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Thinning Lodgepole Pine Increases Tree Vigor and Resistance to Mountain Pine Beetle

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ABSTRACT. Thinned and unthinned stands of lodgepole pine in eastern Oregon were evaluated in 1980 to determine their vigor and susceptibility to attack by outbreak populations of the mountain pine beetle. Application of a vigor rating system, based on amount of stem growth per square meter of crown leaf area, showed that thinnings from below improved vigor of residual stand and reduced beetle attack. Beetle mortality was significant in unthinned and lightly thinned stands where current annual growth of stemwood of residual trees averaged less than 80 g/m^2 of foliage. Stands with mean vigor ratings of about 100 were beginning to suffer beetle attack. There was no mortality in heavily thinned stands where vigor ratings exceeded 120. These findings suggest that lodgepole pine can be managed through stocking control to obtain fast-growing, large-diameter trees and to avoid attack by the mountain pine beetle. FOREST SCI. 29:204–211.

ADDITIONAL KEY WORDS. *Pinus contorta, Dendroctonus ponderosae.*

MOUNTAIN PINE BEETLE (*Dendroctonus ponderosae* Hopkins) infestations in western United States and Canada have been disastrous in lodgepole pine (*Pinus contorta* Dougl.) stands in recent years (McCambridge and others 1979); and outbreaks have been recorded as long ago as 150 years (reference cited in Wellner 1978). Several chemical and cultural techniques have been tried to reduce damage, but most entomologists generally agree that silvicultural control is more promising (Safranyik and others 1974, Amman 1976, Klein 1978).

Research in the Intermountain and Rocky Mountain regions of the United States and Canada have documented outbreak and endemic patterns of this pest for several years. It appears that once an outbreak begins, beetles select the largest trees in the stand, at low and middle elevations, and in stands 60 years old or older (Cole and Amman 1969, Roe and Amman 1970, Cole and others 1976). Outbreaks then accelerate because larger trees generally have thicker phloem and support more beetles per unit area of bark surface than trees with thin phloem (Amman 1972, Amman and Pace 1976, Berryman 1976, Klein and others 1978). Our observations suggest a similar pattern of beetle outbreaks in eastern Oregon.

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Observations of stand conditions have led some investigators to recommend reducing mountain pine beetle damage by growing trees on shorter rotations or, in existing stands, by cutting the larger and intermediate diameter trees (Cole and Cahill 1976, Hamel 1978). Other investigators believe that the beetle confines its attacks to weakened trees, only rarely attacking trees that are growing vigorously (Berryman 1976, 1978; Mahoney 1978). If trees in natural stands are killed in large numbers, it is because the stand is overstocked and individual trees are weakened or growing measurably less than the environment will permit. The mountain pine beetle detects and colonizes these types of trees.

First-year results of a study in central Oregon by Waring and Pitman (1980) add to the theory of interaction between tree stress, mountain pine beetle attack, and subsequent tree mortality. Their data suggest that when a tree is freed from competition so the crown can become more efficient photosynthetically, as in a widely spaced, thinned stand, it will soon approach its growth potential and become more resistant to beetle attack. This indeed was observed even though the trees in their study were 120 years old.

The study reported here was conducted in 1980 in thinned and unthinned stands in the beetle outbreak area of eastern Oregon. The objective was to determine whether thinning to leave the better trees increases residual tree vigor and reduces beetle attack.

Methods

Tree vigor is defined as the current growth (grams of stemwood produced) per square meter of crown leaf surface (Waring and others 1980). The latter depends on the linear relationship between sapwood area at breast height and leaf surface (Grier and Waring 1974), with each cm^2 of sapwood representing 0.15 m^2 of crown leaf area (Waring 1980). We estimated stem weight from the equation developed by Gholz and others (1979) for lodgepole pine:

$$\text{Log}_e W = \text{Log}_e \text{dbh}(2.4287) - 2.9849$$

where W equals weight of bole in kg and dbh is diameter in cm. Growth is determined by establishing the stem weight last year and subtracting it from current stem weight. Thus, to determine tree vigor, we used three tree measurements from the field—dbh and width of the last annual ring to determine stem growth, and sapwood depth to determine foliage area. Sapwood thickness and width of the last annual ring were averages from two increment core measurements taken at breast height on opposite sides of the tree. Sapwood thickness was measured with a ruler in the field; and the last annual ring was measured with a microscope in the laboratory.

