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Information pertinent to the deterioration of fire-killed timber relative to existing standards of utilization in British Columbia is lacking. Kimmey and Furniss (1943) furnish good guidelines but their data do not meet current operational requirements and their loss factors seem high for conditions observed in coastal British Columbia.

A complete study of fire-killed timber could not be entertained within existing resources. However, the August 1967 Taylor River Burn at Sproat Lake, Vancouver Island, offered an opportunity to examine insect damage and decay in fire-killed Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco, western hemlock (Tsuga heterophylla (Raf.) Sarg.) and western red cedar (Thuja plicata Donn) to provide general guidelines for assessing deterioration in burned coastal Douglas-fir stands until a more comprehensive study could be undertaken.

Methods

Twenty-nine months after the fire, six sites, representative of the conditions over 2000 acres of the burn, were sampled, five in mature

timber and one in an immature 50-year-old stand. Twelve Douglas-fir, four western hemlock and three western red cedar trees were dissected in each site in the mature timber; 14 Douglas-fir, 4 hemlock and 3 cedar in the immature stand.

Sample trees were felled and bucked according to normal bucking practices. An average of 5 stem cross sections were removed over the length of each tree for analysis of decay. Bark was removed from the top and lower side of the stem adjacent to each cross section and the log surface examined for insect attack. Holes in the sapwood were classified and recorded as to the number per square foot of log surface. Dendroctonus egg galleries were recorded, while other insects mining in the phloem which did not enter the sapwood were observed, but population levels were not quantified.

Each stem cross section was examined for sap rot at 8 or more points around the circumference. The patterns of visible decay were recorded on "deterioration tree analysis sheets" and the stage of wood breakdown was categorized as "advanced" (wood could not be used even for pulp) or "incipient" (although subject to severe degrade, the wood still possessed sufficient strength to allow its use in one or more of the products plywood, lumber or pulp).

Results

Douglas fir

Insects

Ninety-five per cent of the mature Douglas-fir trees examined were attacked by one or more of the 3 wood-boring insects, ambrosia beetles,

round headed borers (Cerambycidae) and wood wasps (Siricidae), found commonly throughout the fire-killed stand (Table 1). Infested samples showed an average of 4.8 holes per square foot; average for all samples was 3.6. Insect attack was general throughout the burn and showed no correlation with site or elevation.

Ambrosia beetles and cerambycids were the most abundant, attacking over 87% of the trees and infesting over 50% of the sample area; siricids were present in 27% of the trees and infested 11% of the sample area. Ambrosia beetle attack was heaviest in the lower bole and siricids in the upper bole; the cerambycids attacked relatively uniformly throughout the commercial length of the bole.

Table 1. Percentage of mature Douglas-fir trees with wood borer attack and extent of infestation relative to position on the bole 29 months after fire killing, Taylor River.

Insect	% trees attacked	Region on bole	% of samples infested	Avg no. holes / sq ft	
				infested samples	all samples
ambrosia beetles	90	stump	78	5.6	4.4
		lower	82	4.0	3.3
		middle	68	3.0	2.1
		upper	20	2.4	0.5
		whole bole	54	4.0	2.2
cerambycids	87	stump	40	2.9	1.2
		lower	55	2.9	1.6
		middle	53	2.5	1.3
		upper	50	2.1	1.1
		whole bole	50	2.5	1.3
siricids	27	stump	3	3.0	0.1
		lower	5	2.0	0.1
		middle	13	1.8	0.2
		upper	17	1.8	0.3
		whole bole	11	1.8	0.2
one or more	95	stump	83	6.7	5.6
		lower	85	5.8	5.0
		middle	80	4.5	3.6
		upper	63	3.0	1.9
		whole bole	75	4.8	3.6

Wood borers were recorded in 85% of the immature Douglas-fir trees sampled (Table 2). Ambrosia beetles and cerambycids infestations were lighter than those recorded in mature trees, while siricid attack was significantly greater. The region of the bole attacked by each insect was similar to that noted in mature trees; the attack density was not quantified because of the small sample size.

