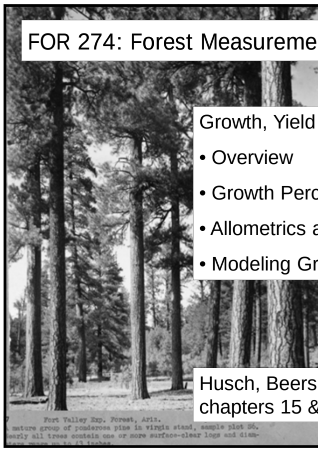
FOR 274: Forest Measurements and Inventory

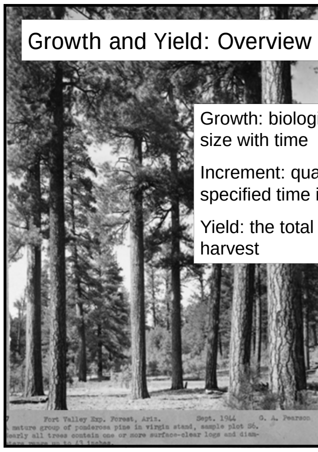


Growth, Yield and Biomass

- Overview
- Growth Percentage
- Allometrics and Volume
- Modeling Growth and Yield

Husch, Beers and Kershaw pp250-257, chapters 15 & 16

Growth and Yield: Overview

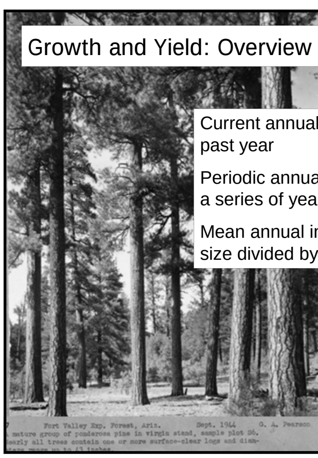


Growth: biological phenomenon of increase in size with time

Increment: quantitative increase in size in a specified time interval due to growth

Yield: the total amount (of timber) available for harvest

Growth and Yield: Overview



Current annual increment: growth within the past year

Periodic annual Increment: average growth of a series of years (5 or 10)

Mean annual increment: Current (cumulative) size divided by the age

Growth and Yield: Overview

Factors affecting growth include:

- genetics
- climatic factors (temp, precip, wind, etc)
- soil factors (moisture, ph, etc)
- topography (slope, elevation, aspect)
- competition (influence of other trees)

Growth and Yield: Overview

To evaluate the usefulness of different treatment options we often use “growth and yield models” to forecast the dynamics of a stand.

Stand dynamics: Growth, mortality, reproduction, and other stand changes

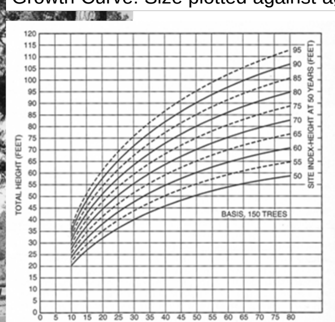
Growth and yield models produce stand estimates (basal area, volume, trees per acre, etc)

