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W.G.H. Ives and C.L. Rentz

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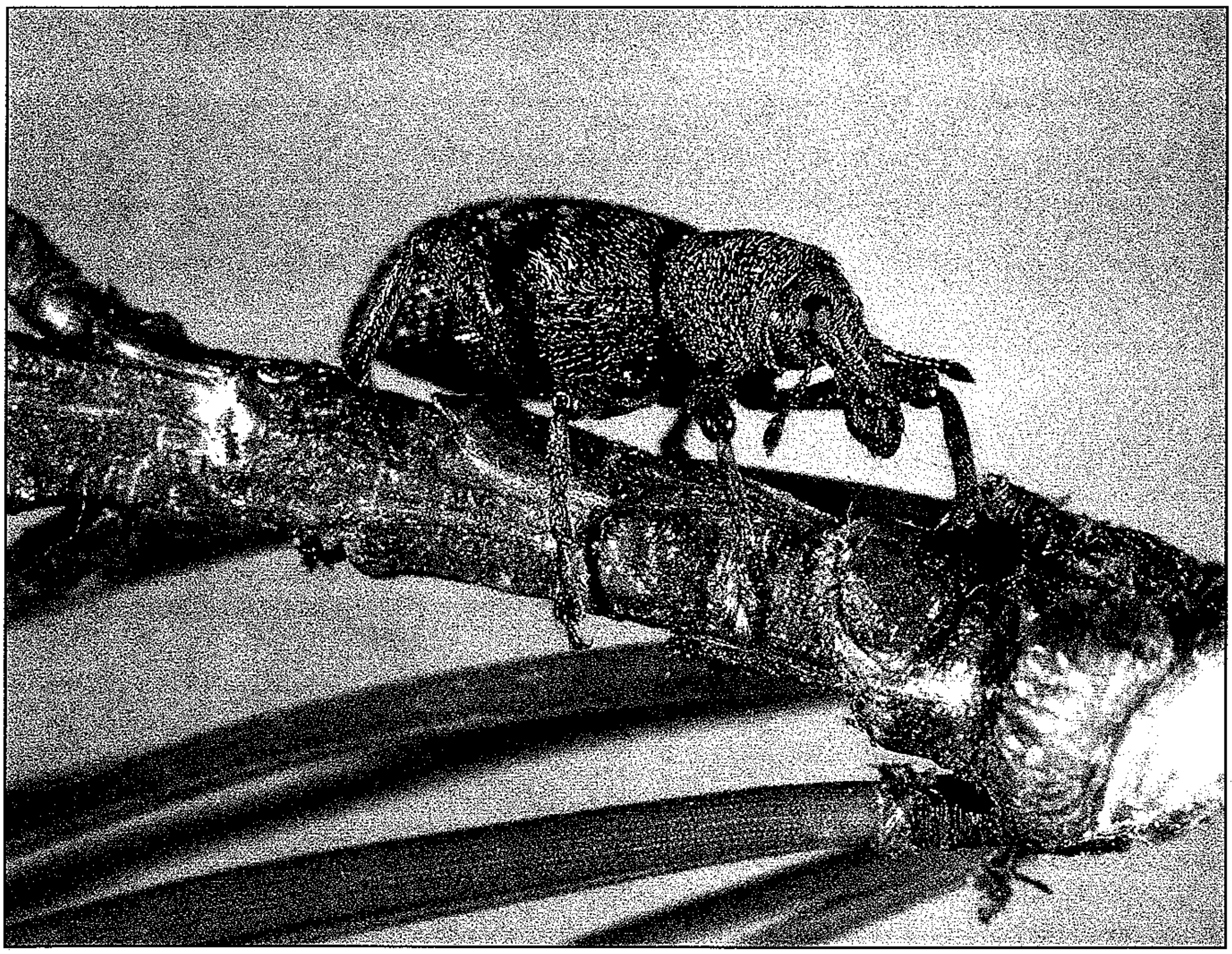

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ABSTRACT

Plots were established to monitor the survival of immature lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.) in over 70 cutover areas in the subalpine and boreal forest regions of west-central Alberta. A method for rating site productivity, based on weights assigned to soil associations, drainage classes, and elevations was used to group the areas into three productivity classes. Three-year survival rates spanning a 9-year period are given for most of the sampling areas, grouped according to site productivity. The major causes of mortality were rodents, western gall rust (*Endocronartium harknessii* [J.P. Moore] Y. Hiratsuka), Armillaria root rot (*Armillaria* spp.), Warren rootcollar weevil (*Hylobius warreni* Wood), blister rust (*Cronartium* spp.), browsing, blowdown, as well as undetermined causes. Mammal damage of all types and pitch blister moth (*Petrova albicapitana* [Busck] and *Petrova metallica* [Busck]) infestations were considerably higher in thinned stands. Armillaria root rot and the Warren rootcollar weevil caused more damage to dense stands.

RÉSUMÉ

Des parcelles de surveillance du taux de survie de jeunes pins tordus (*Pinus contorta* var. *latifolia* Engelm.) ont été établies dans plus de 70 parterres de coupe à blanc des régions forestières subalpine et boréale du centre-ouest de l'Alberta. Une méthode de classement de la productivité des stations, basée sur des coefficients de pondération attribués aux associations de sols, aux classes de drainage et à l'élévation, a servi à regrouper les parcelles dans 3 classes de productivité. Les taux de survie triennale, pendant une période de 9 ans, sont présentés pour la plupart des endroits échantillonnés, groupés selon la classe de productivité. Les principales causes de mortalité sont les rongeurs, la rouille-tumeur globuleuse du pin (*Endocronartium harknessii* [J.P. Moore] Y. Hiratsuka), le pourridié-agaric (*Armillaria* spp.), le charançon de Warren (*Hylobius warreni* Wood), la rouille-tumeur vésiculeuse (*Cronartium* spp.), le broutage, le déracinement par le vent, ainsi que d'autres causes indéterminées. Les dégâts attribuables aux mammifères et à des infestations de noduliers (*Petrova albicapitana* [Busck] et *Petrova metallica* [Busck]) sont beaucoup plus importants dans les peuplements éclaircis. Le pourridié-agaric et le charançon de Warren ont causé des dégâts plus importants dans les peuplements denses.

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INTRODUCTION

This study was initiated in an attempt to provide information on the factors responsible for mortality and damage to immature lodgepole pine, and to provide quantitative estimates of their impact on tree survival in the foothills of west-central Alberta.

Most of the naturally regenerated lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.) stands in the foothills of western Alberta are of fire origin (Smithers 1961), and some stands are dense or even stagnant. Many of these stands may eventually produce merchantable timber, but the rotation age will be extended because of slow growth. Early studies (Alexander 1960; Smithers 1961) have shown that thinning of dense pure young lodgepole pine stands, and mixed stands where intraspecific competition limits individual tree growth, results in a dramatic increase in diameter growth, but this may be at the expense of volume in stands where height repression is not a factor (Johnstone 1983; McCarter and Long 1986). The increased diameter growth has prompted some forest products companies to adopt thinning of dense lodgepole pine regeneration on cutover areas as a routine management practice in order to shorten rotation. The cost of these thinning operations continues to increase, however, and this cost is sometimes difficult to justify, primarily because there is a dearth of information on long-term quantitative assessment of the amount and causes of mortality occurring in young lodgepole pine stands. There is also some indication that the incidence of some of the pests affecting young pine may be influenced by stand density. Western gall rust (*Endocronartium harknessii* [J.P. Moore] Y. Hiratsuka) spreads from pine to pine (Hiratsuka 1987) primarily in young stands (Bella and Navratil 1988), and the infection rates may be greater in open stands (Bella 1985a, b). Similarly, the lodgepole terminal weevil (*Pissodes terminalis* Hopping), a serious pest in young stands, prefers trees on stand edges (Drouin et al. 1963) or unshaded terminals (Langor et al. 1992), and may be more abundant in open stands (Bella 1985a).

Life tables summarize the amount of mortality occurring during particular periods in an organism's life cycle. They have long been used by insurance companies to determine the average human life expectancy for various age groups, and were first used by entomologists to assess mortality factors influencing spruce budworm (*Choristoneura fumiferana* [Clemens]) populations (Morris and Miller 1954). They have since been used extensively in forest entomology (Morris 1963; Ives 1976) to study factors affecting insect populations.

Several workers have used life tables to study the demography of various annual and perennial plants, including grasses (Harper and White 1974). The procedure is very laborious, and there have been few attempts to utilize the technique for the assessment of mortality factors affecting forest trees. Waters (1969) first suggested using the life table approach to evaluate the impact of insects upon trees, and Morse and Kulman (1984) used life tables to assess mortality in young white spruce plantations. No other references to the use of life tables for studying tree mortality could be found. The current study, designed to monitor the survival of sample trees, is notable because it is the first major attempt to adapt the life table approach to the study of factors affecting tree mortality from the time of stand establishment to crown closure about 30 years later. The compilation of composite life tables from a conglomeration of data, representing various site and age classes, was the only feasible way of obtaining the necessary data in a relatively short period of time. Large samples were used to ensure valid results, and although some may question the approach used, there seemed to be no alternative. This report summarizes data collected between 1981 and 1990 and provides background information. The results show that a similar amount of mortaility (about 1%/year) occurred in most of the site and age classes studied, but the factors responsible were different.

MATERIALS AND METHODS

A preliminary selection of sampling areas was chosen using company maps and cutting records. The areas selected represented a variety of age classes in several compartments within Weldwood of Canada Ltd.'s Hinton Division Forest Management Area (Fig. 1). No suitable site productivity rating systems for cutover areas were available when the sampling areas were selected, but an attempt was made to select areas in each compartment representative of a variety of age classes. Selection criteria included: years since original stand was cut; accessibility; size and uniformity of cutover; and categories needed to fill gaps in age-class or compartment.

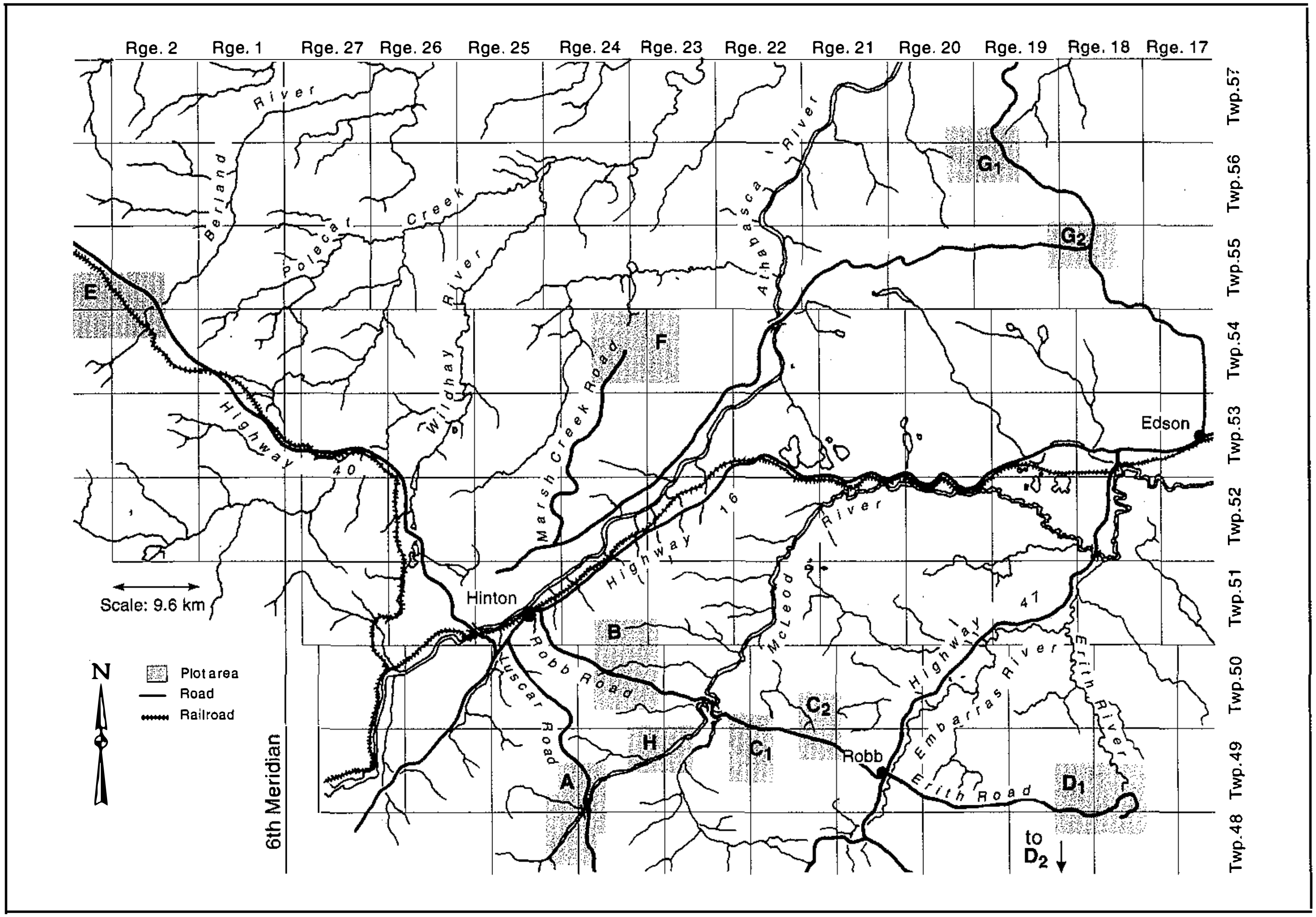

Figure 1. General locations of sampling areas established near Hinton, Alberta to monitor the survival of lodgepole pine regeneration in various compartments of Weldwood of Canada Ltd.'s Forest Management Area: A = McLeod II; B = McLeod IX; C1 and C2 = McLeod VI; D1 = Embarras III; D2 = Embarras I; E = Berland III; F = Athabasca XIX; G1 = Marlboro III; G2 = Marlboro VII; and H = McLeod VII. Note: details for boxed areas are given in subsequent figures.

Location of Sampling Areas

Plots were established between 1981 and 1989 in areas cut between 1956 and 1982 (Table la, b). All age classes were fairly well represented, as shown by the following breakdown: 8 areas were cut between 1956 and 1960; 20 between 1961 and 1965; 21 between 1966 and 1970; 16 between 1971 and 1975; and 8 between 1976 and 1982. There was inadequate representation of the early years because of the lack of accessability to sites; roads to several potentially suitable areas had either been permanently barricaded or were otherwise impassable. A limited number of plots in the 1976–82 age classes were established to provide ongoing representation in young stands.

The cutover areas were located in a number of compartments of the company's Forest Management Area (Fig. 1). The sampling areas were: McLeod II, 9 sites (Fig. 2); McLeod IX, 6 sites (Fig. 3); McLeod VI, 16 sites (1 with 3 lines of plots) (Fig. 4a, b); McLeod VII, 1 site (Fig. 5a); Embarras III, 3 sites (1 with 2 lines of plots) (Fig. 6); Embarras I, 1 site (Fig. 5b); Berland III, 7 sites (Fig. 7); Athabasca XIX, 17 areas (2 with 2 lines of plots each) (Fig. 8); Marlboro III, 4 sites (Fig. 9a); and Marlboro VII, 4 areas (Fig. 9b). There were more sites located in the McLeod VI and Athabasca XIX compartments because of accessability, quality, and variety of pine sites from which to select. Other compartments were not as well represented, but there was enough sampling to provide a good cross section of broad site classes, because a wide range of soil types and elevations were used (Table la).

A marker was positioned near an access road or trail to provide a reference point from which the bearing and distance to a stake marking a comer of the first plot could be measured. After all the plots had been established in an area, aluminum plates bearing pertinent information were prepared and bolted to the marker. Bearing and distance measurements were recorded. Posts were then driven at fixed intervals (usually 12.2 m) on a transect across the cutover area, to mark the left front comer (looking down the line of stakes) of temporary 10-m^2 square plots.

The numbers of trees (by species) and the predominant ground vegetation were recorded for those plots in which at least one lodgepole pine was present. Groups (up to 20) of dominant or codominant trees representing potential crop trees in and around each fixed-area plot, at a spacing approximating that used during thinning operations (about 2.5 $\times$ 2.5 m) were then painted and tagged. Double-numbered tags representing plots and trees were used. A tag indicating the plot number was nailed to the stake marking the comer of the fixed-area plot. The remaining tags in each series were used for identifying the selected trees in and around each fixed-area plot. Tree height and condition were recorded. The approximate location of each tagged tree was mapped for each plot.

The aspect of each sampling area was noted. Soil pits were dug in each area to determine the soil association and drainage class. An altimeter or topographic maps were used to determine elevation. A provisional site productivity rating for each area was determined (Table 1a). Trees were examined annually between mid-July and late August. Mortality was recorded and, if possible, the responsible agent. The condition of all tagged living trees was also noted.

Analytical Methods

An asymmetric matrix of computer readable symbols, corresponding to various combinations of damage symptoms, was used to code field-collected data on tree conditions for convenience of computer data entry and sorting. The notes on tree conditions were originally intended to provide information on the possible cause of death to trees that died during the study. In addition, the progress of various pest infestations through stands of different ages were recorded, specifying pests or damage[1]. The data were then sorted into two categories, present or absent, for each of the pests or damage. Statistical analysis of the data was relatively simple. The formulae appropriate to the estimation of proportions and their variances for data collected in groups (Cochran 1953) were used to calculate survival and infection rates, along with their 95% confidence limits.

Several groupings of data were used in preparing summaries of results. In the first grouping, the areas were sorted according to site productivity. There were no clear breaks in the scatter diagram (Fig. 10), and values were arbitrarily chosen that would break the data into three similar-sized groups. The groups were defined as follows:

low productivity—areas with an index $\leq$2.7;
medium productivity—areas with an index >2.7 but $\leq$3.7; and
high productivity—areas with an index >3.7.

[1] An establishment report listing all of the codes used is available from the author.

Table 1a. Areas selected in 1981–89 near Hinton, Alberta, to monitor the survival of young lodgepole pine regeneration

Area number	Cut area[a]	Year cut	Mean height[b] (metres)	Mean density[c] Pine	Conifers	Aspect[d]	Soil type[e]	Elevation (metres)	Drainage class	Site productivity rating
McLeod II compartment										
01	16	1960	3.04	4.28	5.19	Flat	JRV3	1310	2	2.0
02	27	1961	3.56	3.95	4.23	SSE	RBB1	1340	3	3.2
03	179	1965	1.52	14.53	15.88	ESE	RBB4	1540	3	2.1
04	182	1965	1.55	11.79	12.38	ENE	RBB1	1480	5	2.9
05	187	1967	1.06	11.85	16.28	Flat	JRV3	1400	2	2.0
06	188	1967	0.77	7.42	8.48	Flat	JRV3	1400	2	1.7
07	527	1968	0.74	8.66	8.66	Flat	JRV3	1310	3	2.4
08	562	1975	0.12	7.35	7.38	Flat	RBB1 + RBB3	1440	3	2.7
09	684	1980	0.39	11.46	11.49	Flat	RBB1	1480	3	2.4
McLeod VII compartment										
10[f]	104	1982	0.27	5.30	5.30	Flat	RBB1	1310	3	3.4
McLeod IX compartment										
11	8	1956	4.70	3.62	5.05	NW	MLB3	1370	3	2.6
12	23	1956	4.47	2.44	6.04	S	MLB3 + MLB3/T	1380	3-4	2.9
13	24	1956	4.55	1.31	2.25	Flat	MLB3 + MLB3/T	1395	3	2.5
14	244	1972	0.55	11.25	11.25	Flat, E	MLB2	1300	3	2.5
15	245	1972	0.39	4.50	4.53	W to NW	MLB2	1290	3	2.6
16	246	1972	0.35	4.82	4.84	Flat	MLB2	1285	4	3.1
McLeod VI compartment										
21	43	1964	2.78	4.58	4.84	N to NW	RBB1	1310	3	3.4
22	56	1964	2.55	5.71	8.53	N	RBB1	1310	3	3.4
23	57	1964	2.58	5.30	6.22	Flat	MLB4	1295	3	3.5
24	119	1962	2.43	4.70	12.14	E	RBB1	1250	3	3.8
25	120	1962	2.17	5.56	6.11	E	RBB1	1235	3	3.9
26	139	1961	2.44	5.56	6.11	S	RBB1	1280	3	3.6
27	165	1963	2.87	4.39	6.42	N	MLB6 + MLB6/T	1160	3	4.3
28	189	1970	1.52	12.71	13.57	E to SE	MLB6 + MLB6/T	1235	4	4.7
29	189	1970	1.21	6.70	9.93	Valley	MLB6 + MLB6/T	1220	4	4.8
30	189	1970	1.43	7.55	8.45	Ridge	MLB6 + MLB6/T	1235	4	4.7
31	209	1966	2.07	8.04	8.13	NE and SW	RBB1	1295	3	3.5
32	214a	1973	0.27	6.57	6.69	Flat, N to NE	RBB1	1305	4	4.2
33	215	1971	0.58	5.56	6.49	N to NE	RBB1	1305	4	4.2
34	528	1969	1.51	13.96	14.36	Flat, SE	RBB1	1235	3	3.9
35	534	1969	1.46	4.60	4.65	S	RBB1	1310	3	3.4
36	536	1969	1.96	5.27	5.91	N	RBB1	1325	5	4.0
37	537	1969	1.96	4.10	5.70	NE	RBB1	1310	3	3.4
38[f]	696	1981	0.74	32.42	32.60	Flat	MLB6	1160	3	4.3
Embarras III compartment										
41	9	1960	4.63	2.38	2.62	Flat	MLB6	1130	4	4.5
42	18	1973	0.56	11.93	13.65	Flat	MLB6	1130	4	4.5
43[g]	27	1974	0.41	10.63	10.89	Flat	BKM3	1130	4	4.5
44[g]	27	1974	0.40	19.28	19.28	Flat	BKM3	1130	4	4.5
Embarras I compartment										
45[f]	39	1981	0.63	7.56	8.28	S	RBB1 + MSK1	1280	3	

