11.0 Assessing Stand Growth & Yield (to quantify its nature)

Only PAST growth of trees & stands can be measured directly – future growth must be predicted (projected / estimated / extrapolated).

Yield of standing trees is measured by recording age and the variable of interest at a single point in time

- Easily accomplished by installing and measuring TSPs (Temporary Sample Plots)

Growth measurement is more problematic

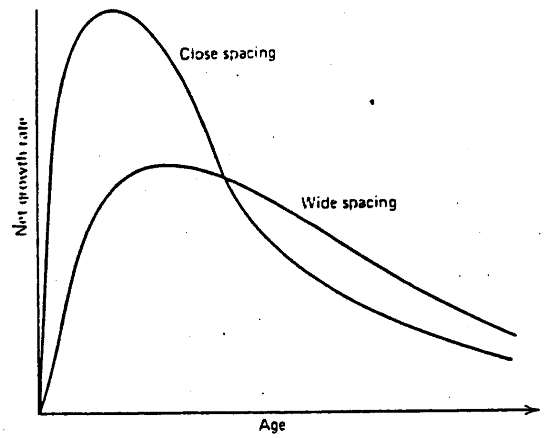
- DBH growth can be measured directly from increment cores
- Height growth can be measured in species that have distinct annual whorls
- Direct measurement of growth of any other variables at any single point in time requires destructive sampling of tree through stem analysis

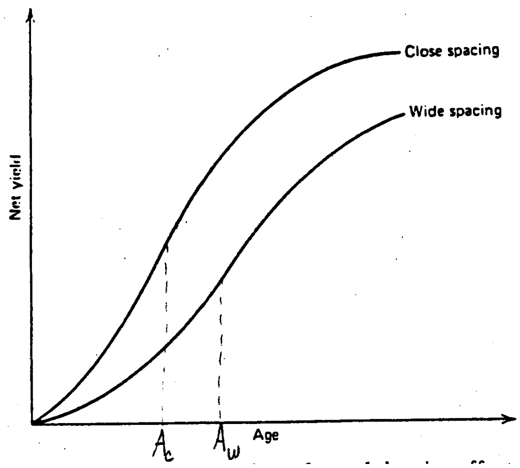
  (e.g., Kantavichai, R. 2012. Effect of climate and thinning on coastal Douglas-fir annual biomass growth at four sites. PhD Dissertation, SEFS, UW, Seattle, WA 98195).

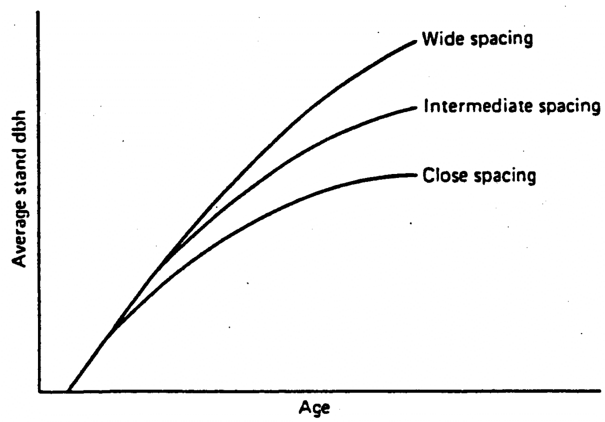
Monitoring becomes important for collecting the data necessary for growth estimation

- Growth of stands can be measured using PSPs (Permanent Sample Plots)
  - Large and expensive, usually located selectively or systematically, seldom randomly
  - Continuous Forest Inventory (CFI) plots are located systematically
  - Generally CFI plots make use of sub-plots (small trees, understory, etc.)
  - Many problems can occur:
    - Loss of plots (natural catastrophe, vandalism, harvest, …)
    - Loss of trees on plots
    - Missing measurements
  - Measurement interval depends on speed of change in stand
    - Typically 5 – 10 yr.
    - Information needed from PSPs must be anticipated

Ubiquitously observed, quasi-quantitative, general trends

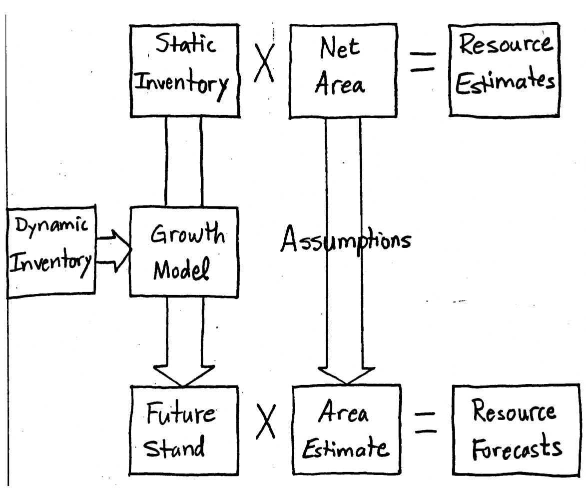






Estimating (extrapolating, projecting, predicting, forecasting) G & Y

Use past growth, present stand conditions & biological knowledge and assumptions to project growth



Two chief methodologies

1. Direct Methods

   Based on an analysis of a given stand from measured variables

   i) Total Stand Projection

   ii) Stand Table Projection

2. Indirect Methods

   Make use of growth or yield information from tables or equations based on stands OTHER than the given stand, but similar in constitution, composition, …

11.1 Components of Forest Growth

(Read: Beers, T.W. 1962. Components of forest growth. J. For. 60: 245 – 248, for complete treatment of the topic.)

