A REVIEW OF FOREST BIOMASS ACCUMULATION

John Turner and Dale W. Cole
University of Washington

Estimates of forest biomass and its distribution are essential to the understanding of many aspects of forest ecology and ecosystem dynamics, as they can provide a basis for determination of productivity, energy flow, and chemical composition for mineral cycling studies. Most work dealing with productivity of forest systems has been concerned only with the merchantable volume of mass of timber, ignoring such components as leaves, branches, bark, and roots; therefore many of the early biomass studies were carried out only in relation to management programs. This involved estimating the biomass and its chemical composition, calculating what proportion would be removed in logging or cropping, and then estimating possible site deterioration (135, 229, 233).

With the increasing interest in terrestrial productivity, especially within the IBP, a new impetus has been given to investigators in the field of biomass accumulation. Some syntheses of studies have been published, but they covered only limited aspects of the problem. Because of the complexity of the population under study problems in sampling and methodology arise, and it is often difficult to compare directly the results of one study with those of another even when both studies are done by the same investigator.

This report presents a reference list of available studies on aboveground forest biomass, together with (1) methods of sampling and estimation and some of the problems and errorsassociated with each method (given as an aid to comparison of data), (2) some results obtained from the literature of field estimates tabulated in an accessible form, and (3) a brief discussion of some of the results to show the principles and consistencies involved. All papers found are given in the list of references, but not all are specifically cited. [Contrary to our usual style, the reference list is called "Bibliography" to accommodate uncited listings, and is numbered to facilitate the citation of multiple listings. Ed.] Separate tables were drafted for Douglas-fir and alder because these two species are particularly important in the Pacific Northwest.

The authors realize that not all existent papers containing biomass estimates are listed here. There are many theses covering various aspects of biomass and some have been listed, but many others were unobtainable at the time this report was written.

METHODS USED IN SAMPLING AND ESTIMATING ABOVEGROUND BIOMASS

The various methods of sampling and estimating are discussed in some detail. Some of the workers who used a particular method are cited, so that a direct comparison of data may be made on the assumption that their errors may be comparable.

Mean Tree Approach

The basis of this type of study is selection of a tree of mean dimensions within a given stand. As the sample is rather limited, the method is usually applied to relatively uniform stands such as plantations or uniform regrowth where a good degree of precision in the data can be expected. The closer the selected tree is to the true mean, the better the estimate will be. The method has been used extensively under the above-mentioned conditions (21, 31, 32, 33, 107, 108, 110, 134, 135, 142).

Mean Tree With Stratification

A modification of the mean tree technique involves stratification of the trees within the stand into size classes or some other obvious grouping (e.g., species), usually on the basis of dob, and selection of the mean or typical tree from each of the stratified groups. This method gives a better picture of the variation within the stand than does the mean tree approach, as it takes more trees from a wider selection of sizes (52, 80, 101, 106, 141, 186, 233). The method probably could be used in rather diverse stands (e.g., uneven-aged stands or stands within mixed species).

After some estimate of the weight of individual tree components has been gained by either of the two methods, the estimated figures can be converted to an area basis by multiplying by the number of stems per unit area, or by the number of stems per stratified cell and then by the number of cells per unit area (135, 141, 144, 146). An alternative is the use of basal area allotment based on $Y = Y'(G/G')$, where Y = biomass unit area, Y' = tree biomass, G = tree basal area, and G' = total basal area (6, 193, 195, 197, 199).

Owing to the diverse geometry of a stand, problems may arise as to which tree is of mean size and which factor or factors are to be used to assess mean size (e.g., height, dob, depth of crown, or some combination of these, and so on). A tree of mean diameter need not be the tree of mean height, mean crown dimensions, or mean weight; the error involved is determined by how far the selected tree is from the true mean.

Complete Area Sampling

Complete area sampling involves the removal and weighing of all biomass components in a given area. Obviously the same plot can be used only once; but this method, which gives the most accurate determination, can be used as a point of comparison for the other methods (16, 49, 139, 146, 166, 167).

Allometric Relations

Whereas "mean tree" and "stratified mean tree" describe techniques of sampling and measuring simultaneously, the sampling and measurement can be separated in the method of allometric relations. Regression equations can be calculated from a range of sample trees selected from a stand, and relations can be determined between some easily obtainable measurements on the standing tree and its total biomass or biomass components. A typical form of equation is log (weight) = $\alpha + \beta$ log (dimension). The accuracy and precision are determined by the parameters used and the component to be estimated. If dob is used a fairly good estimate of bole weight can be expected, but other components, especially those in which other outside factors have great influence (e.g., a mass of dead branches), may be highly variable. Baskerville (52) gives details on transformations of data and the assumptions involved, pointing out that logarithmic relations are more correct than such transformations as D^2H.

The more parameters that are used, the more precise are the biomass estimates; but there is a cutoff point beyond which the added work is not worth the added precision obtained from the extra parameters. In a hypothetical example, dob may give a fairly good estimate of total biomass, and the addition of tree height data may improve the estimate by 20%. Taking into account the diameter at 7.6 m (25 ft), the depth of crown, and the length of branches adds a further 5% improvement, but the amount of work involved would have to be tripled.

Allometric methods are applicable and have been applied to a range of forests, from uniform single-species plantations to tropical rain forests of complex structure where a different equation is needed for each species. References for this technique are extensive (9, 10, 14, 28, 40, 68, 74, 76, 86, 88, 89, 106, 113, 121, 126, 127, 128, 135, 141, 143, 150, 151, 152, 158, 161, 163, 165, 168, 169, 170, 171, 172, 174, 179, 180, 195, 197, 199, 200, 203, 204, 206, 215, 240, 246). Allometric approaches can be used nondestructively, so that a plot can be followed with time, or other studies can be carried out with no direct effect on the stand.

Some attempts have been made, by means of regression equations, to develop allometric relations to cover a species in general or all similar species (145), but, as might be expected, with each development from plot to species and from one species to all species, precision is lost. If the allometric method is used, it is advisable that preliminary tests be made by taking a few sample trees, and that the required precision be ascertained before extensive determinations are made.

To gain more parameters for regression analysis, Cole and Dice (42) proposed what they called dimension analysis, which involves the use of a theodolite set up at a series of stations within the stand to measure a range of points on the trees, thus developing a three-dimensional model of the stand. At the time that the aforementioned paper (42) was presented the U.S. Army Corps of Engineers had been developing a similar method for three years, but no practical estimates had been given so no figures are available.

Table 1 shows a comparison between the allometric method, the mean tree approach, and the stratified mean tree approach of estimating tree biomass.

Dimension Analysis of Mixed Forests

Dimension analysis is a complex development of the regression technique, as proposed by Whittaker and Woodwell (224 [quoted below], 225, 227).

> The method is designed to use the complex structure of forests--through measurements on the various parts of plants including those critical marks of rates of growth that occur in most temperate forests, wood rings and bud scale scars--to measure or estimate the productivity of the fractions of woody plants.

The method is not easily applicable, and Whittaker and Woodwell suggest that data sheets be filled out and sent to them for analysis. No comparable results outside their limited situation are listed.

BIOMASS ACCUMULATION

Many studies have been carried out in forest ecosystems to determine the distribution of biomass (phytomass), but because of different methods of estimating and of recording data, even by the same investigator, only broad comparisons can be made. In the presentation of data, foliage, branch, and bole weight, and in some cases net annual increment, have been given. As very few studies included root mass and in our studies we are concerned mainly with aboveground biomass, the root mass component has been excluded from this review.

Some of the factors to be considered, that affect biomass variations, are: (1) changes with time, (2) genera or species differences or both, (3) management changes, (4) altitudinal differences, (5) latitudinal differences, and (6) site quality differences. These categories are intended to be broad, and thus there is some overlap.

Variation with Age

Satoo (164), in his study on *Pinus densiflora*, noted that stem biomass is a function of age and that branch biomass is affected by stand density and also by age. Leaf biomass of closed stands appears to be influenced by few factors (107, 166). Leaf biomass cannot increase indefinitely with forest growth, and there must be a limit specific to species or to groups of ecologically similar species (163, 166).

The essence of the time study is to determine what changes are taking place in distribution and amount of organic matter within the forest stand as it ages. There are several ways of effecting this determination, one of which is measurement of a single stand at different ages. Many problems can thus be solved, especially those associated with site variability, but a long period of time is required before results can be obtained.

An alternative method involves the use of a series of age classes within a forest stand. One assumes that the sequences being measured are simultaneous expressions of different stages of stand development, and also that site factors are uniform. Because of their general uniformity, plantations are amenable to this system of study, and consequently have been used frequently. The time studies listed here have been divided, for convenience, into evergreen and deciduous.

Evergreen

Most evergreen time studies have been carried out on *Pinus* spp. by use of a series of stands of different ages, usually in plantations because the exact site and management history of the stand is known. Ovington (135) used a series of planted *Pinus sylvestris* stands, ranging from 3 to 55 years old, in Britain (Table 2). In his detailed study Ovington gives estimates of standing biomass, and also estimates of total biomass produced, by taking into account thinnings, prunings, and mortality. Only the standing biomass studies are listed here.

Wright and Will (233), in Scotland, carried out work on *P. sylvestris* and also on *Pinus nigra* var. *austriaca*. Their study used only three age classes for each species: 18, 20, and 48 years for *P. nigra*, and 18, 28, and 60 years for *P. sylvestris* (Table 2). Although the number of age classes is limited, Wright and Will's study compares well with Ovington's because, based on height-age curves, the stands have the same site quality.

The comparison of the two stands shows basically the same development, but the proportions vary. Figure 1 shows that the two *P. sylvestris* studies are similar in total tree biomass, but the foliage and total crown weights differ by a factor of almost two. This discrepancy possibly reflects differences in sampling procedure, as Ovington sampled only the mean tree in the older size classes, while Wright and Will sampled the mean tree plus two trees from other size classes (i.e., mean tree sampling versus mean tree sampling within stratified units).

Switzer et al. (186) studied *Pinus taeda* in Florida, using stands ranging from 3 to 60 years old (Table 2). Although there are great similarities to the previous studies, Switzer's work shows obvious differences in the rates of development. Crown weights take a much longer period of time to stabilize, if, indeed, they do. The two site qualities used give a good comparison of the variation in site quality previously mentioned, especially with regard to foliage development. (See also Satoo (163), who found leaf biomass in closed stands of *Cryptomeria japonica* to be influenced only by site quality.) A further study of pine was conducted by Forrest and Ovington (52), who used *Pinus radiata* growing in eastern Australia and ranging in age from 3 to 12 years (Table 2). The noticeable feature of this sequence is its rapid development (Figure 1), with the trees in full control of the site by age eight (approximately). A comparison of results with those of Will (229) is useful, as Will's was also a 12-year-old stand of *P. radiata* but of much higher site quality, where stand development was even more rapid.

Paddock (145) examined *Pseudotsuga menziesii* in the Pacific Northwest, using both densely and sparsely stocked stands with an age sequence of 12, 30, 39, and 75 years (Table 3). The table shows a decline in productivity of the 75-year-old stand (compared with the younger stands), possibly indicating high interplot variability. The density comparison shows that stand constants (such as constant foliage weight per hectare, and so on) apply only after the trees take full control of the site. After crown closure the foliage becomes constant in weight (more so than that of the pines), as does the total crown weight. A study in Japan on planted *Acacia mollisima* (192) up to seven years old (Table 4) shows a great degree of interplot variability, but results are consistent with other species.

The foregoing studies, while varying in total amounts and proportions, show a great deal of consistency, which can be summarized as follows: (1) All tree components of the stand continue to increase with age until crown closure, at which point the trees are in control of the site. After crown closure, bole weight is the only major component that continues to increase. Time of crown closure varies between 8 and 30 years. (2) After site control foliage biomass becomes constant, generally at about 8-10 x 10^3 kg ha^{-1}; major variations are due to site index; stand density and minor fluctuations are due to yearly climatic variations. (3) Total crown weight becomes stable at about 30 x 10^3 kg ha^{-1}. Branch weight appears to be age dependent for *P. taeda*, but not so for the other evergreen species. There is a possible relationship between foliage and branch weights--a foliage amount/distribution balance. Compare studies of *P. taeda* in Japan (2) with those of Switzer et al. (186) mentioned previously (Table 2). The high density shown in the Japanese study has led to rapid stand development with 19 x 10^3 kg ha^{-1} of foliage at eight years and a total crown of only 27 x 10^3 kg ha^{-1}. These figures may represent only a fluctuation that, with development, will stabilize, followed by a drop in foliage weight and an increase in branch weight. They may indicate a peak of foliage development at crown closure (also borne out by other studies). As the stand develops, in many instances the undergrowth declines, becoming almost nonexistent after crown closure. Figure 2 shows the relationship involved.

Deciduous

A smaller number of detailed time sequence studies has been carried out with deciduous species. Ovington and Madgwick (142), in Great Britain, studied *Betula verruccosa* using stands ranging from 6 to 55 years old (Table 5). Greater variation occurs between the plots (e.g., see the height/age curve in Figure 3), but the variation may be due to management procedures. As with evergreen species, total tree biomass increases with time. By comparing the *B. verruccosa* studies with those on the stand of *P. sylvestris* (135), which is in a fairly similar geographical location and of comparable height, and on which similar methods of biomass estimation were used, one may see that there is great similarity in total biomass development (compare Figure 1 and 4, drawn on the same scale). Differences occur in foliage weight and total crown biomass development.

Foliage weight in *Betula* reaches a maximum of about 2 x 10^3 kg ha^{-1}. Rather than attaining a level constant with time, as in conifers (Figure 5), *Betula* appears to undergo periodic fluctuations. Total crown weight does not come to a stable level, but continues to increase with time in a manner similar to the increase of total biomass.

Van Cleve et al. (210) studied biomass accumulation in stands of alder (*Alnus incana* [L.] Moench subsp. *tenuifolia* [Nutt.] Breitung) near Fairbanks, Alaska. The age sequence was 0, 5, 15, and 20 years, and corresponded to periods when fire had caused the initiation of new alder stands. The trends are shown in Table 6 and Figure 4. Total biomass and foliage are similar to those of the *Betula*, but branch weight is higher. The alder has a much faster initial stand development than does the birch. Additional alder studies were carried out by Zavitkovski and Stevens (250); as their results are not available in tabular form, they are indicated here in graphic form (Figure 6).

Post (150), in Canada, studied *Acer spicatum* with a sequence of 1 to 26 years. As shown in Table 5 and Figure 4, the stand development is similar to that of the two stands previously discussed.

Tadaki et al. (194), in Japan, studied *Fagus crenata* in three age classes, 34, 40, and 50 years. Even though there is the complicating factor of a variation in elevation (from 400 to 580 m), Tadaki's results give some idea of the processes involved in older deciduous stands (Table 5). Total tree biomass increases with time. Foliage weight is stable, but the branch (and hence total crown) weight is variable. The foliage weight is much greater than that of other deciduous species.

Differences in Genera or Species, or Both

Many studies on differences in genera or species have been carried out. Comparisons of species may be made by examination of some of the results mentioned under Variations with Age, and also shown in Tables 7 and 8. Care must be taken to use directly comparable data (i.e., preferably the same author, geographical location, age, treatment, and the like).

Wright and Will's study (233), previously mentioned, shows some of the variations between *Pinus nigra* and *Pinus sylvestris* over a period of time in a similar location in Scotland. By comparing two sets of data of Ovington (135, 142) taken from *P. sylvestris* and *B. verrucosa* in England, two genera may be compared with minimal variation due to author and location. Although total production is similar (as previously mentioned), the actual distribution differs greatly, especially with regard to foliage.

Ovington (134) studied a range of species at three sites in England (Tables 2, 3, 4, 5, 6, 9). The species studied are *Abies grandis*, *Alnus incana*, *Betula alba*, *Castanea sativa*, *Nothofagus obliqua*, *Chamaecyparis lawsoniana*, *Fagus sylvatica*, *Larix decidua*, *Larix eurolepsis*, *Picea abies*, *Picea amorasa*, *Pinus nigra*, *Pinus sylvestris*, *Pseudotsuga taxifolia* (*menziesii*), *Quercus robur*, *Thuja plicata*, and *Tsuga heterophylla*. Beyond the general statement that conifers have the greatest standing plantation weight, and bole weight removed as thinnings, Ovington finds other factors difficult to determine because of great intraspecies variation. Crown weights are highly variable and inconsistent with later studies, possibly because of changes in sampling technique.

Satoo (166) compared leaf biomass of pure, single-species stands in Japan. Tadaki (191), before Satoo's work was published, produced a detailed table of biomass studies, which is reproduced here (Table 10).

Management Effects

Factors such as spacing, thinning, and fertilizing can have a profound effect on the biomass of a stand. It appears that the principal effect of increasing the number of trees per unit area is the acceleration of developmental stages such as canopy closure, and hence the advancement of crown stability. Much of the biomass that, at wider spacing, would become undergrowth in an open system becomes a component of trees; that is, there is a redistribution of biomass in the system. No single study has been specifically planned to delineate these differences.

Thinning has the obvious effect of removing sections of the biomass, and the development of the stand therefore fluctuates. The effect of thinning is demonstrated in Ovington's (135) study on *Pinus sylvestris*. Fluctuations in the general stability of a stand also may be caused by management practices, as shown in the study by Forrest and Ovington (52) of a series of stands of *Pinus radiata* of which the nine-year-old component had undergone pruning shortly before the study began.

