Volume calculations of coarse woody debris

Commissioned by Ministry of Agriculture, Nature and Food Quality, DWK research programme 381 and the DWK research cluster EHS.

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Evaluation of coarse woody debris volume calculations and consequences for coarse woody debris volume estimates in forest reserves

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Alterra-rapport 1257

Alterra, Wageningen, 2005

ABSTRACT

Wijdeven, S.M.J., O.H.B. Vaessen, A.F.M. van Hees & A.F.M. Olsthoorn, 2005. *Volume calculations of coarse woody debris; evaluation of coarse woody debris volume calculations and consequences for coarse woody debris volume estimates in forest reserves*. Wageningen, Alterra, Alterra-rapport 1257. 50 blz.; 10 figs.; 6 tables.; 18 refs.

Dead wood is recognized as one of the key indicators for sustainable forest management and biodiversity. Accurate assessments of dead wood volume are thus necessary. In this study New volume models were designed based on actual volume measurements of coarse woody debris. The New generic model accurately estimated volumes for all encountered tree parts (whole trees, stems, branches), is based on diameter and length only, and thus generally applicable for most studies. Therefore this New generic dbh-based coarse woody debris volume model was selected as the most appropriate one. Consequences for coarse woody debris volume estimates of forest reserves vary. Total dead wood volume can even be much larger when fine woody debris, dead wood attached to living trees and tree stumps are included.

Keywords: coarse woody debris, dead wood, forest reserves, volume calculations

ISSN 1566-7197

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[Alterra-rapport 1257/12/2005]

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Preface

This study was initiated by Ad van Hees and was part of the Dutch Forest Reserves Research Program. We would like to thank the Dutch Ministry of Agriculture, Nature and Food Quality for the financial support and R.J. Bijlsma for his helpful comments on the manuscript.

Summary

Dead wood becomes an increasingly important aspect of forest policy and management with its great ecological value acknowledged in various studies and guidelines. However, volume estimates are often still based on simple mathematical equations or on traditional wood production based stem volume models. Accurate estimates of total dead wood amounts, including stem and branches, are thus necessary. To be generally applicable, these estimates should preferably be based on simple measurement variables, commonly used in most monitoring schemes.

In this and many other studies, only dead wood with a minimum diameter of >10cm is included in the assessments. In this report we therefore refer to Coarse Woody Debris (cwd). In order to accurately assess cwd volumes the following aspects were addressed in this study:

- analyses of New cwd volume models
- comparison with Current volume models and actual volume measurements
- assessment of volume estimate consequences in forest reserves

New volume models were based on diameter, length, species and decay state, or a selection of these, and fitted by means of multiple linear regressions on actual volumes. Two New models produced most accurate volume assessments; the New species specific model (containing species, diameter and length) and the New generic model (containing only diameter and length). The Current volume model is a mathematical model, based on a (topped) cone shaped volume calculation.

Comparing the performance of the New models (New species specific and New generic) and Current models indicates the following:

- the decay state did not have a significant effect on volume estimates, it is however not clear if there is no effect or that there are not enough tree parts of later decay state available for the analyses,
- although the factor species has a significant effect, most species however do not significantly differ in volume estimates,
- the more simple New generic model produces comparable volume estimates with a similar goodness of fit and mean square error than the New species specific model,
- dbh based models (Current and New) produce better estimates than mid-diameter based models,
- the New generic model has a higher goodness of fit, a smaller mean square error and systematic error compared to the Current model.

Therefore the New generic coarse woody debris (dbh-based) volume model:

Ln(vol) = -2.2845 + 2.0349*Ln(dbh) + 0.6594*Ln(length)

(with dbh in cm, length in m and volume in dm^3)

is selected as the most accurate and generally applicable cwd volume model, producing estimates with a goodness of fit of 98%.

However, large tree parts were underrepresented in the dataset, hampering volume estimates of larger trees. When sufficient larger dead wood tree parts become readily available a reanalyzes of volume models is advised. Moreover, this model is based on volume estimates for trees with a minimum diameter of 10cm. In other studies total dead wood volume was found to be substantial larger due to the inclusion of primarily fine dead wood, but also to dead wood attached to living trees and stumps.

Nevertheless, the New generic model greatly improves coarse woody debris volume estimates. Consequences for coarse woody debris estimates in forest reserves vary, mainly due to the variability in cwd composition in the Forest Reserves. The New generic model generally produces 22% higher estimates compared to traditional wood production based stem volume calculations, due to the implicit inclusion of branches.

1 Introduction

Nowadays it is increasingly recognized that dead wood is part of the forest ecosystem and that dead wood has an important role in maintaining biodiversity. Dead wood is a key habitat for many species (invertebrates, fungi, bryophytes, lichens, birds and mammals), can provide regeneration sites, can act as water storage element and is a long-term nutrient storage (see e.g. Harmon et al., 1986, Siitonen, 2001, Stokland et al., 2004, Christensen et al., 2004). Ecosystem Management, Nature based/oriented, Integrated or Multifunctional Forest Management aim, amongst others, at maintaining and developing biodiversity in combination with wood production. The amount, sizes and number of trees of (standing and fallen) dead wood are key management parameters. The Ministry of Agriculture, Nature and Food Quality in the Netherlands identifies dead wood as one of the key components in forest biodiversity conservation and actively promotes dead wood in forests. Moreover, dead wood is regarded internationally as one of the prime indicators of sustainable forest management and biodiversity conservation (e.g. BEAR, MCPFE, EEA).

