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SURVEY REPORT OF THE WEEVIL, *HYLOBIUS WARRENI* WOOD, IN THE FOOTHILLS OF ALBERTA

by

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SUMMARY

An extensive survey of the weevil, *Hylobius warreni* Wood, was conducted in even-aged lodgepole pine stands at 56 locations throughout the Alberta foothills (Fig. 1). Weevil-population estimates, expressed as average numbers per tree and per acre, were given for each of the 56 locations; these estimates varied from 0 to 631 per acre. Estimates of weevil density per acre suggested that populations can reach similar levels of abundance in young (i.e., 18 yrs.) and older stands (i.e., 37, 44 and 45 yrs.) alike. Tree mortality (3.7%) from weevil injuries was noted in only one plot -- an 18-yr-old stand originating from natural seeding after prescarification and clearcutting. No weevil incidence was observed in stands above 5200 ft. Differences were found in the attack pattern of the weevil in relation to stand age and tree size, between the Lower and Upper Foothill Sections (Figs. 3 to 21, Table 3).

The percentages of trees within plots with old attacks (Y_1) were related to average tree diameter, average tree age, stand density, average duff depth, elevation, several interactions of diameter, age and density and percentage of trees with current attacks. Similarly, the percentages of trees with current attacks (Y_2) were related to the same

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stand and tree variables. In the former, 51.07 to 53.81% of the variability in Y_1 was explained by all variables, while in the latter, only 22.67% of the variability in Y_2 was explained by all variables. Mean tree-diameter per plot was the single most important variable accounting for the variability in Y_1 and Y_2. The data suggest that weevil population levels within stands may be regulated to a degree by reduction of the average tree-diameter through selective cutting.

INTRODUCTION

The weevil, Hylobius warreni Wood, presents a potential hazard to lodgepole pine (Pinus contorta Dougl. var. latifolia Engelm.) in Alberta. During its life cycle, the larvae feed in the root-collar zone of trees, causing partial or complete girdling, open wounds, and resinosis (Warren, 1956; Cerezke, 1969). Trees may be killed by girdling of the main stem and roots, suffer growth losses from partial girdling and repeated attacks (Cerezke, 1970), or the wounds may serve as points of entry for root and stem diseases (Warren and Whitney, 1951; Whitney, 1952, 1961, 1962). Trees are susceptible to attack from about age 6 yrs. to maturity, but most mortality is confined to stands less than 30 yrs. old (Cerezke, 1969).

Because of its destructive potential and widespread occurrence in Alberta, an extensive survey was conducted in lodgepole pine stands throughout the foothills. The purposes of this survey were (a) to obtain estimates of weevil abundance in a variety of pine stands growing under different site conditions, (b) to obtain estimates of damage incidence in each stand type and (c) to examine damage incidence in relation to several stand and site variables for the purpose of evaluating which ones are most useful for predicting favorable and non-favorable weevil sites.

Previous studies on H. warreni populations had shown that, within even-aged pine stands, weevil numbers were related directly to the percentage of trees currently attacked (Cerezke, 1969, 1970). This relation formed the basis of the sampling technique adopted in the survey carried out by personnel of the Federal Forest Insect and Disease Survey.

METHODS

The survey of H. warreni was conducted along two transects; the first, sampled in 1967, extended from near Grande Prairie south eastward to the International Boundary (Fig. 1, map locations 1 to 45 inclusive). The second transect, sampled in 1968, extended from near Rocky Mountain House northward to Chip Lake (map locations 46 to 56 inclusive). The first transect included pine stands between 2800 and 6000 ft above sea level and was confined mostly to the Upper Foothills Section (B.19c) of the Boreal Forest Region (Rowe, 1959). The second transect included stands between 2700 to 3500 ft and within the Lower Foothills Section (B.19a). In all sampled stands, lodgepole pine was the dominant species, while the stand character was even-aged. The survey was restricted to routes along accessible roads, and pine stands, mostly greater than 20 acres in extent, were sampled.

At each of the 56 locations shown in Fig. 1, usually three sample plots were established, the number of plots being dependent upon the extent of the pine type, stand density, and uniformity of the stand. An attempt was made to locate plots in representative portions of the stands at a minimum distance of 75 to 100 ft from stand peripheries.

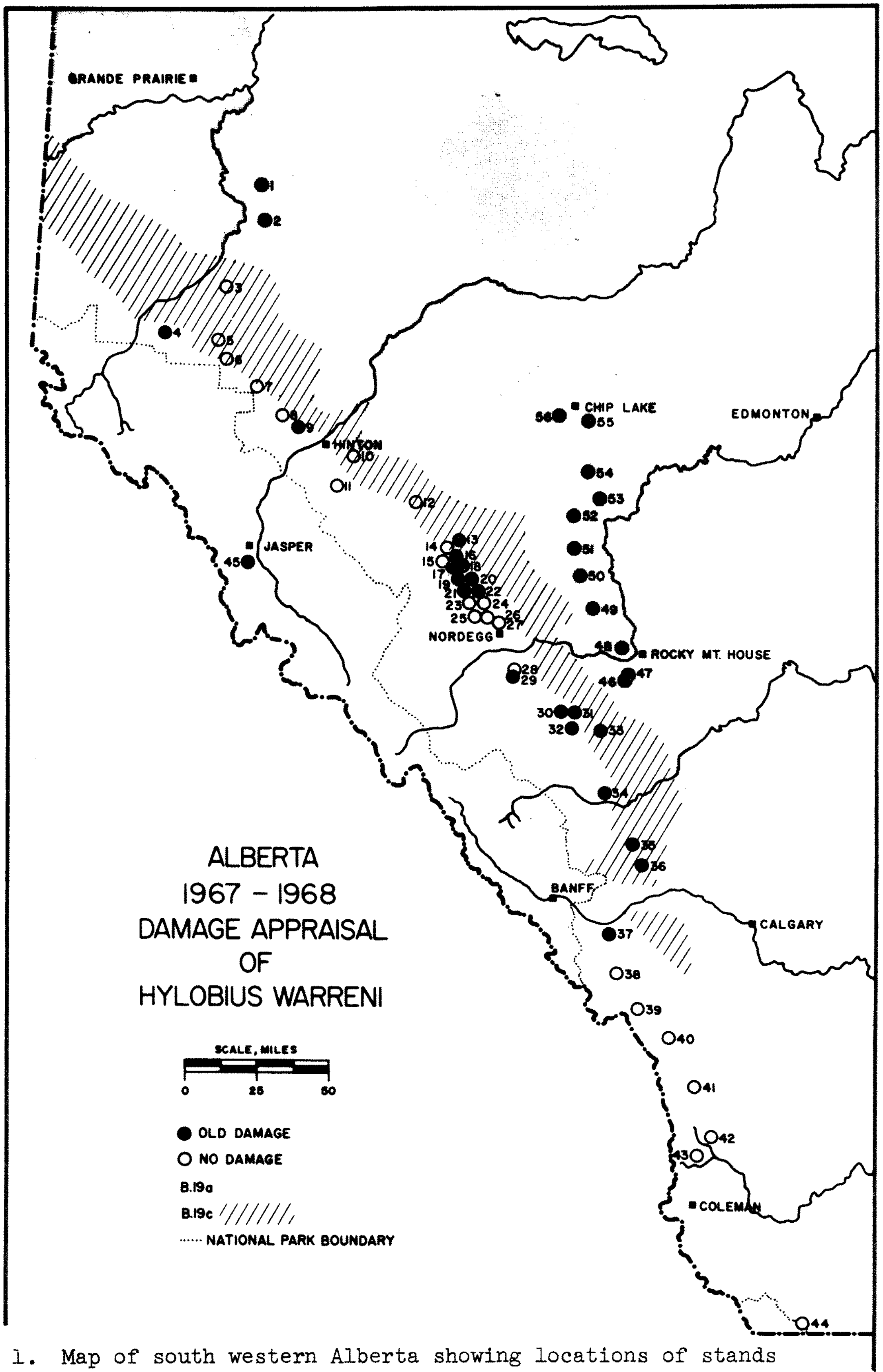


Fig. 1. Map of south western Alberta showing locations of stands sampled for Hylobius warreni and its incidence of old damage. B.19a and B.19c, respectively, designate Lower and Upper Foothills Sections of the Boreal Forest Region (Rowe, 1959).

Plots were 1/50th or 1/20th acre in size, and a minimum of 100 trees were sampled at most locations. The total number of sample plots established was 142.

All plots were circular. The 1/50th-acre size had a radius of 16.7 ft while the radius of 1/20th-acre plots was 26.3 ft. The procedure of tree examination was as outlined previously (Cerezke, 1970) and is briefly described here. All pine trees within each plot were examined for the presence of current and old wounds from weevil larval feeding; current feeding was characterized by the presence of live larvae, pupae and/or teneral adults, whereas old wounds had no weevils associated with them. Each sampled tree was thus classified as having no weevil damage, current feeding only, old damage only, or current and old damage. The latter three categories could often be decided with only partial examination of individual trees. Current feeding was decided when the first live weevil was located.

After sampling was completed within a plot, the percentages of trees with old damage and those with current damage were calculated as described previously (Cerezke, 1970). Tree density per acre was calculated from a count of the total number of pine trees in each plot. The diameter of each sampled tree was measured at the 10-inch stump height and tree age was obtained from increment borings made at this stump height. Duff depth (in inches) in each plot was estimated from an average of four measurements taken near the centers of four equal plot sectors; each measured the depth from the surface of the forest floor to mineral soil. Altitude at each plot location was read to the nearest 100 ft on topographical maps.

An estimate of the average number of weevils per tree in each plot was obtained by applying the percentage value of trees currently attacked directly on the X-axis in Fig. 2 and locating a corresponding value on the Y-axis. The latter value was then multiplied by tree density per plot to derive an estimate of weevil numbers per acre.

Originally, the data were to be analyzed from individual stands (i.e., map locations). However, it became apparent after the data were collected that age differences between plots at the same map location sometimes differed by more than 10 yrs. The data have, therefore, been summarized in general form by map location and in greater detail by individual plots.

Multiple regression analyses were used to determine, in step-wise procedure, which stand and site variables were most useful for predicting weevil incidence (i.e., current and old weevil attacks). In the first analysis, the dependent variable Y_1 (% trees with old attacks), was tested against the following independent variables and their interactions; the values used were plot averages.

