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Control of Dwarf Mistletoe in a Heavily Used Ponderosa Pine Recreation Forest at Grand Canyon, Arizona

by

Paul C. Lightle, Principal Plant Pathologist

and

Frank G. Hawksworth, Principal Plant Pathologist
Rocky Mountain Forest and Range Experiment Station[1/]

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Introduction

Southwestern dwarf mistletoe (Arceuthobium vaginatum subsp. cryptopodum (Engelm.) Hawks. & Weins) has long been known as a serious disease of ponderosa pine (Pinus ponderosa Laws.) on the South Rim of Grand Canyon, Arizona, where mortality caused by this disease was recorded before the turn of the century (MacDougal 1899). Concern about the dwarf mistletoe situation along the South Rim was expressed by the National Park Service as early as 1933.[2/] The severity of the infestation was noted by Gill (1940, 1946) and Mielke (1945), and National Park Service personnel were becoming increasingly concerned over the impact that dwarf mistletoe was making in the ponderosa pine stands east of Grand Canyon Village. Severe mortality in pole-sized and mature pines was occurring and the growth of trees in all size classes was seriously affected. However, a factor of even more consequence to the esthetics of the area was the observation that in some places, the ponderosa pine type was being replaced by Gambel oak (Quercus gambelii Nutt.).

In August 1947, at the request of the National Park Service, Division of Forest Pathology personnel[3/] met with Park Service personnel[4/] to review the situation on the ground. As a result of this meeting the Division of Forest Pathology was requested to make a preliminary study to determine (1) the need for, and feasibility of, control and (2) the general procedures to be followed if control was to be practiced. The survey was made in the fall of 1947 and the results summarized in a report by Gill (1949).

Acknowledgments

So many people have assisted in various phases of the project since its initial planning in 1947, that it is impossible to acknowledge them all. However, we would particularly like to thank S. T. Carlson, W. G. James, Eslie Lampi, and Clyde Fauley of the National Park Service for their sustained interest and cooperation in the project. Dr. Lake S. Gill provided technical direction of the project from its inception until the mid 1950's and followed it with interest even after his retirement in 1960. S. R. Andrews and T. E. Hinds of the U.S. Forest Service also assisted in technical aspects of the work.

The Forest and Dwarf Mistletoe

The topography of the plateau south of the rim is fairly uniform, with slightly rolling hills. Elevations range from 7,300 to 7,600 feet. The draws are usually less than 200 feet lower than adjacent ridges. In the eastern part of the area (from about 2 miles west of Grandview Point) the forest is nearly pure ponderosa pine. However, in the western portions, ponderosa pine predominates in the bottom sites with pinyon-juniper (Pinus edulis Engelm.-Juniperus osteosperma (Torr.) Little) on the ridges. Gambel oak is a frequent associate of ponderosa pine throughout the South Rim area. Douglas-fir (Pseudotsuga taxifolia (Mirb.) Franco), white fir (Abies concolor (Gord. & Glen.) Lindl.), and aspen (Populus tremuloides Michx.) occur at or below the canyon rim, but are insignificant components of the forests on the plateau south of the rim.

Gill's report received thorough consideration by the Park Service in the light of Service policy, and the possibility that undesirable changes in the ponderosa pine stands, due to control work, might occur. Park Service personnel decided that the dwarf mistletoe infestation was so serious that a control project was warranted in order to save the stands along the East Rim Drive where Gambel oak was replacing the pines killed by dwarf mistletoe.

Financing for the control project was obtained by the National Park Service under Pest Control funds. Initial control was begun in September 1949 and continued until June 1952. Since then the area has been sanitized three more times at approximately 5 year intervals. As part of the project, ten sample plots were established in the treated areas and in nearby untreated stands so that the effectiveness of control could be assessed.

This is the first large-scale attempt to control dwarf mistletoe in a recreational forest. Since the project is well known and has been visited by many foresters, biologists and forest pathologists, we feel that a thorough documentation of the project is warranted. To present as complete an account as possible, we have included references to several unpublished reports. The purpose of this paper is to evaluate the control effort after 20 years.

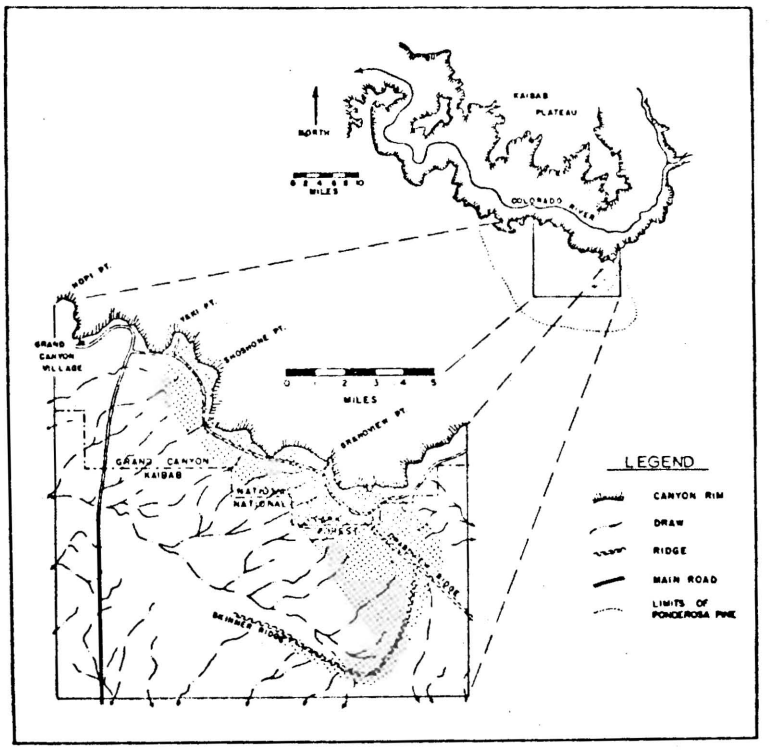


FIGURE 1. The South Rim of Grand Canyon showing the location of ponderosa pine stands and those with dwarf mistletoe (stippled area). from Hawksworth 1967.

Dwarf mistletoe occurs on ponderosa pine from near Yaki Point for about 10 miles along the East Rim to near the east end of the ponderosa pine type (Hawksworth 1967, fig. 1). The ponderosa pine stands near Grand Canyon Village and the Park Headquarters are apparently free of the parasite.

Control

Control Strategy

Gill (1949) emphasized that first priorities before control was to be considered were the Park Service's long-range plans for the area, and whether or not ponderosa pine, near the Rim at least, was worth preserving for future generations. He pointed out that, left unchecked, the ponderosa pine stands would continue to deteriorate, but that a decision to control the parasite must include the commitment to retreat the area at least once. After thorough studies of the area and detailed evaluation of Gill's report, the Park Service decided that, because of the esthetic and recreational potential of the East Rim Drive, and certain off-highway areas, a control program was warranted. It was fully realized that ponderosa pine dwarf mistletoe was a native parasite and that attempts would be made to control, not eradicate, the parasite. No control was to be attempted in areas that were not to be developed for scenic and recreational purposes.

Although dwarf mistletoes, as native parasites, are generally in long-term equilibrium with their hosts, the stands at Grand Canyon appear to be an exception, possibly in part, because of their marginal status. In many areas it is apparent that former ponderosa pine stands now support mainly Gambel oak. Ponderosa pine dwarf mistletoe is known to reduce seed production in heavily infected trees (Korstian and Long 1922). Apparently as older trees on the South Rim are killed out by mistletoe, oak is taking over the sites. The increase in oak on the South Rim is significant because it is due, not only to root suckering, but also to seedling establishment. Increase of oak in other ponderosa pine stands has been found to be due almost exclusively to suckering.

Methods

The feasibility of controling ponderosa pine dwarf mistletoe by a systematic program of sanitation has been previously demonstrated by studies at the Fort Valley Experimental Forest, near Flagstaff, Arizona (Gill and Hawksworth 1954). Sanitation consists of pruning lightly to moderately infected trees and killing heavily infected ones.