Fertilization has a major effect on biomass development, increasing the rate of development and also changing the "normal" component distribution for the site. For example, Madgwick et al. (100) showed that potassium fertilization of *Pinus resinosa* caused an increase in the total amount of foliage held by the trees (probably because the older needles were held longer than normally). Harada (60), studying the effects of fertilization on *Cryptomeria japonica* in Japan, found that two years after the fertilization program the control trees had the most foliage (17.71×10^3 kg ha^{-1}), those fertilized with nitrogen were next (16.25×10^3 kg ha^{-1}), and those receiving nitrogen-phosphorus-potassium treatment had the least foliage. Total production and stem production were in the reverse order. Heilman (64) studied Douglas-fir in the Pacific Northwest under various fertilization regimes, and the effect was a general increase in biomass components.

A further management effect was discussed by Tadaki et al. (199), in which cuttings and seedlings of *Cryptomeria* of the same age were compared. The results show that trees propagated from cuttings have a much higher stem weight and total production, but lower foliage and branch weights.

Variation with Environment

Altitudinal changes

It appears that, in certain environments, with an increase in altitude there is an increase in production and then a decrease. Yamada (235) showed this effect in a single-species study of *Fagus crenata* in Japan. Yoda (240) studied a series of communities in Nepal (Table 11, Figure 7), and found that the peak of total productivity occurs at 2700 m while the peak in foliage biomass occurs over a much wider range commencing at 2900 m. In analyzing these peaks it is interesting to note that total biomass is age dependent and foliage biomass is age independent. The foliage-to-bole ratio increases with increasing altitude, until at very high altitudes the biomass is all foliage in the form of grasses. These peaks and changing ratios reflect possible changing foliar efficiencies, which as yet have not been detailed.

Latitudinal changes

Few studies have attempted to show, other than in very general terms, the variations in biomass due to latitudinal location. One problem is the control of other complicating variables such as rainfall differences. Several tables have been used here to show some of the variations: Table 12 is compiled from Art and Marks (7), and Table 13, representing a more limited distribution, is from Rodin and Bazilevich (156). The general trend shows increased productivity toward the tropics. Further details of tropical biomass figures are shown in Table 14.

Site quality differences

Differences in site quality have been examined in various ways. Satoo (163) found that site index gave a difference in foliage quantity of *Pinus densiflora*. Madgwick et al. (100) showed that fertilization of *P. resinosa* stands with potassium caused a 9% increase in foliage, which he attributed in part to the longer retention of the foliage. Such differences are not always consistent. In comparing the 12-year-old *P. radiata* of Forrest and Ovington (52) in Australia (site index 26 m at 20 years) with that of Will (229) in New Zealand (approximately 33.5 m at 20 years), we find a great difference in total biomass and in rate of accumulation, but the foliage weight is essentially the same. This may reflect different foliar efficiencies owing to a greater moisture stress in Australia. Switzer et al. (186) showed poor and good stands of *Pinus taeda* where, contrary to the results of Satoo (163) and Madgwick et al. (100), the poor site produced more foliage than the good site.

Jurgenson and Leaf (75) studied the effect on *P. resinosa* biomass of soils where depths to the water table varied. The results showed that there was a peak in foliar production where the water table depth was 106.7 cm, but production dropped off in locations with both higher and lower water tables. The total biomass followed a similar pattern (Table 2, Figure 8). Ando (6) studied *Pinus thunbergii* from sites of different qualities. Stands 1, 2, and 5 were the best based on height, foliage, and productivity, while stand 4 had the lowest site quality and the foliage and total biomass were correspondingly lower.

Table 1. A comparison of mean tree, stratified mean tree, and regression or allometric techniques for tree biomass estimation shown by Ovington and Madgwick (141).

Tree component	Mean tree ($kg \times 10^3/ha$)	Stratified mean tree ($kg \times 10^3/ha$)	Regression ($kg \times 10^3/ha$)
Leaves	0.34	0.37	0.38
Living branches	0.63	0.70	0.72
Dead branches	0.43	0.49	0.47
Boles	5.94	5.96	6.03
Roots	1.47	1.63	1.64
Living trees	8.39	8.89	9.02

Table 2. Summary of biomass components of *Pinus* spp. throughout the world, roots and forest floor not included (P = plantation, N = natural or uncertain).

Species	Location	Age	Foliage wt.	Total crown	Bole wt.	Total biomass (above-ground)	Net accumulation	References and comment
	(country)	(yr)		(kg x 10³/ha)			(kg x 10³/ha/yr)	
P. banksiana	U.S.A.	- N	4.84	13.79	39.66	53.45		45
P. contorta	U.S.A.	71 N	5.0	19.9	32.4	52.3		251
do	U.S.A.	72 N	8.4	28.1	94.4	122.5		251
do	U.S.A.	77 N	17.4	57.8	216.8	274.6		251
do	U.S.A.	100 N	12.3	25.9	209.3	235.2		73
do	U.S.A.	100 N	14.0	37.3	151.0	188.3		73
do	U.S.A.	100 N	7.0	20.9	67.1	88.0		73
P. densiflora	Japan	13 P					12.2	163
do	Japan	13 P					11.0	163
do	Japan	13 P					12.5	163
do	Japan	13 P					15.0	163
do	Japan	16 P				59.20		136
do	Japan	16 P				104.7		136
do	Japan	15 N				63.9	15.8	164
do	Japan	15 N					14.9	163
P. echinata	U.S.A.	- N				181.4	8.75	221
do	U.S.A.	- N				131.2	9.91	221
P. nigra	U.K.	18 P		48.82	125.05	173.87	10.3	134
do	U.K.	22 P		31.53	90.85	122.38	5.8	134
do	U.K.	22 P		36.97	104.90	141.87	6.7	134
do	U.K.	46 P		30.17	212.03	242.20	9.3	134
P. nigra var. *austriaca*	U.K.	18 N	3.08	9.35	15.95	25.3		233
do	U.K.	28 N	4.73	15.40	51.3	66.7		233
do	U.K.	48 N	5.5	16.50	93.5	110.0		233
P. radiata	Aust.	3 P	0.5	0.7	0.4	1.1	3.75	52
do	Aust.	5 P	2.1	3.3	2.4	5.7	7.2	52
do	Aust.	7 P	11.6	26.5	23.8	50.3	25.6	52
do	Aust.	9 P	8.8	18.7	53.8	72.5	12.7	52
do	Aust.	12 P	9.5	28.2	89.5	117.7	15.7	52
do	N.Z.	12 N	8.96	34.7	132.7	165.8	39.2 to 44.8	229
P. resinosa	U.S.A.	32 P	10.9	39.9	78.0	118.0		234
do	U.S.A.	32 P	13.5	42.8	97.3	140.2		234
do	U.S.A.	32 P	11.3	34.4	85.6	120.0		234
do	U.S.A.	32 P	11.7	39.4	79.2	118.7		234
do	U.S.A.	26 P	15.8	35.6	130.4	171.4		Water table 0.67 m 75
do	U.S.A.	26 P	17.8	41.7	150.9	192.6		Water table 1.07 m 75
do	U.S.A.	26 P	14.09	30.33	95.54	125.86		Water table 2.44 m 75
do	U.S.A.	26 P	13.73	30.94	112.33	143.37		Water table 2.53 m 75
do	U.S.A.	26 P	12.98	29.14	96.56	125.70		Water table 3.29 m 75
do	U.S.A.	26 P	10.29	21.96	70.86	92.82		Water table 4.88 m 75
P. rubra	U.S.A.	67 N				93.5		245
P. strobus	U.S.A.	34 N				48.5		245
do	Japan	41 P	7.4	26.0	78.7	104.7		245
do	Japan	41 P	10.1	24.2	180.0	204.2		245

Table 2. (cont)

Species	Location	Age	Fol. wt.	Total crown	Bole wt.	Total biomass	Net accum.	References and comment
P. sylvestris	U.K.	47 P		26.97	129.48	156.6	7.9	134
do	U.K.	3 P	0.01	0.02	0.01	0.03	22.0	135
do	U.K.	7 P	2.12	3.08	1.01	4.09	22.0	135
do	U.K.	11 P	5.80	10.15	5.25	15.36	22.0	135
do	U.K.	14 P	6.69	15.88	8.41	22.93	22.0	135
do	U.K.	17 P	8.97	20.93	16.24	35.36	22.0	135
do	U.K.	20 P	10.48	28.90	27.11	51.31	22.0	135
do	U.K.	23 P	5.06	31.92	44.34	63.63	22.0	135
do	U.K.	31 P	8.28	31.13	81.65	99.55	22.0	135
do	U.K.	35 P	9.83	24.68	98.81	118.96	22.0	135
do	U.K.	55 P	7.24	29.52	96.68	116.65	22.0	135
do	U.K.	33 P	7.30	31.0	118.8	149.8		141
do	U.K.	18 N	6.05	18.92	34.98	53.9		233
do	U.K.	28 N	4.62	18.37	74.03	92.4		233
do	U.K.	64 N	4.62	21.01	95.59	116.6		233
do	U.K.	11 N	13.34	24.94	17.40	51.63		135
do	U.K.	14 N	4.44	14.44	24.70	49.39		135
P. taeda	Japan	8 N	18.0	27.0	72.0	99.0		2
do	Japan	34 P	9.5	33.5	168.0	226.5		4
do	Japan	34 P	8.5	34.56	151.0	185.6		4
do	U.S.A.	10 N	0.88		19.47	29.70	5.0	186
do	U.S.A.	20 N	3.52		38.94	59.40	5.0	Poor site 186
do	U.S.A.	30 N	5.94		58.41	89.10	5.0	186
do	U.S.A.	40 N	7.70		72.71	114.40	2.6	186
do	U.S.A.	50 N	8.80		87.01	139.70	2.6	186
do	U.S.A.	60 N	8.74		101.31	168.3	2.6	186
do	U.S.A.	10 N	2.20		42.13	55.00	2.7	186
do	U.S.A.	20 N	4.18		84.26	110.00	2.7	Good site 186
do	U.S.A.	30 N	4.51		126.39	165.00	2.7	186
do	U.S.A.	40 N	4.18		139.62	193.60	2.3	186
do	U.S.A.	50 N	3.41		152.85	232.20	2.3	186
do	U.S.A.	60 N	3.41		166.08	249.70	2.3	186
P. thunbergii (1)	Japan	10 N	11.92	23.09	33.42	56.51		6
do (2)	Japan	10 N	13.77	29.63	38.14	67.77		6
do (3)	Japan	10 N	10.68	19.15	18.68	37.83		6
do (4)	Japan	10 N	6.23	10.47	10.70	20.44		6
do (5)	Japan	10 N	10.10	20.67	23.42	44.09		6
do (6)	Japan	10 N	5.74	11.37	11.25	22.62		6
P. pinaster	Aust.	14 P	24.4	49.9	71.1	122.6	7.2	80
do	Aust	14 P	19.8	38.8	60.3	100.8	8.8	80

Table 3. Biomass of aboveground component parts of Douglas-fir stands (in thousands of kilograms per hectare). (* = dead stands included.)

Location	Treatment	Age (yr)	Needles	Branches	Total crown	Bark	Wood	Total stem	Total above-ground	References
Washington	+Alder	28	9.81	18.59	28.40	9.76	14.56	123.84	134.72*	185
do		28	7.84	7.66	14.70	2.54	26.43	28.96	43.67*	185
do		37	9.90	19.33	29.23	18.26	108.24	126.50	161.71*	185
do		30	8.02	7.62	15.64	3.99	18.90	22.84	38.47	64
do	Fertilizer	30	13.15	10.91	24.06	5.39	29.57	34.96	59.01	64
do		32	5.31	7.21	12.52	4.13	19.20	23.33	35.85	64
do	Fertilizer	32	9.61	12.63	22.24	6.55	34.37	40.93	63.17	64
do		38	8.00	18.67	26.67	18.09	51.65	69.74	96.41	64
do	Fertilizer	38	14.17	30.44	44.61	21.39	63.86	85.25	129.86	64
do		38	8.98	20.62	29.60	14.44	115.48	129.92	159.82	64
do	Fertilizer	38	16.15	25.01	41.19	13.05	91.84	104.89	146.08	64
do		52	11.95	29.14	41.09	27.24	147.36	174.60	215.69	64
do	Fertilizer	52	13.85	30.27	44.13	30.83	142.37	173.21	217.34	64
do		35			30.10			197.20	228.20	154
do		35			40.50			220.20	250.80	154
do		35			26.70			154.30	181.00	154
do		35			39.40			193.60	238.10	154
do		35			25.20			101.30	120.50	154
do	Sparse	12	0.85					1.50*	2.35	145
do	Dense	12	2.07					3.24	5.31	145
do	Sparse	30	7.88	8.58	16.46	2.84	29.60	32.44	49.90*	145
do	Dense	30	10.99	20.81	31.81	10.93	105.91	116.84	154.87*	145
do	Sparse	39	11.08	24.43	35.51	20.45	121.22	141.67	181.19*	145
do	Mature	75	10.84	16.44	27.28	18.54	125.92	144.46	171.74	145
do	Plantation	36	9.10	22.03	31.13	18.73	121.75	140.48	171.61	43
U.K.	Plantation	21			24.48			90.3	114.78	134
do	Plantation	22			79.38			88.8	168.18	134
do	Plantation	22			86.10			95.3	181.4	134
do	Plantation	47			49.72			202.7	252.4	134

Table 4. Biomass components of nonbroadleaf evergreen species other than pines (in thousands of kilograms per hectare).

Species	Location	Age (yr)	Foliage	Branches	Total crown	Bole wt.	Total above-ground	Net accum.	Ref.
Abies balsamea	Canada	40-50	8.52	9.35	17.97	34.43	55.77	9.44	14
do	Canada	40-50	7.92	8.42	16.34	33.77	53.64	9.35	14
do	Canada	40-50	8.36	8.36	16.72	38.28	59.79	9.62	14
do	Canada	40-50	9.02	8.25	17.27	45.43	69.19	10.58	14
do	Canada	40-50	9.13	8.03	17.16	51.81	74.03	11.64	14
do	Canada	40-50	9.57	8.03	17.60	57.53	81.29	12.58	14
A. fraserii	U.S.A.						210.0	5.66	221
do	U.S.A.						200.1	6.53	221
A. grandis	U.K.	21			126.2	229.2	355.4	18.40	134
do	U.K.	24			56.7	108.2	164.9	9.25	134
A. sachalinensis	Japan	26						13.4	163
do	Japan	8	0.43	0.26	0.69	0.34	1.03		239
do	Japan	12	4.23	2.59	6.82	8.45	15.29		239
do	Japan	23	11.32	8.62	19.94	33.10	53.04		239
do	Japan	29	13.40	15.81	29.21	48.08	77.29		239
do	Japan	35	21.95	50.60	72.55	123.57	196.12		239
A. veitchii	Japan	25	16.70	15.69	32.39	190.24	122.63		195
do	Japan	25	17.61	15.48	33.09	107.63	140.72		195
do	Japan	25	13.95	8.67	22.62	45.73	88.35		195
do	Japan	4	5.5	1.8	7.3	4.9	12.2		195
do	Japan	60	18.79	32.36	51.05	205.68	256.73		195
do	Japan	60	13.31	16.94	30.25	129.23	159.48		195
do	Japan	23	21.30	17.01	38.31	44.98	83.29		195
do	Japan	25	18.27	13.61	31.88	42.11	73.99		195
do	Japan	5	7.29	3.45	10.74	9.26	20.00		195
Acacia dealbata	Japan	4	4.4	7.4	11.8	24.0	37.1		56
do	Japan	4	3.9	7.9	11.8	17.9	29.7		56
do	Japan	4	2.6	3.6	6.2	7.0	13.2		56
A. harpophylla	Aust.						159.5		114
A. mollissima	Japan	4	10.0	14.1	24.1	54.0	71.6		56
do	Japan	4					80.6	35.3	192
do	Japan	3	5.74	9.40	15.14	27.94	44.38	25.5	197
do	Japan	3	5.14	7.55	12.69	23.18	37.01	21.3	197
do	Japan	5	7.27	9.94	17.21	75.47	96.07	31.7	197
do	Japan	5	10.59	12.71	23.30	95.98	123.81	40.3	197
do	Japan	5	6.73	7.13	13.86	56.77	73.39	23.8	197
do	Japan	7	5.11	11.32	16.43	59.67	78.25	24.1	197
do	Japan	7	6.70	14.79	21.49	77.65	101.94	31.1	197
Chamaecyparis lawsonii	U.K.	21			43.4	163.5	206.9	10.6	134
C. obtusa	Japan	28	11.7	8.0	19.7	32.6	52.3		62
do	Japan	28	17.5	16.4	33.9	82.0	115.9		62
do	Japan	30	12	12	24	115	139	10.6	238
do	Japan	40	19	25	44	219	263	9.6	238

Table 4. (cont)

