe was present, but losses were not projected for approximately 3300 acres.

Deschutes National Forest, Oregon

A third approach to determine loss on a Forest-basis is being attempted for the Deschutes National Forest, Oregon. For this Forest, we will estimate cubic-foot volume loss using growth parameters from existing inventory data.

Table 3--Cubic-foot net growth and net volume per acre for the average plot tree[1/] in dwarf mistletoe non-infested and infested plots from the Prescott National Forest.

		Non-infested plots[2/]	Infested plots[3/]	Difference
NET GROWTH	Site I	1.8	1.7	0.1
	Site II	1.4	1.8	-0.4
	Site III	1.1	1.1	0.0
NET VOLUME	Site I	72.7	59.3	13.4**
	Site II	62.0	56.3	5.7
	Site III	48.1	50.9	-2.8

[1/] Ponderosa pine only

[2/] Column derived from 72 plots

[3/] Column derived from 21 plots

** Statistically significant at 1 percent level

Region 6 timber management personnel will search timber inventory tapes for the Deschutes National Forest, and retrieve and record the following 10 parameters for each tree entry:

1. Plot number
2. Site class
3. Net growth in cubic feet
4. Diameter at breast height
5. Height (site trees only)
6. Age
7. Crown class
8. Dwarf mistletoe rating
9. Tree history
10. Condition class

Net growth recorded on the forest's data tape is a derived entry. Actual observed net growth for plot trees is available only from the original field data cards on the first three points of a 10-point cluster plot. These data entries have been retrieved by hand, and will be appended to the newly-produced data tape file.

Volume loss estimates will be made in two ways. The first will provide estimates for hypothetical stands by site class and dwarf mistletoe rating using actual measured net volume growth as the dependent variable. The total number of entries used for this summary will be approximately 30 percent of the total number of ponderosa pine trees sampled during the inventory. Since future estimates cannot rely on the manual transposition of field records for data input, the second estimate of growth loss volume will come directly from the Forest's plot summaries. These will consist of net growth for each plot by site and by average plot DMR using all individual tree entries. Growth loss estimates, derived in these two ways, will then be compared to determine the reliability of the latter method.

REVISED APPROACH TO GATHERING INFORMATION

The Dwarf Mistletoe Loss Assessment Working Group met again in January 1978, reviewed the results reported in this paper, and made several changes in our approach to loss assessment.

The Group still was committed to the belief that Forest Inventory and Forest Survey systems remain the only feasible way to collect and store certain insect- and disease-caused loss information applicable over large areas. However, our approach to gathering interim data has changed. We are requesting that each Region update estimates that were made in 1975. Many Regions have recent data that should improve the reliability of their 1975 estimate. Other Regions plan to use the road survey procedures previously discussed to add to their data base. Other sources may be consulted.

The Forest Survey unit of the Pacific Northwest Forest and Range Experiment Station is presently working with dwarf mistletoe incidence data for state and private lands in Washington and Oregon. This information has been summarized at this Symposium. Data were

Table 4--Cubic-foot volume loss derived from the RMYLD simulator using 1970 dwarf mistletoe data from the Prescott National Forest.

Infested Acres	Cubic-foot volume loss		
	overstory	understory	total
3322	0	0	0
5984	37,000	46,200	83,200
9306	37,000	46,200	83,200

collected using Hawksworth's rating system. When they have completed their summary work, specialists in Regions 5 and 6 can use the incidence data to estimate volume loss.

Region 5 FI&DM personnel recently collected dwarf mistletoe incidence data for the San Bernardino National Forest as part of the Pest Damage Inventory (PDI). These supplemental data were collected to determine whether or not the RMYLD simulator could be used in southern California. Other data from the Pacific Southwest Forest and Range Experiment Station will be consulted to determine how suitable they are for making volume loss estimates for Region 5.

The diverse methods and data sources being used to make interim loss estimates illustrates the inconsistency in existing data from area to area. The diversity of approaches points out the need to incorporate more complete insect and disease information in the regional timber inventory systems and Forest Survey wherever possible. The Dwarf Mistletoe Loss Assessment Working Group still believes that the timber inventory data base is the logical place to maintain data on insects and pathogens which influence forest productivity. The data would be beneficial to most administrative levels, from the timber manager on the Ranger District to the U.S. Office of Management and Budget in Washington, D.C. This approach would require greater commitment by FI&DM personnel to training timber inventory crews, possibly even providing one well-trained individual per crew for the insect and disease recognition portion of the inventory. This person need not be a professional, but could be a technician thoroughly trained in insect and disease recognition.

LITERATURE CITED

Baranyay, J.A., and L. Safranyik.
1970. Effect of dwarf mistletoe on growth and mortality of lodgepole pine in Alberta. Can. Dep. Fish and Forest. Publ. 1285, 19 p.

Edminster, C.B.
1977. Computation of yield tables for even-aged and two-storied stands. USDA Forest Serv. Res. Paper. Rocky Mountain Forest and Range Exp. Stn., Ft. Collins, Colo.

Hawksworth, F.G.
1958. Survey of lodgepole pine dwarf mistletoe on the Roosevelt, Medicine Bow, and Bighorn National Forests. Rocky Mountain Forest and Range Exp. Stn. Paper 35, 13 p.

Hawksworth, F.G.
1956. Upper altitudinal limits of dwarf mistletoe on lodgepole pine in the central Rocky Mountains. Phytopathology 46:561-562.

Hawksworth, F.G., and T.E. Hinds.
1964. Effects of dwarfmistletoe on immature lodgepole pine stands in Colorado. J. For. 62:27-32.

Weir, J.R.
1916. Mistletoe injury to conifers in the Northwest. U.S. Dep. Agric., Agric. Bull. 360, 39 p.

IMPACT EVALUATION FOR DWARF MISTLETOE-INFESTED PONDEROSA PINE IN THE SOUTHWEST[1/]

James W. Walters[2/]

Abstract: Southwestern dwarf mistletoe (Arceuthobium vaginatum subsp. cryptopodum) occurs on more than one-third of the commercial ponderosa pine forest in Arizona and New Mexico. Annual volume loss from this disease is estimated at 150-200 million board feet on National Forests in the Southwestern Region. The simulated yield program SWYLD2 is used to help evaluate impact of southwestern dwarf mistletoe. A survey procedure and data summary program have been designed to compile input for the SWYLD2 program. This program provides resource managers with simulated yield tables for dwarf mistletoe-infested stands of ponderosa pine. Yield tables help quantify timber volume loss, and allow resource managers to examine various management alternatives and their effects on dwarf mistletoe levels.

Southwestern dwarf mistletoe (Arceuthobium vaginatum subsp. cryptopodum) is the most destructive disease on ponderosa pine in the Southwest. This disease occurs on all National Forests in Arizona and New Mexico. Andrews and Daniels (1960) calculated southwestern dwarf mistletoe to be present on at least 2.5 million acres of commercial ponderosa pine forest in Arizona and New Mexico. Annual volume loss from this disease is estimated to exceed half of the annual allowable cut on National Forests in Region 3. Principal hosts for southwestern dwarf mistletoe include ponderosa pine, Pinus ponderosa var. scopulorum, P. ponderosa var. arizonica, and Apache pine, P. engelmannii. The adverse effects of southwestern dwarf mistletoe have been quantified in several ways. Mortality estimates have been made for infested stands, potential safety hazard in recreation areas has been evaluated, and timber volume loss has been quantified on a stand basis. The latter is perhaps the most useful tool for evaluating dwarf mistletoe effects over large areas.

Three factors contribute to timber volume loss: growth reduction, tree mortality, and defect. Growth reduction is the most important and most difficult value to estimate. Heavily-infected trees may sustain a 30-60 percent growth reduction, compared to non-infected trees. The amount of reduction depends on time and intensity of infection, tree size and age, site factors, and many other aspects of tree environment.

Tree mortality is the second most important volume loss factor. Mistletoe-caused mortality can be difficult to quantify due to invasion of infected trees by insects. Assigning the primary mortality factor often becomes impractical. Andrews and Daniels (1960) estimated annual mortality losses in mistletoe-infested ponderosa pine at 55-75 million board feet in the Southwest.

Defect caused by dwarf mistletoe is related to grain distortion and resin impregnation at infection sites. This aspect of volume loss is seldom measured, and its overall importance is not well-defined for Southwestern forests.

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Commonly used evaluation techniques, such as measurement of volume loss, frequently estimate only one of the many effects resulting from a dwarf mistletoe infestation. For example, expressing adverse effects of dwarf mistletoe in terms of cubic foot loss per acre emphasizes the timber production aspect. It becomes more difficult to apply cubic foot loss to deterioration of wildlife habitat, recreational opportunity, or watershed productivity. In fact, what is an adverse effect on one resource may be beneficial to other resources. When a disease such as dwarf mistletoe alters the forest environment, questions must be answered to determine the total effects on all resources and resource users. These effects, when identified and quantified, constitute the impact of a forest disease. Can we measure this complex of effects? Do we have the expertise to evaluate such a vast array of factors? What terminology do we use to express positive and negative effects? These questions must be answered before impact evaluation can be realized.

There may be some confusion about who has responsibility for impact evaluation of dwarf mistletoe. In the U. S. Forest Service, personnel in Forest Insect and Disease Management cooperate with designated National Forest System personnel to develop impact data on dwarf mistletoe. In the Southwest, a forest disease specialist provides an assessment of the effects dwarf mistletoe is and will be having on infested stands (biological evaluation). This information is provided to the resource manager, so that, jointly, an impact evaluation can be prepared. Resource managers call on other specialists to help evaluate impact of dwarf mistletoe on other resources. In essence, a team of specialists provides input to the resource manager relative to mistletoe effects and their area of specialization. The resource manager then combines this information and completes the impact evaluation. An important factor to note is that we, in Forest Insect and Disease Management, really do not evaluate impact of a forest disease per se. We evaluate the current status of a disease, quantify certain effects of that disease, project the disease situation into the future, whenever possible, and assess or recommend potential control measures.

More finitely, in relation to southwestern dwarf mistletoe, we most frequently estimate only timber volume loss in an infested stand. This quantity then, constitutes our major input in the impact evaluation process.

Dwarf mistletoe evaluation efforts in the Southwest have been concentrated in high priority resource areas. Such areas are characterized by high-timber production potential (i.e., site index and accessibility) high-value recreational opportunity, or areas of special interest to resource managers (i.e., difficult regeneration areas). Economics define these types of areas as locations where adverse effects of dwarf mistletoe can be efficiently reduced. If a resource manager does not have sufficient funds to control dwarf mistletoe, there is little benefit in quantifying those effects. Exceptions occur in areas where quantifying disease effects can alter priorities (i.e., dollars and personnel). Eventually, we hope to participate in evaluating impact for all dwarf mistletoe-infested stands, but a system of priorities must be followed to obtain maximum benefit from our efforts.

Current Region 3 evaluations of southwestern dwarf mistletoe use the simulated yield program SWYLD2 (Myers et al. 1976, Edminster and Hawksworth 1976). This program provides resource managers with simulated yield tables for dwarf mistletoe-infested stands of ponderosa pine. Yield tables help quantify timber volume loss caused by dwarf mistletoe. Resource managers can examine various management alternatives and their effects on dwarf mistletoe levels. In addition, they can better evaluate the benefits and consequences of controlling dwarf mistletoe.

Application of the SWYLD2 program is restricted to even-aged or two-storied stands that are at least 90 percent ponderosa pine. Stands not meeting these requirements are not necessarily precluded from the mistletoe evaluation process, but our assessment lacks the predictive aspect.

Basic input in the SWYLD2 program is relatively uncomplicated. Stand condition variables needed for SWYLD2 input include: site index, average age, height and d.b.h., number of trees per acre, and stand DMR or percent trees infected with dwarf mistletoe. Stand DMR is the average dwarf mistletoe rating, based on the six class system, for all trees in a stand. These values must be provided for both stories in a two-storied stand. We have designed a survey procedure for gathering this information in even-aged or two-storied ponderosa pine stands.

Sample points are located on a grid throughout the survey area. Grid interval varies with stand size. A 4- by 4-chain grid may be used in a 200-acre stand, while a 10- by 10-chain grid may be selected for use in a 1,000-acre area. Fixed and variable radius plots (B.A.F.) are established at each sample point. The sample consists of all live trees 4.5 feet tall to 5.9 inches d.b.h. on the fixed plot, and live tally trees 6.0 inches d.b.h.

and larger on the B.A.F. plot. Presence/absence of dwarf mistletoe or dwarf mistletoe rating (DMR) and d.b.h. are recorded for all sample trees. A sketch map of plot locations is made during the survey for later use in showing dwarf mistletoe distribution. A specified number of age and height measurements are taken to estimate site index. Age and height measurements are also taken from a specified number of codominant or dominant trees in each story of the stand. Data are recorded on forms specifically designed for rapid transfer of information into a computer summary program.

Field data are then processed through the SWSUMMARY computer program. This program was designed to accommodate data from the previously outlined survey. SWSUMMARY prepares stand summary tables and calculates SWYLD2 stand condition variables from survey data. The program also summarizes age and height information for three sets of selected trees. These selected trees represent (1) maximum site potential of the stand, (2) average age and height of overstory dominant and codominant trees, and (3) average age and height of understory "dominant" and "codominant" trees. The summary tables provide a stand inventory and are useful in determining SWYLD2 management options.

Resource managers develop various management options and combine them with stand condition variables to produce simulated yield tables. Comparison of various management alternatives helps the resource manager quantify effects of dwarf mistletoe in an infested stand.

A cost analysis was made for eight survey areas completed in 1977. A 10- by 10-chain grid was used for all surveys. Cost estimates are based on field crew of two forestry technicians (i.e., $4/hr./technician) working 40 hours per week. Average cost, including travel time from Ranger District office to survey area, was 30¢ per acre. Pure survey cost, excluding travel to the survey area, averaged 23¢ per acre. Reducing the grid interval from 10- by 10-chains to a closer spacing will increase survey cost. However, we estimate that even at a 4-chain interval, survey cost will not exceed 75¢ per acre. The range in survey cost from 23¢ to 75¢ per acre appears reasonable for use of an intensive forest management tool.

Once the resource manager has a set of yield tables displaying volume loss caused by dwarf mistletoe over a rotation, various degrees of control can be simulated. Management alternatives which best meet the resource manager's needs can then be selected for implementation. SWYLD2 output is expressed in total cubic foot volume, merchantable cubic foot volume, and board foot volume on a per-acre basis. These values can be converted into dollar estimates by each individual resource manager. Individual conversion to dollar values is essential as market values vary with accessibility to production facilities, access to a labor force, etc. Once loss estimates are converted from cubic or board foot volume to dollar value, resource managers can determine the cost of dwarf mistletoe control; then, a cost/benefit ratio can be determined. Often, impact on other resource values can be quantified and compared with mistletoe control costs at various management intensities.

The final step in the evaluation process deals with follow-up on mistletoe evaluations. When a resource manager implements a silvicultural treatment, as projected by the SWYLD2 program, Forest Insect and Disease Management personnel may resurvey the stand. Follow-up survey data provide an assessment of how well simulated stand conditions match on-the-ground conditions. When actual conditions do not match those projected, an attempt is made to determine where the discrepancy occurred. In addition, simulations are made for the residual stand after treatment. Thus, the resource manager has an opportunity to correct inadequate treatments and to reassess the dwarf mistletoe situation for future years. This, in turn, provides more finite information for future timber management planning.

Through this follow-up procedure, for instance, we have found that maximum diameter limits and/or spacing restrictions in precommercial thinnings result in poor mistletoe control. These factors also can make simulation of such treatments less reliable. Such information is valuable to the resource manager who has based an impact evaluation on SWYLD2 projections.

As forest management continues to intensify, use of simulated yield programs will increase. Yield simulations, such as those provided by the SWYLD2 program, will continue to help the resource manager evaluate the impact of a forest disease such as southwestern dwarf mistletoe.

Dwarf mistletoe poses an unquestionable threat to the potential of forest resource production in the Southwest. Various techniques have been used to quantify the magnitude of this threat. Of the techniques used, summarizing timber volume loss over a designated time period appears to be the most efficient. The simulated yield program SWYLD2 has provided the methodology to complete this task. Resource managers can now begin to assess, in a more finite manner, the overall effects of dwarf

mistletoe on all resources. Thus, the capability to evaluate impact of southwestern dwarf mistletoe is in the final development stages.

LITERATURE CITED

Andrews, S. R., and J. P. Daniels.
1960. A survey of dwarfmistletoe in Arizona and New Mexico. U. S. Dep. Agric., For. Serv., Rocky Mt. For. and Range Exp. Stn., Stn. Pap. 49. 17 p.

Edminster, C. B., and F. G. Hawksworth.
1976. User's guide to SWYLD2: Yield tables for even-aged and two-storied stands of southwestern ponderosa pine, including effects of dwarf mistletoe. U. S. Dep. Agric., For. Serv. Gen. Tech. Rep. RM-23. 8 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colorado.

Myers, C. A., C. B. Edminster, and F. G. Hawksworth.
1976. SWYLD2: Yield tables for even-aged and two-storied stands of southwestern ponderosa pine, including effects of dwarf mistletoe. U. S. Dep. Agric., For. Serv. Res. Pap. RM-163. 25 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colorado.

Control Operations and Accomplishments

INTRODUCTION TO DWARF MISTLETOE CONTROL[1/]

Lewis F. Roth[2/]

ABSTRACT

Dwarf mistletoes are parasitic, destructive and economically damaging in the coniferous forests where they occur. Timber volumes of native forests infected with dwarf mistletoes are lower than are timber volumes in healthy forests of the same age. In the past, human activities in the forests--such as logging and fire control measures--actually encouraged the spread of the mistletoes. Positive steps toward control of dwarf mistletoe must now be taken or future stands will suffer even more acutely than those of the contemporary forests. Differences in climate and in distribution of hosts, site quality, and stand structure are known, natural limitations to spread of infection. Most dwarf mistletoe plants are visible so that boundaries of disease occurrence are easily observed, and development of the parasite in space and time is now well understood. After evaluating form and extent of damage, forest managers should plan appropriate strategies to contain dwarf mistletoe spread well within the critical threshold of infection. Because fire can influence shifting population balances in forest communities, it may become a tool for dwarf mistletoe control. In addition, resistance to dwarf mistletoe will be raised as a secondary benefit of silvicultural treatment through selection of better crop trees.

Dwarf-mistletoes are indigenous members of many coniferous forest communities. Dwarf mistletoes are by nature parasitic and are destructive and economically damaging in the stands where they occur. Timber volumes of infected native forests have long been recognized as lower than volumes in healthy forests of the same age. This reduction of volume demonstrates above all else, a slower rate of growth of the host in the presence of the parasite. Forestry practices during the first half of the present century or longer seem to have aggravated the dwarf mistletoe problem. Fire control as well as logging practices that were poorly suited to infected stands appear especially to have been responsible. Because of this early neglect positive steps must now be taken in many infected or threatened stands to control these pests. If they are not taken, young and future stands will suffer even more acutely than the contemporary forest.

While sometimes perplexing, dwarf mistletoes should not seem as mysterious to the forester as are diseases caused by widely and erratically distributed microscopic fungus spores, or by invisible environmental causes. Though some dwarf mistletoe plants are in fact not visible most may be readily seen, and disease symptoms often are striking. This visibility enables recognition of boundaries of disease occurrence in the forest, even by observers with limited experience and training, and allows fairly accurate evaluation of levels of severity, both current and anticipated. Mystery, therefore, should not be an obstacle preventing the manager from undertaking dwarf mistletoe control. However, earlier speakers have shown that a fairly sophisticated knowledge of mistletoe parasitism and of stand development in the presence of the parasite is required.

The fact that our indigenous coniferous forest produced timber of unexcelled quality and quantity demonstrates that these forests comprised ecosystems that were biologically stable and were in balance with their physical environment. This is good evidence that destructive disease outbreaks occurring today necessarily must have originated from disturbing human activities in the forest. The most important of these disturbances appear to

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1/ Presented at the Symposium of Dwarf Mistletoe Control Through Forest Management, Berkeley, Calif., April 11-13, 1978.

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be: first, stand modifications accompanying logging, which were forced upon the forest and often conducted with indifference or lack of understanding; second, introduction of exotic pathogens; and finally, fire control. It is logical, therefore, to look to contemporary human activity in the forest for many of the specifics that have caused dwarf mistletoe to increase, and for solutions to the problem as well.

Since the dwarf mistletoes are not exotics we can turn directly to interactions among components of the natural forest communities and their environment for control strategy. Absence of adequate resistance of the host necessitates that either we destroy the sources of inoculum by exterminating the pest from production units or alternatively that we manage our relatively susceptible hosts by special procedures in the presence of the pathogen. Both options may be employed in a well rounded control program.

Dwarf mistletoes develop in a context of space and time that is now reasonably well understood. There have been real natural limitations on mistletoe development. These limitations are evident from the fact that the parasite does not occur throughout the Western coniferous forest type or throughout any particular forest and it does not wholly destroy any infected stand. The limitations appear to be more physical than biological in as much as the fossil record shows the parasite to have been present for a long time without the evolution of reasonably effective genetic resistance in the host. Differences in climate and in distribution of hosts appear predominant in limiting general occurrence of the pests. Site quality greatly influences local severity. Fire limits both local severity and distribution, and stand structure especially influences damage within the stand.

The form and extent of damage must be evaluated at appropriate management levels: industry or agency, forest, timber stand and unit, before policy decisions to undertake control - perhaps at any level - can be soundly made. While dwarf mistletoe is rather easily detected, evaluation of damage is complicated and sometimes is so difficult as to be debatable among qualified professionals. Evaluation must first consider the existence and extent of damage - not just the presence of the parasite - and should then determine whether the disease trend, in the absence of control, is toward increased severity or toward improvement. If it is not toward improvement, decisions will be required as to: 1) levels of control that are intended or are acceptable (this can range from complete control to none); 2) feasibility of the undertaking; and 3) costs; and probable benefits. While these decisions are subject to economic considerations, long term management objectives, and utilization opportunities, the pathoglogist's attention is directed primarily toward the effect of mistletoe on stand productivity.

Most past practice was directed toward destruction of the mistletoe plants themselves, usually within supernumerary trees of the current crop. Limitation of lateral spread of the pathogen and reduction of growth loss within infected stands now appear to be more appropriate primary control objectives, with eradication to follow in subsequent rotations.

In most undisturbed stands, as indicated earlier in the symposium, manifestation of dwarf mistletoe in the forest is in, or near, a delicate state of equilibrium whether measured by size of plants, number of plants or damage to the host. This equilibrium is highly dependent on site and other features influencing host growth. Pure stands such as ponderosa pine on very poor sites may stagnate indefinitely when infected and may be unresponsive to treatment. Contrarily, on superior sites infected stands appear to be capable of sustained production at or near site capacity without special management attention.

Stands that are intermediate between the extremes of damage are of greatest concern for the forester because of their potential, on one hand, to become worse and, on the other, because of the control opportunities they afford. The exact thresholds of infection at which the pest can be made harmless or, if not harmless, then manageable, depend on site quality and other growth opportunities. These thresholds are unlikely to be constant. Whatever the circumstances, dwarf mistletoe control procedures should be such that the stands stay well on the safe side of the critical thresholds. If excessively damaged stands are treated, benefits are likely to be short term. Treatment probably should be applied only at a stage of stand development when a single treatment will improve growth enough to carry the stand to merchantable size. Younger stands on poorer sites probably should be destroyed and the sites sanitized and regenerated.

Mistletoe control procedures applicable to pure stands are limited primarily to tree spacing and the removal of heavily infected trees or branches. However, where site and other considerations are suited to more than one tree species, new control opportunities

arise. Dwarf mistletoes tend to be host specific. If growth and production conditions allow, balance within the disease system may be swung away from the parasite by altering stand composition or, if necessary, converting to an alternative species. Deliberate changes of species on the margins of infested areas provide effective barriers to further lateral spread of the parasite.

Fire has long been an influence in shifting population balances in forest communities and has had an important historical effect on dwarf mistletoe. Fire may offer much as a tool for control when its use in forest management is more completely investigated.

Many years of observation of the diversity shown by western dwarf mistletoe on ponderosa pine have led me to believe that a genetically broad base of horizontal resistance to dwarf mistletoe exists. While resistance has been badly eroded in the past by fires that destroyed progeny naturally selected for resistance, I believe that the level of horizontal resistance will be raised as a secondary benefit of silvicultural treatment through selection of better crop trees. Further improvement of the genetic tool for dwarf mistletoe control can be made by the tree breeder.

Whatever approaches to dwarf mistletoe control may be undertaken, I expect that none will succeed without a thorough understanding of both dwarf mistletoe dynamics and manipulation of forest stands. This knowledge is to be gained from our panel.

GENETIC CONTROL OF DWARF MISTLETOE[1/]

Lewis F. Roth[2/]

ABSTRACT

Trees in natural ecosystems in the course of their evolution have acquired less resistance to dwarf mistletoes than to many other native diseases. Nevertheless trees do resist mistletoe by: 1) taxonomic resistance, as a consequence of evolution, 2) single gene, vertical resistance, 3) polygenic horizontal resistance and 4) escape by means of heritable structural characteristics. Silvicultural control by change of species is based on taxonomic resistance. Practices include: selective treatment in mixed stands, special regeneration procedures, underplanting of shelterwoods, or establishment of non-host barriers to spread. In the absence of vertical resistance silvicultural control often is achieved at the price of reduced productivity. The silvicultural objectives can be met to a degree by horizontal resistance. Existing horizontal resistance can be further strengthened by silvicultural improvement of infected stands. Consequently genetic control of dwarf mistletoe is immediately available.

Genetically based resistance to infection resulting from co-evolution of forest trees and their pathogens has been the chief means of disease control in natural ecosystems (Van der Plank 1975). Serious disease outbreaks are absent from the forest except when the environment fluctuates widely or is artifically modified; or when introduction of either foreign hosts or pathogens occurs. Contrarily, the native dwarf mistletoes are regularly destructive in natural forests. Consequently they are properly regarded as exceptions. However, their dominance over their hosts is only partial and genetic resistance is a potential tool for their control. It is appropriate therefore to ask why so little attention has been given to genetic control and to consider future prospects.

Genetically based features have been used by forest managers, for control of dwarf mistletoe far more extensively than is generally realized. At the same time genetic resistance has been inadvertently, if not intentionally, ignored in tree improvement programs. The assumption used to justify this omission has been that the whole mistletoe control requirement can be expeditiously met by silvicultural treatment.

Although silvicultural methods are likely to dominate the control effort it will be well to examine our silvicultural practices more analytically and to broaden our concept of genetic control as these practices concern management of the dwarf mistletoe problem.

Trees resist damage by dwarf mistletoe in four genetically related ways: 1) by immunity accompanying co-evolution of the Pinaceae and Arceuthobium during, perhaps, the last 20 million years, 2) by vertical resistance (possession of specific resistant genes that match mistletoe genes for pathogenesis) (Van der Plank 1975), 3) by horizontal resistance (possession of polygenically regulated factors which in the aggregate suppress infection and limit disease (Robinson 1976) and 4) by disease escape based on heritable characters.

In spite of its great potential, vertical resistance is our least used genetic tool. This is partly because of challenging technical difficulties, including the necessary painfully slow conventional breeding methods that have discouraged its development. It is unfortunate that the historical dominance of single gene (vertical) resistance in the thinking of forest scientists should, for so long, have obscured other opportunities for mistletoe control by genetic means.

Immunity to plant disease is regarded by some (Robinson 1976) to be the rule rather than the exception. The form of immunity most often encountered by the dwarf mistletoes has developed during the course of evolution

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accompanying host speciation (Hawksworth and Weins 1972). It is expressed in the inability of one mistletoe, A. douglasii Engelm. on Douglas-fir for example, to attack another conifer such as ponderosa pine, when the two trees grow together in a mixed stand. Host immunity to the dwarf mistletoes is not absolute.

One tree species occasionally may be parasitized by a mistletoe having another tree species as its principal host. Thus secondary hosts occur which, though infected, usually cannot alone sustain the mistletoe population. Larch mistletoe (A. laricis [Piper] St. John) for example, may occur on white firs, mountain hemlock, lodgepole and ponderosa pines, Engelman spruce and white pines, but never in damaging amounts in the absence of the principle host, western larch.

Single gene resistance to dwarf mistletoe probably is rare. Such resistance is known against an endemic leaf pathogen, Didymascella thujina in western red cedar (Soegaard 1964). Hypersensitive reaction (sudden death of cells at the point of host penetration) which is commonly regarded as an indicator of single gene resistance, has been observed with dwarf mistletoe on ponderosa pine by Roth and Adams (unpublished data). Roth (1966) pointed out that survival of young ponderosa pine selected out of the existing gene pool as resistant to A. campylopodum is almost impossible under forest circumstances favorable for selection. The high flammability of the heavily infected stands where selection is progressing has made them particularly vulnerable to destruction by fire. Host species of other mistletoes may fare better.

If single gene resistance occurs, nothing is known of its heritability and hence little of its usability. Horizontal resistance seems more likely to occur because it can develop in the absence of selection pressure. It can also arise from a wide range of gene combinations so is likely to be more immediately usable.

Discovery of trees that are good candidates for resistance is difficult because so many forest influences determine whether a tree will be infected. Among non-genetic factors are tree size, characteristics of the inoculum source and, position of the suscept tree in the stand. Nevertheless, considerable resistance occurs among some individuals in natural stands even though all stands are so susceptible, as communities, as to require protection or control in the presence of the parasite. This resistance of individuals is horizontal resistance. It is seen, for example, in grafts of 40 to 50 ponderosa pines selected and tested under field conditions. These trees have remained mostly mistletoe free during 10 or more years (23 for 7 trees) of testing (Roth, unpublished data, Roth 1974a). Occasional mistletoe plants have appeared over the years on most of the "parent" trees. However, one notable parent has stood in the annual mistletoe seed shower from a heavily infected, large pine for more than 100 years without becoming infected. This pine appears to be immune to pine dwarf mistletoe (A. campylopodum).

Older trees are more resistant to dwarf mistletoe than young trees (Roth 1974a). While small trees may remain practically uninfected under an infected overstory for as long as 10 years these trees should not be regarded as resistant. Their safety lies in the small target they present to the mistletoe seeds (Wicker and Shaw 1967). Large trees collect many more mistletoe seeds than small trees. If large trees remain substantially mistletoe free under conditions of high exposure they probably are exhibiting horizontal resistance at a useful level.

A further expression of horizontal resistance has been noted (Roth 1974b) in the differential ability of ponderosa pines to tolerate infection by A. campylopodum. Trees in which diseased tissue is localized because of resistance of the phloem to invasion of the endophytic (absorptive) system of the mistletoe are lightly damaged. Such trees produce short, only slightly damaging, spindleshaped swellings in the presence of the endophyte. These trees contrast sharply with those lacking resistance of the phloem. Branches on the latter are abnormally thickened with long and tapered swellings. Their tissues are extensively occupied by the endophyte. We assume them to be extensively damaged physiologically.

Disease escape is a further means of limiting dwarf mistletoe. Escape mechanisms expressed through host morphology may be directly useful to the manager during stand improvement work or indirectly in a breeding program. Drooping foliage in ponderosa pine is an example. Dwarf mistletoe seeds are intercepted by needles of the potential host and depend on rain in order to slide into stem positions on thin-barked branchlet tips favorable for infection (Roth 1959, Scharpf and Parmeter 1967). Most seeds on drooping needles are washed from the needle tips onto

the ground. On good sites in southwestern Oregon where drooping needles are a predominent foliar habit, mistletoe is rare.

Geographic escape should perhaps be mentioned also. Though the respective hosts are susceptible, escape is seen, for example, in Douglas-fir dwarf mistletoe that does not significantly enter the heart of the Douglas-fir region. Similarly, southwestern dwarf mistletoe (A. vaginatum Engelm.) does not occur on ponderosa pine, its principal host, in the Pacific Northwest.

Now briefly consider applications of these relationships in forest management. Immunity accompanying speciation (taxonomic immunity) is a mainstay of silvicultural control of dwarf mistletoe. It allows reforestation with an alternate tree species when site sanitation is not possible. It enables safe underplanting of shelterwoods and is particularly valuable where the overstory must be kept for longer than 10 years (Wicker 1975). It allows plantings of alternative species around cutting units in order to establish immune border strips against infected stands. In mixed stands it allows the manager to sacrifice the severely diseased and damaged species and to carry the residual stand of alternative species to rotation age. It must be considered, however, that a mixed forest is more than the sum of its species. It is unlikely that any of the components, alone or in combination, can occupy the site to the productivity level achieved by the natural mixture, even though fully stocked. In many cases, if not in most, a trade-off in productivity will be required to accomplish the mistletoe control.

In this trade-off lies the misfortune of our failure long ago to pursue a breeding program for dwarf mistletoe control, including vertical resistance. With stock possessing high resistance, or immunity such as that of the pine mentioned earlier, all of the preceding silvicultural practices could be accomplished with no sacrifice of stand quality. Fortunately, there is a chance that objectives of some of these practices can be achieved through horizontal resistance even though of a lower level than immunity. Availability of such resistant stock might not be too distant if it were aggressively pursued.

Though it has not been experimentally demonstrated, there are indications that strong gains in horizontal resistance are made when heavily diseased young stands are treated for mistletoe control during timber stand improvement. Thinning after stands are 50 years old will have allowed most of the highly susceptible trees, during their juvenile period, to disclose their susceptibility and need for removal. By this time, also, the larger but less resistant trees will have become conspicuously infected, or will already have weakened in competition with their more resistant, less heavily infected associates and will be removed. The rate of disease development in these stands after treatment certainly will be slower than would have been the case in stands of equal stocking of the original genotypic composition at equivalent spacings.

Many stands of ponderosa pine in the Pacific Northwest treated for mistletoe in the early years of the young-growth control program should be nearing reproductive age and might quite reasonably be examined for gain in resistance if not for potential of development as seed orchards. If stands cannot be found that are suitable for orchard development, then timely steps should be taken to develop such stands.

In closing, opportunities for improved "resistance" through escape from infection should be briefly mentioned. Trees likely to escape, especially those with growth characteristics conducive to non-retention of dwarf mistletoe seed, drooping needles being perhaps the best known, can in some cases be recognized and left in the stand during thinning. Morphological features contributing to escape are appropriate material for the tree breeder. Clearly genetic considerations have a part to play now and in the future in a complete mistletoe control policy.

LITERATURE CITED

Hawksworth, F. G. and Delbert Wiens.
1972. Biology and classification of dwarf mistletoes (Arceuthobium) U.S. Dep. Agric., Agric. Handb. 401, 234 p.

Robinson, Raoul A.
1976. Plant pathosystems. 184 p. Springer-Verlag. Berlin.

Roth, Lewis F.
1959. Natural emplacement of dwarf mistletoe seed on ponderosa pine. Forest Sci. 5: 365-369.

Roth, Lewis F.
1966. Foliar habit of ponderosa pine as a heritable basis for resistance to dwarf mistletoe. pp. 221-228 In Gerhold, H. D. et al. (Eds.). Breeding Pest Resistant Trees, Permagon Press. Oxford. 505 p.

Roth, Lewis F.
1971. Dwarf mistletoe damage to small ponderosa pines. For. Sci. 17: 373-380.

Roth, Lewis F.
1974a. Juvenile susceptibility of ponderosa pine to dwarf mistletoe. Phytopathology 64: 689-692.

Roth, Lewis F.
1974b. Resistance of ponderosa pine to dwarf mistletoe. Silvae Genetica 23: 116-120.

Scharpf, R. F. and J. R. Parmeter.
1967. The biology and pathology of dwarf mistletoe, Arceuthobium campylopodum f. abietinum parasitizing true firs (Abies spp.) in California. U.S. Dep. Agric. Tech. Bull. 1362. 42 p.

Soegaard, Bent.
1964. Variation and Inheritance of Resistance to attack by Didymascella thujina in Western Red Cedar and Related Species. pp. 83-88. In Gerhold, H. D. et al. (Eds.) Breeding Pest Resistant Trees. Permagon Press. Oxford. 505 p.

Van der Plank, J. E.
1975. Principles of Plant Infection. 216 p. Academic, New York.

Wicker, E. F. and C. G. Shaw.
1967. Target area as a klendusic factor in dwarf mistletoe infections. Phytopathology 57: 1161-1163.

DWARF MISTLETOE MANAGEMENT IN THE PACIFIC NORTHWEST [1/]

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and
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Abstract: Most Pacific Northwest foresters know how to control dwarf mistletoes. High levels of control are being obtained because foresters are assigned control responsibility, training is continuously provided, and money is available. Dwarf mistletoes are managed by treatment unit layout, overstory removal, residual removal, sanitation thinning, stand replacement, species manipulation, pruning, and combination treatments. Dwarf mistletoe control techniques are an integral part of forest management.

INTRODUCTION

Dwarf mistletoes are estimated to reduce Oregon and Washington forest productivity by 148 million cubic feet annually. There are eight dwarf mistletoe species and 19 tree species affected. The most serious damage occurs in Douglas-fir, western hemlock, ponderosa pine, lodgepole pine, and western larch. Dwarf mistletoes are thought to occur on about one-half of the forest land in these two States. True mistletoes occur on Oregon oak, incense cedar, and juniper.

Projects with the sole objective of controlling dwarf mistletoes were not initiated in the Pacific Northwest until 1959. This seems somewhat surprising because as early as 1916 James Weir, one of the first forest pathologists to visit the Pacific Northwest, had clearly documented the seriousness of dwarf mistletoe damage. He suggested control procedures which are still appropriate today.

Dwarf mistletoes were certainly not ignored by Pacific Northwest foresters prior to 1959. They were considered in most forest operations; their presence influenced selection of sites to be cut, methods of harvesting, size of cutting units, and reforestation practices. Mistletoes were being controlled by routine forest operations.

When dwarf mistletoe control programs first began in the early 1960's, the idea was to eliminate all or nearly all mistletoe from treatment areas. Eradication is possible in clearcutting operations but in thinnings and uneven-aged management, primarily east of the Cascades, total mistletoe removal can seldom be. Now foresters ask "How much dwarf mistletoe can I tolerate and still grow a productive forest?" This makes mistletoe management more compatible with other forest management practices and it calls for much more professional judgment.

The goal of Pacific Northwest dwarf mistletoe management is to reduce the parasites to levels that allow trees and stands to grow at acceptable rates without incurring undue costs in control efforts.

Most Pacific Northwest foresters understand how to control dwarf mistletoes and are applying mistletoe management practices. Dwarf mistletoe management is more than ever before an integral part of management activities on most forest lands in Oregon and Washington. Mistletoe control is viewed along with precommercial thinning, selection of genetically superior trees, and fertilization as an intensive management tool to increase forest productivity. Many thousand acres receive dwarf mistletoe treatments each year. Part of this high level of control can be attributed to the good growing conditions in the Region and the favorable economic position of forest-

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ry, but mostly it is due to the average forester's good understanding of dwarf mistletoes. Mistletoes are managed more intensely on Federal and State forests than on most private holdings, but many of the industrial forestry companies are aggressively controlling the disease.

GAINING COMMITMENT

It may seem to some that a discussion on gaining commitment is out of place at this symposium. However, based upon our combined 19 years of experience with dwarf mistletoe control in the Pacific Northwest, we feel strongly that without foresters' commitment, control programs will not work. Most western foresters know the damaging effects of mistletoes. Forest pathologists incessantly speak of the evils of dwarf mistletoes and exhort foresters to control them. However, in many cases these actions are not enough. Control opportunities are missed because there is lack of commitment at one or more organizational levels.

The importance of gaining foresters' commitment to dwarf mistletoe control has been recognized by most people responsible for developing the programs in Oregon and Washington. Three actions have been taken--public agencies and some companies have officially declared it their policy to control mistletoes, training is being provided continuously, and funds are made available for dwarf mistletoe management.

The Forest Service Pacific Northwest Region and Washington State Department of Natural Resources (WDNR) have declared it their policy to reduce losses caused by dwarf mistletoes on lands they administer. These declarations assign responsibilities for mistletoe management. Guidelines are provided for managing mistletoes in numerous Pacific Northwest forest conditions. Other public forest land managing agencies have policies calling for reduction of disease losses but dwarf mistletoes are not specifically identified in the statements.

Dwarf mistletoe control guidelines and policy statements have to be clearly understandable, present attainable goals, and be based on facts. If they are too general, difficult to understand, or present unattainable goals, they will be ignored. People charged with carrying out these instructions have more commitment if they are involved in their formulation.

The issuance of directives is not, of course, totally responsible for commitment to control mistletoes. They are a contributing factor because they can be used to hold people accountable for their actions or lack of them. Without written policies and guidelines dwarf mistletoe management is left to the discretion of individuals. This has usually resulted in only interested people performing control and widely varying standards of work quality. This problem can be seen on some private lands.

Training has probably been among the most effective means of attaining high levels of commitment to dwarf mistletoe control in Oregon and Washington. The Forest Service conducts forest insect and disease management workshops on at least six National Forests per year. Dwarf mistletoes are a major topic, with emphasis being placed on practical management approaches. State forestry organizations provide the same type of training. In addition, the Forest Service has developed a 2-day dwarf mistletoe workshop which is presented upon request. Training pays big dividends because it keeps dwarf mistletoe on foresters' minds, provides an outlet for research findings, exposes the subject to those unfamiliar with mistletoes, and provides exposure of pathologists to people who need their services. Plans are well underway to provide dwarf mistletoe training to privately employed foresters in the two States under the auspices of the Northwest Forest Pest Action Council.

Oregon and Washington State forestry agencies and the Forest Service have all prepared easy to read how-to-do-it dwarf mistletoe publications. The latest is "Dwarf Mistletoes of Oregon" by the Oregon State Department of Forestry. One of the first management publications was "A Training Aid on Dwarfmistletoe and Its Control" by Donald Graham, issued in 1967. Several thousand copies were distributed and requests are still being received. This one publication probably contributed more to Pacific Northwest foresters' knowledge of mistletoes than anything else.

The WDNR and Forest Service have demonstration areas for training foresters how to recognize and manage dwarf mistletoes. Both good and bad techniques are shown. The purpose of the areas is to demonstrate how prescriptions offered in guidelines, publications, and training sessions are actually applied and look. In most cases demonstration areas are also study plots. Plans call for establishment of many more demonstration sites.

Directives and training are important to gaining commitment, but it is money that accomplishes dwarf mistletoe control in the Pacific Northwest. Allocation of funds for dwarf mistletoe control emphatically states management commitment.

Appropriation of funds by the Forest Service specifically for dwarf mistletoe control started in 1959 and reached a peak early in the 1970's with close to $400,000 being spent in one year. The WDNR has made about $190,000 available to its districts for control. Crown Zellerbach Corporation has recently budgeted money for hemlock dwarf mistletoe control in Washington. Since 1959, close to 2 million dollars have been obligated specifically for control in the Pacific Northwest.

A highly important benefit achieved by allocating these funds is stimulation of foresters' awareness of the need for and value of dwarf mistletoe control. Dwarf mistletoe control funds have served as seeds to spark interest. Once foresters become aware of the desirability and feasibility of controlling dwarf mistletoes, they rely less on funds specifically earmarked for control and more on regular timber stand improvement and sale preparation funds. Today at least five times as much acreage is treated with these funds than with dwarf mistletoe control funds.

We believe that these actions, specific policy direction, training, and funding form the basis for the high level of commitment Pacific Northwest foresters have to dwarf mistletoe control.

DWARF MISTLETOE MANAGEMENT TECHNIQUES

Treatment Unit Layout

Layout of dwarf mistletoe treatment units is important both in keeping costs down and preventing spread into new regeneration or sanitized stands. Borders of treatment units should incorporate natural and manmade barriers to prevent or slow reinvasion. Barriers which have been used include: Small natural openings in stands, larger meadow edges, timber type species changes, uninfected edges of the same timber type, rock outcrops, streams, lakes, roads, power lines, adjacent clearcuts, and others. Ridge tops do not make good boundaries because upwelling winds can carry dwarf mistletoe seed over the top. Valley bottoms are better. Barriers should be about 1 chain wide, but we have recommended narrower strips; particularly if the dwarf mistletoe species present does not discharge its seeds long distances.

Dwarf mistletoe infestations do not normally occur continuously over large areas. Instead, the pattern consists of infected, then noninfected zones scattered throughout stands. Foresters are encouraged to include entire stands in control units rather than treat infected portions so drastically different that new smaller stands are created where only one previously existed. For example, we would recommend that foresters not patch cut 1- to 2-acre mistletoe-infected spots in a 50-acre pole-size stand but consider sanitizing the entire stand. Generally, the smallest unit of commerical forest land managed separately is 5 acres. Smaller units are considered too costly to manage.

Clearcut corridors along edges of treatment units are discouraged primarily because of cost. It is better to readjust boundaries if possible. Cleared strips are sometimes used where treated acres adjoin old-growth infected trees of different ownership. Since dwarf mistletoes are quite host specific, infested or susceptible species are kept out of a 1 chain wide strip separating treated and untreated stands. Resistant species are either retained, planted, or allowed to regenerate naturally in the strip.

Treated units are often left with infected perimeters when adjacent stands will be harvested within 5 to 10 years. Only a small amount of dwarf mistletoe infection would occur in this short time. This requires careful long-term planning and follow-up.

Foresters are encouraged to design treatment units, especially clearcuts, with as large an area-to-perimeter ratio as compatible with other management considerations to prevent rapid reinvasion. In infected stands, where there is little opportunity to create uninfected edges, large, circular shaped clearcuts are favored over smaller long, narrow, clearcuts. To illustrate the potential importance of this point, consider the following example. There are two 30-acre clearcuts. One is circular, the other rectangular with dimensions of 10 by 30 chains. If the entire perimeters of both are infected and they are regenerated with susceptible tree species, the rectangular unit will be reinvaded fastest. After 15 years, 23 acres of the circular unit will be uninfected; but in the rectangular unit slightly less than 21 acres will be uninfected. Recommendations on size and shape of treatment units should be developed in consultation with landscape architects and wildlife biologists to avoid potential conflicts.

Overstory Removal

Dwarf mistletoes spread most rapidly in multi-story stands. Control activity is usually directed at creating single story stands. For example, an infected stand of old-growth ponderosa pine with a well-stocked but infect-

ed understory would first have the overstory removed, then the infected understory would receive a sanitation-precommerical thinning. Overstory removal is practically always accomplished by timber sales. Occasionally, scattered infected overstory will be either dropped or left standing and girdled.

A simple technique we have found useful in overstory removal is to paint the stumps of overstory trees which are infected. This alerts crews who will be thinning at a later date to examine trees surrounding painted stumps closely for infections.

The shelterwood system is a proven method for successfully regenerating Douglas-fir and other species on certain sites. Occasionally it is necessary to leave infected trees to provide shelter. When susceptible regeneration develops under infected shelterwood, the infected overstory should be removed as soon as the regeneration is established. The Forest Service uses a rule that infected overstory should be removed before regeneration reaches 3 feet tall or 10 years old, whichever occurs first. WDNR recommends for western hemlock management that infected overstory be removed within 5 years.

Most commerical forest land in the Pacific Northwest is, or will be, under even-age management, so removal of infected overstory trees is considered standard operating procedure.

Residual Removal

Infected trees often remain after stands are clearcut or burned. Pacific Northwest loggers, a proud group of rugged individualists, often consider it beneath them to cut unmerchantable size trees when clearcutting. Standard clauses in Forest Service and WDNR clearcut timber sale contracts require all trees above 4 inches dbh be cut. Smaller trees which may be infected can be left. The WDNR has clauses which may be inserted in timber sale contracts requiring a cleancut where all stems are to be severed when dwarf mistletoe is present. Many agencies, companies, and small landowners have no requirements concerning removal of trees in clearcuts. Many clearcuts are not broadcast burned, allowing infected residuals to survive. Wildfires usually do not kill all trees within burns.

These residuals constitute an infection threat to susceptible regeneration. For example, it was shown that dwarf mistletoe plants in one western hemlock on Vancouver Island, British Columbia, cast seeds over an area encompassing 5,800 square feet (0.13 acre). Less than eight of these trees, evenly spaced, could serve to spread mistletoe seeds over an entire acre. It is not at all uncommon to have more than eight infected residuals left per acre after clearcutting. We estimate that untreated residuals will cause at least 8,000 square feet around them to be unproductive in a normal rotation.

In many cases, infected residuals left after clearcutting will be killed by slash burning. Residuals are also removed for other reasons, such as firewood cutting or to reduce hazards to brush spraying helicopters.

Residual removal is one of the most effective and least costly dwarf mistletoe control techniques used in the Pacific Northwest. Considering that more than 360,000 acres are clearcut each year and that about 30 percent of this area may be infected, residual removal provides excellent opportunity for greatly reducing losses, particularly when it can be accomplished during logging.

Mistletoe control is frequently the only reason residuals are destroyed. Forest Service policy is to use money (K-V) from timber sales for this. When these funds are not available, other funds (P&M or FIDM) will be allocated. Top priority for Forest Service dwarf mistletoe control funds in the Pacific Northwest is residual removal.

Existing management guidelines do not specify how many infected residuals per unit area are required for control to be initiated. However, we would certainly recommend treatment even if there were as few as one tree per acre. If clearcuts are less than 5 years old, all living residuals of the infected tree species are killed. When there are numerous residuals and the stands will not be broadcast burned, we recommend treatment efforts be concentrated on those 3 or more feet tall; but we would prefer to see all destroyed. Foresters are encouraged not to attempt to save apparently uninfected trees because they may have latent infections. If clearcuts are 5 or more years old, only visibly infected trees have to be killed although we encourage all trees be treated.

Cutting residuals is preferred to girdling or poisoning because it guarantees trees will be killed and it is easier to check work thoroughness. In some instances, trees are girdled or poisoned, particularly if needed for wildlife.

There have been several occasions when an agency or company with several thousand acres

of clearcuts, ranging from less than a month to more than 20 years old, has decided to initiate residual removal for dwarf mistletoe control. Usually we advise them not to do residual removal as a separate operation on units more than 15 years old. It should be combined with sanitation precommercial thinning. The 10- to 15-year-old units are treated first because studies have shown the rate of stand infection increases rapidly once trees reach this age. The 5- to 10-year-old units are treated next and finally the 0 to 5 units until the backlog is eliminated.

Experienced crews can treat residuals during slow seasons, instead of being terminated. Unemployed people or youth crews can do this work with a small amount of training.

Residual removal costs vary tremendously depending upon number and size of trees, topography, and availability of labor. We have seen costs from $5 to over $200 per acre. Costs seem to average less than $40 per acre.

Foresters are urged to eliminate residuals during logging or reforestation. We have had success in getting loggers to knock over residuals as they are yarding logs to landings. High lead logging destroys more residuals than tractor, skyline, helicopter, or balloon logging. Broadcast burns are advocated, if ecologically sound for the sites. Pathologists advocate cleancuts instead of clearcuts.

Sanitation Thinning

In the late 1960's when dwarf mistletoe control was first begun on WDNR lands east of the Cascades, a few problems were encountered. Logical steps to control are to: (1) remove infected overstory, (2) sanitize infected understory by specialized precommercial thinning, and (3) follow-up 5 to 7 years later if necessary. Managers had difficulty finding acres eligible for precommercial thinning-sanitation because infected overstory was almost always present. Years of selective logging with occasional regard for dwarf mistletoe control had produced these stands.

It often became necessary to set up special timber sales just to provide acres for the precommercial thinning-dwarf mistletoe control. The cart was before the horse! Now, a better approach is being used: (1) dwarf mistletoe problem areas are identified, (2) the infected area is gradually converted to single story management through carefully planned overstory removal timber sales, and (3) the more or less even-aged shorter stand is sanitized while being precommercially thinned.

Note that the order of doing things is about the same as described above but the priorities are different! Instead of trying to find suitable stands for precommercial thinning first, the manager begins with the timber sale recognizing that if dwarf mistletoe is to be reduced only one level of canopy can exist. The disease control operation is now integrated with normal management.

Dwarf mistletoe sanitation on WDNR lands has been concentrated in ponderosa pine stands. The Hawksworth mistletoe rating system is used to select trees for removal. The amount of infection a tree can have and still be kept in a stand depends upon its size. The following table lists allowable ratings.

dbh Class	Maximum Allowable Rating
1-2	0
3-4	1
5-6	2
7+	3

Cutters are required to cut or kill all trees exceeding these ratings. Oregon State Department of Forestry advocates the same system.

