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Forest Fire Frequency and Western Spruce Budworm Outbreaks in Western Montana

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ABSTRACT

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Duration and intensity of western spruce budworm (*Christoneura occidentalis* Freeman) outbreaks have increased with the decrease in forest fire frequency in western Montana since 1910. Frequency of budworm outbreaks, however, was not affected. Feeding activity and fire occurrence were measured in 20 mixed Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco)-ponderosa pine (*Pinus ponderosa* var. *ponderosa* Dougl. ex Laws.) stands representing dry Douglas-fir habitat types. Outbreak frequency, duration, and intensity were inferred from analyses of radial increment cores and fire history from basal fire scars on old-growth pines and firs. Data were compared between the pre-fire suppression period (1814-1910) and the fire suppression period (1911-1983). Since 1910, Douglas-fir, a shade-tolerant conifer and host for budworm, has invaded and dominated sites previously occupied by non-host ponderosa pine. This increase in the abundance of host is a response to decreased wildfire frequency and has resulted in stand conditions favorable for budworm populations, an important factor contributing to current widespread and damaging populations of western spruce budworm.

Judicious use of ground-fire, thinning, and other silvicultural treatments that favor seral non-host conifers, reduce stand density, and minimize the number of canopy layers in managed stands would reduce the amount and quality of budworm habitat and significantly reduce the risk of damaging outbreaks.

INTRODUCTION

Western spruce budworm (WSB; *Choristoneura occidentalis* Freeman) is a widely distributed defoliating insect indigenous to the forests of western North America. This insect causes extensive growth loss and some mortality of host trees in infested stands; at times this damage is economically important and of considerable interest to forest managers (Johnson and Denton, 1975). The most common conifer hosts are Douglas-fir (*Pseudotsuga menziesii* var. *glauca*

(Beissn.) Franco), grand fir (*Abies grandis* (Dougl.) Forbes), subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.), white fir (*Abies concolor* (Gord. & Glend.) Lindl.), Engelmann spruce (*Picea engelmannii* Parry), and western larch (*Larix occidentalis* Nutt.).

Three major budworm outbreaks occurred in western Montana between 1926 and 1972 (Johnson and Denton, 1975), coincident with the forest fire suppression program that began about 1910. Reduced fire frequency changed forest successional patterns and altered stand structure and species composition. These changes in successional patterns resulted in vast acreages of multi-storied Douglas-fir stands that are exceptionally good budworm habitats (Wright and Heinselman, 1973; Arno, 1976; Fellin, 1980; McCune, 1982, 1984; Carlson et al., 1986). We hypothesized that reduced forest fire frequency indirectly contributed to the massive budworm oubreaks of the past 50–60 years. This study was designed to determine relationships between forest fire frequency, stand conditions, and WSB outbreaks in Douglas-fir habitat types common in the Northern U.S. Rocky Mountains.

METHODS

Twenty sites were sampled in western Montana during the fall of 1983 and spring of 1984. Habitat types (Pfister et al., 1977) representing potential vegetation at these sites were PSME/PHMA (*Pseudotsuga menziesii/Physocarpus malvaceous*), PSME/SYAL (*P. menziesii/Symphoricarpos albus* (L.) Blake), and PSME/FESC (*P. menziesii/Festuca scabrella* Torr.), all of which are relatively dry. Stands were dominated by Douglas-fir and ponderosa pine (*Pinus ponderosa* var. *ponderosa* Dougl. ex Laws.). Old-growth Douglas-fir and ponderosa pine were present on all the sites; little or no evidence of past logging was found. These sites were selected because: (1) they represented habitats favorable to budworm (Johnson and Denton, 1975); (2) fire frequency was higher on dry sites prior to the early 1900's (Arno, 1976); and (3) fire histories were known for some of the sites.

To determine fire histories, three to five old-growth pines or Douglas-firs with the greatest number of externally visible fire-scars were selected at each site (Arno and Sneck, 1977). Historic fire sequences (Fig. 1) were determined by analyzing cross-sections cut from the fire-scars (Arno and Sneck, 1977; Arno and Petersen, 1983). Mean fire intervals (MFI) were calculated for the pre-fire suppression period from 1814 to 1910 and the fire suppression period from 1911 to 1983. Mean fire interval is the arithmetic average of the number of years between successive fires in a designated area during a designated time (Romme, 1980). After 1910, sustained organized control of wildfire became policy for land-managing agencies. The year 1814 was set because we did not find enough older trees to provide a suitable earlier record.

