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C O N T E N T S

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INTRODUCTION

Spruce-fir is one of the major forest types in the central Rocky Mountains. Engelmann spruce, _Picea engelmanni_ Parry, is usually the predominant species with subalpine fir, _Abies lasiocarpa_ (Hook.) Nutt., making up one-fourth or less of the total volume. Lodgepole pine, _Pinus contorta_ Dougl. ex Loud., is frequently present at the lower elevations of the spruce-fir type.

The objectives of this study were to obtain preliminary information on the rots of subalpine fir and to relate decay with age and site conditions. Information was also desired on entrance points for rot fungi, the identification of these fungi, and external indicators of decay.

Most spruce-fir stands are mature to overmature (LeBarron and Jemison, 1953). Cutting has been relatively limited in the type because of inaccessibility and severe climate. However, the rate of harvesting is increasing.

In the central Rocky Mountains the spruce-fir type reaches its maximum development in western Colorado between 9,000 and 11,000 feet, but the type extends from 8,000 to 11,500 feet (Alexander, 1958).

The species composition in spruce-fir forests varies. In the plots studied, the approximate proportion of basal area in trees larger than 10 inches in diameter was 75 percent spruce, 20 percent fir, and 5 percent lodgepole pine. The proportion of fir ranged from zero to 33 percent.

REVIEW OF LITERATURE

A review of all studies of decay of North American true firs was made by Basham, Mook, and Davidson (1953).

Very little has been published on decay in subalpine fir. The only comprehensive study of this species is that by Bier, Salisbury, and Waldie (1948) for the Upper Fraser region of British Columbia. This study demonstrated a consistent relationship between age and decay. Decay was present, but not serious, in trees less than 80 years old. A pathological rotation of 121 to 140 years was suggested on the basis of the maximum net periodic increment. Twenty-one decay fungi were isolated, but _Stereum sanguinolentum_ (Fr.) Fr. and _Echinodontium tinctorium_ E. and E. were responsible for 87 percent of the total decay. _Stereum sanguinolentum_ alone accounted for 47 percent of the decay.

Foster (1954) presented further data based on the study by Bier, Salisbury, and Waldie (1948). He found that alpine firs having forked stems or bearing sporophores were complete culls. Twenty-six percent of the cull trees were in these two classes. It was suggested that site quality and also age and size of the associated species may influence decay in subalpine fir, but no quantitative data were given.

Information on defect in mature and overmature subalpine fir, lodgepole pine, and Engelmann spruce in Colorado was presented by Hornibrook (1950). For all species, 87 percent of the defect was due to decay. Hornibrook indicated that Fomes pini (Fr.) Karst. and Stereum sanguinolentum were the primary decay fungi in subalpine fir, but he did not compare their relative importance. Other decay fungi found in this species were Coniophora cerebella Pers. (occasional), Polyporus tomentosus Fr. var. circinatus (Fr.) Sartory & Maire (rare), and Armillaria mellea (Fr.)Quel. (rare). Mechanical scars in subalpine fir were frequently associated with decay. Other indicators of decay were discussed for all three trees (fir, pine, and spruce) as a whole and their significance for each species was not recorded.

Thomas (1958) recognizes 17 ecological habitats in which subalpine fir occurs in British Columbia. The tree was attacked by the heart-rot fungus, Echinodontium tinctorium, in all but one of these habitats. However, the abundance of the fungus varied considerably in the different habitats. More than 25 percent of the trees bore sporophores in only two habitats. The fact that many subalpine firs were not infected was thought to indicate a degree of natural resistance.

Guides for timber stand improvement operations in the spruce-fir type in the central Rocky Mountains are given by Alexander (1957). Logging scars, fire scars, frost cracks, sunscald, worm or carpenter ant holes, and sporophores were listed as external indicators of decay in subalpine fir.

METHODS

The present study was conducted in two general parts. The first, the intensive study, involved dissection of all subalpine fir in selected sample plots. In the second part, the extensive study, information was obtained on decay in subalpine firs felled in commercial logging operations.

