DEPARTMENT OF FORESTRY QUEENSLAND

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ONE-WAY VOLUME EQUATIONS FOR NORTH QUEENSLAND RAINFOREST SPECIES

BY

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ABSTRACT

The history of rainforest volume equation preparation in Queensland is briefly reviewed.

Analyses by individual species are presented from data previously used to generate equations for species groups based on silvicultural desirability rather than similarity of volume relationships. The many significant differences between species indicate that such grouping is undesirable.

No differences were found between trees of the same species from virgin and previously logged areas. The relationship between volume and basal area is strongly linear for most well represented species, but a reduction in slope above *ca.* 80-90 cm dbh is desirable in some species. For species with only a few data, volume lines constrained to pass through a fixed origin, as in tariff systems, are suggested. A general equation is provided for application to species not represented in the data.

INTRODUCTION

Apart from very early (pre-war) volume tables for assessment purposes, the production of volume functions for North Queensland rainforest species commenced in the 1950's following the location of research personnel at Atherton and the commencement of a program of detailed sample tree measurement. Early work involved the graphical construction of two-way (dbh and merchantable height) volume tables for the important "A" group species such as Queensland maple, northern silky oak and kauri pine. Equations were developed in 1966 and 1971, using all available sample tree data, including trees measured by M. Passmore's survey gang as well as the research material. These equations were produced to meet the requirements of users in research and resources to estimate volumes by the then current silvicultural groups -

1966 (1) A group species

(2) B, C and D group species combined

1971 (1) A group species

(2) B, C and D groups, non-buttressed species only

(3) B, C and D groups, buttressed species only

These equations estimated volumes as calculated from the sample tree measurements, assuming a 60 cm stump, and subsequent checks showed that they seriously overestimated the volumes of logs actually obtained in marketing operations (Henry, 1980). In addition to failure to account for high stumps, butting and other defect, doubts exist as to the method of dbh measurement used. At that time there was a school of thought which held that dbh should be measured at 1.3 m above ground, irrespective of the presence of buttresses or other stem irregularities. The anomalous stem shape and bark thickness at the base of some of the sample trees suggest that this procedure was indeed followed. While the sample trees remain an essential source of information on bark thickness and stem taper, their use in functions to predict log volume is questionable.

Higgins (1977) prepared two-way equations for the same species groups (A and BCD) from data obtained in logging operations. The independent variables were dbh or diameter above buttresses (dab) as appropriate, and log length instead of merchantable height, while the dependent variable was the log volume as calculated in marketing practice. Functions relating log length to dbh were also developed. The equations are included in Appendix 6 of Vanclay *et al.* (1987). Higgins also generated one-way equations by substituting his log length functions into the two-way equations. However, these equations have always been suspect[†], and it appears that a high proportion of the recorded dbh's were estimated rather than measured. The log length functions were unsatisfactory, explaining less than 10 per cent of the variance in all cases, which must cast doubts on their use in preparing the one-way equations. In addition, validation with more recent data suggested that the regression model used was inappropriate.

More data were collected over the period 1968-80 in the course of logging damage studies, removals from inventory plots and as special collections in current logging operations. The dbh or dab measurements were carried out by research or resources personnel in accordance with present standards, while log length, centre diameter and volume were obtained from marketing records. These total about 2 000 trees, and meet all the basic requirements for the development of equations to predict log volume from the data normally recorded in inventory and research plots. They were used to prepare one-way equations for Resources in 1981 and Research in 1982, with groups as follows -

1981 (1) virgin, species group 1
(2) virgin, species group 2
(3) virgin, species group 3
(4) virgin, species group 4
(5) logged, species group 1
(6) logged, species group 2
(7) logged, species group 3
(8) logged, species group 4

1982 (1) virgin, silvicultural group A
(2) virgin, silvicultural groups B, C & D
(3) logged, silvicultural group A
(4) logged, silvicultural groups B, C & D

These equations are listed in Appendix 6 of Vanclay *et al.* (1987). The species groups used were derived from the requirements of treemarking and other silvicultural operations, without any consideration of similarity of volume relationships. The distinction between "virgin" and "logged" was made on the assumption that second cut stands would have relatively lower volumes because of lower average log lengths, and appeared to be supported by overall comparisons of the grouped data. A major criticism of this method of arbitrary species grouping lies in the assumption that the distributions of species and sizes are comparable in the data and the stands in which the equations will be used. The present data set largely comprises a small number of intensive, geographically restricted collections, and the relative species frequencies reflect this.

In 1985, the same data set was used to prepare three two-way equations (dbh and log

† Examination of Higgins' working documents indicates that he was fully aware of the limitations of his volume equations. At the time he was concerned with developing an overall system rather than optimizing individual functions.

length), with grouping into high, medium and low volume species based on actual volume relationships rather than arbitrary external criteria (Appendix 6 of Vanclay *et al.*, 1987). For individual species, there was little correspondence between these groups and those to which they had been previously assigned. The inclusion of log length as a variable in the two-way equations explains a major part of the variation in volume and permits this simple method of grouping to give satisfactory results when the equations are applied over wide areas. However, in the case of one-way equations, species with similar bark thickness and taper may have markedly different average log lengths, and not fit into groups appropriate for two-way equations. The present study arose from the need for improved one-way equations for use in yield calculations where the inventory did not include estimation of log length, and for long term growth projections in the absence of effective functions for predicting changes in log length over time.

MATERIALS AND METHODS

The data set used to develop the 1981 and 1982 one-way equations, and the 1985 two way equations, was again employed in the present study. In all, 1 982 trees covering 99 species were included, with a wide range in numbers and size class representation (Appendix 1). As a preliminary step, volume was plotted against basal area for each species (Appendix 3). Eight anomalous points , as shown in Table 1, were rejected as outliers after checking for errors in transcription or data entry.

Table 1. Details of rejected data

species code*	dbh/dab (cm)	log length (m)	volume (m^3)	reason
BRC	76.8	15.3	7.828	high
BRO	77.0	3.3	0.701	low
CHS	88.5	4.5	1.403	low
MRR	51.8	13.2	2.778	high
NSR	85.2	3.9	1.501	low
QWN	168.5	15.6	14.152	low very high dbh
RBS	40.4	6.3	1.093	high centre diameter>dbh
STS	96.5	8.1	1.885	low

* The three character "FRB code" is used for all species references. See Appendix 2 for full botanical and common names.