Table 2. Extent of wood borer attack in immature Douglas-fir 29 months after fire killing, Taylor River.

Insect	% trees attacked	% of samples infested	Avg no. holes / sq ft infested samples	Avg no. holes / sq ft all samples
ambrosia beetles	71	30	4.0	1.2
cerambycids	57	20	1.8	0.4
siricids	78	35	2.7	0.9
one or more	85	62	4.0	2.5

Decay

Of the total volume of mature Douglas-fir, 12% exhibited decay 29 months after the burn (Table 3). Variation in total decay among the sites was not significant.

Table 3. Decay as a percentage of the Douglas-fir tree volume 29 months after fire-kill for each site at Taylor River.

Site elev ft	No. of sections	Avg diam	% advanced decay	% incip. decay	% all decay
		Mature trees			
200	59	20	6	6	12
350	58	13	10	5	15
1000	60	18	4	8	12
1350	59	17	4	7	11
1650	60	16	1	9	10
all sites	296	17	5	7	12
		Immature trees			
200	71	10	1	10	11

The percentage of decay increased with an increase in the height of the section in the tree (Table 4). Only 12% of the 56 samples cut at stump height contained measurable amounts of visible decay, whereas sections cut from midway up the first log and above had appreciable infection.

Table 4. Decay as a percentage of the volume of mature Douglas-fir at various regions in the bole 29 months after fire-kill, Taylor River.

Region of bole	No. of sections	% advanced decay	% incip. decay	% all decay
stump	55	trace	1	1
lower	64	4	5	9
middle	119	7	13	20
upper	58	13	15	28
whole bole	296	5	7	12

The percentage of sapwood decayed was considerably less in the immature compared to the mature timber; only 31 of the 71 sections examined had visible infection. However, because of the smaller average diameter and consequently greater proportion of the sections composed of sapwood in the immature compared to the mature, the percentage of the total volume decayed was almost equal for the two (Table 3).

Fungi responsible for the major proportion of the decay were Haematostereum (Stereum) sanguinolentum, Amylostereum chailletii and Fomes pinicola.

Western hemlock

Insects

Wood borer attack was only slightly less frequent in mature western hemlock than that recorded for Douglas-fir; 90% of the trees were

attacked and 59% of the samples were infested (Table 5). Although the same insect species were responsible for the damage, it is interesting to note the change in their relative importance; siricids assumed the most destructive role in western hemlock while ambrosia beetles and cerambycids occurred somewhat less frequently. Infestation of the lower bole of western hemlock by ambrosia beetles and siricids was consistently higher than that which occurred in Douglas-fir: cerambycid attack was confined to the middle and upper bole.

Siricids were also the most destructive wood borer found in immature western hemlock, all trees having at least some infestation (Table 6). Cerambycid damage was not found in immature hemlock and the ambrosia beetle incidence was less than half that recorded in mature hemlock. The average number of holes per square foot from all wood borers found in immature western hemlock was about half (1.2) that recorded in mature trees (2.2).

Table 5. Percentage of mature western hemlock trees with wood borer attack and extent of infestations relative to position on the bole 29 months after fire killing, Taylor River.

Insect	% trees attacked	Region on bole	% of samples infested	Avg no. holes / sq ft infested samples	Avg no. holes / sq ft all samples
ambrosia beetles	75	stump	25	3.4	0.9
		lower	35	3.7	1.3
		middle	40	3.0	1.2
		upper	28	2.8	0.8
		whole bole	31	3.2	1.0
cerambycids	35	stump	0	0	0
		lower	0	0	0
		middle	20	1.5	0.3
		upper	15	1.3	0.2
		whole bole	10	1.4	0.1
siricids	80	stump	20	1.8	0.4
		lower	25	2.4	0.6
		middle	55	1.8	1.0
		upper	65	2.5	1.6
		whole bole	46	2.3	1.1
one or more	90	stump	30	4.0	1.2
		lower	45	4.2	1.9
		middle	60	4.2	2.5
		upper	80	3.3	2.6
		whole bole	59	3.7	2.2

Table 6. Extent of wood borer attack in immature western hemlock 29 months after fire killing, Taylor River.

