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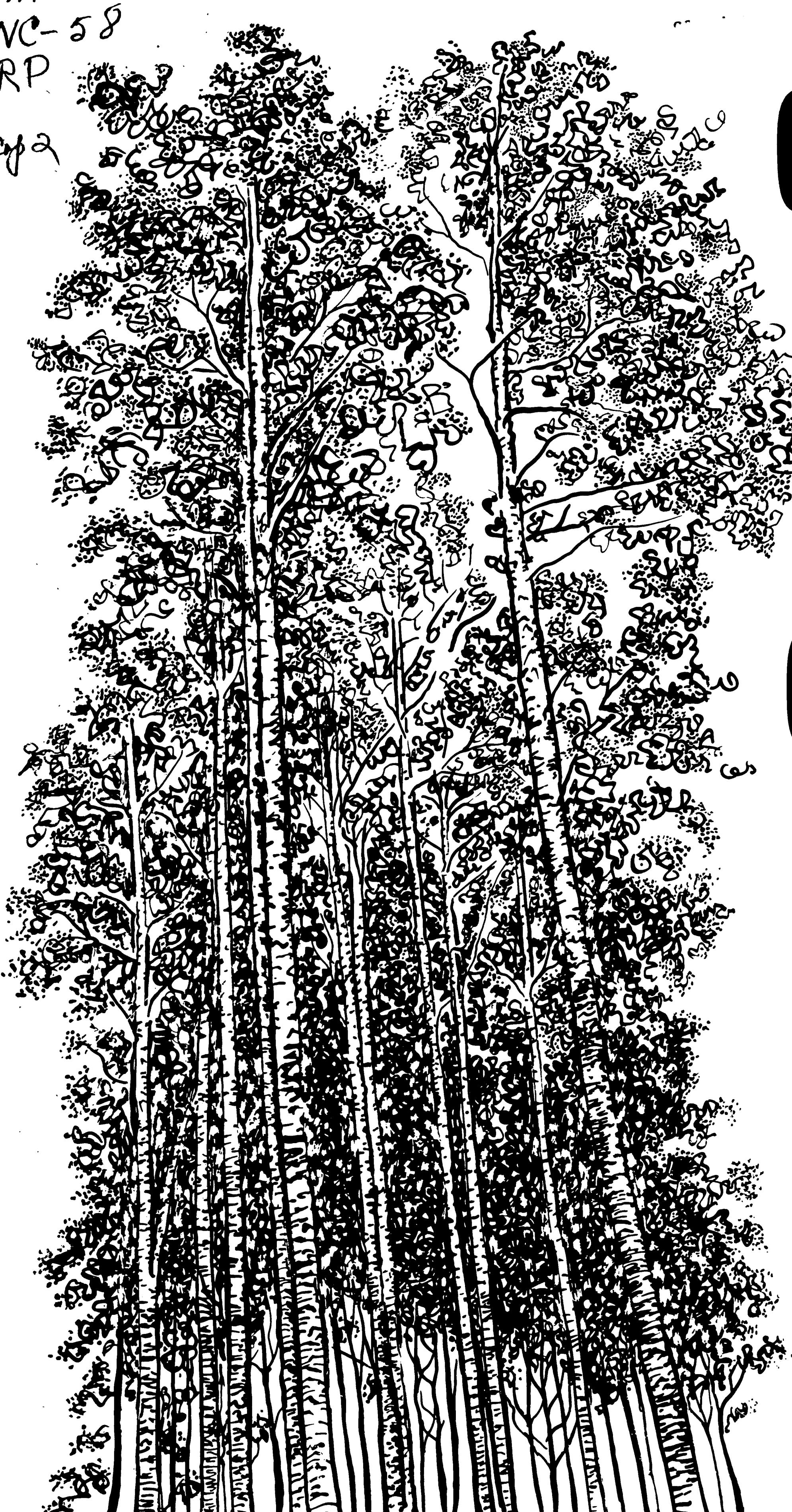

GROWTH and YIELD of QUAKING ASPEN IN NORTH-CENTRAL MINNESOTA

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GROWTH AND YIELD OF QUAKING ASPEN IN NORTH-CENTRAL MINNESOTA

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Quaking aspen (*Populus tremuloides*) (Michx.) is the predominant tree of the largest timber type in the Lake States, the aspen-birch type. This type occupies 6¼ million acres in Minnesota alone (Stone 1966), and 15½ million acres in the Lake States (Findell *et al.* 1960, Stone and Thorne 1961, Stone 1966). Growth and yield estimates of quaking aspen are an integral part of managing the aspen-birch type.

