Lesson 3

Biological Concepts of Timber Production

1.5 hours

Lesson Objectives

- To promote a common understanding of biological principles that underlie the effects of density management
- To provide an overview of wood quality and forest health as they relate to density management.

Method: Introduce the Guidelines – Q&A, Lecturette, Video

- Introduce biology section
- Show biological concepts video
- Go over points to emphasize concepts
- Present recent information on wood quality as it relates to density
- Review the main points of Pacific Forestry Centre Technology Transfer Note No. 12, November 1998 regarding forest health and density management.

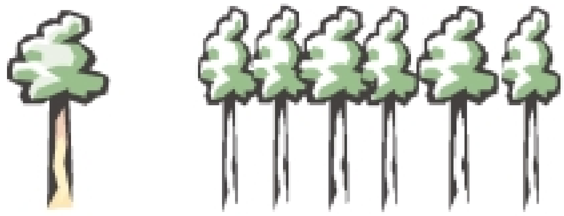
Audio Visual Requirements

- Overhead projector

Handout

- Technology Transfer Note No. 12, November 1998

Why Do Density Management?



STAND DENSITY MANAGEMENT REGIMES 3 • 1

Benefits of Density Management

- Turn to your neighbour exercise – 5 minutes for contemplation, 10 minutes to summarize as a group.

What possible management objectives do you believe density management (particularly pct [pre-commercial thinning]) will achieve?

- Alleviate timber supply gaps
- Improve habitat or riparian function
- Set up stands for future entries
- Reduce risk of blowdown or snow damage

Any others?

- Employ forest workers

Mention only:

Pruning

- Provides clear wood

Fertilization

- Additional volume if all things go well (i.e., appropriate site, species and treatment).

We will concentrate on density manangement.

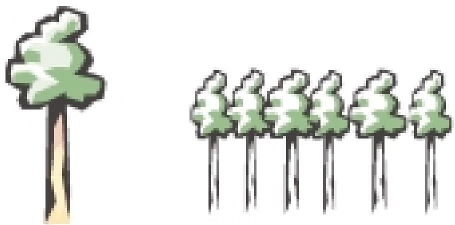
We now want to translate the objectives from above to identify structural attributes that are behind the assumptions.

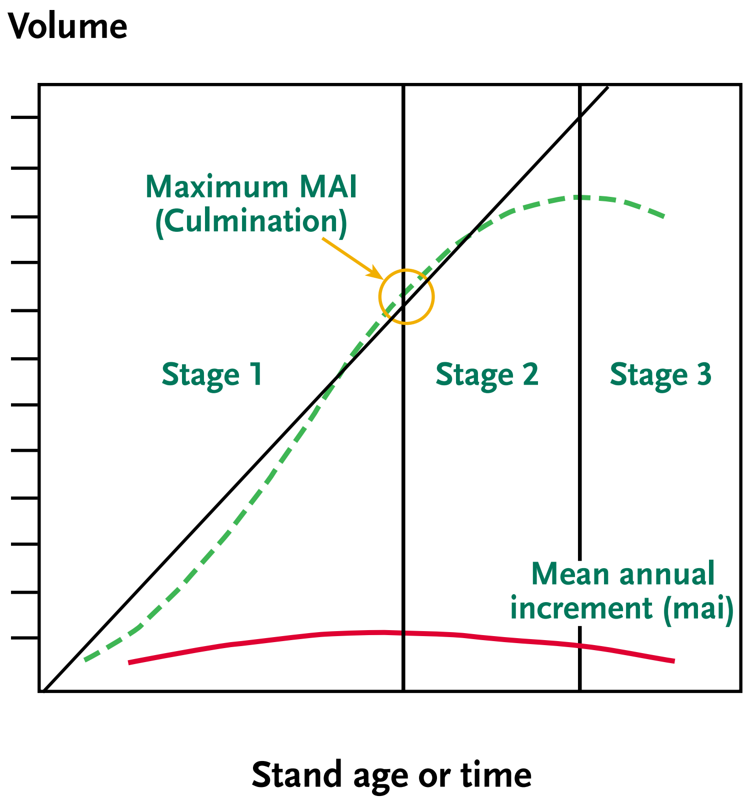
How does density affect individual tree growth and volume production? (from the executive summary)

- Stands regenerated or spaced (pct) to relatively high densities (e.g., 1500–10 000 trees/ha) have small differences in volume and diameter at harvest.
- Stands regenerated or spaced (pct) to relatively low densities (e.g., 250–1000 trees/ha) have larger piece sizes at harvest because more growing space is available to each tree, lower volumes per hectare because of slow site occupancy following treatment, and longer biological rotations.
- That is, there is a trade-off between tree diameter and stand volume which is most clearly reflected in stand and stock tables as opposed to volume per hectare and average diameter. The diameter benefits of spacing diminish the longer treatment is delayed beyond crown closure

We will look more closely at the key factors that influence the magnitude of the generalized statements provided.

Volume Over Time – The Basics





Growth and Yield – Measures Over Time

Volume over age – how the various measures of growth interact

The lines on the graph:

This line depicts the total volume (over some determined minimum diameter) over time. Note it goes through three stages on the graph.

Stage 1 – This early period is where the stand grows rapidly and puts on the most volume over the shortest period of time.

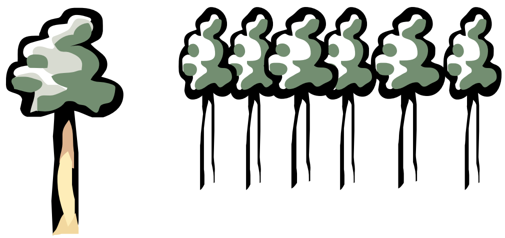
Mean annual increment – the total increment to a given age in years divided by that age.

Stage 2 – Begins where MAI culminates. This occurs at the inflection point on the volume over age curve). This point is called culmination of mean annual increment, as MAI slows after this point. As can be seen the total volume is still increasing but at a lower rate than in stage 1.

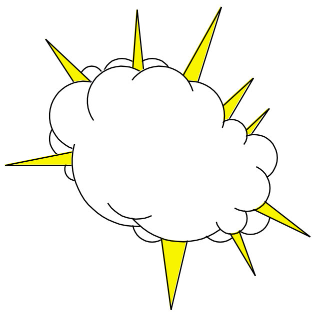
Stage 3 – Is the stage where volume growth declines – larger and larger trees die, with the loss of each it affects the total volume on site. Height growth continues to slow in this phase resulting in less volume growth.

This stage often has reduced stocking due to insect and disease and other age-related mortality factors.

Volume Over Time – The Basics

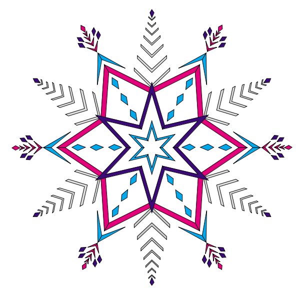


Site productivity is relatively



FIXED

Climate and site dictate productivity.



STAND DENSITY MANAGEMENT REGIMES 3 • 3

Site Productivity is Relatively Fixed

The production potential of a particular population of trees growing on a given site is a function of site and tree resources.

The productivity of the site resource, for example, is determined by the inherent characteristics of the soil and climate.

These characteristics are essentially fixed, although the effects of external factors (e.g., poor soil management, adverse climatic change, industrial pollutants) may temporarily or permanently impair site productivity.

Intensive forestry practices such as cultivation, irrigation, drainage, and fertilization may also effect temporary or permanent increases in production potential. Large productivity gains are rarely practical, however, because production-limiting factors are costly to manipulate.

The productive capacity of a particular species or species mixture is governed by its ability to utilize the site resource. This is a function of the physiological and functional characteristics of the species, and is largely fixed. There are, however, notable exceptions:

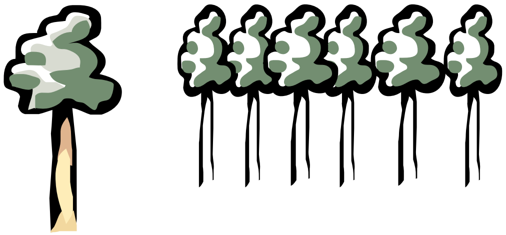
Go over these exceptions.

1. Silvicultural selection for tree vigour can either increase or decrease the efficiency of production because of the wide variation in the productive potential of individual trees.
2. Inadvertent use of unsuitable provenances can lower species productivity.
3. Selection and use of improved growing stock in future managed stands may increase natural productivity through genetic gain.
4. Repression, a biological phenomenon that is particularly important in lodgepole pine, can substantially reduce the height growth and productivity of all trees in stands established at high densities, particularly on sites of average or low productivity.

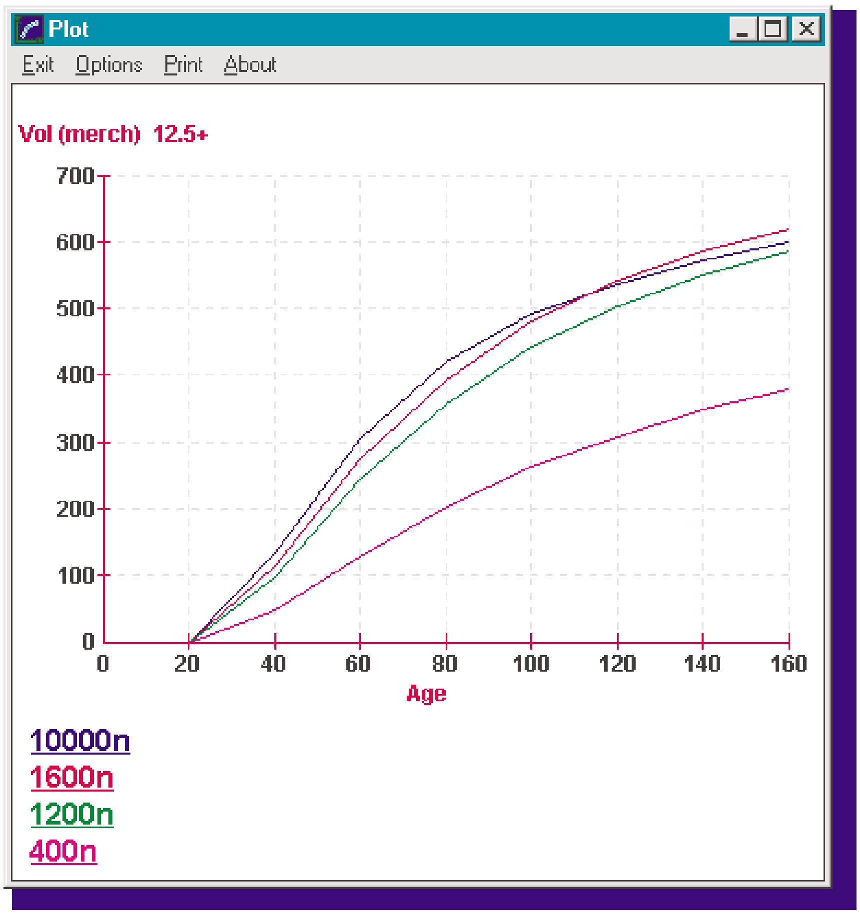
Apart from these site and species exceptions, it is reasonable to assume that stand productivity potential is fixed.

We will now look at what spacing does to the volume over age curve using TIPSY output.

