Pine Plantation
Growth and Yield

4 State
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Most Forester’s Thoughts on G&Y…

\[ S = H_D \times [0.30323/(1 - \exp(-0.014452A))] \]

\[ N_2 = 100 + [(N_1 - 100) - 0.0003425^2 \times S \times (A_2^{1.97472} - A_1^{1.97472})]^2(1/0.745339) \]

\[ \ln(B) = -42.689283/A + 36.7244 \times \ln(N) + 6.59985 \times \ln(H_D) + 2.012724 \times \ln(N)/A + 7.703502 \times \ln(H_D)/A \]

\[ \ln(Y) = b_0 + b_1 \times \ln(H_D) + b_2 \times \ln(B) + b_3 \times \ln(N)/A + b_4 \times \ln(HD)/A + b_5 \times \ln(B)/A \]

One look at this leads to this……
Math. Ugh.

Too Complicated!

Frustration…

Black box?

Yield Table

<table>
<thead>
<tr>
<th>Age (y)</th>
<th>Site Index (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>1, 2, 4</td>
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<tr>
<td>4</td>
<td>11, 17, 25</td>
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<td>5</td>
<td>36, 59, 78</td>
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<td>134, 169, 212</td>
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<td>7</td>
<td>201, 246, 301</td>
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<td>8</td>
<td>276, 330, 395</td>
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<tr>
<td>9</td>
<td>356, 418, 491</td>
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<tr>
<td>10</td>
<td>438, 507, 630</td>
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<tr>
<td>11</td>
<td>520, 594, 670</td>
</tr>
<tr>
<td>12</td>
<td></td>
</tr>
</tbody>
</table>

Yield Equation: \( \log(V+1) = 3.534 - 1.472 \)

\[ V = B_0 N + \beta_1 \Sigma d + \beta_2 \Sigma d^2 \]

Computer Programs

??

Frustration…

@#$!!
Lucky you, this talk is NOT about models, equations or math.

It’s about **OUTCOMES**...
What we will cover

1. What values we *should* see and how they have changed over time

2. The fact that *good* estimates *can* be made using (some) growth and yield models

3. Accurate growth and yield modeling is only *one part* of a complete forest information system (*hint*: there are three parts)
Yield Changes: 1960’s to the future


(I know where I would like to be on this graph)
How has average yield changed?

Foresters only believe what they have seen – a conservative bunch!!

- We have grown much more wood than most foresters think possible
- Yes, it is expensive, but it is possible
- An unimproved site prepared plantation could be expected to grow 3 tons/ac/yr
- Current operationally intensive plantations can grow 5-7 tons/ac/yr

But wait! We have the ability to grow much more than that
Experimental Production at age 10

- 2\textsuperscript{nd} Gen Genetics
- Intensive mgmt.: multiple fert. and aggressive weed control
- 900 + densities

Growing more than 12 tons/ac/yr!
What about total production/acre?

- We have grown many stands to more than 200 tons per acre
  - Since most foresters are used to clearcuts that are 60-100 tons/ac they tend to not believe this
- Look back at Miscellaneous Publication 50 published in 1929 (*next slide*)
  - These are for fully stocked natural stands
  - Site index 90 (base age 50) at age 40 has 6200 ft³/ac or 186 tons/ac and at age 50 has 7200 ft³ or 216 tons/ac
## Yield in Cubic Feet Per Acre

**[Total volume—unpeeled]**

<table>
<thead>
<tr>
<th>Age, years</th>
<th>Site index in feet</th>
<th>60</th>
<th>70</th>
<th>80</th>
<th>90</th>
<th>100</th>
<th>110</th>
<th>120</th>
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<tbody>
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<td></td>
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<td></td>
<td></td>
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<tr>
<td>20</td>
<td></td>
<td>1,000</td>
<td>1,250</td>
<td>1,550</td>
<td>1,900</td>
<td>2,200</td>
<td>2,600</td>
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<td>1,900</td>
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<td>3,300</td>
<td>3,850</td>
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<td>2,650</td>
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<td>4,400</td>
<td>5,100</td>
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<td>3,350</td>
<td>4,000</td>
<td>4,700</td>
<td>5,400</td>
<td>6,200</td>
<td>7,150</td>
</tr>
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<td></td>
<td>3,300</td>
<td>3,950</td>
<td>4,700</td>
<td>5,500</td>
<td>6,350</td>
<td>7,250</td>
<td>8,350</td>
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<tr>
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<td>7,800</td>
<td>9,000</td>
<td>10,250</td>
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<td>4,300</td>
<td>5,200</td>
<td>6,150</td>
<td>7,200</td>
<td>8,400</td>
<td>9,650</td>
<td>11,000</td>
</tr>
</tbody>
</table>
Possibilities, not Recommendations