Species	Location	Age (yr)	Foliage	Branches	Total crown	Bole wt.	Total above-ground	Net accum.	Ref.
Cryptomeria japonica	Japan	5	26.5	1.8	28.3	50.7	97.3	29.1	196
do	Japan	11					63.6	9.7	198
do	Japan	22					135.7	14.0	198
do	Japan	24					170.5	15.1	198
do	Japan	28	13.0	11.7	24.7	37.0	61.7		62
do	Japan	28	17.2	12.9	30.1	98.3	128.4		62
do	Japan	31					159.8	16.7	198
do	Japan	34					176.4	9.6	198
do	Japan	34					182.5	14.0	198
do	Japan	34					191.7	16.0	198
do	Japan	34					154.0	12.3	198
do	Japan	49					174.5	8.9	198
Ilex aquifolium	U.K.	82					211.0	15.4	146
do	U.K.	100					131.0	9.7	146
do	U.K.	92					38.0	2.2	146
do	U.K.	94					72.0	3.8	146
do	U.K.	80					60.0	3.6	146
I. opaca	U.S.A.	150					178.3	10.8	7
Picea abies	U.K.	20			61.1	157.2	218.3	11.25	132
do	U.K.	47			31.9	107.9	139.8	7.45	132
do	U.K.	47			80.3	182.4	262.7	9.39	132
do	Japan	39	24.6	5.8	30.4	138.3	168.7		136
do	Japan	46	16.9	6.7	23.6	63.2	88.2		136
do	Japan	46	18.6	8.6	27.2	140.2	169.2		136
do	Sweden	52	10.8	18.9	29.7	105.8	132.2		136
do	Switz.	98						8.2	39
do	Japan	37						13.3	163
do	Japan	45						8.73	163
do	Japan	46						12.77	163
do	Japan	46						13.00	163
do	Japan	46						14.01	163
do	Sweden	58					108.6		136
do	U.S.S.R.	24	3.0			69.1	101.2		183
do	U.S.S.R.	38	9.6			113.1	160.8		183
do	U.S.S.R.	60	11.1			195.6	271.4		183
do	U.S.S.R.	93	10.0			249.5	324.9		183
P. amerka	U.K.	21			100.0	198.9	298.9	14.3	134
Picea sp.	U.S.S.R.						100.0	4.5	156
do	U.S.S.R.						260.0	7.0	156
do	U.S.S.R.						330.0	8.5	156
Picea mariana	Canada	65					93.5	1.56	215
Picea - Abies	U.S.A.						340.9	10.2	221
do	U.S.A.						310.1	9.4	221
do	U.S.A.						300.0	14.0	221

Table 4. (cont)

Species	Location	Age (yr)	Foliage	Branches	Total crown	Bole wt.	Total above-ground	Net accum.	Ref.
Picea and *Rhododendron*	U.S.A.						321.0	8.12	221
Thuja plicata	U.K.	22			16.12	52.16	68.3	3.1	134
T. occidentalis	U.S.A.	90					134.5		245
Tsuga heterophylla	U.K.	23			61.19	188.42	249.6	12.94	134
do	U.S.A.	26	21.1	20.7	41.8	150.9	192.7	30.7	55
T. canadiensis	U.S.A.						610.0	11.8	221
Tsuga-Fagus	U.S.A.						193.0	13.3	221
Tsuga - Rhododendron	U.S.A.						511.0	10.2	221
Tsuga sieboldii- Abies fua	Japan		8.85	13.38	22.23	68.60	90.83		57

Table 5. Biomass components and net accumulation (excluding roots and understory) of hardwood species throughout the world (in thousands of kilograms per hectare).

Species	Location	Age (yr)	Foliage	Branches	Total crown	Bole wt.	Total above-ground	Net accum.	Ref.
Acer rubrum	U.S.A.	44					15.23		245
A. spicatum	Canada	1	0.37	0.37	0.74		0.74	0.74	150
do	Canada	3	0.69	1.70	2.39		2.39	0.80	150
do	Canada	8	0.90	2.42	3.32	9.61	12.93	1.62	150
do	Canada	11	0.86	3.85	4.71	11.16	15.87	1.44	150
do	Canada	13	1.03	6.80	7.83	15.36	23.19	1.78	150
do	Canada	16	1.14	7.54	8.68	16.85	25.53	1.60	150
do	Canada	18	0.86	7.19	8.05	13.36	22.41	1.24	150
do	Canada	21	1.20	11.19	12.39	21.11	33.50	1.59	150
do	Canada	23	1.12	10.43	11.55	19.73	31.28	1.36	150
do	Canada	26	1.42	13.71	15.13	25.32	40.45	1.56	150
Betula spp.	U.S.S.R.						220.0	12.0	157
Betula alba	U.K.	22			17.72	45.11	62.84	2.86	134
do	U.K.	22			17.72	41.09	58.81	2.67	134
B. ermanii	Japan	22					62.52		163
B. maximow	Japan	44						6.07	163
do	Japan	47						7.51	163
do	Japan	47						6.32	163
do	Japan	47	1.8	11.1	12.9	77.7	90.6		136
do	Japan	47	2.6	12.1	14.7	128.3	143.0		136
do	Japan	47	2.2	14.8	17.0	100.0	117.0		136
B. papyrifera	U.S.A.	32					118.08		245
B. platyphylla	Japan	10					19.22	5.0	204
B. verrucosa	U.S.S.R.	20	3.8	11.3	15.1	45.7	80.3		136
do	U.S.S.R.	40	3.3	12.7	16.0	190.7	247.6		136
do	U.S.S.R.	67	2.8	11.3	14.1	156.7	213.9		136
do	Sweden	25	2.7	5.8	8.5	38.9	47.4		205
do	U.K.	6	0.1	0.5	0.6	0.9	1.5		142
do	U.K.	24	2.4	6.5	17.1	48.0	65.1		142
do	U.K.	27	1.3	9.5	10.8	68.2	79.0		142
do	U.K.	32	1.6	12.2	13.8	52.8	66.6		142
do	U.K.	38	0.7	14.5	15.2	58.9	74.1		142
do	U.K.	42	1.1	13.6	14.7	58.5	73.2		162
do	U.K.	46	1.6	18.9	20.5	102.3	122.8		142
do	U.K.	53	2.3	33.1	35.4	139.8	175.2		142
do	U.K.	55	2.5	28.7	31.2	134.5	165.7		142
Castanea sativa	U.K.	47			8.24	108.37	116.6	3.75	134
Cinnamomum camphora	Japan	46					196.0	15.0-16.6	163
do	Japan	52						15.26	163
Eucalyptus regnas	Aust.	51	7.0	22.0	29.0	272.0	301.0		11

Table 5. (cont)

Species	Location	Age (yr)	Foliage	Branches	Total crown	Bole wt.	Total above-ground	Net accum.	Ref.
Fagus spp.	Europe						370.0	13.0	157
do	Neth.	46						13.5	95
F. crenata	Japan	35	4.8	31.4	56.2	168.0	258.4	17.4	194
do	Japan	42	4.7	43.5	48.2	166.5	272.9	18.7	194
do	Japan	750	4.9	39.5	89.4	202.2	296.5	19.3	194
F. grandifolia	U.S.A.						130.01	6.68	221
do	U.S.A.						170.1	9.06	221
Fagus sylvatica	U.K.	39			35.45	97.88	133.4	5.05	134
do	Switz.	80						9.67	31
Populus deltoides	U.S.A.	6	2.42	3.30	5.72	35.52	41.24		41
do	U.S.A.	7	3.74	11.88	15.62	55.22	70.84		41
do	U.S.A.	7	2.64	14.30	16.94	38.94	55.88		41
do	U.S.A.	7	3.52	7.04	10.56	45.98	56.54		41
do	U.S.A.	8	3.52	10.56	14.08	54.78	68.86		41
do	U.S.A.	8	2.64	14.52	17.16	55.00	72.16		41
do	U.S.A.	8	2.42	7.48	9.90	36.08	45.98		41
do	U.S.A.	9	1.98	10.34	12.32	55.0	67.32		41
Quercus sp.	U.K.	44			16.37	76.01	92.38	3.24	134
do	U.S.S.R.	22	2.1				55.7		183
do	U.S.S.R.	42	3.2				139.3		183
do	U.S.S.R.	56	3.8				192.2		183
do	U.S.S.R.	200	3.2				403.3		183
Q. borealis	U.S.A.						137.0	8.28	221
Q. petrea	U.K.	21			14.14	28.29	42.43	2.02	134
Q. primus	U.S.A.						422.5	14.7	221
Q. robur	U.K.	47			21.69	106.61	128.3	3.94	134
do	Sweden	125					240.0	15.6	5
Q. rubra	U.K.	21					228.0	20.0	134
Q. rapanea	Japan	80					218.0	23.0	77
do	Japan	80					265.0	28.0	77
do	Japan	80					264.0	28.0	77
Quercus mixed	U.S.A.						87.7	5.68	221
Quercus-Camellia	Japan						228.0	20.0	77
do	Japan						212.0	18.0	77
do	Japan						198.0	18.0	77
Quercus-Carya	U.S.A.						157.0	5.42	113
do	U.S.A.						370.15	12.03	113
Quercus-Fagus	Belgium	70-75					156.0	14.40	47
Quercus-Fraxinus	Belgium	115-160					380.0	14.30	47
Shavea robusta	India	18	10.9	33.3	44.2	88.8	133.0	6.7	104
do	India	30	5.7	45.4	91.1	188.0	234.1	8.8	104
do	India	50	13.7	66.7	80.4	500.1	580.5	16.9	104

Table 6. Accumulated biomass in stands of alder (in thousands of kilograms per hectare).

Species	Location	Age	Foliage	Branch	Total crown	Bole	Total	Ref.
Alnus incana	U.K.	22			32.95	91.74	124.7	134
do	U.K.	22			23.01	74.52	97.5	134
Alnus rubra	U.S.A.	50					250.0	248
do	U.S.A.	30	4.57	15.57	20.14	47.59	76.25	185
Alnus spp.	Alaska	5	1.89	1.43	3.32	5.42	8.75	210
do	Alaska	15	1.63	5.81	7.78	20.23	28.01	210
do	Alaska	20	2.14	9.16	11.33	31.41	42.34	210

Table 7. Comparison of some forest stands approximately 10 years old (range 8-12 yr).

Species	Age	Total crown (kg x 10^3/ha)	Total tree biomass (kg x 10^3/ha)	Comments	Ref.
Pinus radiata	9	18.7	74.6	SQ_{20} 80 [a]	52
do	12	28.2	119.2	SQ_{20} 80	52
do	12	34.7	165.8	SQ_{20} 110	229
P. sylvestris	11	10.15	15.36	planted	135
do	11	24.98	51.63	regenerated	135
P. taeda	8	27.0	99.0	high density	2
do	10		29.70	poor site	186
do	10		55.00	good site	186
P. thunbergii	10	23.09	56.51	good site	6
do	10	29.63	67.77	good site	6
do	10	19.15	37.83	moderate	6
do	10	10.47	20.44	poor	6
do	10	20.67	44.09	good	6
do	10	11.37	22.62	moderate	6
Betula platyphylla	10		19.22		204
Acer spicatum	8	3.32	12.93		150
do	11	4.71	15.87		150
Cryptomeria japonica	11		63.6		198

[a] SQ_{20} = site quality 20 years.

Table 8. Comparison of biomass of some stands approximately 30 years old (range 28-32 yr).

Species	Age	Crown weight (kg x 10^3/ha)	Total biomass (kg x 10^3/ha)	Ref.
Pinus nigra	28	15.40	67.1	233
P. resinosa	32	39.5	124.2	234
P. sylvestris	31	31.13	99.55	135
do	28	18.37	92.4	233
P. taeda	30		89.10	186
do	30		165.00	186
Pseudotsuga menziessi (alder understory)	28	28.4	132.72	185
P. menziessi	28	14.69	43.67	185
do	30	15.64	38.47	64
do	30	28.06	59.01	64
do	32	12.52	35.85	64
do	32	22.24	63.17	64
Betula verrucosa	32	13.8	66.6	142
B. papyrifera	32		118.08	245
Cryptomeria japonica	31		159.8	198
do	28	24.7	61.7	62
do	28	30.1	128.4	62
Chamaecyparis obtusa	28	19.7	52.3	62
do	28	33.9	115.9	62

Table 9. Accumulated biomass in plantations of larch (*Larix* spp.), (in thousands of kilograms per hectare).

Species		Age	Total crown	Bole	Total above-ground	Productivity (kg x 10^{-1} $ha^{-1}yr^{-1}$)	Ref.
Larix decidua	U.K.	46	43.6	145.8	189.4	5.98	134
do	Switz.	50				4.92	33
do	Switz.	105				4.26	33
do	Switz.	220				0.76	33
Larix eurolepsis	U.K.	23	72.7	75.1	147.6	9.64	134
do	Japan	21				19.44	163
do	U.K.	22	34.1	51.9	86.0	4.73	134
do	U.K.	22	23.7	54.7	78.5	4.39	134
do	Japan	39	19.1	145.4	164.4		167

Table 10. Leaf biomass in forests (after Tadaki 1966).

Plant community	Location	Oven dry weight (kg x 10^3/ha)	Leaf area index (ha/ha)	Ref.
Fagus sylvatica	Denmark	2.1-2.7	4.3-5.5	108, 109
do	Denmark	3.1	5.4	21
do	Switz.	3.2	6.2-7.9	31, 36
Fagus crenata	Japan	2.81		130
do	Japan	2.9-3.0		236
do	Japan	6.7	5.2	70
Nothofagus truncata	New Zealand	2.7		102
Quercus robur	Denmark	1.7-2.0	2.6-3.1	108
do	Switz.	5.3		34
Quercus borealis	U.S.A.	3.5		136
Quercus	U.S.S.R.	2.1-3.8		183
Quercus serrata	Japan	2.33		130
Quercus mongolica v. *grosseserrata*	Japan	0.93		130
Quercus acutissima	Japan	1.9-4.5		130
Fraxinus excelsior	Denmark	2.7	5.4	21
Fraxinus mandshurica	Japan	2.2	4.3	203
Betula	Scand.	1.5		123
do	Scand.	1.6		90
Betula verrucosa	England	0.7-2.5	1.7-6.5	142
do	U.S.S.R.	2.8-3.8		182
Betula maximowiczii	Japan	1.8-2.6		163
Betula platyphylla v. *japonica*	Japan	1.2	3.5	204
Betula ermani	Japan	2.4	5.2	85
Sapium sebiferum	Japan	1.1-2.2	2.1-6.9	85
Populus davidiana	Japan	2	2.2	168
Populus sieboldii	Japan	1.3		130
Populus grandientata	Canada	1.55		26
Populus tremuloides	U.S.A.	3.69	6.3	26
Zelkova serrata	Japan	3	4	170
do	Japan	1.2-1.8		130
Ulmus parvifolia	Japan	3	7	203
Alnus spp.	Japan	1.2-4.7		207
Alnus hirsuta v. *sibirica*	Japan	2-4	3-5	177
Salix gracilistyla	Japan	3.5		177
Salix vulpina	Japan	2.3		177
Ligustrum tschonoskii	Japan	2.5		177
Robinia pseudoacacia	Japan	2.5-4.0	5-7	207
Dipterocarp savanna forest	Thailand	4.9	4.3	127
Mixed savanna forest	Thailand	4.9	4.2	127
Machilus-Shiia	Japan	10.1-13.1	7.4-9.6	87
Distylium racemosum	Japan	11.4	8.8	87
Castanopsis-Machilus	Japan	9.7		122
Castanopsis cuspidata	Japan	11.4	12.5	202

Table 10. (cont)

Plant community	Location	Oven dry weight (kg x 10³/ha)	Leaf area index (ha/ha)	Ref.
Castanopsis cuspidata	Japan	6.8-9.6	6.0-8.3	78
do	Japan	7.4	8.0	189
Cinnamomum camphora	Japan	4.1		163
Camellia-Machilus	Japan	12.6	6.3	105
Acacia mollissima	Japan	6.9-8.1		197
Acacia mollissima	Japan	9.9	9.7	192
Tropical rain forest	Thailand	7.8	12.9	84
Evergreen gallery forest	Thailand	19.5	16.6	126
Temperate evergreen forest	Thailand	14.5	12.6	126
Tropical evergreen forest	Congo	6.5		59
Larix decidua	Switz.	1.8-2.6	5-7	33
do	Denmark	2		108
Larix leptolepis	Japan	3.3		175
do	Japan	2.03		130
do	Japan	2.8-4.5		178
do	Japan	3.69		178
Pinus sylvestris	Switz.	5	6.6-7.3	32
do	England	5.1-10.5	5.3-10.8	135
do	Scotland	4.7		233
Pinus nigra	Scotland	5.6		233
Pinus densiflora	Japan	5.3-5.4		169
do	Japan			101
do	Japan	5.5-9.7		79
do	Japan	4.0-7.0		63
Pinus thunbergii	Japan	8		76
Pinus longifolia	W. Pakistan	2.8		79
Pinus exeelsa	W. Pakistan	4.5-4.7		79
Pinus strobus	Switz.		14-17	29
do	Japan	7.4-10.1		173
Pinus pumila	Japan	21.67		176
Picea abies	Denmark	12	13.1	108
do	Switz.	15-20	17-28	32
do	U.S.S.R.	9.6-11.1		183
do	Japan	16.9-24.6		163
do	Sweden	9.1-10.8		205
Picea glehnii	Japan	7.35		177
Picea mariana	Canada	8.56	9.8	215
Pseudotsuga douglasii	Switz.		18.4-27.1	30
Pseudotsuga taxifolia	U.S.A.	8.0-12.0		64
Abies alba	Switz.		17	37
Abies sachalinensis	Japan	19.1		177
Abies mariesii - A. veitchii	Japan	8.6-12.1		131
Abies veitchii	Japan	7.6-14.4		8

Table 10. (cont)

Plant community	Location	Oven dry weight (kg x 10^3/ha)	Leaf area index (ha/ha)	Ref.
Chamaecyparis obtusa	Japan	9.5-10.0		171
do	Japan		11.04	53
do	Japan			208
Cryptomeria japonica	Japan	17-18		208
Cryptomeria japonica (Yabukuguri cultivar)	Japan	16.5-22.7	9.4-13.0	198
Cryptomeria japonica (Aka cultivar)	Japan	17.3-25.6	10.0-14.7	198
Cryptomeria japonica	Japan	16.7-21.8	10.7-13.5	198, 201
do	Japan	26.5	17.2	196

Table 11. Biomass and component parts of a series of forest communities in eastern Nepal (lat. 27° 45') in ascending altitude (in thousands of kilograms per hectare), (after Yoda 1968).