To further document fire history, we calculated fire years for each stand. A

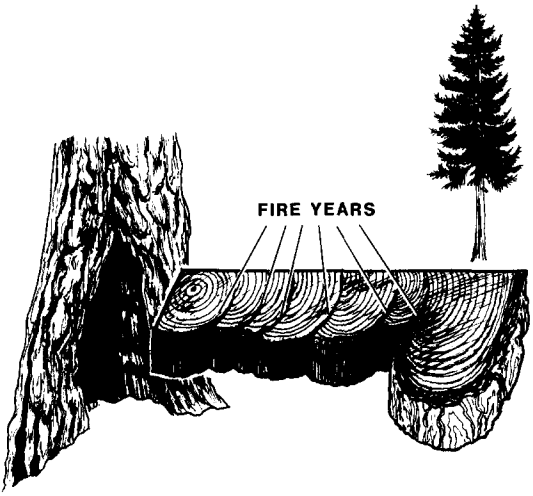

Fig. 1. How fire years are determined on a mature conifer. (From Arno and Sneck, 1977.)

fire year was defined as a year in which at least one fire occurred in the stand. The number of fire years was then summed by decade (1801–1810, 1811–1820, ..., 1971–1980) across all stands, serving as a general indicator of fire history for the study.

Past activity of WSB was assessed by radial increment analysis of cores from paired WSB host/nonhost conifers (Carlson and McCaughey, 1982). Five host/nonhost pairs were selected in each stand; each tree was dominant or codominant, alive, at least 130 years old, and at least 20 m from cutting boundaries, stumps, or roads. For determining WSB history we preferred to use the same trees as used for determining fire history. However, because some trees used to estimate fire intervals were rotton or pitchy near the pith, cores were taken from alternate sample trees.

Two increment cores were extracted from opposite sides of each tree at breast height parallel to the topographic contour. The cores were stored in labeled, sealed plastic straws to prevent breakage or shrinkage. Annual increments were measured to 0.1 mm. Duration and severity of WSB outbreaks were estimated for the presuppression and suppression periods (Fig. 2). Annual increment of host and nonhost was squared, cumulated, and plotted against year of growth (Carlson and McCaughey, 1982). The non-host pine served as a reference for climatic and site effects on annual growth. The host curve was compared subjectively to the non-host curve and outbreaks were inferred if cumulative growth of Douglas-fir departed negatively from that of ponderosa pine for at least 6 years. Severity of outbreaks was estimated by comparing actual host increment (A) to potential host increment (P) in the absence of WSB. Severity index was defined as $1 - A/P$ (Carlson and McCaughey, 1982) and could vary from

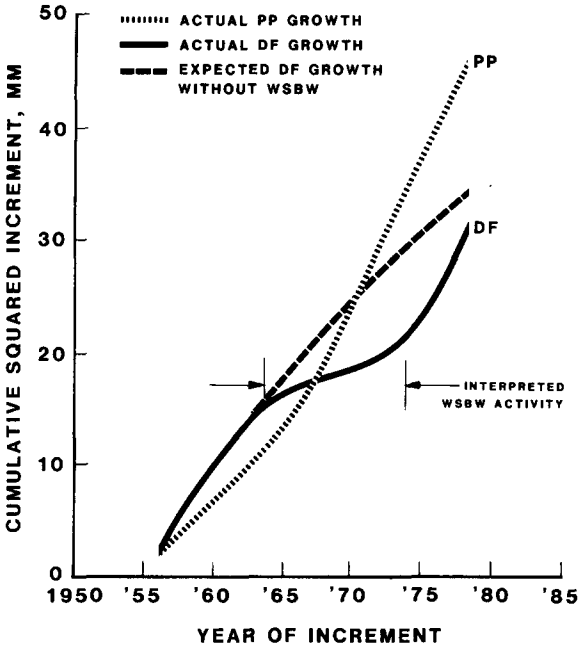

Fig. 2. Graphical method used to infer duration and severity of budworm feeding periods. (From Carlson and McCaughey, 1982.)

0.0 to 1.0, with 1.0 indicating the highest impact. Outbreak frequency for each period was the number of outbreaks divided by number of years in the period.

Historic species composition and stand structure were reconstructed for five of the 20 sites to determine whether frequency of Douglas-fir increased relative to pine since fire suppression began. A 375-m^2 circular plot was centered at each of three trees selected for fire history analysis. The number of trees in each plot was recorded by 5-cm diameter classes. Increment cores were taken from three trees in each size class and the rings counted to determine age. Live crown ratios were recorded for sample trees, and basal area per hectare recorded for each plot. Ingrowth was summed by decade (1801–1810, 1811–1820, ..., 1971–1980) collectively for the five stands.