Table 1a. Concluded

Area number	Cut area[a]	Year cut	Mean height[b] (metres)	Mean density[c] Pine	Conifers	Aspect[d]	Soil type[e]	Elevation (metres)	Drainage class	Site productivity rating
Athabasca XIX compartment										
51	26	1964	2.01	2.21	2.31	Flat, NW	MLB6	1295	5	4.2
52	33	1964	2.36	3.18	4.97	Flat, NE	MLB6	1265	3	3.2
53	34	1964	2.53	17.64	18.00	NNE	MLB5	1250	4	4.5
54	34	1964	2.98	12.00	12.18	NNE	MLB5	1250	4	4.5
55	36	1964	2.32	3.45	3.67	Flat, E	MLB6	1250	3	3.8
56	61	1964	2.32	10.79	10.87	Flat, rolling	MLB5	1315	3	3.4
57	61	1964	0.74	10.80	12.00	Flat	MLB5	1310	3	3.4
58	113	1967	1.28	5.86	13.78	Flat, W	MLB6/S	1355	3	3.2
59	133	1969	1.33	11.77	14.33	W	MLB5	1265	4	4.5
60	173	1968	1.24	9.34	10.03	Hillcrest	MLB6/S (MLB5)	1335	4	3.9
61	176	1969	0.99	9.95	11.08	Rolling	MLB5	1325	4	4.0
62	555	1969	1.07	9.11	9.14		MLB6 (MLB5)	1295	3	3.5
63	601	1972	0.46	17.59	17.59	Flat, gullies	MLB6	1280	3	3.6
64	624	1972	0.49	13.02	13.02	Flat, S	MLB6	1310	3	3.4
65	633	1972	0.47	15.26	15.26	Ravine	MLB6	1305	3	3.5
66[h]	611	1977	0.17	10.48	10.48	Flat	HRT(BKM)	1245	2	2.6
67[h]	629	1976	0.30	26.60	27.08	Flat	MLB5	1310	3	3.4
68[i]	609	1978	0.21	13.13	13.23	Flat	MLB6	1280	3	3.6
69[i]	661	1977	0.36	11.23	11.23	Flat	MLB6/S	1355	5	3.8
Berland III compartment										
71	15	1959	2.62	3.77	4.45	S	RBB1	1525	3	2.3
72	C15	1970	0.47	4.80	4.80	SW	RBB1	1510	3	2.3
73	C23	1970	0.37	2.51	2.54	Flat	JRV3	1450	2	1.5
74	33	1962	2.05	4.35	4.43	Flat/crest	MLB6	1465	3	2.5
75	41	1961	2.44	4.18	4.30	NE and NNE	MLB6	1430	3	2.7
76	501	1973	0.20	12.22	12.02	N and E	MLB6	1430	3	2.7
77	514	1973	0.21	8.49	9.00	Flat, S	RBB1	1530	3	2.2
Marlboro VII compartment										
81	2	1958	3.89	5.03	5.24	Flat	MBN2/S/T	1030	3	5.1
82	7	1958	5.43	3.88	4.36	Ridge top	MBN2	1030	3	5.1
83	530	1971	0.96	11.21	11.21	Flat	MBN2	1030	3	5.1
84	567	1972	0.57	8.32	8.32	Flat	MBN1/SRBB1	1050	3	5.0
Marlboro III compartment										
85[g]	51	1965	1.52	8.21	9.39	Flat	MBN3/S	1355	3	3.2
86[g]	61	1970	0.94	10.36	13.05	Flat	MBN3/S	1390	3	2.9
87[g]	67	1970	0.79	6.76	8.47	Flat	MBN3/S	1400	3	2.9
88[g]	78	1969	0.80	12.93	14.80	Flat	MBN3/S	1400	3	2.9

[a] Company designated numbers.

[b] Mean height of tagged trees at a spacing approximating that following thinning.

[c] Mean density of lodgepole pine and total conifers in 10 m temporary positive plot established to right and beyond plot post.

[d] N = north; S = south; E = east; W = west.

[e] JRV = Jarvis; RBB = Robb; MLB = Marlboro; MSK = Maskuta; HRT = Heart; BKM = Blackmud; MBN = Mayberne.

[f] Plots established in 1989.

[g] Plots established in 1982.

[h] Plots established in 1983.

[i] Plots established in 1984.

Table 1b. Plot information for sampling areas selected to monitor the survival of young lodgepole pine regeneration

Area number	Bearing to first plot[a] (degrees)	Distance to first plot[a] (metres)	Bearing of post line (degrees)	Number positive plots[b]	Number negative plots	Post locations with negative plots[c]	Remarks
McLeod II compartment							
01	350	22.9	23	34 (32)	6	4, 7, 13, 15–17	Thinned August 1977
02	260	18.3	260	34 (34)	3	2, 5, 8	Thinned July 1977
03	78	12.2	78	34 (32)	3	8, 9, 36	First 12 plots thinned fall–winter 1985–86
04	90	24.4	90	34 (34)	1	21	
05	142	15.2	210	40 (39)	0		
06	144	23.8	205	33 (31)	7	6, 8, 20, 23, 33, 37, 38	
07	298	61.0	38	37 (35)	3	26, 33, 40	
08	244	137.2	285	37 (37)	4	36, 38–40	
09			340	39 (39)	1	25	L-M[d] winter browning
McLeod VII compartment							
10[e]			44	20 (20)	5	11, 12, 14, 20, 21	L-M winter browning
McLeod IX compartment							
11	212	23.8	295	23 (21)	17	8, 10, 11, 18, 22–30, 32, 36–38	
12	70	25.9	108	27 (27)	6	17, 18, 23, 29, 31, 32	Bearing change to 86° at post 15
13	360	30.5	304	16 (16)	24	1, 3, 6–8, 14–19, 21, 23, 25, 27–29, 31–34, 35–37, 40	Areas 12 and 13 thinned August 1979
14	70	21.0	94	36 (36)	1	16	T-post not near road
15	110	24.4	310	30 (30)	10	11, 14 ,18, 19, 23, 25, 27, 28, 37, 38	
16	186	18.9		33 (33)	7	8, 10, 12, 28, 33, 35, 37	
McLeod VI compartment							
21	144	26.8	80	31 (31)	9	3, 4, 6, 7, 9, 10, 13, 26, 30	Thinned June 1978
22	38	44.2	38	35 (34)	5	19, 24, 27, 29, 39	Thinned May 1978
23	27	61.0	98	36 (36)	4	10, 28, 30, 40	Thinned June 1978
24	200	30.5	290	21 (21)	19	2, 4, 6, 9, 11, 12, 17, 18, 19, 22, 24, 25, 26, 28, 30, 31, 35, 36, 38	No plot 9 tags, severe hail damage
25	220	30.5	295	23 (22)	11	12, 15, 20, 22–24, 26, 31, 32, 35, 36	No plot 21 or 22 tags, severe hail damage
26	325	12.2	325	18 (18)	2	12, 17	Tag numbers 21–28 used
27	61	45.7	25	31 (31)	5	3, 21, 24, 27, 29	Areas 26 and 27 thinned May 1979
28	37	87.2	118	28 (28)	1	18, 26	
29	37	120.7	118	27 (27)	3	7, 19, 23	
30	37	163.4	118	22 (22)	8	6, 9, 10, 21, 24, 26–28	
31	164	21.9	258	23 (23)	17	15, 17–21, 23, 25, 26, 28–30, 32, 35, 36, 38, 40	
32	332	12.2	330	26 (26)	14	11, 13, 18, 19, 25, 27, 29–34, 38, 40	Bearing change to 324° at post 21
33	200	30.5	130	39 (39)	1	30	
34	360	30.5	110	25 (25)	0		Severe hail damage
35	298	12.2	298	20 (20)	0		Tags 21-40 used
36	155	15.2	155	23 (22)	17	2, 4, 5, 12–17, 20, 21, 27, 32, 34, 35, 37, 39	
37	22	42.7	50	20 (20)	20	10–14, 21–25, 28–34, 37–39	
38[e]	138	201.0	318	40 (40)	0		24.4 m between plots 16 and 17
Embarras III compartment							
41	156	15.2	132	29 (29)	11	4, 5, 8, 12, 14, 16, 17, 20, 21, 32, 38	Thinned August 1980
42	232		323	40 (40)	0		
43[f]	328	36.6	50	19 (19)	0		
44[f]	200	9.1	120	21 (21)	1		Tags 20-40 used
Embarras I compartment							
45[e]	240	77.0	150	32 (32)	8	6, 12–15, 27, 29, 33	Trace winter browning

Table 1b. Concluded

Area number	Bearing to first plot[a] (degrees)	Distance to first plot[a] (metres)	Bearing of post line (degrees)	Number positive plots[b]	Number negative plots	Post locations with negative plots[c]	Remarks
Athabasca XIX compartment							
51	262	20.1	334	30 (29)	10	7, 8, 22, 24, 25, 29, 34, 37, 39, 40	Thinned May 1981
52	66	36.0	48	21 (21)	6	23, 26, 32, 34, 36, 38	Thinned January–March 1981
53	32	26.2	340	17 (17)	3	2, 12, 15	Areas 53 and 54 thinned fall–winter 1984–85
54	340	12.8	14	17 (17)	3	7, 12, 19	Tags 21–40 used, bearing change to 340° at post 16
55	270		230	33 (33)	7		Thinned January–March 1981
56	100	22.9	180	38 (38)	2	19, 20	Areas 56 and 57 thinned fall–winter 1984–85
57	102	9.1	75	35 (35)	2	3, 33	
58	270	35.1	180	36 (36)	4	10, 33, 37, 40	
59	84	16.5	60	39 (39)	1	10	
60	350	55.5	52	33 (33)	2	7, 33	
61	270	11.6	250	37 (37)	3	22, 31, 39	
62	292	19.8	330	35 (35)	5	7, 15, 16, 31, 38	
63	210	47.5	280	32 (32)	8	3, 15, 16, 34, 36, 38–40	Thinned fall–winter 1984–85
64	160	22.9	160	38 (37)	1	16	
65	23	23.8	258	38 (38)	2	35, 37	
66[g]	271	65.5	8	25 (25)	0		
67[g]	44	44.2	17	25 (25)	0		
68[h]	4	24.4	57	36 (35)	4	14, 15, 16, 21	
69[h]	180	18.3	231	33 (31)	0		
Berland III compartment							
71	43	38.4	110	36 (35)	4	4, 12, 15, 22	Thinned May 1981
72	26	28.3	10	35 (35)	4	8, 9, 11, 31	
73	240	32.9	310	37 (37)	3	2, 35, 36	Planted
74	80	18.3	80	40 (40)	0		Thinned July 1980
75	170	39.6	170	33 (33)	7	4, 5, 19, 26, 28, 30, 33	Thinned September 1980
76	242	29.3	230	36 (36)	4	7, 8, 16, 31	
77	52	31.1	136	33 (33)	8	10, 11, 24, 25, 31, 34, 36, 37	Bearing change to 140° at post 4
Marlboro VII compartment							
81	360	48.8	10	34 (34)	6	3, 15–18, 30	Thinned August 1978
82	330	12.8	324	33 (33)	7	28, 29, 34, 37–40	Plots 1–8 thinned August 1977
83	360	30.2	7	33 (33)	7	5, 33, 35–39	Bearing change to 354° at post 26
84	220	36.6	194	34 (34)	6	27, 28, 30, 32–34	
Marlboro III compartment							
85[f]	88	41.1	33	29 (28)	11	4, 8, 12, 16, 19, 33, 35–39	
86[f]	24	82.3	20	33 (33)	7	13, 14, 25, 26, 30, 32, 35	
87[f]	66	24.7	347	34 (34)	6	2, 7, 8, 13, 18, 38	
88[f]	70	44.5	70	40 (40)	0		

[a] Bearing and distance from metal T-post to first post marking plot locations.

[b] Information on number of trees in some stocked quadrats not recorded: numbers in parentheses used to calculate stand density.

[c] Posts marking plot locations were placed at uniform spacings (usually 12.2 m) but were not numbered if plot was negative.

[d] L-M = light to moderate.

[e] Plots established in 1989.

[f] Plots established in 1982.

[g] Plots established in 1983.

[h] Plots established in 1984.

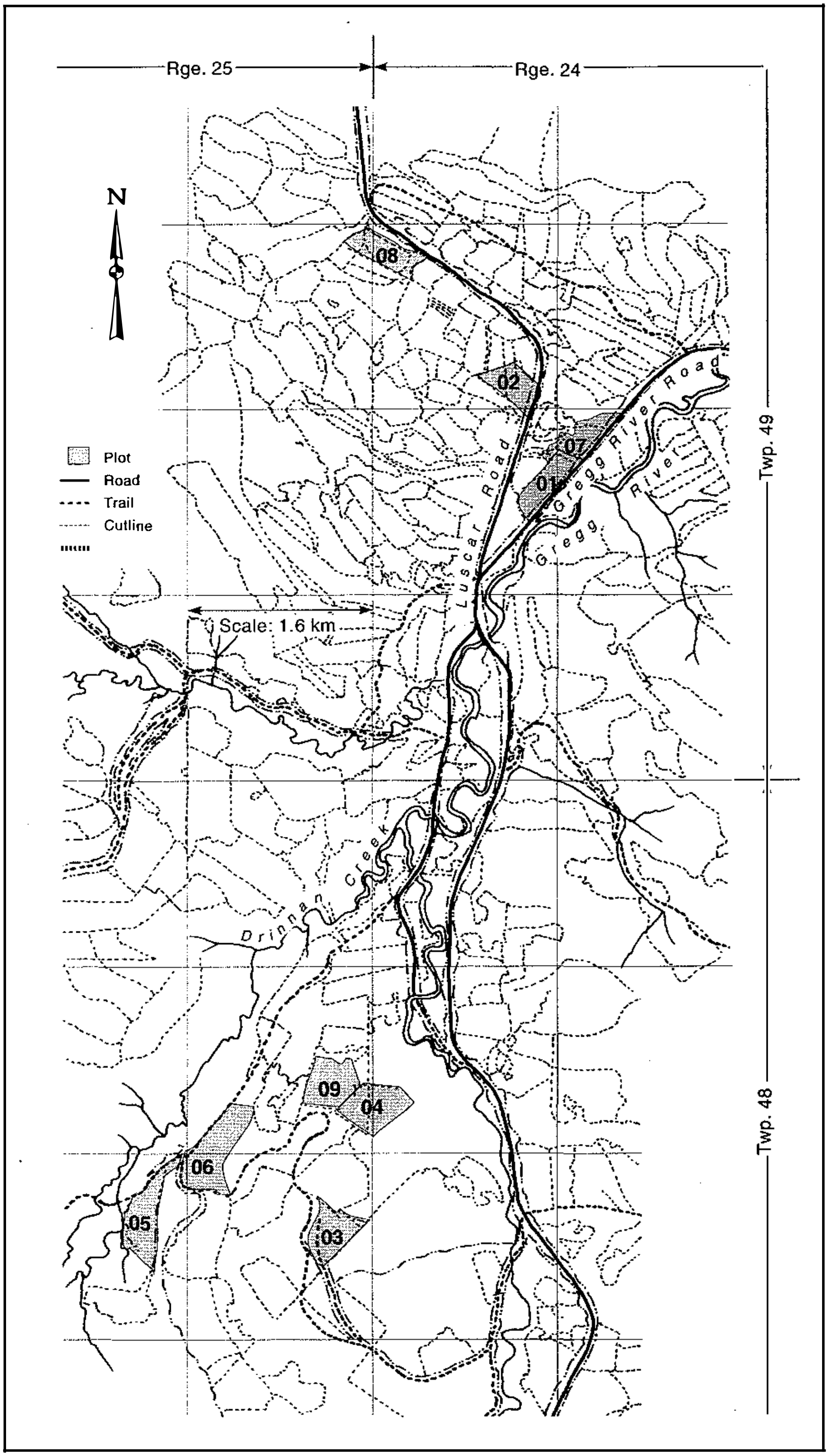

Figure 2. Detailed locations of sampling areas 01–09 in the McLeod II compartment.

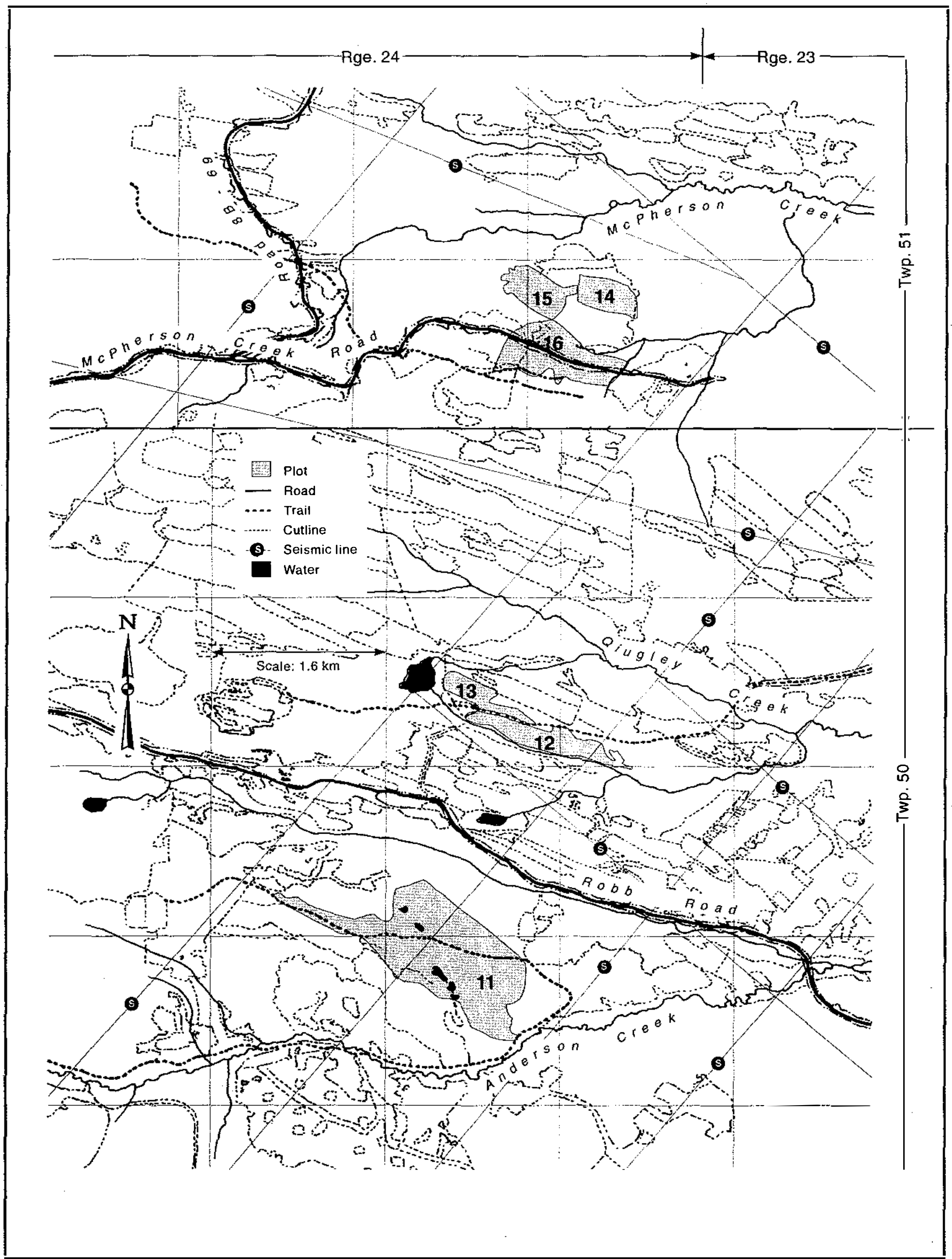

Figure 3. Detailed locations of sampling areas 11–16 in the McLeod IX compartment.

