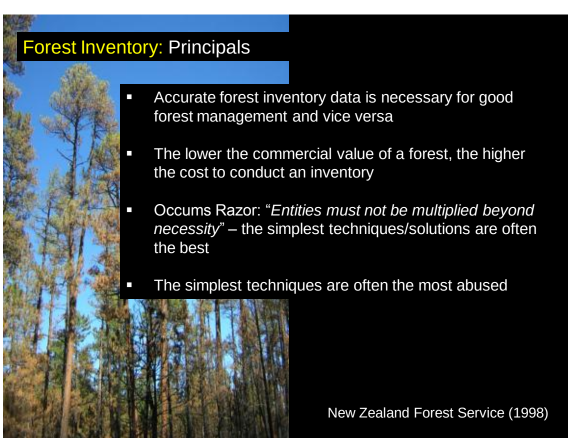

FOR 373: Forest Inventory Techniques
Monitoring and Statistics Made Sensible?
Reading
Listen to your Customers (website)
Elementary Forest Sampling
• Pages 1-13


FOR 474: Forest Inventory Techniques
Course Overview:
• Principals of a Forest Inventory
• What Can Monitoring Tell Us?
• What Sampling Designs Should We Use?
• How Do We Analyze Monitoring Data?
• How Do We Monitor at Landscape Scales?
• How Do We Monitor Forest Disturbances?
• Why do we care about Standard Error?
"The person ho knows HOW to do the work will always have a job … and the person who knows WHY … will be his boss."


Forest Inventory: Principals
▪ Accurate forest inventory data is necessary for good forest management and vice versa
▪ The lower the commercial value of a forest, the higher the cost to conduct an inventory
▪ Occums Razor: "Entities must not be multiplied beyond necessity" – the simplest techniques/solutions are often the best
▪ The simplest techniques are often the most abused
New Zealand Forest Service (1998)

Forest Inventory: Principals

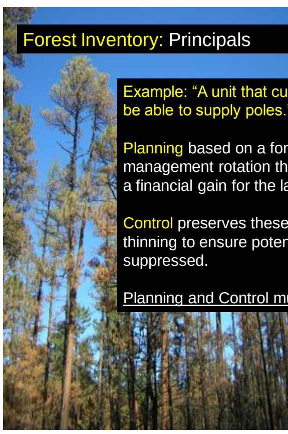
Forest Measurements deal with the measurement of features (diameter, heights, etc) that make up a forest.

Forest Inventory is the process of measuring and analyzing characteristics of a forest. This requires knowledge of why particular forest metrics are measured and how they are used to inform management.

Forest Inventories are often conducted to generate defensible data for use in planning silvicultural treatments or control of forest operations.

A plan is a systematic set of tasks that maximizes future benefits, while control refers to actions that keep the plan on track.

New Zealand Forest Service (1998)



Forest Inventory: Principals

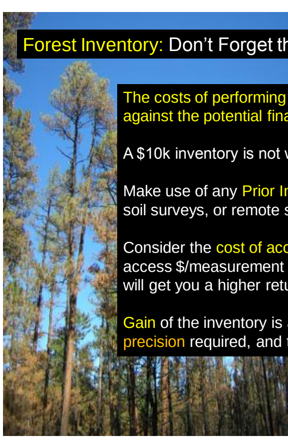
Example: "A unit that currently only supplies firewood, might be able to supply poles."

Planning based on a forest inventory may lead to a management rotation that harvests these poles, leading to a financial gain for the landowner.

Control preserves these potential assets. This could include thinning to ensure potential pole trees do not get suppressed.

Planning and Control must be based on quantitative data!

New Zealand Forest Service (1998)



Forest Inventory: Don't Forget the Costs

The costs of performing an inventory must be weighed against the potential financial gain from the plan.

A $10k inventory is not worth the cost for $10k of pulp …!

Make use of any Prior Information, whether past cruises, soil surveys, or remote sensing / GIS data.