Sanitized areas are examined 5 to 7 years after treatment to determine success and decide if additional treatment is necessary.

Forest Service dwarf mistletoe sanitation thinning guidelines differ somewhat from those of the WDNR. The guidelines apply to all tree species and a different infection severity rating system is used.

Sanitation is an integral part of all thinnings in infected stands. Expenditure of funds for sanitation is limited to lightly infected precommercial size stands from which all overstory has been removed. Severely infected stands are replaced rather than thinned.

Stand infection severity is not based directly upon the standard 0 to 6 rating system even though it is used in routine stand examination surveys. Stand infection intensity is rated none, light, or severe. It is based upon the number of potential crop trees for the site. Silviculturists have determined acceptable stocking levels for many tree species by site index. Presence of mistletoe affects crop tree potential. In stands where the average potential crop tree dbh is less than 2 inches, crop trees should have no visible infections. They should meet all other crop tree criteria. In stands with potential crop tree dbh averaging 2 inches or larger, priorities for crop tree selection are as follows.

1. Uninfected dominants and codominants.

2. Dominants and codominants with dwarf mistletoe confined to branches in the lower one-third of live crown.

3. Dominant and codominants with dwarf mistletoe confined to less than 50 percent of the branches in the lower one-half of live crown.

4. Intermediates with no visible infections.

These priorities correspond roughly to ratings of 0, 1, and 2, 3, and 0 using the standard mistletoe rating system.

If enough trees meeting these criteria exist to achieve acceptable stocking, the stand would be rated lightly infected. Stands are considered severely infected if there are not enough trees with the above characteristics to meet minimum stocking guidelines for the particular site.

This approach allows selection of trees based upon severity and location of infections. Trees with upper crown infections are not potential crop trees. Research has shown high crown infections cause more growth impact and contribute more tree-to-tree spread than lower crown infections. We feel one of the strong points of this crop tree selection method is that foresters must consider other tree and site characteristics in addition to mistletoe.

In the first several years of the Forest Service mistletoe control program, emphasis seemed to be placed upon eliminating infected trees during thinning. Little regard was paid to superior tree characteristics, resulting in many stands that look like silvicultural abominations. Dominant and codominant trees were felled, even if they were only lightly infected, and suppressed trees were chosen for crop trees because they were seemingly uninfected. Large openings were created where all infected trees were cut, regardless of infection intensity. Spacing and stocking was erratic. Good silvicultural practices were abandoned in the zeal to eliminate mistletoe. Fortunately, this problem has been corrected. Stands sanitized under present standards often contain infected trees to provide adequate stocking but they will grow at acceptable rates. Tree killing by dwarf mistletoe is uncommon in thinned stands.

Forest Service sanitation thinning guidelines recommend against spending funds for resanitizing stands. We feel foresters will remove the most severely infected trees in the first entry. Infected trees which may be left are capable of reaching merchantable size by the time of normally scheduled commercial thinnings or regeneration cuts. Infected trees may cause some infection in adjacent trees, but usually these new infections will be low in the crown and have little effect on growth.

The importance of spacing is stressed in stands with infected crop trees. A minimum spacing distance of 12 feet is recommended in precommercial size stands if infected trees are to be left. Infection by contagion declines when spacing between trees increases. Theoretical calculations for ponderosa pine have indicated that infection by contagion is greater at spacings of 9 feet and lower at 18 feet. Infected crop trees must have sufficient space for good growth response so annual height increment will exceed upward spread of dwarf mistletoe. Spacings suggested for mistletoe-infected stands are essentially the same used in healthy stands.

Existing sanitation guidelines apply uniformly to all species. However, we advise foresters to discriminate more severely against infected Douglas-fir and hemlocks than true firs, pines, or larch, because they suffer more damage.

Forest Service and Oregon State Department of Forestry sanitation guidelines suggest use of a Canadian developed formula to assist thinners in locating infected trees. It assumes spread from a single source, such as a residual to surrounding regeneration. The formula is distance (ft.) = initial spread + ([years since logging - 5] x 2). Trees within this distance of an infected residual should be examined carefully for infections. For example, in a hemlock stand logged 15 years ago the following calculations would apply.

Distance = 40 + ([15 - 5] x 2) = 60 ft.

Forest Service pathologists are frequently asked for advice on thinning stands which appear to be severely infected. Usually the best trees average at least 4 inches dbh. They are too small for commercial thinning and too large for precommercial thinning. Left untreated, such stands tend to disintegrate. Frequently we recommend they be thinned even though leave trees may have numerous infections. We suggest these thinned stands be grown to minimum merchantable product size and then replaced early rather than carrying them the normal rotation period. Infected trees which are 4 inches dbh can usually be grown at least 8 or 9 inches in 20 years, even on poor sites.

Sometimes it is desirable to delay sanitation thinning infected western hemlock stands of precommercial size until the average potential crop tree is 4 to 5 inches dbh. If infected trees are released when they are only 1 to 3 inches dbh, hemlock mistletoe intensifies rapidly and causes severe reductions in growth. When these stands are allowed to grow in their normal dense condition, many infections which are located low in the crowns become shaded and die. When these trees reach 4 to 5 inches dbh the top halves of crowns are often mistletoe free. After the stands are thinned, canopies usually close in 5 years and trees often grow to merchantable size in 10 or less years on the best sites.

Occasionally, two-storied stands are found which have a moderately dense infected overstory and fully stocked understory. It may be difficult to tell if the understory is severely infected because shading has not allowed vigorous development of aerial plants and witches' brooms. If such sites are not difficult to regenerate, the recommendation often given is to remove all overstory then wait 3 years before thinning the understory. The 3-year period will allow most mistletoe present at the time of overstory removal to become readily detectable. If the stand appears to be severely infected at this time, it would be destroyed and the site regenerated.

The importance of having thinners trained to recognize dwarf mistletoe infections is stressed. Most sanitation thinning is accomplished by contractors and many, when first starting, do not recognize dwarf mistletoes. Aids are provided to help them select proper crop trees. Contracts describe desirable crop trees; some require thinners to use the 0-6 rating system for crop tree selection. Others use the previously described crop tree criteria. Contract descriptions have to be simple to be understood and applied.

Stand Replacement

The only practical alternative for severely infected stands is to regenerate them so site potential can be realized. Under Forest Service guidelines a stand is considered severely infected if removal of undesirable trees would leave it understocked.

Clearcutting is the most common method of regeneration cutting. It is most frequently employed west of the Cascade Crest but has been used many times to remove mistletoe-infected stands on the east side. Shelterwood cutting is increasingly used. Both systems have already been discussed.

Some interesting methods have been used to replace severely infected stands on sites considered difficult to regenerate. On at least two severely infected sites all merchantable volume was removed. The stands were then burned, and seedlings were planted in the shade of dead trees. Consideration has been given to spraying severely infected stands with herbicides then planting in the shade. Another approach used in ponderosa pine stands was to remove merchantable volume, followed by a mechanical brush cutter to create cleared swaths approximately 20 feet wide through the very dense, severely infected understory. Leave strips were 4 to 6 feet wide. Seedlings were planted in the cleared swaths and as soon as they become established the remaining infected trees will be destroyed.

Forest Service guidelines recommend that infected stands of small diameter true firs not be destroyed for the sole purpose of dwarf mistletoe suppression. Research conducted by the PSW Station indicates true firs with good crowns will usually grow well in spite of infections if they are released.

Species Manipulation

Most dwarf mistletoe species found in the Pacific Northwest have limited host ranges. One major exception is hemlock dwarf mistletoe, which in addition to infecting western and mountain hemlocks, commonly infects all true firs (Abies) and occasionally western white pine.

Species manipulation is used as a dwarf mistletoe management technique in several ways in the Pacific Northwest. Where perimeters of stands adjoining plantations contain infected trees that can cast mistletoe seeds onto regeneration in the cut areas, 50- to 100-foot wide strips along the edges are sometimes planted with nonsusceptible trees. Occasionally it might be necessary to remove susceptible seedlings which regenerate naturally in the strips. A variation of this approach that has been used only occasionally is to harvest infected species for a distance of 50 to 100 feet into stands surrounding plantations.

Shelterwood cuts are becoming increasingly common in the Pacific Northwest. Nonsusceptible species of seedlings are often planted under infected shelter trees. Ponderosa pine is frequently planted under infected lodgepole pine. Douglas-fir is often planted under or close to infected hemlock and true firs.

Species manipulation is advantageous during thinnings. Uninfected species are favored

as crop trees. Common examples include favoring Douglas-fir instead of hemlock in infected stands in western Oregon and Washington, and white fir instead of infected Douglas-fir in eastern Oregon and Washington. In some areas, particularly southern Oregon, there may be three different species of dwarf mistletoe on a single acre--Douglas-fir, hemlock, and white fir--and all tree species may be infected. Foresters will favor trees least damaged by mistletoe, usually white or red fir. Another example occurs in higher elevations in the Cascades where hemlock mistletoe often infects true firs and hemlocks in the same stands. True firs are favored because mistletoe damages them less than hemlock. This situation often becomes complicated because some true firs are severely damaged on these sites by balsam woolly aphid. Fortunately, true fir susceptibility to the aphids varies with elevation.

Species manipulation provides about the only hope for uneven-age management of dwarf mistletoe-infected stands. It also is one of the very few ways to manage infected stands that have been designated for rotations as long as 200 years because of visual or wildlife management considerations. Numerous examples of species manipulation have been applied in stands visible from heavily travelled highways in eastern Washington and Oregon. West of Wenatchee, Washington, foresters have removed mistletoe-infected Douglas-fir and larch from stands which also contain white fir, Engelmann spruce, ponderosa pine, and lodgepole pine. The area was referred to as a silvicultural slum because of the large number of dead trees. It is now much more scenic because of the species manipulation.

Pruning

Pruning is not recommended in forestry operations, except in incidental cases where infections can be removed at no additional cost while precommercial thinning. It is recommended only in campgrounds or recreational sites where trees are a premium.

Coastal recreation sites are frequently located in western hemlock stands. Heavily infected crowns produce dwarf mistletoe brooms that may weigh up to 200 pounds or more. Falling broomed branches could severely damage property or injure recreationists. Pruning heavy brooms in these stands is a good practice.

East of the Cascades, pruning of dwarf mistletoe brooms is occasionally done to enhance tree vigor in recreation sites. Ponderosa pine responds most favorably to pruning when at least half of the upper crown is either uninfected or only lightly infected. The lower infected crown is pruned away. Douglas-fir benefits even more from pruning of brooms.

Combination Treatments

In many dwarf mistletoe-infected stands, a combination of control treatments is used. For example, in two-storied ponderosa pine stands overstory is removed, then infected understory receives a sanitation thinning. If the understory is severely infected, it might be destroyed and the overstory partially removed. The site is then planted and as soon as the seedlings become established, the remaining overstory is removed. In some stands, severely infected spots may be destroyed, while adjacent lightly infected areas are thinned, favoring uninfected species.

In older clearcuts residual removal is combined with sanitation thinning, species manipulaton, and sometimes removal of infected edge trees.

Dwarf mistletoe control treatments frequently reduce other pest damage. For example, sanitation thinning infected ponderosa pine stands makes them less susceptible to mountain pine beetle attacks and possibly Elytroderma needle blight.

Contracts

Practically all dwarf mistletoe control on WDNR and Forest Service lands is done by contractors.

Mistletoe contract clauses must be uncomplicated. Long, detailed descriptions of dwarf mistletoe conditions on trees were found undesirable and unreal in early control contracts. The WDNR incorporates the 0-6 Hawksworth rating system into their precommercial thinning contracts and issues walletsize cards with rules on them to aid thinners. They have found this system highly reliable. Timber sale contracts have a standard list of clauses managers can choose that will help reduce the parasites.

The Forest Service has contracted several dwarf mistletoe surveys. In all cases other stand information has been collected during the same surveys.

Post Suppression Evaluation

Quality of dwarf mistletoe suppression must be monitored. Forest pathologists continuously monitor control programs, even those which are not accomplished with dwarf mistletoe control funds. All work done under contract is examined for compliance. WDNR uses a plot system to evaluate long-term control effectiveness.

NEEDED IMPROVEMENTS

Although we feel the mistletoe control programs in Oregon and Washington are successful, they can be considerably improved.

Training.--Privately employed foresters and small landowners presently are not receiving training on dwarf mistletoes. Fortunately, it looks like this is soon to change because the Northwest Forest Pest Action Council is going to conduct insect and disease workshops. How-to-do-it publications and slide-tape programs are needed because many foresters are unable to attend training sessions. More demonstration plots should be established. Mistletoe needs to stay in the news.

Impact.--Research is needed on the ability of infected trees of all species to respond to release. This information is practically nonexistent for western hemlock and scanty for Douglas-fir. Much of the past mistletoe research was conducted in unmanaged stands--we are interested in managed stands.

Yield Programs.--Simulated yield programs such as RMYLD are not available for the Pacific Northwest. They would be helpful management tools.

Economics.--The economic benefits of dwarf mistletoe control have not been adequately investigated. We strongly suspect control has a favorable benefit/cost ratio, but with some exceptions this has not been confirmed. More economics research is needed.

Coordination.--There is a need for better coordination between forest pathologists, landscape architects, wildlife biologists, ecologists, and silviculturists. In numerous occasions these disciplines have offered conflicting advice to foresters. Landscape architects and wildlife biologists need a better understanding of mistletoe epidemiology and damage. Pathologists need to understand the other disciplines' objectives and techniques.

DWARF MISTLETOE CONTROL ON THE ROGUE RIVER NATIONAL FOREST IN OREGON[1/]

R. Duane Kingsley[2/]

Abstract: Dwarf mistletoe treatment strategy is reviewed for clearcuts, shelterwoods, and uneven-aged management areas on the Rogue River National Forest in southwest Oregon. Stand cleaning is not attempted in old-growth stands, but is instead concentrated at the time of regeneration cutting, with some follow-up stand cleaning in young stands. Administration requires data gathering that is location oriented and job specific, with a good record keeping system. Each unit manager should be held responsible for the effectiveness of the dwarf mistletoe control program on his unit.

Key words: Dwarf mistletoe, stand cleaning, regeneration cutting, clearcuts, shelterwood, uneven-aged management.

INTRODUCTION

The Rogue River National Forest is one example of a Pacific Northwest dwarf mistletoe situation. A considerable amount of control work has been done, and the results look promising.

The Rogue River National Forest contains about 621,000 acres of land in extreme southern Oregon and northern California on the west slope of the Cascades and the northern part of the Siskiyou Mountains. The center of the Forest is about 100 miles inland from the Pacific Ocean, so the climate is essentially warm and moist in the winter, but hot and dry in the summer.

About 80 percent of the Forest is managed for some type of commercial wood production. The average elevation of these lands is 4,300 feet, with extremes as low as 1,800 feet and as high as 7,000 feet elevation.

We are blessed by 10 major timber species of conifers, principally Douglas-fir (Pseudotsuga menziesii), white fir (Abies concolor), Shasta red fir (Abies magnificia var. shastensis), ponderosa pine (Pinus ponderosa), sugar pine (Pinus lambertiana), western white pine (Pinus monticola), and some western hemlock (Tsuga heterophylla). But at the same time, we are cursed by 5 species of dwarf mistletoe, sometimes up to 3 species on the same acre. By far the worst in terms of virulence and damage on this Forest are Douglas-fir (Arceuthobium douglasii) and hemlock dwarf mistletoe (A. tsugense).

We have some kind of dwarf mistletoe problem on approximately 75 percent of the Forest, but using the guidelines I will describe, we have cleaned about 100,000 acres from dwarf mistletoe.

[1/] Presented at the Symposium on Dwarf Mistletoe Control Through Forest Management, Berkeley, Calif. April 11-13, 1978.

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To understand what we have done, and what is still unfinished, one must first know something about the overall timber management cycle from old-growth, to plantation, to pole stand, to mature timber.

No stand cleaning is attempted in old-growth stands. The first dwarf mistletoe treatment in mature stands is a regeneration cut to remove all the excess trees, prepare the site, and start a new plantation.

As the plantation grows, it is pre-commercially thinned at about age 15 to leave the best 320 trees per acre. At about age 40, the average stand will receive a commercial thinning to remove the excess trees and leave the best. Thereafter, a light thinning will be done every 15 years until the stand is mature at about age 85. At that time the stand will be regenerated again with a new plantation.

In review, many old-growth stands are heavily infected with dwarf mistletoe. We make no attempt to clean these stands by partial cutting. The best chance to rid an area of dwarf mistletoe happens only once every 90 years, during the regeneration cut. We feel that if we bungle this opportunity, chances are we will have condemned the land to another 85 years of infection with all the associated growth losses, mortality, etc.

Therefore, the regeneration cut is where our major effort is placed. With some subsequent stand cleaning during future entries, we feel the program will be successful.

OPPORTUNITIES FOR DWARF MISTLETOE CONTROL DURING REGENERATION CUTTING

Each type of regeneration cutting requires a somewhat different treatment approach.

Dwarf Mistletoe Control in Clearcuts

In clearcutting, all the trees on a block of land are cut at once. After disposal of the slash, usually by burning, the area is reforested clean of dwarf mistletoe. Our job is to keep it clean by removing sources of reinfection.

Using Douglas-fir as an example, reinfection can occur if any infected Douglas-fir residual whips or seedlings are left in the area after cutting and burning. These must all be cut, injected, or otherwise killed. When the tree dies, so does the mistletoe. Even though these trees often contain some usable wood, they must be killed. If they can be utilized in some way, such as for fuelwood, fine. But any wood lost is likely to be insignificant in comparision with the damage reinfection could cause.

A second source of infection in clearcuts is from the surrounding uncut timber. There are several treatement options.

1. In mixed species stands, log out the infected species at least a chain or more back into the timber, so dwarf mistletoe seeds cannot pop out into the new plantation. With good planning this chain wide strip can often be included in the sale and logged at the same time as the clearcut, or

2. If it is not possible to remove infected edge trees before planting, they should be removed before the susceptible seedlings reach 3 feet in height or 10 years of age, whichever occurs first, or

3. Where it is not possible to move the infection edge away from the susceptible seedlings, then the susceptible seedlings must be moved away from the timber. A strip extending about 100 feet into the plantation should be reforested with a tree species not susceptible to that species of dwarf mistletoe. In some cases it may be necessary to remove susceptible natural seedlings which become established in the strip.

Dwarf Mistletoe in Shelterwoods

Shelterwood is another system used to regenerate a timber stand. Shelterwood cutting on the Rogue River National Forest is usually done in blocks, some as small as 10 acres, and some as large as 700 acres. In this type of cut the canopy is rather uniformly opened by logging, while leaving sufficient trees to provide seed and shelter for a new crop of seedlings.

When the plantation is well established, the remaining overstory trees are removed, either in a series of cuts or all at once, depending on the physical situation at each site. Where frost protection is a major consideration, the overstory may have to be left for long periods of time, even up to 40 years.

In block shelterwoods, reinfection of the plantation can be prevented in several ways:

1. Remove all the trees of the infected species the first cut. For instance, if Douglas-fir is infected, and Douglas-fir is to be used for reforestation, leave no Douglas-fir overstory trees in the overstory. Select leave-trees only from species other than Douglas-fir, or

2. Remove the infected overstory species shortly after the susceptible species in the plantation are established, before the seedlings reach 3 feet in height or before they reach 10 years of age, whichever occurs first.

Recognize that some infection will probably occur, and that all subsequent thinnings will require careful stand cleaning wherever infection centers are found. In this case, it is helpful to mark the stumps of the infected overstory trees so the potential infection centers can be identified later.

It is also helpful to use a broad mix of native tree species in the plantation. This helps to prevent the rapid spread of dwarf mistletoe seeds from tree to tree. It also makes it possible to clean out an entire group of trees of the infected species, and still have sufficient trees of other species to stock the spot, or

3. Shift the species composition of the plantation to some less susceptible species. For instance, if Douglas-fir is infected in the overstory, plant pine underneath, or white fir, or whatever species fits the site.

The problem is that Douglas-fir will surely seed in, and those seedlings might become infected. However, Douglas-fir can be discriminated against during precommercial thinning and commercial thinning so as to keep it a minor component of the stand. And assuming that a good job was done in establishing the other species in the plantation, the losses in the Douglas-fir will be a minor part of total stand production.

4. In all cases, protect the perimeters of shelterwood plantations from infections in the surrounding timber, as discussed in the section on clearcuts. After overstory removal, shelterwoods look like clearcuts anyhow, so the same guidelines apply.

Dwarf Mistletoe Control in Uneven-aged Management Areas

Uneven-aged management is a silvicultural system that carries trees of all sizes on the same acreage, without any massive regeneration cut at any one time. Instead, a few trees of each size class or a small group of trees are cut on some periodic re-entry cycle, such as every 15 years. The holes created are reforested, and the stand tends to remain about the same through time.

Uneven-aged management is suited to certain special situations such as campgrounds, scenic highway strips, important streamsides, sensitive trails, unstable landslide areas, and areas of poor site or extreme reforestation difficulty.

Dwarf mistletoe control in uneven-aged situations is very difficult, though not entirely hopeless. The stand situations favorable to dwarf mistletoe propagation are all present. A source of infection is always available in the older trees. There is plenty of sunlight. And there are always younger trees to become infected and carry on the disease.

It might sometimes be possible to remove all the trees of the infected species, and install a clean plantation of the susceptible species. But this alternative will seldom be possible because of the light cuts inherent to uneven-aged management and because so many of the infected trees are smaller than merchantable size.

Generally, the only strategy we have available for uneven-aged stands is some type of species manipulation within the timber stand.

This could be done by planting immune species underneath the infected stand, and discriminating against the susceptible species until all the susceptible trees are gone in that portion of the stand. When there is no remaining source of infection, the susceptible species can be reintroduced into the cleaned area by planting.

If dwarf mistletoe is spotty, then only the infection centers need such treatments. But if the infection is widespread, then a species shift would be necessary in the whole block.

If several species of dwarf mistletoe exist on the same acre, it may be impossible to clean all the species at once. Instead, the manager may have to decide which dwarf mistletoe species he is going to eradicate and which he is going to ignore for the present.

ADMINISTRATION

In closing, let me describe some problems we are having in hope that others might be able to avoid them or solve them.

1. Dwarf mistletoe surveys, or careful walk-throughs, or whatever is used to identify dwarf mistletoe problems, should be location oriented. Building a large volume of coded plot cards will expend the funds, but may not accomplish anything if they are lost in the storeroom or in a computer bank someplace. We want maps with specific locations and work orders so we can go out and get the needed work done.

2. A good record keeping system is needed showing what has been done and what needs to be done in the future. Do your records show what is to be done, where, when and why? Could a stranger figure it out, or do you have to be there to explain it?

3. Record keeping systems must be capable of prompting future actions. As an example, how will the land manager 20 years from now be prompted to make a careful inspection and sanitize the dwarf mistletoe infected Douglas-fir trees in the south 1/2 of unit 217? If your system does not provide for this type of prompting for future actions, the benefits of any dwarf mistletoe actions taken now will probably dribble away in time.

4. The effectiveness of a unit's dwarf mistletoe control program should be made a part of every manager's performance rating.

Someone must be charged with the responsibility for getting the job done. To date, in most organizations, the managers have been made aware of what needs to be done, and they are encouraged to proceed. But if they don't happen to take an interest, or they decide it's not important, nothing happens. They can still get high ratings for civil rights, and getting out the cut, etc., and move on up the promotion ladder, but leave a dwarf mistletoe mess behind them that no one can straighten out later.

So in the process of growing up, the technique of dwarf mistletoe control has passed its infancy. We now know what to do, and have a pretty good idea how to do it. The program has matured. It is now time to demand accomplishment, and not just give it lip service.

INTERMEDIATE CUTTINGS IN MISTLETOE-INFESTED LODGEPOLE PINE AND SOUTHWESTERN PONDEROSA PINE STANDS[1/]

Frank G. Hawksworth[2/]

Abstract: Intermediate cuts in mistletoe-infested lodgepole pine and ponderosa pine stands include "sanitation cuttings" (where all visibly infected trees are cut) and "sanitation thinnings" (where emphasis is on spacing and cutting the trees that are most heavily infected). Sanitation cuttings are recommended only in stands where less than about 40 percent of the trees are infected. Usually such stands are less than 30 years old. Sanitation thinnings are usually applied to stands over 30 years, but are not recommended in heavily infested stands because heavily infected residual trees will show little response to thinning. Presently, we do not suggest thinning in stands with an average dwarf mistletoe rating (6-class system) of 3 or more. Yield simulation procedures are available for mistletoe-infested lodgepole pine stands in the central Rockies and for southwestern ponderosa pine.

INTRODUCTION

Intermediate cuts include all the cutting treatments made following establishment of the new stand until the time to replace it. Cuttings are made when needed, normally at specific intervals, to increase the quantity and quality of timber produced, and to salvage material which would otherwise be lost. Common intermediate cuts are: (1) thinnings, and (2) improvement cuttings, including sanitation and salvage (Myers 1974). For practical purposes here we will consider "sanitation cuttings" (where removal of all visibly infected trees is attempted) and "sanitation thinnings" (where the emphasis is on spacing and usually only the most severely diseased trees are removed).

This paper considers lodgepole pine (*Pinus contorta* Dougl. ex Loud. subsp. *latifolia* [Engelm. ex Wats] Critchf.) stands in the central Rocky Mountains affected by the dwarf mistletoe *Arceuthobium americanum* Nutt. ex Engelm. and ponderosa pine (*P. ponderosa* Laws. var. *scopulorum* Engelm.) in the Southwest affected by *A. vaginatum* (Willd.) Presl. subsp. *cryptopodum* (Engelm.) Hawks. & Wiens.

THINNING IN UNINFESTED STANDS

Before discussing thinning in mistletoe-infested stands, it would be helpful to summarize thinning recommendations in noninfested stands, which form the basis for thinnings in diseased stands.

Lodgepole pine

The following thinning recommendations are summarized from Alexander (1974) and Cole (1975).

a. If stands have fewer than 2,500 stems per acre, thinning can be delayed until age 30 (total age).

b. If stands have more than 2,500 stems per acre, thinning should be done before age 30, ideally between ages 10 and 20, and should leave 1,200 to 1,500 stems per acre.

c. If stands have 2,500 to 4,000 stems per acre, thinning will show some reponse up until about age 70, but wider spacings should be used than in younger stands.

d. Stands with more than 2,500 to 4,000 stems per acre or more than about 70 years old generally will not recover sufficiently to cover costs of thinning.

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Later thinning recommendations in lodgepole pine are based on the growing stock level (GSL) concept (Edminster 1978). The GSL's are numerical indices representing residual basal areas when the average tree diameter reaches 10 inches or more. In stands where average tree diameter is more than 10 inches d.b.h., GSL and basal area are the same.

Ponderosa pine

Thinning recommendations for ponderosa pine in the Southwest and in Colorado are also based on GSL (Schubert 1974, Myers 1974). The GSL recommended depends on the management objectives for the particular stand. For example, if timber volume production is the primary objective, a moderately high GSL (e.g., 100 to 120) is suggested. However, if other forest values need to be considered, such as grazing and recreation, lower levels (e.g., GSL 40 to 60) are frequently recommended).

Ponderosa pine remains physiologically young and responds to thinning up to at least 200 (Pearson 1950). However, from a practical standpoint, thinning in older stands may not be economical.

SANITATION CUTTINGS

"Sanitation cutting" as used here involves removal of all visibly infected trees in a stand, usually in conjunction with a thinning operation. In lodgepole pine and ponderosa pine, stands in which sanitation is feasible are usually less than 30 years old. In older stands, dwarf mistletoe infestation frequently develops to such an extent that removal of all infected trees would create too large openings.

An important consideration is the number of latent dwarf mistletoe plants (i.e., those overlooked in the first operation or incipient). As a guide from our studies in lodgepole pine, supported somewhat by results in other species, we developed the "half-again rule." This states that the proportion of trees infected about 5 years after an initial sanitation will be about half the amount removed in the first operation. For example, if 12 percent of the trees were infected at the time of the first operation, about 6 percent more will develop infections. This guide seems to apply to stands with up to about half of the trees infected before the first sanitation.

Interim results from sanitation cuttings in young lodgepole pine stands provide some guides (Baranyay 1975, Hawksworth et al. 1977). The degree of infestation in the stand, not strictly stand age, is the best criterion to decide whether sanitation is practical. A general guide is that stands with more than about 40 percent of the trees infected are too heavily infected to attempt strict sanitation cutting (removal of all infected trees). In such stands, the large numbers of reinfected trees would necessitate removal of so many trees that stocking would be seriously reduced. In these studies, all of the 20-year-old, and most of the 30-year-old stands had fewer than 40 percent of the trees infected. Most of the 40-year-old stands had more than 40 percent of the trees infected, but in the one that had less than 20 percent infestation, sanitation appears to have been successful.

SANITATION THINNINGS

It wasn't too many years ago that to recommend any thinning in mistletoe-infested stands would have been considered to be the height of folly. For years, I was a strong advocate of the "no-thinning" philosophy. When I began working on dwarf mistletoes in the Southwest in the early 1950's, I was shown several infested stands that had been thinned some 15-20 years previously. These stands were real "disaster areas" and they made quite an impression on me. The ground in these stands was jackstrawed with the carcasses of mistletoe-killed trees and the few surviving trees were so severely infested that their days, too, were numbered. The theory was that the increased light in thinned stands stimulated the parasite, so it was able to rapidly intensify and kill the residual trees. Obviously the only answer was not to thin in infested stands.

But, as I began to examine other thinnings in infested stands, both in ponderosa pine in the Southwest and in lodgepole pine in the central Rockies, I noticed there were some stands that did not break up after thinning, but rather, seemed to be growing more volume than before.

We still don't know why thinnings are successful in some stands and not in others, but we think that at least two important factors are involved: (1) the degree of infestation in the stand, and (2) site quality.

The present evidence suggests that thinnings in infested stands can increase volume increment, provided infection is not too heavy. It is not known where this cutoff line is, and how it varies with type of stand, age class, or site quality. For example, we think that effects of dwarf mistletoe are site-related;

that is, a given degree of infection will have relatively less effect on growth on a good site than on a poor one. However, mistletoe incidence frequently is not site-related. For example, the dwarf mistletoes occur on the best lodgepole pine sites that we have seen in the Central Rockies and on the best ponderosa pine sites in the Southwest, but their effects on these good sites are relatively insignificant.

At present, we do not recommend thinning in stands that have an average dwarf mistletoe rating ($\overline{DMR}$) of 3.0 or more (6-class system, Hawksworth 1977). This may seem rather low, but as shown in figure 1, about 90 percent of the trees in such stands are infected, leaving relatively few uninfected or lightly infected trees to work with. We recommend removal of as many infected trees as possible without creating large openings. Usually, trees with a DMR of 4 or higher should not be retained. It is better to sacrifice some spacing to remove such heavily infected trees, since they will usually show little growth response after thinning.

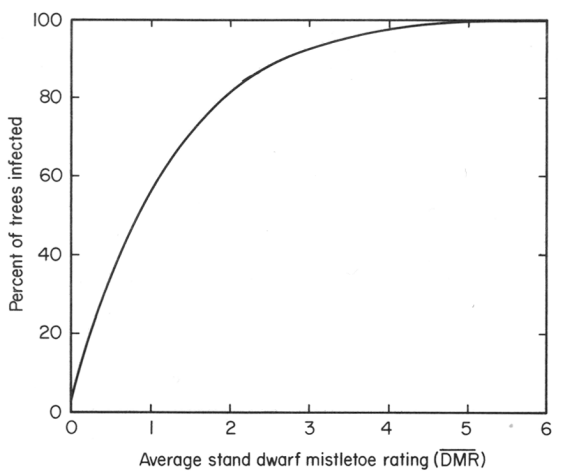

Figure 1--Relationship between percent of trees infested and average stand dwarf mistletoe rating ($\overline{DMR}$) for lodgepole pine stands.

Dwarf mistletoe levels in residual trees should be low in young stands because it will be many years before they are of merchantable size. Conversely, higher levels can be left in older stands, since they will be harvested before the mistletoe levels increase to damaging proportions.

At present, there are no "hard and fast" rules to determine whether sanitation thinning will help a particular stand. Each stand must be analyzed considering the: (1) protected yields, (2) market conditions, and (3) economics. Research can now provide information only on the first, using simulated yield projections.

Yield projections for mistletoe-infested stands have been published for even-aged lodgepole pine in the central Rocky Mountains (Myers et al. 1971) and for even-aged and two-storied ponderosa pine in the Southwest (Myers et al. 1976, Edminster and Hawksworth 1976). These are being adapted and tested on other areas and for other host-parasite combinations.

Using these programs on a stand basis, the forest manager can examine many options for a very low cost and then decide on the treatment that will give maximum yields commensurate with management objectives for the area. For example, he can compare cubic feet vs. board feet yields. He can examine such options as: (1) do nothing, (2) thin to various growing stock levels, (3) thin at various intervals, and (4) delayed thinnings. Also, he can compare yields in infested stands with uninfested stands to determine potential yields on the site.

Examples from the lodgepole pine program are given from two stands in the Routt National Forest in northern Colorado (tables 1-3).

Table 1 shows the projected yields in relation to GSL. In this case, if the stands are not treated, after 100 years, we can expect no board feet volume, since the trees will not reach the 6.5 inches minimum stand diameter. After 100 years, thinning to GSL 70 will yield about 15,200 board feet per acre and to GSL 90 about 16,600 feet. In general, higher GSL's yield more volume in uninfested stands; the converse is true for moderately to heavily infested stands. In this case, higher GSL results in higher project yields, presumably because mistletoe was relatively light (only 27 percent of the trees infected). Table 2 shows an analysis of cutting cycles in the same stand. Examining just three alternatives shows that cutting cycles at 30-year intervals will increase both merchantable and board feet yields.

Table 1--Effects of growing stock level (GSL) on simulated yields in a 30-year old lodgepole pine stand, Porcupine Creek, Routt National Forest, Colorado. Present stand conditions: avg. d.b.h. - 2 inches, Site Index - 60, trees per acre - 2,680, and percent of trees infested - 27.

Treatment	100-year yield/acre Merchantable cubic feet	Board feet
None	2,460	0
Thin GSL 70 (30-year intervals)	3,290	15,200
Thin GSL 90 (30-year intervals)	3,810	16,600

Table 2--Effects of length of cutting cycle (at GSL 90) on simulated yields in a 30-year old lodgepole pine stand, Porcupine Creek, Routt National Forest, Colorado. Present stand conditions: avg. d.b.h. - 2 inches, Site Index - 60, trees per acre - 2,680, and percent of trees infested - 27.

	100-year yield/acre Merchantable cubic feet	Board feet
None	2,460	0
Thin 30-year intervals	3,810	16,600
Thin 50-year intervals	3,510	14,700

Table 3 shows an older stand (age 70 years which is generally considered to be near the upper limit of thinning feasibility. However, even in this case, we can see a market improvement by thinning. The stand, if left alone, will not yield merchantable or board feet volume because the trees will not reach the average 6.0 and 6.5 inches, respectively, for calculation of these volumes. Thinning can yield 9,000-10,000 board feet per acre after 60 years.

Table 3. Effects of one vs. two thinnings (at GSL 90) on simulated yields in a 70-year old lodgepole pine stand, Snyder Creek, Routt National Forest, Colorado. Present stand conditions: avg. d.b.h. - 3 inches, Site Index - 55, trees per acre - 4,330, and percent of trees infested - 34.

Treatment	60-year yield/acre Merchantable cubic feet	Board feet
None	0	0
Thin age 70 and 100; harvest age 130	2,350	9,000
Thin age 70; harvest age 130	2,930	9,900

To estimate the relative effects of dwarf mistletoe in ponderosa pine and lodgepole pine, yield simulations were made for the same hypothetical stand conditions: present stand age - 30; average d.b.h. - 3 inches; density - 1,000 stems per acre; Site Index - 40, 60, and 80; and mistletoe infection - none, or 50 percent of trees infected. Projections were made for 90 years (until stand age 120) assuming (1) no thinning, and (2) thinning to growing stock levels 60, 80, and 100 at ages 30, 60 and 90.

Some of the results are given in Table 4 for lodgepole pine and in Table 5 for ponderosa pine. Thinning to GSL 100 is shown for these examples only. Some of the results of these analyses are:

1. For noninfested stands, increased yields per acre due to thinning are about the same regardless of Site Index, but the proportion of the increase is much higher on poorer sites.

2. For a given amount of infection, assuming the same stand treatments, dwarf mistletoe losses are significantly greater in ponderosa pine than in lodgepole pine.

3. If infested stands are not thinned, the cubic foot losses are greater on site 80 than on site 40, but the proportional loss is greater on the lower sites. For example, in the case cited for lodgepole pine in Table 4, the volume in the infested stand was 64 percent of that of the uninfested stand in site 40, but the

Table 4--Simulated 90-year yields in lodgepole pine stands now 30 years old. Average d.b.h. = 30 inches, 1,000 trees per acre. Treatment stands thinned at age 30, 60, and 90.

Stand Condition	Treatment	Merchantable cubic foot volume acre site index 40	60	80
No mistletoe	None	1,490	5,220	8,610
	thin GSL 100	2,680	5,530	9,610
	Difference			
	cubic feet	+1,190	+ 310	+1,000
	percent increase	180	106	112
50% trees infected ($\overline{DMR}$ = .07)	None	960	3,840	7,240
	thin GSL 100	2,490	5,420	9,310
	Difference			
	cubic feet	+1,530	+1,580	+2,070
	percent increase	259	141	129
Uninfected vs. 50% trees infected	None			
	Difference			
	cubic feet	- 530	-1,380	-1,370
	percent decrease	64	74	84
Uninfected vs. 50% trees infected	Thin GSL-100			
	Difference			
	cubic feet	- 190	- 110	- 330
	percent decrease	93	98	97

comparable figure on site 80 was 84 percent.

4. For a given site index, the relative gains due to thinning (e.g., yields in thinned stands/yields in unthinned stands) increase as dwarf mistletoe intensity increases. For example, in lodgepole pine, on site 60, increase in yields due to thinning in stands with only 10 percent of the trees infected is only about 6 percent (essentially the same as for noninfested stands), but in stands with 50 percent of the trees infected, yields are increased by 40 percent.

Table 5--Simulated 90-year yields in ponderosa pine stands now 30 years old. Average d.b.h. = 3.0 inches, 1,000 trees per acre. Treated stands thinned at age 30, 60, and 90.

Stand Condition	Treatment	Merchantable cubic foot volume acre site index 40	60	80
No mistletoe	None	1,840	4,180	6,480
	thin GSL 100	2,570	4,640	7,280
	Difference			
	cubic feet	+ 770	+ 460	+ 800
	percent increase	143	111	112
50% trees infected (DMR = 0.8)	None	170	740	2,670
	thin GSL 100	850	2,630	6,240
	Difference			
	cubic feet	+ 680	+1,890	+3,570
	percent increase	500	355	234
Uninfected vs. 50% trees infected	None			
	Difference			
	cubic feet	- 1670	-3,440	-3,810
	percent decrease	9	18	41
Uninfected vs. 50% trees infected	Thin GSL-100			
	Difference			
	cubic feet	-1,720	-2,010	-1,040
	percent decrease	33	57	86

CONCLUSIONS

Many studies have shown that dwarf mistletoes are stimulated by opening up stands by thinning. However, it has not been determined whether this is due to increased light or to improved tree vigor of the residual trees, or, as I suspect, to a combination of both factors. We also know that the effects of dwarf mistletoe are less pronounced in more vigorous trees, so the beneficial effects of thinning will be evident in increased growth rates, despite the fact that mistletoe might also increase. However, thinning can not be recommended in heavily infested stands. We do not know exactly when a given stand is too heavily infested to thin, but we tentatively suggest that thinning be confined to stands with a DMR of 3 or less.

Although these are some guides to help determine whether a given infested stand should be thinned or not, each stand must be evaluated on an individual basis.

We don't know how close our projections are to actual yields, except that our data are based on actual stands and should be reliable. Some pathologists and foresters

think that we are overestimating losses, others think we are underestimating them, so perhaps we are on the right track. To monitor the effects of thinning in dwarf mistletoe infested stands, we are establishing a series of plots in infested lodgepole pine stands in Colorado and in ponderosa pine in Colorado and Arizona. Stands with various intensities of dwarf mistletoe (including mistletoe-free stands) are being thinned to several GSLs. Periodic examination of the plots will show how close our projections are to the actual yields and will provide data for adjusting growth and mistletoe-effects equations as needed.

LITERATURE CITED

Alexander, Robert R.
1974. Silviculture of subalpine forests in the central and southern Rocky Mountains: The status of our knowledge. USDA For. Serv. Res. Pap. RM-121, 88 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Baranyay, J. A.
1975. Dwarf mistletoe as a factor in the management of lodgepole pine forests in western Canada. Management of lodgepole pine ecosystems. Symp. Proc. Wash. State Univ., D. A. Baumgartner, editor. Vol. 1: 359-367.

Cole, Dennis M.
1975. Culture of immature lodgepole pine stands for timber objectives. Management of lodgepole pine ecosystems. Symp. Proc. Wash. State Univ., D. A. Baumgartner, editor. Vol. 2:536-555.

Edminster, Carleton B.
1978. RMYLD: Computation of yield tables for even-aged and two-storied stands. USDA For. Serv. Res. Pap. RM-199, 26 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Edminster, Carleton B., and Frank G. Hawksworth
1976. User's guide to SWYLD2: Yield tables for even-aged and two-storied stands of southwestern ponderosa pine, including effects of dwarf mistletoe. USDA For. Serv. Gen. Tech. Rep. RM-23, 8 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Hawksworth, Frank G.
1977. The 6-class dwarf mistletoe rating system. USDA For. Serv. Gen. Tech. Rep. RM-48, 7 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Hawksworth, F. G., T. E. Hinds, D. W. Johnson, and T. D. Landis
1977. Silvicultural control of dwarf mistletoe in young lodgepole pine stands. USDA For. Serv., Rocky Mt. Reg., For. Insect and Disease Manage. Tech. Rep. R2-10, 10 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Myers, Clifford A.
1974. Multipurpose silviculture in ponderosa pine stands of the Montane Zone of central Colorado. USDA For. Serv. Res. Pap. RM-132, 15 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Myers, Clifford A., Frank G. Hawksworth, and James L. Stewart
1971. Simulating yields of managed, dwarf mistletoe-infested lodgepole pine stands. USDA For. Serv. Res. Pap. RM-72, 15 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Myers, Clifford A., Carleton B. Edminster, and Frank G. Hawksworth
1976. SWYLD2: Yield tables for even-aged and two-storied stands of southwestern ponderosa pine, including effects of dwarf mistletoe. USDA For. Serv. Res. Pap. RM-163, 25 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Pearson, G. A.
1950. Management of ponderosa pine in the Southwest. U. S. Dep. Agric. Monogr. 6, 218 p.

Schubert, Gilbert H.
1974. Silviculture of southwestern ponderosa pine: The status of our knowledge. USDA For. Serv. Res. Pap. RM-123, 71 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

ECOLOGICAL BASES FOR SILVICULTURAL PRESCRIPTIONS FOR CONTROL OF DWARF MISTLETOE IN LODGEPOLE PINE[1/]

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Abstract: Preparation of silvicultural prescriptions is a complex process in lodgepole pine ecosystems. Ecological factors and management decisions must be considered. The presence or absence of dwarf mistletoe in a stand is one ecological factor that must be considered. Control of dwarf mistletoe is possible through application of sound silvicultural principles.

Key Words: Silvicultural prescriptions; dwarf mistletoe control; Arceuthobium americanum; Pinus contorta.

SILVICULTURE AND ECOLOGY

Silviculture has been defined as "the art and science of growing trees". The art of growing trees refers to management of trees by instinct, "gut feelings" and at times flying by the seat of our pants. There always has been and probably always will be a place in silviculture for this art which comes from familiarity with a given ecotype and experience in how the ecotype reacts to a given type of treatment. The art should not, however, be our dominant form of management.

The science of growing trees is plant ecology.

Past management efforts by foresters often placed much more emphasis on the art than on the science. There are many reasons for this, but the main ones are: 1) The difficulty of remaining professionally current in a field as diverse as forestry; and, 2) The lack of time to prepare prescriptions that analyze and document the bases for management actions.

This reliance on the art rather than the science of stand management resulted in some stand treatments in lodgepole pine (Pinus contorta Dougl.) that were ecologically questionable and/or socially insensitive.

Adverse public reaction to large clearcuts and drastic site preparation and brush disposal methods necessitated some change in our ways of treating stands. It soon became obvious that it was time to rely more on the sciences of forest and plant ecology than on the art of growing trees.

SILVICULTURAL PRESCRIPTIONS

Reasons for Silvicultural Prescriptions

All of our research, education, training and experience are of little value if they are not eventually expressed in on-the-ground treatments. The silvicultural prescription provides the medium for translating this knowledge into a plan of action. Northern Region Guidelines for Development of Silvicultural Prescriptions list four basic purposes of a prescription:

1. The prescription provides a logical method of analysis of a stand to determine alternative cultural treatments. The prescription will also assist in the evaluation of the environmental impact of such treatments.

2. The prescription provides direction for carrying out cultural treatments.

3. The prescription documents the scientific basis for the alternative treatments.

4. The prescription is a record that allows for later evaluation of the effectiveness of the cultural treatments (Anon. 1976).

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Uses of Standard Prescriptions

We used to prescribe treatments that were considered as standard for certain tree species in a given locality. Examples of these might include "clearcut, burn, and plant white pine" in northern Idaho; "thin to favor larch" in western Montana; and "the bigger the better" when referring to clearcuts in dwarf mistletoe--(Arceuthobium americanum Nutt. ex. Engelm.) infected lodgepole pine. Each region, state and private company has used standard prescriptions.

The more you prescribe treatment for various stands, the more evident it becomes that these standard prescriptions are no longer acceptable. Complex ecosystems require more in-depth analysis than can be applied through standard treatments. This is true even in lodgepole pine type, which appears to be both consistent and monotonous. Lodgepole pine has been identified in 82 habitat types or phases of habitat type in Montana alone (Pfister et al. 1977). Lodgepole pine is one of the most widespread tree species in western North America. The capacity of lodgepole to grow in such a variety of environments over such a broad geographic area is surpassed by few other conifers in North America (Critchfield 1957, Tackle 1961, 1965). Pfister and Daubenmire noted that lodgepole pine occurs in 166 of 264 identified forest habitat types, community types, sample stands, forest zones, forest associations, site types and biogeoclimatic zones, from the central and northern Rockies and the Inland Empire in the United States northward into Alberta and British Columbia in Canada (Pfister and Daubenmire 1975).

The broad ecological amplitude indicates that lodgepole pine is a more complex ecological entity than is often recognized.

Management Direction

Silvicultural prescriptions must state clearly how treatments will meet management direction as defined in the land use planning process or as expressed by land managers (Anon. 1976).

In the Forest Service, this involves an interdisciplinary team. The manager (Forest Supervisor or District Ranger) with input from the team, resolves any conflict between competing resource uses on the same piece of ground and establishes the management direction for a large area.

It is then up to the silviculturist to prescribe an ecologically sound treatment that meets the management goals for a particular timber stand.

Primary Prescription Elements

The Northern Region has identified seven elements all-inclusive that must be included in a silvicultural prescription (Anon. 1976):

1. Objectives - After obtaining the land management objectives, the silviculturist defines silvicultural objectives which satisfy management objectives.

2. Site Data - Slope, aspect, elevation, physiographic site, landform, geology, soils, climate, habitat type and relative productivity are described. Areas of potential resource damage or conflict are identified. These areas include streams, bogs, frost pockets, areas of concentrated wind, critical big-game habitat, or landscape management features.

3. Stand Data - These data include species composition, stand structure by age as well as size class distribution, density, stand history and successional trend, true crown condition, growth rates, timber volumes, and understory conditions. The status of insects and diseases (including dwarf mistletoe), windthrow hazards, estimates of fuel loadings within and around the stands, and factors affecting slash disposal, site preparation or regeneration are discussed.

4. Treatment - The treatment to be applied at this stand entry is described. This description is detailed enough so that marking guides or other pertinent preparation guides can be written from it. Some of the details discussed include the following:

    a. Type of treatment: (1) Timber Cutting: What type silvicultural system is to be applied; intermediate, salvage or regeneration cut? What method of the system is to be applied? The composition and density of the resultant stand must be indicated. (2) Site Preparation: What method is to be applied and to what degree? (3) Reforestation: What method is planned? What species and stocking level is desired? When is

the desired stocking level to be achieved?

b. Logging method proposed - Silviculturists are not logging systems specialists, but they must be aware of the capabilities of the various logging systems to meet the silvicultural objectives of the prescribed treatment.

c. Methods for hazard reduction and protection to a manageable understory.

d. Insect and disease protection and/or control. So far I have said little about dwarf mistletoe or its impact on timber stands. There are numerous examples of stands which were treated without regard to the presence of dwarf mistletoe. These treatments almost invariably have serious long term impacts on stand productivity. Susceptibility of the stand to insects and other diseases must also be considered. In the case of lodgepole pine, if the stand is of the size, vigor, phloem thickness and age to be highly susceptible to attack by the mountain pine beetle (Dendroctonus ponderosae Hopkins), a final removal should be prescribed in the near future or anticipated losses should be documented (Amman 1975). The prescription must consider presence of, and stand susceptibility to, insects and diseases.

e. Effect of the treatment on the site. The effect of the treatment on the basic site resource must be evaluated. For example, site productivity can be drastically reduced through compaction of soils if the soils are of a type highly susceptible to compaction (silts or silt loams). In stands where organic matter is a scarce component within the surface soil horizons, drastic site preparation, either by burning or by machine, can drastically reduce site productivity. The same may be true on well-drained, deep soils in areas of moderate to high rainfall, where nutrient loss through leaching of bare soil may contribute to site degradation.

f. Genetic implications of the treatment. Gains in tree improvement in the near future will be far more dramatic from application of genetically sound silvicultural prescriptions than from controlled breeding programs. This will be true throughout most of the west for the next several years because acreage reforested with certified improved seed or planting stock will be small compared with the total acreage reforested. Natural regeneration will continue to play the major role in reforestation efforts in the West. Gains in genetic quality of stands will be of two types: The quality of parents that are selected for the next generation; and the constant selection of superior phenotypes as crop trees in intermediate stand entries.

g. Effect of the treatment on wildlife populations. Interactions between wildlife and silvicultural treatments can be a two-edged sword. Silvicultural stand entries may improve the habitat for some wildlife species at the same time they degrade the habitat for others. In stands critical to the survival of important wildlife herds, silvicultural treatment may need to be deferred or foregone. On the other hand, game animals, rodents, and birds can be extremely damaging to young tree regeneration (Lawrence 1961, Lindsey 1975).

h. Effect of the treatment on use of the area by man, his visual and other values. Recreational use of the National Forests has greatly increased the demand for amenities such as natural beauty, solitude and opportunities for dispersed recreation. A prescription must evaluate the demands for and impacts on these amenities created by the proposed treatment.

i. Needs and possible methods for livestock use and control. Livestock, like wildlife, can be extremely damaging to reproduction. A prescription must analyze whether or not livestock needs to be controlled, anticipated damage, and methods for protection of regeneration.

5. Long Term Prescription - Treatments applied to timber stands today will affect future management at least until the next regeneration cut. The genetic impacts of today's treatments may last for two or more rotations. A silviculturist should consider these long range implications and project stand treatments and returns from the present through the next regeneration period. Anticipated growth and yield due to the prescribed treatments should be analyzed as well as anticipated

losses to insects, diseases, and wildfire.

6. Economic Comparisons - All prescriptions should include a brief economic analysis comparing returns on the investment prescribed with deferred action and other possible alternatives.

7. Alternatives - Viable alternatives should be described briefly. Deferred treatment should be one of the alternatives considered. Reasons for not recommending each alternative should be given.

