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Cone Production and Insect-Caused Seed Losses of Ponderosa Pine in Idaho and Adjacent Washington and Montana

John W. Dale and John A. Schenk

INTRODUCTION

Cone and seed insects of the western United States were first investigated by Miller (1914, 1915). Interest waned, however, until tree improvement programs were initiated on a large scale in the 1950s (Keen 1958).

This emphasis on tree improvement programs and the need for an easily accessible seed source provided the impetus for the establishment of progeny-test plantations and for the organization of a forest tree improvement program in Idaho. Federal, state and private cooperators agreed to concentrate their initial efforts on the improvement of ponderosa pine, *Pinus ponderosa* Laws., because of its commercial importance and its extensive use in artificial regeneration (Wang 1967). A reliable supply of large quantities of quality seed is required for these reforestation programs to meet state and national needs.

Seed orchards and seed-production areas will not eliminate the need for natural stands as an important seed source in the near future; thus, the need for reducing insect-caused losses in selected natural stands prior to cone collection also will remain. Furthermore, a knowledge of fluctuations in cone and seed insect populations relative to annual fluctuations in cone crops, environmental factors and seed losses would allow collection of a maximum quantity of undamaged seed at minimum cost. Application of this knowledge also would be helpful in the timing of regeneration cuttings in stands nearing economic maturity, to obtain maximum reproduction under given climatic conditions.

Therefore, this study was conducted from 1967 through 1970 to determine the extent of damage caused by the more abundant insect species, ascertain life histories of the major species present, and evaluate factors influencing cone and seed losses in relation to the establishment and management of seed orchards and seed-production areas of ponderosa pine in Idaho and adjacent Washington and Montana. The results of the damage evaluation are reported here.

METHODS

Study Sites

Twenty sites (10 for intensive study and 10 supplemental) were selected throughout the range of ponderosa pine within the study area (Fig. 1). Intensive study sites were selected for potential as seed-production areas and for frequency of cone crops, the latter determined by the number of old cones on the ground and the number of scars and remnants of old rosettes on the branches. Supplemental sites were selected for the purpose of determining the distributional range of the major insect species, and to gain additional information on their life histories and habits. An intensive study site was visited at least twice each season for cone collection and observation of insect damage, biology and habits. A supplemental site was visited only once or twice during the entire study period.

Circular 0.1-acre (0.04-ha) plots were established on a grid pattern of 2-chain (40.2-m) intervals on each intensive site (Fig. 1, A-J). The number of plots per site varied with the size of the site, but the percentage of the area sampled was about the same (18-27%) in each case. One codominant ponderosa pine on each of 10 plots per site was measured for height, diameter at breast height (dbh) and age. Growth performance of each of the 10 trees was determined from ring counts per outer inch (2.54 cm) of increment cores. Percent stocking, species composition and cone production were measured at each

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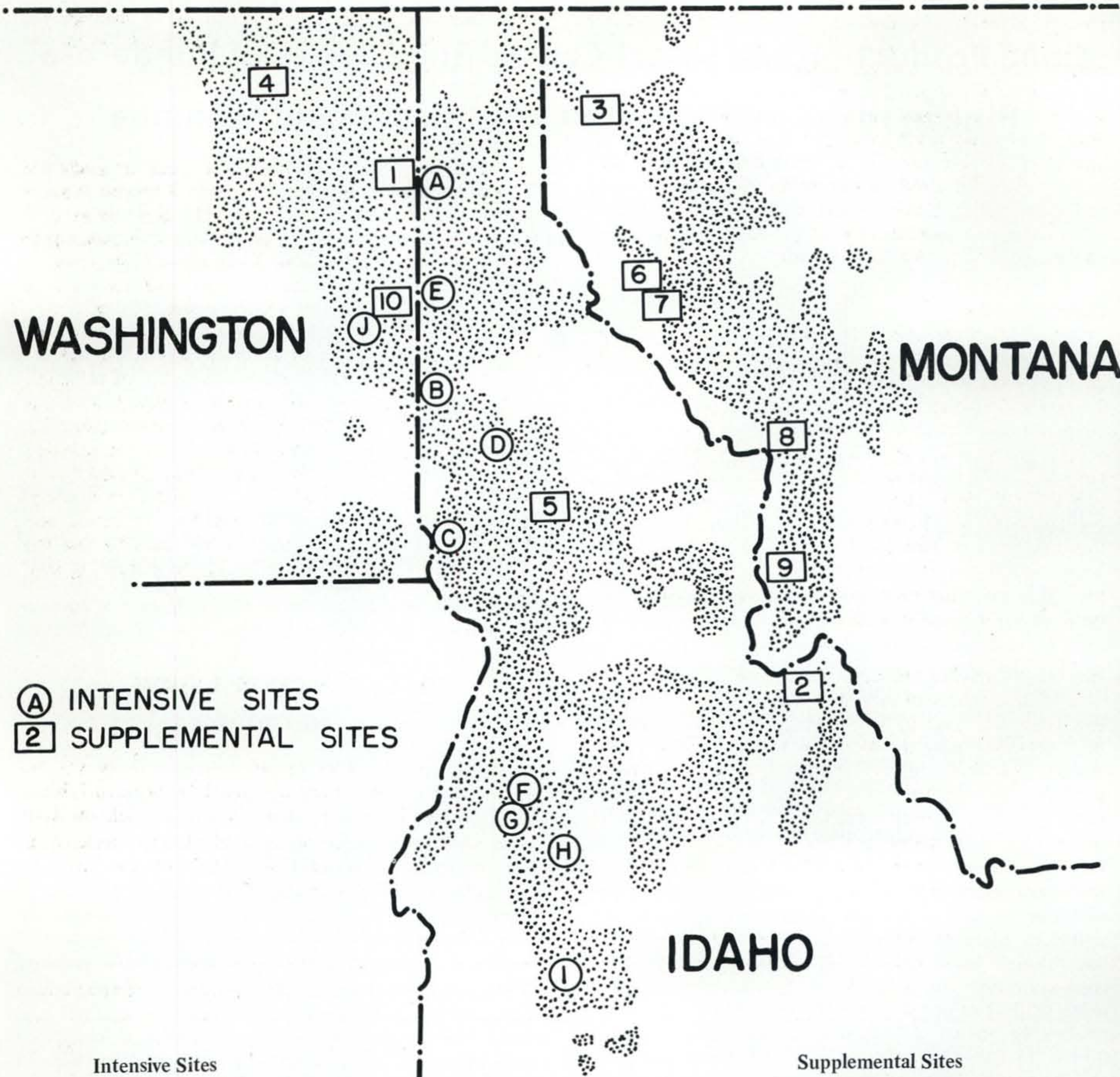