Consider the cost of access & the cost of measurement. If access $/measurement $ is high, then extra measurements will get you a higher return on your costs.

Gain of the inventory is a function of the purpose, the precision required, and the measurement cost.

New Zealand Forest Service (1998)

Forest Inventory: Types

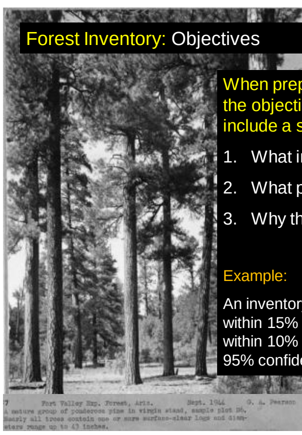
National / Regional: (e.g., US FIA program) – used for long-term strategic planning

Individual Forest: Often used for medium term planning

Stand Inventories: Often for short-term specific purposes such as pre-harvest. Pre-harvest inventories are usually conducted within 2 years of the harvest date for the purpose of *planning* logging operations, marketing, sales, workforce, and cash flow.

Permanent plots are re-measured (aka monitored) to validate silvicultural predictions

New Zealand Forest Service (1998)



Forest Inventory: Objectives

When preparing an inventory plan/report the objectives should be well defined and include a statement of:

1. What information is required
2. What precision is required
3. Why the data is requested

Example:

An inventory to estimate standing volume to within 15% of the total volume per unit and within 10% of the total forest value, both at the 95% confidence level.

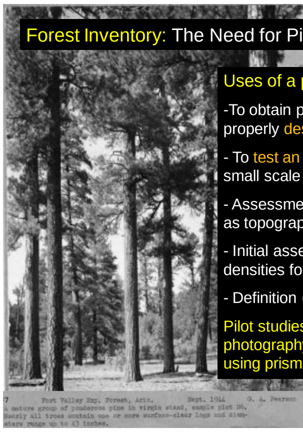
Forest Inventory: Population

The population boundary of the inventory should be well defined. Your plan/report should contain maps (hard copy or GIS files)

- Area Estimation
- Topography Description
- Ownership Information
- Accessibility and Transport Data

Any prior data should also be included such as data from prior inventories, details of logistical problems, access, deck size, etc.

Forest Inventory: The Need for Pilot Inventories



Uses of a pilot inventory (or study):

-To obtain preliminary data necessary to properly design full inventories (SRS lecture)

- To test an untried technique or treatment on a small scale

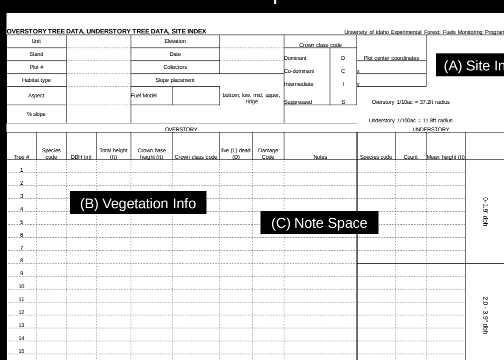
- Assessment of logistical issues (access) such as topography, understorey, visibility issues, etc

- Initial assessment of stem and basal area densities for potential strata (Stratified lectures)

- Definition of stand or unit boundaries

Pilot studies can be conducted using aerial photography, SRS, quick field methods such as using prisms

Field Sheets: The Usual Suspects


OVERSTORY TREE DATA, UNDERSTORY TREE DATA, SITE INDEX

University of Idaho Experimental Forest: Fuels Monitoring Program

Unit		Elevation		Crown class code
Stand		Date		Dominant D
Plot #		Collectors		Co-dominant C
Habitat type		Slope placement		Intermediate I
Aspect		Fuel Model	bottom, low, mid, upper, ridge	Suppressed S
% slope				