Gross Growth - The difference in yield of living trees between the beginning (time 1) and end (time 2) of a defined time period (Y_2 - Y_1), less the yield from any ingrowth (I), plus the harvest (C) and mortality (M) that took place over the period. In equation form, it is expressed as

$$G_g = Y_2 - Y_1 - I + C + M$$ (*a.k.a. gross growth of initial volume*)

Net Growth - The difference in yield of living trees between the beginning and end of a period less ingrowth plus harvest. It equals gross growth less mortality. In equation form it is expressed as

$$G_n = Y_2 - Y_1 - I + C$$

MAI - Mean Annual Increment. The average growth rate (i.e., the average production) of a stand attribute over the course of its life (from age “0” to the present age). Expressed mathematically:

$$MAI_t = \frac{Y_t}{t}$$ (NOTE: MAI_t can be expressed as net or gross.)

Because

$$Y_t = \sum_{i=1}^{t} G_{ni},$$ then

$$Net\ MAI_t = \frac{\sum_{i=1}^{t} G_{ni}}{t}$$

$$Gross\ MAI_t = \frac{\sum_{i=1}^{t} \left(G_{ni} + M_i\right)}{t} = \frac{\sum_{i=1}^{t} G_{gi}}{t}$$

CAI - Current Annual Increment (yearly growth). Calculated as the difference in yield between two consecutive years or as the first derivative of a mathematical equation depicting yield as a function of time:

$$CAI_t = Y_t - Y_{t-1} = dY(t)/dt$$

11.2 Direct Methods of Growth Forecasting (Prediction): TSP & STP

Total Stand Projection

Recall the combined variable tree volume equation

$$v = f \cdot b \cdot h$$

where f = tree form factor
b = tree basal area
h = tree height

Similarly, pertains to the stand as well

$$V = \bar{f} \cdot B \cdot H$$

where $\bar{f}$ = stand average form factor
B = stand basal area
H = stand average height

Assuming the above, and letting 0 (zero) denote a past measurement, 1 denote current measurement, and 2 denote the future time for which an estimate is desired, then

$$\frac{V_2}{V_1} = \frac{\bar{f}_2 \cdot B_2 \cdot H_2}{\bar{f}_1 \cdot B_1 \cdot H_1}$$

Further assuming stand average form does not change much over reasonably short intervals, say 5 – 20 years (depending on stage of stand development), then

$$\frac{V_2}{V_1} = \frac{B_2 \cdot H_2}{B_1 \cdot H_1} \quad \Rightarrow \quad V_2 = V_1\left(\frac{B_2 \cdot H_2}{B_1 \cdot H_1}\right)$$ (a.k.a. the “two-way” method)

Prediction of stand basal area and stand height at time 2 (in the future) are the key

For basal area,

$$B_2 = B_1 + I_B$$

where I_B = predicted stand basal area Increment

$$\doteq B_1 \cdot \frac{G\%}{100} = B_1\left(\frac{QMD_1^2 - QMD_0^2}{QMD_1^2}\right) = B_1\left(\frac{\sum dbhib_1^2 - \sum dbhib_0^2}{\sum dbhib_1^2}\right)$$

For height,

$$H_2 = H_1 + I_H$$

where I_H = predicted stand Height Increment

$= H_1 - H_0$, for trees w/ determinant growth, or $\doteq H_{d_2} - H_{d_1}$, for those w/o

Calculated from direct observation in those species with distinct annual whorls or estimated from site curves for those species without

Stand Table Projection

Method creates future stand / stock tables from the current ones using actual past diameter growth

- Past performance may not be the best indicator of future growth, esp. if stand structure changes drastically due to natural or anthropomorphic disturbances
- Best results are achieved if projection period is 5 – 10 years at most
- Method deals with site / density implicitly
- Two different ways to predict how trees will grow
    - Like other trees that in the past were their size now (most realistic?)
    - Like they did in the past (most typical assumption)
- Three alternative methods for assigning increment to DBH classes
    - Apply average DBH increment to midpoint of the class – fails to account for dispersion of sizes within the class
    - Apply average DBH increment to trees in the class assuming they are uniformly distributed within the class – most commonly applied assumption (Growth Index Ratio, GIR method)
    - Apply variable diameter increment to actual diameters within the class

Example Stand Table Projection
(Direct method of growth prediction)

Understocked, immature ponderosa pine stand

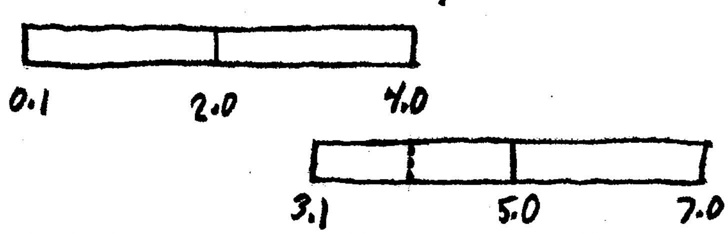
We desire stand information ten years hence

