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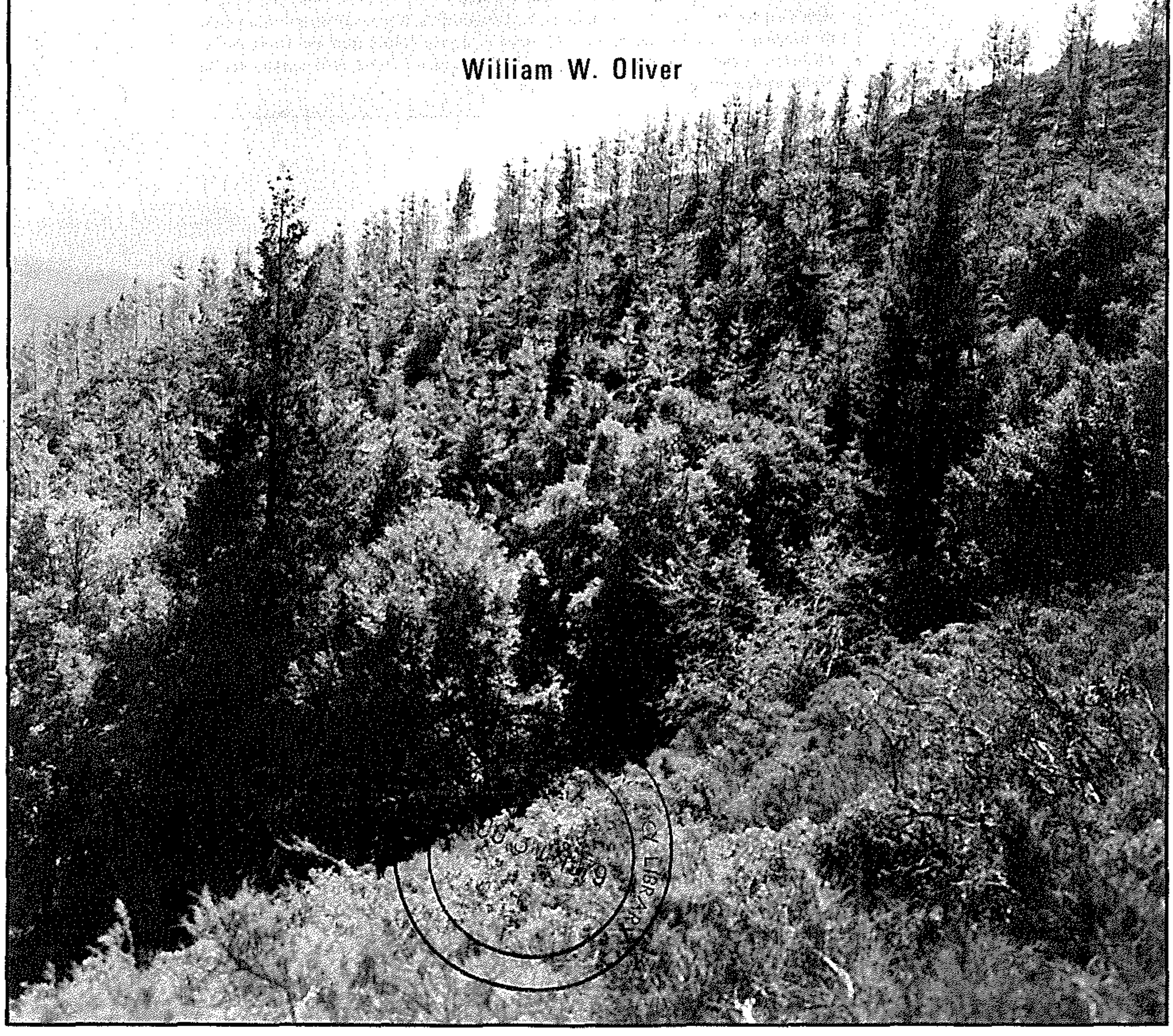
Growth and Mortality of Thinned Knobcone X Monterey Pine Saplings Affected by Engraver Beetles and a Hard Freeze

William W. Oliver



RESEARCH PAPER PSW-139

The Author

WILLIAM W. OLIVER is doing silvicultural research on Sierra Nevada conifer types, with headquarters at Redding, California. He earned a B.S. degree (1956) in forestry from the University of New Hampshire, and an M.F. degree (1960) from the University of Michigan. A native of Pennsylvania, he joined the Station in 1962, after working for the Michigan Department of Natural Resources.

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Retrieval Terms: Pinus attenuata × Pinus radiata, growth, mortality, thinning, *Ips paraconfusus,* freeze damage.