Accurate estimates of dead wood amounts are thus necessary to: (a) be able to quantify the effects, (b) compare dead wood amounts in time and between areas, and (c) develop guidelines for forest policy and management.

The Dutch Forest Reserves Network studies spontaneous developments in unmanaged forests. Forest structure, composition and dynamics are monitored, with standing and fallen dead wood as one of the components. Information from this monitoring program is used as a reference for more nature oriented forest management.

In most studies, including this one, the dead wood which is measured and described constitutes of dead wood parts with a minimum diameter of 10cm. Therefore, we use in this report the more accurate term Coarse Woody Debris (cwd) for the measured and analyzed dead wood.

At the moment cwd volume assessments are generally based on measurements of diameter and length of all, or a subset, of the coarse woody debris parts in a stand. Volume calculations are then based on general and simple mathematical formulas or on wood production based stem volume models (e.g. Dik, 1984). It is however not clear to what extent these practical and simple approaches adequately estimate present total cwd volumes, including branch volume. Moreover, it is very well possible that cwd volume estimates are not only related to diameter and length, but are also species specific (cf wood production stem volume studies; Dik, 1984, 1996), and influenced by the decay state.

In order to accurately assess cwd volumes based on present monitoring schemes the following aspects were addressed in this study:

- analyses of New volume models based on existing monitoring schemes,
- comparison of Current volume models and New models with actual measured volumes,
- evaluation of volume models,
- assessment of volume estimate consequences in forest reserves.

2 Methods

2.1 Study sites

Coarse woody debris was measured in three Forest Reserves, located in the central part of the Netherlands. In the selected reserves, ample amounts of cwd are present, consisting of most of the main tree species in the Netherlands. The reserves are: Galgenberg, het Leesten and Pijpebrandje, all owned by the State Forest Service. More details of the study sites are presented in the monitoring reports of these reserves (Bartels, 1995, Knoppersen, 1995 & 1997, Clerkx et al., 2000, Wijdeven, 2003).

2.2 Measurements

In the three study sites, three transects per ha of approximately 100m in length were investigated. Cwd was found as either complete fallen trees, as fallen branches or as fallen stem or branch parts. Therefore, in this study, we use the term 'tree parts' for all measured cwd elements. Encountered cwd parts larger than 10cm in diameter were measured. General aim was to acquire a good distribution over all species and diameter classes, and if possible, over all decay classes. Per tree part the species was identified (according to bark, leaves/needles, wood structure) and decay state (table 1) was assessed.

Table 1. Decay classes of dead wood (Clerkx et al., 2003).

Decay class	Status
0	Unknown
1	Fresh, recently dead
2	Superficial decay
3	Moderate decay
4	Largely decayed
5	Remains in litter layer

General aim is to accurately assess and test cwd volume models based on length of the coarse woody debris part and dbh or mid-diameter, parameters measured in the present monitoring scheme. Therefore, we compared: (a) two Currently used mathematical based models (dbh and mid-diameter; see below) here referred as 'Current models', with (b) New developed statistical volume models (see below) here referred as 'New models' and related these to detailed actual volume measurements (segments; see below). The following items were therefore measured. Of all dead tree parts the length, diameter at 1.3m from the base and the mid-diameter of the total tree part were assessed. Minimum diameter of the tree part 'base' was 10cm and length was based up to a top diameter of 5cm. For the actual volume, detailed measurements were made. All tree parts were divided in 2m length segments and mid-diameter of each segment was measured (see figure 1). The segment method is generally regarded as an accurate estimate of the actual volume, following Kramer & Akça (1987) and Dik (1984).

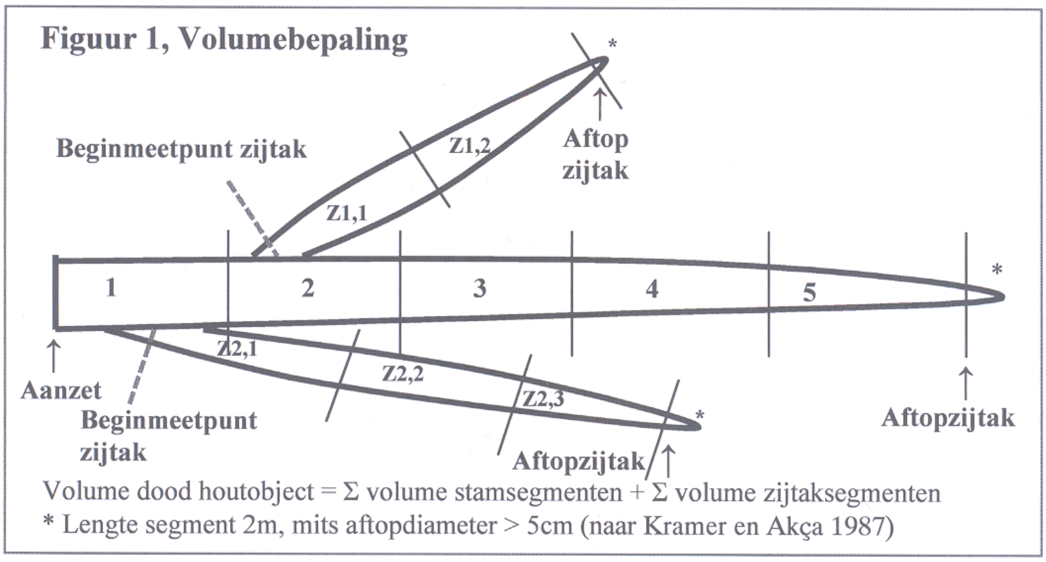


Figure 1. Schematic overview of the segment method for actual volume calculations (after Kramer & Akça, 1987). With segment lengths 2m and top diameter 5cm.