Thinned and unthinned stands were evaluated for mortality and vigor at four localities: Beatty Creek, Wallow-Whitman National Forest; Battle Creek and Kelsay Creek, Umatilla National Forest; and Phipps Creek, Malheur National Forest. The mountain pine beetle outbreak in these locations started after each area had been thinned and had declined to near zero when stands were evaluated in 1980. The nearly pure lodgepole stands at Beatty, Battle, Kelsay, and Phipps Creeks had been thinned at ages 50 (1965), 80 (1973), 80 (1970), and 70 (1970), respectively. Degree of thinning and sizes of residual trees in each stand are summarized in Table 1.

The Beatty Creek stand was an old research area with several degrees of thinning established on ten 0.08-ha plots, each with a surrounding 10-m wide buffer strip. An additional plot of equal size was established in an adjacent unthinned stand in 1980. For each plot, dbh and beetle mortality were recorded for all trees and cores for vigor ratings were taken from 10 randomly selected trees above 10 cm

TABLE 1. *Summary of measurements in each study stand of lodgepole pine.*

Locality and treatment		Average dbh		Trees per ha	Basal area per ha	CCF	Vigor rating		Leaf area index	Beetle mortality
							Mean	SE		
Beatty Creek		*cm*	*SD*	*number*	m^2		.... g/m^2			*percent*
Thinned	#1	15.8	1.0	1,401	27.5	162	78	7.3	2.8	34.8
	#2	18.0	1.1	704	17.9	94	120	8.0	1.9	5.4
	#3	16.1	1.0	1,154	23.5	138	75	5.2	2.6	16.0
	#4	15.7	1.0	1,784	34.5	184	65	4.6	3.6	26.0
	#5	15.5	1.0	746	14.1	80	101	6.9	1.5	0
	#6	12.8	1.3	887	11.4	75	103	4.9	1.3	0
	#8	17.9	1.1	820	20.6	96	85	6.6	2.2	7.5
	#9	18.8	1.1	264	7.3	40	170	14.2	0.9	0
	#12	17.1	0.9	660	15.1	82	109	4.0	1.8	1.9
	#14	17.5	0.9	370	8.9	42	151	5.4	1.1	0
Unthinned		8.2	1.8	6,845	68.6	288	42	4.6	7.5	0
Battle Creek										
Thinned		17.9	1.2	459	11.6	60	80	4.2	1.2	0
Unthinned		15.2	1.2	2,693	48.9	223	39	3.3	4.5	11.6
Kelsay Creek										
Thinned		20.8	0.9	291	9.9	45	86	6.3	1.0	0
Unthinned		14.6	1.6	1,591	26.6	141	35	2.8	2.6	40.0
Phipps Creek										
Thinned		23.2	1.2	294	12.4	46	72	8.5	1.2	25.8
Unthinned		15.5	1.8	1,742	32.9	137	61	5.5	3.4	25.3

dbh. Thinnings in the other three localities were operational treatments to release selected crop trees, each thinning covering at least 4 ha. Tree measurements were made on two 1-ha plots in each locality, one in the thinned stand and a paired plot in an adjacent unthinned stand. Sampling was conducted in these plots on a grid of 12 prism points, using a 10-factor prism (Dilworth and Bell 1972). Mortality and dbh were recorded for every tree at every prism point. At alternate prism points, cores for vigor ratings were taken for the first five trees 10-cm dbh or larger; age was recorded for the first tree.

RESULTS

Thinning improved the mean vigor of residual trees in all stands except Phipps Creek, where the small improvement observed (compared to the adjacent unthinned plot) was not significant ($P < 0.01$) (Table 1). The degree of improved stand vigor in the thinned stands, with the exception of Phipps Creek, was related to the degree of thinning when correlated with stand basal area, crown competition (CCF), trees per hectare, and leaf area index (LAI)[1] (Fig. 1). Note that although tree vigor decreases with increasing CCF, mortality from beetle attack may actually decrease (McGregor and others 1981) if tree diameter also decreases (Waring and others 1981, Krajicek and others 1961).

Tree mortality from mountain pine beetle attacks increased noticeably at vigor ratings below 80 grams wood production per m^2 of foliage (Fig. 2). Mortality and

[1] The leaf area index is a number which relates leaf surface area of tree canopy to the surface area of the forest floor. For example, a LAI of 2.5 indicates 2.5 m^2 of leaf area in the canopy for every m^2 of ground surface.