Regression analysis was carried out with the programs **plot**, **frap** and **fras**, and **mult** was used for comparisons; **genstat** was used for multivariate analysis. A few small programs were written for data manipulation and calculation of standard errors for weighted regression.

RESULTS

From the plots of data by individual species, the relationship between volume and basal area generally appeared to be strongly linear, but with a wide range of slopes, intercepts and variance in volume (Appendix 3).

Before proceding further, differences between data from virgin and previously logged stands were re-examined on an individual species basis. Regressions for eleven species with at least 10 trees from each of virgin and logged areas were considered, with results as shown in Table 2.

Table 2. Comparisons of regressions for virgin and logged stands

species code	number of trees		difference (p=0.05)
	virgin	logged	
HKA	11	29	ns
KRS	18	17	ns
MSW	97	68	ns
NKR	56	33	ns
NSO	69	70	ns
NSS	20	35	ns
QMP	33	55	intercept
QSA	31	17	ns
RDT	26	13	ns
YLS	14	18	ns
YWN	27	55	ns

In all cases, differences in slope were not significant, and only one species (QMP - Queensland maple) showed a small significant difference in level. Examination of the data suggests that this is an artifact associated with an unusual size distribution in the logged subset, which includes a group of small trees derived from commercial thinning in a 40 year old enrichment planting.

On the basis of this analysis, it may be accepted that separate equations for virgin and previously logged areas are not justified for individual species. The differences found with the grouped data in 1981/82 appear to result from the uneven species representation in the two subsets. There may also be confounding geographic or site effects, but the data are insufficient for analysis of these variables.

To test the assumption of linearity in the volume-basal area relationship, nine species were selected with a good representation of data extending to large sizes (> 100 cm dbh). After partitioning at 90 cm dbh and also at the median dbh for each species, separate volume lines were calculated for the small and large trees. The results of comparisons are presented in Table 3.

Table 3. Comparison of regressions for small and large trees

species code	number of trees	partitioned at dbh of (cm)	difference (p=0.05)	partitioned at dbh of (cm)	difference (p=0.05)
MSW	165	90.0	ns	66.0	ns
NKA	15	90.0	ns	96.4	ns
NKR	89	90.0	ns	83.0	ns
NSO	139	90.0	ns	75.6	ns
QMP	88	90.0	ns	60.0	ns
QWN	23	90.0	ns	96.5	ns
STS	121	90.0	ns	70.0	ns
WES	34	90.0	slope	84.7	slope
YWN	82	90.0	ns	68.5	intercept

Examination of plots of the WES data indicates that the slope difference is due mainly to two large trees. Similarly, the difference in intercepts for YWN, which is dependent on the point of partitioning, is accounted for by a group of middle-sized trees. In both cases, there would be no practical advantage in using more complex models. A quadratic can be fitted to WES, but it overestimates for small trees, and would grossly overestimate volumes of large trees if extrapolated. Other variables do not enter the YWN equation in the presence of a linear term. In general, these analyses confirm that a simple volume-basal area line is adequate for both large and small trees within a species.

A further check on model validity was carried out on the six best represented species (MSW, NKR, NSO, QMP, STS and YWN). For each of these, subsets of 40 to 50 data covering the full size range were extracted and the volume equations compared. In all cases the differences were not significant. However, when this process was extended to subsets of 20 trees, significant differences between equations began to appear. While examination of the data generally suggested a reason for the differences, such as large trees with above or below average log length, the need to exercise care and judgement when dealing with small data sets is evident.

Since the nine species included six (MSW, NKA, NKR, NSO, QMP and QWN) which had previously been included in a single "A" group equation, the individual volume lines were compared to determine whether such grouping was justified. Results are summarized in Table 4.

Table 4. Comparison of regressions for nine species

	NKA	NKR	NSO	QMP	QWN	STS	WES	YWN
MSW	I	S	V(s)	V(s)	I	V(n)	N	V(s)
NKA		S	I	N	V(n)	N	V(n)	N
NKR			V(s)	V(s)	S	V(s)	S	V(s)
NSO				S	V(n)	N	V(n)	I
QMP					V(s)	S	V(s)	N
QWN						V(n)	N	N
STS							N	S
WES								N

V = species differ in variance
S = species differ in slope (homogeneous variance)
I = species differ in intercept (homogeneous variance, same slope)
N = species are not significantly different
Lower case characters in parentheses indicate nominal test results if non-homogeneity of variance is ignored.

Even closely related species (MSW & QMP, NKA & NKR) differ significantly, and there is little indication of any groups which could be built without loss of precision. The many differences in variance support the retention of individual species if valid estimates of error are to be obtained.

A further attempt at grouping was carried out using 64 species for which a reasonable volume line could be obtained. However, multivariate analysis of the regression parameters (slope, intercept and residual mean square) did not indicate any obvious groups, and it was decided to proceed on the basis of preparing a separate equation for each species. Computational convenience may have been a factor in the use of a small number of groups previously, but this is no longer a problem.

Since the individual volume lines when plotted together bear some resemblance to a "tariff" volume table system (Hummel, 1955; Hummel *et al.*,1962; Turnbull and Hoyer, 1965;

Hamilton, 1975), and the use of a fixed origin had proved effective previously for the two-way equations, the possibility of using this approach was examined. Analysis of the 64 volume lines indicated a tariff origin at a basal area of 0.155 m^2 and a volume of 0.868 m^3, which is above the minimum dbh limit required for application of the equations in practice (40 cm dbh or 0.126 m^2 basal area), and neither this nor an arbitrarily selected lower origin showed much promise. However, some elements of the tariff system were later adopted for species with only a few data points.

It was noted that some equations predicted very small or even negative volumes at 40 cm dbh, but any trees of this size either included in the data or enumerated for volume estimation would contain at least a 2.4 m minimum log length, representing an appreciable volume. The relationship between log length and volume at 40 cm dbh is illustrated in Figure 1, using data for all species in the dbh range 39.0 to 40.9 cm.