2.3 Analysis

The ***Actual*** volume is based on a topped-cone (Kramer & Akça, 1987) and measured on 2m segments. The volume per segment is then calculated as:

$$V_{act} = (\pi/4 * D_{dm}^{2} * L)/10 \qquad (1)$$

With V_{act} as the actual segment volume (in dm^3), D_{dm} as mid-diameter of the segment (in cm) and L as length of the segment (in m). Actual volume of tree parts is then the sum of the individual segments (see figure 1).

The ***Current*** volume models based on the total length of the tree part and either the dbh (equation 2) or mid-diameter (equation 3) (Koop unpublished).

$$V_{Cdbh} = (\pi/6 * D_{dbh}^{2} * L)/10 \qquad (2)$$

$$V_{Cdm} = (\pi/4 * D_{dm}^{2} * L)/10 \qquad (3)$$

With V_{Cdbh} as the Current dbh based volume (in dm^3), D_{dbh} as diameter at 1.3m from the base (in cm) and L as length of the tree part (in m). And with V_{Cdm} as the Current mid-diameter based volume (in dm^3), Dm as the mid-diameter (in cm) and L as length of the tree part (in m).

New cwd volume models were fitted with multiple linear regression (Genstat 8.11), based on diameter (dbh or mid-diameter) and length, and using species and decay state as possible differentiating factors. Actual volume, diameter and length were Ln transformed to improve normality of the data. Both forward and backward regression analyses were performed. Regression models were then compared to a simple model containing diameter and length only. Model evaluation was based on the goodness of fit, homogeneity of the residuals, number of variables in the model, variance coefficients and extent of total and systematic mean square error (Wallach & Goffnet, 1987, 1989 in Kramer & Mohren, 2001). The (systematic) mean square error (MSE) is calculated as:

$$MSE = \sum (V_{observed} - V_{predicted})^2 / N \quad (4a)$$

$$MSE_{unsystematic} = \sum (V_{mean} - V_{observed})^2 / N \quad (4b)$$

$$MSE_{systematic} = \sum (V_{mean} - V_{predicted})^2 / N \quad (4c)$$

Both the accuracy of the *Current* models and best (*New*) regression models were then compared to the *actual* cwd volumes. Evaluations of volume model performances were based on practicality and general applicability of the model, goodness of fit, and total and systematic error.

Finally, the application of individual tree part cwd volume models were evaluated at the stand level in the three study sites. Then for all forest reserves and monitoring dates total cwd volume is recalculated according to the Current and New models and differences were compared.

3 Results

3.1 Coarse woody debris composition and sizes

In the three study sites, cwd was encountered over a range of species and sizes. Generally, conifer trees are more abundant (74%) than deciduous trees, as can be seen in figure 2.

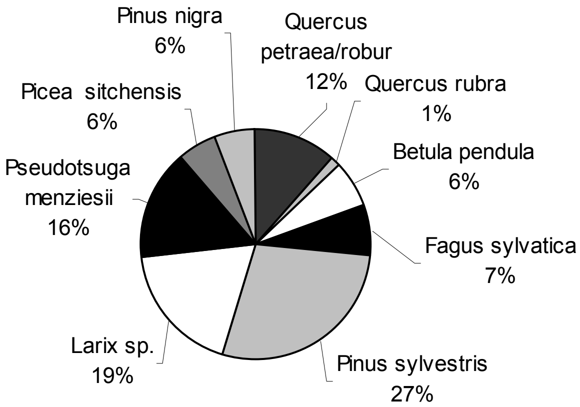


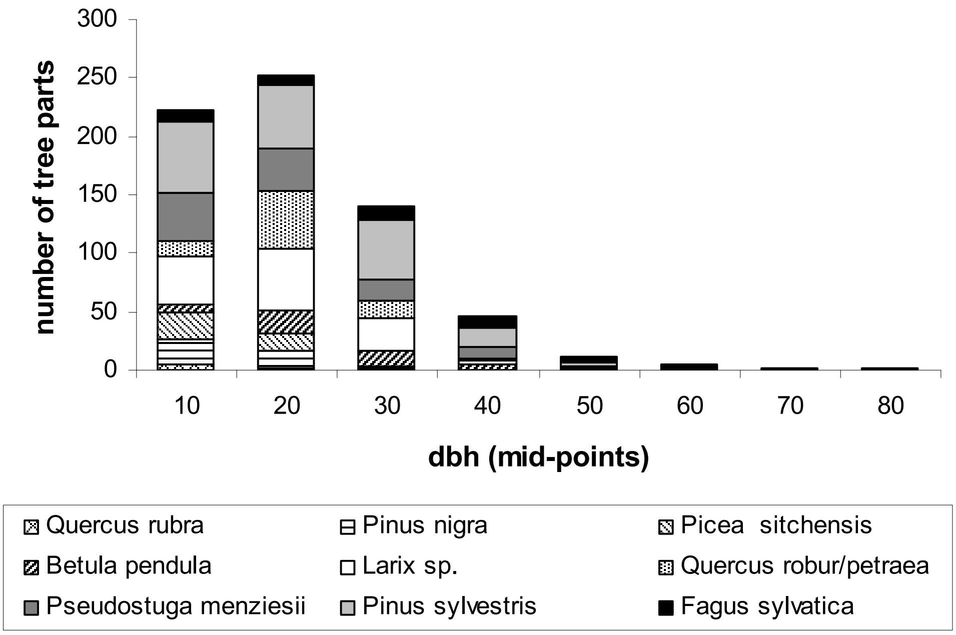
Figure 2. Encountered composition of coarse woody debris tree parts in the three study sites.

