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PROCEDURES FOR ESTIMATING REDWOOD AND DOUGLAS FIR SITE INDEXES IN THE NORTH COASTAL REGION OF CALIFORNIA

by

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Abstract

Field procedures, stand components, and sample sizes necessary for various accuracy levels in estimating site index are detailed. Methods of converting site index estimates made under systems different than the ones currently considered to be most appropriate for the region are also described. In situations where sufficient sample site trees of a given species are unavailable, procedures for converting between redwood and Douglas fir site indexes are given. The use of alternative species is also examined.

I Introduction

This report details procedures and methods of estimating site index for redwood and Douglas fir in the North Coastal Region of California. The site curve basis used for redwood is that developed by Krumland and Wensel (1977). For Douglas fir, the curves developed by King(1966) are currently considered to be most appropriate(Krumland and Wensel,1976).

Both site curve systems use breast high age and total tree heights as part of the classification basis. Appendix I contains graphical, tabular, and mathematical descriptions of both site curve systems.

II Stand Components

Redwood site classification utilizes dominant redwood sprouts as the stand component for which site index is defined. Douglas fir site classification requires trees to be selected from the upper fifth of the diameter distribution of a stand. This component is comprised largely of dominants. (Ninety-two percent of the trees utlized by King in constructing the Douglas fir site curves were dominants).

Trees to be included in a site sample should be distributed over the entire area for which an estimate of site index is desired.

III Site Index Computations and Sampling Errors

Site index is the average height of trees in a specific stand component at a specified base age. When the ages of sample site trees are not coincident with the base age, site index must be estimated. Estimation procedures require site index estimates to be made for each tree in a site sample. The graphs, tables, and mathematical expressions listed in Appendix I can be used for this purpose. These individual estimates are then averaged to obtain an estimate of site index for the stand in question.

As with all sampling designed to provide estimates of a mean, the estimated site index is subject to sampling error. The number of sample site trees required to have the estimate of site index be within specified limits (expressed in feet of site index) of the estimated site index can be determined by the formula:

$$n = \frac{t^2_{1-\frac{\alpha}{2},n-1} \; S^2}{D^2}$$

where

n = number of sample site trees required
t = Student's 't' value corresponding to a probability level of $1-\alpha$ with n-1 degrees of freedom.
S = sample standard deviation
D = precision requirement expressed as the desired half width of the confidence interval.

Based on 153 redwood site samples and 143 Douglas fir site samples, sample standard deviations were found to average 11.3 when the average breast high age of sample site trees was less than twenty years and 8.3 for twenty years and greater. There were no significant differences between species. Using these values, table 1 shows the number of sample trees required at different probability levels for various precision requirements.

Table 1. Estimated number of sample trees needed to estimate site index within stated precision levels by average breast-high age group.

Desired half width of confidence interval (feet of site index)	95% probability (age group)		90% probability (age group)	
	20<	20+	20<	20+
5	22	13	15	9
10	7	5	5	4

While various suggestions have been made regarding the number of sample trees that should be taken, the principal mensurational use of site index is in predicting stand growth. Rational recommendations on the desired precision would therefore depend on how sensitive growth estimates are to changes in site index. Almost by definition, height growth is directly proportional to site index. Studies have shown that basal area and diameter growth are much less correlated with site index, after accounting for such items as density and age. Mortality has been found to be almost entirely uncorrelated with site index.

The overall impacts of the precision of site index estimates on estimated stand volume growth cannot at this time be reasonably quantified with any reliability. This item will be analyzed in more detail as growth model development progresses.

IV Conversions From Other Site Index Systems

For situations where site index estimates based on other site classification systems have already been made, tables were prepared to facilate conversions to the ones used in this report. The site classification systems commonly used in the region are those of Lindquist and Palley(1961) for redwood and McArdle's(1949) for Douglas fir. Both of these systems use different methods and stand components to determine site index than the systems proposed in this report. Hence, direct conversions between systems would not be totally accurate. However, attempts to develop direct regression relationships between site index systems of a given species indicated that functional specifications were probably a much greater source of error than those due to methodological differences in defining site index. Consequently, the following procedures were used.