DBH class (in.)	initial #stems per ac.	Avg. 10-yr Inc.	GIR	movement			future stand table
				0 class	1 class	2 class	
2	20	3	0.75	5	15	0	5
6	12	4	1.00	0	12	0	15
10	8	3	0.75	2	6	0	14
14	4	1	0.25	3	1	0	9
18	0	-	-	0	0	0	1
Total	44						44

DBH class width is 4 inches

$$\text{Growth Index Ratio (GIR)} = \frac{\text{Avg. Inc.}}{\text{class width}}$$

for 2" class $GIR = \frac{3}{4} = 0.75$



11.3 Indirect Methods of Estimating Growth & Yield: Tables & Functions

Two methods

- Yield tables (equations)
- Computerized forest simulation models

Yield Tables

- Display stand conditions at various ages in tabular format
- Information varies considerably, but vol/acre is usually included
- Different tables for different species groups and site classes

The different types of yield tables available trace the history of the advancements in the field of G & Y

- Normal yield tables (McArdle, Meyer, and Bruce 1949, rev. 1961- “Bulletin 201”)
    - Stands fully utilizing the growing space (occupying the site)
    - Do not really portray historical development of any individual stand
    - Few stands in nature are truly Normal
    - Under certain assumptions can be used to predict growth & yield
- Empirical yield tables (Chambers and Wilson 1972)
    - Average conditions of stands across the landscape
    - Roughly the same advantages / disadvantages as Normal tables
- Variable-density yield tables (Buckman 1962. Growth & Yield of Red Pine in Minnesota. USDA Tech. Bulletin 1272)
    - Explicitly incorporate some measure of observed density into the prediction for yield (via mathematical equation) - adjusts yield estimates for density
- Managed stand yield tables (Curtis et al. 1981)
    - Predict yield in stands that have experienced some treatment
    - For ease of display and use, only a few regimes are included
    - Tables themselves are usually generated by mathematical equations (growth models)

Normal yield table-based growth & yield projections

The most typical assumption made is that growth in the observed stand is directly proportional to its normality percentage

Veracity of this assumption varies with species, age, site, density

TABLE 2.—*Yield tables for Douglas fir on fully stocked acre, total stand*

TOTAL NUMBER OF TREES

Age (years)	Site Class V		Site Class IV			Site Class III			Site Class II			Site Class I		
	Site index 80	Site index 90	Site index 100	Site index 110	Site index 120	Site index 130	Site index 140	Site index 150	Site index 160	Site index 170	Site index 180	Site index 190	Site index 200	Site index 210
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
20	6,920	5,500	4,150	3,069	2,324	1,815	1,460	1,210	1,012	880	756	654	571	490
30	2,700	2,200	1,800	1,472	1,219	1,030	865	735	640	555	483	408	350	300
40	1,530	1,275	1,090	927	798	680	585	510	445	385	335	282	240	203
50	1,050	890	764	659	572	496	430	377	331	290	248	208	176	150
60	780	670	580	500	439	380	337	296	261	228	195	164	138	116
70	625	537	468	405	352	310	274	242	214	186	160	135	113	95
80	525	455	394	345	303	266	232	207	182	159	136	115	97	81
90	451	398	347	304	266	235	205	180	158	138	118	100	84	71
100	403	352	311	271	239	209	184	161	142	123	106	89	75	64
110	362	319	281	247	217	188	166	146	128	111	95	81	69	58
120	331	292	259	224	197	173	152	134	116	101	87	74	63	53
130	305	271	240	209	184	161	141	124	108	94	80	69	59	49
140	284	252	224	195	171	149	131	115	101	88	75	64	55	45
150	266	238	211	184	160	141	123	108	95	82	71	60	51	42
160	250	225	200	175	152	133	117	102	90	78	67	57	48	40

