Epicormic Branching on Pruned Coastal Douglas-Fir

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ABSTRACT: *In theory, pruning is an attractive silvicultural technique because there is a great potential for increased production of clear wood after its execution. Much of the currently available literature on the pruning of Douglas-fir* (Pseudotsuga menziesii) *concerns the effects of pruning on diameter and height growth. Other aspects of the pruning response need to be considered, because clear wood production cannot be guaranteed merely because the trees were pruned. The Stand Management Cooperative, headquartered at the University of Washington, conducted a regional study to examine how Douglas-fir trees respond to pruning. Epicormic branching responses are reported here. Some anecdotal observations, as well as some intuitive ones, are confirmed. Epicormic branching was most severe on the south and west sides of trees. When epicormic branching was severe, sprouts occurred both at nodes (or whorls) and along internodes. Less severe or moderate sprouting tended to originate mainly in nodes. The risk of epicormic branching is minimal as long as the pruning treatment does not reduce the live crown by more than 40% and the stand has 500 or more stems/ha. The highest risk of epicormic branching was found to be when the live crown is reduced by more than 40%, and the stand carries less than 500 stems/ha. West. J. Applied For. 16(2):80–86.*

Key Words: Epicormic branching, *Pseudotsuga menziesii,* pruning.

Pruning is one of the most expensive silvicultural investments that a forest manager can make. The decision to prune or not depends on whether the anticipated benefits (which may include "intangibles" such as aesthetics) of the operation can justify the economic costs of the treatment. Pruning, if done properly, can increase the volume of the more valuable clear wood grown in a given rotation, thus increasing the final value of the harvest. However, a mistiming or misapplication of the selected pruning regime can just as easily fail to increase the amount of clear wood produced. One factor to be considered when pruning is the possibility that the trees will respond by producing epicormic branches. While there is a substantial body of literature on diameter- and height-growth response to pruning in a number of species including Douglas-fir (see Hanley et al. 1995, references therein), relatively little attention has been paid to the potential impacts of epicormic branching on wood quality, particularly in conifers. Isaac (1945), Stein (1955), and Eckstein (1974) have all reported that epicormic branching occurs as a response to "severe" pruning of Douglas-fir. The definition of "severe" appears to be >50% reduction in the live crown of an individual tree, though it is not stated explicitly in any of these papers.

Epicormic branches can sprout either from dormant buds under the bark or from new buds that form in callus tissue resulting from the pruning treatment. These buds can sprout in response to changes in heat, light, and/or stem tissue hormonal balances. Thus, a change in stand conditions brought about by thinning, mortality, pruning, or mechanical damage to the trees or some combination of these or other factors can induce the dormant buds on the trees to sprout. Epicormic branching as a response to some silvicultural practices (not only pruning) is a common concern in hardwood silviculture. There is a substantial body of literature on silvicultural regimes designed to balance hardwood growth with stem quality that include controlling the occurrence of epicormic branches. A recent example is Schmaltz et al. (1997), where a spacing trial was examined to determine the optimal spacing for growing *Quercus petraea* in Germany to produce the highest stem quality. Kerr (1996) states that in Great Britain,

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the "free growth" style of plantation silviculture (heavy thinning and high pruning) is not practiced on oak because of the high cost of epicormic branch control.

With a few exceptions, epicormic branching is not generally regarded as a problem in softwood silviculture for timber production. Sitka spruce (*Picea sitchensis*) is noted for sprouting in reaction to thinning (Herman 1964). Other conifers used for timber production that may produce epicormic sprouts in response to silvicultural treatments include white spruce (*Picea glauca)* (Berry and Innes 1967), white fir (*Abies concolor*) (Cosens 1952), and radiata pine (*Pinus radiata*) (Hingston 1990).

