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Edward H. Holsten, USDA Forest Service, State and Private Forestry, Forest Pest Management, 201 East 9th Avenue,
Anchorage, Alaska 99501

Spruce Beetle Attacks and Surviving Beetle Brood in Limbed and Bucked Spruce in South-Central Alaska

Abstract

The current policy in south-central Alaska for treatment of spruce slash to prevent increase of spruce beetle populations is to limb felled trees that remain on the site and buck the stems into bolts about 0.6 m long. In this study, bucking of stems into short lengths, a costly treatment which failed to reduce bark moisture content, also failed to reduce beetle attack densities or numbers of brood that developed into adults. Limbed bolts, however, produced fewer two-year adults than unlimbed bolts on warm sites, but not on cool sites where numbers of two-year adults were low in both limbed and unlimbed bolts. This information should assist land managers in developing flexible policies for treatment of spruce slash.

Introduction

Right-of-way clearings for highway and powerline construction result in large quantities of spruce (*Picea* spp.) slash and debris. If left untreated, spruce slash can contribute substantially to build-up of spruce beetle (*Dendroctonus rufipennis* Kby.) populations (Schmid 1977) because downed spruce, whether windfelled or cut, are preferred by spruce beetles over standing live spruce (Schmid and Beckwith 1975, Schmid 1981). When downed spruce are not burned or removed, the current policy in south-central Alaska is to limb spruce slash and buck stems that are 15 cm or larger in diameter to about 0.6-m lengths. The rationale for the more labor intensive procedure of bucking is that short bolts should dry more rapidly than long bolts and should thus reduce survival of spruce beetle brood. Therefore, the number of surviving brood that could spread from slash to surrounding live trees should be reduced.

Bucking of slash into short lengths has proven effective for restricting spruce beetle numbers in areas with warm, dry summers such as in the southern Rocky Mountains (Mitchell and Schmid 1973). The primary objective of this study was to determine whether bucking of felled spruce on the Kenai Peninsula into 0.6-m bolt lengths would effectively reduce numbers of spruce beetle attacks and new adults as compared to bolts 2 times, 4 times, or 8 times longer. Secondary objectives were to determine the effects of sample location along bolt surfaces and the effects of limbing on those same response variables.

Study Areas and Methods

The experiment was conducted at five areas on the Kenai Peninsula: three sites near mileposts (MP) 14, 34, and 64 on the Seward Highway north of Seward, a site at Tern Lake near the junction of the Seward and Sterling Highways, and a site at the south end of Snug Harbor Road on Kenai Lake near Cooper Landing. Differences in summer climate and spruce species among study areas suggested a randomized block experimental design with the five study areas as experimental blocks. Sites at MP14 and MP34 lie within a cold-wet fire season climatic zone based on integration of precipitation effectiveness index and temperature efficiency index whereas the remaining study sites lie within a warm-dry fire season climatic zone (Trigg 1971).

In April 1987, eight mature Sitka spruce (*P. sitchensis* (Bong.) Carr.) at MP 14, and eight mature Lutz spruce (*P. x lutzii* Little), the hybrid of Sitka and white spruce (*P. glauca* (Moench) Voss), at each of the four remaining sites were felled into openings exposed to the sun. All sample trees were roughly equal in diameter at 1.7-m height.

Four trees selected at random were limbed and the remaining four trees were left unlimbed at each study area. The lower 9.2-m bole length of each tree in each study area was bucked into four bolts of differing lengths. To ensure that each of the four selected lengths was distributed among the larger and smaller bole diameters, each limbed and unlimbed tree in each experimental block were

randomly assigned without replacement one of the following bucking sequences from lower to upper bole:

- A. 0.6 m, 1.2 m, 2.4 m, 4.9 m
- B. 1.2 m, 2.4 m, 4.9 m, 0.6 m
- C. 2.4 m, 4.9 m, 0.6 m, 1.2 m
- D. 4.9 m, 0.6 m, 1.2 m, 2.4 m

Therefore, the four sequences were replicated twice in each block. Cut ends of adjacent bolts were separated for increased exposure to the air and sun to hasten drying, and bolts were left in place for subsequent spruce beetle attacks.