DIAMETER OF AVERAGE TREE AT BREASTHEIGHT

Age (years)	Site index 80	Site index 90	Site index 100	Site index 110	Site index 120	Site index 130	Site index 140	Site index 150	Site index 160	Site index 170	Site index 180	Site index 190	Site index 200	Site index 210
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
20	1.3	1.5	1.8	2.2	2.6	3.0	3.4	3.8	4.2	4.5	4.9	5.3	5.7	6.2
30	2.6	3.0	3.4	3.9	4.4	4.9	5.5	6.0	6.5	7.0	7.6	8.3	9.0	9.8
40	3.8	4.4	4.9	5.5	6.1	6.8	7.4	8.0	8.7	9.4	10.2	11.2	12.2	13.3
50	4.9	5.6	6.3	7.0	7.7	8.5	9.3	10.1	10.9	11.8	12.8	14.0	15.3	16.7
60	6.0	6.8	7.6	8.5	9.3	10.2	11.1	12.0	12.9	14.0	15.2	16.6	18.2	19.9
70	7.0	7.9	8.8	9.8	10.8	11.8	12.8	13.8	14.8	16.0	17.5	19.1	20.9	22.8
80	7.9	8.9	9.9	10.9	12.0	13.1	14.3	15.4	16.6	17.9	19.6	21.3	23.3	25.5
90	8.7	9.7	10.8	11.9	13.1	14.3	15.6	16.9	18.2	19.6	21.4	23.3	25.6	28.0
100	9.4	10.5	11.6	12.8	14.2	15.5	16.9	18.2	19.7	21.2	23.1	25.1	27.6	30.1
110	10.1	11.3	12.4	13.7	15.2	16.6	18.0	19.5	21.0	22.6	24.6	26.9	29.4	32.2
120	10.7	11.9	13.2	14.6	16.1	17.6	19.1	20.7	22.3	24.0	26.1	28.5	31.1	34.2
130	11.3	12.5	13.9	15.3	16.9	18.5	20.1	21.7	23.5	25.3	27.5	30.0	32.7	36.0
140	11.9	13.1	14.5	16.0	17.7	19.4	21.1	22.8	24.5	26.5	28.8	31.4	34.3	37.8
150	12.4	13.7	15.1	16.7	18.4	20.2	22.0	23.8	25.6	27.7	30.0	32.8	35.8	39.4
160	12.9	14.2	15.7	17.4	19.1	21.0	22.8	24.7	26.6	28.9	31.2	34.1	37.2	41.0

TOTAL BASAL AREA

Age (years)	Site index 80	Site index 90	Site index 100	Site index 110	Site index 120	Site index 130	Site index 140	Site index 150	Site index 160	Site index 170	Site index 180	Site index 190	Site index 200	Site index 210
	Sq. ft.	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*
20	64	70	76	81	86	89	92	95	97	98	99	100	101	102
30	96	105	114	122	129	135	140	144	147	150	152	153	154	155
40	121	132	143	153	162	170	177	182	186	189	191	193	195	196
50	140	153	165	177	187	196	204	210	214	217	220	222	224	226
60	154	169	182	195	207	217	226	232	237	241	244	246	248	250
70	166	183	197	211	224	235	244	251	256	260	264	266	268	270
80	177	194	210	224	238	249	259	266	271	276	280	283	285	287
90	185	204	220	235	249	262	272	279	285	290	294	297	299	301
100	193	212	229	245	260	273	283	291	297	302	306	309	312	314
110	200	220	238	254	269	282	292	301	307	313	317	320	323	325
120	206	226	245	261	277	290	301	310	316	322	326	329	332	335
130	213	233	251	268	284	298	309	318	325	331	335	338	341	344
140	218	238	257	275	291	305	317	326	333	338	343	347	350	353
150	223	243	263	281	298	312	324	333	340	346	351	354	357	360
160	227	248	268	287	304	318	331	340	347	353	357	361	364	367

TOTAL YIELD IN CUBIC FEET

Age (years)	Site index 80	Site index 90	Site index 100	Site index 110	Site index 120	Site index 130	Site index 140	Site index 150	Site index 160	Site index 170	Site index 180	Site index 190	Site index 200	Site index 210
	Cu. ft.	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*
20	520	620	730	870	990	1,120	1,250	1,380	1,490	1,550	1,650	1,730	1,830	1,920
30	1,330	1,610	1,930	2,270	2,630	2,980	3,300	3,610	3,880	4,110	4,330	4,530	4,750	4,990
40	2,110	2,520	3,020	3,560	4,150	4,690	5,250	5,750	6,160	6,550	6,900	7,220	7,500	7,830
50	2,840	3,410	4,080	4,780	5,540	6,300	7,050	7,730	8,300	8,840	9,320	9,770	10,150	10,560
60	3,500	4,200	5,010	5,880	6,880	7,760	8,700	9,490	10,200	10,860	11,450	12,000	12,500	12,960
70	4,090	4,920	5,820	6,830	8,000	9,100	10,150	11,060	11,900	12,660	13,300	13,950	14,500	15,080
80	4,580	5,510	6,530	7,690	9,000	10,240	11,350	12,400	13,360	14,220	14,990	15,700	16,350	16,970
90	5,000	6,010	7,120	8,400	9,810	11,160	12,390	13,500	14,600	15,540	16,400	17,190	17,880	18,500
100	5,350	6,420	7,620	9,000	10,510	11,940	13,270	14,460	15,600	16,610	17,550	18,370	19,140	19,820
110	5,640	6,780	8,050	9,500	11,080	12,610	14,000	15,290	16,500	17,560	18,510	19,390	20,200	20,940
120	5,900	7,080	8,410	9,920	11,580	13,180	14,600	15,990	17,240	18,340	19,320	20,220	21,090	21,870
130	6,130	7,340	8,720	10,290	12,000	13,650	15,140	16,560	17,870	19,000	20,000	20,980	21,840	22,660
140	6,340	7,600	9,020	10,620	12,370	14,080	15,610	17,090	18,410	19,590	20,640	21,610	22,520	23,360
150	6,520	7,810	9,280	10,920	12,710	14,490	16,080	17,560	18,910	20,130	21,270	22,250	23,170	24,030
160	6,670	8,000	9,500	11,200	13,040	14,850	16,490	18,010	19,380	20,650	21,820	22,830	23,780	24,660

From: McArdle, R.E., W.H. Meyer, D. Bruce. 1930 (rev. 1949, 1961). The yield of Douglas fir in the Pacific Northwest. US Dept. Agriculture, Washington, D.C. Tech. Bull. 201. 74 p.