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IN BRIEF...

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The knobcone (*Pinus attenuata* Lemm.) × Monterey pine (*P. radiata* D. Don) is a drought-hardy, fast-growing hybrid, popular for stabilizing soils and screening campgrounds. The hybrid seems suited, also, to produce roundwood on a short rotation, especially on marginal timber sites. Stand management techniques have been little known, however. This paper reports the growth and mortality of an 8-year-old knobcone × Monterey pine plantation 5 years after thinning to three different spacings and 4 years after a hard freeze.

The plantation lies at 3200 feet (976 m) elevation on a steep east-facing slope in the Klamath Mountain Province of northern California. Summers are dry and hot and winters are moist and cool, with temperatures seldom below 10° F (−12° C).

In February 1964, about 5 acres (2 ha), cleared of dense chaparral, were planted with 1-0 stock. Early survival and growth was extraordinary. Eight growing seasons later, in the fall of 1971, crowns had closed and intertree competition was intense when the stand was thinned from below. For the thinning study, three spacing treatments were assigned randomly to two each of six 0.1-acre (0.04-ha) plots. Spacings were 8 by 8 feet (2.4 by 2.4 m), 12 by 12 feet (3.7 by 3.7 m), and 16 by 16 feet (4.9 by 4.9 m).

By July 1972, 8 months after thinning, the California five-spined engraver (*Ips paraconfusus*) had killed 15 percent of the trees. Mortality was evenly distributed throughout all plots and was not related to spacing. No trees died from engraver attacks after July 1972. Apparently, the engraver population reached epidemic levels by breeding in slash during the winter and early spring—an unusual occurrence.

Beginning on December 8, 1972, one growing season after thinning, northern California was gripped by severe cold. Minimum temperatures of between 0° F and −10° F (−18° C and −23° C) for 4 days created the most severe conditions in 40 years. The foliage of most trees was injured and 20 percent of the trees were killed, apparently from winter desiccation. Again, no pattern was discernible among treatment plots. As expected, however, mortality was concentrated in trees with greater foliar damage.

The engraver and the freeze accounted for all mortality in the 5 years since thinning. Although a few more trees died in the plots with narrower spacings, the proportion of trees killed by both the engraver and freeze increased with wider spacing from 17 percent for trees spaced 8 by 8 feet (2.4 by 2.4 m) to 48 percent for trees spaced 16 by 16 feet (4.9 by 4.9 m).

Diameter growth of the average tree surviving the freeze was reduced significantly the following year. Trees that had been growing 0.50 inch (1.3 cm) in diameter before the freeze grew only 0.20 inch (0.5 cm) the year following—a 60 percent drop. The duration of reduced diameter growth cannot be determined, however. Certainly the decline in growth lasted 2 years. But the third and fourth years after the freeze, growth leveled off at a rate well below that before the freeze. Failure of diameter growth to return to pre-freeze rates may have been caused by (a) secondary agents attacking freeze-weakened trees, (b) below-normal precipitation, (c) intertree competition, or (d) age.

Severity of freeze damage also influenced the amount of subsequent diameter growth. As expected, trees on which a greater proportion of the needles had turned brown grew less rapidly following the freeze than did those with a smaller proportion of brown needles.

Mortality and residual effects of the freeze may have overshadowed the influence of spacing on most growth measures. Diameter growth, however, was strongly influenced by spacing. Trees grew 0.28-inch (0.7-cm) annually when spaced 8 to 9 feet (2.4 to 2.7 m) apart to 0.48-inch (1.2-cm) when spaced 14 to 22 feet (4.3 to 6.7 m) apart.

Freeze damage and mortality must be considered in the management of knobcone × Monterey pine plantations if temperatures as low as −10° F (−23° C) can be expected at the planting site. Precommercial thinning probably would not have been necessary or desirable if trees had been planted to a 6- or 8-foot (1.8- or 2.4-m) spacing. Freeze mortality would have provided adequate thinning.

The pine hybrid knobcone (*Pinus attenuata* Lemm.) × Monterey pine (*P. radiata* D. Don) was produced first in 1939 (Stockwell and Righter 1946). Since then, many small exploratory plantings demonstrate that the hybrid inherits much of the drought and frost hardiness of the knobcone pine and the spectacular juvenile growth of the Monterey pine. These attributes have created a demand for about 50,000 seedlings per year (Kitzmiller 1976). Present uses for the hybrid are for erosion control and screening of recreation areas. The tree seems suited, also, for roundwood production on very short rotations, especially on marginal timber sites.