Volume Over Time – TIPSY Runs



Using TIPSY to see how density affects volume

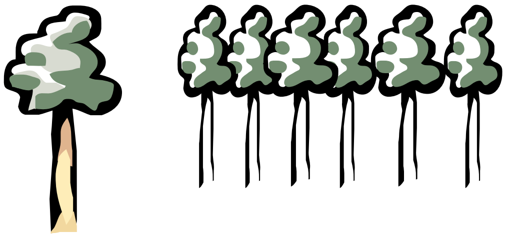


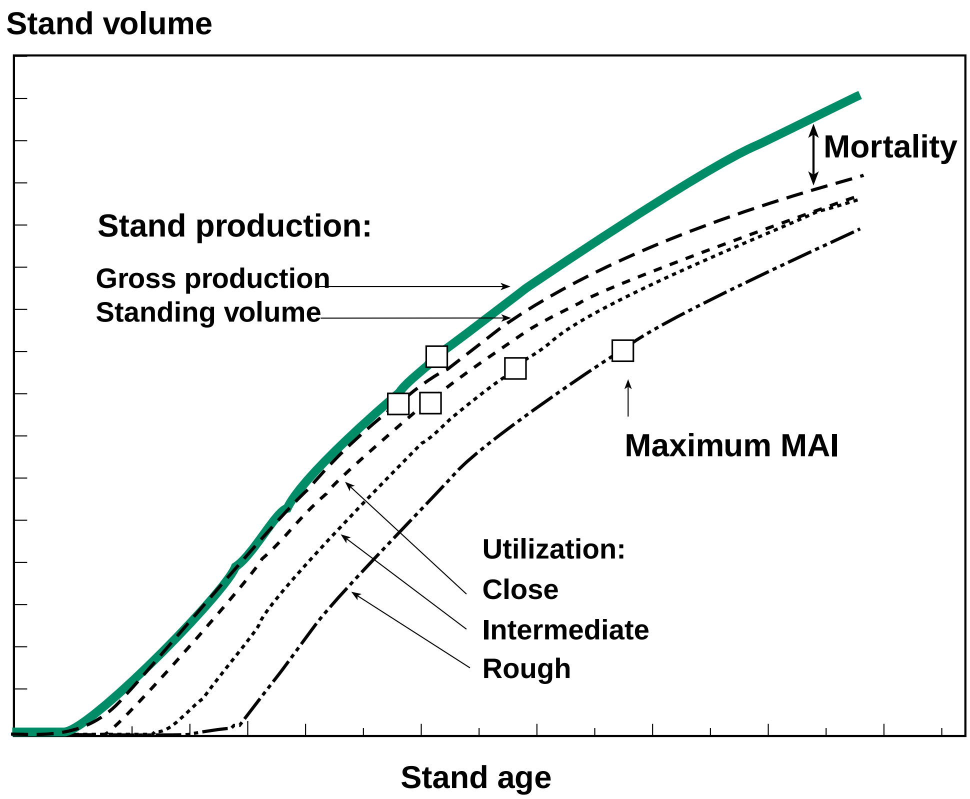
TIPSY Output

TIPSY is the acronym for Table Interpolation Program for Stand Yields – from a database generated by the growth model TASS. TIPSY was originally created in May 1991. TASS is an abbreviation for Tree and Stand Simulator. It is a biologically oriented model. It grows stands tree by tree in a three dimensional space in a computer and simulates silvicultural treatments.

This diagram shows TIPSY over age runs of Pl SI 20 with no OAF adjustments for starting densities of 10 000 sph, 1600 sph, 1200 sph and 400 sph (all natural regeneration).

Stand Production





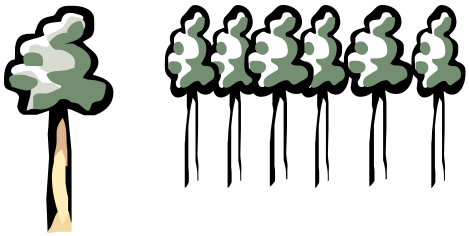
Stand production

Theoretically, near-maximum production in monocultures is realized when a stand fully occupies the site quickly, and performs to its potential throughout the rotation. Actual stand production is lower if crown closure and site occupancy are delayed by low establishment density. Similar yield reductions occur if portions of the site remain unoccupied because of factors such as inadequate stocking, brush competition and pests.

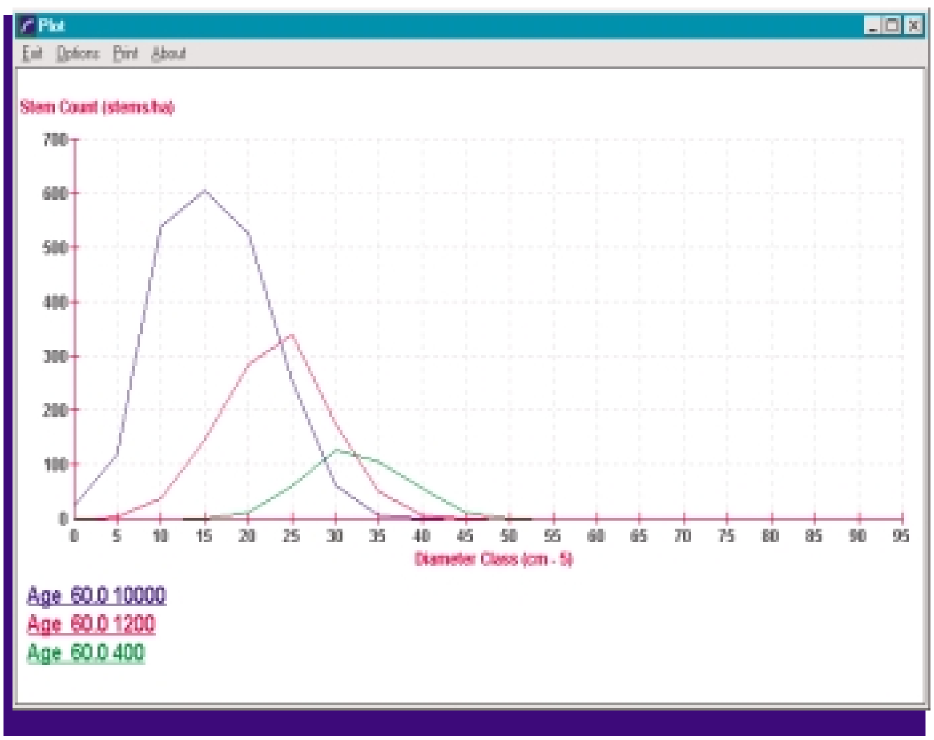
Full utilization of stem wood is achieved if all mortality is harvested as is illustrated by the gross production curve in Figure 2 from the guidelines. The difference between gross production and standing volume represents the volume lost to mortality.

Maximum theoretical stand production must be tempered by consideration of economic merchantability. Merchantability standards, such as top diameter, stump height and minimum diameter at breast height (DBH) are economic constraints that reduce the yield of the stand, particularly when the trees are small. The difference between the curves for standing volume and close utilization shows that tops, stumps and trees less than 12.5 cm reduce the volume by a fairly constant amount throughout the rotation.

TIPSY Runs



TIPSY derived diameter distribution from different densities



STAND DENSITY MANAGEMENT REGIMES 3 • 6

TIPSY Output

One of the main objectives of pre-commercial thinning (pct) is growing larger stems faster. The following TIPSY graph shows how TIPSY derived stems are distributed at year 60 for the same Pl SI 20 stand.

The tree lines are for 10 000 naturals/ha, 10 000 naturals pre-commercially thinned to 1200 sph, 10 000 naturals pre-commercially thinned to 400 sph.

- You will note that all have bell shaped distributions.
- There are significantly fewer stems in the thinned stands and in general, the stems are larger.
- The smallest stems were removed from the thinned stands.

What this means is we will have fewer logs to handle, a more uniform piece size, with a limited number of larger stems overall. We will still have a range of diameters including some smaller stems. For the most part we will not have an assemblage of only large trees.

Let us now look at an example showing this response with real data. In BC we do not have many long term spacing trails. We do have the Schenstrom plots at Cowichan Lake (multiple thinnings) established in 1929, but due to the multiple entries looking at results is complex. Instead we will look at a simple spacing trial for Hw established in the Pacific Northwest in the 1960s.

Spacing Trial Results

Target average spacing after thinning (m)	Actual post-thin density (stems/ha)	Actual post-thin average spacing (m)	Standing vol. at last common ht. (26.8 m)	Cum. yield vol. at last common height (26.8 m)	Cum. prod. vol. at last common ht. (26.8 m)	Est. thinning vol. (12.5+)	Cum. mort. (12.5+)
Control	8000	1.12	574.5	574.5	582.5	0.0	8.0
1.83	1975	2.25	601.7	604.6	621.3	2.9	16.7
2.44	1544	2.54	619.4	619.7	638.5	0.3	18.8
3.05	963	3.22	534.6	538.0	538.0	3.4	0.0
3.66	803	3.53	606.7	610.2	610.7	3.4	0.5
4.27	519	4.39	439.4	442.3	458.6	2.8	16.3

Stock table – Volume per ha (m^3/ha)

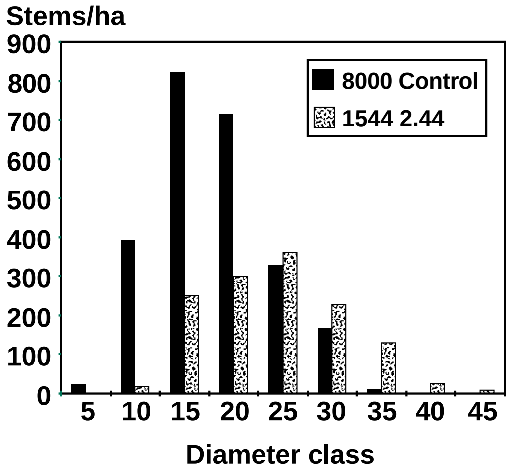
Diameter class (cm)	8000 Control	1975 1.83	1544 2.44	963 3.05	803 3.66	519 4.27	sph spacing
<2.5							
5							
10	4.3	1.6					
15	98.2	39.3	29.8	11.3	1.5		
20	191.0	112.8	84.7	22.1	18.2	4.5	
25	154.8	151.9	178.2	116.8	82.3	12.6	
30	120.3	176.4	162.6	184.1	117.2	34.5	
35	10.2	47.0	124.1	175.5	227.8	95.2	
40		35.1	29.1	24.8	139.0	80.8	
45		39.2	11.0		20.8	111.9	
50						100.0	
55							
Total	579	603	620	535	607	439	

Data from a Coastal Experiment

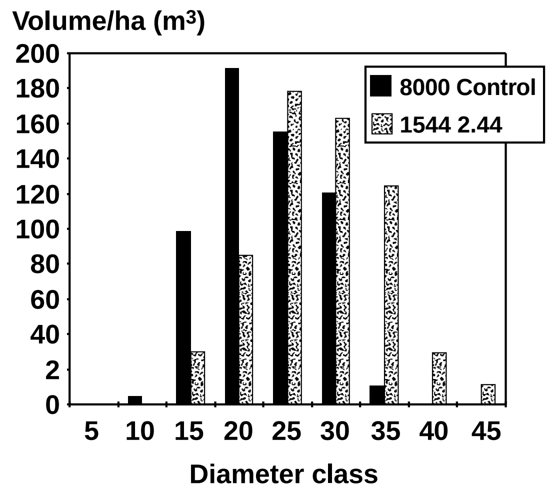
This is data from a Hw pre-commercial thinning trial conducted on the Olympic Peninsula (established in the 1960s). The following table provides a summary of treatments and volume at the last common measurement height (28.6 m). The site was monitored from age 13 to 38, the site index is 36 m SI_{50}.