Redwood site index - for a given site index under the Lindquist and Palley system, total height at a given age was used to determine the corresponding 50 year age base site index. These site indexes are listed in table 2. For example, if a redwood site index estimate of 160 was made with the Lindquist and Palley 100 year base age system and the average breast-high age of sample site trees was 60 years, the corresponding 50 year base age site index would be 106.

Douglas fir site index - Initially, as suggested by King(1966), King's site curves were adjusted to total age by adding the following years to breast high age

King's site class	years to breast height
135+	6
115-135	7
95-115	8
75- 95	9
75<	10

Next, as suggested by Staebler(1948), height in King's site index was reduced by the following amount to approximate the average heights of dominants and codominants

$$\text{Reduction} = 2.66 + .04(\text{height})$$

The procedures described under redwood conversions were then followed. The corresponding values are listed in table 3.

Table 2. Fifty year age base redwood site indexes corresponding to Lindquist and Palley sites at various breast-high ages.

Breast-high age of site trees when classified (years)	Lindquist and Palley site index (100 year base age)							
	100	120	140	160	180	200	220	240
	(fifty year base age site index)							
10	11	26	40	61	81	100	124	142
20	38	59	81	104	123	144	162	182
30	48	68	89	108	127	146	164	183
40	54	72	88	107	124	141	158	175
50	57	73	89	106	122	138	155	171
60	59	75	91	106	122	138	154	169
70	61	76	91	106	121	136	152	168
80	63	78	93	108	123	138	153	169
90	65	79	93	108	123	138	153	169
100	66	80	94	108	123	138	154	170

Table 3. Fifty year age base Douglas fir site indexes corresponding to McArdle's site indexes at various total ages.

Total age of site trees when classified (years)	McArdle site index (Bul. 201) (100 year age base)					
	100	120	140	160	180	200
	(fifty year age base site index)					
20	110	130	139	145	160	164
30	98	117	130	144	161	172
40	91	109	123	138	155	168
50	86	101	117	132	146	160
60	83	98	113	127	143	157
70	81	97	111	125	140	154
80	80	95	109	124	138	152
90	80	94	109	122	137	151
100	79	94	108	121	135	149

V. Relationships Between 50 Year Age Base Redwood and Douglas Fir Site Indexes

In instances where a sufficient number of redwood or Douglas fir sample site trees are unavailable, the site index of one species may be indirectly estimated from the site index of the other. Regression analysis of paired redwood-Douglas fir site index estimates from 123 growth plots in Del Norte, Humboldt, and Mendocino counties yielded the following estimation equations.

Redwood site = 46.5 +.465(Douglas fir site index)

$$R^2 = .29$$
$$s_{y \cdot x} = 14.3$$

Douglas fir site = 80.15 + .471(Redwood site index)

$$R^2 = .289$$
$$s_{y \cdot x} = 14.36$$

For each observation, site index estimates for each species were based on three to twelve trees. For both of these equations, the constant terms were significantly different from zero and the slope terms were significantly different from one at the one percent level of probability. Various transformations of both dependent and independent variables did not result in any significant reduction in the residual variance.

An extensive analysis of covariance was also made to see if these relationships were significantly different with respect to topography (flats and valley bottoms, slopes, and ridgetops), aspect(southern exposures, other exposures) and latitude(Del Norte and Humboldt county, Mendocino county). In no case were any significant differences found.

IV Use of Other Species

Information to adequately examine the correlations between redwood and Douglas fir site indexes and the age-height relationships of other species is currently unavailable. A small sample from 29 even-aged plots where the average heights of dominant white fir could be compared with average heights of dominant Douglas fir indicated that the difference in dominant heights between these two species was insignificant. Bruce(1923) also reported similar results. It would seem that if sufficient site sample trees of Douglas fir were unavailable, white fir could be reasonably substituted.