- These are for unthinned stands
- These are NOT recommendations for the way to manage
- However, these yields ARE possible under some types of management
- With intensive management unthinned plantations can approach these yields at much younger ages than 40-50.
What info do we need to estimate growth?

- assessment of ‘growth potential’ of site (i.e. site index)
- genetic makeup of seedlings
- age(s) of trees on site
- planting density (i.e. trees per acre)
- other silvicultural ‘treatment(s)’:
  - chemical site preparation
  - herbaceous weed control
  - fertilization
  - tree thinning(s)
  - woody competition release
  - Etc.
What picture does this info paint?

Gives avg. height and/or basal area at a given age.
A good growth and yield model will incorporate all of these site characteristics and ‘treatments’ to estimate 1) growth and 2) product breakdown at a given age.
But it depends on the painter…

Traditional model for growth and yield

\[ Y = f(Age, \text{Site Index}, \text{Trees/Acre}) \]

Modern, sophisticated models for growth and yield

Traditional good models PLUS add effects of fertilization, weed control, genetics, history, etc.
Why do we need G&Y Models?

- Many foresters would argue that we don’t need them.

I will convince you otherwise, especially if you are managing even relatively large acreages!
A small example

Treatments are applied at the stand level. The need for treatments is determined largely by having an understanding of the rate of stand development or the state of stand development.

For example: want to conduct a first thin to leave 75 ft² of basal area that will remove at least 25 tons of pulpwood.

All very well and good, but… when will this (activity =cash flow!) occur?

Without good growth and yield models you don’t really know.
The Key is Information

Answering the ‘when’ and ‘how much’ questions (as well as many more) is possible only by knowing what you have in each stand at all times.

Most people don’t know what they have in a stand at ANY time, let alone sometime in the future.
Therefore..

An information system is necessary!

Three components of such an system:

1. Inventory
2. Growth and Yield Model
3. Harvest and Activity Scheduling capability
Let’s make an analogy…
Timber vs. Stock or Bond Assets

Timber for timber’s sake

Many timber investors view timber like other real estate in terms of valuation

- Land and residential and commercial real estate typically have their values estimated by appraisal
- As a result values are only obtained periodically due to relatively high cost to obtain

Timber as an investment

Timber is a commodity that has a value. This value can be closely estimated annually

- Unfortunately most timber owners do not know the value of the timber they own at a given point in time
Are you convinced yet?

AGREE
(same as "yes")
Three parts of the info system

1. **Inventory** (accurate is best!)

2. **Growth and Yield Model**

3. **Harvest and Activity Scheduling capability** (preferably one that can handle constraints)
#1: Inventory

The beginning point of information in the system...

- Traditional business inventories are straightforward
  - i.e. Count number of identical items on hand (often in cases of 12, 24, etc.)
  - Bar codes or RFID tags

Think....

Inventory is then used to make decisions on: what to stock, when to stock it, how much to stock...

- Comes from information on what is selling or NOT and when
Timber Inventory is Much More Difficult

Trees pose some issues. They:

- are unique in size, form, disease
  - no identical items in convenient case lots

- have no bar codes or RFID tags
  - if they did have them the information transmitted would soon be out of date

- are not all found in a 40,000 ft² building, but are (much less expediently) distributed across acres with swamps, creeks, etc.
  - Could possibly have more than 400,000 trees on 1000 acres
    - How many would that be on 2 million acres?
Aye, the rub!

**Therefore:** no annual 100% inventory for trees.

Instead, most land managers *sample* only 2-3 times during the life of a timber stand (if ever).
So how do you figure out what you have?

Somehow you must bridge the gap between knowing the timber value at inventory age (in the past) and knowing the value at the current (or future) age.
The Answer!