Community	Alt. (m)	Stand ht. (m)	Stand density (St/ha)	Foliage	Total crown	Bole	Roots	Total
Quercus Machilus	2,270	20-30	745	6.6	136.6	320.0	92.0	548.0
Quercus Cinnamommum	2,390	20-30	600	8.4	140.4	339.0	96.0	575.0
Tsuga-Quercus	2,720	40	220	5.7	95.7	461.0	126.0	682.7
Tsuga-Dumosa	2,760	40	280	12.9	82.9	429.0	127.0	638.9
Abies-Tsuga	2,920	20	913	20.6	71.6	346.0	102.0	519.6
Abies spectabilis	3,120	20	563	20.6	61.6	339.0	100.0	500.6
do	3,280	20	713	20.0	54.0	271.0	80.0	405.0
do	3,420	20	488	17.0	53.0	289.0	85.0	427.0
do	3,530	20	275	12.5	40.5	231.0	67.0	338.5
Abies-Rhododendron	3,680	10	1,450	10.6	32.6	127.0	38.0	197.6
Juniperus-Rhododendron	3,830	4-5	3,320	11.0	39.0	68.0	24.0	131.0
Juniperus scrub	3,870	1-2	201,600	4.8	7.0	11.0	6.7	24.7
Rhododendron scrub	4,050	0-2	1,350,000	1.5	1.5	1.65	2.5	5.65
Alpine grass	4,080	0-1		0.3			0.7	0.10
do	4,260	0-05		0.24			0.23	0.47

Table 12. Average biomass and net primary production for forest types (in thousands of kilograms per hectare), (after Art and Marks 1971).

Species or forest type	Tree biomass ($kg \times 10^3/ha$)	Net primary production ($kg \times 10^3\ ha^{-1}yr^{-1}$)	Reference
Boreal forest	200.0	8.0	222
Beech	184.5		138
Temperate *Betula*	148.4		138
Temperate *Picea*	164.8		138
Temperate *Pinus*	162.0		138
Pseudotsuga menziesii	139.1		138
Temperate coniferous[a]		28.0 ± 25%	216
Temperate *Quercus*	174.6		138
Temperate deciduous[a]		12.0 ± 25%	216
Temperate forest	300.0	13.0	222
Subtropical deciduous	410.0	24.5	156
Tropical forest	450.0	20.0	222
do	450.0	20.0	222
Tropical rain forest	7500.0	32.5	156
do	270.9		138
do[a]		500.0 ± 20%	216

[a]Probable maximum for the type.

Table 13. Biomass and net primary production of some northern coniferous stands (USSR) in various latitudinal locations (in thousands of kilograms per hectare), (after Rodin and Bazilevich 1967).

Forest type	Location	Biomass	Net primary production (per yr)
Picea	Northern taiga	100	4.50
Picea	Taiga	260	7.0
Picea	Southern taiga	330	8.50
Pinus	Northern taiga	80.7	
Pinus	Southern taiga	280	6.10

Table 14. Biomass components of some tropical forests (in thousands of kilograms per hectare).

Forest type	Location	Foliage	Total crown	Bole	Total above-ground	Roots	Ref.
Mixed dipterocarp	Thailand	5.0		45.4[a]	66.9		136
Evergreen seasonal	Camb. (12°N)	18.4	215.9	370.7	586.6	95.9	67
do	do	7.20	95.9	201.3	297.2	50.8	67
Melaleuca leucodendron	do	2.13	6.00	7.40	13.40	3.87	67
Evergreen gallery	Thailand	19.8	275.2[a]	383.7			136
Tropical forest							
Age 50 yr	Ghana				389.7		59
Age 18 yr	Congo				191.5		59
Tropical rain forest	Thailand	7.3	106.3	215	321.3 NAR = 28.5	61	84
do	Thailand				404.0		127
do	do	8.4	101.4	230	331.4 NAR = 28.6	32.0	85
Lower montane	P.R.	10.18	70.35	293.64	363.99	124.2	143
Ranvert (La Verde)	do	11.34	72.79	267.99	340.78	104.5	143
do	do	9.21	45.65	153.64	199.29	61.9	143
do	do	9.48	53.76	182.75	236.51	81.6	143
do	do	6.39	37.01	111.13	138.14	41.6	143
do	do	2.59	11.52	37.05	48.57	16.8	143
do	do	3.46	15.89	51.10	66.99	22.6	143
do	do	7.54	38.83	125.18	104.01	57.9	143
do	do	5.27	30.36	103.03	133.39	68.8	143
do	do	7.23	57.12	204.46	261.58	112.2	143
do	do	10.24	49.48	161.73	211.21	58.1	143

[a]Plus branch weight.

1. AKAI, T., and S. ASADA. 1965. Productivity in forests of Betula ermanii. Trans. 75th Meet. Jap. For. Soc. (1964), p. 349-351. (From Satoo 1970.)
2. AKAI, T., S. UEDA, and T. FURONO. 1970. Mechanisms related to (dry) matter production in a young slash pine forest. Bull. Kyoto Univ. For. 41:56-79.
3. AKAI, T., S. UEDA, and T. FURONO. 1971. Mechanisms related to matter production in a young white pine forest. Bull. Kyoto Univ. For. 42:143-162.
4. AKAI, T., S. UEDA, T. FURONO, and H. SAITO. 1972. Mechanisms related to matter production in a thrifty loblolly pine forest. Bull. Kyoto Univ. For. 43:85-105.
5. ANDERSSON, F. 1970. Ecological studies in Scandian woodland and meadow area, southern Sweden. II. Plant biomass, primary production and turnover of organic matter. Bot. Not. 123:8-51.
6. ANDO, T. 1965. Estimation of dry-matter and growth analysis of the young stand of Japanese pine (Pinus thunbergii). Adv. Front. Plant Sci. 10:1-10.
7. ART, H. W., and P. L. MARKS. 1971. A summary table of biomass and net annual primary production in forest ecosystems of the world. IN: H. E. Young (ed.), Forest biomass studies, p. 1-32. (16th IUFRO Congr.) Univ. Maine Press, Orono.
8. ASADA, S., and T. AKAI. 1963. On the treatments of forests in sub-alpine zone. Nagano-Rinyu 38/7:2-49. (From Tadaki 1966.)
9. ATTIWILL, P. M. 1962. Estimating branch dry weight and leaf area from measurements of branch girth in eucalyptus. For. Sci. 8:132-141.
10. ATTIWILL, P. M. 1966. A method for estimating crown weight in eucalyptus and some implications of relationships between crown weight and stem diameter. Ecology 47:795-804.
11. ATTIWILL, P. M. 1971. On the cycling of nutrients in native Eucalyptus obliqua forest. Aust. For. Nutr. Conf., Canberra, August 1971. (Conf. preprint.) 8 p.
12. ATTIWILL, P. M., and J. D. OVINGTON. 1968. Determination of forest biomass. For. Sci. 14:13-15.
13. BAKER, J. B. 1962. Dry matter production in plantations of loblolly pine. M.F. thesis, Duke Univ., Durham, N.C. 45 p.
14. BASKERVILLE, G. L. 1965a. Dry matter production in immature forest stands [French summary]. For. Sci. Monogr. 9:1-42.
15. BASKERVILLE, G. L. 1965b. Estimation of dry weight of tree components and total standing crop in conifer stands. Ecology 46:867-869.
16. BASKERVILLE, G. L. 1966. Dry matter production in immature balsam fir stands: Roots, lesser vegatation and total stand. For. Sci. 12:49-53.
17. BASKERVILLE, G. L. 1972. Use of logarithmic regression in the estimation of plant biomass. Can. J. For. Res. 2:49-53.
18. BLACKMAN, B. G., and C. W. RALSTON. 1968. Dry weight of several piedmont hardwoods. J. For. 66:418-420.
19. BOKHANOVA, N. S. 1971. The aerial phytomass of flood-plain oak forests. Lesoved. Mosk. 2:71-75.
20. BOYER, W. D. 1968. Foliage weight and stem growth in longleaf pine. USDA For. Serv. Note SO-86.

21. BOYSEN-JENSEN, P. 1932. Die Stoffproduktion der Pflanzen. Fischer-Verlag, Jena. 108 p. (From Tadaki 1966.)
22. BRAY, J. R. 1961. Measurement of leaf utilization as an index of minimum level of primary consumption. Oikos 12:70-74.
23. BRAY, J. R. 1962. The primary productivity of vegetation in central Minnesota, U.S.A., and its relationship to chlorophyll content and albedo. IN: H. Leith (ed.), Die Stoffproduktion der Pflanzendecke, p. 102-108. Stoffproduktionstaden, vol. 4. Fischer-Verlag, Stuttgart.
24. BRAY, J. R. 1963. Root production and the estimation of net productivity. Can. J. Bot. 41:65-72.
25. BRAY, J. R. 1964. Primary consumption in three forest canopies. Ecology 45:165-167.
26. BRAY, J. R., and L. A. DUDKIEWICZ. 1963. The composition, biomass, and productivity of two Populus forests. Bull. Torrey Bot. Club 90:298-308.
27. BRAY, J. R., and E. GORHAM. 1964. Litter production in forests of the world. Adv. Ecol. Res. 2:101-157.
28. BUNCE, R. G. H. 1968. Biomass and production of trees in a mixed deciduous woodland. I. Girth and height as parameters for the estimation of tree dry weights. J. Ecol. 56:759-775.
29. BURGER, H. 1929. Holz, Blattmenge und Zuwachs. I. Die Weymouthsföre. Mitt. Schweiz. Centralanst. Forstl. Versuchswes. 15:243-292.
30. BURGER, H. 1935. Holz, Blattmenge und Zuwachs. II. Die Douglasie. Mitt. Schweiz. Centralanst. Forstl. Versuchswes. 19:21-72.
31. BURGER, H. 1940. Holz, Blattmenge und Zuwachs. IV. Ein 80 jähriger Buchenbestand. Mitt. Schweiz. Centralanst. Forstl. Versuchswes. 21:307-348.
32. BURGER, H. 1941. Holz, Blattmenge und Zuwachs. V. Fichten und Föhren verschiedener Herkunft auf verschiedener Kulturorten. Mitt. Schweiz. Centralanst. Forstl. Versuchswes. 22:10-62.
33. BURGER, H. 1945. Holz, Blattmenge und Zuwachs. VII. Die Lärche. Mitt. Schweiz. Centralanst. Forstl. Versuchswes. 24:7-103.
34. BURGER, H. 1947. Holz, Blattmenge und Zuwachs. VIII. Die Eiche. Mitt. Schweiz. Centralanst. Forstl. Versuchswes. 25:211-279.
35. BURGER, H. 1948. Holz, Blattmenge und Zuwachs. IX. Die Föhre. Mitt. Schweiz. Centralanst. Forstl. Versuchswes. 25:435-495.
36. BURGER, H. 1950. Holz, Blattmenge und Zuwachs. X. Die Buche. Mitt. Schweiz. Centralanst. Forstl. Versuchswes. 26:419-468.
37. BURGER, H. 1951. Holz, Blattmenge und Zuwachs. XI. Die Tanne. Mitt. Schweiz. Centralanst. Forstl. Versuchswes. 27:247-286. (From Tadaki 1966.)
38. BURGER, H. 1952. Holz, Blattmenge und Zuwachs. XII. Fichten im Plenterwald. Mitt. Schweiz. Centralanst. Forstl. Versuchswes. 28:109-156.
39. BURGER, H. 1953. Holz, Blattmenge und Zuwachs. XIII. Fichten im gleichalterigen Hochwald. Mitt. Schweiz. Centralanst. Forstl. Versuchswes. 29:28-130.
40. CABLE, D. R. 1958. Estimating surface area of ponderosa pine foliage in central Arizona. For. Sci. 4:45-49.
41. CARTER, M. C., and E. H. WHITE. 1971. Dry weight and nutrient accumulation in young stands of cottonwood (Populus deltoides Bartr.). Auburn Univ., Agric. Exp. Stn. Circular 190. 14 p.

42. COLE, D. W., and S. F. DICE. 1969. The universality of regression prediction methods for forest biomass assessment. Paper presented at Int. Bot. Congr., Seattle, Wash.
43. COLE, D. W., S. P. GESSEL, and S. F. DICE. 1967. Distribution and cycling of nitrogen, phosphorus, potassium and calcium in a second-growth Douglas-fir ecosystem. IN: H. E. Young (ed.), Primary productivity and mineral cycling in natural ecosystems, p. 197-213. (AAAS Symp.) Univ. Maine Press, Orono. 245 p.
44. CROW, T. R. 1970. The estimation of biomass in a natural stand of jack pine. Ph.D. thesis, Univ. Minnesota. 143 p.
45. CROW, T. R. 1971. Estimation of biomass in an even aged stand--Regression and mean tree techniques. IN: H. E. Young (ed.), Forest biomass studies, p. 35-50. (16th IUFRO Congr.) Univ. Maine Press, Orono.
46. DICE, S. F. 1970. The biomass and nutrient flux in a second growth Douglas-fir ecosystem (A study in quantitative ecology). Ph.D. thesis, Univ. Washington, Seattle. 165 p.
47. DUVIGNEAUD, P., and S. DENAEYER-DE SMET. 1968. Biomass, productivity and mineral cycling in deciduous mixed forests in Belgium. IN: H. E. Young (ed.), Primary productivity and mineral cycling in natural ecosystems, p. 167-186. (AAAS Symp.) Univ. Maine Press, Orono. 245 p.
48. DUVIGNEAUD, P., and S. DENAEYER-DE SMET. 1970. Biological cycling of minerals in temperate deciduous forests. IN: D. E. Reichle (ed.), Analysis of temperate forest ecosystems, p. 199-225. Springer-Verlag, Heidelberg. 304 p.
49. EGUNJOBI, J. K. 1971. Ecosystem processes in a stand of Ulex europaeus L. I. Dry matter production, litterfall and efficiencies of solar energy utilization. J. Ecol. 59:31-38.
50. FORD, E. D., and P. J. NEWBOULD. 1970. Stand structure and dry weight production through the sweet chestnut (Castanea sativa Mill) coppice cycle. J. Ecol. 58:275-296.
51. FORREST, W. G. 1969. Variations in the accumulation, distribution and movement of mineral materials in radiata pine plantations. Ph.D. thesis, Australian National Univ., Canberra. 276 p.
52. FORREST, W. G., and J. D. OVINGTON. 1970. Organic matter changes in an age series of Pinus radiata plantations. J. Appl. Ecol. 7:177-186.
53. FUJII, S. 1959. Intercepted rainfall by Hinoki (Chamaecyparis obtusa S. et Z.) forest. J. Jap. For. Soc. 41:262-269. (From Tadaki 1966)
54. FUJIMORI, T. 1971a. Analysis of forest canopy on the basis of a Tsuga heterophylla forest. Jap. J. Ecol. 21:134-140.
55. FUJIMORI, T. 1971b. Primary productivity of a young Tsuga heterophylla stand and some speculations about biomass of forest communities on the Oregon coast. USDA For. Serv. Res. Pap. PNW-123. 11 p.
56. FUJIMORI, T., and K. YAMAMOTO. 1967. Productivity of Acacia dealbata stands--A report on four-year old stands in Okayama prefecture. J. Jap. For. Soc. 49:143-149.
57. FURONO, T., and S. KAWASAKI. 1967. Investigations on the productivity of Japanese fir (Abies fuma Sieb. and Zucc.) and hemlock (Tsuga sieboldii Carr.) stands in Kyoto University Forest in Wakayama. I. On the growth of Japanese fir stands. Bull. Kyoto Univ. For. 39:9-26.

58. FURONO, T. 1971. Investigations on the productivity of Japanese fir (Abies fuma Sieb. et Zucc.) and hemlock (Tsuga sieboldii Carr.) stands in Kyoto University Forest. Bull. Kyoto Univ. For. 42:128-142.

59. GREENLAND, D. J., and J. M. KOWAL. 1960. Nutrient content of the moist tropical forest of Ghana. Plant Soil 12:154-174.

60. HARADA, H. 1970. On the growth and nutrient content of Cryptomeria trees and the effect of forest fertilization on these characters [in Japanese, English summary]. Bull. Gov. For. Exp. Stn. Tokyo, 230:1-104.

61. HARADA, H., and H. SATO. 1966. On the dry matter and nutrient contents of the stem of mature Cryptomeria trees and their distribution to the bark, sapwood and heartwood. J. Jap. For. Soc. 48:315-324.