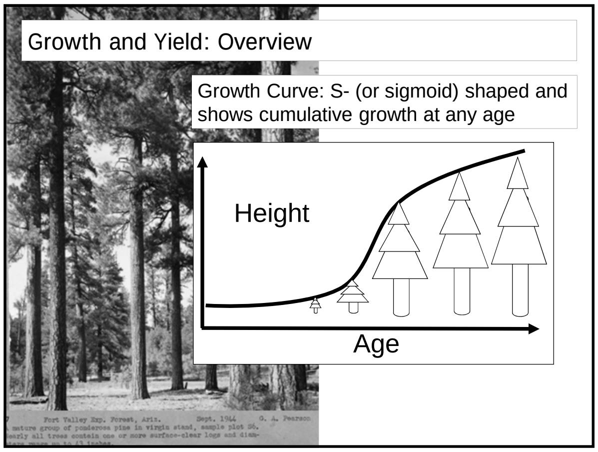
Growth and Yield: Overview

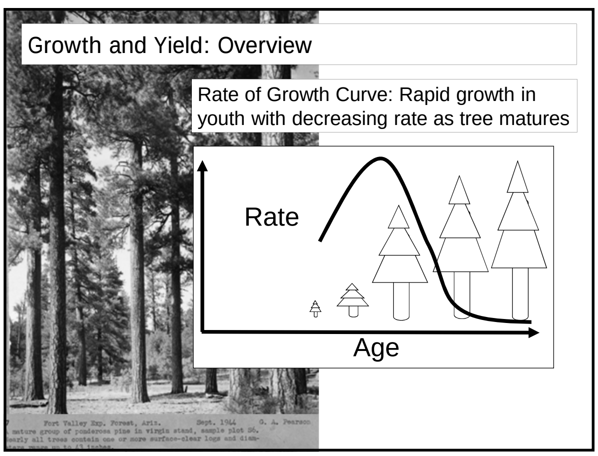
Growth Curve: Size plotted against age

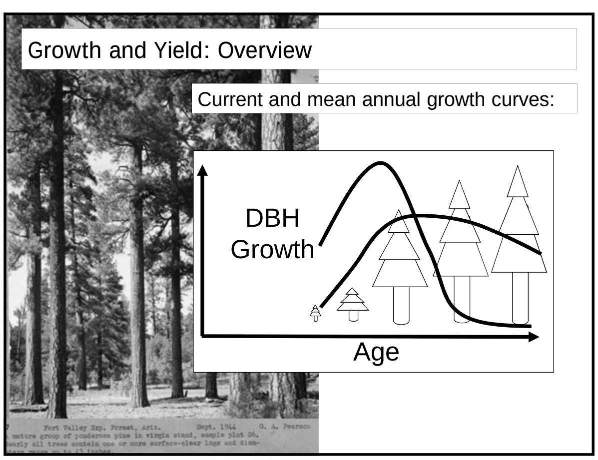
Sizes Include:

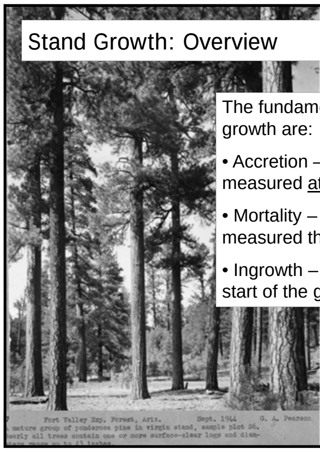
- Heights
- Volumes
- Diameter
- Weight




Growth and Yield: Overview
Growth Curve: S- (or sigmoid) shaped and shows cumulative growth at any age
Height
Age


Growth and Yield: Overview
Rate of Growth Curve: Rapid growth in youth with decreasing rate as tree matures
Rate
Age

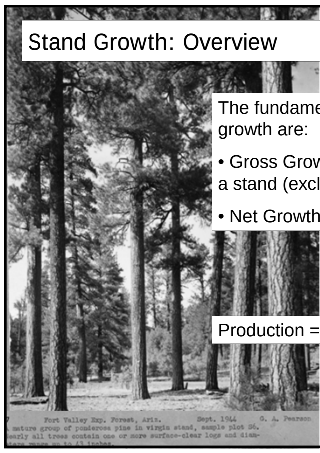

Growth and Yield: Overview
Current and mean annual growth curves:
DBH Growth
Age



Stand Growth: Overview

The fundamental components of stand growth are:

- Accretion – growth of all the trees as measured <u>at the start</u> of the growth period
- 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)

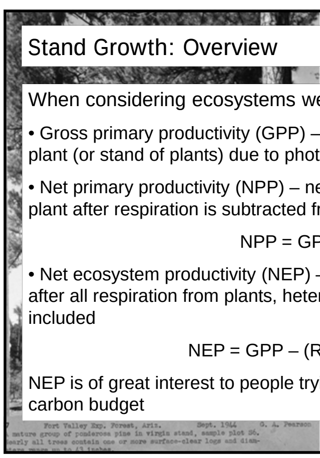


Stand Growth: Overview

The fundamental components of stand growth are:

- Gross Growth – change in total volume of a stand (excluding mortality)
- Net Growth – including mortality

Production = Net Growth + Ingrowth



Stand Growth: Overview

When considering ecosystems we use the following terms:

- Gross primary productivity (GPP) – total amount of CO_2 fixed by a plant (or stand of plants) due to photosynthesis
- Net primary productivity (NPP) – net amount of CO_2 fixed by the plant after respiration is subtracted from GPP