Plot center coordinates: x y

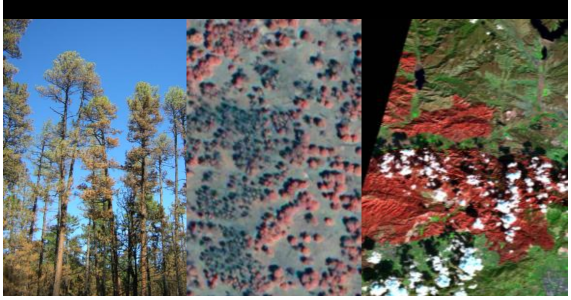
Overstory 1/10ac = 37.2ft radius

Understory 1/100ac = 11.8ft radius

OVERSTORY									UNDERSTORY			
Tree #	Species code	DBH (in)	Total height (ft)	Crown base height (ft)	Crown class code	live (L) dead (D)	Damage Code	Notes	Species code	Count	Mean height (ft)	
1												0-1.9" dbh
2												
3												
4												
5												
6												
7												
8												
9												2.0 - 3.9" dbh
10												
11												
12												
13												
14												
15												
16												

Monitoring: Why and What Can it Tell Us?

Definition: The process through which repeated observations and analyses can evaluate the condition of an object



Monitoring: Why and What Can it Tell Us?

Adaptive Management: The process where activities are implemented (with uncertainty in their effectiveness), the response of these activities are monitored and analyzed, and the results drive future decisions.

Nyberg (1998)

Terry Spivey, USDA Forest Service, www.forestryimages.org

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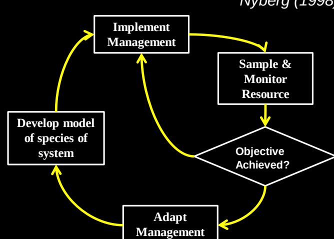
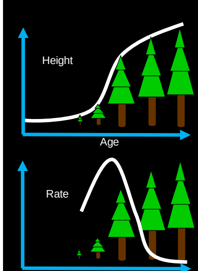


Elzinga Chapter 1

Monitoring: What Can Monitoring Tell us?

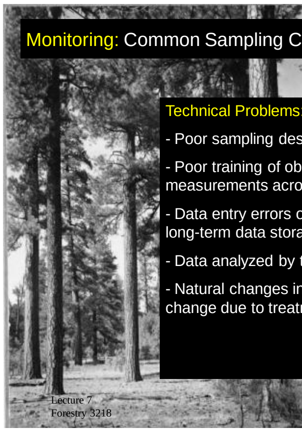
Inventories: Only provide a snap-shot of how much is present

Monitoring: Allows the measurement and analysis of “rates of change” AND how that information impacts the management objective



- Mortality => Volume of trees initially measured that died and not utilized
- Ingrowth => Volume of trees grown after start of the growth period (e.g., seedlings)
- Gross Growth => change in total volume of a stand (including mortality)
- Net Growth => excluding mortality
- Productivity = Net Growth + Ingrowth

Monitoring: Common Sampling Challenges



Technical Problems:

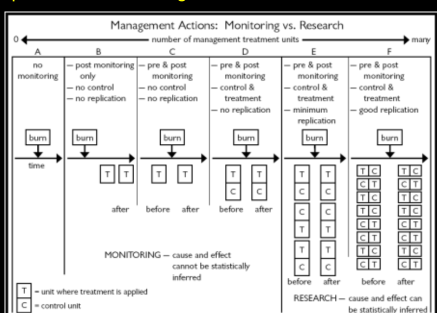
- Poor sampling designs lead to inconclusive results
- Poor training of observers or differences in measurements across observers (bias)
- Data entry errors or poor recording practices, poor long-term data storage
- Data analyzed by third parties
- Natural changes in the resource obscures potential change due to treatment

Elzinga Chapter 1

Lecture 7
Forestry 3218

Monitoring: Why and What Can it Tell Us?