DWARF MISTLETOE CONTROL PROJECT

GRAND CANYON

Legend

ORIGINAL CONTROL AREA - 1949 - 1952

EXTENSION AREA A - 1954 - 1955

EXTENSION AREA B - 1966 - 1970

PAVED HIGHWAY

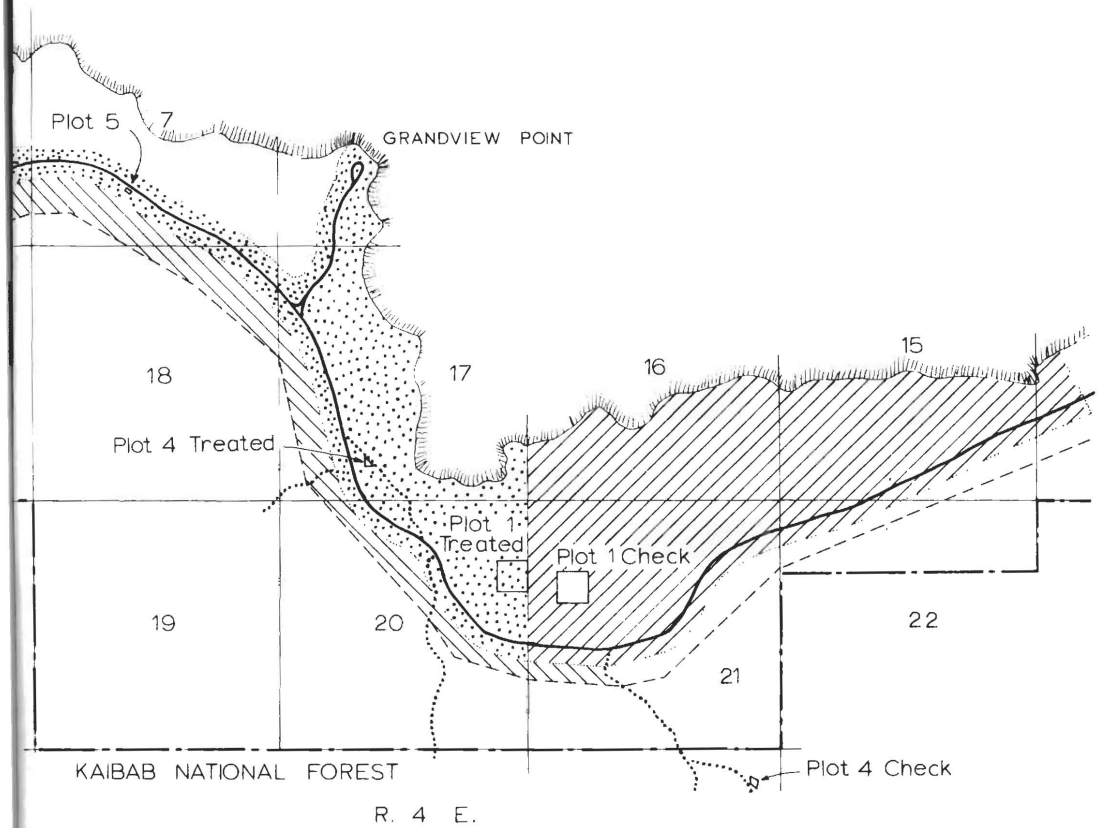
DIRT ROAD

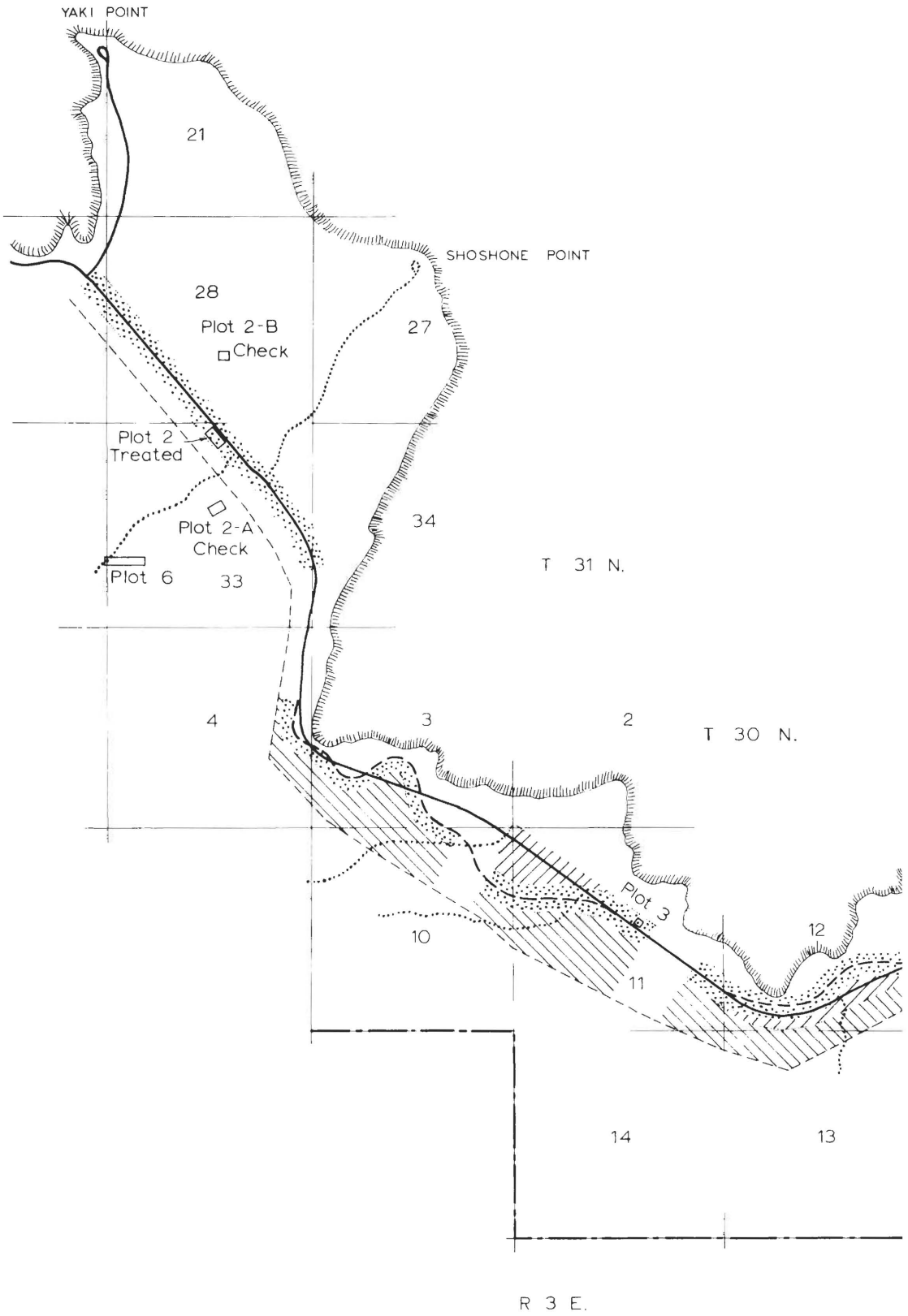
PARK BOUNDARY

TELEPHONE LINE

CANYON RIM

1 mile




YAKI POINT
21
SHOSHONE POINT
28
Plot 2-B
Check
27
Plot 2
Treated
Plot 2-A
Check
34
Plot 6
33
T 31 N.
4
3
2
T 30 N.
Plot 3
10
12
11
14
13
R 3 E.

The purpose of the Grand Canyon control project was to protect the ponderosa pine forest in the scenic and intensively used portions of the South Rim by reducing the levels of dwarf mistletoe. This was to be accomplished by removing mistletoe infections from trees to be protected or otherwise isolating these trees from mistletoe infection (Anonymous 1949). The plan was to apply control measures in all of sections 17 and 20 between the canyon rim and the East Rim Drive and Grandview Spur Road, a 300-foot strip along the south side of the East Rim Drive in sections 17 and 20, and a 300-foot roadside strip along both sides of this drive between Yaki Point Junction and the west boundary of section 17 (fig. 2). In sections 17 and 20 serious dwarf mistletoe damage has been known for several decades (McDougal 1899; Gill 1949). Dwarf mistletoe infected ponderosa pine was present on 680 acres (or 62 percent) of the 1,100 acres within the control area.

In connection with the proposed realignment of the East Rim Drive in 1956, Park personnel made a reconnaissance survey of the area east of the original control area between the canyon rim and the proposed new road alignment, extending east through sections 21 and 15 into section 14 to the end of the ponderosa pine type (James 1956). The survey showed that dwarf mistletoe was present throughout the area, and so an appraisal survey by the Albuquerque Forest Disease Laboratory was requested (Hawksworth 1956). The decision was then made by Park personnel to include this area in the control unit in order to save the ponderosa pine type, to have a continuous roadside area pleasing to the visitor, and to have a consolidated control area that would

be easier to maintain. Control measures were to be applied to the ponderosa pine type, between the canyon rim and the East Rim Drive, in sections 14, 15, 16, 21, and 22, and to a 300-foot strip south of the Drive in the same area (fig. 2) (A 10-acre plot in section 21 was left untreated to compare with a 10-acre treated plot located nearby in section 20). Initial control work began in November 1956 and was completed in December 1957 (James 1958). This new area, which has been designated as extension A, contained about 840 acres, most of which was uniformly and heavily infested with dwarf mistletoe.