Intensive Sites

Blanchard, ID	A
Potlatch, ID	B
Waha, ID	C
Helmer, ID	D
Mica, ID	E
New Meadows, ID	F
Council, ID	G
Cascade, ID	H
Idaho City, ID	I
Cheney, WA	J

Supplemental Sites

Elk, WA	1
Salmon, ID	2
Libby, MT	3
Kettle Falls, WA	4
Kooskia, ID	5
Thompson Falls, MT	6
St. Regis, MT	7
Lolo, MT	8
Darby, MT	9
Rockford, WA	10

Fig. 1. Distribution of ponderosa pine in Idaho and adjacent Washington and Montana, and the location of intensive and supplemental study sites, 1967-1970.

plot to obtain estimates for the site. Aspect, percent slope, elevation, stand history and topography also were recorded for each site. All observations were evaluated in relation to the presence and abundance of cone and seed insects, and their damage at each site. Site indices were determined from curves provided by Lynch (1958) and each site was identified to habitat type (Daubenmire and Daubenmire 1968; Steele et al. 1975; Steele, Arno and Pfister 1976). A circular plot of 125 m^2 was established on each site to provide data on presence, constancy and abundance of the understory vegetation.

Cone Production

Annual fluctuations in cone production per acre were estimated for each site from counts of all cones on all cone-bearing ponderosa pine trees on the 10 plots. To eliminate future need for tree climbing to obtain total cone counts, a method of predicting cones per tree was sought by means of regression analyses between the actual cone crop per tree and the following independent variables, selected for their ease of measurement during normal inventory cruises: 1) crown index (% of tree height bearing live branches), 2) percent of the tree crown bearing cones, 3) number of cone-bearing branch tips per tree, and 4) the sum of the number of whorls bearing cones on either the north or south aspect or both aspects.

Relative Abundance and Importance of Insect Species

The numbers of seed moths and cone midges were estimated each year by multiplying the estimated number of cones per acre by the mean number of insects per cone. Annual abundance of cone beetles and cone moths per acre was determined by multiplying the number of infested cones per acre obtained from the 10 plots per site by the mean number of insects per cone. The number of cones infested by each species was obtained from collections made for damage evaluation purposes. Estimates of insect abundance and of the type and amount of damage per cone were used to subjectively evaluate the relative importance of each insect species.

Evaluation of Damage

Ten cone-bearing ponderosa pine trees per study site (1 per plot) were selected for more intensive damage evaluation (a cone-bearing tree near the plot was selected if one was not present on the plot). Cone collections were made from these trees in May, June, July and August each year to determine cone damage levels and life histories and habits for each insect species present. Samples consisted of 8 cones (4 each from the north and south sides) from the upper third of the tree crown. Branch size and low cone production precluded efficient sampling of the lower crown. Two cones from each side were placed in rearing chambers to obtain adult insect specimens; the remaining cones were examined by the axial-slice technique, followed by a complete scale-by-scale examination. The number of insects and the number of seeds damaged were recorded by insect species, as were the numbers of sound and aborted seeds. Regression analysis was used to test the reliability of the axial-slice technique in estimating seed damage per cone.

RESULTS AND DISCUSSION

The characteristics of the intensive study site are summarized in Tables 1 and 2, and habitat types in Table 3. Identification of habitat types south of the Salmon River in Idaho were based on Steele et al. (1975), Steele, Arno and Pfister (1976) and those north of the river on Daubenmire and Daubenmire (1968).

Table 1. Location and characteristics of intensive ponderosa pine study sites in Idaho and Washington, 1967-1969.[a]

Location	Symbol[b]	Elevation (ft)	Aspect	Slope (%)	Basal area (ft^2/ac)	Stems/acre	% crown closure
Blanchard	A	2300	S	1	154.0	312	50
Cheney	J	2250	S	1	140.0	152	40
Mica	E	3200	S	7-12	11.4	28	20
Potlatch 1	B	2560	N	0-25	133.5	110	75
Potlatch 2	B	2600	NW	4-30	169.0	219	50
Potlatch 3	B	2560	S	4-30	125.0	141	65
Helmer	D	3100	S	2-10	21.0[c]	17[c]	25
Waha	C	3800	S	15	41.0	97	50
New Meadows	F	4500	NW	5	61.2	184	40
Council	G	4400	SW	5-40	95.5	71	50
Cascade	H	4900	SW	0-30	56.8	104	75
Idaho City	I	4900	S	2-25	100.0	190	45

[a] 1 ft = 0.305 m; 1 ft^2 = 0.093 m^2; 1 acre = 0.405 ha; 1 ft^2/ac = 0.023 m^2/ha

[b] Refers to locations on Fig. 1 (facing page).

[c] Site composed of groups of ponderosa pine bordering abandoned homestead.

Table 2. Characteristics of the ponderosa pine component of the intensive study sites in Idaho and Washington, 1967-1969.[a]

Site	Stocking BA (%)	Stocking Stems/acre (%)	Mean height (ft)	Mean DBH (inch)	Mean age (years)	Mean growth index[b]	Site index (base 100)
Blanchard	91.6	83.0	72	15.0	84	14	77
Cheney	100.0	100.0	61	13.5	80	19	68
Mica	96.5	96.4	39	10.5	30	5	93
Potlatch 1	95.9	98.2	97	15.9	80	15	106
Potlatch 2	100.0	100.0	98	15.2	84	15	105
Potlatch 3	100.0	100.0	80	15.6	86	18	85
Helmer	100.0[c]	100.0[c]	62	14.4	35	6	115
Waha	100.0	100.0	57	12.9	52	11	84
New Meadows	99.7	99.5	59	14.9	52	10	89
Council	95.3	94.3	71	15.6	50	9	100
Cascade	98.6	98.1	59	13.2	49	11	89
Idaho City	88.0	94.2	77	14.8	58	14	100

[a] 1 inch = 2.54 cm; 1 ft^2 = 0.093 m^2; 1 acre = 0.405 ha

[b] Number of rings/inch.

[c] Site composed of groups of ponderosa pine bordering abandoned homestead.

Predicting Cone Production

Estimated cone production per acre for each of the study sites is presented in Table 4 for 1967 through 1969 (the latter a year of regional crop failure). Individual tree data from 5 of the 12 sites sampled in 1968 were pooled and used to derive regression equations that would provide estimates of cone production per tree (Table 5). The equation that accounted for the highest proportion of the variation (R^2 = .935) and the least standard error was obtained with the inclusion of both numbers of cone-bearing whorls (X_3) and cone-bearing branch tips (X_4). However, the interdependency of these variables could cause substantial error in estimates of these parameters if used for extrapolation beyond the range of the data (as reflected in the substantial change in the value of the coefficients between model forms). Thus, even though the error in the predictors may be acceptable for some purposes, a reasonable estimate (r^2 = .87) of cone production per tree (acre) may be obtained using the number of cone-bearing branch tips (X_4) as the sole independent variable. Addition of percent cone-bearing crown (X_2) as a second variable increased accountability (R^2 = .90) and decreased the error (36 cones/tree), but also produced a substantial negative value for the intercept (-40.8 cones/tree). This also may reflect some interdependency between variables, the range of values in the predictor variables, or on the model form being used. Further testing, refinement and determination of observer error are necessary before field application.