X_1 = altitude (ft)

X_2 = ave. duff depth (ins.)

X_3 = ave. tree diameter (ins. at 10-inch stump height)

X_4 = tree density per acre

X_5 = ave. stand age

Y_2 (or X_6) = % trees with current attacks

Interactions = $X_3 X_4$, $X_4 X_5$, $X_3 X_5$ and $X_3 X_4 X_5$

In the second analysis, Y_2 (% trees with current attacks) was tested against X_1, X_2, X_3, X_4, X_5, $X_3 X_4$, $X_4 X_5$, $X_3 X_5$ and $X_3 X_4 X_5$.

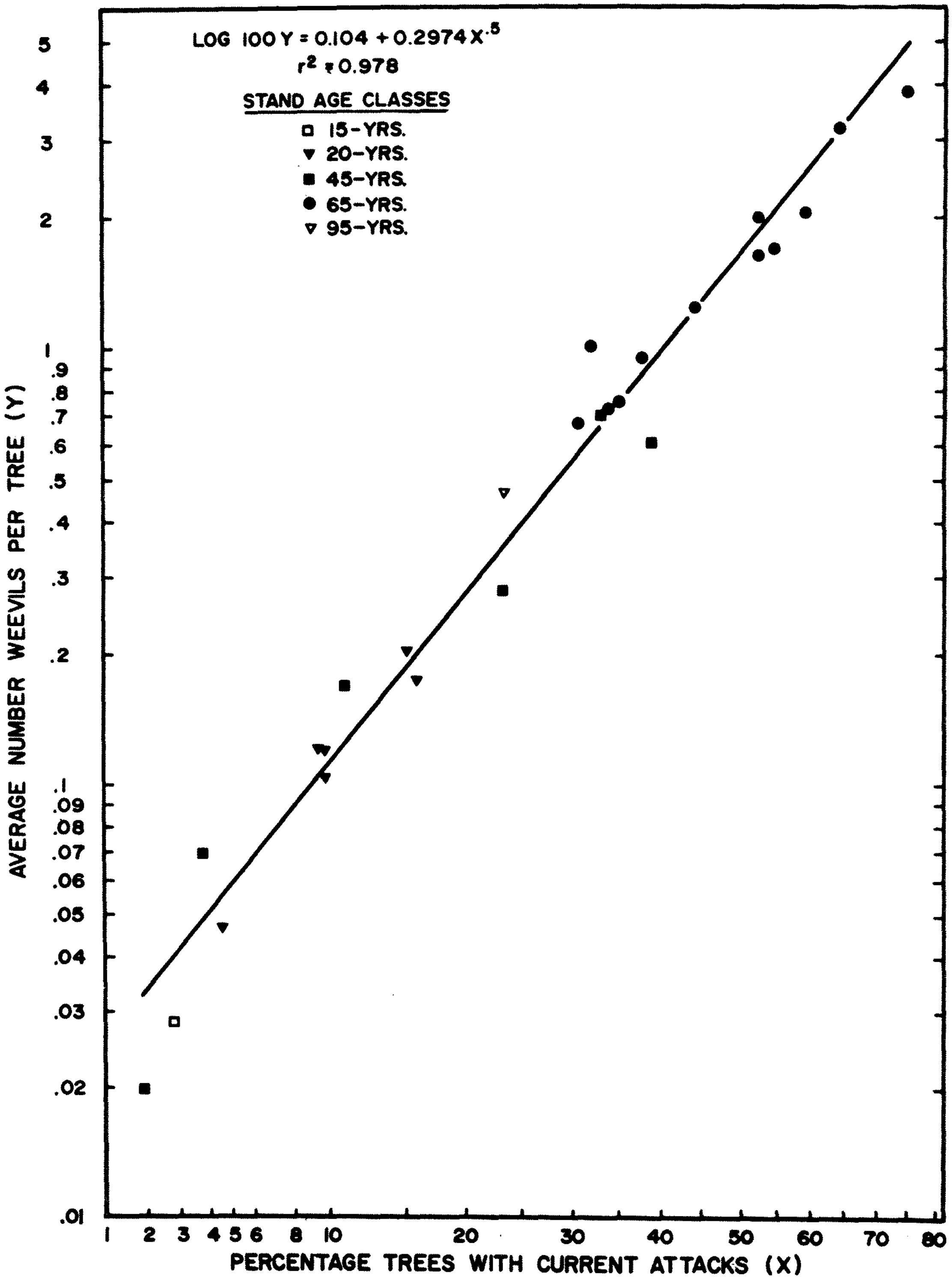


Fig. 2. Relation between mean number of H. warreni per tree and percentage of trees with current attacks (reproduced from Cerezke, 1970).

RESULTS

H. warreni Distribution and Abundance

A summary of the weevil sampling at the 56 map locations (Fig. 1) is given in Tables 1 and 2. The age of stands sampled ranged from 18 to 93 yrs., and one stand was 162 yrs. The altitudinal range of the plots varied from 2700 to 6000 ft; no weevils were found above 5200 ft. Estimates of weevil density per acre varied from 0 to 631. Of those locations with 200 or more weevils per acre, the average stand ages varied from 18 to 75 yrs. Location 47 (Fig. 1) is of special interest since it represented an 18-yr-old stand that originated from natural seeding after prescarification treatment, clearcutting, and lopping and scattering of slash (Crossley, 1955). Data for this location suggested that weevil abundance was relatively high (Table 2), while tree mortality from weevil feeding was 3.7%. It was surmised from the diameters of the dead trees that they were intermediate and co-dominant trees, although no record was made of the time when the trees had been girdled; none had current attacks. Mortality from weevil feeding was negligible in all other plots.

Weevil Attack Patterns in the Lower and Upper Foothills

The 56 sampled locations (Fig. 1) were classified as having either old H. warreni damage or no damage. Hence, within the Alberta foothills, no weevils were found in pine stands south of location 37, west of Calgary. Farther north within the B.19c, weevil incidence tended to be sporadic in comparison with that in the B.19a. So, data from the two Foothill Sections were analyzed separately to determine how the attack

Table 1. Summary of lodgepole pine stands sampled in the Alberta foothills during the survey of H. warreni damage incidence and abundance.

Map location	Altitude (ft)	Area sampled (acres)	No. trees sampled	Tree density /acre	Ave. tree diam. (ins.)	Ave. tree age (yrs)	Ave. duff depth (ins)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1	2800	.10	156	1560	3.69	61	1.5
2	4300	.15	78	520	7.76	45	4.5
3	4300	.10	95	950	6.62	50	4.5
4	4000	.15	193	1287	4.40	57	4.0
5	4500	.04	110	2750	3.92	65	2.9
6	4800	.04	82	2050	4.63	54	4.0
7	4500	.10	40	400	8.99	162	4.7
8	4000	.10	105	1050	6.37	58	2.7
9	3900	.15	98	653	6.75	62	3.0
10	4200	.10	47	470	8.42	54	2.8
11	4500	.10	72	720	6.61	58	5.8
12	4600	.10	42	420	10.01	66	5.2
13	4600	.15	139	927	7.04	72	5.6
14	4400	.07	45	643	6.47	63	3.5
15	4400	.10	37	370	8.66	58	2.2
16	4400	.06	84	1400	5.70	69	2.9
17	4800	.12	80	667	6.22	63	3.3
18	4600	.15	104	693	6.97	59	3.2
19	4600	.06	73	1217	7.17	66	3.8
20	4400	.15	154	1027	5.69	51	2.4
21	4600	.15	115	767	6.62	54	3.6
22	4600	.06	90	1500	4.94	69	3.0
23	4600	.06	65	1083	5.99	69	3.3
24	4800	.06	118	1967	4.40	66	2.6
25	5000	.04	39	975	7.63	64	2.0
26	4800	.05	19	380	8.18	83	2.0
27	4600	.04	33	825	7.91	93	2.5
28	4000	.05	60	1200	4.94	44	3.0
29	4000	.15	102	1700	4.44	41	3.7
30	4200	.15	261	1740	4.11	43	2.8
31	4400	.15	110	733	6.36	44	1.8
32	4400	.15	64	427	10.11	76	2.7
33	4600	.15	114	760	6.63	80	2.6
34	5000	.15	88	587	7.43	65	1.5
35	5200	.15	111	740	5.91	47	2.2
36	4400	.15	44	293	7.73	92	5.9
37	4600	.15	143	953	5.78	54	3.2
38	5000	.10	126	1260	3.49	35	0.5
39	5500	.10	84	840	5.26	45	1.2
40	5500	.10	135	1350	4.69	51	2.6

Table 1 (cont'd)...

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
41	6000	.10	119	1190	5.23	93	2.8
42	5500	.10	134	1340	4.02	64	1.7
43	5300	.10	137	1370	4.77	54	2.9
44	4500	.10	74	740	6.18	88	1.7
45	3700	.10	83	830	5.72	61	2.5
46	3500	.20	101	505	8.43	87	4.3
47	3500	.025	189	7560	.98	18	1.7
48	3300	.20	92	460	9.40	59	3.9
49	3400	.05	151	3020	2.47	37	4.2
50	3400	.15	110	733	7.82	65	3.7
51	3400	.15	104	693	8.01	55	4.9
52	3100	.30	92	307	10.63	75	5.0
53	2900	.10	100	1000	5.08	68	4.0
54	3000	.10	135	1350	4.36	21	2.4
55	2700	.15	131	873	6.39	67	4.0
56	2800	.15	112	747	6.56	63	6.8

Table 2. Summary of lodgepole pine stands sampled in the Alberta foothills giving the percentages of trees with old and current <u>H. warreni</u> attacks, and estimates of weevils per tree and per acre.