Four 2-cm diameter bark disks were removed in late June from each bolt at mid-length: one from the bottom side, one from each lateral side, and one from the top side. Disks from each bolt were combined and frozen in a separate small plastic bag for laboratory determination of bark percent moisture content on a dry-weight basis. Bark was re-sampled in the same manner in August to determine degree of drying by the end of the first summer.

Four of the experimental trees in each study area were randomly selected for spruce beetle sampling in the early fall of 1987. Four 15.24-cm by 15.24-cm bark squares were removed from each tree bolt at mid-length, one from the upper surface, one from the lower surface, and one from each side to determine mean numbers of attacks and recently matured adults visible at the cambial surface. In south-central Alaska, a variable proportion of beetles, depending on exposure to warm temperatures, matures by the end of the first summer and the remainder matures during the second summer (Werner and Holsten 1985). These beetles are referred to, respectively, as "one-year" and "two-year" adults.

The remaining sample trees were sampled in the early fall of 1988 to determine densities of two-year adults, but twelve 45.6 cm² bark disks (diameter = 7.6 cm) were removed from each bolt, four about 15 cm from each end and four from midbolt. Each subset of four disks was distributed around the circumference of the bolt as with 1987 samples.

Larger numbers of samples were taken per bolt in 1988 to assess the effect of horizontal as well as vertical positioning along the bolt on production of two-year adults. Smaller individual samples were chosen in 1988 because they were considered adequate to assess two-year adult popula-

tions, which are usually higher than densities of attacks of one-year adults, and because the smaller samples could be dissected more easily. Dissection allowed accurate counts of two-year adults that were distributed throughout the phloem in each sample disk.

Numbers of beetle attacks and one-year or two-year adults per 100 cm² were transformed to natural logarithms, $\ln(X + 1)$. These data were analyzed by the General Linear Models (GLM) multivariate analysis of variance (MANOVA), a procedure appropriate for balanced data (SAS Institute 1987), to test for (a) significant differences in spruce beetle attacks and (b) new adults among sample areas, sample bolt lengths, and position on sample bolts.

By mistake, only one limbed tree versus three unlimbed trees at MP 14 and three limbed trees versus one unlimbed tree at Snug Harbor were chosen for sampling in 1987. This left three limbed trees versus one unlimbed and one limbed versus three unlimbed trees at MP 14 and Snug Harbor, respectively, for sampling in 1988. Only limbed trees were sampled in 1987 and only unlimbed trees were sampled in 1988 at MP 64. Therefore effect of limbing on density of two-year adults, only, was analyzed by the GLM procedure for unbalanced data analysis of variance (ANOVA) (SAS Institute 1987), but MP 64 data were excluded. Densities of attacks and one-year adults were eliminated from this analysis because there were no apparent differences in means between limbed and unlimbed bolts (Fig. 2AB).

Because separate variables measured on the same sample units are commonly correlated, significance level for all analyses was set conservatively at $\alpha = 0.01$.

Results and Discussion

Sample block was significant for densities of attacks and two-year adults (Table 1A), so blocking by study area in a randomized block experimental design was effective (Lentner *et al.* 1989).

Bolt length had no significant effect on any response variable (Table 1A, Table 2). Mean bark moisture content generally differed little between June and August 1987 among limbed or unlimbed bolts regardless of bolt length for combined experimental blocks from warm-dry or cold-wet zones (Figure 1AB). We do not know why bark moisture remained high through the summer but the Kenai

TABLE 1. Probability of a greater F for spruce beetle response variables by sources of variation. A. GLM MANOVA for all study areas and B. GLM ANOVAs for all study areas except Granite Creek.

Source of Variation	1987		1988
	Attacks	One-year adults	Two-year adults
A.			
Sample block	0.0001	0.012	0.006
Bolt length	0.74	0.65	0.76
Bolt position ^a			0.02
Bolt side	0.0001	0.0001	0.0001
Interactions: ^b			
Position x side			0.006
B.			
Limbing			0.33

^aButt end, middle, or upper end of bolts sampled in 1988

^bOnly those that were significant.

Peninsula is not arid (U.S. Department of Commerce 1989). Furthermore, sample trees in most areas were moistened several times by light rains and by dew from adjacent tall grasses (*Calamagrostis* spp.), that occupy many natural clearings.