The Operational Monitoring and Research Continuum



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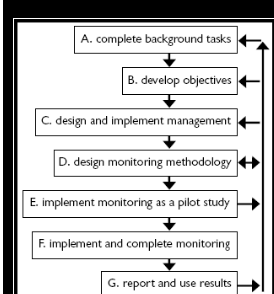
Monitoring: An Example of an Adaptive Management Process

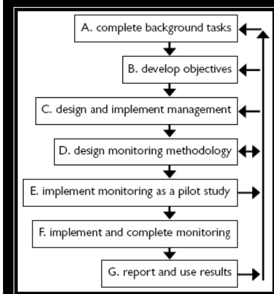


Background Tasks:

- Compile existing data (maps, data)
- Review management and NEPA docs
- Identify key species / populations
- Evaluate available resources
- Determine Scale
- Determine monitoring intensity
- Review and brief management

Elzinga Chapter 2

Monitoring: An Example of an Adaptive Management Process



Develop Objectives:

- Will you use or develop a model?
- Identify an indicator (key species, etc)
- Identify sensitive measurements
- How long and When will you monitor?
- What are the likely management responses

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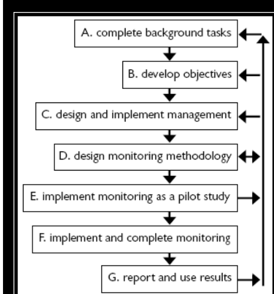
Monitoring: An Example of an Adaptive Management Process



Pilot Study:

Pilot studies are useful to collect preliminary data.

This data can be used to establish sample sizes or to provide an initial assessment (often over a limited scale) of the results.

Pilot studies are invaluable at determining whether field methods are practical with the available resources.

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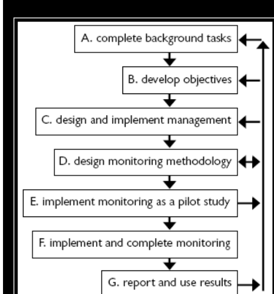
Monitoring: An Example of an Adaptive Management Process



Design and Implement:

- Design general methodology
- Design approach to reduce variability between observers
- Identify number of measurement units: Sample or Census
- Identify sampling design

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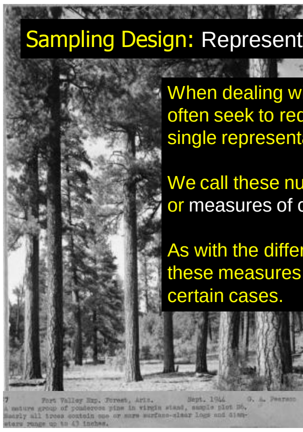


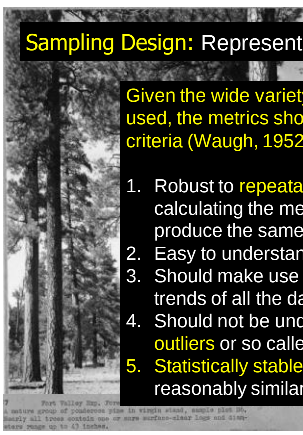
Sampling Design: Representative Measures

When dealing with vast amounts of data we often seek to reduce all the data down to a single representative number.

We call these numbers or metrics averages or measures of central tendency.

As with the different sampling methods, these measures are only appropriate in certain cases.

Johnson

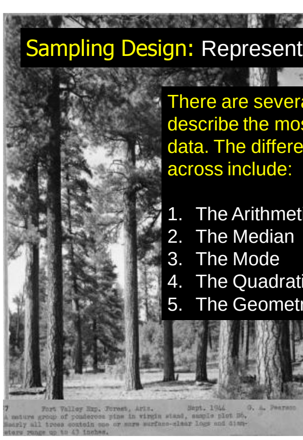


Sampling Design: Representative Measures

Given the wide variety of metrics that can be used, the metrics should exhibit the following criteria (Waugh, 1952):

1. Robust to repeatable observations; i.e. calculating the metric multiple times should produce the same result
2. Easy to understand and interpret
3. Should make use of all, or at least the main trends of all the data, in the distribution
4. Should not be unduly influenced by single outliers or so called rogue-values
5. Statistically stable (value for group of samples reasonably similar to value of another group)

Johnson



Sampling Design: Representative Measures

There are several ways that we can describe the most common occurrences of data. The different measures you will come across include:

1. The Arithmetic Mean
2. The Median
3. The Mode
4. The Quadratic Mean
5. The Geometric Mean

Sampling Design: The Arithmetic Mean

This is the most commonly used and is also called the mean or average.