We know little about the performance of knobcone × Monterey pine stands. Information on the optimum spacing for wood production is particularly needed. But because no managed stands of the hybrid have been studied, observations of unmanaged stands of knobcone pine and experience with Monterey pine as an exotic in the southern hemisphere provide the only guidelines.

An opportunity to explore spacing-growth relationships arose when a plantation of knobcone × Monterey pine saplings, 9 years old when thinned in 1971, was severely damaged a year later by an unusual cold wave.

This paper reports the growth and mortality on study plots in this stand, 5 years after thinning to three different spacings and 4 years after the freeze.

PLANTATION

The plantation, administered by the U.S. Bureau of Land Management, lies at 3200 feet (976 m) elevation in the Klamath Mountain Province, 4.5 (7.2 km) miles southeast of Douglas City, Trinity County, California. It extends from the top to midslope on the east side of a narrow spur ridge jutting from a broad south slope *(cover)*. The steepness of the convex slope is 40 to 70 percent. The Spring Gulch Plantation (Griffin and Conkle 1967), designed to evaluate the hybrid produced from southern Oregon sources of knobcone pine, is about 200 feet (61 m) distant along the same narrow ridge. The soil, a deep clay loam overlying Pre-Silurian mica schist, is now classified as Orn Series, an Ultic Haploxeralf (U.S. Dep. Agric. Soil Conserv. Serv. 1975).

The area has hot, dry summers with negligible rainfall between June and October. Weaverville, the nearest weather station, 8.8 miles (14.1 km) northwest and 1200 feet (366 m) lower in elevation than the plantation, reports mean maximum August temperatures of 94° F (34° C) with many days exceeding 100° F (38° C). Winters are cool and wet with about 50 inches (1270 mm) of precipitation, 10 percent of which falls as snow especially in January. In Weaverville, January temperatures include a mean minimum of 27° F (-3° C), a mean maximum of 47° F (8° C), and an extreme low of -7° F (-22° C). At the plantation, however, winter temperatures probably never dropped below 10°F (-12° C) until 1972.

Dense chaparral, mostly chamise (*Adenostoma fasciculatum* H. & A.) and green leaf manzanita (*Arctostaphylos patula* Greene), was cleared from the site the year before planting. Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) and evergreen hardwoods grow in the draws but the slopes and ridge tops probably were never well-forested. Site index based upon height intercept of ponderosa pine (*Pinus ponderosa* Laws.) planted nearby is 50 to 55 feet (15 to 17m) at 50 years (Powers and Oliver 1978).

In February 1964, the Redding District, U.S. Bureau of Land Management, hand planted about 5 acres (2 ha) with 1-0 stock. The hybrids were produced from native knobcone pines growing at Pennsylvania Point on the Eldorado National Forest, and Monterey pines of unknown origin growing at the Institute of Forest Genetics at Placerville, both in El Dorado County, California. The seedlings were closely planted at about 4 by 4 feet (1.2 m).

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Early survival and growth were extraordinary: over 90 percent of the planting stock survived, and three growing seasons after planting the average tree was 5 feet (1.5m) tall. By the fall of 1971, eight growing seasons after planting, crowns had closed and intertree competition was intense. Trees averaged 14 feet (4.3 m) tall and 2 inches (5 cm) d.b.h. (*table 1*).

Heavy, wet snow, common at this elevation, bent the trees each winter, but until the winter of 1970-71, most stems straightened out the following growing season. The snow damage that year was so severe that many trees did not recover because they were bent horizontal and root sprung. Damage was largely confined to the most densely stocked areas. The decision to thin the stand in fall 1971 was based on a desire to lessen growth losses and snow damage from high stand density.

Table 1 —*Stand characteristics before and after thinning of 9-year-old knobcone × Monterey pine saplings*