The diameter distribution is presented in figure 3. Most tree parts are smaller than 35cm in diameter and only few very large parts were encountered.

Cwd of most species is relatively small in diameter. Only for beech and Scots pine larger parts of cwd have been found. Of the most abundant species many tree parts are included in the data set covering a range in sizes (table 2). Most tree parts are in the early decay stages, a consequence of management history of the studied stands. Tree parts in later stages of decay are virtually absent in most (formerly managed) forests.

Table 2. Number and range of tree parts of the different tree species, with Dbh as the diameter at 1.3m from the base and Dm as the mid-diameter of the total tree part length.

		Range		
species	n	Dbh (cm)	Dm (cm)	Length (m)
Quercus rubra	8	8-32	5-20	5-12
Betula pendula	44	8-49	7-32	3-18
Fagus sylvatica	50	9-82	9-41	1-27
Pseudotsuga menziesii	107	6-41	5-39	1-26
Quercus robur/petraea	80	7-46	7-32	1-23
Pinus sylvestris	189	6-58	6-39	1-24
Larix sp.	126	8-45	6-34	1-28
Picea sitchensis	38	7-25	6-17	5-16
Pinus nigra sp.	39	9-28	7-24	5-18



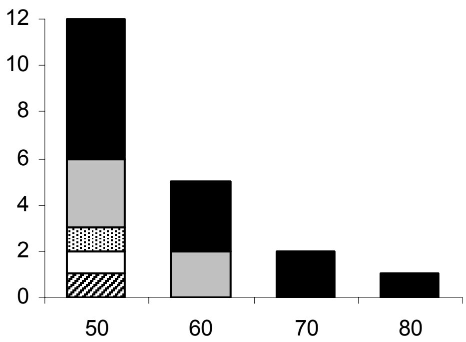


Figure 3. Cwd dbh distribution (class mid-points, range from 5-85cm) for the different tree species (r. oak is Quercus rubra, oak includes Quercus robur and Q. petraea) with the total distribution in the top figure and enlarged figure of the 50 to 80cm classes in the bottom figure (legend applies to both figures).

3.2 New species specific and decay based volume model analyses

New models were fitted on (i) dbh and length or (ii) mid-diameter and length, using species and decay state as additional variables. Multiple linear regressions in backward or forward direction were used. Data were Ln transformed to improve normality. Here three candidate models are presented of both dbh-based models and mid-diameter bases models. For both dbh-based and mid-diameter based methods the most appropriate model is selected according to the criteria: explained variance, homogeneity of the residuals and number of variables included in the model. In the next paragraph these models will be compared to the most simple, species independent model, containing only diameter and length (paragraph 3.3). Then the best ***New*** model will be selected.

Dbh based models

Candidate model 1

Backward selection
R^2 = 98.0%
Ln(vol) = F(species; decay; Ln(dbh); Ln(length); Ln(dbh)*species;Ln(length)*species; Ln(dbh)*decay; Ln(length)*decay; Ln(dbh)*Ln(length); Ln(dbh)*Ln(length)*species; Ln(dbh)*Ln(length)*decay)

Candidate model 2
Forward selection
R^2 = 97,9%
Ln(vol) = F(species; Ln(dbh); Ln(length); Ln(dbh)*Ln(length))

Candidate model 3
Forward selection
R^2 = 98.1%
Ln(vol) = F(species; Ln(dbh); Ln(length))

Of the potential variables, dbh, length and species all have a significant effect on the volume estimates (RSearch procedure Genstat, Fprob <0.001) while the decay state has not (Fprob = 0.222)). Only in interaction with other variables has the decay stage a significant effect. Of the three candidate models, model 3 is chosen as the most appropriate one, given the goodness of fit and lowest number of variables. The parameters and coefficients per species are presented in Annex 1.

$$\text{Ln(vol)} = c1 + c2 * \text{Ln(dbh)} + c3 * \text{Ln(length)} \qquad (5)$$

With volume in dm^3, dbh in cm and length in m.