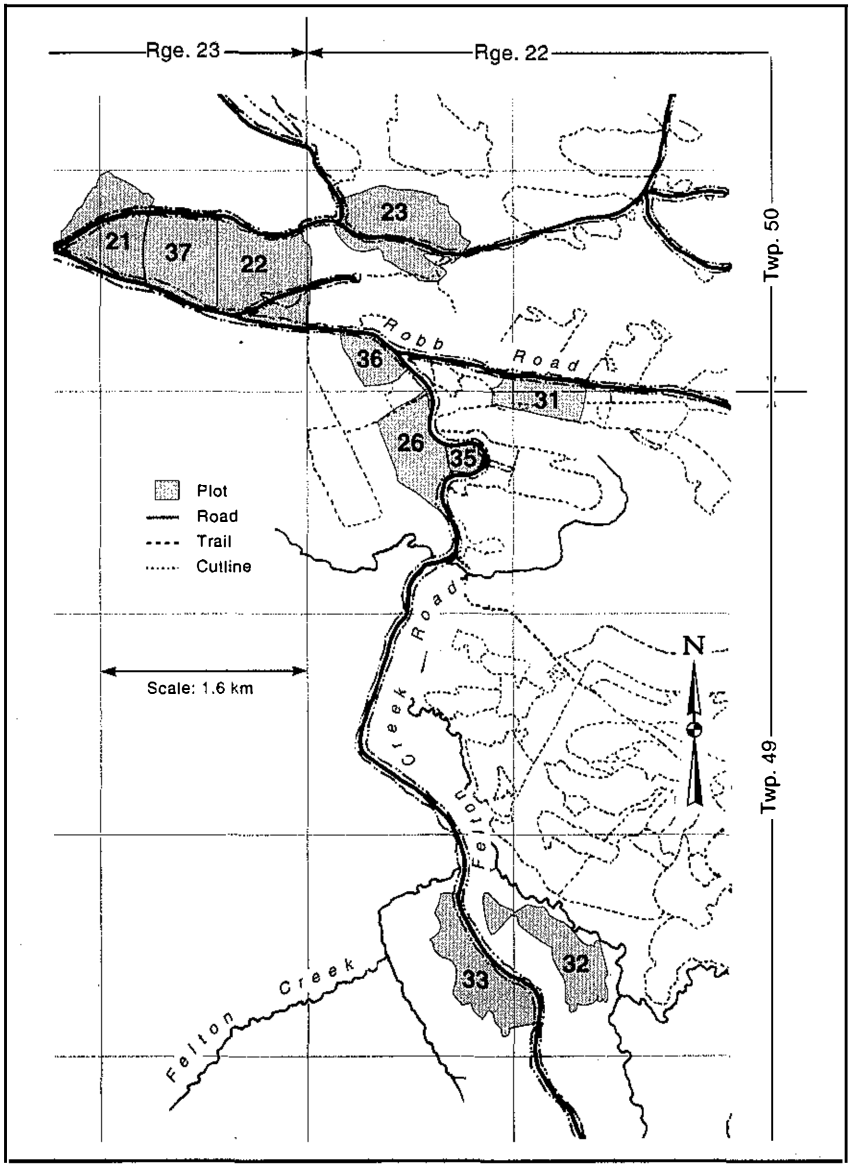

Figure 4a. Detailed locations of sampling areas, 21, 22, 23, 26, 31, 32, 33, 35, 36, and 37 in the McLeod VI compartment.

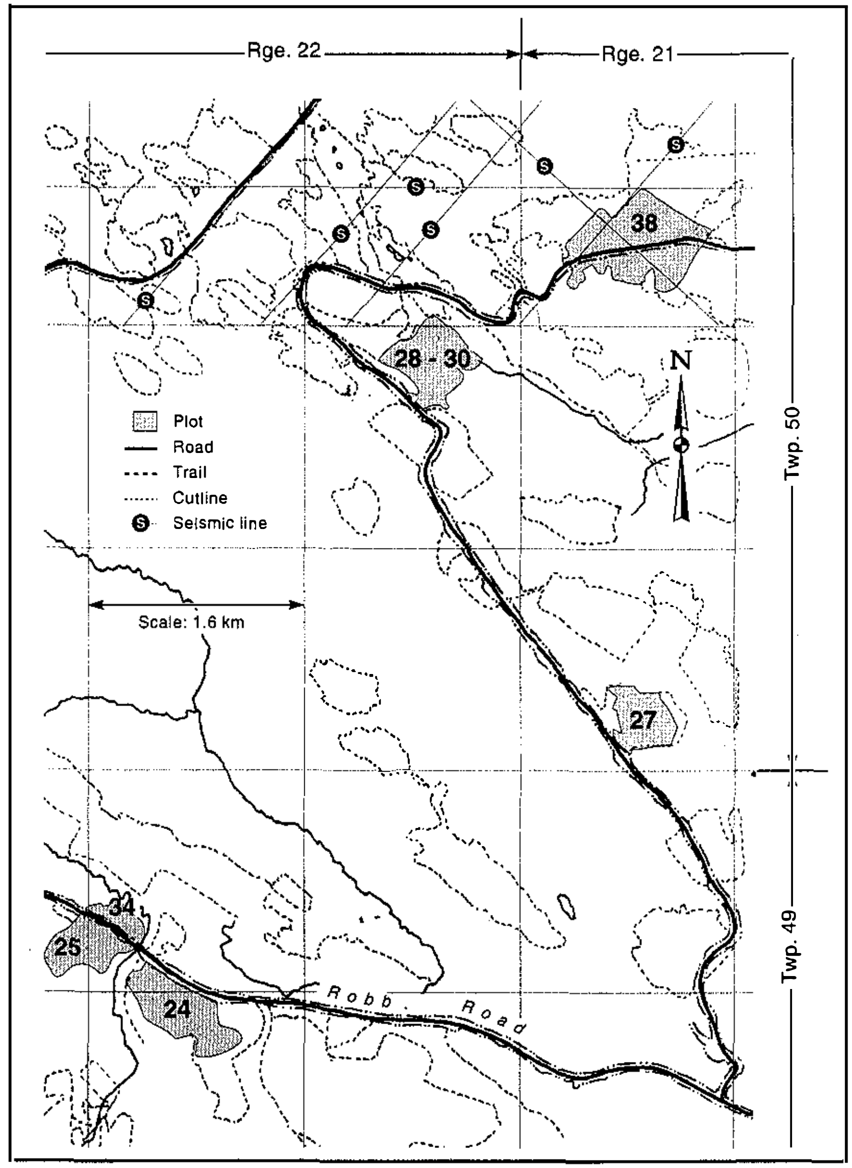

Figure 4b. Detailed locations of sampling areas, 24, 25, 27, 28, 29, 30, 34, and 38 in the McLeod VI compartment.

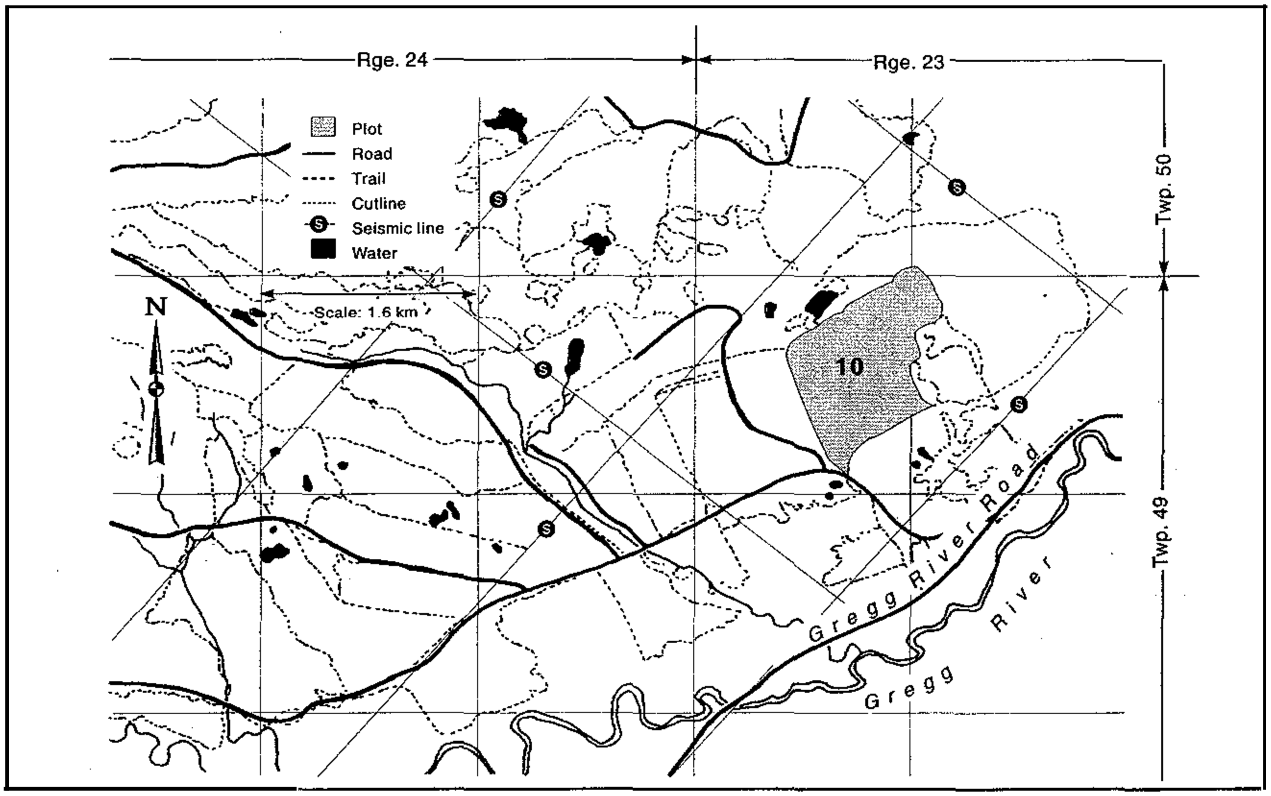

Figure 5a. Detailed location of sampling area 10 in the McLeod VII compartment.

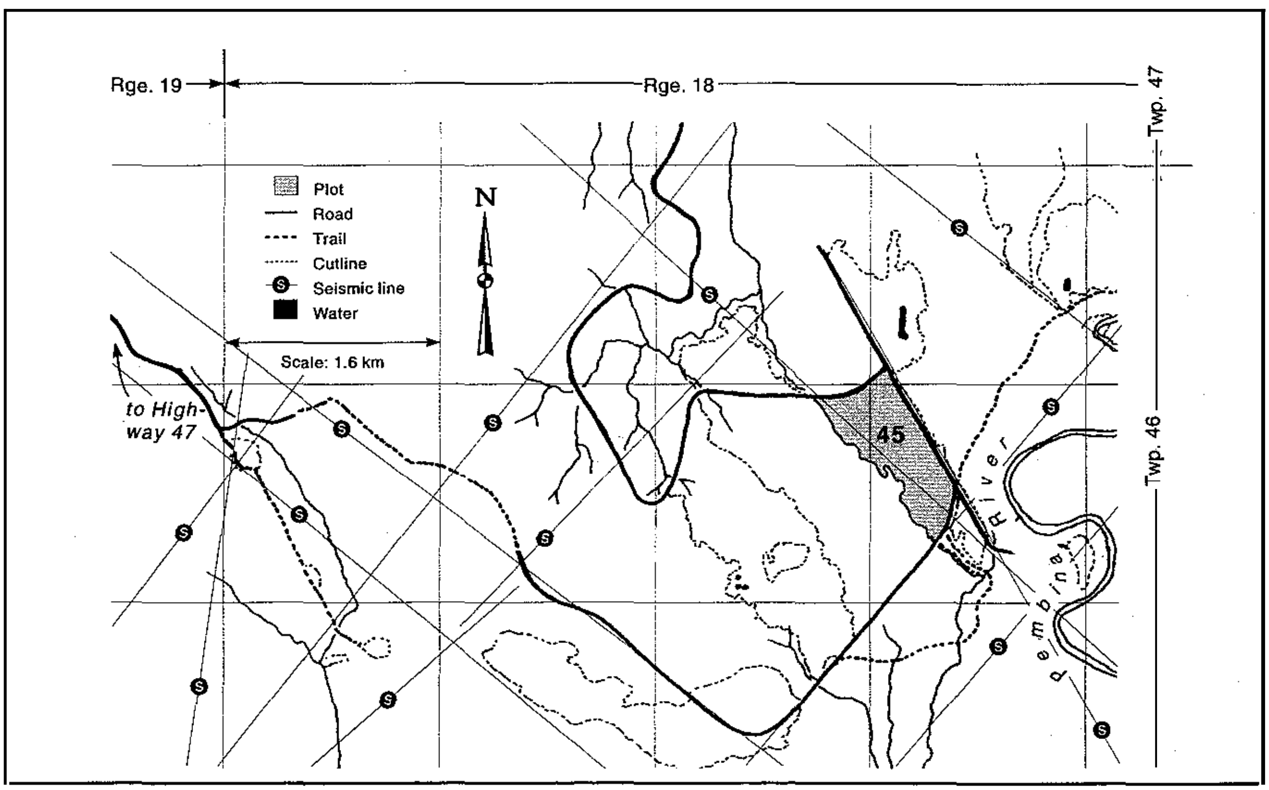

Figure 5b. Detailed location of sampling area 45 in the Embarras I compartment.

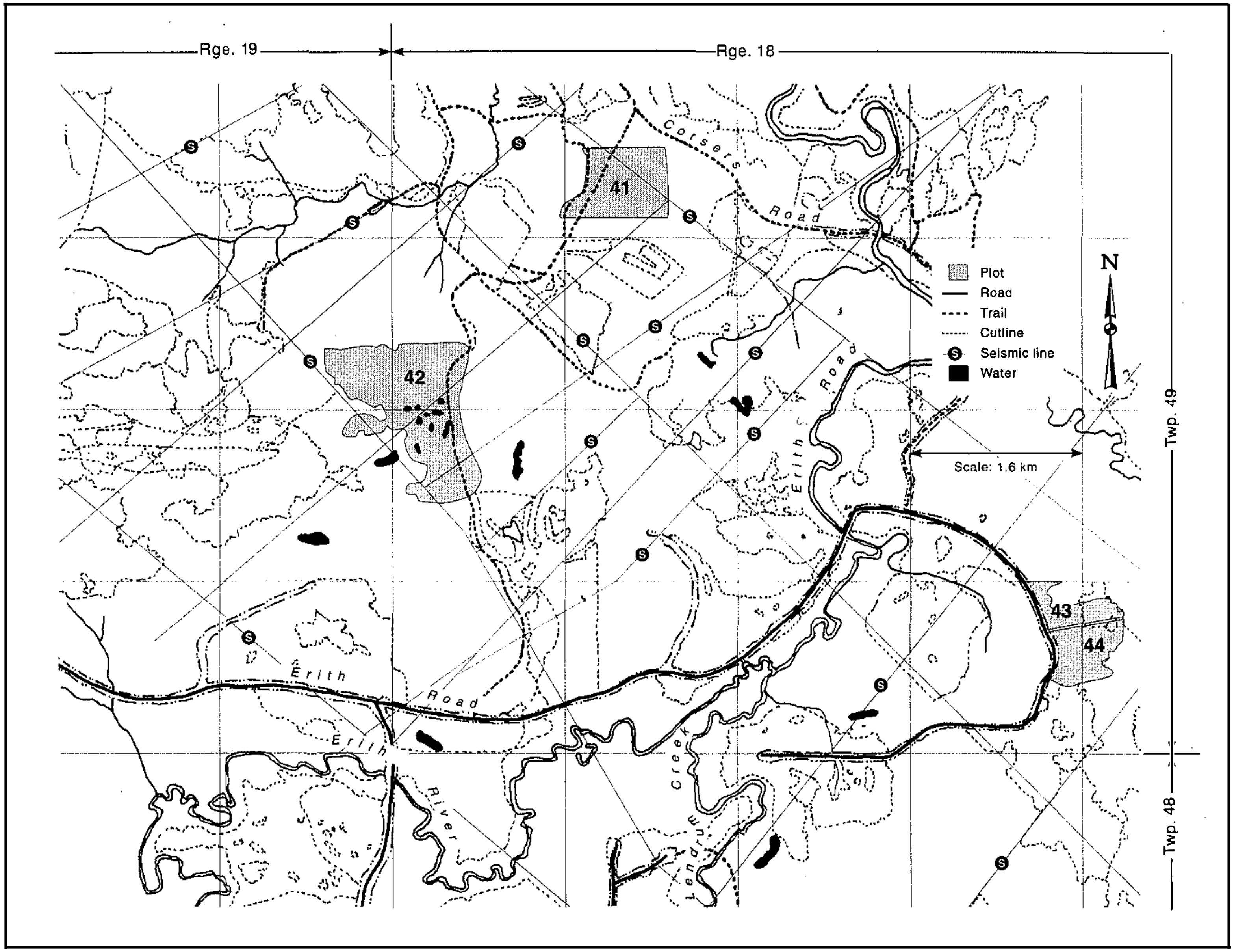

Figure 6. Detailed locations of sampling areas 41–44 in the Embarras III compartment.

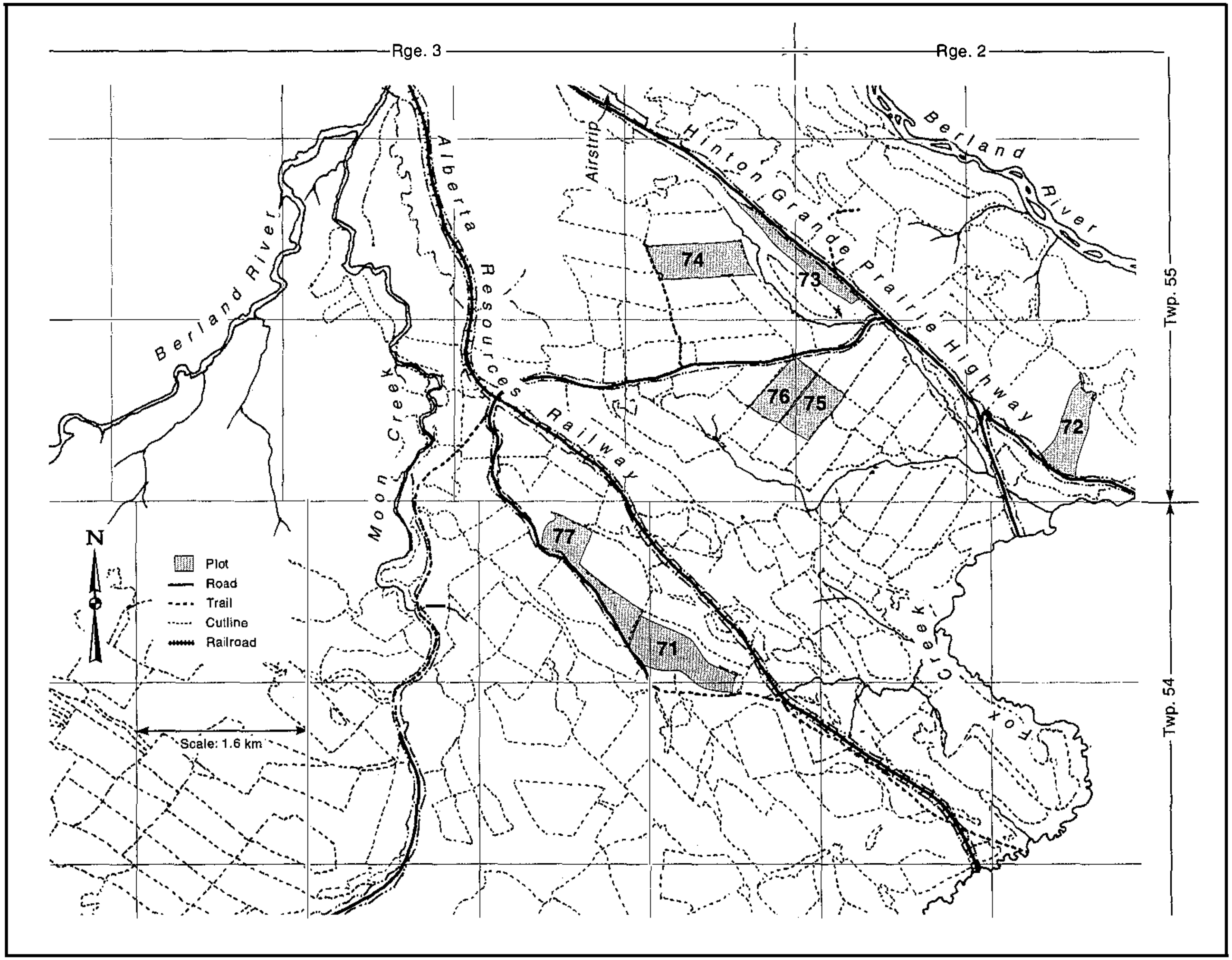

Figure 7. Detailed locations of sampling areas 71–77 in the Berland III compartment.

