

CONTENTS

PREFACE	v		
INTRODUCTION	1		
AUSTRALIA			
<i>Acacia</i>	7		
<i>Eucalyptus</i>	8		
<i>Pinus</i>	19		
<i>Pseudotsuga</i>	22		
BELGIUM			
<i>Alnus/Betula</i>	23		
<i>Fagus</i>	24		
<i>Quercus</i>	25		
<i>Picea/Pseudotsuga</i>	29		
BRAZIL			
Tropical forest	30		
BRITAIN - see UNITED KINGDOM			
BULGARIA			
<i>Fagus</i>	31		
BURMA			
Bamboo	32		
CANADA			
<i>Acer</i>	33		
<i>Populus</i>	36		
<i>Abies</i>	39		
<i>Picea</i>	41		
<i>Pinus</i>	44		
<i>Pseudotsuga</i>	51		
<i>Tsuga</i>	52		
CHILE			
Bamboo	53		
COLOMBIA			
Tropical forest	54		
CZECHOSLOVAKIA			
<i>Carpinus</i>	56		
<i>Quercus/Abies</i>	57		
DENMARK			
<i>Fagus</i>	58		
<i>Fraxinus</i>	60		
FINLAND			
<i>Betula</i>	61		
<i>Picea</i>	62		
<i>Pinus</i>	63		
		FRANCE	
		<i>Carpinus/Betula</i>	65
		<i>Fagus</i>	66
		<i>Quercus</i>	67
		<i>Pinus</i>	69
		<i>Pinus/Pseudotsuga</i>	71
		GERMANY (FDR)	
		<i>Fagus</i>	72
		<i>Picea</i>	73
		GHANA	
		Tropical forest	74
		GREENLAND	
		<i>Betula</i>	75
		GUATEMALA	
		Tropical forest	76
		HUNGARY	
		<i>Quercus</i>	77
		INDIA	
		<i>Eucalyptus</i>	78
		<i>Shorea</i>	79
		<i>Tectona</i>	82
		Tropical forest	84
		IRELAND	
		<i>Picea</i>	85
		ITALY	
		<i>Fagus</i>	86
		<i>Abies</i>	87
		IVORY COAST	
		Tropical forest	90
		JAMAICA	
		Tropical forest	92
		JAPAN	
		<i>Acacia</i>	93
		<i>Betula</i>	96
		<i>Camellia</i>	99
		<i>Castanopsis</i>	102
		<i>Cinnamomum</i>	106
		<i>Cyclobalanopsis</i>	107
		<i>Fagus</i>	111
		<i>Populus</i>	118
		<i>Quercus</i>	119
		<i>Sasa</i> (bamboo)	121
		<i>Zelkova</i>	122
		<i>Abies</i>	123