62. HARADA, H., H. SATO, I. HOTTA, and Y. TADAKI. 1969. On the amount of nutrient contained in 28-year-old Cryptomeria forest (C. japonica D. Don.) and Chamaecyparis forest (C. obtusa Sieb. et Zucc.). J. Jap. For. Soc. 51:125-133.

63. HATIYA, K., K. DOI, and R. KOBAYASHI. 1965. Analysis of the growth in Japanese red pine (Pinus densiflora) stands. A report on the matured plantation in Iwate Prefecture. Bull. Gov. For. Exp. Stn., Tokyo 176:75-88.

64. HEILMAN, P. E. 1961. Effects of nitrogen fertilization on the growth and nitrogen distribution of low-site Douglas-fir stands. Ph.D. thesis, Univ. Washington. 214 p.

65. HONER, T. G. 1971. Weight relationships in open- and forest-grown balsam fir trees. IN: H. E. Young (ed.), Forest biomass studies, p. 63-78. (16th IUFRO Congr.) Univ. Maine Press, Orono.

66. HOZUMI, K. 1963. Allometry in higher plants. 2. Allometry in trees, especially on the allometry relating to DBH (in Japanese). Seicho 2:1-18.

67. HOZUMI, K., Y. KOYJI, S. KOKAWA, and T. KIRA. 1969. Production ecology of tropical rain forests in southwest Cambodia. 1. Plant biomass. Nat. Life Southeast Asia 6:1-51.

68. HUGHES, M. K. 1971. Tree biocontent per production and litterfall in a deciduous woodland. Oikos 22:62-73.

69. HUTNIK, R. T. 1964. Accumulation and production of dry matter on red pine plantations of various spacings. Ph.D. thesis, Duke University.

70. IKUSHIMA, I. 1964. Flora and plant communities of Tanzawa Mountains. Rep. Sci. Tanzawa Mountains, Kanagawa Pref., p. 106-125. (From Tadaki 1966.)

71. ILINSKI, V. V. 1968. Biomass of pine in stands of different site classes (in Russian). Lesn. Khoz. 3:34.

72. IWAKI, H. 1958. The influence of density on the dry matter production of Fugropyrum esculertum. Jap. J. Bot. 16:210-226.

73. JOHNSTONE, W. D. 1971. Total standing crop and tree component distributions in three stands of 100-year-old lodgepole pine. IN: H. E. Young (ed.), Forest biomass studies, p. 81-92. (16th IUFRO Congr.) Univ. Maine Press, Orono.

74. JORDAN, C. F. 1971. Productivity of a tropical forest and its relation to a world pattern of energy storage. J. Ecol. 59:127-142.

75. JURGENSEN, M. F., and A. L. LEAF. 1965. Soil moisture--fertility interactions related to growth and nutrient uptake in red pine. Soil Soc. Am. Proc. 29:294-300.

76. KABAYA, H., I. IKUSHIMA, and M. NUMATA. 1964. Growth and thinning of Pinus thunbergii stand--Ecological studies of coastal pine forest. I. Bull. Mar. Lab. Chiba Univ. 6:1-26
77. KAN, M., H. SAITO, and T. SHIDEI. 1965. Studies of the productivity of evergreen broad leaved forests (in Japanese, English summary). Bull. Kyoto Univ. For. 37:55-75.
78. KAN, M., T., SHIDEI, and T. TSUTSUMI. 1962. On the productivity of evergreen broad leaved forest (preliminary report on Castanopsis stand). Rec. 72nd Meet. Jap. For. Soc., p. 249-250. (From Tadaki 1966.)
79. KAWANABE, S., T. SHIDEI, and G. IWATSUBO. 1962. Organic matter production of pine stands in Pakistan and Japan. Rec. 72nd Meet. Jap. For. Soc., p. 242-244. (From Tadaki 1966.)
80. KEAY, J., and A. G. TURTON. 1970. Distribution of biomass and major nutrients in a maritime pine plantation. Aust. For. 34:39-48.
81. KHODZHAMKULYEV, A. 1971. Productivity of plantation of Ulmus carpinifolia in southeast Turkmenia. Lesoved. Mosk. 5:71-75. (From For. Abstr. 33:2267.)
82. KIMURA, M. 1960. Primary production of the warm temperate laurel forest in the southern part of Osumi Peninsula, Kyushu, Japan. Misc. Rep. Res. Inst. Nat. Resour. 52-53:36-47.
83. KIRA, T., and H. OGAWA. 1968. Indirect estimation of root biomass increment in trees. IN: M. S. Ghilarov, V. A. Kovda, L. N. Novichkova-Ivanova, L. E. Rodin, and V. M. Sveshnkova (eds.), Methods of productivity studies in root systems and rhizosphere organisms, p. 96-101. USSR Academy of Science and Nauka, Leningrad.
84. KIRA, T., H. OGAWA, K. YODA, AND K. OGINO. 1964. Primary production by a tropical rain forest of southern Thailand. Bot. Mag. (Tokyo) 77:428-429.
85. KIRA, T., H. OGAWA, K. YODA, and K. OGINO. 1967. Comparative ecological studies on three main types of forest vegetation in Thailand. IV. Dry matter production, with special reference to the Khao Chong rain forest. Nat. Life Southeast Asia 5:149-174.
86. KIRA, T., and T. SHIDEI. 1967. Primary production and turnover of organic matter in different forest ecosystems of the western Pacific. Jap. J. Ecol. 17:70-87.
87. KITAZAWA, Y., M. KIMURA, Y. TEZUKA, H. KURASAWA, M. SAKAMOTO, AND M. YOSHINO. 1959. Plant ecology of the southern part of Osumi Peninsula. Misc. Rep. Res. Inst. Nat. Resour. 49:19-36. (From Tadaki 1966.)
88. KITTREDGE, J. 1944. Estimation of the amount of foliage of trees and stands. J. For. 42:905-912.
89. KITTREDGE, J. 1945. Some quantitative relations of foliage in the chaparral. Ecology 26:70-73.
90. KNUDSEN, F., and O. G. MAURITZ-HANSSON. 1939. Om produktionen af lövförna och dennas sammen sättning i et mellansvenskt kjörkestånd. Svenska Skogvårdsför, Tidskr., Stockholm. (From Tadaki 1966.)
91. KNYAZANA, L. A. 1971. Productivity of plantations in the dry steppes of West Kazakhastan (in Russian). Rast. Resur. 7:548-560.
92. KOZAK, A. 1970. Methods for ensuring additivity of biomass components by regression analysis. For. Chron. 46:402-404.
93. KUSUMOTO, T. 1961. An ecological analysis of the distribution of broad-leaved evergreen trees, based on the dry matter production. Jap. J. Bot. 17:307-331.

94. LAK'YANETS, V. B. 1971. The aerial phytomass in plantations of oak originating from different forest types. Lesoved. Mosk. 5:32-36.

95. LEITH, H. (ed.) 1962. Die Stoffproduktion der Pflanzendecke. Stoffproduktionsdaten, vol. 4. Fischer-Verlag, Stuttgart.

96. LOOMIS, R. M., R. E. PHARES, and S. S. CROSBY. 1966. Estimating foliage and branchwood quantities in shortleaf pine. For. Sci. 12:30-39.

97. MADGWICK, H. A. I. 1967. Some factors affecting the vertical distribution of foliage in pine camopies. IN: H. E. Young (ed.), Primary productivity and mineral cycling in natural ecosystems, p. 223-265. (AAAS Symp.) Univ. Maine Press, Orono. 245 p.

98. MADGWICK, H. A. I. 1968. Seasonal changes in biomass and annual production of an old-field Pinus virginiana stand. Ecology 49:149-152.

99. MADGWICK, H. A. I. 1971. The accuracy and precision of estimates of the dry matter in stems, branches and foliage in an old-field Pinus virginiana stand. IN: H. E. Young (ed.), Forest biomass studies, p. 103-112. (16th IUFRO Congr.) Univ. Maine Press, Orono.

100. MADGWICK, H. A. I., E. H. WHITE, G. K. XYDIAS, and A. L. LEAF. 1970. Biomass of Pinus resinosa in relation to potassium nutrition. For. Sci. 2:155-159.

101. MARUYAMA, I., and T. SATO. 1953. Estimation of amount of foliage of tree and stand. I. On the Akamatsu of Iwate district. Bull. Gov. For. Exp. Stn. Tokyo 65:1-10.

102. MILLER, P. (Unpubl. MS cited in: J. D. Ovington. 1962. Quantitative ecology and the woodland ecosystem concept. Advan. Ecol. Res. 1:103-192.)

103. MISRA, R. 1969. Studies on the primary productivity of terrestrial communities at Varanasi. Trop. Ecol. 10:1-15.

104. MISRA, R., J. S. SINGH, and K. P. SINGH. 1967. Preliminary observations on the production of dry matter by sal (Shorea robusta Gaertin. f.). Trop. Ecol. 8:94-104.

105. MIYATA, I., and T. SHIOMI. 1965. Ecological studies on the vegetation of Akiyoshidai limestone platueau. I. Structure of the forest community of "Chojaga-mori." Jap. J. Ecol. 15:29-34. (From Tadaki 1966.)

106. MOIR, W. H., and R. FRANCIS. 1972. Foliage biomass and surface area in three Pinus contorta plots in Colorado. For. Sci. 18:41-45.

107. MÖLLER, C. M. 1945. Untersuchungen über Laubmenge, Stoffverlust und Stoffproduktion des Waldes (Danish summary). Forstl. Forsogsvaes. Dan. 17:1-287.

108. MÖLLER, C. M. 1947. The effect of thinning, age, and site on foliage, increment, and loss of dry matter. J. For. 45:393-404.

109. MÖLLER, C. M., D. MÜLLER, and J. NIELSEN. 1954a. Loss of branches in European beech. Forstl. Forsogsvaes. Dan. 21:253-271.

110. MÖLLER, C. M., D. MÜLLER, and J. NIELSEN. 1954b. Graphic presentation of dry matter production of European beech. Forstl. Forsogsvaes. Dan. 21:327-335.

111. MÖLLER, W. E. 1965. Number of branchlets on red pine in young plantations. For. Sci. 11:42-49.

112. MONK, C. D. 1966. Root-shoot dry weights in loblolly pine. Bot. Gaz. 127:246-248.

113. MONK, C. D., G. I. CHILD, and S. A. NICHOLSON. 1970. Biomass, litter and leaf surface area estimates of an oak-hickory forest. Oikos 21:138-141.

114. MOORE, A. W., J. L. RUSSELL, and J. E. COALDRAKE. 1967. Dry matter and nutrient content of a subtropical forest of Acacia harpophylla F. Muell. (Brigalow). Aust. J. Bot. 15:11-24.
115. MUKHAMEDSHIN, F. D. 1971. Methods of determining the aerial biomass in Central Asian juniper stands. IN: (Symposium on) Materialov po Voprosam Lesn. Khoz. Tazisy. Dokl. Frunze (publ.), Krygyzstan. (From For. Abstr. 33:2262.)
116. MÜLLER, D., and J. NIELSEN. 1965. Production brute, pertes par respiration et production nette dans la foret ombrophile tropicale (Danish summary). Forstl. Forsogsvaes. Dan. 29:69-160.
117. NELSON, L. E., G. L. SWITZER, and W. H. SMITH. 1968. Dry matter and nutrient accumulation in young loblolly pine (Pinus taeda L.). IN: C. T. Youngberg and C. B. Davey (eds.), Tree growth and forest soils, p. 261-274. Oregon State Univ. Press, Corvallis.
118. NEWBOULD, P. J. 1963. Production ecology. Sci. Prog. 51:93-104.
119. NEWBOULD, P. J. 1967. Methods for estimating the primary production of forests. International Biological Programme Handbook no. 2. Blackwell, Oxford and Edinburgh. 62 p.
120. NEWBOULD, P. J. 1968. Methods of estimating root production (in English, French summary). IN: F. E. Eckardt (ed.), Functioning of terrestrial ecosystems at the primary production level, p. 187-190. UNESCO, Paris.
121. NOMOTO, N. 1964. Primary productivity of beech forest in Japan. Jap. J. Bot. 18:385-421.
122. NOMURA, Y., and H. SATO. 1963. Vegetation of Iriomote Island. Sci. Rep. Osaka City Univ. Exp. Yaeyama Archipelago, p. 177-196. (From Tadaki 1966.)
123. NORDFORS, G. A. 1923. Nagot om björken, dess förhallande til gronen O.S.V. Norrlands Skogvårdsför. Tidskr., Stockholm. (From Tadaki 1966.)
124. ODUM, E. P., and H. T. ODUM. 1959. Fundamentals of ecology. 2d ed. Saunders, Philadelphia. 546 p.
125. OGASAWARI, R. 1971. Studies on productivity of Japanese red pine forests on Tottori University Forest in Mizoguchi. I. Biomass and growth of about 20-25 years old stands. Bull. Tottori Univ. For. 8:29-37. (From For. Abstr. 33:2263.)
126. OGAWA, H., K. YODA, and T. KIRA. 1961. A preliminary survey on the vegetation of Thailand. Nat. Life Southeast Asia 1:21-157.
127. OGAWA, H., K. YODA, K. OGINO, and T. KIRA. 1965. Comparative ecological studies on three main types of forest vegetation in Thailand. II. Plant biomass. Nat. Life Southeast Asia 4:49-80.
128. OGINO, K., M. MORITA, and T. SHIDEI. 1967. Branch dry weight and its growth. I (in Japanese, English summary). Bull. Kyoto Univ. For. 39:79-90.
129. OGINO, K., S. SABHASRI, and T. SHIDEI. 1966. The estimation of the standing crop of the forest in northern Thailand. Southeast Asia Stud. 1:89-97.
130. OHMASA, M., and K. MORI. 1937. The amount of fall and decomposition of the leaf-litter of the forest. Bull. For. Exp. Stn. Imp. Household Tokyo 3/3:39-107.

131. OSHIMA, Y., M. KIMURA, H. IWAKI, and S. KUROIWA. 1958. Ecological and physiological studies on the vegetation of Mt. Shimagare. 1. Preliminary survey of the vegetation of Mt. Shimagare. Bot. Mag. Tokyo 71:289-301. (From Tadaki 1966.)

132. OVINGTON, J. D. 1954. Studies of the development of woodland conditions under different trees. 2. The forest floor. J. Ecol. 42:71-80.

133. OVINGTON, J. D. 1955. Studies of the development of woodland conditions under different trees. 3. The ground flora. J. Ecol. 43:1-21.

134. OVINGTON, J. D. 1956. The form, weights and productivity of tree species grown in close stands. New Phytol. 55:289-304.

135. OVINGTON, J. D. 1957. Dry-matter production by Pinus sylvestris L. Ann. Bot. n.s. 21:289-314.

136. OVINGTON, J. D. 1962. Quantitative ecology and the woodland ecosystem concept. Adv. Ecol. Res. 1:103-192.

137. OVINGTON, J. D. 1963. Flower and seed production. A source of error in estimating woodland production, energy flow and mineral cycling. Oikos 14:148-153.

138. OVINGTON, J. D. 1965. Organic production, turnover and mineral cycling in woodlands. Biol. Rev. 40:295-336.

139. OVINGTON, J. D., W. G. FORREST, and J. S. ARMSTRONG. 1967. Tree biomass estimation. IN: H. E. Young (ed.), Primary productivity and mineral cycling in natural ecosystems, p. 4-31. (AAAS Symp.) Univ. Maine Press, Orono. 245 p.

140. OVINGTON, J. D., D. HEITKAMP, and D. B. LAWRENCE. 1963. Plant biomass and productivity of prairie, savanna, oakwood and maize field ecosystems in central Minnesota. Ecology 44:52-63.

141. OVINGTON, J. D., and H. A. I. MADGWICK. 1959a. Distribution of organic matter and plant nutrients in a plantation of Scots pine. For. Sci. 5:344-355.

142. OVINGTON, J. D., and H. A. I. MADGWICK. 1959b. The growth and composition of natural stands of birch. 1. Dry-matter production. Plant Soil 10:271-283.

143. OVINGTON, J. D., and J. S. OLSEN. 1970. Biomass and chemical content of El Verde lower montane rain forest plants. IN: E. P. Odum (ed.), A tropical rain forest, p. H53-H78. U.S. Atomic Energy Comm.

144. OVINGTON, J. D., and W. H. PEARSALL. 1956. Production ecology. II. Estimates of average production by trees. Oikos 7:202-205.

145. PADDOCK, R. W. 1962. Certain quantitative nutrient descriptions for different stages of plant succession of the Fern Lake watershed. M.F. thesis, Univ. Washington. 102 p.

146. PETERKEN, G. F., and P. S. NEWBOULD. 1966. Dry matter production by Ilex aquifolium L. in the New Forest. J. Ecol. 54:143-150.

147. PETERSON, E. B., Y. H. CHAN, and J. B. CRAGG. 1970. Aboveground standing crop, leaf area and caloric value in an aspen clone near Calgary, Alberta. Can. J. Bot. 48:1459-1469.

148. POLLARD, D. F. W. 1971. Mortality and annual changes in distribution of above ground biomass in an aspen sucker stand. Can. J. For. Res. 1:62-66.

149. POLLARD, D. F. W. 1972. Above ground dry matter production in three stands of trembling aspen. Can. J. For. Res. 2:27-33.