Time period, spacing treatment (ft), and plot	Trees per acre	Average d.b.h.	Average height	Basal area	Net volume[1]
		Inches	*Ft*	*Ft²/acre*	*Ft³/acre*
Before thinning:					
4 by 4					
5	1980	2.22	15.4	53.2	415
6	2030	1.72	12.9	32.8	222
2	2160	2.11	15.0	52.3	391
3	2100	2.16	15.4	53.7	400
1	2660	1.92	13.4	53.6	382
4	2090	2.16	15.3	53.4	400
After thinning:					
8 by 8					
5	700	2.72	19.1	28.3	247
6	680	2.16	14.8	17.4	126
12 by 12					
2	330	2.68	19.9	12.9	114
3	330	2.75	18.0	13.9	125
16 by 16					
1	170	2.78	19.5	7.1	62
4	180	2.90	20.0	8.3	78
Two years later:					
9 by 9					
5	570	3.31	22.3	34.1	356
6	580	2.78	17.6	24.4	218
14 by 14					
2	230	3.34	23.8	14.0	135
3	210	3.48	21.3	13.8	148
22 by 22					
1	90	3.76	23.4	7.0	75
4	90	3.84	23.5	7.2	76
Five years later:					
9 by 9					
5	570	4.11	26.4	52.4	610
6	580	3.49	20.9	38.5	374
14 by 14					
2	230	4.41	27.6	24.4	263
3	210	4.49	24.9	23.1	266
22 by 22					
1	90	5.19	26.4	13.2	155
4	90	5.24	25.8	13.5	140

[1]Gross volume (inside bark from 1-foot stump to tip) less mortality.

METHODS

Before the largest planting of about 3.5 acres (1.4 ha) was thinned to an 8- by 8-foot (2.4 m) spacing, we installed six 0.1-acre (0.04-ha) study plots. Each of three spacing treatments was randomly assigned to two of the six plots. The spacings—8 by 8 feet (2.4 m), 12 by 12 feet (3.7 m), and 16 by 16 feet (4.9 m)—span the recommendations of many investigators working with Monterey pine 5 to 10 years old as an exotic in the southern hemisphere (Roy 1966).

The plots were thinned by the usual standard: the most vigorous, well-formed dominant and codominant trees were left, as far as possible with reasonable uniform spacing. Slash was not treated because the trees were small and their branches limber.

Immediately after thinning, each tree was tagged, measured, and described. Diameter at breast height to the nearest 0.1 inch (0.25 cm) was recorded for all trees. Twenty percent of the trees, randomly assigned on each plot, were measured for total height, crown length, and crown width, all to the nearest 1 foot (0.3 m). Total stem volume was estimated for each plot from detailed stem measurements of 10 trees. These trees were chosen with probability proportional to size. Upper stem diameters and lengths were measured directly. Stem volumes inside bark from a 1-foot (0.3-m) stump to tip were calculated by Grosenbaugh's (1967) STX computer program. Plots were remeasured outside the growing season 2 and 5 years after thinning (1973 and 1976). Also at the 5-year remeasurement, an increment core was extracted from every fifth tree or at least five trees in each plot to determine annual diameter growth. Stand characteristics were calculated from plot data on an acre basis *(table 1)*.

RESULTS AND DISCUSSION

Mortality

The California five-spined engraver (*Ips paraconfusus* Lanier) and a hard freeze accounted for all mortality in the plots in the 5 years since thinning. Although a few more trees died in plots with narrower spacings, the proportion of trees killed by both the engraver and the freeze increased with wider spacing from 17 percent for trees spaced 8 by 8 feet to 48 percent for trees spaced 16 by 16 feet *(table 2, fig. 1)*. This relationship was highly significant ($p \leq 0.01$). Total mortality per plot, for plots thinned to the same spacing, was similar and uniformly distributed, and resulted in spacings of 9 by 9, 14 by 14, and 22 by 22 feet (2.7, 4.3, and 6.7 m) for the surviving trees.

Table 2—*Mortality of knobcone × Monterey pines as result of attack by Ips paraconfusus followed by a hard freeze*

Spacing treatment (feet) and plot	Original number of trees	Trees killed by Ips, spring 1972	Surviving trees killed by freeze December 1972	Total mortality[1]	Resultant spacing
		Pct.	*Pct.*	*Pct.*	*Feet*
8 by 8					
5	70	4	15	19	9 by 9
6	68	6	9	15	9 by 9
12 by 12					
2	33	18	15	30	14 by 14
3	33	15	25	36	14 by 14
16 by 16					
1	17	41	10	47	22 by 22
4	18	6	47	50	22 by 22
Mean		15	20	26	

[1]Percentages are not additive because they are based upon different numbers of trees.