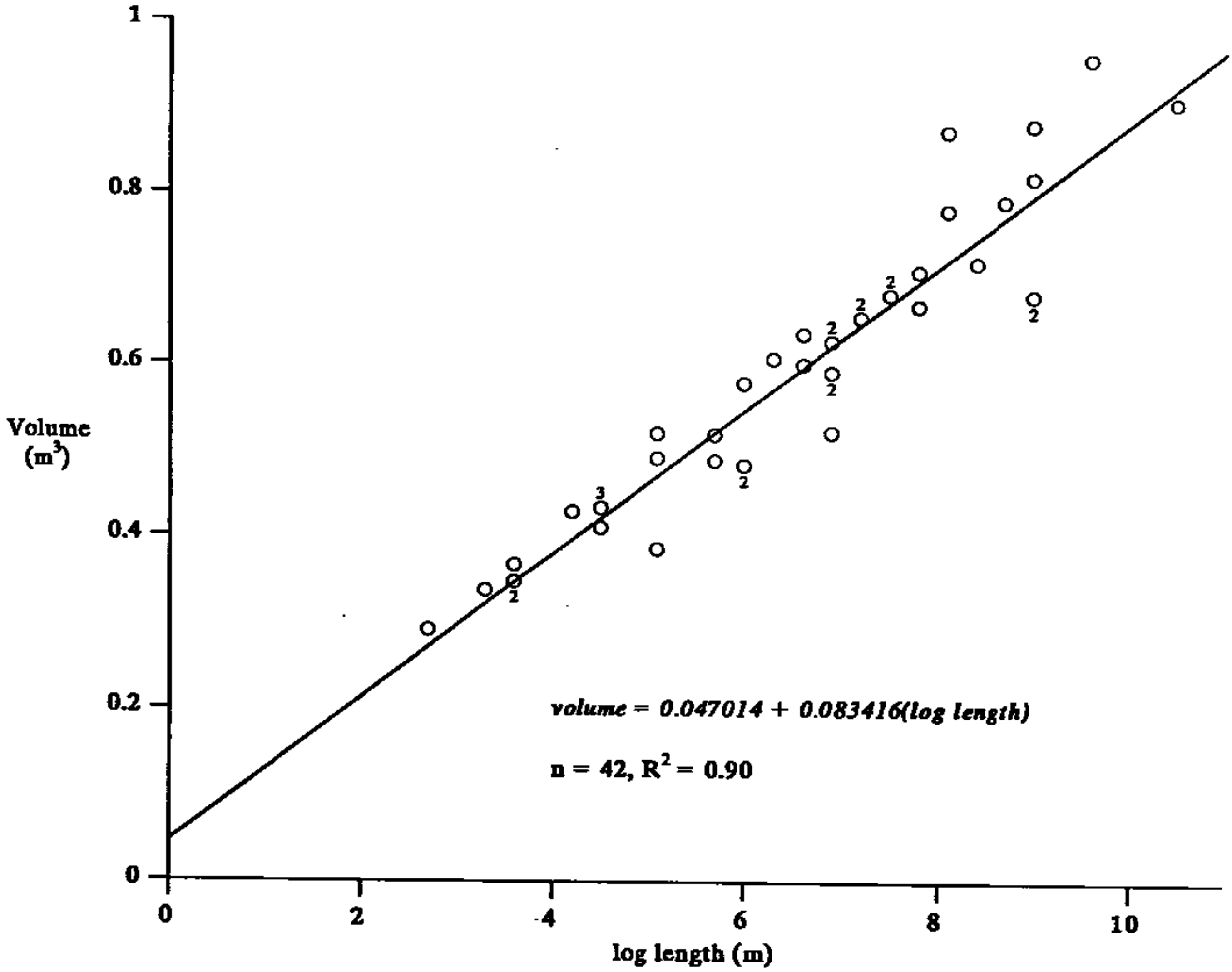

Figure 1. Relationship between log length and volume at 40 cm dbh.0

The equation predicts a volume in the range of 0.247 m^3 for the minimum 2.4 m log to 0.923 m^3 for the maximum log length encountered of 10.5 m. Species in which the volume equation predicted values outside this range were critically examined to determine whether some corrective action was desirable. Often weighted regression was effective, using the reciprocal of basal area squared as weight. However, this was not appropriate in all cases, and other techniques were also employed, as discussed below. Although weighting is commonly required to normalize variances when generating volume equations, many rainforest species exhibit unexpectedly uniform variance as compared with eucalypts, for example. However, when diverse species are grouped, as in the 1981 and 1982 equations, the usual trend of increasing variance with increasing basal area becomes evident.

Although the general suitability of the volume-basal area line had been established, it was clear that simply computing a regression for each species would not be sufficient in all cases. Seven categories were recognized as requiring separate consideration, and these are discussed below. Full details of the equations adopted for all species are presented in Appendix 2, and are shown plotted with the data in Appendix 3.

1. Species with a very wide range of sizes and a strong linear trend throughout.

MSW NKA NKR NSO QMP QWN STS WES YWN

These are the nine species considered previously, and include some of the most important and valuable commercial species. Together they represented almost half the total cut in 1984-85 (Table 14 of Vanclay *et al.*, 1985). They include species with the highest maximum dbh (100 cm) for retention in treemarking, and most are well represented in the volume equation data. The simple volume lines were adopted, except that weighted regression was used for NSO and STS to improve the fit for small trees.

2. Species with a more restricted size range (usually less than 90 cm dbh), and linear throughout.

BLA BLO BNQ BRO BRQ BRT BSO BWD CBH CLO
FSO GCB HKA NSS QSA RBN RBS RCD RDT RES
RSR SBH SPO SSW WBH YEV

Most of the 26 species in this category are commercially important, but generally do not attain the large individual diameters of category 1. A straight line relationship is again adequate for all species, but with quite a wide range of standard errors. Weighting was required for ten species(BLA BNQ BRQ BSO BWD CBH GCB QSA RBS RES), either to standardize variances or to improve the fit for small trees. Data extend at least up to the maximum retention dbh in all except a few species. The latter include GCB and RCD which develop prominent butresses and might not fit into this category if the sample included some very large trees. Comparisons amongst the 26 equations showed significant differences in the majority of cases, but there are indications that grouping of some species might be considered for further investigation. The technique suggested by Vanclay (1989) would be a good starting point.

3. Species with a wide range of sizes, linear up to about 90 cm dbh, but with larger trees of relatively low volume

BBN CHS GRS JHR KRS LPS MGN PPW RAL SLQ
WCW YLS (also for BSL NSR PBS STO)

These species are also commercially important, with an aggregate volume cut greater than for category 2. While generally they yield relatively few large trees (>90 cm dbh), those that are present in the data often have volumes below those predicted by extrapolation of the well defined lines for smaller sizes. This is clearly due to the development of defect, and consequent reduction in effective log length, in large trees. The use of two-way volume equations can greatly reduce the effect, but the problem remains for one-way equations. Rejection of these points as outliers will introduce bias in volume estimates and weighting does not give a satisfactory result. In addition, the data are too few and too variable to define a better form of equation. However, an appropriate correction can be introduced by reducing the slope of the volume line for the large sizes.