Table 3. Habitat types for the intensive ponderosa pine study sites in Idaho and Washington, 1967-1969.

Location	Habitat Type
Blanchard	Intergrade: *Pseudotsuga/Physocarpus – Pseudotsuga/Calamagrostis, Arctostaphylos* phase
Cheney	*Pinus ponderosa/Agropyron spicatum*
Mica	*Pseudotsuga menziesii/Physocarpus malvaceus*
Potlatch 1	*Pseudotsuga menziesii/Physocarpus malvaceus*
Potlatch 2	*Pseudotsuga menziesii/Physocarpus malvaceus*
Potlatch 3	*Pseudotsuga menziesii/Physocarpus malvaceus*
Helmer	*Abies grandis/Pachistima myrsinites*
Waha	*Pseudotsuga menziesii/Symphoricarpos albus*
New Meadows	*Pseudotsuga menziesii/Physocarpus malvaceus*
Council	*Abies grandis/Spirea betulifolia*
Cascade	*Pseudotsuga menziesii/Symphoricarpos albus*
Idaho City	*Pseudotsuga menziesii/Carex geyeri*

Seed Abortion

The observed abundance of aborted seed (defined as seeds that for any reason showed arrested development) in 1967 suggested a need for a quantitative evaluation of this cause of seed loss. Such a study in 1968 revealed that abortion substantially reduced the potential crop on several sites (Table 6). Average seed abortion ranged from 16 to 45 percent of the total number of seeds per cone, but reached as high as 93 percent of the seeds per cone on one site.

Evaluation of Axial-Slice Technique

Linear regression analyses were run to ascertain the accuracy of the axial-slice technique for estimating three dependent variables: 1) total number of seeds per cone (Y_1), 2) number of damaged seeds per cone (Y_2), and 3) number of *Laspeyresia* larvae per cone (Y_3). The number of seeds exposed on the surface of the axial-slice served as

Table 4. Cone production of ponderosa pine at intensive study sites in Idaho and Washington, 1967-1969.

Study Site	Number of cones per acre[a]		
	1967	1968	1969[b]
Blanchard	720	1037	0
Cheney	2723	4478	0
Mica	601	848	200
Potlatch 1	3335	6195	0
Potlatch 2	1711	1689	0
Potlatch 3	2376	1606	0
Helmer	577	1595	0
Waha	2130	2380	0
New Meadows	335	377	3
Council	1242	2063	0
Cascade	286	612	0
Idaho City	789	1081	0

[a] 1 acre = 0.405 ha

[b] Almost complete regional cone crop failure.

the independent variable to estimate Y_1, while the number of exposed damaged seed per slice was used as the independent variable for estimating both Y_2 and Y_3. The axial-slice technique did not provide an adequate estimate of either of the dependent variables. Although statistically significant (α = 0.01), coefficients of determination of only .54, .64 and .54 for Y_1 through Y_3, respectively, may be of little practical value.

Relative Abundance and Importance of Insect Species

A total of 48 insect species, representing 24 families and 8 orders, were identified as inhabiting the cones of ponderosa pine. Only 16 of these species are classed as damaging, while 26 are entomophagous and 6 are inquilines or secondary invaders. A listing of all species is included in a checklist of the cone and seed insects of Idaho (Kulhavy, Dale and Schenk 1975).

The seed moths, *Laspeyresia miscitata* Heinrich and *L. piperana* (Kearfott), were the most ubiquitous pest species. However, the cone beetle, *Conophthorus ponderosae* Hopkins, is potentially the most damaging pest in seed orchards and seed production areas, because each attack destroys an entire cone, whereas the seed moths may leave some undamaged seed in infested cones. Damage from the cone borer, *Eucosma ponderosa* Powell, consists primarily of mined scale tissue, although as much as one-third of the seeds may be destroyed in some cones. The seed midge, *Asynapta keeni* (Foote), was never found responsible for damaging more than 1 percent of the total seed crop, although losses in individual cones were 14 percent on occasion. The cone moths, *Dioryctria auranticella* (Grote) and *D. abietella* (Denis and Schiffermueller) usually were of minor importance, but are potential pests in years of low cone production on the several host tree species. The seed chalcid, *Megastigmus albifrons* Walker, was not collected at any site, although reported as a pest of ponderosa pine seed.

Table 5. Summary of regression analyses of various tree characteristics (X_i) on the number of cones per tree (Y) from five study sites in Idaho, 1968.[a]

df	R^2 or r^2	t	$S_{y.x}$	Regression equation[b]
36	0.186	**	106.6	$Y = -156.64 + 5.87X_1$
36	0.794	**	53.6	$Y = -16.88 + 10.17X_3$
15	0.841	**	44.0	$Y = -92.55 + 6.38X_2$
14	0.845	**	45.0	$Y = -127.17 + 0.88X_1 + 0.11X_2$
36	0.874	**	41.9	$Y = 7.42 + 3.58X_4$
14	0.900	**	36.1	$Y = -40.83 + 3.16X_2 + 1.69X_4$
14	0.935	**	29.1	$Y = -12.15 + 4.19X_3 + 1.98X_4$
13	0.935	**	30.2	$Y = -7.96 + 0.09X_1 + 4.17X_3 + 1.99X_4$
13	0.935	**	30.2	$Y = -11.22 + 0.07X_2 + 4.24X_3 + 1.99X_4$

[a] Blanchard, Idaho City, Cascade, Waha, New Meadows

[b] Y = Number of cones per tree; X_1 = crown index; X_2 = percent crown cone-bearing; X_3 = number of cone-bearing whorls; X_4 = number of cone-bearing branch tips; ** = $P < 0.01$.

Table 6. Extent of seed abortion in ponderosa pine at intensive study sites in Idaho and Washington, 1968.