In southern Colorado, corkbark fir, Abies lasiocarpa var. arizonica (Merr.) Lemm., is common. No attempt was made to separate this variety from typical subalpine fir (A. lasiocarpa var. lasiocarpa) in these studies.

INTENSIVE STUDY

Sample plots from 1/4 to 1/2 acre were selected in spruce-fir stands. All subalpine firs, 6.0 inches in diameter or larger, were felled and dissected into 8-foot lengths to a top diameter of 4.0 inches. If decay was found, the bolts were further dissected or split open to measure the extent of decay. The total height, diameter at breast height, age at stump height (1 foot), and dominance class were recorded for each tree. Notes of decay were made and isolations attempted whenever the causal fungus was questionable.

Cubic-foot volumes for each 8-foot bole were determined by use of Smalian's formula

$$\frac{A + a}{2} \times \ell$$

when A = area of top cross section
a = area of bottom cross section
ℓ = length in feet

This same formula was used to calculate cubic foot decay volume if the rot extended through the bolt. If decay was present on any one end of the bolt, the rot volume was calculated as a cone. Board-foot volumes were determined by plotting the trees on cards and marking off 16-foot logs. A 3-inch trimming allowance was made. A top diameter of 7.6 inches was used. The top log was the largest even-foot length possible between 8 and 16 feet. Board foot decay was calculated by using the basic deduction formula

$$\frac{A \times B \times \ell}{15} = \text{decay volume in board feet}$$

when A and B = cross-section dimensions (in inches) of the decay column. One inch is added to each dimension as a safety factor

ℓ = length of the decay column (in feet)

EXTENSIVE STUDY

In the extensive study, plots of about 1 acre were set up in spruce-fir sale areas just before cutting. All trees larger than 9.6 inches in diameter were tagged. The d.b.h., crown class, and abnormalities that might indicate decay were recorded for each tree. The trees were then felled by loggers and bucked into 16-foot or smaller logs, as is usual in local practice. The total height was then measured to the closest 1 foot. As many measurements as possible were made of diameter inside bark and rot diameters at various points up the tree. The trees were then reconstructed on cards and the cubic foot gross and decay volumes calculated as in the intensive study. Board foot gross and decay volumes were measured directly from the logs.

RESULTS

A summary of the basic plot data for the ten intensive and six extensive plots is given in table 1. Only the 277 trees, 9.6 inches d.b.h. or larger, are included in this table. An additional 42 trees between 7.6 and 9.5 inches in diameter were measured in the intensive study. The location of the 16 study areas is shown in figure 1. Data from the intensive and the extensive plots were combined for the following analyses. The plots cut in 1959 had about one-third more decay (41 percent, board foot basis) than the plots cut earlier (30 percent). However, it is not possible to compare the two sets of data directly, since stand ages were not obtained for three of the 1959 plots. The 1959 measurements were obtained from logs cut in the woods, hence these are probably more representative of cull percentages for commercial operations under current utilization standards.

DECAY IN RELATION TO AGE, TREE DIAMETER, AND SITE

The average proportion of decay for all trees larger than 9.5 inches in diameter was 35 percent on a board foot basis and 9.9 percent in cubic feet.

A general, but poorly defined, increase in volume of decay with increasing age is apparent from plot averages (fig. 2). The differences between plots were very marked. For example, plot L (Grand Mesa-Uncompahgre National Forest) with an average stand age of 153 years showed 33 percent decay, while on plot F (White River National Forest) where the trees were nearly 80 years older, the decay amounted to only 18 percent.