Map location	% trees with old attacks	% trees with current attacks	Ave. number weevils per tree	Ave. number weevils per acre
(1)	(2)	(3)	(4)[a]	(5)[b]
1	4.5	0	0	0
2	83.3	30.8	.580	302
3	0	0	0	0
4	36.8	6.7	.076	98
5	0	0	0	0
6	0	0	0	0
7	0	0	0	0
8	0	0	0	0
9	51.0	10.2	.120	78
10	0	0	0	0
11	0	0	0	0
12	0	0	0	0
13	7.2	.7	.023	21
14	0	0	0	0
15	0	0	0	0
16	1.2	1.2	.027	38
17	77.5	17.5	.230	153
18	71.2	22.1	.320	222
19	69.9	9.6	.105	128
20	44.8	11.7	.135	139
21	87.0	13.1	.155	119
22	34.4	6.7	.076	114
23	3.1	0	0	0
24	2.5	0	0	0
25	0	0	0	0
26	0	0	0	0
27	0	0	0	0
28	0	0	0	0
29	29.3	10.7	.120	204
30	40.6	8.1	.090	157
31	65.5	26.4	.440	323
32	81.3	20.3	.280	120
33	42.1	16.7	.215	163
34	52.3	13.1	.155	91
35	1.8	2.7	.039	29
36	61.4	18.2	.245	72
37	1.4	0	0	0
38	0	0	0	0
39	0	0	0	0
40	0	0	0	0

Table 2 (cont'd)...

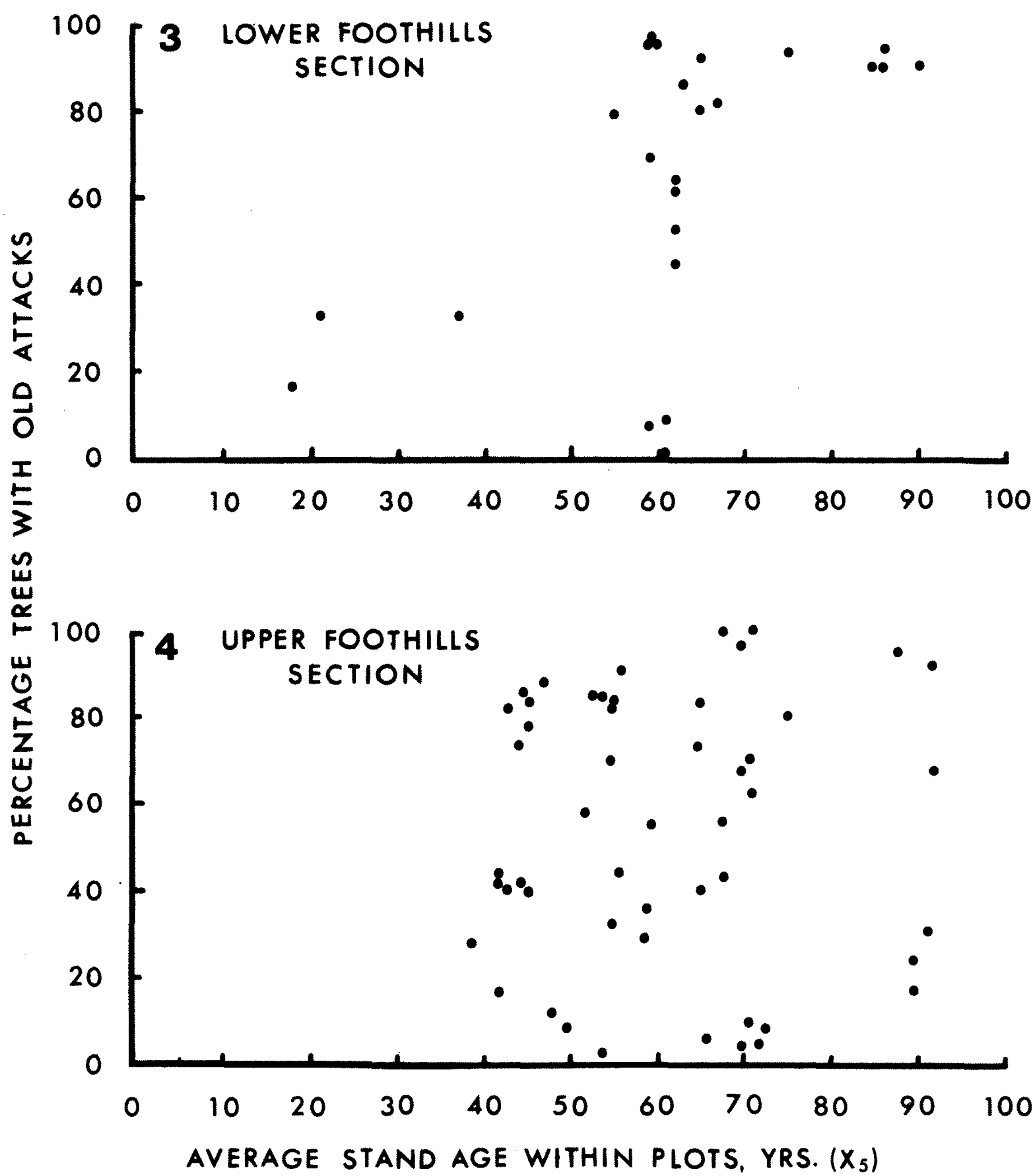
(1)	(2)	(3)	(4)[a]	(5)[b]
41	0	0	0	0
42	0	0	0	0
43	0	0	0	0
44	0	0	0	0
45	36.1	3.6	.048	40
46	78.0	12.8	.150	76
47	14.8	3.1	.043	325
48	88.0	13.3	.155	71
49	32.6	7.0	.079	239
50	84.5	17.0	.220	161
51	86.5	38.5	.910	631
52	90.2	33.5	.690	212
53	60.0	9.9	.110	110
54	31.9	6.9	.079	107
55	80.8	13.6	.160	140
56	78.6	10.3	.115	86

[a] Weevil numbers estimated from values given in column (3) and applied in Fig. 2.

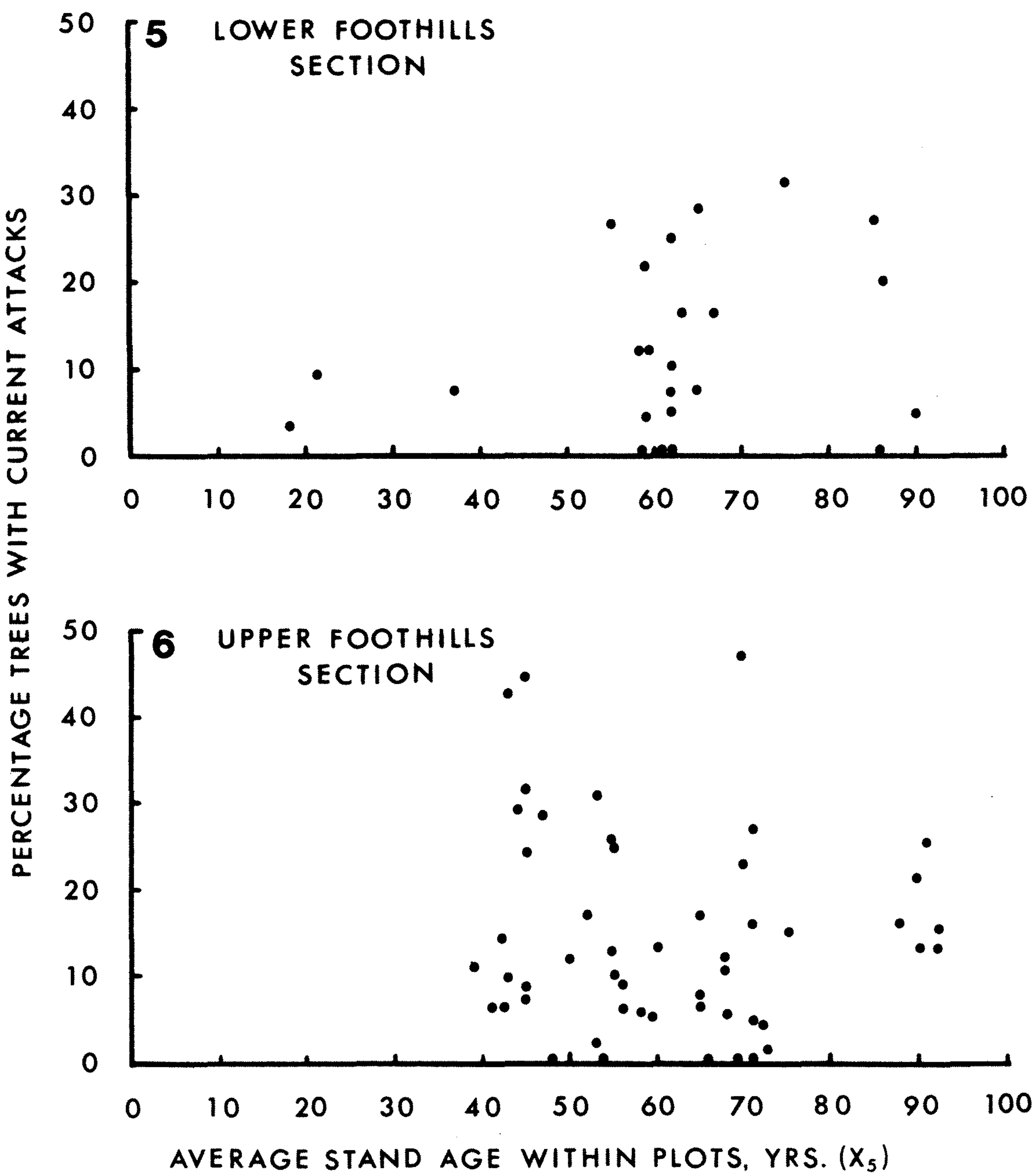
[b] Weevil density estimated from values given in column (4) and in column (5) of Table 1.

patterns differed in relation to stand age (Figs. 3-6) and tree size (Figs. 7-20). Figure 3 suggests that, in even-age pine stands of the Lower Foothills, weevil-attack incidence began near age 10 yrs., rose gradually to age 60 yrs. and levelled-off thereafter. Thus, in stands 60 yrs old and older, 90% of the trees on the average had old attacks. The attack pattern in the Upper Foothills (Fig. 4) appeared similar to that in the Lower Foothills, except that the levelling-off period occurred at a lower level of incidence (average of 50 to 60% old attacks). There was also a greater scatter of points for the B.19c data as compared with that in the B.19a. Some differences in the patterns of current attack in the two Foothill Sections (Figs. 5 and 6) also seem apparent, although the data varied widely.

