CHOOSING STAND DENSITY WHEN SPACING JUVENILE LODGEPOLE PINE IN PRESENCE OF RISK OF PEST ATTACK

by
Darrell Errico

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Choosing Stand Density
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Darrell Errico

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Research Branch
B.C. Ministry of Forests
31 Bastion Square
Victoria, B.C
V8W 3E7

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# TABLE OF CONTENTS

1. INTRODUCTION ........................................... 1
2. THE PROBLEM ........................................... 2
3. STAND-LEVEL EFFECTS OF PEST DAMAGE ................. 5
4. FOREST-LEVEL EFFECTS OF PEST DAMAGE ................. 8
5. DISCUSSION ........................................... 14
6. SUMMARY AND RECOMMENDATIONS ....................... 16
7. REFERENCES ........................................... 18
FIGURES

1 Sensitivity of final stand volume (for stems of 12.5+ cm dbh at 24 m site height) to changes in stocking levels at 6 m stand height. ........................................ 6

2 Sensitivity of final stand volume (for stems of 22.5+ cm dbh at 24 m site height) to changes in stocking levels at 6 m stand height. ........................................ 6

3 Sensitivity of final stand dbh (for all stems at 24 m stand height) to changes in stocking levels at 6 m stand height. ........................................ 7

4 Distribution of pest damage for an imaginary forest pest. ........................................ 9

5 Distributions of final stand densities after pest damage has taken place for the imaginary pest being considered. ........................................ 10

6 Final stand volume-per-hectare averages and ranges for the prescriptions of Figure 5 and the desired ideal. The middle mark of each bar is the weighted average. . . . 12

7 Final average stand diameter at breast height averages and ranges for the prescriptions of Figure 5 and the desired ideal. The middle mark is the weighted average. ........................................ 13
1. INTRODUCTION

Juvenile spacing programs for interior British Columbia lodgepole pine stands exceed those of other species. In 1988 approximately 6000 hectares were spaced. Costs of this program are in excess of $2 million annually.

For stands of 20 years of age or younger there is disagreement on the appropriate spacing density. Spacing targets have been established which assume that a certain degree of mortality normally occurs after spacing. There is a tendency, however, to leave additional stems to hedge against abnormal mortality. In practice, this margin of extra stems is large. As well, it is not well-understood which stands are at higher risk or to what degree damage will take place. The inclination, therefore, is to leave additional stems everywhere, on all projects.

The question which requires addressing is: In light of this lack of precise knowledge, what spacing policy maximises the number of stands which reach the desired target density, at least cost?

In the discussion to follow, the problem will first be more fully described. Next, some arithmetic examples will be presented to outline the consequences of different spacing policies in the presence of a particular level of damage. Following that a synthesis of the results will be presented.

The following terms will be used throughout:

**Damage** This applies to any abnormal stand damage. It may result from agents other than pests, although the focus is on damage from forest pests.
Target  This is the density (at age of juvenile spacing) which is expected to yield a final stand of some desired attributes. This stocking allows for normal losses which, for lodgepole pine, may be as high as 400 stems per hectare throughout the life of the stand.

Prescription  This is the density that is prescribed through spacing.

2. THE PROBLEM

If the extent of future tree mortality were known, the problem would be simple. The spacing prescription could be tailored to the known number and spatial pattern of future mortality.

This requires perfect knowledge, however. Actually, very little is known about what will happen on a site. Moreover, little is known regarding what will happen, on average, over many sites for an area. It is merely known that significant damage will occur in some stands. Leaving a higher density than the target on spaced sites ensures that if major damage occurs, a stand remains which has a density close to the target.