Table 1.--Summary of basic plot data from the subalpine fir decay study based on trees over 9.5 inches in diameter

Plot No. and national forest	Tree basis	Average age	Site index[1]	Board foot basis: Gross volume	Board foot basis: Decay	Cubic foot basis: Gross volume	Cubic foot basis: Decay
	No.	Years		Bd. ft.	Pct.	Cu. ft.	Pct.
INTENSIVE STUDY (1953-54)							
E White River	3	120	Minus	100	0	38.4	0.3
C Rio Grande	7	139	Plus	1,000	22	219.7	7.1
G Routt	12	140	Minus	1,150	22	268.9	6.7
A Rio Grande	19	195	Minus	3,560	41	739.9	11.7
B Rio Grande	20	204	Plus	5,620	44	1,120.0	12.9
H Routt	6	207	Minus	620	24	173.0	2.9
J San Juan	23	229	Plus	3,580	24	830.2	5.9
F White River	28	231	Plus	4,860	18	1,084.5	7.8
D White River	34	248	Minus	4,460	26	1,037.1	8.1
I Routt	22	265	Minus	3,180	34	702.4	11.8
All intensive plots	174	--	--	28,130	30	6,214.1	9.2
EXTENSIVE STUDY (1959)							
L Grand Mesa-Uncompahgre	20	153	Plus	4,990	33	999.2	12.6
P Routt	28	215	Plus	6,110	45	1,222.9	11.7
N Roosevelt	13	320	Plus	1,660	34	384.4	7.7
K Roosevelt	6	([2])	Minus	410	10	96.7	3.9
M Grand Mesa-Uncompahgre	29	([2])	Plus	4,320	55	784.8	12.2
O Routt	7	([2])	Plus	770	23	172.9	5.2
All extensive plots	103	--	--	18,260	41	3,660.9	11.1
All plots	277	--	--	46,390	35	9,875.0	9.9

[1] Based on height-age relationship of associated Engelmann spruce (Hornibrook, 1942). Plus sites, sites 80 or better; minus sites, sites 70 or poorer.

[2] Sample insufficient to obtain a reliable estimate of stand age.

When trees on all plots were sorted into age classes, it appeared that decay bore a cyclic relation to age (fig. 3). Percent decay was negligible in the few trees younger than 100 years, but increased rapidly with increasing age to 35 percent (board-foot basis) in the 150-199 year age class. Percent decay found then decreased with increasing age through the 200-249 and 250-299 year age classes. Only 18 percent of the board-foot volume of the latter class was decayed. The percent of decay found then increased again with increasing age in stands older than 300 years. Nearly 60 percent of the gross volume of the seven trees in the 350-399 year age class was decayed.

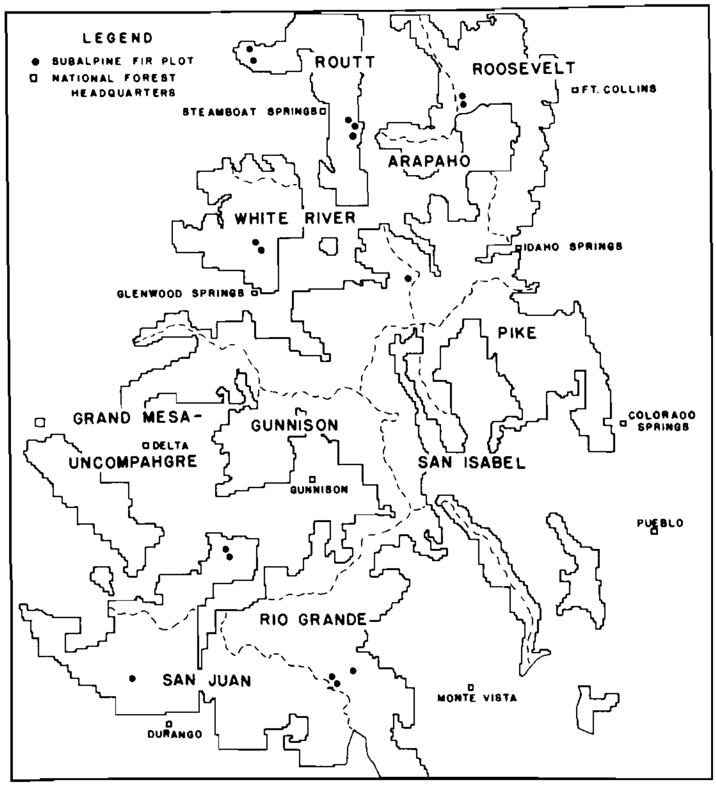


Figure 1. --Map of Colorado showing the location of subalpine fir decay study plots.