Literature cited

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Appendix 1

SITE INDEX GRAPHS, TABLES, AND EQUATIONS

Site Index Equations

Redwood

The redwood site index equation as reported by Krumland and Wensel(1977) is given by

$$H = a_1 S^{a_2} \left[1. - \left[1. - \left[\frac{S}{\left(a_1 S^{a_2} \right)} \right]^{\left(a_5 S^{a_6} \right)} \right] e^{\left\{ (A-50.) \left(a_3 S^{a_4} \right) \right\}} \right]^{\frac{1}{\left(a_5 S^{a_6} \right)}}$$

where

H = Total height of dominant redwood sprouts

A = Breast-high age

S = Site index (total height at a breast-high age of 50)

a_1 = 9.4366

a_2 = .68174

a_3 = -.0011842

a_4 = .46112

a_5 = .63885

a_6 = .14567

e = Base of the natural logarithms (2.7182)

$Q_1 = a_1 S^{a_2}$

$Q_3 = a_3 S^{a_4}$

$Q_5 = a_5 S^{a_6}$

$$H = Q_1 \left\{ 1 - \left[1 - \left(\frac{S}{Q_1} \right)^{Q_5} \cdot e^{(A-50) Q_3} \right\}^{\frac{1}{Q_3}}$$

Douglas fir

The Douglas fir site index equation as reported by King(1966) is given by

$$H = \frac{A^2}{a_1 + a_2A + a_3A^2} + 4.5$$

where

H = total height of site trees

$a_1 = -.954038+.109757(Z)$

$a_2 = (.0558178+.00792236(Z))$

$a_3 = (-.000733819+.000197693(Z))$

$Z = \frac{2500}{S-4.5}$

A = breast-high age in years

S = site index - 50 year age base

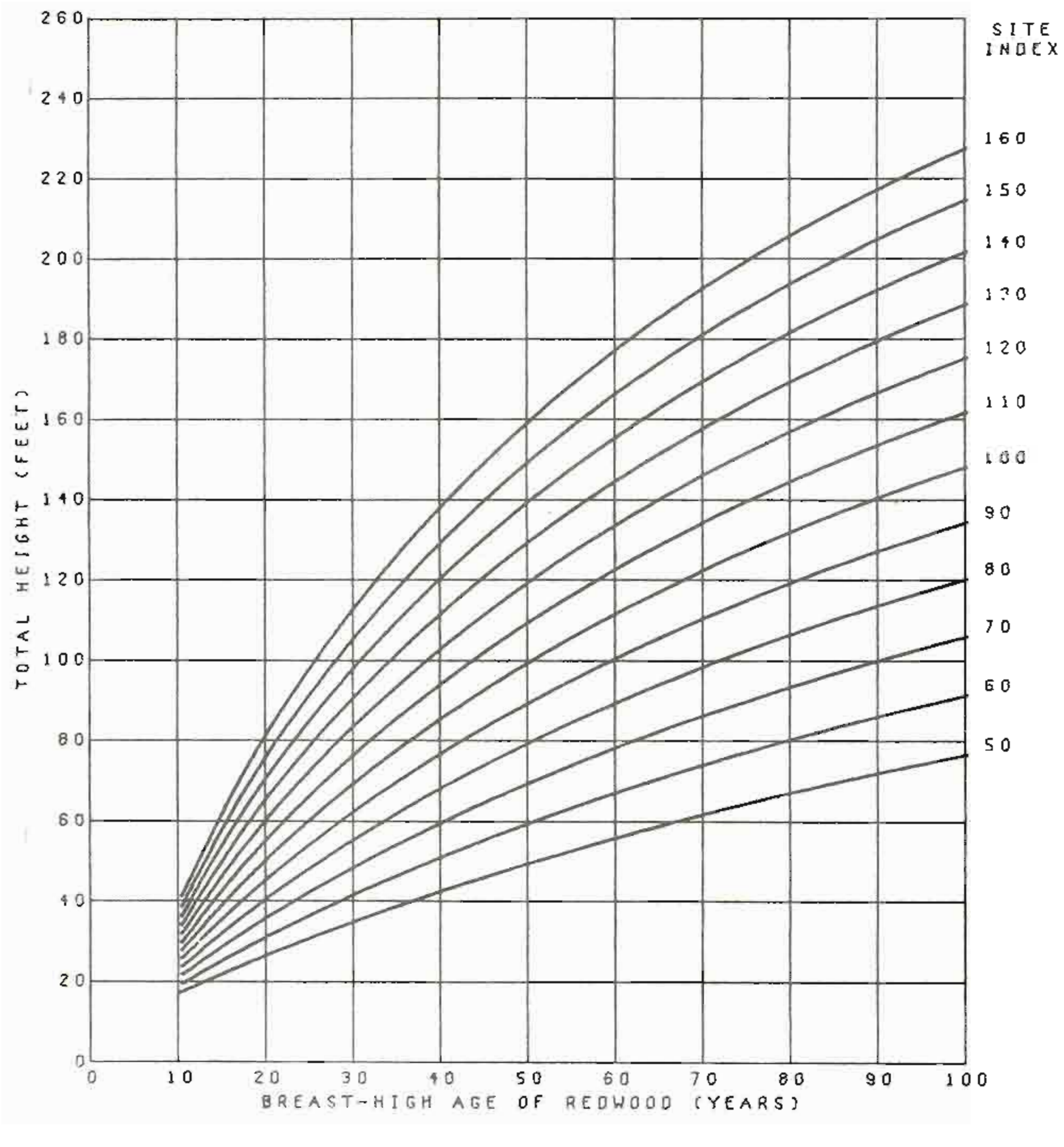

Figure 1. Fifty Year Age Base Site Index Curves for Dominant Young-Growth Redwood Sprouts.

Table 1. Average Total Heights of Dominant Redwood Sprouts by breast high age and site index.

BH	REDWOOD SITE INDEX											
AGE	50	60	70	80	90	100	110	120	130	140	150	160
10	17	20	22	24	26	28	30	32	34	37	39	42
12	19	22	25	28	30	33	36	39	42	45	48	51
14	21	25	28	31	35	38	41	45	48	52	56	60
16	23	27	31	35	39	43	47	51	55	59	63	68
18	25	30	34	38	43	47	51	56	61	66	70	75
20	27	32	37	41	46	51	56	61	66	72	77	83
