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Population Density of Western Spruce Budworm as Related to Stand Characteristics in the Bitterroot National Forest

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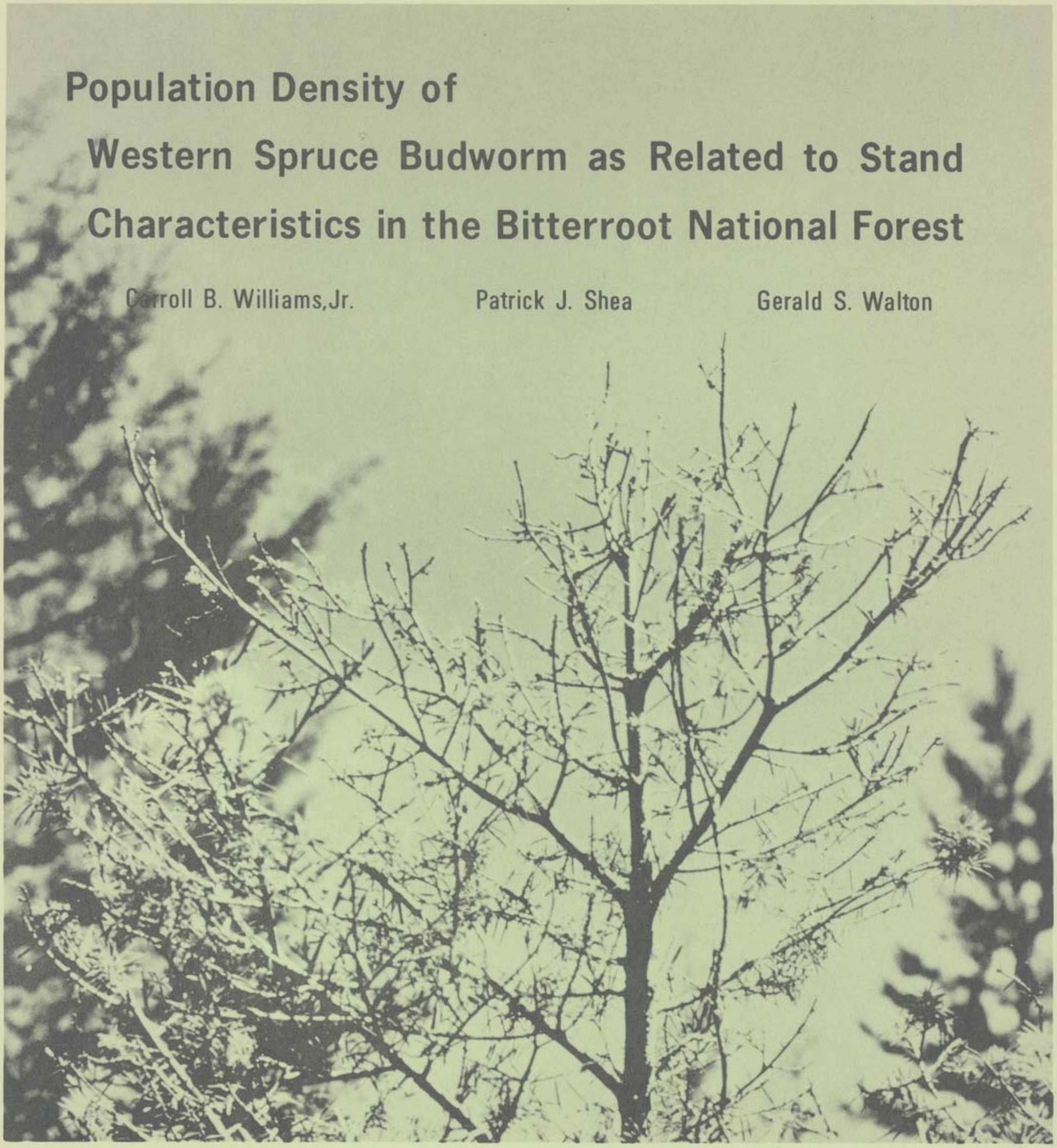

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The Authors

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Damage by the western spruce budworm *(Choristoneura occidentalis* Freeman*)* is widespread throughout the Western United States. The main host trees are Douglas-fir *(Pseudotsuga menziesii* [Mirb.] Franco*)*–usually the most cornmon–Engelmann spruce *(Picea engelmannii* Parry*)*, and the true firs *(Abies* spp.*)*. High budworm populations severely defoliate the trees, reducing growth–and trees often die after several years of defoliation. True firs are particularly vulnerable to defoliation damage. In eastern Oregon, grand fir *(A. grandis* [Doug].) Lindl.*)* suffer heavier damage than associated Douglas-fir (Williams 1966, 1967).