Combining the data for twelve species permitted the development of separate overall volume lines for small and large trees. The data were initially partitioned at a basal area of 0.636 m^2, corresponding to a dbh of 90 cm, but a few iterations established 0.554 m^2 (84 cm dbh) as a better average value. The two equations were

Below 0.554 m^2 *volume = -0.48268 + 9.21868 (basal area)* ($n=341$, $R^2=0.62$)

Above 0.554 m^2 *volume = +3.30782 + 2.41209 (basal area)* ($n=57$, $R^2=0.50$)

The ratio of these slopes (2.41209/9.21868 = 0.26165) was then used as a multiplier to adjust the slopes of the upper parts of the volume lines for individual species. In six species (BBN JHR KRS LPS WCW YLS) the dbh of 84 cm was a suitable point for the change of slope, but examination of plots of the data indicated that 90 cm was more appropriate for five (CHS GRS MGN PPW RAL), while 95 cm was used for SLQ. The two equations are shown for each of these species in Appendix 2. The simplest method of use is to evaluate both equations for each tree and accept the smaller value.

This adjustment was also applied to four other species with only a limited size range in the data (BSL NSR PBS STO), on the basis of known development of defect in large trees (E. J. Rudder pers. com.). The change of slope was made at 70 cm dbh for BSL, 84 cm for NSR and PBS, and 90 cm for STO.

4. Species with only a few sets of data (typically less than 5)

BGC BLD BOW BRW BSH BSW BWA CBM CCA CDG
CKS CMY DMN EVD HAL HMW NBM NRW NTG NYB
PKA PKS PMR RMH RPN RSW SBN SKC SMH SSA
TRQ WBW WCB WSO YBA YBW

Individually, most of the species in this category comprise only a small proportion of the total merchantable stand, although the relatively limited areas from which the samples were obtained may contribute to the poor representation in some cases. Collectively, however, they represent a significant volume. The data for individual species are too few to permit the fitting of meaningful equations directly, nor does combining the data give a satisfactory overall equation for the group, because of differences between species. The tariff concept, which had been rejected as a general approach (p. 5 *supra*) was then re-examined as a means of producing acceptable volume lines from small numbers of data.

"...tariff studies are concerned with the characterization of the volume-dbh relationship of the trees in an even age homogeneous stand, this relationship usually being accepted as one of linearity between 'usable timber volume', (V say) and 'basal area' (BA say), the line being constrained to pass through a fixed point on the BA axis" (Rennolls and Tee, 1983)

The most important part of this definition in the present context lies in the lines being constrained to pass through a fixed point. Rainforest is neither even aged nor homogeneous, but the linear relationship between volume and basal area has been clearly established for individual species. A tariff origin of zero volume at 0.0484 m^2 basal area was determined from the equation for all species (other than the nine of category 1) as used for category 7 below. This was considered more satisfactory as a general origin than one derived only from the species with few data.

Regressions constrained to pass through the tariff origin were computed for each species, and these are included in Appendix 2. Because of the fixed origin, these tariff volume lines are all quite reasonable, even for the extreme case of a single data point. However, the small numbers of data and lack of independent validation mean that they must be applied with caution. An alternative is to use the all species equation.

Other aspects of tariff methodology, such as the use of fixed tariff numbers and determination of a mean tariff number from the individual sample trees were not included in the present study, but would be worth pursuing if suitable data were available. Another useful feature of a tariff system is that relativity between species is maintained for all sizes.

5. Anomalous species (very low slope, high slope, large intercept, low correlation, etc)

ALB BKP BRC BRP BTP MRR NEV NHQ NTQ PMH
STC STP

These species were identified after the preliminary regression analyses, but were not initially considered with the tariff group.

ALB, BRC, BRP and MRR gave non-significant regressions with low slopes and positive intercepts. In the case of ALB, which does not reach large size, the effect appears to be an artifact of the limited range in the small data set. The use of the tariff approach as in category 4 above provides a satisfactory alternative, which also avoids the prediction of excessively high volumes for small trees. A high level of defect, increasing with size, is characteristic of BRC, and explains both the widely scattered data and the low slope of the volume line. Here again the tariff can be used to give more reasonable volume estimates for small trees, but since large, defective trees are occasionally encountered, a reduction in slope as in category 3 above is also considered necessary. The change of slope has been arbitrarily set at 80 cm dbh. MRR is another species in which defect increases with size, as a result of buttress development. Estimates of small tree volumes are again rather high, but are supported by the data and the regression as calculated has been retained. The data for BRP, though few, cover the size range normally encountered, and as the regression is a satisfactory fit it has also been accepted.

BKP, NEV, STC and STP produced significant regressions with very high slopes and large negative intercepts, which would predict impossibly low volumes for small trees. There is no satisfactory explanation for this behavior, but the limited size range in the data may be a contributing factor. The tariff approach resolves this problem.

The data for PMH also cover a very small size range, but with no obvious relationship between volume and basal area. The tariff is again effective.

BTP, NHQ and NTQ gave regressions which did not reach significance at the conventional 0.05 probability level. Although the data were rather widely scattered, the volume lines were considered satisfactory and have been accepted.

6. Species which are grouped in marketing practice

FRB codes	grouped H & M code
BNQ + BRQ	BRQ
BRT + BTP	BRT
CBH + CBM	CBH
NKA + NKR	NKP
QSA + SSA	QSA
STC + STP	STP
YBA + YBW	YBW

Species with similar timber properties may not be distinguished in marketing practice, but simply referred to by a single group name (the "H & M" code). This procedure has also commonly been followed in resource assessments. In order to provide equations for these groups the only possible approach is to combine the available data for the component species, even though the individual species may have significantly different equations, and the proportions of each species in the group may be unrepresentative. Weighting was used for BRQ, CBH and QSA, as in the individual equations. It was also required for the combined NKP, which merged two significantly different data sets.