To better understand the dynamics of the response of coastal Douglas-fir to pruning, the Stand Management Cooperative (SMC 1998) has undertaken live crown reduction experiments in the Pacific Northwest region. These experiments include fifty-six 0.08 ha pruning plots in 18 installations in British Columbia, Oregon, and Washington. As part of the monitoring process, a subset of 38 plots in 12 installations was examined for the occurrence and size of epicormic branches 4 yr after the initial pruning treatments. This report details our findings on epicormic sprouting in response to pruning. Specifically, we wish to determine how frequently epicormic branches occur, where they occur on the bole, whether or not their occurrence is related to stand density or the amount of crown removed, and how epicormic sprouting may affect log grade.

Methods

Field Procedures and Data Collection

At selected installations, three 0.08 ha pruning plots were established. These plots were thinned to residual densities that would not exceed an operationally feasible number of trees per hectare to prune by leaving one-half (ISPH/2), or one-quarter (ISPH/4), or one-eighth (ISPH/8) of the initial stems/ha (ISPH). The three pruned plots in each installation occur in one of two possible configurations. One configuration consists of two ISPH/2 plots and one ISPH/4 plot; the other consists of two ISPH/4 plots and one ISPH/8 plot. Most installations have three "control" plots that were not pruned that match the density of the three pruned plots, but some installations have only two matching plots. The plots were pruned when the dominant height of the stand reached 9.1 m. In most cases, the plots were spaced at the time of pruning, but about one-third of the plots were spaced 4 yr prior to pruning. All trees in each plot were measured for total height, diameter at breast height (dbh), height to crown base, and height to the lowest contiguous live whorl. Plots were randomly assigned one of three pruning treatments: live crown reduction by 20, 40 or 60%. Lift height was determined by measuring the live crown length then multiplying by the appropriate crown reduction ratio. The trees were pruned with either clippers or pole saws, and then the final live crown ratio was determined. Trees will be repruned to the same post-first lift live crown ratio every 4 yr until a final pruned height of 9.8 m is reached. The trees are measured for height and dbh every 2 yr.

Prior to the second pruning, pruned plots on 12 installations containing 1,261 trees were examined for epicormic branches. The pruned portion of each tree bole was divided vertically (lower, middle, and upper third) and circumferentially (north, south, east, and west quadrants) producing 12 sectors for observation. The number, origin (nodal or internodal), and size (small or large, large being > 30 cm long) of epicormic branches in each sector were recorded. The size classification was based on the belief that larger epicormic branches are most likely to create significant knots and thereby reduce wood quality if permitted to remain on the stem.

Propensity to produce epicormic branches might also be genetically controlled or might be affected by seedling stock type. The installations in this study differ in terms of site and seedling stock planted by the owner, but there are no data on the genetics and only some information on seedling stock types. Owners planted what they believed to be the "best" material for the location. Therefore, any attempt to attribute differences in epicormic branching among installations to genetics or seedling stock type will be confounded with site differences. Statements about relationships among epicormic branching, pruning severity, branch location, and stand density are still valid, though, because all planting stock is well within the range of parameters considered operational in this region, and the research sites are distributed across different productivity classes, densities, elevations, slopes, and aspects (Table 1).

Analysis Procedures

While data were obtained for 12 observational sectors, analyses reported here are restricted to one of three levels: (1) installations (or sites where all height thirds, quadrants, and pruning intensities are combined), (2) height thirds (where all quadrants are combined), or (3) quadrants (height thirds combined). The data were first examined for possible trends across sites. Table 1 contains the proportion of clear stem quadrants (height thirds, pruning intensities, and stand densities combined), as well as the descriptive parameters of each installation. On an installation basis, it will be seen that conventional site descriptors such as site index, elevation, or average age do not appear to be associated with the overall frequency of epicormic branching in general, though there is considerable variation among installations. Site quality would probably be a consideration in deciding which stands to prune (lower sites being less attractive due to slower accumulation of clear wood), so site quality was expected to affect epicormic branching somewhat as well. However, site quality cannot yet be discounted as a factor in determining the extent of epicormic branching as a response to pruning or thinning because of the limited range of site qualities sampled thus far. Depiction of gross trends in epicormic branching across installations in this set of data is also complicated by the fact that each installation has a different mix of plot densities and pruning intensities.