In 1965 it appeared that dwarf mistletoe was reinvading the control area from the untreated stands to the south. A utility right-of-way about 30? feet wide had been clearcut near, and more-or-less parallel to the south boundary of the control project. Park personnel decided to extend the control area to this clearcut strip in order to retard reinvasion of the treated area. Treatment of this area, called extension B, was begun in 1966 (fig. 2). About 580 acres of ponderosa pine type, most of which was heavily infested by dwarf mistletoe, are included in extension B.

Initial control involved pruning, poisoning, or felling infected trees (Hawksworth 1951). For esthetic reasons, as many trees as possible were left for pruning. Trees were considered not prunable if:

(1) Over one-half of the crown would be removed in pruning operations. This basic rule was not followed strictly but was influenced by (a) the distribution of the mistletoe in the tree, (b) general tree health, (c) appearance of the tree after treatment, and (d) allowance for the later removal of additional infected branches that were not visibly infected at the time of the original treatment.

(2) Mistletoe shoots were on or within 18 inches of the main stem. (In 1961 and subsequent years this was reduced to 12 inches). Exceptions were: (a) some trees with infections on small branches, and (b) some trees with bole infections where the bole diameter was 12 inches or larger.

Gill (1949) emphasized that a satisfactory degree of control could not be achieved in one operation. Subsequent examination and sanitations were planned as an integral part of the project. The number of sanitations that would be required was not known at the beginning of the project but inspections were to be made at 3 to 5 year intervals to determine the need for, and timing of, the next operation. A complicating factor in determining the extent of subsequent sanitation was that pruning was used very extensively in an attempt to save as many trees as possible (over half of the trees treated in the initial operation were pruned). It was realized at the outset that more sanitations would be needed for this type

of operation than for control projects in timber production forests which involve mostly cutting infected trees and very little pruning (for example at the Mescalero Apache Reservation, New Mexico -- Hawksworth and Lusher 1956; Lightle, Andrews and Mouser 1967).

Operations

The entire control area comprises about 2,520 acres as follows.

Control Unit	Area (Acres)	Sanitation Operations	
		Initial (Years)	Subsequent (Years)
Original area	1100	1949-1952	1954-1955, 1961-1962, 1966-1970
Extension A	840	1956-1957	1961-1962, 1966-1970
Extension B	580	1968-1970	none

A total of 68,400 trees (or 27.8 per acre) of all size classes were treated in all operations on the entire control area. Complete records are not available on the type of treatment for all years of the operation but apparently about one-third were pruned and two-thirds killed by cutting or poisoning. It is not known from the records how many individual trees were treated because some trees were pruned from two to four times. Also some trees pruned in the initial operation later developed so much mistletoe that they had to be killed.

The initial operations in 1949-1952 on the original control area relied much more heavily on pruning (52 percent of the trees treated) than did the first sanitations in extension area A in 1956-1957 (33 percent) or extension area B in 1968-1970 (20 percent). Factors involved in this change were the recognition of the high cost of pruning trees and the frequent need for their retreatment.

A chronology of the operations in the various control units is given in Appendix A. The three areas covered by the control project - initial control area, extension area A, extension area B - will be discussed separately.

Original Control Area. Initial control on the 1,100 acres (fig. 2) was done in 1949-1952. Additional sanitations of the area were made in 1954-1955 and 1961-1962. Most of the area (except along the east Rim Drive west of section A) was again treated in 1966-1970. Thus most of the area has been retreated about 5, 10, and 20 years after the initial sanitation.

A summary of the number of trees treated in the initial (1949-52) and second (1954-1955) sanitations is given in Table 1. Only trees over 6 feet high are included because records for the smaller trees are incomplete.

A total of 6,932 trees (6.3 per acre) was treated in the initial sanitation and 4,220 (3.8 per acre) in the second (Table 1). Fifty-three percent of the trees were pruned initially and 70 percent in the second sanitation. The proportion of trees pruned was highest in mature trees - 63 percent initially and 84 percent in the second sanitation.

Data are not available on the number of trees treated in 1961-1962 and 1969-1970 on the original control area because the totals were combined with those from extension area A.

Table 1. Number of trees (over 6 feet high) treated in the initial and second sanitations on the original control area (1100 acres).

Size Class	Pruned		Killed		Total Treated	
	Initial	Second	Initial	Second	Initial	Second
Mature (over 30" dbh[1/])	751	1,059	440	204	1,191	1,263
Intermediate (Trees 4 1/2 to 30" dbh)	2,016	950	2,115	313	4,131	1,263
Sapling (Trees 6' high to 4 1/2" dbh)	921	931	689	763	1,610	1,694
Totals	3,688	2,940	3,244	1,280	6,932	4,220

1/ Diameter at breast height.

Extension Area A. Initial control work was done in the 840 acres in extension area A (fig. 2) in 1956-1957; a second sanitation of the area was made in 1961-1962, and a third in 1966-1970. Thus this area was sanitized about 5 and 13 years after the initial control. Data on the number of trees treated in area A are available only for the initial sanitation because data for 1961-1962 and 1969-1970 operations were combined with those for the original control area.

A total of 9648 trees of all size classes was treated during the initial operations on extension area A. Of these, 3209 (3.8 per acre) were pruned and 6439 (7.7 per acre) killed. Only about 33 percent of the trees in area A were pruned in the initial operation compared with over half for the original control area.

Extension Area B. Initial operations were done on the 580-acre extension area B in 1966-1968 (fig. 2): there have been no further sanitations to date. Data are not available on the number of trees treated in extension area B because the totals were combined with those from other areas.

Permanent Plots

Description

Ten permanent study plots totaling 31.17 acres were established in or near the original control area (fig. 2). Five plots were within the treated area and were subjected to the same control measures as in the surrounding stands; the other five plots were outside the control area and were left untreated. Treated Plots 1, 3, and 4 were first treated in 1949-1952, subsequent sanitations were made in 1954-1955, 1961-1962 and 1966-1970. As will be discussed later, treated Plot 2 has not yet had its scheduled third sanitation. All plots, except Plot 6, were established in 1950 (Hawksworth 1951). Plot 6 was set up in 1952. Examinations of all trees on the plots were made in 1955, 1961, 1966, and 1970.

Individual tree data were obtained on these plots by tagging trees over 4 inches in diameter at breast height (d.b.h.) in 1950. At the time of the 1961 examination, all trees over 3.5 inches d.b.h. were tagged.

The ten plots were divided into 6 series as follows:

Plot 1 Series, 2 plots -- a 10-acre treated, and a 10-acre untreated plot. This series was established to determine the effectiveness of control measures in heavily-infected overmature stands in the eastern portions of the area.

Plot 2 Series, 3 plots -- a 2.62-acre treated plot, and two untreated plots of 1.25 and 1.05 acres. This series was established to determine the effectiveness of control measures in heavily-infected blackjack stands in the western portions of the area.

Plot 3, 1 plot of 0.51 acre. This plot was established to study effectiveness of treatment in a single infection center in a blackjack stand.

Plot 4 Series, 2 plots -- a treated plot of 0.41 acre, and an untreated plot of 0.52 acre on the Kaibab National Forest just south of the National Park boundary. This series was established to determine the effectiveness of control measures in heavily-infected reproduction and pole stands.

Plot 5, 1 plot of 0.01 acre. This plot was established to determine the effectiveness of control measures in severely-infected dense reproduction.

Plot 6, 1 plot of 4.80 acres. This plot was established to determine the rate of invasion of dwarf mistletoe through an untreated stand.

Results

Plot 1 Series.--These two 10-acre plots were selected to represent the heavily-infected mature ponderosa pine forests in the eastern portion of the control area (figs. 3-5). The stand disease situation in 1950 and 1970 on the treated and untreated plots are summarized in table 2. Details on the numbers of trees and basal areas on these plots are given in the Appendix in tables B, C, D. and E. The plots were comparable before treatment in 1950. Plot 1--Treated had 21 trees per acre (over 6 feet high) which averaged 13.5 inches d.b.h., while the untreated plot had 29 trees per acre averaging 14.5 inches d.b.h. Dwarf mistletoe infection was also similar: 78 percent of the trees infected with an average plot rating of 2.8 on the 6-class scale on the treated plot, and 77 percent of the trees infected with an average plot rating of 2.7 on the untreated plot. The number of dead standing trees killed by mistletoe was similar on both plots: 22 on the treated plot, and 27 on the untreated plot. In the original sanitation, 9.0 trees per acre were killed, and 7.1 pruned on the treated plot. Subsequently 3.0 more trees per acre were killed, and by 1970, 9.6 trees per acre remained, but 95 percent of these were mistletoe free. In contrast, 7.6 trees per acre were killed by dwarf mistletoe on the check plot, and the proportion of trees infected increased from 77 to 79 percent.