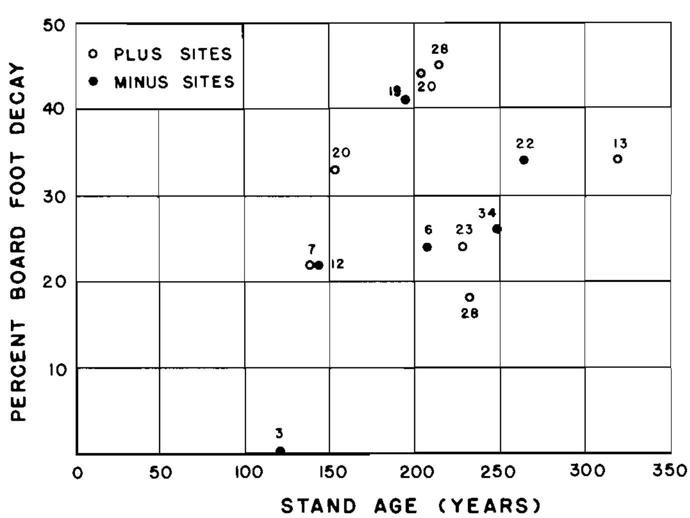


Figure 2. --Percent decay in relation to average stand age in 16 subalpine fir plots. The tree basis for each plot is indicated by the figures.

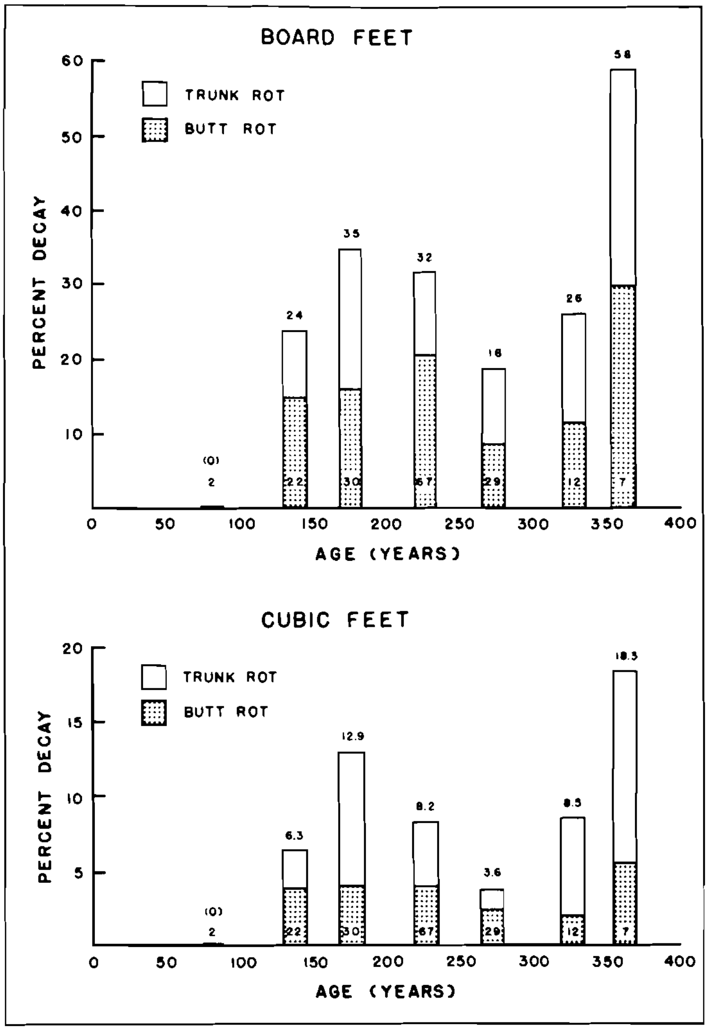


Figure 3. --

Proportion of board-foot and cubic-foot decay by 50-year age classes. Percent decay is indicated by the figure on top of each bar and the tree basis for the age class is shown by the lower figure in each bar. The proportion of butt and trunk rots in each age class is also shown. Total basis: 169 trees.