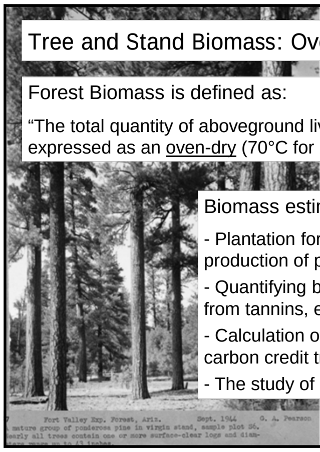
$$NPP = GPP - R$$

- Net ecosystem productivity (NEP) – the net primary production after all respiration from plants, hetertophs, and decomposes are included

$$NEP = GPP – (R_p + R_h + R_d)$$

NEP is of great interest to people trying to understand the global carbon budget

Tree and Stand Biomass: Overview



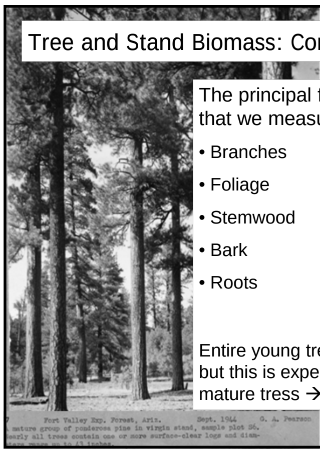
Forest Biomass is defined as:

"The total quantity of aboveground live organic floristic matter expressed as an oven-dry (70°C for 24hrs) weight"

Biomass estimation is important for:

- Plantation forests that are managed for production of pulpwood or energy
- Quantifying bark etc for products produced from tannins, etc
- Calculation of carbon pools and stocks for carbon credit trading
- The study of other biogeochemical cycles

Tree and Stand Biomass: Components



The principal forest biomass components that we measure include:

• Branches

• Foliage

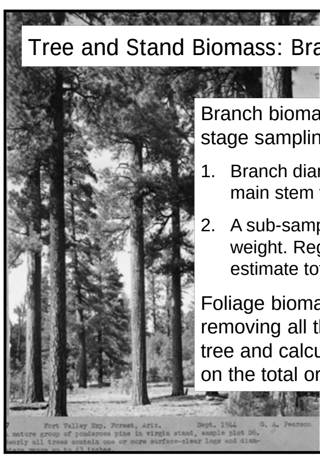
• Stemwood

• Bark

• Roots

Entire young trees can be measured by felling but this is expensive and impracticable for mature tress → sampling methods

Tree and Stand Biomass: Branches and Foliage

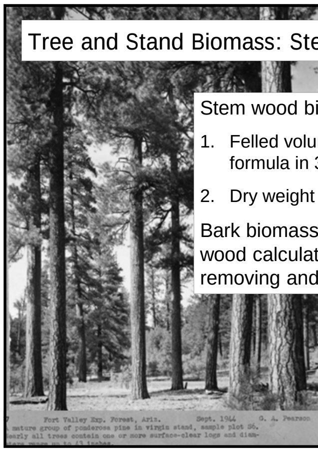


Branch biomass is often measured by a 2-stage sampling method:

1. Branch diameter is measured 1-2" from main stem for all branches
2. A sub-sample are used to estimate over weight. Regression model the used to estimate total branch weight.

Foliage biomass is often measured by removing all the needles/leaves from the tree and calculating the oven-dry weight on the total or from a 25% sample

Tree and Stand Biomass: Stemwood and Bark

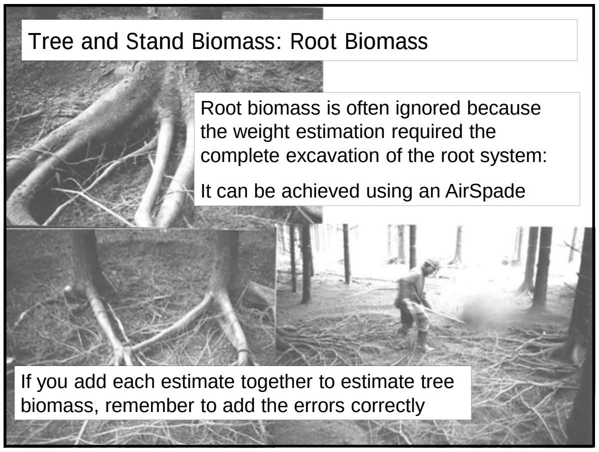


Stem wood biomass is often measured by:

1. Felled volume measured using Smalian’s formula in 3-10’ sections
2. Dry weight is calculated on cookies

Bark biomass is often clumped into stem wood calculations or can be achieved by removing and oven-drying the bark.