Mid-diameter based models
Candidate model 1

Backward selection
R^2 = 97.0%
Ln(vol) = F(species; decay; Ln(md); Ln(length); species*decay; Ln(md)*species;Ln(length)*species; Ln(md)*decay; Ln(length)*decay; Ln(md)*Ln(length); Ln(md)*Ln(length)*species; Ln(md)*Ln(length)*decay)

Candidate model 2
Forward selection
R^2 = 96.7%
Ln(vol) = F(species; Ln(md); Ln(length); Ln(md)*Ln(length)*species)

Candidate model 3
Forward selection
R^2 = 96.4%

Ln(vol) = F(species; Ln(md); Ln(length))

Of the potential variables, md (mid-diameter), length and species have a significant effect on the volume estimates (RSearch procedure Genstat, Fprob <0.001) while the decay state has not (Fprob = 0.463), and addition of the decay variable has not a significant effect on the model. Only in interaction with other variables has decay a significant effect. Of these models candidate model 3 is chosen as the most appropriate model, given the goodness of fit and lowest number of variables. The parameters and coefficients per species are presented in Annex 2.

$$Ln(vol) = c1 + c2*Ln(dm) + c3*Ln(length) \quad (6)$$

With volume in dm^3, dm in cm and length in m.

3.3 Comparison of New species models with New generic models

Generic models (not species specific) based on length and (i) dbh (r^2=97.9, P<0.001, equation 7) and (ii) on mid-diameter (r^2=96.3, P<0.001, equation 8) have a high goodness of fit.

$$Ln(vol) = -2.2845 + 2.0349*Ln(dbh) + 0.6594*Ln(length) \quad (7)$$

$$Ln(vol) = -2.4053 + 1.9540*Ln(md) + 1.0345*Ln(length) \quad (8)$$

With volume in dm^3, Dbh or Md in cm and length in m. Standard errors for dhb formula are: c_1 0.044, c_{dbh} 0.0180, c_{lengte} 0.0129 and for the md formula are: c_1 0.0611, c_{md} 0.0235 and c_{lengte} 0.0152.

To what extent do the ***New generic*** models differ from the ***New species specific*** models? Both models (New generic model and New species specific model) produce comparable total volume estimates with an overlap of the standard errors (figure 4). They underestimate the actual volume, although differences are larger for the mid-diameter based models (bottom figure).

The relation between the actual volume and the New species specific model is indicated by the broad dotted lines (dbh: $V_{New\_species}$ = 0.941x + 16.164, r^2 = 97.8%; mid-diameter: $V_{New\_species}$ = 0.720x + 86.489, r^2 = 83.6%) and for the actual volume with the New generic models by the fine dotted lines (dbh: $V_{New\_generic}$ = 0.927 + 21.468, r^2 = 97.2%; mid-diameter: $V_{New\_generic}$ = 0.651x +108.720, r^2 =77.5%).

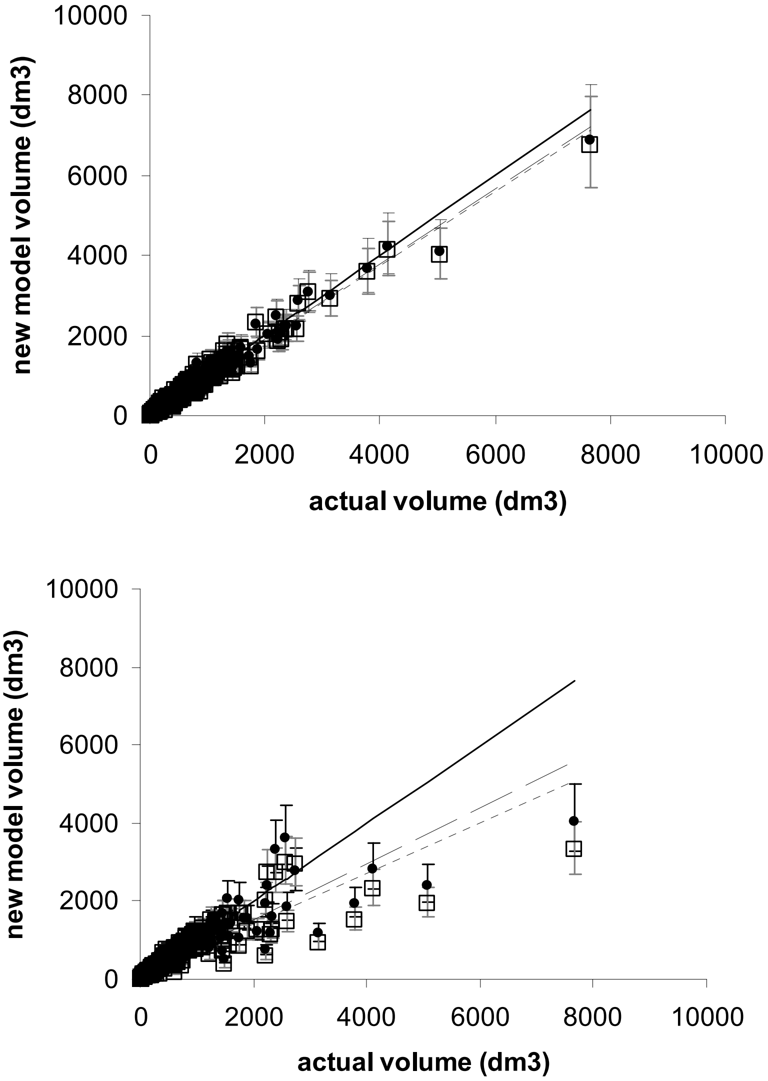


Figure 4. Comparison of New species model volume (black dots) and New generic model volume (open squares) predictions with the actual volume (observed = predicted thick solid line) for dbh based assessments (top) and mid-diameter based assessments (bottom figure) together with the standard errors (black for New species model, grey for New generic model).