A growth and yield system that incorporates the treatment effects as discussed earlier to “grow” the inventory information to the current age.

This is a major role of a G&Y model in a forest information system.
Let’s get back to the Inventory

There are several ‘flavors’
Not all are good.

or particularly useful for growth and yield...
Foresters (many/most of them) collect information that defines what the stand is worth at the current age.

- They measure (hopefully) diameters (dbh) and for sawlog sized trees call number of sawlogs. For smaller trees they measure dbh and typically a merchantable height for the local pulpwood market.

These measures are usually adequate for obtaining current volumes and value. These are not adequate for inputs to G&Y models.
Management Inventory

**Objective:** to provide information that allows a G&Y model to accurately estimate yields *at the time of the inventory* (and *beyond!*).
Types of Management Inventory Measurements

- **Dbh**
  - especially in 1 inch classes or less

- **Total height**
  - allows for determining merchantability as tree grows if there are no defects

**O.K.**

- Using ‘logs’ as merchantable height measurement
  - for any tree we do not know if the height can be mathematically ‘increased’ or not as the tree grows, as forks or other defects may preclude increasing

**NOT O.K.**
More good measurements to take during a management inventory

- **Stopper height** (if applicable)
  - i.e. a height where merchantability is limited by fork, canker, sweep, crook, etc.

- **Product potential for every tree measured**
  - even if it is considered ‘pulpwood always’ (others might be ‘pole’, ‘plylog’, etc.)

Honestly, this is only slightly more time consuming than collecting data for an acquisition or sales inventory. The benefits far outweigh the costs.
Three parts of the info system

1. **Inventory** (accurate is best!)

2. **Growth and Yield Model**

3. **Harvest and Activity Scheduling capability** (preferably one that can handle constraints)
Part #2: Let the fun begin!

Now that we have collected the necessary information in the inventory, we need to use it in the G&Y model.
Mars vs. Venus?

Sadly, the G&Y model development folks and the inventory folks are not usually on the same page.

So, G&Y models have been developed that grow stands using stand level inputs such as age, site index, and trees per acre, but that DO NOT allow inputs of individual tree information such as dbh and tree quality.
Result: stuck with poor model input systems

- No place to put the more detailed inventory information in the model,
- Often there is no place to put the more detailed information in the organizations database *at all* (GIS or otherwise)

**Reason:** In a database stand level characteristics take up much less ‘space’ than tree level characteristics.
The erroneous “solution”

- Have the G&Y model *simulate* a dbh distribution that *should be* reasonable for the age, site index, trees per acre, etc.

Results:
- lost resolution on dbh AND
- *complete* loss of valuable ‘degrade’ and product potential information
What is needed for Model vs. Inventory Consistency

1. Thought put into what input information is needed to grow detailed timber volumes in the G&Y model

2. An inventory process that collects the needed input information for the G&Y model
The larger investment organizations have this consistency in their systems, but many (read: ‘most’) organizations that do this type of work for clients do not have it.

Yes, you get ‘numbers’, but how accurate are they?
It is worth saying… if forced to use existing data that is not detailed, the G&Y model is severely hampered from obtaining an accurate estimate.
Poor data process

Gather minimal data on sample of trees with paper tally sheets.

Summarize it.

‘Grow’ summary data with model(s) or by some %.

Develop ‘standard curve’ to represent trees based on summarized data.

Throw away the good stuff…
a far cry from reality and what’s actually on the ground…
Assumptions forced by poor data

- Current inventory stand level values
  - What genetics, competition control, fertilization, thinning, etc. treatments were applied?
    - How a stand got to where it is at inventory is important to where it will grow from that time

- Degrade % for solid wood trees and how is it distributed over the dbh classes
  - For that matter, how many solid wood trees are there per acre?
    - we are forced to estimate this typically through a thinning
Still more assumptions…

How can we estimate future solid wood tons provided when we do not know how they were obtained? *Growing by some percentage has been shown to work particularly poorly.*

At some point so many assumptions are being made that model outputs must be viewed with some *ahem* skepticism.

***This is the source of the belief that G&Y models provide no aid for timber management!***
Superior data process

Gather all relevant data on trees’ current status and product potential using digital handheld devices.