7. Other species not represented in the data

The "Treemarking Guidelines for North Queensland Rainforests" (Appendix 1 of Preston and Vanclay, 1988) lists 101 compulsory and 33 non-compulsory commercial rainforest species, for which volume estimates may be required, while the present data set includes representatives of 81 of the compulsory and 11 of the non-compulsory species. All of the A and B group, and 80 per cent of the C group species are included, most of the unrepresented species being in the less desirable D and non-compulsory groups. In order to obtain volume estimates for the unrepresented species, a general equation has been provided. This was derived simply by pooling all the data except for the nine species of category 1, and is very similar to the B, C & D group equations of 1982. Because of the diverse volume relationships within the grouped data, variance increases markedly with increasing basal area, as compared with many of the individual species. The large, low-volume trees of category 3 were also included, but are no longer obvious amongst the general variation.

APPLICATION

Since the volume equations will be used almost entirely within computer programs, there is little need to evaluate them for presentation as traditional volume tables, nor is the large number of equations a problem so long as efficient software is available to access them. The equations listed in Appendix 2 have all been added to the computer files used by the native forest volume equation system, and can be accessed by software developed by Peter Gordon. A description of this software is included here as Appendix 5. The 1977 Higgins equations, the 1981 and 1982 one-way equations, and the 1985 two-way equations can also be accessed within the system, giving the user a range of options for estimating volumes or for checking previous calculations.

CONCLUSIONS

The work reported in this paper has demonstrated the wide range of volume relationships to be found amongst rainforest species, and the effect of this on the development of one-way equations. Groups based on silvicultural desirability, as used in the past, include many species now shown to have significantly different volume equations, and the use of individual species rather than group equations must give more precise volume estimates. Previous consideration of group equations had indicated that trees in logged stands yielded lower log volumes than trees of the same dbh from virgin stands. However, no significant differences were detected when individual species were compared.

A linear relationship between basal area and volume was generally found to be an adequate description, but the slope in the upper part of the volume line was reduced in a few species where the data included a small number of large trees of consistently low volume. Although the data are insufficient to define the relationship precisely, the adjustment is considered necessary and of the right order. This has implications for hardwood volume equations also, where a similar distribution of large tree data has been observed.

The poor representation of many of the less common species is a particular problem with rainforest data when volume equations for individual species are being produced. Adoption of a fixed origin, as in tariff systems, permits the construction of reasonable volume equations, without the need to combine data and lose information on species differences. This and other aspects of tariff methodology would be worthy of further consideration in relation to native forest volume equations generally.

While species have been kept separate on the basis of significant differences between equations and deficiencies in previous grouping methods, there is scope for investigating other grouping algorithms.

ACKNOWLEDGEMENTS

John Rudder assembled and validated the data, and provided information on individual species based on his extensive experience. Marks Nester developed the program mult, Paul Allen carried out the multivariate analyses and Jerry Vanclay made several useful suggestions. Peter Gordon added the equations to the existing volumation software.

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Appendix 1. Rainforest volume equation data - dbh distribution

FRB code	Total number	<40	40-49.9	50-59.9	60-69.9	70-79.9	80-89.9	90-99.9	100-109.9	110-119.9	120-129.9	130-139.9	140-149.9	150-159.9	160-169.9
ALB	9		4	4	1										
BBN	20			3	3	8	4	2							
BGC	2			1		1									
BKP	8			2	6										
BLA	31		3	9	12	3	3	1							
BLD	2				1	1									
BLO	13		4	8	1										
BNQ	14		2	1	4	2	3	1	1						
BOW	1					1									
BRC	40		3	11	11	11	3	1							
BRO	10		7	1		2									
BRP	5		2	3											
BRQ	24			9	7	2	3	2	1						
BRT	45	1	12	20	8	2	1	1							
BRW	4				2	2									
BSH	1			1											
BSL	15		1	6	6	2									
BSO	22		3	7	7	4		1							
BSW	3		1	2											
BTP	12		4	6	2										
BWA	1				1										
BWD	12	1	2	6	3										
CBH	9	1		2	5	1									
CBM	1			1											
CDG	3			1	2										
CHS	12		1		2	2	4	3							
CKS	1			1											
CLO	24		3	7	8	2	2	2							
CMY	1			1											
DMN	4		1	2		1									
EVD	2		1	1											
FSO	5				1		1	1	2						
GCB	17	1	1	9	5	1									
GRS	48		2	11	12	9	5	5	2	1	1				
HAL	4			2	2										
HKA	40		7	16	12	3	1	1							
HMW	2		2												
JHR	44		4	5	18	10	3	2	2						
KRS	35		5	14	5	7	3		1						
LPS	15			2	4	3	5		1						
MGN	23		2	2	8	5	5				1				
MRR	8		2	2	3	1									
MSW	165	2	17	22	31	28	32	17	10	1	5				
NBM	5				2	2	1								
NEV	6		1	3	1	1									
NHQ	6			3	3										
NKA	15		2	1	3		3		3		2	1			
NKR	89		1	3	14	24	17	8	9	6	3	2	1	1	
NRW	1					1									
NSA	2			2											

Appendix 1. Rainforest volume equation data - dbh distribution

FRB code	Total number	<40	40-49.9	50-59.9	60-69.9	70-79.9	80-89.9	90-99.9	100-109.9	110-119.9	120-129.9	130-139.9	140-149.9	150-159.9	160-169.9
NSO	139	2	6	20	30	19	22	20	4	6	4	6			
NSR	13		1	3	6	1	2								
NSS	55		5	25	16	6	1	2							
NTG	3		3												
NTQ	5		1	4											
NYB	3				2	1									
PBS	8			2	3	1	1	1							
PKA	4		2	2											
PKS	2				1	1									
PMH	6			3	2	1									
PMR	1									1					
PPW	20		1	7	7	2	1	2							
PTR	2			2											
QMP	88	8	32	5	10	8	14	7	2		1	1			
QSA	48		7	6	13	12	3	6	1						
QWN	24			1	2	1	5	7	4	1	1	1			1
RAL	26		1	4	6	5	5	4		1					
RBN	24	1	4	9	6	3	1								
RBS	21	2	5	6	6	2									
RCD	18	2	10	4			2								
RDT	39		5	3	10	11	5	2		2	1				
RES	16				1	4	5	1	2		2	1			
RMH	5			1		1	1	1		1					
RPN	3					1	2								
RSR	8			1	2	5									
RSW	1						1								
SBH	10		1	2	5	2									
SBN	1		1												
SKC	2		1		1										
SLQ	116	2	34	37	24	10	5	1	1		2				
SMH	3			1		1			1						
SPO	13			9	1	3									
SSW	25	3	12	5	4	1									
STC	6		1	3	2										
STO	19	1	2	1	6	7	1	1							
STP	6		1	2	2	1									
STS	122		10	19	30	28	19	13	1	1	1				
TRQ	3	1	2												
WBH	12			3	5	2	1	1							
WBW	1			1											
WCB	2			1		1									
WCW	7		1			5				1					
WES	34		3	4	4	5	4	5	7	1	1				
WSO	1					1									
YBA	1		1												
YBW	3			1	1	1									
YEV	18	2	15	1											
YLS	32		1	14	11	5	1								
YWN	82		2	20	25	14	9	5	6	1					
TOTAL	1982	30	269	446	458	317	207	130	61	24	25	12	1	1	1