Study site	Viable seed per cone	Seed aborted per cone	Range of aborted seed per cone	
	(no.)	(mean %)	No.	%
Blanchard	64	30.0	1–84	1.5–72.3
Cheney	77	17.7	0–61	0.0–77.2
Mica	62	27.7	0–84	0.0–73.4
Potlatch 1	52	29.6	0–62	0.0–75.0
Potlatch 2	51	24.2	0–58	0.0–70.9
Potlatch 3	84	15.9	4–56	1.1–52.8
Helmer	60	41.7	10–122	7.9–92.7
Waha	57	45.0	8–120	8.2–90.6
New Meadows	62	23.4	0–57	0.0–70.9
Council	53	27.8	3–47	2.8–71.6
Cascade	64	22.1	5–52	5.4–52.0
Idaho City	55	27.9	3–48	4.6–66.7

Table 7. Levels of damage and infestation by *Laspeyresia* spp. in ponderosa pine cone crops in various locations in Idaho, Washington and Montana, 1967-1968.

	Number cones		Cones infested		Number larvae per cone		
					All cones		Infested cones
Study site	Per acre[a]	Examined	No.	%	Mean	Max.	($\bar{X}$)
1967							
Blanchard	720	46	43	93.5	4.2	16	4.5
Mica	601	45	25	56.1	1.7	19	3.0
Helmer	577	68	13	19.1	0.5	6	2.5
Waha	2130	40	3	7.1	0.3	6	4.3
New Meadows	335	42	42	100.0			
Council	1242	20	1	5.0	0.1	3	3.0
Cascade	286	41	39	95.0			
Idaho City	789	41	34	82.5			
Elk		63	54	85.7	2.5	12	3.0
Cheney	2723	24	16	67.7	4.5	13	6.8
Libby		23	15	65.2	2.3	7	3.5
Total		453	285	62.9			
1968							
Blanchard	1037+[b]	42	39	92.8-[b]	4.3	12	4.6
Mica	848+	80	58	72.5+	4.0	17	5.5
Potlatch 1	6195	40	37	92.5	5.0	16	5.4
Potlatch 2	1689	40	40	100.0	5.1	13	5.1
Potlatch 3	1606	40	37	92.5	4.9	16	5.3
Helmer	1595+	42	13	30.9+	0.7	8	2.4
Waha	2380+	38	29	76.3+	4.3	21	5.7
New Meadows	337+	51	49	96.1-	7.5	21	7.8
Council	2063+	36	6	16.9+	0.5	5	2.6
Cascade	612+	44	40	90.9-	5.3	12	5.8
Idaho City	1081+	36	35	97.2+	9.4	15	9.7
Salmon		14	14	100.0	7.2	11	7.2
Cheney	4478+	41	37	90.3+	5.5	14	6.1
Kettle Falls		40	40	100.0			
Total		584	474	81.2			

[a] 1 acre = 0.405 ha

[b] + or - indicates increase or decrease of cone crop or infestation level from previous year.

Damage Characteristics and Evaluation

Laspeyresia spp. (Lepidoptera: Olethreutidae)

The nature and extent of damage by the two species of *Laspeyresia* could not be differentiated. However, on the basis of rearing records, the ratio (7.5 *miscitata* to 1 *piperana*) and geographic source of emerged adults suggests that *L. miscitata* was the major pest species at most study sites. *L. piperana* was relatively abundant at only two sites (Waha and Salmon), and predominant only at Council, where losses caused by both species were very low (Table 7).

In 1967, an average of 63 percent of all the cones examined were infested by *Laspeyresia* larvae (Table 7), whereas 81 percent were infested the following year, in which a substantially larger cone crop also was present. It is of interest to note that an increase in cone crop at a given site usually resulted in an increase in the proportion of cones infested (Table 7), suggesting a response of the population to increased food supply (habitat).

Number of larvae per cone varied considerably between sites in one year, and between years on any given site (Table 7). The average number of larvae per cone increased from two to five in one year. Fourteen or more larvae were found in a single cone in approximately 5 percent of the cones examined, with a maximum of 19 per cone in 1967 and 21 per cone in 1968. During a concurrent study, 34 larvae were found in a single cone. The axes of cones with high infestation levels were completely destroyed by the mining of the late instar larvae, leaving only very thin partitions between mines. Cannibalism did not occur even with extremely dense populations, although some larvae were forced to vacate the axis and overwinter in the seeds.

Each larva is capable of destroying an average maximum of 18 seeds; however, the average seed loss per larva was 4 in 1967 and 5 in 1968 (Table 8). The extremely high seed loss per larva is due to their wasteful feeding habits, whereby many seeds are only partially consumed. Although Koerber (1967) found a high degree of association between the number of larvae per cone and the number of seeds destroyed, relatively low correlation ($r^2 = .568$) was found in this study for 1968. This may be attributable to the high larval populations within each cone, which were more than sufficient to damage all the seed in the cones.

Five study sites suffered seed losses greater than 50 percent in 1968, in contrast to a maximum of 26 percent in 1967. Loss of 100 percent of the seed in individual cones was not uncommon in 1968 (Table 8). Losses may increase to relatively high levels when good cone crops occur, such as at the Potlatch, Waha, Idaho City and Cheney sites (Tables 7 and 8); however, sufficient seed may remain for natural regeneration or normal collection needs. On the other hand, such losses would be unacceptable in high value seed orchards, or during years of low cone production and high seed requirements.

Table 8. Damage intensity by *Laspeyresia* spp. in ponderosa pine seed crops in selected locations in Idaho, Washington and Montana, 1967-1968.

Date and location	Average number seeds/cone	Average % seed loss	Maximum % seed loss/cone	Number seeds destroyed per larva $\bar{X}$	Number seeds destroyed per larva Range
1967					
Blanchard	74	26.3	87.1	4.9	2.0–6.7
Mica	90	8.8	85.0	4.5	2.0–9.4
Helmer	66	3.0	42.3	4.2	1.8–13.3
Waha	76	1.7	43.5	4.2	2.0–9.2
Elk	68	18.4	81.8	4.9	1.5–11.0
Libby	82	11.1	38.4	4.0	2.0–8.0
1968					
Blanchard	64	38.0	100.0	5.6	2.0–12.8
Mica	62	21.8	83.3	3.3	1.3–7.0
Potlatch 1	52	56.4	100.0	5.9	1.7–15.0
Potlatch 2	51	61.1	100.0	6.1	1.7–18.0
Potlatch 3	84	24.2	69.5	4.1	1.8–13.3
Helmer	60	6.9	75.4	5.6	2.0–9.2
Waha	57	33.3	96.0	4.4	1.0–16.5
New Meadows	62	58.5	100.0	4.8	2.0–13.2
Council	53	4.0	55.4	5.2	2.0–8.3
Cascade	64	40.0	81.9	4.9	1.3–12.8
Idaho City	55	66.0	81.4	4.6	2.0–7.7
Salmon	60	72.9	100.0	6.0	3.2–11.3
Cheney	77	30.6	76.9	4.3	1.2–10.7

Table 9. Relationship between selected ponderosa pine stand or site characters and cone damage or population levels of *Laspeyresia* spp. in Idaho, Washington and Montana, 1967-1968.