Contingency table analysis was selected as the most suitable approach to examine the data because the data are classified counts. To facilitate this, sprouting severity classes were defined as "clear" where no epicormic sprouts occurred, "moderate" where one to four epicormic branches sprouted, and "severe" where there were five or more epicormic sprouts

Table 1. Description of sampled installations.

Installation ID	Elevation (m)	Aspect* (deg)	Slope (%)	Latitude (d m N)	Longitude (d m W)	Site index (m)	ISPA (no./ha)	BH age (yr)	Percent clear
704	183	270	20	46° 12’	122°	36	1,482	8	84
705	823	180	30	47° 10’	121° 43’	27	1,730	7	96
706	91	270	25	46° 45’	123° 44’	38	1,606	6	84
708	274	999	5	46° 27’	122° 5’	38	988	3	76
711	174	999	0	48° 19’	122° 11’	37	1,235	4	81
713	242	180	5	48° 30’	121° 37’	37	1,359	4	73
717	305	360	10	44° 48’	123° 25’	38	1,112	7	88
718	335	888	10	44° 39’	122° 42’	39	1,235	8	78
722	671	270	10	44° 52’	122° 33’	36	1,112	5	64
724	537	180	30	49° 3’	122° 1’	35	1,606	10	82
735	52	999	0	47° 56’	124° 27’	38	1,112	8	69
736	183	270	40	47° 35’	121° 43’	36	988	5	87

* 999 indicates that the installation is level with no aspect while 888 indicates a variable aspect.

in any given positional category. Initially, analyses were performed using epicormic branch position as the basis to examine some of the more biologically and physiologically related hypotheses. To this end, stem quadrants and vertical stem sections were classified by sprouting severity class (i.e., according to the number of sprouts present in the quadrant or third). As an example of this type of hypothesis, consider that if sprouting is stimulated by heat and/or light, then the number of epicormic sprouts occurring in the various quadrants on each tree should be different since the sun will tend to warm and illuminate the quadrants differentially. Further, one might hypothesize that distance from carbohydrate source (the green crown) would affect sprouting severity.

Finally, analyses were conducted using individual trees as the basis to examine one more physiologically related hypothesis and a product quality related hypothesis. Trees were sorted according to epicormic sprouting severity class and sprouting origin. This enables us to determine if sprouts originate mostly in nodes or internodes and whether or not place of origin differs when sprouting is moderate versus severe. Trees were then re-sorted according number of quadrants with sprouts, pruning intensity, and stand density class. Since the number of clear quadrants is often a log grading criterion, considering the pruned portion of each tree as a log will show what proportion of pruned logs may be degraded because one or more faces contain knots resulting from large epicormic branches.

The following tests are not strictly independent of each other because portions of the data are reused in several of the tests. However, even if the overall (experiment-wise) Type I error rate is controlled using a Bonferroni-type procedure (Snedecor and Cochran 1980) and set at the nominal 0.05 rate, the conclusions would remain unchanged.

Results and Discussion

Position-Based Analyses

A total of 1,011 (20%) of the 5,044 examined stem quadrants were found to contain at least one epicormic branch. All of these epicormic branches had green needles and appeared to be growing vigorously. To test the anecdotally generated hypothesis that epicormic branching occurs differentially among quadrants, we examined the number of quadrants not affected, moderately affected, and severely affected by epicormic sprouts, and we found that southern quadrants have significantly higher epicormic branch frequency than the others (Table 2, $\chi^2 = 34.9$, $P < 0.001$). The overall average frequency of occurrence for all sites and densities therefore supports the conjecture that warmer and/or lighter exposures are associated with a greater frequency of epicormic sprouting (Figure 1).

Next, we sought to test the hypothesis of independence of epicormic sprouting and distance from the source of carbohydrate production, more specifically, the live crown base, using the same severity classes as before for the bottom, middle, and top thirds of the pruned tree bole as shown in Table 3. The hypothesis of independence between branching severity and bole position is rejected ($\chi^2 = 41.9$, $P < 0.001$).