Yield information for Minnesota aspen is presently available in Gevorkiantz and Duerr's (1938) normal yield tables and Buckman's (1961) stand volume equations. Neither source, however, is fully adequate as an estimator of aspen growth and yield; Gevorkiantz and Duerr do not include stand basal area as a yield variable, and Buckman's equations are a composite for red and jack pine as well as aspen. Thus, new variable density growth and yield information is needed for aspen.

This paper presents recent growth and yield information from permanent sample plots in Minnesota. A total cubic-foot yield table for representative densities and heights is presented. Also included are merchantable yields to 3- and 5-inch top diameters as well as equations for predicting future stand basal area, diameter, and height.

METHODS AND PROCEDURES

The data, from three stand density studies in north-central Minnesota, include 34 permanent sample plots that were established in pure aspen stands 10, 20, and 30 years old. The stands were thinned initially to various basal area densities and were not thinned again. The trees range from 10 to 57 years of age, the stands from 20 to 140 square feet of basal area, and the site indexes from 66 to 90. The study area is relatively flat with medium-textured soils.

On each plot, all trees 0.6 inch d.b.h. and larger were measured and classified by crown class. In addition, sample trees were measured for total height. Total tree volumes were estimated from tables prepared by Gevorkiantz and Olsen (1955). Merchantable height was measured on an additional sample of 85 trees[1]. The plot data were then summarized and regression equations derived for total yield, merchantable yield, basal area growth, height growth, and diameter growth.

PREDICTING PRESENT YIELD

All volume yields were estimated in cubic feet inside bark. Total cubic-foot yield includes the entire stem volume of all trees over 0.5 inch d.b.h. A number of yield models reported in the literature were fitted to the data and the regression model finally chosen was:

$$Y = 0.41898\ (BH) \qquad (1)$$

where Y = the total stand cubic-foot yield per acre, inside bark,

B = total stand basal area in square feet per acre, and

H = average total height, in feet, of dominants and codominants.

The standard error of this ratio estimate is 0.00068. This equation, along with the site index curves of figure 1, was used to prepare table 1 (total cubic-foot yield).

Merchantable volume is expressed as a ratio of merchantable stand volume to total stand volume. The assumption is that as the average stand diameter increases, the proportion of merchantable volume will asymptotically approach some constant, the constant being less than 1 but approaching 1 as merchantability limits become smaller. The equations used to predict the merchantable volume ratios, derived by techniques suggested by Stevens (1951), are:

[1] *I would like to thank Boise Cascade Corporation of Minnesota for supplying data from 37 trees.*

Table 1.—Total yield per acre in tens of cubic feet, excluding bark, by total stand age, site index, and basal area density (all trees 0.6 inch d.b.h. and larger)

Total stand age (years)	Basal area per acre							
	20	40	60	80	100	120	140	160
SITE INDEX 65								
20	35	70	105	140	176	211	246	281
30	45	90	134	179	224	269	314	359
40	51	101	152	202	253	304	354	405
50	54	109	163	218	272	327	381	436
60	57	114	172	229	286	343	401	458
SITE INDEX 70								
20	38	76	113	151	189	227	265	302
30	48	97	145	193	241	290	338	386
40	55	109	164	218	273	327	382	436
50	59	117	176	235	293	352	411	469
60	62	123	185	246	308	370	431	493
SITE INDEX 75								
20	40	81	121	162	202	243	283	324
30	52	103	155	207	259	310	362	414
40	58	117	175	234	292	350	409	467
50	63	126	189	251	314	377	440	503
60	66	132	198	264	330	396	462	528
SITE INDEX 80								
20	43	86	130	173	216	259	303	346
30	55	110	165	221	276	331	386	441
40	62	125	187	249	312	374	436	499
50	67	134	201	268	335	402	469	536
60	70	141	211	282	352	422	493	563
SITE INDEX 85								
20	46	92	138	184	230	276	321	367
30	59	117	176	235	293	352	411	469
40	66	132	199	265	331	397	463	530
50	71	142	214	285	356	427	499	570
60	75	150	224	299	374	449	524	599
SITE INDEX 90								
20	49	97	146	194	243	292	340	389
30	62	124	186	248	310	373	435	497
40	70	140	210	281	351	421	491	561
50	75	151	226	302	377	452	528	603
60	79	158	238	317	396	475	554	633