There are reasons for and against leaving these additional trees. If damage on all sites alters the density in the amount and pattern implied by the extra trees then this is the appropriate decision. If damage does not occur then a second entry into stands to perform additional spacing may be necessary. If a second entry is possible then this might provide the best solution. Most of the uncertainty is removed and the target can be reached with more reliability if the time can be identified
when major risk to damage has passed. Many claim this second entry is not financially justified. If the second entry is not possible (due to budget limits or for financial reasons) then a less desirable stand will result. Even if a second entry is possible, the value which is saved in damaged stands should exceed the cost of the second entry into the undamaged stands. If only a few sites are heavily damaged it may be better to forego their lost value rather than force a second entry on remaining undamaged sites.

In addition, some believe that leaving a more densely-stocked stand reduces the risk of pest attack. For example, some pests are attracted to more vigourous, larger trees. If trees are smaller as a result of overcrowding, then attack is less likely. There is the alternate viewpoint that since some pests tend to attack stressed trees, reducing density reduces stress and increases tree resistance. These aspects are subtleties which should be addressed only after the larger, more critical questions regarding pest damage have been answered.

Some simple analysis follows to provide a more systematic basis for spacing prescriptions and for determining data requirements.

In order to conduct this analysis the following points require review:

a. Correctness of stocking targets. This study will not question target densities. What will be addressed here is how any target should be adjusted where there is abnormal damage.

b. Damage and mortality. Some damage does not kill a tree but instead slows growth or reduces quality. The tree still
competes for space and nutrients. If a second spacing entry is possible then that tree can be removed and prescribing extra stems makes sense. If the second entry is not possible, then leaving extra stems does not help. In the present study, the damage being considered is that which leaves a tree dead or as though dead in its influence on neighbouring trees.

c. **Acceptable number of stand entries.** It will be assumed that only a single stand entry is allowed.

d. **Timing and duration of damage.** When leaving additional stems, consideration must be given to the age at which damage will take place. If additional trees are left but the expected damage takes place at a much later age, then the stand will have essentially grown in an overstocked state. The analyses to follow will only deal with damage which occurs fairly soon after spacing such that it has a similar effect on the stand as additional juvenile spacing.

e. **Area of application.** Stand treatment guidelines (for example stocking standards) apply to large areas such as a biogeoclimatic subzone. A similarly large area will be dealt with here.

f. **Spatial distribution.** Spatial distribution of damage can be clumped or disbursed (MacLaughlin, B.C. Forest Service, pers. comm., June, 1989). Both situations will be examined.

The next section will review effects of pest damage on a stand.
3. STAND-LEVEL EFFECTS OF PEST DAMAGE

It is useful to review some information adapted from Goudie (1984, 1985), in which the growth and yield of lodgepole pine stands was simulated. Vyse (1985) provides some helpful interpretations by showing the impact of spacing choices on the final form of a stand. The following figures display the sensitivity of results, or how final stand parameters might change with spacing density. Because of the limited simulations available for juvenile-spaced stands, data were drawn from the more abundant simulations that were performed using different stand establishment densities. In these simulations there were no other treatments. The premise used here is that stands of identical spacing at the same age will develop from that point in similar (but not exact) fashion, whether that spacing was achieved through natural means or juvenile spacing. Based on a visual inspection of the data, this seems to be a reasonable assumption.

Figure 1 relates the final stand volume (for stems of 12.5+ cm dbh at site height of 24 m) to spacing at 6 m stand height. Each bar has three horizontal marks. The middle mark denotes the final volume for that particular spacing. The upper and lower marks denote the range in final volume resulting from a plus or minus 100 stems-per-hectare change in density at the 6 m stand height. These are based on a linear interpolation and are an approximation. The lengths of the bars, therefore, provide a visual impression of the sensitivity of final volume to early density changes. This graph shows that the choice of early stocking can have a large effect on the final stand volume. Sensitivity shows a moderate decrease as the juvenile density increases. Thus the consequences of density decisions are greater at lower juvenile densities.
Figure 1. Sensitivity of final stand volume (for stems of 12.5+ cm dbh at 24 m site height) to changes in stocking levels at 6 m stand height.