IMPACTS OF ECOLOGICAL FACTORS AND MANAGEMENT OBJECTIVES ON CONTROL OF DWARF MISTLETOE IN LODGEPOLE PINE

Preparation of a silvicultural prescription involves consideration of the ecosystem, management direction, and impacts of prescribed treatments. It is an involved process similar to working through a complex maze. There are many ways in which the analysis can affect our efforts to control dwarf mistletoe in lodgepole pine. First let's review our options.

Use of Silvicultural Systems to Control Lodgepole Pine Dwarf Mistletoe

Control does not mean eradication (Hawksworth 1975). The incidence of dwarf mistletoe in future managed stands will be negligible and growth losses will be immeasurably small. Eradication is neither feasible nor desirable.

In order to accomplish control, it is essential to know the location and extent of infected areas. A well designed stand examination can identify and map infected areas.

After the examination, a prescription is then prepared, taking into account the ecological and management bases previously discussed.

The soundest and most feasible control practice is to protect young stands and prevent the invasion of uninfected stands from adjacent infected ones (Baranyay 1975, Hawksworth 1975). If the stand is heavily infected, it should be sanitized and regenerated by using one of these three silvicultural systems:

1. Clearcutting - Eradication of the existing stand, followed by regeneration is the simplest and usually cheapest method of control. This is done by cutting merchantable trees, followed by site preparation and slash disposal and finally removing any remaining "whips" or small trees. Clearcutting more nearly appraoches the natural system of regenerating lodgepole pine than any other system.

2. Shelterwood - The shelterwood system can also be used to regenerate lodgepole pine. Some considerations are:

   a. Is it needed for ecological or management purposes?

   b. What is the danger of windfall?

   c. How will leaving the shelterwood volume affect the economic feasibility of a commercial sale?

   d. How long can the shelterwood be held on the stump without seriously infecting the regenerated stand?

   The shelterwood system is useful in regenerating species that need only partial sunlight for germination and establishment (Smith 1962). It is also useful on harsh sites. Overuse of the system to blunt the visual impact of clearcutting must be avoided, however. In substituting shelterwood cuts for clearcuts, we run the risk of cutting larger acreages to meet volume goals. In a few years, we may find that the regeneration is not tall enough to ameliorate the visual or environmental impacts caused by shelterwood removal. By removing the shelterwood, we have created the same condition we would have had in a regenerated clearcut.

   The shelterwood system can be useful in lodgepole pine if management or environmental constraints do not allow clearcutting, if there is sufficient volume after the shelterwood is left to make a viable timber sale, if the danger of windfall is low, and if the shelterwood is removed before it infects the regeneration.

   The seed cut must be followed by sanitation of the stand through eradication of residual stems during or immediately following slash disposal and site preparation.

3. Seed-Tree - The same considerations

apply to the seed-tree system as to the shelterwood system. Cone serotiny is a factor in determining numbers of seed trees necessary to regenerate a stand. Most seed from nonserotinous cones is disseminated within 200-300 feet of the parent tree (Tackle 1961, 1965). This means that a minimum of 1 to 1-1/2 trees per acre is necessary to seed the cutover area.

The seed-tree system can be useful in regenerating lodgepole pine if the same conditions are met as with the shelterwood system.

4. Selection - The selection system is generally not applicable to lodgepole pine. In dwarf mistletoe-infected stands, the selection system creates conditions most favorable to spread and intensification of the parasite. There is one area on the Gallatin National Forest near West Yellowstone, Mont., where application of the system appears possible.

The soils around West Yellowstone are composed of obsidian sands of alluvial origin (Pfister et al. 1977). Lodgepole pine is climax. The habitat type is lodgepole pine/bitterbrush. Apparently, the sites are too frosty to support Douglas-fir and too dry (excessively well drained) for subalpine fir or Englemann spruce (Pfister et al. 1977). Stands vary from moderately dense to moderately open. The stands are not all aged but are definitely uneven aged. Dwarf mistletoe-infected areas are well defined and mappable (Dooling et al. 1977).

Numerous clearcuts, some quite large, have contributed to these management decisions. The area receives very heavy recreation use because of its proximity to Yellowstone National Park. Therefore, any additional even-aged regeneration cuts should be designed with small blocks and irregular boundaries.

Uninfected stands could be used to break up the effect of the clearcut blocks, and may be harvested using individual tree and group selection. Use of this combination enables sale of timber in an area where clearcutting of comparable volumes or acreages would no longer be acceptable.

5. Intermediate Cuttings - Hawksworth has described, in this symposium, the effects of intermediate entries into dwarf mistletoe-infected lodgepole pine stands so I will not dwell on the subject. There are two concepts that have worked well for me that I would like to discuss.

Some stands that are predominantly lodgepole pine have an understory of lodgepole pine plus more tolerant species. Nonhost trees often make up a large proportion of the residual stand. If the dwarf mistletoe infection level in the lodgepole pine reproduction is low to moderate (infection levels 1-3) (Hawksworth 1977) and if the regeneration of the tolerant species is manageable, leaving as many of the tolerant trees as possible will lessen the impact of scattering dwarf mistletoe-infected lodgepole pine. This does not mean that we manage advanced regeneration that is composed of moderately to heavily infected (infection classes 4-6) (Hawksworth 1977) lodgepole pine or badly suppressed tolerant trees with little or no hope of release.

The concept is to remove all moderately to heavily infected lodgepole pine and favor healthy, vigorous nonhost species.

Some indicators of manageability in subalpine fir and spruce advanced regeneration include:

a. Good current height growth. It is not reasonable to expect trees under an overstory to grow at the same rate that they would in a free growing condition. In eastern Montana, trees that have been growing six inches or more in height annually for the past several years and appear healthy and vigorous will probably release with overstory removal and thinning.

b. Age. Guidelines for the Central Rockies suggest that 50 years for subalpine fir and 75 years for spruce are the maximum ages to expect response to release and thinning (Roe et al. Undated).

c. Absence of disease or injury. Diseased or injured trees of tolerant species, particularly true

firs are not good risks as crop trees.

This concept should be applied only by silviculturists experienced in the management of the species involved and familiar with local variations. If a District Ranger or silviculturist uses this discussion to justify trying to manage a 100 year old, badly suppressed true fir stand that has little hope of survival, much less release, they have missed the point.

The second concept that I would like to stress is that dwarf mistletoe should be discriminated against at every stand entry. This does not mean that "the only good dwarf mistletoe-infected tree is a dead one," but it does mean that infection class is one of the strongest selection criteria in intermediate stand entries.

LITERATURE CITED

Amman, Gene D.
1975. Insects affecting lodgepole pine productivity. In Management of lodgepole pine ecosystems. Vol. 1. David M. Baumgartner, ed. Coop. Ext. Serv., Coll. Agric., Washington State Univ., Pullman, Wash., 495 p., illus.

Anonymous.
1976. Forest Service Manual 2478.3. Region 1 Supplement 190. U.S. Dep. Agric., Forest Serv., Northern Region, Missoula, Mont.

Baranyay, J.A.
1975. Dwarf mistletoe as a factor in the management of lodgepole pine forests in Western Canada. In Management of lodgepole pine ecosystems. Vol. 1, David M. Baumgartner, ed. Coop. Ext. Serv., Coll. Agric., Washington State Univ., Pullman, Wash. 495 p., illus.

Critchfield, W.B.
1957. Geographic variation of Pinus contorta. Maria Morrs Cabot Found. Publ. 3, Harvard Univ., Cambridge, Mass.

Dooling, Oscar J., J.D. Bortz, and M.W. Maxwell.
1977. Dwarf mistletoe survey, Hebzen Lake Ranger District, Gallatin National Forest, Montana. U.S. Dep. Agric. Forest Serv., Northern Reg. Rep. 77-13, 5 p. Missoula, Mont.

Hawksworth, Frank G.
1977. The 6-class dwarf mistletoe rating system. U.S. Dep. Agric. Forest Serv., Gen. Tech. Rep. RM-48, 7 p. Rocky Mountain Forest and Range Exp. Stn., Fort Collins, Colo.

Hawksworth, Frank G.
1975. Dwarf mistletoe and its role in lodgepole pine ecosystems. In Management of lodgepole pine ecosystems. Vol. 1, David M. Baumgartner, ed. Coop. Ext. Serv., Coll. of Agric., Washington State Univ., Pullman, Wash. 495 p., illus.

Hawksworth, Frank G.
1972. Biology and classification of dwarf mistletoes (Arceuthobium). U.S. Dep. Agric., Agric. Handb. 401, 234 p., illus.

Lawrence, William H.
1961. Guide to wildlife feeding injuries on conifers in the Pacific Northwest. West. For. and Conserv. Assoc., Portland, Oreg., 44 p., illus.

Lindsey, Gerald D.
1975. The influence of animals on lodgepole pine regeneration. In Management of lodgepole pine ecosystems. Vol. 1, David M. Baumgartner, ed. Coop. Ext. Serv., Coll. Agric., Washington State Univ., Pullman, Wash. 495 p., illus.

Pfister, Robert D., Bernard L. Kovalchik, Stephen F. Arno, and Richard C. Presby.
1977. Forest habitat types of Montana. U.S. Dep. Agric. Forest Serv. Gen. Tech. Rep. INT-34, 174 p., illus. Intermountain Forest and Range Exp. Stn., Ogden, Utah.

Pfister, Robert D., and R. Daubenmire.
1975. Ecology of lodgepole pine. In Management of lodgepole pine ecosystems. Vol. 1, David Baumgartner, ed. Coop. Ext. Serv., Coll. Agric., Washington State Univ., Pullman, Wash. 495 p., illus.

Roe, Arthur L., Robert R. Alexander, and Milton D. Andrews.
(Undated) Engelmann spruce regeneration practices in the Rocky Mountains. U. S. Dep. Agric. Forest Serv. Prod. Res. Rep. 115, 32 p.

Smith, David M.
1972. The continuing evolution of silvicultural practice. J. For. 70:89-92.

Smith, D. M.
1962. The Practice of Silviculture. 7th Ed. John Wiley and Sons, Inc., New York, New York. 578 pp. illus.

Tackle, D.
1965. Ecology and Silviculture of Lodgepole Pine. Proc. S.A.F. Meeting 1964:112-115.

Tackle, D.
1965. Silvics of Lodgepole Pine. U.S.D.A. Forest Service, Intermountain Forest and Range Exp. Station Misc. Publication 18. 24 pp. (revised).

DWARF MISTLETOE CONTROL IN RESIDENTIAL FORESTS[1/]

John G. Laut[2/]

Abstract: Residential forests -- where forests are maintained primarily for their effects on people -- present unique problems and opportunities for control of dwarf mistletoe. Five case studies are presented to demonstrate feasibility of pruning-thinning treatments in these situations.

INTRODUCTION

One spin-off from the environmentalist movement of recent years has been an increased public awareness of trees and their values. All through the West and, especially in Colorado, the forest resource is coming under tremendous people-pressure. These people demand answers to questions about tree management -- not necessarily forest management. Questions arise, in the biological fields dealing with tree diseases, insects and physiology, that forest pathologists, entomologists and silviculturists can't easily answer.

Forest entomology and pathology, however, do have much background expertise that can be useful in managing people-stressed vegetation. Compared to traditional forest management and forest pathology, the realities of heavy people-pressures present new problems with new dimensions that demand new potential solutions. In forest pathology and entomology control development and research direction have been largely dictated by forest economics. Control must be economically feasible, but in this new field, with new values based on individual trees, the chief criterion is now biological feasibility. With these new values, if a treatment method is biologically feasible, it is very likely to be economically feasible. Under the more stringent economics of commercial forestry how many forest diseases have been controlled? The opportunities to effect control in residential forestry, on single trees or small stands that now have extremely high values, are essentially unlimited. Our customers in residential forests cry for a way to "save my tree." No method should be discarded because of so-called economic unfeasibility based on traditional forestry practices.

For purposes of definition, residential forests are those areas on which trees are maintained primarily for their effects on people. This definition requires attention to trees on city streets, yards and parks -- urban trees in the true sense -- as well as to trees in the forest where people have chosen, or are choosing, to live. The forest resource of Colorado is under tremendous people-pressure. Pathologists and entomologists are also under heavy people-pressure as a result of a developing tree-awareness in both the forests and the cities.

The human foot is trampling the forest floor; construction damage, drainage changes, and chemical additions to soil, water and air rapidly create sick trees, both in their own right and by enhancing the syndromes of existing but hitherto latent pathogenic situations. An example of this is dwarf mistletoe. Trees with non-lethal infections, or at least not immediately in danger of dying, are particularly susceptible to additional stress. As soon as someone builds a house under or near such a tree it very soon may die. Trees on extremely poor sites, as many of our Colorado East Slope ponderosa pine sites are, suffer from any additional stresses put on them.

1/ Presented at the Symposium on Dwarf Mistletoe Control Through Forest Management, Berkeley, Calif. April 11-13, 1978.

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Where does this lead us? Just as the discovery of Dutch elm disease can lead to a tree awareness in the city dweller, the fading of a pine tree shading his new forest home awakens the forest resident to some new facts of life. You may be tempted to say that we have always had people living in the forests and trees have always died so what is new? What is new is the type of resident. The older resident was there most likely through necessity -- his livelihood came from the forest, one way or another. The new resident very often is there by choice. The trees are part of his investment and even can be the reason behind his choice. Each tree is important. Couple this personal awareness with the overall concern for the environment that has developed in the last decade and the result is concern for trees -- not necessarily forests, but trees!

Does this field belong to foresters or to horticulturists? The answer is both if both want it. If one defaults the other will carry it completely. I believe the forestry profession cannot afford to default.

Some examples of our experiences in Colorado will illustrate my thesis that forest pathologists can and should fill a role in residential forestry.

Dwarf mistletoes, especially *Arceuthobium vaginatum* subsp. *cryptopodum* (Engelm.) Gill on ponderosa pine and *A. americanum* Nutt. ex Engelm. on lodgepole pine cause the most destructive diseases in the Rocky Mountain area. Traditional forest management of these diseases is based on silvicultural systems -- thinning, clearcutting, and so forth, aimed at rejuvenation of stands to increase growth rate. Our forest resident, however, is little concerned with production or how fast his trees grow. He wants to keep each tree alive. A tree for tree's sake!

We have established several test areas in Colorado to demonstrate that, in relatively small, high value areas within the general infestation areas, protection of those values can be accomplished by very selective cutting and by pruning of individual trees.

CASE 1

Trail West Village is a subdivision located at the foot of the Collegiate Range four miles west of Buena Vista. It lies in the transition zone between the ponderosa pine and the pinon-juniper cover types with the majority of the area in the ponderosa. Residential lots, one to three acres each, were laid out in clusters of three to five acres with dedicated "green-belts" or natural strips of varying sizes between the clusters.

In 1970 the resident manager of Trail West, recognizing that something was "wrong" with the ponderosa pine on the property, requested advice from the Colorado State Forest Service District Forester. Subsequent examination of the area led to the recommendation to control dwarf mistletoe *Arceuthobium vaginatum* subsp. *cryptopodum* in the green-belts by cutting severely infected and pruning the more lightly infected trees. This recommendation, predicatably, was received rather cooly and with some apprehension and misunderstanding -- you want to log our beautiful forest?

Continuing discussions led to agreement by the subdivision management to establish a small demonstration area in one of the green-belts to show the residents what the area would look like, and to determine the trees' response to treatment. We were to do the work and residents of the area would clean up the logs and slash.

An area was selected and two adjacent plots were laid out at the edge of a heavily infected pocket, so that one plot was lightly infected and the other in heavily infected portions of the pocket. Stand characteristics for each plot are shown in table 1. In each plot, every tree was examined, given a dwarf mistletoe rating (DMR)[1/] from 0-6, DBH was measured and recorded and a decision made whether to leave (0 DMR), prune infected branches or to cut. Leave trees and prune trees were tagged with numbered aluminum tags. Trees to be cut were marked with tree paint.

In general trees with DMR of 3 or less were considered prunable. It was apparent, however, that this criterion would result in removal of too many trees. Subsequently trees with DMR of 4, that had no dwarf mistletoe visible in the upper one-third of the crown were also left for pruning. Bole infections were not considered in these judgments.

Of the 52 diseased trees, 31 were assessed as having too much infection for pruning; thus were removed from the stand. The remaining 21 were pruned. All treatments

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1/ Hawksworth, Frank G. 1977. The 6-class dwarf mistletoe rating system. USDA Forest Serv. General Technical Report RM-48.

Table 1

Ponderosa Pine Dwarf Mistletoe Control Demonstration
Stand Characteristics

Location	Plot Size (acres)	Approximate Basal Area (sq.ft/acre)	Average DBH (inches)	Density Trees/ Acre	Actual Healthy	# Trees Infected	Average DMR	Cut #	Cut %	Pruned #	Pruned %
Trail West Light	0.2	100	10.2	130	12	14	1.6	1- 4		13-50	
Trail West Heavy	0.2	140	9.0	220	0	38	5.2	30-79		8-21	
Stonewall	0.3	110	7.0	200	11	49	2.5	17-28		32-47	
Air Force Academy	0.3	80	4.9	423	38	89	2.6	53-42		36-28	
Genesee Mtn. Park (pine component)	0.4	120	8.2	212	19	67	3.3	41-49		25-29	

All treatments were carried out immediately by the foresters that marked the area.

CASE 2

A similar demonstration plot was also established in 1971 at Stonewall in the south end of the Front Range (Las Animas County). The selected stand was pure ponderosa pine and was also part of a subdivision for summer homes. The characteristics of the selected plot are shown in table 1.

Of the 49 diseased or dead trees, 17 were removed (1 dead) and 32 were pruned. Criteria for these decisions were similar to those developed for Trail West. The only difference was that only trees of DMR of 3 or less were saved and pruned if necessary. As in the Trail West area, local residents disposed of all slash and debris after we had finished.

CASE 3

The United States Air Force Academy, south of Colorado Springs, has an extensive area of ponderosa pine, much of which is infected with *A. vaginatum*. The third pruning demonstration plot in 1971 was established, in cooperation with the Resident Forester, in a pure pine stand designated as "greenbelt" adjacent to the Staff residential area known as Douglas Village (table 1).

On this plot, as indicated by the lower average diameter and higher density of the stand, the decision to either cut or prune a tree was based on crown class, appearance (vigor), spacing and DMR. Consequently, some trees were cut in all of the infected DMR classes (i.e., 1-6). Of the 89 trees in question on the plot, 53 were cut (6 dead) and 36 were pruned. All trees were marked for either cutting or pruning by our crew and in this case, the subsequent work and clean up was done by the Academy's forestry crews.

CASE 4

The City of Denver owns extensive acreages, in many small parcels, of forested mountain lands west of the City, which are managed and developed as parks. Depending on degree of development and proximity to the City, these parks are extremely high-use areas. In common with most of the Front Range, ponderosa pine in these parks is moderately to heavily infected with dwarf mistletoe and in 1973 was imminently threatened by mountain pine beetle. The Colorado State Forest Service was then invited to install a dwarf mistletoe control demonstration in one of the Denver Mountain Parks. Genesee Park, approximately 10 miles west of the City, adjacent to Interstate 70, was selected and a 0.4 acre plot established next to the main picnic area. This stand was 85 percent ponderosa pine and 15 percent Douglas-fir (see table 2).

The plot was marked, cut and pruned by the local Colorado State Forest Service District crews after they had received training in dwarf mistletoe assessment and pruning techniques. Of the 67 infected or dead trees 42 were cut (1 dead) and 25 were pruned. Cut trees and larger branches were cut into firewood length. The smaller material was chipped on-site and distributed over the site. All work was done in July, during the peak of the day-use season. All firewood bolts from each day's work literally disappeared overnight which eliminated the disposal problem.

Table 2

Plot Summary -- After Treatment

Location	DMR	Total Trees	Number Dead	Number Cut	Number Pruned	Number Healthy	Total Remaining	Percent Residual
Trail West Light	1.6	26	0	1	13	12	25	96
Trail West Heavy	5.2	38	6	30	8	0	8	21
Stonewall	2.5	60	1	16	32	11	43	72
Air Force Academy	2.6	127	6	47	36	38	74	58
Genesee Mtn. Pk.	3.3	86	1	41	24	19	43	50

Table 2 summarizes the treatments that were applied to each plot.

Figure 1 illustrates the relationship between the original stand average DMR and the number of trees that are removed in this type of treatment. Basically, for every 0.1 rise in the stand DMR there is a rise of about 2 percent in the number of trees that should be removed. If we assume that the average property owner can tolerate removal of a maximum of 60 percent of the stand the breaking point is stand DMR of somewhat less than 4.0.

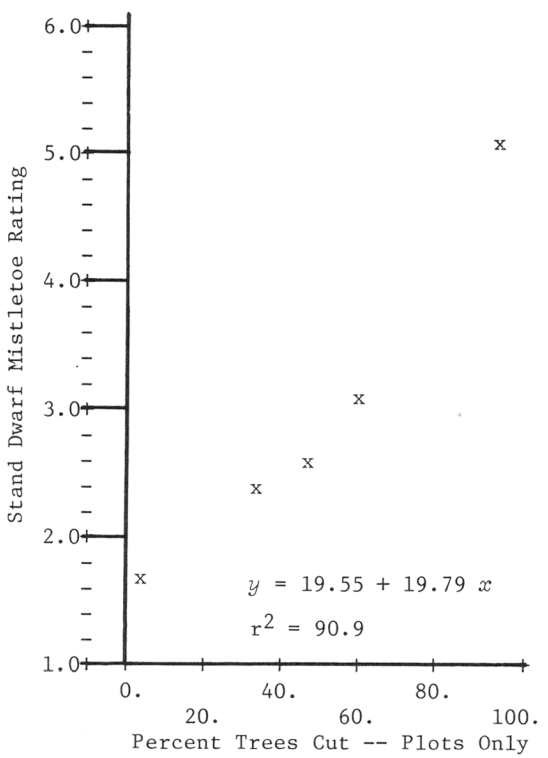

Figure 1--Relationship between stand dwarf mistletoe rating and tree removal.

The parallel between this and the tree DMR, i.e., 4.0 is the maximum for which pruning is feasible, is striking and provides more evidence of the validity of the 6-point rating system.

Table 3 shows the changes, on a per acre basis, of the total stand characteristics. Figures 2 and 3 show changes in basal area and density in relation to the average DMR.

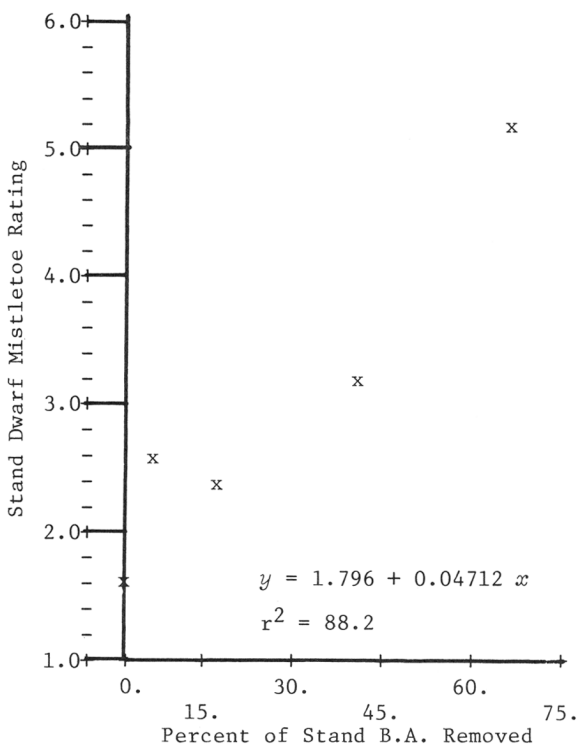

Figure 2--Relationship between stand dwarf mistletoe rating and percent of basal area removed.

All the previous cases dealt with ponderosa pine, infected by *Arceuthobium vaginatum* in forest-residential situations. The last case I will present was an experience with lodgepole pine -- *A. americanum* -- in an incorporated municipality.

Table 3

Plot	DMR Original	Approximate B.A. Orig.	Approximate B.A. Residual	Pct. of Original	T/A Density Orig.	T/A Density Residual	Pct. of Original	Average DBH Orig.	Average DBH Residual
Trail West Light	1.6	100	100	100	130	125	96	10.2	10.2
Trail West Heavy	5.2	140	45	34	220	35	16	9.0	13.0
Stonewall	2.5	110	90	82	200	147	74	8.4	8.5
Air Force Academy	2.6	80	75	94	423	247	58	4.9	5.5
Genesee Mtn. Pk.	3.3	120	70	58	212	112	53	8.2	8.8

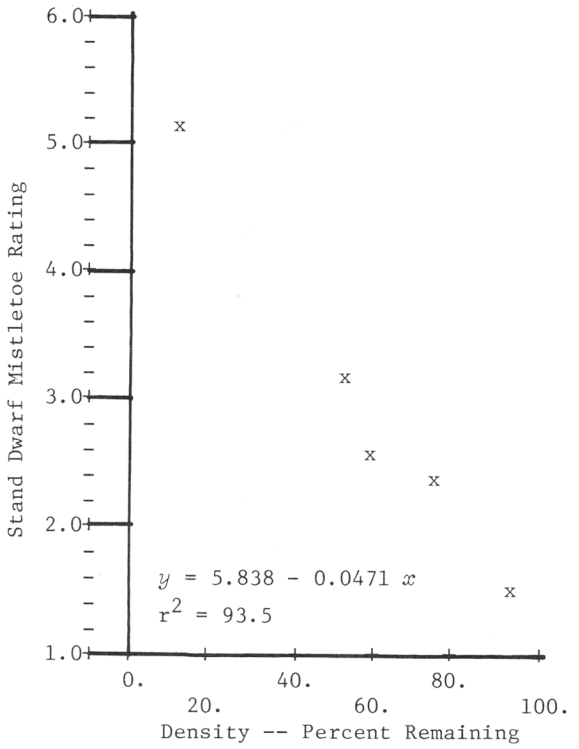

Figure 3--Relationship between stand dwarf mistletoe rating and trees per acre left after treatment.

CASE 5

The small City of Dillon has a permanent population of less than 500 and a transient population of approximately 3,000 during the summer and the skiing season. It is situated in the midst of the Rocky Mountains approximately 9,100 feet above sea level. It was established in the early 1960's on about 172 acres of lodgepole pine forest that was and still is heavily infested with dwarf mistletoe. The fathers of the town exhibited some foresight by designating a total of 30 acres, 17.5 percent of the total area, as green-belt or park area. In early 1974, the City Administration requested assistance and advice on managing the dwarf mistletoe infestations in these green-belts prior to developing them for recreation purposes. The Colorado State Forest Service evaluated the areas, wrote prescriptions and marked trees for either removal (severely diseased) or pruning (light or moderately diseased). Concurrently, the City retained a landscape architect to design picnic areas, nature trails and recreation sites in these green-belts.

A preliminary reconnaissance showed that, as is usually the case, dwarf mistletoe was distributed throughout the area but varied considerably in intensity. Some patches of trees were in fact free of visible infections, some were completely feasible for pruning, some needed thinning and some should be clearcut.

A visit with the architect at this time revealed that his preliminary plan called for tree removal in some areas in order to place various structures, opening up other areas for easier use and placement of trails, playgrounds, tennis courts, picnic spots and parking areas.

Our first accomplishment was to convince the architect and the City Administration that the two plans, forest management and park development, should be made together with the dwarf mistletoe control prescriptions to lead. In fact, the winning argument was the discovery that the preliminary plan called for construction of a building in the spot presently occupied by the only mistletoe-free stand in the whole green-belt system. It was then agreed that we would make a detailed reconnaissance of the areas, make our various recommendations, and mark the trees that needed cutting or pruning. Then, the landscape architect would draw up his plans for the park.

The 30-acre total is divided into 5 discrete units in the town site and around the lake shore that forms the south and east boundaries of the City. Within these 5 areas we distinguished 18 stands identifiable by the dwarf mistletoe incidence and treatments required.

Seven different treatments were proposed as shown below.

Recommended Treatment

1. Do nothing -- healthy stand
2. Sanitize -- remove dead and dying only and clean up slash and old debris
3. Remove infected overstory to protect abundant regeneration
4. Remove dead and heavy mistletoe (DMR 4+) and prune infected residual
5. Remove dead and dying, prune residuals and underplant
6. Prune infected trees
7. Clearcut

This plan, prescriptions and the landscape architect's subsequent plans were presented to the townspeople and Administration at a public meeting, following which the City agreed to initiate the program in key parts of the green-belt if we would follow up and train their Parks Department Personnel.

Two of the units (approximately 13 and 3.5 acres) were marked by us and two Dillon seasonal employees. All trees requiring either cutting or pruning were marked.

Decisions were again based on the 6-class rating system. Trees with DMR of 3 or less were pruned, Class 4 trees were judged individually and Class 5 and 6 trees were automatically cut. No data were recorded.

The actual treatments were conducted, throughout the next two summers, by the City Park Personnel.

SUMMARY

What has happened since? Public reaction in all 5 areas has been favorable. Initial fears of cutting trees, destruction of a "forest environment" and so forth were delayed.

Many of the principles and ideas developed here are incorporated in forest management plans written by Colorado State Forest Service field foresters for private forest lands. The City of Dillon, within the limits imposed by budgets, are interested in continuing and have asked us to mark additional units for 1978. Private landowners in Dillon, observing the improvement in pruned trees, have worked on their own trees. Denver Mountain Parks management have included dwarf mistletoe pruning-thinning in their management plans for several other Mountain Parks. The Air Force Academy includes control in their management plans. Other subdivisions and mountain municipalities have expressed interest in dwarf mistletoe control prescriptions.

What are the biological results? A re-tally of the 5 ponderosa pine plots this past winter yielded the data shown in table 4.

Table 4

Basal Area and Diameter Increments Since Pruning

Location	Basal Area		Average DBH	
	1971	1978	1971	1978
Trail West Light	100	112	10.2	10.6
Trail West Heavy	45	48	13.0	13.8
Stonewall				
Air Force Academy	75	84	5.5	5.9
Genesee Mtn. Pk.	70	81	8.8	9.5

One intriguing observation within the 5 small ponderosa pine plots is that mountain pine beetle, while becoming or remaining at high levels in adjacent stands have not attacked the pruned trees within the plots. This effect is particularly evident at Genesee Mountain Park. The beetle, since the plot was established, has killed approximately 40 percent of adjacent trees. The mortality has occurred right up to the plot boundary. Only 1 tree within the plot was attacked the first year after treatment, but that attack was unsuccessful. No other attacks have been recorded through 5 beetle attack periods. The pruned plot at the Air Force Academy has also been free of mountain pine beetle while the surrounding stands have been infested each year.

To summarize, forest disease problems, and specifically dwarf mistletoe, are the same in a residential management situation as in a product management situation. Even the methods available to solve those problems are presently the same. Values are different! Tree owners, as opposed to forest owners, talk different economics. In the types of situations such as I have discussed here, if a control method is biologically feasible, economics seldom are a limiting factor in the application of that method.

Cures and preventive measures that may have occurred to the research community as they have worked on particular problems but were discarded because of forest product-based economics are now needed. If it will work, bring it to the residential forest owners. They will try it.

DWARF MISTLETOE CONTROLS IN BRITISH COLUMBIA[1/]

G.A. Van Sickle and R.B. Smith[2/]

Abstract: The distribution and impact are briefly reviewed for the four species of dwarf mistletoe in British Columbia, which mainly affect western hemlock, lodgepole pine, Douglas-fir and western larch. Control measures employed or tested by foresters in recent years, including aerial and ground surveys, stand thinning, residual removals, treatment of advance regeneration, fringe planting, scarification and selection cutting are described and discussed.

INTRODUCTION

British Columbia's forest area of 52.7 million hectares is 1¼ times the size of the state of California. Although managed under various land tenures, 95 percent of this forest is owned by the Province and forestry is the foremost industry, contributing 50 cents of every dollar of economic activity in the Province. The four species of dwarf mistletoe in British Columbia are mainly on western hemlock, lodgepole pine, Douglas-fir and western larch (Baranyay and Smith 1972). These tree species rank second, third and fourth in annual volumes harvested, and although larch is a minor species provincially, it is significant regionally, particularly in the southeastern corner of the Province.

In B.C., dwarf mistletoes occur over a great variety of vegetational zones which are influenced by a range in annual precipitation from as little as 30 cm up to 665 cm, by elevations from sea level to 1600 m, and by forest management systems ranging from a selective basis to clear cutting. Some comments on the distribution, major hosts, impact, surveys and control efforts for dwarf mistletoes in B.C. follow.

1/ Paper presented at "A Symposium: Dwarf Mistletoe Control Through Forest Management", Berkeley, California, April 11-13, 1978.

2/ Research Scientists, Canadian Forestry Service, Pacific Forest Research Centre, 506 West Burnside Road, Victoria, British Columbia. V8Z 1M5. The willing cooperation of numerous industrial and B.C. Forest Service personnel in providing details of specific field trials was appreciated.

DISTRIBUTION, HOSTS AND IMPACT

Arceuthobium tsugense (Rosendahl) G.N. Jones

Two races of this species occur in British Columbia, one primarily on western hemlock (Tsuga heterophylla (Raf.) Sarg.), the other primarily on shore pine (Pinus contorta Dougl. ex Loud.). Both races are restricted to the forests west of the Coast Mountains.

Hemlock dwarf mistletoe occurs throughout coastal western hemlock forests from sea level to 1460 m. The most eastern extensions occur in major river valleys up to 180 km from saltwater. The principal host, western hemlock, is a climax tree species and one of the major species in the Coastal Western Hemlock Biogeoclimatic Zone (Krajina 1969). Stands with western hemlock dominating cover about 4 million ha, of which 15% are estimated to be infected with dwarf mistletoe. Current losses in stand volume growth in a 110-year-old stand were 4 - 5 m^3/ha/yr (Smith 1969). Extending these figures, annual growth losses in British Columbia are about 1.7 million m^3. Other damage includes bole swellings [12 percent of the merchantable volume of severely infected trees in one 110-year-old stand (Hunt 1971)], up to 30 percent larger knot size and increased bole taper (Smith 1969).

Within the Coastal Western Hemlock Zone, western hemlock is both a climax species and an important constituent of regeneration after logging and other disturbances. It also survives well as an understory tree, and small residuals and advanced regeneration often remain after logging.

Hemlock dwarf mistletoe also occurs in the Coastal Douglas-fir Zone but, in this drier zone, it is restricted to the edaphically

wetter sites suited to hemlock. Clear cutting in this zone will reduce disease incidence because of the considerable regeneration of resistant species.

In B.C., only one record exists of hemlock dwarf mistletoe on mountain hemlock (Tsuga mertensiana (Bong.) Carr.), a strong contrast to northern California where mountain hemlock is the principal host.

Shore pine dwarf mistletoe severely damages some shore pine stands in south coastal B.C., particularly in the Coastal Douglas-fir Zone up to 725 m elevation. Shore pine is highly shade intolerant and forms nearly pure stands only where water deficits or excesses limit establishment of competing tree species.

With the relatively low commercial value of shore pine, growth impact studies have not been done. However, the intensification of mistletoe on shore pine is more rapid than on hemlock and equals that reported for lodgepole pine mistletoe (Wass 1976).

Arceuthobium americanum Nutt. ex Engelm.

Lodgepole pine dwarf mistletoe is the widest ranging mistletoe in B.C., infecting roughly 1.8 million ha. It is restricted largely to areas east of the Coast Mountains and south of Latitude 57°N, with a few extensions westward along major river valleys. The elevational range is 150 - 1600 m.

The most extensive infestations occur in the Aspen-Lodgepole pine-Douglas-fir Biogeoclimatic Zone in the south-central Interior. Here, lodgepole pine maintains a near-climax role as a result of the cold, dry climate and a high frequency of fire.

Lodgepole pine dwarf mistletoe also occurs in the Sub-boreal Spruce, Engelmann Spruce-Subalpine Fir and Interior Douglas-fir Zones, where lodgepole pine is essentially a pioneer species. A lack of extensive infestation in the Interior Western Hemlock Zone reflects the low frequency of fires and a highly varied composition of resistant regeneration species.

Growth impact data are available from several studies. From single-tree comparisons, estimated stand volumes in Alberta were reduced 18 to 32 percent by mistletoe infection (Baranyay and Safranyik 1970). Data of Dobie and Britneff (1975) indicate a 30 percent lower growth rate in infected than in healthy trees. Similar growth losses were found in surveys of the Cariboo District, which will later be discussed in more detail. Applying an average estimated growth loss of 1.4 m^3/ha/yr to the infected acreage, the annual loss in B.C. is about 2.5 million m^3.

Arceuthobium laricis (Piper) St. John

The principal host, western larch (Larix occidentalis Nutt.), is a particularly shade intolerant species restricted to southeastern British Columbia. Larch mistletoe occurs throughout most of the host range at elevations from 300 to 1460 m. It is present mainly in the Interior Western Hemlock Dry Subzone and the Interior Douglas-fir Wet Subzone.

Although the area affected is much less than that infected by hemlock and lodgepole pine mistletoes, impacts are locally very important. Increased mortality and drastic effects on merchantable yields found elsewhere [less than 20 percent of potential (On and Dooling 1969)] could be expected in British Columbia.

Arceuthobium douglasii Engelm.

Douglas-fir dwarf mistletoe has the smallest range of the B.C. mistletoes. It is confined to the extreme southern interior, primarily in the Okanagan Valley and along the south end of Kootenay Lake. It occurs almost exclusively on Douglas-fir at elevations from 300 to 1350 m in the wetter portion of the Ponderosa Pine Zone and in the Interior Douglas-fir Zone.

Damage is severe in individual trees and stands. Top killing is common. Reductions in merchantable volumes of 73 percent have been reported for western Montana (Haglund and Dooling 1972) and similar losses might be expected in B.C. Total growth impact is small compared to hemlock and lodgepole pine mistletoes, but forest management in these zones is often on a selective-cut basis, making control of Douglas-fir mistletoe a greater problem.

MISTLETOE SURVEYS

Dwarf mistletoes have been collected in B.C. since 1901, with more than 1500 records now present in the Canadian Forestry Service's Forest Insect and Disease Survey Herbarium in Victoria. A prism plot survey in 1969 in 121 areas of known mistletoe indicated the severity of infection in 80- to 200-year-old stands and provided for each species a graphical relationship between the proportion of host trees infected and the severity of infection

(i.e., incidence vs. intensity).

The presence of dwarf mistletoe is one of the nine indicators used by the B.C. Forest Service Inventory Division to indicate a suspect tree in which some cull (non-merchantable portion owing to defect) may be expected. Each year several thousand inventory plots are established or revisited; however, as staff is largely seasonal, and only stem swellings are included, the results are of limited value. A resurvey of 16 areas by the Forest Insect and Disease Survey indicated a great diversity in the completion of pathological remarks and, on average, a 70 percent underestimate of the incidence of dwarf mistletoe. An assessment of growth loss or mortality owing to mistletoe is not yet included in the inventory system.

Roadside surveys for dwarf mistletoe have been employed in various states. In 1972 and 1973, the late J.A. Baranyay initiated a similar survey of lodgepole pine mistletoe in the Cariboo Forest District, an area with 6.9 million ha of forest land in B.C.'s central Interior. This district was selected because lodgepole pine comprises almost half the mature volume in the district and has the greatest concentration of lodgepole pine mistletoe. B.C. Forest Service 1:15840 scale forest-type maps were used to preselect accessible areas in which lodgepole pine was predominant. Of 1118 km travelled through lodgepole pine stands, 28 percent were judged healthy, and 41 percent lightly, 20 percent moderately and 11 percent severely infected. Additional ground sampling involving 473 one twenty fifth-hectare plots in 24 stands indicated that the roadside surveys may adequately classify the level of infection in a broad forest district, but they were only accurate about half the time for specific, individual stands. On average, moderately and severely infected trees were 2.7 to 3.7 m shorter, respectively, than healthy trees of similar diameters, and volumes per acre were reduced 25 to 35 percent.

Detection of dwarf mistletoe on aerial photographs was demonstrated for jack pine in Alberta (Muir and Robins 1973), but the smaller or less frequent brooms and the lower mortality and subsequent stand opening in lodgepole pine compared to jack pine may require modification for B.C. conditions. A study in lodgepole pine by Baranyay (1968), largely thwarted by technical and contract difficulties, suggested that oblique aerial photos were preferable to verticals; that at a 1:7920 scale, stand structure anomalies (openings, stocking or canopy) on color photos may indicate high disease intensity; and at a 1:2400 scale, individual, heavily infected trees preselected during ground surveys were distinguishable. In 1975, the B.C. Forest Service endeavored to determine the distribution and severity of lodgepole pine dwarf mistletoe in a management unit, using air calls, low level photography and ground surveys (Hanson 1975). Ground plots employing the six-class mistletoe rating system were almost immediately discounted as too time-consuming for the information obtained and because access was often restricted. Subjective observational records in stands and along roadsides were accepted as a first order estimate of the abundance of disease. The most promising survey method comes with the observation that an experienced classifier in a helicopter, and very familiar with conditions on the ground, could usually recognize and classify the mistletoe infection level of various type islands. An oblique view of large mistletoe brooms in the lower crown or in trees near stand openings was the basis for identification and the information was recorded directly onto aerial photographs, then transferred to forest-type maps. Brooming was not distinguishable in low level, vertical photography. Typing of 1:15840 scale photography directly for mistletoe infection was not possible, but the typical open, overmature pine stands produced by numerous light ground fires are visible and highly suspect for such stands in the central Interior are frequently infected with mistletoe.

SILVICULTURAL TREATMENTS IN YOUNG STANDS

Juvenile spacing has not been widely practised in B.C., totalling only slightly more than 1200 ha on crown Public Sustained Yield Units in 1976. However, several companies on the coast are now treating up to 1000 ha per year. The Provincial Forest Service contracts out the majority of its spacing, but incorporates specific requirements if mistletoe is recognized as a problem. According to the species of mistletoe present, susceptible species are identified and selected against, all medium to heavily infected trees must be cut and the spacing requirement is waived to accommodate this regulation, and in some areas a corridor around the infection is cut of all susceptible trees, regardless of size and condition.[3/]

To date, spacing by forest companies has fortunately been mainly in non-susceptible or

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3/ B.C.F.S. Reforestation Div. 1976. Contract specifications for juvenile spacings.

uninfected stands; however, a recent trial in a 9 ha severely infected young stand provided some indication of possible problems in coastal western hemlock stands. Spacing in 1976 reduced the stocking of this stand from 8350 to 950 stems per ha but, changed the mistletoe situation very little. Of the selected crop trees, 98 percent were infected, with an average infection rating of 2.1 compared to 83 percent and 2.5 for the cut trees. Based on a stump examination, 62 percent of the trees were residual from the logged stand, averaging 37 years compared to 20 years for the regeneration. At the time of logging, these advanced regeneration averaged 2.2 m in height. With a significant decrease in the acreages now being slash burned, mistletoe will be an increasingly important problem, necessitating greater emphasis on "clean" logging with a minimum of residuals left, and earlier spacing of infected stands before a high proportion of the trees are infected.

Only with time will we know if spacing of the above stand will greatly stimulate mistletoe intensification because of increased seed production and dispersal efficiency, or if host height growth will sufficiently exceed the upward spread of the disease to confine the mistletoe to the lower crown level. In 1976, on average, infections were contained within the lower 42 percent of the live crown length but, 1 year after treatment, 80 percent of the tagged, older and apparently dormant swellings had produced an average of 7.3 aerial shoots, and the number of shoots on active swellings had doubled.

Eradication and Thinning Trials in Lodgepole Pine as a Dwarf Mistletoe Control

In the central interior of B.C., vast but unquantified acreages of young, infected lodgepole pine exist. Silvicultural treatments have been considered as a means of preventing or reducing the loss in stand values from the progressive intensification of dwarf mistletoe, but precise information on the effectiveness of such sanitation procedures was lacking. In the event that management of such stands would some day be economic and more widely applied, the late J.A. Baranyay, in 1967, initiated a Canadian study to determine the effectiveness of two thinning methods to control dwarf mistletoe. The 23 fifth-hectare plots were re-examined in 1976-77 and the data are being summarized.

In the 9 years of the study, the average percentage of trees infected gradually increased from 45 to 68 percent (+ 23 percent) on the infected untreated plots, while decreasing from 42 to 37 percent (- 5 percent) with thinning and pruning treatments and from 52 to 18 percent (- 34 percent) when complete eradication was attempted. Comparable changes in average stand infection ratings were + 0.62, - 0.08 and - 0.64, respectively. However, despite the three treatments each plot received at 3-year intervals, mistletoe was not eradicated from any stand. Assuming an average increase in stand infection index, the eradication plots would reach the 3.0 level at which growth losses are felt to be significant in about 40 years, a 20 year gain over comparable untreated plots. Nonetheless, such trained-labor intensive treatments in immature lodgepole pine are unlikely to be common soon, and better returns would result from control measures done in conjunction with the harvesting of infected stands to establish vigorous, healthy regeneration.

Post Harvest Removal of Residuals to Control Dwarf Mistletoe

Several companies have undertaken residual removals in coastal western hemlock, usually as off season work for a small, permanent crew whose primary task is tree planting. Trees are usually felled or girdled to guarantee results and to avoid possible environmental or worker safety concerns from the use of herbicides. At least one company has attempted to "hack and squirt" the few severely infected residuals on more than 16 ha. Tordon 101 and Glowon (MSMA) were injected, but both trials were judged failures, with 5 percent of the trees killed, or only a few branches killed, respectively. Neither treatment had any apparent effect on the aerial shoots of the mistletoe until the host branch or tree died. Axe or saw girdling was very effective if done below the lowest live branch, but trees treated in July 1975 retained sufficient vigor that mistletoe seeds were discharged normally in September. To prevent seed dispersal, trees had to be girdled early in April before flush.

TREATMENTS BEFORE, DURING AND AFTER STAND HARVEST

Residual falling

With the current level of forest management in B.C. and considering dwarf mistletoes' symptoms, host specificity, and its nature and slow rate of spread, this disease can best and most economically be controlled during the logging and stand re-establishment stage. Specifically, this involves cut block layout, adherence to a residual falling rule, and elimination of infected advance regeneration,

particularly in the coastal hemlock and interior lodgepole pine zones. Old-growth harvesting still dominates B.C. forestry but, in some cases, special early harvesting of severely infected coastal hemlock stands before rotation age has been allowed with the objective of quickly returning high site land to its full productive potential. There is, however, no firm Provincial policy for assessing stand productivity or silvicultural programs, and much depends on the personal convictions, influence and initiative of local forestry officers and industrial personnel.

A condition of harvest, applied and sometimes enforced by the B.C. Forest Service, may require the operator in a clear-cut area to remove or destroy all trees over 3 m in height. The purpose may be either aesthetic, fuel hazard abatement, or for silvicultural purposes primarily to control the spread of dwarf mistletoe. Slash disposal to reduce fire hazard can also effectively reduce the potential mistletoe problem; however, burning is not always environmentally and locally accepted and acreages treated have declined in recent years. Also, spot and landing burns have been favored more than broadcast burning, leaving, in some cases, living infected residuals which should be cut. In the absence of critical cost-benefit analysis covering the wide range of site and disease levels encountered, some forest companies, particularly on the Coast, are questioning the universal application of the residual falling clause. In such cases, an evaluation of the mistletoe in the stand before logging is an important, but often ignored consideration which may allow guidelines to be more site specific, with the greatest efforts directed toward the relatively pure hemlock stands. Alternatively, some companies attempt to alter the forest stand composition by planting non-susceptible species, usually Douglas-fir, provided the site is acceptable.

Control Efforts in Lodgepole Pine

In 1976, 85 percent of the stand improvement work for mistletoe control in the Province was in the Interior lodgepole pine region of the Cariboo Forest District. Control efforts were scattered and token until 1974, but since then the area treated each year has gradually increased, the licensee undertaking a greater proportion of the work each year. In 1977, of the 2270 ha treated for mistletoe, 230 ha were drag scarified, residual falling was conducted on 40 ha, and advanced regeneration was eradicated by hand on 2000 ha; 77% by the licensee, 23% by the Provincial Forest Service. Even so, with 6800 ha of infected lodgepole pine harvested in this District each year, control efforts are still minimal and ad hoc. No method of priorizing stands for treatment is applied, nor is the presence of mistletoe systematically classified and recorded.

Control measures employed and tested in recent years are mainly before, during and after harvest of infected mature stands. When a cut application is received and mistletoe is recognized as a problem, future control costs can be minimized by careful planning of the cut block boundaries. Non-susceptible or uninfested stands, water, rights-of-way, etc., are used to minimize the length of infected margin created, and cut block size is usually regular and maximized around 80 ha to provide the greatest area with the least perimeter. Where unacceptably large clear-cuts would result from expanding cutting boundaries to the infection limits, a high priority is placed on the adjacent fringes for cutting at a later date, usually once the regenerated stand provides adequate game cover. With current logging by tractor-mounted shears or feller-bunchers to a 15 cm diameter stump-height limit, only skinny poles and advance regeneration remain. With some instruction and guidance, machine operators can make several passes through susceptible patches while leaving any existing non-host species undamaged.

Post logging mistletoe control has mainly involved eradication of advance regeneration, using hand shears. Since 1974, more than 4850 ha have been treated at an average cost of $20 per hectare. Drag scarification with chains or shark finned barrels and chains has been used on more than 250 ha to eradicate dense stocking of advance regeneration. Although initially many wounded saplings sprung back up behind the drag, very few residual stems remained 2 years after treatment. However, these sites were highly exposed and recent summers have been hot and dry; hence, there remains a concern that dragging may not kill saplings as effectively in wetter sites or years. Some combinations of partial scarification and hand eradication have been used in attempts to also control stocking. Average treatment costs were $54/ha, comparable to $62/ha in the Prince George District further north.

Fringe planting a 36-m wide strip adjacent to infected borders with resistant species such as Douglas-fir or spruce totals about 47 km, equivalent to 170 ha. The treatment may reduce the spread of mistletoe but does not prevent it, owing to the rapid natural regeneration and competition by lodgepole pine. Since periodic eradication of the pine would

be additionally expensive, the planted stock are often off-site with poor survival, and initial planting costs are high ($270/ha), fringe planting is not likely to be more widely applied.

In 1976, in conjunction with a mechanical thinning trial, 8 ha of infected immature edge were removed, partly by hydro axe and partly by windrowing with a small dozer and then burning. An average cost for the trial was $370/ha. Such treatments may be more economical and widely practised when adjacent stands are logged as a means of removing the, by then, young infected stands adjacent to heavily infected mature borders.

An estimate is not available of the acreage of young second-growth pine on which dwarf mistletoe is a problem but, with about 6800 ha logged each year, the backlog is substantial. In areas felled by hand or without enforcement of residual falling, individual trees and patches of infected residuals often remain. Falling of the residuals is being done as time and money permits. To date, 170 ha have been treated, but costs are highly variable ($37-300/ha), depending on the density, distribution and size of the residual trees.

Selection Cutting of Infected Douglas-fir in the Okanagan Valley

Douglas-fir mistletoe is scattered but common in the Okanagan and Kootenay valleys and, as indicated by one 1975 Tree Farm Licence inventory, about 25% of the timber may be infected. As early as 1965, the Forest Service sanitized a 4.7 ha previously logged area as a pilot control project. Visibly infected trees were piled and burned, small trees with single branches infected were pruned, and a road and 15 m isolation strip surrounded the plot. Additional infections throughout the plot were removed in 1971, but it became apparent that complete eradication was not feasible and a reduction of the mistletoe to a reasonable level is all that can be expected.

Since 1969, one forest company has logged or relogged 727 ha and removed infected residuals on an additional 1000 ha in an attempt to control dwarf mistletoe. Efforts have been complex because Douglas-fir, lodgepole pine and larch mistletoes all occur in varying proportions in parts of the area (ponderosa pine is the only common resistant commercial species) and yet overstory shade is critical for successful regeneration in these very dry sites. Treatments in merchantable stands have included diameter limit cutting with felling of infected residuals, some scarification, piling and burning of slash, leaving non-host seed trees, trial plantings to change the species composition, and two or three pass strip logging. Areas of non-commercial volume, still unidentified and unmeasured, will require a special program of rehabilitation before they again support a productive forest.