Coastal Experiment

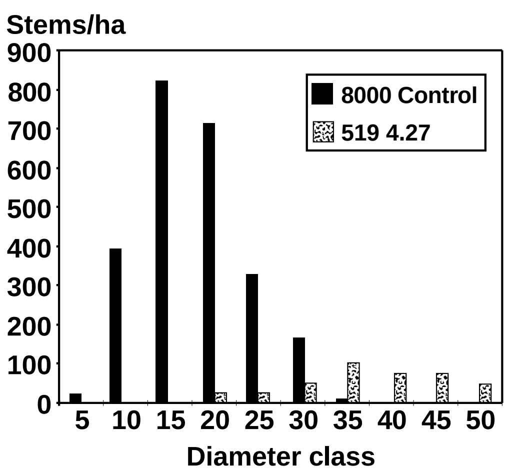
Stand Table at 26.8 m
Control vs 1544 sph pct spacing



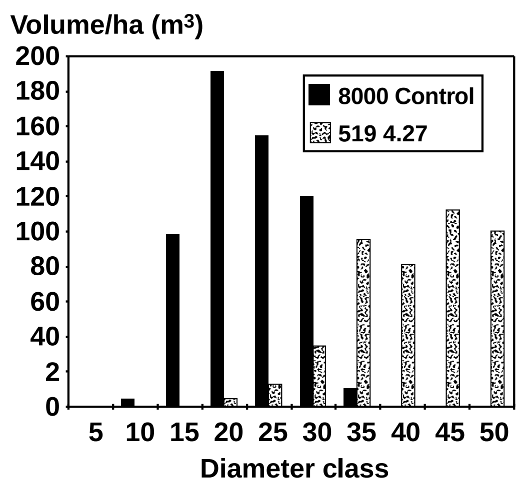
Stock Table at 26.8 m
Control vs 1544 sph pct spacing



Stand table at 26.8 m
Control vs 519 sph pct spacing

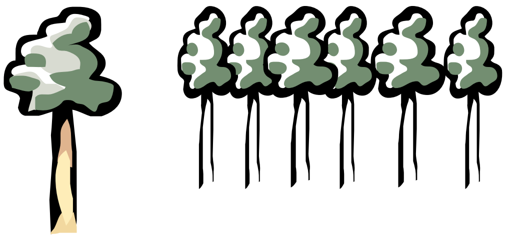


Stock Table at 26.8m
Control vs 519 sph pct spacing

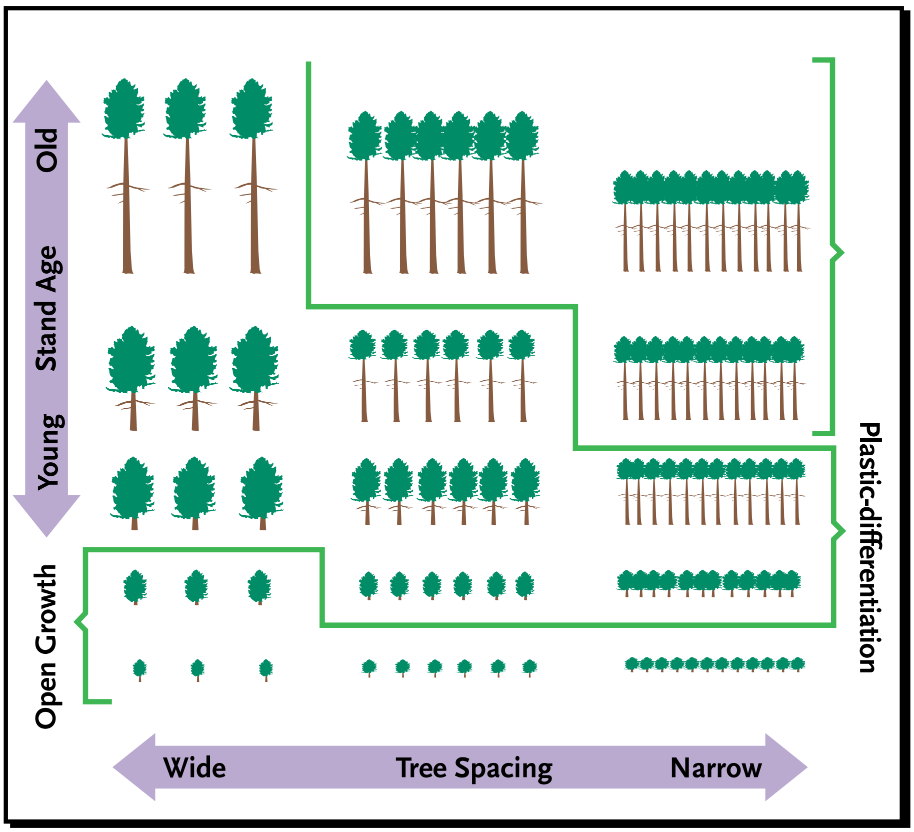


Data from a Coastal Experiment

Variation in Growth – Espacement



How Trees Grow in the Forest



How Forests Grow

The next series of overheads are adaptations of the stand structural stages as described in Oliver and Larson, 1996. They show how stands grow and what various factors will influence growth and hence data collection and treatment decisions.

- What constitutes wide versus narrow. Wide spacing is likely near minimum stocking values (700 sph is 4.06 m intertree distance using triangular spacing, 400 sph is 5.37 m.) Dense spacing likely means 10 000 sph plus.
- The left axis shows young open grown at the bottom and old above.

What is being influenced by tree spacing?

- Tree height – the most dense stand is the shortest and has the least live crown.

Is this conventional wisdom? Is this how it works in the real world?

- For Pl above a certain density it does (from 10 000 to 30 000 total stems per ha are densities where height repression can begin for Pl). This phenomenon is called height repression and will be discussed later.

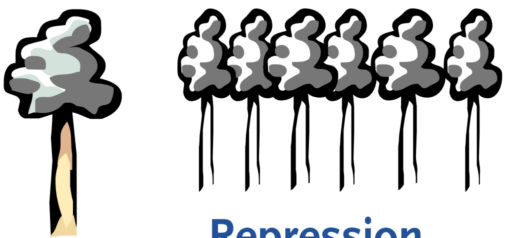
What is it about this stand structure that seems somewhat peculiar?

- No differentiation – all trees are the same size. Normally there will be some form of differentiation, unless there is no genetic or microsite variation (e.g., cones in a farm field).

KEY – in BC repression has been found in Pl. To avoid reduced heights and volumes, treatment is required to reduce density .

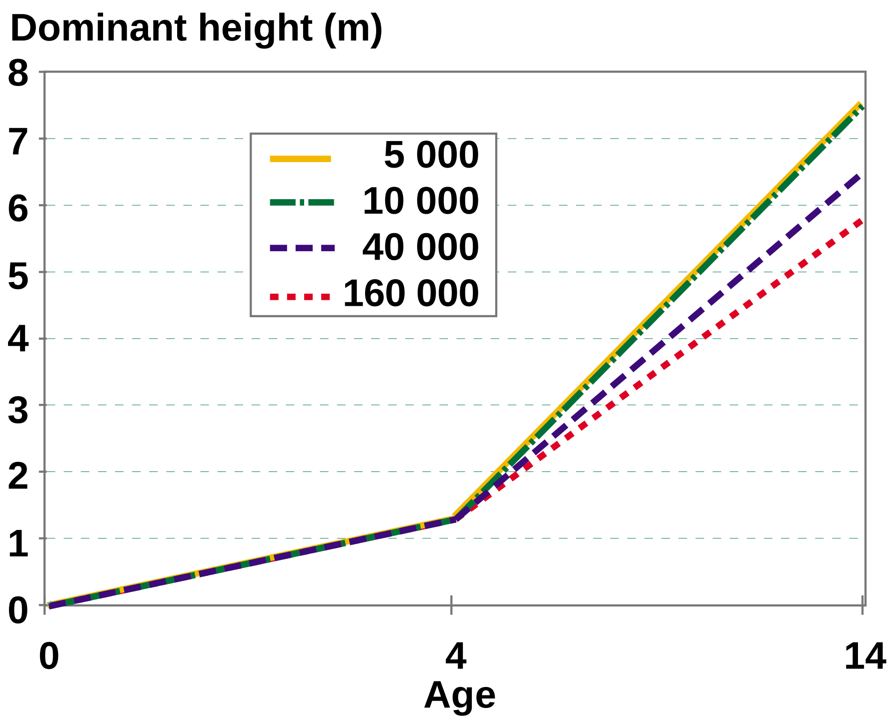
Stand Differentiation

How Trees Grow in the Forest



Repression

Height Growth of Pl



Adapted from the guidelines (page 7).

Repression

Repression is a biological phenomenon whereby tree growth and stand development fail to exploit the potential productivity of the site. The impact is widespread (Goudie 1996) in stands of lodgepole pine but not in other species.

Biology

Repression curtails height and volume increment of lodgepole pine shortly after the growing space is fully utilized in stands established at extreme densities. The process usually begins before trees reach a height of 2.0 metres, although stands with 1 000 000 trees/ha may be affected when only 0.2 metres tall.

Espacement trials (Carlson and Johnstone 1983) show that the height growth of plantations with 13 500 or more planted trees are affected (Figure 1), and future measurements may indicate minor repression in stands planted with 10 000 trees. The pattern of growth and development of repressed stands resembles that of stands growing on sites of much lower productivity; consequently, merchantable yields will be achieved considerably later than had repression been avoided. Repression does not, however, cause stands to "stagnate" or cease development, as was once believed.

Impact – Mainly on fire origin stands

Growth losses are particularly dramatic in repressed fire-origin stands of lodgepole established with more than 50 000 trees per hectare (Mitchell and Goudie 1980), particularly on sites of relatively low productivity. At extreme densities (500 000 + trees/ha), stand production may be reduced by as much as 60 per cent.

Repression is not likely to be a serious problem in stands that regenerate after logging because establishment densities are much lower, trees seed-in over 5 to 10 years (instead of 2 to 3 years), and clumped (less uniform) tree distributions are more common. The lower densities and greater tree-size diversity of post-logging stands minimizes the risk of repression losses.

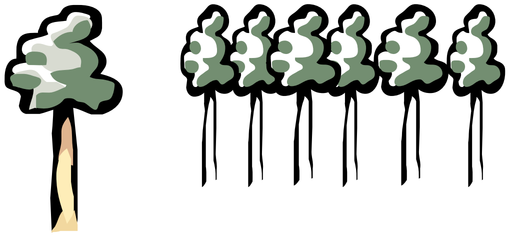
Repression is also unlikely in plantations, unless supplemented by concurrent, natural, in-fill regeneration. The impact of dense, but delayed, natural regeneration on planted lodgepole pine stands is not presently known.