Site and growth conditions affect mortality and damage to the trees. Turner (1952) examined mortality of balsam fir *(A. balsamea* [L] Mill*)* caused by the spruce budworm *(C. fumiferana* Clemens*)* in Ontario. He found that percentage mortality of fir increased as basal area of fir per acre increased. Shephard (1959) reported that more defoliation damage by the 2-year-cycle budworm *(C. biennis* Freeman*)* occurred in Englemann spruce-subalpine fir forest stands growing on dry, poor sites than in stands growing on relatively moist, more productive sites in the Canadian Rocky Mountains.

On the Bitterroot Range in Montana, we found only a few Douglas-fir trees growing near streams or in the open stands on the south-to-west facing slopes that had been killed by defoliation. We observed much greater mortality in the dense, small, heavily defoliated sawtimber stands of Douglas-fir growing on the upper portions of the north-facing slopes. Competition for water in these dense stands appeared to contribute to mortality of the defoliated trees.

Forest entomologists have devised various schemes that attempt to describe, group, or classify the variations in current defoliation and cumulative damage caused by defoliation and to show their relation to reductions in tree growth (Church 1949; Williams 1967). Many of these schemes have not related variation in damage to actual insect population levels. If they are strongly related to budworm population density then they can be used as indirect measures to classify population levels as well as to describe damage and indicate reductions in individual tree growth.

To reduce their sampling work forest entomologists have assumed that the average population density of the western spruce budworm is situated at mid-crown in infested trees. This assumption is based on the population distribution of the spruce budworm within the crowns of balsam fir in New Brunswick as reported by Morris (1955). This assumption must be checked for the situation in the West since the population distribution of the western spruce budworm in tree crowns may differ among its host tree species. If the assumption is false then sampling only the mid-crowns of host trees may give biased information.

Forest managers might be able to reduce the frequency and severity of western spruce budworm outbreaks and damage by regulating stand and tree conditions that contribute to high population levels. Research is needed to identify conditions that can be manipulated by cutting and other stand management practices. To see if there is a relationship between levels of western spruce budworm populations and forest stand and tree conditions we related budworm density to eight characteristics, ranging from tree species to the study areas, on four budworm-infested drainages in the Bitterroot National Forest in Montana.

This paper reports on the study and offers some suggestions on damage survey and forest management based on the results.

STUDY AREAS

A series of plots were laid out in four V-shaped drainages that are tributary to the west fork of the Bitterroot River about 50 miles southwest of Hamilton, Montana. The four drainages range from 1,000 to 1,200 acres. *C. occidentalis* was found on Douglas-fir, Engelmann spruce, and subalpine fir *(Abies lasiocarpa* [Hook] Nutt.*)*. In an earlier study (Williams and Walton 1968), two of the drainages (Tough Creek and Mud Creek) were aerially sprayed with insecticides and the remaining two drainages (One-Two and Blue Joint Creeks) were used as check areas. The budworm population data used in the study reported here were obtained from the pre-spray sampling work, which was carried out in early July when most of the population was in the fifth instar.

Three stand types predominate in each of the four drainages: (1) open stands of large ponderosa pine with a mixed pine and Douglas-fir understory on the south-to-southwestern slopes; (2) dense mixed stands of scattered large pine and Douglas-fir with a predominantly Douglas-fir understory on the northeast-facing slopes; and (3) dense stands of large Engelmann spruce, subalpine fir, and Douglas-fir on the moist to wet flood plains. Study plots established in each type consisted of at least four Douglas-fir trees and up to four each of subalpine fir and Engelmann spruce trees.

Four study plots were established in Blue Joint Creek drainage and eight plots in each of the remaining three drainages. Two plots were on the flood plain; two on the exposed, southwest-facing slopes; and the remaining four on the northeast-facing slopes for Tough, Mud, and One-Two Creek drainages. At Blue Joint Creek, two plots were on the flood plain and one each on the south-facing and north-facing slopes.