In Figs. 7-13 (Lower Foothills) and Figs. 14-20 (Upper Foothills), all stands having old damage were grouped into 10-yr age classes. Trees within each class were divided into 1-inch-diameter classes, and the percentage of trees with old attacks was then calculated for each diameter class. These values were plotted against tree diameter and graphs were fitted visually. The graphs show the cumulative nature of attacks in relation to tree diameter, and suggest that a relatively stable pattern occurs in all age classes. For comparison, the tree diameter at which 50% of all trees had old damage was drawn on each graph. This value, designated here as D_{50} (i.e., diameter at 50% damage incidence), provides a useful weevil-site index that reflects the weevil's temporal pattern of success in relation to stand conditions. The D_{50} values summarized in Table 3 are, with one exception, smaller in the Lower Foothills than in the Upper Foothills; the average D_{50} of the former was 2.44 ins. less than that in the latter. This suggests that stand conditions are generally more



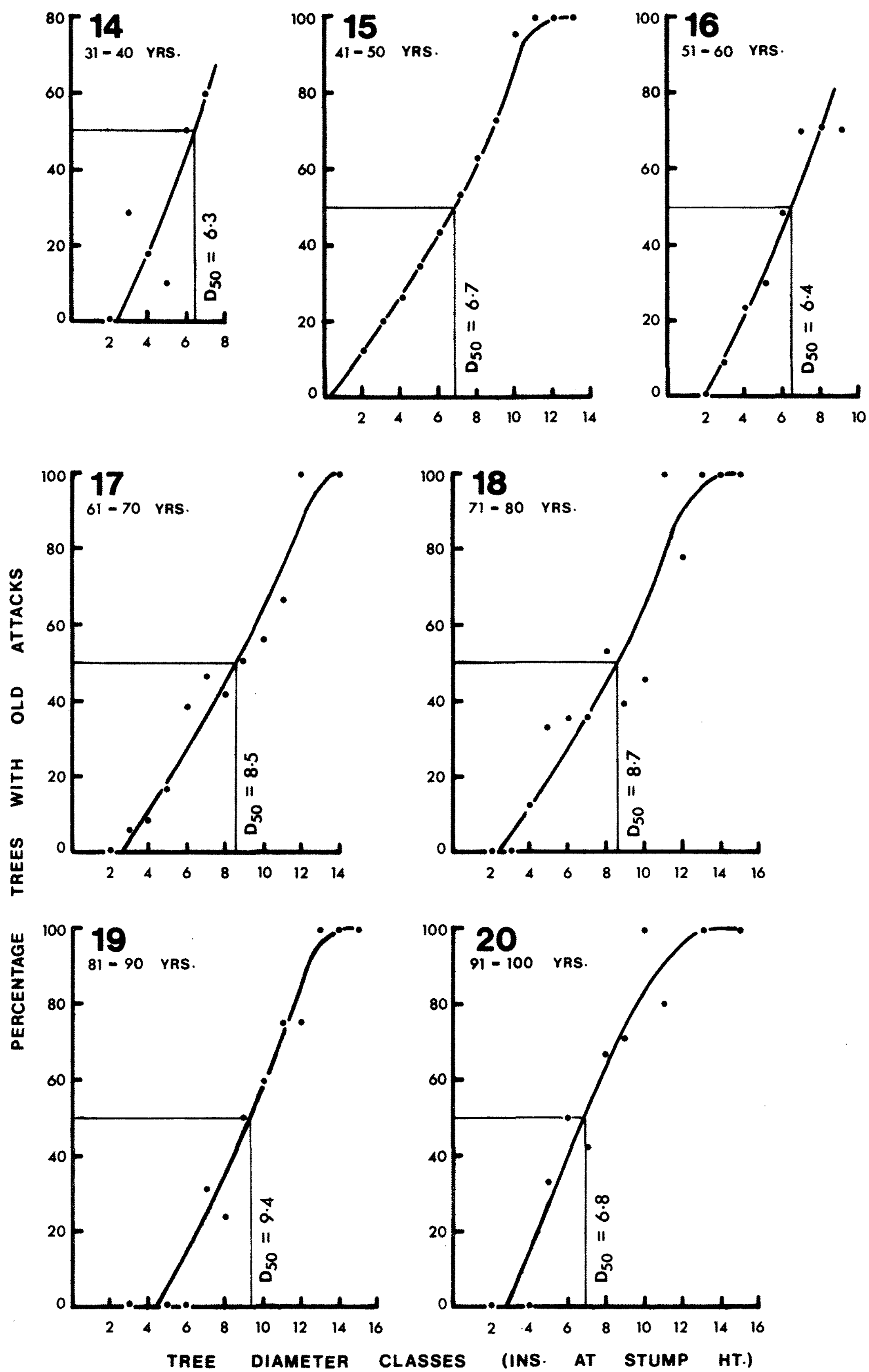
Figs. 3 and 4. Relation between incidence of old H. warreni attack and age of lodgepole pine stands sampled in the Lower (3) and Upper (4) Foothill Sections of Alberta.



Figs. 5 and 6. Relation between incidence of current H. warreni attack and age of lodgepole pine stands sampled in the Lower (5) and Upper (6) Foothill Sections of Alberta.

Figs. 7-13. Relation between percentage of trees with old _H. warreni_ attacks and tree diameter classes for various stand age classes in the Lower Foothills. Figs. 7 to 13 show respectively the following stand age classes: 11-20 yrs, 21-30 yrs, 31-40 yrs, 51-60 yrs, 61-70 yrs, 71-80 yrs and 81-90 yrs. D_{50} values represent the tree diameter at which 50% of the trees have old attacks.

Figs. 14-20. Relation between percentage of trees with old *H. warreni* attacks and tree diameter classes for various stand age classes in the Upper Foothills. Figs. 14 to 20 show respectively the following stand age classes: 31-40 yrs., 41-50 yrs., 51-60 yrs., 61-70 yrs., 71-80 yrs., 81-90 yrs., and 91-100 yrs. D_{50} values represent the tree diameter at which 50% of the trees have old attacks.



14
31 - 40 YRS.
D50 = 6·3
15
41 - 50 YRS.
D50 = 6·7
16
51 - 60 YRS.
D50 = 6·4
17
61 - 70 YRS.
D50 = 8·5
18
71 - 80 YRS.
D50 = 8·7
19
81 - 90 YRS.
D50 = 9·4
20
91 - 100 YRS.
D50 = 6·8
PERCENTAGE TREES WITH OLD ATTACKS
TREE DIAMETER CLASSES (INS. AT STUMP HT.)

favorable to the weevil in the Lower Foothills than in the Upper Foothills.

Further evidence of a change in weevil habitat conditions with increasing altitude is reflected in Fig. 21, in which the percentages of plots sampled with no weevil incidence were plotted against elevation classes. Only stands 60 yrs. old and older were used in order to eliminate some of the variability owing to stand age.

Weevil Incidence Related to Stand and Tree Variables

The factors considered most likely related to weevil-attack incidence (Y_1 and Y_2) were altitude at sampling locations (X_1), mean duff depth (X_2), mean tree diameter (X_3), tree density (X_4) and average stand age (X_5). Percentage of old attacks (Y_1) in each plot was therefore plotted against each of the X-variables and against Y_2 (% current attacks) (Figs. 22-27). The amount of scatter is large in each graph, making it difficult to assess visually the relative importance of each factor in relation to Y_1. Y_2 was similarly plotted against the five X-variables (figures not included) and the amount of scatter was also considerable. Each X-variable was in turn plotted separately against all other X variables to determine which interactions might be important; only apparent relationships have been included (Figs. 28-30). The data suggested that the important interactions were $X_3 X_4$, $X_4 X_5$, $X_3 X_5$ and $X_3 X_4 X_5$. Interactions between Y_2 and X-variables were not considered in the analysis of Y_1. Only those plots were used that had a positive record of old attacks, and in which measurements of all X-variables were complete. Thus, 66 plots were used in one instance (Table 4) and 75 in another (Table 5).

Table 3. Summary of various lodgepole pine stand age classes sampled for *H. warreni* incidence and abundance in the Lower and Upper Foothill Sections; D_{50} values are given for each age class.

Stand age classes	Lower Foothills Section			Upper Foothills Section		
	Map locations sampled	Total trees sampled	D_{50} [a]	Map locations sampled	Total trees sampled	D_{50}
11-20	47	189	3.4	--	--	--
21-30	54	136	6.7	--	--	--
31-40	49	151	4.0	29	39	6.3
41-50	--	--	--	2,20,29,30, 31,35	742	6.7
51-60	45,48,51	235	5.9	4,17,18,20, 21,34,37	575	6.4
61-70	1,45,53, 55,56	651	5.3	9,13,16,17,18, 19,22,23,24,32	589	8.5
71-80	52	92	5.0	13,16,22,32 33,34	220	8.7
81-90	46	101	5.4	32,33	82	9.4
91-100	--	--	--	36	44	6.8
Totals		1555	35.7		2291	52.8
Overall mean			5.10			7.54

[a] Tree diameter at which 50% of the trees have old attacks.