Appendix 2. Rainforest one-way volume equations

FRB code	H&M code	eqn. no.	common name	botanical name	H&M group	rat dbh	tot no.	subset used	no.	wt?	intercept	slope	sig	R²	se%	large trees intercept	large trees slope
ALB	ALB	0057	almondbark	*Prunus turneriana*	D-2	50	9	tariff			-0.42642	8.81025			32.6		
BBN	BBN	0058	black bean	*Castanospermum australe*	C	80	20	<84 cm	15	no	-0.85114	8.62221	***	.70	22.5	+2.67689	2.25600
BGC	BGT	0059	barringtonia	*Barringtonia calyptrata*	C	80	2	tariff			-0.42312	8.74218					
BKP	BKP	0060	black pine	*Prumnopitys amara*	B	90	8	tariff			-0.45262	9.35170			29.6		
BLA	BLA	0061	blush alder	*Sloanea australis*	D-1	60	31	all	31	yes	+0.21565	5.45541	***	.37	44.8		
BLD	BLD	0062	blushwood	*Hylandia dockrillii*	nc		2	tariff			-0.49800	10.28917					
BLO	BLO	0063	blush silky oak	*Opisthiolepis heterophylla*	C	80	13	all	13	no	-0.71921	9.08603	***	.71	27.9		
BNQ	BRQ*	0064	brown quandong	*Elaeocarpus ruminatus*	C	80	14	all	14	yes	-0.92542	11.02248	***	.76	50.9		
BOW	BOW	0065	Boonjie blush walnut	*Beilschmiedia sp.(=AFO 1479)*	C	80	1	tariff			-0.53298	11.01202					
BRC	BRC	0066	brown cudgerie	*Canarium baileyanum*	nc		40	tariff	39		-0.26000	5.37182			47.8	+1.73367	1.40554
BRO	BRO	0067	brown silky oak	*Darlingia darlingiana*	D-2	50	10	omit 1	9	no	-0.55440	7.66521	***	.92	26.0		
BRP	BRP*	0068	brown pine	*Podocarpus grayi*	D-2	50	5	all	5	no	+0.34838	4.34660	ns	.76	13.5		
BRQ	BRQ*	0069	brown quandong	*Elaeocarpus coorangooloo*	C	80	24	all	24	yes	-0.80687	9.99708	***	.67	31.8		
BRT	BRT*	0070	brown tulip oak	*Argyrodendron trifoliolatum*	D-1	60	45	all	45	no	-0.67105	10.39357	***	.84	24.1		
BRW	COW*	0071	coach walnut	*Endiandra dichrophylla*	nc		4	tariff			-0.46168	9.53889			23.8		
BSH	BSH	0072	bumpy satinash	*Syzygium cormiflorum*	nc		1	tariff			-0.39862	8.23591					
BSL	BSL*	0073	brown salwood	*Acacia aulacocarpa*	D-2	50	15	<70 cm	13	no	-0.65872	9.33342	**	.56	29.1	+1.99337	2.44209
BSO	BSO	0074	briar silky oak	*Musgravea heterophylla*	B	90	22	all	22	yes	-1.45297	13.54984	***	.84	26.2		
BSW	BSW	0075	bolly silkwood	*Cryptocarya oblata*	C	80	3	tariff			-0.28623	5.91378			97.9		
BTP	BRT*	0076	brown tulip oak	*Argyrodendron polyandrum*	D-1	60	12	all	12	no	-0.17838	6.27232	ns	.23	49.9		
BWA	BRW	0077	brown walnut	*Beilschmiedia sp.(=AFO 1487)*	C	80	1	tariff			-0.39566	8.17478					
BWD	BWD*	0078	bollywood	*Litsea leefeana*	D-2	50	12	all	12	yes	-0.60280	8.24581	**	.62	53.3		
CBH	CBH*	0079	canary beech	*Polyalthia nitidissima*	D-1	60	9	all	9	yes	-0.45394	8.43496	***	.85	26.6		
CBM	CBH*	0080	canary beech	*Polyalthia michaelii*	D-1	60	1	tariff			-0.42027	8.68334					
CCA	BTR	0081	blush touriga	*Calophyllum calaba var. australianum*	nc		2	tariff			-0.31779	6.56588					
CDG	CDG	0082	cadaga	*Eucalyptus torelliana*	hwd	90	3	tariff			-0.37508	7.74951			25.9		
CHS	CHS	0083	cherry satinash	*Syzygium luehmannii*	D-1	60	12	<90 cm	8	no	-0.72603	10.50737	**	.75	27.0	+4.20947	2.74925
CKS	CKS	0084	creek satinash	*Syzygium australe*	D-2	50	1	tariff			-0.33695	6.96181					
CLO	CLO	0085	caledonian oak	*Carnarvonia araliifolia*	nc		24	all	24	no	-0.00278	6.04345	***	.43	49.9		
CMY	CMY	0086	cream mahogany	*Chisocheton longistipitatus*	C	80	1	tariff			-0.49126	10.15005					
DMN	DMN	0087	damson	*Terminalia sericocarpa*	C	80	4	tariff			-0.25668	5.30333			48.2		
EVD	EVD	0088	evodia	*Euodia elleryana*	C	80	2	tariff			-0.32498	6.71454					
FSO	FSO	0089	fishtail silky oak	*Neorites kevediana*	C	80	5	all	5	no	-0.25296	7.69055	*	.77	21.1		
GCB	GCB	0090	grey carabeen	*Sloanea macbrydei*	C	80	17	all	17	yes	-0.38925	7.79385	**	.45	44.9		
GRS	GRS	0091	grey satinash	*Syzygium gustavioides*	C	80	48	<90 cm	39	no	-0.62868	8.45844	***	.60	33.5	+3.34440	2.21315
HAL	HAL	0092	hard alder	*Pullea stutzeri*	nc		4	tariff			-0.43923	9.07494			26.0		
HKA	HKA	0093	hickory ash	*Flindersia ifflaiana*	A	90	40	all	40	no	-0.55843	8.11707	***	.75	27.6		
HMW	HMW	0094	hard milkwood	*Alstonia muelleriana*	D-2	50	2	tariff			-0.59947	12.38567					
JHR	JHR	0095	Johnstone River hardwood	*Backhousia bancroftii*	B	70	44	<84 cm	37	yes	-0.32320	9.03223	***	.49	28.7	+3.37260	2.36328
KRS	KRS	0096	Kuranda satinash	*Syzygium kuranda*	C	60	35	<84 cm	34	yes	-0.62795	10.49174	***	.84	23.4	+3.66505	2.74516
LPS	LPS	0097	lillipilli satinash	*Acmena smithii*	D-1	60	15	<84 cm	12	no	-0.73740	7.92569	**	.62	27.2	+2.50563	2.07376
MGN	MGN	0098	magnolia	*Galbulimima belgraveana*	C	80	23	<90 cm	22	no	-0.54353	11.56735	***	.87	14.1	+4.88987	3.02660
MRR	MRR	0099	mararie	*Pseudoweinmannia lachnocarpa*	D-1	60	8	omit 1	7	no	+0.57839	2.92508	ns	.50	23.0		
MSW	MSW	0100	maple silkwood	*Flindersia pimenteliana*	A	100	165	all	165	no	-0.66106	8.96955	***	.77	34.5		
NBM	NBM	0101	brush mahogany	*Geissois biagiana*	C	80	5	tariff			-0.49936	10.31739			19.1		
NEV	NEV	0102	northern evodia	*Euodia vitiflora*	C	80	6	tariff			-0.42131	8.70484			29.0		
NHQ	NHQ	0103	hard quandong	*Elaeocarpus sericopetalus*	D-2	50	6	all	6	no	-0.87958	9.69214	ns	.46	31.8		
NKA	NKP*	0104	Queensland kauri pine	*Agathis atropurpurea*	A	100	15	all	15	no	-0.91985	10.63621	***	.95	13.1		
NKR	NKP*	0105	Queensland kauri pine	*Agathis robusta*	A	100	89	all	89	no	-0.83696	12.77657	***	.91	18.8		
NRW	NRW	0106	rose walnut	*Endiandra cowleyana*	D-1	60	1	tariff			-0.47854	9.88541					