We found subtle differences in vegetation composition among the four study areas, with Blue Joint Creek having the greatest difference. Generally, Douglas-firs were the most numerous trees in the stands, although ponderosa pines were the largest trees, particularly on the dry, west-facing plots. Subalpine fir and Engelmann spruce were generally restricted to the moist and sheltered situations, reaching their best development with Douglas-fir on the flood-plain plots. Aspen *(Populus tremuloidea* Michx.*)* and cottonwood *(P. trichocarpa* T. and G.*)* were restricted to wet areas in Blue Joint Creek.

Although the understory plant unions were complex, the vegetation on the four drainages appeared to fit Daubenmire's (1952) Douglas-fir/ninebark habitat type. The tree reproduction is mainly Douglas-fir. Clearly, forest succession in the four drainages, in the absence of fire, is rapidly going from ponderosa pine to Douglas-fir, a more budworm-susceptible forest.

METHODS

The relation between manageable aspects of the forest environment and high levels of insect density was studied through data gathered in the field and subjected to analysis of variance. To ensure that the results could be unambiguously interpreted, only main effect variables were included in a model. Further, data were analyzed for site and tree variables which could be modified by forest management. Besides counting insects, we measured defoliation and damage. These variables, although dependent on density, were included in the analysis so that the degree of dependence could be determined. These variables can be observed by the forester and might be useful to him in making management decisions.

The dependent variable used in the analysis of variance was loge ((1 + C)/A), in which *C* was the insect count and *A* the surface area of the branch sample. The independent variables consisted of one concomitant variable (plot basal area) and eight sets of classification variables: (1) tree species; (2) crown level; (3 and 4) 10 levels of current and total defoliation (0-1-, 10-20...,90-100 percent) estimated for each tree; (5) four intensities of cumulative damage (damage classes) estimated for each tree; (6) five levels of bud defoliation on each 15-inch twig; (7) five levels of total twig defoliation for each 15-inch twig; and (8) study area.

We recognize that the defoliation and damage variables could also be used as dependent variables in an analysis, since they are in themselves indicators of population density. We found it more practical, however, to center the analysis on density.

We estimated 38 parameters, including the population mean, from 1,098 observations. One problem with this analysis is that, with 1,060 degrees of freedom available for estimating the mean-squared error, tests for significance are so powerful they detect differences too small to be of practical interest. This limitation should be kept in mind in the discussion that follows.

RESULTS

Budworm populations are notoriously dynamic, but the study data are apparently representative, since our analyses revealed associations with stand factors and damage conditions similar to those found in other forest types in North America with other *Choristoneura* sp. These associations had not been previously examined for *C. occidentalis* in Douglas-fir forests. Therefore, the information from the study reported here should be valuable to western entomologists and forest managers even though only 1 year's data were available for analysis.

Plot basal area, tree species, and crown level were related to population densities at a significance level of less than 0.005 percent *(table 1)*. The implication with regard to basal area is that higher budworm densities occurred on open-grown trees. Budworm populations were generally higher on subalpine fir than on Douglas-fir and Engelmann spruce. Population densities were highest in the upper third of tree crowns and lowest in the lower third. Generally population densities at mid-crown approximated the average for the tree (see estimated coefficients for tree crown *[table 1]*). The fact that no difference in budworm population density was detected between areas (significance level over 5 percent *[table 1]*) is noteworthy in that it implies that the only differences between the drainages were explained by the other variables used in the analysis. However, the areas are so close together that noticeable regional effects would not be expected.

Shoot defoliation and current year's defoliation were also related to budworm density at the 0.005 percent level. Up to a point, more budworms were found on the more heavily defoliated branches than elsewhere *(table 1)*. Total cumulative defoliation and damage class estimates have little practical relevance to current budworm population density, although the differences we detected are real. Since these variables include previous as well as present damage, they are more closely related to total annual insect population densities for the entire outbreak to date than to current population density. Estimates of defoliation of twigs proved to be of marginal value.

DISCUSSION

The analyses show strong relationships between western spruce budworm population densities and various methods of classifying defoliations and damage caused by this insect. Significant relationships were logically expected between current population densities and those classifications describing current defoliations. However, what was surprising were the highly significant relationships between current populations densities and total (cumulative) damage evaluations.

The analyses also showed that the number of classes for current year's and total defoliation can be reduced by combining the several classes bracketed in *table 1*. Tables can be prepared collating the mean, standard error of the mean, and range of population density data with the various classes of the revised defoliation and damage classification schemes. These revised classifications can be rechecked in the field at various places and times to determine the range of their applicabilities in damage surveys.