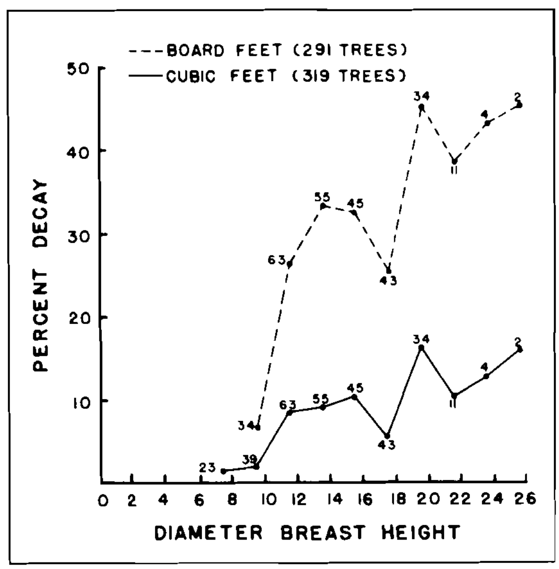
The apparent cyclic relationship between age and decay in subalpine fir is similar to that reported by Boyce and Wagg (1953) for Fomes pini in Douglas-fir in Oregon. At least two factors may be involved in this relationship in subalpine fir: (1) some of the trees infected with decay early in life are killed directly by parasitism of the decay fungi or indirectly by windthrow or wind breakage, and (2) growth of the remaining trees is enhanced by the release due to the loss of the more decadent trees. It seems likely that butt rots are a primary reason for death of infected trees. Butt rots accounted for nearly 60 percent of the decay (board-foot basis) in stands less than 250 years old. The proportion of trees with butt and top rots is shown in table 2. This also points out the high incidence of butt rots in stands younger than 250 years.

There was a marked relationship between percent decay and tree diameter (fig. 4). Decay (board-foot basis) ranged from less than 7 percent in trees under 10 inches d.b.h. to more than 40 percent for trees over 20 inches in diameter.

Table 2. --Trees with butt and trunk rots by 50-year age classes

Age class (Years)	Tree basis	Proportion of trees with-- Butt rot	Trunk rot	All rots
	Number	- - -	Percent	- - -
50- 99	2	0	0	0
100-149	22	32	18	41
150-199	30	40	27	53
200-249	67	60	31	67
250-299	29	34	31	55
300-349	12	58	17	58
350-399	7	43	43	57

Figure 4. -- Decay in relation to diameter. The tree basis for each point is indicated by the figure.



There was no consistent relationship between site class and prevalence of decay (see fig. 2). Also, the following tabulation shows that decay on the two sites was similar. (For this analysis, plot E, in which only three trees were cut, was excluded.)

	Site class (based on associated Engelmann spruce--Hornibrook, 1942) 80 or better	70 or poorer
Average age of trees (years)	213	211
Decay (percent):		
Board-foot basis	34	32
Cubic-foot basis	10.1	9.5
Basis:		
Plots (number)	7	5
Trees (number)	139	93

DECAY FUNGI

Identifications of fungi were made for 58 percent of the decay infections and these accounted for about the same proportion of the total decay volume. For all trees, butt rots accounted for about one-third of the total decay volume and trunk rots for two-thirds. Identified decays accounted for 74 percent of the total trunk rot volume, but only 17 percent of the butt rot volume was associated with identified decays.

Eighteen rot fungi were identified (table 3). Some of the fungi listed require further study for positive identification. At least two additional butt rot fungi were isolated (one isolated eight times and the other five times) but these cannot yet be identified from their cultural characteristics. Six fungi were associated with trunk decay and 12 associated with butt rots were identified. Relatively few of the butt rot fungi were isolated. Also, in many instances, two or more infections were found in the same part of the butt, so it was difficult to assign an accurate volume of decay to a particular fungus.