Response to Treatment

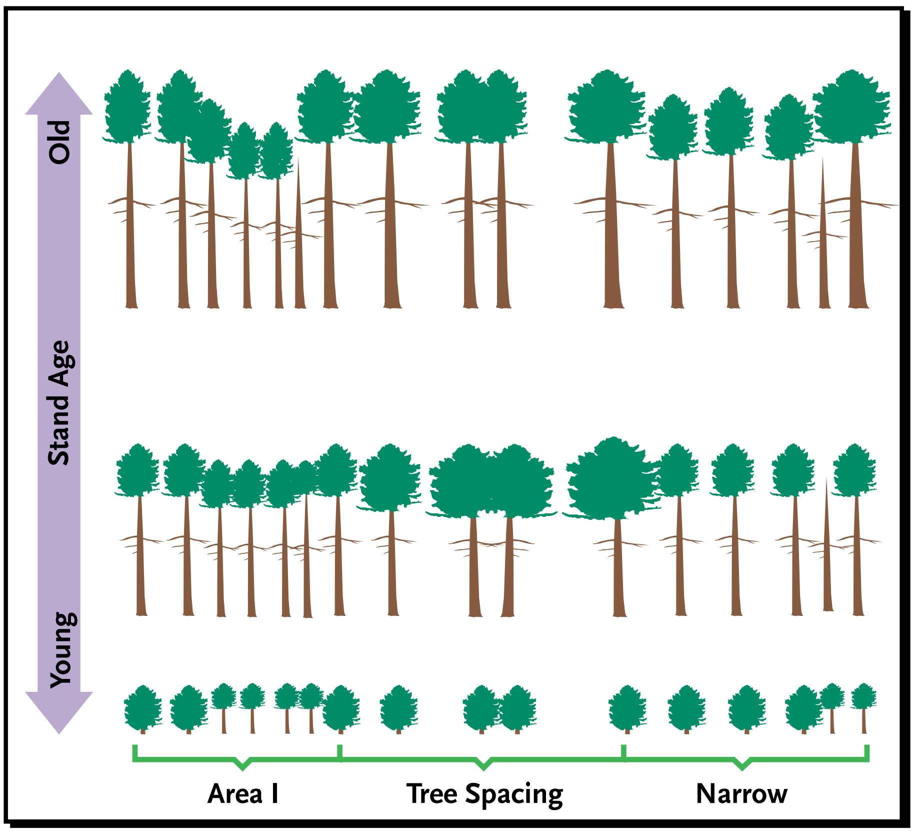
Stand density interventions are an effective means of preventing repression in lodgepole pine if treatment occurs before the onset of repression. Stands which are thinned after the onset of repression do not show a consistent height growth response to treatment (J.S. Thrower and Assoc. 1993). However, there is evidence of an independent response in diameter growth.

Until more is known about treatment response it is reasonable to assume that the early height growth of repressed stands is indicative of future productivity.

Growth Variation – Espacement



How Trees Grow in the Forest



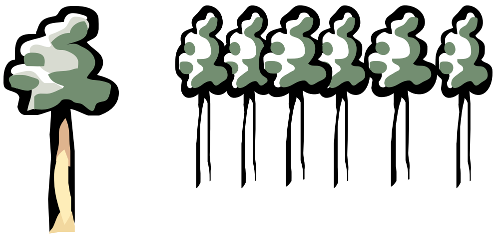
How Stands Grow – The Effect of Espacement

Note this is not the total story.

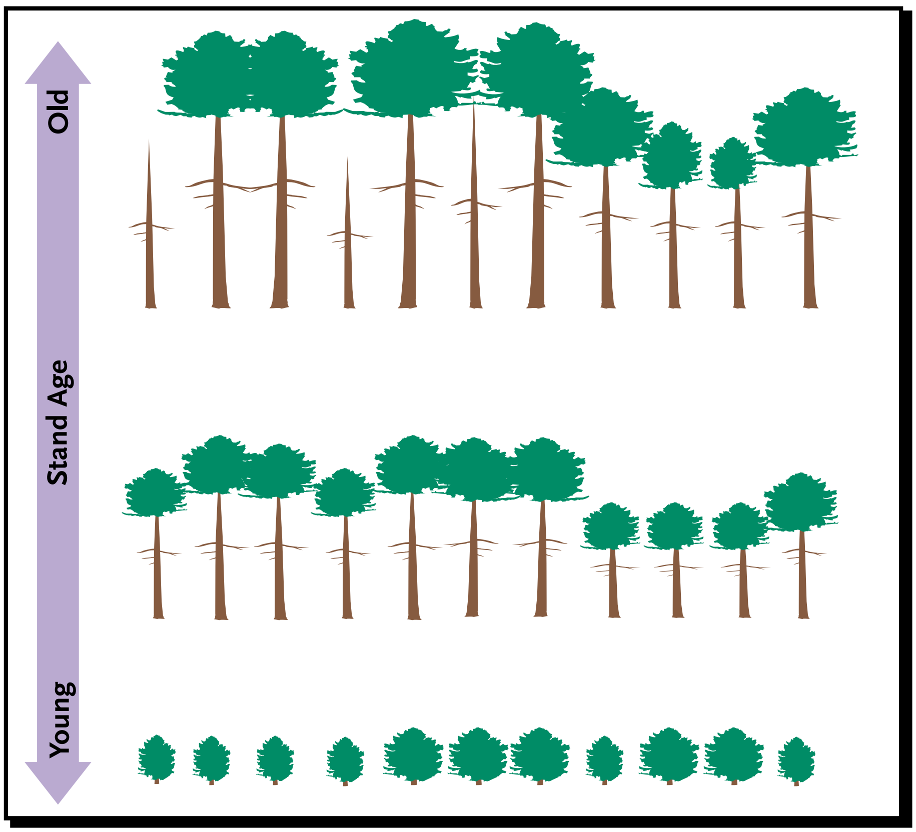
This overhead depicts the variation in growth due to original spacing. What does the diagram show us?

- What the spacing trials show is that trees with more room to grow will have larger crowns and larger diameter growth potential. Dense stands will have some stems in understorey positions that will be suppressed by their neighbours.
- Area 1 is relatively dense from the start. Crowns lift early resulting in thin stems with reduced growth potential – the clumps found in this stand show better growth on the edges. Therefore, any treatment response needs to take into account the size of the clumps, the density in the centre and whether the vigour of the trees is sufficient for response if density is reduced. If we wait too long (crowns are now small) diameter increases will be slowed, reducing its effect.
- Note (rule of thumb – from OSU Extension Services, 1997, EC 1189) – If the clump is over three crown widths wide, the clump should be managed the same as the rest of the stand. If not, leave along the edges slightly closer than the prescribed spacing (they are already somewhat open due to their position on the edge of clump). **Don't leave overdense areas to compensate for holes in the stand.**
- The key element of this diagram is that crowns respond differently depending upon density. Thus, removing trees from the middle of clumps and leaving the edges intact will provide more trees access to more light. This will result in larger crowns, allowing the trees to grow larger.

Growth Variation – By Genes and Microsite Variation



How Trees Grow in the Forest



How Stands Grow – Due to Genetic Makeup and Microsite Variation

Remember: This too is not the total story – what is left? (Differential establishment times, different species in the mix.)

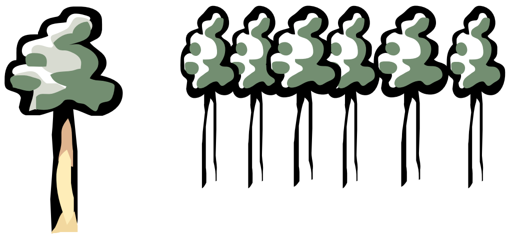
This overhead depicts the variation in growth due to microsite and genetic variation. What does the diagram show us?

- Sometimes even where trees are well spaced they will not achieve the size of others due to genetics and microsite differences.
- It is likely good to think in terms of the tree living within a probability matrix. As the Duke brothers found out in *Trading Places* neither nurture nor nature acts alone.
- The simplified matrix looks something like this.

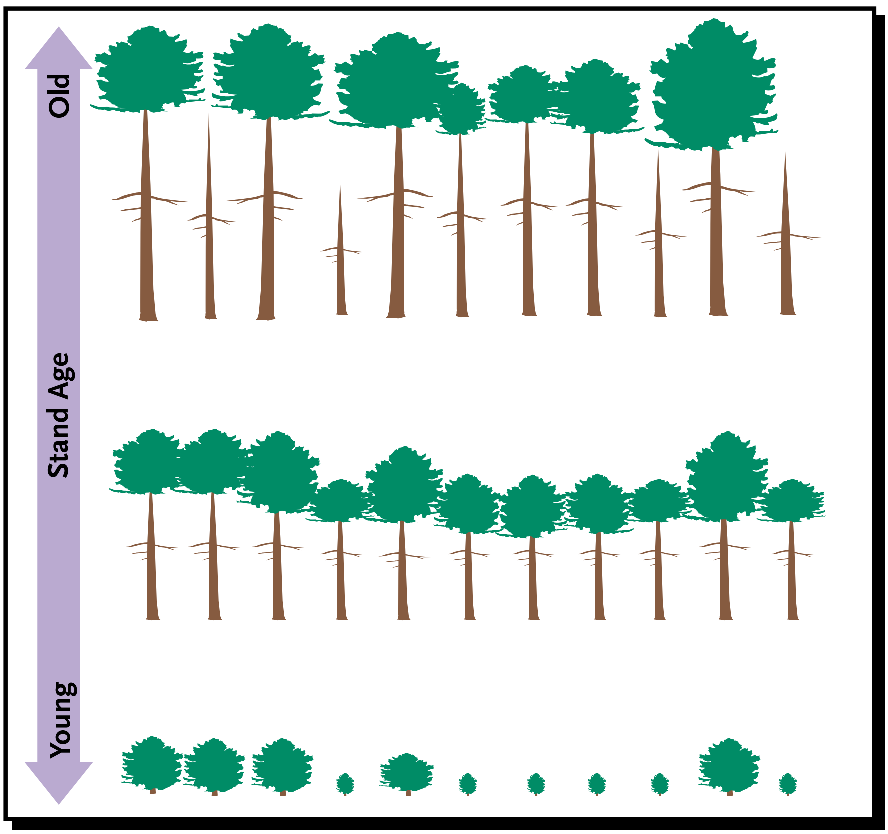
Good Microsite Good Genes *Big Trees*	Good Microsite Lousy Genes *Medium Trees*
Poor Microsite Good Genes *Medium Trees*	Poor Microsite Lousy Genes *Small Trees*

Because of this we are likely to get a range of sizes on each site. However as the bottom boxes attest the best we will be able to get on poor sites are smaller trees within the same time frame as on better sites.

Timing of Establishment
Stand Differentiation



How Trees Grow in the Forest



How Stands Grow – Timing of Establishment

This too is not the total story – what is left? (Different species in the mix.)

This overhead depicts the variation in growth due to differences in the time of establishment. What does the diagram show us?

- Depending upon stand density and aspect, the late starters will likely never be in the top portion of the crown (unless they are climax species and outlive the early successional overstorey). Late starters can be on good sites and have good genes but, if they are slow to grow in the early years, they will not have access to the sun that their neighbours do, resulting in smaller crowns and less growth.

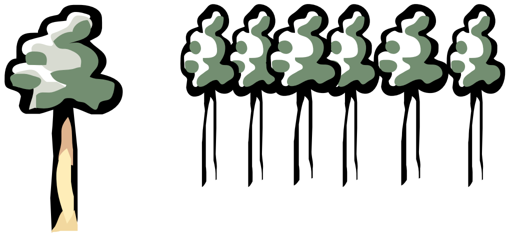
Stand differentiation

Mortality in stands is natural and will happen with time. One of the objectives of incremental silvicultural activities is to capture some of the growing space that would have gone to mortality and channel it onto a potential crop tree.