Figure 2 shows the volume sensitivity for stems of 22.5+ cm dbh. It demonstrates that there is an upper volume limit associated with juvenile density. At densities higher than 1500, the interpretation of the sensitivity bars is reversed. Increases in early density imply a decrease in final stand volume.

Figure 2. Sensitivity of final stand volume (for stems of 22.5+ cm dbh at 24 m site height) to changes in stocking levels at 6 m stand height.
A similar depiction of final average stand diameter (for all stems) related to juvenile stocking can be made. This is given in Figure 3. (Note that the vertical axis has a lower range of 19 cm.)

![Average stand dbh at 24 m stand height](image)

**Figure 3.** Sensitivity of final stand dbh (for all stems at 24 m stand height) to changes in stocking levels at 6 m stand height.

In this case, an increase in density results in a decrease in average final stand diameter. In general, the sensitivity of average diameter decreases with an increase in density, although the trend is less pronounced and less consistent than that of volume.

To evaluate the effects of stocking decisions both of these views require simultaneous consideration. Increasing density can increase total volume production, but the size of trees decreases. Where saw logs are valued more highly than pulp logs it may be desirable to sacrifice final stand volume in the interest of producing larger logs. The dilemma facing stand managers is not simply in understanding this volume-value trade-off, but in understanding how it will develop in the future. If markets become more oriented to simple wood fibre, regardless of
tree size (ignoring logging costs for the moment), then the stand volume sacrifice taken today will not be the best decision.

Thus stand management must be viewed as attempting to achieve some volume-diameter (value) optimum rather than simply maximising either volume or diameter alone. In this paper, achieving of this optimum is assumed to be accomplished by obtaining a target density. Departing from this optimum is viewed as being undesirable, regardless of whether it is due to under- or over-stocking.

Introducing risk of pest damage only adds complexity. These figures show a moderate increase in the robustness of stands of higher density—they are more likely to deliver a known final stand product regardless of damage. This must be balanced by the fact that the choice of higher densities has a large impact on final stand outcome.

4. FOREST-LEVEL EFFECTS OF PEST DAMAGE

Consider an area containing 15-year-old lodgepole pine stands which are candidates for juvenile spacing. This may be as large as several thousand hectares and may consist of many geographically dispersed stands.

Consider an imaginary pest to which these stands will be susceptible over a relatively small time. The damage from this pest results in immediate mortality. Like most pests, the number of stems per area which it kills varies from stand to stand. Figure 4 shows the expected distribution of the extent (percentage area) and intensity (number of stems per hectare) of damage. Percentage damage figures are used rather than absolute numbers as they are conceptually easier. Remember that the same
percentage means different numbers of stems at different densities.

![Graph showing distribution of pest damage](image)

**Figure 4.** Distribution of pest damage for an imaginary forest pest.

The discrete values shown in Figure 4 might be class midpoints of a continuum of levels of damage. For the present discussion spatial distribution of damaged trees is assumed to be disbursed. This order of magnitude of pest damage is probably realistic for large forested areas of interior British Columbia.

For a particular spacing prescription a range of stand densities will remain after mortality has taken place. Figure 5 shows the final distributions of stand densities for three spacing density prescriptions.

Suppose that the target density is 1000 stems per hectare. This is the density desired at this age after any extraordinary damage has taken place. From Figure 5 the following observations can be made:
Figure 5. Distributions of final stand densities after pest damage has taken place for the imaginary pest being considered.

a. When the spacing prescription is 1000 stems per hectare, the final density is either at the target or below. The lowest is 700 stems per hectare. Figure 1 implies that this stocking reduction will yield a large change (about one-quarter to one-third) in stand volume from that which is desired. There is a minor corresponding increase in average dbh at harvest. These changes occur, however, on only 5 percent of the total spaced area.
Ninety-five percent of the area achieves a final density that is within 100 stems per hectare of the target and therefore shows smaller differences in final stand volume and diameter. Hence, with this amount of damage, the rule of spacing to the target density is reasonable for 95 percent of area. The other 5 percent of area is of a density which delivers stands of possibly unacceptable characteristics.