Table 2.--Comparison of the mature stands on Plots 1 treated and untreated.

Characteristics		Treated	Untreated
Trees per acre	1950	20.7	29.0
	1970	9.6	24.5
20 year difference		-11.1	- 4.5
Percent healthy	1950	22	23
	1970	95	21
20 year difference		+73	- 2
Basal area per acre	1950	29.0	46.1
	1970	13.6	38.2
20 year difference		-15.4	- 7.9
Percent healthy	1950	10	12
	1970	97	12
20 year difference		+87	0
Plot dwarf mistletoe rating	1950	2.8	2.7
	1970	0.1	3.5
20 year difference		+2.7	+0.8
Average d.b.h. live trees	1950	13.5	14.5
	1970	14.2	13.9
20 year difference		+ 0.7	- 0.6
Natural mortality, trees killed per acre, 1950-1970		0.5	7.6

Perhaps the most meaningful comparison is the average plot mistletoe ratings in 1950 and 1970. This figure is based on all live trees in the plot so it gives a useful overall comparison of the amount of mistletoe present. The treated plot had a 1950 rating of 2.8 but in 1970 it was only 0.1. However, infection in the untreated plot rose from 2.7 in 1950 to 3.5 in 1970. Thus, the extent of infection on the untreated plot in 1970 was about 35 times that on the treated plot. In another 15 years or so the untreated stand will have lost more trees than were killed or died on the treated area, and the untreated area will still be heavily infected with dwarf mistletoe. Also Gambel oak is replacing many of the pines that have died. Reproduction that becomes established in the treated area will remain free from infection and should eventually produce a healthy mature stand but reproduction established on the untreated area will undoubtedly become infected at an early age and will never reach maturity, even if it should survive long enough to produce a pole stand. Dwarf mistletoe adversely affects a tree's ability to produce viable seed and so the likelihood of reproduction is much reduced on the untreated area. Control clearly accomplished its objectives in these mature stands.

Plot 2 Series.--The three plots in this series (1 treated plot of 2.625 acres and 2 untreated plots totaling 2.30 acres) were selected as representative of the heavily infected blackjack stands in the western portions of the control area (figs. 6-7). The stand and disease situation on the treated and untreated plots are summarized in table 3. Details on the numbers of trees and basal areas on these plots are given in the Appendix in tables F, G, H, and I. The plots were comparable before treatment in 1950. The treated plot had 107 live trees per acre and an average tree diameter of 9.2 inches; the untreated plots had an average of 97 trees per acre and they averaged 10.4 inches d.b.h. The original dwarf mistletoe situation was also similar: 61 percent of the trees were infected on both plots; the average plot mistletoe rating on the treated plot was 1.7 while that on the untreated plots was 1.8.

Since control started, 2 trees per acre on the treated plot have died of natural causes, and 21 trees per acre have been killed by treatment; 24 (34 percent) of the remaining trees were infected in 1970. On the untreated plots 14 trees per acre have died, and 72 percent of the trees were infected in 1970. The average dwarf mistletoe rating was reduced from 1.7 in 1950 to 0.7 in 1970 by the control operations, but on the untreated plots the rating during this 20-year period increased from 1.8 to 2.9.

Table 3. Comparison of blackjack stand on Plots 2 treated and untreated.

Characteristics		Treated Plot	Untreated Plots
Trees per acre	1950	106.7	94.8
	1970	71.2	80.9
	20 year difference	- 35.5	-13.9
Percent healthy	1950	39	39
	1970	66	28
	20 year difference	+27	-11
Basal area per acre	1950	22.8	32.8
	1970	19.6	32.3
	20 year difference	- 3.2	- 0.5
Percent healthy	1950	38	38
	1970	63	32
	20 year difference	+25	- 6
Plot dwarf mistletoe rating	1950	1.7	1.8
	1970	0.7	2.9
	20 year difference	-1.0	+1.1
Average d.b.h. of live trees	1950	9.2	10.4
	1970	10.3	11.5
	20 year difference	+ 1.1	+ 1.1
Natural mortality, trees killed per acre 1950-1970		1.9	14.3

Control appears to have been less effective for this heavily infected blackjack stand than it was for the mature stand represented by the Plot 1 Series. Additional considerations are necessary to understand this situation.

At the time of the 1970 examination, Plot 2 Treated had not yet received its scheduled fourth sanitation and has had no treatment since 1961. Fifty-two of the 63 trees now infected with dwarf mistletoe were infected in 1966 and should have been treated at that time. Had this been done 12 trees would have been killed and the rest pruned. The number of trees showing new infections in 1970 would undoubtedly have been reduced to a figure much lower than the 11 that were found, and the number of previously infected trees that are still infected would have been correspondingly lower.

What has happened on Plot 2 Treated is a good indication of what will happen when control efforts are stopped. A popular picnic area was installed in the north-east corner of this treated plot after its establishment. Without further treatment to control dwarf mistletoe, tree mortality in this area will accelerate. The stand adjacent to the picnic ground can be expected to deteriorate further so that its usefulness will be greatly impaired, and may have to be abandoned for its present use.

Plot 3.--This 0.51-acre plot was established to demonstrate the extent to which control could be accomplished in a single infection center in a 100-year-old blackjack stand (Appendix, table J). The infection center covered about 1/4-acre and involved 31 trees, 7 of which had been killed by dwarf mistletoe. An additional 18 uninfected trees surrounding the infection center were included in the plot. In sanitizing this plot, 9 trees were killed and 16 pruned. One tree died in the 1950-1970 period from causes other than mistletoe. Only 3 of the original trees in the infection center were infected in 1970 and there have been no newly infected trees. In 1950, 57 percent of the trees on the plot were infected, and the average plot mistletoe rating was 1.5. In 1970, 9 percent of the trees were infected and the average mistletoe rating was only 0.1. Control has clearly reduced the dwarf mistletoe population to an insignificant level.

Plot 4 Series.--The purpose of these plots was to study the effect of control operations in heavily-infected reproduction and pole stands. At the time of establishment, the treated plot contained groups of saplings, small poles, and very heavy reproduction in the south half. The stand composition is shown in the Appendix (table K). The untreated stand differed in that there was much less reproduction and some of the dominant trees were larger (Appendix, table L). Dwarf mistletoe infection was comparable on the plots. The treated plot had 73 percent of the trees infected, and an average plot rating of 2.8; the untreated plot had 79 percent of the trees infected, and an average plot rating of 2.4.

No detailed comparison can be made between the plots because the trees on the untreated plot on the Kaibab National Forest were destroyed in 1968. The treated area had 258 trees per acre killed at the time of the original treatment in 1950, and an additional 241 trees per acre were killed in retreatments, but only 5 trees have died. Of the 141 trees per acre in 1970, 5 percent were infected, and the average plot mistletoe rating had been reduced from 2.8 in 1950 to 0.05. At the time of the last examination of the untreated plot, in 1966, 83 trees per acre had died, and 86 percent of the remaining 121 trees per acre were dwarf mistletoe-infected. The average plot rating increased from 2.4 in 1950 to 4.3 in 1966.

Even these marked differences do not portray the whole story because the treated plot is now covered with a thrifty stand of young, mostly uninfected trees, whereas the untreated plot had virtually nothing but small dead and dying trees when it was destroyed.

Plot 5.--The purpose of this plot was to determine the effectiveness of control measures in severely infected, dense reproduction. Although the overstory trees which were responsible for the infection were killed during treatment, or died due to dwarf mistletoe, the reproduction was subjected to infection prior to treatment. All of the tagged trees were subsequently removed during retreatment of the area. The remaining stand of young trees, however, is thrifty, and virtually free from dwarf mistletoe.