Tree and Stand Biomass: Root Biomass

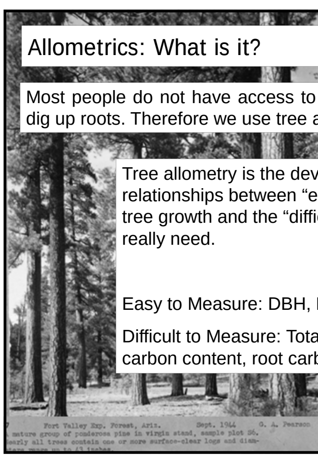


Root biomass is often ignored because the weight estimation required the complete excavation of the root system:

It can be achieved using an AirSpade

If you add each estimate together to estimate tree biomass, remember to add the errors correctly

Allometrics: What is it?



Most people do not have access to the equipment or personnel to dig up roots. Therefore we use tree allometry.

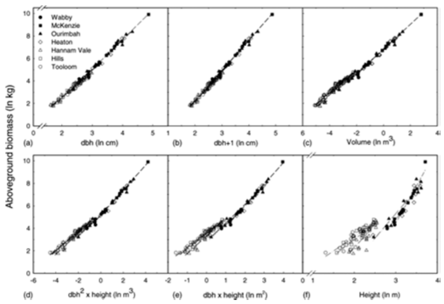
Tree allometry is the development of quantitative relationships between “easy to measure” properties of tree growth and the “difficult to measure” metric you really need.

Easy to Measure: DBH, Heights, Leaf Area Index

Difficult to Measure: Total standing tree volume, total carbon content, root carbon

Allometrics: What is it?

Allometric relations are derived based on well observed relationships between DBH (sometimes height) and volume.



Allometrics: DBH only Relationships

Many types of allometric relationships exist. The simplest type all have equations of the form:

$$M = aD^b$$

Where,

M = oven-fry weight of the biomass component (kg), D = DBH (cm), and a and b are relationship specific parameters

You already know 1 allometric eqn: $BA = 0.005454*DBH^2$!!!

Alder, speckled (*Alnus rugosa* (DuRoi) Spreng.)											
AB:	0.2612	2.2087	3–9 [a]	30	n/a	n/a	calc	n/a	comp	Maine	Young et al., 1980
ST:	0.0456	2.5847	3–8	30	0.934	n/a	log	n/a	comp	Maine	Ribe, 1973
	0.0463	2.5755	3–9 [a]	30	0.967	n/a	ln	n/a	comp	Maine	Young et al., 1980
FL:	0.0461	1.2643	3–8	30	0.667	n/a	log	n/a	comp	Maine	Ribe, 1973
	0.0479	1.2274	3–9 [a]	30	0.802	n/a	ln	n/a	comp	Maine	Young et al., 1980
BR:	0.0620	1.5184	3–8	30	0.776	n/a	log	n/a	comp	Maine	Ribe, 1973
	0.0617	1.5201	3–9 [a]	30	0.879	n/a	ln	n/a	comp	Maine	Young et al., 1980

Allometrics: DBH only Relationships

A review of hundreds of tree allometric relations was conducted by: Ter-Meikaelian and Korsukhin (1997):

M	*a*	*b*	*D* range	*N*	R^2	SEE	Mtd	C.f.	SI	Region	Author
Alder, red (*Alnus rubra* Bong.)											
FL:	0.0100	1.9398	3–63	53	0.929	0.444	ln	1.104	comp	Oregon, Washington	Snell and Little, 1983 [b]
BR:	0.0069	2.6516	3–63	53	0.936	0.574	ln	1.179	comp	Oregon, Washington	Snell and Little, 1983 [b]
Alder, speckled (*Alnus rugosa* (DuRoi) Spreng.)											
AB:	0.2612	2.2087	3–9 [a]	30	n/a	n/a	calc	n/a	comp	Maine	Young et al., 1980
ST:	0.0456	2.5847	3–8	30	0.934	n/a	log	n/a	comp	Maine	Ribe, 1973
	0.0463	2.5755	3–9 [a]	30	0.967	n/a	ln	n/a	comp	Maine	Young et al., 1980
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	0.0617	1.5201	3–9 [a]	30	0.879	n/a	ln	n/a	comp	Maine	Young et al., 1980