Bolt side had a significant effect on mean densities of attacks and densities of one- and two-year adults (Table 1A), with highest mean densities usually occurring on the bottom side and lowest numbers on the top side. This pattern follows the distribution reported for spruce beetles in logging slash in British Columbia (Dyer and Taylor 1971) and windfelled spruce in the Rocky Mountains (Schmid 1981), which was attributed to the beetle's preference for attacking shaded host material and to higher brood mortality in upper bole surfaces during both winter and summer.

Mean densities of two-year adults were consistently higher at mid-bolt than at the bolt ends regardless of bolt length (Table 3). Whether the slightly lower mean densities of adults near bolt ends were a result of more rapid phloem deterioration, higher brood parasitization, or predation is unknown because parasite and predator populations were not monitored.

The interaction of bolt position x bolt side was significant for two-year adults (Table 1A) presumably because approximately equal mean densities on bottom and lateral sides occurred at the upper ends, only, of bolts (Table 3). This resulted in non-parallel curves of two-year adult

TABLE 2. A. Spruce beetle attacks, B. one-year adults, and C. two-year adults per 100 cm² ($\bar{X} \pm SE$).

Bolt Length (m)	Study Area				
	MP 14	MP 34	Tern Lake	Snug Harbor	HP 64
A.					
0.6	0.38 ± 0.11	0.66 ± 0.10	0.68 ± 0.16	0.70 ± 0.14	0.45 ± 0.09
1.2	0.25 ± 0.08	1.15 ± 0.16	0.39 ± 0.10	0.95 ± 0.20	0.38 ± 0.14
2.4	0.09 ± 0.05	0.91 ± 0.16	0.48 ± 0.12	0.83 ± 0.19	0.34 ± 0.11
4.9	0.23 ± 0.10	0.81 ± 0.14	0.77 ± 0.13	0.63 ± 0.14	0.39 ± 0.11
Mean	0.24 ± 0.04	0.88 ± 0.07	0.58 ± 0.07	0.78 ± 0.08	0.39 ± 0.05
B.					
0.6	0.20 ± 0.07	0.54 ± 0.22	1.06 ± 0.38	1.04 ± 0.31	0.41 ± 0.16
1.2	0.25 ± 0.07	1.09 ± 0.49	0.45 ± 0.13	0.34 ± 0.19	0.26 ± 0.14
2.4	0.27 ± 0.18	0.66 ± 0.24	1.31 ± 0.67	0.65 ± 0.26	0.43 ± 0.20
4.9	0.36 ± 0.16	0.61 ± 0.23	0.72 ± 0.27	1.11 ± 0.33	0.48 ± 0.22
Mean	0.27 ± 0.06	0.73 ± 0.16	0.88 ± 0.20	0.78 ± 0.14	0.41 ± 0.09
C.					
0.6	3.44 ± 0.93	3.32 ± 0.86	3.11 ± 0.73	3.62 ± 0.96	4.92 ± 1.24
1.2	1.71 ± 0.46	3.26 ± 0.85	3.20 ± 0.54	6.09 ± 1.04	6.70 ± 1.31
2.4	1.92 ± 0.47	1.77 ± 0.47	4.90 ± 1.17	9.17 ± 1.54	8.13 ± 1.86
4.9	3.44 ± 0.80	1.22 ± 0.40	3.93 ± 1.15	6.27 ± 1.05	4.71 ± 1.36
Mean	2.63 ± 0.35	2.38 ± 0.34	3.78 ± 0.47	6.29 ± 0.60	6.24 ± 0.75