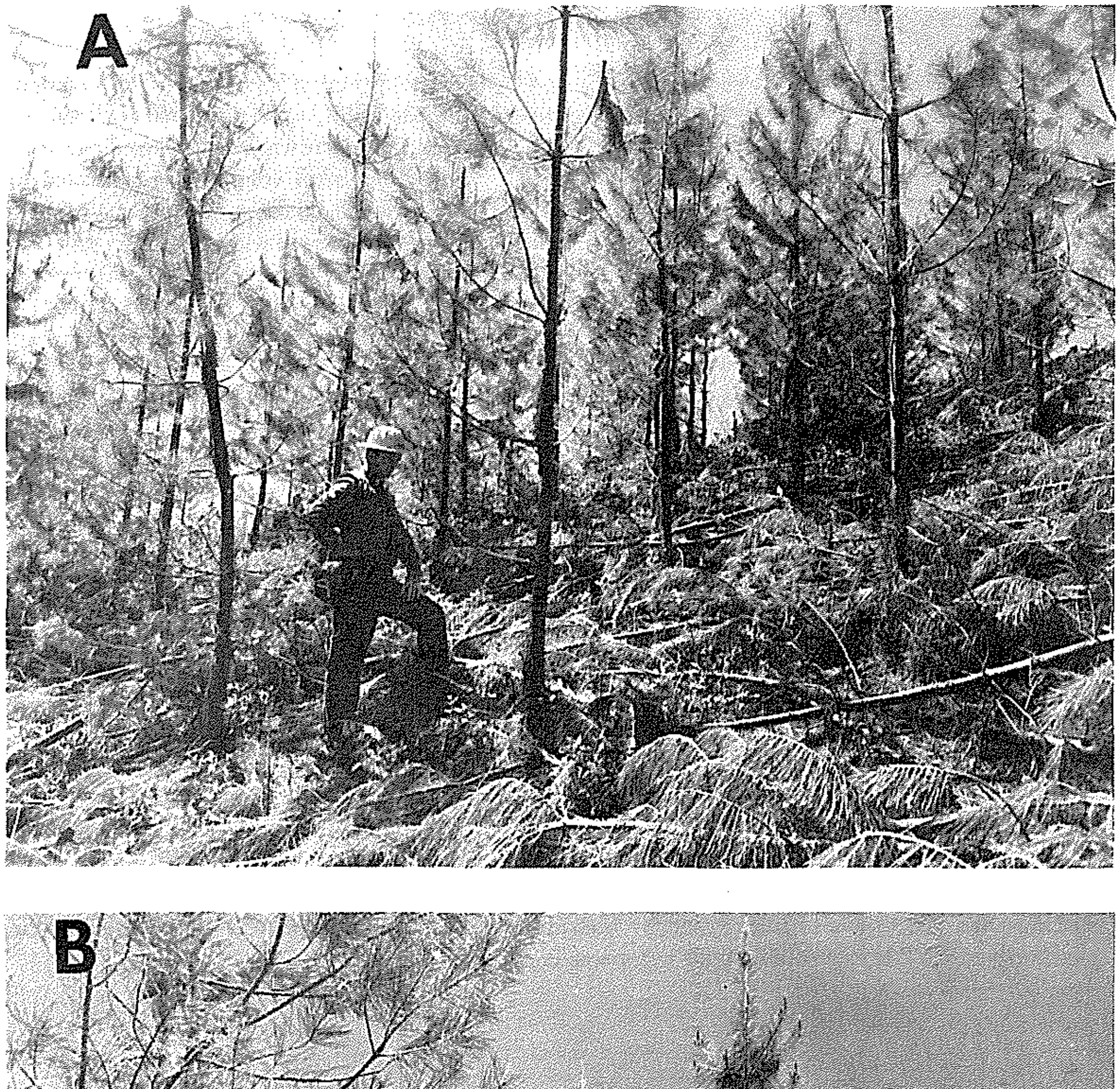
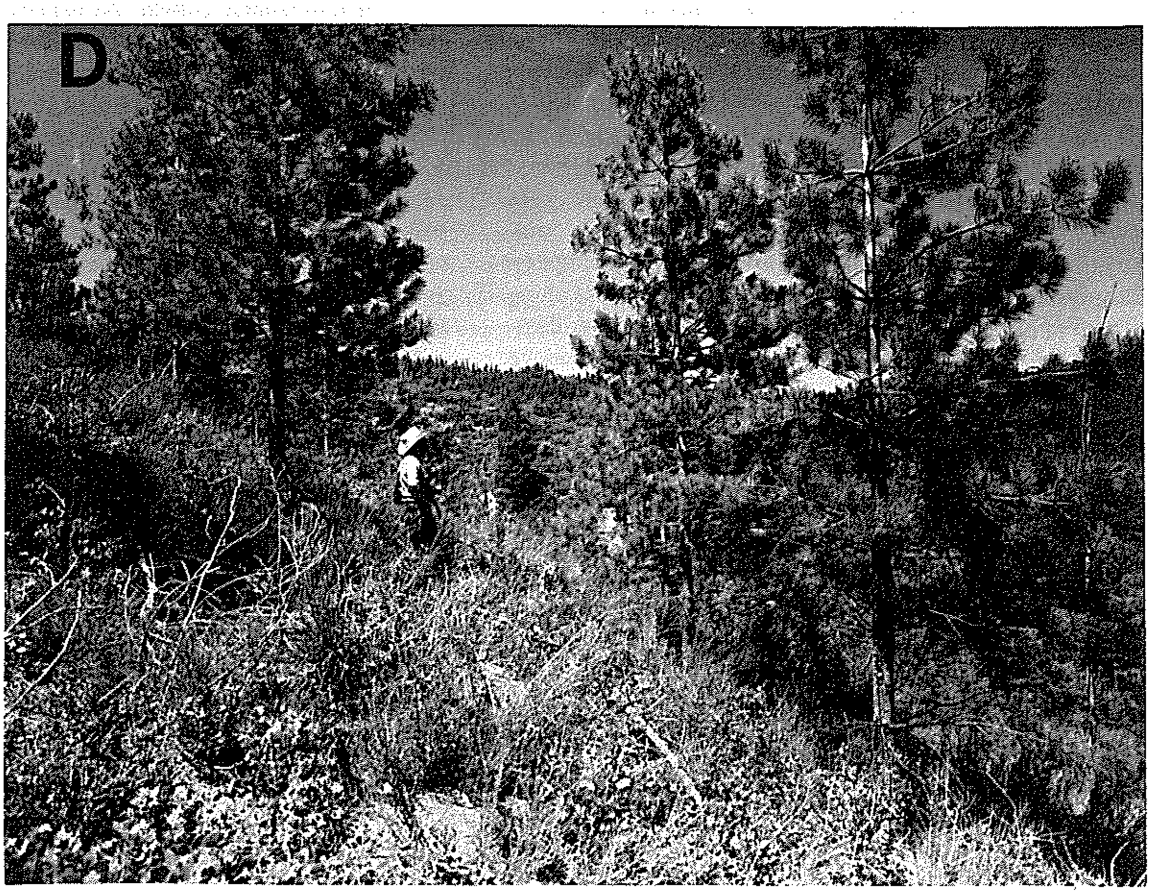