Table 3. --Fungi associated with 164 identified decay infections in subalpine fir in Colorado (intensive and extensive studies)

Fungus	Type of rot	Infections		Decay volume	
		No.	Pct.	Cu. ft.	Pct.
Trunk rots:					
Stereum sanguinolentum (Fr.) Fr.	White	61	66.3	418.5	76.9
Fomes pini (Fr.) Karst.	White	12	13.0	82.8	15.2
Stereum chailletii (Fr.) Fr.	White	11	12.0	28.0	5.1
Stereum abietinum (Fr.) Fr.	Brown	4	4.3	7.5	1.4
Fomes robustus Karst. var. tsugina (Murr.) Overh.	White	3	3.3	7.5	1.4
Peniophora luna Rom.	Brown	1	1.1	0	0
Total trunk rots		92	100.0	544.3	100.0
Butt rots:					
Corticium radiosum (Fr.) Fr.	White	16	22.2	Trace	0
Coniophora spp.[1]	Brown	12	16.7	9.6	17.8
Armillaria mellea (Fr.) Quel.	White	11	15.3	8.5	15.8
Pholiota squarrosa (Fr.) Kummer	White	10	13.9	8.5	15.8
Coniophora olivacea (Fr.) Karst.	Brown	8	11.1	6.5	12.0
Polyporus tomentosus Fr. var. circinatus (Fr.) Sartory & Maire	White	5	6.9	5.7	10.6
Pholiota alnicola (Fr.) Singer	White	4	5.5	1.8	3.3
Helicobasidium corticioides Bandoni	Brown	2	2.8	1.5	2.8
Polyporus balsameus Pk.	Brown	1	1.4	5.8	10.8
Fomes nigrolimitatus (Rom.) Egel.	White	1	1.4	6.0	11.1
Stereum sulcatum Burt	White	1	1.4	Trace	0
Coniophora arida (Fr.) Karst.	Brown	1	1.4	Trace	0
Total butt rots		72	100.0	53.9	100.0

[1] Probably mostly C. puteana (Fr.) Karst. as this species is common on subalpine fir but specific determinations were not made.

Stereum sanguinolentum was by far the most important decay fungus in subalpine fir (fig. 5C, 5D). It accounted for two-thirds of the identified trunk rot infections and 77 percent of the trunk rot volume. Fomes pini was the next most important trunk rot fungus and accounted for about 15 percent of the identified trunk rot volume. Other trunk rot fungi isolated were Stereum chailletii, S. abietinum, Peniophora luna, and Fomes robustus var. tsugina (fig. 5A). The latter fungus is parasitic. Although it was isolated from only three living trees, it was found fruiting on several firs broken off near the ground level. These trees were mostly less than 10 inches in diameter; this suggests that some of the early mortality in subalpine fir stands may be due to F. robustus var. tsugina.

Corticium radiosum, a white rot fungus which was recently reported from living trees for the first time (Davidson and Hinds, 1958), was the most frequently isolated butt rot fungus, but it produced only negligible amounts of decay.

Twenty-one infections were associated with Coniophora spp. These cause brown cubical butt rots. Two species, C. olivacea (eight infections) and C. arida (one infection), were determined. It seems likely that most of the remaining isolates were of C. puteana although specific determinations were not made.

Armillaria mellea was isolated 11 times. However, it is likely that this fungus is more common, for many isolations of decay that appeared to be caused by A. mellea were either unsuccessful or yielded only contaminants.

Other white rot fungi isolated from butt decays were Pholiota squarrosa, P. alnicola, Polyporus tomentosus var. circinatus, Stereum sulcatum, and Fomes nigrolimitatus (fig. 5B). In addition, two fungi causing brown cubical butt rots were identified: Polyporus balsameus and Helicobasidium corticioides. The latter fungus was described recently from decay in Rocky Mountain subalpine fir (Davidson and Hinds, 1958).