Allometrics: Branch Allometrics

A study by Monserud and Marshall (1999) developed equations to predict branch and crown area, leaf mass, and branch wood mass:

Table 3. The b coefficients in the full allometric equation $Y = b_0 X_1^{b_1} X_2^{b_2} X_3^{b_3} X_4^{b_4}$ and the reduced allometric equation $Y = b_0 X_1^{b_1} X_4^{b_4}$ for branch leaf area (m^2), dry branch wood mass (kg), and dry needle mass (kg) for sample branches from each of three species: Douglas-fir, ponderosa pine, and western white pine.

Dependent variable and species	Sample size	Coefficient in $Y = b_0 X_1^{b_1} X_2^{b_2} X_3^{b_3} X_4^{b_4}$ b_0	b_1	b_2	b_3	b_4	Explained variation (%)	Coefficient in $Y = b_0 X_1^{b_1} X_4^{b_4}$ b_0	b_1	b_4	Explained variation (%)
Branch leaf area											
Douglas-fir	176	0.1171	1.8566		0.4688	0.1946	82	0.1216	1.9179		80
Ponderosa pine	175	0.2937	0.7147	0.9533	0.4090		83	0.1026	1.6046		73
Western white pine	168	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]
[illegible]											
Ponderosa pine	176	0.0872	0.8956	0.8226	0.4765		84	0.0300	1.6509		73
Western white pine	168	0.0314	1.8010		0.2176		84	0.0227	1.7103		82

Note: Dry branch wood mass does not include needles and leaf areas are projected (one-sided). The independent variables are as follows: X_1, branch diameter (cm); X_2, branch length (m); X_3, foliated length (m); X_4, distance from top of tree (m).

When the volume equations are based on one variable (e.g., DBH) they are called single-entry equations. Multiple-entry equations are based on more than one variable.

Volume: Form Class Tables

Combining our knowledge of log volumes with allometrics allows the creation of tree volume and weight tables.

Standard Volume Table, International 1/4in Rule, Form Class 80

DBH (in)	Volume by 16-ft logs (bd-ft) 1	2	3	4
10	39	63	80	
12	59	98	127	146
14	83	141	186	216
16	112	190	256	305
18	144	248	336	402
20	181	314	427	512
22	221	387	528	638
24	266	469	644	773
26	315	558	767	931
28	367	654	904	1096
30	424	758	1050	1272
32	485	870	1213	1480
34	550	989	1383	1691
36	620	1121	1571	1922
38	693	1256	1772	2167
40	770	1403	1977	2432

Form class equations:

Provides an estimate of volume from DBH, height, and tree form regardless of species

Disadvantages:
- Forms vary within and across species
- Rough estimates of form class
- Variations in taper, especially upper stem taper, can lead to large volume errors

Fort Valley Exp. Forest, Ariz. Sept. 1944 G. A. Pearson
A mature group of ponderosa pine in virgin stand, sample plot S6.
Nearly all trees contain one or more surface-clear logs and diameters range up to 43 inches.

Volume: Taper Functions

If the taper form of a tree species is generally known the volume of that tree can be given by:

Taper functions

DON’T PANIC !!!

Leading to:

Volume: Taper Functions

For those not familiar with calculus, this can be simplified to:

Where, b is given by:

For coastal Douglas fir the coefficients are:
b_0 = 0.85458, b_1=-1.29771, and b_3=0.44313

Forest Growth Model Systems: FVS

The Forest Vegetation Simulator (FVS) was developed by the USDA Forest Service and is a widely used to estimate forest growth in simulated stands.

Advantages: FVS is easy to use and includes modules that incorporate fire use and insects. Is being adapted to include spatial data and climate change. Outputs are things forest managers understand.

http://www.fs.fed.us/fmsc/fvs/software/setup.php

Disadvantages: Predominately based on correlations between growth and stand variables. Need relationships for each species. These relationships might change with changes in climate.