Douglas-fir was the most abundant host tree on the study areas and comprised most of the sample trees. The population distribution of the western spruce budworm within the crowns of sample trees reflects the situation in Douglas-fir *(table 1)*. The estimated coefficients indicate the average population density is approximately at mid-crown.

The population densities on subalpine fir shifted downward from the top third of the crown. This condition was probably due to lack of feeding sites at the time of sampling because of the almost complete defoliation and stem dieback observed on the top portions of subalpine fir crowns. Engelmann spruce trees had relatively low budworm populations, and no conclusions can be made at this time on population distribution in spruce trees.

The remaining discussion will concern the relationships between budworm population levels and various stand and environmental factors that influence budworm survival and tree mortality.

Much of the work to date on the population dynamics of the spruce budworm species complex has been done by various workers in eastern Canada with spruce budworm and by Shephard (1959) with the 2-year cycle budworm *(C. biennis* Free.*)* in Alberta. In general, they found that weather and character of the forest are the two major factors responsible for development of spruce budworm outbreaks. Outbreaks have tended to follow periods of relatively dry weather during the larval stage in forested areas with

Table 1–*Analysis of variance related to density of western budworm population, Bitterroot National Forest, Montana, 1965*

Variable factors and level	Estimated coefficient B	Sum of squared residuals with treatment B's=0[1]	F-Test for B 's=0	Degrees of freedom[2]	Significance of F-Test
					Percent
Plot basal area	-0.03893	491.442	21.656	1	0.005
Tree species:					
Subalpine fir	.14872	496.825		2	.005
Douglas-fir	.13240				
Engelmann spruce	-.28112				
Shoot defoliation (pct.):					
0 - 10	-.46530	513.511	17.547	4	.005
10 - 25	-.03191				
25 - 50	.23892				
50 - 75	.18359				
75 - 100	.07470				
Tree crown:					
Lower third	-.29167	534.042	57.687	2	.005
Middle third	.04850				
Upper third	.24317				
Current year's defoliation (pct.):					
Class I 0-10	-.0036	541.984	14.762	9	.005
[3]{ II 10-20	-				
III 20-30	-.53147				
IV 30-40	.08334				
[3]{ V 40-50	-.01576				
VI 50-60	-.06599				
VII 60-70	-.27972				
VIII 70-80	.42525				
IX 80-90	.48678				
X 90-100	.40563				
Total defoliation (cumulative):					
I 0-10	-.20958	496.877	3.731	9	.015
II 10-20	-.21702				
III 20-30	.05582				
IV 30-40	-.10696				
V 40-50	.07268				
VI 50-60	.08121				
VII 60-70	.33303				
VIII 70-80	.20494				
IX 80-90	.08935				
X 90-100	-.30347				
Damage class:					
Class I	.06118	486.888	3.865	3	.893
II	-.20502				
III	-.32651				
IV	.47035				
Twig defoliation:					
0 - 10	-.15290	485.834	2.318	4	5.467
10 - 25	-.08425				
25 - 50	.07790				
50 - 75	.04211				
75 - 100	.11714				
Areas:					
Tough Creek	.02682	482.542	.676	3	56.88
Mud Creek	.02550				
One-Two Creek	.01835				
Blue Joint Creek	-.07067				

[1]Complete model: 481.621.

[2]Complete model: 1,060.

[3]Bracketed classes may be combined without significant

extensive stands of mature and over-mature balsam fir (Balch 1946; Wellington, *et al.* 1950; Morris and Bishop 1951; Graham 1956; Greenbank 1956). Hot dry weather favors larval feeding, development, and survival in all instars more than does cloudy, rainy weather (Wellington 1949, 1950a, 1950b; Greenbank 1956). Because solar radiation directly affects rate of evaporation, any stand characteristic that increases tree crown exposure to solar radiation and thereby reduces the relative humidity surrounding the budworm feeding and resting sites will favor budworm survival.

The study reported here showed that open-grown trees (i.e., those with the greatest crown exposure) supported the greatest western spruce budworm populations. Apparently, the survival of larvae between the bud attack period and pupation (fourth to sixth instars) is increasingly favored with increased exposure to solar radiation. We concluded that defoliation of the tree crown altered the feeding larva's exposure to solar radiation and favored large larval survival up to the point where food shortage occurred. Our findings support observations made elsewhere (Mott 1963).