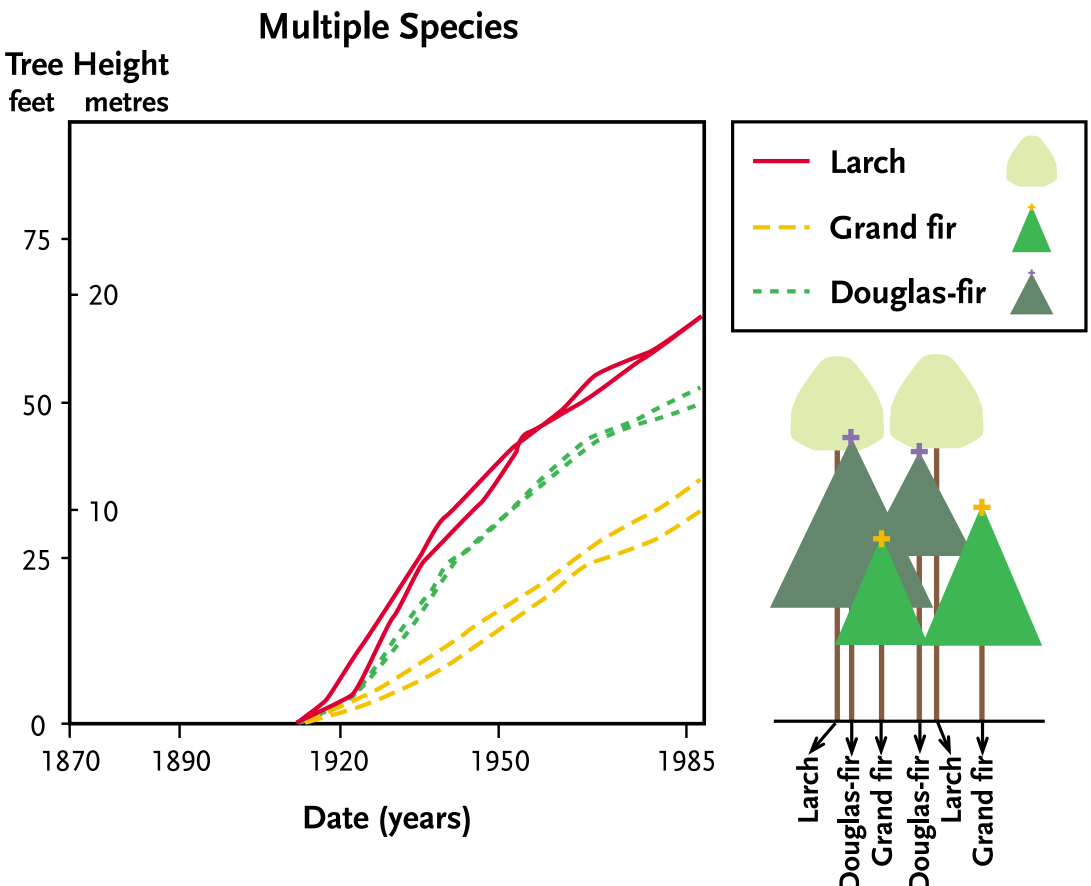
Stand differentiation is the result of stand density, genetics, growing environment, and time of establishment and is further tangled by multiple species. The resultant stand will likely have some dominant trees, mostly codominants and some intermediate and suppressed trees. The intent of most juvenile spacing treatments is to maintain or enhance the diameter growth of the trees left on site.

We will look now at the role of species in stand differentiation.

Stand Differentiation – Multiple Species



How Trees Grow in the Forest



Oliver and Larson (1996, p. 247)

How Stands Grow – Multiple Species

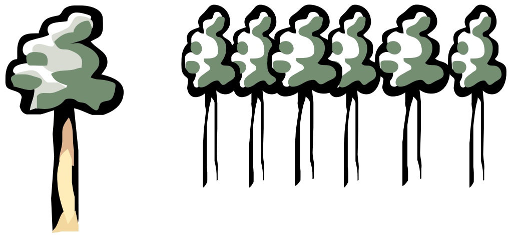
This overhead depicts the variation in growth due to **species differences.** In some cases species are adapted to grow in an understorey position (e.g., grand fir), or grow with other species (e.g., Fdi and Larch). In other cases, if one species gets a head start on the other species they will likely succumb to mortality first resulting in lower numbers of the slower growing species after crown closure. In other cases, the initial stratification may change over time if the component species have different patterns of height-growth. For example, the height growth of paper birch slows dramatically after about age 40. Other species in the stand may subsequently overtake and surpass the birch in height. The stratification can also be altered by insects and diseases that preferentially damage and weaken one species or stratum in the mixture.

In stands of mixed species, the variation in tree size is even more pronounced because of the wider range of inherent rates of juvenile height growth. Stand mixtures of species tend to differentiate into distinct layers or strata when differences in height growth are large. This initial stratification can persist if the slower-growing species are shade tolerant, or if sufficient sunlight can pass through the foliage of trees in the upper stratum.

Diameter distributions in mixed-species stands generally reflect the height stratification. The species in the upper and lower canopy occupy the larger and smaller diameter classes, respectively. If the slower-growing species are shade tolerant, diameter distributions are often skewed toward smaller sizes. Broadleaf species sometimes exhibit a different height-diameter ratio than conifers and consequently appear lower down in the diameter distribution than they are in the height distribution.

Canopy stratification patterns can be altered if the species with slower juvenile height growth have an advantage in early stand development. They may regenerate in advance of the faster-growing species, or density control measures may free them from competition during the juvenile phase of slow growth, thereby ensuring they do not lag far behind the faster-growing species at the time of stand canopy closure. Silvicultural treatments undertaken at or shortly after establishment can create single-layered stands of species that would otherwise naturally form stratified canopies.

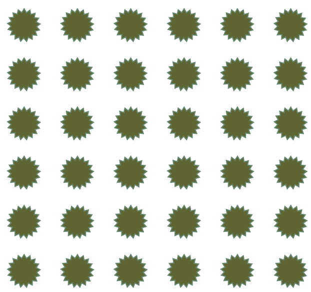
Stand Differentiation – Multiple Species

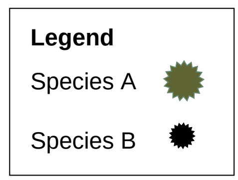


How Trees Grow
in the Forest

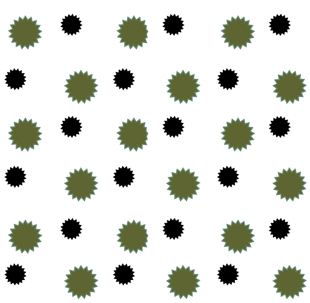
Multiple Species

1. Species monoculture

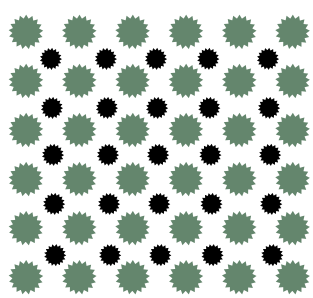




2. Species mixture – substitution



3. Species mixture – addition



How Stands Grow – Substitution and Addition

Relative to monocultures, the yield relationships of **stand mixtures** are less well defined because of the numerous possible combinations of constituent species and their relative proportions.

- The yields from stand mixtures can be either greater than or less than the yield from corresponding single species stands depending on the component species, stand density, height stratification patterns and site quality.

In order to better understand the complexity of mixtures and how they relate to monocultures, it is helpful to visualize mixed species stands from the perspectives of substitution and addition.

Substitution

In the **substitution** perspective, a mixture is derived from a monoculture by substituting trees in the monoculture with trees of another species, keeping the total stand density constant.

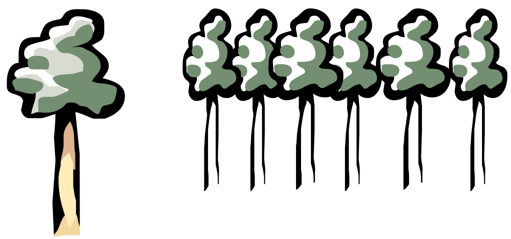
In this overhead, for example (Figure 3 from the guidelines) the monoculture of species ***A*** (larger stars) at 600 per ha can be transformed into a mixture by substituting 300 trees of species ***B*** (smaller stars). The yield of mixtures created by substitution are almost always intermediate between the yields of the two species in separate monocultures. Notable exceptions are combinations in which one species enhances the growth of another, such as some mixtures of Douglas-fir and red alder. Otherwise, the stand yield of the mixture is usually close to the average production of the component monocultures when weighted by the species proportions in the mixture.

Addition

In the **addition** perspective, a mixture is derived by adding to a monoculture some trees of a different species.

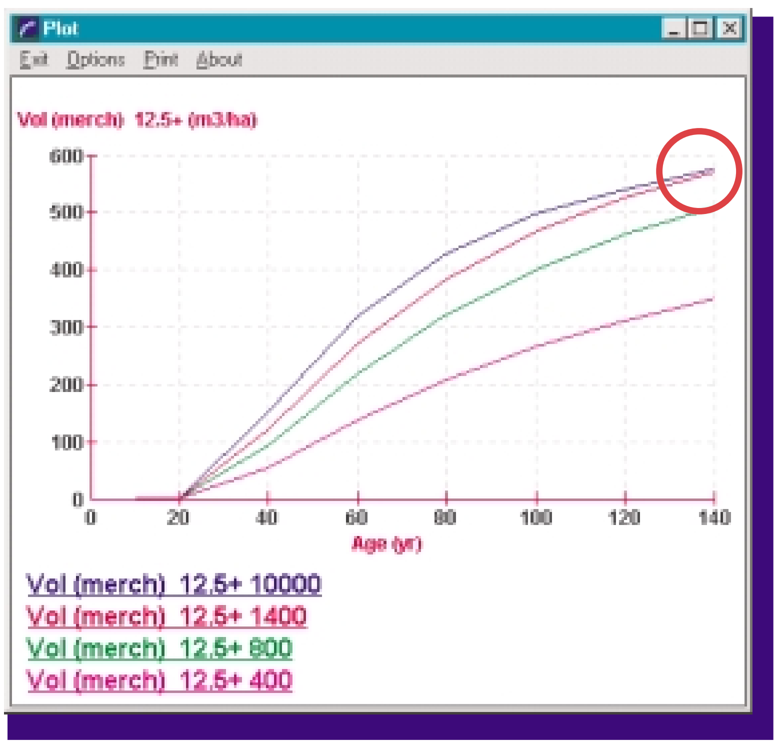
From the monoculture of species ***A*** at 600 per ha, we can create a mixture by adding another 600 per ha of species ***B*** (3), bringing total stand density to 1200 per ha. Yields of mixtures created by addition can be greater than yields of monoculture simply because there are more trees.

Density Management Practices



Espacement

Holes reduce growth potential



Lodgepole pine SI 20

What is crossover? Does it occur?

Espacement

Plantation espacement in B.C. since 1940 ranged from:

- about 2 metres (2500 trees/ha) to 4 metres (625/ha).
- Espacement in natural stands covers a much wider range, for example 1–1 000 000 trees/ha., and is much less regular.
- Full site occupancy is achieved quickly if the establishment density is moderately high and the spatial distribution of trees is uniform. **Uniformity increases in importance as establishment density decreases as more holes will be created.**

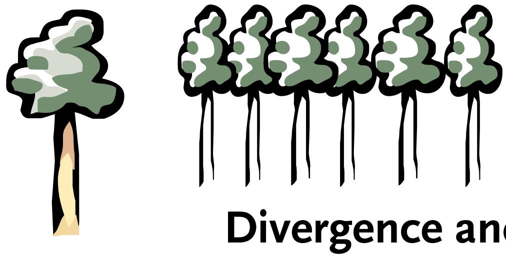
Volume production in the overhead **indicates less volume with decreasing establishment density.** Any clumping of the same number of stems will reduce the stand yield even further.

It should be noted that it is the unoccupied growing space or **"holes" in the stand canopy that reduce timber yield – not the clumpiness itself.** Low density stands produce less volume initially because there are too few trees to exploit the available growing space. The rate of stand growth improves after crown closure.