Insect	% trees attacked	% of samples infested	Avg no. holes / sq ft infested samples	Avg no. holes / sq ft all samples
ambrosia beetles	25	15	4.3	0.7
cerambycids	0	0	0	0
siricids	100	35	1.4	0.5
one or more	100	45	2.6	1.2

Decay

Twenty-nine months after fire-killing, 24% of the total volume of mature hemlock was visibly decayed (Table 7); a loss approximately 12% greater than that recorded for Douglas-fir. No correlation in extent of infection was found with elevation of the sample site or with diameter of the stem at point of sectioning. Decay was greatest in the middle and upper bole but losses were relatively high throughout the commercial length of the trees (Table 8).

Over half of the volume of immature hemlock was visibly decayed (Table 7), damage at and above the top of the first log being consistently high. As with Douglas-fir, the percentage of the total volume decayed was almost equal for immature and mature trees.

The fungi responsible for the major portion of the decay were Amylostereum chailletii, Fomes annosus and Fomes pinicola.

Table 7. Decay as a percentage of mature western hemlock tree volume 29 months after fire-kill for each site at Taylor River.

Site elev ft	No. of sections	Avg diam	% advanced decay	% incip. decay	% all decay
			Mature timber		
200	20	14	8	10	18
350	16	14	24	9	33
1000	20	20	2	22	24
1350	20	14	9	16	25
1650	20	14	3	12	15
all sites	96	15	8	16	24
			Immature timber		
200	20	8	13	11	24

Table 8. Decay as a percentage of the volume of mature western hemlock at various regions in the bole 29 months after fire-kill, Taylor River.

Region of bole	No. of sections	% advanced decay	% incip. decay	% all decay
stump	20	7	2	9
lower	19	5	15	20
middle	38	8	25	33
upper	19	10	30	40
whole bole	96	8	16	24

Western red cedar

Insects

Wood borer attack in mature western red cedar was much less common than in Douglas-fir and western hemlock; attack had not occurred in 2 of the 5 sites, less than half the trees had been damaged and only 22% of the samples were infested (Table 9). The average number of holes per square foot, all samples, was only a third to a fifth of that found in the other species.

Attack in immature cedar, on the other hand, equalled or exceeded that found in immature Douglas-fir and hemlock. All trees showed some damage, with 67% of the samples infested (Table 10). The average number of holes per square foot, all samples, was 2.1, all of which were attributable to cerambycids and siricids; no ambrosia beetle attack was recorded.

Table 9. Percentage of mature western red cedar trees with wood borer attack and extent of infestations relative to position on the bole 29 months after killing, Taylor River.

Insect	% trees attacked	Region on bole	% of samples infested	Avg no holes / sq ft infested samples	Avg no holes / sq ft all samples
ambrosia beetles	27	stump	7	5.0	0.3
		lower	7	2.0	0.1
		middle	7	1.0	0.1
		upper	14	2.0	0.3
		whole bole	10	2.3	0.2
cerambycids	20	stump	0	0	0
		lower	0	0	0
		middle	0	0	0
		upper	4	1.0	tr
		whole bole	11	1.0	tr
siricids	33	stump	7	4.0	0.3
		lower	13	3.0	0.4
		middle	13	3.5	0.5
		upper	25	2.3	0.6
		whole bole	16	2.8	0.5
one or more	40	stump	13	4.5	0.6
		lower	20	2.7	0.5
		middle	20	2.7	0.5
		upper	29	3.1	0.9
		whole bole	22	3.1	0.7

Table 10. Extent of wood borer attack in immature western red cedar 29 months after fire killing, Taylor River.