Dependent variable				Independent variable							
Insects /acre	% cones infested	Seed loss/acre	% seed loss	BA/acre	Stems/acre	% crown closure	Growth rate[a]	Seeds/acre	df	R^2 or r^2	*t*-test
Y				X					14	.270	*
Y				X	X				13	.402	**
Y						X			14	.097	**
Y							X		14	.418	**
Y								X	14	.640	**
	Y				X				14	.499	**
	Y			X					14	.388	**
	Y						X		14	.355	*
		Y			X				14	.402	**
		Y		X					14	.271	*
		Y		X	X				13	.425	**
		Y					X		14	.347	*
		Y						X	14	.599	**
			Y		X				14	.402	**
			Y	X					14	.277	*
			Y				X		14	.272	**

[a] Average number of annual rings per outer inch of ten codominant pines.
* = $P < 0.05$
** = $P < 0.01$

Three damage measures and one population measure were selected as dependent variables and regressed against one or more of five stand-site characters serving as independent variables. The results of those analyses showing significance at $\alpha \leqslant .05$ are shown in Table 9, but all were unsatisfactory. The highest coefficients of determination usually were obtained through simple linear regression. Addition of a second or third variable only rarely increased the coefficient of determination.

Growth rate and basal area per acre showed a significant relationship to all dependent variables, and the density of ponderosa pine showed a highly significant relationship to all but number of insects per acre. As expected, the number of insects and seed loss per acre were related to the number of seeds per acre, and the highest values of r^2 were derived from those variables (.640 and .599, respectively). The relatively large negative constant terms may be acceptable when considered in terms of very large seed crops per acre.

Regression analysis also was run using number of *Laspeyresia* larvae per acre as the dependent variable and number of cones per acre as the independent variable (Fig. 2). As indicated earlier, there is a highly significant relationship between insect and cone population levels (r^2 = .801). This was even more evident when five sites with very low seed losses (indicated by circles in Fig. 2), were omitted from analysis, in which case r^2 increased to .964. Additional regression analyses showed no significant relationship between number of cones per acre (X) and percent seed loss (Y) or number of larvae per cone (Y).

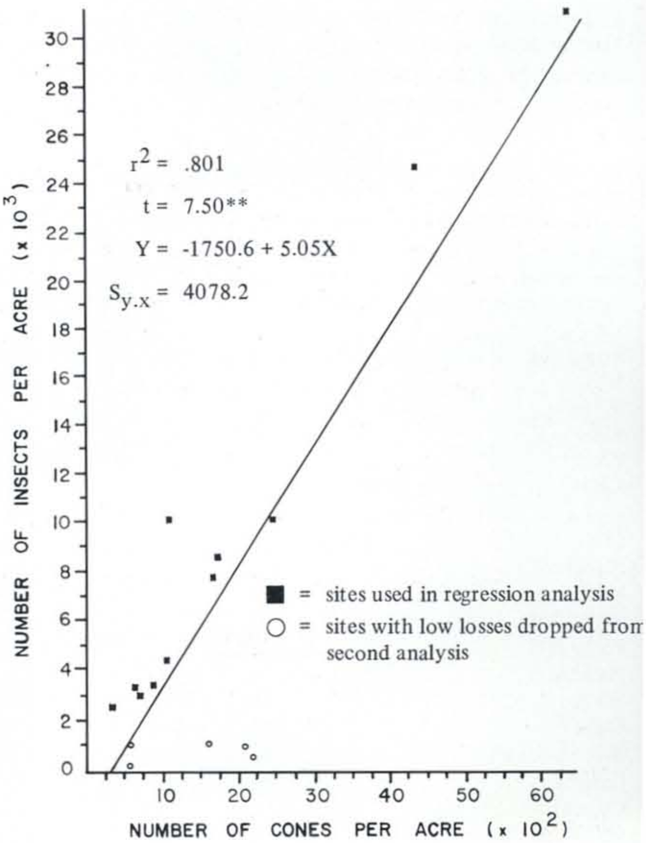

Fig. 2. The relationship of cones per acre and immature *Laspeyresia* spp. per acre in Idaho, Washington and Montana, 1967-1969.

Conophthorus ponderosae **Hopkins (Coleoptera:Scolytidae)**

The damage caused by the ponderosa pine cone beetle has been described by Miller (1915), Keen (1958), Ruckes (1963) and Koerber (1967). The female beetle kills the cone by boring into the base near the petiole, where she constructs a spiral mine which usually severs the vascular tissue. Death of the cone results even if the female is pitched out at or near completion of the spiral mine. Upon completion of that mine, the female mines an egg gallery along one side of the cone axis towards the tip of the cone. Only one gallery is constructed, but the female may turn and continue to mine proximally on the side of the cone opposite to the initial gallery, thus forming a V-shaped gallery.

An attack occasionally may fail to completely sever the conducting tissue and not kill the cone; however, the seeds in such cones do not mature normally. Very rarely, only a portion of a cone is killed. Although Koerber (1967) reported that in California, brood development did not occur in partially killed cones, one instance of normal development was observed at the Mica site in 1969.

Infested cones possess the following characteristics: 1) stunted growth, 2) a small entrance hole at the base surrounded by a pitch tube composed of pitch and frass, and 3) the spiral gallery. Infested cones gradually desiccate and by July begin to turn reddish-brown.

Gregarious attacks in cones, as reported by Morgan and Mailu (1976) for *C. coniperda* (Schwarz), were not observed for *C. ponderosae*. Single *C. ponderosae* females were found mining in conelets in late May and June, and in new lateral shoots, which then drooped and turned reddish-brown. Twig attacks generally occurred in the upper, westerly portion of the crown. Herdy and Thomas (1961) reported that *Conophthorus* sp. attacks both the lateral and the terminal shoots of jack pine, *Pinus banksiana* Lamb; however, terminals damaged by *C. ponderosae* were not observed during this study.

Three types of lateral shoot damage occur: 1) mining of a conelet or bud, with extension down the twig for 3 to 4 cm, similar to that described for *C. lambertiana* Hopkins (Ruckes 1963); 2) construction of a spiral mine 4 to 15 cm below the bud, with no extension of the mine (beetle exits from the twig on the side opposite attack); 3) construction of a spiral mine well below the bud, with extension distally. The maximum number of shoots damaged per beetle could not be determined; however, as many as 18 damaged shoots per tree were counted. Neither egg niches nor larvae were found in any shoot or conelet.