Although an open stand favors survival of late-instar larvae by providing full crown exposure, it is not favorable for first and second instar larvae. These are dispersed by the wind, the first after hatching, and the second at emergence from hibernation. During dispersal periods, larvae are more likely to land on host trees in a dense stand than in an open stand. The highest mortality of the generation occurs during these dispersal periods (Miller 1958).

Early and late instar larvae would probably have the maximum chance of survival in a stand of essentially even-aged trees, stocked with one or more host species but few nonhost species, and having considerable lateral crown exposure and no large openings. Most Douglas-fir stands east of the Continental Divide in Montana fit this description. Many of them have been infested by high populations of western spruce budworm for many years, and some have suffered high tree mortality.

Douglas-fir is at the eastern limits of its geographical range in eastern Montana. It grows in essentially even-aged stands on sites where soil moisture appears to be limiting. Competition for water affects tree mortality at a given level of budworm defoliation. We examined more than 100 increment cores from trees near Big Timber in eastern Montana. They showed that trees growing in shallow soil on dry knolls died after about 5 years of severe defoliation; those growing on wetter sites endured as much as 40 years of defoliation. Tree mortality in dense stands on dry, rocky slopes was heavy.

Nearly all understory trees in most Douglas-fir stands observed were killed. Larvae dropped on them from adjacent larger trees. The small crowns of understory trees are normally sparsely foliated and cannot support as high a budworm density as larger, more full grown neighbors. Dominant trees win out in the competition for water during the dry summers.

RECOMMENDATIONS

The results of this study and observations in eastern Montana suggest the following stand management practices to reduce the vulnerability of western forest stands to excessive damage from defoliation by the western spruce budworm:

• *Maintain a stand of thrifty, rapidly growing trees.*

A stand open enough to provide good crown exposure to solar radiation and preclude excessive competition for water is required. Sub-economic weeding and thinning before the stand reaches commercial size may be necessary to meet this need.

Our study showed that trees growing in stands of low basal area (i.e., high crown exposure) generally had higher budworm population densities than trees in very dense stands (low crown exposure). However, these relatively open-grown trees could sustain a high budworm population level and still survive because they are thrifty and they produce many more normal and adventitious buds than trees having less crown exposure growing in dense stands. Although these thrifty trees produce more budworm feeding sites, they can survive and more quickly recover from defoliation than trees with much fewer buds because their food reserves are greater.

Relatively open-grown trees can withstand greater stress from defoliation and survive better than trees which must compete for moisture in dense stands.

• *Reduce the true-fir complement in all budworm susceptible forest stands.*

Budworm density was generally higher on grand fir[1] and subalpine fir in stands where these species

[1]Williams, Carroll B., and Patrick J. Shea. *Trapper Creek Zectran tests 1966.* (Unpubl. rep. on file Pacific SW. Forest & Range Exp. Sta., Berkeley, Calif.)

grow in association with Douglas-fir and Engelmann spruce. Relatively few stands held substantial numbers of mature true firs. These stands were at the higher elevations or on relatively moist sites or both. Consequently, these stands can be logged without difficulty. A diversified forest type should be encouraged to break up continuous canopies of budworm host species.

• *Harvest Douglas-fir and burn cutting units to favor ponderosa pine over all firs in the succeeding stands.*

Wherever feasible ponderosa pine should be encouraged on those sites where it can grow well. In Montana these sites tended to be at relatively low elevations and the southern and western exposures and ridge tops at the middle elevations. The natural forest succession in the absence of fire, from pine to Douglas-fir and true-firs, should be prevented or retarded.

The harvesting method should be patch clearcutting, in patches large enough to discourage rapid takeovers of the site by Douglas-fir regeneration. Planting pine when necessary in a series of patch clearcuts in the forest would help increase losses among dispersing budworm in the first and second instars.

These suggestions, in general, are similar to recommendations made for other forest types (see Morris 1955). A series of detailed and simultaneous population studies are needed in areas where climate and vegetation differ. With such data, the vulnerability of various forest types from site to site and the possibilities for controlling budworm populations through stand manipulation could be determined. Once the budworm and host subsystems and their interactions are accurately modeled, then, with the proper economic data, various forest management operations can be planned for maximum production of various forest resources with minimum budworm damage.