In table 3 a summary of model performance and errors is presented. Mid-diameter based models have in general a slightly lower goodness of fit, a higher coefficient of variation and a much higher (systematic) error. Of the dbh based models the New species model performs in general better than the New generic model, but differences are very small.

Table 3. Analyses of model performance and model error for the New species model and New generic model based on dbh and mid-diameter assessments.

	New species model	New generic model
Dbh based models		
Goodness of fit	98.1	97.9
Variation coeff.	16.9	17.8
Mean square error (MSE)	8032.27	10160.89
MSE % systematic	15.4%	18.4%
Mid-diameter based models		
Goodness of fit	96.9	96.3
Variation coeff.	21.7	23.6
Mean square error (MSE)	61735 .79	83919.49
MSE % systematic	45.3%	50.2%

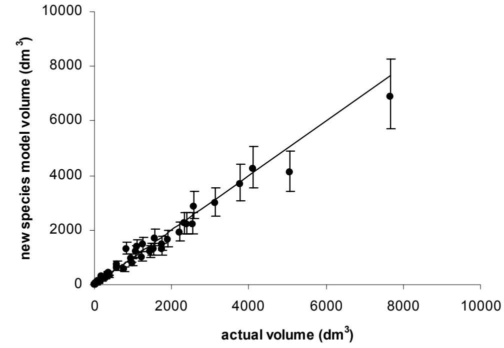
Although the New species model has a slightly better performance than the New generic model, to what extent can the differences be attributed to addition of the actual species to the model? In figure 5 the (dbh based) volume estimates are presented per species. Both models have a considerable overlap in standard error and produce estimates in line with the actual volume.

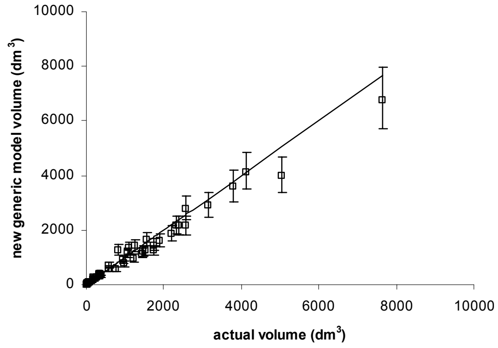
Not only have the two models comparable estimates and standard errors, they also have a similar small systematic deviation compared to the actual volume amount. The models slightly overestimate small volumes and underestimate large volumes. Only for birch is the systematic trend reversed, and for Douglas fir are the estimates systematically higher than the actual volume (see Annex 3).

Although the variable 'species' has a significant effect on the model, it is not clear whether the species significantly differ. When comparing the species effects in the dbh based models, using red oak (Quercus rubra) as a reference level, then only oak (Quercus robur & Q. petraea) differs significantly (t pr. =0.019). For mid-diameter based models only beech (t pr. =0.008) and the unidentified tree parts (t pr. <0.001) differ significantly.

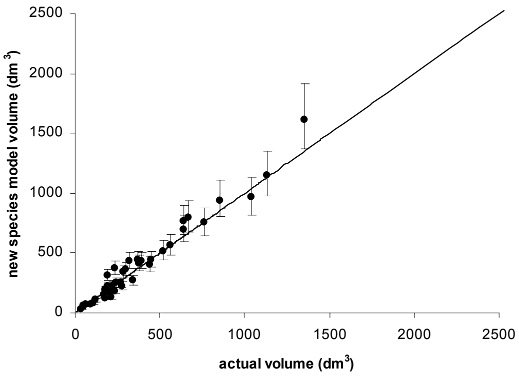
Apparently, the different species have a similar effect on the volume estimates, given the non-significant differences between almost all species. Both models perform almost equally well, with only minor differences in goodness of fit, coefficient of variation and comparable (systematic) errors. Furthermore, for all species both models largely overlap in mean estimate and standard error.