150. POST, L. J. 1970. Dry-matter production of mountain maple and balsam fir in northwestern New Brunswick. Ecology 51:548-550.

151. RIEDACKER, A. 1968a. Methode d'estimation de la biomasse d'un arbre. Internal publication of Centre National des Recherches Forestieres, Nancy, France.
152. RIEDACKER, A. 1968b. Methodes indirectes d'estimation de la biomasse des arbres et des peupplementes forestiers. Internal publication of Centre National des Recherches Forestieres, Nancy, France.
153. RIEDACKER, A. 1970. Measurements of different components of trees for physiological investigations. Internal publication of Centre National des Recherches Forestieres, Nancy, France.
154. RIEKERK, H. 1967. The movement of phosphorus, potassium and calcium in a Douglas-fir forest ecosystem. Ph.D. thesis, Univ. Washington. 142 p.
155. RODIN, L. E., and N. I. BASILEVICH. 1966. The biological productivity of the main vegetation types in the Northern Hemisphere of the Old World. For. Abstr. 27:369-372.
156. RODIN, L. E., and N. I. BASILEVICH. 1967. Production and mineral cycling in terrestrial vegetation. Translated by G. E. Fogg. Oliver & Boyd, Edinburgh and London. 288 p.
157. RODIN, L. E., and N. I. BASILEVICH. 1968. World distribution of plant biomass (French summary). IN: F. E. Eckardt (ed.), Functioning of terrestrial ecosystems at the primary production level, p. 45-52. UNESCO, Paris.
158. ROTHACHER, J. S., F. E. BLOW, and S. M. POTTS. 1954. Estimating the quantity of tree foliage in oak stands in the Tennessee Valley. J. For. 52:169-173.
159. SAITO, H., and T. KAWAHARA. 1970. Productivity of young stands of Metasequoia glyptostroboides (in Japanese, English title and summary). Bull. Kyoto Univ. For. 41:80-91.
160. SAITO, H., T. SHIDEI, and T. KUA. 1965. Dry-matter production by Camellia japonica stands (in Japanese, English title and summary). Jap. J. Ecol. 15:131-139.
161. SATOO, T. 1962. Notes on Kittredge's method of estimation of amount of leaves of forest stand (Japanese summary). J. Jap. For. Soc. 44:267-272.
162. SATOO, T. 1965. Further notes on the method of estimation of amount of leaves of forest stand. J. Jap. For. Soc. 47:185-189.
163. SATOO, T. 1966. Production and distribution of dry matter in forest ecosystems. Misc. Inf. Tokyo Univ. For. 16:1-15.
164. SATOO, T. 1967. Primary production relations in woodlands of Pinus densiflora. IN: H. E. Young (ed.), Primary productivity and mineral cycling in natural ecosystems, p. 52-80. (AAAS Symp.) Univ. Maine Press, Orono. 245 p.
165. SATOO, T. 1968. Materials for the study of growth in stands. 7. Primary production and distribution of produced dry matter in a plantation of Cinnamomum camphora (Japanese summary). Bull. Tokyo Univ. For. 64:241-275.
166. SATOO, T. 1970a. A synthesis of studies by the harvest method: Primary production relations in the temperate deciduous forests of Japan. IN: D. E. Reichle (ed.), Analysis of temperate forest ecosystems, p. 55-72. Springer-Verlag, Heidelberg. 304 p.
167. SATOO, T. 1970b. Primary production in a plantation of Japanese larch, Larix leptolepsis--A summarized report of JPTF-66KOIWAI. J. Jap. For. Soc. 57:154-158.

168. SATOO, T., R. KUNUNGI, and A. KUMEKAWA. 1956. Materials for the studies of growth in stands. 3. Amount of leaves and production of wood in an aspen (Populus davidiana) second growth in Hokkaido (in Japanese, English summary). Bull. Tokyo Univ. For. 52:33-51.
169. SATOO, T., K. NAKAMURA, and M. SENDA. 1955. Materials for the studies of growth in stands. 1. Young stands of Japanese red pine of various density. Bull. Tokyo Univ. For. 48:65-90.
170. SATOO, T., K. NEGISHI, and M. SENDA. 1959. Materials for the studies of growth in stands. 5. Amount of leaves and growth in plantations of Zelkova serrata supplied with crown thinning (in Japanese, English summary). Bull. Tokyo Univ. For. 55:101-123.
171. SATOO, T., and M. SENDA. 1958. Materials for the studies of growth in stands. 4. Amount of leaves and production of wood in a young plantation of Chamaecyparis obtusa (in Japanese, English summary). Bull. Tokyo Univ. For. 54:71-100.
172. SATOO, T., and M. SENDA. 1966. Materials for the studies of growth in stands. 6. Biomass, dry matter production, and efficiency of leaves in a young Cryptomeria plantation (in Japanese, English summary). Bull. Tokyo Univ. For. 62:117-146.
173. SENDA, M., and T. SATOO. 1956. Materials for the study of growth in stands. 2. White pine (Pinus strobus) stands of various densities in Hokkaido. Bull. Tokyo Univ. For. 52:15-31.
174. SHANKS, R. E., and E. E. C. CLEBSCH. 1962. Computer programs for the estimation of forest stand weight and mineral pool. Ecology 43:339-341.
175. SHIBAMOTO, T. 1951. Productivity of forest soil in Japan and fertilizer for plantation. Midori 3/3:9-16. (From Tadaki 1966.)
176. SHIDEI, T. 1963. Productivity of Hiamatsu (Pinus pumila) community growing in alpine zone of Tateyama-range. J. Jap. For. Soc. 45:169-173.
177. SHIDEI, T., et al. 1960. Studies on the productivity of the forest. 1. Essential needle-leaved forests of Hokkaido. Kokusaku Pulp Inc. Co., Tokyo. 100 p. (From Tadaki 1966.)
178. SHIDEI, T., et al. 1964. Studies on the productivity of the forest. 2. Larch (Larix leptolepis Gord.) forests of Shinshu district. Jap. For. Tech. Assoc., Tokyo. 61 p. (From Tadaki 1966.)
179. SHINOZAKI, K., K. YODA, K. HOZUMI, and T. KIRA. 1964a. A quantitative analysis of plant form--The pipe model theory. 1. Basic analyses. Jap. J. Ecol. 14:97-105.
180. SHINOZAKI, K., K. YODA, K. HOZUMI, and T. KIRA. 1964b. A quantitative analysis of plant form--The pipe model theory. 2. Further evidence of the theory and its application to forest ecology. Jap. J. Ecol. 14:133-139.
181. SILVER, G. T. 1962. The distribution of Douglas-fir foliage by age. For. Chron. 38:433-438.
182. SMORNOVA, K. M., and G. A. GORODENTSSEVA. 1958. The consumption and rotation of nutritive elements in birch wood. Bull. Soc. Nat. Moscow (Biol.) 62:135-147. (From Tadaki 1966).
183. SONN, S. W. 1960. Der Einfluss des Waldes auf die Boden. Gustav Fischer-Verlag, Jena. 166 p.
184. STAPLES, G. R. 1969. Productivity of red pine. I. Foliage distribution in tree crown and stand canopy. Agric. Meteorol. 6:275-282.
185. SWANK, W. T. 1960. A quantitative analysis of vegetation on the Fern Lake watershed. M.F. thesis, Univ. Washington. 90 p.
186. SWITZER, G. L., L. E. NELSON, and W. H. SMITH. 1966. The characterization of dry matter and nitrogen accumulation by loblolly pine (Pinus taeda L.). Soil Sci. Soc. Am. Proc. 30:114-119.

187. SWITZER, G. L., L. E. NELSON, and W. H. SMITH. 1968. The mineral cycle in forest stands. IN: G. W. Bengston (chm.), Forest fertilization--Theory and practice. Tennessee Valley Authority, Muscle Shoals, Ala.

188. TADAKI, Y. 1963. Studies on the production structure of forest. 4. Some studies on leaf-amount of stands and individual trees. J. Jap. For. Soc. 45:249-256.

189. TADAKI, Y. 1965a. Studies on production structure of forest. 7. The primary production of a young stand of Castanopsis cuspidata. Jap. J. Ecol. 15:142-147.

190. TADAKI, Y. 1965b. Studies on production structure of forest. 8. Productivity of an Acacia mollissima stand in higher stand density. J. Jap. For. Soc. 47:384-391 (in Japanese).

191. TADAKI, Y. 1966. Some discussion on the leaf biomass of forest stands and trees. Bull. Gov. For. Exp. Stn. Tokyo 184:135-161.

192. TADAKI, Y. 1968. The primary productivity and the stand density control of Acacia mollissima. Bull. Gov. For. Exp. Stn. Tokyo 216:99-126.

193. TADAKI, Y., K. HATIYA, and H. MIYAUCHI. 1967a. Studies on the production structure of forest. 12. Primary productivity of Abies veitchii in the natural forests at Mt. Fuji. J. Jap. For. Soc. 49:421-428.

194. TADAKI, Y., K. HATIYA, and K. TOCHIAKI. 1969. Studies on the production structure of forest. 15. Primary productivity of Fagus crenata in plantation. J. Jap. For. Soc. 51:331-339.

195. TADAKI, Y., K. HATIYA, K. TOCHIAKI, H. MIYAUCHI, and U. MATSUDA. 1970. Studies on the production structure of forest. 16. Primary productivity of Abies veitchii forest in the subalpine zone of Mt. Fuji. Bull. Gov. For. Exp. Stn. Tokyo 229:1-20.

196. TADAKI, Y., and Y. KAWASAKI. 1966. Studies on the production structure of forest. 9. Primary productivity of a young Cryptomeria plantation with excessively high stand density. J. Jap. For. Soc. 48:55-61.

197. TADAKI, Y., N. OGATA, and Y. NAGATOMO. 1963. Studies on the production structure of forest. 5. Some analyses on productivities of artificial stands of Acacia mollissima. J. Jap. For. Soc. 45:293-301.

198. TADAKI, Y., N. OGATA, and Y. NAGATOMO. 1965. The dry matter productivity in several stands of Cryptomeria japonica in Kyushu. Bull. Gov. For. Exp. Stn. Tokyo 173:45-66.

199. TADAKI, Y., N. OGATA, and Y. NAGATOMO. 1967b. Studies on the production structure of forest. 11. Primary productivities of 28-year-old plantations of Cryptomeria of cuttings and of seedlings origin. Bull. Gov. For. Exp. Stn. Tokyo 199:47-66.

200. TADAKI, Y., N. OGATA, Y. NAGATOMO, and T. YOSHIDA. 1966. Studies on the production of forest. 10. Primary productivity of an unthinned 45-year-old stand of Chamaecyparis obtusa. J. Jap. For. Soc. 48:387-393.

201. TADAKI, Y., N. OGATA, Y. NAGATOMO, K. YOSIOKA, and Y. MIYAGAWA. 1964. Studies on the production structure of forest. 6. Productivities of scaffolding producing stands of Cryptomeria japonica. J. Jap. For. Soc. 46:246-253.

202. TADAKI, Y., N. OGATA, and T. TAKAGI. 1962. Studies on the production structure of forest. 3. Estimation of standing crop and some analyses on productivity of young stands of Castanopsis cuspitada. J. Jap. For. Soc. 44:350-359.

203. TADAKI, Y., and T. SHIDEI. 1960. Studies on the productive structure of forest. I. The seasonal variation of leaf amount and the dry matter production of deciduous sapling stand (Ulmus parvifolia). J. Jap. For. Soc. 42:427-434.

204. TADAKI, Y., T. SHIDEI, T. SAKASEGAWA, and K. OGINO. 1961. Studies on the productive structure of forest. 2. Estimation of standing crop and some analyses on productivity of young birch stand (Betula platyphylla). J. Jap. For. Soc. 43:19-26.

205. TAMM, C. O., and C. CARBONNIER. 1961. Vaxtnaringen som skoglig produktionsfaktor. Kungl. Skogsvårdsfoeren. Lantbruksakad. Sammantrade Tidskr. 100(Suppl.):95-124.

206. TEZUKA, Y. 1961. Development of vegetation in relation to soil formation in the volcanic island of Oshima, Izu, Japan. Jap. J. Bot. 17:371-402.

207. TSUTSUMI, T. 1963. Influence of the development of forest vegetation and clear cutting on some properties of forest soil. I. Soil changes with the development of forest vegetation. Bull. Kyoto Univ. For. 34:37-64.

208. TSUTSUMI, T., T. KAWAHARA, and T. SHIDEI. 1968. The circulation of nutrients in forest ecosystems. On the amount of nutrients contained in the above-ground parts of single tree of stand. J. Jap. For. Soc. 50:66-74.

209. UTKIN, A. I. 1969. The main directions of foreign [i.e., non-Russian] research on the biological productivity of forest phytocoenoses. Lesoved. Mosk. 1:62-68.

210. VAN CLEVE, K., L. A. VIERECK, and R. L. SCHLENFELD. 1971. Accumulation of nitrogen in alder (Alnus) ecosystems near Fairbanks, Alaska. Arc. Alp. Res. 3:101-114.

211. VATKOVSKY, O. S. 1969. Phytomass of oak woods on solonetz soil. Lesoved, Mosk. 1:90-94.

212. VYAS, L. N., S. K. AGARWAL, and M. P. S. RANAWAT. 1971a. Relation between aboveground biomass, girth and number of growth rings in three species of the deciduous forest of Udaipur, Rajasthan. Jap. J. Ecol. 21:52-54.

213. VYAS, L. N., R. K. GARG, and M. P. S. RANAWAT. 1971b. Observations on the dry matter production in Mitragyna parvifolia Karth. Jap. J. Ecol. 21:227-230.

214. VYAS, L. N., R. K. GARG, M. P. S. RANAWAT, and R. R. DAS. 1971c. Method for estimation of biomass and rate of production in a tropical tree. Jap. J. Ecol. 21:244-246.

215. WEETMAN, G. F., and R. HARLAND. 1964. Foliage and wood production in unthinned black spruce in northern Quebec. For. Sci. 10:80-88.

216. WESTLAKE, D. F. 1963. Comparisons of plant productivity. Biol Rev. 38:385-425.

217. WHITTAKER, R. H. 1961. Estimation of net primary production of forest and shrub communities. Ecology 42:177-180.

218. WHITTAKER, R. H. 1962. Net production relations of shrubs in the Great Smoky Mountains. Ecology 43:357-377.

219. WHITTAKER, R. H. 1963. Net production of heath balds and forest heaths in the Great Smoky Mountains. Ecology 44:176-182.

220. WHITTAKER, R. H. 1965. Branch dimensions and estimation of branch production. Ecology 46:365-370.

221. WHITTAKER, R. H. 1966. Forest dimensions and production in the Great Smoky Mountains. Ecology 47:103-121.
222. WHITTAKER, R. H. 1970. Communities and ecosystems. Macmillan, London. 162 p.
223. WHITTAKER, R. H., N. COHEN, and J. S. OLSON. 1963. Net production relations of three tree species at Oak Ridge, Tennessee. Ecology 44:806-810.
224. WHITTAKER, R. H., and G. M. WOODWELL. 1967. Surface area relations of woody plants and forest communities. Am. J. Bot. 54:931-939.
225. WHITTAKER, R. H., and G. M. WOODWELL. 1968a. Dimension and production relations of trees and shrubs in the Brookhaven Forest, New York. J. Ecol. 56:1-25.
226. WHITTAKER, R. H., and G. M. WOODWELL. 1968b. Estimating primary productivity in terrestrial ecosystems. Am. Zool. 8:19-30.
227. WHITTAKER, R. H., and G. M. WOODWELL. 1969a. Structure, production and diversity of the oak-pine forest at Brookhaven, New York. J. Ecol. 57:155-174.
228. WHITTAKER, R. H., and G. M. WOODWELL. 1969b. Measurement of net primary production of forests. IN: IBP Conference on Forest Productivity of the World, Bruxelles, Belgium, 27-31 October 1969. 43 p.
229. WILL, G. M. 1966. Root growth and dry matter production in a producing stand of Pinus radiata. N.Z. For. Res. Note 44. 15 p.
230. WOODWELL, G. M., and P. F. BOURDEAU. 1965. Measurement of dry matter production of the plant cover. IN: Methodology of plant ecophysiology: Proceedings of the Montpellier Symposium, p. 519-527. UNESCO, Paris.
231. WOODWELL, G. M., and W. R. DYKEMAN. 1966. Respiration of a forest measured by carbon dioxide accumulation during temperature inversions. Science 154:1031-1034.
232. WOODWELL, G. M., and T. G. MARPLES. 1968. Production and decay of litter and humus in an oak-pine forest and the influence of chronic gamma irradiation. Ecology 49:456-465.
233. WRIGHT, T. W., and G. M. WILL. 1958. The nutrient content of Scots and Corsican pines growing on sand dunes. Forestry 31:13-25.
234. XYDIAS, G. K. 1964. Dry matter and nutrient-element relations in Pinus resinosa Ait. plantations. M.S. thesis, Syracuse Univ. 57 p.
235. YAMADA, M. 1955. Forest physiographical studies on the microtopographical analysis (in Japanese). Tokyo Rinya Kosaikai. (From Satoo 1970a.)
236. YAMADA, M., and K. MARUYAMA. 1962. Ecological studies on beech stands. Rec. 72d Meet. Jap. For. Soc., p. 245-248. (From Tadaki 1966.)
237. YAMADA, S., K. MARUYAMA, and S. MIYAZAWA. 1957. Standing crop of mature red pine (Pinus densiflora) and some analyses as related to micro-topography. Rec. Meet. Jap. For. Soc. 67:218-222.
238. YAMAHWA, T., H. SAITO, and T. SHIDEI. 1972. Investigations on the primary productivity and production structure of Chamaecyparis obtusa (Sieb. et Zucc.) stands. Kyoto Univ. For. 43:106-123.
239. YAMAMOTO, T., and E. SANADA. 1970. Nutrients uptake by planted Todo fir (Abies sachalinensis Mast.) nutrient circulation and a change in soil in forest land. Bull. Gov. For. Exp. Stn. Tokyo 229:89-121.
240. YODA, K. 1968. A preliminary survey of forest vegetation of eastern Nepal. II. Plant biomass in the sample plots chosen from different vegetation zones. J. Coll. Arts Sci. Chiba Univ. (Nat. Sci. Ser.) 5:277-302.