$$V3/VT = 0.9858 - 5.4737\ (0.4876)^D \quad (2)$$
$$V5/VT = 0.9804 - 12.3277\ (0.57)^D \quad (3)$$

where V3/VT = ratio of merchantable stand volume (3-inch top) to total stand volume (merchantable volume above a 6-inch stump for all trees 3.6 inches d.b.h. and larger),

V5/VT = ratio of merchantable stand volume (5-inch top) to total stand volume (merchantable volume above a 6-inch stump for all trees 5.6 inches d.b.h. and larger), and

D = average stand diameter of all stems 0.6 inch d.b.h. and larger; i.e., the diameter of the tree of average basal area.

The first coefficient given in Equation 2 is the asymptotic constant that V3/VT approaches. Or, as the average stand diameter increases, the merchantable volume to a 3-inch top approaches 98.6 percent of the total volume. The same analogy is also true for Equation 3.

Tables 3 to 8, presented at the end of this paper, were prepared by substituting several stand diameters into Equations 2 and 3 and applying the resulting ratios to table 1.

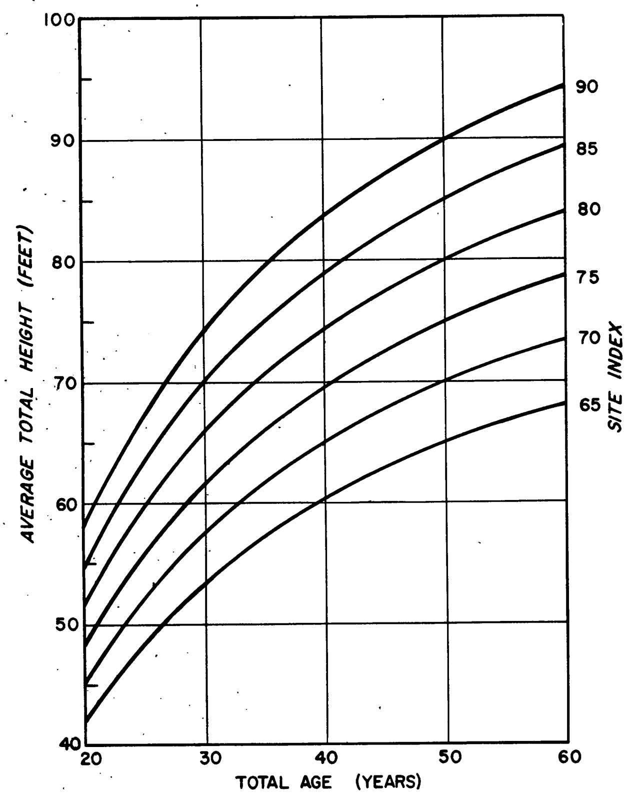

Figure 1.—Site index curves for quaking aspen in north-central Minnesota.

PREDICTING FUTURE YIELD

To predict future stand volume, future values of the stand basal area, average total height, and average diameter must be estimated. Ways of predicting these parameters were developed from the growth data.

Stand Basal Area

Total stand basal area for each measurement period was calculated by summing the basal areas of all trees 0.6 inch d.b.h. and larger. Net periodic annual growth is the difference between two successive basal area measurements divided by the number of years in the period. These growth values were then fitted to a model by Clutter (1963) and the resulting equation is:

$$BAG = B\ (5.3903 - \text{Ln}B)\,A^{-1} \quad (4)$$

where BAG = net periodic annual basal area growth in square feet per acre (table 2),

B = total stand basal area in square feet per acre,

A = total stand age in years, and

Ln = natural logarithm.

This equation accounts for 45.34 percent of the variation in BAG; the standard error is 1.01 about a mean of 2.72 square feet per acre per year. By using Equation 4, annual basal area increments can be obtained and summed to give periodic growth.