22	29	34	39	45	50	55	61	66	72	78	84	89
24	30	36	42	48	53	59	65	71	77	83	90	96
26	32	38	44	50	57	63	69	76	82	89	95	102
28	34	40	47	53	60	67	73	80	87	94	101	108
30	35	42	49	56	63	70	77	84	92	99	106	114
32	37	44	51	59	66	73	81	88	96	104	111	119
34	39	46	54	61	69	77	85	92	100	108	116	124
36	40	48	56	64	72	80	88	96	104	113	121	129
38	42	50	58	66	75	83	91	100	108	117	126	134
40	43	52	60	69	77	86	95	104	112	121	130	139
42	44	53	62	71	80	89	98	107	116	125	134	143
44	46	55	64	73	83	92	101	110	120	129	138	148
46	47	57	66	76	85	95	104	114	123	133	142	152
48	49	58	68	78	88	97	107	117	127	136	146	156
50	50	60	70	80	90	100	110	120	130	140	150	160
52	51	62	72	82	92	103	113	123	133	143	154	164
54	53	63	74	84	95	105	116	126	136	147	157	167
56	54	65	75	86	97	108	118	129	139	150	161	171
58	55	66	77	88	99	110	121	132	142	153	164	175
60	56	68	79	90	101	112	123	134	145	156	167	178
62	58	69	80	92	103	114	126	137	148	159	170	181
64	59	70	82	94	105	117	128	139	151	162	173	184
66	60	72	84	95	107	119	130	142	153	165	176	187
68	61	73	85	97	109	121	133	144	156	167	179	190
70	62	75	87	99	111	123	135	147	158	170	182	193
72	63	76	88	101	113	125	137	149	161	173	184	196
74	64	77	90	102	115	127	139	151	163	175	187	199
76	65	78	91	104	116	129	141	153	166	178	190	201
78	67	80	93	105	118	131	143	156	168	180	192	204
80	68	81	94	107	120	133	145	158	170	182	194	206
82	69	82	95	108	121	134	147	160	172	184	197	209
84	70	83	97	110	123	136	149	162	174	187	199	211
86	71	84	98	111	125	138	151	164	176	189	201	214
88	72	85	99	113	126	139	152	165	178	191	203	216
90	72	87	100	114	128	141	154	167	180	193	205	218
92	73	88	102	116	129	143	156	169	182	195	207	220
94	74	89	103	117	131	144	158	171	184	197	209	222
96	75	90	104	118	132	146	159	172	186	199	211	224
98	76	91	105	119	133	147	161	174	187	200	213	226
100	77	92	106	121	135	149	162	176	189	202	215	228