241. YOUNG, H. E. 1965. The complete tree concept--A challenge and an opportunity. Proc. Soc. Am. For. 1964:231-233.

242. YOUNG, H. E. (ed.) 1967. Primary productivity and mineral cycling in natural ecosystems. (AAAS Symp.) Univ. Maine Press, Orono. 245 p.

243. YOUNG, H. E. 1968. Challenge of complete tree utilization. For. Prod. J. 18:83-86.

244. YOUNG, H. E. 1971. Biomass and sampling methods for puckerbrush stands. IN: H. E. Young (ed.), Forest biomass studies, p. 177-190. (16th IUFRO Congr.) Univ. Maine Press, Orono.

245. YOUNG, H. E., and P. M. CARPENTER. 1967. Weight, nutrient element and productivity studies of seedlings and saplings of eight tree species in natural ecosystems. Maine Agric. Exp. Stn. Tech. Bull. 28. 39 p.

246. YOUNG, H. E., L. STRAND, and R. ALTENBERGER. 1964. Preliminary fresh and dry weight tables for seven tree species in Maine. Maine Agric. Exp. Stn. Tech. Bull. 12. 76 p.

247. ZAR, J. H. 1968. Calculation and miscalculation of the allometric equation as a model in biological data. BioScience 18:1118-1120.

248. ZAVITKOVSKI, J. 1970. Biomass and primary productivity of red alder (Alnus rubra Bong.) ecosystem. I. Tree layer. Bull. Ecol. Soc. Am. 51:30-31.

249. ZAVITKOVSKI, J. 1971. Dry weight and leaf area of aspen trees in northern Wisconsin. IN: H. E. Young (ed.), Forest biomass studies, p. 193-205. (16th IUFRO Congress.) Univ. Maine Press, Orono.

250. ZAVITKOVSKI, J., and R. D. STEVENS. 1972. Primary productivity of red alder ecosystems. Ecology 53:235-242.

251. MOIR, W. H. 1972. Litter, foliage, branch and stand production in contrasting lodgepole pine habitats of the Colorado [Front] Range. IN: J. F. Franklin, L. J. Dempster, and R. H. Waring (eds.), Proceedings--Research on coniferous forest ecosystems--A symposium, p. 189-198. USDA Forest Service, Portland. 322 p.

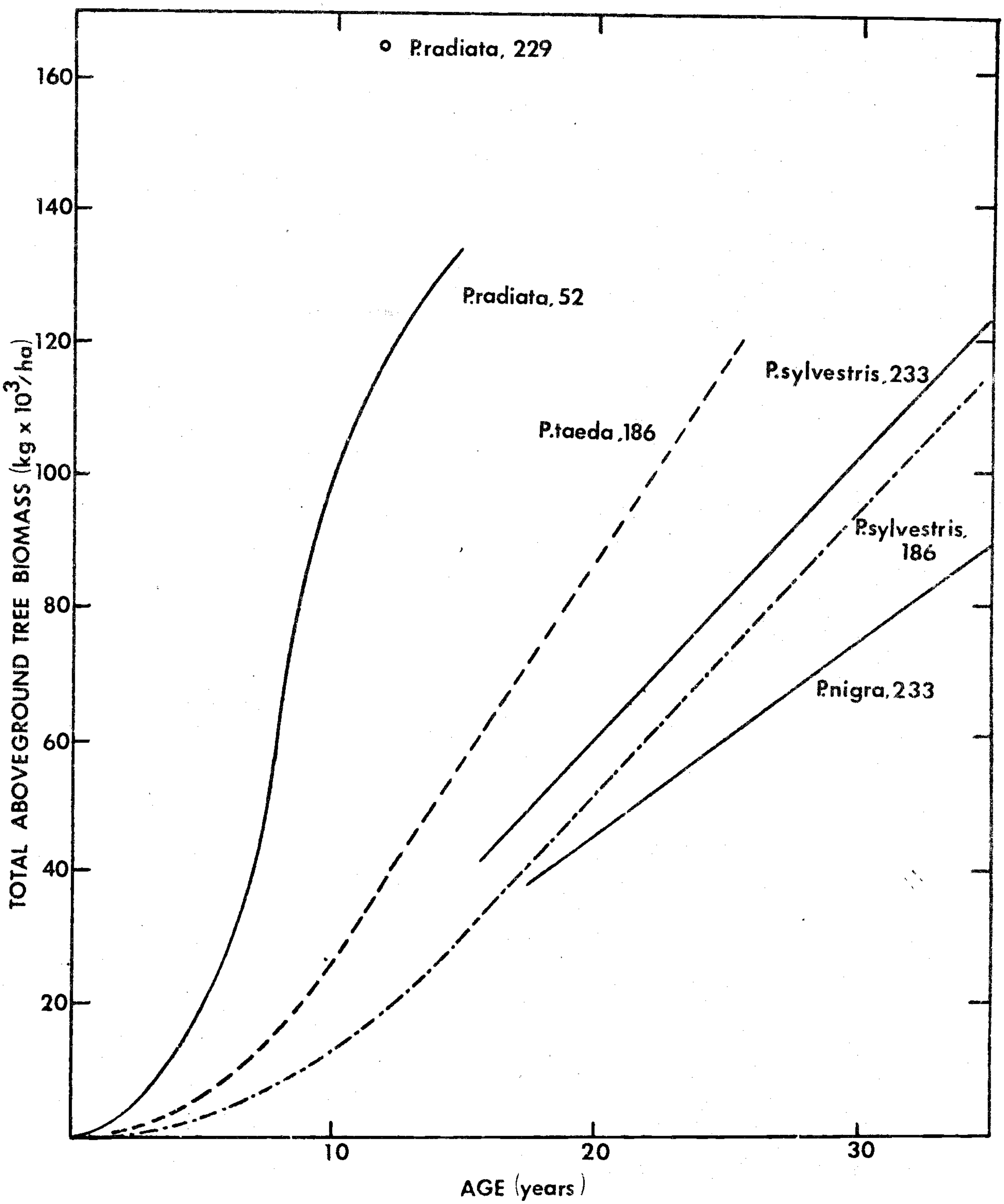

Figure 1. Comparison of total aboveground tree biomass in selected *Pinus* species. Reference numbers follow species names.

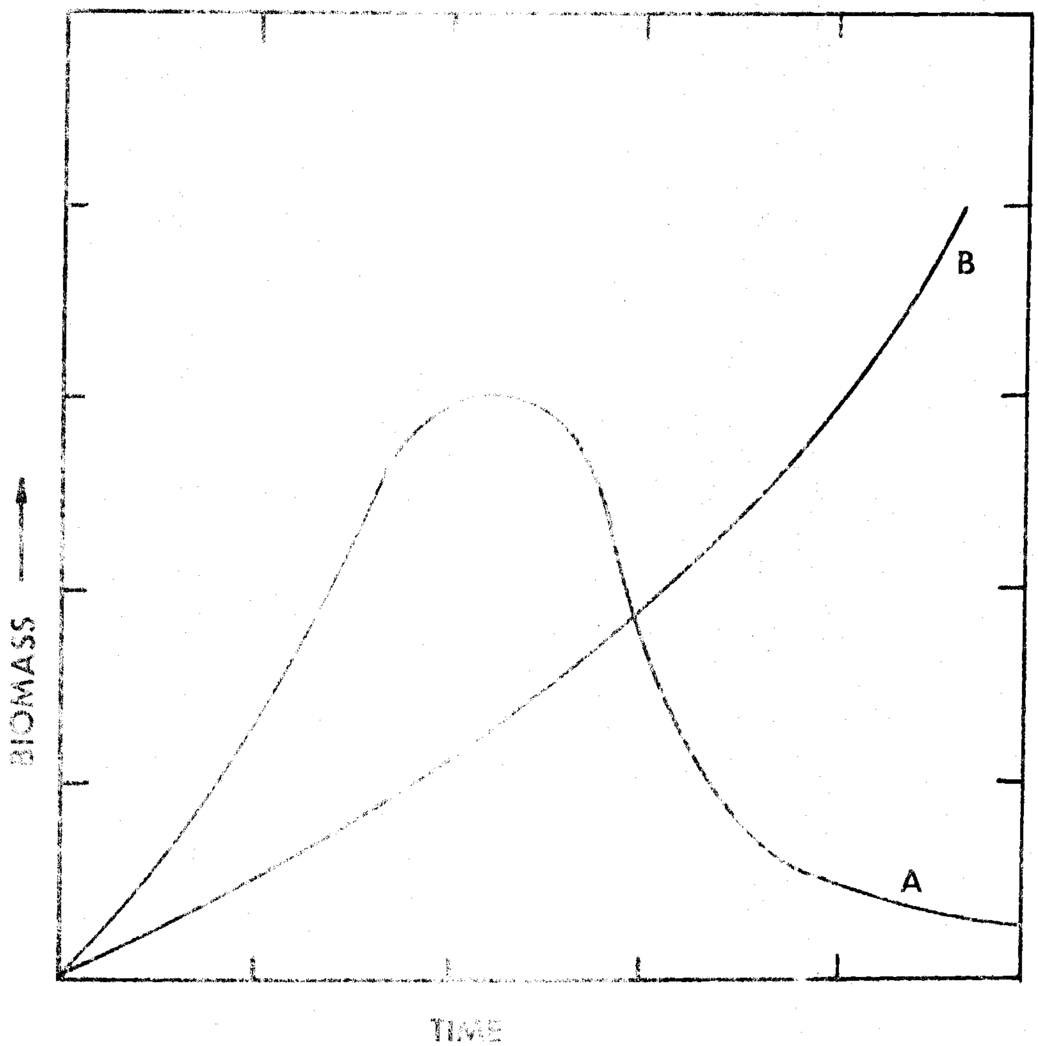

Figure 2. Generalized diagram of understory development as related to the developing forest stand. Curve A shows typical development of understory within an evergreen forest starting with some major disturbance such as clearing for planting or a fire. There is rapid accumulation but, as the trees develop and close their crowns, the understory declines and drops to a relatively steady state, which in many cases is negligible. Curve B shows development of understory species in alder (a generalization of Van Cleve's [210] study in Alaska). The understory continues to develop with time and, as the alder declines, an understory made up of such species as black spruce becomes predominant.

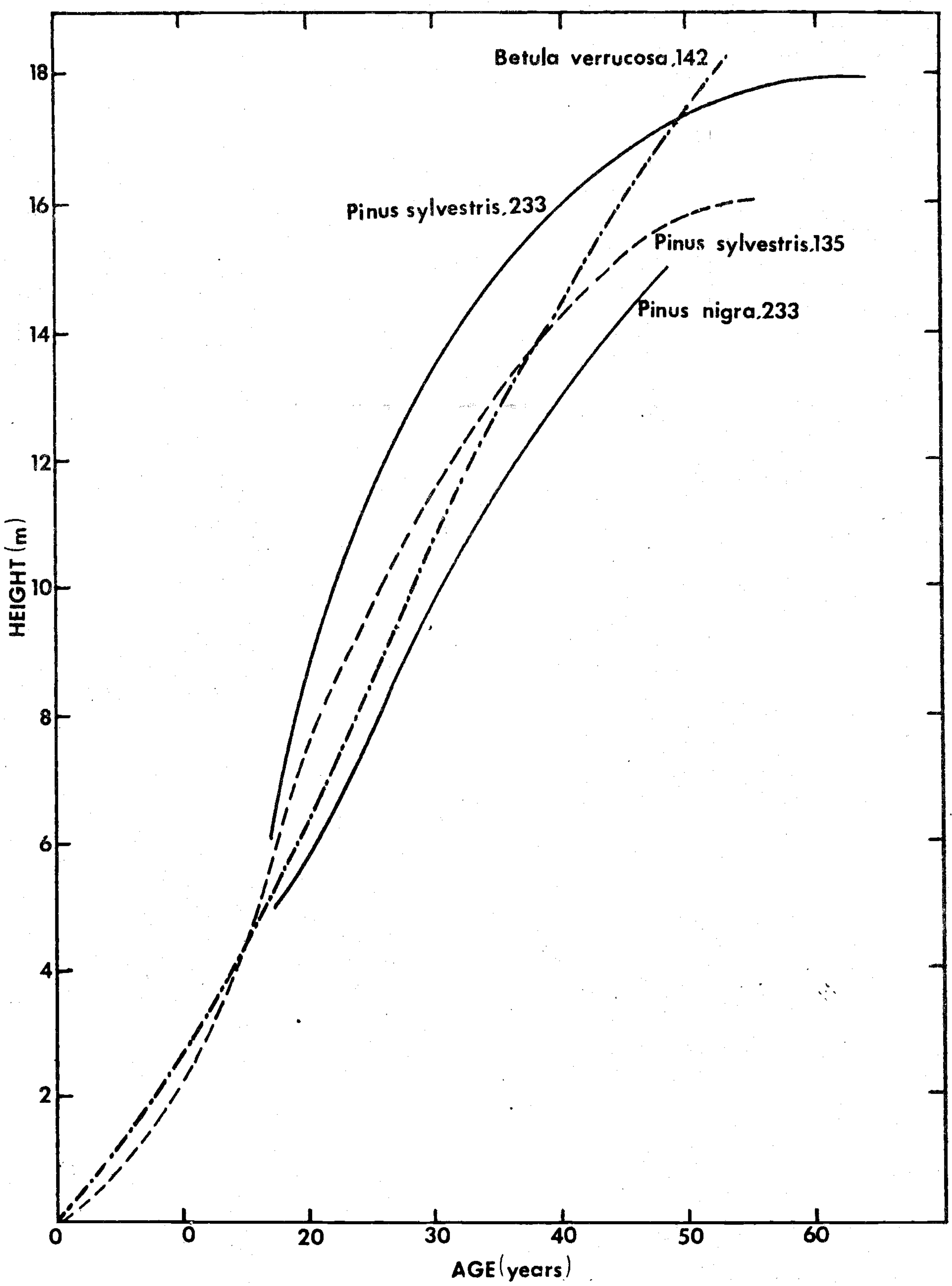

Figure 3. Height-age curve for *Pinus sylvestris*, *Pinus nigra*, and *Betula verrucosa* in similar locations for comparison of the studies of Ovington (157), Ovington and Madgwick (142), and Wright and Will (233). Reference numbers follow species names.

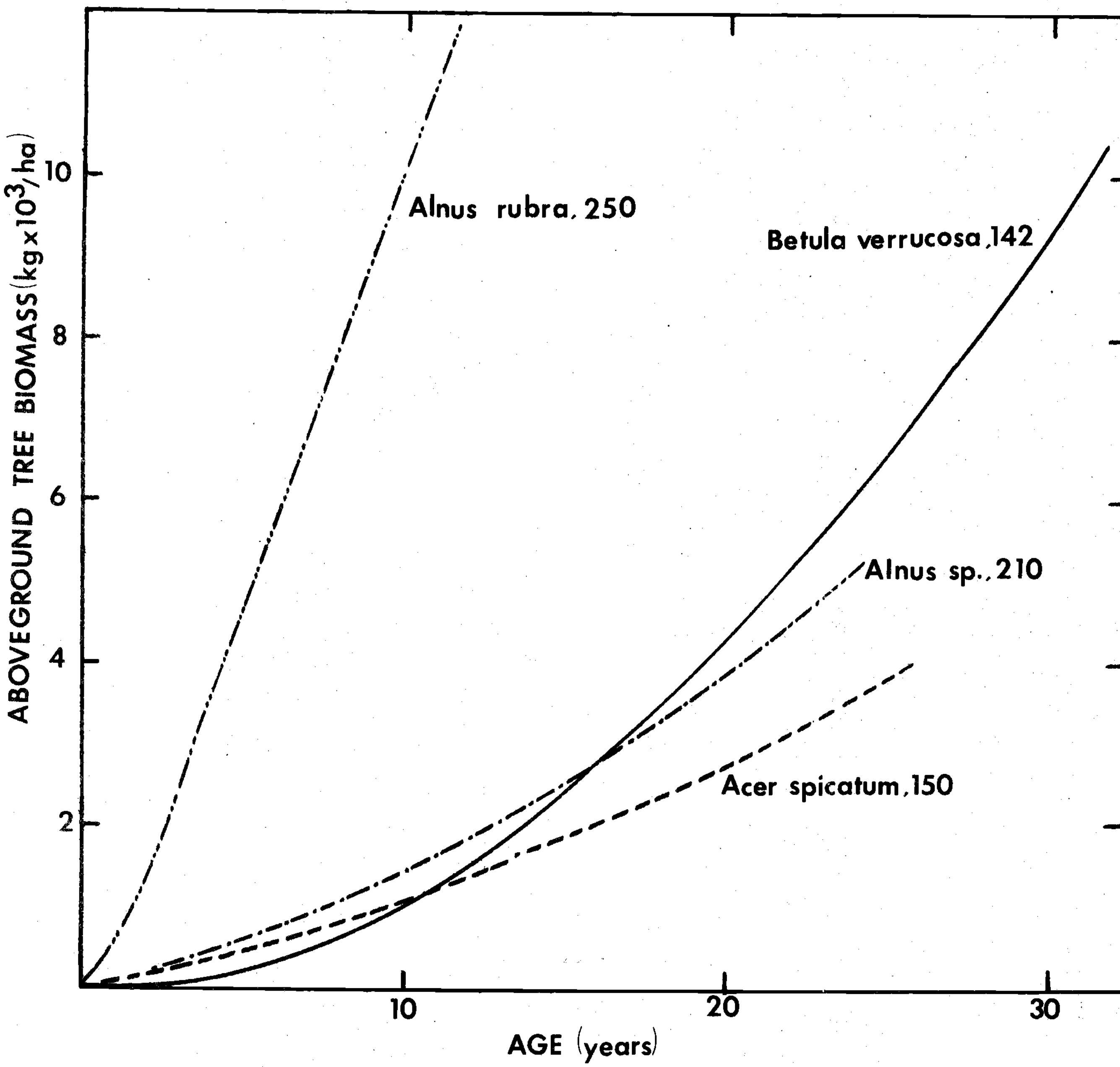

Figure 4. Comparison of tree biomass in selected deciduous hardwood species. Reference numbers follow species names.