DWARF MISTLETOE MANAGEMENT AIDS REQUIRED OR UNDER DEVELOPMENT

Current efforts in dwarf mistletoe research at the Pacific Forest Research Centre are mostly directed to the development of a mathematical model of hemlock mistletoe spread, based on the data collected since 1964 on seed dispersal, interception, infection and rates of intensification. The model will generate values of the infection level and pattern in regeneration at varying densities and distances from infected residuals to assist forest managers in determining the timing, degree and cost of sanitation spacing treatments. Surveys and advice will continue to be provided to foster an awareness and practice of all reasonable management alternatives aimed at reducing current and future losses from dwarf mistletoe.

Numerous people, companies and forest service groups scattered throughout B.C. are expending considerable effort toward the control of dwarf mistletoes through forest management. Much, however, is ad hoc, relying largely on an individual's conviction, persuasiveness and perhaps stubbornness to initiate and complete any treatments. Major requirements for improved management include several inter-related factors:

i. a Provincial policy and funding for silvicultural programs aimed at pest management.

ii. quantified, long-term forestry data to identify and assess losses and provide the basis of assigning specific control actions according to economic or forest site values.

iii. monitoring of current control projects to obtain a biological and economic assessment of present control practices. Currently most effort is expended solely in the hope of having mistletoe-free or acceptable second-growth stands.

LITERATURE CITED

Baranyay, J.A.
1968. Experiment with aerial colour photography for detecting dwarf mistletoe infected lodgepole pine stands in the Alberta-Territories region. Can. Dep. For. Internal Rep. A-12. Calgary, Alberta. 35 p.

Baranyay, J.A. and L. Safranyik
1970. Effect of dwarf mistletoe on growth and mortality of lodgepole pine in Alberta. Can. Dep. Fish. and For., For. Serv. Publ. 1285.

Baranyay, J.A. and R.B. Smith
1972. Dwarf mistletoes in British Columbia and recommendations for their control. Can. For. Serv. BC-X-72, p. 18. Victoria, B.C.

Dobie, J. and A.A. Britneff
1975. Lumber grades and volumes from lodgepole pine infected with dwarf mistletoe. Wood and Fiber 7(2): 104-109.

Haglund, S.A. and O.J. Dooling
1972. Observations on the impact of dwarf mistletoe on Douglas-fir in western Montana. USDA, For. Serv., Northern Region, Rep. D-72-1.

Hanson, G.F.
1975. Lodgepole pine dwarf mistletoe survey -- Westlake public sustained yield unit. BCFS, special project. Mimeo. report. Victoria, B.C.

Hunt, K.
1971. A comparison of kraft pulping of sound and dwarf mistletoe-infected western hemlock wood. Can. Dep. Fish. and For., For. Serv., Inform. Rep. VP-X-78. Vancouver, B.C.

Krajina, V.J.
1969. Ecology of forest trees in British Columbia. Ecology of West. North Amer. 2(1): 1-147.

Muir, J.A. and J.K. Robins
1973. Detection of dwarf mistletoe of jack pine on aerial photographs. Plant Dis. Reptr. 57: 951-954.

On, D. and O. Dooling
1969. A study of the effect of dwarf mistletoe infection on the growth of western larch. USDA, For. Serv., Div. State and Private For., Missoula, Mont. Misc. Rep.

Smith, R.B.
1969. Assessing dwarf mistletoe on western hemlock. For. Sci. 15(3): 277-285.

Wass, E.F.
1976. Ecology of shore pine stands infested with dwarf mistletoe on southeastern Vancouver Island. Can. For. Serv., Rep. BC-X-142.

EVALUATION AND SUCCESS OF DWARF MISTLETOE CONTROL IN CALIFORNIA'S EAST-SIDE JEFFREY PINE TYPE[1/]

Philip H. Intorf[2/]

Abstract: The first and most intensive attempts at dwarf mistletoe control on the Plumas National Forest were made in the Milford Ranger District on the east side of the Sierra Nevada. These control attempts were possibly the most extensive in the Forest Service's California Region. Survey and control procedures were based on the limited knowledge of dwarf mistletoe available at the time. Experience and success were achieved largely by trial and error as knowledge in control of dwarf mistletoe was gained. Many hundreds and thousands of acres of formerly heavily infected, deteriorating, and dying stands of Jeffrey pine are now producing acceptable increments of growth. More knowledge needs to be gained in determining just what degree of dwarf mistletoe control is necessary to produce acceptable growth gains and still not allow this plant pest to seriously damage the ultimate regeneration of the Jeffrey pine stands.

INTRODUCTION

Some dwarf mistletoe control was attempted on the east side of the Plumas National Forest on the Milford Ranger District as early as 1955 and 1956. Post-sale silvicultural work at that time consisted almost entirely of quality pruning of trees selected as the potential crop trees. No pre-commercial thinning was done in connection with the quality pruning at the time.

The work aimed at controlling dwarf mistletoe consisted primarily of supplemental pruning of dwarf mistletoe-infected branches on the quality pruned trees. In addition, the most severely infected trees in very heavily infected stands of small regeneration only were cut. A complete pre-commercial thinning was not attempted, because this was not then an accepted region-wide post-sale silvicultural treatment. It soon became apparent that occasional pruning and individual tree cutting was not too effective because relatively little control work was being done and because large amounts of dwarf mistletoe infection remained in some trees not being treated. Also, many large infected over-story trees had not been removed in the timber sales preceding the post-sale silvicultural work.

In 1958, the California Regional Office personnel--particularly specialists in insect and disease control--became interested in the dwarf mistletoe problem because of the reports by the District Ranger, Leonard Beltz, that severe dwarf mistletoe infection was being found in reproduction and pole size stands. He estimated that about 10,000 acres were heavily infected with dwarf mistletoe and that some degree of infection occurred on over 25,000 additional acres.

A Plumas check scaler, Herb Hard, who had previously worked on the Milford District as the Timber Sale Officer reported that some of the heavily infected stands were in areas that did not have much infection at the time he was scaling and marking timber on the District. Thus, the District was concerned that the intensity of dwarf mistletoe was increasing tremendously in the stands that had been opened up by the first timber cutting.

[1/] Presented at the Symposium on Dwarf Mistletoe Control Through Forest Management, Berkeley, Calif., April 11-13, 1978.

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FIRST DWARF MISTLETOE SURVEYS

The Regional Office personnel who became interested in the dwarf mistletoe problem at the time were Tom Harris, Reed Miller, Roy Blomstrom, and Neil MacGregor. The first approach to the problem was to make an intensive dwarf mistletoe survey before a timber sale in some areas of intense dwarf mistletoe infection. Infected trees in the area were to be sampled, and the area was to be mapped as having heavy, medium (or light), or no infections. In the timber sale preparation, all overstory trees of merchantable size, and infected with dwarf mistletoe were to be marked for removal in the subsequent timber sale. Post-sale silvicultural work in infected stands of regeneration was to consist of removal of trees with bole infections and of trees heavily infected with dwarf mistletoe. Limb infections were to be pruned from all leave trees.

Pre-commercial thinning of young stands was just starting in the California Region at this time. It was decided not to thin, however, because just how much latent infection would show up in the leave trees was not known.

The first area chosen for an intensive dwarf mistletoe survey and a trial dwarf mistletoe control project was Snow Lake because the area was planned for timber sale and because the stands were heavily infested with dwarf mistletoe. The predominant species there was Jeffrey pine, but some ponderosa pine, white fir and incense cedar were present. Elevation averaged about 6,000 feet, and the soils were mostly of granitic origin. The sites were low, mostly III and IV, and rainfall averaged 20 inches or less annually. The area had been logged 18 years earlier and had been marked on a high risk basis. The cut averaged about 65 percent of the original volume so that dwarf mistletoe could have intensified appreciably in the 18 intervening years. All in all the area looked ideal for a pilot dwarf mistletoe survey and control project.

SAMPLING METHOD

The study approach was to survey the area and record all dwarf mistletoe infected trees on the sampled areas before any timber sale cutting took place. The area was sampled by a continuous strip survey, with strips ½ chain wide and 10 chains apart resulting in a 5 percent sample.

All trees on the strips were inspected and recorded as reproduction, poles, or merchantable trees more than 13 inches dbh. Nonmerchantable trees were recorded as uninfected or infected. For merchantable trees, infection was reported as none, light, medium, or heavy and all infected trees were to be cut. For reproduction and poles, all infected trees were tallied by 3 inch dbh classes judged as to whether they could be pruned or were to be cut because of infection too severe to prune. Infection was recorded by size class so that the cost of pruning and cutting trees could be estimated. No extensive thinning had previously been done, so costs of treatment had to be determined before control was to be attempted. Data were segregated and summarized by 5-chain transects, and a map of dwarf mistletoe intensity was prepared. Site was also systematically recorded.

From the survey data, a map was prepared showing stand infection rating based on the percentage of trees infected (1,600 acres sampled):

Infection	Percent	Acres
Little or none	0-3	70
Light	3-15	454
Medium	15-33	49
Heavy	over 33	1027
Total		1600

This pattern of intensity ultimately seemed to follow on most subsequent surveys, with the bulk of the acreage in the heavy and light infection categories and small acreages in the medium and noninfection categories.

RECOMMENDATIONS

The original recommendations called for: (1) Marking and removal by timber sale of all infected trees more than 16 inches dbh; (2) treatment for dwarf mistletoe control of all areas with little, light, or medium infection; and (3) no treatment of areas of heavy infection. This recommendation was later changed to have all remaining trees and slash in heavily infected areas of site IV and better, bulldozed into windrows, burned, and the entire area replanted with Jeffrey pine seedlings. What actually happened on the Snow Lake trial area was this: (1) The timber sale area was marked and advertised but there were no bidders for the sale. (2) Additional uninfected timber area adjacent to the Snow Lake sale was added to the sale area to make it more attractive for bidders. The area was re-advertised, and sold about 2 years later. In the meantime in the intervening delay, about one-third of the trees marked in

the original Snow Lake sale died--undoubtedly because of the combination of (a) the very heavy dwarf mistletoe infection, (b) the severe drought conditions during the period of 1958 to 1961, and (c) Ips and Dendroctonus insect attacks. (3) Much of the heavily infected area was clearcut, and the remaining heavily infected reproduction, poles, and slash were bulldozed into windrows and burned. The area was then replanted with Jeffrey pine seedlings. (4) Areas of light and medium infection were thinned lightly by removing the heaviest infected reproduction and poles. Mistletoe infested branches were then pruned from the remaining potential crop trees. After about 3 years, the area was reworked by completing the thinning by removing trees that showed up with bole infections or additional heavy branch infections. The remaining crop trees were inspected for new infections and pruned. After another 5 years the areas were reworked again by pruning additional dwarf mistletoe infections.

LATER DWARF MISTLETOE SURVEYS

In all subsequent timber sales, a dwarf mistletoe survey preceded all timber sale layout and timber marking. At first the very intensive surveys, as described, were used but later changed to more extensive surveys to delineate the areas of dwarf mistletoe infection intensity only. Finally, the separate dwarf mistletoe surveys were discontinued, and presence or absence of dwarf mistletoe and its intensity were mapped along with the timber sale layouts.

In the early stages of dwarf mistletoe control on the Milford District, it was not known just what results would come about. Precommercial thinning was new to disease control, pruning procedures were new, and certainly the results to be obtained were unknown. One definite requirement at the time was that, if dwarf mistletoe control was to be attempted in any area, it must be conducted as a 100 percent eradication or not attempted at all. All infested trees had to be cut or pruned free of mistletoe. This requirement resulted in the necessity for very difficult and expensive high branch pruning or removal of trees with branch infections too high to prune. Buffer strips were cut around areas where it was decided that 100 percent control could not be achieved; it was to be an "all-or-none" operation.

As more experience was gained and more knowledge became available in dwarf mistletoe behavior, the dwarf mistletoe control and precommercial thinning procedures were continually being modified. In the first control operations it was not known how much latent or new infections and bole infections would show up in the selected potential crop trees. And so excess numbers of potential crop trees were left and pruned at considerable additional cost. Also, as was the standard procedure in all early precommercial thinning, all stands were pre-marked before work commenced. Some of the changes which evolved were: (1) Two stage thinning--first, all obvious heavily-infected trees were cut out to open up the stands, and allowing for a better selection of uninfected or lightly infected crop trees before the remaining stand was marked. (2) Crop tree selection by force account crews, followed by pruning of crop trees (instead of pre-marking). (3) Contracting for thinning of pre-marked stands followed by pruning of crop trees by force account crews. Pruning by contractors did not result in acceptable removal of limb infections. (4) Contract thinning by cutter selection of crop trees followed by pruning by force account crews.

Over the years it became obvious that 100 percent control or complete eradication of dwarf mistletoe is a practical impossibility. Therefore, the "all-or-no control" requirement was relaxed. The questions then became: How much infection should be removed from a tree or stand? How much infection can be tolerated without an appreciable reduction in growth rate?

CURRENT STUDIES

At present studies are being conducted on the Milford District by the Pacific Southwest Forest and Range Experiment Station and the University of California by Dr. Robert F. Scharpf and Dr. J. R. Parmeter to determine what growth response has been achieved in the stands that had various combinations of pruning and thinning to control dwarf mistletoe. The studies are being made in stands that were (a) heavily infected and not treated, (b) heavily infected and thinned only, (c) stands with varying levels of infection that were thinned and pruned once, and (d) stands with several levels of infection that were thinned and pruned more than once.

The results should have a tremendous value in determing how much money, if any, should be spent in the future in reducing the intensity of infection on crop (leave) trees after thinning or pruning. The results may show that for the past 15 years of dwarf mistletoe control the increase in growth rate of treated stands is due largely to the effects of thinning and little to pruning.

SUMMARY AND CONCLUSIONS

Several factors might be considered with regard to the past control efforts. The intense

control efforts, including heavy pruning, were followed because early prescriptions for dwarf mistletoe control work required 100 percent effort at control and not partial attempts. Results of these past efforts are now enabling us to study this approach, because new approaches are not possible without results of past trials as a foundation. The treatment of thousands of acres of infected stands during the past 15 years--even if done so to an unnecessarily intense degree--has resulted in vigorously growing healthy stands that undoubtedly would have been decimated by drought disease and insects in the meantime had they not been treated. During the past 2 years of extreme drought, none of these treated stands have been observed to have been hit by the drought or insects, while some other adjacent stands have been.

A study of results of the past 10 to 15 years may not be a long enough period on which to base future prescriptions. Perhaps over the years of an entire rotation some degree of dwarf mistletoe pruning may be necessary to prevent disease intensification that could ultimately cause unacceptable growth reduction. Some sort of shelterwood or partial cutting prescription may be necessary in many stands to ensure economical establishment of regeneration. And over the years of a rotation the buildup of dwarf mistletoe in the unpruned stand could result in severely infected regeneration if shelterwood prescriptions are to be depended on for regeneration establishment.

In the areas of very intense infection where all merchantable trees were cut and residual infected trees bulldozed and burned and the area replanted, successful regeneration could not always be achieved or could not be achieved economically because of several low-site factors. Rainfall averages 20 inches or less annually. Thus, soil moisture is not always adequate in the spring to assure seedling survival. Moisture holding capacity of loose granitic soils is low. Browsing of seedlings by cattle and deer is common. Some areas experience excessive damage by gophers. And competition for moisture by annual and perennial grasses, herbs, and brush is a problem. Replanting of some areas may be impossible without spraying grass and brush with herbicides before replanting. But the present restrictions on herbicide application makes this approach somewhat dubious for the future.

Thus, control of dwarf mistletoe through artificial regeneration of eastside Jeffrey pine stands is of limited value until problems of establishing successful plantations can be resolved.

CONTROL OF DWARF MISTLETOE ON TRUE FIRS IN THE WEST[1/]

Robert F. Scharpf[2/]

Abstract: The dwarf mistletoe *Arceuthobium abietinum* is a serious parasite of true firs (*Abies* spp.) growing on the Pacific Coast. Damage is most severe in old-growth and unmanaged fir stands. With information now available, the forest manager can develop management guides for control of dwarf mistletoe. Such information includes parasite-host specificity, size at which young trees become infected, growth rate of trees in relation to dwarf mistletoe buildup and spread, and effects of dwarf mistletoe on tree growth rate and mortality.

INTRODUCTION

The true firs (*Abies* spp.) are among the more important commercial softwood timber species in the Western United States. They are not only widely utilized in the United States but also are a valuable commodity in foreign timber markets. Unfortunately, fir stands in the West are often severely infested with dwarf mistletoe. This problem is caused almost entirely by a single species of dwarf mistletoe--*Arceuthobium abietinum*.

The firs are abundant in the West--particularly along the Pacific Coast. In California, for example, two fir species--white fir (*Abies concolor*), and red fir (*A. magnifica*)--make up about a third of the State's net cubic foot volume--or about 15 billion cubic feet out of the estimated total net volume of 51 billion cubic feet of commercial softwood. The Western States combined contain a net volume of about 45 billion cubic feet of true fir growing stock (Anonymous 1972).

Dwarf mistletoe is common on true firs--particularly in California and Oregon. Forest disease surveys conducted by the U.S. Forest Service in California in the 1950's and 1960's show that true firs are among the most heavily infested commercial conifer species in the State. About 40 percent of the red fir and about 30 percent of the white fir stands were found to be severely infested by dwarf mistletoes (California Forest Pest Control Action Council 1961). Thus, literally thousands of acres of pure fir and mixed conifer stands containing fir species are infested with this parasite.

The losses of timber attributed to this parasite in fir stands are not precisely known but are estimated to be enormous. For instance, old-growth firs, in particular, suffer severe losses. Reduction in growth and vigor from heavy infection, broken trees resulting from decay entering trunk infections, and mortality caused by insects attacking weakened trees account for much of the losses. Infected trees are also more subject to mortality from other factors, such as root decay fungi and moisture stress brought about by drought conditions. The losses attributed to dwarf mistletoe are not limited to timber values alone but also affect recreational and water shed values as well. Losses caused by dwarf mistletoes either directly or indirectly will probably continue at severe levels unless many fir stands in the West are brought under intensive management including dwarf mistletoe control as an integral part of the management plan.

[1/] Presented at the Symposium on Dwarf Mistletoe Control Through Forest Managment, Berkeley, Calif., April 11-13, 1978.

[2/] Plant Pathologist, Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Berkeley, Calif.

PAST CONTROL EFFORTS

Within the last decade or two, control of dwarf mistletoe in true firs has been attempted almost entirely by harvesting old-growth stands. Fir stands, particularly pure stands, were harvested primarily by clearcutting, often in large blocks. Unfortunately, firs do not naturally reseed large clearcut areas well, and reliable fir planting stock has not always been available for regenerating fir sites. Also, other species selected for planting have not developed well on pure fir sites--Jeffrey pines in California, for example.

Clearcutting controlled dwarf mistletoe in many areas, but it has often created more problems than it cured. Today, where clearcutting is used, the trend is toward cutting smaller blocks or narrow strips in order to obtain natural regeneration of fir from adjacent stands. As good fir planting stock becomes available, many clearcut areas will no doubt also be planted. Although dwarf mistletoe has been controlled in the past by clearcutting in many pure fir stands, clearcutting today--particularly over large areas--is highly controversial--and many clearcuttings cause management problems more serious than dwarf mistletoe infestation. Therefore clearcutting should not be considered the only solution to dwarf mistletoe control in infested fir stands in the West.

With some exceptions, control of dwarf mistletoe in mixed conifer stands with fir, was almost entirely overlooked or disregarded before about 1960. In fact, because of early logging practices, the infestation by dwarf mistletoe in these mixed species stands has probably gotten worse. For example, until fairly recently in the West, firs were considered less desirable than other conifer species and commanded a relatively low market value. Thus, the higher value species, such as pines and Douglas-fir, were often selectively logged, leaving the infected true fir component of the stand behind. These residual firs often seeded into openings after logging. This practice of selective logging increased the proportion of firs in many stands. Dwarf mistletoe was able to readily spread from infested overstory to understory fir trees--particularly in the absence of pines and other nonsusceptible tree species that act as barriers to spread of seeds of the parasite. Thus, I feel certain that past logging practices in many mixed conifer stands has aggravated rather than alleviated the dwarf mistletoe problem in true firs.

PRESENT APPROACHES TO CONTROL

Enough information is now available to forest managers to allow them to develop guidelines for control. As more information becomes available from research, management guidelines can be improved and refined. A variety of factors bear on the development of guidelines for control.

The Parasite is Host Specific

It has long been known that the dwarf mistletoe on true firs is very host specific (Parmeter and Scharpf 1963, Hawksworth and Wiens 1972). One of the problems that confused foresters in the past is that occasionally more than one species of fir was found to be infected in some stands. Subsequent studies have shown that for the most part, only one dwarf mistletoe species infects firs, but it is made up of two indistinguishable plant forms that infect different fir species. These forms cannot be separated on the basis of outward physical characteristics, but they can be separated on the basis of the fir species they infect (table 1).

Table 1--*The species of dwarf mistletoe that infect true firs*

MISTLETOE	HOSTS
WHITE FIR DWARF MISTLETOE (ARCEUTHOBIUM ABIETINUM F. SP. CONCOLORIS)	WHITE FIR, GRAND FIR *PACIFIC SILVER FIR
RED FIR DWARF MISTLETOE (A. ABIETINUM F. SP. MAGNIFICAE)	RED FIR, NOBLE FIR
HEMLOCK DWARF MISTLETOE (A. TSUGENSE)	*PACIFIC SILVER FIR *NOBLE FIR

* occasional hosts

The white fir dwarf mistletoe is parasitic on white firs and grand firs, whereas red fir and noble fir are the principal hosts of the red fir dwarf mistletoe. Thus, in California, for example, the dwarf mistletoe that infects white fir will not infect red fir and vice versa. Also, seldom do both forms of the mistletoe occur on firs where the range of two or more fir species overlap. One additional factor that made the fir-mistletoe situation even more confusing is that firs growing in mixture with hemlock often become infected with hemlock mistletoe. But this situation is relatively uncommon in the West, and hemlock mistletoe is not considered a major concern in the management of fir stands.

Knowledge of the host specificity of dwarf mistletoes is of use in planning harvest cuts, thinning, and regenerating fir stands. The use of host specificity is probably the only method of silviculturally managing for dwarf mistletoe control that can be used for both even-aged and uneven-aged stand situations. The following examples of information useful for dwarf mistletoe control apply only to even-aged stand management.

Small Firs are Seldom Infected in Infested Stands

Studies have shown that red firs less than 3 feet in height are seldom infected by dwarf mistletoe, even in the presence of abundant overstory mistletoe (fig. 1) (Scharpf 1969). Infection rates increase dramatically in trees taller than 3 feet, however. Similarly, intensity of infection on small trees was low, but increased with tree size (fig. 2). Being able to regenerate an area either naturally or artificially until seedlings are 3 feet tall without fear of appreciable infection from dwarf mistletoe gives the manager a practical working tool for stand regeneration. Most plantation trees and natural regeneration that are 2 to 3 feet tall are considered well established, and infected overstory or residual trees that were left as a seed source or for shade should at this point be cut or harvested to avoid infection of regeneration. This knowledge of the relationship of seedling height to infection from surrounding overstory is particularly useful where infested fir stands are to be regenerated naturally by narrow strip clearcut, seedtree, or shelterwood methods.

Infected Firs Free From Overstory Infection and Growing Well in Height will Outgrow the Spread and Buildup of Dwarf Mistletoe

Results of long-term dwarf mistletoe studies Dr. J. R. Parmeter and I have made, provide information about the biology, spread, and buildup of dwarf mistletoe in young fir stands that is important in developing guidelines for control (Scharpf and Parmeter 1967, Scharpf and Parmeter 1976). We have found, for example, that the spread and buildup of dwarf mistletoe in young red and white firs is

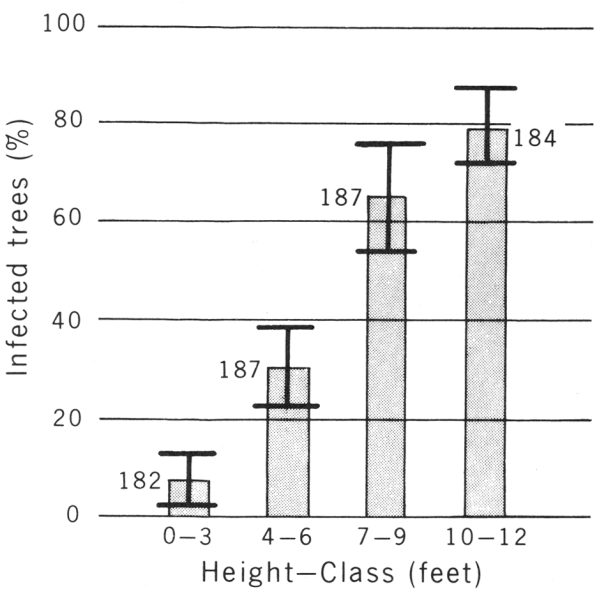


Figure 1--*Percentage of red fir infected in each height-class, with 95 percent confidence intervals.* (Scharpf 1969)

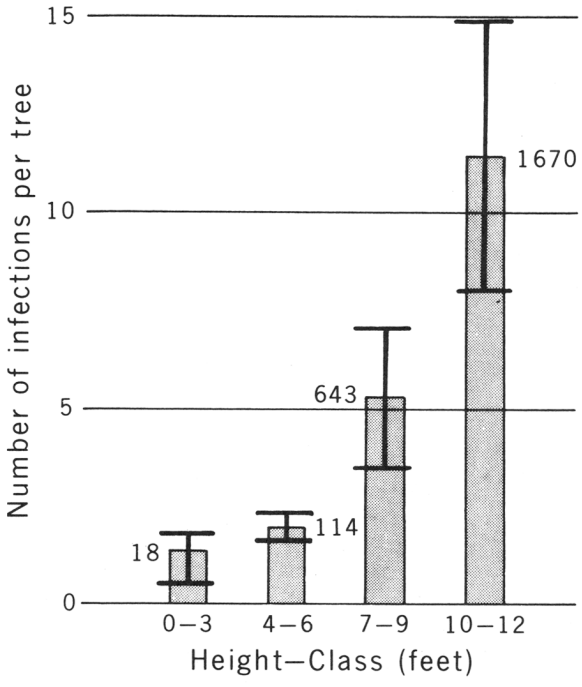


Figure 2--*Number of infections per infected tree in each height-class, with 95 percent confidence intervals.* (Scharpf 1969)

inherently quite slow. Also, certain factors keep population levels low and help check the spread of the parasite. An important factor that influences spread and buildup is that the generation time of a mistletoe plant from seed production to infection and development of a new seed bearing plant is 5 years or longer. Furthermore, female dwarf mistletoe plants do not regularly produce fruit every year; often abundant fruit is produced only about once every 3 years. In addition, the percentage of the total number of seeds dispersed that cause infection is quite low. For instance, not all seeds land on susceptible branches but of those that do, we have found that usually less than 5 percent of them cause infection. Thus, the long generation time, sporadic seed production, and low infection rates result in a slow rate of buildup and spread of the parasite.

The physical characteristics or growth form of firs also limits spread of the parasite. The dense persistent foliage of true firs limits both the upward as well as the lateral spread of the parasite. For example, results from our long-term studies show that average distance of vertical spread of dwarf mistletoe in red firs and white firs is about 3 inches or less a year. In addition, most mature seed bearing plants on firs are located within the crown of infected firs and not out on branch tips. Thus, lateral spread of mistletoe seeds outside the crown to other trees is limited. As a result, most of the new infections that occur develop inside the tree crown and within one or two branch whorls of the seed bearing mistletoe plant.

Consequently, young trees on good sites and trees that are growing an average of about a foot or more in height will "outgrow" the vertical spread of dwarf mistletoe (fig. 3). In addition, infections in trees in well managed even-aged stands contribute little to infection of adjacent trees. Of course, it must be kept in mind that infection levels will buildup in trees on poor sites, in suppressed trees, in overstocked stands or in young trees exposed to heavily infected overstory.

Mortality and Growth Impact From Dwarf Mistletoe in Young Managed Stands is Often Low

Recent unpublished studies by Scharpf on infested released red fir stands in California indicate that both mortality and growth impact

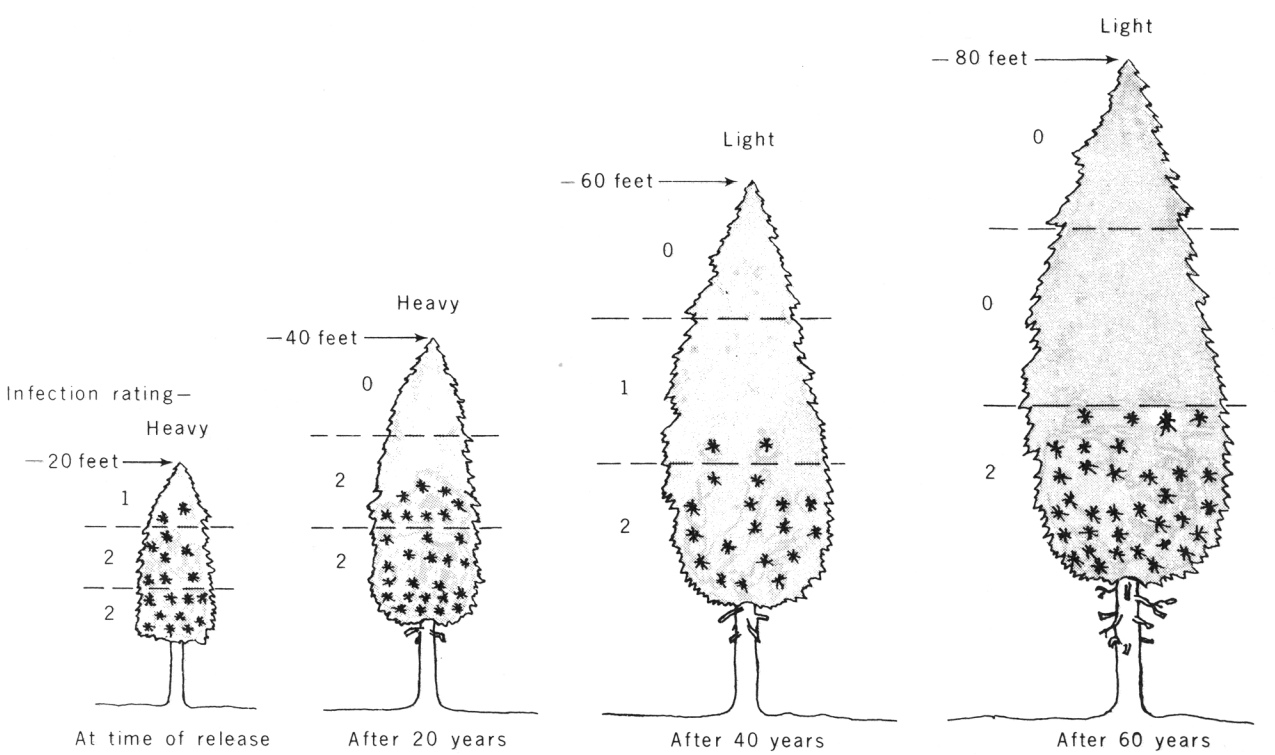


Figure 3--*Rate of vertical spread of dwarf mistletoe is less than the height growth for this released red fir (a hypothetical model).*

in infected trees is low and within currently acceptable management levels. Five years of study have shown that no mortality could be attributed to dwarf mistletoe irrespective of level of infection in any of several released red fir stands investigated. Where mortality from dwarf mistletoe does become a problem, as indicated by a recent USFS pest damage inventory, is when trees in infected stands are killed by a combination of two or more factors, such as, dwarf mistletoe, fir engraver beetle, *Fomes annosus* and *Armillaria mellea* (Byler 1975). Mortality from pest complexes is also higher than normal in dwarf mistletoe infested stands during periods of prolonged drought (Forest Insect and Disease Management Staff 1977). The canker fungus *Cytospora* also causes branch flagging and some top kill in firs weakened by both moisture stress and dwarf mistletoe (Scharpf and Bynum 1975). However, well released, vigorous fir stands with dwarf mistletoe have not shown above normal mortality on our test plots, even during the severe drought of 1976-77. Therefore, I question whether dwarf mistletoe caused mortality will be a major problem in well managed stands, even in combination with other pests or during periods of adverse climatic conditions.

Dwarf mistletoe affects the radial and height growth of red firs. But this effect may not be as severe as growth loss from suppression and other factors in unmanaged stands. Therefore, before dwarf mistletoe control is undertaken in young or second-growth firs, the stands should first be brought under silvicultural mangement; that is, increasing tree vigor commensurate with proper stocking levels and other management considerations. Release cutting in mixed size and age classes, thinning overstocked stands, brush control and possibly fertilization are examples of possible management approaches to increase vigor. Increased vigor automatically results in increased height and radial growth rates and reduction in the intensity of dwarf mistletoe. Any attempt to control dwarf mistletoe in unmanaged stands is not aimed at the heart of the problem and will result in wasted resources and effort.

In the management plan, how and when should dwarf mistletoe be controlled? To begin with, control initially need not be considered as a separate operation. A good deal of control will take place in the process of bringing stands into a well managed condition. For example, Gordon (1973) reported that noninfected young firs in California responded well to release cutting by increasing in height and radial growth. I obtained similar results in my studies of both dwarf mistletoe infected and noninfected red firs. Radial growth rate essentially doubled within 10 years after release for both infected and noninfected trees (fig. 4). Live crown ratio was an important factor in the subsequent radial growth of released trees (fig. 5). So long as trees, both infected and noninfected had a good live crown ratio, growth increased markedly after release.

The effect of release on height growth of trees was not investigated in detail, however, from field observations, I feel that height growth of infected and noninfected red firs also increases markedly after release. At any rate, height growth of study trees, even heavily infected ones, averaged more than a foot a year within 5 to 10 years following release (fig. 6).

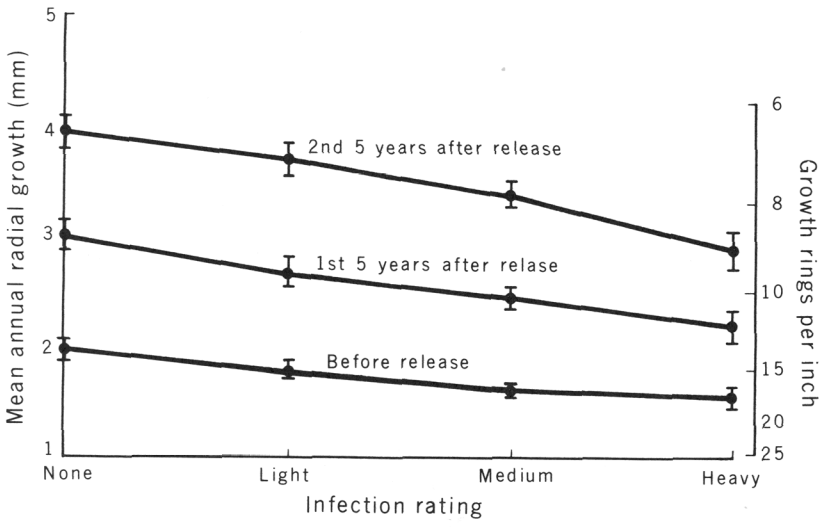


Figure 4--*Radial growth rate of red fir with various rated levels of dwarf mistletoe before and after release with 95 percent confidence intervals.*

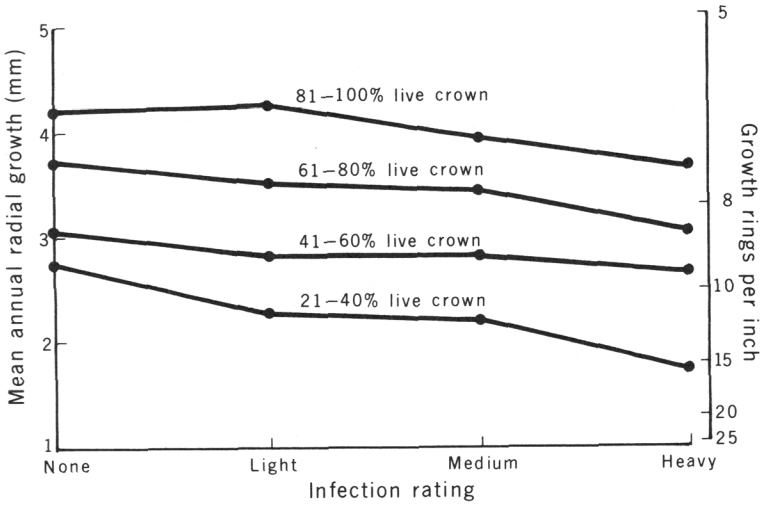
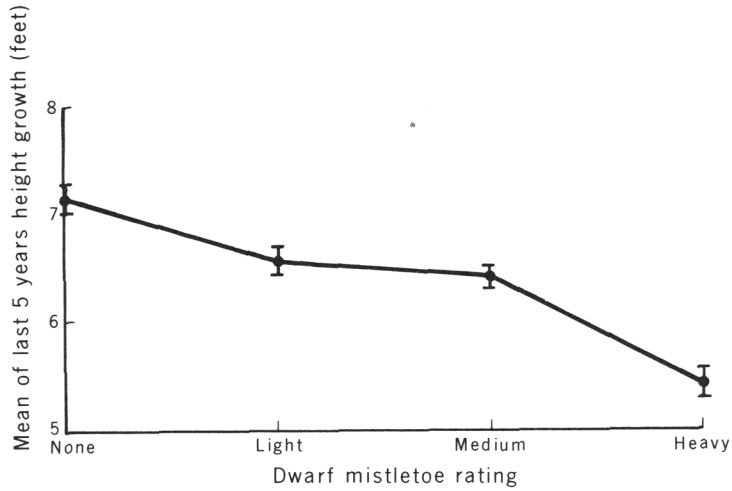


Figure 5--*Radial growth of red firs after release in relation to live crown ratio and dwarf mistletoe rating (10 years after release).*

Figure 6--*Mean of last 5 years of height growth of released red firs in relation to intensity of infection by dwarf mistletoe with 95 percent confidence intervals.*



The maintenance of good height growth means that (1) over time, the parasite will be limited to the lower portion of the crown, (2) dwarf mistletoe intensity will diminish over time, and (3) any growth reduction caused by the parasite will become less and less severe in the developing stand. Of course, in releasing trees or in thinning operations, the manager has the option of further reducing impact from dwarf mistletoe by leaving the less severely infected trees as crop trees, as long as they have live crown ratios equal to or greater than the infested ones. Management of infested true fir stands for timber production in the situation I just described I feel will require no additional efforts, at least for the first rotation, to control dwarf mistletoe even though some volume loss may occur from dwarf mistletoe infection. Attempts at more complete control of the parasite should be considered in the final harvest and in the planning of the next generation forest.

One of the questions often asked by managers is: Won't dwarf mistletoe trunk infections in young firs develop into the large, open, decayed bole swellings commonly observed on older trees in infested stands? My observations and unpublished results by Dr. Parmeter[3/] suggest that the large dwarf mistletoe trunk swellings commonly found on old-growth trees will not develop and become a problem in the management of dwarf mistletoe infested, second-growth stands. The cull and degrade commonly associated with larger bole infections on old-growth firs will almost certainly not be a problem in well managed, short rotation, second-growth stands. In addition, recent studies I

have completed have shown that dwarf mistletoe does not increase trunk taper in red firs as is often the case with heavily infested pines and some other species (Scharpf 1977). Thus, volume losses from increased tree taper is not expected to be a problem in infested, second-growth fir stands in the West.

One problem involving dwarf mistletoe in young stands that has not been fully investigated is the association between dwarf mistletoe and the canker fungus *Cytopsora abietis*. This fungus attacks and kills many branches infected by dwarf mistletoe. It could kill enough of the live crown in infected trees so that tree vigor and growth rate would be markedly decreased. Further studies to provide answers to this problem are in progress.

CONCLUSIONS

Control of dwarf mistletoe in true firs in the West shows promise because of the variety of management options, other than clear-cutting, open to forest managers. The primary consideration should be to get infested fir stands under good silvicultural management irrespective of the dwarf mistletoe situation. Good management should result in increased tree growth and vigor--and this will in itself reduce the impact of and problems caused by dwarf mistletoe and associated pest complexes. Efforts to control the parasite in true firs can be built into and implemented as part of the management plan for the stand. Development of the management plan should be based not only on timber management goals and the silvical characteristics of the stand, but also on the biology and epidemiology of the parasite. For the fir dwarf mistletoe, such planning requires understanding of parasite-host specificity, the age or size at which young trees become infected, the rates of growth required for firs to "grow away" from spread and buildup of the parasite, and the projected impact in relation to tree growth rates and dwarf mistletoe intensity. Armed with this information, the forest manager should be able to make management decisions that will be silviculturally sound and effective in the control of dwarf mistletoe in true fir stands in the west. As more information from research becomes available and as management of fir stands become more intensive, further refinement of control efforts to elimate losses from dwarf mistletoe can be achieved.

3/ Verbal communication from J.R. Parmeter, Jr., Department of Plant Pathology, University of California, Berkeley, February, 1978.

LITERATURE CITED

Anonymous.
1972. Forest Statistics for the United States, by state and region, 1970. 96 p. Forest Service, U.S. Dep. Agric., Washington, D.C.

Byler, James W.
1975. Pest damage inventory In Proceeding of joint meeting of western forest insect work conference and western international forest disease work conference. p. 30-35.

California Forest Pest Control Action Council
1961. Forest pest conditions in California. Sacramento, Calif. p. 12

Forest Insect and Disease Management Staff
1977. 1976 and 1977 drought/pest caused tree mortality in national forests of northern California. Calif. Reg. Forest Serv., U.S. Dep. Agric., San Francisco, Calif. 8 p.

Gordon, Donald T.
1973. Released advance reproduction of white and red fir--growth, damage, mortality. USDA Forest Serv. Res. Paper PSW-95. 12 p., illus. Pacific Southwest Forest and Range Exp Stn., Berkeley, Calif.

Hawksworth, Frank G., and Delbert Wiens
1972. Biology and classification of dwarf mistletoes (*Arceuthobium*). U.S. Dep. Agric., Agric. Handb. 401, 234 p. illus.

Parmeter, J. R. Jr., and R. F. Scharpf
1963. Dwarf mistletoe on red fir and white in California. J. For. 61(5):371-374.

Scharpf, Robert F.
1969. Dwarf mistletoe on red fir--infection and control in understory stands. USDA Forest Serv. Res. Paper PSW-50, 8 p. illus. Pacific Southwest Forst and Range Exp. Stn., Berkeley, Calif.

Scharpf, Robert F.
1977. Dwarf mistletoe does not increase trunk taper in released red firs in California. *USDA Forest Serv. Res. Note PSW-326*, 3 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Scharpf, Robert F. and H. H. Bynum
1975. Cytospora canker of true firs. U.S. Dep. Agric., Forest Pest Leaflet 146, 5 p. illus.

Scharpf, Robert F., and J. R. Parmeter Jr.
1967. The biology and pathology of dwarf-mistletoe, *Arceuthobium campylopodum* f. *abietinum* parasitizing true firs (*Abies* spp.) in California. U.S. Dep. Agric. Tech. Bull. 1362, 42 p. illus.

Scharpf, Robert F., and J. R. Parmeter Jr.
1976. Population buildup and vertical spread of dwarf mistletoe on young red and white firs in California. USDA Forest Serv. Res. Paper PSW-122, 9 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

PRESCRIBED FIRE - A TOOL FOR THE CONTROL OF DWARF MISTLETOE IN LODGEPOLE PINE[1/]

S. J. Muraro[2/]

This paper deals with the application of fire management principles to satisfy land management needs. What is fire management? Briefly, fire management is the application of fire related knowledge to achieve specific land management objectives. In this case, the required fire related knowledge is mainly ecological and fuel - weather - fire behaviour relationships. The overall land management objective is to establish healthy, optimally stocked stands to maximize fiber production. On areas infested with lodgepole pine dwarf mistletoe (Arceuthobium americanum) Nutt. ex Engelm., the treatment therefore has two specific objectives: sanitation and stand establishment.

It is not the intent of this paper to discuss the pros, cons or economics of mistletoe control but to suggest some techniques after the politicing and decision making has been done. I am presuming that the land manager has decided to institute a policy of mistletoe control or at least is evaluating the costs of various treatments subject to selecting a treatment. Prescribed fire, previously suggested by a number of researchers (Baranyay and Smith 1972, Donoghue and Johnson 1975, Gottfried and Emby 1977, Kiil 1969, and others listed by Alexander and Hawksworth 1975), is merely one of a number of tools which may be appropriate to the job. In the case of lodgepole pine (Pinus contorta var. latifolia Engelm.), which is relatively easy to kill, and has a perpetual and ready supply of seed held in serotinous cones, fire has to be a strong candidate. If burning conditions are right, there is no cheaper way to cover an area than with fire; however, there may be either environmental or political restraints or unfavourable weather regimes that preclude operational use of fire.

Keep in mind, mistletoe elimination is an intermediate objective - the end objective is economical fiber production. With this in mind, cost comparisons of various treatments must include costs of stand establishment if the means of stand establishment are destroyed by the sanitizing treatment.

The specific area discussed in this paper is a triangular portion of the Interior plateau of British Columbia known as the Chilcotin, bounded on the east by the Fraser River, on the southwest by the Coast mountains and on the north by Highway 16. Latitudes 54°N and 51°N and longitude 122°W enclose the north, south and east sides, respectively. The terrain is gently rolling to flat, ranging in elevation from 700 to 1500 metres. Major drainages deeply dissect the plateau. The dominant forest cover on the plateau areas are multi-aged, multi-leveled stands of lodgepole pine, the result of extensive low intensity fires occurring at 20- to 40-year intervals. Each fire, in turn, thins the stand, prepares a seed bed, opens a varying number of serotinous cones and allows nonserotinous cones to open through increased exposure. The opened stand permits sufficient light to the forest floor to permit establishment of advanced regeneration which, in turn, is infected with dwarf mistletoe from the overstory remnants. Occasional small areas of denser, even-aged stands, indicating areas of higher fire intensities are scattered throughout the area. These even-aged, denser, more typical lodgepole pine stands tend to be free of mistletoe.

In general, these Chilcotin pine stands rank low on the spectrum of market value of lodgepole pine and because of the cold, dry climate (annual precipitation 429 mm ("16.5") growing sites are predominantly poor. However, the assigned site class based on height-age relationship of the current growth probably reflects to some extent the predominance of dwarf mistletoe. Notwithstanding, the generally

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low site classes suggest that forestry practices, especially those that require the longest term, such as sanitation and reforestation, should involve minimum investment.

Judicious use of prescribed fire offers exciting prospects for meeting low cost sanitation and reforestation objectives for a wide range of control programs. Some of these techniques, most of which are not new, are applicable to other areas; however, they are particularly appropriate to the Chilcotin because of three conditions, (a) there is restricted or controlled fire use but not fire prohibition, (b) the areas generally do not involve conflict in value of understory and overstory species, and (c) low to moderate sites prevail, suggesting minimum capital investment for reforestation and sanitation.

In the Chilcotin generally all multistoried pine stands are infected. These stands are clearly evident on aerial photographs. Infected stands range from advanced regeneration on previously logged areas to overaged decadent stands and undersized immature. Because of the prevalence of mistletoe, some priority for control must be established. Recommended priorities for initiating mistletoe control projects from the standpoint of operational feasibility, lowest cost and administrative acceptance are:

(1) merchantable stands - stands that are currently in demand by operators, no inducements necessary.

(2) marginally merchantable stands - stands that are not in demand by operators and inducements to harvest are required.

(3) non-merchantable stands - stands that are definitely not merchantable now, nor in the forseeable future either because of extreme decadence, small diameter or slow growth rate.

Operational areas have been selected to provide combined research and demonstration units to evaluate the effectiveness and operational feasibility of fire use to achieve the dual purpose of sanitation and regeneration.

Merchantable stands (stands that are currently in demand)

From an operational standpoint, elimination of mistletoe from merchantable stands presents an absolute minimum of problems. The key to fire use in these stands is fuel management. Traditionally, at least in the Chilcotin, lodgepole pine stands are clear cut using feller - bunchers and full tree forwarding with grapple or choker equipped rubber-tired skidders. Topping and limbing is done either manually or by machine on the landing. This type of logging is favoured and has been advocated by fire protection interests and, except on winter logged areas, generally results in more than sufficient stocking. Waste piles at the lands are subsequently ignited during the late fall and allowed to burn out through the winter. This method is an extremely effective way of fuel hazard abatement; in fact, so effective that prescribed burning can only be accomplished in extreme burning conditions. The problem of burning these areas is accentuated by summertime grazing, which prevents the development of sufficient grass to aid fire spread. The objective of fuel hazard abatement was admirably accomplished and, if the silvicultural implications of nutrient removal can be accommodated, the practice should be continued where burning is not necessary. The acceptance of the broadened role of protection to include insect and disease, however, brings this fuel management practice of hazard abatement into conflict with requirements for the use of fire for mistletoe control. Thus the first task after acceptance of responsibility for a control program is to designate the specific area of each cutblock where control is necessary. Both the general and specific zoning of possible mistletoe areas can be achieved from aerial photos. The presence of open, fire thinned stands is almost a guarantee of mistletoe presence. The essential ingredient dictating the need for post logging sanitation is the presence of advanced regeneration. Remember these are not homogenous stands, and localized areas within a cutblock will support denser, even-aged stands that are mistletoe free or are too dense to permit advance regeneration. Such areas should be designated and ground checked prior to logging, because they will be difficult to distinguish from the remainder of the cutblock after the area is logged. If designated prior to cutting, they can be isolated by guards or roads integrated into the logging plan. Of course, the common sense perimeter measures recommended for mistletoe areas should be observed.

The key to achieving a fuel complex that favours fire use is to be aware of the requirement prior to selling the timber. At this time, the contract can be written to ensure that limbing either by hand or by mechanical means is done prior to forwarding. After about four weeks, the red foliaged lodgepole pine slash provides a fuel complex that will provide excellent fire coverage with minimum drying. This allows a land manager in virtually any climatic regime to achieve good sanitation with a minimum of ignition effort. A wide latitude of burning conditions are also avail-

able, dependent on the need for seedbed exposure requirements and fire control. Summer night burns, when adjacent timber stands will not carry fire, involve a minimum of ignition effort and low control costs. Treatment costs of less than $10 per acre should be expected. Fuel complexes that favour fire use can be created with lower costs because only useable material is forwarded. Savings in energy, landing expansion and cleaning and finally the need to burn landing piles is eliminated. Fire guard construction must be specified in the contract and completed while machines are still on the operation. Perimeter guards, one cat blade wide are sufficient for control. If care is exercised to ensure vehicular access, savings in perimeter mop up and patrol, using porta tankers will be possible. One pass, drivable construction is possible with a D7 or larger dozer at a rate of about 1 km (.6 miles) per hour; this equates to a cost of about $50/km ($80/mile). Mop up efforts will be minimized if waste from guard construction is pushed to the outside of the area and kept as low as possible. A clean inner perimeter will virtually eliminate hang fires at these critical locations.

Although excellent mistletoe sanitation can be achieved on currently logged areas by these simple techniques, there is a strong possibility that the seed in slash-borne cones will be destroyed and planting will be required. We know that fast spreading, short residence time fires can leave surviving seed both in slash and on advanced regeneration. Of question is whether it is operationally feasible. That is, is there sufficient latitude in fire behaviour between complete seed mortality and adequate stocking and good fire coverage to be operationally feasible. In the case of winter logging, where mineral seedbed is lacking, the longer fire residence period required to provide mineral soil suggests that all slash-borne seed will be destroyed.

There are, however, other alternatives for stand establishment; a seed tree cut followed by burning, or seeding of clear cut broadcast burned areas will be less costly than planting.

In any event, even with a token mistletoe control policy, the low cost of fire sanitation on future harvest areas must receive highest priority and should be conducted as routine procedure.

Marginal stands: stands that are not in demand and inducements to harvest are necessary.

The main difference between these stands and the merchantable stands is that extra cost either in stumpage allowance or direct subsidies may be required to induce harvest. Marginality may be due to low volume, small diameter, or decadence. These stands should receive second priority for treatment except if they occur on a particularly good growing site. If this is the case, then sanitation and rehabilitation should be initiated as soon as practical. If the growing site is favourable, then logging should be induced with subsidies if necessary and the fuel management practice suggested for the merchantable stands followed. Presumably the better growing sites are better able to show economic returns on the higher reforestation cost but greater success expected from planting.