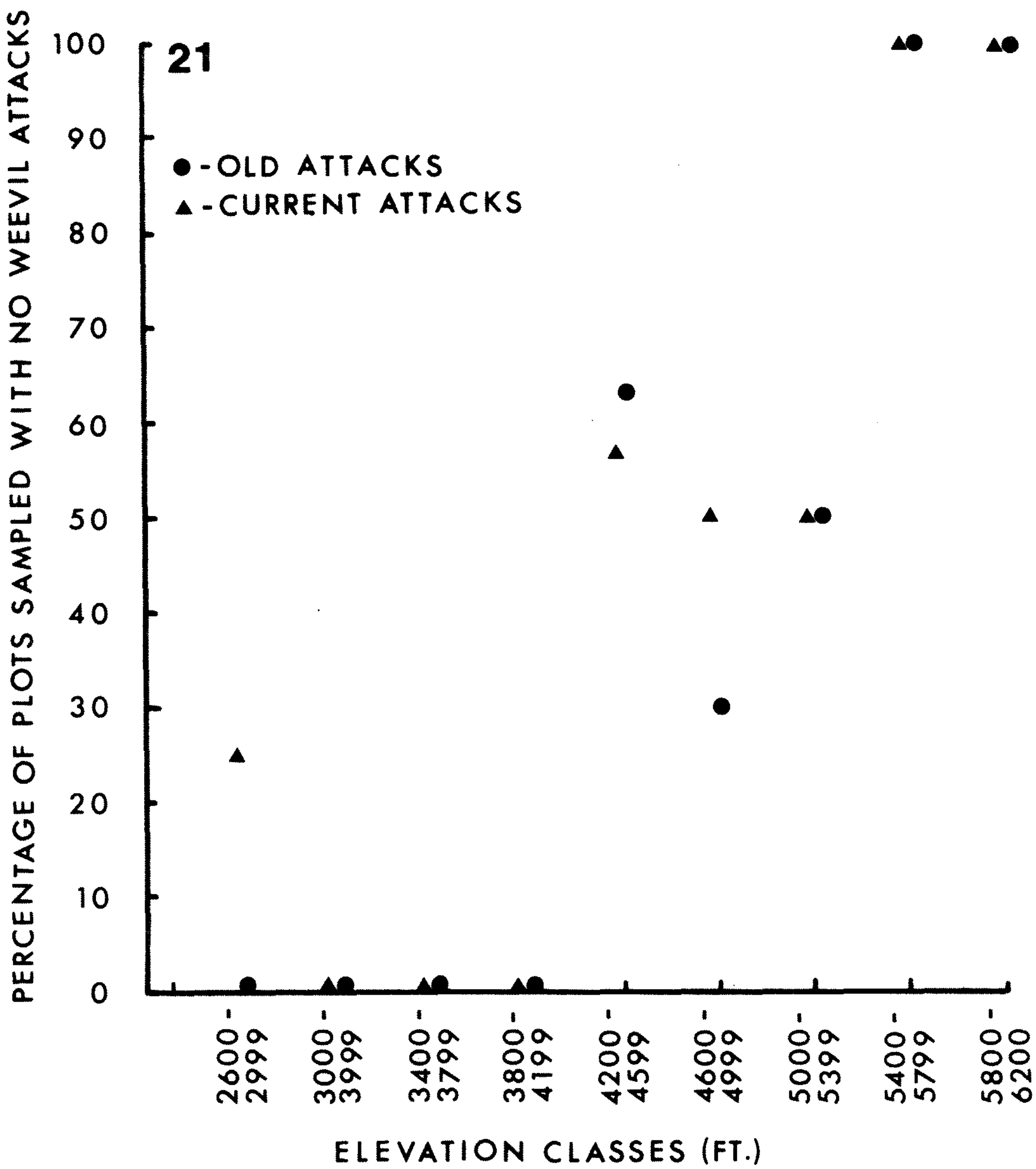


Fig. 21. Relation between the percentage of plots sampled with no old or current H. warreni attacks and elevation classes. All plots in stands 60 yrs. old and older were used.

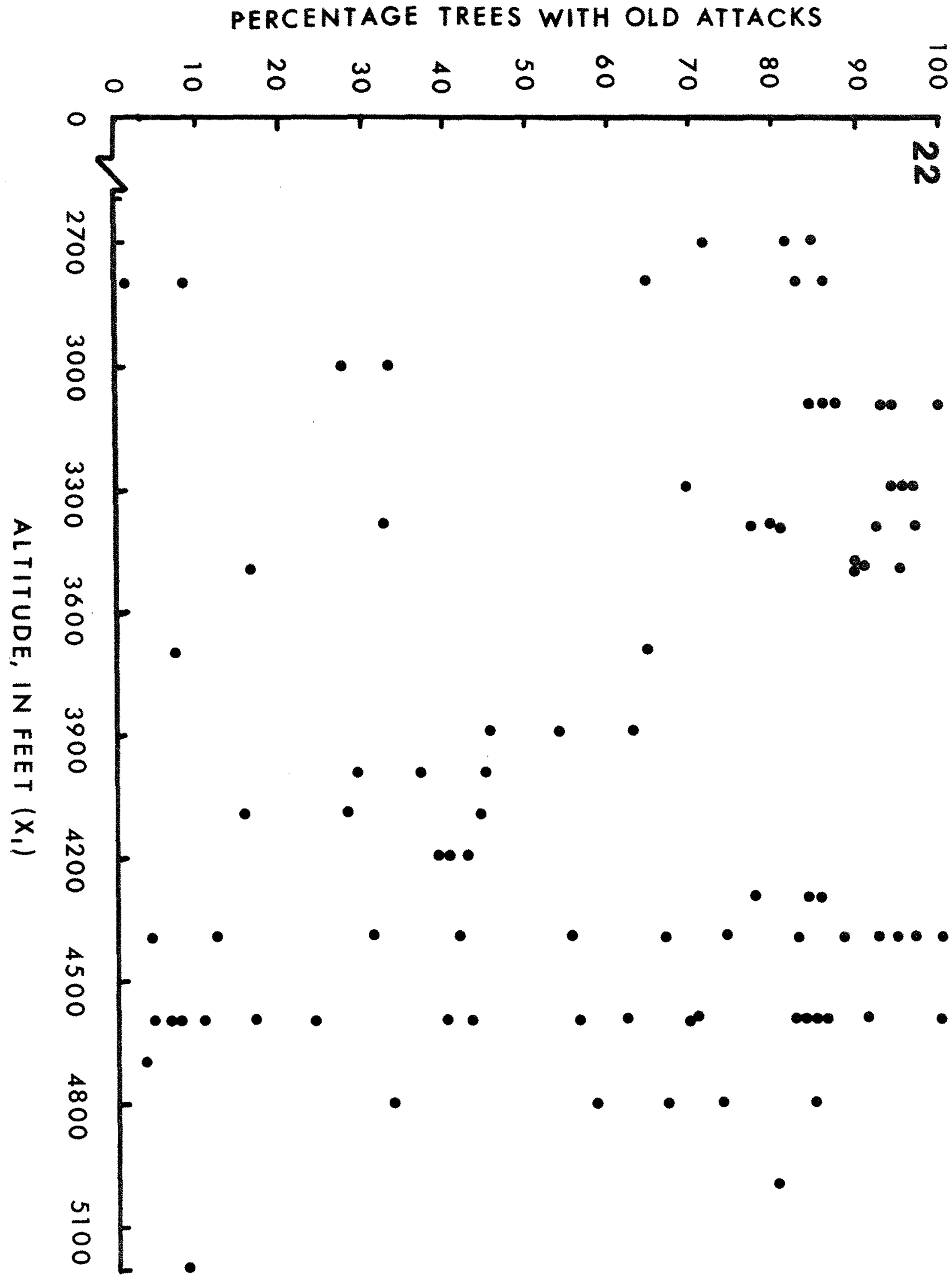


Fig. 22. Relation between percentage of old <u>H</u>. <u>warreni</u> attacks (Y_1) and altitude in feet (X_1).

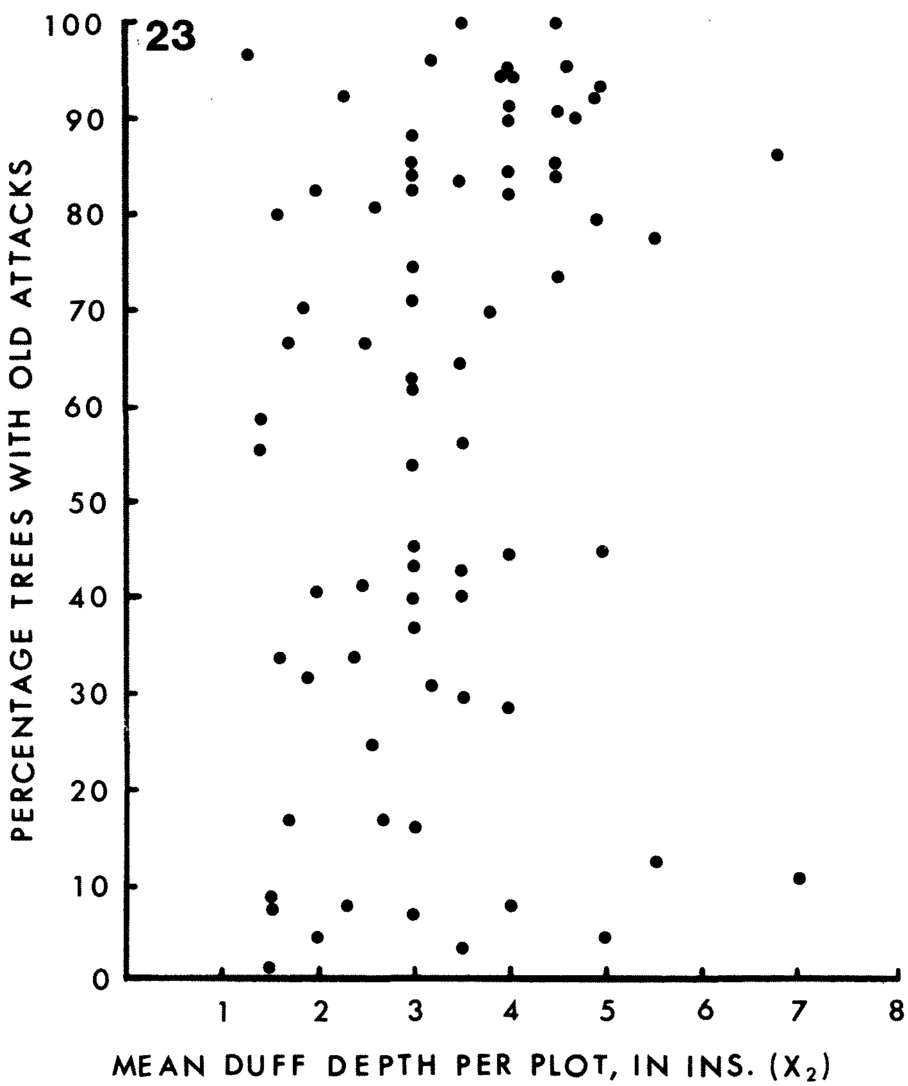


Fig. 23. Relation between percentage of old _H. warreni_ attacks (Y_1) and average plot duff depth in inches ($\bar{X}_2$).

