Appendix I
Examples of Rotation Selection

In Trinidad, provisional yield tables for teak *(Tectona grandis)* were developed based on 80 plots on two sites corresponding to mean heights of about 26 and 23 m at age 50 (Miller 1969b). The mean annual increment (MAI) decreased with age over 10 years (table I–1). *Pinus caribaea hondurensis* in Trinidad illustrates well the trends of current and mean annual increment (table I–2; Miller 1969a). The MAI rises continuously to 24 to 25 years of age.

The trend of MAI after age 20 has been documented for *P. merkusii* in Java (Alphen de Veer 1954). On good sites, it drops from 30 to 27 cubic meters per hectare per year between age 20 and 30. On mediocre sites, MAI continues to rise, from 20 to 21 m^3/ha/yr. On poor sites, the rise is more rapid, from 10 to 16 m^3/ha/yr. The implication is that on good sites growth is not only greater but also culminates earlier than on poor sites.

Yield trends of *Araucaria angustifolia* have been clarified by the development of yield tables based on numerous plantations in Brazil (Heinsdijk 1972). The effect of age on volume in plantations of 1,000 trees per hectare is shown in table I–3. The MAI occurs at about year 20 regardless of site. However, the peak is steepest on the best sites and relatively flat on the poor sites. Interestingly, Brazilian data indicate that MAI culminates at about the same age in plantations on the best sites stocked with either 600 trees per hectare (14.6 m^3) or 1,600 trees per hectare (928.6 m^3).

The wood-production potential of *A. angustifolia* was then derived from plantations where the number of trees ranged from 3,150 per hectare at age 8 to 730 per hectare at age 35 for site 3 (tree height at age 25: 10–14 m) (table I–4; Heinsdijk 1972). This table indicates that maximum annual production would be obtained with a

Table I–1.—Relation of age to growth and mean annual increment (MAI) for teak *(Tectona grandis)* in Trinidad

Age (yr)	No. of trees per hectare	Mean d.b.h. (cm)	Mean height (m)	MAI (m^3/ha/yr)
		Site I		
10	370	21	18	14
20	160	34	22	12
30	100	43	24	11
40	80	51	25	10
		Site II		
10	480	18	15	10
20	240	27	18	9
30	160	35	21	8
40	120	41	22	7

Source: Miller 1969b.

Table I–2.—Mean annual increment (MAI) of *Pinus caribaea hondurensis* in Trinidad as related to age and site quality

Age (yr)	No. of trees per hectare	Mean d.b.h. (cm)	Mean height (m)	MAI (m^3/ha/yr)
		Site I		
0	1,330			
10	490	23	18	14
15	370	31	23	17
20	300	37	26	19
25	230	44	28	20
		Site II		
0	1,330			
12	540	23	17	12
18	410	29	21	14
24	320	33	25	16

Source: Miller 1969a.

Table I–3.—Age/volume trends in *Araucaria angustifolia* plantations of 1,000 trees per hectare in Brazil (m^3/ha/yr)

Age (yr)	Site index[a] 18–22	14–18	10–14
10	14.1	4.9	3.3
15	19.3	9.4	4.5
20	20.7	10.0	4.8
25	20.5	10.0	4.8
30	19.7	9.6	4.6
35	18.7	9.1	4.4

Source: Heinsdijk 1972.
[a]Tree height in meters at age 25.

Table I–4.—Wood production potential of *Araucaria angustifolia* in Brazil

Age (yr)	No. of trees per hectare	Mean d.b.h. (cm)	Mean annual production per hectare	
			Pulpwood (steres[a])	Timber (m^3)
8	3,150	8	10.3	0
11	1,880	11	13.5	0
14	1,400	15	14.7	0
17	1,160	17	14.9	0
20	1,010	19	14.6	0
23	920	20	6.5	5.7
27	830	22	6.0	5.5
31	770	23	5.6	5.3
35	730	24	5.2	5.0

Source: Heinsdijk 1972.

[a]1 stere equals 1 stacked cubic meter.

rotation of about 17 years for pulpwood and about 23 years for timber. However, if larger diameters were wanted, a longer rotation apparently would not mean a large decline in yield.