Future basal areas can be obtained by adding summations from Equation 4 to the present basal area. Or, considering future basal area as a projection in time of present basal area, integrating Equation 4 from initial stand age (A_i) to future stand age (A_f) gives:

$$B_f = \exp\,[5.3903 - A_i\,(5.3903 - \text{Ln}B_i)\,A_f^{-1}] \quad (5)$$

where exp = e — the base of the natural logarithms, and

B_i, B_f = initial and future stand basal area.

Table 2.—Net periodic annual basal area growth per acre per year by age and basal area

Total stand age (years)	Basal area per acre						
	20	40	60	80	100	120	140
	Square feet						
20	2.39	3.40	3.89	4.03	3.92	3.62	3.14
25	1.92	2.72	3.11	3.23	3.04	2.89	2.51
30	1.60	2.27	2.59	2.69	2.62	2.41	2.09
35	1.37	1.94	2.22	2.30	2.24	2.07	1.79
40	1.20	1.70	1.94	2.02	1.96	1.81	1.57
45	1.06	1.51	1.73	1.79	1.74	1.61	1.40
50	0.96	1.36	1.56	1.61	1.57	1.45	1.26
55	0.87	1.24	1.41	1.47	1.43	1.32	1.14

Stand Height

Future stand height is commonly estimated from a set of site index curves. Gevorkiantz' (1956) harmonized site index curves developed from temporary plot data were inadequate to show the actual height growth of trees in this study. Therefore, a new set of site index curves were developed (fig. 1) from the measured height growth on the permanent sample plots. Although the data are from a restricted area, the curves represent height growth from repeated measurements and are therefore believed to be more reliable than those prepared from single tree measurements. Additional testing is required to determine their reliability in other areas.

Bruce and Schumacher's (1950) technique was used to construct the curves. The guide equation is:

$$\text{LnH} = 4.5338 - 14.6111\ (A^{-1}) \qquad (6)$$

where H = total tree height in feet, dominants and codominants only, and

A = total tree age in years.

Bruce and Schumacher suggest that if the coefficient of variation of tree height increases with age, then the site index curves should be adjusted to take this into account. Plotting coefficient of variation over age showed that no trend existed and that the coefficient of variation could be considered constant over age. Thus, no adjustment in the curves is necessary.

Because site curves represent height growth, future height can be found by following the curve to the desired age and reading the corresponding height. Future stand height can also be computed by the equation:

$$H_f = H_i \bullet \exp\,[14.6111\ (A_i^{-1} - A_f^{-1})] \qquad (7)$$

where H_i, H_f = initial and future total stand height, and

A_i, A_f = intial and future total stand age.

Stand Diameter

The preceding methods of predicting future stand basal area and height will enable the user to estimate future stand volume using Equation 1. In order for Equations 2 and 3 to be used for estimating future merchantable volume, the method of projecting average stand diameter will also be needed.

The relationship between average stand diameter and age was found, by means of a scatter diagram, to be linear. This relationship can be estimated by the equation:

$$\text{Average DBH} = 0.5305 + 0.1841\ (\text{Age}), \qquad (8)$$

which gives the average stand diameter that can be expected for the average site index and stand density. However, Equation 8 is not to be used to estimate average stand diameter from a given stand age, but is presented as a basis for predicting future stand diameter, given an initial value. From equation 8 the average stand diameter is increasing at a rate of 0.1841 inch per year. Therefore, future stand diameter (DBH_f) can be estimated from Equation 9 if the initial stand diameter (DBH_i) is known:

$$DBH_f = 0.1841\ (A_f - A_i) + DBH_i. \qquad (9)$$

ACCURACY OF EQUATIONS

Accuracy of the total stand volume estimate from table 1 for a known stand age, stand basal area, and site index, is dependent upon the accuracy of Equation 1. The standard error of Equation 1 is 0.00068 or $\pm$ 0.317 percent at the 95-percent confidence level.

Predicting future stand volume is more variable because it is dependent on predicting stand basal area and height growth. The standard error of the annual basal area growth equation is 1.01, or 37 percent of the mean. Additional error in predicting height growth also influences the accuracy. The errors involved in projecting stand volume ahead for long periods of time should be easily recognized.

DISCUSSION

The preceding sections have presented equations for predicting present and future stand volumes. The user should keep the following things in mind when extrapolating values presented in this paper.