If these marginally commercial stands are on poor to medium sites, then a least-cost treatment that accomplishes both sanitation and reforestation should be attempted.

Fire can be applied to accomplish both objectives in a variety of methods subject to constraints on condition and intended use of the harvested wood. If the stand is basically sound and processing includes chipping, then fire scorched wood must be minimized. In this instance, a seed tree cut leaving 20 to 30 trees per hectare will serve as the seed source. The fuel management practice of limbing on the area will provide fuel for good fire coverage to sanitize and adequate heat to liberate seed from the serotinous cones. This fire prescription must call for exposure of about 60% mineral soil and be of sufficient intensity to kill the seed trees. If mortality of seed trees is not achieved, they must be felled within three years.

If decadence is prevalent and long butting is required or if processing does not include chipping of mill waste, then underburning the stand using a controlled intensity surface fire will provide sanitation, seedbed and seed. Regulation of fire intensity is achieved by strip head fires and varying and distance between subsequent strips. The fire intensity required is dependent on the quantity of seed necessary to provide the desired stocking and the position of the cone crop relative to the flame zone. If the distance between the flame zone and the cones is large, little seed will be liberated; if the distance is small, a near maximum amount of seed will be liberated. Further stocking control can be exercised during the logging operations. If judged to be understocked, then tops can be left on the area; if satisfactorily stocked by the fire, then tops should be removed to reduce additional liberation of seed from slash-borne cones. Fire prescriptions for this procedure

must ensure that about 60% of the area has exposed mineral soil if winter logging follows the burn. If the area is to be logged in the summer, then the exposure of mineral soil by machinery precludes the need for mineral soil exposure by fire. In this case, the prescription merely requires spread indices that will ensure good coverage and adequate intensities to affect the cone zone.

Non-merchantable stands: Stands that are definitely not merchantable now, nor in the future.

Treatment of these stands would be included in the most intense level control program. Not only does treatment of these areas incur full direct costs of control to the agency, they also involve the area of most uncertainty. Who can say for certain that a stand will not be merchantable or at least marginally merchantable in ten years' time? In some cases of extreme decadence or extremely heavily infected young stands, there may not be much doubt, but there will be instances of both types of stands that will be in a gray area. However, I started out by saying I wasn't going to deal with the "treat - don't treat" question. I repeat, we are in the treatment selection phase. It is assumed that the full cost of treating these areas will have to be borne by the land management agency without any immediate return. With this in view, not only should the worst stands be treated first to give as much leeway for error in future merchantability estimates but, also, the best growing site should receive priority. Treatment of these areas need not consider damage to material; however, it is important that the one shot effort achieve dual objectives of sanitation and restocking to desired levels. To achieve these objectives in both decadent and immature stands, the controlled intensity surface fire mentioned for marginal stands is used. Prescriptions must provide for sufficient fire residence time to provide either a very thin residual of organic material or exposed mineral soil to ensure a receptive seedbed. Most importantly, however, the prescription must achieve a high kill rate even at the risk of overstocking. Strip head fires serve as the seed release mechanism; but, in cases of young stands, flame length might have to be restricted to only two or three metres. The post burn microclimate of areas treated in this manner will be considerably less severe than that of logged areas. Shade will be provided by the remaining snags and, in addition, to immediate nutrient release from the fire, the needle cast will provide further nutrient and protection to the freshly fallen seed.

This treatment attempts to duplicate the effects of wildfires with two important exceptions. The modified intensity provides stocking control, and follow-up by hand felling crews removes the surviving trees to eliminate the source of infection to the new stand.

The cost of rehabilitation of these stands is relatively low if all objectives are satisfied and if 50 to 70 hectare blocks are treated. Cost of treatment will be most sensitive to the amount of hand felling required to remove residuals.

LITERATURE CITED

Alexander, M.E. and F.G. Hawksworth
1975. Wildland fires and Dwarf Mistletoes: A literature review of ecology and prescribed burning. USDA, USFS Tech. Rep. RM-14, 12 p. - Rocky Mt. For. and Range Exp. Stn. Fort Collins, Colorado.

Baranyay, J.A. and R.B. Smith
1972. Dwarf mistletoe in British Columbia and recommendations for their control. Can. For. Serv., PFRC Inform. Rep. BC-X-72. Victoria, B.C. 18 p.

Donoghue, Linda R. and Von J. Johnson
1975. Prescribed burning in the North Central States. USDA, USFS Res. Rep. NC-111, 8 p. North. Cent. For. Expt. Stn. St. Paul Minn.

Gottfried, Gerald J. and Robert S. Embry
1977. Distribution of Douglas-fir and Ponderosa pine Dwarf Mistletoes in a virgin Arizona mixed conifer stand. USDA, USFS Res. Pap. RM-192, 16 p. Rocky Mt. For. and Range Exp. Stn. Fort Collins, Colo.

Kiil, A.D.
1969. Basic considerations in the planning and use of prescribed fire. For. Res. Lab. Inform. Rep. A-X-21. Edmonton, Alberta. 11 p.

LOSS EVALUATIONS IN FOREST RECREATION AREAS[1/]

Richard S. Smith, Jr.[2/]

Abstract: We defined a set of management goals for recreation forest stands which say that we will attempt to maintain a healthy and vigorous, all-aged, mixed species, properly stocked stand with numerous old-growth trees. An infestation of dwarf mistletoe may well prevent us from reaching most of these goals. The dwarf mistletoes affect the trees both directly and indirectly through other pests. All dwarf mistletoe evaluations and control efforts should include consideration of associated pests. Recreation forest stands require proper silvicultural management for adequate disease prevention.

INTRODUCTION

Before we can consider some of the ways in which dwarf mistletoe infestations affect recreation forests we should recognize that there are several administratively different types of recreation forests. There are multiple-use forests, where recreation is a secondary use, and others where it is the primary use. There are restricted-use recreation areas, such as some wilderness areas, where forest management activities are not allowed, and other areas where various levels of management are required. Among these managed recreation areas are two general types: the dispersed recreation area, with or without secondary uses; and the developed recreation area, such as the campground, picnic area, visitor center, or other. It is mainly the latter areas -- the developed, intensively used, single-purpose recreation sites -- which we are usually concerned with when we talk about dwarf mistletoe effect on forest recreation areas, and it is mainly these areas I will discuss in this paper.

In this discussion, I will cover the goals of forest management in recreation sites, how dwarf mistletoe has kept us and can keep us from realizing these goals or make these goals more costly to achieve, some actual examples of dwarf mistletoe and associated pests effects in developed recreation sites and, lastly, forest recreation management philosophy and the prevention of insect and disease losses in forest recreation areas.

MANAGEMENT GOALS IN FOREST RECREATION AREAS

Before we can assess the adverse effects of a pest activity, we must first determine what our management goals are for the stand, area, or forest. The four southern-most National Forests in California, because of tremendous recreation use and pressures, have been designated as "recreation forests"; that is, they are forests where recreation will be the primary use and all other uses will be secondary, or not allowed. Because of this new responsibility in recreation, forest managers have pushed ahead in attempting to describe objectively and accurately the management objectives of a recreation forest. I personally am enthusiastic about their views and selection of management objectives in recreation forests and would like to use the goals they developed in our discussion of loss evaluations. These are:

1. Maintain attractive forests for recreational use and enjoyment.

2. Provide protection from excessive insect and disease losses.

3. Provide favorable conditions for maintenance of water flow and yield.

4. Reduce the potential for loss by uncontrolled fire.

5. Maintain and enhance wildlife and

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fisheries habitats.

6. Utilize trees removed from the forest in achieving the preceding goals.

7. Provide educational and interpretive services.

I would expect that these goals would be generally applicable to most forest recreation areas in the West. Managers at these southern forests also list second order objectives pertaining to stand management:

1. Maintain an all-aged or irregular sized stand structure.

2. Retain old growth trees as long as possible.

3. Control stocking to desirable levels.

4. Maintain mixed species composition.

5. Maintain healthy, vigorous trees.

6. Maintain a natural appearing stand.

The second order objectives are more specific and therefore are easier to relate losses against than are the more generalized primary objectives. You may view the stand management goals for your forest recreation areas somewhat differently, but for purposes of this discussion, I will use the above as objectives in describing the effects of dwarf mistletoe infestations on forest recreation goals.

EFFECTS OF DWARF MISTLETOE ON FOREST RECREATION GOALS

Having developed a set of primary and secondary goals, and using the more specific secondary goals, we can now look at how dwarf mistletoe infestations may prevent us from reaching these goals, or permit us to reach them at a higher cost. These goals and projected infestation effects are as follows:

Maintain an All-Aged Stand.

Infection of the overstory by dwarf mistletoe will result in the infection and eventual destruction of all, or most all, of the understory trees of the same and other susceptible species within the immediate vicinity of the infested overstory trees. The trend will be away from the desired all-aged stand toward an even-aged infested overstory. The real effect of this trend will usually not be felt until the last stages of stand development, when we find ourselves with an infected, overmature, thinning, even-aged overstory and few or no younger age classes which can be used to replace the decadent overstory. The forest recreation area is gradually denuded and loses much of its aesthetic value. At this point we may be left with the alternatives of either closing the recreation site or attempting to regenerate it slowly through a series of small selective overstory clearcuts and plantings. The attempt to regenerate the stand during the continued use of the site gives us the additional problems of coordinating our regeneration actions with recreation use and protecting our plantings from recreation-use damage. Either of the options -- to close the site and regenerate or to regenerate during continued use -- is costly.

Retain Old-Growth Trees

As trees age and move into the overmature age class, their vigor starts to diminish. Dwarf mistletoe infection adds additional stress to these trees causing them to decline in vigor at a more rapid rate. These declining trees are more susceptible to attack by bark beetles and other pests. Thus, the picturesque old-growth trees we wish to retain tend to die off more quickly if infected by dwarf mistletoe. In some cases, we can alleviate the stress by pruning the large, broomed branches -- caused by dwarf mistletoe infection -- from these trees. This is a costly operation and broom pruning often is considered undesirable by the landscape architects.

Control Stocking to Desired Levels

The recreation objectives of stocking control in an all-aged stand should be to maintain adequate cover (overstory) for shading, protection, and aesthetics, and sufficient understory and lesser vegetation for purposes of overstory replacement, screening, and aesthetics. The stand management stocking objectives should be to develop a stand which is not stressed by overstocking and which meets secondary objectives 1 and 2. Dwarf mistletoe infection of a stand may result in an understocking of the infested stand which is less than desirable or acceptable to the recreation stocking goals. The effects of dwarf mistletoe on the overstory is to put stress on the infected trees, increase their susceptibility to other pests -- particularly bark beetles -- and to cause the overstory to gradually thin.

The effect on the understory will be more dramatic. The rain of dwarf mistletoe seeds from the infected overstory will result in heavy

infection of the understory and the direct killing of the susceptible trees by the dwarf mistletoe. The thinning of the overstory and the lack of replacement trees in the understory will result in the gradual decrease in stocking over time of the forest recreation area. Artificial regeneration with nonsusceptible species, or patch cutting of infected overstory and regeneration with susceptible species, are the alternative control procedures.

Maintain Mixed Species Composition

Infection of a tree species by dwarf mistletoe in a mixed conifer stand will tend to eliminate this species gradually from current and future stands. Infected overstory trees will be at a competitive disadvantage with overstory trees of other species. Susceptible understory species will become infected and die, and their removal will result in less species mix in the replacement stand. The elimination of a species from a mixed conifer stand will increase the stand's vulnerability to destruction by other pests and decrease its aesthetic value.

Maintain a Healthy, Vigorous Stand

The presence of dwarf mistletoe in a stand means that a portion of the stand is not healthy. The added stress brought on by this pest will result in decreased vigor of the infected trees and increased susceptibility of the stand as a whole to other pests, such as bark beetles. These other pests may build up on the dwarf mistletoe infected trees and from them spread out and infect or infest and kill trees not infected by dwarf mistletoe. Thus the dwarf mistletoe infected trees may pose more of a threat to the health and vigor of the stand than just the number of infected trees indicates. Secondly, dwarf mistletoe infections may provide for the entrance of other pests into the infected trees. Decay fungi frequently enter the older dwarf mistletoe bole swellings of true fir causing a heart rot, making the trees susceptible to stem failure, and thereby increasing the hazard to recreationists in these stands. Cytospora canker infects red fir at sites of dwarf mistletoe infections causing branch mortality. In many instances excessive branch mortality has further decreased the vigor of the infested stand.

Maintain a Natural Appearing Stand

Most recreationists would probably not notice an unnatural appearance until a stand has experienced a good deal of mortality and the stocking of overstory and understory were seriously affected. If this is the case, dwarf mistletoe would affect the other goals long before its effects would be felt here. Basically, I view the maintenance of a natural appearing stand as a key goal. I believe the purpose of the first five goals, in part, is to prevent our failing in this goal. And, if we do fail in achieving the other goals, it is only a matter of time until we fail to achieve this one.

COMBINED PEST EFFECTS

The effects of dwarf mistletoe on a stand do not occur alone. In real life these effects occur in combination with the effects from other pests. These other pests may or may not influence or be influenced by the dwarf mistletoe problem. Our evaluations of the dwarf mistletoe effects should include, therefore, an evaluation of the other pest problems, present or imminent. The dwarf mistletoe controls we institute must consider the effects of these other pests on the stand and the effects of our control procedures on these pests, and the losses they cause. In the Forest Service's California Region, we feel so strongly about this need to consider the total pest complex in a stand that we now are using a team approach in our pest evaluations. A basic team would include both an entomologist and a pathologist who would look at all major insects and diseases affecting the stand. To illustrate this need for teamwork I would like to describe briefly the pest evaluations we conducted this year on two very different recreation areas. In each case, dwarf mistletoe was a major problem and the pest evaluation was conducted by a pathologist, entomologist, and local forest manager.

Recreation Area A is a large area surrounding a lake and containing several campgrounds, picnic areas, summer homes, tracts, and considerable acreage for dispersed recreation. The stand is basically a young sawtimber overstory with a sapling understory, varying from absent to very thick. It is a mixed stand of ponderosa pine, incense cedar, white fir, sugar pine, and black oak. The overstory is heavy to ponderosa pine. Incense cedar predominates in the understory. Islands of old growth ponderosa pine are scattered throughout the stands. Last year the area experienced considerable mortality of ponderosa pine. A survey of the area revealed that 90 percent of the mortality was caused by a complex of insects and diseases. The major pests in this complex were dwarf mistletoe, pine engraver beetle, western pine beetle and Annosus root disease. Seventy-two percent of the dead trees had a Hawksworth dwarf mistletoe rating of 4, 5, or 6.

Thirty-eight percent of the trees had signs of pine engraver beetle attack and over 50 percent of the dead trees has been attacked by the western pine beetle. Overstocking was considered to be a contributing factor. The mortality was diagnosed as resulting from the combined effects of dwarf mistletoe, the two bark beetles, and overstocking. The prognosis was for additional mortality to occur in the near future resulting from the combined continued effects of these pests and Fomes annosus.

In planning for removal of the dead and partially dead trees, we had to consider the production of slash and its potential for creating another build up of the pine engraver beetle. In addition, over 60 percent of the dead trees still had green butts and root crowns which, when cut, would create stumps susceptible to infection by Fomes annosus. Annosus root disease centers created during previous sanitation-salvage cuttings were found in developed recreation sites. Stump treatment with borax was, therefore, a consideration in the control plan. With the prognosis for dwarf mistletoe and overstocking to stress trees and contribute to or cause future bark beetle problems, plans for a combined dwarf mistletoe-thinning program were also considered. The evaluation of area A identified four major pests, concluded that interactions between these pests did occur, and suggested control options in which all four pests and the losses they caused were considered. The stand is still young, with adequate stocking and a good species and age class mix. Much of the pest control could, therefore, be accomplished at little cost and disruption.

Stand B is an over-mature, mixed conifer stand with sparse understory and a thinning overstory. The stand is mainly ponderosa pine, Jeffrey pine, and white fir with occasional incense cedar and sugar pine. A survey identified dwarf mistletoe on ponderosa and Jeffrey pines, true mistletoes on white fir and incense cedar, air pollution, flatheads, Jeffrey pine beetle, fir engraver, and western pine beetle acting together in various combinations to cause most of the mortality. The stand has a long history of dwarf mistletoe and other pest problems. The prognosis was for continued mortality in the overstory and loss of the understory pines resulting in the loss of most conifers. Because the stand was so old, stocking so thin, regeneration difficult to establish and dying from dwarf mistletoe when established, stand management and pest management options were limited and costly.

Broom pruning of infected overstory trees was suggested as a means of reducing stress and lowering mortality in the near future. Other control options such as overstory removal, thinning, and planting would have to be tailor-made for small groups of trees and should consider species composition, all major pests present, tree vigor, and stand structure. The flexibility for control and stand management we had in Stand A is not available here in Stand B. But, the now younger Stand A could, without stand management and pest control, develop over time into a stand-pest condition similar to that of Stand B.

STAND MANAGEMENT IN FOREST RECREATION AREAS

Forest recreation stands are dynamic, interacting, growing, changing ecological systems. They are not static and will not remain unchanged regardless of our actions or inactions. These are statements I believe we can all accept on a biological basis. But we appear to have a problem accepting these ideas on a management and administrative basis. How many forest managers practice the same level of silviculture in recreation forest stands as in timber stands? Are recreation forest stands worth more or less than timber stands, and is the investment in maintaining these stands commensurate with the values placed upon them?

In the area of recreation stand management, we are still suffering from the effects of an older out-dated philosophy which advocated that man influence or affect the recreation site as little as possible so as to keep it "natural." This, of course, meant that we should do no stand management. We can no longer accept this older philosophy if we are to achieve the newer management goals described earlier in this paper.

Proper stand management and silvicultural management are the basis of an effective insect and disease prevention program in our recreation forest stands. The longer sound stand management is excluded from recreation stands, the more severe the insect and disease losses will become in these stands and, as we saw in comparing Stands A and B, the fewer and more costly will be our control options. This is particularly true of dwarf mistletoe problems where silvicultural controls are the most effective controls available to us.

Refining and Improving Control Techniques

COOPERATIVE RESEARCH AND MANAGEMENT EFFORTS LEADING TO BETTER CONTROL[1/]

Richard S. Smith, Jr.[2/]

Abstract: Past research-management cooperation done on a personal basis has been effective in providing us with the dwarf mistletoe controls we now use. Recent developments have brought us new opportunities to improve the control of dwarf mistletoe and other pests through increased cooperation between research, extension and management. The current stylized concept of the relationship among research, extension service, and management is inadequate to meet our future needs because it lacks the two-way flow of information, the flexibility, and the long-term closeness that will be required in the future. Forest managers, extension specialists and researchers should be encouraged and supported in long-term cooperative efforts in integrating the control of dwarf mistletoe losses with the control of pest-caused losses and with the intensive silvicultural management of stands.

INTRODUCTION

Talking about the merits of cooperation among research, extension service, and forest management is much like praising motherhood in that we all agree that it is good, that it is needed, and that it has been productive. And so I am not going to tell you about the past accomplishments of the cooperative efforts of researchers, extension specialists, and forest managers that led to the dwarf mistletoe control practices you now use. Instead, I would like to indicate where we now are in the area of research-extension-management cooperation, and what our future opportunities and needs are, and to describe some new ways or areas in which such cooperation can be more productive. And I hope that in exploring this subject together, we may all be inspired to cooperate with one another more often, in more ways, leading to more fruitful relationships.

This symposium was originally designed for and directed to forest managers and forest silviculturists. But in talking about the subject of research-extension-management cooperation it would be inappropriate to address just one member of the cooperative team. And since representatives of all three groups are here, I am addressing this talk to all of them. I do so with the thought that after my presentation, representatives from research, extension, and management will respond with their particular points of view so that we can start to develop more of an understanding of how we might better cooperate with one another to achieve our immediate and long-range goals.

Research-extension-management cooperation in the area of dwarf mistletoe control up to this point has resulted mainly from the efforts of several dedicated persons in each group. These efforts have been very productive, in fact in my judgment, they are among the most productive of the cooperative efforts in forest disease control. The organizations these people work for have supported these efforts financially and have generally encouraged cooperation on a personal basis. But they have usually not become involved to the point of setting specific organizational goals, assigning responsibilities and accountabilities, and evaluating progress toward these goals. I believe that these organizations do have roles in this area of research-extension-management cooperation beyond the general encouragement of such cooperation and that increased organizational involvement and dedication at all administrative levels will be needed if we are to meet the challenges of the future.

[1/] Presented at the Symposium on Dwarf Mistletoe Control Through Forest Management, Berkeley, Calif., April 11-13, 1978.

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NEED FOR RESEARCH-MANAGEMENT COOPERATION

Several conditions have recently emerged that, in my estimation, are going to require an increased sophistication, coordination and cooperation among forest research, extension and management if we are to improve on current and future operational forest pest control techniques and methods. Central among these conditions are:

1) A change in our goals from that of controlling pests and pest populations to that of reducing forest losses caused by pests.

2) An increase in intensive forest management activities and a corresponding increased emphasis on and availability of silvicultural control options.

3) The development of the dual concepts of pest complexes and integrated pest management.

These new conditions are responsible for changes in the operations and needs of forest pest management systems. And they are providing us the opportunities to strengthen our control methods through the coordinated efforts of forest research, extension, and management.

The thought that our goals in regard to forest pests should be to reduce the losses they cause is not a new one. It is a concept, however, that was over-shadowed until recently by the idea that our goals should be to reduce or control pest populations. Under this philosophy our efforts were usually aimed directly at controlling damaging pests so as to control a current epidemic by eliminating all or a large portion of the pest population. We talked in the now familiar terms of direct control, suppression, eradication, and, of course, pest control. The success of our control efforts was measured in terms of numbers of pests killed by or remaining after a control operation. Such evaluations usually were made shortly (1 to 3 years) after the control operation. Some of our early efforts in dwarf mistletoe control, in line with this philosophy, were aimed directly at this pest in an effort to eradicate it from stands by pruning and thinning. The effectiveness of these control efforts was based upon the number of dwarf mistletoe infections evident at the next stand entry a year or two later. Often a stand was worked 3 or more times in our efforts to eradicate this pest.

Reduction In Forest Losses

Recently our philosophy has undergone a slight but fundamental shift to where our goals now are to reduce forest losses that the forest manager finds unacceptable. Consequently, our control efforts must be evaluated on the basis of how effectively they reduce losses -- and not how effectively they control pest populations. Forest losses are no more difficult to measure than pest populations, but changes in losses resulting from control operations do require a longer period of time to express themselves. Such evaluations of pest losses must be based upon the goals and values of the forest manager. Thus, evaluations of pest-loss control must be made over longer periods, possibly a complete rotation and with the cooperation, assistance and guidance of the forest manager. And therefore, the development, testing and modification of control methods to reduce losses must be done with the cooperation of and input from the forest manager. The forest manager is needed to 1) define production goals and losses and 2) manage the test forest and keep adequate records so that a creditable evaluation of the control methods can be made -- one that will fulfill both research and management's needs.

The increased emphasis and great reliance on silvicultural control methods is going to demand a greater cooperative effort between the researchers, extension pathologists and forest managers. The development and testing of silvicultural control methods is usually done in a few, limited stand types and consequently the results of such tests are known to be applicable to only those types of stands within the test. Stands vary widely because of differences in age, structure, species composition, density, size, etc., and the initial research and operational testing of any control method cannot encompass all possible combinations of these variables. The research organizations have neither the time nor the resources to undertake responsibility for testing under so many varied conditions.

Limitations In Evaluation

On the other hand, forest managers who utilize the best information available and frequently employ control methods tested on other stand types do not have the time or resources needed to take the detailed information required to evaluate fully the control methods from the research or development standpoint. Usually what has happened in the past is that the extension pathologist has

tried to meet the control needs of the forest manager by extrapolating as best he can from the available research information. Usually such control recommendations made to the forest manager have received only limited evaluations by the manager or the recommending pathologist or both to see if the manager's goals are achieved. Researchers and extension specialists who have tried to evaluate these operations some years later usually have found that the kind, amount, and detail of the stand and pest information taken both before and after such a control operation has been inadequate to meet their research and evaluation needs.

It appears quite logical that a cooperative effort between the forest manager, extension pathologist, and the research pathologist would go a long way in solving these problems. I am sure such cooperation has been discussed and recommended before. But it has yet to develop to the degree or in the amount we need if we are to do our part in developing the pest control portions of intensive silvicultural management systems. The cooperation between interested parties must be maintained over long periods for the successful evaluation of silvicultural control and prevention methods. All persons involved at all administrative levels must approve, support, and organize such cooperation if it is to be successful.

Pest Complexes

Within the last few years we have become more aware that our forest losses are not caused by single pests but more often by two or more pests working together to kill a tree. And in mixed conifer stands, total tree mortality is the result of several pest complexes working on different host trees or under different conditions. Control efforts against these major pests must be integrated with one another and with the silvicultural and management goals for the stand. And again, silvicultural and prevention type controls are the most desirable methods we see today.

If the long-term control of any one pest will require cooperation between the forest manager, the extension pathologist, and the research forester, imagine the complexity and the coordination and cooperation required for the simultaneous long-term control of several pests. To me, this will require more integration of the work of researchers, extension specialists, and managers than any of today's pest control methods. It is not a goal that we will reach easily or quickly. It is one that will require long periods of study and restudy as we attempt to fine-tune combinations of control techniques for greater effectiveness under varying ecological conditions. To do this effectively, the researchers must be active members of the planning and pre- and post-evaluation teams, and the forest manager must have a strong voice in the direction and goals of the research program.

COOPERATIVE RESEARCH-MANAGEMENT RESOURCES

What are the resources we have at our disposal to develop a more productive research-extension-management relationship? Broadly speaking, they are the people and organizations which have been with us right along. They are:

1. The forest managers representing Federal, State, and private forest land managing agencies, whose jobs are to manage the forests to meet the goals of their particular organization.

2. The extension specialist, including county agents, university extension pathologists, State forest pest control pathologists and Federal Forest Service pathologists.

3. The research pathologists and silviculturists from the universities and colleges and the Forest Service research stations.

As forest management intensifies and concepts change, these people and their organizations can and must find new and more productive ways to interact if dwarf mistletoe control operations are to be improved on the scale required by the forest manager.

DEVELOPMENT OF RESEARCH-MANAGEMENT COOPERATION

How do we use these resources most effectively in developing cooperative research-extension-management efforts and systems with the goal of improving dwarf mistletoe control? I am sure that management, extension and research each have valuable and constructive suggestions which would help to do just that. In fact, I might go so far as to suggest that in each geographic area we do get together to discuss just how research and management can cooperate towards improving dwarf mistletoe control and get administrative approval and support for the developed cooperative efforts. In the meantime, I offer these observations and suggestions:

First, the current stylized model of research-management cooperation is inadequate

to meet future needs. It has neither the flexibility nor tenacity that we must have. This model is chiefly concerned with information transfer from research to management and often as not portrays this transfer as a unidirectional flow of information from research to management (fig. 1). This interchange between research and management is also viewed as temporary. When new research information is developed, research and management get together to field test it cooperatively -- often by means of a pilot control project. When the test is completed, they each go their own way.

This model may be adequate for this transfer of certain types of research information into management uses, but it does not meet our needs in the area of silvicultural control of dwarf mistletoes or other forest pest problems. The full integration of silvicultural control information into complex and variable biological systems requires the long-term two-way flow of research and management information. For example, we cannot hope to pilot-test new silvicultural control methods in many stand-site conditions. Using our best judgment, we will often be called on to extrapolate and use these new incompletely proven controls in new stands and site conditions. There is a real need to get the results of such an application back to researchers in terms he can use to evaluate its effects. The only way this can be done effectively is for management to communicate its plan to researcher so that he can plan and arrange to get the field data required to analyze these effects. This calls for closer long-term ties between research and management in a system which fosters and supports two-way communication and cooperation.

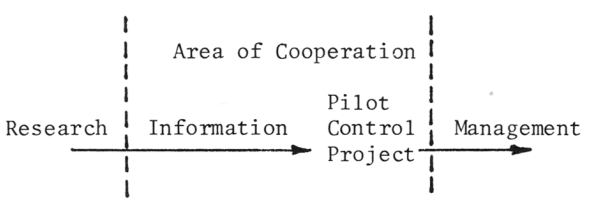

Figure 1-- Model of information flow and cooperation between research and management.

Establishing Two-Way Communication

This system of consistent two-way communication, up to now, has been difficult to establish except on a personal basis. The flow of information back to the researcher has been neglected for a number of reasons: 1) The field of operational silviculture is dispersed and dwarf mistletoe control is only one of a silviculturist's many concerns; 2) personnel turnovers are frequent and communication dependent upon personal contacts must be frequently re-established; 3) the need for two-way communication may not be recognized by either the research pathologist or the silviculturist; 4) recognition and reward for cooperation and accomplishments in this area is minimal or nonexistent; and 5) communication has to be extended over long periods of time before the results of silvicultural operations are known.

Other opportunities for productive research-management cooperation exist. Forest management organizations are rapidly developing more formalized methods of silvicultural operation combining periodic stand inventory, stand examination, written detailed silvicultural prescription and record keeping. In such a system, the stand is inventoried periodically (once every 10 years). These data are analyzed for basal area, basal area growth, mortality, potential crop trees, etc. The stand is examined for other site and stand factors, including such pests as dwarf mistletoes, and experts are consulted when and where needed. From the inventory and examination, stand management goals are defined and a written silvicultural prescription is prepared and implemented. The prescription is filed for reference so at the time of the next examination, the silviculturists may evaluate the effectiveness of the prescription against the goals set 10 years earlier.

This appears to be an ideal system into which, with the cooperation of the silviculturist, we could tie more detailed evaluations of pest control operations into a broader management planning system. The silviculturist could supply stand productivity information while the pathologist could supply the pest and pest control information. Together these two would make a more complete evaluation of the effectiveness of a control method which would form a basis for future stand planning and management activities.

Involving Research In Testing

Forest managers often do testing on their own without involving research. Here is another area where cooperation of research in the planning and evaluating stages would be very desirable. A forest manager is responsible for a living, growing and changing system which require or demand that certain decisions be made at certain times using the latest and best available information. Often this best available information is untested under these conditions but basic research, experience, extrapolation from use under other conditions, and/or logic indicates a certain option would be

successful in preventing or controlling a forest pest. The forest manager may choose to use this unproven control method -- especially if as in many silvicultural control methods, the cost is minimal and the alternatives are undesirable. Here is a recurring situation in which those involved in research testing and extension type pilot testing may effectively and economically cooperate with the forest manager. But all too often the lines of communication are not open or have not been established and an opportunity is missed.

I am sure that there are many other areas in which research-management cooperation would be effective and productive. The challenge to us as forest managers, extension pathologists, research pathologists, and administrators is to support actively and build vigorously such cooperation in a way that will meet our current and future needs.

CONCLUSIONS

Cooperation between research and management has been effective in the past in developing operational dwarf mistletoe control methods. Several recent changes have brought us new opportunities to improve the control of dwarf mistletoe and other pests through increased cooperation between research, extension, and management. They include (1) a change in management goals for controlling pests to reducing losses, 2) increased opportunities in intensive forest management and the silvicultural control of forest pests, and 3) the development of the concepts of pest complexes and integrated pest management.

The current stylized concept of the relationship among research, extension service, and management is inadequate to meet our future needs because it lacks the two-way flow of information, the flexibility, and the long-term closeness that will be required in the future. Instead, the forest managers, extension specialists, and researchers should be encouraged and supported in their long-term cooperative efforts in integrating the control of dwarf mistletoe losses with the control of other pest-caused losses and in the intensive silvicultural management of stands in a variety of stand-site conditions.

REFINEMENT AND QUANTIFICATION OF DATA FOR REGULATING DWARF MISTLETOE POPULATIONS: AN ECOSYSTEMS APPROACH[1/]

Ed F. Wicker[2/]

Abstract: Some examples of existing quantitative data on tree growth reduction resulting from dwarf mistletoe infections are presented and evaluated. The need for accurate and reliable quantitative data is explained. The role of diseases in the plant ecosystem is discussed. Application of principles and concepts of plant ecology to control dwarf mistletoes in the ecosystem is advocated.

INTRODUCTION

Dwarf mistletoes (Arceuthobium spp.) cause some of the most important disease problems confronting managers of coniferous forests of western North America. These pathogens are not new. They are as much a part of our American heritage as the vast coniferous forests themselves. Their effects on our forest resources are viewed as problems to management of these resources because of the demands man has placed on the forests for goods and services. Recent estimates of timber losses attributed to dwarf mistletoes in the Western United States and Alaska exceed 3.3 billion board feet annually.

Despite the prevalence of dwarf mistletoes, many billion board feet of timber has been harvested from the Western United States since the arrival of the first settlers. As this country grows and its population increases, the demands on our forest land for both goods and services will increase proportionately. Simultaneously, the total area of forest land will decrease, giving way to higher priority use such as housing, highways, power line rights-of-way, reservoirs for hydro-electric projects, etc. The challenge is written. If societies are to continue to enjoy the pleasures and comforts of the many goods and services derived from the forest, then we must produce more and more of these amenities on a continuously shrinking forest land base.

While there are several options for meeting this challenge, one of the more viable alternatives is to maintain our forest lands in a state of high productivity. One of the more logical starting points for improving forest land productivity is to capture those losses to diseases such as dwarf mistletoes. Dwarf mistletoes provide a good example because their biology is well understood and their populations are readily amenable to management by several silvicultural practices.

The importance of dwarf mistletoes as pathogens in coniferous forests was demonstrated and recorded in the early part of the twentieth century (Weir 1916a,b). Foresters have been slow to realize the full extent of losses caused by these pests. There are several reasons for this situation. One is the fact that the Western United States was blessed with an abundance of coniferous forests. This is conspicuously evident today as attested by some of the issues and responses concerning accelerated cutting of the "surplus" growing stock on the Federal forest lands reported in "The Resources Planning Act: A Progress Report" (USDA Forest Service 1978). Until this decade, man has been content to occupy himself, primarily, with harvesting of these forests, deferring their perpetuation to the present generation of mankind.

[1/] Presented at Symposium on Dwarf Mistletoe Control through Forest Management, Berkeley, Calif., April 11-13, 1978.

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The second reason we have been slow to deal effectively with dwarf mistletoes is the dearth of quantified data that would enable the land manager to assess damage, determine needs for control, predict growth and yield, and calculate cost-benefit ratios of control operations for dwarf mistletoes. An enormous knowledge of these pests is available in the published literature, as papers already presented at this Symposium will attest. Perusal of this literature reveals that a perponderance of the information is documented in qualitative terminology. Furthermore, it is virtually impossible to transpose this information into quantitative terms because of limitations of time, purpose, and methodology of original data collection. This deficiency of effective quantitative data is especially conspicuous when one attempts to use systems technology such as computers and mathematical models as aids for land management decisions. Let us have a brief look at some examples of the quantitative data of dwarf mistletoe impacts that have been reported. You be the judge of its effectiveness with respect to today's needs.

STATUS OF DWARF MISTLETOE DATA

More than 60 years ago, J. R. Weir investigated many aspects of the dwarf mistletoes in the Pacific Northwest. During a period of some 15 years, he published evidence of the prevalence of these parasites and displayed a recognition for their capacity to damage coniferous forests (Weir 1916a,b; 1918). His many reports warned of the destructive nature of these pests. As early as 1916, Weir was recommending silvicultural measures for control of dwarf mistletoes in the national forests of the Northwest (1916c).

Weir (1916a) published one of the first reports of growth impact of dwarf mistletoes on western larch. Comparing average 10-year radial growth of 29 infected trees with 12 uninfected trees, he reported a 59 percent reduction in lightly infected trees, a 65 percent reduction in moderately infected trees, and a 84 percent reduction in heavily infected trees. The practical significance of these data is lost because of the tremendous age variation among sample trees (30 to 623 years) and Weir's failure to describe his criteria for classifying disease intensity. Another equally serious limitation of these data will be related later in this paper.

In the same year, Weir (1916b) reported on the growth impact of dwarf mistletoes in lodgepole pine, ponderosa pine, western larch, and Douglas-fir. The growth impact data are summarized in table 1.

Hawksworth and Lusher (1956) reported the growth impact of dwarf mistletoe on Douglas-fir in the Southwest. Mortality in all infected Douglas-fir stands was 4 times greater than in uninfected stands. Mortality in infected cutover areas was 4 times greater than in uninfected cutover areas and 2 times greater than in uninfected virgin areas. This loss was directly correlated with dwarf mistletoe intensities.

Unpublished reports by Graham (1956)[3/] revealed a 7-, 24-, and 47-percent diameter growth reduction for light, moderate, and heavily infected western larch, respectively.

Growth impact data from lodgepole pine stands in Colorado and Wyoming (Hawksworth 1958) showed 1.5 times greater gross merchantable volume in uninfected stands as compared to infected stands. Mortality in virgin stands was 1.3 times greater in dwarf mistletoe infection areas than in uninfected areas. Mortality in large poles was 5 times higher in infected stands as compared to dwarf mistletoe free stands.

Pierce (1960) studied the effects of infection intensities on total height and basal area in respect to site, age, and stand density. Although his sampling techniques were inherently deficient, his results are in general agreement with those previously reported.

A major limitation common to all these data is the absence of a uniform and proven system for describing the environmental variation that existed within and between the test data. Weir (1916a) recognized the importance of ecology to the host-parasite relationship. He struggled to compare and explain the differences in the ecological amplitudes of Arceuthobium laricis (Piper) St. John and Larix occidentalis Nutt. It was a struggle because knowledge of plant ecological relationships was not so advanced as it is today and there were no proven systems for the ecological identification and classification of forest communities.

THE ECOSYSTEMS CONCEPT AND THE ROLE OF DISEASES

The individual plant constitutes the basic component of a plant community. Beginning as a sprout, the plant is immediately affected by the actions and interactions of the many fluctuating biotic and abiotic factors of its environment. Each of these factors affect the plant simultaneously. Their individual effects upon the plant are modified and compensated for one another. The composite of their actions and interactions is known as the environmental complex.

[3/] Records on file, Forestry Sciences Laboratory, Moscow, Idaho.

Table 1--Growth reduction of lodgepole pine, ponderosa pine, Douglas-fir, and western larch caused by dwarf mistletoes.

Host	No. trees	Average age class	Growth of infected trees as percentage of that in uninfected trees: Average height	Average d.b.h.	Average total annual growth
Pinus contorta					
Infected	50	65	72.6	80.8	31.7
Uninfected	50	60			
Pinus ponderosa					
Infected	50	100	64.1	82.0	28.9
Uninfected	50	100			
Pseudotsuga menziesii					
Infected	40	97	84.9	77.9	66.3
Uninfected	40	97			
Larix occidentalis					
Infected	80	144	55.0	59.0	59.0
Uninfected	80	144			

Environment is highly heterogeneous, even more so than most of us can conceive. Through eons of development, living systems have exhibited an expanding potential to adapt to environmental variability and change. Plants are no exception. Their accumulated features resulting from adaptation are well documented. Such adaptations result from interactions between the genetic constitution of the plant and natural selection activities of the environment. They may be genetically fixed or environmentally induced. While genes may function as templates for morphologic and physiologic features of living systems, their products are screened by a selective sieve--the environment.

The ecologic amplitude of plants is expansive but not unlimited. The plant has definite tolerance limits for each factor of environment. When variation in any single factor or combination of factors exceeds the tolerance limits of the plant, the plant will lose its competitive position. It will be discriminated against rather than selected by environment. Its vigor and vitality will decline. If this decline is unabated, the plant will become extinct in that environment. Thus, as a plant community develops, there is a continuous, gradual change in its physiognomy as a result of the rigors of environmental selection. We see the resulting community as a product of a multiplicity of interactions encompassing the total heterogeneity of environment and ecologic amplitude of the taxa represented. The plant community influences the environment and the environment influences the plant community. The two are inseparable.

I consider plant diseases as an integral phase of all plant ecosystems. They are actively functional factors of the natural selection process. Diseases constantly and continuously influence patterns of change, development and equilibrium of ecosystems. Simultaneously, every aspect of their behavioral patterns are conditioned by the functional activities of the ecosystem.

Some diseases are nonselective in their actions of altering plant communities while others reflect varying degrees of selectivity. In either case, the action of disease in altering these communities is largely incompatible with man's desires and objectives for managing the plants. Their significance to mankind is based mainly on land use. The conspicuous disadvantages of the unplanned and mainly unpredictable nature of disease actions masks any insidious advantages. Advantages do exist, however.

Effects of diseases upon development of vegetation are highly variable. The magnitude of variation becomes perceptible when one compares enphytotic with epiphytotic disease conditions, diseases caused by exotic versus indigenous agents, or the same disease in different environments. This variability is reflected in floristics, succession, physiognomy, density, dominance, distribution, vitality, and vigor throughout all successional stages, finding its ultimate manifestation in productivity. Indirectly, they strongly influence land use and management decisions.

ECOLOGICAL APPROACH TO MANAGEMENT AND SILVICULTURE

Success in production of goods and services from the forest to meet societies' needs of the future will depend on man's ability to develop and apply management practices that minimize the effects of diseases. To achieve this, we need to re-examine our thinking and expand our knowledge of just what really constitutes a forest. It is more than a stand of trees or a timber type. It is an association of plants that represents the current product of all the interactions of those plants and their environment. It fits the synecologic concept of an ecosystem. We must think in terms of managing entire ecosystems. We cannot succeed if we continue our attempts to manage certain segments, ignore some segments, and eradicate still other segments because the bonds of these segments are interlocking and indissoluble. Management practices to minimize the effects of disease do not exist, for many disease situations. In fact, many current practices optimize rather than minimize the effects of disease. Why do such situations exist? There are two prevalent reasons. Either we do not have the information necessary to develop the practices or we are not applying the information that is available.

In an earlier presentation, we heard silviculture defined as the art and science of culturing forests. The art was described as "flying by the seat of your pants" and the science described as ecology. In the past, we have perpetrated a lot of the former either under the disguise of the latter or the cloak of ignorance. What we need now is a better understanding and application of the latter. To be successful in this endeavor means that we must accept and intentionally project protection of the forest from diseases and other pests as an integral activity of silviculture. This can be accomplished by using the ecosystems concept as our approach to silviculture. This has not been the prevailing concept and attitude of the past and is a major reason why we are forever in trouble with forest tree diseases. Such an approach may be difficult to follow for some geographic areas of western North America because their ecology has been so drastically disturbed by man that their ecosystems have deteriorated beyond recognition. Fortunately, this is not the case in the Northern Rocky Mountains, Pacific Northwest, and Western Canada. Systems for classifying vegetation using synecological principles and concepts have been developed for these areas (Daubenmire and Daubenmire 1968; Pfister and others 1977; Franklin and Dyrness 1969; Krajina 1969) and assure us the opportunity to apply the ecosystems approach to the practice of silviculture.

INVENTORY

In order to properly manage a forest for goods and services, the land manager needs an appraisal of the total array of natural resources encompassed by the forest. This appraisal should be recorded in both qualitative and quantitative terms. The manager needs to know what he has to manage, where it is located, and its condition. I view this as an ecological inventory of the natural resources to be managed; a recording of data that can be accepted as representing the present ecology. Our current inventory systems of gathering information for planning management action do not satisfy the needs of the land manager. This is one of the reasons he is "flying by the seat of his pants." The land manager himself should not be expected to develop the technology and decide what data to collect. This should be done in consultation and cooperation with a research organization that can provide input from persons possessing specialized skills and knowledge of forestry and related sciences. There is no need to collect data that has no utility.

DATA INTERPRETATION AND UTILIZATION

Another task confronting the land manager is understanding data in terms of plant growth and how he can use them to achieve his objectives. After all, data have little meaning and even less utility unless we can understand and explain their origin. Again, this task must be achieved in concert with research. If pest control strategies are required, they should be integrated with resource management activities. It is imperative that land managers and researchers work together on these activities and not independently and in isolation of one another as so often has occurred in the past.

Our ecological and silvicultural knowledge of ecosystems is very meager because of the intricate complexity of such systems. We have managed to collect and record some of the simple, easy, and obvious information of their functioning. As the information becomes more complex, corrections, additions, and continuation of this record will come more slowly and with increasing difficulty. How do we resolve this dilemma?

It has been suggested that we start with improvement and development of automated data processing and management systems that will efficiently handle infinite data entries (Waters 1975). Next, we need to develop the capability to integrate the interlocking fragments of data collected on functional factors of ecosystems. It appears that mathematical models composed of a series of differential equations can provide such capability. Such

models are being developed and tested for the forests of the Rocky Mountains (Meyers and others 1971; Stage 1973, 1975) for growth and yield predictions of goods and services. Models to be used for predictive purposes and subsequent action programs, require exacting, accurate, and reliable, quantified data. Otherwise, they are reduced to just another system of generating guesstimates (Waters 1975). We have too many of these now. With such a requirement, one can readily reason why we are in a dilemma with the dwarf mistletoe impact data available.

In 1975, Intermountain Station's Research Work Unit 2205, Moscow, Idaho, established a study to quantify tree growth reduction in the Northern Rocky Mountain forests resulting from dwarf mistletoe infections. The objectives were to provide quantitative data for a dwarf mistletoe submodel to the prognosis model for stand development (Stage 1973) and to develop dwarf mistletoe growth loss curves. Preliminary analyses of western larch and Douglas-fir data are extremely encouraging for successful achievement of both objectives. It is interesting to note that these analyses show habitat type to be a highly significant variable ($P = 0.01$) affecting height growth. The field work is expected to continue for another 2 to 3 summers until the Northern Rocky Mountain forests are sampled.

Once acceptable automated data processing, management, and modeling systems are available, the forest inventory system must be updated. Inventory must provide the quality and type of data on the ecosystem needed by the land manager to effectively utilize the automated systems for predictive purposes and as aids to land management decisions.

SUMMARY

Continued increase of the population of man is rapidly becoming a burden upon the natural resources that sustain life by providing man with food and shelter. We are being challenged to increase productivity of goods and services derived from forests at an inopportune time when the total forest land base is rapidly shrinking. One way to face this challenge is to recover those losses in productivity due to pests. Pests that cause diseases are an integral part of forest ecosystems. Strategies to regulate the impact of diseases on forest productivity must be integrated with judiciously planned activities of managing the total forest ecosystem, not just a segment. We can no longer afford to operate in a realm of thinking where a forest is merely a group of trees and its pests are a completely separate entity. The efforts and knowledge of the land manager, the pest control specialist, and the research scientist must be coordinated and integrated into a systems approach to forest land management. This will require refinements and improvements in data collection, processing, interpretation, utilization, and application. More important, it will require recognition of and respect for ecological reality. Greater sophistication in automated data processing and mathematical modeling appears promising for enhancing our capability to process, interpret, and integrate the myriad of data needed to manage forest ecosystems as a renewable natural resource.

LITERATURE CITED

Daubenmire, R., and J. B. Daubenmire.
1968. Forest vegetation of eastern Washington and northern Idaho. Wash. Agric. Exp. Stn. Tech. Bull. 60, 104 p.

Franklin, J. F., and C. T. Dyrness.
1969. Vegetation of Oregon and Washington. USDA For. Serv. Res. Pap. PNW-80, 216 p. Pacific Northwest Forest and Range Exp. Stn., Portland, Oreg.

Hawksworth, F. G.
1958. Survey of lodgepole pine dwarfmistletoe on the Roosevelt, Medicine Bow, and Bighorn National Forests. USDA For. Serv., Rocky Mountain For. and Range Exp. Stn., Stn. Pap. 35, 13 p. Ft. Collins, Colo.

Hawksworth, F. G., and A. A. Lusher.
1956. Dwarfmistletoe survey and control on the Mescalero-Apache Reservation, New Mexico. J. For. 54:384-390.

Krajina, V. J.
1969. Ecology of forest trees in British Columbia. Ecol. West. North Am. 2:1-147.

Meyers, C. A., F. G. Hawksworth, and J. L. Stewart.
1971. Simulating yields of managed, dwarf mistletoe-infected lodgepole pine stands. USDA For. Serv. Res. Pap. RM-72, 15 p. Rocky Mountain Forest and Range Exp. Stn., Fort Collins, Colo.

Pfister, R. D., B. L. Kovalchik, S. F. Arno, and R. C. Presby.
1977. Forest habitat types of Montana. USDA For. Serv. Gen. Tech. Rep. INT-34, 174 p. Intermountain Forest and Range Exp. Stn., Ogden, Utah.

Pierce, W. R.
1960. Dwarf mistletoe and its effect upon the larch and Douglas-fir of western Montana. Mont. State Sch. For. Bull. 10, 38 p.

Stage, A. R.
1973. Prognosis model for stand development. USDA For. Serv. Res. Pap. INT-137, 32 p. Intermountin Forest and Range Exp. Stn., Ogden, Utah.

Stage, A. R.
1975. Prediction of height increment for models of forest growth. USDA For. Serv. Res. Pap. INT-164, 20 p. Intermountain Forest and Range Exp. Stn., Ogden, Utah.

Waters, W. E.
1975. Forest pest management: present prospectives and a look ahead. In Proc. Joint Meetings 26th WFIWC and 22nd WIFDWC, Monterey, Calif., p. 11-14.

USDA Forest Service.
1978. The Resources Planning Act: A Program Report. USDA For. Serv., 52 p.

Weir, J. R.
1916a. Larch mistletoe: some economic considerations of its injurious effects. U.S. Dep. Agric. Bull. 317, 25 p.

Weir, J. R.
1916b. Mistletoe injury to conifers in the Northwest. U.S. Dep. Agric. Bull. 360, 39 p.

Weir, J. R.
1916c. Some suggestions on the control of mistletoe in the National Forests of the Northwest. For. Quar. 14:567-577.

Weir, J. R.
1918. Effects of mistletoe on young conifers. J. Agric. Res. 12:715-718.

IMPROVING EXTENSION AND TRAINING PROGRAMS

FOR

DWARF MISTLETOE CONTROL[1/]

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Abstract: Integration of dwarf mistletoe control into forestry planning and operational activities is stressed. A survey indicated that managers are concerned about disease control. Their needs are identified with regard to dwarf mistletoe control. Suggestions on conducting training sessions include hints on good slide or slide-tape and graphic preparations. Guides for smooth field trips (take a bus,not 40 cars), oral presentations (what to do about jitters) and written material (quick reading comprehension test) are presented. Field aid preparation, timber sale clauses to reduce dwarf mistletoe and a sample sanitation-thinning contract are also included.

A major problem facing pathologists regarding dwarf mistletoe control is that they are so few in proportion to the millions of problem acres. Approximately 60 field pathologists must devise all manner of ways to spread themselves thinner in order to train the greatest number of forest managers in control methodology.

There are a variety of ways to put this message across. But, no matter what, the approach must be interesting, straight forward and well presented. Fast moving slide presentations at staff meetings or special workshops combined with field trips; written, illustrated guides; demonstration plots in regional areas and pocket field aids are all effective methods. Group size might range from this symposium to "one on one."

Perhaps the best thing about dwarf mistletoe control is that it can be programmed into any existing timber management system without a great deal of expense in either training or operations. In these days of the rapid move to intensive forest management, reduction of dwarf mistletoe is (for certain stands) as good a means to increase production as fertilization or thinning. The parasite reduces growth while thinning and fertilization increase it. Wouldn't dwarf mistletoe removal give similar overall increased growth?

Dwarf mistletoe has several characteristics which aid in developing positive control attitudes. It is a highly visible parasite, not a mysterious underground root disease. It has large visible seeds traveling known distances, not microscopic spores traveling on the whims of the wind. It spreads slowly (except for bird or animal spread), not rapidly or over wide distances like the seemingly hopeless blister rust. It can be controlled silviculturally. All aspects of the disease can easily be understood by a layman.

Effective training is a prerequisite for stimulating good dwarf mistletoe control attitudes regardless of owner. Such attitudes do not develop overnight. Sometimes it takes years to thoroughly infiltrate bastions of resistance within a management team. The old guard is naturally skeptical at first. It's a sales job! The training group must culture "disciples" in the field, who, upon becoming dedicated "DM control nuts" serve to "infect" their cohorts. They in turn spread the word to bosses, underlings and peers alike.