<i>Chamaecyparis</i>	134	THAILAND	
<i>Cryptomeria</i>	145	<i>Rhizophora</i>	233
<i>Larix</i>	167	Tropical forest	234
<i>Metasequoia</i>	168	UNITED KINGDOM	
<i>Picea</i>	169	<i>Alnus</i>	237
<i>Pinus</i>	171	<i>Betula</i>	238
<i>Thujaopsis</i>	183	<i>Castanea</i>	239
<i>Tsuga</i>	185	<i>Quercus</i>	240
KAMPUCHEA		<i>Ilex</i>	241
Tropical forest	187	<i>Picea</i>	242
KENYA		<i>Pinus</i>	243
<i>Camellia</i>	189	U.S.A.	
MALAYSIA		<i>Acer</i>	248
<i>Elaeis</i>	190	<i>Aesculus</i>	250
<i>Hevea</i>	192	<i>Alnus</i>	251
Tropical forest	195	<i>Betula</i>	256
NEPAL		<i>Carnegieia/Cercocarpus</i>	258
<i>Quercus</i>	197	<i>Fagus</i>	259
<i>Rhododendron/Juniperus</i>	198	<i>Fouquieria</i>	261
<i>Abies</i>	199	<i>Larrea</i>	262
<i>Tsuga</i>	200	<i>Liriodendron</i>	263
NETHERLANDS		<i>Populus</i>	266
<i>Quercus</i>	201	<i>Prunus</i>	275
<i>Pinus</i>	202	<i>Quercus</i>	276
NEW ZEALAND		<i>Rhododendron</i>	286
<i>Eucalyptus</i>	203	<i>Taxodium/Nyssa</i>	287
<i>Nothofagus</i>	204	<i>Abies</i>	289
<i>Pinus</i>	205	<i>Cupressus</i>	293
NIGERIA		<i>Juniperus</i>	294
<i>Elaeis</i>	207	<i>Picea</i>	295
<i>Pinus</i>	208	<i>Pinus</i>	299
PANAMA		<i>Pseudotsuga</i>	329
<i>Rhizophora</i>	209	<i>Sequoia</i>	345
Tropical forest	210	<i>Thuja</i>	347
PAPUA NEW GUINEA		<i>Tsuga</i>	348
Tropical forest	212	U.S.S.R.	
POLAND		<i>Betula</i>	352
<i>Fagus/Quercus</i>	213	<i>Carpinus</i>	354
<i>Pinus</i>	214	<i>Populus</i>	355
PUERTO RICO		<i>Quercus</i>	356
<i>Rhizophora</i>	215	<i>Tilia</i>	359
Tropical forest	216	<i>Picea</i>	360
RUMANIA		<i>Pinus</i>	369
<i>Fagus/Quercus</i>	219	VENEZUELA	
<i>Fagus/Abies</i>	220	Tropical forest	370
SPAIN		ZAIRE	
<i>Pinus</i>	221	<i>Musanga</i>	373
SWEDEN		Tropical woodland	374
<i>Betula/Acer/Quercus</i>	222	ZIMBABWE	
<i>Quercus</i>	223	Tropical woodland	375
<i>Fagus/Picea</i>	224		
<i>Picea/Pinus</i>	225	AUTHOR INDEX	377
<i>Pinus</i>	226		
SWITZERLAND		SPECIES INDEX	382
<i>Fagus/Quercus</i>	229		
<i>Quercus/Abies</i>	230	SUBJECT INDEX	389
<i>Picea</i>	231		
<i>Pinus</i>	232		

I N T R O D U C T I O N

Scope

The forest studies chosen for this book were those published by mid-1981 that provided data on the dry biomass of stems, branches and foliage per hectare. Among those studies, preference was given to data sets that included information on stand structure (tree number, height, basal area etc.) and estimates of stand production. The term 'production' here means the *current* net annual increment of stems, branches, foliage etc. plus losses due to mortality and litterfall, usually measured over periods of 1 to 10 years. This book does not include data from studies confined to estimates of stem biomass, foliage biomass, root biomass, leaf area index or litterfall alone. Readers interested in those aspects will find many more values by consulting *Forestry Abstracts*, appropriate review papers, and forestry stand volume tables which can be used to estimate merchantable stem biomass and increment. Those interested in the mineral nutrient content of forest biomass should consult the subject index and the footnotes in this book, which state whether nutrient contents were determined.

The approach used to compile this book was first to search the papers and references given in the following books and reviews, many reporting work promoted during the International Biological Programme: Rodin and Bazilevich (1967), Duvigneaud (1971), Young (1971), Ellenberg (1971), Art and Marks (1971), Golley and Golley (1972), Young (1973), Golley and Medina (1975), Lieth and Whittaker (1975), Young (1976), Shidei and Kira (1977), Lamotte and Bourlière (1978), Lieth (1978), Pardé (1980) and Reichle (1981). A literature search was then conducted within forestry and ecological journals, with a bias towards the west European, English-language and Japanese literature: of the 1200 or so forest stands included, 332 were in the USA and 384 were in Japan. Most of the data on forests in the USSR were taken from Rodin and Bazilevich (1967) or DeAngelis *et al.* (1981). No attempt was made to trace all the titles given in *Forestry Abstracts*, nor to include stands of woody species used in horticulture. However, all of the 116 studies detailed by DeAngelis *et al.* (1981) in the Oak Ridge IBP Woodland Data Set were covered, and most of the Japanese studies which provided English summaries and table legends have been included. Data are also given on stands of bamboo, some shrub stands, *Hevea* rubber, oil palm and tea plantations, as well as all kinds of natural and man-made forests. In some instances it was possible to obtain unpublished theses, and a few data were supplied by correspondence, but for the most part the data given here were abstracted from the publications cited. Data were supplied by the original authors only if there were serious discrepancies or omissions, or where it was not clear what was included in certain values.