Figure 1—When photographed, these nine-year-old knobcone × Monterey pines had just been thinned *(A)* in Plot 6 to an 8-foot spacing, and *(B)* in Plot 4 to a 16-foot spacing. Five years later, engraver beetles



and a hard freeze had killed *(C)* 15 percent of the trees in Plot 6, leaving survivors at a 9-foot spacing, and *(D)* 50 percent of the trees in Plot 4, leaving survivors at a 22-foot spacing.

Engraver Beetle

The engraver beetle killed 15 percent of the leave trees by July 1972—8 months after thinning. As few as 4 percent of the trees died in one plot spaced 8 by 8 feet and as many as 41 percent in another spaced 16 by 16 feet *(table 2)*. Mortality was evenly distributed throughout all plots and tended to be higher in plots with trees at wider spacings. This trend was not statistically significant ($p > 0.05$), however. No trees died from engraver attack after July 1972.

Apparently the engraver population, breeding in slash during the winter and early spring after thinning, reached epidemic levels. This was unusual, but the California five-spined engraver is notoriously unpredictable. Thinning in the fall is encouraged (Struble and Hall 1955) because usually the engraver overwinters in small numbers and cannot reach a high population before slash dries out the following spring. Similar rare outbreaks have been attributed to warm, dry winters. But during the winter of 1971-72 as reported at Weaverville, temperatures were below normal and rainfall was only slightly below normal—4 inches (102 mm) below the normal of 25 inches (635 mm) between December and July. Leaving the slash unlopped may have contributed to the outbreak.

Freeze

Beginning on December 8, 1972, one growing season after thinning, northern California was gripped by 5 days of severe cold. Minimum temperatures at Weaverville, the lowest in 40 years, were -7° F (-22° C) on December 8, and -10° F (-23° C) on December 9, and did not rise above 0° F (-18° C) until December 12.

In March 1973, foliage of most trees on the plots was brown. Some buds and exposed branchlets were dead, also. Apparently it was winter desiccation—a common injury associated with low night-time temperatures and sunny days. Monterey pine plantations along the coast of northern California suffered similar damage during the freeze (Hood 1975). I rated the damage by a four-point scheme:

1 - no apparent damage
2 - <50 percent of the needles brown
3 - >50 percent of the needles brown
4 - all needles brown

By the end of the first growing season following the freeze, 20 percent of all trees within the plots had died *(table 2)*. Again, no pattern was discernible. Mortality ranged from 9 to 47 percent, was dispersed throughout each plot, and was not significantly related to either spacing or tree size. Genetic variability may have overridden other influences. In Monterey pine, cold hardiness is highly variable (Hood 1975).