I have gone away from the complete "everything you wanted to know about all diseases" discussions. I now use highly animated, rapidly moving staff presentations, covering only one or two diseases or disease

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1/ Presented at the Symposium on Dwarf Mistletoe Control Through Forest Management, Berkeley, Calif., April 11-13, 1978.

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control aspects. I believe it is better to saturate smaller groups with less material, more intensively presented. Normal district or management staffs of 10-20 persons are ideal. I like to come back to the same staff many times with different material. Over time, the trainees become interested authorities.

INTEGRATING CONTROL

All dwarf mistletoe control training must be integrated with other forest management activities. The overriding philosophy must be well in hand first. The manager must ask, "Can I eradicate it?" (evenage management, clearcut), or "Should I reduce it to a level that allows good volume production?" (unevenage management, sanitation-thinning).

The two following examples illustrate how integration of planning and control operations might work:

It is important to note that dwarf mistletoe is not compatible with two-storied or multistoried stand management. In unevenage management, the primary objective should be to control dwarf mistletoe in the infected overstory. Therefore, timber sales should be planned with this objective in mind. Sanitation of the understory follows. The order should not be reversed.

Where recreation and forest management objectives conflict, modification of control principles often must be made to satisfy both uses. In south-central Washington, the Department of Natural Resources retained a narrow corridor of infected old growth ponderosa pine leading to a scenic canyon. The forest surrounding the corridor was marked for overstory removal to reduce the dwarf mistletoe. The corridor and horse trail down its center lead to a scenic outlook. Future recreationists will appreciate the retained trees which could be pruned if necessary. Impact to timber management will be minimal.

Mindful of varying objectives, the manager must be trained to fit dwarf mistletoe control into context and even use it to advantage. For instance, he might reason as follows: "Can I use some of that infected overstory to regenerate the stand?" How soon must I remove the overstory to avoid infecting the regeneration?" The manager might also ask, "How can I 'dwarf mistletoe proof' this stand? Will periodic prescribed fire help me?" I believe it will, but it must be done at the right time under proper conditions. Once the manager is trained to ask the right questions, the control success will come naturally. Realistically, this manner of thinking does not develop overnight.

Forestry schools have traditionally taught forest entomology, pathology and fire courses separately from silviculture. Except in rare instances foresters are left to their own devices to merge these subjects to provide answers for complex management decisions. Not all foresters do it. Not even all foresters take the courses mentioned above. Minimizing one pest might encourage another. It's like trying to submerge 100 ping pong balls in the bathtub simultaneously. There is need for a single integrated course, perhaps utilizing team teaching, that brings elements of silviculture together with entomology, pathology, fire and even ecology into a totally integrated approach. My bet is that students would find it fascinating. This same approach would also make a challenging and interesting regional symposium.

WHAT DOES THE MANAGER WANT?

Audience

It is important to know your audience. How much do they know? What do they need? What do they want? What is their background? How many will receive the training? Your approach and intensity will vary with the audience. Tailor the material to the group; for example, do not talk about details of larch mistletoe to coastal Oregon foresters. View every meeting with a forester as a training opportunity. Ask participants beforehand what they want.

The Pacific Northwest Forest Pest Action Council (Russell, Howard, Weir, Johnson and Nelson, 1975) conducted a survey to help determine priorities of forest diseases in the Pacific Northwest. Comprehensive questionnaires were sent to the region's forest managers asking them to assign priorities to forest disease groups. A section of the resulting booklet was devoted to miscellaneous written comments returned with the questionnaire. A few of these with slight edit to emphasize dwarf mistletoe control are worth repeating here.

"The majority of forest disease research publications and surveys I read are informative but do not help me in my day to day silvicultural decisions."

"Literature reviews and experimental designs are great but not for busy field

foresters. Tell me briefly what you did and how it applies to management."

"Write in plain, simple English!"

"Provide a clearing house for information."

"What is the impact of dwarf mistletoe on allowable cut calculations?"

"We need simplified economic justifications for dwarf mistletoe control."

"Make sure the material provided pertains to solutions for the man on the ground."

"How can we handle dwarf mistletoe in shelterwoods?"

The above statements clearly indicate the vein of content needed for dwarf mistletoe control training.

PREPARING THE TRAINING SESSION

Material

Know your stuff inside out. Include interesting biology if it ties in with management. Have access to all mistletoe literature. Know who the experts are and consult them--have them review material. Update as required. Consult texts on making presentations.

Coordinate training with other area pathologists so everyone gives essentially the same message. Schedule training to avoid conflicts with foresters' crunches like planting and fire seasons. Evaluate the success of any training effort to identify areas needing improvement.

When foresters come to a training session, they want something to take home. Make the subject matter apply to specific aspects of their jobs. Above all, provide useable information that can be taken home.

This is why I prefer the repeat appearance covering different disease groups each time. I learn more about the problems managers are having this way. I begin to get a feeling for their needs. I also learn about conflicts with controlling groups (other Divisions) that may suppress (not necessarily intentionally) what I'm saying. These types of sessions allow the pathologist and clientele to form a better two-way avenue for exchange.

One failing (I'm guilty too!) is not allowing time for adequate discussion. There have been times when meaningful discussions were twice as long as the presentations. It wasn't planned that way.

Slides

A variety of visual aid equipment is available. Unfortunately, instructors don't always use aids to full advantage or quality. Well prepared slides are most effective and hard to beat. Seek and use professional advice in making slides. There is no quicker way to lose a group than to say "Sorry you can't make this out back there . . . ." If a slide cannot be easily read at normal reading distance of 12-14 inches, then the print is too small. Toss it! Commercial artists are a big help if you are short on artistic ability. There are several excellent publications on preparing slide presentations. Consider multiple projectors for larger audience talks.

Always ask these questions during preparation of your presentation. "Is there too much detail on one slide? Did I cover only one point at a time? Can I use a series of slides adding one point at a time to build a story?" Move on rapidly (only a few seconds per slide). If you keep points simple, the listener takes more home and retains it longer. Weyerhaeuser Company's professionally prepared graphic slides are excellent examples to follow. Their high quality is known and appreciated all over the Northwest.

If you are short a critical title or data slide and the talk is tomorrow morning, try this! Type the words or data needed on an A. B. Dick stencil or a sheet of onion skin. Cut the paper or stencil to fit a slide blank. Press it in with a warm iron. The stencil gives a white letter with a neat fibrous blue background. The onion skin gives a black letter with gray background. The same could also be done using a copy machine to produce a transparency (similar to one for overhead projection). Black letters with clear background result, or, if colored plastic is inserted in the slide holder, any background color could be obtained.

There are advantages in using this method; the letters are very large, the process is quick (minutes) and the small slide with regular typing limits copy to a single word or a few words or numbers.

Slide-tapes

An advantage of the slide-tape is that they can be viewed at any convenient time. Often, the persons who really wanted to hear the presentation were probably out hustling logs when it was given. Upon return, they can retire to a dark room and digest the material. The program can be stopped, studied or repeated.

The average slide-tape show is appropriately geared to the 80 or 100 tray Kodak Carousel. Use of the 140 slide tray is not recommended for any large group presentation. The least little "dog ear" on a slide may cause it to hang up - an embarrassing situation. A full tray or less is recommended per single program with a tape. A full tray of fast moving slides can be utilized in a 12-14 minute presentation. Anyone can operate the equipment. All that is needed is the projector, a good quality cassette tape recorder (such as a portable Bell and Howell educator model) and a listener. The high quality portable recorder can be used in a large room for as many as 50 people. The $29.95 "special" recorder is definitely not recommended for this job. More sophisticated equipment is also available.

Consider the possibilities of background music and a professional narrator. Most organizations have access to both. Slide-tapes are easy to produce. They have a definite value in effective training.

One of the best slide-tape programs available is Rx for Wounded Trees (Shigo, 1976). It tells the story in 80 concise, well designed and illustrated slides. Anyone can understand it. It has music and was professionally narrated. It could be used as a guide for a slide-tape on dwarf mistletoe.

There is one pitfall that can occur during production of a program. There seems to be a point during its production when it is "just right." Learn to look for and sense arrival of this point. I have seen examples of a fine program or film ruined by tampering because the author wanted to "improve" it. There is quality in simplicity.

Field Trips

Have them well planned. Confusion on a field trip or lost people causes chaos and dissention. Pick sites carefully before the session. Group stops to avoid long travel. Use a bus instead of 40 cars. Use signs to describe the attractions; e.g., This is larch dwarf mistletoe. Make walking easy; remove the brush. Use research plots where applicable. Establish demonstration plots complete with signs. Allow plenty of time. Provide written descriptions of problem viewed.

MAKING THE ORAL PRESENTATION

Audience

Do not talk down to the audience. Join right in at their level and use vocabulary they will understand. Humor, cleverly worked in is good but don't overdo it. Dress neatly but don't come on like a dandy. Have the best person do the training. Put the green employee in the audience to learn. Do not worry about saying, "I'm sorry. I don't know, but I'll try to find out." Invite someone who is a good stimulator of discussion.

Involve the audience in the learning process. Ask them questions. Even let the audience do some of the teaching by asking them leading questions. This method is very successful but takes practice. Be dynamic but not high pressure or overbearing.

Equipment

Know your equipment. Slides backwards? Can you change a bulb? In the dark? Where is the light switch? Can you fix a jammed Carousel? (Use a coin to turn the release screw in the center, lift the tray off, extract the offending slide, turn the tray upside down and rotate the metal plate until it clicks back into place. Reinstall tray.)

Meeting Room

Become familiar with it. Are there obstructions or other peculiarities? Start with it cool and plenty of fresh air. Each human gives off approximately 100 watts of heat. One hundred people will heat the room several degrees before you are through. Sense your audience's mood. If they are overly relaxed maybe you should take a break or at least a quick stand-up breather. Also take this opportunity to refresh the air in the room.

Jitters

Relax and plan on them. They help you give a good presentation. Everyone has butterflies - even politicians and actors. They come in a variety of ways and timing. Fear of failure helps make a good talk. You have one thing going for you. Outward signs of stage

fright are hard if not impossible to detect. Your knees can be knocking so hard you can hear them. No one else will know! If you faint dead away though, heaven help you! When you're up there all alone with bright lights and facing that formidable audience, the shakes almost always disappear.

PREPARING WRITTEN MATERIAL

Written material for schedule bound forest managers must be short. Avoid extraneous detail. Scientific writing "turns'em off." It doesn't hurt to begin a written guide with a few topic sentences detailing the contents. No jargon, complex sentences or long dull paragraphs allowed. Did you ever face a one page single spaced letter consisting of one paragraph? Ugh! Get a frank and extensive review of your production before putting it out.

I once heard a writing consultant who advised two simple criteria for judging readability. He counted average sentence and paragraph length in professionally prepared articles. Sentences should average 13 words and paragraphs should be no longer than 9 lines for easy reading comprehension. He further advised that this pattern is ideal for 8th grade readers. Now I don't wish to insult managers and scientists alike, but using this approach makes the reading faster and more comprehensive. Anyway, I liked his advice. There are more complex methods available to judge readability, but the system described here is simple. Try it!

I counted 18 consecutive sentences in this report and found my sentence length averages 15.6 words. Shooting for 13 and allowing for extra wind brings the average up, and my readability level increases a bit. Try digesting an article that averages 26 words per sentence. Your head will swim! Maybe you've even written a few. Count the average words per sentence in one of your insurance policies.

How about using the newspaper column pattern? The human eye reads best in short bursts across a page. Newspaper columns are about 2.5 inches wide, the distance for optimum eye movement and smooth reading. Secretaries can type double columns quite easily on standard size paper.

How attractive is the written material? Pictures help and today's copy and multilithing ease make the use of pictures a simple process. Consider including color or using professional illustrations. For written material to be produced in limited numbers, try color copying machines. Their quality is amazingly good and cost is relatively low compared to color printing processes.

Will the forester who is worried about ordering parts for a broken bulldozer read your production while waiting for the busy phone line? If so, it is probably worth reading. Spending time doing professional eye-pleasing layout is well worth the effort. Do not be afraid to spend money on your effort; it can pay big dividends.

Provide interesting reading laced with a few unusually put but easy to remember biological facts about dwarf mistletoe (below). Excerpts taken from training material on hemlock dwarf mistletoe control show an attempt to do this (Russell, 1976). Note short sentences, paragraphs and simple easy to remember facts (60 MPH, 40 feet of the plant, 10 well dispersed infested trees).

"The mechanism of seed firing is one of the most interesting in the plant kingdom. It resembles NASA technology. As the wheat grain sized berry or capsule matures, the stem curves downward and elongates. The capsule orients to the brightest light with point down. The special viscin (a glue-like substance) filled cells between embryo and capsule become primed with pressure. At the moment of blast-off the capsule falls away and the single viscin coated 2-3 mm long seed propelled by highly pressurized viscin and water 'fuel' ejects from the attached end of the capsule. It arcs away into the sunlight trailing a 'contrail' of glue and water. 'All the other seeds cheer.' Night firings are conducted also, but at a much reduced number."

and further on . . . . .

"Most seeds fall within 40 feet of the plant. Maximum seed distance is about 60 feet. Wind can affect seed distribution. Smith showed that almost 70 percent of the seeds were trapped in the southern sector. Density of the stand and the branches of the host tree influence distance shot. 'Muzzle velocity' of these unique seeds is about 90 feet per second, or roughly 60 MPH. Seed bearing plants tend to orient as much as possible to brightest light source. On warm fall days, low sun offers optimum firing angle. A study of seed germination and infection found that 18 percent of A. tsugense seeds that were tagged in the spring caused infection. This did not account for those lost during the winter."

"A single western hemlock overstory tree

is capable of dispersing seeds over about 6000 square feet. This means that fewer than 10 well dispersed infected trees per acre could potentially infect all new or existing regeneration."

Forest Management Manuals

The Washington State Department of Natural Resources Manual contains sections on dwarf mistletoe control. Since western hemlock dwarf mistletoe Arceuthobium tsugense occurs only west of the Cascades, it has a separate section of the manual. It stresses simply, clean clearcuts. (The commonly used skyline, balloon or helicopter systems do not destroy advance regeneration and special treatment may be necessary to reduce the parasite.)

Manual guides for eastern Cascades dwarf mistletoe control are treated separately because management there is generally uneven age. Instructions for marking timber sales are contained on only two pages. The guide for treating young stands after infected overstories have been removed is not completed but will be equally short.

Field Aids

The WDNR maintains a set of field aids for all district personnel. They provide a condensed manual prepared on waterproof paper in a vest pocket size notebook. They make use of tables and line drawings to get the point across. Two or three pages of these will be prepared for various aspects of dwarf mistletoe control. Only limited biological detail will be given as this information is available in manual references. Field personnel like these quick self helps.

A wallet card is also used by WDNR that is patterned after one prepared in the Southwest by the Forest Service. It is intended for use by pre-commercial thinning operators.

Rules for spacing crop trees and rating infected cut trees are indicated. It is important that simplicity be uppermost in preparing any of these types of field aids. Some of the operators are barely literate.

One of the main reasons for the wallet card is that the unit administrator and the operator can discuss "leave or cut" tree criteria using concrete guides. There is little or no argument between a trained forester and the operator about whether an infected tree should be cut. The simple rules will tell them. Ambiguity is removed.

Contracts

In a way, timber sale contract preparation functions as a training help. The WDNR contracts are made up using a series of carefully prepared clauses that, when assembled, describe the contract. The manager using his guide merely lists the clause numbers desired. One such clause is shown below. It can be used for a variety of purposes including dwarf mistletoe control.

Non-merchantable Trees

"Within areas to be clearcut, all live trees (over ___ft. in height or over ___inches in diameter), excepting such areas of young or immature timber specifically designated by the State, shall be felled concurrently with the logging operation."

Instructions--"To be used when broadcast burns of clear cut areas are planned and it is desired to have all of the non-merchantable trees felled to accomplish a more complete burn. Also for the felling of undesirable or diseased residuals to be disposed of prior to site rehabilitation. The cost of this work must be provided for in the appraisal."

Contract description and instructions for a typical non-commercial thinning--dwarf mistletoe sanitation unit follow:

District

Omak Unit: 15-9

Name of Thinning

Irene Mountain

Contract Supervisor's Representative

Joe Bnox

Approximately 91 net acres in Section 16, Township 38 North, Range 31 East, W. M., require treatment. Douglas-fir, ponderosa pine, western larch and lodgepole pine species are on this unit. The unit boundary is well defined with fence and ribbon on the north, ribbon on the east, fence and ribbon on the south and ribbon on the west. The unit topography is level to 50 percent slope. Unit has year-round

access. Approximately 475 stems per acre are on this unit, and approximately 305 stems per acre will be mechanically treated to maintain an average of 170 trees per acre at 16 x 16 foot spacing. The average d.b.h. of the trees to be mechanically treated is 3 inches. Dwarf mistletoe is to be removed as described in the following instructions.

Period of Contract

This contract shall terminate June 15, 1978.

Buffer Zone

All slash within 100 feet of the county road and within 50 feet of all other truck roads shall be piled. Piles will be placed so that they can be burned with the least possible damage to standing trees and young growth.

Leave Tree Specifications

Areas Or Tree Groups Free of Mistletoe Infection--All conifer trees larger than 6 inches d.b.h. are designated as crop trees and are to remain.

Crop or leave trees in addition to those designated by size, are to be selected by Contractor at 16 x 16 foot spacing.

In any area more than double the spacing across that does not have a crop tree identified by size, Contractor shall select and leave uncut the largest live conifer trees of good form and vigor that will maintain average specified spacing.

Areas Or Tree Groups Having Mistletoe Infection--All uninfected conifers larger than 6 inches d.b.h. are designated as crop trees and will remain.

Uninfected conifers smaller than 6 inches d.b.h. designated as crop trees are to be spaced at 16 x 16 foot intervals.

Spacing is waived whenever dwarf mistletoe is encountered. Acceptable crop trees are selected by priority as follows:

Priority 1. Free from visible infection.

Priority 2. Hawksworth infection rating maximums allowed by diameter class.

d.b.h. Class (in.)	Maximum Hawksworth Infection Rating Allowed
1 - 2	0
3 - 4	1
5 - 6	2
7 +	3

Trees To Be Removed

Except for crop or leave trees as specified above, mechanically treat the following:

All surplus conifer trees more than 4 feet tall.

All hardwoods within 20 feet of a conifer crop tree.

Trees of poor form and vigor.

All porcupine damaged trees.

All lodgepole pine.

All trees with dwarf mistletoe infection according to the infection rating-diameter class table.

All trees with dwarf mistletoe trunk infection.

Miscellaneous Instructions

Trees of nearly equal height and diameter in the unit will be ranked in priority or value by species as follows: Douglas-fir, western larch and ponderosa pine.

Trees will be cut below lowest live limb and not more than 12 inches above the ground. The trees cut must be on the ground and not "hung up" or leaning against a crop tree. All trees must be cut completely free of stump.

If snow depth exceeds 12 inches, trees will be cut below the lowest live limb and not more than 18 inches above the ground.

All damage to fences resulting from operations on this contract will be repaired immediately. All trees adjacent to fence shall be felled away from fence and all slash falling on fence shall be removed.

CONCLUSION

Dwarf mistletoe control is a proven forest management activity. The parasite need not

be a problem to future forests. Training is uncomplicated and treatment is no more costly than any other activity. Contact your state or federal pest specialists for further training. Training is available for private landowners and industrial, state or federal foresters alike.

LITERATURE CITED

Russell, K. W.
1976. Operational aspects of disease control: Dwarf mistletoe. Proc. Hemlock Symposium., University of Washington, Union, Wash.

Russell, K. W., B. Howard; L. C. Weir; D. W. Johnson, and E. E. Nelson.
1975. Forest Disease Priorities in the Pacific Northwest. Special Bulletin. Pacific Northwest Forest Pest Action Council. Portland, Oreg., 15 p.

Shigo, A. L.
1976. Rx for wounded trees. Slide-tape with written text. USDA Forest Serv. Northeastern Forest Experiment Station. Upper Darby, Pa.

BIOLOGICAL AND CHEMICAL CONTROL OF DWARF MISTLETOE[1/]

Donald M. Knutson[2/]

Abstract: Biological and chemical control agents for control of dwarf mistletoe could likely be developed if we elected to develop them. Current attitudes, however, marshal against adequate study of such widespread and virulent fungal parasites as *Cylindrocarpon gillii* and *Colletotrichum gloeosporioides*.

Key words: *Wallrothiella arceuthobii*, *Colletotrichum gloeosporioides*, *Cylindrocarpon gillii*, dwarf mistletoe, biological control, chemical control.

INTRODUCTION

Forest managers and forest pathologists have long discussed the idea of controlling the dwarf mistletoes with living organisms and with chemicals that can be applied to infected trees and which selectively kill the dwarf mistletoe. After many years, however, we do not have effective chemical poisons nor have we harnessed natural enemies--such as fungi or insects--to use in those situations when silvicultural control isn't effective or appropriate. Why is this so? Is it because dwarf mistletoe has no natural enemies? Is it because these organisms can't be manipulated to our advantage? Is it because the vast North American chemical industry can't develop a selective mistletoe poison?

I would now like to examine biological and chemical control of dwarf mistletoe in more detail. I hope to convince you that the current absence of chemical and biological control agents is more the result of our attitudes than the lack of appropriate organisms or chemicals.

The basic attitude has been that forests are low-value crops and that we cannot afford special treatments, such as flying over an area and spraying spores. Since we can't afford to use them, why bother developing them? We are better off using our talents to refine normal management practices such as harvesting and thinning as a means of disease reduction. This attitude still prevails, effectively preventing the development of alternative control systems. And, since we have no alternative control schemes, of course there is no way to reduce the cost of these systems. Thus they can never be economically feasible. Neither are they available in situations where cost is not a primary consideration (parks, campgrounds). Another basic attitude on biological control is that if it really worked, dwarf mistletoe wouldn't be a problem, although many report that insects and fungal parasites of mistletoe can be locally damaging. These are the basic attitudes that keep impractical ideas from becoming practical ones.

BIOLOGICAL CONTROL

Let's talk about biological control first. Like other indigenous plants, the dwarf mistletoes have a number of organisms that do them damage--most are fungi and insects. Some are casual parasites, but many appear to have no other host.

It is probably safe to say that more than half of them are yet to be described. Someday, perhaps we will be able to knowledgeably discuss virus and mycoplasma parasites of the dwarf mistletoes.

The first dwarf mistletoe parasite was reported from New York State (Peck 1875). This was a fungus, *Wallrothiella arceuthobii* (Peck) Sacc. This ascomycete has since been reported throughout much of Canada, the Western United States and Northern Mexico.

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It parasitizes female fruits of the spring flowering dwarf mistletoes--those on Douglas-fir and lodgepole pine in the West and jack pine and black spruce in the East.

Early forest pathologists were basically mycologists with a strong conviction that we cannot manipulate plant systems unless we understand them well. Thus they concentrated their efforts on the biology and classification of organisms. They were, however, very aware of the potential value of manipulating these organisms for human benefits.

In 1915, when speaking of *Wallrothiella* in the Idaho-Montana forest region, James Weir said, "It is found to be so abundant as to have some economic significance." Eleanor Dowding said much the same about this fungus on lodgepole pine mistletoe in Alberta in 1929; "...Its presence is probably of considerable importance in limiting the spread of *Arceuthobium*."

They went on to do some very good work on the biology and epidemiology of this fungus, but no attempts were made to use the fungus for biological control.

Lake Gill, another leader in the field of forest pathology, discovered (in 1932) a white fungus attacking dwarf mistletoe aerial shoots. In his 1935 publication he said it was "apparently responsible for the premature death of large numbers of [mistletoe] shoots in that area."

This fungus, now called *Cylindrocarpon gillii* (Ellis) J. A. Muir, was found by Gill on the dwarf mistletoes of western hemlock, true fir, western spruce and Mexican white pine, *Pinus strobiformis* (Gill 1935). The list of dwarf mistletoes parasitized by this fungus was expanded by Ellis (1939, 1946) to include those of Douglas-fir, piñon pine, ponderosa pine, sugar pine, limber pine and Digger pine. Later Gill (1952) reported this fungus on lodgepole pine dwarf mistletoe from Montana where the dwarf mistletoe "suffered heavy mortality." Wicker and Shaw (1968) added western larch dwarf mistletoe to the list.

The fungus has been reported from the States of Arizona, California, Montana, New Mexico, Oregon, Utah, Washington, Wyoming, and from the provinces of British Columbia, Alberta, and Saskatchewan (Kuijt 1960-61). A recent paper details the distribution of *Wallrothiella* along with *Cylindrocarpon* and *Colletotrichum*, the three major fungal parasites of the dwarf mistletoes (Hawksworth et al. 1977).

Certainly a fungus attacking so many dwarf mistletoes, often severely, over such a vast region deserves our professional attention. So let's focus on this fungus as our object-organism, follow it through the years since it was described, and see why it's still in the scientific journals instead of in the land manager's tool kit.

After noting the severity of the fungus and after sketching in the general geographic range, Ellis took the correct next step: he did a comprehensive study of the biology of this fungus (Ellis 1946), making the following main points:

1. It is found on dwarf mistletoe on 29 tree species.

2. Female plants are more frequently infected than are male plants.

3. Both immature and mature dwarf mistletoe plants are attacked.

4. It is a cool weather disease, growing slowly at 5°C, best at 17°C, and not at all at 22°C.

5. Of some 1,100 inoculated dwarf mistletoe shoots, 27 percent (range 0-90 percent) became infected. Most tests were on Douglas-fir dwarf mistletoe, but he also inoculated dwarf mistletoes on several pines in the Southwest.

He concluded by saying, "It is quite evident that *Septogloeum gillii* (now *Cylindrocarpon*) is responsible for considerable control of dwarf mistletoe under natural conditions, but further studies will be necessary to determine whether or not its introduction into new areas for purposes of biological control would be practical."

Thirteen years elapsed until Mielke (1959) published results of a study he did on establishing *Cylindrocarpon* in new areas. It didn't work well, but for understandable reasons.

Mielke collected spores on the Kaibab plateau in July from infected piñon pine and did his experiments 2 weeks later on the Cache National Forest in northern Utah and the Targhee National Forest in eastern Idaho, inoculating infected lodgepole pine. He did establish the fungus in 42 of 50 inoculated trees. It maintained its presence for 3 years and then died out. We have learned that moving plants too far from their place of origin often yields questionable and erratic results. Also, using spores from piñon pine mistletoe and

inoculating lodgepole pine dwarf mistletoe is somewhat chancey. In culture dishes, *Cylindrocarpon's* growth is distinct enough so that we can tell the dwarf mistletoe host by the characteristics of the fungus colony. I would expect some host specificity in the forest also. In any case, it is exactly at this point in the drama that pathologists should become interested in asking--and answering--some sound pathology questions.

- What is the host specificity and pathogenicity of these isolates?
- Are spores not being produced?
- Are the spores not germinating?
- Is the dew-period too short, or temperatures too cold for the germ tube to grow and penetrate?

These, and other questions, would help establish the factors limiting the success of the organisms. Conversely, what characterized areas where this fungus is causing severe infection?

Both Gill (1952) and Mielke (1959) suggest that wet weather promotes growth and spread of *Cylindrocarpon*; however, the optimum dew-period, moisture drop size, etc. have not been established. Wet weather alone is not sufficient to cause epidemic levels of *Cylindrocarpon*. Marys Peak in the Oregon Coast forest is very wet for a large portion of the year, yet *Cylindrocarpon* is not found on every hemlock dwarf mistletoe plant. It is possible that insufficient moisture occurs at the time the temperature is warm enough for maximum spore production. Again, this is easy to determine. The Marys Peak hemlock dwarf mistletoe infestation is not a vigorous epidemic. *Cylindrocarpon* and a resin disease are both contributing to the debilitation of the mistletoe. There are probably other undiscovered influences.

A third very important fungal parasite of the dwarf mistletoes is *Colletotrichum gloeosporioides* Penz. This was first reported by Parmeter et al. (1959) from California. Current known range includes all Western States except Nevada and Wyoming (Hawksworth et al. 1977). It has been studied in the lab and in the forest and possesses characteristics that make it a promising biological control agent. Spores are easily produced, and these germinate over a wide range of temperatures. Disease development is rapid (2-3 weeks) and the damage severe (Parmeter et al. 1959).

These three fungi are well respected, but currently unemployed. I hope current interest in biological control (Baker and Cook 1974) coupled with the development of techniques for determining how safe these organisms are (Wapshere 1974) will help make biological control more attractive in forest management.

CHEMICAL CONTROL

Of 95 references in the mistletoe FAMULUS[3/] reference file on chemical control, 28 mention dwarf mistletoe. Of these 28, 14 are anonymous references to interim reports, annual summaries of activities, and other non-technical outlets. There has been a strong interest in chemicals by persons concerned with the dwarf mistletoe problem who felt the need for alternatives to silvicultural control. This interest and concern began to surface in the reports of spraying results that first appeared in the early 1950's and continued at the rate of about one report per year for a decade. Most compounds tested were commercially available herbicides.

Results were largely negative and persistently erratic, prompting Harold Offord (1960) to state, "Of the many compounds and formulations so far tested on dwarf mistletoes, none has looked very exciting." The following year Shea (1961) said,"We urgently need development of promising chemicals that will permit selective absorption and translocation in the parasite and host plant."

Clarence Quick (1964) published a summary of 246 tests on 2,516 trees of Jeffrey, ponderosa and sugar pine in California. He optimistically concluded his report saying, "When all established tests have matured, it is believed that a safe, reasonably effective direct chemical control of dwarf mistletoe on pines can be defined." It has been 14 years since Quick's report; and many attempts later, we must conclude that the development of an effective, selective chemical poison for dwarf mistletoe is still in the early stages. Like Edison and his light bulb, we know a lot of things that don't work! And there are some slim leads. Greenham and Leonard (1965) discovered an amino acid, hydroxyproline, in true fir dwarf mistletoe, but not in the host tree. They propose that analogs of this amino acid might be used for mistletoe control: "How toxic analogs would be to plants containing free hydroxyproline is not known at present.

3/ On file at Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

So many factors are involved in selective toxicity that the effectiveness of a potential selective herbicide can be gauged only by direct experimentation. The above investigation has given leads worthy of further attention." These leads have not been followed up.

Leonard and Hull have also published several comprehensive papers on translocation, nutrition, and photosynthesis of dwarf mistletoes (Leonard and Hull 1965; Hull and Leonard 1964). Among other important papers, one is on translocation (Rediske and Shea 1961) and two on water relations of dwarf mistletoe (Mark and Reid 1971; Fisher 1975). Work at Portland State University, Oregon, on dwarf mistletoe photosynthesis and respiration (Miller and Tocher 1975; Gustafson and Tocher, personal communication), dwarf mistletoe hormones (Paquet and Tinnin, personal communication), and aspects of dwarf mistletoe stomates and phloem tissue (Calvin, personal communication) is helping to provide ground work for understanding some of the main aspects of the problem of chemical control of dwarf mistletoe, namely:

1. Moving the poison throughout the tree.

2. Moving the poison to the infections.

3. Moving a poison from the tree tissue into the mistletoe tissue.

Of these, number 3 is the most important. If efforts here are successful, aspects 1 and 2 will be relatively easy.

In summary, biological and chemical control agents are not now operational options available to managers. Nor will they be in the future unless we convince ourselves that we truly need control methods other than the chain saw.

LITERATURE CITED

Baker, K. F. and R. J. Cook.
1974. Biological control of plant pathogens. W. H. Freeman and Co., San Francisco. 433 p.

Dowding, E. S.
1929. The vegetation of Alberta. III. The Sandhill areas of central Alberta with particular reference to the ecology of *Arceuthobium americanum* Nutt. J. Ecol. 17:82-105.

Ellis, D. E.
1939. A fungus disease of *Arceuthobium*. Phytopath. 29:995-996.

Ellis, D. E.
1946. Anthracnose of dwarf mistletoe caused by a new species of *Septogloeum*. J. Elisha Mitchell Society 62:25-50.

Fisher, J. T.
1975. Water relations of dwarf mistletoe on pine. Ph.D. Thesis, Colorado State Univ., Fort Collins, Colo.

Gill, L. S.
1935. *Arceuthobium* in the United States. Trans. Conn. Acad. Arts and Sciences 32: 111-245.

Gill, L. S.
1952. A new host for *Septogloeum gillii*. Plant Dis. Rep. 36(7):300.

Greenham, C. G. and O. A. Leonard.
1965. The amino acids of some mistletoes and their hosts. Amer. J. Bot. 52(1): 41-47.

Hawksworth, F. G., E. F. Wicker, and R. F. Scharpf.
1977. Fungal parasites of dwarf mistletoe. USDA, For. Serv. Gen. Tech. Rep. RM-36, 14 p., illus. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Hull, R. J. and O. A. Leonard.
1964. Physiological aspects of parasitism in mistletoes (*Arceuthobium* and *Phoradendron*). I. The carbohydrate nutrition of mistletoe. II. The photosynthetic capacity of mistletoe. Plant Physiol. 39:996-1017.

Kuijt, J.
1960-61. Distribution of dwarf mistletoes and their fungus hyperparasites in western Canada. *From* Nat. Museum of Canada, Bull. No. 186, Contrib. to Bot. p. 134-148.

Leonard, O. E. and R. J. Hull.
1965. Translocation relationships in and between mistletoes and their hosts. Hilgardia 37(4):115-153.

Mark, W. R. and C. P. P. Reid.
1971. Lodgepole pine dwarf mistletoe water potentials. For. Sci. 17:470-471.

Mielke, J. L.
1959. Infection experiments with *Septogloeum gillii*, a fungus parasitic on dwarf mistletoe. J. For. 57:925-926.

Miller, R. J. and R. D. Tocher.
1975. Photosynthesis and respiration of *Arceuthobium tsugense* (Loranthaceae). Amer. J. Bot. 62(7):765-769.

Offord, H. R.
1960. New approaches to forest disease control by chemicals. Fifth World For. Congr. Proc. 2:882-887.

Parmeter, J. R., J. R. Hood, and R. F. Scharpf.
1959. *Colletotrichum* blight of dwarf mistletoe. Phytopath. 49:812-815.

Peck, C. H.
1875. Report of the botanist. New York State Museum of Natural History, Ann. Rep. 27:111.

Quick, C. R.
1964. Experimental herbicidal control of dwarf mistletoe on some California conifers. USDA, For. Serv. Res. Note PSW-47. 9 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Rediske, J. H. and K. R. Shea.
1961. The production and translocation of photosynthate in dwarf mistletoe and lodgepole pine. Amer. J. Bot. 48(6): 447-452.

Shea, K. R.
1961. Dwarf mistletoe of ponderosa pine: present status and future needs. *In* Recent Advances in Bot. p. 1541-1544.

Wapshere, A. J.
1974. A strategy for evaluating the safety of organisms for biological weed control. Ann. Appl. Biol. 77: 201-211.

Weir, J. R.
1915. *Wallrothiella arceuthobii*. J. Agric. Res. 4(4):369-378.

Wicker, E. F. and C. G. Shaw.
1968. Fungal parasites from dwarf mistletoes. Mycologia 60(2):372-383.

Pest Damage and Integrated Control

INTEGRATING DWARF MISTLETOE CONTROL WITH FOREST MANAGEMENT[1/]

William E. Waters[2/]

Abstract: A broader, more comprehensive concept of forest pest management is needed to make it a really integral part of forest resource management. A generalized model structure of a forest pest management system is presented, and the major components are discussed briefly. Predictive models are the primary mechanism of information flow to decision and action in the system. General considerations affecting the kind and number of these models are discussed, with particular reference to the dwarf mistletoes. The whole-system approach to dwarf mistletoe management is urged.

The focus of this symposium is on dwarf mistletoe *control*. Each of the symposium sections -- including this, the last -- has the word *control* in its title. The various papers presented thus far have covered the relevant biology of the mistletoes, their ecological relations with host trees and stands, their effects on growth and yield and some damage statistics for different host types and geographic regions, and various control techniques for prevention or amelioration of the damage to be expected. The term *management* has crept in at times, and this has been expanded to *integrated management* in several contexts. The nature of dwarf mistletoe effects on forests has made the use of these terms fairly common, in fact. But what do we really mean by integrated pest management, or integrated management of dwarf mistletoes?

The concept of forest pest management -- the notion that destructive diseases (and insects) are an integral part of forest ecosystems, that they have both ecological and economic impacts on those ecosystems and the resource values involved, and that somehow their effects have to be kept at tolerable levels in ways compatible with forest management objectives and practices -- is not new (Meinecke 1916; Hopkins 1909). However, the concept has little reality in practice. The attitude of forest managers and administrators generally has been to play the game of "wait and see," followed by seat-of-the-pants decisions on action when a pest becomes obvious, intrusive, or intolerable. This attitude has affected research priorities, time schedules, and methodology accordingly.

If we better understand the full meaning of integrated pest management -- its space-time dimensions, the complexities and interactions of its ecological and economic components, and the social and political factors that inevitably have a part in planning and decision-making -- perhaps we can better set our sights on the research now needed and improve the odds of getting forest resource managers and administrators to put our collective knowledge and technology to work. Our real goal should be a forest protection system that incorporates dwarf mistletoe control -- and control or regulation of all other destructive agents that may be involved -- into the total resource management process on a long-term, continuing basis.

Let us look at the basic components of a forest pest management system. Figure 1 shows a generalized model structure of such a system (Waters and Cowling 1976). There are four basic components (enclosed by the dotted lines): (1) the population dynamics and epidemiology of the insects and diseases involved, (2) the dynamics of forest stand development, (3) the socioeconomic impacts of pest-caused damage on resource values, and (4) the treatment strategies. Each component is a complex subsystem in itself; each requires detailed analysis and

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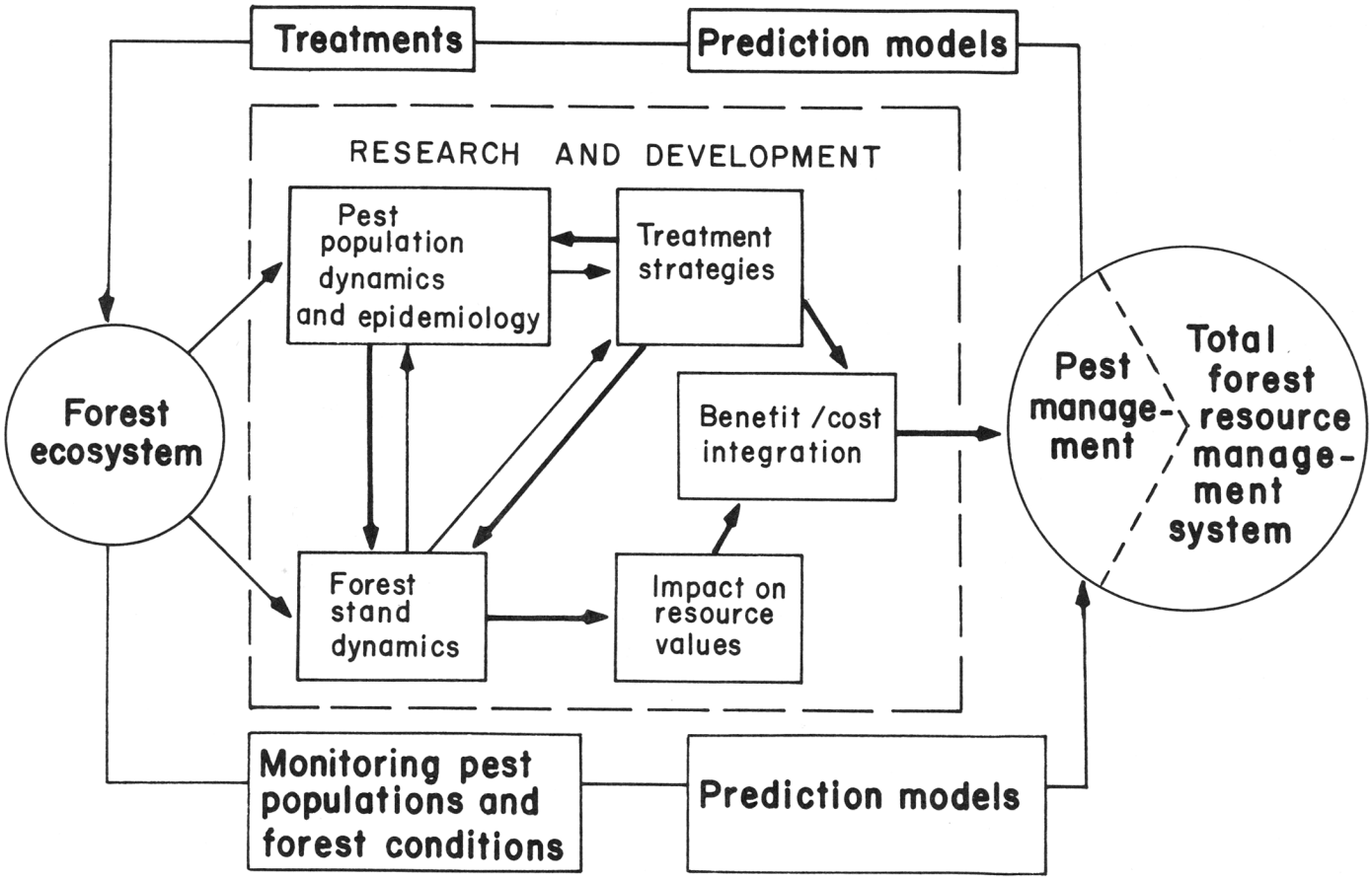

Figure 1--Generalized model structure of a forest pest management system.

understanding to provide the particular predictive models called for in the operational system. The heavier arrows show the primary linkages, or information flows, in the planning-decision process. The focal point of the system is the benefit/cost integration, whereby the benefits (values saved or gained) and the costs of alternative treatments or actions are assessed.

Figure 2 shows the same general model in a different configuration (Campbell and McFadden 1977). This emphasizes the different resource values and management objectives that may be at stake.

Predictive models are the primary mechanism of information flow to decision and action in an operational system (Waters and Ewing 1975). We must have the capability to anticipate the occurrence, abundance, and trends in pest populations. We must be able to estimate their potential effects on stand growth and yield and other stand parameters of concern, and to put these in terms of the values that will be affected. And we have to be able to specify in advance the expected outcomes of different treatments or management activities, including no action, not just in terms of the effects on the pest(s) but in terms of values lost, saved, or gained as well. This look-ahead feature is a major distinction between pest management and pest control.

The kind and number of predictive models in the system depend in part, of course, on the pest or pest complex involved. But some general considerations apply in all cases, including the management of dwarf mistletoe. These are:

(1) The time-span of the tree "crop"--cutting cycles and rotation ages will differ with tree species, location, and management objectives. This is a factor certainly with

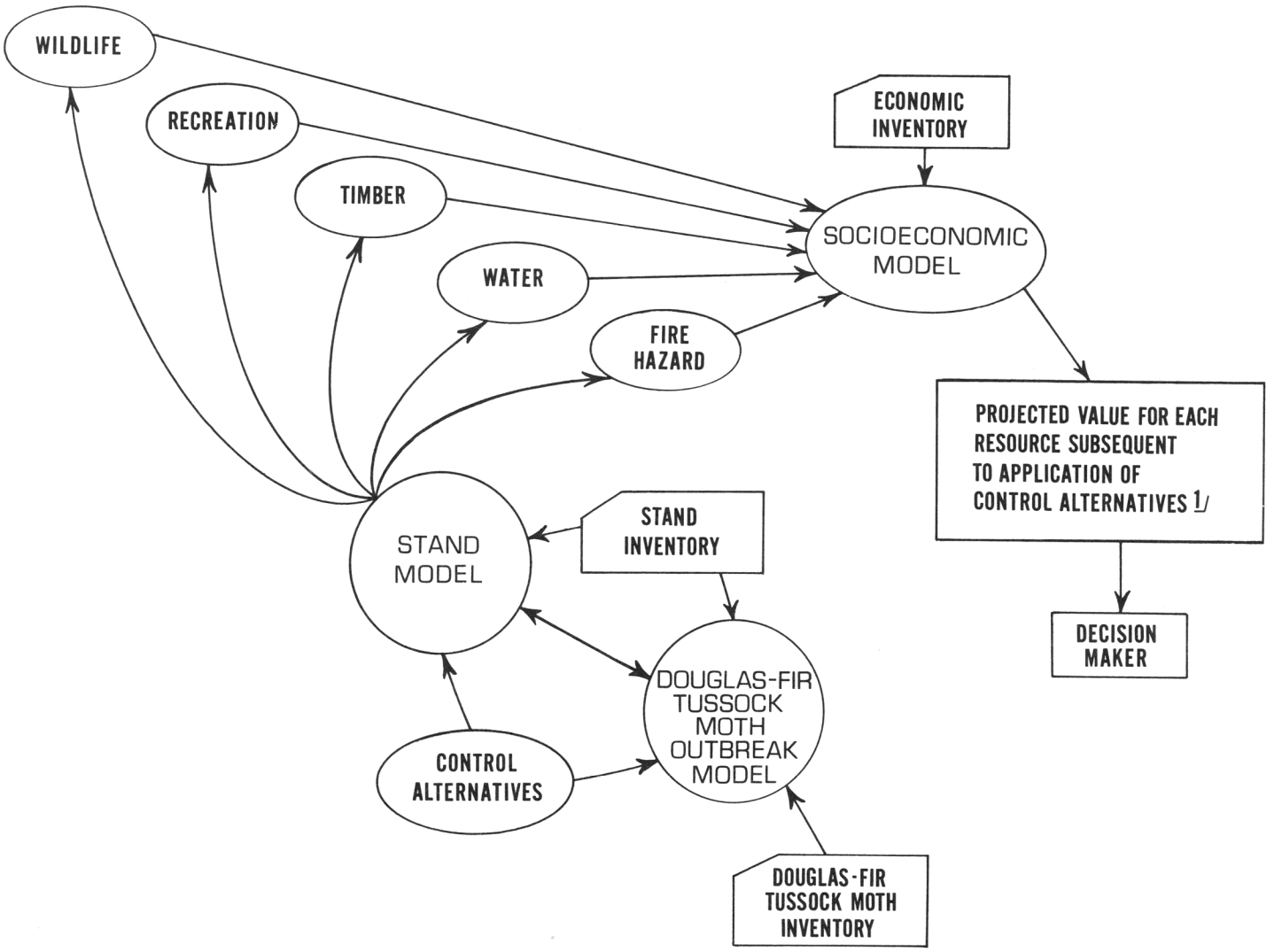

Figure 2--Information inputs, flows, and outputs in the Douglas-fir tussock moth research and development program (from Campbell and McFadden 1977).

dwarf mistletoes, considering the wide range of situations in which they are involved.

(2) The phenology of the tree(s) relative to the life cycle and activity of the pest--the extent to which critical stages of the pest, such as establishment and infection, are dependent on being synchronized with host plant development. This may not be very important with the dwarf mistletoes.

(3) The annual number of generations and seasonal abundance of the pest--whether the pest has one, two, or more generations or cohorts a year; the

rate of increase in each cohort; and the potential for increase in successive years. As I understand it, there is some variation in this factor among the dwarf mistletoes over the range of hosts and conditions in which they occur.

(4) The manner of spread and dispersal capability of the pest--whether spread or dispersal is active or passive, short- or long-range, random or contagious (dependent on direct contact of infected hosts), regular or irregular in frequency, etc. This factor, along with host conditions, determines the pattern and rate of spread of infection or infestation in stands or areas. It certainly is an important consideration with the dwarf mistletoes.

(5) The kind and rate of damage inflicted --whether the effect on stands is qualitative (*i.e.* cosmetic) or quantitative; whether outright tree mortality, growth loss, or some combination of these is involved; the age-size distribution of trees affected; the relation between rate of damage and loss and pest numbers or infection sources; and the shifting interplay between measured damage and loss and management objectives, expressed as thresholds for action. All of these factors are involved in the prediction of damage and loss due to dwarf mistletoes in particular situations.

(6) The kind and frequency of treatments --whether biological, cultural, chemical, or an integrated mix of methods are to be employed, and the time sequence in which they will be applied (within a given year and over successive years). For every pest or pest complex, including dwarf mistletoes, every alternative will have a different expectation of outcomes in terms of protection afforded and cost.

(7) The scope and objectives of the pest management program--the space-time frame of the program; whether prevention, suppression, long-term regulation, or some combination of these is intended. This determines the dimensionality of the entire set of predictive models in the system.

(8) Silvicultural considerations and management objectives--whether the stands are to be managed under an even-aged, 2-storied, group selection, individual tree selection, or some other silvicultural system, and the frequency of operations related to these; the products or product mix and other uses and values intended. These considerations establish constraints on all components of the system -- on the stand dynamics and impact models particularly.

This all sounds complicated -- and it can be. We don't, in fact, have all the pieces for any major pest. But some simplifications -- in methodology, not in the overall concept -- can be made as a start. Where do we stand with the dwarf mistletoes, for example?

Firstly, all of the current knowledge of dwarf mistletoe biology and epidemiology -- and this is well summed up at this Symposium -- can be wrapped up in two models which express (1) the conditional probabilities of dwarf mistletoe occurring in individual stands or management units based on tree and stand characteristics, proximity of infection sources, and other quantifiable variables, and (2) the rate of increase in mistletoe damage, including mortality, by tree species, age class, a spatial index, infection level, and, again, other quantifiable variables determining predictive accuracy and precision. An approach to developing such models for disease management, utilizing a logical simulation of the processes of disease establishment and buildup, has been described by Waggoner (1976). Stage (1973, 1975) has provided a computerized, algorithmic basis for putting expectations of pest incidence and damage into projections of stand growth and development for forest management planning. A more detailed exposition of the rationale and mathematics of integrating forest pest dynamics and stand dynamics into the management decision-making process has been given by Stage and Long (1976). The incorporation of earlier whole-stand models of lodgepole pine and ponderosa pine infested by dwarf mistletoe (Myers et al. 1971, Myers et al. 1976) into a new computer program by Edminster (1978) covering a wider range of stand conditions is a significant step in developing the practicable kind of input needed on mistletoe incidence and effects over time. These approaches, and the models and computerized procedures to utilize them, combine in effect the information contained in the pest population and stand dynamics boxes of the general model.

The assessment and projection of potential impacts of destructive insects and diseases -- their cumulative net effects on the productivity, usefulness, and value of a tree species or forest type with respect to different resource uses and management objectives -- is an area which forest pathologists (and ento-

mologists) have usually avoided. Properly so. The ecological, economic, and social complications of this aspect of pest management were dissected and reconstructed at a U.S. Forest Service-sponsored work conference at Marana Park, Arizona, in 1972. The report of that conference did much to clarify terms and to distinguish explicitly between the measurement and prediction of changes in stand parameters brought about by the activities of diseases and insects and the effects of those changes in terms of values affected (U.S. Forest Service 1972). The ecological and economic complications, research and applied approaches to impact evaluation, and data requirements in an operational system, have been more fully summarized by Waters (1976). I believe we now have a clear communication link with forest economists and forest managers and, importantly, a better basis for mutual understanding of where and how value judgments should be entered into the general model for planning and decision. Specifically, in the case of dwarf mistletoes, it would seem that the current values and related economic parameters of managed stands of most, if not all, of the host tree species are well enough known and sufficiently amenable to simulation for a reasonable number of years ahead that this component of the dwarf mistletoe management model could now be filled in.

Similarly, from research and management experience, it should be possible to develop reasonably accurate estimates of the costs and effectiveness of silvicultural treatments, or management practices, for prevention or amelioration of dwarf mistletoe damage for a realistic spectrum of infestation conditions.

With regard to benefit/cost integration -- the place where the whole process comes together -- new applications of simulation and optimization techniques have been developed specifically for pest management (Shoemaker 1976). Even more relevant methods are being developed in the "big bug" programs -- the USDA Combined Forest Pest Research and Development Program aimed at the Douglas-fir tussock moth, southern pine beetle, and gypsy moth (Ketcham and Shea 1977).