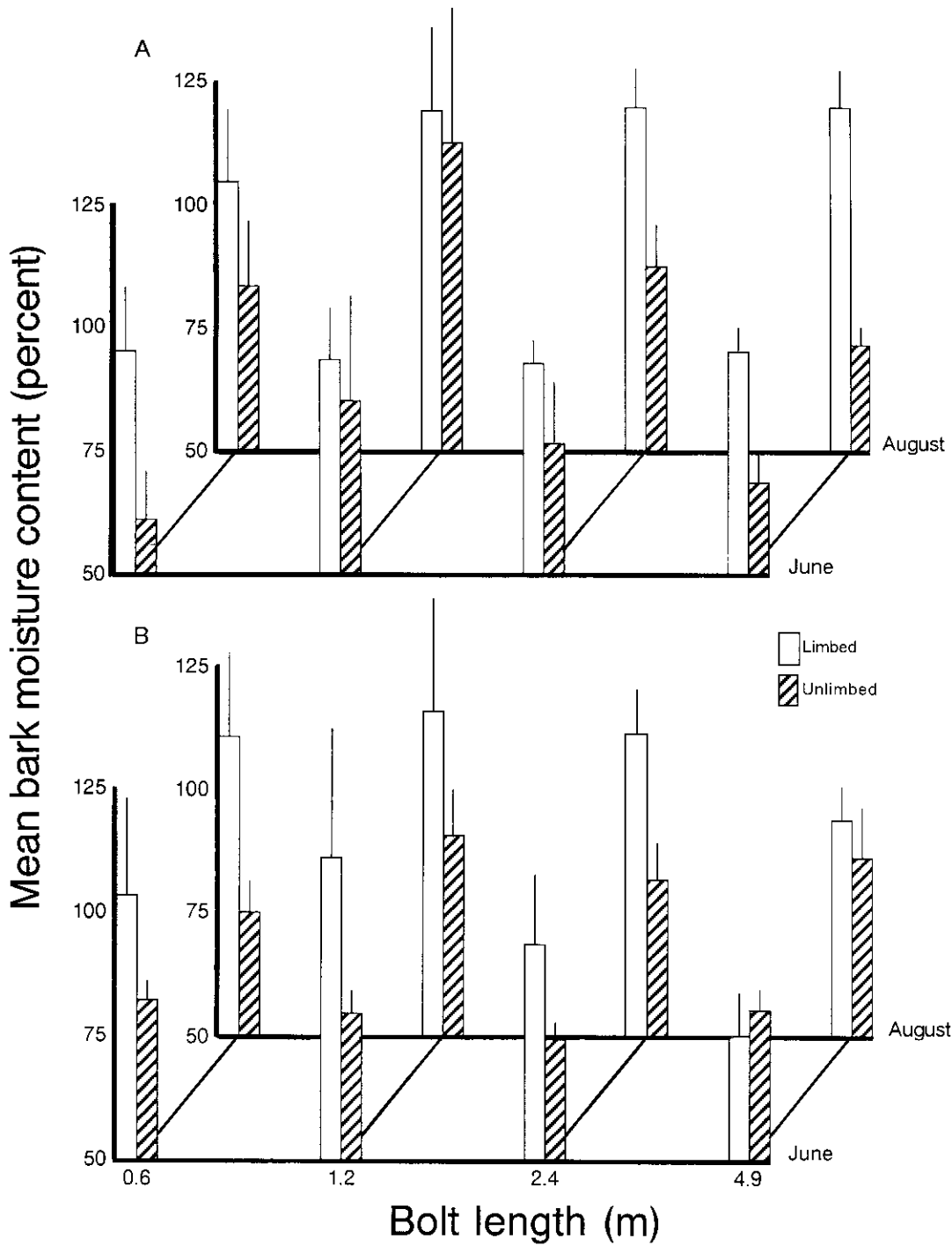


Figure 1. Mean bark moisture content by bolt length and 1987 sample month. A. Warm-dry zone (Trigg 1971): Tern Lake and Snug Harbor combined B. Cold-wet zone (Trigg 1971): MP 14 and MP 34 combined. Vertical lines extending above bars equal one SE.

TABLE 3. Spruce beetle two-year adults per 100 cm² in limbed versus unlimbed bolts from all study areas ($\bar{X} \pm SE$).