First, all of the data are from pure, thinned aspen stands. Second, the study area is geographically limited. The plots are located on or near the Pike Bay Experimental Forest in north-central Minnesota, thus the range of site conditions is small. Third, aspen has large genetic variability. This means that growth patterns may differ greatly from stand to stand. No attempt was made to quantify clonal differences in this study, although some clonal variation was noted.

The question now arises as to the applicability of the information in this paper to natural stands of either pure or mixed aspen. Tests have indicated there should be no problem utilizing this information in pure, natural stands. However, when projecting basal area over long periods (over 15 years), it should be realized that longer projections result in greater estimation errors. The yield information presented here should have utility for the aspen component of mixed stands. However, use of the growth equations in mixed stands is not recommended.

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Table 3.—Merchantable yield in tens of cubic feet, excluding bark, to a 3-inch top inside bark, by age, site index, and basal area density, when average stand diameter is 6 inches (all trees 3.6 inches d.b.h. and larger)

Total stand age (years)	Basal area per acre							
	20	40	60	80	100	120	140	160
SITE INDEX 65								
20	32	64	96	128	161	192	224	256
30	41	82	122	163	204	245	286	327
40	47	92	139	184	231	277	323	369
50	49	99	149	199	248	298	347	398
60	52	104	157	209	261	313	366	418
SITE INDEX 70								
20	35	69	103	138	172	207	242	275
30	44	88	132	176	220	264	308	352
40	50	99	150	199	249	298	348	398
50	54	107	161	214	267	321	375	428
60	57	112	169	224	281	337	393	450
SITE INDEX 75								
20	36	74	110	148	184	222	258	295
30	47	94	141	189	236	283	330	378
40	53	107	160	213	266	319	373	426
50	57	115	172	229	286	344	401	459
60	60	120	181	241	301	361	421	482
SITE INDEX 80								
20	39	78	119	158	197	236	276	316
30	50	100	150	202	252	302	352	402
40	57	114	171	227	285	341	398	455
50	61	122	183	244	306	367	428	489
60	64	129	192	257	321	385	450	513
SITE INDEX 85								
20	42	84	126	168	210	252	293	335
30	54	107	161	214	267	321	375	428
40	60	120	181	242	302	362	422	483
50	65	130	195	260	325	389	455	520
60	68	137	204	273	341	409	478	546
SITE INDEX 90								
20	45	88	133	177	222	266	310	355
30	57	113	170	226	283	340	397	453
40	64	128	192	256	320	384	448	512
50	68	138	206	275	344	412	482	550
60	72	144	217	289	361	433	505	577

Table 4.—Merchantable yield in tens of cubic feet, excluding bark, to a 3-inch top inside bark, by age, site index, and basal area density, when average stand diameter is 8 inches (all trees 3.6 inches d.b.h. and larger)

Total stand age (years)	Basal area per acre							
	20	40	60	80	100	120	140	160
SITE INDEX 65								
20	34	68	102	136	170	204	238	272
30	44	87	130	173	217	260	304	348
40	49	98	147	196	245	294	343	392
50	52	106	158	211	263	317	369	422
60	55	110	166	222	277	332	388	443
SITE INDEX 70								
20	37	74	109	146	183	220	257	292
30	46	94	140	187	233	281	327	374
40	53	106	159	211	264	317	370	422
50	57	113	170	227	284	341	398	454
60	60	119	179	238	298	358	417	477
SITE INDEX 75								
20	39	78	117	157	196	235	274	314
30	50	100	150	200	251	300	350	401
40	56	113	169	227	283	339	396	452
50	61	122	183	243	304	365	426	487
60	64	128	192	256	319	383	447	511
SITE INDEX 80								
20	42	83	126	167	209	251	293	335
30	53	106	160	214	267	320	374	427
40	60	121	181	241	302	362	422	483
50	65	130	195	259	324	389	454	519
60	68	136	204	273	341	408	477	545
SITE INDEX 85								
20	45	89	134	178	223	267	311	355
30	57	113	170	227	284	341	398	454
40	64	128	193	257	320	384	448	513
50	69	137	207	276	345	413	483	552
60	73	145	217	289	362	435	507	580
SITE INDEX 90								
20	47	94	141	188	235	283	329	377
30	60	120	180	240	300	361	421	481
40	68	136	203	272	340	408	475	543
50	73	146	219	292	365	438	511	584
60	76	153	230	307	383	460	536	613