Table 2. Number of quadrants classified by cardinal direction and epicormic branching severity class.

Quadrant*	Clear	Moderate	Severe	Total
	(count / %)			
N	1,046 / 83.0	182 / 14.4	33 / 2.6	1,261
E	1,034 / 82.0	194 / 15.4	33 / 2.6	1,261
S	948 / 75.2	245 / 19.4	68 / 5.4	1,261
W	1,005 / 79.7	212 / 16.8	44 / 3.5	1,261
Total	4,033 / 80.0	833 / 16.5	178 / 3.5	5,044

* Top, middle, and bottom thirds combined.

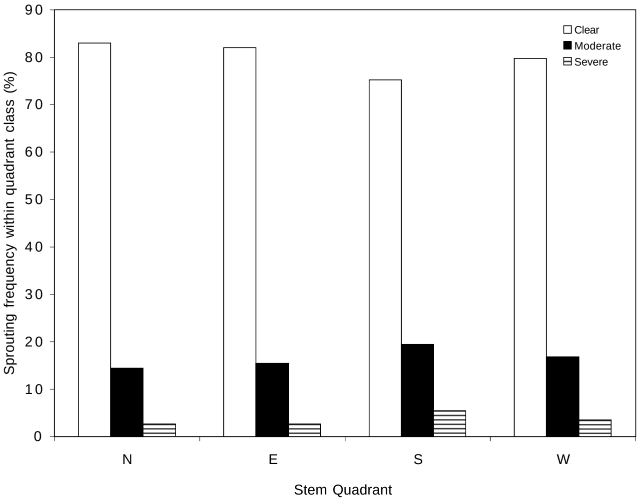

Figure 1. Distribution of epicormic branching severity for each directional quadrant. Clear indicates zero sprouts, moderate indicates one to five sprouts, severe indicates greater than five sprouts present. Note the apparent dip in frequency of clears and concomitant increase in frequency of both moderate and severe cases of sprouting for south facing quadrants.

Row percentages indicate that epicormic branching is most severe in the middle third of the pruned stems and least severe in the bottom third.

Epicormic sprouting may also be related to intensity of pruning. Table 4 shows the number of quadrants examined classified by pruning intensity and branching severity class, while Table 5 shows the same classification for large epicormic branches only. It is immediately obvious from these two tables that there are differences in the frequency of occurrence and size of epicormic branches associated with pruning intensity. It does indeed appear that epicormic branching becomes more severe as more live crown is removed; the most severe branching is found as a response to a 60% crown reduction (Figure 2). This holds true when attention is restricted to large epicormic branches as well.

As seen in Table 5, there are no large epicormic branches in the 20% crown reduction treatment. In the 40% live crown removal treatment, <4 % of the stem quadrants examined had large epicormic branches. In contrast, the 60% live crown removal treatment had large epicormic branches in >25 % of the examined quadrants. The χ^2 statistic is still reliable when there are many classes with zero observed counts (as in Table 5). However, in partitioning the table in order to restrict attention to the 2 × 3 subtable found by excluding the 20% pruning row, the χ^2 statistic is highly significant indicating that proportion of quadrants in each sprouting severity class varies among pruning severity classes.

Tree-Based Analyses

The positional analyses described above are important for gaining insight into, or to confirm, hypotheses regarding the resultant effects of the physiological, ecological, and/or biological processes involved with epicormic branching as a response to pruning and thinning. One further question along these lines, however, is best analyzed using tree-based responses. When epicormic branches sprout on a tree, do they sprout from the pruned whorls (in nodes), from between the whorls (in the internodes), or both? Further, is severe epicormic sprouting (more than five branches on a stem) somehow related to sprouting origin? Table 6 shows the number of trees with sprouts tallied by sprouting severity class and sprouting origin. The null hypothesis that epicormic branch occurrence severity is independent of sprouting origin was tested and rejected (χ^2 = 367.5, $P << 0.001$). Where the sprouting response can be viewed as moderate, the sprouting tends to occur primarily on the pruned whorls (116 of 205 cases). However, if the sprouting response to pruning is severe, the epicormic branches sprout both from the whorls and between the whorls (193 of 215 cases).