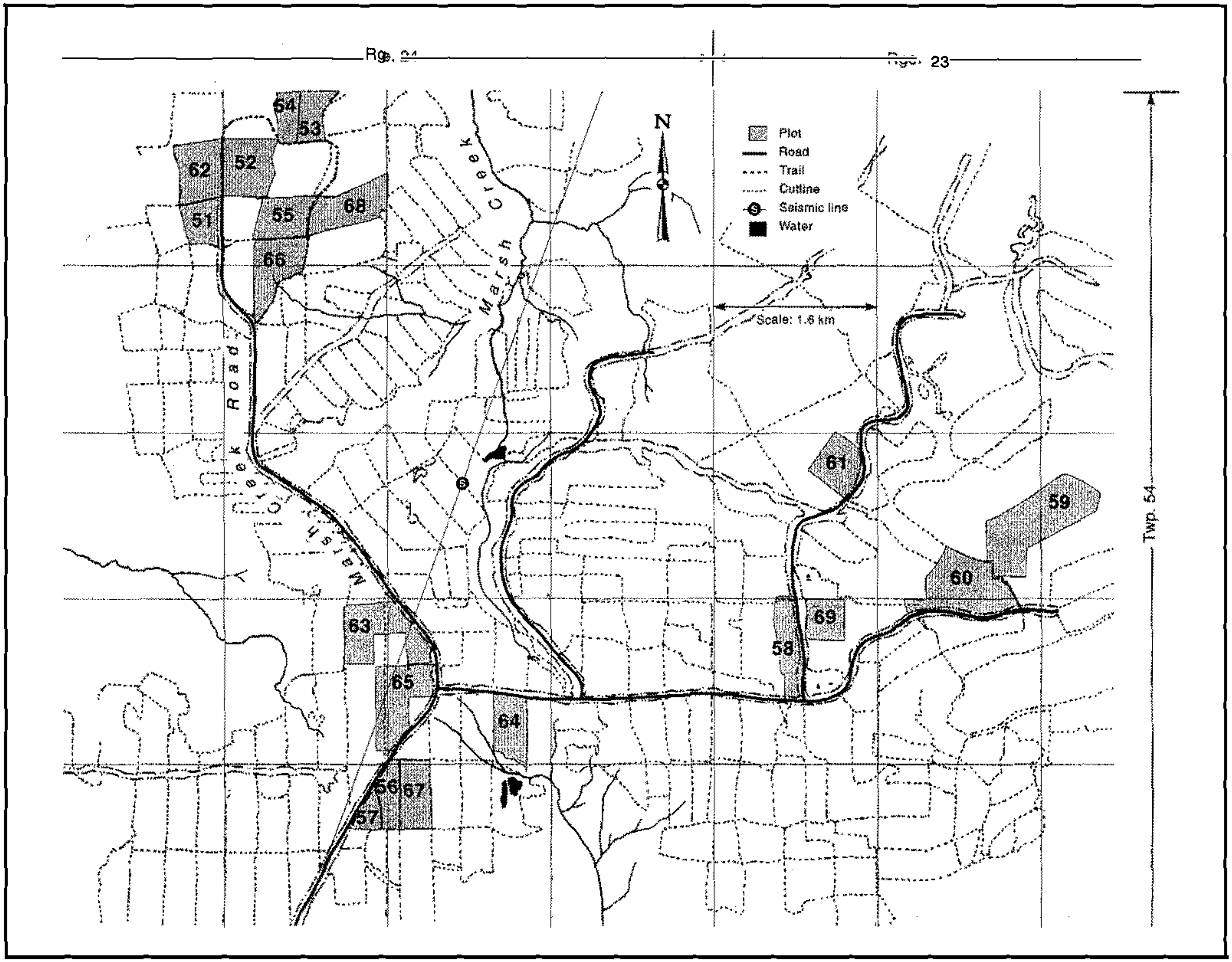

Figure 8. Detailed locations of sampling areas 51–69 in the Athabasca XIX compartment.

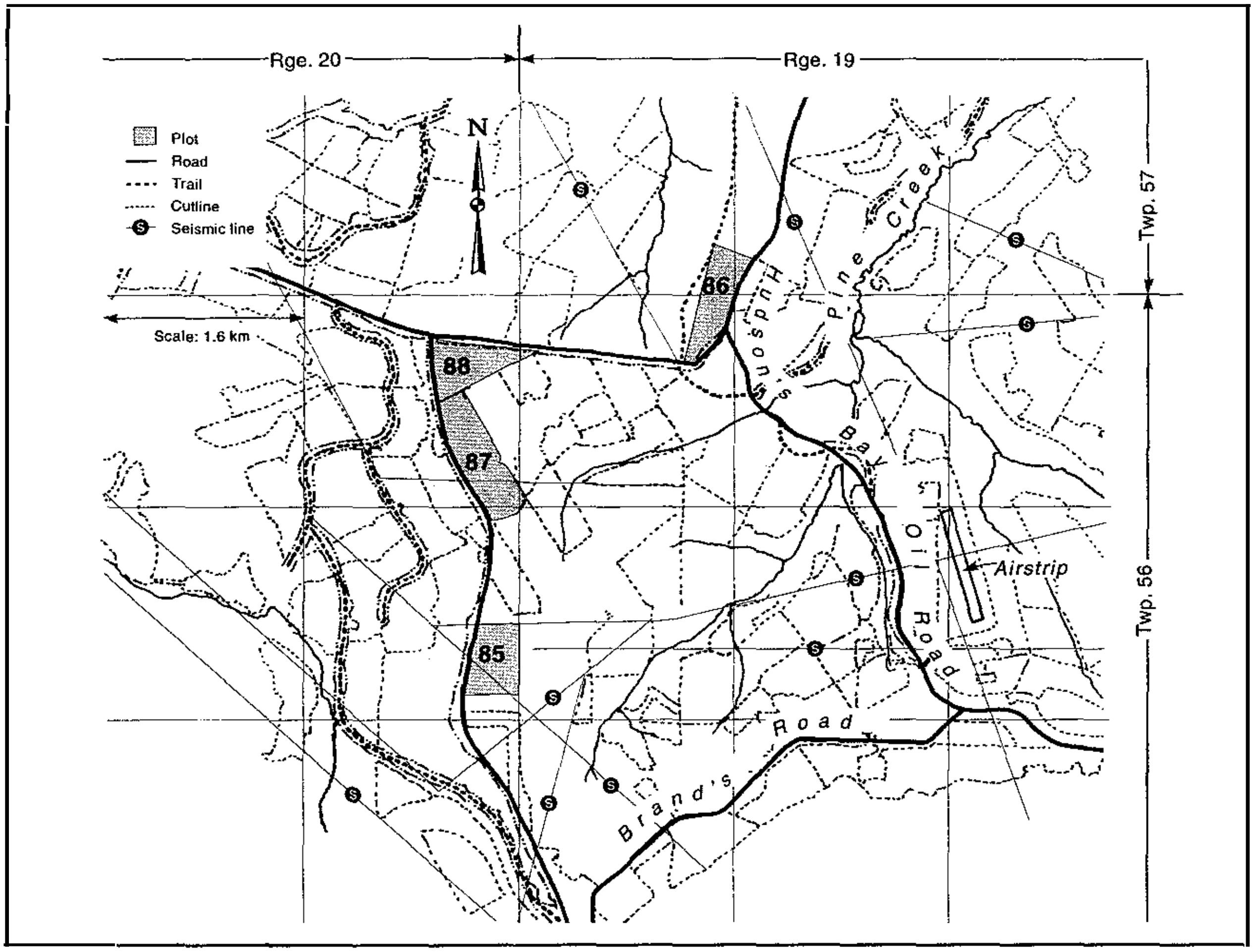

Figure 9a. Detailed locations of sampling areas 85–88 in the Marlboro III compartment.

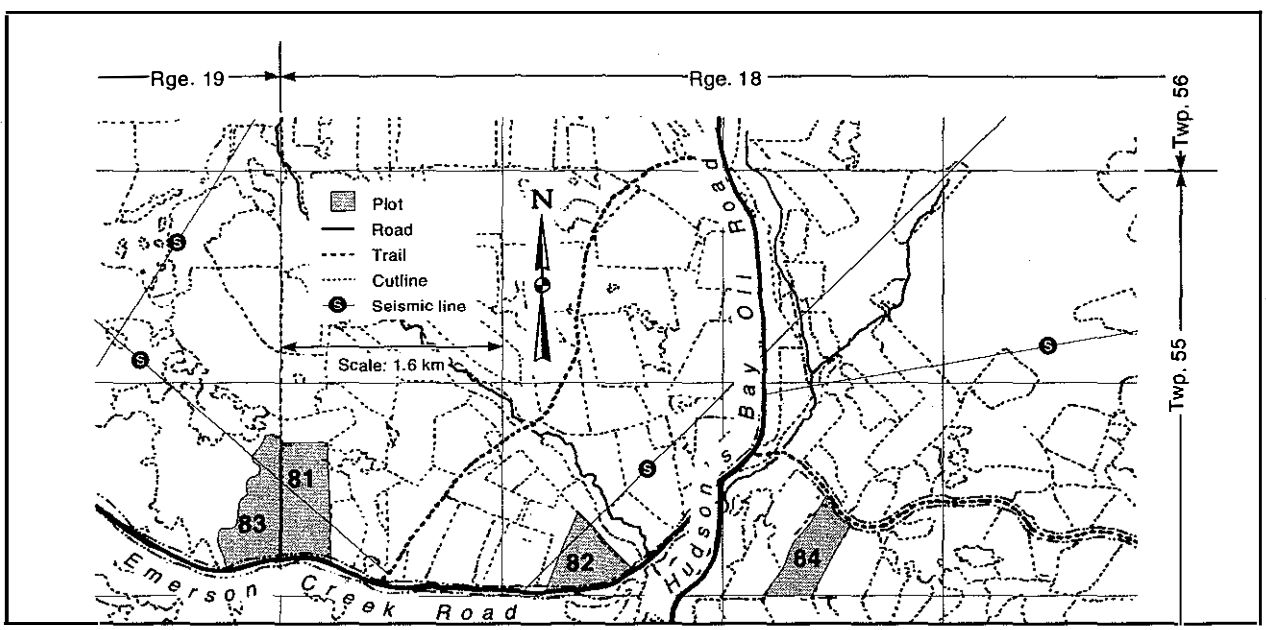

Figure 9b. Detailed locations of sampling areas 81–84 in the Marlboro VII compartment.

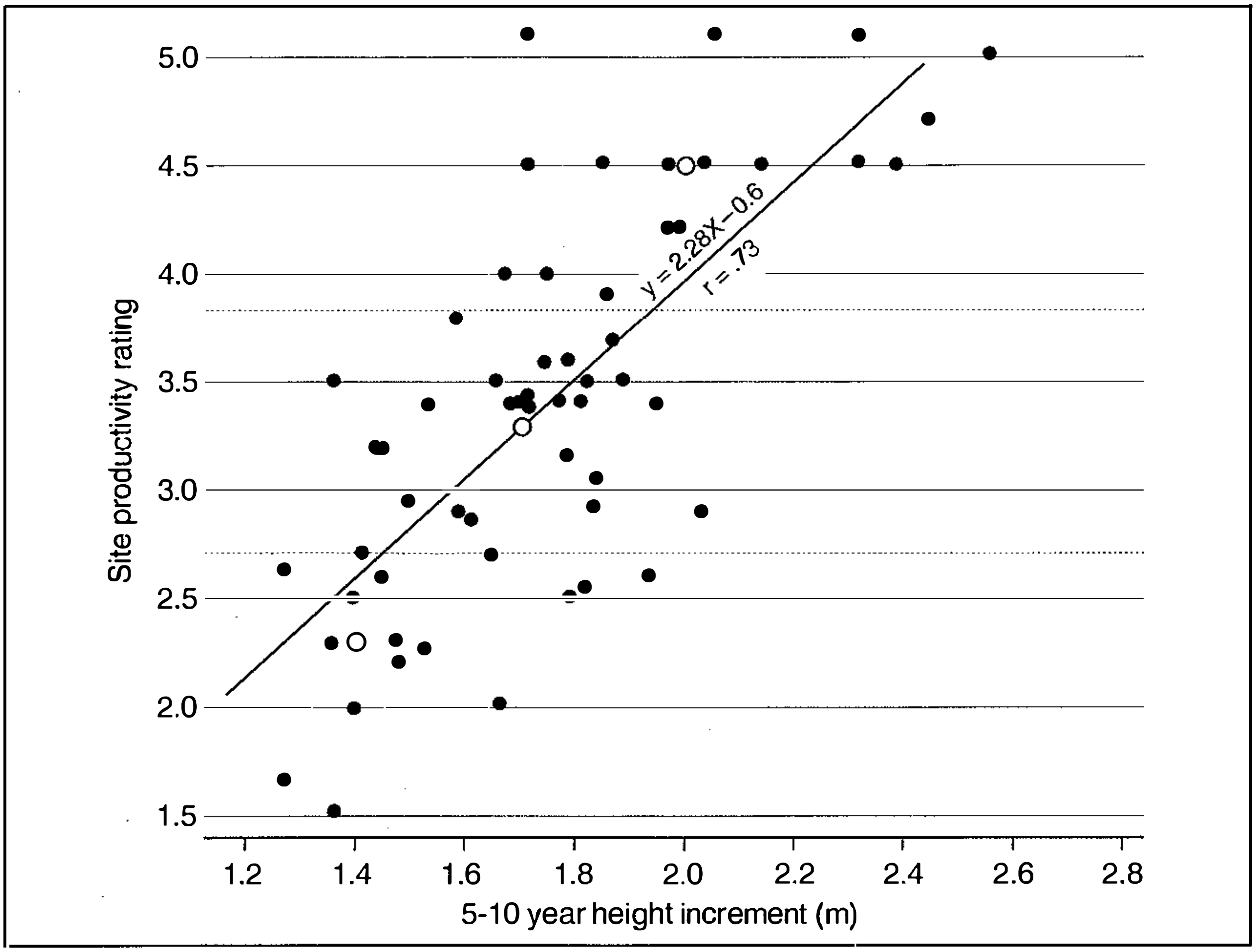

Figure 10. Site productivity rating in relation to 5- to 10-year height increment.

The approximate locations of these lines are shown in Figure 10. Low productivity areas in the Berland III compartment were separated from others in the same category because of the apparent lack of pest problems in this compartment. The data were further grouped according to the number of years since stand establishment, which was arbitrarily considered to be 6 years after the original stand was cut. The sites were first grouped into age classes (as of 1981 for most areas) represented by the series: 0, 3, 6, 9, ...; 1, 4, 7, 10, ...; or 2, 5, 8, 11, ... because survival data for a 9-year period was available for most sampling areas. This grouping provided data summaries for each sample site, without the confounding effect of data pooling.

The sample areas within site productivity groupings were also grouped into 5-year age classes (0–5, 5–10, ..., 25–30), again as of 1981 for most areas, for preparing life tables. The same 5-year groupings of age classes were used for summarizing pest damage, mostly to living trees, but lodgepole pine density (< or >6000 trees/ha) was used instead of site productivity.

Site Productivity Rating

Estimates of the productivity of forest sites may be based on the heights of tallest trees (Schönau 1988) or mean heights of dominant or codominant trees in well-stocked stands at a specified age, often 50, 70, or 100 years (Goudie et al. 1990; Mason and Tigner 1972), or upon repeated height measurements of individual trees at a number of different ages (McDill and Amateis 1992). The mean annual increment to total volume or basal area can be used for the same purpose (Dahms 1966). Whichever method is used, suitable stands of trees are needed on or near the site to be classified, otherwise alternative estimators have to be used in a multiple regression approach (Brown and Stires 1981; Farrar 1981; Golden et al. 1981).

Corns and Pluth (1984) showed that indicator species of vegetation could be used to help differentiate site productivity, but the species composition in cutover areas changes as the age of the cutovers progress (Corns and La Roi 1976). A better understanding of the interactions between nutrient and water cycles is therefore needed in order to estimate the forest productivity of cutover areas (Gholz 1988). There is a marked difference in tree growth among the study areas (Table 1a), presumably related to site quality; however, as the preceding literature review indicates, none of the available methods are suitable for determining the productivity of cutover areas. An attempt was therefore made to relate some of this difference to site factors that were independent of stand history. Dumanski et al. (1973) studied the productivity of lodgepole pine forests in the same area in which the present studies were conducted. They attempted to associate periodic annual increment of trees at least 12.6 cm in diameter at breast height to a number of factors thought to influence tree growth. The most important factors were soil parent material, climate, and drainage. Their ranking of productivity for the various soil associations can be summarized as follows: Marlboro IV, V, and VI were almost twice as productive as Marlboro II; Mayberne was slightly more productive than Marlboro V and VI; Maskuta was roughly as productive as Marlboro IV; Blackmud was about as productive as Robb; and Jarvis was about as productive as Marlboro II. A hierarchial listing follows: Mayberne; Marlboro VI; Marlboro IV and V; Maskuta; Blackmud and Robb; and Marlboro II and Jarvis.

The height increments, between their fifth and tenth years of age, for a subsample of dominant trees in each sampling area were compared to the soil association for each area (Dumanski et al. 1972), and the results obtained were in general agreement with those of Dumanski et al. (1973). Many of the sample areas were in the Robb association; however, and it was found that tree growth in this association was similar to areas in the Marlboro V and VI associations, which is at variance with their findings, but they pointed out that the Robb and Marlboro associations were lithologically similar, and attributed the poor growth in the former study to adverse climate. Perhaps the sample areas in this study were in more favorable locations or perhaps productivity constraints in the Robb soils are not manifested until a greater age when the larger trees measured in the earlier study put a greater demand on the resources of the site.

Analysis of variance tests, using the mean 5- to 10-year height increments as the dependent variable, showed elevation ($p = 0.0008$) and soil associations ($p = 0.0087$) to be highly significant factors in determining growth rate when tested individually. Drainage class differences were also significant ($p = 0.0411$) when all three factors were tested simultaneously, but were nonsignificant when tested individually. This information as used as a starting point for grouping the data (Table 2).

Low productivity soils (Jarvis III and Marlboro II) were arbitrarily assigned a weighting factor of 2.5,

Table 2. Provisional site classification for young lodgepole pine stands near Hinton, Alberta. (The site class rating is obtained as the product of all three factors.)

Soil type		Elevation[a]		Drainage	
Description[b]	Weighting factor	Metres	Weighting factor	Class	Weighting factor
JRV 3 MLB 2	2.5	1599	0.5	2	0.8
AV (HRT) MLB 3	3.0	Actual elevation	Sliding scale between 0.5 and 1.5	3	1.0
BKM 3 MBN 1–3/S MLB 4–6 RBB 1	3.5	1000	1.5	4 or 5	1.2

[a] Elevation weighting factor = 1.5 – proportion of range:

i.e., $1540 = 1.5 - \frac{1540 - 1000}{600} = 1.5 - 0.9 = 0.6$;

and $1035 = 1.5 - \frac{1035 - 1000}{600} = 1.5 - 0.06 = 1.44$.

[b] JRV = Jarvis; RBB = Robb; MLB = Marlboro; MSK = Maskuta; HRT = Heart; BKM = Blackmud; MBN = Mayberne; AV = alluvium.

medium productivity soils (Marlboro III and Heart) were given a weight of 3.0, and the rest were assigned a weight of 3.5. Excessively drained soils (Drainage class 2) were weighted at 0.8, adequately drained soils (Drainage class 3) were given a weight of 1.0, and imperfectly drained soils (Drainage classes 4 and 5) were assigned a weight of 1.2. Elevation was used as a parameter to reflect climate, with weights, based on actual elevation, ranging from 0.5 at 1600 m to 1.5 at 1000 m. A provisional site productivity rating was obtained by multiplying the above three weighting factors. Although not statistically rigorous, this grouping recognizes that soil associations and elevation are the two major factors influencing site productivity, with some modification due to soil drainage.

The 5- to 10-yearmean height increment of a sample of one dominant tree from each plot was plotted against the corresponding site productivity index (Fig. 10). There is a considerable amount of scatter, but the correlation coefficient of 0.73 ($R^2 = 0.53$) indicates that the index is useful. Site productivity indexes for each sample area are therefore included with other pertinent data in Table la.

RESULTS AND DISCUSSION

Life Tables

The 3-year survival rates for all sampling areas, grouped according to site productivity, are shown in Tables 3–5. The data in these tables list the survival by 3-year periods and give the principal mortality factors responsible; however, because so many areas were involved it was not considered to be feasible to carry these individual area analyses any further. The individual area records are included because they may be useful to forest managers in pinpointing localized problems.

Survival, in general, was relatively high, but there were some notable exceptions. Area 11 (Table 3) suffered consistently high mortality for the duration of the study. The principal mortality factors were: basal girdling by hares and squirrels, western gall rust, and blowdown. Most of the blowdown was primarily a result of weakening by one of the other two factors. Snowshoe hares were exceptionally abundant in this area during the early 1980s. They probably contributed to some of the observed basal girdling.

Typical winter girdling and browsing by snowshoe hares were responsible for most of the mortality occurring in areas 21, 31, and 37 (Table 4) and in area 36 (Table 5) during the 1981--84 period, but some of the mortality in area 37 was caused by Armillaria root rot and Warren rootcollar weevil. These two factors appeared to be more prevalent in high productivity sites and were among the agents responsible for the relatively high mortality recorded in area 81 in 1981–84 and in areas 42 and 44 in 1984--87.

Generation survival is equal to the product of the survival during each of the life stages (Morris 1963); this principle has been used in the calculation of the composite life tables. Trees have no clearly defined life stages; consequently, survival was grouped by 5-year periods. The data have been referred to as partial life tables because only the immature phase of the trees' life cycle is covered. The range in age classes needed to cover the life span of lodgepole pine on cutover areas is not yet available.

The survival data can be regarded as a series of miniature partial life tables, most covering a 9-year span in the life of the trees; however, these data are not appropriate for further pooling because of the overlapping of the 3-year periods. The original survival data were used where the number of living trees at the beginning of each 1-year period for each area had been recorded. At the following annual examination, the number of trees killed was noted and the agent responsible recorded whenever possible (Table 6). Thus the number of living trees at the end of each period became the number used for the beginning of the next period. Each successive sample was treated as though it was independent of those preceding or following it in order to allow vertical summation. Furthermore, each sample within a 5-year period was considered to be estimating the same survival rate. This assumption seems to be valid on the basis of 3-year survival rates given in Tables 3–5. The annual subtotals (Table 6) were pooled to obtain an average survival rate for the period and area under consideration. The 5-year survival rate was obtained by raising this value to the fifth power.