Arrangement

The data have been arranged by country, and within each country data on broadleaved

species precede those on conifers, each in approximate alphabetical order of the main species in each stand. Non-alphabetical ordering occasionally occurs where a study included similar mixed species stands with different compositions (e.g. on page 123 a stand in Japan in which 52% of the biomass was *Tsuga sieboldii* has been listed with its associated species *Abies firma* because other stands in that study were dominated by *A. firma*). However, where a study included several stands with completely different species compositions (e.g. Whittaker, 1966), the study details have been repeated so that the stands could be placed in their correct alphabetical positions. Readers wishing to locate the work of particular authors should consult the author index.

Footnotes

One major difficulty encountered when arranging these data in a standard format was that not all authors used the same definitions or recognized the same division of components. Some included branches with stems, others included current year's twigs with foliage, understorey shrubs with overstorey trees, roots with above-ground woody parts, and so on. Authors defined the numbers and heights of trees in uneven-aged multi-storeyed stands in different ways, few authors gave estimates of losses from mortality or consumption, some omitted woody and foliage litterfall altogether, while others measured litterfall without estimating woody increments. Rather than list all possible combinations of biomass and production values, it was decided to maintain the simplest possible basic format and to use footnotes to tell readers what was or was not included in particular values. The footnotes are, therefore, an integral part of each table.

Another problem of using a standard format was that studies with very different objectives and of different merit were given equal space. Some studies were based on small samples, or small plots, or used simple assumptions about the ratios between tree parts, while others were based on large samples and detailed analyses. Consequently, where information was available, the footnotes state the number of trees sampled (i.e. cut down and divided), the size of the sample plots, whether roots were excavated, and the general approach used to extrapolate from sample tree values to stand values, recognizing the following four basic methods (see also Pardé, 1980; Ogawa and Kira, 1977).

1. All trees within a sample plot were harvested and weighed.
2. Regression equations were developed between the dimensions of sample trees and the dry weights of their component parts, and those equations were applied to all individuals within sample plots. The dimensions used were normally breast-height diameter D , and tree height H , and this method has been abbreviated in the footnotes by statements such as 'stand values were derived from regressions on D and H '.
3. It was assumed that the ratio of the sum of the biomass of sample trees to the biomass of the stand was equal to the ratio of their respective basal areas, abbreviated in the footnotes as 'stand values were derived by proportional basal area allocation' (a method, and phrase, commonly used by Japanese researchers).
4. The dry weights of trees of about average D and H were multiplied by the numbers of trees per hectare.

However, the footnotes do not describe the many methods used to estimate production values, and readers intending to make detailed comparisons between studies may wish to consult the original publications to see whether differences occurred in the ways in which sample trees were subsampled, in the variance of regression equations used, in the use of corrections for bias after logarithmic transformations, in the number of years over which increments were estimated, and so on. The footnotes on methodology provide only a basic guide to help readers to decide whether particular data sets are likely to be valuable for their purposes.

Guide to users

When consulting the data in this book it is important to bear in mind the following points.

Units. All published values have been converted to metric units, and bearing in mind the errors involved in all estimation procedures, biomass values have usually been rounded to the nearest 0.1 t/ha, and production values to the nearest 0.01 t/ha. Units of t/ha were preferred to g/m² although sample plots rarely exceeded 1 ha. Also, where it might be helpful, values have been given for individual sample plots within stands, rather than the overall stand means, recognizing that values for small plots may sometimes not apply over areas of one hectare.