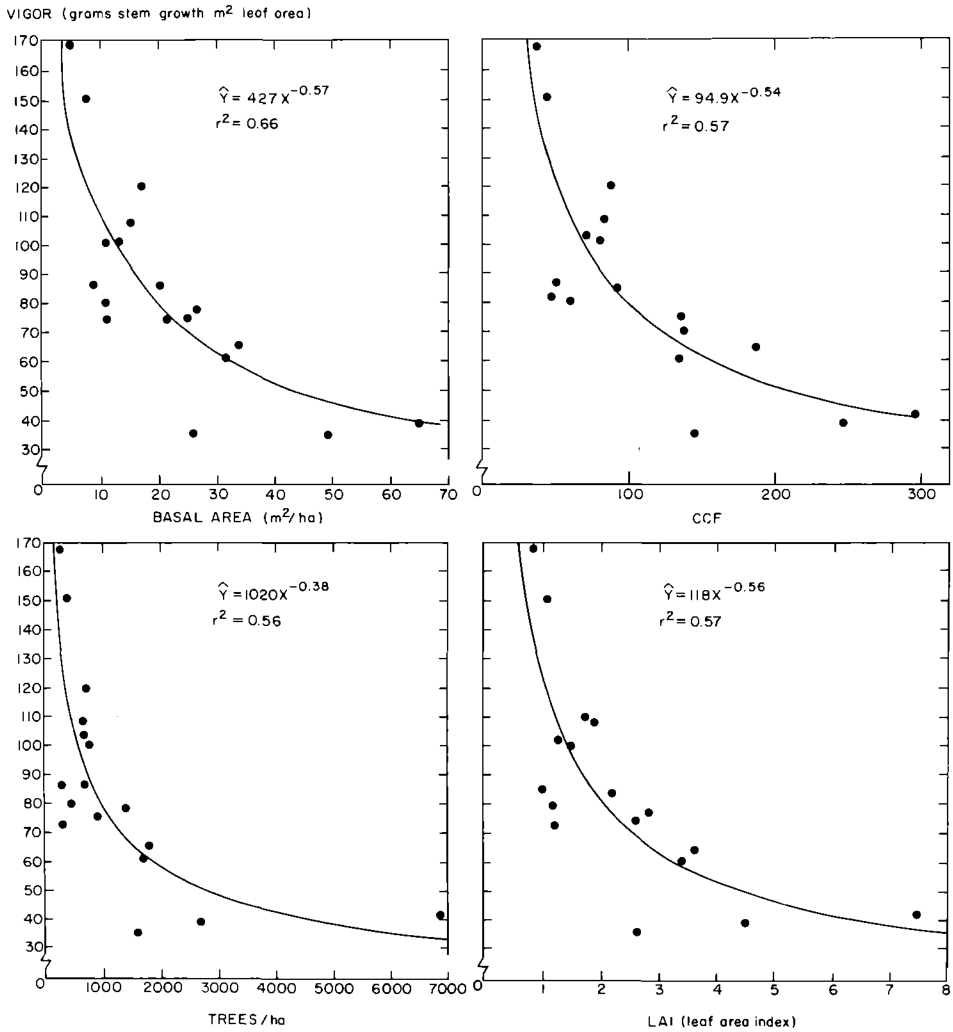

FIGURE 1. Relationship of tree vigor to four kinds of stand density measurements.

survival were most variable between vigor ratings of 80 and 120, although individual trees with vigor ratings of 100 or more were rarely attacked or killed. Beatty Creek plots with ratings above 150 (plots 9 and 14) had large diameters, low stocking, and experienced no attacks.

The correlation in Figure 2 for vigor ratings and beetle mortality is a modified boundary limit analysis and is designed to show a "worse-case" situation. Plots with no mortality, where mean vigor ratings were between 80 and 120, were excluded from analysis because beetle pressure in these stands was likely less than in stands of similar vigor where trees were killed. In this vigor range, a normal pattern of variation means there is good probability that some low vigor trees will be present in the stand and that beetles will find them. If one tree is attacked, then beetle pressure on the adjacent trees is increased because the aggregation pheromone produced at the attacked tree draws more beetles to the area. Another plot with no mortality, the unthinned plot at Beatty Creek, was excluded because trees were uniformly small (< 10 cm dbh) and would be poor candidates for attack