Appendix 2. Rainforest one-way volume equations

FRB code	H&M code	eqn. no.	common name	botanical name	H&M group	ret dbh	tot no.	subset used	no.	wt?	intercept	slope	sig	R^2	se%	large trees intercept	large trees slope
NSO	NSO	0107	northern silky oak	*Cardwellia sublimis*	A	100	139	all	139	yes	-0.84952	9.36163	***	.88	24.9		
NSR	NSR	0108	scentless rosewood	*Synoum muelleri*	D-1	60	13	omit 1	12	no	-0.69210	8.11548	***	.77	23.9	+2.62858	2.12342
NSS	NSS*	0109	sassafras	*Doryphora aromatica*	C	80	55	all	55	no	-0.53259	9.47488	***	.70	28.8		
NTG	NTG	0110	nutmeg	*Myristica insipida*	D-2	50	3	tariff			-0.59275	12.24686			2.7		
NTQ	NTQ	0111	northern quandong	*Elaeocarpus foveolatus*	D-2	50	5	all	5	no	-0.40106	7.21713	ns	.48	19.0		
NYB	NYB*	0112	yellow boxwood	*Planchonella obovata*	D-1	60	3	tariff			-0.36126	7.00118			115.8		
PBS	PBS	0113	paperbark satinash	*Syzygium papyraceum*	D-1	60	8	all	8	no	-0.59271	5.62807	*	.66	44.6	+1.71018	1.47258
PKA	PKA	0114	pink ash	*Alphitonia petriei*	D-2	50	4	tariff			-0.45658	9.43343			18.5		
PKS	PKS	0115	pink satinash	*Syzygium sayeri*	D-2	50	2	tariff			-0.37429	7.73318					
PMH	PMH	0116	pink mahogany	*Dysoxylum oppositifolium*	D-1	60	6	tariff			-0.24008	4.96036			40.2		
PMR	PMR	0117	pink myrtle	*Metrosideros queenslandica*	C	80	1	tariff			-0.17735	3.66422					
PPW	PPW	0118	pepperwood	*Cinnamomum laubatii*	C	80	20	<90 cm	18	no	-0.83679	11.09749	***	.64	31.3	+4.37591	2.90366
QMP	QMP	0119	Queensland maple	*Flindersia brayleyana*	A	100	88	all	88	no	-1.03533	11.08892	***	.90	32.5		
QSA	QSA*	0120	silver ash	*Flindersia bourjotiana*	A	90	48	all	48	yes	-0.89653	9.95908	***	.85	26.9		
QWN	QWN	0121	Queensland walnut	*Endiandra palmerstonii*	A	100	24	omit 1	23	no	-0.31085	9.28548	***	.78	22.8		
RAL	RAL	0122	rose alder	*Caldcluvia australiensis*	C	80	26	<90 cm	20	no	-0.95289	10.20727	***	.55	41.0	+3.84165	2.67073
RBN	RBN	0123	rose butternut	*Blepharocarya involucrigera*	C	80	24	all	24	no	-0.29907	8.17962	***	.84	19.5		
RBS	RBS	0124	roughbark satinash	*Syzygium trachyphloium*	D-1	60	21	omit 1	20	yes	-0.28146	6.48778	***	.58	52.7		
RCD	RCD	0125	red cedar	*Toona australis*	A	100	18	all	18	no	-0.56942	8.83996	***	.82	48.0		
RDT	RDT*	0126	red tulip oak	*Argyrodendron peralatum*	B	90	39	all	39	no	-0.98176	12.39260	***	.87	25.3		
RES	RES	0127	red Eungella satinash	*Acmena resa*	C	80	16	all	16	yes	-1.11583	9.22213	***	.65	30.9		
RMH	RMH	0128	rose mahogany	*Dysoxylum fraserianum*	C	80	5	tariff			-0.28828	5.95620			38.1		
RPN	RPN	0129	red penda	*Xanthostemon whitei*	C	80	3	tariff			-0.45177	9.33400			38.3		
RSR	RSR	0130	red siris	*Paraserianthes toona*	B	90	8	all	8	no	-0.42914	7.92298	*	.51	26.1		
RSW	RSW	0131	red silkwood	*Palaquium galactoxylum*	B	90	1	tariff			-0.79056	16.33389					
SBH	SBH	0132	stony backhousia	*Backhousia hughesii*	C	80	10	all	10	no	-0.18107	7.20676	**	.62	24.9		
SBN	SBN	0133	salmon bean	*Archidendron vaillantii*	D-1	60	1	tariff			-0.24760	5.11570					
SKC	SKC	0134	silky celtus	*Celtis paniculata*	nc		2	tariff			-0.64467	13.31957					
SLQ	SLQ	0135	silver quandong	*Elaeocarpus grandis*	C	80	116	<95 cm	113	no	-0.54903	9.60879	***	.75	32.1	+4.47981	2.51414
SMH	SMH	0136	spur mahogany	*Dysoxylum pettigrewianum*	C	80	3	tariff			-0.23363	4.82701			49.5		
SPO	SPO	0137	spotted silky oak	*Buckinghamia celsissima*	nc		13	all	13	no	-1.31906	12.46324	***	.83	20.4		
SSA	QSA*	0138	silver ash	*Flindersia schottiana*	A	90	2	tariff			-0.32101	6.63249					
SSW	SSW	0139	silver silkwood	*Flindersia acuminata*	A	90	25	all	25	no	-0.54548	8.90142	***	.69	37.3		