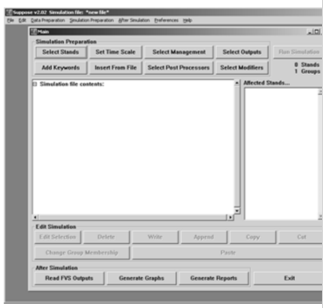
Forest Growth Model Systems: FVS

In timber management, FVS is widely used in the United States to summarize current and predict future stand conditions.

Other FVS uses include:

- Evaluating management decisions on stand structure and composition
- Evaluating wildlife habitats
- Evaluating hazard ratings and estimating timber losses from insects, diseases, and fire

Forest Growth Model Systems: FVS



Using FVS is very easy.

From file/select locations file you can view one of the 3 pre-built examples

Numerous management options can be planned on specific years: thinning, harvest, Rx fire, etc

Output is tabular or using the SVS Movies post processor you can generate animations

Forest Growth Model Systems: FVS Output

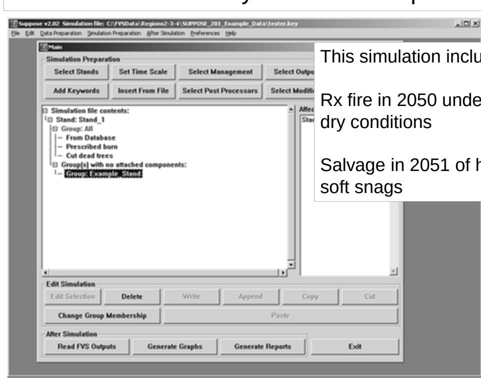
Typical FVS Output Summary:

SUMMARY STATISTICS (PER ACRE OR STAND BASED ON TOTAL STAND AREA)

		START OF SIMULATION PERIOD									REMOVALS				AFTER TREATMENT					GROWTH THIS PERIOD					
YEAR	AGE	NO OF TREES	BA	SDI	CCF	TOP HT	QMD	TOTAL CU FT	MERCH CU FT	MERCH BD FT	NO OF TREES	TOTAL CU FT	MERCH CU FT	MERCH BD FT	BA	SDI	CCF	TOP HT	RES QMD	PERIOD YEARS	ACCRE PER	MORT YEAR	MAI MERCH CU FT	FOR TYP	SS ZT
2007	100	473	115	248	120	49	6.7	2318	1636	5692	0	0	0	0	115	248	120	49	6.7	10	49	4	16.4	281	13
2017	110	462	130	272	134	53	7.2	2764	1979	7307	0	0	0	0	130	272	134	53	7.2	10	52	5	18.0	281	13
2027	120	452	145	295	149	56	7.7	3229	2305	9599	0	0	0	0	145	295	149	56	7.7	10	53	6	19.2	281	13
2037	130	441	159	317	163	60	8.1	3695	2676	11450	0	0	0	0	159	317	163	60	8.1	10	56	7	20.6	281	12
2047	140	431	174	339	177	63	8.6	4180	3089	13343	0	0	0	0	174	339	177	63	8.6	10	35	135	22.1	281	12
2057	150	162	123	211	120	67	11.8	3182	2299	10546	0	0	0	0	123	211	120	67	11.8	10	40	5	15.3	281	13
2067	160	159	133	224	129	69	12.4	3531	2589	12217	0	0	0	0	133	224	129	69	12.4	10	40	5	16.2	281	13
2077	170	155	143	237	138	72	13.0	3880	2862	13921	0	0	0	0	143	237	138	72	13.0	10	40	6	16.8	281	13
2087	180	151	153	248	146	73	13.6	4215	3097	15044	0	0	0	0	153	248	146	73	13.6	10	38	7	17.2	281	13
2097	190	148	162	259	154	75	14.2	4521	3312	16190	0	0	0	0	162	259	154	75	14.2	10	37	8	17.4	281	13
2107	200	144	171	269	161	76	14.8	4818	3544	17264	0	0	0	0	171	269	161	76	14.8	0	0	0	17.7	281	12

What happened between 2047 and 2057?