	N	Samples
1	N	Samples
2		
3	1	3
4	2	4
5	3	10
6	4	2
7	5	8
8	6	18
9	7	5
10	8	17
11	9	9
12	10	10
13		
14	=AVERAGE(B3:B12) = 8.6	
15		

Population:

$$\mu = \frac{\sum_{i=1}^{N} y_i}{N}$$

Sample:

$$\bar{x} = \frac{\sum_{i=1}^{n} y_i}{n}$$

Sampling Design: The Arithmetic Mean

When dealing with per unit area data collected in stands of variable area we need to use a weighted mean

C13 =SUM(C2:C11)/SUM(A2:A11)

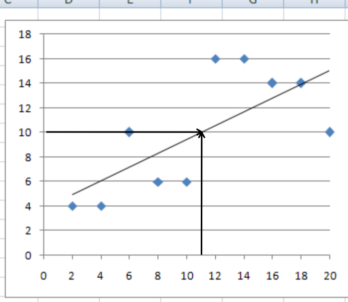
	A	B	C
1	Stand Area	Mean V per Acre	A*V
2	40	202	8080
3	35	170	5950
4	42	194	8148
5	37	260	9620
6	41	170	6970
7	39	190	7410
8	20	204	4080
9	35	186	6510
10	28	150	4200
11	30	156	4680
12			
13		188.2	189.2

$$\bar{y}_w = \frac{\sum_{i=1}^{n} A_i y_i}{\sum_{i=1}^{n} A_i}$$

Sampling Design: The Arithmetic Mean

The mean of both your X and Y data should produce a X-Y coordinate that is a real value on the function fitted to your data

	A	B
1	N	Samples
2	2	4
3	4	4
4	6	10
5	8	6
6	10	6
7	12	16
8	14	16
9	16	14
10	18	14
11	20	10
12		
13	11	10



Sampling Design: The Median

This is the value that occupies the midpoint (M.P.) value in a distribution of data

A13 | f_x =(COUNT(A1:A11)+1)/2

	A	B	C	D	E	F
1	1	78				
2	2	89				
3	3	92				
4	4	94				
5	5	96				
6	6	98				
7	7	124				
8	8	135				
9	9	148				
10	10	159				
11	11	201				
12						
13	6	=MEDIAN(B1:B11)				

$$M.P. = \frac{n+1}{2}$$

Median = 98

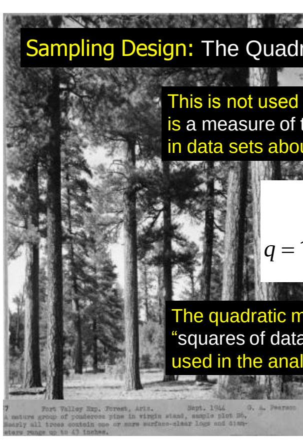
Sampling Design: The Mode

This is the value that appear most in the distribution of data

	A	B	C
1	1	78	
2	2	89	
3	3	92	
4	4	94	
5	5	96	
6	6	96	
7	7	124	
8	8	135	
9	9	148	
10	10	159	
11	11	201	
12			
13		=MODE(B1:B11) = 96	

Mode = 96

Sampling Design: The Quadratic Mean



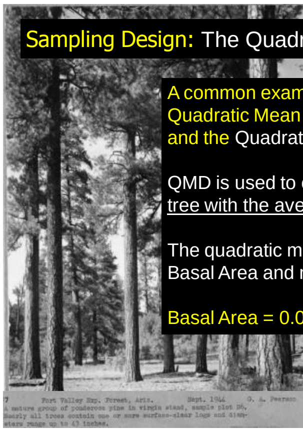
This is not used as an "average" but rather is a measure of the variability or dispersion in data sets about the arithmetic mean

$$q = \sqrt{\frac{\sum_{i=1}^{n} y_i^2}{n}}$$

The quadratic mean is used when the "squares of data", rather than the raw data is used in the analysis