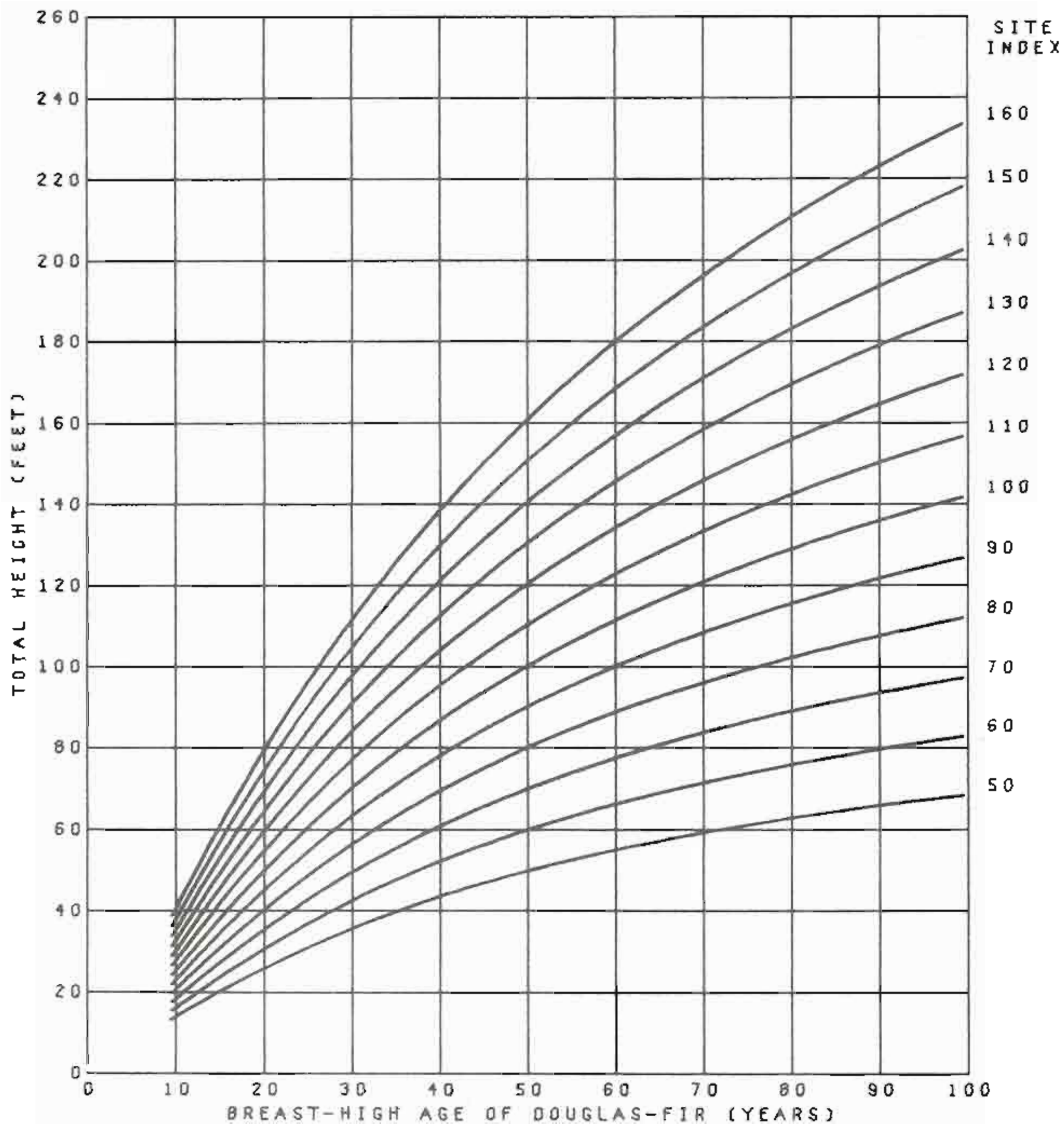

Figure 2. King's (1966) Site Index Curves for Douglas Fir.

Table 2. Average Total Heights of Douglas-Fir Trees by breast high age and site index.

BH AGE	Douglas-Fir Site Index - Base Age = 50 Yrs @ Breast Height											
	50	60	70	80	90	100	110	120	130	140	150	160
10	14	16	18	20	22	25	27	29	32	34	37	39
12	16	19	21	24	27	30	33	35	38	41	44	47
14	19	22	25	28	31	35	38	41	45	48	52	55
16	21	25	28	32	36	40	44	47	51	55	59	63
18	23	28	32	36	40	45	49	53	57	62	66	71
20	26	30	35	40	44	49	54	59	63	68	73	78
22	28	33	38	43	48	54	59	64	69	74	80	85
24	30	35	41	47	52	58	63	69	75	80	86	92
26	32	38	44	50	56	62	68	74	80	86	92	98
28	34	40	47	53	59	66	72	79	85	92	98	104
30	36	42	49	56	63	70	76	83	90	97	104	110
32	37	45	52	59	66	73	80	88	95	102	109	116
34	39	47	54	62	69	77	84	92	99	107	114	122
36	41	49	56	64	72	80	88	96	104	111	119	127
38	42	50	59	67	75	83	91	100	108	116	124	132
40	44	52	61	69	78	86	95	103	112	120	129	137
42	45	54	63	72	80	89	98	107	116	125	133	142
44	46	55	65	74	83	92	101	110	119	129	138	147
46	48	57	67	76	85	95	104	114	123	133	142	151
48	49	59	68	78	88	97	107	117	127	136	146	156
50	50	60	70	80	90	100	110	120	130	140	150	160