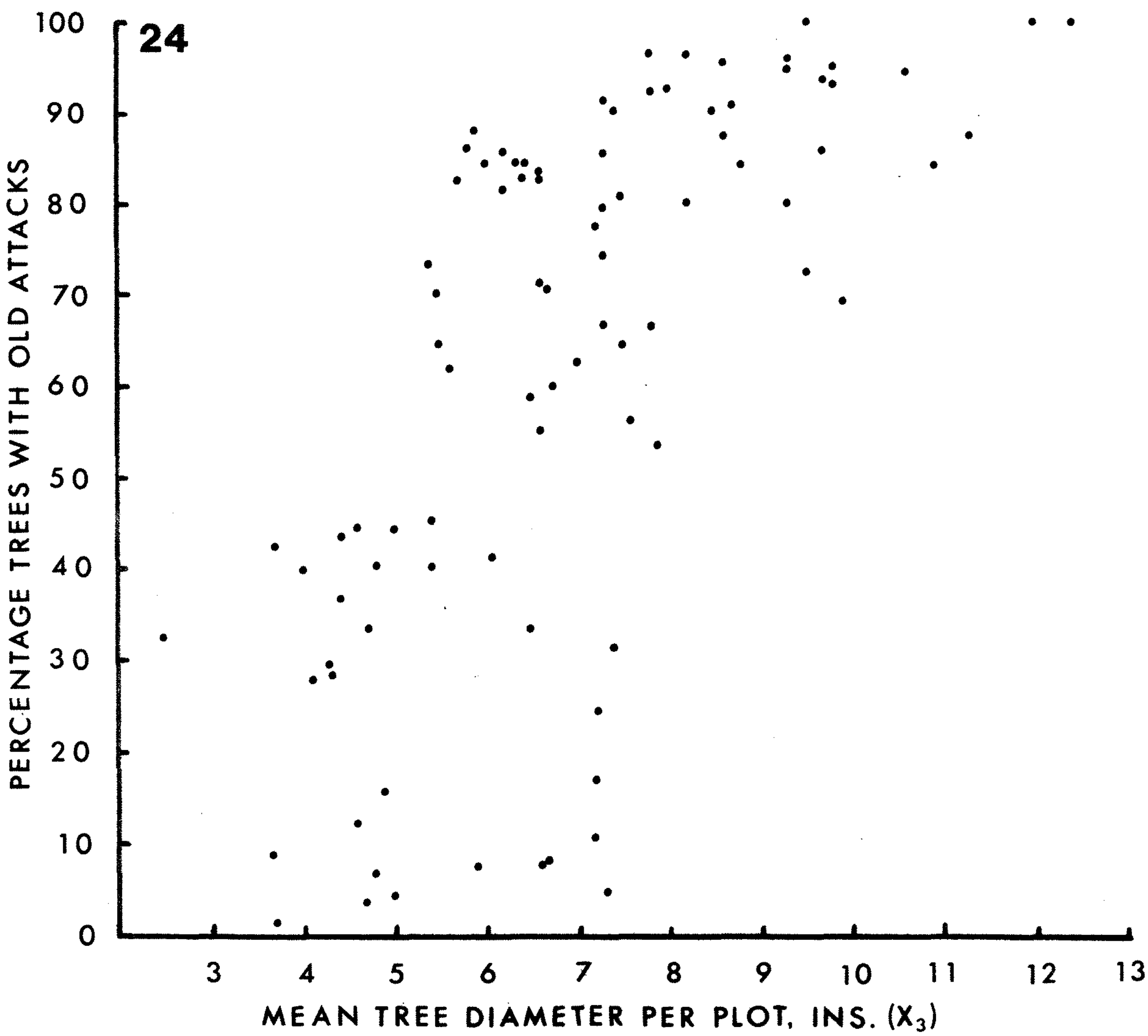


Fig. 24. Relation between percentage of old H. warreni attacks (Y_1) and average tree diameter per plot in inches (X_3).

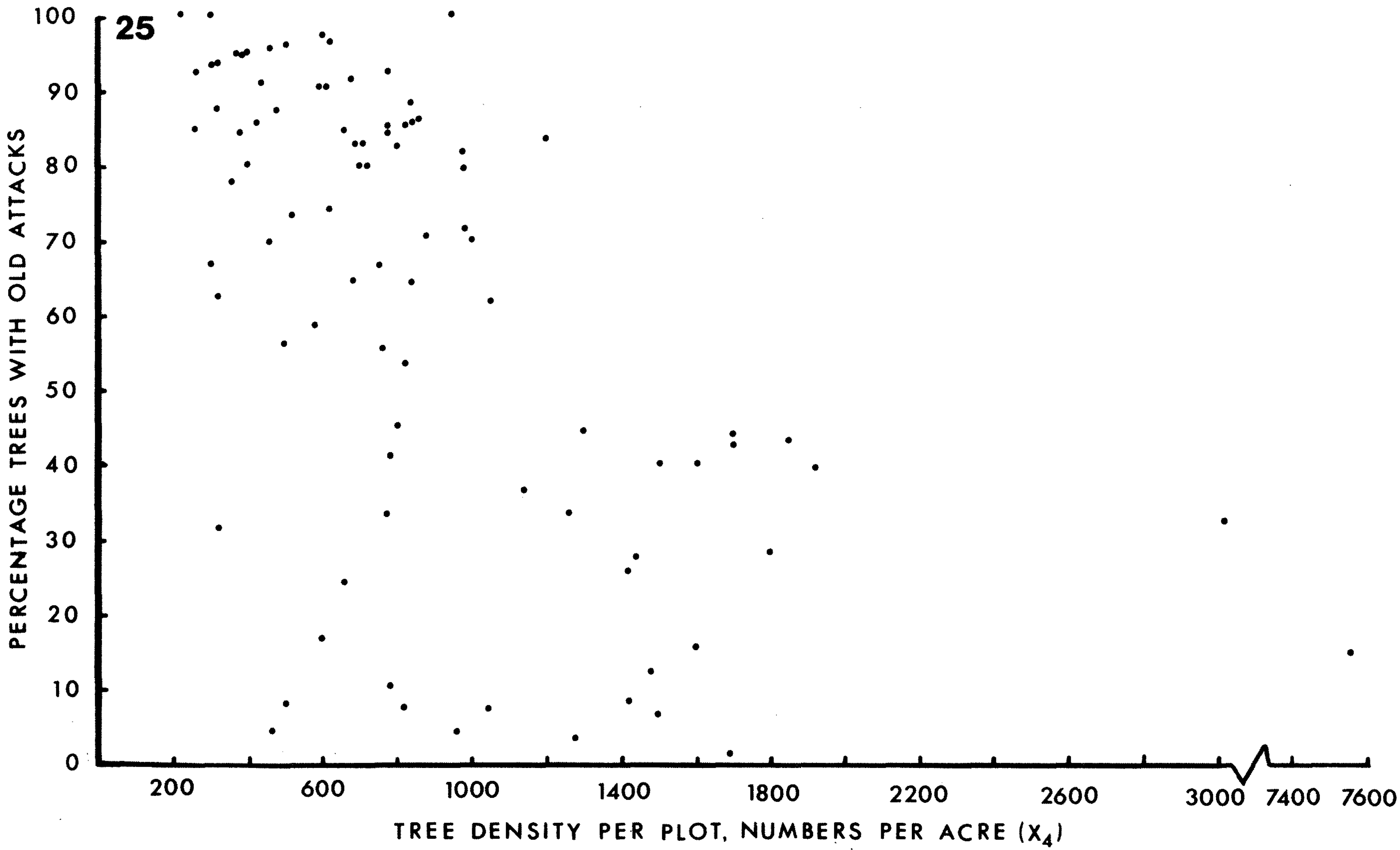


Fig. 25. Relation between percentage of old *H. warreni* attacks (Y_1) and tree density (trees per acre) per plot (X_4).

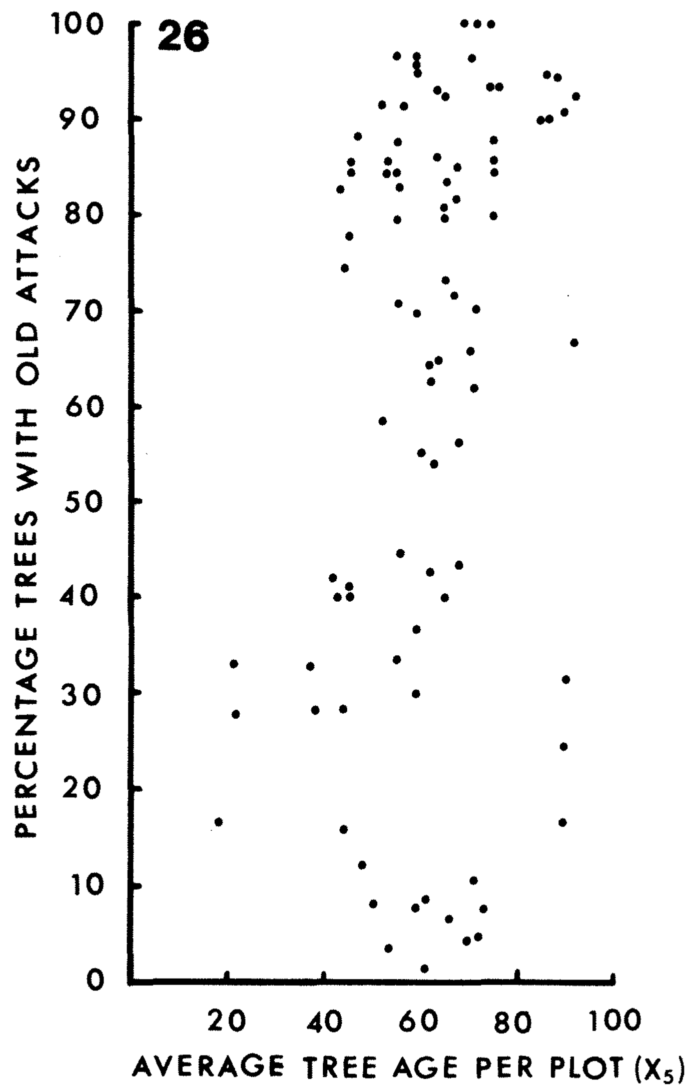


Fig. 26. Relation between percentage of old H. warreni attacks (Y_1) and average stand age per plot (X_5).