Since branches are the source of knots, there is much interest in how epicormic sprouting might influence log grade. The number of clear quadrants (or faces) is one of the chief criteria used in many log grading schemes (Bell and Dilworth 1997). To establish the relationship among stand density, pruning severity, and log grade, another tree-based analysis was conducted. Trees with large epicormic branches were tallied by pruning intensity and number of quadrants containing epicormic branches for each of two stand density classes (high and low). Note that the pruning intensities tested to date chiefly affect just the first log in the trees. The results for the low density class, defined as <500 stems/ha (SPH), are presented in Table 7 and those for the high density class, i.e., ≥ 500 SPH, are shown in Table 8. There were no large epicormic branches in the 20% crown removal treatments in either of the two stand density classes. Contingency table analyses were conducted for each density class to test the hypothesis that the distribution of trees across number of affected quadrants is the same for the 40 and 60% crown reduction treatments (considering only the 40 and 60% classes results in 2 × 5 subtables).

Pruning >40% of the live crown can potentially affect the final quality of the pruned log in low density stands (Table 7, $\chi^2 = 43.724$, $P < 0.001$). The 40% pruning intensity class has 82% of the trees completely clear while the one-quadrant category has 11%. The totally clear category plummets to 52% of the trees for the 60% pruning intensity class. For the

Table 3. Number of pruned bole sections (bottom, middle, or top third) classified by relative height and epicormic branching severity class.

Relative height	Clear	Moderate	Severe	Total
		(count / %)		
Bottom*	1,003 / 79.6	212 / 16.8	46 / 3.6	1,261
Middle*	923 / 73.2	232 / 18.4	103 / 8.2	1,261
Top*	1,032 / 81.8	168 / 13.3	61 / 4.8	1,261
Total	2,958 / 78.2	615 / 16.3	210 / 5.5	3,783

* N, S, E, W quadrants combined.

Table 4. Number of quadrants* by pruning intensity and epicormic branching severity class.

Pruning intensity (%)	Clear	Moderate	Severe	Total
		(count / %)		
20	1,587 / 99.7	5 / 0.3	0 / 0.0	1,592
40	1,564 / 89.5	171 / 9.8	13 / 0.7	1,748
60	882 / 51.8	657 / 38.6	165 / 9.6	1,704
Total	4,033 / 79.0	883 / 17.5	178 / 3.5	5,044

* Top, middle, and bottom thirds combined.

Table 5. Number of quadrants* by pruning intensity and epicormic branching severity class, large epicormic branches only.

Pruning intensity (%)	Clear	Moderate	Severe	Total
		(count / %)		
20	1,592 / 100.0	0 / 0.0	0 / 0.0	1,592
40	1,682 / 96.2	64 / 3.7	2 / 0.1	1,748
60	1,233 / 72.4	433 / 25.4	38 / 2.2	1,704
Total	4,507 / 89.4	497 / 9.8	40 / 0.8	5,044

* Top, middle, and bottom thirds combined.

60% pruning intensity class, the one-quadrant category contains 22% (twice the figure for the 40% pruning intensity class), and both the two-quadrant and three-quadrant categories pick up 11% of the trees each (two to three times more than the 40% pruning intensity class).

As with low density stands, pruning >40% of the live crown can potentially affect the final quality of the pruned log in high density stands (Table 8, $\chi^2 = 125.174$, $P << 0.001$). Table 8 shows that while essentially all of the trees in the 20 and 40% pruning intensity classes are totally clear, there is a significant proportion of trees falling in each of the nonclear quadrant categories for the 60% pruning intensity class. There are, namely, 21, 13, 10, and 7% of the trees in the one-, two-, three-, and four-quadrant affected categories, respectively.