So long as some information essential to the whole-system approach to managing a particular pest is lacking, with attendant uncertainties, probably the best procedure for short-term decisions is decision-tree analysis. With this approach, the available information on pest-forest interactions compacted into predictive models, and cost estimates for alternative actions, are combined with subjective probabilities to form a discrete set of pathways to an array of outcomes, from which a choice is made based on some utilitarian criterion such as maximum benefit per unit cost (Valentine et al. 1976). The limitation to this approach is that the risks of a bad choice may be quite high depending on the caliber of the data and the assumptions used in constructing the decision-tree. A more serious shortcoming is that it cannot be incorporated easily into a forest management model. Numerous decision-trees may be needed for a given pest or pest complex, and the variables and criteria used may be more or less unique for the situation involved. Regardless, this approach has a strong appeal as an interim procedure, at least, and it undoubtedly would be useful for many dwarf mistletoe situations.

In the longer view, there is good reason to set our sights on a complete management system for the dwarf mistletoes -- and, ultimately, on total protection systems against all destructive agents affecting the coniferous forests of the Western United States. The long-range program goals of the Renewable Resources Planning Act of 1974 and the mandate of the National Forest Management Act of 1976 both give protection of our forest resources high priority. The environmental benefits to be derived also support this view. There is an opportunity for the dwarf mistletoes to serve as the prototype for forest disease management on the scale envisioned here. I, for one, believe we should get at it.

LITERATURE CITED

Campbell, R.W., and M.W. McFadden.
1977. Design of a pest management research and development program. Bull. Ent. Soc. Amer. 23:216-220.

Edminster, C.B.
1978. RMYLD: Computation of yield tables for even-aged and two-storied stands. USDA Forest Serv. Res. Paper RM-199. Rocky Mt. Forest and Range Exp. Stn., Fort Collins, Colo. (In press).

Hopkins, A.D.
1909. Insect depredations in North American forests and practical methods of prevention and control. USDA Bur. Entomol. Bull. 58, Part V. 101 p.

Ketcham, D.E., and K.R. Shea.
1977. USDA combined forest pest research and development program. J. Forestry, 75: 404-407.

Meinecke, E.P.
1916. Forest pathology in forest regulation. USDA Bur. Plant Industry Bull. 275. 62 p.

Myers, C.A., C.B. Edminster, and F.G. Hawksworth.
1976. SWYLD2: Yield tables for even-aged and two-storied stands of southwestern ponderosa pine, including effects of dwarf mistletoe. USDA Forest Serv. Res. Paper RM-163. Rocky Mt. Forest and Range Exp. Stn., Fort Collins, Colo. 25 p.

Myers, C.A., F.G. Hawksworth, and J.L. Stewart.
1971. Simulating yields in managed, dwarf mistletoe-infested lodgepole pine stands. USDA Forest Serv. Res. Paper RM-72. Rocky Mt. Forest and Range Exp. Stn., Fort Collins, Colo. 15 p.

Shoemaker, C.
1976. Management models for integrated pest control -- mathematical structure and solution. *In* Modeling for Pest Management: Concepts, Techniques, and Applications (R.L. Tummala, D.L. Haynes, and B.A. Croft, eds.), pp. 32-39. Michigan State University, East Lansing.

Stage, A.R.
1973. Prognosis model for stand development. USDA Forest Serv. Res. Paper INT-137. Intermountain Forest and Range Exp. Stn., Ogden, Utah. 32 p.

Stage, A.R.
1975. Stand prognosis in the presence of pests -- developing the expectations. *In* Management of Lodgepole Pine Ecosystems (D.M. Baumgartner, ed.), pp. 233-245. Washington State Univ. Coop. Extension Service, Pullman, Wash.

Stage, A.R., and G.E. Long.
1976. Forest stand dynamics as a basis for integrated management of forest pests. *In* The Bases for Integrated Pest Management, Proceedings of Group 6, XVIth IUFRO World Congress, Oslo, Norway, June 1976 (D.L. Kibbee, ed.), p. 19-28. University of Idaho, Moscow, Idaho.

U.S. Forest Service.
1972. Report of the Workshop on Impacts of Insects and Diseases on Uses, Values, and Productivity of Forest Resources. USDA Forest Service, Washington, D.C. 64 p. (Processed).

Valentine, H.T., C.M. Newton, and R.L. Talerico.
1976. Compatible systems and decision models for pest management. Environ. Entomol. 5:891-900.

Waggoner, P.E.
1976. Predictive modeling in disease management. *In* Modeling for Pest Management: Concepts, Techniques, and Applications (R.L. Tummala, D.L. Haynes, and B.A. Croft, eds.), pp. 176-186. Michigan State University, East Lansing.

Waters, W.E.
1977. Evaluation of insect impacts on forest productivity and values. *In* The Bases for Integrated Pest Management, Proceedings of Group 6, XVIth IUFRO World Congress, Oslo, Norway, June 1976 (D.L. Kibbee, ed.), pp. 15-18. University of Idaho, Moscow, Idaho.

Waters, W.E., and E.B. Cowling.
1976. Integrated forest pest management: a silvicultural necessity. *In* Integrated Pest Management (J.L. Apple and R.F. Smith, eds.), pp. 149-177. Plenum Press, New York.

Waters, W.E., and B. Ewing.
1975. Development and role of predictive modeling in pest management systems -- insects. *In* Modeling for Pest Management: Concepts, Techniques, and Applications (R.L. Tummala, D.L. Haynes, and B.A. Croft, eds.), pp. 19-27. Michigan State University, East Lansing.

THE PEST DAMAGE INVENTORY IN CALIFORNIA[1/]

James W. Byler[2/]

Abstract: The Pest Damage Inventory (PDI) is a survey procedure used by the U.S. Forest Service's California Region for measuring pest-caused damage over large forested areas. Similar procedures are followed in each survey, but photo and ground sampling techniques may differ. Six PDI surveys have been completed to date. Results show that dwarf mistletoe is a major contributor to tree mortality. The parasite is but one major class of tree pests, and pest management systems must integrate treatments for the entire pest complex. Pest management prescriptions should be integrated with stand management prescriptions.

INTRODUCTION

The Pest Damage Inventory (PDI) is a survey system that provides estimates of damage caused by forest pests. The PDI measures the damage from all pests in one survey, rather than makes multiple surveys for the various insects and diseases. The total damage is partitioned among pathogens, insects, abiotic factors, and complexes of these agents.

The PDI provides information for integrated control in the broad sense. Pest management strategies for each of the major pests and pest complexes are integrated with silvicultural treatments to form stand prescriptions aimed at achieving the desired stand structure, composition, and productivity. The emphasis is on forest management for insect and disease prevention, rather than on remedial insect or disease control.

This paper describes methods and selected results from inventories made in several National Forests in California during the past 5 years. It centers on dwarf mistletoes as causes of mortality and growth loss. But the results and discussion are not confined to dwarf mistletoes. My approach will be to put dwarf mistletoes in perspective as causes of tree mortality, to suggest a method for measuring growth loss and dwarf mistletoe incidence, and to describe an approach for integrating dwarf mistletoe treatments into silvicultural prescriptions that is being used in the Forest Service's California Region.

MORTALITY SURVEYS

Pest Damage Inventory methods are used for measuring tree mortality over large forested areas. The estimates of loss obtained from the surveys are used mainly for two purposes.

1) Biological evaluations: The California Region's Forest Insect and Disease Management Staff uses the PDI for biological evaluation surveys where the areas of concern are large and where tree mortality is the primary concern. The Staff evaluates specific insect and/or disease problems in response to requests from the National Forest Supervisors and other land managers. These evaluations contain estimates of the level of damage and cause of the damage that are obtained from surveys.

2) Administrative uses: Estimates of the level of tree mortality and the cause of that mortality are also used by administrators in setting action and research priorities. PDI estimates for the 12 National Forests in northern California are being used for such purposes.

To date, six tree mortality surveys have been completed: the Moore Creek Compartment of the Stanislaus National Forest in 1972;

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eight townships on the Eldorado National Forest in 1973; the commercial forest land of the Stanislaus National Forest in 1974; the pine and mixed conifer types on the San Bernardino National Forest in 1976; Laguna Mountain on the Cleveland National Forest in 1977; and a drought survey of tree mortality on 12 National Forests in northern California in 1977.

The six surveys had three objectives in common: (1) to measure the tree mortality that occurred during a one year period; (2) to identify the insects and diseases, separately or in combination, that were responsible for that mortality; and (3) to identify the stand and site conditions that are associated with above-normal mortality.

Loss estimates from four surveys are given as examples in this report: the Eldorado National Forest area, the San Bernardino National Forest, Laguna Mountain, and the drought survey of 12 National Forests.

METHODS

Similar procedures were followed in each survey. But the surveys differed in the photo and ground sampling technique and in sampling intensity.

Photo Plot Selection

Aerial photographs were used to detect dead trees. One hundred percent photo coverage was used on the Laguna Mountain area. Random sampling was used for the remaining surveys: random photo plot placement in the commercial forest type for the drought survey, and stratified random sampling by timber type for the remainder.

Photo plots were square and covered 284 acres unless part of the area was out of the timber type or was off the forest. Plots with less than 50 acres of commercial forest type were excluded from the San Bernardino and Eldorado National Forest surveys. Plots with less than 140 acres were excluded from the drought survey sample.

Each sample plot (or the entire area in case of 100 percent coverage) was photographed at a scale of 1:8000 by using 75 percent overlap for stereo viewing. Nine-and-one-half-inch wide Ektachrome MS film (type 2448), a Zeiss RMK camera with an 8¼ inch lens, HF 3 or 4 haze filters, and an antivignetting filter were used.

Photointerpretation

The aerial photos were examined for dead tree groups by delineating photo plot boundaries on the center photograph of each triplet and viewing the plots in stereo at 4x to 8x magnification. Each tree or group of dead trees within the photo plot that appeared yellow-to-sorrel at the time of photography was encircled on the photograph. Such faded trees were considered to have died within 1 year prior to the time of photography. For each dead tree group, the photointerpreter recorded the number of dead trees, and the species and size class of each dead tree. Three size classes were used: less than 50 feet; 50 feet to 100 feet; greater than 100 feet.

Ground Survey

A stratified sample of photo-detected dead tree groups was selected for ground sampling. Trees were stratified by height class for the drought survey, and by height class and tree species for the other surveys. The selected dead-tree groups were visited on the ground to gather data used to calculate estimates of tree mortality. These data included number of trees in the group, the species and size class of each tree, and the year in which each tree died. The year of death was estimated primarily from color and condition of the foliage, and the condition of the bark.

Stand, tree, and pest data were recorded for all trees that were found to have faded within the year prior to photography. Trees were examined for pests in the following manner: crowns and upper boles were observed through binoculars, bark was removed from lower boles, and axe cuts were made at the root crown and in the uppermost roots. Pests present in each tree were rated and recorded. In addition, those pests that were considered the most important found on all trees in the mortality group were included in the pest complex for that group. Only known tree-killing pests or conditions were included in the pest complex, and these were listed only when symptoms and signs indicated that the pest had contributed to the death of the trees.

Fomes annosus was included when typical stain, decay, or conks were found on the tree or other trees in the same disease center, or when the presence of the fungus could be verified by incubating wood samples. Wood samples were collected and incubated whenever Fomes annosus was suspected but could not be confirmed by stain, typical decays, or conks.

Armillaria mellea is both a parasite and a saprophyte on conifers in California. It was

included in the pest complex only when a dead oak was present on the site near enough to provide a food base (a condition under which the fungus is a virulent pathogen), or when symptoms and signs indicated that the fungus had caused root decay and killing by the time of tree death. Frequently, both A. mellea and F. annosus were present, especially on true firs. In such cases, only F. annosus was listed in the pest complex, although it should be recognized that the decay and killing was caused by both root pathogens.

Dwarf mistletoes were included in the pest complex when a tree was rated four or more in Hawksworth's six class system (Hawksworth and Lusher 1956). Lighter infections tended to be restricted to the lower half of the crown, and were not considered to be serious enough to be a cause of a tree's death.

Dendroctonus spp., Scolytus ventralis, and other insects were listed as pests when their distinctive brood galleries indicated their presence and successful attack of the tree.

The pest complex was used to calculate the proportions of trees killed by individual insects, pathogens, and pathogen/insect combinations (fig. 1-5). Tree mortality was said to be "induced" by an insect or pathogen if that insect or disease was listed in the pest complex. As it is used here, the term "induced" does not mean that a pest was the sole cause, but one of the contributors to the death of the tree.

The inventory design was multi-stage sampling with variable probabilities and stratification. Unbiased estimates of tree mortality and their standard errors were computed using methods suited to the sampling design.

RESULTS AND APPLICATION

Northern California National Forests

Three pilot tests of PDI mortality survey methods were made during years of normal mortality: the 10,000-acre Moore Creek Compartment on the Stanislaus National Forest in 1972, 87,000 acres of the Eldorado National Forest in 1973, and the entire timber-producing lands of the Stanislaus National Forest (about 1 million acres) in 1974. The tests showed the feasibility of obtaining reliable estimates of current tree mortality for large areas.

Dwarf mistletoes were implicated in the deaths of a substantial proportion of the trees in each area. Mortality estimates from the Eldorado National Forest survey area are used as an example (fig. 1). Twenty-three percent

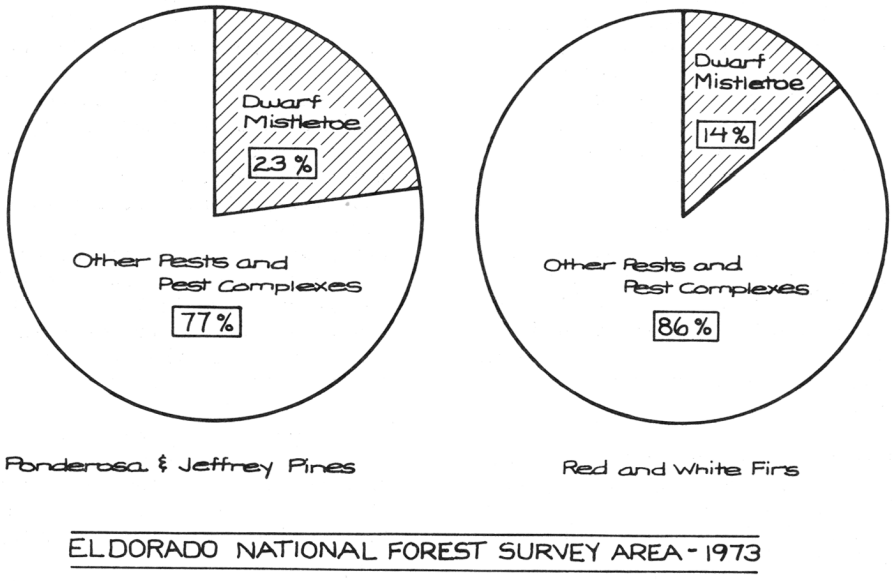

Figure 1 -- The relationship between dwarf mistletoe-induced mortality and total mortality of yellow pines and true firs in the Eldorado National Forest survey area.

of the ponderosa and Jeffrey pines and 14 percent of the red and white firs were heavily infested with dwarf mistletoe at the time of death (dwarf mistletoe ratings of 4-6). I concluded that the heavy infestation was one of the factors that brought about their death, although the exact level of dwarf mistletoe infection necessary to kill trees in the presence and absence of other pests is not known.

Nearly all of the dead pines and firs also showed evidence of successful insect attack. Brood galleries of tree-killing bark beetle species were present under the bark of the trees, and these likely played a role in killing the trees also.

The apparent association between "insect-killing" and dwarf mistletoe infestation has been recognized for some time. Miller and Keen (1960) discussed the role of pathogens, including dwarf mistletoe, in increasing pines' susceptibility to insect attack. More recent survey information from other Forest Service Regions, for example, Region 2 (Frye and Landis 1975, Johnson and others 1976), Region 3 (Parker and others 1975), and Region 4 (Parker and Stipe 1974) indicates that trees with high mistletoe ratings are more likely to be attacked by insects and killed than are uninfested ones.

The PDI was used operationally in 1977 to survey 12 northern California Forests (6.3 million acres of commercial Forest Service land) to measure the drought-associated tree mortality. The survey was designed to obtain volume loss estimates for administrative purposes. The estimated level of mortality was 4.5 $\pm$ 0.8 million trees or 1.2 $\pm$ 0.3 billion Schribner board feet for the 1 year period from May 1976 to May 1977 (0.71 trees/acre). This level was about three times the estimated normal loss.

Because of the limited ground sampling the estimates of loss by pest and pest complex have high standard errors. However, they suggest that dwarf mistletoe was associated with a sizable proportion of the mortality (fig. 2). The proportion of the recently killed pines with dwarf mistletoe ratings of 4 to 6 was especially high -- 79 percent. Again, insects infested nearly all of the trees, suggesting that they too contributed to their deaths.

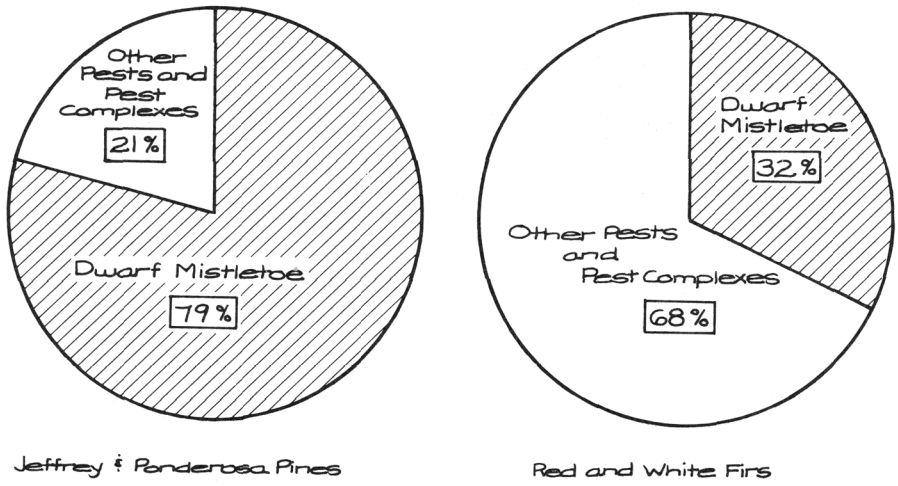

Figure 2 -- The relationship between dwarf mistletoe-induced mortality and total mortality of yellow pines and true firs in the drought survey of 12 northern California National Forest.

Root pathogens were also important in inducing tree mortality in the 12 forests. Root pathogens appeared to be more important than dwarf mistletoes in causing the death of the true firs (fig. 3), although they were associated with fewer dead pine trees than was dwarf mistletoe. Root damage and heavy crown infestations of dwarf mistletoe were both present on a sizable proportion of the recently-killed firs (fig. 3).

F. annosus was the predominant root pathogen, but signs of A. mellea and F. annosus were frequently present on the same tree. Some firs appeared to have been killed by A. mellea in the absence of F. annosus, but in those cases a dead oak or oak stump was usually present to serve as a food base for A. mellea.

Recent reports on root disease in California (Bega and others 1966, Stark and Cobb 1969, and Cobb and others 1974) and in Idaho (Partridge and Miller 1972, Miller and Partridge 1974) show that root pathogen/insect associations are common, and indicate that pathogens predispose trees to insect attack.

These northern California results indicate that dwarf mistletoes are important contributors to tree mortality. They may be especially important during periods of drought, or when stocking densities are high and the trees are under additional stress.

But perhaps more importantly, the results indicate that other pathogens and insects also contribute to tree mortality and should not be overlooked. The role of each major pest must be understood if control efforts are to be maximized. Stand treatments may and frequently should aim to reduce the levels of dwarf mistletoe in the stand. But little benefit may result unless stand treatments also prevent or reduce the damage from root pathogens and make the stand less susceptible to insect attack.

Southern California National Forests

In southern California, the pine forests on Laguna Mountain, Cleveland National Forest, were surveyed in 1977, and the pine and mixed conifer forest types on the San Bernardino National Forest are now being surveyed. The San Bernardino survey (a cooperative effort among the University of California, Berkeley; Environmental Protection Agency; and Forest Service) was begun in 1976 and is scheduled to last

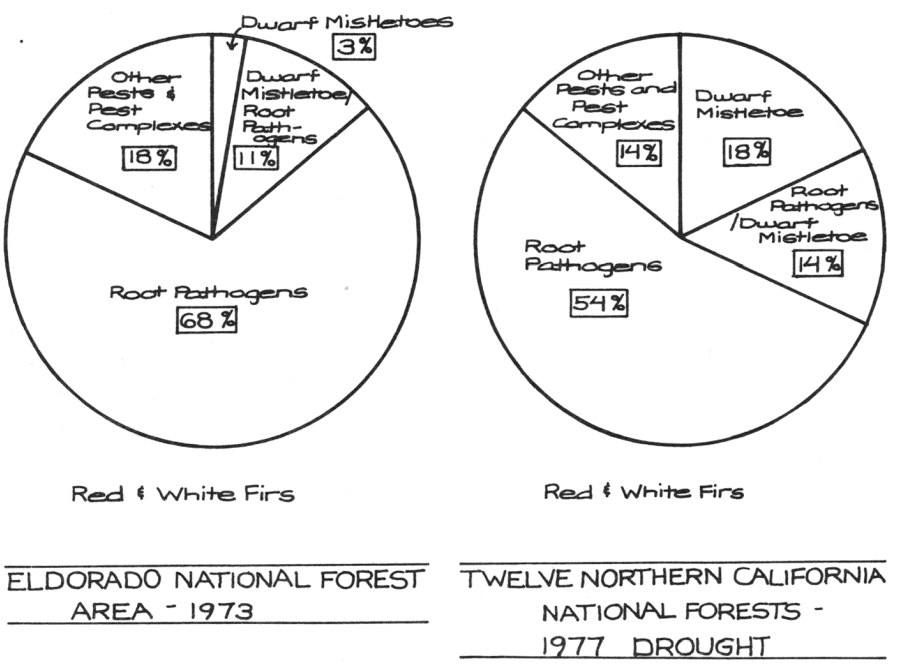

Figure 3 -- The relationship between dwarf mistletoe and root pathogen-induced mortality of true firs in the Eldorado National Forest survey area, and the drought survey of 12 northern California National Forests. Fomes annosus was the major root pathogen.

3 years.

Information from the Laguna Mountain survey and the first year of the San Bernardino survey are described here. The levels of tree mortality (0.62 trees/acre/year on Laguna Mountain and 0.07 trees/acre/year on the San Bernardino National Forest) are considered at or below normal for these areas, since rainfall was normal or greater.

Heavy dwarf mistletoe infection was associated with a large proportion of the pine mortality in both survey areas (fig. 4). Forty percent of the dead Jeffrey pines on the San Bernardino and 60 percent on Laguna Mountain were heavily infested with dwarf mistletoe at the time of their death. Dwarf mistletoe was not the only important pine pathogen on the two southern California Forests. Root diseases were implicated in the death of nearly as many pines as were dwarf mistletoes (fig. 5). And sizable proportions of the pines in both areas had both root damage and heavy dwarf mistletoe infestations at the time of death (fig. 5). F. annosus was the major root pathogen in both areas.

Insects were also associated with most of the pathogen-induced mortality as was the case on the northern California Forests. Pathogen/insect complexes killed 70 percent of the trees of all species on the San Bernardino National Forest and 77 percent on Laguna Mountain.

The mortality survey results indicate that dwarf mistletoe is one of the most important causes of tree mortality on these two southern California Forests. The problem is especially acute because one of the two primary management goals is to provide for recreational use. The desirability of maintaining a tree cover on presently-forested land indefinitely intensifies the dwarf mistletoe impact. The option of making large regeneration cuts, thereby eliminating the parasite from the new stand is not feasible in such intensively used areas.

In the past, forest management in the southern California Forests was largely custodial, consisting primarily of sanitation-salvage cutting to reduce the number of insect high risk trees from the stands. Dwarf mistletoe suppression projects were separate activities, and were carried out only in limited areas. Insect suppression projects consisted of falling infested trees and treating them with chemicals.

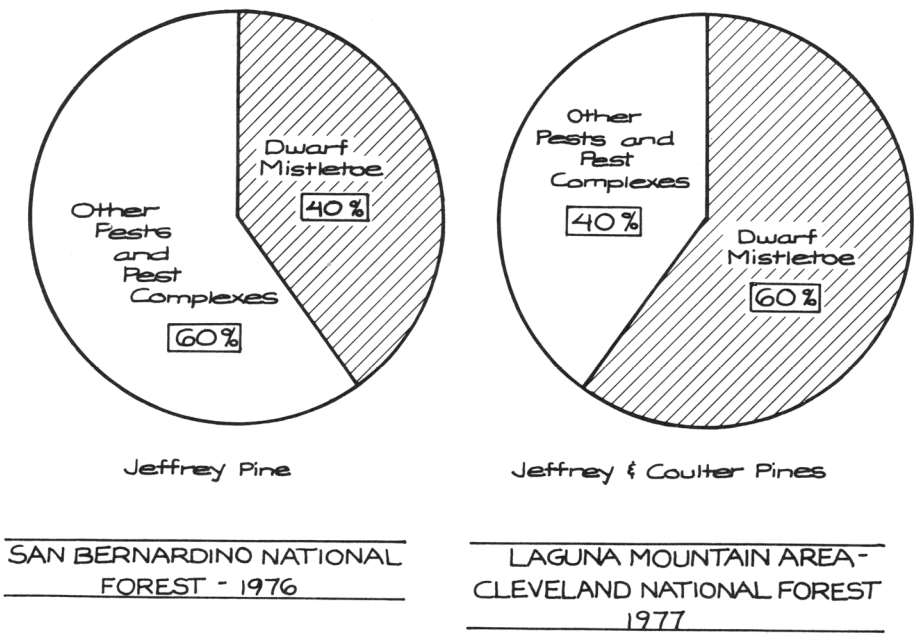

Figure 4 -- The relationship between dwarf mistletoe-induced mortality and total mortality of two yellow pine species on two southern California National Forests.

But insect and dwarf mistletoe control treatments alone have not resulted in the most desirable recreation stands. To some extent they may have been detrimental: the removal of trees for dwarf mistletoe control, insect control, and sanitation-salvage cutting appears to have intensified the annosus root disease problem by creating stumps suitable for infection. F. annosus infects a freshly cut stump by means of airborne spores, colonizes the stump and spreads from the roots of the infested stump to those of adjacent living trees, thereby causing an enlarging center of root damage and tree death.

The emphasis on southern California Forests is now changing from a holding action to one of active forest management. The management procedure is the one taught as a part of the California Region's silvicultural certification course (California Region, Forest Service 1976). A certified silviculturist examines the present stand structure in light of management objectives and prescribes treatments that will achieve and maintain a suitable future structure. Preventive and remedial insect and disease treatments are carried out as an integral part of the stand prescription, not as separate suppression activities.

The dwarf mistletoe prevention and suppression treatments that are incorporated into an integrated management system need not be complex. The treatments include the tools with which we are all familiar: species conversion, cutting of infected trees during thinnings, and overstory removal. But I believe the key is to incorporate them into one prescription whose aim is not dwarf mistletoe control but forest management.

GROWTH EFFECTS SURVEY

In 1977, we began testing PDI methods for a survey to measure the incidence of, and the growth loss caused by, insects and pathogens. We called this survey a Growth Effects Survey. Our approach for this survey is to

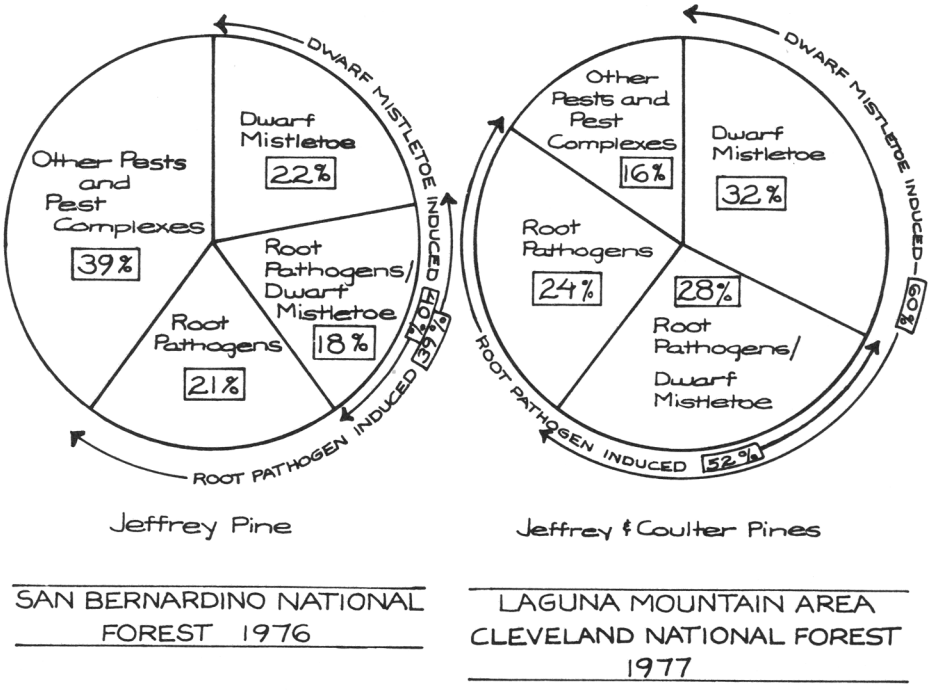

Figure 5 -- The relationship between dwarf mistletoe root pathogen-induced mortality and total mortality of two yellow pine species in two southern California National Forests. Fomes annosus was the major root pathogen.

collect pest data during the Compartment Inventory [3/]. Trees measured by Compartment Inventory crews are also rated for insects, diseases, and defect. Information gained from Growth Effects Surveys are to be used mainly for two purposes:

1. Timber management: Estimates of the incidence of specific insects and pathogens and the damage (growth loss and defect) they are causing are obtained for compartments, and for strata within the compartments. These estimates are to be used in setting treatment priorities between strata, and for formulating stand prescriptions that include treatments for the prevention and reduction of insect and disease loss.

2. Administrative uses: When sufficient data have been collected from compartments in the Region, reliable estimates of growth loss and defect caused by dwarf mistletoes and other damaging pathogens and insects can be made.

Stratum Treatment Priority and Silvicultural Prescriptions

To date, data summaries are available for only one compartment, the Barton Flats Compartment on the San Bernardino National Forest (table 1). The compartment is divided into type strata that are sampled for growth and standing volume as well as pests. Thirty prism points were selected to represent each stratum (six randomly selected locations for L-shaped

Table 1. The incidence of pests in the Barton Flats Compartment, San Bernardino National Forest. (Sampling strata were based on tree species composition (pine or mixed conifers), average d.b.h. class (1 = 0-4.9"; 2 = 5-10.9"; 3 = 11-20.9"; 4 & 5 = 21" or more), and stand stocking density (percent crown closure: — = 0-19; ⚌ = 20-39; ☰ = 40-69; ≣ = 70-100).)

Stratum			Sample Size (No. Prism Points)	Percentage of Prism Points with:					
Type	D.B.H. Class	Stocking Density		Pest Problems	Ozone Injury	Annosus Root Disease	Dwarf Mistletoe	True Mistletoe	Other Pests
Pine	Two Storied	All	30	33	17	7	0	3	6
Pine	3	—	23	43	13	4	26	4	0
Pine	3	☰	27	11	0	0	4	0	7
Pine	4 & 5	All	30	67	23	20	0	3	21
MC	3	All	30	47	7	17	7	10	6
MC	4 & 5	All	28	61	14	7	7	7	26
All Strata			168	46	14	10	7	4	13

[3/] Compartments are land areas used in the National Forests of California for vegetative sampling. Ranging from 3,000 to 8,000 acres, they have boundaries that are defined by easily identified physical features.

clusters of 5 points). A few points were not usable and excluded from the summaries. Statistics on stratum growth, stocking, and pest incidence are used to write silvicultural prescriptions for stands within the strata.

Nearly half of the prism points had pest problems (table 1), thereby supporting the contention that the compartment is one needing management. A pest problem was defined as a "damaging level" of a pest:dwarf mistletoe rating of 4 or higher, F. annosus root disease on the plot, the presence of insect killed trees, or ozone symptoms on second-year pine needles.

Differences in pest intensity can be used to select strata and stands for immediate treatment -- and those in which treatment can be deferred. The proportion of prism points with pest problems varied by stratum ranging from 11 percent to 67 percent.

Pest data can also be used for making silvicultural prescriptions. A closer look at the pests in Barton Flats Compartment strata suggests that treatment options will vary between strata. For example, the two young sawtimber sized strata appear quite different with regard to pest problems. The P 3≡ stratum appears relatively free of pests. Removal of dwarf mistletoe infected trees during thinning may be the only special pest management necessary to maintain a relatively healthy young stand.

The P 3- stratum, on the other hand, may present a more difficult management problem. The stocking density is already low and the high incidence of dwarf mistletoe infection suggests more trees will die. Regeneration with pine will be a problem, unless the infected pine overstory is removed. But, the removal of the infected overstory, a substantial number of trees, is not desirable on this southern California Forest where maintaining an attractive appearance is important.

The mature pine stratum (P 4 & 5) had the greatest incidence of pest problems. Additional mortality may be expected -- especially in years of environmental stress. Stand prescriptions should allow for their replacement, either by release or regeneration cutting. The data suggest that dwarf mistletoe is not a major problem, and regeneration with pine appears feasible -- even near pine overstory trees. Ozone injury to pine is likely to be a continuing problem, however, and annosus root disease is an important consideration for both pine and fir.

Prescriptions are made for stands, not strata. Nevertheless, compartment inventory analysis results are used to project average stand growth, and to predict the general response of stands within the stratum to different treatment options. Pest effects are also relevant to those predictions, and the pest data can be efficiently collected as a part of the compartment examination process. If additional information is needed for specific stands, additional compartment inventory data, including pest data, can be collected.

Growth Loss

The second major goal of growth effects surveys is to provide growth loss estimates associated with each of the most damaging pests for administrative purposes. A larger data base is required before valid estimates can be made. Our approach is to compare stand growth in stands with pests, and those free of pests. Growth loss from all pests will be the difference between growth in infested and uninfested stands when differences in stocking density, site and species composition have been accounted for. Effects of individual pests and pest complexes will be expressed as a portion of the total loss.

CONCLUSIONS

Dwarf mistletoes are major contributors to tree mortality. Dwarf mistletoe-induced mortality is usually not a major problem in timber producing forests where even-aged management is practiced and when the pathogen will be eliminated or reduced to low levels during thinnings or eliminated at the end of relatively short rotations. But dwarf mistletoe-induced mortality is especially important in recreation areas, and other areas where management options are reduced. The value of the trees, the rates at which dwarf mistletoes build up in the stands, and the goal of maintaining a tree cover for long periods makes the dwarf mistletoes an important management consideration. Regeneration with susceptible tree species is especially difficult if the removal of infected overstory trees is precluded.

Dwarf mistletoes are but one important class of tree pests, and pest management systems must integrate treatments for the entire complex of pests. Failure to do so may limit the effectiveness of dwarf mistletoe control, since the anticipated benefits of reduced mortality and increased growth may not be realized if other pests are also present. At least one dwarf mistletoe control project, on Laguna Mountain, aggravated the root disease problem by creating

stumps that served as F. annosus infection courts.

Stand management objectives can best be accomplished through the integration of pest management prescriptions and stand prescriptions. Stand management, not dwarf mistletoe control alone, is usually required to attain and maintain the desired stand structure. The process is most efficient when dwarf mistletoe (and other pest) considerations are built into forest/compartment/stand inventories, stand prescriptions, and stand treatments. If dwarf mistletoe levels are reduced during stand management, dwarf mistletoe damage to the stand will be prevented, and fewer special remedial control efforts will be required in the future.

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LITERATURE CITED

Bega, R. V., D. Dotta, D. R. Miller and R. S. Smith, Jr.
1966. Root disease survey at Boggs Mountain State Forest, California. Plant Dis. Reporter. 50:439-440.

Cobb, F. W., Jr., J. R. Parmeter, Jr., D. L. Wood and R. W. Stark.
1974. Root pathogens as agents predisposing ponderosa pine and white fir to bark beetles. Fourth Conf. on Fomes annosus. Athens, Ga. p. 8-15.

California Region, Forest Service
1977. R5 compartment inventory handbook. 46 pages. San Francisco, Calif.

Frye, R. H., and T. D. Landis.
1975. Biological evaluation -- mountain pine beetle and dwarf mistletoe, Lake Creek Area, San Carlos Ranger District, Pike-San Isabel National Forest. USDA Forest Serv., Rep. R-2-75-4, Lakewood, Colo. 10 p.

Hawksworth, F. G., and A. A. Lusher.
1956. Dwarf mistletoe survey and control on the Mescalero-Apache Reservation, New Mexico. J. For. 56(6):384-391.

Johnson, D. W., L. C. Yarger, C. D. Minnemeyer and V. E. Pace.
1976. Dwarf mistletoe as a predisposing factor for mountain pine beetle attack of ponderosa pine on the Colorado Front Range. USDA Forest Serv., Region 2, Tech. Rep. R2-4. Lakewood, Colo. 7 p.

Miller, D. L., and A. D. Partridge.
1974. Root rot indicators in grand fir. Plant Dis. Reporter 58(3):275-276.

Miller, J. M., and F. P. Keen.
1960. Biology and control of western pine beetle. USDA Misc. Publ. 800. 381 p.

Parker, D. L., and E. L. Stipe.
1974. Does mountain pine beetle select and kill dwarf mistletoe-infected lodgepole pine? USDA Forest Serv., Region 4. Ogden, Utah. 4 p.

Parker, D. L., J. W. Walters, and A. H. Smith.
1975. Assessment of factors causing ponderosa pine mortality on the Lincoln National Forest. USDA Forest Serv., Region 3, Albuquerque, N.M. 19 p.

Partridge, A. D., and D. L. Miller.
1972. Bark beetles and root rots related in Idaho conifers. Plant Dis. Reporter 56:498-500.

Stark, R. W., and F. W. Cobb, Jr.
1969. Smog injury, root diseases and bark beetle damage in ponderosa pine. Calif. Agric. 23(9):13-15.

DEVELOPMENT OF GROWTH AND YIELD MODELS FOR DWARF MISTLETOE-INFESTED STANDS[1/]

Carleton B. Edminster[2/]

Abstract: Forest stand growth and yield models have conceptual, developmental, and output utility. Three categories of stand models are commonly recognized: models requiring individual tree records with intertree distances; models requiring individual tree records without intertree distances; and models requiring whole stand summary information only. Relationships describing the development of dwarf mistletoe infestation and effects on stand growth and yield may be incorporated in all three model types depending on stand structure and need for detailed information by land managers.

INTRODUCTION

Models of biological systems are typically expressions of sets of "fuzzy" laws in mathematical terms. A fuzzy law is a biological, physical, or mathematical concept which is not known with a high degree of accuracy. In contrast, many physical systems may be characterized by sharp laws which are known to a very high degree of accuracy (Zadeh 1965).

Usually, it is not the laws which are fuzzy or sharp but our perception, understanding, and expression of them. All models are defective to some degree; some aspects of the modelers' concepts do not apply to the problem at hand. Further complications arise because we usually synthesize predictive models from limited data representative of small experimental areas. All this would seem to indicate that models of biological systems would usually be of limited value. However, models of systems do have value at three recognized levels: (1) conceptual, (2) developmental, and (3) output (Innis 1973).

First, conceptualizing a system in terms of a model provides a frame of reference. Conceptual utility results from identifying major components of the system and major interactions among components.

Second, developmental utility results from the usefulness of what the modeler learns from the process of constructing the model. The modeler is forced into very precise, if not necessarily accurate, thinking. The modeler must deal with interactions of systems components and resolve inconsistencies from the conceptual stage. Model development requires that complex, seemingly intractable systems be broken down into relatively simple pieces. Casual synthesis of the pieces of the modeled system may produce unstable model behavior. Only careful formulation can lead to important insights into system dynamics. Experience in developing models will lead to enhanced perception and understanding of the system. In addition, the modeling effort can be used to guide future research to fill gaps in current knowledge.

The third value of system modeling lies in user benefits or output utility. Output utility is derived by persons outside the modeling effort from model documentation and computer printed output. Many existing models have large developmental utility but are of limited practical use. This is probably due to our current level of modeling expertise. The land manager needs usable tools to aid in

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decisionmaking. Models which require unavailable data, cost too much to use, or produce inaccurate results are not efficient tools. Potential model users must be included in the modeling process from the beginning to insure output utility.

MODELING FOREST PESTS AND FOREST STANDS

Most modeling has dealt with either forest pests or forest stands, with little regard to building an integrated management framework. This situation has resulted from the makeup of modeling groups which all too often are composed of specialists in only one subject area. We are concerned with developing growth and yield models for dwarf mistletoe-infested stands. To accomplish this, an integrated pest-host model to effectively describe the complex interactions of the pest-host system is essential.

Modeling Forest Pest Populations

Studies of pest populations seem to focus on the pest's life cycle, factors controlling its development, and association with its host. The life table technique, with many modifications, has been used in the study of forest insects. Examples of the technique for forest pests include:

Mountain pine beetle (Dendroctonus ponderosae) in Black Hills ponderosa pine (Pinus ponderosa) (Knight 1959) and in lodgepole pine (P. contorta) (Cole 1974).

Pine saw flies (Neodiprion fulviceps) (Dahlsten 1967).

Needle miner (Recurvaria starki) (Stark 1952).

Dwarf mistletoes (Arceuthobium americanum and A. vaginatum) (Hawksworth 1965).

Progress is being made in quantifying interactions of pests and hosts. The association of mountain pine beetle dynamics in lodgepole pine stands with stand diameter structure, phloem thickness, and host resistance have been quantified in empirical models (Cole et al. 1976, Berryman 1976). A model for the spread and intensification of western dwarf mistletoe (A. campylopodum) in thinned stands of sapling ponderosa pine has been developed by Strand and Roth (1976). Limitations of the model are assumptions of even tree spacing and uniform tree height. However, dwarf mistletoe development is related to spacing and tree crown characteristics, so that provisions are available for generalization to more realistic forest stands. This model is an excellent example of the developmental work needed in building integrated models. General pest population models require integration of submodels of intensification (or productivity) and spread (or migration). Complex pest-host-environment interactions then must be quantified before the effects of pests on growth and yield of host populations can be examined.

Modeling Forest Stands

Few models of growth and yield of forest stands are being used by land managers, largely due to low output utility. Most of the models have been empirical rather than theoretical or process oriented. An empirical model should adequately describe the results of biological processes without trying to simulate the complex processes themselves. Empirical models can be formulated in very simple regression type relations and sophisticated mathematical functions. Process models of tree development may describe system behavior at a level of resolution too detailed for land managers. An example is modeling tree physiology as an aggregation of physical and chemical processes to simulate the mechanisms of photosynthesis, respiration, translocation, and assimilation.

Stand projection methods and models give good estimates of current growth which can be used for short-term projections based on current management conditions (Larson and Goforth 1974). These methods are not well adapted to making long-term projections or evaluating alternative management strategies since only current average growth and mortality rates are used. These rates do not allow for changes due to treatment. A few stochastic or probabilistic models have been developed for stand projection. A notable example is a Markov model developed by Peden et al. (1973). Also, Moser (1972) formulated a system of differential equations to describe development of an uneven-aged stand. The introduction of cultural treatments and possible long-term structural and species changes seems rather difficult in both of these models.

Fairly simple stand models may be constructed to adequately describe the development of even-aged stands, but these models will probably be totally inadequate for uneven-aged stands. An even-aged stand is composed of one main age class over an area large enough to be recognized as a management unit. This represents a rather simple forest condition. An uneven-aged stand may include two to many age classes, and arrangement may vary

from even-aged groups to mixtures of all age classes over small areas.

Curtis (1976) provides an excellent summary of differences in yield prediction methods for even-aged and uneven-aged stands. Some of the complicating factors in going from an even-aged model structure to uneven-aged include: (1) possible inadequacy of site index for site classification, (2) need for larger experimental areas to include a full range of stand conditions, (3) possible unstable species composition and stand structure, (4) need for a meaningful measure of tree competition and requirements for reproduction, and (5) allowance for a wide range of possible silvicultural treatments.

Munro (1974) distinguishes three "modeling philosophies" to conveniently characterize stand models by the primary model units and intertree dependency. The first philosophy assumes the primary unit in the stand model is the individual tree, requiring intertree distance relationships. The second philosophy again assumes the individual tree is the primary unit, but intertree distances are not necessary. The third philosophy assumes the stand itself is the primary unit; individual tree information and intertree distances are not needed.

Stand models which use the individual tree as the primary unit and are distance dependent can produce very detailed information about the structure and development of the stand. This type of model has been used by Newnham (1964), Lee (1967), Mitchell (1969), Bella (1971b), Arney (1972), Ek and Monserud (1974), and others for a variety of tree species. Each of these models depends on a measure of intertree competition related to distances from a subject tree to neighboring trees and the size of the subject tree relative to its neighbors. This measure of competition often takes the form of overlapping circles proportional in size to the competitive status of the subject tree and its neighbors (Bella 1971a). An alternative method based on available growing space polygons has been developed by Adlard (1974).

Models which include crown dimension increments (Mitchell 1969, Arney 1972) have the potential for studying intertree competition, bark beetle attack and migration, insect defoliation, top dieback, and dwarf mistletoe spread and intensification. The linkage of such stand models with the dwarf mistletoe model of Strand and Roth (1976) seems fairly straightforward. Clearly, such stand models can be used in examining effects of thinning and tree spacing and can be adapted to even-aged or uneven-aged stands. The major disadvantage of distance dependent modeling is the requirement for a stem map and excessive computer time to assess intertree competition (Munro 1974). Operational use of such models is limited since stem maps are not generally available. Most of these models have the provision for generating an artificial stem map to be used with sample tree measurements, but then the model is really functioning in a distance independent mode. Perhaps development of underlying spatial patterns as proposed by Matérn (1971) can be used in generating more realistic stem maps.

Stand models which use the individual tree as the primary unit and are distance independent can be more efficient for operational use in studying the effects of cultural treatments. This type of stand model does not require intertree distance measurements. Sample tree measurements are more likely to be available for input to this model, and tedious computations of competition measures are eliminated. Examples of this type of model have been produced by Botkin et al. (1972) and the Stand Prognosis Model by Stage (1973, 1975) with additions for mortality by Hamilton and Edwards (1976). A Stand Outbreak Model has been added to the Prognosis Model to project the interaction of the tussock moth (Orgyia pseudotsugata) and Douglas-fir (Pseudotsuga menziesii) stands. Mountain pine beetle impact has also been added for lodgepole pine stands.

These models are capable of producing detailed tree and stand information, including stand and stocking tables. Because stem maps are eliminated, fast computing time permits examination of many alternative thinning and spacing strategies. These models are also adaptable to even-aged and uneven-aged stands. The major disadvantage of individual tree models which are distance independent is that the growth of a specific tree can not be predicted with any reliability. Examination of development of individual tree crowns and boles also is not reliable. A model for intensification of dwarf mistletoe and resultant loss of growth and yield could be integrated with such a model. A dwarf mistletoe spread model might not be quite so easy to incorporate, depending on variability of stand spatial patterns.

Whole stand models which are distance independent are probably most familiar to foresters. The conventional normal yield table is an example of such a model. This modeling philosophy holds that the whole stand is the primary unit as characterized by some average values, such as average tree d.b.h., height, volume, age, and basal area or number

of stems per unit area. This model has the capability of examining a variety of thinning and spacing strategies, and uses computer time very efficiently. Whole stand models do not provide any individual tree information, and stand and stocking tables are usually lacking. Whole stand models are capable of predicting yields for even-aged stands of a single species, but more complex age or species composition generally can not be simulated. Use of conventional inventory information for program input makes this model attractive for operational use.

Two whole stand models which are operational have been developed for dwarf mistletoe-infested stands: LPMIST for even-aged lodgepole pine in the central Rocky Mountains (Myers et al. 1971), and SWYLD2 for even-aged and two-storied stands of southwestern ponderosa pine (Myers et al. 1976). The extension of whole stand models to a two-storied stand in SWYLD2 probably represents the limit of generalization from true even-aged conditions. These programs have been combined into a new program, RMYLD (Edminster 1978), designed to provide for more flexible management strategies and a wider range of stand conditions.

Dwarf mistletoe relationships in these programs were added as adjustments to noninfested stand performance. These relationships reflect only average dwarf mistletoe intensification in infested stands, and the ability to measure spread is lacking. This demonstrates that the primary unit in the stand model will be on the same level as the pest model. Dixon (1977) has incorporated whole stand growth and yield relationships into a spread and intensification model for southwestern ponderosa pine. These models attempt to handle many of the silvicultural treatments for the host species as described by Alexander (1974), Hawksworth et al. (1977), Schubert (1974), and Myers (1974), but the limitation to simple stand structure is a serious shortcoming, in many instances.

INTEGRATED DWARF MISTLETOE AND FOREST STAND MODELS

Development of a successful integrated model requires formation of a modeling team before the conceptual stage. This team should be composed of people with a wide variety of expertise and experience (i.e., a mensurationist, silviculturist, forest pathologist, and mathematical statistician from research and a forest manager and disease specialist from the projected user groups). As mentioned earlier, users are included hopefully to insure model output utility. The ultimate goal of the modeling effort should be to develop a usable management tool.

The workings of such a team have been summarized by Anderson et al. (1976) for the lodgepole pine-mountain pine beetle system. The steps of developing impact models, pest population dynamics models, pest-host interaction models, and stand models also apply to dwarf mistletoe-infested forest stands. Conceptual stand models are available to match any combination of tree ages, species, and sizes. Development of complementary pathogen models also is underway. The modeling philosophy must be chosen early in model development. This will be dictated largely by stand and dwarf mistletoe conditions of interest, as well as the kind of information needed by the user (Murdie 1971).

Data input requirements must be kept reasonable. The model should be kept as simple as possible and still produce accurate results. As the model becomes more complex, developmental costs increase, user costs increase, and use decreases.

Bruce (1977) provides an excellent summary of what to expect of the modeling effort. Differences will occur between predicted model results and stand performance. Modeling is an evolutionary process, and at each stage, the model should become more accurate, efficient, and useful.

LITERATURE CITED

Adlard, P. G.
1974. Development of an empirical competition model for individual trees within a stand. p. 22-37. In Growth models for tree and stand simulation: Proc. IUFRO working party S4.01 in 1973. Jöran Fries, ed. Royal Coll. For. Res. Notes 30, Stockholm, Sweden.

Alexander, Robert R.
1974. Silviculture of subalpine forests in the central and southern Rocky Mountains: The status of our knowledge. USDA For. Serv. Res. Pap. RM-121, 88 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Anderson, L. S., A. A. Berryman, D. G. Burnell, W. H. Klein, E. L. Michalson, A. R. Stage, and R. W. Stark.
1976. The development of predictive models in the lodgepole pine-mountain pine beetle ecosystem. p. 149-164. In Modeling for pest management. Concepts, techniques, and applications. Ramamohan L. Tummala, Dean L. Haynes, and Brian A. Croft, eds. Mich. State Univ., East Lansing.

Arney, James D.
1972. Computer simulation of Douglas-fir tree and stand growth. Ph.D. Thesis, Oregon State Univ., Corvallis, 79 p.

Bella, I. E.
1971a. A new competition model for individual trees. For. Sci. 17:364-372.

Bella, I. E.
1971b. Simulation of growth, yield and management of aspen. Ph.D. Thesis, Univ. of British Columbia, Vancouver, 190 p.

Berryman, Alan A.
1976. Theoretical explanation of mountain pine beetle dynamics in lodgepole pine forests. Environ. Entomol. 5:1225-1233.

Botkin, D. B., J. F. Janak, and J. R. Wallis.
1972. Rationale, limitations, and assumptions of a northeastern forest growth simulator. IBM J. Res. Dev. 16:101-116.

Bruce, David.
1977. Yield differences between research plots and managed forests. J. For. 75:14-17.

Cole, Walter E.
1974. Competing risks analysis in mountain pine dynamics. Res. Popul. Ecol. 15:183-192.

Cole, W. E., G. D. Amman, and C. E. Jensen.
1976. Mathematical models for the mountain pine beetle-lodgepole pine interaction. Environ. Entomol. 5:11-19.