Average stand values of MFI and WSB outbreak frequency and duration and severity were compared between the presuppression and suppression periods using unpaired t-tests; percentages were transformed to arcsin of the square root of the percentage (Sokal and Rohlf, 1969). Significance was determined at the 5% level. Change in stand composition and structure relative to fire history was evaluated subjectively by comparing graphs of ingrowth by decade to fire years by decade.

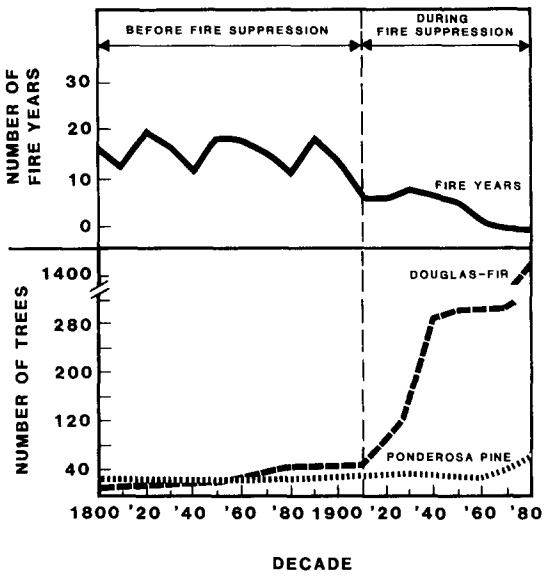

Fig. 3. Top. Number of fire years by decade in western Montana between 1800 and 1980. Bottom. Frequency of ponderosa pine and Douglas-fir ingrowth by decade.

RESULTS AND DISCUSSION

As expected, the incidence of wildfire in our stands decreased dramatically after 1910. A total of 233 fires were inferred from the data. Of these, 202 occurred between 1814 and 1911, whereas only 31 occurred since then. Mean fire interval increased significantly from 15.1 years before 1910 to 49.3 years since. The number of fire years per decade decreased after 1910 and the number and proportion of Douglas-fir increased substantially (Fig. 3). This invasion by Douglas-fir resulted in tiered or stratified canopy structures.

Evidence of past feeding by WSB was detected in 15 of the 20 stands sampled. Twenty-eight feeding periods occurred, some stands had multiple episodes, and five stands had no evidence of budworm feeding activity (Table 1). Budworm outbreaks usually are not restricted to individual stands but tend to occur over relatively large areas. Our sites were located in western Montana, a small part of the Northern Rockies, and the feeding periods we detected in individual stands likely were associated with general outbreaks. If so, our data indicate that three major outbreaks occurred in the 96 years before fire suppression (one every 32 years) and two in the 70 years since (one every 35 years), suggesting that outbreak frequency has not changed (Fig. 4). In the unlikely situation that each feeding period in each stand represented a separate outbreak, the same conclusion is reached; outbreak frequency averaged 0.01/year before and after 1910.

TABLE 1

Mean fire interval and western spruce budworm feeding duration and severity before and during fire suppression in western Montana