The decay fungi associated with subalpine fir in Colorado were very different from those reported for fir -- subalpine and silver firs (Abies amabilis (Dougl.) Forbes) combined--in the upper Fraser region of British Columbia (Bier, Salisbury, and Waldie, 1948). The main difference was the absence of the Indian paint fungus, Echinodontium tinctorium, in subalpine fir in Colorado. In British Columbia, E. tinctorium caused nearly as much decay as Stereum sanguinolentum. E. tinctorium is, however, common on white fir (Abies concolor (Gord. & Glend.) Lindl.) in Colorado.

None of the heart rot fungi in Colorado subalpine fir consistently form fruiting bodies, so there are no positive external indicators of infection.

The brown stringy rot caused by Stereum sanguinolentum, the brown cubical rots of Coniophora spp., and the white pocket rots caused by Fomes pini and F. nigrolimitatus are distinct enough so that they can be fairly reliably diagnosed from the appearance of the decay alone. However, even for these, certain infections could not have been identified without cultures.

Butt rots accounted for about one-third of the total decay, and these are thought to be of major significance in the history of subalpine fir stands because they lead to windthrow. Little is known of the extent of parasitism by root and butt rot fungi in subalpine fir or other Rocky Mountain conifers. This is an important field for future investigations.

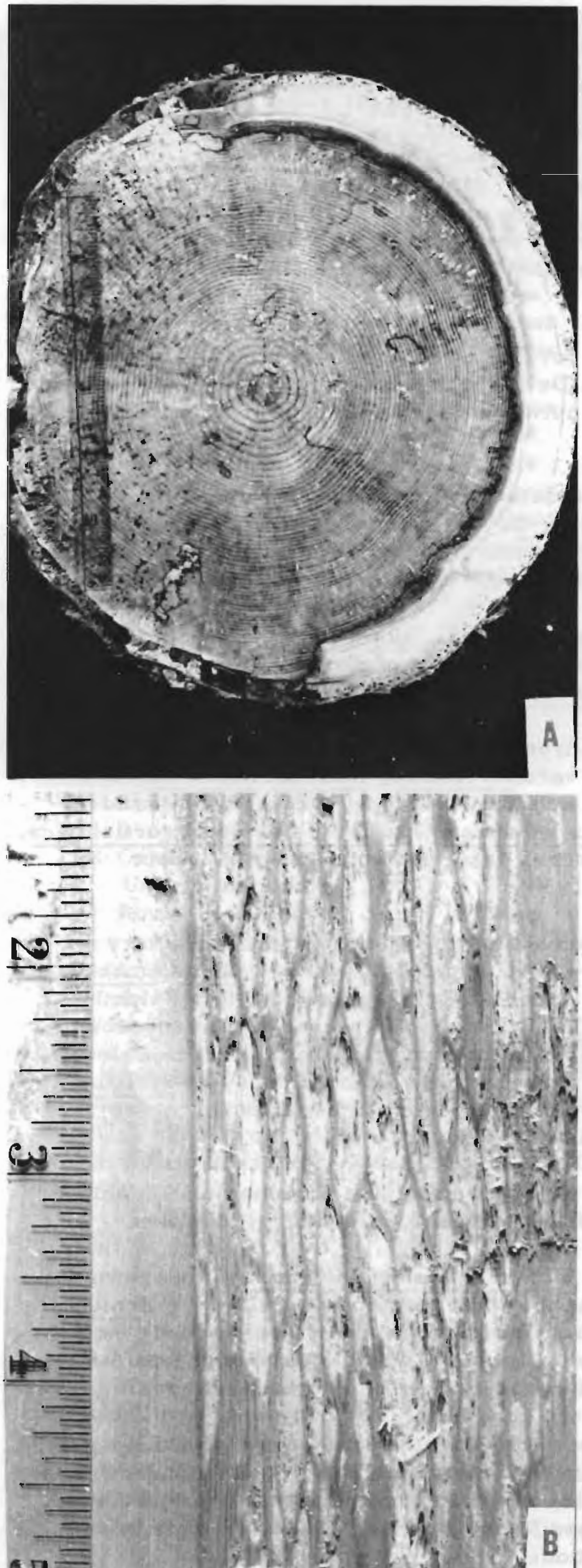
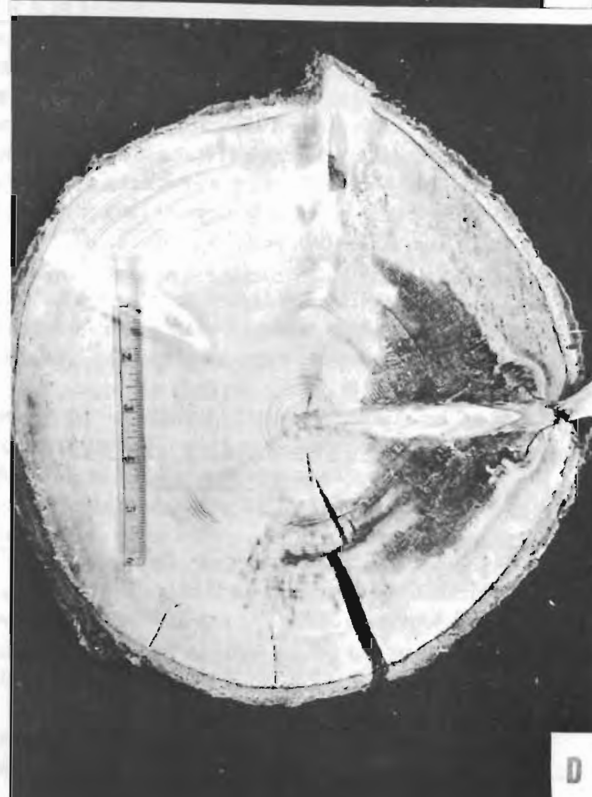