Table 3. Three-year survival rates for immature lodgepole pine growing on low productivity sites in the Berland III and McLeod II and IX compartments near Hinton, Alberta

Sampling area	Berland III compartment											
	Years since stand establishment[a]									Mortality factors[b]		
	1–4	4–7	7–10	10–13	13–16	16–19	19–22	22–25	25–28	1981–84	1984–87	1987–90
71	–	–	–	–	–	1.000	1.000	0.996	–	–	–	Gr, Br
74	–	–	–	–	1.000	1.000	0.998	–	–	–	–	Br
	2–5	5–8	8–11	11–14	14–17	17–20	20–23	23–26	26–29			
75	–	–	–	–	0.998	1.000	0.996	–	–	U	–	U
72	–	0.997	0.997	0.997	–	–	–	–	–	R, U	Br	Br, U
73	–	0.993	0.993	0.998	–	–	–	–	–	Gr, A, U	Br, Gr, U	W
76	0.997	0.998	0.998	–	–	–	–	–	–	U	U	Gr
77	1.000	0.996	0.998	–	–	–	–	–	–	–	Gr	Gr
	McLeod II and IX compartments[c]											
Sampling area	Years since stand establishment									Mortality factors		
	0–3	3–6	6–9	9–12	12–15	15–18	18–21	21–24	24–27	1981–84	1984–87	1987–90
01	–	–	–	–	–	0.992	0.988	0.992	–	R, Gr	R, B, Gr	Gr, A, U
14	–	0.973	0.949	0.972	–	–	–	–	–	A, U, R	A, W, R, Br	Gr, A, W, U
15	–	0.977	0.926	0.935	–	–	–	–	–	A, Br, B	A, W, Br, Gr	A, U, W, Br
08	0.996	0.982	0.946	–	–	–	–	–	–	A, U	Gr, A, W, U	Gr, U, W, R
	1–4	4–7	7–10	10–13	13–16	16–19	19–22	22–25	25–28			
11	–	–	–	–	–	–	0.864	0.863	0.898	R, B, Gr	R, Bd, Gr	R, Gr, Bd
13	–	–	–	–	–	–	0.984	0.935	0.983	R	R, Gr, U	R
03	–	–	–	0.967	0.973	0.968	–	–	–	A, Br, Gr	A, U, W, R	W, A, Gr, R
07	–	–	1.000	1.000	0.993	–	–	–	–	–	–	Gr, A, U
09	1.000	–	–	–	–	–	–	–	–	–	–	–
	2–5	5–8	8–11	11–14	14–17	17–20	20–23	23–26	26–29			
05	–	–	0.991	0.982	0.991	–	–	–	–	R, Br, W, U	Br, Gr	Br, R, U
06	–	–	0.981	0.976	0.986	–	–	–	–	U, A	Br, A, U	Br, A
66	0.998[d]	0.968	0.923	–	–	–	–	–	–	W	A, U, W	Gr, A, W, Br

[a] Considered to be 6 years after original stand was cut.

[b] Major mortality factors: Rodents (hares and squirrels) (R); Western gall rust (Gr); Armillaria (A); Rootcollar weevil (W); Blister rust (Br); Browsing (B); Blowdown (Bd); and Unknown (U).

[c] Except for Area 66, which is in Athabasca XIX compartment.

[d] Based on 1 year's data.

Table 4. Three-year survival rates for immature lodgepole pine growing on medium productivity sites near Hinton, Alberta

Sampling area	Years since stand establishment[a]									Mortality factors[b]		
	0–3	3–6	6–9	9–12	12–15	15–18	18–21	21–24	24–27	1981–84	1984–87	1987–90
31	–	–	–	0.656	0.944	0.980	–	–	–	R, B	R, W, B	R, B, Br
35	–	–	0.904	0.953	0.954	–	–	–	–	R, B, A, W	Br, R, A	B, Br, A, W
37	–	–	0.840	0.946	0.938	–	–	–	–	R, B, A, W	R, Gr, A, U	R, Gr, Br, Bd, U
62	–	–	0.973	0.990	0.973	–	–	–	–	R, A, W, Gr	R, Gr, Br	Gr, R, U
88	–	–	0.990	0.991	0.996	–	–	–	–	A	A, U	Gr, U
16	–	0.984	0.948	0.958	–	–	–	–	–	A	A, W, Br	A, W, Br
63	–	0.981	0.924	0.949	–	–	–	–	–	A, W	A, U	Gr, W, U, B
64	–	0.997	0.992	0.985	–	–	–	–	–	A	A, W, Gr, U	Gr, U
65	–	0.975	0.930	0.960	–	–	–	–	–	A, W, Gr	A, W, Gr	Gr, A, W, B
45	0.991[d]	–	–	–	–	–	–	–	–	–	–	W, A
	1–4	4–7	7–10	10–13	13–16	16–19	19–22	22–25	25–28			
12	–	–	–	–	–	–	0.911	0.967	0.983	R, Gr, A, B	R, Gr, A, Bd	R, U
04	–	–	–	1.000	0.986	0.991	–	–	–	–	R, Gr, U	U, Gr, Br
85	–	–	–	1.000[c]	0.996	0.990	–	–	–	–	W, Gr	Br, W, Bd, U
68	0.957	0.945	–	–	–	–	–	–	–	–	A, U, W	U, W, A, Gr
	2–5	5–8	8–11	11–14	14–17	17–20	20–23	23–26	26–29			
02	–	–	–	–	0.983	0.980	0.983	–	–	W, A, Gr	Gr, B, W	Gr, A, B, U
26	–	–	–	–	0.969	0.989	0.993	–	–	A, R, Gr	Gr, U	B, U
21	–	–	–	0.862	0.971	0.978	–	–	–	R, B	R, Gr, B	R, U, Br, Bd
22	–	–	–	0.933	0.972	0.971	–	–	–	R, B, A, Gr	B, Gr, U	Gr, W, R
23	–	–	–	0.974	0.963	0.980	–	–	–	R, W, Gr, B, U	R, Gr, A, B	R, Gr, W, A, U
52	–	–	–	0.963	0.955	0.948	–	–	–	R, A, B, Gr	A, B, Gr, W	Gr, R, W, U
56	–	–	–	0.978	0.957	0.963	–	–	–	A, R, B	R, Gr, A, U	R, Bd, Br, W
57	–	–	–	0.964	0.973	0.977	–	–	–	A, B, W	A, Gr, R, U	Gr, R, Bd, U
58	–	–	0.961	0.980	0.964	–	–	–	–	A, Gr, W	U	A, Gr, W, Bd, U
86	–	0.980[c]	0.975	0.988	–	–	–	–	–	A, W	A, Gr, U	Gr, Br, Bd, W, U
87	–	0.993[c]	0.992	0.995	–	–	–	–	–	A	–	Gr, W
32	0.995	0.992	0.995	–	–	–	–	–	–	A, U	A, Gr, U	Gr
67	0.996[d]	0.983	0.957	–	–	–	–	–	–	W	A, U	A, Gr, W, Br, U
10	0.940[d]	–	–	–	–	–	–	–	–	–	–	A, B

[a] Considered to be 6 years after original stand was cut.

[b] Major mortality factors: Rodents (hares and squirrels) (R); Western gall rust (Gr); Armillaria (A); Rootcollar weevil (W); Blister rust (Br); Browsing (B); Blowdown (Bd); and Unknown (U).

[c] Based on 2 years' data.

[d] Based on 1 year's data.

Table 5. Three-year survival rates for immature lodgepole pine growing on high productivity sites near Hinton, Alberta

Sampling area	Years since stand establishment[a]									Mortality factors[b]		
	0–3	3–6	6–9	9–12	12–15	15–18	18–21	21–24	24–27	1981–84	1984–87	1987–90
41	–	–	–	–	–	0.984	0.990	0.961	–	W	Gr, Br, U	Gr, W, Br, Bd, A, U
27	–	–	–	–	0.964	0.958	0.973	–	–	W, Gr, A, B, U	A, Br, Gr, R, W	Gr, U, B, Br
34	–	–	0.925	0.952	0.956	–	–	–	–	A, U	A, Gr, W, U	Gr, U, A, Br, W
36	–	–	0.670	0.944	0.978	–	–	–	–	R, U	R, U	R, Gr
59	–	–	0.989	0.972	0.973	–	–	–	–	A, W, U	A, U	U, A, W, Gr, B
61	–	–	0.984	0.981	0.980	–	–	–	–	A, W, Gr	A, Gr, U	W, A, R, Gr, B
84	–	0.967	0.965	0.925	–	–	–	–	–	W, A, B	A, U, Br	Br, A, Gr, R, W, B, U
	1–4	4–7	7–10	10–13	13–16	16–19	19–22	22–25	25–28			
24	–	–	–	–	0.987	0.982	0.977	–	–	U	A, U, Gr, Bd	Gr, U
25	–	–	–	–	0.983	0.986	0.980	–	–	A, R, Gr	Gr, A, U	Gr
60	–	–	0.977	0.986	0.963	–	–	–	–	A	A, U	R, W, A, Gr, U
33	–	0.996	0.996	0.992	–	–	–	–	–	U	A, Gr	U, Gr
83	–	0.933	0.962	0.972	–	–	–	–	–	A, W, R	A, W, Br, U	R, Bd, Br, W, U
43	0.960[c]	0.921	0.975	–	–	–	–	–	–	A, W	A, W, Br	A, W, Gr, U
44	0.913[c]	0.871	0.952	–	–	–	–	–	–	A, Gr	A, W	A, U
69	0.998	0.968	–	–	–	–	–	–	–	–	A	Gr, A, U
	2–5	5–8	8–11	11–14	14–17	17–20	20–23	23–26	26–29			
81	–	–	–	–	–	0.884	0.958	0.904	–	R, A, B, W, Br	A, Gr, W	Gr, Bd, Br, W, U, B
82	–	–	–	–	–	0.969	0.987	0.981	–	R, Gr, A	A, Gr, R, U	W, A, R, Bd
51	–	–	–	0.997	0.992	0.986	–	–	–	W	A, B, Gr	Gr, R, W
53	–	–	–	0.978	0.983	0.982	–	–	–	R, B, W	Gr, A, U	W, Gr, Br
54	–	–	–	0.990	0.995	0.990	–	–	–	B	Gr	Gr
55	–	–	–	0.984	0.996	0.969	–	–	–	Gr, W, A, B	Gr, B	Gr, R, B, Bd, U
28–30	0.987	0.983	0.954	–	–	–	–	–	–	A, U, W, R, B	A, U, R, Gr, W	Br, U, B, Bd, Gr, W
42	0.943	0.884	0.946	–	–	–	–	–	–	A, W, R	A, Gr, W	W, A, Gr, U

[a] Considered to be 6 years after original stand was cut.

[b] Major mortality factors: Rodents (hares and squirrels) (R); Western gall rust (Gr); Armillaria (A); Rootcollar weevil (W); Blisterrust (Br); Browsing (B); Blowdown (Bd); and Unknown (U).

[c] Based on 2 years' data.

Table 6. An example of calculations used to obtain estimates of the number of trees surviving attack by various agents during 5-year intervals (high productivity areas, 5–10 years of age)

Area	No. trees alive at start	Mortality factors: Rodents	Browsing	Blowdown	Western gall rust	Blister rust	Armillaria root rot	Collar weevil	Cause unknown	No. trees alive at end
					5–6 year age interval					
84	560	0	1	0	0	0	4	2	1	552
33	667	0	0	0	0	0	0	0	0	667
83	586	1	0	0	0	0	14	3	1	567
43	344	0	0	0	0	1	5	5	1	332
44	369	0	0	0	0	0	10	6	3	350
69	436	0	0	0	3	0	0	0	0	433
28–30	1 403	2	0	0	0	0	4	0	2	1 395
42	692	2	0	0	0	1	8	3	6	672
Subtotal	5 057	5	1	0	3	2	45	19	14	4 968
					6–7 year age interval					
34	492	0	0	0	0	0	0	4	6	482
36	291	57	0	0	0	0	0	0	0	234
59	723	0	0	0	0	0	3	0	0	720
61	636	0	0	0	0	0	1	0	0	635
84	536	0	0	0	0	0	1	0	7	528
33	667	0	0	0	0	0	0	0	1	666
83	567	1	0	0	0	0	0	6	2	558
43	332	0	0	0	0	1	2	4	0	325
44	350	0	0	0	0	0	10	2	0	338
69	433	0	0	0	8	0	0	0	1	424
28–30	1 395	0	0	0	0	0	2	3	2	1 388
42	671	0	1	0	0	0	31	0	1	638
Subtotal	7 093	58	1	0	8	1	50	19	20	6 936
					7–8 year age interval					
34	482	0	0	0	0	0	6	0	6	470
36	234	25	0	0	0	0	0	0	0	209
59	720	0	0	0	0	0	2	0	2	716
61	635	0	0	0	1	0	0	5	0	629
84	528	0	0	0	0	0	0	0	4	524
60	566	0	0	0	0	0	6	0	0	560
33	666	0	0	0	0	0	1	0	0	665
83	558	0	0	0	0	0	1	7	5	545
43	325	0	0	0	0	0	3	0	0	322
44	338	0	0	0	0	0	10	0	1	327
28–30	1 388	0	1	0	0	0	0	0	1	1 386
42	638	0	0	0	0	0	0	0	3	615
Subtotal	7 078	25	1	0	1	0	49	12	22	6 968

Table 6. Concluded

Area	No. trees alive at start	Mortality factors: Rodents	Browsing	Blowdown	Western gall rust	Blister rust	Armillaria root rot	Collar weevil	Cause unknown	No. trees alive at end
					8–9 year age interval					
34	470	0	0	0	0	0	7	0	8	455
36	209	12	0	0	0	0	0	0	2	195
59	716	0	0	0	0	0	0	1	0	715
61	629	0	0	0	0	0	1	0	2	626
84	523	0	0	0	0	1	2	0	3	517
60	559	0	0	0	0	0	3	0	0	556
33	665	0	0	0	1	0	1	0	0	663
83	545	0	0	0	0	1	5	0	0	539
43	322	0	0	0	1	0	1	0	0	320
44	319	0	0	0	0	0	4	0	0	315
28–30	1 386	0	0	0	0	0	0	0	10	1 376
42	615	0	0	0	0	0	20	0	2	593
Subtotal	6 958	12	0	0	2	2	44	1	27	6 870
					6–7 year age interval					
34	455	0	0	0	0	0	0	0	10	445
36	195	6	0	1	0	0	0	0	0	188
59	715	0	0	0	0	0	1	0	11	703
61	626	0	0	1	0	0	1	0	7	617
84	517	0	0	0	0	2	2	0	1	512
60	556	0	0	0	0	0	3	0	0	553
33	663	0	0	0	0	0	0	0	0	663
83	539	0	0	0	0	0	0	0	2	537
43	320	0	0	1	0	0	0	1	1	317
44	315	0	0	0	0	0	0	0	1	314
28–30	1 376	0	0	0	1	0	2	0	2	1 371
42	593	0	0	0	1	0	0	3	0	588
Subtotal	6 860	6	0	3	2	2	9	4	35	6 799
Total	33 046	106	3	3	16	7	197	55	118	32541
Annual survival rate (X)		0.99679	0.99981	0.99991	0.99952	0.99979	0.99404	0.99834	0.99643	0.98482
Five-year survival (X^5)		0.98406	0.99955	0.99955	0.99758	0.99894	0.97055	0.99171	0.98227	0.92630
Mortality (%)		1.59	0.04	0.04	0.24	0.11	2.94	0.83	1.77	7.56

The same procedure was used to calculate the survival rate after each of the mortality factors had operated. The annual survival rate (X) was calculated for each factor, and this value was then raised to the fifth power to provide the 5-year rate (X^5). The percentage mortality values for each factor (Table 6) were obtained directly from the corresponding survival rates.

Extremely low mortality occurred in low productivity sites in the Berland III compartment (Table 7). More than 98% of the trees were still alive 25 years after stand establishment. Western gall rust, blister rust, Armillaria root rot, and Warren rootcollar weevil were the principal identifiable factors involved.

Considerably greater amounts of mortality occurred in the remaining low productivity sites (Table 8). Armillaria root rot and the Warren rootcollar weevil were the major identifiable causes of this mortality until the trees were about 15 years old. Little hare damage from winter feeding occurred in these young stands; however, basal girdling damage by hares and squirrels became a major factor in stands of 20- to 25-year-old trees, and most of the observed blowdown was probably due to weakening caused by earlier basal girdling. The number of trees sampled in the 25- to 30-year age category was too small to provide reliable results, but the trend indicates that high mortality rates will continue into this age class as well.

The survival to age 25 years among trees growing on medium productivity sites (Table 9) is very similar to the low productivity sites (77 versus 78%), but the identifiable agents responsible are different. Armillaria root rot and Warren rootcollar weevil remain important factors in young stands, each causing appreciable mortality until the trees are about 20 years old. Damage to the younger trees is primarily attributable to winter feeding by snowshoe hares, while 20- to 25-year-old trees are being killed by basal girdling. Basal girdling remains the primary identifiable cause of mortality among trees in the 25- to 30-year age group.

The survival to age 25 years among trees growing on high productivity sites (Table 10) is slightly lower (74%) than comparable values for trees growing on medium or low productivity sites. Hares caused a small amount of winter feeding damage in stands up to 20 years of age. Armillaria root rot was the major identifiable cause of mortality among trees up to 10 years of age, and continued to cause appreciable mortality even among 25-year-old trees. The Warren rootcollar weevil also caused appreciable mortality in all age classes. The survival of trees in the 25- to 30-year age class was low. Although the cause of the high mortality is listed as other (unknown), Armillaria root rot is believed to be primarily responsible for these trees' death.

Conditions in the Berland III compartment are relatively poor for tree growth because of the short growing season, which is attributable to high elevation and proximity to the mountains. The poor climatic conditions may also be unfavorable for the development of any of the pests; consequently, tree survival rates are high.

In all other situations within the study area, the survival to age 25 years was very similar, although the factors causing mortality differed. On low and medium productivity sites, hare or squirrel damage was an important factor, possibly because of the proliferation of the shrub layer, alder in particular, which provided a suitable habitat for snowshoe hares. On high productivity sites, the rapid tree growth inhibited shrub development, and hence hare damage was less prevalent. Conversely, the moister conditions generally associated with high productivity were favorable for both Armillaria root rot and the Warren rootcollar weevil.

The health of lodgepole pine in the 25- to 30-year age class is of major concern to the forest manager and trees in this age class should be growing well, with little mortality. Yet the limited data in this study indicate otherwise.

Projected Survival

The life table data in the preceding section gave little indication that the mortality rate was decreasing as the trees aged, as had been anticipated. In fact, the limited data for the 25- to 30-year age interval, the oldest trees for which data are available, indicated that mortality might be increasing. The life table data, excluding Berland III compartment, have therefore been used to make tenuous long-term projections of survival rates.

The survival rates in Tables 7–9 appear to be relatively uniform, and this is confirmed when the cumulative survival rate is plotted against years since stand establishment (Fig. 11). The annual mortality rate is slightly lower (0.86%) in low site productivity areas than in areas with medium or high site productivity (0.95 and 1.06%, respectively). Although extremely tenuous, because there are no data for older cutover lodgepole pine stands, these figures reflect the findings of other researchers. For example, Stiell (1984), reporting on a 10-year study of thinned 55-year-old white pine in Ontario, found an average annual mortality of 0.95%.

Generally, annual tree mortality decreases as stands get older, but no survival data for old cutover stands in

Table 7. Partial life tables for immature lodgepole pine growing on low productivity sites in the Berland III compartment near Hinton, Alberta

Age interval (X)	No. alive at beginning of X (Nx)		No. dying during X (Mx)	Factor responsible for Mx	100Mx/Nx Mx as % of Nx	Survival rate within X (Sx)
0–5 years	10 000		0	Rodents	0.00	
			0	Browsing	0.00	
			0	Blowdown	0.00	
			0	Gall rust	0.00	
			0	Blister rust	0.00	
			0	*Armillaria*	0.00	
			0	*Hylobius*	0.00	
			28	Other	0.28	
		Total	28		0.28	0.9972
5–10 years	9 972		4	Rodents	0.04	
			0	Browsing	0.00	
			0	Blowdown	0.00	
			25	Gall rust	0.25	
			12	Blister rust	0.12	
			4	*Armillaria*	0.04	
			0	*Hylobius*	0.00	
			21	Other	0.21	
		Total	66		0.66	0.9934
10–15 years	9 906		0	Rodents	0.00	
			0	Browsing	0.00	
			0	Blowdown	0.00	
			0	Gall rust	0.00	
			6	Blister rust	0.06	
			0	*Armillaria*	0.00	
			6	*Hylobius*	0.06	
			13	Other	0.13	
		Total	25		0.25	0.9975
15–20 years	9 881		0	Rodents	0.00	
			0	Browsing	0.00	
			6	Blowdown	0.06	
			0	Gall rust	0.00	
			0	Blister rust	0.00	
			0	*Armillaria*	0.00	
			0	*Hylobius*	0.00	
			0	Other	0.00	
		Total	6		0.06	0.9994
20–25 years	9 875		0	Rodents	0.00	
			0	Browsing	0.00	
			0	Blowdown	0.00	
			10	Gall rust	0.10	
			19	Blister rust	0.20	
			0	*Armillaria*	0.00	
			0	*Hylobius*	0.00	
			10	Other	0.10	
		Total	39		0.40	0.9960
25–30 years	9 836					Cumulative survival 0.9836

Table 8. Partial life tables for immature lodgepole pine growing on low productivity sites[a] in the McLeod II and IX compartments near Hinton, Alberta

Age interval (X)	No. alive at beginning of X (Nx)		No. dying during X (Mx)	Factor responsible for Mx	100Mx/Nx Mx as % of Nx	Survival rate within X (Sx)
0–5 years	10 000		0	Rodents	0.00	
			0	Browsing	0.00	
			0	Blowdown	0.00	
			12	Gall rust	0.12	
			0	Blister rust	0.00	
			93	*Armillaria*	0.93	
			25	*Hylobius*	0.25	
			112	Other	1.12	
		Total	242		2.42	0.9758
5–10 years	9 758		23	Rodents	0.24	
			12	Browsing	0.12	
			4	Blowdown	0.04	
			100	Gall rust	1.02	
			27	Blister rust	0.28	
			217	*Armillaria*	2.23	
			96	*Hylobius*	0.98	
			198	Other	2.03	
		Total	677		6.94	0.9306
10–15 years	9 081		3	Rodents	0.04	
			3	Browsing	0.04	
			0	Blowdown	0.00	
			19	Gall rust	0.21	
			81	Blister rust	0.88	
			84	*Armillaria*	0.92	
			45	*Hylobius*	0.50	
			52	Other	0.57	
		Total	287		3.16	0.9684
15–20 years	8 794		104	Rodents	1.19	
			6	Browsing	0.06	
			0	Blowdown	0.00	
			22	Gall rust	0.25	
			28	Blister rust	0.32	
			17	*Armillaria*	0.19	
			28	*Hylobius*	0.32	
			44	Other	0.50	
		Total	249		2.83	0.9717
20–25 years	8 545		465	Rodents	5.44	
			23	Browsing	0.27	
			138	Blowdown	1.61	
			46	Gall rust	0.54	
			0	Blister rust	0.00	
			12	*Armillaria*	0.14	
			0	*Hylobius*	0.00	
			81	Other	0.95	
		Total	765		8.95	0.9105
						Cumulative survival 0.7780

Table 8. Concluded

Age interval (X)	No. alive at beginning of X (Nx)	No. dying during X (Mx)	Factor responsible for Mx	100Mx/Nx Mx as % of Nx	Survival rate within X (Sx)
25–30 years	8 780	495	Rodents	6.36	
		0	Browsing	0.00	
		273	Blowdown	3.51	
		92	Gall rust	1.18	
		0	Blister rust	0.00	
		0	*Armillaria*	0.00	
		0	*Hylobius*	0.00	
		46	Other	0.59	
		Total 906		11.64	0.8836[b]
30–35 years	6 874				Cumulative survival 0.6874

[a] Also includes area 66 in Athabasca XIX compartment.