Example.

We have observed a 52-yr old stand of Douglas-fir with site index 140 ft at 100 years and 5,280 ft^3 of standing volume per acre. We desire an estimate of volume ten years from now at age 62.

Normal yield at age 52 (interpolated from Bulletin 201 Table 2): 7380 ft^3/acre.

$$\%Normality = \frac{5280}{7380}(100) = 71.5\%$$

Normal yield age 62 years (interpolated from Bulletin 201 Table 2): 8990 ft^3/acre.

Expected Normal $PAI_{52-62} = \frac{8990-7380}{10} = 161 ft^3 / acre\ per\ year$

Growth expected if it's proportional to current Normality percentage is

$$0.715 \times 161 ft^3 / acre / year = 115.1 ft^3 / acre / year$$

This corresponds to 1151 ft^3 of periodic growth in ten years

Thus, expected yield ten years hence (at age 62) is the sum of current yield and increment (or growth)

$$5280 ft^3 / acre + 1151 ft^3 / acre = 6431 ft^3 / acre$$

Table A Comparison of McArdle's 100-Year Table and King's 50-Year Table

Total Age	Site Index by McArdle (USDA Tech. Bulletin 201)													
	Class V		Class IV			Class III			Class II			Class I		
	80	90	100	110	120	130	140	150	160	170	180	190	200	210
YEARS	King's Site Index at 50 Years BH Age													
20	76	83	90	97	104	112	119	126	133	140	148	155	162	169
30	74	81	88	95	103	110	117	124	131	139	146	153	160	168
40	72	79	86	94	101	108	115	122	130	137	144	151	158	166
50	70	77	85	92	99	106	113	121	128	135	142	149	157	164
60	68	76	83	90	97	104	112	119	126	133	140	148	155	162
70	66	74	81	88	95	103	110	117	124	131	139	146	153	160
80	65	72	79	86	94	101	108	115	122	130	137	144	151	158
90	63	70	77	84	92	99	106	113	121	128	135	142	149	157
100	61	68	76	83	90	97	104	112	119	126	133	140	148	155
110	59	66	74	81	88	95	102	110	117	124	131	139	146	153
120	57	65	72	79	86	94	101	108	115	122	130	137	144	151
	CLASS V			CLASS IV			CLASS III			CLASS II			CLASS I	

TABLE 3.—*Yield tables for Douglas fir on fully stocked acre, trees 7 inches in diameter and larger*

NUMBER OF TREES

Age (years)	Site Class V		Site Class IV			Site Class III			Site Class II			Site Class I		
	Site index 80	Site index 90	Site index 100	Site index 110	Site index 120	Site index 130	Site index 140	Site index 150	Site index 160	Site index 170	Site index 180	Site index 190	Site index 200	Site index 210
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
20	0	0	0	0	0	0	7	45	76	99	119	134	148	160
30	0	0	31	82	121	165	199	220	235	246	254	255	247	235
40	70	124	173	217	250	278	292	298	300	288	269	245	218	192
50	170	220	261	290	311	322	318	302	282	259	231	201	173	148
60	234	276	306	326	322	308	291	269	244	218	190	162	137	116
70	275	305	322	316	299	279	255	231	207	183	158	134	113	95
80	298	318	312	296	275	250	225	202	179	157	136	115	97	81
90	304	307	295	274	250	224	200	177	156	137	118	100	84	71
100	301	293	276	252	229	204	182	160	141	123	106	89	75	64
110	292	278	259	235	210	186	165	145	128	111	95	81	69	58
120	279	263	243	218	193	171	152	134	116	101	87	74	63	53
130	267	250	229	204	181	159	141	124	108	94	80	69	59	49
140	256	237	216	192	169	149	131	115	101	88	75	64	55	45
150	245	227	205	182	160	141	123	108	95	82	71	60	51	42
160	235	217	196	173	152	133	117	102	90	78	67	57	48	40