Johnson

Sampling Design: The Quadratic Mean



A common example where we use the Quadratic Mean is the standard deviation and the Quadratic Mean Diameter (QMD):

QMD is used to calculate the diameter of the tree with the average basal area

The quadratic mean is justified as we use Basal Area and not the raw DBH values:

Basal Area = 0.005454 * DBH^2

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Sampling Design: The Geometric Mean

The geometric mean is used when the values of the distribution approximate those of a geometric series:

B11 =GEOMEAN(B1:B8)

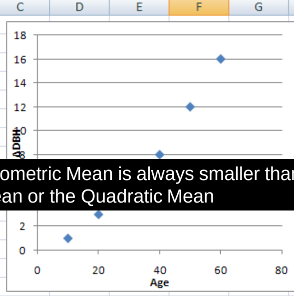
	A	B
1	1	1
2	2	2
3	3	4
4	4	8
5	5	16
6	6	32
7	7	64
8	8	128
9		
10	Arithmetic	31.88
11	Geometric	11.31

$$g = \left(\prod_{i=1}^{n} y_i \right) = (y_1 * y_2 * y_3 * \ldots * y_n)^{1/n}$$

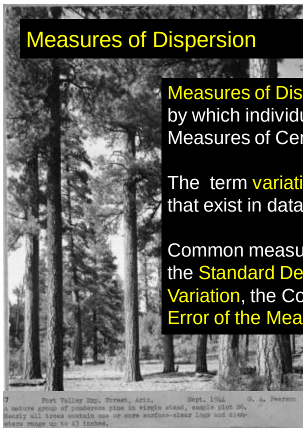
Sampling Design: Geometric Mean for Tree Growth

Assessing average PIPO growth (e.g., DBH) in a stand over a period of 60 years may look like this:

Age	ΔDBH
10	1
20	3
30	5
40	8
50	12
60	16



Note: The Geometric Mean is always smaller than both the Arithmetic Mean or the Quadratic Mean

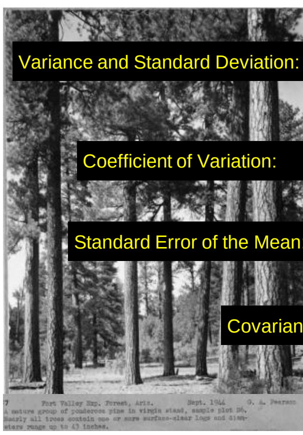


Measures of Dispersion

Measures of Dispersion define the amount by which individual data points vary from the Measures of Central Tendency.

The term variation describes the differences that exist in data that make up a population.

Common measures include the Variance, the Standard Deviation, the Coefficient of Variation, the Covariance, and the Standard Error of the Mean.



Variance and Standard Deviation:

$$\sigma^2 = \frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2$$

Coefficient of Variation:

$$CV = 100 * \frac{\sigma}{\mu}$$

Standard Error of the Mean:

$$SE_{\bar{x}} = \frac{s_x}{\sqrt{n}}$$

Covariance:

$$S_{xy} = \frac{\sum_{i=1}^{N}(x_i - \bar{x})(y_i - \bar{y})}{N - 1}$$

Why we care about Variability?

- The amount of variability influences our confidence in management decisions

$$CI = \bar{x} \pm t \times SE$$

- Can we defend/justify our decision
- Potentially large financial implications

Where is this all headed?

Why we care about Variability?

What if we wanted to know the maximum potential profit from a harvest operation?

What must we consider?

- Mean and variability of volume
- Composition of merchantable material (species mixture)
- Value of individual material (price for species)
- Harvest and delivery cost

What if?