Table 5.—Merchantable yield in tens of cubic feet, excluding bark, to a 3-inch top inside bark, by age, site index, and basal area density, when average stand diameter is 10+ inches
(all trees 3.6 inches d.b.h. and larger)

Total stand age (years)	Basal area per acre							
	20	40	60	80	100	120	140	160
SITE INDEX 65								
20	34	69	103	137	173	207	242	276
30	44	88	132	176	220	264	308	353
40	50	99	149	198	248	299	348	398
50	53	107	160	214	267	321	374	428
60	56	112	169	225	281	337	394	450
SITE INDEX 70								
20	37	75	111	148	186	223	260	297
30	47	95	142	190	237	285	332	379
40	54	107	161	214	268	321	375	428
50	58	115	173	231	288	346	404	461
60	61	121	182	242	302	363	423	484
SITE INDEX 75								
20	39	80	119	159	198	239	278	318
30	51	101	152	203	254	304	355	407
40	57	115	172	230	287	344	402	459
50	62	124	186	246	308	370	432	494
60	65	130	194	259	324	389	454	518
SITE INDEX 80								
20	42	84	128	170	212	254	298	340
30	54	108	162	217	271	325	379	433
40	61	123	184	245	306	367	428	490
50	66	132	197	263	329	395	461	526
60	69	138	207	277	346	414	484	553
SITE INDEX 85								
20	45	90	136	181	226	271	315	360
30	58	115	173	231	288	346	404	461
40	65	130	195	260	325	390	455	520
50	70	139	210	280	350	419	490	560
60	74	147	220	294	367	441	515	588
SITE INDEX 90								
20	48	95	143	191	239	287	334	382
30	61	122	183	244	304	366	427	488
40	69	137	206	276	345	413	482	551
50	74	148	222	297	370	444	518	592
60	78	155	234	311	389	466	544	622

Table 6.—Merchantable yield in tens of cubic feet, excluding bark, to a 5-inch top inside bark, by age, site index, and basal area density, when average stand diameter is 6 inches (all trees 5.6 inches d.b.h. and larger)

Total stand age (years)	Basal area per acre							
	20	40	60	80	100	120	140	160
SITE INDEX 65								
20	20	39	59	78	98	118	137	157
30	25	50	75	100	125	150	175	200
40	28	56	85	113	141	170	198	226
50	30	61	91	122	152	182	213	243
60	32	64	96	128	160	191	224	256
SITE INDEX 70								
20	21	42	63	84	105	127	148	169
30	27	54	81	108	134	162	189	215
40	31	61	92	122	152	182	213	243
50	33	65	98	131	163	196	229	262
60	35	69	103	137	172	206	240	275
SITE INDEX 75								
20	22	45	68	90	113	136	158	181
30	29	57	86	116	145	173	202	231
40	32	65	98	131	163	195	228	261
50	35	70	105	140	175	210	246	281
60	37	74	110	147	184	221	258	295
SITE INDEX 80								
20	24	48	73	97	121	145	169	193
30	31	61	92	123	154	185	215	246
40	35	70	104	139	174	209	243	278
50	37	75	112	150	187	224	262	299
60	39	79	118	157	196	235	275	314
SITE INDEX 85								
20	26	51	77	103	128	154	179	205
30	33	65	98	131	163	196	229	262
40	37	74	111	148	185	222	258	296
50	40	79	119	159	199	238	278	318
60	42	84	125	167	209	251	292	334
SITE INDEX 90								
20	27	54	81	108	136	163	190	217
30	35	70	104	138	173	208	243	277
40	39	78	117	157	196	235	274	313
50	42	84	126	169	210	252	295	336
60	44	88	133	177	221	265	309	353

Table 7.—Merchantable yield in tens of cubic feet, excluding bark, to a 5-inch top inside bark, by age, site index, and basal area density, when average stand diameter is 8 inches (all trees 5.6 inches d.b.h. and larger)