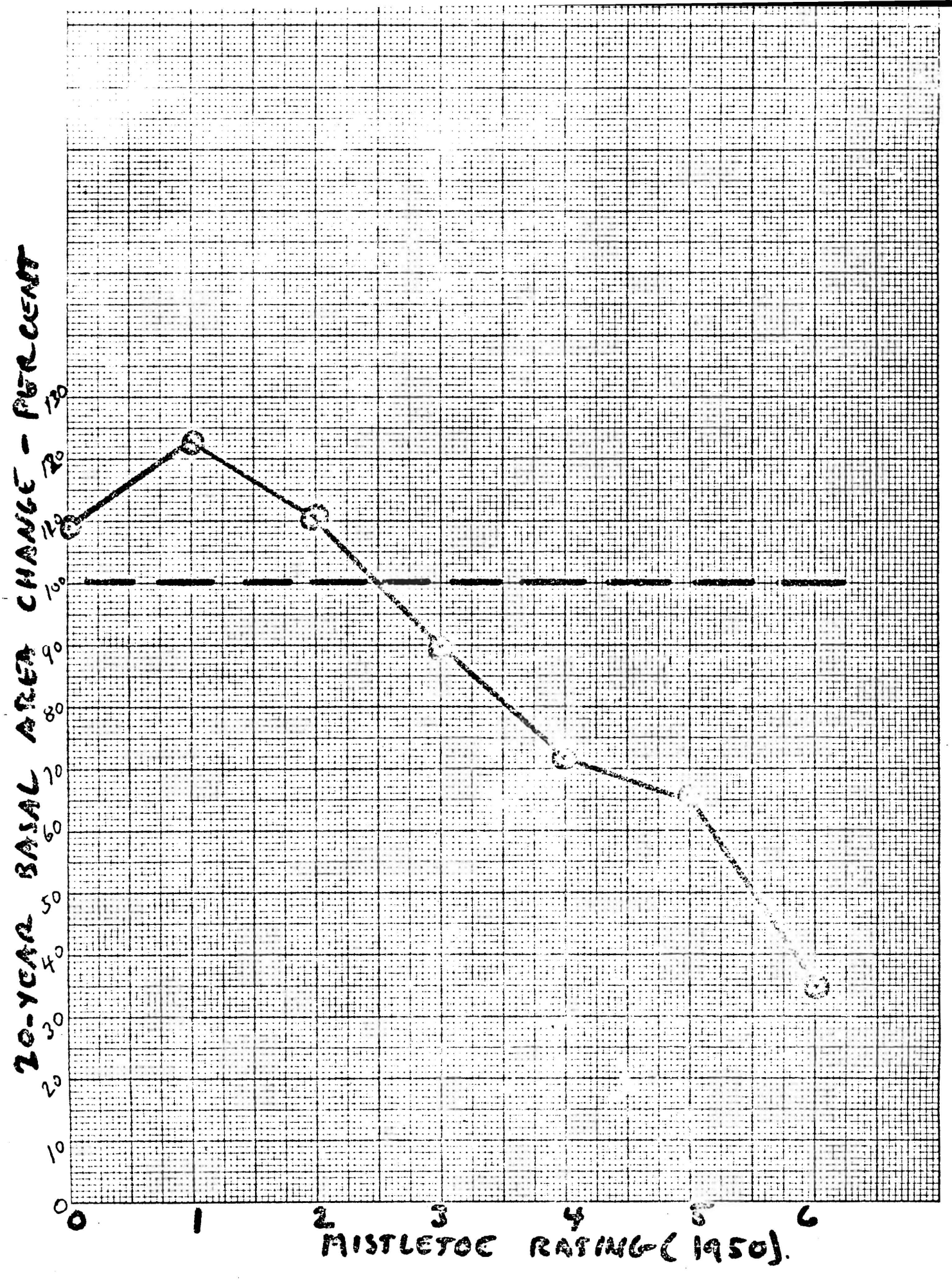
~~area. The remaining stand of young trees, however, is thrifty and virtually free from dwarf mistletoe.~~

Plot 6.--This 4.80 acre plot was established in 1952 to measure the rate of invasion of dwarf mistletoe through a mature ponderosa pine stand. The plot is along the edge of the range of dwarf mistletoe about a mile from the Canyon Rim (fig. 2). In 1952, 17 percent of the 251 trees on the plot were infected and the average plot mistletoe rating was 0.4. In 1970, 33 percent of the trees were infected and the average plot rating had risen to 1.1. Detailed analyses on the rate of spread of dwarf mistletoe on this plot will be published elsewhere.

Plot Summaries.--An analysis of the basal area growth of the 864 trees on the untreated plots (Plots 1, 2, 4, and 6) is given in figure 8. This figure shows the 20-year change in average basal area per tree for trees uninfected and the six mistletoe infection classes in 1950. The data are similar to the 11-year results on these plots published by Lightle (1966). The figures were obtained by dividing the total living basal area in 1950 and 1970 of the trees in each infection class in 1950. Thus, these data give an indication of combined dwarf mistletoe effects due to reduced growth rate and mortality.

Uninfected trees and those in infection classes 1 and 2 increased in basal area by 10 to 20 percent during the period. Growth rate fell below 100 percent between infection classes 2 and 3, and decreased markedly in higher infection classes. For example, trees in infection class 6 had an average of only 35 percent of the living basal area

Figure 8. Comparison of the 20-year basal area growth of 864 trees of various dwarf mistletoe infection on the untreated plots.


20-YEAR BASAL AREA CHANGE - PERCENT
0
10
20
30
40
50
60
70
80
90
100
110
120
0
1
2
3
4
5
6
MISTLETOE RATING (1950).

in 1970 as they had in 1950. The larger growth rate of trees of infection class 1 over that of uninfected trees is presumably due to the larger size of trees in infection class 1 and not to stimulation by dwarf mistletoe. The trees in infection class 1 averaged about 1 inch in diameter larger than the uninfected trees in 1950.

Mortality during the 20-year period was strongly correlated with intensity of dwarf mistletoe:

Dwarf mistletoe Rating (1950)	Tree basis	Trees killed between 1950 and 1970
	(number)	(percent)
0	361	4
1	88	3
2	83	12
3	59	27
4	46	37
5	62	42
6	60	63

Conclusions

The conclusions drawn here apply to the original control area first sanitized in 1949-1952, and to extension area A first treated in 1956-1957. The control on extension area B has been too recent (1966-1968) to evaluate its effectiveness.

The marked reduction in dwarf mistletoe populations in the treated plot was discussed in the previous section but, for the plot 1 series, the extent of dwarf mistletoe infestation (based on average plot mistletoe ratings) is over 35 times as high on the untreated plot as on the treated plot.

In detailed examinations of the control area in 1965 by several Park Service personnel and the senior author, a total of only 287 infected trees in an area of about 750 acres was found during 25 man-hours of intensive searching. The infected trees that were found were generally in small groups, and lightly infected, usually with only 1 or 2 dwarf mistletoe plants per tree.

The results from the permanent plots plus examinations of the control area outside the plots clearly indicate that the original goal of the project -- to reduce the level of dwarf mistletoe and protect the ponderosa pine forest -- has been achieved. This has generally been accomplished without undue alteration of, or disturbance to, the ponderosa pine stands within the treated area. These stands are now thrifty, relatively free of dwarf mistletoe, and contain ample reproduction to insure the perpetuation of ponderosa pine along the scenic East Rim Drive.

Suggestions for Dwarf Mistletoe Control in Recreational Forests

The 20-year result of the Grand Canyon control project have yielded much information that may be useful in future operations under recreational forest conditions.

1. In general, pruning should be limited to lightly infected trees (classes 1 or 2). The number and extent of sanitations necessary is directly related to the proportion of trees pruned initially. In the initial sanitation of the original control area more than half of the trees were pruned in an attempt to save as many trees as possible. This necessitated many subsequent recleanings, because most trees had to be repruned, some of them 2, 3, or even 4 times. Also, pruned trees frequently developed so much reinfection that they had to be killed later. We suggest that the more recent operations, in which about 20 to 30 percent of the trees were pruned, were more successful because pruning was limited to lightly infected trees. Results from the permanent plots show that successful elimination of dwarf mistletoe by pruning is strongly correlated with amount of infection in the tree at the time of the initial operation:

Original Dwarf Mistletoe Rating	Proportion of Trees Alive 20 years later
1	70
2	50
3	40
4	10

2. Pruning should be confined, in so much as possible, to the more isolated trees. Results of pruning of residual trees in once heavily infected groups of pole-sized trees was generally unsuccessful. In such situations nearly all the pruned trees had to be repruned and half of them were so heavily infected that they had to be killed.

3. In pruning, the infected branch should be cut off at the bole. Although it may at first appear easier to remove infected secondary or tertiary branches, the high incidence of latent dwarf mistletoe in the remaining branches makes this practice questionable. In most cases the branch has to be removed in subsequent prunings.

4. If large portions of the crown are removed by pruning, isolated living branches should not be left. Even though dwarf mistletoe may not be apparent in such branches, they almost invariably harbor incipient infections. Where it is possible to do so without removing too many branches, pruning for 2 or 3 whorls above the highest visible mistletoe should eliminate many latent infections and thus save a considerable amount of time in subsequent sanitations.