52	51	61	72	82	92	102	113	123	133	144	154	164
54	52	63	73	84	94	105	115	126	136	147	157	168
56	53	64	75	85	96	107	118	129	139	150	161	172
58	54	65	76	87	98	109	120	131	142	153	165	176
60	55	66	78	89	100	111	123	134	145	157	168	179
62	56	68	79	90	102	113	125	136	148	160	171	183
64	57	69	80	92	104	115	127	139	151	162	174	186
66	58	70	82	93	105	117	129	141	153	165	177	189
68	59	71	83	95	107	119	131	143	156	168	180	193
70	60	72	84	96	109	121	133	146	158	171	183	196
72	60	73	85	98	110	123	135	148	161	173	186	199
74	61	74	86	99	112	124	137	150	163	176	189	202
76	62	74	87	100	113	126	139	152	165	178	191	205
78	62	75	88	101	114	127	141	154	167	181	194	207
80	63	76	89	102	116	129	142	156	169	183	197	210
82	64	77	90	104	117	130	144	158	171	185	199	213
84	64	78	91	105	118	132	146	159	173	187	201	215
86	65	79	92	106	120	133	147	161	175	189	204	218
88	66	79	93	107	121	135	149	163	177	192	206	220
90	66	80	94	108	122	136	150	165	179	194	208	223
92	67	81	95	109	123	137	152	166	181	195	210	225
94	67	81	96	110	124	139	153	168	183	197	212	227
96	68	82	96	111	125	140	155	169	184	199	214	230
98	68	83	97	112	126	141	156	171	186	201	216	232
100	69	83	98	112	127	142	157	172	188	203	218	234