Cross-over

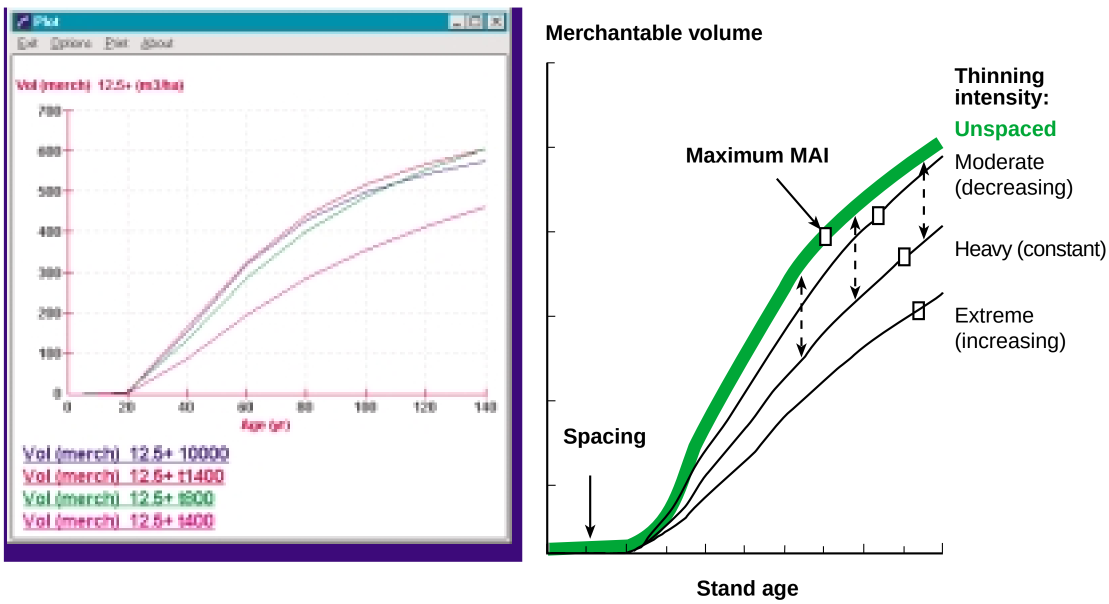
Theoretically, the growth rate of a low density stand could eventually surpass that of a dense stand, as predicted by yield projection models. This phenomenon, called *cross-over*, has not been observed in research plots in British Columbia, which are still too young to confirm or reject the theory. **Ministry data and models predict that cross-over is not likely to occur until well beyond acceptable rotation ages based on the culmination of mean annual increment.**

Density Management Practices



Volume Over Time in Spaced Stands

Divergence and Convergence



Lodgepole pine SI 20 and Figure 5 (guidelines)

Things to promote:

1. Leave crop trees of high vigour
2. PCT when height growth is expressed
3. PCT extremely dense Pl stands early
4. Maintaining potential "additive" trees

Volume Over Time – What Happens to Pre-commercially Thinned Stands

Pre-commercial thinning immediately reduces the number of trees, the occupancy of growing space and the standing volume per hectare.

- The magnitude of the reduction is related to the intensity of treatment.
- The subsequent development of the stand is more complex.

Crown cover normally increases at a diminishing rate until complete canopy closure occurs, and then levels off.

- The number of trees in the spaced stand remains fairly constant until the onset of crown closure, competition and mortality.
- Volume increment is reduced until the vacant growing space created by pct is fully utilized by the residual stand.
- The corresponding volume curves of the spaced and untreated stands will initially diverge and later parallel one another.
- Convergence of the curves usually starts shortly after mortality begins in the pct stand. The duration of each phase depends on the intensity of pre-commercial thinning and the level of utilization.

If only overtopped trees are removed and 100% crown cover is maintained, convergence will begin immediately without any divergence. On the other hand, a very heavy spacing will initiate a lengthy phase of divergence that could extend until the stand is harvested. Since one phase tends to dominate, volume curves can be described in terms of *decreasing*, *constant* or *increasing* departure as illustrated in the graph on the right.

The graph on the right (Figure 5 from the guidelines) shows a generalized situation. The degree of divergence or convergence will depend upon the situation. The TIPSY example shows extreme spacing (to 400 sph) results in increasing departure (divergence), while pct from 10 000 to 1400 actually results in greater volume production than the unspaced stand at 10 000 sph.

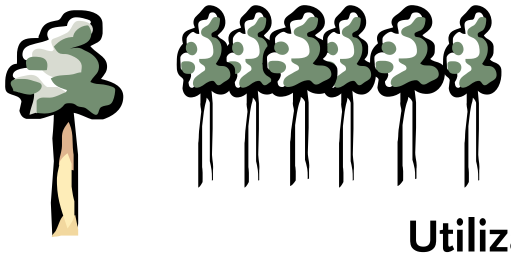
Key – at low densities you will lose volume, but not necessarily if you choose the residual density with this in mind.

Things to avoid

If you are trying to maintain stand volume at the same time as increasing individual tree diameter, avoid:

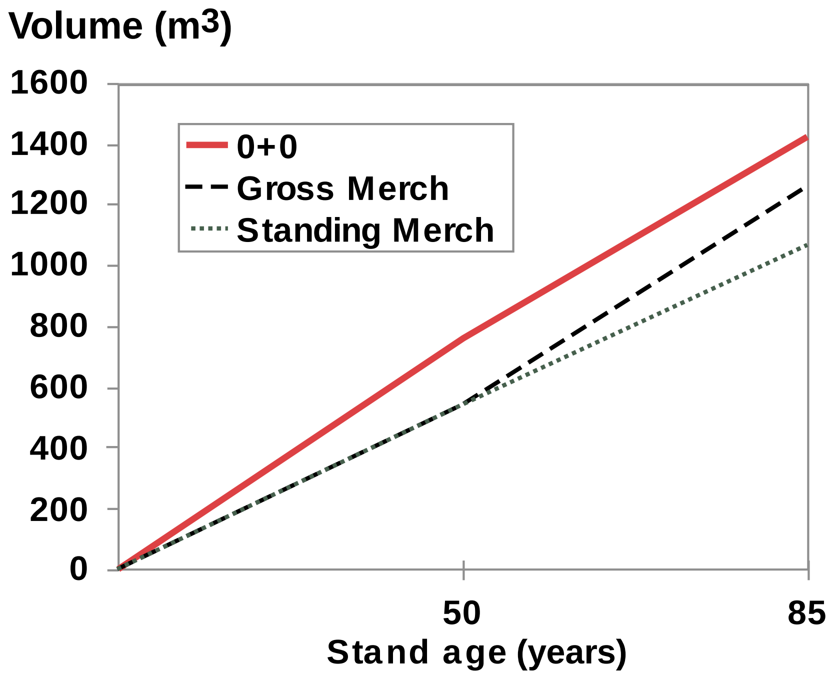
1. choosing crop trees of low vigour due to uniformity of spacing taking precedence
2. height growth potential is not obvious
3. pre-commercial thinning of extremely dense Pl stands is delayed past the onset of height repression
4. thinning out shade tolerant species that could add volume by growing in the understorey.

Commercial Thinning



How much volume is available from mortality?

Utilization



Potential volume gains

- ▲ 12.5 cm utilization – 160 m^3 (20%)
- ▲ If all mortality were captured – 350 m^3 (30%)

Is this reasonable/realistic?

Commercial Thinning

Commercial thinning occurs much later than pre-commercial thinning when the trees are larger. It creates relatively large holes in the stand canopy which are reoccupied slowly by the crowns of leave trees. The invading branches grow slowly because height growth is declining, as is the overall vigour of the stand.

When thinning commercially in British Columbia it is common to carry out a single entry not long before the final harvest.

- This entry would remove a wide range of tree sizes, with most coming from the lower diameter classes.
- In Europe, it is common practice to conduct a series of frequent, light, low thinnings intended to capture wood which would be lost to mortality if untreated.
- One typically compares the harvest volume of the untreated stand with the total volume (final harvest + all thinnings) taken from the treated stand.
- Lower utilization limits in Europe also increase the merchantable volume available from thinnings. A limit of 7 cm is common for both DBH and top diameter.

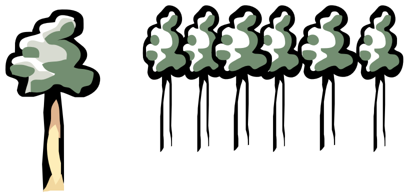
If we look at the mortality in an unthinned plot of Douglas fir from B.C. we can see how much volume is potentially available from a series of frequent, light, low thinning entries. That is, we will assume we are able to harvest and utilize each overtopped tree just before it dies.

- **In the graph, the uppermost "gross production" curve is what we get if all wood is salvaged by thinning without regard for merchantability limits.**
- **The middle "gross merchantable" curve shows what is left if tops (<10 cm), stumps (<30cm) and small trees (<12.5 cm) are not merchantable.**
- **The lowermost curve indicates the merchantable volume of standing trees if the stand was not thinned. The graph indicates that if all mortality in the stand is captured through repeated, light, low thinnings, it is possible to increase the harvest volume (12.5 cm+) by 20% at age 85 years. This increases to 30% with the harvest of all trees (0.0 cm+), tops and stumps.**

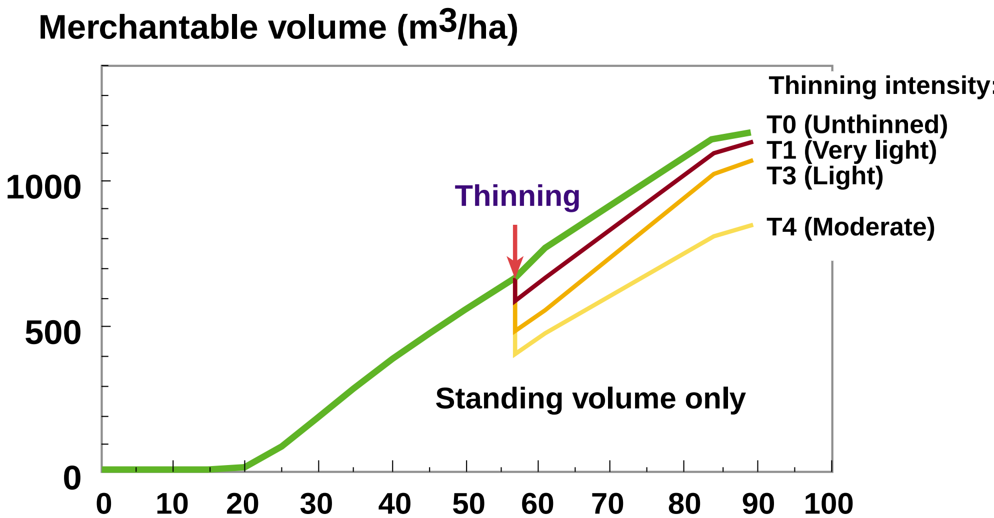
The lowermost curve in the graph displays the standing merchantable volume if the stand was not thinned (pages 16 and 17 in the guidelines).