5. Prunability of branches is related to branch diameter. The rule applied in the early work-that trees with infections within 18 inches of the main stem (later reduced to 12 inches) were not considered to be prunable--has been found to be too restrictive. Extent of the endophytic (or root) system of ponderosa pine dwarf mistletoe is now known to be as follows (Hawksworth and Andrews 1965):

Branch diameter at bole (inches)	Minimum safe distance from bole to closest shoots (inches)
under 1	6
1 to 2	8
2 to 3	10
3 to 4	12

6. Pruning heavily infected trees improves host vigor. To determine the extent to which heavily infected trees would recover if the infected branches were pruned out, a small study was established. These heavily infected trees were ususally of infection class 4 or even 5 and would have been cut in accordance with the marking rules for the rest of the control area. A series of 45 trees were pruned in 1950. Many of these were so severely infected that the tops of the crowns were thin and off color due to the effects of the parasite. The results (figs. 9-10) show that such trees can recover even though dwarf mistletoe is not necessarily eliminated from them. By removing the lower infected branches which are seriously reducing the vitality of the tree, the life span of the tree can be prolonged considerably. While such drastic pruning is not recommended as a routine control measure, it can be used to lengthen the life of particularly valuable or needed trees.

7. All trees with bole infections need not be killed. The original guides suggested that trees larger than 12 inches in diameter did not need to be killed merely because they had infections in the main stem. This was based on the observation that infections on the boles of large trees are usually not vigorous, hence, are negligible sources of infection to surrounding trees. Research is now underway to determine more precisely the relationship between diameter and vigor of bole infections. We tentatively suggest, however, that trees with infections on the bole, where it is over 8 inches in diameter, offer very little threat to surrounding trees and need not be a reason to sacrifice the tree.

Footnotes

1. Central headquarters maintained in cooperation with Colorado State University at Fort Collins. Authors are stationed at Albuquerque, New Mexico and Fort Collins, respectively.
2. Letter from Ansel F. Hall, Chief, Division of Education and Forestry, Office of National Parks, Buildings, and Reservations, to E. P. Meinecke, Principal Pathologist, Office of Forest Pathology, Bureau of Plant Industry.
3. Lake S. Gill, Principal Pathologist, Albuquerque. This division was transferred from the Bureau of Plant Industry, Soils and Agricultural Engineering to the U.S. Forest Service in 1954 and became the Division of Forest Disease Research.
4. L. F. Cook, Assistant Regional Forester, Washington Office; S. T. Carlson, Southwestern Regional Forester, Santa Fe; and Perry E. Brown, Chief Ranger, Grand Canyon National Park.
5. For this 6-class rating scheme, the crown of each tree is divided horizontally into thirds (Hawksworth 1961). Each third is then given a rating of zero (no mistletoe), 1 (light mistletoe), or 2 (heavy mistletoe). The three ratings are then totaled to give a tree rating which may range from zero (no mistletoe) to 6 (each third of the crown heavily infected). The ratings of each live tree are then averaged to obtain a plot rating.

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Table
Appendix A. Chronology of dwarf mistletoe sanitations at Grand Canyon National Park.

Years	Sanitation	Area Treated
1949-1952	Initial	Original control area
1954-1955	Second	Original control area
1956-1957	Initial	Extension area A
1961-1962	Third	Original control area
	Second	Extension area A
1966-1968	Fourth	Original control area south of highway in sec. 17 and 20, roadside west of section 4.
	Third	Extension area A south of highway in sec. 21 and western portions of sec. 4.
	Initial	Extension area B
1969-1970	Fourth	Original control area north of highway in sec. 17 and 20.
	Third	Extension area A in sec. 14, 15, 16, and 21.

Appendix Table B. Stand composition and dwarf mistletoe infection on Plot 1 Treated.

Dia. class	1950						1951-1970			1970		
		Living								Living		
	Dead	Inf.	Uninf.	Total	Killed	Left	Ingrowth	Killed	Died	Inf.	Uninf.	Total
	number of trees											
- 5"	1	28	22	50	11	39	9	4	2	0	5	5
6-11"	6	35	13	48	14	34	3	11	0	3	42	45
12-23"	12	71	10	81	54	27	0	11	0	?	29	31
24" -	3	27	1	28	11	17	0	4	1	0	15	15
Total	22	161	46	207	90	117	12	30	3	5	91	96

Appendix Table C. Stand composition and dwarf mistletoe infection on Plot 1 Check.

Dia. class	1950					New tagged trees	1951-70	1970			
		Living						Living			
	Dead	Inf.	Uninf.	Total	Kill 1/		Died	Inf.	Uninf.	Total	Kill 1/
	number of trees										
- 5"	1	32	29	61	(9)	15	11	15	13	28	(12)
6-11"	9	56	23	79	(19)	16	18	59	28	87	(36)
12-23"	15	84	11	95	(32)	0	29	80	7	87	(48)
24" -	2	51	4	55	(26)	0	18	39	4	43	(25)
Total	27	223	67	290	(86)	31	76	193	52	245	(121)

1/ Trees that would have been killed if control had been done.

Appendix Table D Basal area per acre dwarf mistletoe-infected and uninfected on Grand Canyon Plot 1 Treated

Dia. class	1950						1951-1970			1970		
		Living								Living		
	Dead	Inf.	Uninf.	Total	Killed	Left	Ingrowth	Killed	Died	Inf.	Uninf.	Total
	square feet											
-5"	T[1]	0.2	0.2	0.4	0.1	0.3	0.1	0.1	T[1]	0.0	0.1	0.1
6-11"	0.3	1.4	0.5	1.9	0.6	1.4	0.1	0.4	0.0	0.2	1.7	1.8
12-23	1.9	13.2	1.9	15.1	9.8	5.2	0.0	1.7	0.0	0.2	4.9	5.2
24" -	1.1	11.2	0.4	11.6	4.5	7.0	0.0	1.5	0.4	0.0	6.5	6.5
Total	3.3	26.0	3.0	29.0	15.0	13.9	0.2	3.7	0.4	0.4	13.2	13.6
		89.8%								2.8%		

1/ Basal area less than 0.1 square feet.

Appendix Table E. Basal area per acre dwarf mistletoe-infected and uninfected on Grand Canyon Plot 1 Check.

Dia. class	1950					1950-1970		1970			
		Living						Living			
	Dead	Inf.	Uninf.	Total	Kill[1]	Ingrowth	Died	Inf.	Uninf.	Total	Kill[1]
	square feet										
-5"	T[2]	0.3	0.3	0.6	(0.1)	0.1	0.1	0.2	0.1	0.3	(0.1)
6-11"	0.4	2.7	0.9	3.6	(1.0)	0.5	0.9	2.8	1.2	4.0	(1.8)
12-23"	1.9	14.5	2.4	16.8	(5.4)	0.0	4.6	13.0	1.3	14.3	(7.6)
24" -	0.8	23.0	2.1	25.1	(11.7)	0.0	8.2	17.5	2.1	19.6	(11.3)
Total	3.1	40.5	5.7	46.1	(18.2)	0.6	13.8	33.5	4.7	38.2	(20.8)
		87.7%						87.5%			

1/ Basal area that would have been killed if control had been done.

2/ Basal area less than 0.1 square feet.

Appendix Table F. Stand composition and dwarf mistletoe infection on Plot 2 Treated.

Dia. class	1950						1951-1970			1970		
		Living								Living		
	Dead	Inf.	Uninf.	Total	Killed	Left	Ingrowth	Killed	Died	Inf.	Uninf.	Total
	number of trees											
- 5"	4	57	39	96	29	67	34	22	3	10	23	33
6-11"	2	77	49	126	31	95	1	22	0	32	70	102
12-23"	1	35	19	54	8	46	0	11	1	20	29	49
24" -	0	2	2	4	0	4	0	0	1	1	2	3
Total	7	171	109	280	68	212	35	55	5	63	124	187

Appendix Table G. Stand composition and dwarf mistletoe infection on Plot 2 Check.

Dia. class	1950					New tagged trees	1951-70 died	1970			
		Living						Living			
	Dead	Inf.	Uninf.	Total	Kill 1/			Inf.	Uninf.	Total	Kill 1/
	number of trees										
- 5"	0	27	35	62	(6)	1	9	22	17	39	(11)
6-11"	8	50	18	68	(20)	0	11	53	11	64	(36)
12-23"	2	55	29	84	(24)	0	13	56	23	79	(30)
24" -	0	1	3	4	(0)	0	0	2	2	4	(0)
Total	10	133	85	218	(50)	1	33	133	53	186	(77)

1/ Trees that would have been killed if control had been done.

Appendix Table H . Basal area per acre dwarf mistletoe-infected and uninfected on Grand Canyon Plot 2 Treated.