DIAMETER OF AVERAGE TREE AT BREASTHEIGHT

Age (years)	Site index 80	Site index 90	Site index 100	Site index 110	Site index 120	Site index 130	Site index 140	Site index 150	Site index 160	Site index 170	Site index 180	Site index 190	Site index 200	Site index 210
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
20	0	0	0	0	0	0	7.3	7.5	7.7	7.9	8.1	8.3	8.5	8.7
30	0	0	7.4	7.6	7.8	8.0	8.3	8.6	8.8	9.1	9.4	9.7	10.2	10.7
40	7.6	7.8	8.1	8.4	8.7	9.0	9.3	9.7	10.1	10.5	11.1	11.8	12.7	13.6
50	8.1	8.4	8.7	9.1	9.5	9.9	10.4	11.0	11.6	12.3	13.1	14.2	15.4	16.8
60	8.6	9.0	9.4	9.9	10.5	11.1	11.7	12.4	13.3	14.2	15.4	16.7	18.2	19.9
70	9.1	9.6	10.1	10.7	11.5	12.3	13.1	14.0	15.0	16.1	17.5	19.1	20.9	22.8
80	9.6	10.1	10.8	11.6	12.5	13.4	14.4	15.5	16.6	17.9	19.6	21.3	23.3	25.5
90	10.0	10.7	11.5	12.5	13.5	14.6	15.7	16.9	18.2	19.6	21.4	23.3	25.6	28.0
100	10.5	11.3	12.2	13.3	14.4	15.6	16.9	18.2	19.7	21.2	23.1	25.1	27.6	30.1
110	10.9	11.9	12.9	14.0	15.3	16.6	18.0	19.5	21.0	22.6	24.6	26.9	29.4	32.2
120	11.4	12.4	13.5	14.8	16.2	17.6	19.1	20.7	22.3	24.0	26.1	28.5	31.1	34.2
130	11.9	12.9	14.1	15.5	16.9	18.5	20.1	21.7	23.5	25.3	27.5	30.0	32.7	36.0
140	12.4	13.5	14.7	16.1	17.7	19.4	21.1	22.8	24.5	26.5	28.8	31.4	34.3	37.8
150	12.8	13.9	15.3	16.8	18.4	20.2	22.0	23.8	25.6	27.7	30.0	32.8	35.8	39.4
160	13.2	14.4	15.8	17.4	19.1	21.0	22.8	24.7	26.6	28.9	31.2	34.1	37.2	41.0

BASAL AREA

Age (years)	Site index 80	Site index 90	Site index 100	Site index 110	Site index 120	Site index 130	Site index 140	Site index 150	Site index 160	Site index 170	Site index 180	Site index 190	Site index 200	Site index 210
	Sq. ft.	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*
20	0	0	0	0	0	0	2	14	26	34	42	50	59	67
30	0	0	10	26	42	58	74	88	100	112	122	131	139	146
40	22	43	63	84	106	124	141	154	165	174	181	186	190	194
50	60	86	109	133	154	172	186	198	206	213	217	221	224	226
60	95	124	148	171	190	206	218	227	234	239	243	245	248	250
70	124	152	177	197	215	229	240	248	254	259	263	266	268	270
80	148	174	196	216	233	247	257	264	271	276	280	283	285	287
90	165	190	212	231	248	261	271	279	285	290	294	297	299	301
100	178	203	224	242	259	272	283	291	297	302	306	309	312	314
110	189	213	234	252	268	281	292	301	307	313	317	320	323	325
120	199	222	243	200	277	290	301	310	316	322	326	329	332	335
130	207	229	250	267	284	298	309	318	325	331	335	338	341	344
140	213	236	256	274	291	305	317	326	333	338	343	347	350	353
150	219	242	263	281	298	312	324	333	340	346	351	354	357	360
160	225	248	268	287	304	318	331	340	347	353	357	361	364	367

YIELD IN CUBIC FEET

Age (years)	Site index 80	Site index 90	Site index 100	Site index 110	Site index 120	Site index 130	Site index 140	Site index 150	Site index 160	Site index 170	Site index 180	Site index 190	Site index 200	Site index 210
	Cu. ft.	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*
20	0	0	0	0	0	0	150	340	460	590	760	950	1,170	1,330
30	0	0	280	630	1,020	1,500	2,000	2,420	2,880	3,270	3,660	4,000	4,370	4,700
40	380	930	1,520	2,180	2,850	3,650	4,360	5,040	5,640	6,120	6,610	7,000	7,390	7,800
50	1,320	2,080	2,940	3,780	4,730	5,690	6,550	7,400	8,090	8,720	9,230	9,740	10,150	10,560
60	2,340	3,280	4,220	5,260	6,400	7,480	8,500	9,380	10,150	10,840	11,440	12,000	12,500	12,960
70	3,230	4,260	5,300	6,490	7,770	8,970	10,040	11,020	11,900	12,660	13,300	13,950	14,500	15,080
80	3,970	5,060	6,200	7,480	8,860	10,170	11,340	12,400	13,360	14,220	14,990	15,700	16,350	16,970
90	4,520	5,680	6,920	8,300	9,760	11,120	12,390	13,500	14,600	15,540	16,400	17,190	17,880	18,500
100	5,000	6,200	7,500	8,930	10,490	11,940	13,270	14,460	15,600	16,610	17,550	18,370	19,140	19,820
110	5,390	6,630	7,960	9,470	11,080	12,610	14,000	15,290	16,500	17,560	18,510	19,390	20,200	20,940
120	5,740	6,980	8,340	9,910	11,580	13,180	14,600	15,990	17,240	18,340	19,320	20,220	21,090	21,870
130	6,010	7,270	8,680	10,290	12,000	13,650	15,140	16,560	17,870	19,000	20,000	20,980	21,840	22,660
140	6,240	7,520	8,980	10,620	12,370	14,080	15,610	17,090	18,410	19,590	20,640	21,610	22,520	23,360
150	6,450	7,750	9,280	10,920	12,710	14,490	16,080	17,560	18,910	20,130	21,270	22,250	23,170	24,030
160	6,640	7,970	9,500	11,200	13,040	14,850	16,490	18,010	19,380	20,650	21,820	22,830	23,780	24,660