	Mean fire interval[a]		Outbreak frequency				Outbreak duration, years		Outbreak severity[b]	
Stand	Before 1910	After 1910	Before 1910	After 1910	Outbreak number	Outbreak start	Before 1910	After 1910	Before 1910	After 1910
1	21.8	72.0	0.0	0.0	—	—	—	—	—	—
2	23.2	72.0	0.0	0.0	—	—	—	—	—	—
3	12.4	72.0	0.021	0.028	1	1841	9	—	0.36	—
					2	1861	12	—	0.30	—
					3	1916	—	29	—	0.75
					4	1968	—	14	—	0.71
4	13.8	72.0	0.01	0.014	1	1892	6	—	0.57	—
					2	1968	—	14	—	0.67
5	20.0	72.0	0.01	0.0	1	1888	25	—	0.70	—
6	12.3	24.0	0.0	0.014	1	1966	—	16	—	0.69
7	6.6	32.0	0.01	0.014	1	1885	17	—	0.23	—
					2	1912	—	26	—	0.56
8	15.9	72.0	0.0	0.014	1	1916	—	33	—	0.72
					2	1949	—	33	—	0.72
9	7.5	18.3	0.01	0.028	1	1887	11	—	0.28	—
					2	1916	—	29	—	0.76
					3	1959	—	6	—	0.33
10	16.0	10.3	0.021	0.0	1	1866	7	—	0.50	—
					2	1890	15	—	0.47	—
11	8.9	72.0	0.01	0.014	1	1862	17	—	0.45	—
					2	1916	—	26	—	0.64
12	19.5	23.7	0.0	0.0	—	—	—	—	—	—
13	10.5	24.5	0.01	0.014	1	1844	7	—	0.70	—
					2	1915	—	32	—	0.76
14	12.5	72.0	0.021	0.014	1	1854	23	—	0.50	—
					2	1887	24	—	0.57	—
					3	1961	—	21	—	0.63
15	29.0	72.0	0.01	0.0	1	1842	8	—	0.54	—
16	14.3	18.7	0.01	0.0	1	1868	9	—	0.40	—
17	10.3	72.0	0.0	0.0	—	—	—	—	—	—
18	17.5	72.0	0.01	0.0	1	1872	10	—	0.33	—
19	7.9	24.0	0.0	0.0	—	—	—	—	—	—
20	22.0	18.3	0.01	0.0	1	1892	8	—	0.75	—
Mean	15.1	49.3	0.01	0.01			13.0	23.2	0.48	0.66
S.E.	1.35	5.83					1.7	2.6	0.04	0.04

[a]Pre-fire suppression period (1814-1910).
Fire suppression period (1911-1983).
[b]Severity index can range from 0.0 to 1.0. From Carlson and McCaughey (1982).

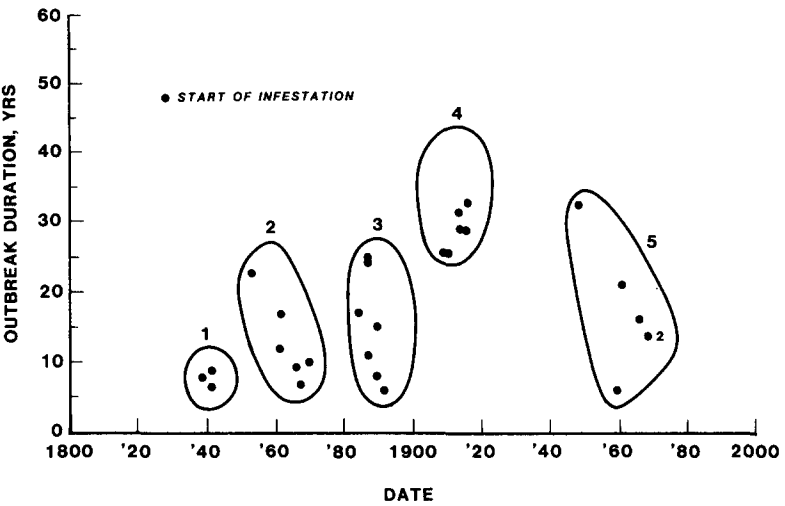

Fig. 4. General outbreaks of budworm interpreted from start of feeding periods.

Even though outbreak frequency did not differ between fire history periods, the duration and intensity of feeding activity by WSB were significantly greater since fire suppression began (Table 1). Duration in stands averaged 13.3 years prior to 1910 but 25.4 years since then. The severity index of presuppression outbreaks was 0.48 but increased to 0.66 during the suppression years, indicating that WSB numbers in the local outbreaks may have increased. A similar conclusion is reached after grouping the feeding periods into the five general outbreaks (Table 2). However, the duration of outbreak 5 (Table 2) is underestimated because budworm was still active at all five sites when fieldwork was done.

Outbreak duration likely was overestimated in most cases. We detected durations from 6 to 33 years in the increment data, but outbreaks actually ob-

TABLE 2

Duration and severity of five budworm outbreaks in western Montana

Outbreak	Period	No. of stands	Length (years)		Severity	
			Average	S.E.	Average	S.E.
1	1814-1850	3	8.0	0.58	0.53	0.10
2	1851-1880	6	13.0	2.44	0.41	0.03
3	1881-1910	7	15.1	2.80	0.51	0.07
4	1911-1940	6	29.2	1.20	0.70	0.03
5	1941-1982	6	17.3	3.70	0.63	0.06

served between 1922 and 1953 lasted from 1 to 30 years (Johnson and Denton, 1975). Most lasted only 1–5 years. Tree growth may remain depressed for many years following defoliation, depending on the intensity of the infestation. We had no way of correcting our data for this differential lag and believe the true lengths of infestations were shorter than inferred. Thus, duration should be interpreted as an index of the true outbreak length. Even though the magnitude may be overestimated, the trends appear clear — recent infestations lasted longer and were more severe than before 1910.