As expected, mortality was concentrated in trees with the higher damage ratings. Eighty-five percent of the trees in injury category 4, and 25 percent of those in category 3, had died. Death of trees less severely damaged was negligible.

Growth

Following the engraver beetle attack and hard freeze, most trees that survived grew more slowly in diameter. Residual effects of the freeze and, to a lesser extent, close spacing seemed to have caused the loss in growth.

Freeze Effects

Diameter growth of the average tree surviving the freeze was reduced significantly the year following. Trees that had been growing 0.50 inch (1.3 cm) in diameter, on the average, for the 2 years before the freeze grew only 0.20 inch (0.5 cm) the year following—a 60 percent drop *(table 3)*. The second year, trees grew 0.27 inch (0.7 cm) on the average—better than the first year but still significantly less than before the freeze. Diameter growth in the third growing season increased to 0.35 inch (0.9 cm) and remained at about the same rate the fourth year. This rate was still significantly lower than that before the freeze.

Severity of freeze damage influenced the amount of subsequent diameter growth. As expected, trees with greater damage grew less rapidly following the freeze than did those less severely damaged, regardless of spacing.

Trees given damage rating 1 (undamaged) grew 0.32 inch (0.8 cm) the first year after the freeze *(table 3)*. This drop to only 63 percent of the prefreeze rate was significant, statistically. Diameter growth increased slightly the second year and again the third year, stabilizing at 77 percent—rates significantly different from that before the freeze.

Diameter growth of trees given damage rating 2 fell significantly the first year to 0.21 inch (0.5 cm)—only 43 percent of its prefreeze rate. The second year following the freeze, growth increased to 55 percent of the prefreeze rate, but trees in all spacings were still growing significantly more slowly in diameter than they were before the freeze. During the third and fourth years, growth was about 70 percent of, and significantly below, the prefreeze rate.

Trees given damage rating 3 grew most slowly the year after the freeze—only 0.09 inch (0.2 cm). The second year, diameter growth more than doubled but was still only 45 percent of that before the freeze. During the third and fourth years, growth increased

Table 3—*Mean annual diameter growth[1] by damage rating of knobcone × Monterey pines before and after thinning and a hard freeze*

Damage rating[2]	Annual diameter growth					
	1971 (before thinning)	1972 (after thinning, before freeze)	1973	1974	1975	1976
	Inches					
1 (n = 12)	0.48a	0.53a	0.32b	0.34b	0.39ab	0.39ab
2 (n = 26)	.48a	.50a	.21b	.27c	.36d	.33d
3 and 4 (n = 17)	.48a	.49a	.09b	.22c	.29c	.26c
Mean (n = 55)	.48a	.51a	.20b	.27c	.35d	.32d

[1] Diameters followed by the same letter in the same row are not significantly different at the 5 percent level.
[2] Damage was rated by a four-point scheme:
1 = no apparent damage, 2 = <50 percent of the needles brown,
3 = >50 percent of the needles brown, 4 = all needles brown.

nonsignificantly to 57 percent of the prefreeze rate.

Duration of the reduced diameter growth following the freeze is not clearly evident. Certainly the dramatic decline in diameter growth lasted 2 years, at least. In the third and fourth years after the freeze, growth leveled off within each spacing and damage rating. But the rate was well below that before the freeze, especially in trees of damage rating 3. Probably, freeze damage, aided by secondary agents attacking freeze-weakened trees, suppressed growth longer than 2 years. For example, in 1976, 12 percent of the trees had large patches of dead cambium and 3 percent had thin foliage, whereas neither were found in 1971. More than twice as many trees in 1976 than in 1971 had defective form including spiked and forked tops. And 15 percent of the trees were attacked by bark beetles (indicating poor vigor) in 1976, whereas bark beetle attacks were negligible in 1971.

Failure of diameter growth to reach prefreeze rates after 4 years may have been the effect of causes other than the freeze. In 1976, precipitation at Weaverville was only 45 percent of normal. Increasing intertree competition probably contributed to a big drop in growth of trees spaced 9 by 9 feet. And finally, this hybrid stand may have passed the age when current annual diameter growth normally peaks. Annual basal area growth returned to prefreeze rates by the third year following the freeze.