To determine the effect of stand density, one can hold pruning intensity constant, while varying stand density. Using the 40% pruning intensity rows from each of Tables 7 and 8 forms a 2 × 5 subtable, which allows testing the hypothesis that the distribution of affected quadrants is similar between stand densities for the 40% live crown removal class. The hypothesis is rejected (table not shown, $\chi^2 = 26.046$, $P < 0.001$) and we conclude that significantly more trees have one, two, and three quadrants affected in low density stands than in high density stands when 40% of the green crown is removed (Figure 3). For the 60% pruning intensity treatment, similar proportions of quadrants are affected in both low and high density stands (table not shown, $\chi^2 = 1.14$, $P = 0.886$), therefore a higher stand density cannot counteract the effects of pruning intensely on epicormic sprouting (Figure 4).

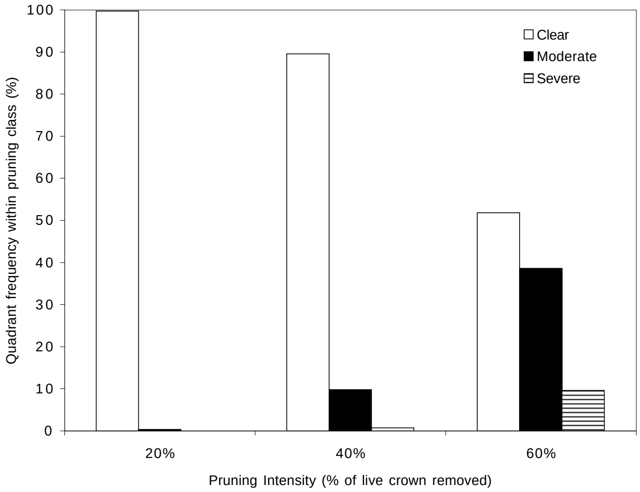

Figure 2. Distribution of stem quadrants among epicormic branching severity classes for each pruning intensity. Clear indicates zero sprouts, moderate indicates one to five sprouts, severe indicates greater than five sprouts present.

Taken together, these results show that controlling stand density will only limit the occurrences of large epicormic branches if the tree crowns are not overly reduced by the pruning treatment. There are potential trade-offs associated with maintaining high density stands to keep epicormic branch incidence low, which may reduce growth rates and slow the production of clear wood, and maintaining low stand density to speed the production of clear wood but potentially increasing epicormic branch incidence. The trade-off is not expected to be great, however, because in this analysis the average density of stands in the high density class is 590 SPH, which is not likely to slow growth substantially due to competition. Also, the results of this study are based on stands where all trees are pruned. Another strategy may be to leave some unpruned trees in the stand that provide sufficient shade to prevent epicormic sprouting on the pruned stems. Since the unpruned trees will have the larger crowns, there is a chance that they will begin to outgrow and overtop the pruned trees, so they must be thinned at a later date but prior to final harvest.

Table 6. Number of trees by epicormic branch origin and branching severity class.

Location	Moderate	Severe	Total
Whorl only	116	17	133
Internode only	36	5	41
Both	53	193	246
Total	205	215	420

Table 7. Number of trees with large epicormics in low density stands classified by pruning intensity and number of affected quadrants (quads).

	Number of quadrants affected by large epicormics					
Pruning intensity (%)	None	1 quad	2 quads	3 quads	4 quads	Total
20	210	0	0	0	0	210
40	163	21	9	5	1	199
60	95	40	20	19	9	183
Total	468	61	29	24	10	592

Table 8. Number of trees in high density stands with large epicormics classified by pruning intensity and number of affected quadrants (quads).