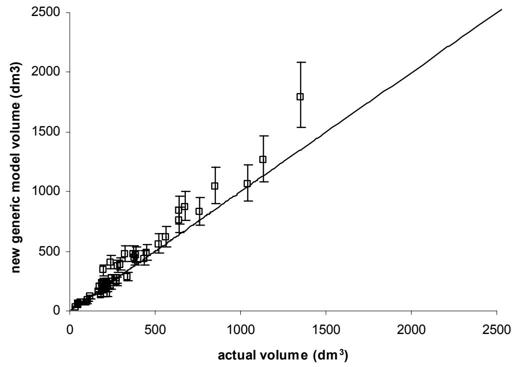
Fagus sylvatica



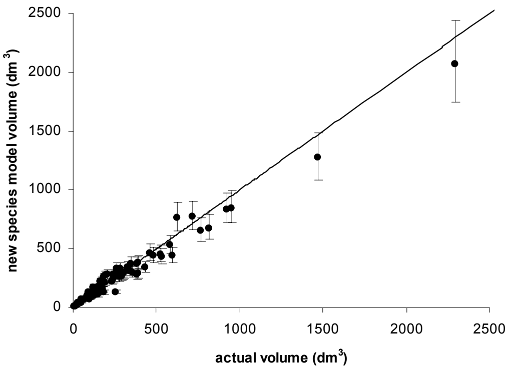


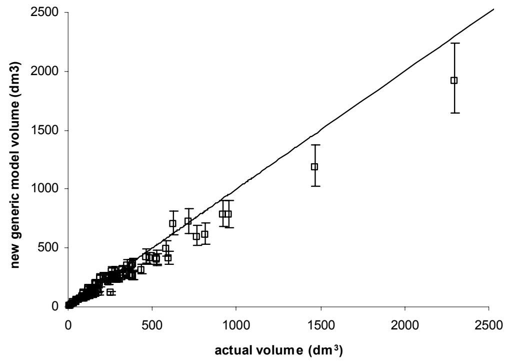
Betula pendula



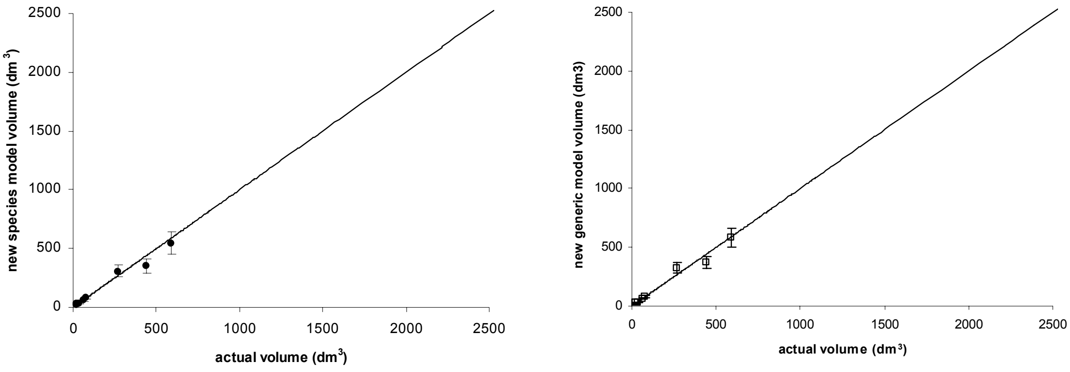


Quercus robur/petraea

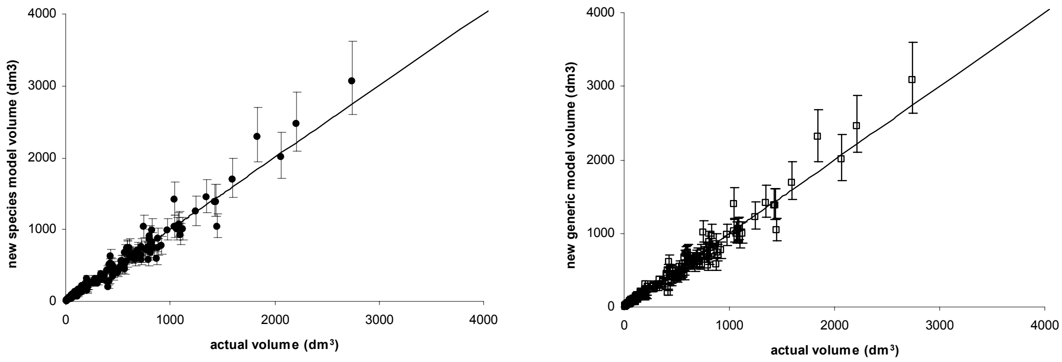




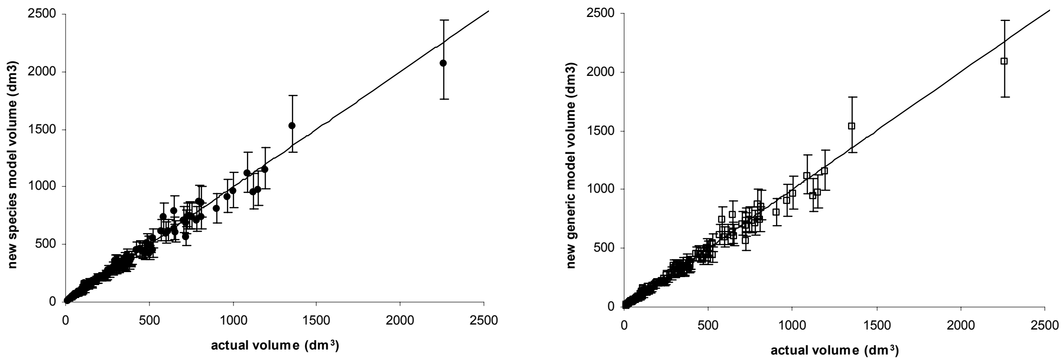
Quercus rubra



Pinus sylvestris



Larix sp.