Similar yield tables were derived for *Cunninghamia lanceolata* in Brazil (Heinsdijk 1972). Age/volume relations for plantations of 1,000 trees per hectare appear in table I–5. Again, the peaking of MAI occurs at about the same age regardless of site quality. Plantations of 1,600 trees per hectare on the best sites also culminate at age 15 (30.1 m^3). The decline in the means with longer rotations appears small, but the current annual growth from 15 to 20 years averages about 15 percent less than the mean up to that period.

Table I–5.—Age/yield trends with *Cunninghamia lanceolata* plantations of 1,000 trees per hectare in Brazil (m^3/ha/yr)

Age (yr)	Site index[a]		
	22–26	18–22	14–18
10	20.6	14.9	9.0
15	22.9	16.6	10.0
20	22.2	16.1	9.7
25	20.7	15.0	9.0
30	19.1	13.9	8.3
35	17.6	12.8	7.7

Source: Heinsdijk 1972.

[a]Tree height in meters at age 25.

The wood productivity potential of *C. lanceolata,* based on actual plantation densities, is shown for site indices 10 to 14 in table I–6 (Heinsdijk 1972). The yields of *C. lanceolata* are higher than those of *A. angustifolia* (table I–4) because of the greater tree density tolerated by *C. lanceolata,* resulting in more than twice as many trees at maturity.

Yield tables were also made for *Cryptomeria japonica* in Brazil (Heinsdijk 1972). Age/volume trends for plantations of 1,000 trees per hectare are summarized in table I–7. As with *Cunninghamia lanceolata,* the mean annual volume growth of *Cryptomeria japonica* may culminate at about age 15, or possibly even earlier. In plantations on the best sites with 1,600 trees per hectare, growth also culminates at about age 15 (25.7 m^3).

The wood-production potential of plantations of *C. japonica,* with the number of trees actually found on site indices 10 to 14 at each age, appears in table I–8 (Heinsdijk 1972). Great similarity between *C. japonica* in table I–8 and *Cunninghamia lanceolata* in table I–6 is apparent. A rational decision for a rotation for each would depend on these yield data as well as on information on the economics of tree size and carrying charges.

Yield tables for *Cupressus lusitanica* have been prepared from plantations in Piedras Blancas, Colombia (Falla 1968). Summarized in table I–9, they suggest a rotation

Table I–6.—Wood production potential of *Cunninghamia lanceolata* in Brazil

Age (yr)	No. of trees per hectare	Mean d.b.h. (cm)	Mean annual production per hectare	
			Pulpwood (steres[a])	Timber (m^3/ha)
8	2,430	11	15.1	0
11	2,160	14	18.3	0
14	2,020	15	19.1	0
17	1,930	17	18.9	0
20	1,870	17	18.3	0
23	1,830	18	6.6	8.1
27	1,790	18	6.1	7.6
31	1,760	19	5.6	7.1
35	1,740	19	5.2	6.7

Source: Heinsdijk 1972.
[a]1 stere equals 1 stacked cubic meter.

of about 20 years for maximum usable wood volume per unit of time.

Similar information has been developed for *Eucalyptus.* Yield data for *E. saligna* in Transvaal, South Africa, including stemwood under bark to a 7.6-cm limit, appear in table I–10 (Kotze 1961). These data suggest that the rotation for pulpwood might be longer than 10 years, unless trees then exceed the maximum diameter for chipping.

A record of a remarkably old *E. globulus* plantation in the Nilgiris Hills of India shows the capacity of old trees to sustain growth (Borota 1965). The data in table I–11 are based on a plot of 1.26 ha, which at age 91 had 58 trees per hectare, a basal area of 52 m^2/ha, and a volume of 992 m^3/ha. From age 91 to 99, the periodic annual basal-area growth was still as rapid as in the past, and the volume growth was 26 m^3/ha. At age 99, 10 trees selected at random averaged 72.1 m in height.