[b] The survival of trees 25–30 years of age is based on a very small sample.

Table 9. Partial life tables for immature lodgepole pine growing on medium productivity sites near Hinton, Alberta

Age interval (X)	No. alive at beginning of X (Nx)	No. dying during X (Mx)	Factor responsible for Mx	100Mx/Nx Mx as % of Nx	Survival rate within X (Sx)
0–5 years	10 000	0	Rodents	0.00	
		4	Browsing	0.04	
		0	Blowdown	0.00	
		4	Gall rust	0.04	
		18	Blister rust	0.18	
		116	*Armillaria*	1.16	
		60	*Hylobius*	0.60	
		146	Other	1.46	
		Total 348		3.48	0.9652
5–10 years	9 652	202	Rodents	2.10	
		26	Browsing	0.26	
		3	Blowdown	0.04	
		26	Gall rust	0.26	
		9	Blister rust	0.09	
		253	*Armillaria*	2.62	
		68	*Hylobius*	0.71	
		120	Other	1.24	
		Total 707		7.32	0.9268
10–15 years	8 945	150	Rodents	1.68	
		74	Browsing	0.82	
		7	Blowdown	0.07	
		37	Gall rust	0.41	
		11	Blister rust	0.12	
		72	*Armillaria*	0.81	
		28	*Hylobius*	0.32	
		98	Other	1.10	
		Total 477		5.33	0.9467
15–20 years	8 468	70	Rodents	0.82	
		37	Browsing	0.44	
		28	Blowdown	0.33	
		61	Gall rust	0.72	
		13	Blister rust	0.15	
		18	*Armillaria*	0.22	
		26	*Hylobius*	0.30	
		88	Other	1.04	
		Total 341		4.02	0.9598
20–25 years	8 127	166	Rodents	2.04	
		36	Browsing	0.44	
		60	Blowdown	0.73	
		71	Gall rust	0.88	
		24	Blister rust	0.30	
		60	*Armillaria*	0.73	
		0	*Hylobius*	0.00	
		24	Other	0.30	
		Total 441		5.42	0.9458
					Cumulative survival 0.7712

Table 9. Concluded

Age interval (X)	No. alive at beginning of X (Nx)	No. dying during X (Mx)	Factor responsible for Mx	100Mx/Nx Mx as % of Nx	Survival rate within X (Sx)
25–30 years	7 686	130	Rodents	1.69	
		0	Browsing	0.00	
		43	Blowdown	0.56	
		0	Gall rust	0.00	
		0	Blister rust	0.00	
		0	*Armillaria*	0.00	
		0	*Hylobius*	0.00	
		43	Other	0.56	
		Total 216		2.81	0.9719[a]
30–35 years	7 470				Cumulative survival 0.7472

[a] The survival of trees 25–30 years of age is based on a very small sample.

Table 10. Partial life tables for immature lodgepole pine growing on high productivity sites near Hinton, Alberta

Age interval (X)	No. alive at beginning of X (Nx)	No. dying during X (Mx)	Factor responsible for Mx	100Mx/Nx Mx as % of Nx	Survival rate within X (Sx)
0–5 years	10 000	6	Rodents	0.06	
		6	Browsing	0.06	
		0	Blowdown	0.00	
		18	Gall rust	0.18	
		92	Blister rust	0.92	
		410	*Armillaria*	4.10	
		92	*Hylobius*	0.92	
		132	Other	1.32	
		Total 756		7.56	0.9244
5–10 years	9 244	147	Rodents	1.59	
		4	Browsing	0.04	
		4	Blowdown	0.04	
		22	Gall rust	0.24	
		10	Blister rust	0.11	
		272	*Armillaria*	2.94	
		77	*Hylobius*	0.83	
		164	Other	1.77	
		Total 700		7.56	0.9244
10–15 years	8 545	29	Rodents	0.34	
		54	Browsing	0.63	
		21	Blowdown	0.24	
		47	Gall rust	0.55	
		10	Blister rust	0.12	
		43	*Armillaria*	0.50	
		56	*Hylobius*	0.66	
		91	Other	1.06	
		Total 351		4.10	0.9590
15–20 years	8 194	75	Rodents	0.92	
		31	Browsing	0.38	
		24	Blowdown	0.29	
		55	Gall rust	0.67	
		11	Blister rust	0.13	
		66	*Armillaria*	0.80	
		31	*Hylobius*	0.38	
		104	Other	1.27	
		Total 397		4.84	0.9516
20–25 years	7 797	16	Rodents	0.20	
		0	Browsing	0.00	
		54	Blowdown	0.69	
		75	Gall rust	0.96	
		16	Blister rust	0.20	
		59	*Armillaria*	0.76	
		54	*Hylobius*	0.69	
		86	Other	1.10	
		Total 360		4.60	0.9540
					Cumulative survival 0.7440

Table 10. Concluded

Age interval (X)	No. alive at beginning of X (Nx)	No. dying during X (Mx)	Factor responsible for Mx	100Mx/Nx Mx as % of Nx	Survival rate within X (Sx)
25–30 years	7 437	0	Rodents	0.00	
		83	Browsing	1.12	
		42	Blowdown	0.56	
		0	Gall rust	0.00	
		83	Blister rust	1.12	
		0	*Armillaria*	0.00	
		42	*Hylobius*	0.56	
		990	Other	13.31	
		Total 1240		16.67	0.8333[a]
30–35 years	6 197				Cumulative survival 0.6199

[a] The survival of trees 25–30 years of age is based on a very small sample.

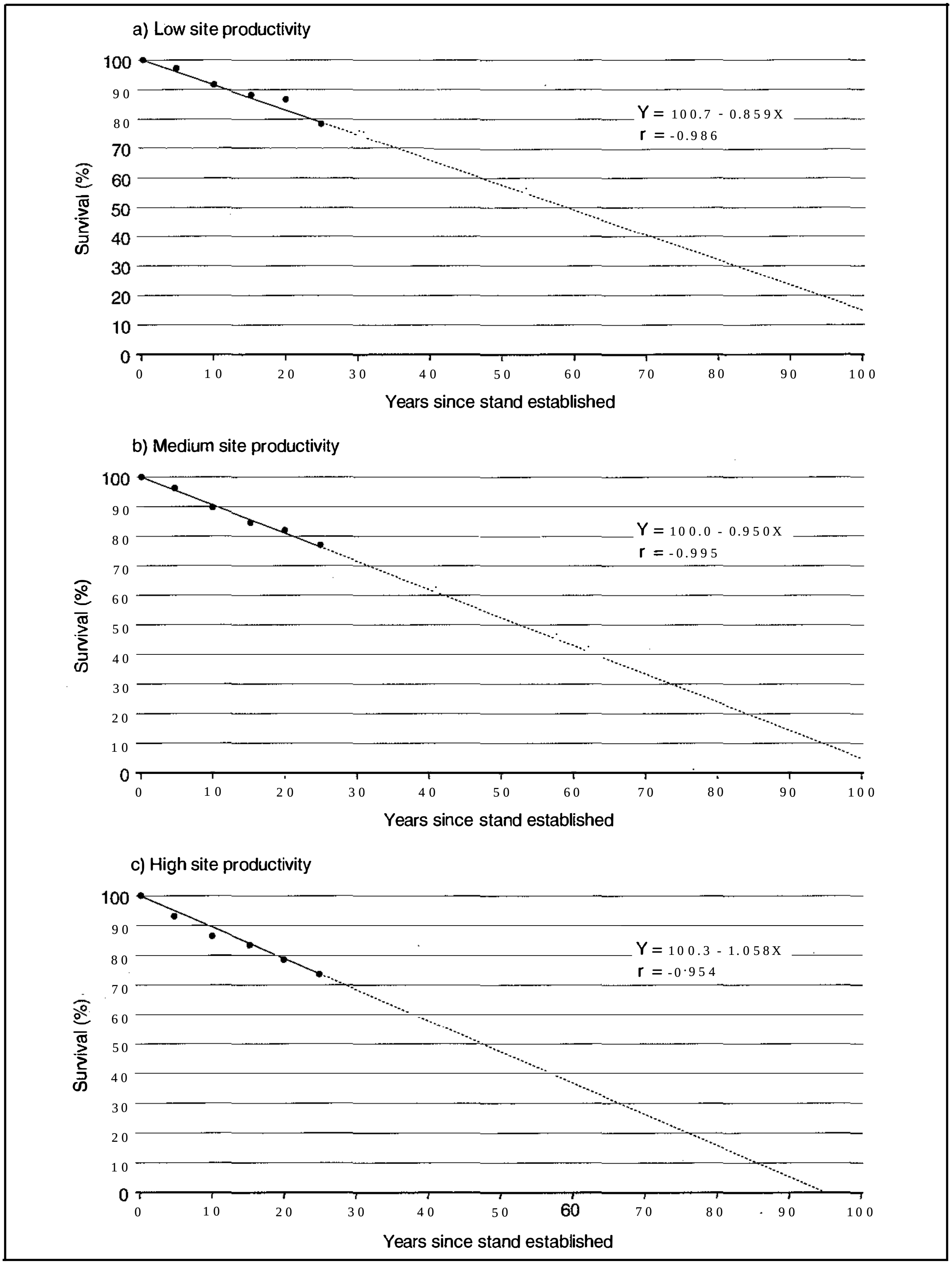

Figure 11. Projected survival of lodgepole pine, based on life table data.

this area are available. The survival projections in Figure 11 are intended only to show what could happen if this decreased mortality does not occur soon and therefore represent a worst-case scenario. In the unlikely event that the current survival rates continue to rotation age, only about 30, 25, and 15% of the original trees will survive for 80 years from stand establishment on low, medium, and high productivity sites, respectively.

Mortality is lower in the thinned stands (Stiell 1984), but Stiell still had an annual mortality of between 0.5 and 0.7% in the thinned stands. In addition, survival rates in the present study apply to potential crop trees, not to the total stand. Since the crop trees are usually the dominant or codominant individuals, the overall stand mortality is expected to be higher than the present estimates. Consequently, even if mortality does level off as the stands get older, there is a danger of understocking at harvest age if the original thinning is too severe, especially if the original numbers of trees are reduced to the 1000–1500 trees/ha level.

Annual Pest Abundance or Damage

The annual incidences of pest abundance or damage to stands of lodgepole pine were obtained by averaging the percentages of pest occurrence or damage in each category. The damage was grouped into four categories for purposes of discussion: 1) chewing by mammals, 2) gall and blister rusts, 3) stem deforming pests, and 4) root and root collar damage.

Chewing by Mammals

Most of the total damage from chewing by mammals was probably caused by snowshoe hares or squirrels, but it was usually difficult if not impossible to determine the cause of browsing damage, and some of this may have been caused by ungulates (Fig. 12). There was relatively little damage in the denser stands (>6000 trees/ha), except for the 15- to 20-year age class (as of 1981 for most areas). The damage was relatively high in 1981 and 1982, dropping to a low in 1985, and gradually increasing until 1990. The amount of damage may be related to fluctuations in snowshoe hare abundance.

The amount of damage was much greater in stands with <6000 trees/ha, and trees in each of the three older age classes showed similar trends. Damage was high in 1981 and 1982, was relatively low in the mid-1980s, and started to increase in 1989 and 1990. Trees in the 10- to 15-year age group experienced the greatest damage in the early 1980s followed by those in the 20- to 25-year age class. All three age classes suffered similar damage in 1989 and 1990. All types of mammal-chewing damage were recorded, even though some damage had no adverse effect on trees.

Moderate-to-severe basal girdling, however, has the potential to weaken or kill the damaged trees. It is more easily defined, and is thought to reflect potential impact, even if the mammal responsible is not known. Basal girdling damaged very few trees in stands with >6000 lodgepole pine/ha (Fig. 13), and most of this damage was limited to trees over 20 to 25 years of age at the time of attack. The incidence of damage was much greater in stands with <6000 trees/ha. Trees in the 20- to 25-year age class were the most severely affected, especially in the early 1980s. It is disturbing to note that these older trees are still being attacked, even though some trees are probably over 35 years old.

Some trees in the 10- to 15-year age category also suffered basal girdling in the early 1980s. This means that trees may be exposed to basal girdling for at least 25 years, and blowdown often occurs long after the initial damage; the consequences of basal girdling may extend throughout most of the tree's life. Damage to the 10- to 15-, 15- to 20-, and 20- to 25-year age classes was again increasing in the late 1980s.

The amount of stem girdling in crowns of trees (Fig. 14) is not of great importance, except as a possible indicator of squirrel abundance. The data for two sample areas with known resident porcupines were not taken into account when these summaries were prepared. Consequently, most of the damage was probably attributable to squirrels. A small amount of damage to trees in the 15- to 20-year age group was noted in the denser stands between 1981 and 1988. There was a slight increase in damage during 1989 and 1990 in the three oldest age classes. Except for what appears to be an anomalous peak in the 10- to 15-year age class in 1985 and 1986, a similar but much more pronounced increase occurred in the more open stands. The trends indicated by this rather crude index of squirrel abundance seem to be substantiated by general field observations: squirrels were more abundant in many of the study areas in 1990 than in any of the previous years.

Gall and Blister Rusts

Infections by gall and blister rust organisms are perennial, and both groups are potential mortality agents. The following discussions relate to the incidence of infection on living trees, however, and not to mortality rates.

Western gall rust total infections

The incidence of total western gall rust infections does not seem to show any marked relationship to stand density (Fig. 15). There is a progressive increase within each age class over the years, and a similar but less

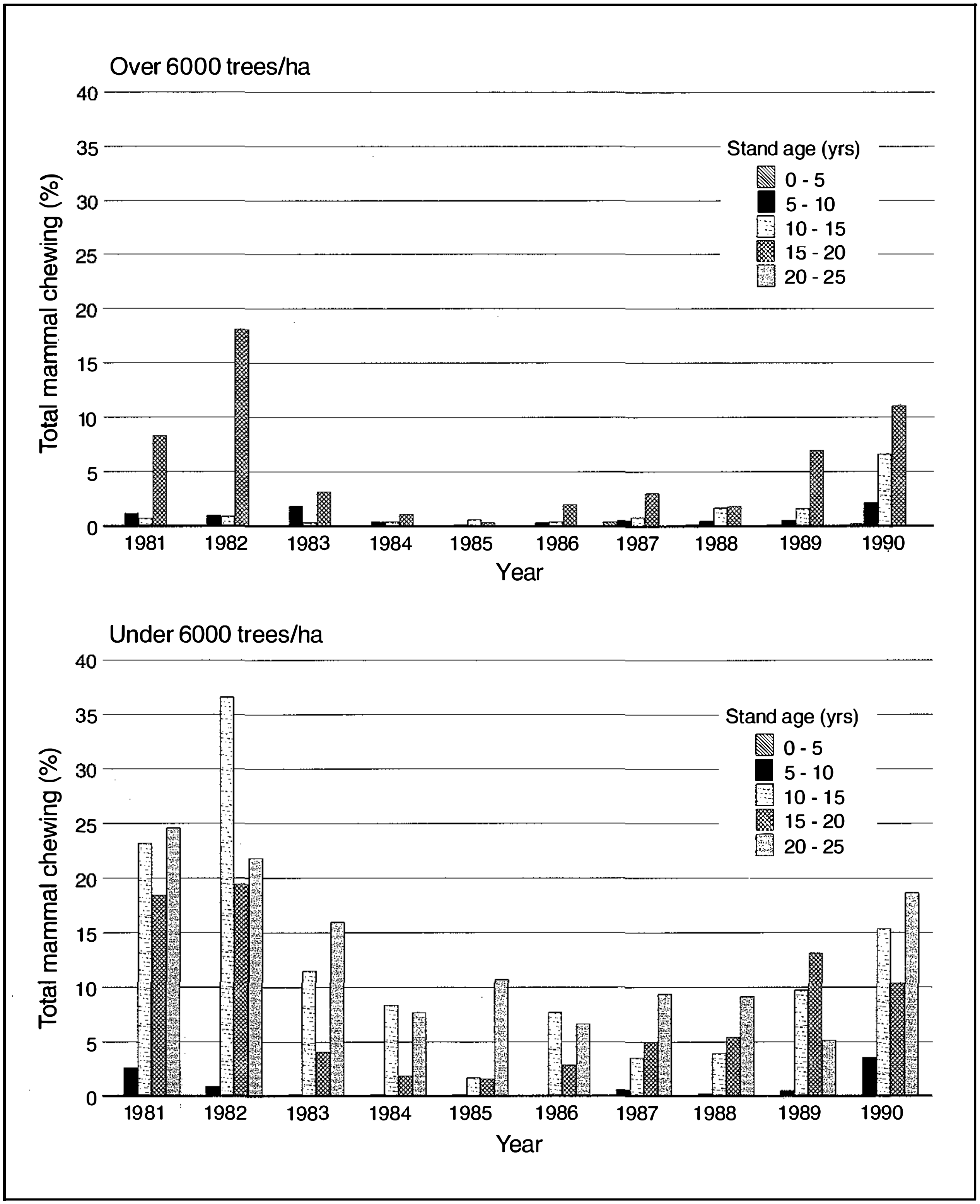

Figure 12. Total chewing by mammals, grouped by years and age classes, for stands with over or under 6000 lodgepole pine/ha.

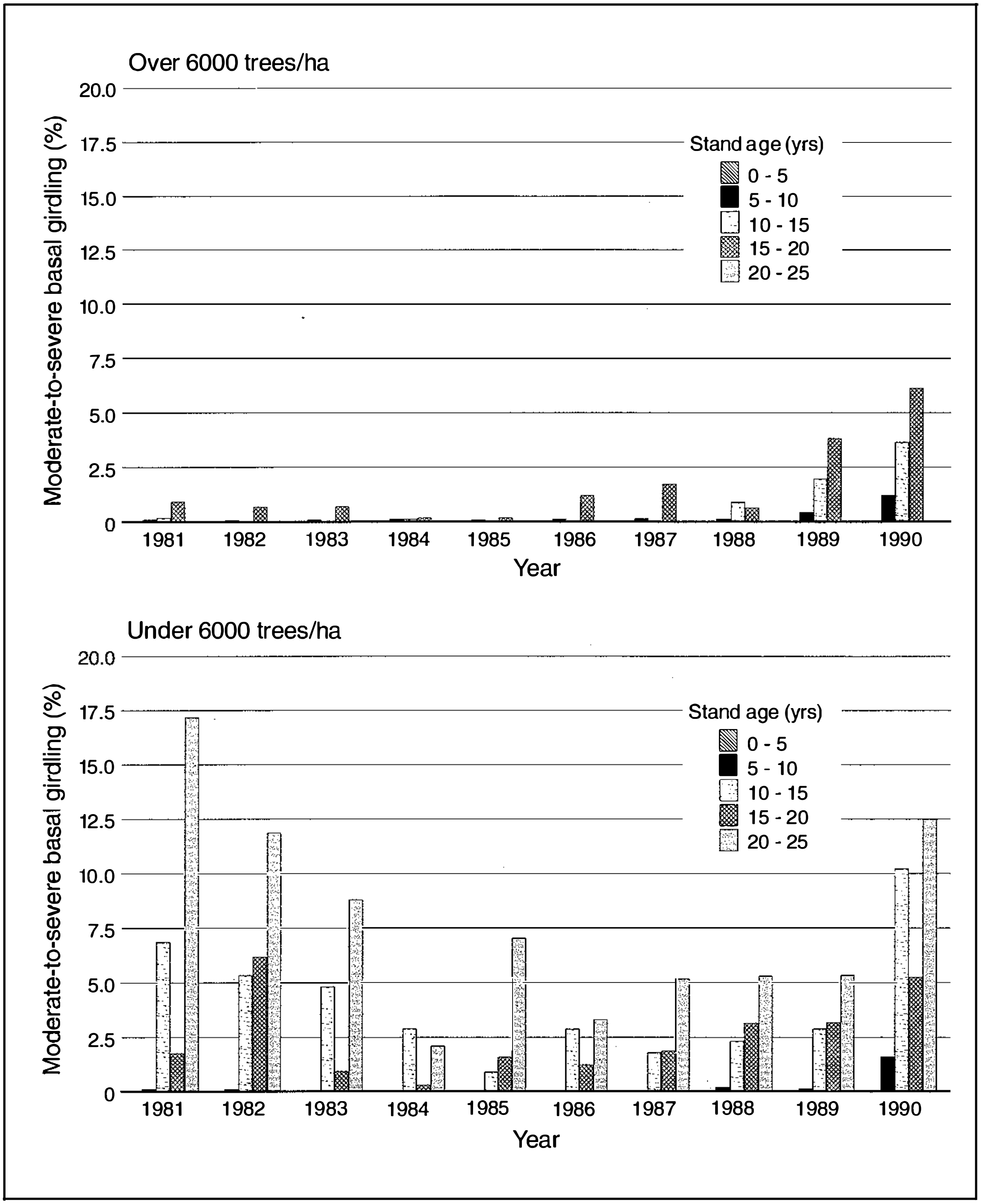

Figure 13. Moderate-to-severe basal girdling, grouped by years and age classes, for stands with over or under 6000 lodgepole pine/ha.