Insect	% trees attacked	% of samples infested	Avg no. holes / sq ft infested samples	Avg no. holes / sq ft all samples
ambrosia beetles	0	0	0	0
cerambycids	100	40	2.5	1.0
siricids	100	47	2.4	1.1
one or more	100	67	3.2	2.1

Decay

Eighty-seven western red cedar sections were examined from the 5 mature and 1 immature sites. Blue stain was recorded in the sapwood of most sections, but visible decay occurred as a small pocket in only one sample and consequently no loss could be attributed to this cause.

Discussion and Summary

Three groups of wood borers, ambrosia beetles, cerambycids and siricids, were the most abundant insects recorded in fire-killed Douglas-fir, western hemlock and western red cedar trees 29 months after a severe burn at Taylor River, Vancouver Island, British Columbia. Except for a somewhat lighter attack in mature cedar, infestation of both mature and immature trees was extensive. Damage was evident to the depth of the sapwood in most samples; cerambycids had started to attack the heartwood.

Siricids were the most abundant wood borer in western hemlock and western red cedar; cerambycid attack, while almost as abundant as ambrosia beetle in Douglas-fir, was relatively light in hemlock and cedar. Both the former insects produce holes far larger than do ambrosia beetles and consequently may be of greater economic concern even though fewer in number in instances where all species occur in the same log. Siricid activity may also result in severe damage to the outer heartwood. Most siricid and cerambycid attacks on western hemlock and western red cedar were complete by the time of this study. However, evidence points to continued activity, and probably at an advanced rate, of both these wood borers in mature Douglas-fir in the third year following the burn.

No correlation was found between extent of sap rot or between immature and mature timber and insect attack at the time of sampling.

Siricids lay eggs in the wood through a fine, needle-like ovipositor and consequently there is no external indication of recent infestation. When infested wood is not kiln-dried, larval activity may continue in the product unnoticed until the insect emerges, leaving a hole as large as 5-7 mm in diameter.

Dendroctonus activity in the phloem of fire-killed timber was rated as extremely light in the areas sampled 29 months after the burn; removal of a large proportion of the insects during salvage logging and their reluctance to attack badly charred bark probably contributed to the low population level. A build-up of Dendroctonus, along with ambrosia beetles, in the peripheral green, root-burned timber was evident in the second year following the fire; additional damage in these trees can be expected and undoubtedly some further mortality will result.

Twenty-nine months after the fire, decay was present to the depth of the sapwood in most of the sections of mature timber examined, except for western red cedar. Western hemlock appeared to be most susceptible to a rapid development of wood decay fungi, with 24% of the total volume infected; Douglas-fir was moderately susceptible, with 12% of the volume decayed. With the exception of blue staining fungi, western red cedar was little affected by decay fungi. Almost half of the decay in Douglas-fir was classed as in the advanced stage, i.e., of no value in the manufacture of lumber or pulp, whereas only a third of the decay in hemlock was in this category.

Wright and Harvey (1967), in a study of beetle-killed mature Douglas-fir, reported losses equal to those found in this species on the Taylor River burn. However, three years after the burn they noted that

very little deterioration had occurred in the top third of the trees. This was not evident in the Taylor River burned timber, where it appeared that the top portion of the bole, 8 inches and less in diameter, would be of little economic value after 3 years. Wright and Harvey's findings may serve as a useful guide in predicting future deterioration. After 5 years, almost all of the sapwood was decayed and significant deterioration of the heartwood had begun; felling breakage occurred at about 75% of the original merchantable height. By 7 years, salvagable material was usually limited to the lower bole, top breakage was common at 9 years, and deterioration was usually complete after 11 years.

Deterioration of fire-killed mature western hemlock can be expected to progress at a rate well in advance of that of Douglas-fir. However, fungal deterioration of mature fire-killed western red cedar may not be significant for many years beyond that reported for Douglas-fir.

References

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