Dia. class	1950						1950-1970			1970		
	Dead	Living Inf.	Living Uninf.	Living Total	Killed	Left	Ingrowth	Killed	Died	Living Inf.	Living Uninf.	Living Total
	square feet											
-5"	0.1	2.6	1.9	4.5	1.3	3.1	1.4	0.6	0.1	0.5	1.2	1.7
6-11"	0.4	11.2	7.3	18.5	4.1	14.5	0.2	3.2	0.0	4.9	10.7	15.6
12-23"	0.6	20.1	10.9	31.0	3.6	27.4	0.0	5.3	0.5	12.3	17.7	30.0
24" -	0.0	3.1	2.8	5.9	0.0	5.9	0.0	0.0	1.4	1.2	2.9	4.1
Total	1.1	37.0	22.9	59.9	9.0	50.9	1.6	9.1	2.0	18.9	32.5	51.4
		61.7%								36.8%		

Appendix Table I. Basal area per acre dwarf mistletoe-infected and uninfected on Grand Canyon Plot 2 Check.

Dia. class	1950					1950-1970		1970			
	Dead	Living Inf.	Living Uninf.	Living Total	Kill[1/]	Ingrowth	Died	Living Inf.	Living Uninf.	Living Total	Kill[1/]
-5"	0.0	1.1	1.0	2.1	(0.2)	T[2/]	0.4	1.0	0.6	1.6	(0.5)
6-11"	1.4	10.3	2.9	13.2	(4.1)	0.0	2.7	10.1	1.9	12.0	(6.9)
12-23"	1.4	33.8	19.1	53.0	(13.9)	0.0	7.9	36.1	17.3	53.4	(18.7)
24" -	0.0	1.8	5.3	7.1	(0.0)	0.0	0.0	3.6	3.8	7.4	(0.0)
Total	2.8	47.0	28.3	75.4	(18.2)	T[2/]	11.0	50.8	23.6	74.4	(26.1)
		62.5%						68.3%			

1/ Basal area that would habe been killed if control had been done.

2/ Basal area less than 0.1 square feet.

Appendix Table J. Stand composition and dwarf mistletoe infection on Plot 3.

Dia. class	1950						1951-70			1970		
		Living								Living		
	Dead	Inf.	Uninf.	Total	Killed	Left	Ingrowth	Killed	Died	Inf.	Uninf.	Total
	number of trees											
- 5"	2	5	4	9	2	7	0	1	0	0	4	4
6-11"	4	5	1	6	3	3	0	0	0	1	4	5
12-23"	1	14	11	25	3	22	0	0	1	2	19	21
24" -	0	0	2	2	0	2	0	0	0	0	2	2
Total	7	24	18	42	8	34	0	1	1	3	29	32

Appendix Table K. Stand composition and dwarf mistletoe infection on Plot 4 Treated.

Dia. class	1950						1951-70			1970		
	Dead	Living Inf.	Living Uninf.	Living Total	Killed	Left	Ingrowth	Killed	Died	Living Inf.	Living Uninf.	Living Total
	number of trees											
- 5"	6	184	70	254	100	154	0	94	2	2	45	47
6-11"	1	11	0	11	6	5	0	5	0	1	10	11
12-23"	1	0	0	0	0	0	0	0	0	0	0	0
24" -	0	0	0	0	0	0	0	0	0	0	0	0
Total	8	195	70	265	106	159	0	99	2	3	55	58

Appendix Table L. Stand composition and dwarf mistletoe infection on Plot 4 Check.

Dia. class	1950					New tagged trees	1951-66	1966			
	Dead	Living Inf.	Living Uninf.	Living Total	Kill 1/		Died	Living Inf.	Living Uninf.	Living Total	Kill 1/
	number of trees										
- 5"	0	44	10	54	(32)	0	29	11	3	14	(11)
6-11"	0	34	9	43	(13)	0	12	34	4	38	(25)
11-23"	0	6	3	9	(1)	0	2	9	2	11	(4)
24" -	0	0	0	0	(0)	0	0	0	0	0	(0)
Total	0	84	22	106	(46)	0	43	54	9	63	(40)

1/ Trees that would have been killed if control had been done.







Figure 3. Views of Plot 1 Treated from the south east corner. Top photo taken in the fall of 1950, about a year after initial sanitation. Middle and lower photos taken in August 1971. Note that reproduction has obscured the view in the middle photo. Lower photo was taken from about 15 feet up in a tree to show the extent of the reproduction.



Figure 4. Views of Plot 1 Check showing trees 93 to 101. The upper left photo was taken in June 1950; the upper right in May 1955; and the lower left photo was taken in May 1971.



Figure 5. Deterioration of the mature forest, represented by Plot 1 Check, due to the effects of dwarf mistletoe. Upper photos taken in June 1950; lower photos of the same trees, in May 1971.

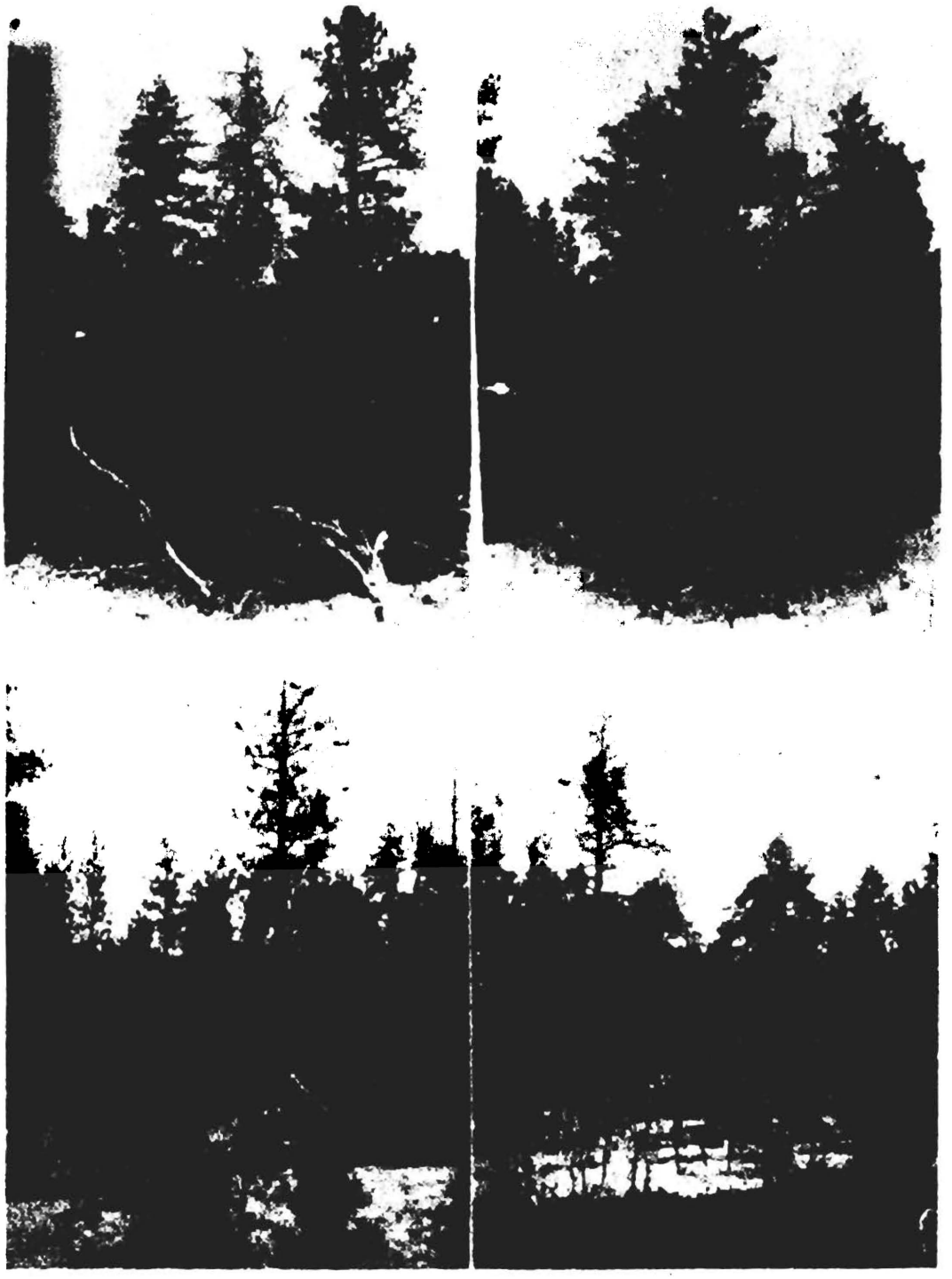


Figure 7. Deterioration of the young forest represented by Plot 2 B Check due to the effects of dwarf mistletoe. Upper photos taken in June 1950; lower photos in May 1971. Note the growth of the Gambel oak.