Infestation levels of *C. ponderosae* at Mica increased from 11 percent to 30 percent in one year in an unthinned stand, concurrently with an increase in cone crop (Table 10). Approximately 43 percent of the crop in a small nearby thinned and pruned seed production area was infested in 1968. Both sites combined produced only 200 cones per acre in 1969, and almost 98 percent of these were destroyed by the cone beetle. At Helmer, damage levels decreased with an almost 3-fold increase in cone production. Light ($< 0.5\%$) damage by *C. ponderosae* also occurred at Potlatch 1 and 2, and at Council.

The general cone-crop failure in 1969 made it necessary to sample ponderosa pine wherever cone bearing trees could be found. Two were sampled near the Potlatch sites at the Potlatch Ranger Station. These produced 588 cones, 96.6 percent of which were killed by the cone beetle. The sources of infestation apparently were neighboring ($\geqslant 0.25$ mi) ponderosa pine stands, as there was no previous infestation observed at the station. Thus, the ability of this pest species to completely destroy small, localized cone crops is further corroborated.

Leptoglossus occidentalis **Heidemann (Hemiptera:Coreidae)**

Damage caused by this leaf-footed bug occurs when the insect inserts the stylet bundle through the scale tissue into the seed, where it feeds on the endosperm. The pathway of the stylets is difficult to detect, and only once was it readily apparent, due to unusual hypertrophy around the wounded tissue.

Table 10. Ponderosa pine cones killed by *Conophthorus ponderosae* on two study sites in northern Idaho, 1967-1969.

Location	1967		1968		1969	
	Cones/acre	% infested	Cones/acre	% infested	Cones/acre	% infested
Mica[a]	601	10.8	848	29.8	200	97.9
Mica[b]	–	–	1757	43.1	–	–
Helmer	577	51.8	1595	31.6	no cone crop	

[a] Unthinned study site of 8 acres (1 acre = 0.405 ha).

[b] Thinned and pruned seed-production area of 2 acres.

The nature of the damage to the seed varies with the stage of seed maturation (Koerber 1967, Krugman and Koerber 1969), and it is very difficult to differentiate seeds damaged by the insect from those aborted from unknown causes. However, examination of seeds furnished to caged adults in the laboratory provided more definitive information on characteristics of feeding damage and allowed differentiation from other anomalies (Fig. 3).

Fig. 3. Damage to seeds of ponderosa pine caused by the feeding of *Leptoglossus occidentalis*. Seeds with normal endosperm above (slight desiccation), damaged seeds below.

This species was widely distributed and was collected at all study sites except Council, Cascade and Cheney. Distribution within a given site was widely dispersed, and the species was abundant only at Waha in 1968. Damage estimates were confined to that site.

A sample of 3682 seeds from 82 cones showed 17 percent damaged by the bug. More specifically, 27 percent of the seed from cones on which adults and nymphs were actually observed feeding or resting was damaged. Individually caged adults damaged an average of 20 percent (0-58%) of the seeds in mature cones over a 2-week period in the laboratory. Similarly, 11 adults caged in the field for 7 weeks on developing cones damaged an average of 28 percent (7-61%) of the seeds.

A great variation in cone color (black, green, tan and black-resinous) occurred at the Waha site. An analysis of the amount of seed damage in relation to cone color showed no statistically significant color preferences by the insect. Adults caged with a cone of each color also did not show any color preference under laboratory conditions.

Dioryctria auranticella (Grote) (Lepidoptera:Pyralidae)

The larvae of the pine cone moth bore extensive spiral, cavernous feeding galleries through scale tissue near the cone axis, destroying many seeds in the process. Frass is removed from the galleries as it accumulates, but some moist frass always remains. Koerber (1967) reported that decay of this residual often results in extensive deterioration of surrounding tissues. In Idaho this was uncommon in the field, but often occurred in cones used in laboratory rearings. Frass removed from the galleries never accumulated in webbing on the exterior of the cone as it does with infestations by *D. abietella*.

The pine cone moth was collected only at Mica, Waha, Idaho City and near (but not at) the Council site. Populations were extremely low at all sites except Mica. Increases at Mica from 1967 through 1969 (Table 11) resulted in increased intraspecific competition within cones, but did not appear to prohibit overall population growth. No infested cones were observed in 1967, and less than 2 percent of the total cone crop at the site was infested in 1968. However, by 1970 the infestation was widespread in the stand. Some trees had more than 75 percent of their cones infested, with as many as 99 larvae per tree. However, a few trees also showed no evidence of cone infestation. Considering interspecific competition imposed by the presence of the cone beetle at the same site (Table 10), it seems reasonable to conclude that 1) populations of the cone moth in a given tree (stand) do not disperse until the carrying capacity of the tree's (stand's) cone crop is reached, and 2) certain trees may be resistant or attractive to the cone moth. Merkel, Squillace and Bingston (1965) also reported evidence of inherent resistance of some slash pine, *Pinus elliotii* Engelm., to *Dioryctria* spp.

Table 11. Ponderosa pine cone damaged caused by *Dioryctria auranticella* at Mica, Idaho, 1967-1970.

	Number of cones per acre[a]		
Year	Total	Infested	% infested
1967	601	0	0.0
1968	848	13	1.5
1969	200	27	13.5
1970	200	114	57.0

[a] 1 acre = 0.405 ha

Fig. 4. Conelets of ponderosa pine killed by the mining of *Dioryctria auranticella*. Expelled frass between conelets, pitch mass below conelet on left.

Only 7 (1%) of 600 conelets examined at Mica in 1970 were killed by the cone moth, and only 2 lateral shoots were found infested. The larvae mine conelets or the cone stalk before entering the shoots. The conelets wilt soon after attack and large amounts of resin may be produced in which the larvae may construct pupal chambers (Fig. 4). This type of damage was more abundant in off-plot trees upslope from the actual study site and was observed only in 1970.

Cones supporting two or more larvae were rare in 1968 and 1969, but this infestation level occurred in 40 percent of cones examined in 1970. These cones averaged 1.94 larvae per cone, with a maximum of 7 per cone. Cones with more than two larvae were completely destroyed, hollow and averaged 68 mm in length at the time the cone moth pupated. In contrast, cones with one to two larvae were only partially destroyed, but failed to dehisce and release the undamaged seeds. Viability of these seeds was not ascertained.