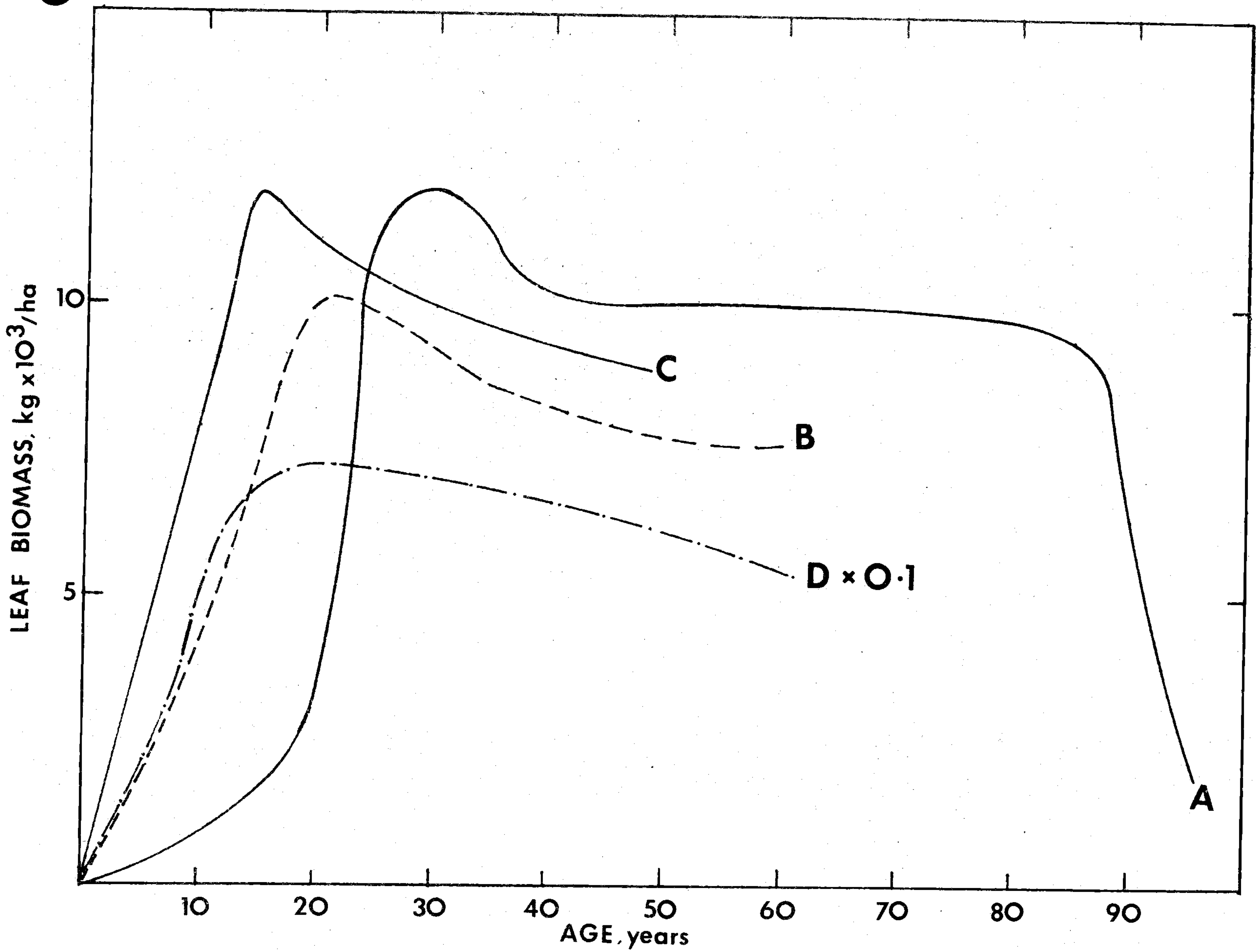

Figure 5. Yearly changes of leaf biomass in forests: (A) *Abies veitchii--A. mariesii* forest, oven dry (131); (B) *Pinus sylvestris*, oven dry (135); (C) *Pinus densiflora*, green weight (101); (D) *Cryptomeria japonica* x 0.1, oven dry.

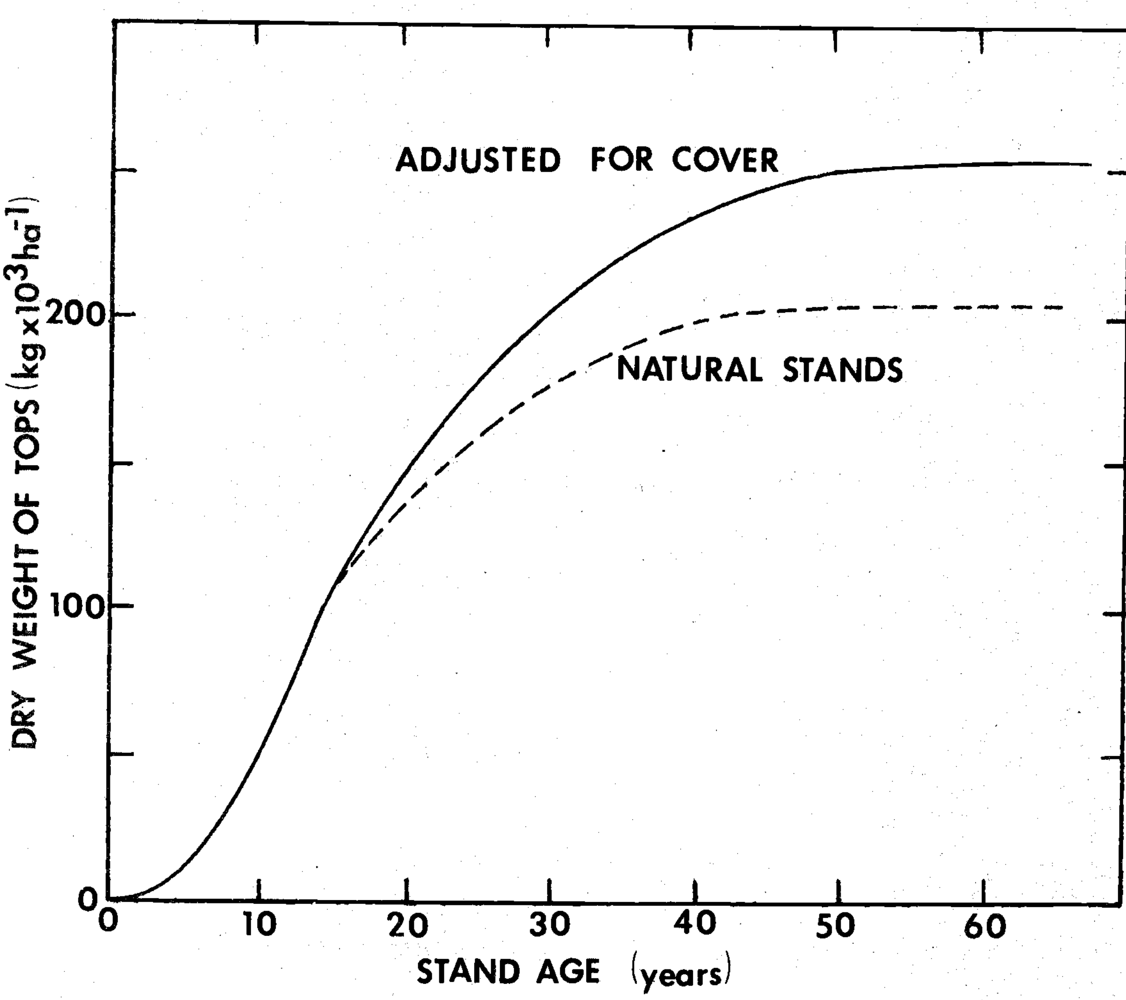

Figure 6. Biomass of red alder stands (after Zavitovski and Stevens [250]).

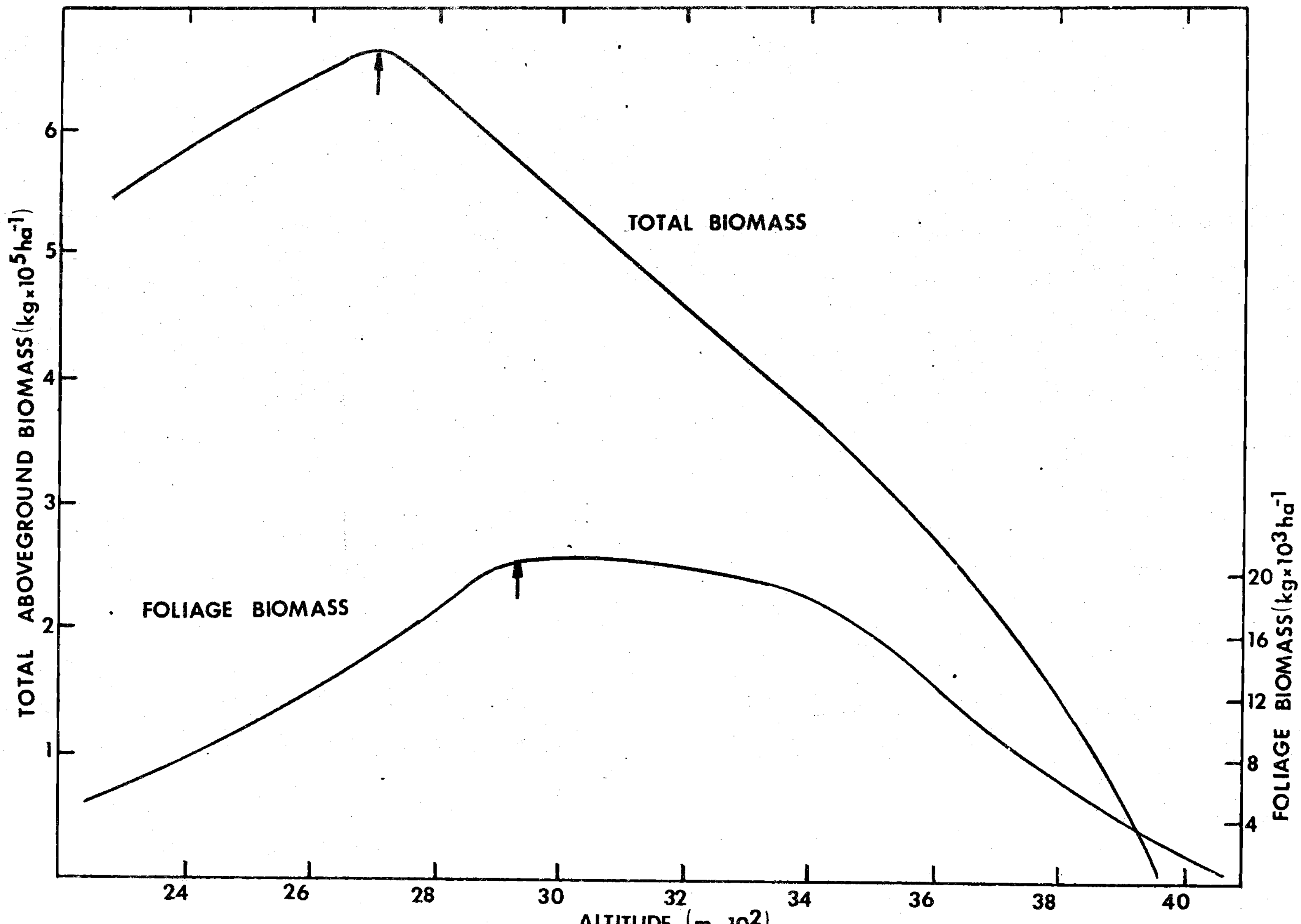

Figure 7. Variation in biomass of forest communities with increasing altitude, in eastern Nepal (after Yoda [240]).

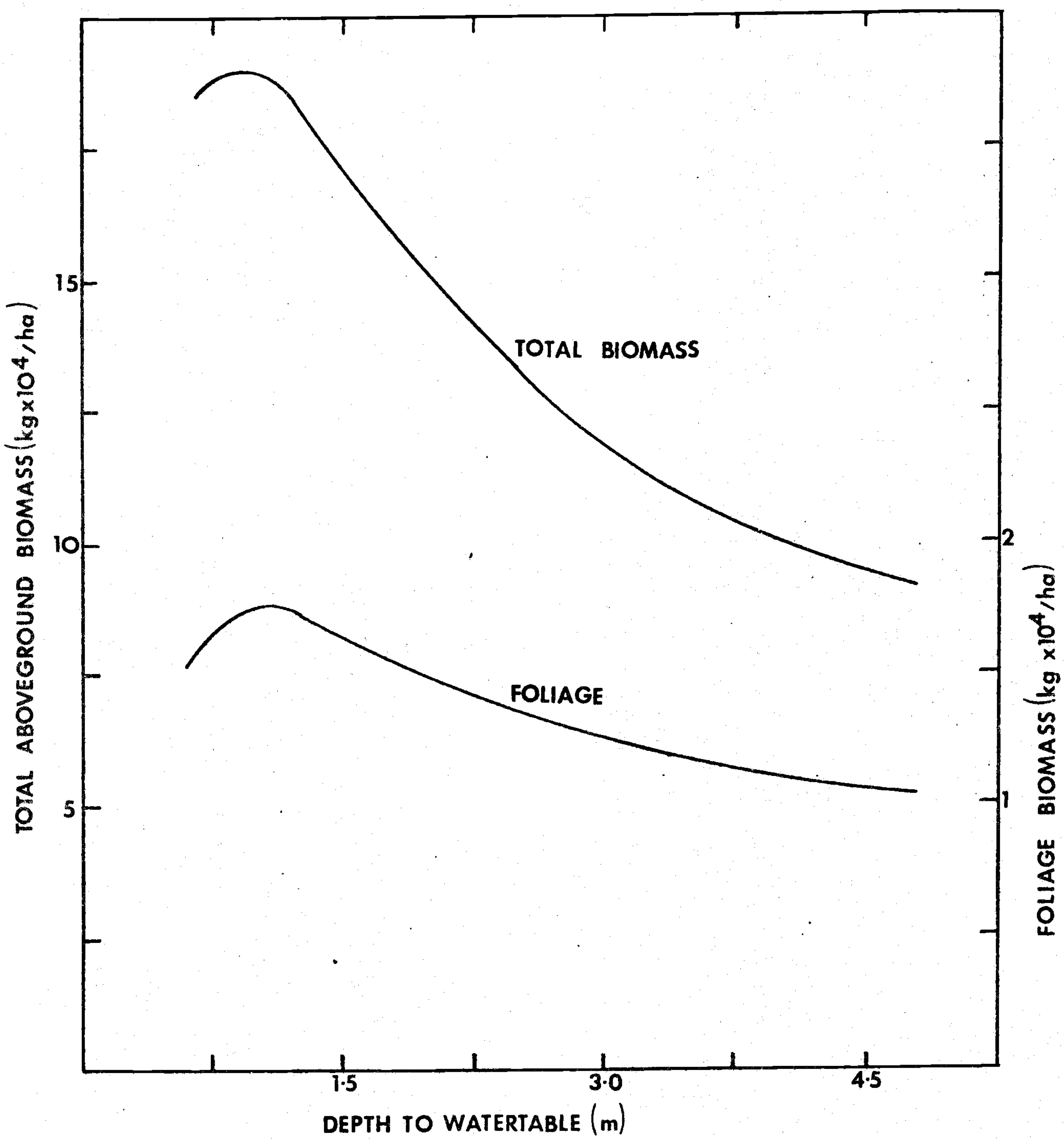

Figure 8. Variation in biomass of *Pinus resinosa* due to varying depth to water table (after Jurgensen and Leaf [175]).