Our evidence reasonably supports the hypothesis that feeding activity of budworm increased since fire suppression began. Severity and duration of feeding increased even though frequency remained about the same. Budworm is a successful native insect and has co-evolved with its hosts. Stand factors such as species composition and stand structure influence budworm populations and, unlike weather and climate, are particularly sensitive to fire. Many seral, fire-maintained communities formerly dominated by ponderosa pine and western larch could not support significant numbers of budworm but have gradually been replaced by multistoried, dense, budworm-susceptible stands dominated by shade-tolerant Douglas-fir. This replacement began in the early 1900's when wildfire was significantly reduced as an ecological force (Dickman, 1978; Arno, 1980).

Furthermore, selective logging during the first half of this century removed much of the seral seed source, and poor site preparation further reduced the likelihood of seral stand regeneration. This has not been a small-scale phenomenon; hundreds of thousands of hectares in the Northern Rocky Mountains now support dense stands of Douglas-fir, nearly unlimited habitat for budworm.

Graphical methods of radial increment analyses used here have some inherent problems. A bias may be introduced in using only living trees to dendrochronologically interpret WSB history. However, this bias tends to be insignificant when the defoliator kills only a small proportion of the host trees. Small trees tend to be impacted more by WSB than large trees because larvae disperse downward and concentrate on the smaller trees. Large trees today once were small trees, and we measured increment cores taken from large trees. This differential impact may have been present in our cores, but we could not account for it.

Radial increment depression could have been caused by the Douglas-fir tussock moth *Orgyia pseudotsugata* McDunnough (Johnson and Denton, 1975). However, tussock moth outbreaks are rather infrequent in Montana (Tunnock, 1973). Needle-cast disease, caused by *Rhabdocline pseudotsugae* Syd., may also reduce radial increment of Douglas-fir, but this disease is sporadic and epidemics seldom last for more than a year or two. Because we counted only growth depression for at least 6 years before an infestation was declared, the probability of misidentification was minimal.

Suppression of radial growth also can be caused by crown scorch resulting from fire on both ponderosa pine and Douglas-fir. In extreme cases, radial

growth of pine can cease for 5 years and then resume (Craighead, 1927). Although some of the periods of growth reduction in Douglas-fir that were labeled as outbreaks occurred immediately after a fire, it was impossible to know if the reductions were actually due to fire-scorch or budworm. The 6-year minimum duration chosen for outbreak determination should have reduced the probability of overestimating WSB activity, because severe fires would likely have similarly affected growth of ponderosa pine and thus precluded our labeling of those periods of growth depression as outbreaks.

Factors other than those influenced by a reduction in fire undoubtedly have affected WSB populations since the early 1900's. Insecticide spray programs between 1950 and 1970 reduced local WSB populations (Johnson and Denton, 1975), but the effects likely were temporary (Fellin et al., 1983). Genetic differences between host-tree populations most certainly influence WSB populations (McDonald, 1979, 1981). In this study, we sampled radial growth analyses only from the older dominant and codominant Douglas-fir. Presuming these trees to be the least vulnerable to WSB, mainly because they survived previous outbreaks, our results probably are conservative. More-vulnerable trees would have shown more growth depression and we may have inferred greater frequency and intensity of outbreaks.

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

Reduced fire frequency for the past 75 years has allowed extensive, continuous areas of forests susceptible to western spruce budworm to develop. Harvesting practices that removed the seral ponderosa pine and western larch aggravated the problem. Forest susceptibility to WSB can be reduced significantly through forest management practices that more closely resemble the pre-1911 fire effects (Carlson et al., 1986). Following harvesting, sites should be prepared to encourage establishment and growth of seral, non-host conifer species. Prescribed fire would do very well in most cases (Fischer, 1978; Martin and Dell, 1978). Seral species should be favored when planting. Prescribed fires in dense stands of Douglas-fir may reduce the density of host and remove the lower canopy layers; this practice may be particularly effective in wilderness areas where timber harvesting is forbidden but budworm-susceptible stands have developed. Drainage-wide mosaics of even-aged seral stands would be relatively nonsusceptible to WSB; if these conditions are realized at some future date, budworm outbreaks may be less intensive and enduring.

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