Sample		Limbed	Bolt Length (m)			
Position	Side		0.6	1.2	2.4	1.9
Butt	Bottom	Yes	6.30 ± 2.94	3.45 ± 1.50	6.30 ± 2.05	2.74 ± 1.48
		No	7.31 ± 3.36	4.20 ± 1.47	7.68 ± 2.10	5.18 ± 1.63
	Lateral	Yes	0.69 ± 0.29	1.64 ± 0.78	2.19 ± 1.04	1.92 ± 1.05
		No	3.02 ± 1.19	4.39 ± 0.89	5.03 ± 1.54	2.29 ± 0.92
	Top	Yes	0.55 ± 0.55	2.19 ± 1.61	0.55 ± 0.55	0.27 ± 0.27
		No	2.74 ± 1.33	3.47 ± 1.54	5.67 ± 2.01	2.79 ± 1.42
	Mean		3.58 ± 0.89	3.38 ± 0.55	4.88 ± 0.76	2.67 ± 0.54
Middle	Bottom	Yes	3.56 ± 2.75	7.95 ± 3.24	3.56 ± 1.09	4.11 ± 2.67
		No	6.98 ± 1.41	8.04 ± 3.08	12.43 ± 3.60	11.16 ± 3.20
	Lateral	Yes	0.82 ± 0.45	1.37 ± 0.78	2.47 ± 1.01	2.47 ± 1.12
		No	4.57 ± 1.18	6.67 ± 2.09	5.12 ± 1.42	6.28 ± 2.10
	Top	Yes	2.19 ± 1.24	0.82 ± 0.58	1.10 ± 0.83	0.00
		No	3.59 ± 1.71	5.67 ± 1.78	4.57 ± 1.99	3.79 ± 1.75
	Mean		3.86 ± 9.66	5.43 ± 0.97	5.37 ± 1.00	5.06 ± 0.99
Upper	Bottom	Yes	3.56 ± 1.60	3.84 ± 0.99	1.92 ± 1.34	1.64 ± 0.90
		No	6.18 ± 1.91	4.75 ± 1.47	7.68 ± 4.01	6.78 ± 2.57
	Lateral	Yes	0.41 ± 0.29	3.15 ± 1.14	1.37 ± 0.58	4.66 ± 1.01
		No	4.75 ± 0.86	7.04 ± 1.72	8.50 ± 2.67	6.18 ± 1.74
	Top	Yes	4.93 ± 2.51	1.37 ± 0.82	0.55 ± 0.55	0.00
		No	1.10 ± 0.57	1.46 ± 0.78	7.68 ± 3.81	2.59 ± 1.14
	Mean		3.55 ± 0.62	3.76 ± 0.58	5.28 ± 1.28	3.89 ± 0.72

densities plotted by bolt sample side over bolt longitudinal position, and thus an interaction effect.

The pervasively higher numbers of two-year adults from unlimbed samples (Table 3) results partially from inclusion of samples from MP 64 which were taken only from unlimbed trees. Results of ANOVAs that excluded MP 64 data showed, however, that limbing had no consistent effect on two-year adult beetle density (Table 1B). Higher densities of two-year adults were found in unpruned bolts only at Tern Lake and Snug Harbor (Figure 2A) near Cooper Landing which has warm, dry summers, whereas MP34 and MP14 are closer to Seward and its maritime climate where cooler, wetter summers prevail.

Mean percent bark moisture content was usually lower in unlimbed bolts (Figure 1AB), apparently because moisture continued to transpire through intact foliage (Johnson and Zingg 1969). These results suggest that limbing may affect production of two-year adults by inhibiting changes in bark moisture content and through increases in daytime bark temperature.

Optimum phloem temperatures for spruce beetle oviposition (Sahota and Thomson 1979), brood development (Dyer *et al.* 1968), or survival (Dyer and Taylor 1971) may be exceeded on limbed trees in warm-dry zones. Conversely, limbing in cold-wet zones may allow phloem temperatures to rise to near optimum levels. Hard (in press) showed that in standing spruce on a warm site, pruned boles were successfully attacked less often by spruce beetles than were unpruned boles. Furthermore, trees with subcortical bark temperatures that exceeded 18°C at solar noon during beetle mass-attacks had fewer successful attacks than trees with lower bark temperatures.

Conclusions

Bucking of downed spruce into short lengths did not hasten drying of bark or reduce emerging spruce beetle populations on the Kenai Peninsula, but limbed bolts had lower densities of two-year adults in warm-dry areas. These results should not be extrapolated, however, to areas off the Kenai Peninsula.