TABLE 3.—*Yield tables for Douglas fir on fully stocked acre, trees 7 inches in diameter and larger*—Continued

YIELD IN BOARD FEET, INTERNATIONAL RULE (1/8-INCH KERF)

Age (years)	Site Class V		Site Class IV			Site Class III			Site Class II			Site Class I		
	Site index 80	Site index 90	Site index 100	Site index 110	Site index 120	Site index 130	Site index 140	Site index 150	Site index 160	Site index 170	Site index 180	Site index 190	Site index 200	Site index 210
	Bd. ft.	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*
20	0	0	0	0	0	0	200	800	1,500	2,100	2,800	3,900	4,900	6,000
30	0	0	1,000	2,400	4,300	6,200	8,400	10,700	13,300	16,000	18,800	21,400	24,400	27,600
40	1,500	3,800	6,400	9,200	13,400	17,400	22,000	26,000	30,500	34,900	39,000	43,000	47,000	51,500
50	5,900	9,500	13,600	19,000	25,100	31,400	37,100	43,300	49,200	55,000	60,000	65,200	70,500	75,300
60	10,500	15,900	21,700	28,900	37,000	44,500	52,000	59,500	66,200	72,800	79,000	85,100	90,800	96,200
70	15,400	22,100	29,500	37,900	47,200	56,500	65,600	74,300	82,000	89,000	96,000	102,400	108,500	114,500
80	20,300	27,800	36,300	45,700	56,300	66,800	77,200	86,800	95,200	103,200	110,900	118,100	124,700	131,100
90	24,900	32,700	41,900	52,200	63,900	75,700	86,700	96,800	106,100	114,700	123,000	130,800	137,700	144,000
100	28,800	37,200	46,700	58,100	70,600	83,000	94,700	105,600	115,100	124,400	133,500	141,500	148,900	155,400
110	32,000	41,000	51,300	63,200	76,300	89,500	101,500	113,000	123,400	133,000	142,000	150,100	157,900	164,900
120	34,700	44,000	55,100	67,500	81,400	94,700	107,200	119,200	130,100	140,300	149,400	157,500	165,500	172,700
130	37,000	46,900	58,600	71,000	85,800	99,300	112,200	124,700	136,200	146,500	155,700	164,000	172,000	179,500
140	39,200	49,500	61,400	74,300	89,700	103,500	116,900	129,900	141,400	152,000	161,300	169,900	178,000	185,400
150	41,300	51,700	63,900	77,500	93,000	107,800	121,100	134,500	146,100	156,700	166,500	175,200	183,300	190,900
160	43,300	54,000	66,200	80,100	96,000	110,900	125,000	138,900	150,400	161,100	171,400	180,300	188,100	196,000

TABLE 4.—*Yield tables for Douglas fir on fully stocked acre, trees 12 inches in diameter and larger*

NUMBER OF TREES

Age (years)	Site Class V		Site Class IV			Site Class III			Site Class II			Site Class I		
	Site index 80	Site index 90	Site index 100	Site index 110	Site index 120	Site index 130	Site index 140	Site index 150	Site index 160	Site index 170	Site index 180	Site index 190	Site index 200	Site index 210
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
20	0	0	0	0	0	0	0	0	0	0	2	5	7	10
30	0	0	0	0	0	2	6	12	18	27	36	46	57	69
40	0	0	0	7	16	26	37	49	61	75	89	101	109	113
50	1	8	17	29	44	61	79	97	110	120	128	129	126	118
60	12	24	39	58	79	101	118	129	137	141	137	129	118	105
70	27	45	65	90	113	129	139	144	145	140	130	118	105	92
80	44	67	92	114	132	143	148	148	143	133	120	107	93	80
90	62	88	112	130	142	149	149	145	136	124	110	97	84	71
100	78	105	126	141	148	149	145	137	127	115	101	88	75	64
110	93	118	136	146	150	146	139	130	119	106	93	81	69	58
120	105	127	142	149	148	142	134	123	111	99	87	74	63	53
130	114	133	146	150	145	138	128	116	105	93	80	69	59	49
140	122	138	148	149	142	133	123	110	99	87	75	64	55	45
150	127	141	149	147	138	129	117	105	94	82	71	60	51	42
160	132	143	147	144	135	125	113	100	89	78	67	57	48	40