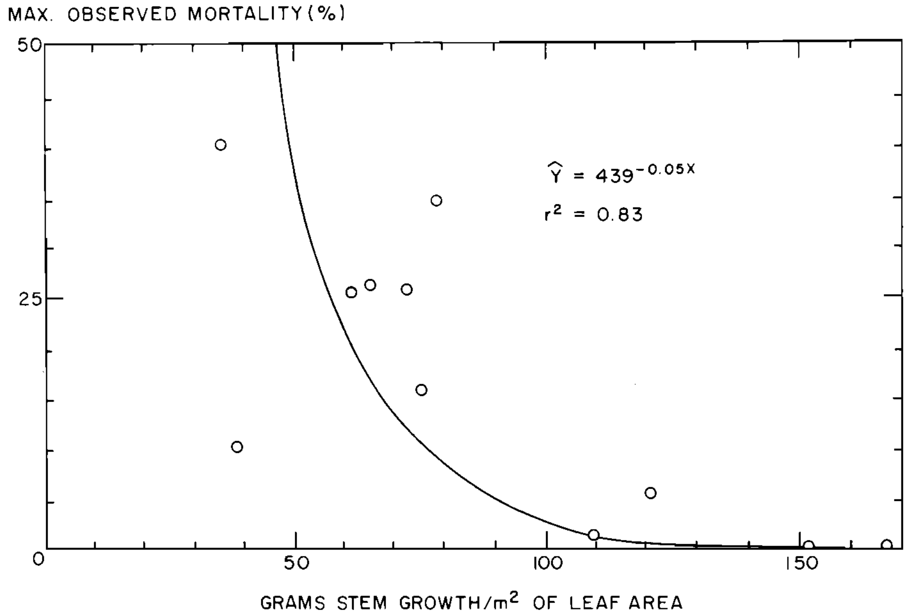

FIGURE 2. Relationship of beetle-caused mortality to the mean vigor rating of the stand.

unless large trees are nearby (Cole and others 1976). Two plots with no mortality that were included in the analysis were Beatty Creek 9 and 14. Their mean vigor ratings were so high that it is unlikely any trees in the stands were susceptible to attack, even if the beetle pressure were severe.

DISCUSSION

Our data, coupled with that of Waring and Pitman (1980), strongly suggest that regulation of lodgepole pine stocking will permit rapid tree growth and long rotations with no appreciable beetle-caused mortality. Sartwell and Stevens (1975) reached similar conclusions in ponderosa pine (*Pinus ponderosa* Laws.). The variation in mortality among thinned stands, with the exception of those noted previously, seem explained by a difference in tree vigor rather than a lack of beetle pressure, since numerous brood trees could be found in and near our plots. Stands with light or no thinning incurred the highest mortality while the more heavily thinned stands escaped heavy beetle kill.

It may be argued that increased vigor in thinned stands has nothing to do with susceptibility to beetle attack; that the beetle either does not like open stands or that the switching mechanism described by Geiszler and Gara (1978) cannot operate when the trees are so far apart. However, the vigor of a plot in Phipps Creek failed to respond to heavy thinning and suffered the same mortality experienced by the adjacent unthinned plot. Occasionally stands do not respond to thinning for unknown reasons (Barrett, personal communication).[2] Variation in response, however, does not detract from the larger issue that thinning usually increases vigor of trees in the residual stand and that a good vigor response will prevent attacks.

The unthinned plot at Beatty Creek is an apparent anomaly because of its low

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[2] James W. Barrett, Silviculture Laboratory, Pacific Northwest Forest and Range Experiment Station, U.S. Forest Service, Bend, Oregon.

vigor rating and low incidence of beetle attack while three adjacent, lightly-thinned plots had higher vigor ratings and suffered heavy beetle-kill. The unthinned plot was not attacked because its mean dbh was only 8.2 cm and beetles attack small trees only when population density is extremely high (Cole and other 1976). Lightly thinned plots, however, provided enough release for residual trees to reach susceptible diameters yet too little space to avoid mutual competition after a short spurt of growth. Accordingly, the stands were in an ideal situation for attack. Thus, if a forest manager thins too lightly, so that entire crowns in the residual stand cannot be used efficiently in photosynthesis, i.e., at leaf area indices between 1 and 2, an outbreak can be invited or worsened. Because thinning does not substantially increase the availability of water or nitrogen to typical lodgepole forests in central Oregon (Waring and Pitman 1982, manuscript in review) diminished sunlight to the entire crown canopy appears to be the major factor limiting growth in most heavily stocked lodgepole pine stands in Oregon.