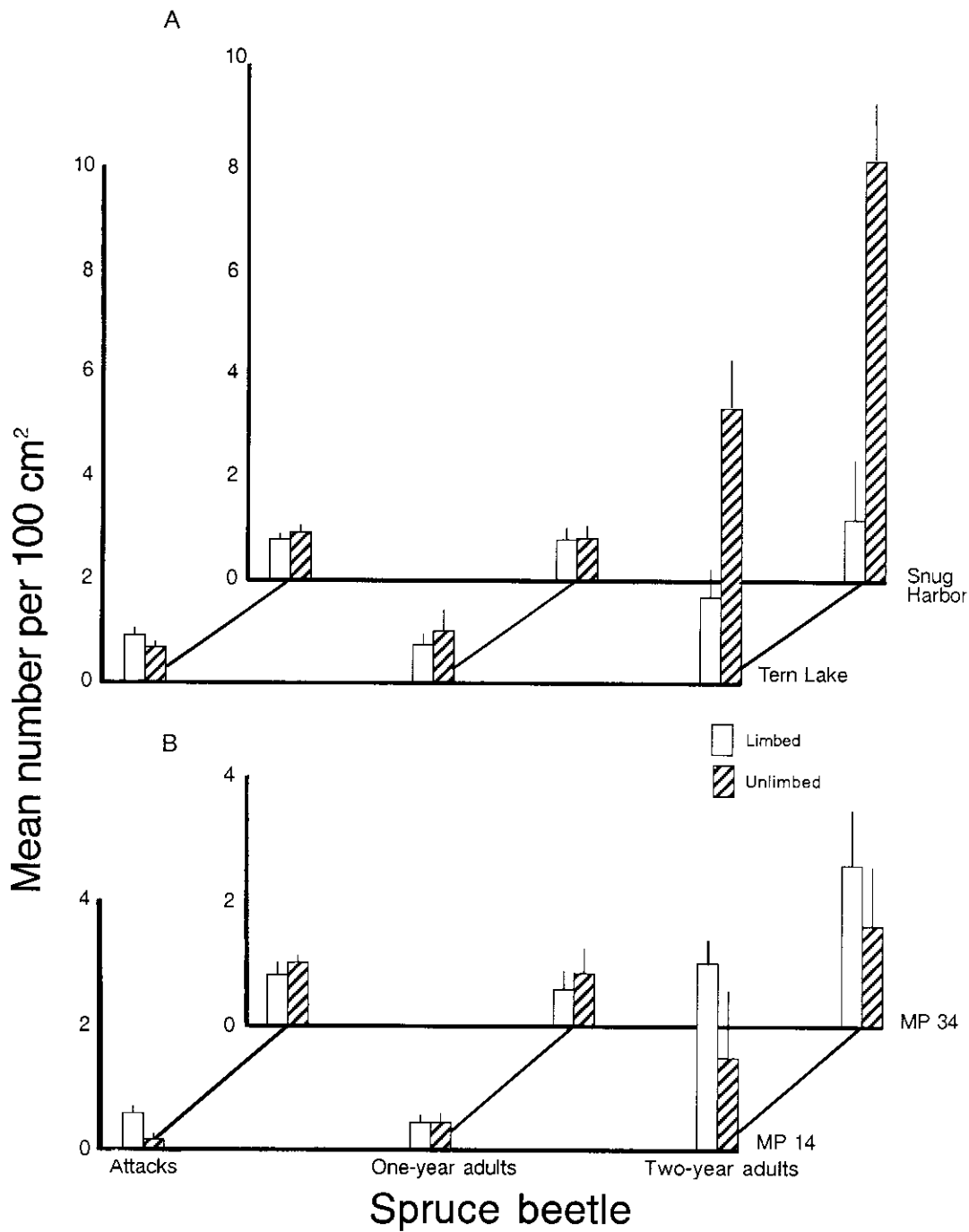


Figure 2. Mean numbers of attacks, one-year adults, and two-year adults from limbed and unlimbed bolts. A. Warm-dry: Tern Lake and Snug Harbor. B. Cold-wet: MP 14 and MP 34. Vertical lines extending above bars equal one SE.

Where spruce slash cannot be burned, treated with pesticide, or removed to prevent beetle population increase, scattering limbed and bucked stems in lengths necessary only to facilitate handling in cleared areas most exposed to the sun may be practical. Limbing and scattering may not prevent beetle population increase in spruce slash but it should slow the rate of increase in areas with warm-dry summers where spruce beetle outbreaks are typically more intense.

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