DIAMETER OF AVERAGE TREE AT BREASTHEIGHT

Age (years)	Site index 80	Site index 90	Site index 100	Site index 110	Site index 120	Site index 130	Site index 140	Site index 150	Site index 160	Site index 170	Site index 180	Site index 190	Site index 200	Site index 210
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
20	0	0	0	0	0	0	0	0	0	0	12.4	12.5	12.6	12.8
30	0	0	0	0	0	12.4	12.5	12.7	12.8	13.0	13.2	13.4	13.7	14.0
40	0	0	12.4	12.6	12.7	12.9	13.1	13.3	13.6	13.9	14.3	14.7	15.2	15.8
50	12.4	12.6	12.8	13.1	13.3	13.6	13.9	14.1	14.5	15.0	15.6	16.3	17.1	18.1
60	12.7	13.0	13.2	13.6	13.9	14.3	14.7	15.2	15.6	16.2	17.1	18.0	19.2	20.6
70	13.0	13.3	13.7	14.1	14.5	15.0	15.6	16.2	16.8	17.7	18.7	20.0	21.4	23.2
80	13.3	13.7	14.1	14.6	15.2	15.8	16.5	17.2	18.0	19.0	20.3	21.8	23.6	25.7
90	13.6	14.0	14.5	15.1	15.9	16.6	17.4	18.2	19.2	20.4	21.9	23.6	25.6	28.0
00	13.9	14.4	15.0	15.7	16.5	17.3	18.4	19.3	20.4	21.8	23.4	25.3	27.6	30.1
10	14.2	14.7	15.4	16.2	17.1	18.1	19.2	20.3	21.6	23.1	24.8	26.9	29.4	32.2
120	14.5	15.1	15.8	16.7	17.7	18.8	20.0	21.3	22.7	24.2	26.2	28.5	31.1	34.2
130	14.8	15.5	16.2	17.2	18.3	19.5	20.8	22.2	23.7	25.4	27.5	30.0	32.7	36.0
140	15.0	15.8	16.6	17.7	18.9	20.2	21.6	23.2	24.7	26.6	28.8	31.4	34.3	37.8
150	15.3	16.1	17.0	18.1	19.5	20.8	22.4	24.0	25.7	27.8	30.0	32.8	35.8	39.4
160	15.6	16.4	17.4	18.6	20.0	21.5	23.1	24.9	26.7	28.9	31.2	34.1	37.2	41.0

Computerized simulation models

- Model is a representation of a real-world system (an abstraction)
- Come in a variety of forms
  - May run the model yourself (DFSIM, ORGANON, LMS, etc.)
  - Maybe only yield tables are available to you (eg., TASS)
- PSP data is required from remeasured plots to develop these models
- Come in several varieties
  - Whole-stand models
    - Input is avg. stand info such as SI, age, density (TPA, SDI, etc.), avg. DBH
    - Output is the same
    - Advantages / disadvantages

      (+) Easy to use, easy to collect stand level info only

      (+) Simple to develop

      (-) Individual tree information is lacking
  - Size class models
    - Input: SI, age, density, coarse stand table
    - Output: Provide info on structure of the stand [though limited]
    - Compromise between whole-stand and single tree models
  - Single-tree (individual-based), distance-independent (spatially implicit)
    - Input: actual list of individual trees, their attributes, their Tree Factors
    - Output: detailed tree attributes & stand info (stand & stock tables)
    - Development requires PSP data with tagged trees, trees don't have to be stem-mapped
    - Trees of similar diameter are grown individually or in groups according to mathematical functions then "summed" to arrive at stand level info.
  - Single-tree, distance-dependent (spatially explicit)
    - Input: actual list of individual trees, their attributes, their Tree Factors, AND their spatial locations (stem map)
    - Output: detailed tree attributes & stand info (stand & stock tables)
    - Usually can also provide info on changes in competitive status of tree due to thinning, pruning, insect defoliation, etc.
    - Difficult to calculate a meaningful metric of spatially explicit, biological competition
    - Expensive to run
- Usually, developing a useful, realistic G & Y model is a time & labor intensive project

11.4 Assessing the Assessments

If a G & Y model is already available, it makes sense to assess how well it performs for the stand types under our management

Benchmarking

Comparing what a growth model predicted would happen with what actually happened

$$Error = G - \hat{G}$$

where $G =$ Actual Growth

$\hat{G} =$ Predicted Growth from growth model

This measure can be "swamped" by large differences on a few plots

$$Rel.Error = \frac{G - \hat{G}}{\hat{G}}(100)$$

Typically, the conclusion is to use the growth model when Relative Error is under 5 to 10%

When there are 2 or more models that could possibly be used, pick the one with the smallest Relative Error that is still under 5 to 10%.

Summary Ideas

Stand growth is usefully viewed as comprised of several parts: Measurable yield (Y) at two given points in time, Ingrowth (I), harvest (or cut, C), and mortality (M)

There are two chief ways to estimate growth & forecast yield of a stand: Direct & Indirect

Direct methods involve measuring at least one component of growth on the stand of interest, such as Total Stand Projection (TSP), and Stand Table Projection (STP);

Indirect methods rely on averages of many past observations in stands of similar nature to the one of interest, requiring only current yield estimates to make predictions, such as Yield Tables or Computerized Simulation models

Yield tables vary in complexity and utility; types include Normal, Empirical, Variable-density, and Managed-stand yield tables

Computerized simulation models also vary in complexity and utility for particular purposes; example types include, Whole-stand, Size-class, and Individual-tree (spatially implicit or spatially explicit)