- $\bar{x} = 1{,}600\ ft^3\ per\ acre$; with $SE = 110\ ft^3\ per\ acre$
- Stand is 120 acres
- Stand is 40% ABGR, 30% PSME, 20% THPL, 10% TSHE
- ABGR - \$170/mbf, PSME - \$290/mbf, THPL - \$350/mbf, TSHE - \$310/mbf
- THPL and TSHE go to a mill 75 min away, w/ 30 min to offload
- ABGR and PSME go to a mill 45 min away, w/ 30 min to offload
- The truck cost \$75 per hour to operate and can carry 5,000 mbf

With 95% confidence what is your expected profit?

$$Maximum = \bar{x} \times k + t \times SE \times k$$

Were k = expansion factor (acres × value)

	ABGR	PSME	THPL	TSHE
$\bar{x}$ =	7.68 mbf/acre	5.76 mbf/acre	3.84 mbf/acre	1.92 mbf/acre
SE=	0.528 mbf/acre	0.396 mbf/acre	0.264 mbf/acre	0.132 mbf/acre

Grand fir

$1{,}045\ mbf = 7.68 \frac{mbf}{acre} \times (120\ acres) + 1.96 \times 0.528 \frac{mbf}{acre} \times (120\ acres)$ $\quad 1{,}045\ \text{mbf} \times \frac{\$170}{mbf} = \$177{,}650$

Douglas-fir

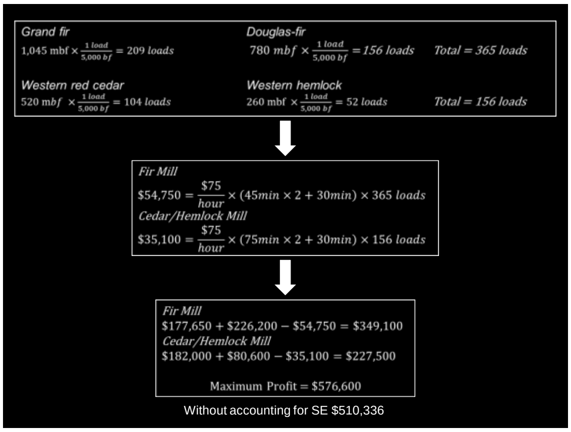
$784\ mbf = 5.76 \frac{mbf}{acre} \times (120\ acres) + 1.96 \times 0.396 \frac{mbf}{acre} \times (120\ acres)$ $\quad 780\ mbf \times \frac{\$290}{mbf} = \$226{,}200$

Western red cedar

$522.9\ mbf = 3.84 \frac{mbf}{acre} \times (120\ acres) + 1.96 \times 0.264 \frac{mbf}{acre} \times (120\ acres)$ $\quad 520\ \text{m}bf \times \frac{\$350}{mbf} = \$182{,}000$

Western hemlock

$261.4\ mbf = 1.92 \frac{mbf}{acre} \times (120\ acres) + 1.96 \times 0.132 \frac{mbf}{acre} \times (120\ acres)$ $\quad 260\ \text{mbf} \times \frac{\$310}{mbf} = \$80{,}600$


Grand fir
1,045 mbf × 1 load / 5,000 bf = 209 loads
Douglas-fir
780 mbf × 1 load / 5,000 bf = 156 loads
Total = 365 loads
Western red cedar
520 mbf × 1 load / 5,000 bf = 104 loads
Western hemlock
260 mbf × 1 load / 5,000 bf = 52 loads
Total = 156 loads
Fir Mill
$54,750 = $75/hour × (45min × 2 + 30min) × 365 loads
Cedar/Hemlock Mill
$35,100 = $75/hour × (75min × 2 + 30min) × 156 loads
Fir Mill
$177,650 + $226,200 − $54,750 = $349,100
Cedar/Hemlock Mill
$182,000 + $80,600 − $35,100 = $227,500
Maximum Profit = $576,600
Without accounting for SE $510,336