Spacing Effects

Mortality and residual effects of the freeze on growth may have eliminated or overshadowed most of the evidence of direct influence of spacing on growth. Nevertheless, because neither mortality nor damage severity changed the relation of spacing treatments to each other, a few observations are possible.

Spacing has influenced diameter growth more markedly than any other stand characteristic investigated *(table 4)*. Annual means during both periods were from 0.28 inch (0.7 cm) for trees spaced 8 to 9 feet apart to 0.48 inch (1.2 cm) for trees spaced 14 to 22 feet apart. Differences were significant only between spacing extremes during the first 2 years and among all spacings during the third through fifth years.

No significant relationship was found between spacing and height growth. Trees in plots spaced at 22 by 22 feet during the second period tended, however, to grow less in height than did trees in plots at narrower spacings.

Stand growth in basal area and net volume (gross volume less mortality) was negligible in plots at the two wider spacings during the first two years after thinning because mortality was high. Although trees spaced 8 by 8 feet grew significantly more basal area and volume during the first 2 years than trees at wider spacings, growth was still only two-thirds of that possible without mortality.

During the second growth period (3 to 5 years after thinning) no trees died and plot growth tended to be related more strongly to spacing. Basal area growth was significantly different only between spacing extremes. The relationship between net volume growth and spacing was not significant, although a strong trend towards greater growth of both measures in plots with trees at narrower spacings was apparent.

Table 4—*Mean annual change in stand characteristics 2 years and 3 to 5 years after thinning knobcone × Monterey pine saplings*[1]

Time period and spacing treatment (ft)	Mean annual change				Mortality		
	Avg. d.b.h.	Avg. height	Basal area	Net volume	Trees killed	Basal area	Volume
	Inches	*Feet*	*Ft^2/acre*	*Ft^3/acre*	*No./acre*	*Ft^2/acre*	*Ft^3/acre*
First 2 years after thinning:							
8 by 8	0.30	1.5	3.2	52	58	2.0	28
12 by 12	0.34	1.8	0.3	11	55	2.4	29
16 by 16	0.48	1.9	-0.3	2	42	1.8	23
Third through fifth years after thinning:							
9 by 9	0.26	1.2	5.4	67	0	0	0
14 by 14	0.35	1.2	3.3	41	0	0	0
22 by 22	0.48	0.9	2.1	24	0	0	0

[1] Data from two plots for each spacing treatment are combined. Means not significantly different are bracketed ($p \leq 0.05$).

CONCLUSIONS

Damage and mortality from freezing must be considered in the management of knobcone × Monterey pine plantations if temperatures as low as -10° F (-23° C) can be expected at the planting site. Even during a rotation as short as 30 years, weather records indicate that the chance of a hard freeze is about 75 percent. A cold wave of similar intensity and duration hit this area in 1932.

Precommercial thinning often does not pay in management of plantations on short rotations for roundwood (Bennett 1971). Thinning probably would not have been necessary or desirable here if trees had been planted to a 6- or 8-foot spacing. Freeze mortality would have provided adequate thinning, if it were needed.

Certainly, thinning plots to 12- and 16-foot spacings followed by severe mortality left so few trees per acre that yields will suffer within the short rotation suitable for this hybrid. Mortality was proportionally less, however, after thinning to an 8-foot spacing. The approximate 9-foot spacing which resulted should provide adequate stocking even through another killing freeze.

Unlike growth loss from mortality, the growth loss of trees surviving the freeze cannot be offset by closer spacing. Winter temperatures at this location probably are too cold for maximum yields of the hybrid. Minimum temperatures at similar marginal timber sites at lower elevations, especially those facing California's Central Valley, were not lethal in December 1972. Whiskeytown Reservoir and Shasta Dam reported minimums of 16° F (-9° C) and 20° F (-7° C), respectively. Both temperatures are well above the 11.8° F (-11.2° C) which Stockwell and Righter (1946) found did not injure 8-year-old knobcone × Monterey pine hybrids. In spite of occasional freeze damage at this elevation (3200 feet), plantations of closely spaced knobcone × Monterey pine producing less than maximum yields should be successful. Its diameter growth is so rapid that even most freeze-weakened trees are growing faster than ponderosa pine of the same age planted nearby.

Possibly, greater freeze resistance can be bred into the hybrid. Damage from the December 1972 freeze to Monterey pine along California's north coast showed high variability which Hood (1975) attributed to the species' genetic diversity. Susceptibility to freeze damage may vary widely in knobcone pine, also. Three-year growth of hybrids produced from knobcone pine parents from the northern end of their range was reported by Griffin and Conkle (1967). Their performance following the 1972 freeze should be evaluated.

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