Literature citations. The first publication cited on each page was the main one consulted. Where appropriate, a list is given of other selected references relating to the particular study, especially if nutrient contents or litterfall were reported separately. Sometimes conflicting data were published in several places, in which case the most recent publication was taken as the most authoritative, or the alternative data sets are given. Journals are cited according to the 4th edition of the World List of Scientific Periodicals.

Location. The locations of the study sites are given by latitude, longitude and altitude, and by country and place name.

Species. The authorities of Latin names are given in the species index. Generic names have been abbreviated only where they occur more than once on the same page. Where possible, for mixed species stands, an estimate is given of the percentage of the stand basal area, biomass or stem volume accounted for by each of the main species. All stands may be assumed to be natural or naturally regenerated (the latter if even-aged), unless they are stated to be plantations. Known recent management treatments, such as thinning and pruning, have been noted.

Site. No attempt has been made to give details of site conditions, but in many instances a brief statement has been included on the soil type. Also, known recent treatments, such as fertilizer applications, have been noted.

Age (years). Stand ages have normally been reckoned by counting growth rings at breast height, or in the case of plantations, from the date of planting. The ages of mature, uneven-aged, natural stands are given as upper values, age ranges, or by the word 'mature'.

Density (trees/ha). Densities include all living trees accounted for in the biomass data. If small-diametered trees were omitted this is noted. For coppiced stands, the density values refer to the number of stems per hectare.

Tree height (m). Unless otherwise stated, these are mean tree heights or height ranges. However, they will often be footnoted as stand top heights or the heights of dominant trees. For multi-storeyed stands the heights are given of each storey where these values were known.

Basal area (m²/ha). Basal areas were usually calculated from diameters at breast height (D) by the authors, but occasionally the compiler has calculated values using published diameter frequency distributions.

Leaf area index. The values given are one-sided leaf areas of broadleaved trees and projected leaf areas of conifers. The all-sided needle areas of most pines are about 2.8 times their projected areas, and for most other conifers the ratio is about 2.3. Wherever authors gave the all-sided leaf area indices of conifers these are given in the footnotes. In most instances the leaf area index given is the maximum value

obtained during the year.

Biomass (t/ha). The biomass is given of stem wood, stem bark, living branches, foliage and roots (including the stumps) of all living trees, plus the biomass of any understorey shrubs. The biomass of any dead trees, or dead branches, is given in the footnotes. The biomass of ground-layer, herbaceous vegetation is not given. Occasionally very different values were obtained using different methods in which case both estimates are given as explained in the footnotes.

Current Annual Increment (CAI, m³/ha/yr). These values are the current (or periodic) annual increments in stem volume including the bark.

Net production (t/ha/yr). Data are given for as many as possible of the following components: the current net annual increment in the standing biomass of stem wood, stem bark, branches, fruits, etc. (including all sexual reproductive parts), foliage and roots, plus annual losses of dry matter due to mortality, all kinds of litterfall, decay, consumption and the turnover of fine roots. However, in most instances some of these components have been pooled or are missing, as is made clear in the footnotes, and in some instances missing values (e.g. mortality or consumption) may have been negligible. *All non-footnoted values refer to increments*: thus stem wood production data presented as 3.12 + 1.00 t/ha/yr mean that the current net annual increment was 3.12 t/ha/yr to which have been added losses of 1.00 t/ha/yr as footnoted.

Annual stem biomass increments were usually estimated for periods of 1 to 10 years, either by repeated sampling or retrospectively, from measured increases in D, H and/or stem volume (see Pardé, 1980; Ogawa and Kira, 1977). Branch increments were often estimated similarly, or from regressions of branch biomass on branch age.

Annual foliage production in deciduous stands may have been assumed to be equal to the foliage biomass in late summer, in which case early summer leaf fall will have been ignored, unless otherwise stated. Alternatively, annual foliage production may have been assumed to be equal to mean annual foliage litterfall, in which case losses due to translocation, decay and consumption will have been omitted. The footnotes often indicate the period over which litterfall was measured, but all values in the tables always refer to periods of one year. For evergreen stands annual foliage production may have been derived from (i) regression equations, (ii) annual foliage litterfall, (iii) the biomass of current year's foliage or (iv) foliage biomass divided by mean foliage longevity.