Light thinning may create fast-growing stands that eventually come under stress due to crown competition. This situation is analogous to the outbreak pattern in unmanaged stands where the larger, apparently faster growing trees are among the first to be attacked and killed. Berryman (1976) noted this pattern and suggested that stress can occur over a relatively short time and in trees that had been fast growers. At the start of an outbreak in the lodgepole pine-mountain pine beetle complex, trees bordering openings, or trees in pockets of less dense trees, are usually the first to be attacked. Because these trees were once the fastest growing trees in the stand, they have the largest diameters and are attractive to attacking beetles because of their silhouettes or because they provide a larger landing surface (Cole and others 1976, Shephard 1966, Hynum and Berryman 1980). They are not the first trees to come under the stress of competition in the stand; but, because they carry a large amount of respiring tissue, competition can bring on a critical level of stress. Accordingly, we find no anomaly in observations that the largest, once fast growing trees are the first to be selected by the mountain pine beetle for attack and colonization. Based on our data, and those of Waring and Pitman (1980), we would expect large trees to undergo a marked reversal in vigor and become preferred individuals at the outset of an outbreak. This also agrees with the observations of Mahoney (1978) and Schenk and others (1980).

We are not yet ready to suggest a particular prescription for operational thinning in lodgepole pine, but pilot studies in several localities and forest types are appropriate. Several degrees of thinning should be attempted in one locality, the aim being to get a variety of vigor responses on either side of 100 g growth per m^2 of leaf area. From Figure 1, it would appear that thinning to about 10–20 m^2 of basal area/ha, or a LAI of 1–2, would be an appropriate middle degree of thinning. Because LAI takes into account crown density as well as tree spacing, it may represent a more desirable index than those based on spacing alone as with CCF.

From the standpoint of comparative analysis, the strength of the vigor rating system used in this study is that it normalizes tree growth on the basis of foliage available to produce that growth. This means on all sites that large trees can be compared with small trees and old trees can be compared with young trees. Another advantage of the system is that it relates vigor to the current health of the tree, not that of previous years.

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Timber Supply From Private Nonindustrial Forests

By Clark S. Binkley. 1981. Bulletin No. 92. Yale University, School of Forestry and Environmental Studies, New Haven, CT, Bulletin 92, 97 pages. $5.95.

Reviewed by Walter C. Anderson, Southern Forest Experiment Station, USDA Forest Service, New Orleans, LA 70113

What can another study add to what is already known about the timber supply from nonindustrial private forests? The "small forest ownership problem" has been one of the topics most discussed by foresters over the decades since they became concerned about the future wood supply from these lands. The cause of the concern was the neglect of management on these lands that constitute a very large part of the commercial forest acreage. The numerous studies of the subject examined only one important part of the problem—the causes and solutions of low productivity. The second major aspect—the decision to harvest—was largely ignored. This aspect is the subject of the bulletin.

The bulletin, which is based on the author's Ph.D. dissertation, is divided into six chapters. The first chapter is the introduction, and the second is a review of literature on the private ownership problem, little of which relates to the study. In chapters 3 and 4 is the microeconomic analysis and statistical estimate of the landowner's decision to harvest. Chapter 5 contains a discussion of the Pilot Woodland Management Program that had been expected to provide data to estimate the technical tradeoffs between timber and nontimber outputs, but the data proved inadequate for the purpose. The conclusions are given in chapter 6.

Chapters 3 and 4 are the heart of the report. Chapter 3 presents a theoretical model of landowner behavior, which considers a forest holding as both an enterprise producing income from timber sales, and a consumptive good providing amenity values such as recreation. In making the harvest decision, the landowner attempts to maximize his utility by balancing the income from timber against the amenity values lost by harvesting timber. The model is based on a number of assumptions. Results of the analysis indicate how owners respond to changes in the variables in the model. Increased timber prices and increased income lead to an increased harvest as do reductions in land holding costs. Beyond a given size of holding likelihood of harvest decreases with increases in size, while below this critical size a decrease in size results in decreased chance of harvest.

The statistical analysis, using data from a sample of private nonindustrial forest owners in New Hampshire, is described in chapter 4. The empirical results agreed with the expectations developed from the theoretical model, i.e., stumpage prices influenced the prob-