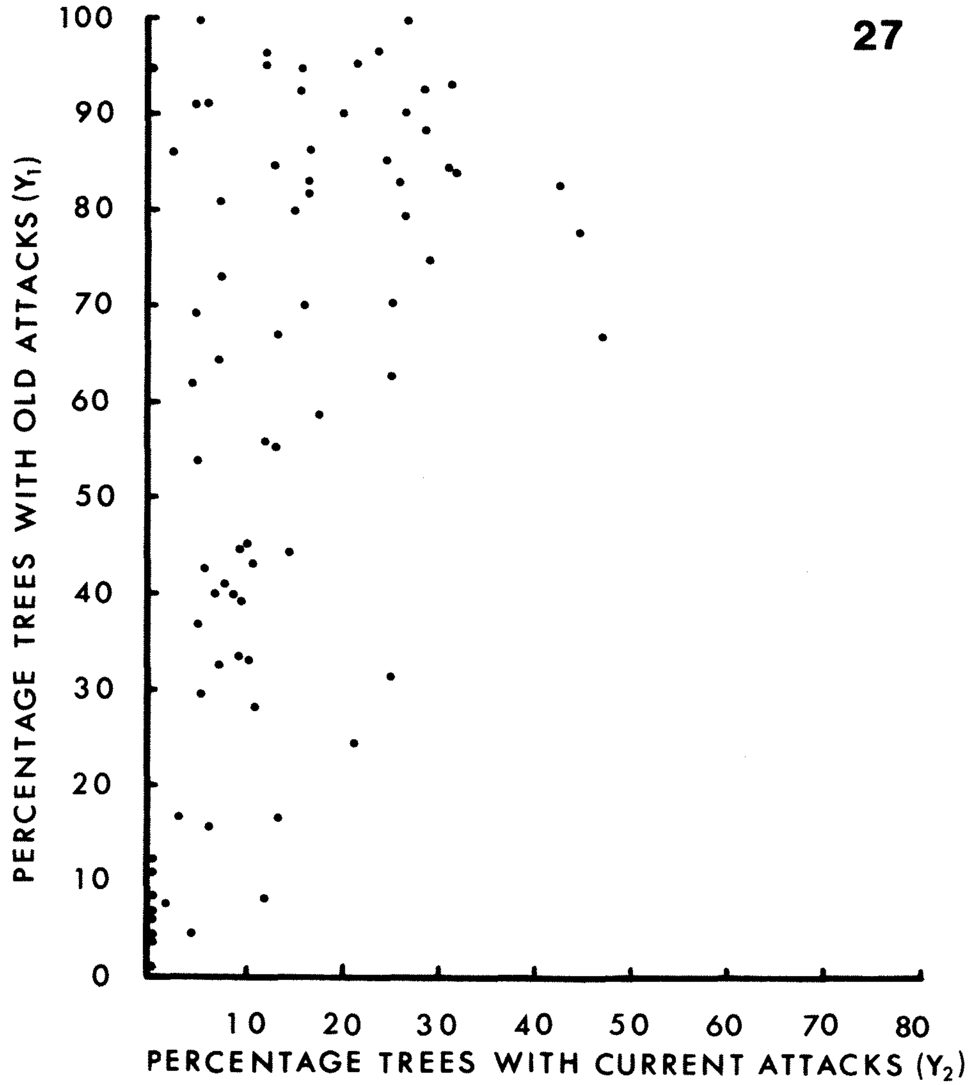


Fig. 27. Relation between percentage of old H. warreni attacks (Y_1) and percentage of current attacks (Y_2).

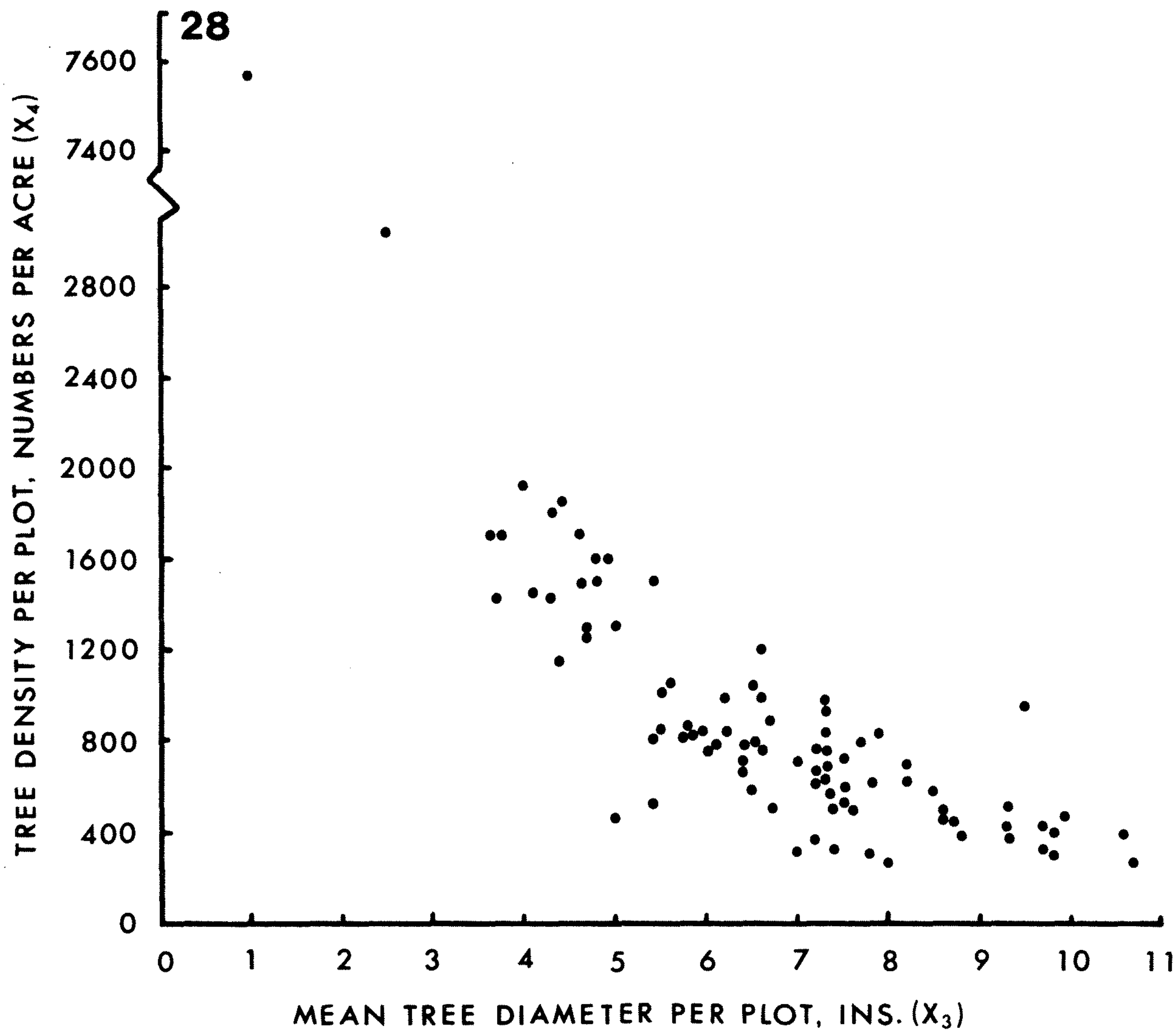


Fig. 28. Relation between lodgepole pine density per plot (X_4) and mean tree diameter per plot (X_3).

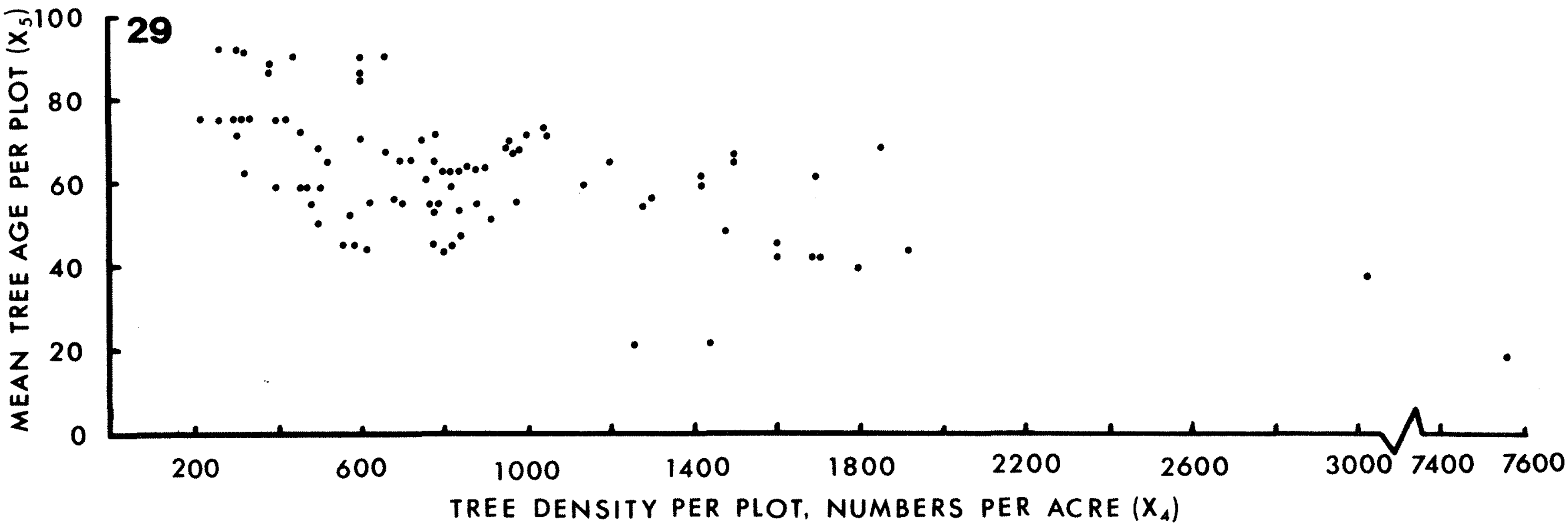


Fig. 29. Relation between lodgepole pine mean tree age per plot (X_5) and tree density (trees per acre) per plot (X_4).