Root production values are by far the least reliable. Recent data on the high turnover of fine roots (e.g. on pages 242, 264, 337 and 341) suggest that most root production values published before about 1975 were underestimates. Most were based on regression equations of root biomass on D, or assumed some other proportionality between the growth of above- and below-ground parts.

References

- Art, H.W. and Marks, P.L. (1971). A summary table of biomass and net annual primary production in forest ecosystems of the world. In: "Forest Biomass Studies" (H.E. Young, ed.), pp. 1-32. University of Maine, Orono, U.S.A.
- DeAngelis, D.L., Gardner, R.H. and Shugart, H.H. (1981). Productivity of forest ecosystems studied during the IBP: the woodland data set. In: "Dynamic Properties of Forest Ecosystems" (D.E. Reichle, ed.), pp. 567-672. Cambridge University Press, Cambridge, London, New York and Melbourne.
- Duvigneaud, P. (ed.) (1971). "Productivity of Forest Ecosystems." UNESCO, Paris.
- Ellenberg, H. (ed.) (1971). "Integrated Experimental Ecology." Springer-Verlag, Berlin, Heidelberg and New York.
- Golley, F.B. and Medina, E. (eds) (1975). "Tropical Ecological Systems." Springer-Verlag, Berlin, Heidelberg and New York.

- Golley, P.M. and Golley, F.B. (eds) (1972). "Tropical Ecology, with an Emphasis on Organic Productivity." Institute of Ecology, University of Georgia, Athens, U.S.A.
- Lamotte, M. and Bourlière, F. (eds) (1978). "Problèmes d'Ecologie: Structure et Fonctionnement des Ecosystèmes Terrestres." Masson, Paris.
- Lieth, F.H. (ed.) (1978). "Patterns of Primary Production in the Biosphere." Benchmark Paper in Ecology. Vol.8. Dowden, Hutchinson and Ross, Stroudberg, Pennsylvania.
- Lieth, F.H. and Whittaker, R.H. (eds) (1975). "Primary Productivity of the Biosphere." Springer-Verlag, Berlin, Heidelberg and New York.
- Ogawa, H. and Kira, T. (1977). Methods of estimating forest biomass. In: "Primary Productivity of Japanese Forests." (T. Shidei and T. Kira, eds), pp. 15-25. University of Tokyo Press, Tokyo, Japan.
- Pardé, J. (1980). Forest biomass. Forestry abstracts review article. *For. Abstr.* 41, 343-362.
- Reichle, D.E. (ed.) (1981). "Dynamic Properties of Forest Ecosystems." Cambridge University Press, Cambridge, London, New York and Melbourne.
- Rodin, L.E. and Bazilevich, N.I. (1967). "Production and Mineral Cycling in Terrestrial Vegetation." Oliver and Boyd, Edinburgh and London.
- Shidei, T. and Kira, T. (eds) (1977). "Primary Productivity of Japanese Forests." JIBP Synthesis Vol.16. University of Tokyo Press, Tokyo, Japan.
- Whittaker, R.H. (1966). Forest dimensions and production in the Great Smoky Mountains. *Ecology* 47, 103-121.
- Young, H.E. (ed.) (1971). "Forest Biomass Studies." College of Life Sciences and Agriculture, University of Maine, Orono, U.S.A.
- Young, H.E. (ed.) (1973). "IUFRO Biomass Studies." College of Life Sciences and Agriculture, University of Maine, Orono, U.S.A.
- Young, H.E. (ed.) (1976). "Oslo Biomass Studies." College of Life Sciences and Agriculture, University of Maine, Orono, U.S.A.

Institute of Terrestrial Ecology,
Bush Estate,
PENICUIK.
Midlothian, Scotland.

Melvin G.R. Cannell

December 1981