Figure 5.--Decays in subalpine fir. (Inch scale shown in each photograph.)

A, Cross section showing decay caused by Fomes robustus var. tsugina that has invaded the sapwood and killed the cambium.

B, White pocket rot caused by Fomes nigrolimitatus.

C, Trunk decay caused by *Stereum sanguinolentum*.



D, Incipient stage of *S. sanguinolentum* decay concentrated back of a dead branch stub.

ENTRANCE POINTS AND EXTERNAL INDICATORS OF DECAY

For most subalpine firs there were no positive external indicators of decay. It has been previously mentioned that none of the heart-rotting fungi consistently form fruiting bodies on living firs. One reason for the lack of external indicators was that more than half of the decay infections apparently entered through the roots.

The apparent entrance points for 322 decay infections are as follows:

Entrance point	Infections (Percent)
Roots	53
Basal wounds	12
Trunk wounds	8
Branch stubs	8
Broken tops	7
Frost cracks	7
Dead leader	3
Forks	2
	100

Broken tops and trunk wounds were usually indicative of extensive decay. *Stereum sanguinolentum* decay was frequently associated with broken tops. However, this fungus also entered through branch stubs.

SUMMARY

Information on decay in subalpine fir was obtained by dissecting 319 trees in 16 plots in Colorado. Decay for all trees larger than 9.5 inches d.b.h. was 35 percent on a board-foot basis and 9.9 percent for cubic feet. There was an irregular relationship between decay and age. Decay increased with age to a peak in the 150-200 year age class, then declined with age to a minimum in the 250-300 year age class, and then increased again with advancing age to a second peak in the 350-400 year age class.

The decline in decay in trees after 200 years may be due to the death (possibly through wind breakage or windthrow) of the more decadent trees. There was no apparent relationship between decay and site quality.

The fungi associated with about 58 percent of the decay volume were identified. *Stereum sanguinolentum* was by far the most important decay fungus, followed by *Fomes pini*. In all, 18 fungi were isolated--6 from trunk decays and 12 from butt rots.

None of the decay fungi consistently fruit on living trees, and there are no consistent external indicators of decay. However, broken tops and trunk wounds were usually indicative of extensive decay.

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