Forest Growth Model Systems: FVS Output



This simulation included:

Rx fire in 2050 under very dry conditions

Salvage in 2051 of hard and soft snags

FVS: A Walkthrough Example

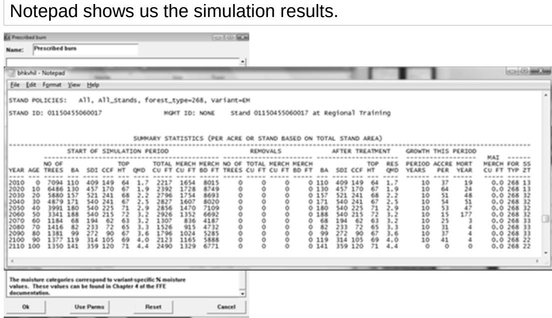
Data can be inputted into FVS using an Access template or more usually by manually entered PLOT and STAND level data into the FVS data file.

FVS: A Walkthrough Example

One data is entered, the simulation stand is selected. The default growth period in FVS in 100 years at 10 year intervals. Pressing the "Select Management" button shows you some options.

FVS: A Walkthrough Example

Lets select a prescribed burn in 2060 under humid summer conditions (hot and moist) and light winds. Viewing the .out file in Notepad shows us the simulation results.



Forest Growth Model Systems: Biome BGC

Biome BGC is a process model that can predict fluxes of carbon, energy, and water in the vegetation and soil

Advantages: Accounts for a wide range of physical and biological processes. As such can be applied to any species in any location; and adaptable to climate changes

Disadvantages: Required measurements more difficult to obtain. Although models "How" the plants grow – does not directly provide measures useful to forest managers – such as available timber for harvest, amount lost in fire, etc

Biome BGC will be covered in detail in FOR 330

Stand Growth: Stand Table Prediction

Growth projections according to DBH class:

- Develop stand table by DBH class

- Determine past growth via corers or past inventories

DBH Class (in)	Present Stand (stem count)	Expected Mortality (%)	Expected Survival (stems)	10-year DBH Growth (in)
6	522	40	313	2.2
8	352	35	229	2.3
10	179	25	134	2.4
12	88	20	70	2.2
14	40	15	34	2.4
16	11	10	10	2.6
18	10	10	9	2.1
20+	8	20	6	1.8
Total	**1210**		**805**	

Stand Growth: Stand Table Prediction

Growth projections according to DBH class:

- Apply past diameter growths to current stand table and estimate mortality and ingrowth

- Periodic stand growth = Volume of future stand - Volume of present stand

DBH Class (in)	Present Stand (stem count)	Expected Mortality (%)	Expected Survival (stems)	10-year DBH Growth (in)
6	522	40	313	2.2
8	352	35	229	2.3
10	179	25	134	2.4
12	88	20	70	2.2
14	40	15	34	2.4
16	11	10	10	2.6
18	10	10	9	2.1
20+	8	20	6	1.8
Total	**1210**		**805**	

Stand Growth: Producing Future Stand Tables

Need to account for “upward movement” of trees into higher DBH brackets

Growth-index Ratio = Diameter Growth / DBH increment = 2.2 / 2 = 1.10

DBH Class (in)	Present Stand (stem count)	Expected Mortality (%)	Expected Survival (stems)	10-year DBH Growth (in)
6	522	40	313	2.2
8	352	35	229	2.3
10	179	25	134	2.4
12	88	20	70	2.2
20+	8	20	6	1.8
Total	**1210**		**805**	

What This Means: 100% of the trees move up 1 DBH bracket and 10% move up two DBH brackets!

Stand Growth: Producing Future Stand Tables

Based off stem count and DBH the current and future volumes can be predicted

DBH Class (in)	Present Stand (stem count)	Growth-index Ratio (g/i)	# DBH brackets stems moving by: None	One	Two	Future Stem Count
6	313	1.10	0	282	31	0
8	229	1.15	0	195	34	282
10	134	1.20	0	107	27	226
12	70	1.10	0	63	7	141
14	34	1.20	0	27	7	90
16	10	1.30	0	7	3	34
18	9	1.05	0	8	1	14
20	6	0.90	1	5	0	12
22	0	…	0	0	0	6
Total	**805**		**1**	**694**	**110**	**805**

Stand Growth: Stand Table Prediction

Limitations:

- Method is limited when mortality is high
- Best suited to un-even aged and low density stands

DBH Class (in)	Present Stand (stem count)	Expected Mortality (%)	Expected Survival (stems)	10-year DBH Growth (in)
6	522	40	313	2.2
8	352	35	229	2.3
10	179	25	134	2.4
12	88	20	70	2.2
14	40	15	34	2.4
16	11	10	10	2.6
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Total	**1210**		**805**	