Dioryctria abietella (Denis and Schiffermueller) (Lepidoptera:Pyralidae)

Damage estimates for this cone moth were obtained from cones collected in late June and early July when damage was not evident, so as to eliminate any tendency towards bias in selection of cones. Highest levels of infestation occurred at sites south of the Salmon River, and the similarity to the geographical results obtained for *Laspeyresia* spp. (Dale and Schenk unpub.) is of particular interest. Damage levels were less than 10 percent except at Idaho City (20%), Cascade (21%) and New Meadows (36%) (Table 12). Cones with low levels of damage from one to two larvae did not always fail to dehisce. Examination of 19 such cones revealed that 52 percent of the total seed was released from the side opposite the damage. Larvae of this species damaged 16 percent of the total number of seeds per cone and 32 percent of the seeds that were not released. The resin midge, *Asynpta keeni* (Foote), noticeably damaged 7 percent of the seed in the cones examined, and may have been responsible for a small portion of the damage attributed to this cone moth.

Table 12. Levels of infestation of *Dioryctria abietella* in ponderosa pine at several locations in Idaho and Washington, 1968.

Site	Number of cones examined	% cone and seed loss[a]
Potlatch 2	68	1.6
Waha	51	2.0
Blanchard	88	2.3
Potlatch 1	72	4.3
Cheney	42	4.8
Mica	96	5.2
Council	82	6.1
Idaho City	70	20.0
Cascade	84	21.4
New Meadows	81	35.8

[a] Assuming that each infested cone did not release any seed.

Table 13. Germination of seeds taken from ponderosa pine cones damaged by *Dioryctria abietella*, Cascade, Idaho, 1968.

Damage level	Number examined: cones	Number examined: seeds	Undamaged seed: Viable No.	Undamaged seed: Viable %	Undamaged seed: Non-viable No.	Undamaged seed: Non-viable %	Damaged seed: Hollow seed No.	Damaged seed: Hollow seed %	Damaged seed: Shriveled endosperm No.	Damaged seed: Shriveled endosperm %
Light[a]	3	48	38	79.2	7	14.6	3	6.2	0	0.0
Heavy[b]	3	48	2	4.2	3	6.2	34	70.8	9	18.8
Control	3	48	24	50.0	14	29.2	10	20.8	0	0.0

[a] Less than 1/3 of the scales damaged by feeding.

[b] More than 2/3 of the scales damaged by feeding.

Germination tests were conducted on the unreleased seed from cones only partially killed by the cone moth to ascertain if collection and extraction of such cones was justified. Nine cones (3 with no damage; 3 with less than 1/3 of the scales damaged; 3 with more than 2/3 of the scales damaged) were selected from trees at the Cascade site. Sixteen seeds with normal-appearing seed coats were removed from each damaged cone in early November and placed on blotter paper in separate petri dishes. The paper was kept moist with distilled water, and 2 drops of guanidine added to suppress fungal growth. The dishes were maintained at 21°C for several weeks (due to lack of cold treatment and stratification) until all germination was complete.

Only 4 percent of the seed germinated from heavily damaged cones, while 71 percent proved hollow, 19 percent had shriveled endosperm and 6 percent was non-viable (Table 13). Germination rates from undamaged and lightly damaged cones were 50 percent and 79 percent, respectively. The higher rates for the lightly damaged cones may be attributed to the greater number of hollow seeds in the control and possibly to undetectable influences of the feeding larvae on the seed in lightly damaged cones. More intensive germination tests should be conducted to provide conclusive evidence of the influence of *D. abietella* damage and to determine the extent of infertility.

Eucosma ponderosa Powell (Lepidoptera:Olethreutidae)

Damage from this species was found only at Idaho City and New Meadows; however, an adult was caught in flight near Moscow in 1969. Cone injury consists primarily of mined scale tissue, with heavily damaged scales retaining only a thin integument and the woody internal fibers. The only external evidence of damage is small, irregular holes in the tips of the scales in late July. The true nature and extent of damage is not clearly evident until the cones open in the fall.

Individual larvae usually mine several scales and an occasional seed in lightly infested cones. They make single irregular-shaped holes in the distal portion of the seeds adjacent to the wing (Koerber 1967). In contrast, *Laspeyresia* spp. penetrate the seed in the proximal portion and at the point of contact of seed pairs. Seeds often are held within a cone by frass that the larvae pack behind them as they feed. This frass is dark brown, fine-grained and compact.

Koerber (1967) frequently found *E. ponderosa* in cone samples in California but concluded that they did not cause serious losses. Similarly, this species caused light damage to the total seed crop at the two Idaho sites, although 65 percent of the cones at Idaho City were infested.

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Table 14. Extent of damage in ten ponderosa pine cones caused by *Eucosma ponderosa* and *Laspeyresi*

E. ponderosa				*Laspeyresia* spp.	
Damaged scales		Damaged seeds[a]		Damaged seeds	
No.	%	No.	%	No.	%
32	48.5	27	24.1	41	36.6
37	58.7	34	33.0	25	24.3
39	61.9	39	35.8	7	6.4
66	100.0	22	22.7	33	45.3
58	87.9	23	29.1	36	45.6
50	80.6	18	20.5	54	61.3
42	62.7	29	24.0	62	51.2
38	61.3	4	4.4	43	47.2
68	97.2	27	31.8	5	5.9
37	69.8	10	9.5	33	31.4
Average:					
47	71.6	23	23.6	35	35.5

[a] Seeds sealed in cone by frass plus seeds damaged by feeding.

Table 15. Extent of damage by *Asynapta keeni* in cones of ponderosa pine at selected sites in Idaho, Washington and Montana, 1967-1969.

Site	1967 Infested cones (%)	1967 Destroyed seed (%)	1967 Max. seed destroyed /cone (%)	1968 Infested cones (%)	1968 Destroyed seed (%)	1968 Max. seed destroyed /cone (%)	1969 Infested cones (%)	1969 Destroyed seed (%)	1969 Max. seed destroyed /cone (%)
Mica	15.5	0.6	32.7	6.2	0.6	9.8			
Waha	0.0			7.4	1.0	19.4			
Idaho City				8.0	0.6	17.5			
Cascade				2.8	0.5	22.5			
Helmer	7.4			5.0	0.3	5.8			
Potlatch 2				2.5	0.3	13.6		Cone crop failure	
Potlatch 3				5.0	0.2	5.7			
Council				2.5	0.2	4.9			
Blanchard	6.5			0.0	0.0	0.0			
Elk	5.2								
Libby	3.2								
New Meadows				17.5	1.1	20.6	16.6[a]	5.2	44.9
Cheney				9.5	0.7	13.3	50.0[b]	10.9	54.7

[a] Only 25 cones at the site.

[b] One tree located 400 yards from the study site.

ponderosa in combined attacks may be an additional loss not accompanied by a significant reduction in the amount caused by *Laspeyresia* spp., although there is considerable variation among cones.

Asynapta keeni (Foote) (Diptera: Cecidomyiidae)

The bright orange larvae of this species feed in dark-stained, pitch-filled cavities near the seeds. These seeds may be of normal size but without endosperm and with a dimpled appearance due to small depressions caused by the feeding larvae, or the seeds may collapse and appear rugose.