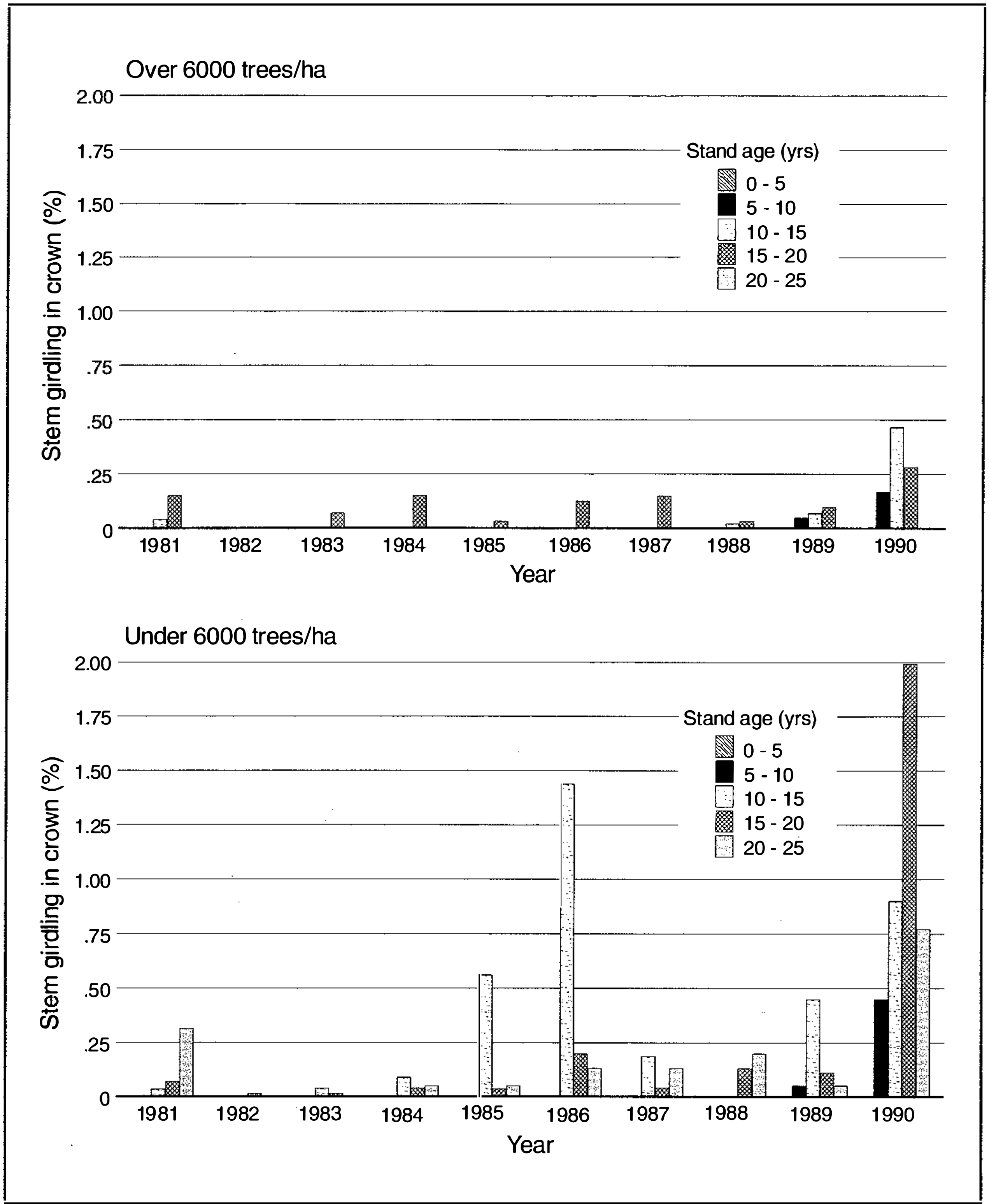

Figure 14. Stem girdling in the crown, grouped by years and age classes, for stands with over or under 6000 lodgepole pine/ha.

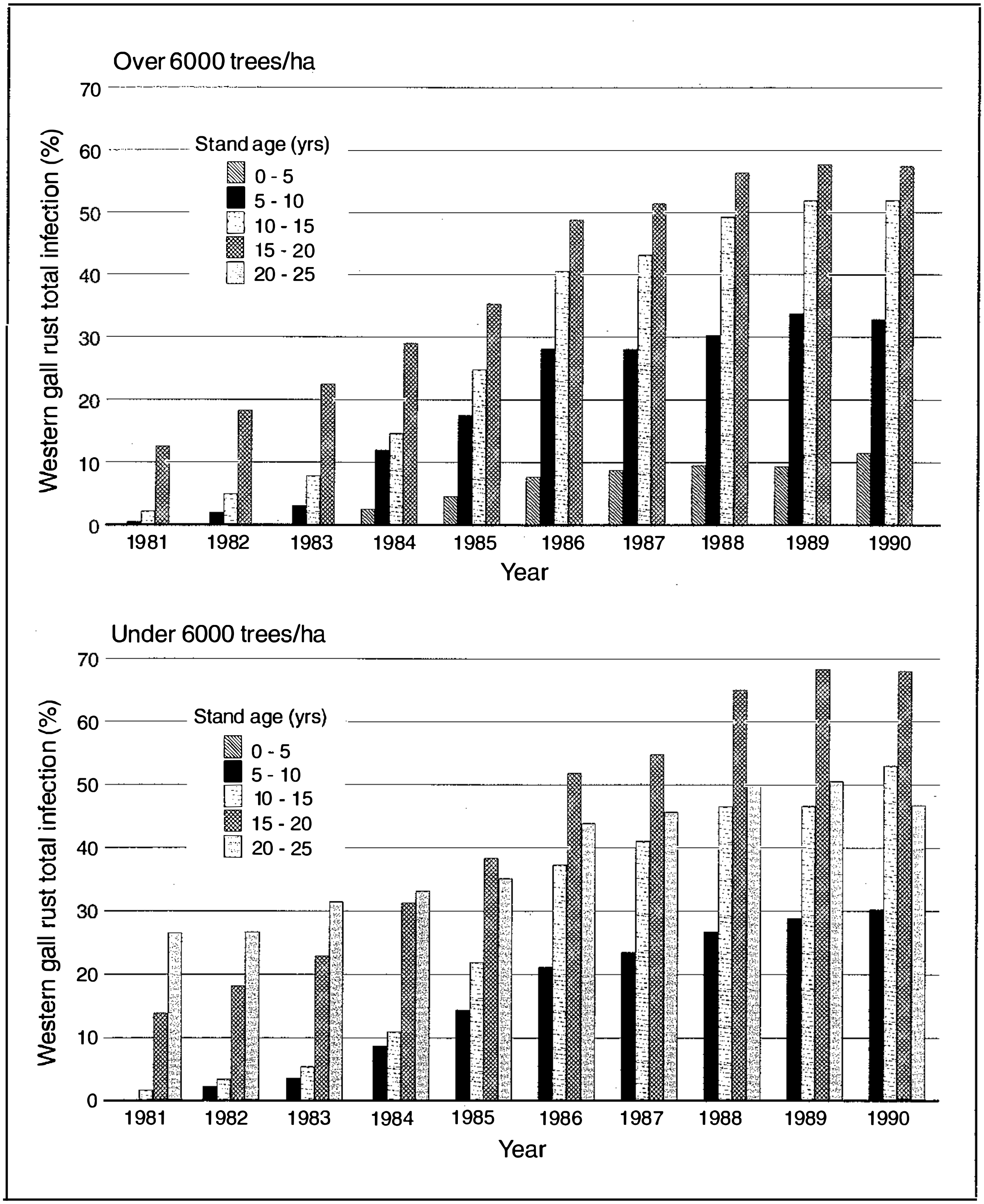

Figure 15. Total infections by western gall rust (*Endocronartium harknessii* [J.P. Moore] Y. Hiratsuka), grouped by years and age classes, for stands with over or under 6000 lodgepole pine/ha.

regular increase within years between age classes. A relative decrease in infection rates occurs once the trees are about 30 years old; infection rates in the 20- to 25-year age class (as of 1981 for most areas) are less than those in the 15- to 20-year age class subsequent to 1985.

Western gall rust stem infections

Trends in stem infections are similar to those in total infections, except that the maximum rates of infection are about 20% lower (Fig. 16). The 1986 to 1990 infection rates in the 10- to 15-year age class are noticeably lower in the less dense stands than in the unthinned ones, but no similar difference is noticeable in the 15- to 20-year-old stands. This may indicate that recent thinning operations have been more effective in removing infected trees than earlier thinning operations. It could also mean that there has been an accelerated rate of increase in stem infections in the more open stands following the early thinning operations.

Blister rust infections

The total incidence of the two blister rusts is very low, and the indicated trend may be nothing more than an artifact (Fig. 17). There appears to have been a slight increase in incidence since 1984 for nearly all age classes, and this increase may be somewhat greater in open stands. There is also a general tendency for incidence within years to be greater in the older stands, but this trend is much more erratic.

Stem Deforming Pests and Their Damage

Two groups of insects, the lodgepole terminal weevil and the pitch blister moths, may cause stem deformities in lodgepole pine and are sometimes abundant in the study areas.

Lodgepole terminal weevil

The incidence of this pest, as revealed by the data (Fig. 18), appears to be unusually low in relation to the amount of damage attributed to it. There may be two explanations for this apparent discrepancy. Firstly, the faded foliage on lightly damaged leaders is difficult to detect at the time the survival studies are conducted, especially when most of the observations are made by relatively inexperienced observers. As a result the actual abundance of the insect is probably underestimated. Secondly, the manifestation of damage, in the form of forked stems or multiple leaders, usually represents the accumulation of several years' damage, because the new leaders require time to assert dominance.

Unlike the rust infections previously discussed, the infestations of lodgepole terminal weevil are often cyclic. Trees of nearly all ages (except for the very young) are attacked, but those over 15 but under 30 years of age are probably most vulnerable. Evidence of the cyclic nature of attack is evident in both the open and dense stands and infestation rates appear to be slightly higher in the more open stands. The first infestation peaked in 1985, and populations were again increasing when the last observations were made in 1990.

Pitch blister moths

Infestations of the two blister moth species (Fig. 19) were high in 1981, when this study began, and have been declining steadily since then. Trees under 5 years of age were sometimes attacked, and open stands had higher infestation rates than dense stands. The most vulnerable group of trees were 15–20 years of age in 1981.

Forked stems or multiple leaders

The annual incidence of forked stems or multiple leaders in the 5- to 10- and 10- to 15-year age classes was similar for open or dense stands (Fig. 20). There may have been a higher incidence of forked tops or multiple leaders in the 15- to 20-year age class in the open stands in some years, but the difference was minimal.

One of the obvious differences between these data and those presented previously is the relatively high incidence of forked tops or multiple leaders in the 0- to 5-year age class. Lodgepole terminal weevil and pitch blister moths have probably both been factors, although unreported browsing may also have been a contributing factor. If the leader had been clipped off in the fall or early spring, the resultant growth would have produced multiple leaders by the time the sampling was done in late summer.

Comparison of the incidence of lodgepole terminal weevil attack with the frequency of forked tops or multiple leaders (Fig. 20) reveals a general similarity for the period 1985–90. There is, however, no similarity between the two sets of data for the 1981–84 period. The latter period coincides with the period of pitch blister moth abundance (Fig. 19). Wong et al. (n.d.) used pheromone traps to show that *Petrova albicapitana* and *Petrova metallica* were about equally abundant in the McLeod compartment in 1983 and 1984. It is, therefore, quite possible that northern pitch twig moths (*P. albicapitana*), were responsible for many of the forked tops and multiple leaders observed during the 1981–84 period.

Root and Root Collar Damage

The incidence of root and root collar damage by Armillaria root rot and the Warren root collar weevil will be discussed separately, although they often occur together. It should be noted, however, that the abundance

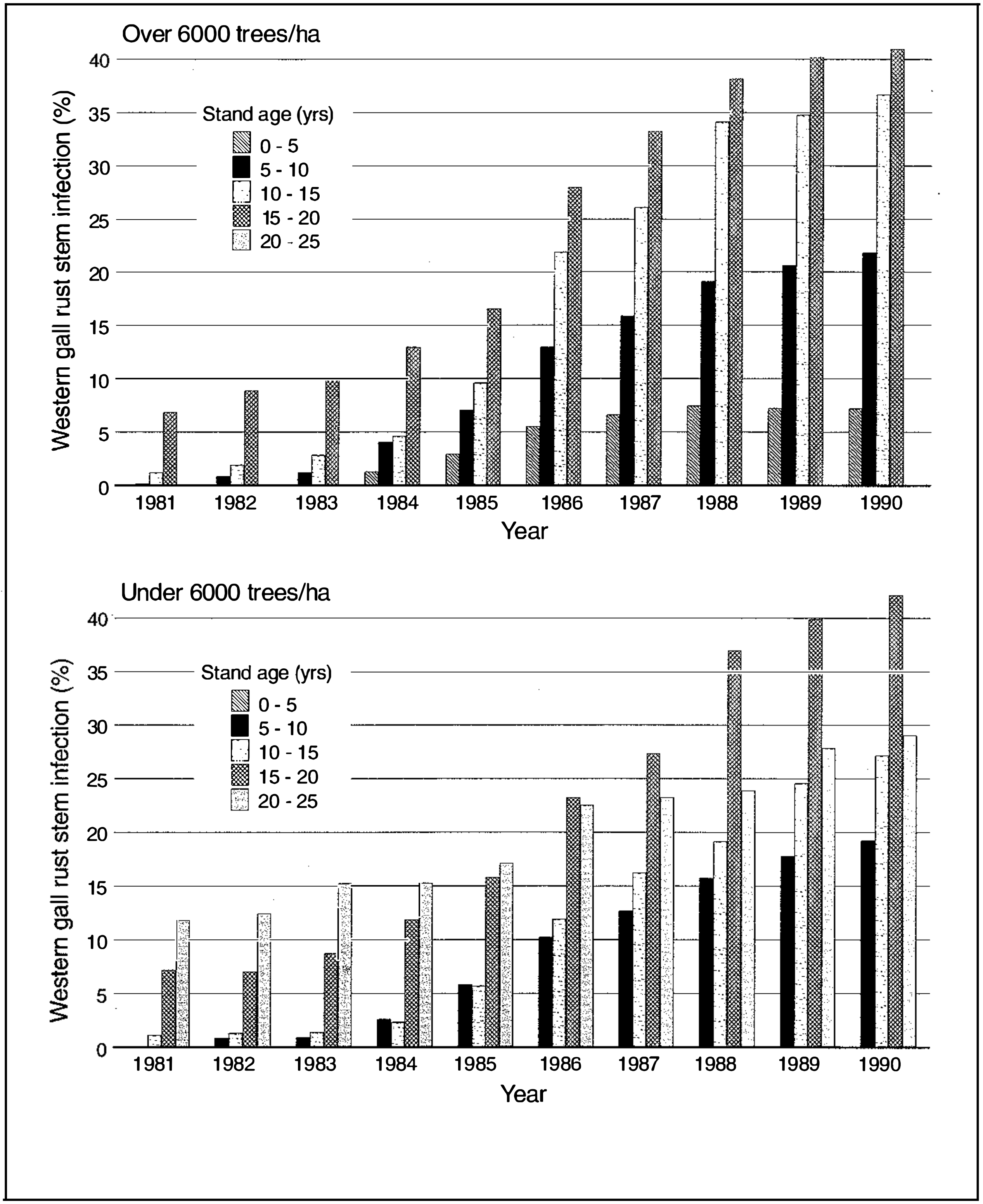

Figure 16. Stem infections by western gall rust (*Endocronartium harknessii* [J.P. Moore] Y. Hiratsuka), grouped by years and age classes, for stands with over or under 6000 lodgepole pine/ha.

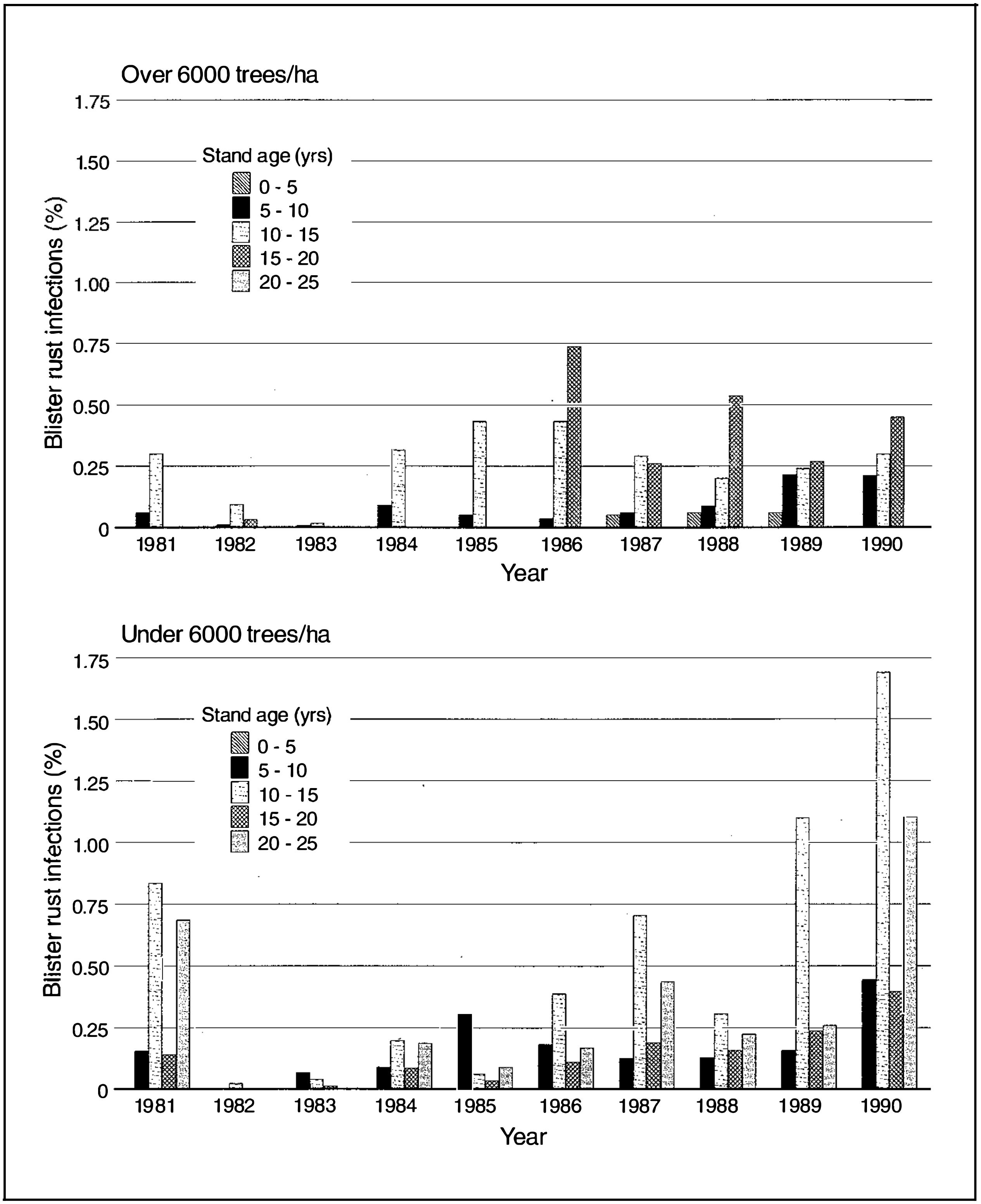

Figure 17. Infections of blister rusts (*Cronartium* spp.), grouped by years and age classes, for stands with over or under 6000 lodgepole pine/ha.