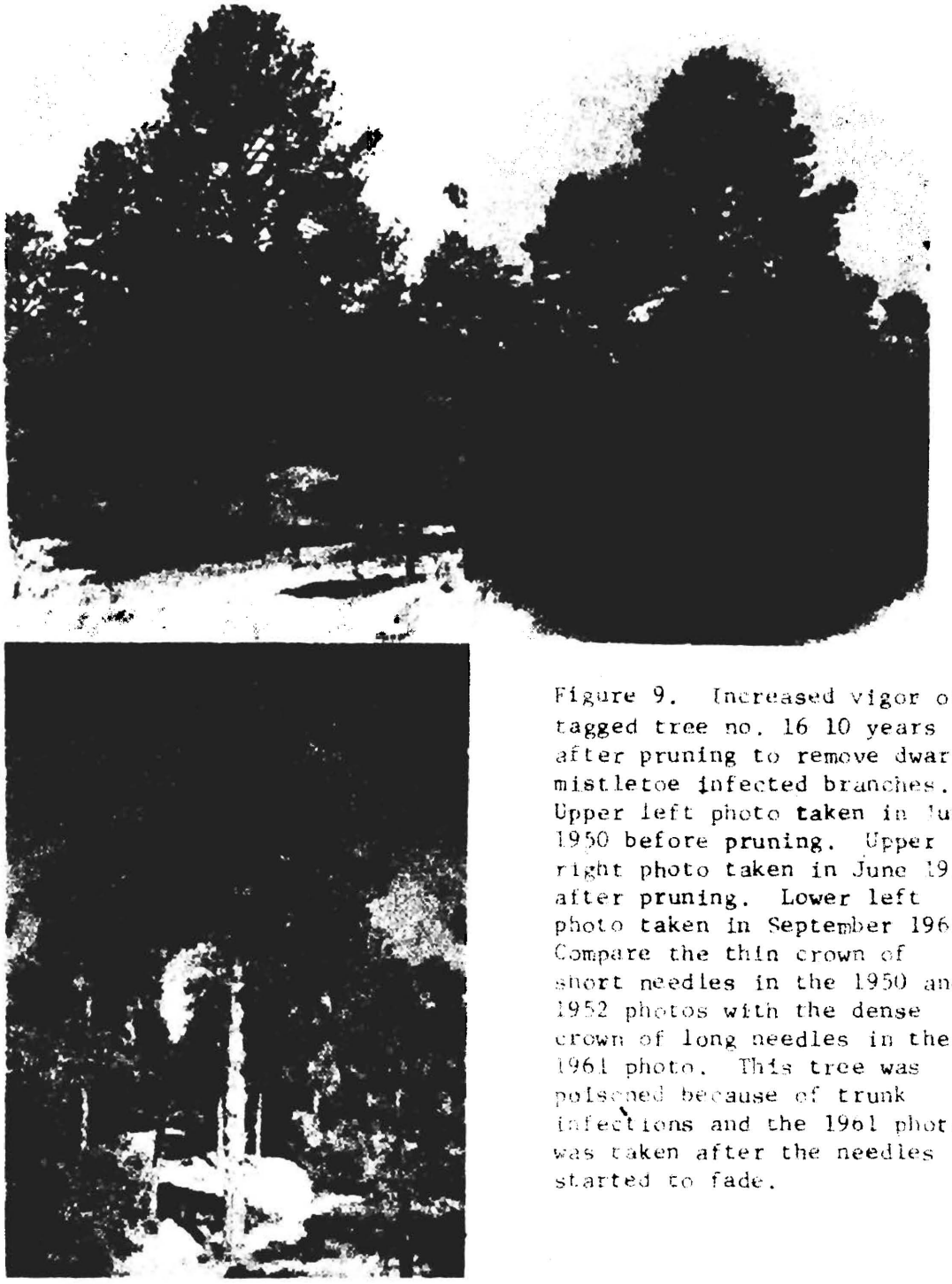


Figure 9. Increased vigor of tagged tree no. 16 10 years after pruning to remove dwarf mistletoe infected branches. Upper left photo taken in June 1950 before pruning. Upper right photo taken in June 1952 after pruning. Lower left photo taken in September 1961. Compare the thin crown of short needles in the 1950 and 1952 photos with the dense crown of long needles in the 1961 photo. This tree was poisoned because of trunk infections and the 1961 photo was taken after the needles started to fade.

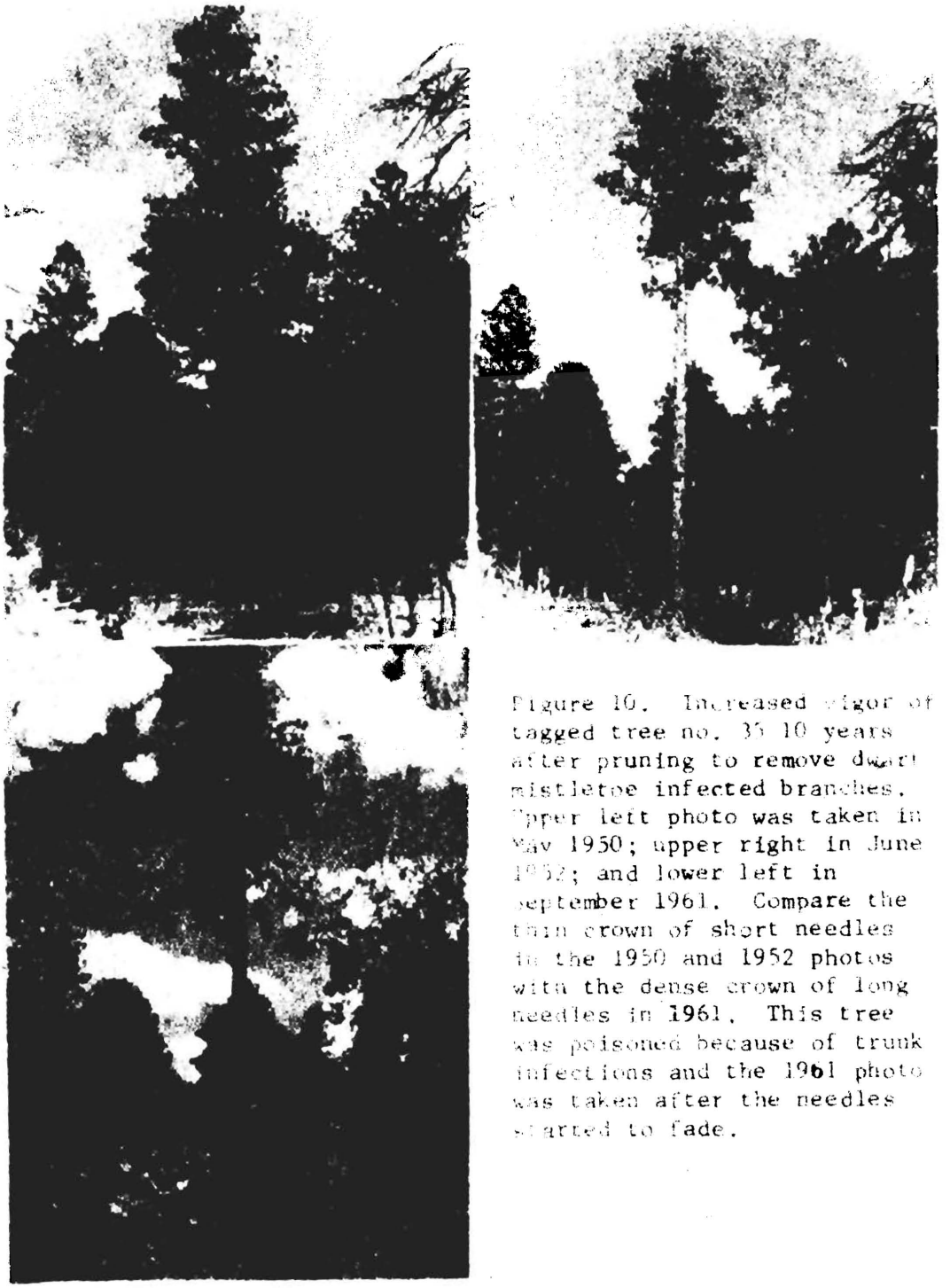


Figure 10. Increased vigor of tagged tree no. 35 10 years after pruning to remove dwarf mistletoe infected branches. Upper left photo was taken in May 1950; upper right in June 1952; and lower left in September 1961. Compare the thin crown of short needles in the 1950 and 1952 photos with the dense crown of long needles in 1961. This tree was poisoned because of trunk infections and the 1961 photo was taken after the needles started to fade.