Total seed losses from *A. keeni* averaged about 1 percent or less at each site during 1967 and 1968, although almost 11 percent of the seed from a single tree was destroyed at Cheney in 1969, a year of general crop failure (Table 15). These small losses contrast with the greater than 40 percent losses reported by Lyons (1957) in cones of red pine, *Pinus resinosa* Aiton. However, seed destruction recorded in this study (Table 15) does not include any losses due to possible lack of cone dehiscence or seed entrapment by the pitch. Maximum seed losses by *A. keeni* often were associated with other types of cone damage such as sun scald. Exposed, interior scale tissues of the cones apparently were an attractive oviposition site.

Evaluation of Monetary Losses

An estimate of the monetary losses attributable to each and all species of cone and seed insects was calculated based on the cost of $10 per pound (454 g) of ponderosa pine seed in 1970 (personal communication, Mr. J. Isaacson, U.S. Forest Service, Coeur d'Alene Forest Nursery, Coeur d'Alene, Id.) (Table 16).

The greatest monetary loss caused by all species was approximately $207 per acre ($511/ha) at the Potlatch 1 site in 1968. However, this does not necessarily reflect the real importance of the damage, because the site still could have served for collection, due to the large number of cones and seeds produced that year. Conversely, even though the percentage loss from all species at Mica in 1968 approximated that at Potlatch, the monetary loss was much less due to small cone crop. Even this relatively small loss per acre could have precluded seed collection at Mica that year, due to collection costs per pound.

Laspeyresia spp. were by far the most economically important species of cone and seed insects infesting ponderosa pine. The values of the seed crops destroyed by these species during 1967 and 1968 ranged from $1 to over $200 per acre, and were highest at Potlatch 1 and Cheney, where *Laspeyresia* spp. were dominant (Table 16). Any application of control to reduce seed losses in ponderosa pine seed orchard or seed production areas should concentrate on these species. Control efforts also may be needed for *Conophthorus ponderosae* and *Dioryctria abietella* in some years.

Table 16. Value per acre of the cone crop destroyed by cone and seed insects on ponderosa pine in [illegible] 1968.[a]

Site	*Laspeyresia* spp.		*Conophthorus ponderosae*		*Dioryctria abietella*		*Dioryctria auranticella*		*Asynapta keeni*		*Leptoglossus occidentalis*		*Eucosma ponderosa*		All species	
	Crop loss (%)	Econ. loss ($)	Crop loss (%)	Econ. loss ($)	Crop loss (%)	Econ. loss ($)	Crop loss (%)	Econ. loss ($)	Crop loss (%)	Econ. loss ($)	Crop loss (%)	Econ. loss ($)	Crop loss (%)	Econ. loss ($)	Crop loss (%)	Econ. loss ($)
1967																
Blanchard	26.3	15.57	0.0	0.00	b		0.0	0.00	b		b		0.0	0.00	26.3	15.57
Mica	8.8	5.29	10.8	6.49	b		0.0	0.00	0.6	0.36	b		0.0	0.00	20.2	12.14
Waha	1.7	3.06	0.0	0.00	b		b		0.0	0.00	b		0.0	0.00	1.7	3.06
Helmer	3.0	1.27	51.8	21.92	b		b		b		b		0.0	0.00	54.8	23.19
1968																
Blanchard	38.0	28.02	0.0	0.00	2.3	1.70	b		b		b		0.0	0.00	40.3	29.72
Mica	21.8	12.74	29.8	17.41	5.2	3.04	1.5	0.87	0.6	0.35	b		0.0	0.00	58.9	34.41
Waha	33.3	50.19	0.0	0.00	2.0	1.00	b		1.0	0.50	17.3	8.68	0.0	0.00	53.6	60.37
Helmer	6.9	7.34	31.6	33.60	b		b		0.3	0.32	b		0.0	0.00	38.8	41.26
Potlatch 1	56.4	201.87	b		4.3	15.39	b		b		b		0.0	0.00	60.7	207.26
Potlatch 2	61.1	58.48	0.0	0.00	1.6	1.53	0.0	0.00	0.3	0.28	b		0.0	0.00	60.3	60.29
Potlatch 3	24.2	36.27	0.0	0.00	0.0	0.00	0.0	0.00	0.2	0.30	b		0.0	0.00	24.4	36.57
New Meadows	58.5	13.58	0.0	0.00	35.8	8.31	0.0	0.00	1.1	0.25	b		b		95.4	22.14
Council	4.0	4.86	b		6.1	7.41	0.0	0.00	0.2	0.24	0.0	0.00	0.0	0.00	10.3	12.51
Cascade	40.0	17.40	0.0	0.00	21.4	9.31	0.0	0.00	0.5	0.22	0.0	0.00	0.0	0.00	61.9	26.93
Idaho City	66.0	43.60	0.0	0.00	20.0	12.21	0.0	0.00	0.6	0.40	b		b		86.6	57.21
Cheney	30.6	117.23	0.0	0.00	4.8	18.39	0.0	0.00	0.7	2.67	0.0	0.00	0.0	0.00	36.1	138.30

[a] Seeds valued at the 1970 price of $10.00 per pound. Current prices, especially for "cultured" seed, are substantially higher.

[b] Present at the site, but damage minor and not estimated.

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ABSTRACT

Losses of cones and seeds of ponderosa pine, *Pinus ponderosa* Laws., were caused primarily by *Laspeyresia miscitata* Heinrich, *L. piperana* (Kearfott), *Conophthorus ponderosae* Hopkins, *Leptoglossus occidentalis* Heidemann, *Dioryctria auranticella* (Grote), *D. abietella* (Denis and Schiffermueller), *Eucosma ponderosa* Powell, and *Asynapta keeni* (Foote). Estimates of damage are given for a 2- to 3-year period. *Laspeyresia* seed moths were the most ubiquitous species, but the cone beetle (*C. ponderosae*) is potentially the most serious pest in ponderosa pine seed orchards and seed-production areas. The cone moths (*Dioryctria* spp.) also exhibited a significant damage potential in years of low cone production. Damage from *E. ponderosa* consisted primarily of mined scale tissues; however, 35 percent of the seeds were destroyed in some cones. Total seed loss from the seed midge (*A. keeni*) always was 1 percent or less, although losses in individual cones were as high as 14 percent. Four methods of estimating the number of cones on young ponderosa pine were evaluated. The axial-slice technique was found to be unsatisfactory for estimating damage and the number of seed moth larvae per cone.

Key words: Cone and seed insects; damage evaluation; ponderosa pine; seed orchards, seed production areas; cone production