b. When the spacing prescription is 1300 stems per hectare, the distribution of densities, after damage, brackets the target. Ninety-five percent of the area has higher stocking. In this case the departures from target are as large as Scenario 1, but a much larger area is involved.

c. The spacing prescription of 1600 stems per hectare, or 60 percent above target, is typical of the margin of additional stems being prescribed for lodgepole pine in British Columbia. In this case, all areas have final density above target, with 95 percent of area being considerably above. Prescribing this large margin of additional trees has greater consequences on final results than does spacing to the target density. For these densities a second spacing entry might be desirable.

Figures 6 and 7 show another aspect of these prescriptions by comparing the minimum, maximum, and average of the distributions of the final average stand diameters and volumes per hectare. These are indicated by the upper, lower, and middle marks on each bar. Also plotted are the desired volume and diameter which would result if no abnormal damage would occur. The reader is cautioned that these values are interpolated from those of Figures 1 and 2 and not directly from yield tables for juvenile spacing regimes. The trends, however, are believed to
be correct. All distributions are similarly skewed; only their locations and scales differ. The middle mark indicates the degree of skew. The closer it is to the upper or lower range marks, the more the observations are clustered towards that end. While there is a wide range of final volumes and diameters when the spacing prescription is 1000 stems per hectare, the values for the majority of areas tend to be close to the ideal. When the prescription is 1300 or higher, the final stand diameter and volume values for the majority of areas show greater departures from the ideal. In other words, if a second stand entry for spacing is not possible then the final forest differs more from the ideal than from that which results from spacing to the target density. Thus, the prescription to space to the target seems most reasonable.

![Graph](image)

**Figure 6.** Final stand volume-per-hectare averages and ranges for the prescriptions of Figure 5 and the desired ideal. The middle mark of each bar is the weighted average.

If a second entry is possible, over-stocking can be corrected. However, the cost of additional spacing required for stands managed under the higher densities should be compared with
the loss in value of stands prescribed lower densities. In Figure 5, for the prescription of 1000 stems per hectare the significant loss in value occurs in the 5 percent of area for which density drops to 700 stems per hectare. The reason for leaving extra stems is to prevent this. This loss should be contrasted with the cost of the second entry required under the prescriptions of 1300 or 1600 to bring the final overstocked stands to their desired target.

![Figure 7. Final average stand diameter at breast height averages and ranges for the prescriptions of Figure 5 and the desired ideal. The middle mark is the weighted average.](image)

Some of these comparisons may be academic. If density control for spacing projects or the precision with which density is measured is poor, two prescriptions may not be practically different. For example, if density differences of 100-200 stems per hectare from the target cannot be reliably measured or implemented then they can be regarded as being within the accepted target range.
5. DISCUSSION

These examples provide a framework for systematic analysis. The distribution of pest damage is based on speculation. Only one pattern of pest damage has been investigated. There are actually an infinite number of possible patterns of damage. Which of these possibilities make the 1300 or 1600 stems per hectare prescriptions reasonable?

A 1300 stems per hectare prescription is appropriate where all stands experience 23 percent of stems suffering abnormal damage. A 1600 stems per hectare prescription is appropriate where all stands experience 37 percent of stems suffering abnormal damage. The more the distribution of damage departs from these the less reasonable these prescriptions become. If the number of stands that experience these amounts of damage is small, then the majority of stands will remain overstocked and the prescription will have failed for the majority of sites. (Of course, if all stands experience these levels of damage, it would no longer be abnormal.) Examples of pest damage of this magnitude are found in some stands in British Columbia. However, they do not appear to represent the average case. What little information there is on the amount of pest damage over large areas in British Columbia suggests that, at least as a broad average, damage is in the approximate range of 5-10 percent of all stems damaged. (See, for example, Heppner and Wood [1984]; Lewis [1987,1989]; Reed and Errico [1987]; Errico and Geisler [1989].) This is considerably smaller than the approximately 25-40 percent average damage that the prescriptions of 1300 and 1600 imply.
Three additional topics require discussion:

**Multiple pests.** The studies cited above focus mainly on damage from a single pest. There is also the case of epidemic populations of more than one pest attacking a stand. Two aspects need to be better understood. The first is how frequently multiple epidemic infestations occur. The second concerns the additivity of damage. If a tree is seriously damaged or killed by one pest, subsequent infestation by a second pest will not change its status. What needs to be established is the degree to which infestation of a stand by a second pest results in additional stems being damaged.

**Changes in stocking standards.** This discussion has focused on a single target density of 1000 stems per hectare. The reasoning does not change if that target is different. For example, if the target is 1600 stems per hectare and the prescription is 2200, then the damage which justifies this prescription is 27 percent stems damaged on all sites. If the target is 2000 stems per hectare and the prescription is 2600, then the damage which justifies this prescription is 23 percent of stems damaged on all sites. These pest damage levels are still much higher than the approximately 5-10 percent that appear to actually exist.

**Spatial distribution.** Not all pests damage trees in a disbursed spatial pattern. For some, clumps of damaged or killed trees result. Under these circumstances, a more appropriate juvenile spacing prescription is the target density. Leaving more stems will result in overstocked stands with interspersed holes or clumps of damaged trees. Average densities may be correct, but local overstocking will take place. Spacing stands to the target density will result in stands of the desired density, but also with interspersed holes or clumps of damaged trees. In either case, the clumps or holes are created. It may be possible
that because of pest and tree-density interactions higher densities result in smaller holes or clumps of trees. If this is true, then leaving more trees will result in more stand area being occupied by trees. This still does not guarantee achievement of the optimum stand diameter and volume. More basic knowledge is required before attempting to deal with these complex issues.

6. SUMMARY AND RECOMMENDATIONS

To offset pest damage, lodgepole pine stand managers tend to prescribe juvenile spacing densities which are substantially higher than actual target densities. There is disagreement about whether this is the best method of producing the desired target stand.

If a second stand entry is possible, leaving extra stems provides the most reliable solution to the problem. It reduces the uncertainty of stocking resulting from pest damage.

If a second entry is not possible, the margins of additional stems being prescribed anticipate amounts of pest damage which do not seem to occur. Moreover, because of the spatial pattern of damage for most agents the problem cannot be solved by simply leaving more stems everywhere.

The analysis provided here suggests that adjusting lodgepole pine spacing standards for pest damage is not warranted. The major barrier to confirming this is the paucity of reliable data on levels of damage. Until this information is obtained, the disagreement will continue.
The following information (in order of priority) is therefore essential to improve understanding of the problem:

a. **Distribution of extent and intensity of pest damage over all stands of the type and age category of interest.** Information to date has often been collected from areas of known prior pest activity. This introduces bias in the estimation of pest incidence. Surveys should be conducted by sampling from the total population of stands of interest. Determining first the order of magnitude would help to narrow the disparity of opinion of the appropriate juvenile spacing prescription.

Understanding pest population behaviour over time is also necessary. For example, one pest might have major outbreaks only once every several decades, while another may have population levels that peak every few years. Spacing prescriptions for either of these would be different.

Collection of this information should recognise the combination and interaction of pests.

b. **Site-specific risk.** Information from (a) above, plus an understanding of pest dynamics may enhance prediction of the degree of pest damage on an individual site. If prediction is reliable then adjusting the spacing prescription to account for site-specific losses will improve the manager's ability to achieve the desired density. Of course, any prediction system would still be subject to uncertainty, and this should be accounted for in the final prescription.

With this information, improved analyses can be conducted to assist the silviculturist in applying spacing prescriptions.
7. REFERENCES