Table I–7.—Age/volume trends with *Cryptomeria japonica* plantations with 1,000 trees per hectare in Brazil (m^3/ha/yr)

Age (yr)	Site index[a]			
	22–26	18–22	14–18	10–14
15	19.7	13.8	9.1	5.3
20	19.1	13.4	8.8	5.0
25	17.8	12.5	8.2	4.8
30	16.4	11.5	7.6	4.4
35	15.2	10.7	7.0	4.1

Source: Heinsdijk 1972.
[a]Mean tree height in meters at age 25.

Early studies of nine species of *Eucalyptus* in Brazil spaced at 2.5 by 2.5 m showed that fuelwood production culminates early (table I–12). More recent yield tables for *Eucalyptus* in Brazil show prospective growth relative to age in much more detail (table I–13; Heinsdijk 1972). The MAI on all sites culminates at about age 12. This is also true for plantations with 1,800 trees per hectare on site index 20-24 (48.2 m^3).

A study of the growth of *E. deglupta* in Papua New Guinea suggests possible rotation lengths (Davidson 1968). Trees spaced at 4.6 by 4.6 m grew to a mean d.b.h. of 54 cm and a mean height of 44 m at age 15 (table I–14). From these data, it is predicted that at age 40 there would be 49 trees per hectare averaging 84 cm in d.b.h.

The use of multiple regressions to predict volumes and growth has greatly increased with the advent of electronic data processing. Examples are seen in the following regression derived for *Eucalyptus* in India (Chaturvedi 1973, 1976). The term r is the coefficient of correlation, d is the diameter, and ba is the basal area.

1. Tree volume (under bark) in cubic meters = 0.0201 d^2 (in centimeters) x top height (in meters) – 0.0015 (r = 0.99).

Table I–8.—Wood production potential of *Cryptomeria japonica* in Brazil

Age (yr)	No. of trees per hectare	Mean d.b.h. (cm)	Mean annual production per hectare	
			Pulpwood (steres[a])	Timber (m^3/ha)
8	2,680	9	14.6	0
11	2,290	12	17.5	0
14	2,090	13	18.1	0
17	1,960	15	17.8	0
20	1,890	16	17.1	0
23	1,830	17	6.5	7.4
27	1,780	17	6.0	6.9
31	1,740	18	5.6	6.4
35	1,710	18	5.2	6.0

Source: Heinsdijk 1972.

[a]1 stere equals 1 stacked cubic meter.

Table I–9.—Age/increment relations for *Cupressus lusitanica* in Colombia

Age (yr)	No. of trees per hectare	Mean d.b.h. (cm)	Volume (m^3/ha)	Mean annual increment (m^3/ha/yr)
10	3,350	9.3	119	11.9
20	1,415	22.3	401	20.1
30	610	36.3	496	16.5

Source: Falla 1968.

Table I–10.—Age/increment trends for *Eucalyptus saligna* in Transvaal, South Africa (m^3/ha)

Age (yr)	Mean annual increment	Next year's increment
2	12	40
4	27	90
6	53	120
8	71	120
10	81	

Source: Kotze 1961.

Table I–11.—Basal-area growth of old *Eucalyptus globulus* in India

Mean d.b.h. (cm) in 1954 at age 91	No. of trees per hectare	Annual basal area growth (cm^2)	
		Mean 1863–1954 Age 0–91	Periodic 1954–62 Age 91–99
70–94	17.5	61	65
94–117	27.0	94	86
117–144	10.3	146	166
144–180	3.2	216	305
Totals/means	**58.0**	**100**	**106**

Source: Borota 1965.

Table I–12.—Fuelwood production of *Eucalyptus* in Brazil

Age (yr)	Growth (m^3/ha/yr) Mean	Periodic
6	26.8	
		41
8	30.4	
		8
10	26.0	
		8
12	23.0	
		10
15	19.8	

Source: Guimaraes 1957.

2. Plantation volume (under bark to 5 cm in diameter) in cubic meters = 0.2869 × (*ba* [in m^2/ha] × top height [in meters]) – 2.5101 ($r = 0.98$).

3. Logarithm_n mean annual increment (in m^3/ha/yr) = 0.628 Log_n *ba* (in m^2/ha) + 2.467 Log_n top height (in meters) – 0.997 Log_n age (in years) – 4.580 ($r = 0.97$).