SITE INDEX 65

Total stand age (years)	Basal area per acre							
	20	40	60	80	100	120	140	160
20	30	59	89	118	148	178	207	237
30	38	76	113	151	189	227	265	303
40	43	85	128	170	213	256	298	341
50	46	92	137	184	229	276	321	368
60	48	96	145	193	241	289	338	386
SITE INDEX 70								
20	32	64	95	127	159	191	223	255
30	40	82	122	163	203	244	285	325
40	46	92	138	184	230	276	322	368
50	50	99	148	198	247	297	346	395
60	52	104	156	207	260	312	363	416
SITE INDEX 75								
20	34	68	102	137	170	205	239	273
30	44	87	131	175	218	261	305	349
40	49	99	148	197	246	295	345	394
50	53	106	159	212	265	318	371	424
60	56	111	167	223	278	334	389	445
SITE INDEX 80								
20	36	72	110	146	182	218	255	292
30	46	93	139	186	233	279	325	372
40	52	105	158	210	263	315	368	421
50	56	113	169	226	282	339	395	452
60	59	119	178	238	297	356	416	475
SITE INDEX 85								
20	39	78	116	155	194	233	271	309
30	50	99	148	198	247	297	346	395
40	56	111	168	223	279	335	390	447
50	60	120	180	240	300	360	421	481
60	63	126	189	252	315	379	442	505
SITE INDEX 90								
20	41	82	123	164	205	246	287	328
30	52	105	157	209	261	314	367	419
40	59	118	177	237	296	355	414	473
50	63	127	191	255	318	381	445	508
60	67	133	201	267	334	400	467	534

Table 8.—Merchantable yield in tens of cubic feet, excluding bark, to a 5-inch top inside bark, by age, site index, and basal area density, when average stand diameter is 10+ inches
(all trees 5.6 inches d.b.h. and larger)

Total stand age (years)	Basal area per acre							
	20	40	60	80	100	120	140	160
SITE INDEX 65								
20	33	66	98	131	165	197	230	263
30	42	84	125	168	210	252	294	336
40	48	95	142	189	237	285	331	379
50	51	102	153	204	255	306	357	408
60	53	107	161	214	268	321	375	429
SITE INDEX 70								
20	36	71	106	141	177	212	248	283
30	45	91	136	181	226	271	316	361
40	51	102	154	204	256	306	358	408
50	55	110	165	220	274	329	385	439
60	58	115	173	230	288	346	403	461
SITE INDEX 75								
20	37	76	113	152	189	227	265	303
30	49	96	145	194	242	290	339	388
40	54	110	164	219	273	328	383	437
50	59	118	177	235	294	353	412	471
60	62	124	185	247	309	371	432	494
SITE INDEX 80								
20	40	80	122	162	202	242	284	324
30	51	103	154	207	258	310	361	413
40	58	117	175	233	292	350	408	467
50	63	125	188	251	314	376	439	502
60	66	132	197	264	329	395	461	527
SITE INDEX 85								
20	43	86	129	172	215	258	300	344
30	55	110	165	220	274	329	385	439
40	62	124	186	248	310	372	433	496
50	66	133	200	267	333	400	467	534
60	70	140	210	280	350	420	490	561
SITE INDEX 90								
20	46	91	137	182	227	273	318	364
30	58	116	174	232	290	349	407	465
40	66	131	197	263	329	394	460	525
50	70	141	212	283	353	423	494	564
60	74	148	223	297	371	445	519	592

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As our Nation grows, people expect and need more from their forests — more wood; more water, fish, and wildlife; more recreation and natural beauty; more special forest products and forage. The Forest Service of the U.S. Department of Agriculture helps to fulfill these expectations and needs through three major activities:

- Conducting forest and range research at over 75 locations ranging from Puerto Rico to Alaska to Hawaii.
- Participating with all State forestry agencies in cooperative programs to protect, improve, and wisely use our Country's 395 million acres of State, local, and private forest lands.
- Managing and protecting the 187-million acre National Forest System.

The Forest Service does this by encouraging use of the new knowledge that research scientists develop; by setting an example in managing, under sustained yield, the National Forests and Grasslands for multiple use purposes; and by cooperating with all States and with private citizens in their efforts to achieve better management, protection, and use of forest resources.

Traditionally, Forest Service people have been active members of the communities and towns in which they live and work. They strive to secure for all, continuous benefits from the Country's forest resources.

For more than 60 years, the Forest Service has been serving the Nation as a leading natural resource conservation agency.