Curtis, Robert O.
1976. Growth and yield in uneven-aged stands. p. 81-97. In Uneven-aged silviculture and management in the western United States. Proc. USDA For. Serv. In-Service workshop. Redding, Calif.

Dahlsten, D. L.
1967. Preliminary life tables for saw flies in the Neodiprion fulviceps complex. Ecology 48:275-289.

Dixon, Gary E.
1977. A spread and intensification model for mistletoe in ponderosa pine. Ph.D. Thesis, Colo. State Univ., Fort Collins, 135 p.

Edminster, Carleton B.
1978. RMYLD: Computation of yield tables for even-aged and two-storied stands. Res. Pap. RM-199. 26 p. Rocky Mt. For. and Range Exp. Stn., For. Serv., U.S. Dep. Agric., Fort Collins, Colo.

Ek, Alan R., and Robert A. Monserud.
1974. FOREST: A computer model for simulating the growth and reproduction of mixed species forest stands. Res. Rep. A2635. Sch. Nat. Resour., Univ. of Wisc., Madison, 13 p.

Hamilton, David A., Jr., and Bruce M. Edwards.
1976. Modeling the probability of individual tree mortality. USDA For. Serv. Res. Pap. INT-185, 22 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Hawksworth, Frank G.
1965. Life tables for two species of dwarf mistletoe I. Seed dispersal, interception, and movement. For. Sci. 11:142-151.

Hawksworth, Frank G., Thomas E. Hinds, David W. Johnson, and Thomas D. Landis.
1977. Silvicultural control of dwarf mistletoe in young lodgepole pine stands. USDA For. Serv., Reg. 2, For. Insect and Dis. Manage., Tech. Rep. R2-10. 13 p.

Innis, George.
1973. Simulation of ill-defined systems: some problems and progress. Simul. Today 9:33-36.

Knight, F. B.
1959. Partial life tables for the Black Hills beetle. J. Econ. Entomol. 52:1200-1202.

Larson, Robert W., and Marcus H. Goforth.
1974. TRAS-a timber volume projection model. USDA For. Serv. Tech. Bull. 1508. 15 p.

Lee, Yam.
1967. Stand models for lodgepole pine and limits to their application. Ph.D. Thesis, Univ. of British Columbia, Vancouver, 331 p.

Matérn, B.
1971. Doubly stochastic Poisson processes in the plane. p. 195-206. In Statistical Ecology, Vol. 1, Spatial Patterns and Statistical Distributions. G. P. Patil, E. C. Pielou, W. E. Waters, eds. Penn. State Stat. Ser.

Mitchell, K. J.
1969. Simulation of the growth of even-aged stands of white spruce. Sch. For., Yale Univ. Bull. No. 75, 48 p.

Moser, John W., Jr.
1972. Dynamics of an uneven-aged forest stand. For. Sci. 18:184-191.

Munro, Donald D.
1974. Forest growth models--a prognosis p. 7-21. In Growth models for tree and stand simulation: Proc. IUFRO working party S4.01 in 1973. Jöran Fries, ed. Royal Coll. For. Res. Notes 30, Stockholm, Sweden.

Murdie, G.
1971. Simulation of the effects of predator/parasite models of prey/host spatial distribution. p. 215-229. In Statistical Ecology, Vol. 1, Spatial Patterns and Statistical Distributions. G. P. Patil, E. C. Pielou, W. E. Waters, eds. Penn. State Stat. Ser.

Myers, Clifford A.
1974. Multipurpose silviculture in ponderosa pine stands of the Montane Zone of central Colorado. USDA For. Serv. Res. Pap. RM-132, 15 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Myers, Clifford A., Frank G. Hawksworth, and James L. Stewart.
1971. Simulating yields in managed, dwarf mistletoe-infested lodgepole pine stands. USDA For. Serv. Res. Pap. RM-72, 15 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Myers, Clifford A., Carleton B. Edminster, and Frank G. Hawksworth.
1976. SWYLD2: Yield tables for even-aged and two-storied stands of southwestern ponderosa pine, including effects of dwarf mistletoe. USDA For. Serv. Res. Pap. RM-163, 25 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Newnham, R. M.
1964. The development of a stand model for Douglas-fir. Ph.D. Thesis, Univ. of British Columbia, Vancouver, 201 p.

Peden, L. M., J. S. Williams, and W. E. Frayer.
1973. A Markov model for stand projection. For. Sci. 19:303-314

Schubert, Gilbert H.
1974. Silviculture of southwestern ponderosa pine: The status of our knowledge. USDA For. Serv. Res. Pap. RM-123, 71 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Stage, Albert R.
1973. A model for the prognosis of forest stand development. USDA For. Serv. Res. Pap. INT-137, 32 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Stage, Albert R.
1975. Prediction of height increment for models of forest growth. USDA For. Serv. Res. Pap. INT-164, 20 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Stark, R. W.
1952. Analysis of a population sampling method for the lodgepole needle miner in Canadian Rocky Mountain Parks. Can. Entomol. 84:316-321.

Strand, M. A., and L. F. Roth.
1976. Simulation model for spread and intensification of western dwarf mistletoe in thinned stands of ponderosa pine saplings. Phytopathology 66:888-895.

Zadeh, L. A.
1965. Fuzzy sets and systems. Symp. on Syst. Theory. Polytech. Press, Polytech. Inst. Brooklyn, N. Y. p. 29-37.

Program Summary

NEEDED RESEARCH AND DEVELOPMENT TO IMPROVE DWARF MISTLETOE CONTROLS[1]

J. R. Parmeter, Jr., F. G. Hawksworth, and R. F. Scharpf[2]

Abstract: The speakers at this symposium have summarized the latest information on and experience with dwarf mistletoe control through forest management. This information, developed over many years by researchers and managers, provides a firm foundation for the control strategies we have discussed these past three days. The questions raised by speakers and participants indicate that the latest word should not be the last, however. Additional information is needed to refine present approaches to control and to explore new control possibilities.

The following is a brief outline of research and development needs as they were highlighted by speakers and participants. The list is not exhaustive, nor does it provide specific details. We hope that it does indicate the scope and magnitude of the job ahead.

In the general area of dwarf mistletoe biology, some important information is lacking or incomplete. Broad aspects of host specialization have been established for most species, but needed details, especially for A. tsugense and A. occidentale/A. campylopodum, are yet unclear. The range and significance of "cross-over" possibilities and their relationship to stand conditions need clarification and evaluation. The basis for the "exclusion principle" (if the principal parasite of a certain host is present in an area, other dwarf mistletoes rarely parasitize that tree) needs investigation, since it may have important implications in the management of mixed stands.

Information on interactions among dwarf mistletoes and other forest pests is sketchy. Preliminary evidence indicates that mistletoes predispose trees to bark beetles and perhaps to root diseases, but the influence of dwarf mistletoes on bark beetle dynamics, root diseases, or other pests needs confirmation and evaluation. Animals or birds may provide for non-ballistic spread of mistletoe seeds into uninfested areas. The frequency, range, and implications of such spread need evaluation.

The incidence, behavior, and impact of dwarf mistletoes vary with differences in geography, topography, habitat type, and environment in ways that are poorly understood. Determination of the bases for these variations may permit recognition of presently unrecognized factors or stand features that limit dwarf mistletoes or their impact.

Most general relationships between forest stand dynamics and dwarf mistletoe damage are well established. Quantitative differences in these relationships among the many host/mistletoe combinations, stand types, and geographic areas are needed to establish accurate rate functions for predictive models and to provide data for sound management decisions. Among these functions, the quantification of : (1) vertical spread rates in relation to host growth and crown closure rates, (2) "laddering" or "cross-walking" rates in relation to stand density, and (3) spread, increase, and damage rates in relation to stand manipulations deserve special emphasis.

Questions regarding effects of dwarf mistletoes on wood quality needs answers in order to develop accurate impact assessments, especially where stem infections are involved.

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[1] Presented at the Symposium on Dwarf Mistletoe Control Through Forest Management, Berkeley, California, April 11-13, 1978.

[2] Respectively: Professor of Plant Pathology, Univ. of Calif., Berkeley; Forest Pathologist, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.; and Forest Pathologist, Pacific Southwest Forest and Range Experiment Station, Berkeley, Calif.

The 6 (or 7) class rating system provides a good standard to quantify dwarf mistletoe intensity, but further data on the relationship of intensity to damage with different host/mistletoe combinations under different stand conditions and management strategies are needed. Additionally, the standard intensity rating system may need modification for small trees.

A pressing need frequently mentioned is that for models to provide accurate stand growth prediction, impact assessment, and cost/benefit analysis. The development of such models for different forest types, regions, and mistletoes species should receive high priority.

Along with research directed to specific problems and needed refinements, effort should also be directed to exploratory or basic research that might lead to the development of new approaches to control. Resistance to dwarf mistletoes has been demonstrated, and possibilities for the development of resistant selections or the elaboration of resistance mechanisms should be explored. While native insects and diseases have not shown promise as biological controls, the search for effective exotic parasites of mistletoes should be continued. Satisfactory chemical controls have not been discovered, but some level of testing should continue. Either chemical or biological controls could provide valuable adjuncts to silvicultural controls.

At present, fire has proved useful mainly in clearing areas of infected residual trees following logging. Fire may also be useful in eliminating brooms or infected branches from the lower crowns of small trees, but research is needed to evaluate such uses.

As the maintenance of trees in parks, high-use recreational areas, and forest home sites becomes increasingly important, the development of special control methods (broom pruning, shoot removal, etc.) for different host/mistletoe combinations becomes increasingly important and deserving of special research effort.

We have come a long way down some important roads to dwarf mistletoe control. One job ahead is to straighten and widen these roads so that they take us most directly and efficiently to our goals. Other roads have scarcely been explored or have proved too difficult to use at present. These should be investigated, and where they show promise, developmental work should begin. Both refinement and exploration require our attention and support.

LITERATURE ON THE DWARF MISTLETOES: DAMAGE AND CONTROL

F. G. Hawksworth[1/] and R. F. Scharpf[2/]

The literature on the dwarf mistletoes (Arceuthobium spp.) is extensive. For our FAMULUS mistletoe literature retrieval system (Scharpf and others 1976) we have assembled nearly 2,500 references on these serious parasites of coniferous trees. For this literature review, we have selected the most important references dealing with damage and control of the dwarf mistletoes of the United States and Canada.

Details on nomenclature, hosts, and distribution of the dwarf mistletoes are given by Hawksworth and Wiens (1972).

1. ARCEUTHOBIUM ABIETINUM - Fir dwarf mistletoe.

   PRINCIPAL HOSTS: Abies concolor, A. magnifica, A. grandis.

   DISTRIBUTION: U.S.: Arizona, California, Nevada, Oregon, Utah, and Washington

   DAMAGE: Aho and Hadfield 1975; Byler 1975; California Forest Pest Control Action Council 1968; Craig and Maguire 1949; Fowells and Schubert 1956a; Gordon 1973a, 1973b; Gordon and Roy 1973; Hallin 1957; Kimmey 1957a, 1957b; Kimmey and Bynum 1961; Kingsley 1977; Parmeter and Scharpf 1963; Pong and Jackson 1971; Scharpf 1964, 1969b, 1977; Scharpf and Bynum 1975; Scharpf and Parmeter 1967; Wilcox and others 1973; Wright 1942.

   CONTROL: Craig and Maguire 1949; Gordon and Roy 1973; Kimmey 1957a; Kingsley 1977; Parmeter and Scharpf 1963; Scharpf 1964; 1969a, 1969b, Scharpf and Parmeter 1967.

2. ARCEUTHOBIUM AMERICANUM - Lodgepole pine dwarf mistletoe.

   PRINCIPAL HOSTS: Pinus contorta, P. banksiana.

   DISTRIBUTION: CANADA: Alberta, British Columbia, Manitoba, Ontario, and Saskatchewan. U.S.: California, Colorado, Idaho, Montana, Oregon, Utah, Washington, and Wyoming.

   DAMAGE: Alexander and others 1976; Baranyay and Safranyik 1970; Dobie and Britneff 1975; Dooling 1974; Hawksworth 1958; Hawksworth and Hinds 1964; Muir 1965; Myers and others 1971; Piirto and others 1974; Roe and Amman 1970; Weir 1916a; Ziegler 1978.

   CONTROL: Alexander 1974, 1975; Baranyay 1970, 1975; Baranyay and Smith 1972; Brown 1977; Dooling 1974; Gill and Hawksworth 1964; Hawksworth and Johnson 1961; Hawksworth and others 1977; Kimmey 1957b; Kimmey and Graham 1960; LeBarron 1952; Lotan and Alexander 1973; Schwandt 1977.

3. ARCEUTHOBIUM APACHECUM - Apache dwarf mistletoe.

   PRINCIPAL HOST: Pinus strobiformis.

   DISTRIBUTION: U.S.: Arizona, New Mexico.

   DAMAGE: Andrews and Daniels 1960; Goodding 1938; Gottfried and Embry 1977; Mathiasen 1977.

   CONTROL: Gottfried and Embry 1977.

4. ARCEUTHOBIUM BLUMERI (No common name)

   PRINCIPAL HOST: Pinus strobiformis.

   DISTRIBUTION: U.S.: Arizona

   DAMAGE: Mathiasen 1977.

   CONTROL: None.

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5. ARCEUTHOBIUM CALIFORNICUM - Sugar pine dwarf mistletoe.

PRINCIPAL HOSTS: Pinus lambertiana. P. monticola.

DISTRIBUTION: U.S.: California, Oregon.

DAMAGE: California Forest Pest Control Action Council 1968; Fowells and Schubert 1956b; Kimmey 1957b; Kingsley 1977; Offord 1961; Scharpf and Hawksworth 1968; Struble 1942, 1965; Weir 1977.

CONTROL: Scharpf and Hawksworth 1968.

6. ARCEUTHOBIUM CAMPYLOPODUM - Western dwarf mistletoe.

PRINCIPAL HOSTS: Pinus ponderosa var. ponderosa, P. jeffreyi.

DISTRIBUTION: U.S.: California, Nevada, Oregon, and Washington.

DAMAGE: Byler 1975; California Forest Pest Control Action Council 1968; Childs and Edgren 1967; Childs and Wilcox 1966; Kimmey and Mielke 1959; Kingsley 1977; Knutson 1970, 1972, Munns 1919; Parmeter and Scharpf 1972; Roth 1953, 1971; Schwandt 1977; Shea 1964a; Shea and Belluschi 1965; Strand and Roth 1976; Wagener 1961, 1965; Weir 1916a, 1918; Weir 1977.

CONTROL: Barrett 1973; Childs 1963; Flora 1966a, 1966b; Hallin 1959; Kimmey 1957b; Kimmey and Graham 1960; Kimmey and Mielke 1959; Kingsley 1977; Knutson 1975; Russell 1971; Schwandt 1977; Shea 1964b; Shea and Lewis 1971; Strand and Roth 1976; Weir 1977.

7. ARCEUTHOBIUM CYANOCARPUM - Limber pine dwarf mistletoe.

PRINCIPAL HOSTS: Pinus flexilis, P. aristata, P. albicaulis.

DISTRIBUTION: U.S.: California, Colorado, Idaho, Montana, Nevada, Utah, and Wyoming.

DAMAGE: Chick 1936; Gillman and Bailey 1977; Landis and others 1977; Urban 1968; Williams and others 1972.

CONTROL: Urban 1968.

8. ARCEUTHOBIUM DIVARICATUM - Pinyon dwarf mistletoe.

PRINCIPAL HOSTS: Pinus edulis, P. monophylla.

DISTRIBUTION: U.S.: Arizona, California, Colorado, Nevada, New Mexico, Texas, and Utah.

DAMAGE: Hreha 1978; Walters 1976.

CONTROL: None.

9. ARCEUTHOBIUM DOUGLASII: Douglas-fir dwarf mistletoe.

PRINCIPAL HOST: Pseudotsuga menziesii.

DISTRIBUTION: CANADA: British Columbia. U.S.: Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Texas, Utah, and Wyoming.

DAMAGE: Andrews and Daniels 1960, California Forest Pest Control Action Council 1968; Chick 1936; Dunning 1923; Gottfried and Embry 1977; Graham 1961; Haglund and Dooling 1972; Hawksworth and Lusher 1956; Hopkins 1959; Hutchinson and Roe 1962; Jones 1974; Kimmey and Graham 1960; Kingsley 1977; Pierce 1960; Schwandt 1977; Shea 1960, 1963a, 1963b; Weir 1916a, 1918.

CONTROL: Baranyay and Smith 1972; Graham 1961; Jones 1974; Kimmey 1957b; Kimmey and Graham 1960; Kingsley 1977; Schwandt 1977; Shea 1960, 1963a; Wellner and Ryker 1973.

10. ARCEUTHOBIUM GILLII - Chihuahua pine dwarf mistletoe.

PRINCIPAL HOST: Pinus chihuahuana.

DISTRIBUTION: U.S.: Arizona, New Mexico.

DAMAGE: Loomis 1972; Walters 1976.

CONTROL: Walters 1976.

11. ARCEUTHOBIUM LARICIS - Larch dwarf mistletoe.

PRINCIPAL HOST: Larix occidentalis.

DISTRIBUTION: CANADA: British Columbia. U.S.: Idaho, Montana, Oregon, and Washington.

DAMAGE: Baranyay and Smith 1972; Boe 1958; Dooling 1971; Graham 1960, 1964; Hutchinson and Roe 1962; McGregor and Williams 1974; On and Dooling 1969; Pierce 1960; Schwandt 1977; Smith and Baranyay 1970; Weir 1916a, 1916b; Weir 1977.

CONTROL: Baranyay and Smith 1972; Dooling 1971, 1974; Kimmey and Graham 1960; Schwandt 1977; Smith and Baranyay 1970; Weir 1916a; Weir 1977.

12. ARCEUTHOBIUM MICROCARPUM - Western spruce dwarf mistletoe.

PRINCIPAL HOSTS: Picea engelmannii, P. pungens.

DISTRIBUTION: U.S.: Arizona, New Mexico.

DAMAGE: Acciavatti and Weiss 1974; Andrews and Daniels 1960; Gottfried and Embry 1977; Hawksworth and Graham 1963; Jones 1974; Mathiasen 1977; Walters 1976.

CONTROL: Gottfried and Embry 1977; Jones 1974; Walters 1976.

13. ARCEUTHOBIUM OCCIDENTALE - Digger pine dwarf mistletoe.

PRINCIPAL HOSTS: Pinus sabiniana, P. radiata, P. muricata.

DISTRIBUTION: U.S.: California.

DAMAGE: California Forest Pest Control Action Council 1968; Hawksworth 1969; Offord 1960; Peirce 1905; Roy 1966.

CONTROL: Kimmey 1957b.

14. ARCEUTHOBIUM PUSILLUM - Eastern dwarf mistletoe.

PRINCIPAL HOSTS: Picea mariana, P. glauca.

DISTRIBUTION: CANADA: Manitoba, New Brunswick, Newfoundland, Nova Scotia, Ontario, Prince Edward Island, Quebec, Saskatchewan. U.S.: Connecticut, Maine, Massachusetts, Michigan, Minnesota, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and Wisconsin.

DAMAGE: Anderson 1949; Anderson and Kaufert 1959; Anderson and Moser 1977; Brower 1960; Doerner 1975; Ostry and Nicholls 1976; Pomerleau 1942.

CONTROL: Anderson 1949; Anderson and Kaufert 1953; Doerner 1975; French and others 1968; Johnston 1977; LeBarron 1948; Nash 1955.

15. ARCEUTHOBIUM TSUGENSE - Hemlock dwarf mistletoe.

PRINCIPAL HOSTS: Tsuga heterophylla, T. mertensiana.

DISTRIBUTION: CANADA: British Columbia, U.S.: Alaska, California, Oregon, and Washington.

DAMAGE: Baranyay and Smith 1972; Etheridge 1973; Hunt 1971; Kingsley 1977; Shea and Stewart 1972; Smith 1969; Sterling 1962; Wellwood 1956.

CONTROL: Baranyay and Smith 1972; Buckland and Marples 1952; Driver 1975; Graham 1967; Kimmey 1957b; Kingsley 1977; Russell 1966, 1971; Shea 1966; Shea and Stewart 1972; Smith and Baranyay 1970; Sterling 1962; Stewart 1976.

16. ARCEUTHOBIUM VAGINATUM subsp. CRYPTOPODUM - Southwestern dwarf mistletoe.

PRINCIPAL HOSTS: Pinus ponderosa var. scopulorum, P. ponderosa var. arizonica, P. engelmannii.

DISTRIBUTION: U.S.: Arizona, Colorado, New Mexico, Texas, and Utah.

DAMAGE: Andrews and Daniels 1960; Edminster and Hawksworth 1976; Gill 1954; Gill and Hawksworth 1954; Gottfried and Embry 1977; Hawksworth 1961; Hawksworth and Lusher 1956; Kortian and Long 1922; Lightle 1966; Lightle and Hawksworth 1973; Lightle and Weiss 1974; Myers and others 1976; Pearson 1950.

CONTROL: Edminster and Hawksworth 1976; Gill 1954; Gill and Hawksworth 1954; Hawksworth 1961; Hawksworth and Andrews 1961; Hawksworth and others 1968; Heidmann 1968; Lightle and others 1967; Lightle and Hawksworth 1973; Lightle and Weiss 1974; Mark and Hawksworth 1974; Myers and others 1976; Pearson 1950; Schubert 1974; Walters 1978.

LITERATURE CITED

Acciavatti, Robert E, and Melvyn J. Weiss.
1974. Evaluation of dwarf mistletoe on Engelmann spruce, Fort Apache Indian Reservation, Arizona. Plant Dis. Rep. 58:418-419.

Aho, Paul, and Jim Hadfield.
1975. How to estimate defect in white fir in south-central Oregon. U.S. For. Serv., Pacific Northwest For. and Range Exp. Stn., Unnumbered Publ., 10 p.

Alexander, N.E., J. H. Borden, and J. M. Vakenti.
1976. A pest management study of a mountain pine beetle outbreak in tree farm license Number 9. Simon Fraser Univ., B.C., Pest Manage. Pap. No. 8, 109 p.

Alexander, Robert R.
1974. Silviculture of subalpine forests in the central and southern Rocky Mountains: The status of our knowledge. USDA For. Serv. Res. Pap. RM-121, 88 p.

Alexander, Robert R.
1975. Partial cutting in old-growth lodgepole pine. USDA For. Serv. Res. Pap. RM-136, 17 p., Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Anderson, Ralph L.
1949. The black spruce dwarf mistletoe in Minnesota. MS thesis, Univ. of Minn., St. Paul, Minn., 139 p.

Anderson, Ralph L., and F. H. Kaufert.
1953. The control of dwarf mistletoe on black spruce. Univ. Minnesota For. Notes 13:1-2.

Anderson, Ralph L., and F. H. Kaufert.
1959. Brooming response of black spruce to dwarfmistletoe infection. For. Sci. 5:356-364.

Anderson, Robert L., and D. G. Mosher.
1977. Occurrence of eastern dwarf mistletoe on black spruce in six national forests in the Lake states. USDA For. Serv. Northeast Area, For. Insect and Dis. Manage. Rep. S-1-77, 8 p.

Andrews, Stuart R., and John P. Daniels.
1960. A survey of dwarfmistletoes in Arizona and New Mexico. U.S. Dep. Agric., For. Serv., Rocky Mt. For. and Range Exp. Stn. Stn. Pap. 49, 17 p.

Baranyay, J. A.
1970. Lodgepole pine dwarf mistletoe in Alberta. Can. Dep. Fish. and For., For. Serv. Publ. 1286, 22 p.

Baranyay, J. A.
1975. Dwarf mistletoe as a factor in the management of lodgepole pine forests in Western Canada. Manage. of Lodgepole Pine Ecosystems, Symp. Proceed., Wash. State Univ., D. A. Baumgartner (ed.), Vol. 1:359-367.

Baranyay, J. A., and L. Safranyik.
1970. Effect of dwarf mistletoe on growth and mortality of lodgepole pine stands in Alberta. Can. Dep. Fish. and For., For. Serv. Publ. 1285, 19 p.

Baranyay, J. A., and R. B. Smith.
1972. Dwarf mistletoes in British Columbia and recommendations for their control. Can. For. Serv. Rep. BC-X-72, 18 p.

Barrett, James W.
1973. Northwestern ponderosa pine. In Silvicultural systems for the major forest types of the United States. U.S. Dep. Agric., Agric. Handb. 445, p. 17-19.

Boe, K. M.
1958. Silvics of western larch. U.S. Dep. Agric., For. Serv. Intermt. For. and Range Exp. Stn. Misc. Publ. 16, 17 p.

Brower, A. E.
1960. Dwarf mistletoe in Maine. Maine Field Nat. 16(2):35-38.

Brown, Donald H.
1977. Management guidelines for lodgepole pine stands infected with comandra blister rust and dwarf mistletoe. USDA For. Serv., Rocky Mt. Reg., For. Insect and Dis. Manage. Tech. Rep. R2-9, 21 p.

Buckland, D. C., and E. G. Marples.
1952. Management of western hemlock infested with dwarf mistletoe. British Columbia Lumberman 36(5):50-51, 136, 138, 140.

Byler, James W.
1975. Pest damage inventory. Proc. 22nd West. Int. For. Dis. Work Conf., 1975: 30-34.

California Forest Pest Control Action Council.
1968. Forest pest conditions in California - 1967. Calif. Div. Forest., Sacramento, Calif. 24 p.

Chick, W. F.
1936. Line transect survey, season of 1935, Bryce Canyon National Park. U.S. Dep. Interior, Natl. Park Serv. Rep., 40 p.

Childs, T. W.
1963. Dwarfmistletoe control opportunities in ponderosa pine reproduction. Pacific Northwest For. and Range Exp. Stn., Portland, Oreg., 19 p.

Childs, T. W., and J. W. Edgren.
1967. Dwarfmistletoe effects on ponderosa pine growth and trunk form. For. Sci. 13:167-174.

Childs, T. W., and Earle R. Wilcox.
1966. Dwarfmistletoe effects in mature ponderosa pine forests in south-central Oregon. J. For. 64:246-250.

Craig, G. A., and W. P. Maguire.
1949. The California pine region forest handbook. Calif. State Board For. 193 p.

Dobie, J., and A. A. Britneff.
1975. Lumber grades and volumes from lodgepole pine infected with dwarf mistletoe. Wood and Fiber 7:104-109.

Doerner, R. G.
1975. Northeastern States (R-9). In Forest insect and disease conditions in the United States - 1973. p. 46-51. U.S. Dep. Agric., For. Serv., Washington, D.C.

Dooling, Oscar J.
1971. Dwarf mistletoe in the Northern Region. USDA For. Serv., Northern Reg., Div. of State and Private For. Insect and Dis. Rep. 15 p., Missoula, Mont.

Dooling, Oscar J.
1974. Dwarf mistletoe control...why and what? USDA For. Serv., Northern Reg., For. Environ. Prot. Rep. 74-16, Missoula, Mont. 11 p.

Driver, Charles H.
1975. (R_X) Prescription for protective management in hemlock. West. For. and Conserv. Assoc. Perm. Assoc. Committees Proc., p. 143-145.

Dunning, Duncan.
1923. Some results of cutting in the Sierra forests of California. U.S. Dep. Agric. Bull. 1176, 27 p.

Edminster, Carleton B., and Frank G. Hawksworth.
1976. User's guide to SWYLD2: Yield tables for even-aged and two-storied stands of southwestern ponderosa pine, including effects of dwarf mistletoe. USDA For. Serv. Gen. Tech. Rep. RM-23, 8 p., Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Etheridge, D. E.
1973. Wound parasites causing tree decay in British Columbia. Can. Dep. Environ. For. Serv., Pacific For. Res. Cent. For. Pest Leafl. 62, 15 p.

Flora, Donald F.
1966a. Economic guides for ponderosa pine dwarfmistletoe control in young stands of the Pacific Northwest. U.S. For. Serv. Res. Pap. PNW-29, 16 p. Pacific Northwest For. and Range Exp. Stn., Portland, Oreg.

Flora, Donald F.
1966b. A method of forecasting returns from ponderosa pine dwarf mistletoe control. U.S. For. Serv. Res. Pap. PNW-132, 17 p. Pacific Northwest For. and Range Exp. Stn., Portland, Oreg.

Fowells, H. A., and G. H. Schubert.
1956a. Seed crops of forest trees in the pine region of California. U. S. Dep. Agric. Tech. Bull. 1150, 48 p.

Fowells, H. A., and G. H. Schubert.
1956b. Silvical characteristics of sugar pine. U. S. Dep. Agric., For. Serv. Calif. For. and Range Exp. Stn. Tech. Pap. 14, 19 p.

French, D. W., M. P. Meyer, and R. L. Anderson.
1968. Control of dwarfmistletoe on black spruce. J. For. 66:359-360.

Gill, L. S.
1954. Dwarfmistletoe of ponderosa pine in the Southwest. U. S. Dep. Agric., For. Serv., Rocky Mt. For. and Range Exp. Stn., Stn. Pap. 14, 9 p.

Gill, L. S., and F. G. Hawksworth.
1954. Dwarfmistletoe control in Southwestern ponderosa pine forests under management. J. For. 52(5):347-353.

Gill, L. S., and F. G. Hawksworth.
1964. Dwarfmistletoe of lodgepole pine. U.S. Dep. Agric., For. Pest Leafl. 18, 7 p.

Gillman, Linnea S., and Wilmer F. Bailey.
1977. Forest insect and disease management annual report, Rocky Mountain Region, 1976. USDA For. Serv., Rocky Mt. Reg., For. Insect and Dis. Manage. 56 p.

Goodding, L. N.
1938. Notes on native and exotic plants of Region 8 with special reference to their value in the soil conservation program. U.S. Dep. Agric., Soil Conserv. Serv. 152 p.

Gordon, Donald T.
1973a. Damage from wind and other causes in mixed white fir-red fir stands adjacent to clearcuttings. USDA For. Serv. Res. Pap. PSW-90, 22 p., Pacific Southwest For. and Range Exp. Stn., Berkeley, Calif.

Gordon, Donald T.
1973b. Released advance reproduction of white and red fir...growth, damage, mortality. USDA For. Serv. Res. Pap. PSW-95, 12 p., Pacific Southwest For. and Range Exp. Stn., Berkeley, Calif.

Gordon, Donald T., and Douglass F. Roy.
1973. Red fir-white fir. In Silvicultural systems for the major forest types of the United States. U.S. Dep. Agric., Agric. Handb. 445, 124 p.

Gottfried, Gerald J., and Robert S. Embry.
1977. Distribution of Douglas-fir and ponderosa pine dwarf mistletoe in a virgin Arizona mixed conifer stand. USDA For. Serv. Res. Pap. RM-192, 16 p., Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Graham, Donald P.
1960. Surveys expose dwarfmistletoes problem in Inland Empire. West. Conserv. J. 17 (1):56-58.

Graham, Donald P.
1961. Dwarfmistletoes of Douglas-fir. U.S. Dep. Agric., For. Pest Leafl. 54, 4 p.

Graham, Donald P.
1964. Dwarfmistletoe survey in western Montana. U.S. For. Serv. Res. Note INT-14, 7 p., Intermt. For. and Range Exp. Stn., Ogden, Utah.

Graham, Donald P.
1967. A training aid on dwarfmistletoe and its control. U.S. For. Serv., Pacific Northwest Region, Misc. Publ., Portland, Oreg.

Haglund, Stephen A., and Oscar J. Dooling.
1972. Observations on the impact of dwarf mistletoe on Douglas-fir in western Montana. USDA For. Serv., Insect and Dis. Rep. D-72-1, Northern Region, Missoula, Mont. 6 p.

Hallin, W. E.
1957. Silvical characteristics of red fir and shasta red fir. U.S. Dep. Agric., For. Serv., Calif. For. and Range Exp. Stn., Tech. Pap. 16, Berkeley, Calif., 8 p.

Hallin, William E.
1959. The application of unit area control in the management of ponderosa-Jeffrey pine at Blacks Mountain Experimental Forest. U.S. Dep. Agric. Tech. Bull. 1191, 96 p.

Hart, Dennis R., and Charles H. Driver.
1970. Protection aspects of western hemlock. Univ. of Washington, Coll. of For. Resour. Institute of For. Prod., For. Res. Monogr. 10, 121 p.

Hawksworth, F. G.
1958. Survey of lodgepole pine dwarfmistletoe on the Roosevelt, Medicine Bow, and Bighorn National Forests. U.S. Dep. Agric., Rocky Mt. For. and Range Exp. Stn., Stn. Pap. 35, 13 p.

Hawksworth, F. G.
1961. Dwarfmistletoe of ponderosa pine in the Southwest. U.S. Dep. Agric. Tech. Bull. 1246, 112 p.

Hawksworth, Frank G.
1969. Rapid intensification and upward spread of dwarf mistletoe in inoculated digger pines. Plant Dis. Rep. 53(8):615-617.

Hawksworth, F. G., and S. R. Andrews.
1961. Guides for pruning dwarfmistletoe-infected ponderosa pine branches. U.S. Dep. Agric., For. Serv., Rocky Mt. For. and Range Exp. Stn. Res. Note 64, 3 p., Fort Collins, Colo.

Hawksworth, F. G., and D. P. Graham.
1963. Dwarfmistletoes on spruce in the Western United States. Northwest Sci. 37:31-38.

Hawksworth, F. G., and T. E. Hinds.
1964. Effects of dwarfmistletoe on immature lodgepole pine stands in Colorado. J. For. 62:27-32.

Hawksworth, F. G., and N. E. Johnson.
1961. Guides for pruning dwarfmistletoe infected lodgepole pine branches. U.S. Dep. Agric., For. Serv., Rocky Mt. For. and Range Exp. Stn., Res. Note 65, 3 p.

Hawksworth, F. G., and A. A. Lusher.
1956. Dwarfmistletoe survey and control on the Mescalero Apache Reservation, New Mexico. J. For. 54:384-390.

Hawksworth, F. G., J. L. Stewart, and W. F. Bailey.
1968. You can save your pines from dwarf mistletoe. U. S. For. Serv. Res. Pap. RM-35, 20 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Hawksworth, F. G., and D. Wiens.
1972. Biology and classification of dwarf mistletoes (Arceuthobium). U.S. Dep. Agric., Agric. Handb. 401, 234 p.

Hawksworth, F. G., T. E. Hinds, D. W. Johnson, and T. D. Landis.
1977. Silvicultural control of dwarf mistletoe in young lodgepole pine stands. USDA For. Serv., Rocky Mt. Region, For. Insect and Dis. Manage., Tech. Rep. R2-10, 12 p.

Heidmann, L. J.
1968. Silvicultural control of dwarf mistletoe in heavily infected stands of ponderosa pine in the Southwest. U.S. For. Serv. Res. Pap. RM-36, 11 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Hopkins, H. G.
1959. Salvaging mistletoe-damaged timber. Proc. 49th Western For. Conf. 1958:36-39, San Francisco, Calif., West. For. and Conserv. Assoc., Portland, Oreg.

Hreha, Alyce M.
1978. A comparative distribution of two mistletoes: Arceuthobium divaricatum and Phoradendron juniperinum (South Rim, Grand Canyon National Park, Arizona). MS thesis, Brigham Young Univ., Provo, Utah, 62 p.

Hunt, K.
1971. A comparison of Kraft pulping of sound and dwarf mistletoe-infected western hemlock wood. Can. Dep. Fish. and For., For. Prod. Lab., Vancouver, Inf. Rep. VP-X-78, 7 p., Vancouver, B.C.

Hutchison, S. B., and A. L. Roe.
1962. Management for commercial timber, Clark Fork Unit, Montana. U.S. Dep. Agric., For. Serv. Intermt. For. and Range Exp. Stn. Res. Pap. 65, 32 p.

Johnston, William F.
1977. Manager's handbook for black spruce in the north-central states. USDA For. Serv. Gen. Tech. Rep. NC-34, 18 p. North-central For. Exp. Stn., St. Paul, Minn.

Jones, John R.
1974. Silviculture of southwestern mixed conifers and aspen: The status of our knowledge. USDA For. Serv. Res. Pap. RM-122, 44 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Kimmey, J. W.
1957a. Application of indicator cull factors to white and red fir stands in the Sierra Nevada. U.S. Dep. Agric., For. Serv., Calif. For. and Range Exp. Stn. For. Res. Note 127, 5 p. Berkeley, Calif.

Kimmey, J. W.
1957b. Dwarfmistletoes of California and their control. U.S. Dep. Agric., For. Serv., Calif. For. and Range Exp. Stn., Tech. Pap. 19, 12 p. Berkeley, Calif.

Kimmey, James W., and Donald P. Graham
1960. Dwarfmistletoes of the Intermountain and northern Rocky Mountain regions and suggestions for control. U.S. Dep. Agric., For. Serv., Intermt. For. and Range Exp. Stn., Stn. Res. Pap. 60, 19 p.

Kimmey, J. W., and H. H. Bynum.
1961. Heart rots of red and white firs. U.S. Dep. Agric., For. Pest Leafl. 52, 4. p.

Kimmey, J. W., and J. L. Mielke.
1959. Western dwarfmistletoe on ponderosa pine. U.S. Dep. Agric., For. Pest Leafl. 40, 7 p.

Kingsley, Duane.
1977. Management of conifer stands infected with dwarf mistletoe in southwest Oregon. Proc. 24th Western Internatl. For. Dis. Work Conf., 1976:51-54, Victoria, B.C.

Korstian, C. F., and W. H. Long.
1922. The western yellow pine mistletoe: Effect on growth and suggestions for control. U. S. Dep. Agric. Bull. 1112, 35 p.

Landis, T., R. Averill, and R. Frye.
1977. Central rocky mountains (R-2). In Forest Insect and Disease Conditions in the United States, 1974. p.28-32. U.S. Dep. Agric., For. Serv., Washington, D.C.

LeBarron, Russel K.
1948. Silvicultural management of black spruce in Minnesota. U.S. Dep. Agric., Circ. 791, 60 p.

LeBarron, R. K.
1952. Silvicultural practices for lodgepole pine in Montana. U.S. Dep. Agric., For. Serv. North. Rocky Mt. For. and Range Exp. Stn., Stn. Pap. 33, 19 p.

Lightle, Paul C.
1966. Dwarf mistletoe reduces basal area growth in ponderosa pine in the Southwest (Abstr.). Phytopathology 56:886-887.

Lightle, P. C., S. R. Andrews, and W. E. Mouser.
1967. Recleaning the dwarfmistletoe control area on the Mescalero Apache Reservation, New Mexico. J. For. 65(11):816-817.

Lightle, Paul C., and Frank G. Hawksworth.
1973. Control of dwarf mistletoe in a heavily used ponderosa pine recreation forest: Grand Canyon, Arizona. USDA For. Serv. Res. Pap. RM-106, 22 p., Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Lightle, Paul C., and Melvyn J. Weiss.
1974. Dwarf mistletoe of ponderosa pine in the Southwest. U. S. Dep. Agric. For. Pest Leafl. 19 (Rev.), 8 p.

Loomis, Robert C.
1972. Disease detection survey. Air Pollution, Coronado National Forest, Arizona. USDA For. Serv. Southwest. Reg., For. Insect and Dis. Manage. Br., 12 p.

Lotan, J. E., and R. R. Alexander.
1973. Lodgepole pine. In Silvicultural systems for the major forest types of the United States, p. 42-44. U.S. Dep. Agric., Handb. 445.

McGregor, M. D., and R. E. Williams.
1974. Forest insect and disease conditions. Northern Region. USDA For. Serv., North. Reg., Div. State and Priv. For. Rep. 74-1, 24 p.

Mark, Walter R., and Frank G. Hawksworth.
1974. How important are bole infections in spread of ponderosa pine dwarf mistletoe? J. For. 72:146-147.

Mathiasen, Robert L.
1977. The taxonomy and epidemiology of dwarf mistletoes parasitizing white pines in Arizona. Ph.D. thesis, Univ., of Ariz., Tucson, Ariz.

Muir, J. A.
1965. Dwarf mistletoe, Arceuthobium americanum Nutt. ex Engelm. (c). Parasitic effects and reproductive ability of dwarf mistletoe. Can. Dep. For., For. Entomol. & Pathol. Br. Ann. Rep. 1965:130-131.

Munns, E. N.
1919. Effect of fertilization on the seed of Jeffrey pine. Plant World 22:138-144.

Myers, Clifford A., Carleton B. Edminster, and Frank G. Hawksworth.
1976. SWYLD2:Yield tables for even-aged and two-storied stands of southwestern ponderosa pine, including effects of dwarf mistletoe. USDA For. Serv. Res. Pap. RM-163, 25 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Myers, Clifford A., Frank G. Hawksworth, and James L. Stewart.
1971. Simulating yields of managed, dwarf mistletoe-infested lodgepole pine stands. USDA For. Serv., Res. Pap. RM-72, 15 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Nash, R. W.
1955. Dwarf or false mistletoe (Arceuthobium pusillum Peck). Maine Forest. Comm., Bienn. Rep. 30 (1953-1954):126-127.

Offord, H.
1960. Pest conditions in California - 1959. In Western For. Pest Conditions 1959. p. 12-13. Western Forest and Conserv. Assoc., Portland, Oreg.

Offord. H. R.
1961. Forest diseases in California. Problems and research program of the Pacific Southwest Station. U.S. Dep. Agric., For. Serv., Pacific Southwest For. and Range Exp. Stn., Tech. Pap. 60, 29 p.

On, D., and O. J. Dooling.
1969. A study of the effect of dwarf mistletoe infection on the growth of western larch. U.S. For. Serv., Div. of Timber Manage. and State and Priv. Forest., Northern Reg. (Unpubl.), Missoula, Mont. 7 p.

Ostry, M. E., and T. H. Nicholls.
1976. How to identify eastern dwarf mistletoe on black spruce. USDA For. Serv. North Cent. Exp. Stn., St. Paul, Minn., 5 p.

Parmeter, J. R., Jr., and R. F. Scharpf.
1963. Dwarfmistletoe on red fir and white fir in California. J. For. 61:371-374.

Parmeter, J. R., Jr., and R. F. Scharpf.
1972. Spread of dwarf mistletoe from discrete seed sources into young stands of ponderosa and Jeffrey pines. USDA, For. Serv. Res. Note PSW-269, 5 p. Pacific Southwest For. and Range Exp. Stn., Berkeley, Calif.

Pearson, G.A.
1950. Management of ponderosa pine in the Southwest. U.S. Dep. Agric., For. Serv. Agric. Monogr. 6, 218 p.

Peirce, G. J.
1905. The dissemination and germination of Arceuthobium occidentale Eng. Ann. Bot. 19:99-113.

Pierce, William R.
1960. Dwarf mistletoe and its effect upon the larch and Douglas fir of western Montana. Montana State Univ., Sch. of For. Bull. 10, 38 p. Missoula, Mont.

Piirto, Douglas D., Donald L. Crews, and Harry E. Troxell.
1974. The effects of dwarf mistletoe on the wood properties of lodgepole pine. Wood and Fiber 6:26-35.

Pomerleau, R.
1942. Le gui de l' epinnette noire dans le Quebec. Natur. Can. 69:11-31.

Pong, W. Y., and G. H. Jackson.
1971. Diagramming surface characteristics of true fir logs. Supplement to log diagramming guide for western softwoods. USDA For. Serv., Pacific Northwest For. and Range Exp. Stn., Portland, Oreg.

Roe, Arthur L., and Gene D. Amman.
1970. The mountain pine beetle in lodgepole pine forests. USDA For. Serv. Res. Pap. INT-71, 23 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Roth, L. F.
1953. Pine dwarfmistletoe on the Pringle Falls Experimental Forest. U.S. Dep. Agric. For. Serv., Pacific Northwest For. and Range Exp. Stn., Res. Note 91, 3 p. Portland, Oreg.

Roth, L. F.
1971. Dwarf mistletoe damage to small ponderosa pines. For. Sci. 17:373-380.

Roy, Douglass F.
1966. Silvical characteristics of Monterey pine (Pinus radiata [D. Don]). U.S. For. Serv. Res. Pap. PSW-31, 21 p. Pacific Southwest For. and Range Exp. Stn., Berkeley, Calif.

Russell, K. W.
1966. Dwarfmistletoe control in state parks. Washington State Dep. Nat. Res., For. Land Manage. Bull. 3, 10 p.

Russell, Kenelm W.
1971. Precommercial thinning in dwarf-mistletoe control. In Precommercial thinning of coastal and intermountain forests in the Pacific Northwest. Symp. Proc., D. M. Baumgartner, (ed.), p. 23-40, Wash. State Univ., Pullman, Wash.

Scharpf, Robert F.
1964. Dwarfmistletoe on true firs in California. U.S. Dep. Agric., For. Pest Leafl. 89, 7 p.

Scharpf, Robert F.
1969a. Dwarf mistletoe on red fir...infection and control in understory stands. U.S. For. Serv. Res. Pap. PSW-50, 8 p. Pacific Southwest For. and Range Exp. Stn., Berkeley, Calif.

Scharpf, Robert F.
1969b. Cytospora abietis associated with dwarf mistletoe on true firs in California. Phytopathology 59:1657-1658.

Scharpf, Robert F.
1977. Dwarf mistletoe does not increase trunk taper in released red firs in California. USDA For. Serv. Res. Note PSW-326, 3 p. Pacific Southwest For. and Range Exp. Stn., Berkeley, Calif.

Scharpf, Robert F., and H. H. Bynum.
1975. Cytospora canker of true firs. U.S. Dep. Agric. For. Pest Leafl. 146, 5 p.

Scharpf, Robert F., and F. G. Hawksworth.
1968. Dwarf mistletoe on sugar pine. U.S. Dep. Agric. For. Pest Leafl. 113, 4 p.

Scharpf, Robert F., Frank G. Hawksworth, and Bernard J. Erickson.
1976. Mistletoe literature of the world: A user's guide to a FAMULUS retrieval system. USDA For. Serv. Gen. Tech. Rep. RM-30, 5 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Scharpf, R. F., and J. R. Parmeter, Jr.
1967. The biology and pathology of dwarf-mistletoe Arceuthobium campylopodum f. abietinum, parasitizing true firs (Abies spp.) in California. U.S. Dep. Agric., Tech. Bull. 1362, 42 p.

Schubert, Gilbert H.
1974. Silviculture of southwestern ponderosa pine: The status of our knowledge. USDA For. Serv. Res. Pap. RM-123, 71 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Schwandt, John W.
1977. Dwarf mistletoe control guidelines for Idaho forests. Idaho Div. For. Res., Bur. Priv. For., For. Insect and Dis. Control Rep. 77-2, 13 p.

Shea, Keith R.
1960. Dwarfmistletoe of Douglas-fir in Oregon and Washington. Weyerhaeuser Co., For. Dep. Bull. 4 p., Feb. 1960.

Shea, Keith R.
1963. Marking guide evolved for mistletoe-hit Douglas fir. For. Indus. 90(1):58-59, Jan. 1963.

Shea, Keith R.
1964a. Diameter increment of ponderosa pine infected with dwarfmistletoe in south-central Oregon. J. For. 62:743-748.

Shea, K. R.
1964b. Silvicultural control of ponderosa pine dwarfmistletoe in south-central Oregon - A five-year study. J. For. 62:871-875.

Shea, Keith R.
1966. Dwarfmistletoe of coastal western hemlock: principles and practices for control. Weyerhaeuser For. Pap. No. 9, 14 p.

Shea, Keith R.,and Peter G. Belluschi.
1965. Effects of dwarfmistletoe on diameter increment of immature ponderosa pine before and after partial logging. Weyerhaeuser For. Pap. 4, 7 p.

Shea, Keith R., and David K. Lewis.
1971. Occurrence of dwarf mistletoe in sanitized ponderosa pine in south-central Oregon. Northwest Sci. 45:94:99.

Shea, K. R., and J. L. Stewart.
1972. Hemlock dwarf mistletoe. U.S. Dep. Agric. For. Pest Leafl. 135, 6 p.

Smith, R. B.
1969. Assessing dwarf mistletoe on western hemlock. For. Sci. 15:277-285.

Smith, R. B., and J. A. Baranyay.
1970. Dwarf mistletoe in British Columbia. Can. Dep. Fisheries and Forest., Victoria For. Serv., Victoria, B. C.

Sterling, R. T.
1962. Dwarfmistletoes parasite of western hemlock. Proc. Fifth World For. Congr., Seattle, Wash., 1960, Vol. II:893-896.

Stewart, James L.
1976. Dwarf mistletoe infection from residual hemlock on cutover stands. USDA For. Serv. Res. Note PNW-278, 3 p. Pacific Northwest For. and Range Exp. Stn., Portland, Oreg.

Strand, M. A., and L F. Roth.
1976. Simulation model for spread and intensification of western dwarf mistletoe in thinned stands of ponderosa pine saplings. Phytopathology 66:888-895.

Struble, G. R.
1942. Crown decadence of sugar pine in relation to attacks by the mountain pine beetle. Prelim. Rep. U.S. Dep. Agric., Bur. Entomol. and Plant Quarantine, For. Ins. Lab., Berkeley, Calif. [Unpubl.]

Struble, G. R.
1965. Attack pattern of mountain pine beetle in sugar pine stands. U.S. For. Serv. Res. Note PSW-60, 7 p. Pacific Southwest For. and Range Exp. Stn., Berkeley, Calif.

Urban, Karl A.
1968. An ecological appraisal of the dwarfmistletoe problem at Craters of the Moon National Monument, Idaho. M.S. thesis, 89 p., Univ. Idaho, Moscow, Idaho.

Wagener, Willis W.
1961. Forty years of dwarfmistletoe on a ponderosa pine plot near Quincy, California. U.S. Dep. Agric., For. Serv., Pacific Southwest For. and Range Exp. Stn., Berkeley, Calif.

Wagener, Willis W.
1965. Dwarfmistletoe removal and reinvasion in Jeffrey and ponderosa pine, northeastern California. U.S. For. Serv. Res. Note PSW-73, 8 p., Pacific Southwest For. and Range Exp. Stn., Berkeley, Calif.

Walters, James W.
1976. A guide to mistletoes of Arizona and New Mexico. USDA For. Serv., Southwest Reg., For. Insect and Dis. Manage., 7 p. Albuquerque, N. Mex.

Walters, James W.
1978. Simulated yield tables for dwarf mistletoe management in ponderosa pine stands (SWYLD2 Program), Phase I. Two-storied stands, 1977. USDA For. Serv., Southwestern Reg., For. Insect and Dis. Manage. Tech. Rep., R-3 78-7, 22 p. Albuquerque, N. Mex.

Weir, James R.
1916a. Mistletoe injury to conifers in the Northwest. U.S. Dep. Agric. Bull. 360, 39 p.

Weir, James R.
1916b. Larch mistletoe: some economic considerations of its injurious effects. U. S. Dep. Agric. Bull. 317, 25 p.

Weir, James R.
1918. Effects of mistletoe on young conifers. J. Agric. Res. 12(11):715-718.

Weir, L. C.
1977. Dwarf mistletoes in Oregon. Oregon State For. Dep., For. Insect and Dis. Notes. 25 p.

Wellner, Charles A., and Russell A. Ryker.
1973. Ponderosa pine and Rocky Mountain Douglas-fir. In Silvicultural systems for the major forest types of the United States. U.S. Dep. Agric., Agric. Handb. 445, p. 35-37.

Wellwood, R. W.
1956. Some effects of dwarf mistletoe on hemlock. For. Chronicle 32(3):282-296, Sept. 1956.

Wilcox, W. Wayne, W. Y. Pong, and J. R. Parmeter.
1973. Effects of mistletoe and other defects on lumber quality in white fir. Wood and Fiber 4:272-277.

Williams, Wayne T., Freida Fortier, and John Osborn.
1972. Distribution of three species of dwarf mistletoe on their principal pine hosts in the Colorado Front Range. Plant Dis. Rep. 56:223-227.

Wright, Ernest.
1942. Cytospora abietis, the cause of a canker of true firs in California and Nevada. J. Agric. Res. 65:143-153.

Ziegler, Robert S.
1978. The vegetation dynamics of Pinus contorta forest, Crater Lake National Park, Oregon. M.S. thesis, Oregon State Univ., Corvallis, Oreg. [Unpubl.]