STC	STP*	0140	scrub turpentine	*Canarium muelleri*	nc		6	tariff			-0.43088	8.90253			22.1		
STO	STO	0141	satin oak	*Oreocallis wickhamii*	B	90	19	<90 cm	18	no	-0.86735	9.93768	***	.77	27.7	+3.80056	2.60019
STP	STP*	0142	scrub turpentine	*Canarium australianum*	nc		6	tariff			-0.39417	8.14406			26.5		
STS	STS	0143	satin sycamore	*Ceratopetalum succirubrum*	C	80	122	omit 1	121	yes	-0.75707	9.78383	***	.79	30.0		
TRQ	TRQ	0144	tropical quandong	*Elaeocarpus largiflorens*	D-2	50	3	tariff			-0.43639	9.01639			17.1		
WBH	WBH	0145	white beech	*Gmelina fasciculiflora*	B	90	12	all	12	no	-0.80086	10.91429	***	.77	30.6		
WBW	WBR	0146	white birch	*Schizomeria whitei*	D-1	60	1	tariff			-0.42452	8.77111					
WCB	WCB	0147	white carabeen	*Sloanea langii*	C	80	2	tariff			-0.42589	8.79935					
WCW	WCW	0148	white cheesewood	*Alstonia scholaris*	B	90	7	<84 cm	6	yes	-1.46746	14.55015	**	.91	24.2	+4.48615	3.80705
WES	WES	0149	white Eungella satinash	*Syzygium wesa*	C	80	34	all	34	no	-0.81196	9.31951	***	.78	31.4		
WSO	WSO	0150	Whelan's silky oak	*Macadamia whelanii*	nc		1	tariff			-0.43086	8.90213					
YBA	YBW*	0151	yellow boxwood	*Planchonella pohlmaniana* var. *asterocarpon*	D-1	60	1	tariff			-0.54900	11.34288					
YBW	YBW*	0152	yellow boxwood	*Planchonella pohlmaniana*	D-1	60	3	tariff			-0.35986	7.43507			36.2		
YEV	YEV	0153	yellow evodia	*Euodia bonwickii*	D-2	50	18	all	18	no	-0.54206	9.86069	***	.86	15.4		
YLS	YLS	0154	yellow satinash	*Syzygium canicortex*	C	80	32	<84 cm	31	no	-0.37114	8.29476	***	.58	29.2	+3.02290	2.17032
YWN	YWN	0155	yellow walnut	*Beilschmiedia bancroftii*	C	80	82	all	82	no	-0.82857	9.91149	***	.76	32.8		

Appendix 2. Rainforest one-way volume equations

FRB code	H&M code	eqn. no.	common name	botanical name	H&M group	ret dbh	tot no.	subset used	no.	wt?	intercept	slope	sig	R^2	se%	FRB codes included
—	BRQ	0156	brown quandong	*Elaeocarpus ruminatus & E. coorangooloo*	C	80	38	all	38	yes	-0.88818	10.49064	***	.72	41.8	BNQ+BRQ
—	BRT	0157	brown tulip oak	*Argyrodendron trifoliolatum & A. polyandrum*	D-1	60	57	all	57	no	-0.76463	10.40196	***	.78	29.4	BRT+BTP
—	CBH	0158	canary beech	*Polyalthia nitidissima & P. michaelii*	D-1	60	10	all	10	yes	-0.43858	8.41618	***	.85	25.9	CBH+CBM
—	NKP	0159	Queensland kauri pine	*Agathis robusta & A. atropurpurea*	A	100	104	all	104	yes	-1.14663	12.98071	***	.87	20.5	NKA+NKR
—	QSA	0160	silver ash	*Flindersia bourjotiana & F. schottiana*	A	90	50	all	50	yes	-0.92346	10.01247	***	.85	27.1	QSA+SSA
—	STP	0161	scrub turpentine	*Canarium muelleri & C. australasicum*	nc		12	tariff			-0.41091	8.48994			22.4	STC+STP
—	YBW	0162	yellow boxwood	*Planchonella pohlmaniana & P. p. var. asterocarpon*	D-1	60	4	tariff			-0.36734	7.58968			32.6	YBA+YBW
MIS	—	0163	general equation	*All except* MSW NKA NKR NSO QMP QWN STS WES YWN			1224	all	1224	yes	-0.41124	8.49850	***	.68	42.7	

Notes-

(1) H&M code — A * indicates that one or more additional species are included in this code. The equations represent the single species defined by the FRB code.

(2) eqn. no. — The equation number for access to departmental volumation software.

(3) H&M group — The species group as defined in the treemarking rules. "nc" = non-compulsory species; "hwd" = compulsory hardwood species.

(4) ret dbh — The maximum dbh for retention as per treemarking rules.

(5) wt? — Whether weighted by $1/BA^2$

(6) tariff — The regression is conditioned to have zero volume at 0.0484 m^2 basal area

(7) large trees — These coefficients apply to dbh's above those shown in the "subset used" column