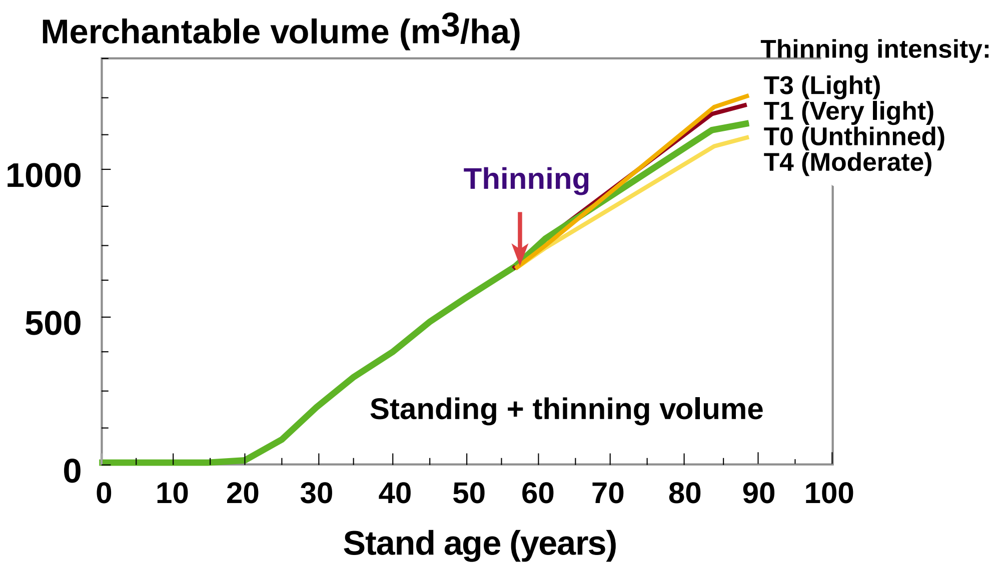
- A series of light entries increases the total harvest because the space vacated by small-crowned trees is small, and frequent entries maximizes the opportunity to salvage trees before they die.
- A single heavy entry, timed well before the final harvest, will likely decrease the total yield because tree removals create large openings, resulting in less than full site occupancy by the residual stand. Furthermore, only one opportunity to harvest impending mortality will result in lost volume between thinning and final harvest.

Commerical Thinning



What does research tell us?





Commercial Thinning

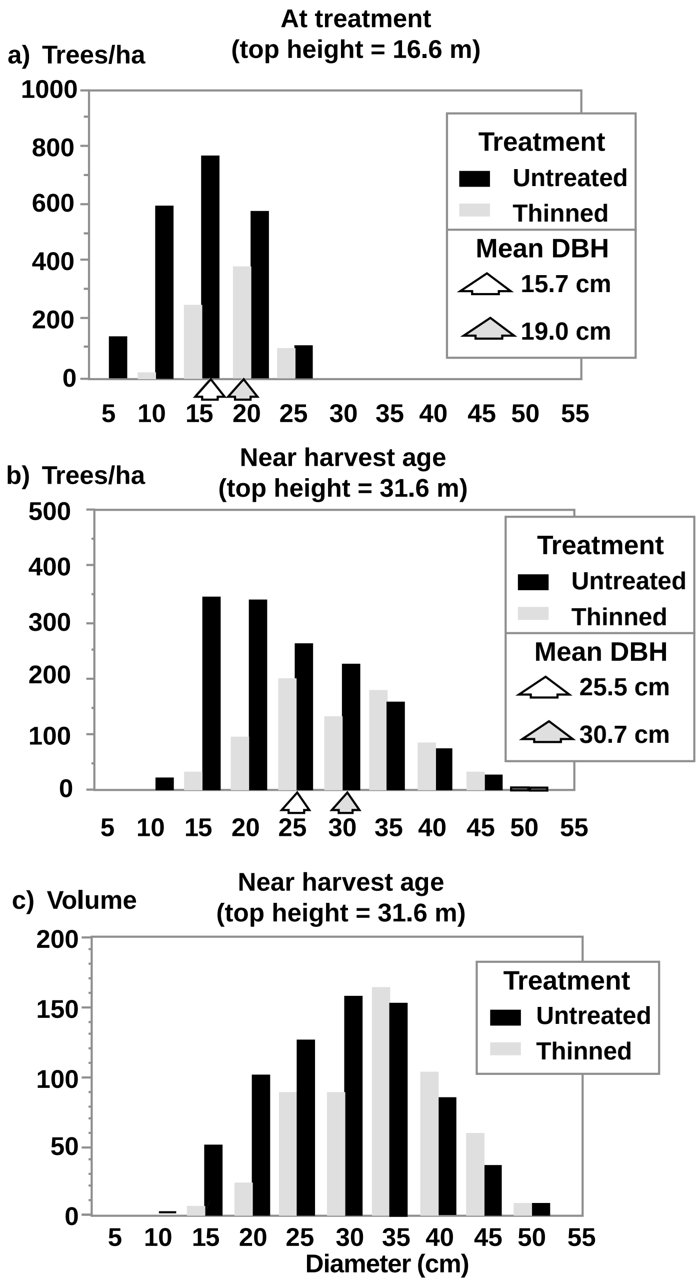
- The graph is from research on Coastal Douglas-fir (Omule 1988). Three levels of thinning intensity are shown along with the control.
- Volume removed – T1–14%, T3–29%, T4–41%.
- The top graph shows how the standing volume of the untreated and thinned plots developed over time. What this shows is the standing volume will go down with the commercial thinning entry. With the light thinning levels the volumes begin to converge and if very light will result in similar standing volume.
- Standing plus thinning volume result in slightly elevated amounts for T1 and T3, (5 and 7%) however they were not statistically significant.

Lower graph

- The point being made here is that CT may not effect final yields with light thinnings. With heavy thinnings the holes in the stand will result in volume reductions (T4–6%).

In the guidelines a hypothetical example is provided to emphasize how heavy thinnings will result in considerably less total volume.

Describing Density



Methods of describing density

- Stand tables
- Stock tables
- Stand or average DBH or volume
- Prime tree average DBH

Describing Density

Stand Tables

Stand tables indicate the number of trees, by diameter class, at a particular stage of stand development.

- Good for visualizing what the stand is made up of and where the majority of stems fit.

Stock Tables

A stock table displays volume, by diameter class, and enhances stand table data by identifying the diameters classes which contain the bulk of the volume. It is important to focus on the upper and middle diameter classes of each plot since they contain the trees of greatest volume.

- Good for visualizing where the bulk of the volume is concentrated
- Graph (c) illustrates a stock table comparison of the thinned and unthinned plots at 31.6 m of top height.
- Note that the “extra wood” in the unthinned stand is concentrated in the smallest diameter classes.

Stand Average DBH or Volume

The average diameter or volume of all trees in the stand provides a useful but narrow view of a stand, compared with a stand and stock table summary of stand structure.

- For example, in graph (a) thinning from below instantly raises the average diameter of the plot (15.7 to 19.0 cm) in what is known as the “chainsaw effect”. This is caused by the removal of small trees during thinning, which inflates the arithmetic average diameter of the remaining trees.

Prime Tree Average DBH

If there is a wide range of establishment densities, it is useful to compare the development of prime trees (largest 250 trees/ha) because these trees will likely survive to harvest in all stands. Furthermore, prime trees are independent of the chainsaw effect in stands thinned from below. For example, the average diameter of the prime trees in the thinned and unthinned stands is 38.3 and 37.5 respectively.

▲ The prime trees in the thinned stand outgrew those in the unthinned stand, but the difference is small because prime trees do not suffer from the same intensity of competition as smaller trees in the stand. Prime tree diameter is largely insensitive to stand density, unless the inter-tree distance is quite large. For example, the stand depicted in the overhead was thinned late (16.6 m) to a residual density of 750 trees which will only stimulate the growth of prime trees for a short period.

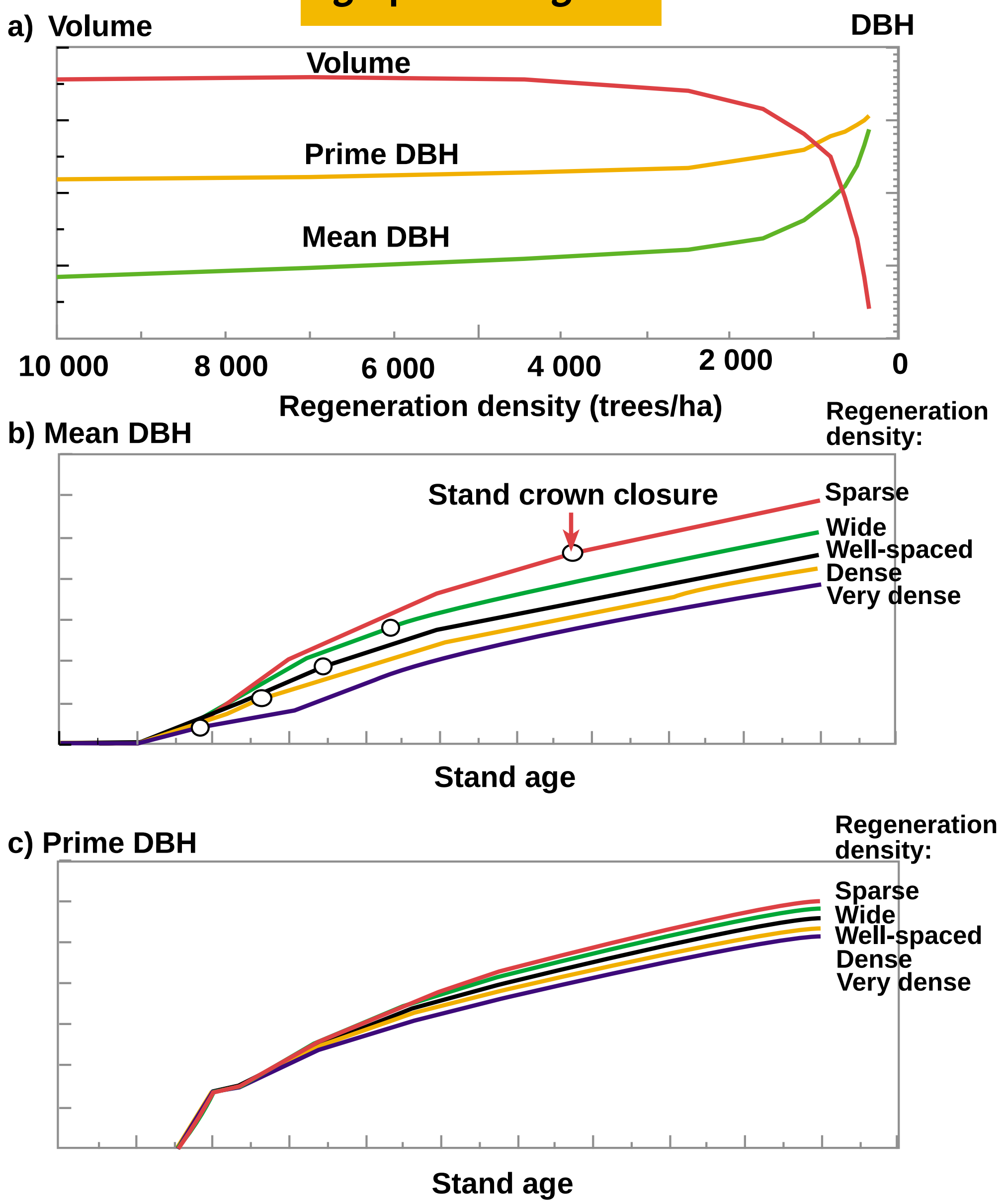
In summary, while average diameter of prime trees and stand average diameter are informative statistics, they must be used cautiously when assessing stand response to density management. Both statistics have shortcomings in portraying stand structure, and neither should be used in isolation of other relevant information (e.g., the range of tree diameters or volumes, the average diameter of non-prime trees and stock and stand tables).

Note: The data shown in this example is from a stand spaced at top height 16.6 m. TIPSY spaces stands at 6 m on the coast and 4 m in the interior. Why?

Example:
- *near commercial size*
- *crowns may (likely) have lifted, slowing reponse*

Volume Diameter Trade-off

What are these graphs telling us?



Volume Diameter Trade-off

The trade-off between stand volume and piece size achieved through espacement, pre-commercial thinning and commercial thinning should be evaluated using stand and stock tables.

- However, in the interest of brevity, volume per hectare and average diameter (all trees and prime trees) will be used in the following example.

The top graph – depicting hypothetical espacement densities shows volume remaining relatively constant over a range of regeneration densities from about 1500 to 10 000.