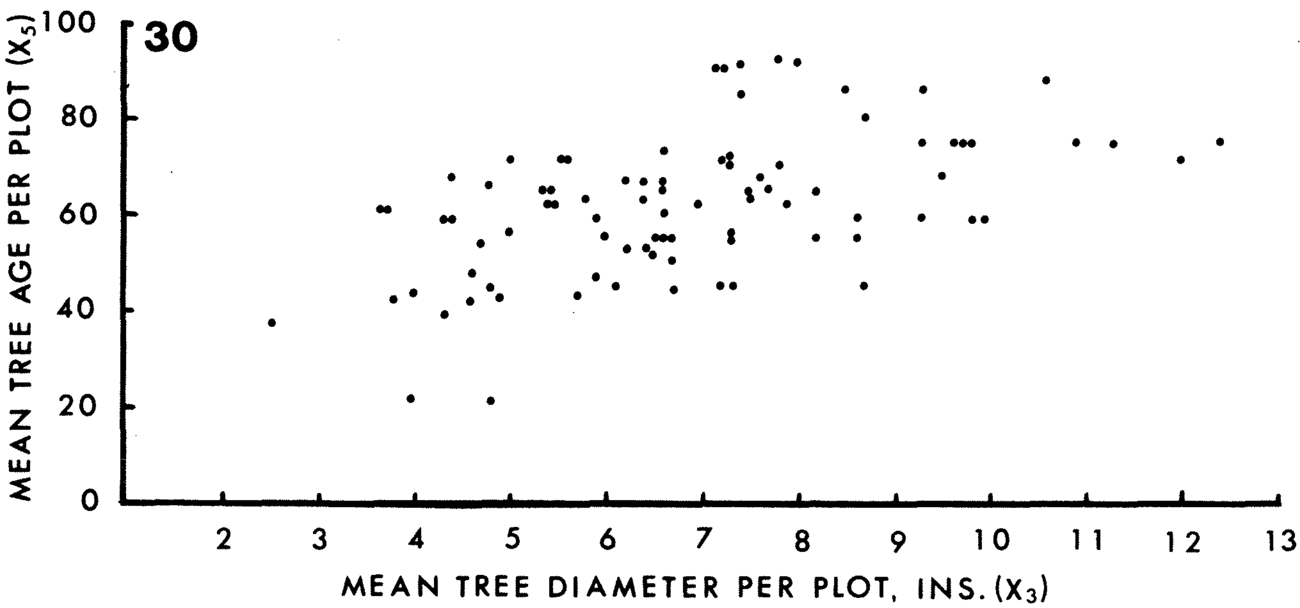


Fig. 30. Relation between lodgepole pine mean tree age per plot (X_5) and mean tree diameter per plot (X_3).

Tables 4 and 5 give the mean, standard deviation, and coefficient of variation for each X, Y, and X-interaction variables. The relative variability was highest for stand density which varied from 260 to 7560 stems per acre. Table 6 shows that all five X-variables and their interactions accounted for only 22.67% of the variability in Y_2, with an overall standard error of estimate ($S.E._E$) of $\pm$ 9.96. However, the regression was not significant at the .05 level. When Y_1 was tested against all X variables, their interactions, and Y_2, 53.81% of the variability of Y_1 was explained ($S.E._E = \pm 22.24$). Similarly, when Y_2 was excluded, 51.07% of the variability in Y_1 was explained ($S.E._E = \pm 23.45$). Regressions for both Y_1's were significant at the .01 level.

For each of the three regression analyses described in Table 6, the three most important variables were selected for all combinations and are summarized in Table 7. While all individual regressions were significant (at either .05 or .01 levels), X_3 was the single most important variable accounting for the variability in Y_1 and Y_2. This variable accounted for 10.64% of the variation in Y_2 and 40.41 to 40.55% of the variation in Y_1. It is suggested, therefore, that in surveys of weevil damage incidence, there appears little to be gained in accuracy of prediction by collecting data on variables other than on X_3. The equations expressing the relationship of Y_1 and Y_2 with X_3 are as follows:

1) $Y_1 = 3.12 + 9.00 X_3$ (n = 66)

2) $Y_1 = -9.83 + 10.28 X_3$ (n = 75)

3) $Y_2 = 3.88 + 1.77 X_3$ (n = 66)

These equations were used to calculate expected old and current attack percentages for tree diameter classes ranging from 1 to 10 ins. (Table

Table 4. Statistical characteristics of all Y, X and X-interaction variables measured in 66 lodgepole pine plots sampled for *H. warreni* attack incidence and abundance.

Variables	Mean	Standard deviation	Coefficient of variation (%)
Y_1 (% old attacks)	63.12	27.40	43.4
Y_2 (% current attacks)	15.70	10.51	67.0
X_1 (altitude-ft)	4143.94	5.82	14.1
X_2 (duff depth-ins.)	3.31	1.12	33.8
X_3 (tree diam-ins.)	6.67	1.93	29.0
X_4 (tree/acre)	960.91	96.49	100.4
X_5 (stand age-yrs)	60.77	16.29	26.8
X_3 X_4	1340.59	40.48	30.2
X_4 X_5	224.89	10.99	48.9
X_3 X_5	276.19	86.10	31.2
X_3 X_4 X_5	9083.75	407.95	44.9

Table 5. Statistical characteristics of Y_1, X and X-interaction variables measured in 75 lodgepole pine plots sampled for *H. warreni* attack incidence and abundance.

Variables	Mean	Standard deviation	Coefficient of variation (%)
Y_1 (% old attacks)	57.52	31.42	54.6
X_1 (altitude-ft)	4121.33	6.05	14.7
X_2 (duff depth-ins.)	3.35	1.24	36.9
X_3 (tree diam-ins.)	6.55	1.95	29.7
X_4 (trees/acre)	983.20	91.75	93.3
X_5 (stand age-yrs)	61.16	15.73	25.7
$X_3\ X_4$	1362.72	50.16	36.8
$X_4\ X_5$	224.53	11.57	51.5
$X_3\ X_5$	270.44	87.28	32.3
$X_3\ X_4\ X_5$	9120.17	451.91	49.6

Table 6. Multiple regression analyses of the relationship between percentage of trees with current (Y_2) and old (Y_1) H. warreni attacks and all X-variables given in Tables 4 and 5.

Dependent variable	Independent variables	No. of plot observations	$S.E._E$	R^2 (%)	F-value
Y_2	X_1 to X_3 X_4 X_5	66	± 9.96	22.67	1.824
Y_1	Y_2, X_1 to X_3 X_4 X_5	66	±20.24	53.81	6.407**
Y_1	X_1 to X_3 X_4 X_5	75	±23.45	51.07	7.54**

** Differences significant 1% probability level; entry without asterisk is not significant.

8). The classes represent the mean stem diameters of stands sampled throughout the Alberta foothills. The expected values are tentative until better models can be developed to predict weevil incidence.

DISCUSSION

The lack of weevils in pine stands above 5200 ft and the differences in attack patterns described for the B.19a and B.19c (Figs. 3-21; Table 3) suggest that a transitional change in weevil-habitat suitability occurs with increasing altitude. It is difficult to give specific reasons for this change but some explanations can be offered. Firstly, the topography of the B.19c is more rugged and undulating, and contains an increasing component of spruce species compared with the B.19a (Horton, 1956; Rowe, 1959). This would tend to give a greater range of site conditions in the B.19c as well as make pure pine types less extensive. Secondly, lower spring and summer temperatures at higher elevations may restrict adult-weevil activity (Cerezke, 1969) and increase the period of life cycle development (Nordic Forest Entomologists' Research Group, 1962).

Weevil numbers per tree and per acre (Table 2) may tend to be underestimated depending upon the experience of the samplers. This derives from two common sources of error; recognition of current feeding characteristics to locate small larvae in the presence of old feeding damage and familiarity with the placement of the pupal chamber. Additionally, the population figures given in Table 2 give no clue of population changes that occur within pine stands, so that damage may be more extensive in some years or periods of years than at other times.

Table 8. Predicted percentages of trees with old and current *Hylobius warreni* attacks calculated for lodgepole pine stands in the Alberta foothills having a mean stem diameter in the range from 1 to 10 inches.

Tree diameter class (ins. at stump ht.)	Percentage of trees with old attacks		Percentage of trees with current attacks
	Calculated from equation 1	Calculated from equation 2	
1	12.1	.5	5.7
2	21.1	10.7	7.4
3	30.1	21.0	9.2
4	39.1	31.3	11.0
5	48.1	41.6	12.7
6	57.1	51.9	14.5
7	66.1	62.1	16.3
8	75.1	72.4	18.0
9	84.1	82.7	19.8
10	93.1	93.0	21.6

Tree mortality from weevil feeding is uncommon in stands over 30 yrs old but common in stands less than 30 yrs (Cerezke, 1969). One reason may be that the more mature roots of older lodgepole pine may exhibit greater resistance to larval feeding. Also, on large trees, more larvae are required to girdle an amount equivalent to that on smaller trees. The percentage of tree mortality observed at location 47 (Fig. 1) may be significant only if they represented potential crop trees. In this stand, it is likely that early immigration of the weevil and its subsequent numerical increase were enhanced by the close proximity of a 'reservoir' population in the adjacent mature stand.

The multiple regression analyses showed that about half of the variability of Y_1 was accounted for by the five X-variables. It is unsafe to speculate what other factors may influence the relative success of the weevil. Some reduction in the variability inherent in the X-variables likely could be made if the sample size of trees per plot were increased. In the development of equations 1, 2, and 3, it was assumed that the dependent variables Y_1 and Y_2 were related rectilinearly to the X variables. Further data may reveal that this assumption was not justified; better predictive equations may thus be possible. The use of average tree diameter per plot (X_3) to predict the incidence of current attacks, and thus, the favorability of weevil sites, is less useful than for predicting percentage of old attacks.

One inference arising from the relation between the incidence of attack and mean tree diameter is that the weevil population within stands may be regulated to a degree by reducing the average tree diameter. This could be done most effectively by selective cutting. However, one danger resulting from this treatment is that the weevils remaining on the cut stumps may migrate to the residual trees. It is unknown at present whether a concentration of weevils on the residual trees would be only temporary, or whether severe damage would result. Similarly, it can be predicted that, in pine stands thinned to reduce the number of stems per acre in the smallest diameter classes, an increase in damage incidence and weevil density per tree will result. Such an effect was observed in two experimentally thinned plots (Cerezke, unpublished data).

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