Volume-growth data on *Gmelina arborea* from Cebu, Philippines, from an unthinned, 0.2-ha plot planted at 2 by 2 m with an annual rainfall of 220 cm appear in table I–15 (Nanagas and Serna 1970). They suggest that,

Table I–13.—Age/volume trends in *Eucalyptus* plantations of 1,000 trees per hectare in Brazil

Age (yr)	Mean annual volume increment by site index[a] (m^3/ha/yr) 24–28	20–24	16–20	12–16
4	26.0	17.8	11.8	7.2
6	43.7	29.7	19.7	12.2
8	52.0	35.4	23.4	14.5
10	54.8	37.4	24.7	15.3
12	55.0	37.5	24.8	15.4
14	53.8	36.7	24.2	15.1
16	52.0	35.4	23.4	14.6
18	49.9	32.6	21.6	13.4
20	47.8	32.6	21.5	13.4

[a]Mean tree height in meters at age 8.

Table I–14.—Age/increment relations for *Eucalyptus deglupta* in Papua New Guinea

Age (yr)	Mean d.b.h. (cm)	Mean height (m) Total	Clear bole
5	22	24	14
10	39	37	23
15	54	44	30

Source: Davidson 1968.

under these conditions, the MAI in basal area and volume hold up well to 8 years. Early practice at Monte Dourado, Brazil, was to clearcut *G. arborea* for pulpwood at 6 to 7 years or for sawlogs at 10 years (Anon. 1979e).

Yield tables for *Anthocephalus chinensis* in West Bengal, India, indicate the effect of rotation length on tree diameter and MAI on the best sites (table I–16; Singh 1981).

Growth of *Casuarina equisetifolia* on sandy hills along the Bay of Bengal in India has been projected in terms of both volume and green weight, assuming no mortality (table I–17; Ray 1971). Actual yields were lower than predicted in the table because of mortality. Records indicate a yield of 9.2 m^3/ha/yr at 12 years, of which 8.3 m^3 was stemwood of 20 cm or larger in diameter at the small end. By the 15th year, the MAI had dropped to 4.2 m^3.

The influence of age on usable wood volume per tree, and thus on the cost of handling prescribed timber volumes, is illustrated by data from a plantation of *P. elliottii* in Misiones, Argentina (table I–18; Molino 1972).

Table I–15.—Age/increment relations for *Gmelina arborea* in the Philippines

Age (yr)	Total height (m)	Mean annual increment D.b.h. (cm)	Basal area (m^2/ha)	Volume (m^3/ha)
4	2.4	2.5	5.0	21.5
6	2.0	2.2	5.7	29.2
8	1.6	1.9	5.6	34.2

Source: Nanagas and Serna 1970.

Table I–16.—Age/increment relations for *Anthocephalus chinensis* in India

Age (yr)	No. of trees per hectare	Mean d.b.h.[a] (cm)	Basal area (m^2/ha)	Mean annual increment[b] (m^3/ha)
5	551	16.7	7.2	8.1
10	464	23.7	13.4	13.4
15	355	28.5	15.8	13.6
20	279	31.8	16.6	12.7
25	228	34.0	16.9	10.8

Source: Singh 1981.

[a]Mean for 125 trees per hectare of those with the largest diameters.

[b]Including branchwood and thinnings.

Table I–17.—Age/increment relations of *Casuarina equisetifolia* in India

Age (yr)	Mean d.b.h. (cm)	Mean height (m)	Mean annual increment of volume under bark[a] (m^3/ha)
2	4.3	5.8	
4	8.1	10.7	3.1
6	10.3	14.8	13.3
8	11.2	17.0	16.9
10	12.0	18.4	17.5
12	12.7	19.8	17.5

Source: Ray 1971.

[a]Presuming a 2- by 2-m spacing, unthinned

Table I–18.—Relation of age to tree volume for *Pinus elliottii* in Argentina

Age (yr)	Mean d.b.h. (cm)	Total height (m)	Stemwood volume per tree (m^3)
5	10.6	5.5	0.02
10	17.2	14.3	0.20
15	26.1	20.0	0.64
19	30.0	23.0	0.98

Source: Molino 1972.