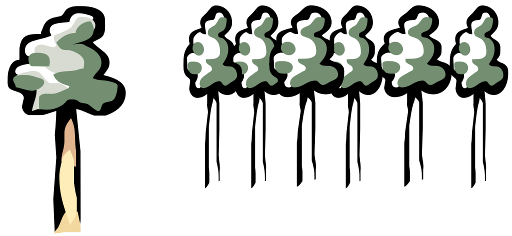
- Below 1500 stems per ha (at regeneration) volume production falls off. This is because it takes longer for fewer stems to reach crown closure, the empty space is not producing wood.
- Mean DBH shoots up below 1500 sph as trees utilize open space prior to crown closure. The prime DBH has a less dramatic effect.

Middle and lower graphs

- The increase in average diameter resulting from wide inter-tree spacing occurs prior to stand crown closure [graph (b)] with little or no increase thereafter attributable to establishment density. Since the graph in the overhead illustrates a stand espacement example, there is no artificial increase in diameter (i.e., chainsaw effect) immediately after treatment. The behavior of prime trees in graph (c) is similar, but much less dramatic.

Note: Rotation ages in graph (a) conform with the culmination of MAI. This ensures maximum sustained volume production. Planners may also use other criteria to determine the age of the final harvest. The attainment of a particular average diameter is a good example. However, they must be aware that technical rotations decrease the long-term stand volume production except in rare cases where the selected rotation age coincides with the culmination of MAI. At the forest level, planners have to consider trade-offs in terms of volume, diameter, rotation length and other relevant variables.

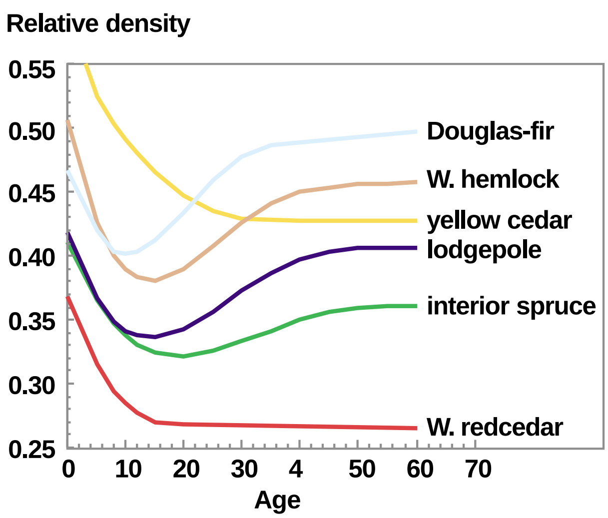
Wood Quality



Stand density and its effect on wood quality

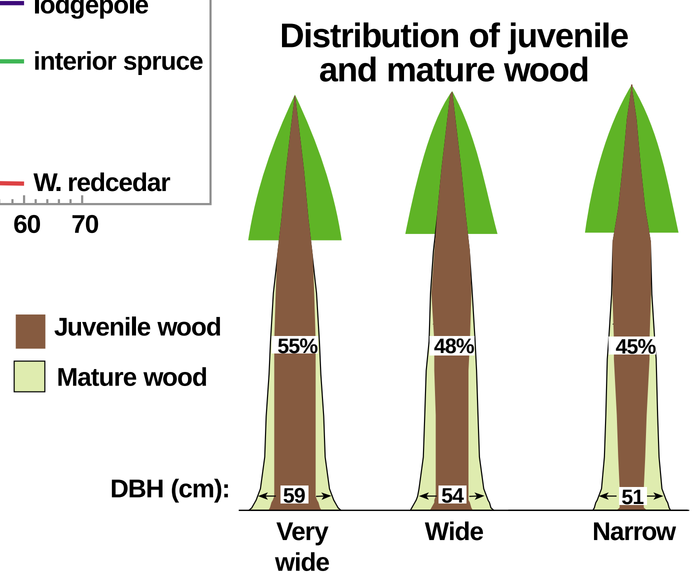
Wood Quality – What is it?

- ▲ It depends on the end product



What attributes are important?

- ▲ Attractive visual features?
- ▲ Dimensional stability?
- ▲ Bracing strength?
- ▲ Strength and stiffness?
- ▲ Ring width



Wood Quality

The interactions between basic tree and wood properties and species, seed source, geographic location, site conditions and management decisions are very complex.

- As a result, it is difficult to discuss these relationships in detail. However, an attempt is made in this section to outline the more important interactions in a general way so that foresters concerned with maximizing timber value are aware that silviculture decisions can affect both the tree volume and wood quality components of timber value. Tree and wood quality refers to specific characteristics that affect the value recovery chain from harvesting of trees to manufacturing and grade recovery of specific products (Zhang 1997).

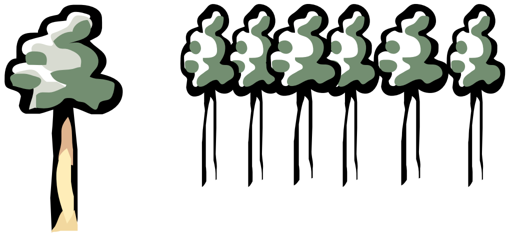
Wood quality characteristics depend on the intended products and are usually defined by relative wood density, ring width, microfibril angle, fibre length, knot size and distribution, spiral grain angle and chemical composition (e.g., lignin-cellulose ratios and extractives). Their affect on product quality and value have been discussed in detail by Jozsa and Middleton (1994).

The key issues that can be affected by treatment are:

- **Juvenile wood vs mature wood** – Juvenile wood is crown derived (and often less dense – see figure 12 in the guidelines). Thus the larger the crown the more juvenile wood. Wider spacing will result in more juvenile wood in each stem (e.g., 55% vs 45% in the example), but how much will depend on the species and spacing density and the time until harvest.
- **Knot abundance and size** – Will affect end use possibilities. Wide spacing will produce larger knots limiting the end products in some cases (e.g., strength and appearance).
- **Appearance** – ring width and consistency. Heavy entries will result in wide variation on ring width and could affect the esthetics of the product.

For more detailed information read *A discussion of wood quality attributes and their practical implications* by L. Jozsa and G.R. Middleton, 1994, Special Publication SP-34 (as suggested in the guidelines).

Density and Other Factors



Other Factors to Consider

Waste and Breakage

- volume may not be recoverable – will technology offset these problems?

Damaging agents

- See Technology Transfer Note #12 for some guidance (both insects and disease).

For example – in a tabular format this is presented

These insects – e.g., Mountain pine beetle

Affect these hosts – Pine species

And cause this type of damage – kill apparently healthy trees...

Thinning may affect it by – modifying vigour, food base, climate...

So forest managers should – not thin when stands are under high stress, not thin stands prone to windthrow or high levels of disease, thin stands in late summer or fall after beetle attack...

Density – Other Factors to Consider

Waste and Breakage

- Managing for high density produces more small slender (larger height/diameter ratio) stems than would occur in stands of lower stocking. These trees have a greater risk of breakage during harvest, and windthrow if left exposed by commercial thinning or partial cutting. Consequently, some of the "extra" volume contained in the smaller diameter classes of untreated stands may be lost to breakage, or not utilized because of size, particularly if markets are poor. These losses may be offset by technological changes in the future.

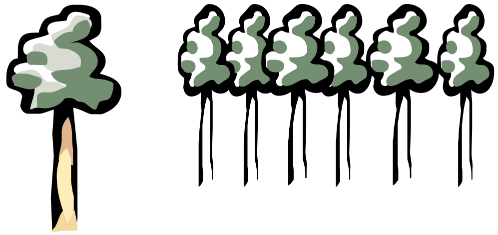
Damaging agents

See Tech Transfer Note #12 for some guidance on insect pests and forest diseases and their effects caused by thinning.

These insects	Affect these hosts	And cause this type of damage	And may be affected by thinning because	So forest managers should
Pine beetles	e.g., Pine	kill apparently healthy trees…	it affects host vigour, food base, stand climate and spacing	not thin in years of high stress not thin in stands prone to windthrow or have a high incidence of disease thin stands during late summer and early fall after the main beetle attacks. The inner bark looses its attractive-ness to beetles the following year.

Similar information is presented for forest diseases.

Density and Other Factors



Other Factors to Consider

Wildlife habitat

Spacing can increase or decrease habitat values for different species.

For example:

Habitat quality decreased	Habitit quality unaffected	Habitat quality improved
Marten	Gray wolf	Coyote
Fisher	Grizzly bear	Black bear
Lynx	Ermine	Long-tailed weasel
		Cougar
		Bobcat

(From: *Stand Tending Impacts on Environmental Indicators*, 1996)

Density – Other Factors to Consider

Wildlife habitat

See references provided in the guidelines for more detail – spacing can increase or decrease habitat – it depends.

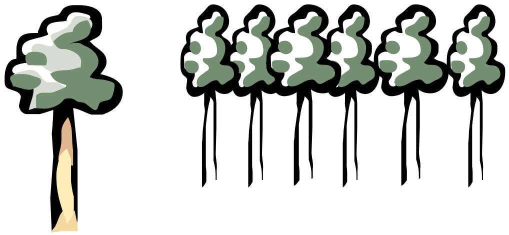
The table provided indicates 'in general' the effects of spacing on habitat quality for a range of carnivores found in interior BC. The example takes a pole sapling stand with 100% crown cover down to 25–65% cover. The classification takes into account both feeding and reproductive requirements.

Habitat Quality Decreased	Habitat Quality Unaffected	Habitat Quality Improved
Marten	Gray wolf	Coyote
Fisher	Grizzly bear	Black bear
Lynx	Ermine	Long-tailed weasel
		Cougar
		Bobcat

As this table shows habitat for a number of carnivores is unaffected or improved by canopy reduction. However:

As can be seen, there will be trade-offs created by using varying densities. Greenough and Kurz (1996) conclude their document with the need for landscape-level analysis. Where large scale treatments are contemplated, this is a must.

Density and Other Factors



Other Factors to Consider

Hydrology

- ▲ No effects of thinning identified to date.

Biotic and abiotic effects of spacing – ?

- ▲ more rapid decomposition
- ▲ possibly more respiration...
- ▲ more rapid movement of root decay inoculum

In Conclusion...

BEWARE: Spacing can result in positive and negative consequences.

You should be aware of the possibilities *before* you start.

Density – Other Factors to Consider

Hydrology

No effects of thinning identified to date. The key is – likely time until crown closure. If this is affected dramatically (e.g., very wide or clumpy spacing) the recovery rate may be significantly reduced. Present density reductions have not been shown to affect hydrological recovery rate.

Biotic and abiotic effects of spacing

Many site and stand factors may be affected by stand density management practices; some may enhance the productive capacity of the stand, while others may introduce elements of uncertainty and risk.
For instance:

- Higher levels of sunlight and warmer soil temperature may influence micro-organisms and the rate of nutrient cycling.
- Increased micro-organism activity may increase the decomposition rates of slash remaining after thinning, and eventually improve mineral nutrient availability for the remaining crop trees.
- Reduced uptake by the stand may influence the diurnal and seasonal availability of soil moisture, thereby influencing the pattern of stomatal activity, duration of photosynthesis, and the rate of biomass production in the standing crop.
- Increased sunlight, warmer air temperatures and increased air movement may increase the respiration rate of the standing crop, partially offsetting increased biomass production rates.
- Cutting activity associated with thinning may increase the concentration and spread of root decay inoculum within the stand, resulting in greater losses of usable timber from the stand.

The characteristics of the site and stand may indicate the potential significance of these biotic and abiotic responses to density management decision making.

In Conclusion...

Beware – spacing can result in positive and negative consequences. You should be aware of the possibilities before you start.

As a parting word on biology and spacing effects – spacing is crown and gap management to achieve a desired result. Stay informed.