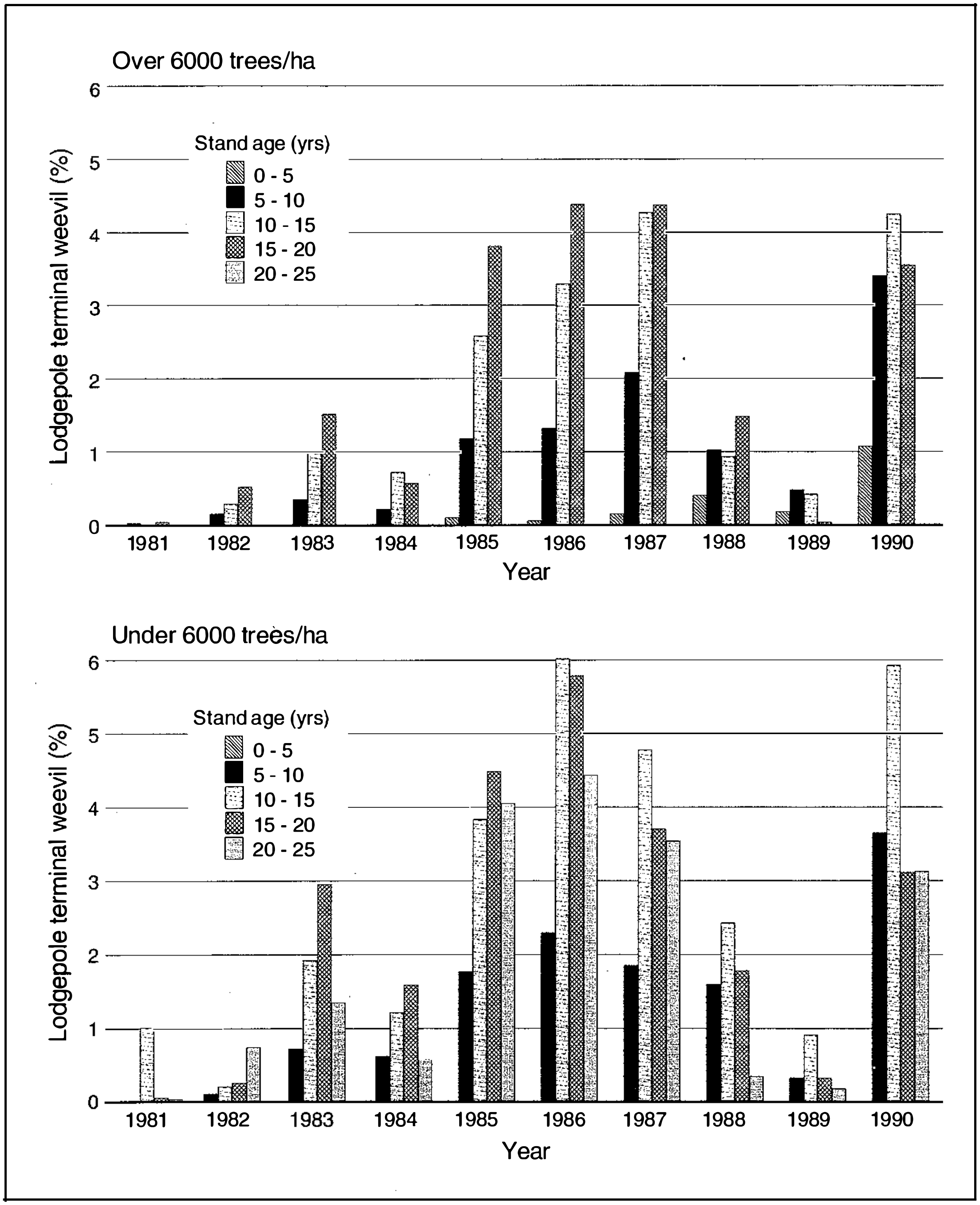

Figure 18. Infestations of the lodgepole terminal weevil (*Pissodes terminalis* Hopping), grouped by years and age classes, for stands with over or under 6000 lodgepole pine/ha.

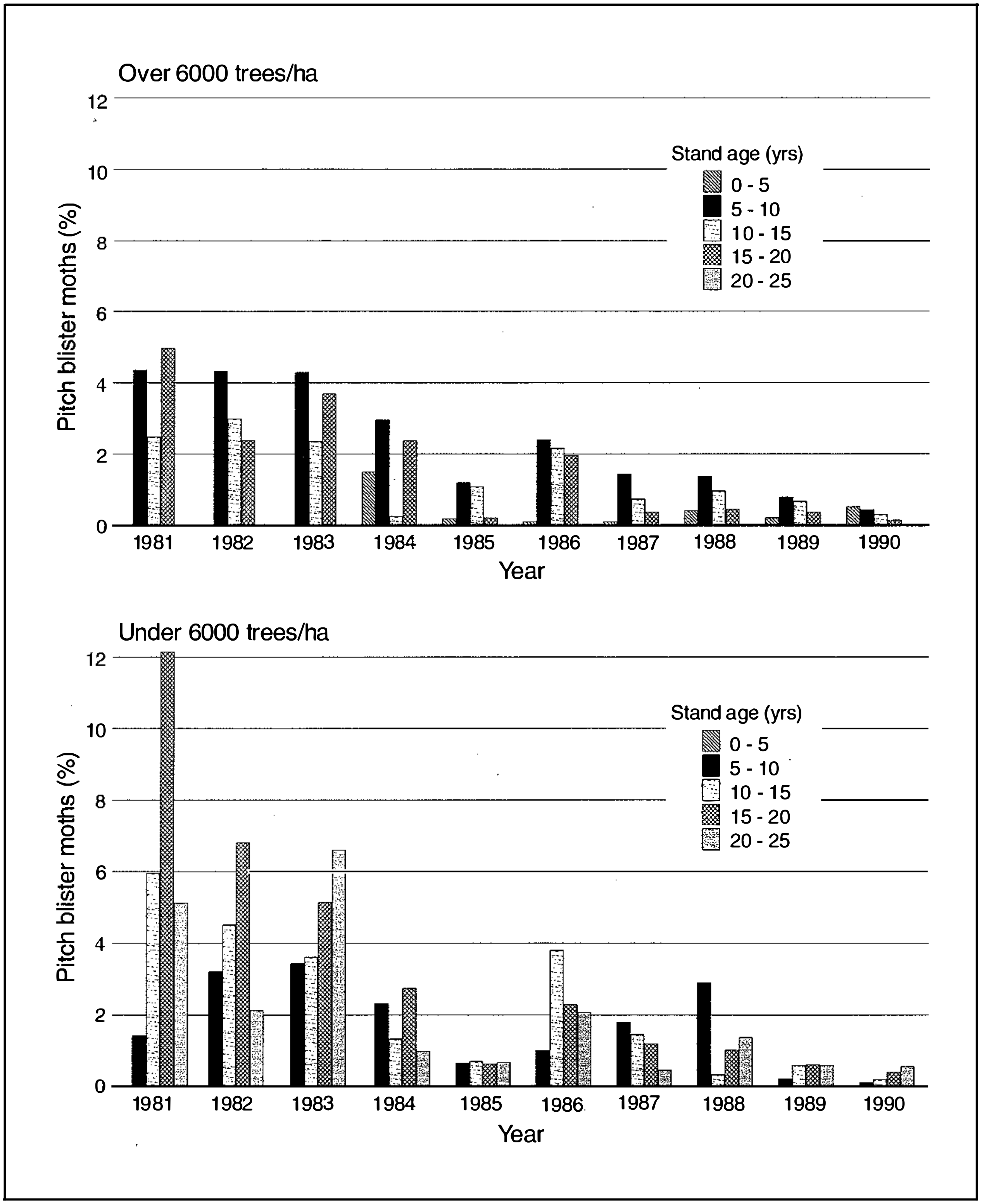

Figure 19. Infestations of pitch blister moths (*Petrova* spp.), grouped by years and age classes, for stands with over or under 6000 lodgepole pine/ha.

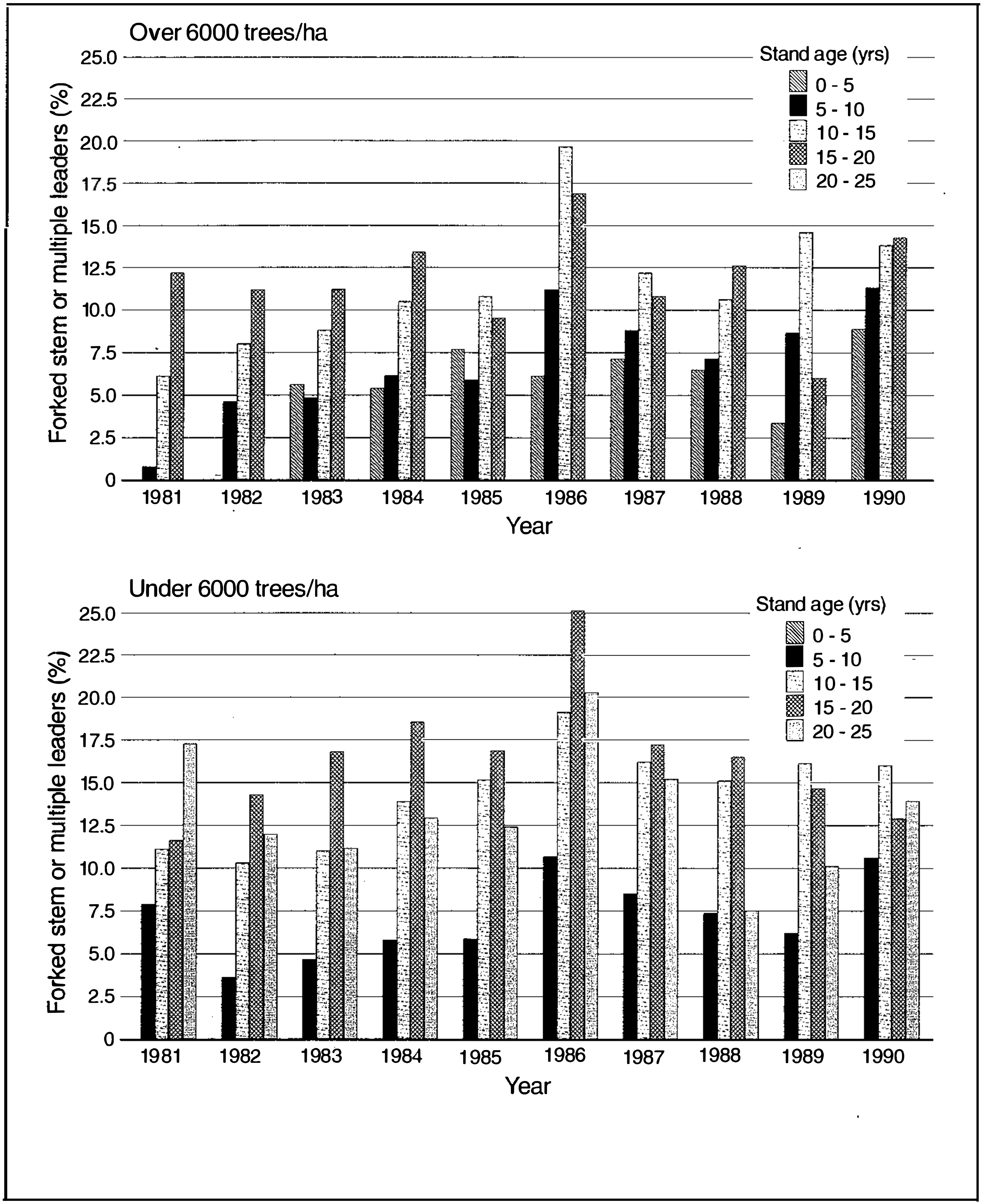

Figure 20. Incidence of forked stems or multiple leaders, grouped by years and age classes, for stands with over or under 6000 lodgepole pine/ha.

of both pests are underestimated because only dead or dying trees were examined.

Armillaria root rot

Most of the trees killed by Armillaria root rot are in the younger age classes (0–5 years and 5–10 years) (Fig. 21). In dense stands, the recorded incidence of disease among the youngest trees increased as of 1990. The prevalence of the disease in 5- to 10-year-old trees (as of 1981 for most areas) peaked in the mid-1980s. In open stands, the peak also occurred in the mid-1980s but in the youngest trees. The incidence of recorded disease in these trees was very low, and therefore any apparent differences between open and dense stands may only be artifacts.

Warren rootcollar weevil

Mortality attributable to the Warren rootcollar weevil (Fig. 22) is even less than that caused by Armillaria root rot. The recorded incidence of the pest appears to be slightly higher in the dense stands, and trees in the 0- to 5- and 5- to 10-year age class (as of 1981 for most areas) are most vulnerable. The fact that young trees are successfully attacked could have serious consequences if cutover areas are planted immediately after harvest. If the original stand is infested with the Warren rootcollar weevil, it is quite possible for the progeny of these beetles to infest the planted trees. Larvae in the cut stumps can complete their development in these stumps (Cerezke 1973), and this may take as long as 3 years. In addition, the adults live for 4 years or more, so that newly planted trees may be large enough to support the weevils before they die out. Thus, even though the adults cannot fly, it is theoretically possible for a major problem to develop, especially in the moister pine sites.

Limitations of the Data

Trees are long-lived organisms and thus it is necessary to pool information on individuals in order to estimate general survival rates in a reasonable time. As with most field observations involving a variety of personnel, the diagnosis of the causes of declining tree conditions was variable. Fortunately, observations in tree death are not affected by this variation in quality. Often environmental conditions also influenced the accuracy of diagnosis. It is much easier, even for a trained observer, to see what is affecting a tree if the day is bright and sunny instead of dull and windy. It is also much easier to thoroughly check a tree that is only 1 or 2 m tall than it is if the height is 10 to 15 m. Another point of discussion is the apparent lack of statistics used in the presentation of the results. Large sample sizes and the graphical approach used provided an indication of trends in survival within the various stands.

The older stands in cutover areas are now suffering an alarming rate of mortality, but this mortality may be an aberration, because many of the old cutover areas are inaccessible. Confirmation of the results should be assessed by future work.

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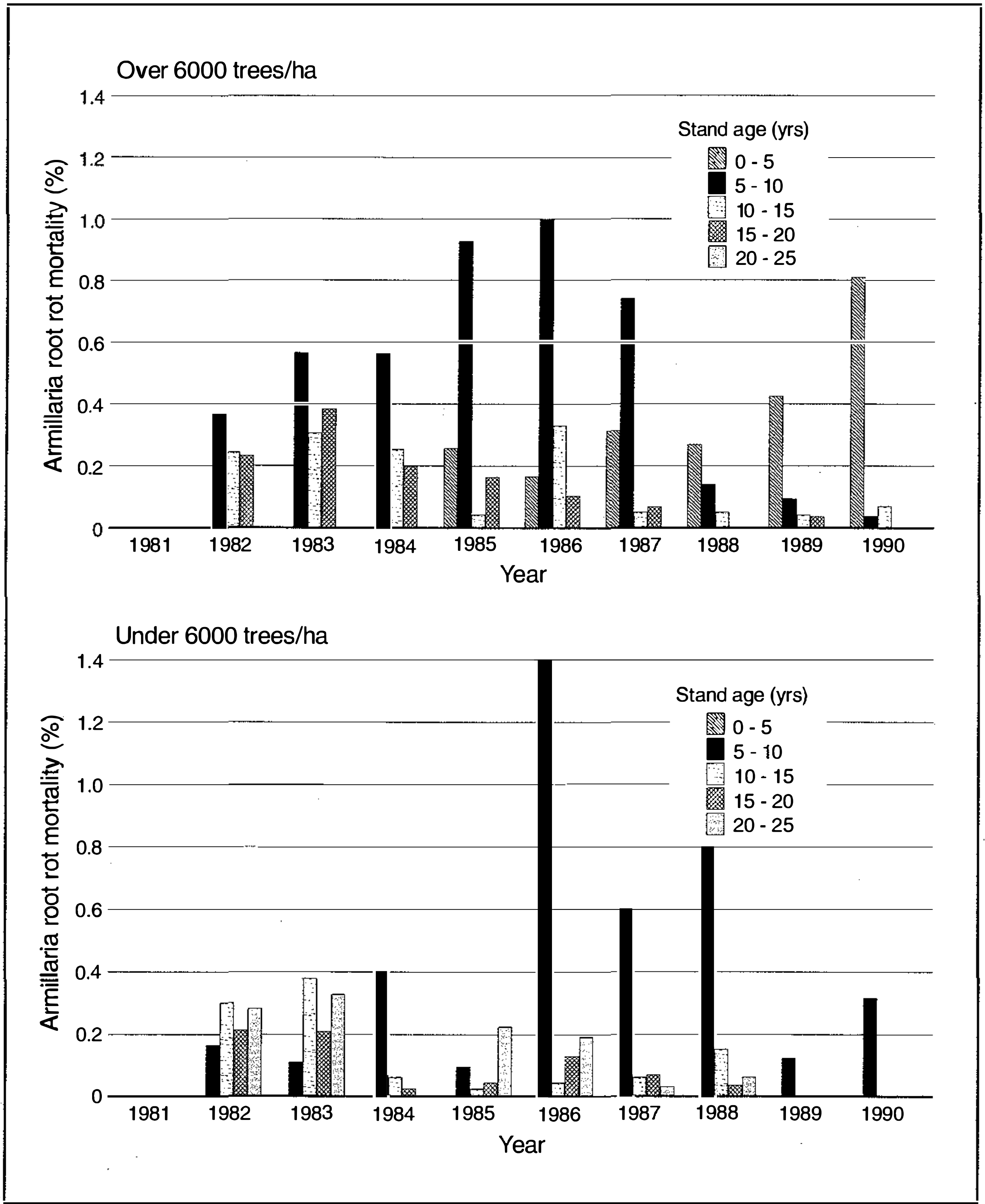

Figure 21. Incidence of mortality caused by Armillaria root rot (*Armillaria ostoyae* [Romagn.] Herink), grouped by years and age classes, for stands with over or under 6000 lodgepole pine/ha.

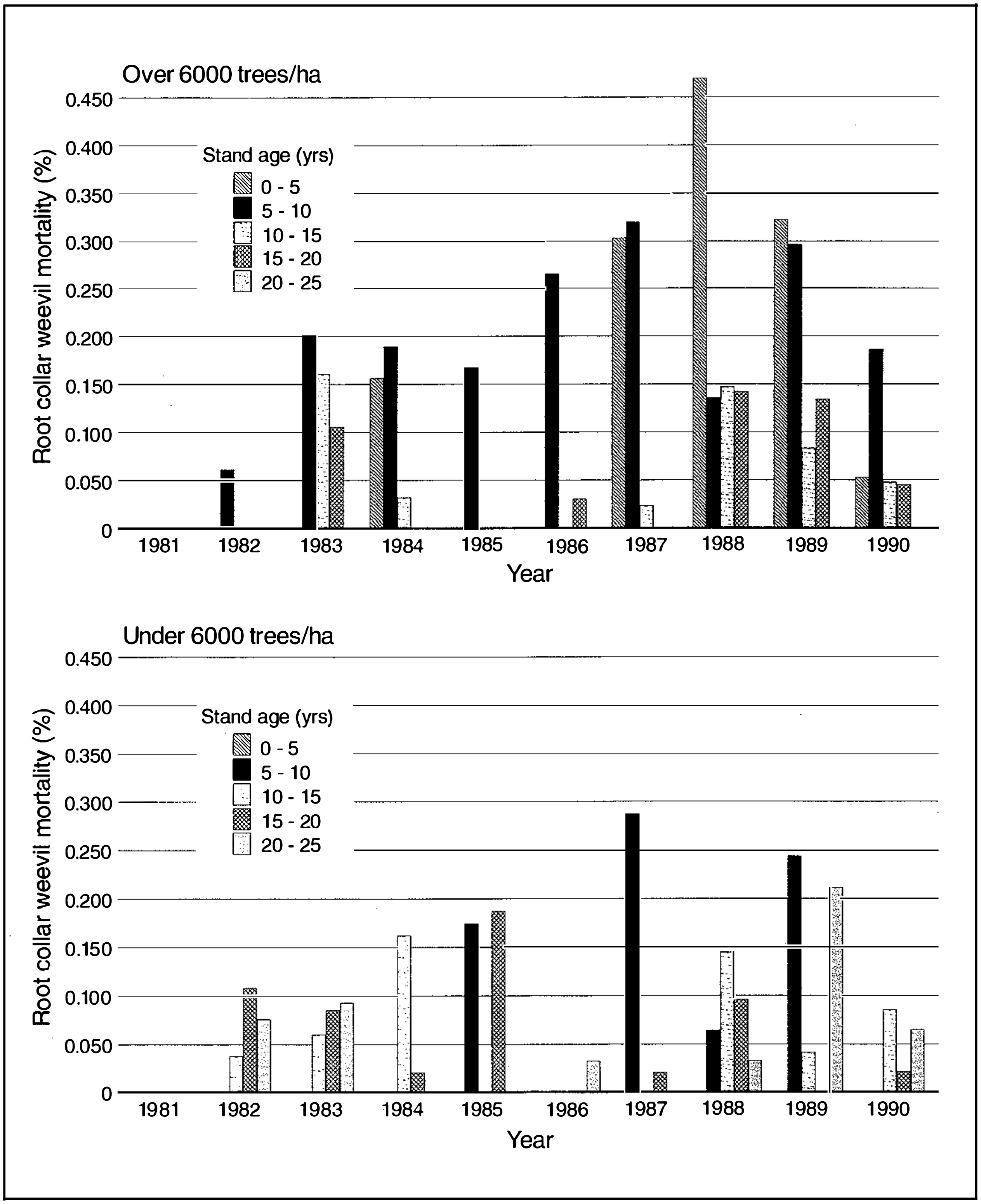

Figure 22. Incidence of mortality caused by the Warren rootcollar weevil (*Hylobius warreni* Wood), grouped by years and age classes, for stands with over or under 6000 lodgepole pine/ha.

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