+ Transfer individual tree data to database.
  Grow individual trees on a stand basis using physiographically specific models and account for stand history and treatments.

=
A dose of reality!

Warts and all... 

...you know at any time exactly what’s there.
Benefits of a ‘consistent’ system

- Can update to current volumes including product breakdowns and value every year
  - Means you have an estimate of what you have on every stand every year, not just when it is inventoried
  - Have an estimate of volumes in each product class

- Because of this, you can:
  - Take advantage of beneficial market conditions
  - Manage your cash flow
  - Make informed management decisions
  - Optimize earnings as well as other objectives simultaneously
Systems built with consistency

- Keeps same trees for future growth estimates
- Re-measurement checks indicate that, overall, this system works well
- It is not *completely* fool proof
  - For example the model thinks trees in TX grew at the normal rate last year in spite of the drought!
  - At present we are not calculating this in our system
Take full advantage of product grade shifts

- Many organizations struggle with estimating transfer rates from lower value products to higher value products
  - A result of using systems that apply % growth per year that have not inspired confidence
Results of a consistent system

We move from having periodic volumes and values at times of inventory to having reliable volumes and values on all stands at all times.

The resulting information allows us to manage inventories more like a WalMart – with knowledge and efficiency.
Timber Management is Large Inventory Management.

The system allows for evaluation of:

- alternative thinning ages
- alternative thinning intensities
- returns due to fertilization, woody release, herbaceous weed control, and other optional investments
- alternative levels of genetic improvement vs. the cost for regenerated stands
Other possibilities…

Are you interested in:

- evaluating the trade-off between raking pinestraw and thinning pine stands?
  - Does it affect timing of thinnings or optimum economic rotation ages?

- Knowing the opportunity cost (if any) of managing first for wildlife or aesthetics with timber management as a secondary objective?

- Having a well informed answer when a timber buyer offers double the going rate for pine pulpwood to clearcut a 17 year old plantation?
Determine optimum economic rotation age

![Graph showing the relationship between BLV (value per acre) and age (years). The graph indicates a peak around the 15-20 year mark, declining steadily thereafter.]
Three parts of the info system

1. Inventory (accurate is best!)
2. Growth and Yield Model
3. Harvest and Activity Scheduling Capability (preferably one that can handle constraints)
Part #3

- Helps to show future growth projection under alternative management
- Helps when scheduling harvest and silvicultural activities
- Works by looking at future management alternatives and evaluates each one for
  1. financial return, and
  2. other considerations of importance to the landowner
    - E.g. financial return may be constrained by some minimum cash flow needed per year
Scheduling Activities

- **Unconstrained Optimum**
  - This looks at a property stand by stand and from *all* alternatives considered finds and selects the one with the highest financial return for that stand

- **Constrained Optimum**
  - Tries to use the highest return for each stand, *but* may choose an alternative to meet cash flow timings, wood flow timings or other constraints

- **Other Objectives**
  - For landowners with primarily wildlife or aesthetics objectives the list of alternatives may be shortened to only include those that meet these objectives first
Evaluating constraints

It is often instructive to inspect the difference in financial return between the unconstrained optimum and the constraints.

This has often led to loosening of constraints or their removal when the financial cost of the constraint became evident.
Summary

- Overall, averages of plantation yields have increased from the 1960’s to today
- The yield/acre/yr that is achieved depends greatly on the management the stand receives
- Sophisticated modern growth and yield models should be able to
  - reflect silvicultural treatments the stand receives, and
  - input and use inventory detail about the stand at the tree level rather than using stand averages
Forestry Information Systems provide needed information for making timber management decisions.

- *Good information Systems have 3 main parts:*
  - **Good inventory**
    - at a level useful for input into a growth and yield model that will “grow” the stand over time from inventory forward
  - **A good growth and yield model**
    - built to receive the detailed information from the inventory and to *keep* all of the detail as the stand is grown forward in time
The bonus points.

- The growth and yield model is also used to project stand yields forward using alternative management.
- Harvest scheduling algorithms are often used on larger properties to objectively find the financial optimum management for stands.
- The optimum may be unconstrained or constrained which will result in lower financial returns.
Are we done yet?!