SUMMARY

Williams, Carroll B. Jr., Patrick J. Shea, and Gerald S. Walton
1971. **Population density of western spruce budworm as related to stand characteristics on the Bitterroot National Forest.** Berkeley, Calif., Pacific SW. Forest & Range Exp. Sta. 8 p. (USDA Forest Serv. Res. Paper PSW-72)

Oxford: 453-145.7 X 18.28 *Choristoneura occidentalis:* 11 : 153 : 174.7 *Pseudotsuga menziesii* [–521.6 + 174.7 *Picea engelmannii* + *Abies* spp.] .
Retrieval Terms: Choristoneura occidentalis: population dynamics; site factors; basal area; *Pseudotsuga menziesii; Picea engelmannii; Abies* spp.; mortality; Bitterroot N.F.

The western spruce budworm *(Choristoneura occidentalis* Freeman*)* is a major defoliator of forests in the Western United States. The main host trees are Douglas-fir *(Pseudotsuga menziesii* [Mirb.] Franco*)*, Engelmann spruce *(Picea engelmannii* Parry*)*, and the true firs *(Abies* spp.*)*. Assumptions about the distribution of this forest pest within tree crowns are based on data for spruce budworm on balsam fir in eastern Canada. Evidence is needed to show whether these assumptions are correct, and to determine if sampling methods should be modified. Information is also needed on how closely various schemes of estimating defoliation and damage are related to budworm population levels so as to increase the usefulness of insect damage surveys.

Forest entomologists and managers are interested in possible relationships between stand factors that can be manipulated and levels of budworm populations. They might be able to reduce the frequency and severity of insect outbreaks and damage by regulating stand and tree conditions that contribute to high population levels.

This paper reports a study of the relation of budworm population density to certain stand conditions and damage indicators in four drainages on the Bitterroot National Forest, in western Montana.

Most western spruce budworm populations were sampled during the peak of the fifth instars. Pole pruners, extendable up to 30 feet, were used to cut two 15-inch twigs from each crown third of Douglas-fir, subalpine fir, and Engelmann spruce sample trees on 28 plots. The length and width of the twigs were

measured and the budworm larvae and new buds were counted. Five levels of shoot and total twig defoliation (0-9, 10-25, 26-50, 51-75, 76-100 percent) were estimated on each 15-inch twig. Ten levels of current year's and total tree defoliation (I=0-10 percent, II=10-20 percent..., X=90-100 percent) and four levels of cumulative damage were estimated for each study tree. Stand basal area was measured at each plot.

The relation between western spruce budworm population density and the variables listed above was examined by analysis of variance. Plot basal area, tree species, crown level, shoot and current year's defoliation were related to budworm density at the 0.005 percent level. Budworm population densities were greater on open-grown trees than on trees in dense stands. Population densities were higher on subalpine fir than on Douglas-fir and Engelmann spruce and were highest in the upper third of tree crowns and lowest in the lower third. The middle third of the crown contained an approximate average population density for Douglas-fir. Up to a point more budworms were found on the more heavily defoliated branches.

Western spruce budworm population densities were also related to total cumulative defoliation at the 0.005 percent level and to damage class estimates at the 0.893 percent level. Total cumulative defoliation and damage class estimates have only slight practical application to current budworm population density because they include previous as well as present damage.

We concluded that:

1. The approximate average population density in Douglas-firs can be obtained by sampling the mid-crown.
2. Shoot and current year's defoliation estimates are valuable indicators of budworm population levels as well as valid descriptions of current damage. The number of current year's defoliation classes can be condensed from 10 to 6.
3. Total cumulative defoliation and damage class estimates are also indicative of current budworm population levels. However, they are more useful in describing cumulative damage impact to the individual trees. The number of total defoliation classes can also be reduced from 10 to 6.
4. Tables collating tree defoliation and damage classification with western spruce budworm population levels should be constructed, tested, and evaluated as possible aids in damage surveys.

The results of this study and observations made in eastern Montana suggest that the vulnerability of western forests to excessive damage by the western spruce budworm can be reduced by:

1. Maintaining stands in thrifty, rapidly growing trees.
2. Reducing the true-fir complement in all budworm susceptible stands whenever feasible.
3. Harvesting mixed stands of Douglas-fir and ponderosa pine in such a way to favor pine regeneration.

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Oxford: 453-145.7 X 18.28 *Choristoneura occidentalis:* 11 : 153 : 174.7 *Pseudotsuga menziesii* [–521.6 + 174.7 *Picea engelmannii* + *Abies* spp.]
Retrieval Terms: Choristoneura occidentalis: population dynamics; site factors; basal area; *Pseudotsuga menziesii; Picea engelmannii; Abies* spp.; mortality; Bitterroot N. F.

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