	Number of quadrants affected by large epicormics					
Pruning intensity (%)	None	1 quad	2 quads	3 quads	4 quads	Total
20	188	0	0	0	0	188
40	189	5	0	1	0	195
60	140	61	37	29	19	286
Total	517	66	37	30	19	669

Conclusions

Based on the data collected for this study, when pruning coastal Douglas-fir, epicormic branches will be a problem only when >40% of the live crown is removed. These results agree with those of Issac (1945) and Stein (1955), who concluded that crown reductions of 50% or more could lead to significant numbers of epicormic shoots. O'Hara (1991) stated that epicormic branching should not be considered a deterrent to pruning of coastal Douglas-fir as long as pruning does not reduce the live crowns by more than 50%. Also, epicormic branches tend to occur on the middle third of the pruned bole and on the southern quadrant of the stem. Moderate occurrences of epicormic branches tend to originate in the pruned whorls, while severe sprouting will occur anywhere on the stem. A genetic or a site factor might influence this since trees with severe epicormic sprouting were not present on all sites.

From a log-quality perspective, if pruning is restricted to <20% of the live crown, no logs will be degraded due to knots forming from large epicormics. Pruning up to 40% of the live crown likely will cause about 20% of the logs to have one or more quadrants with large epicormic branches. The percentage of logs degraded by large epicormics can be reduced to zero by pruning 40% of the live crown only in stands with more than 500 stems/ha. However, stand density had no effect on the proportion of logs potentially degraded when pruning 60% of the live crown, which resulted in 20% of the logs having one quadrant with large epicormic branches and 30% of the logs having two or more quadrants with large epicormic branches.

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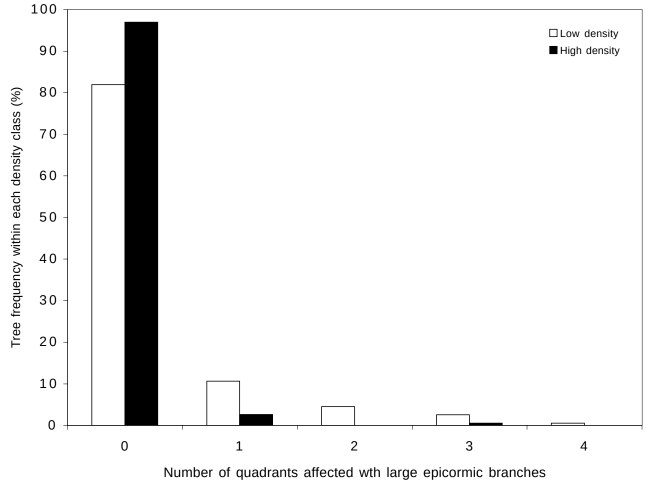

Figure 3. Distribution of 40% pruned trees with 0, 1, 2, 3, or 4 affected quadrants for each density class. Note the apparent increase in frequency of trees in the clear (0 quadrant) class for high density stands, and concomitant decreases in frequency for 1, 2, and 3 quadrant classes.

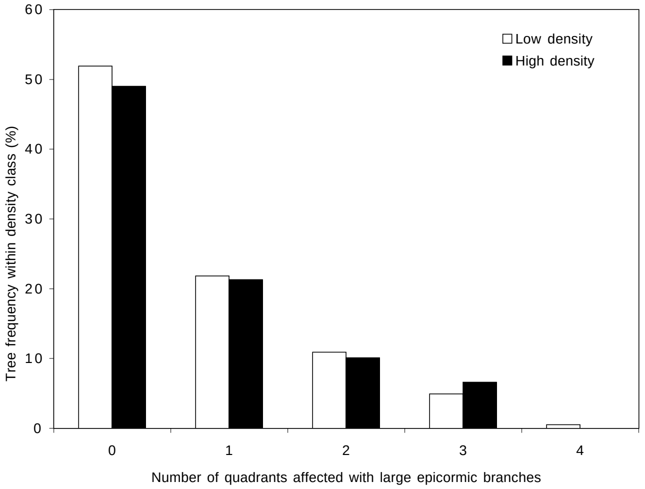

Figure 4. Distribution of 60% pruned trees with 0, 1, 2, 3, or 4 affected quadrants for each density class. Note the similarity in proportions of trees with affected quadrants for each density class.

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