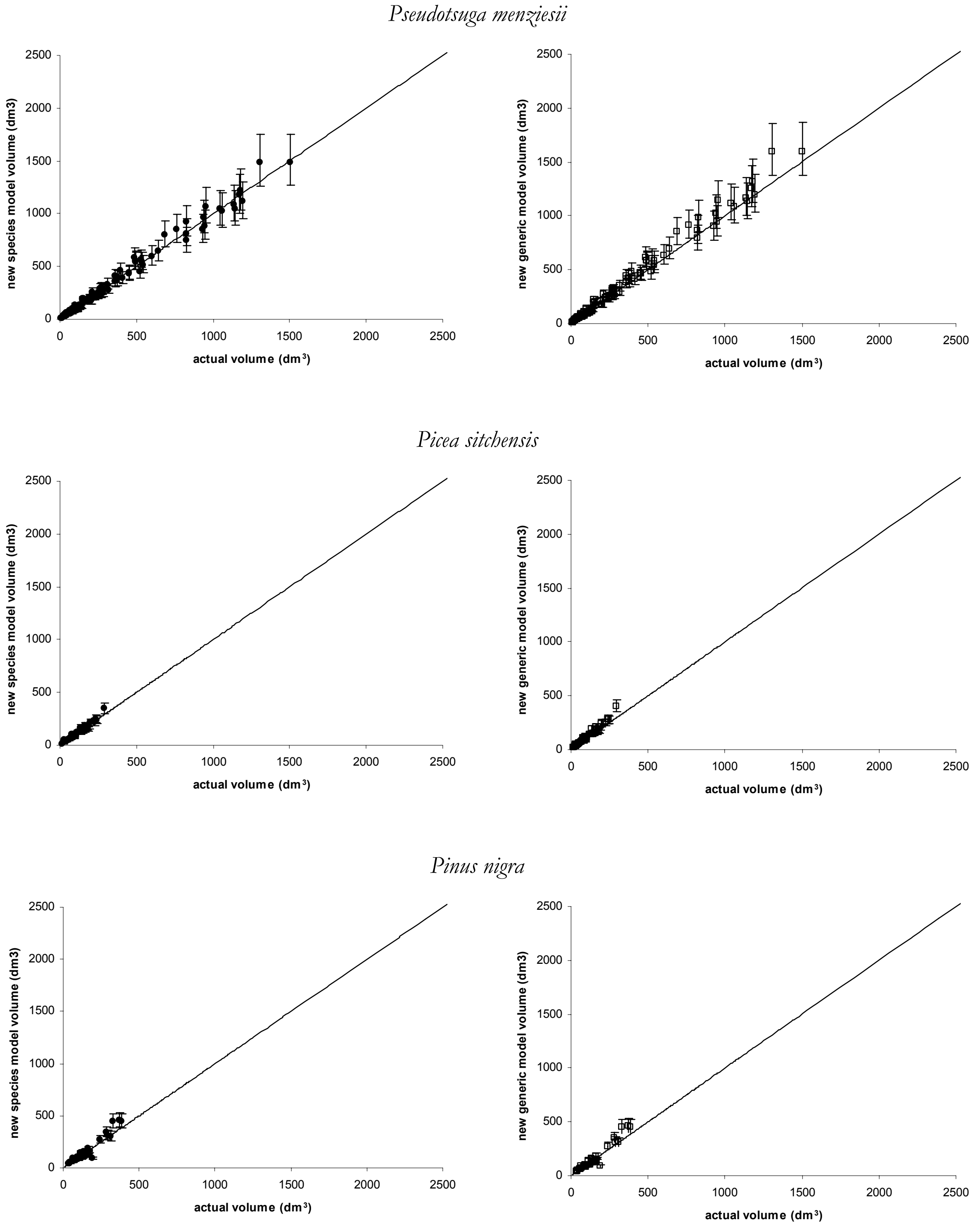


Figure 5. Comparison of (left) the New species model predictions (with standard errors) to the actual volume (solid line; observed is predicted) and (right) the New generic model predictions (with standard errors), for the encountered species. Note the differences in scale for Fagus en Pinus s.

Therefore, the ***New generic model*** is regarded as more appropriate, since it contains fewer variables compared to the New species specific model and is more generally applicable.

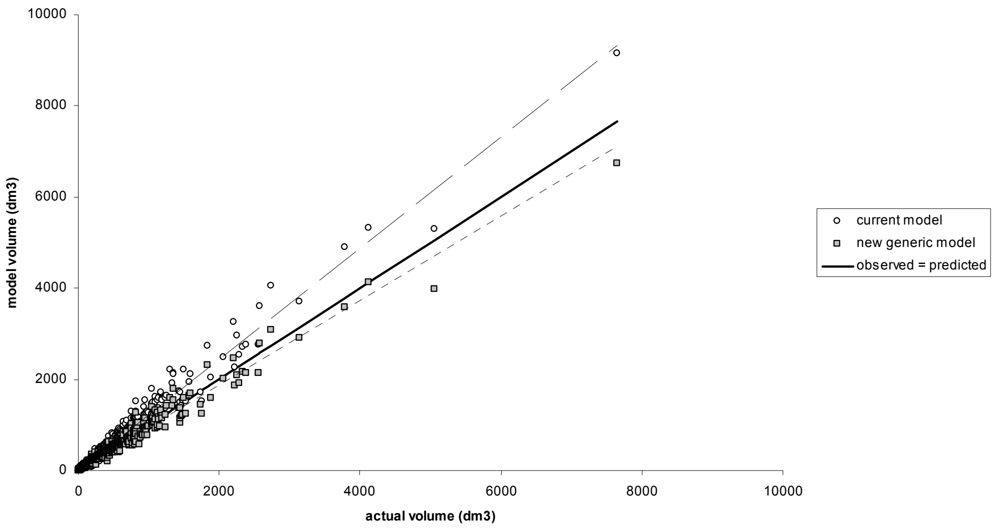
3.4 Comparison of Current model and New generic model

In order to evaluate model performance, the Current model and New generic model are compared. The comparison is based on equation 2 and 3 of the Current model and equation 7 and 8 of the New model, and equation 1 of the actual volume calculation in the three study sites. In figure 6, all the encountered tree parts are included and the Current and New generic volume estimates based on dbh (top figure) or mid-diameter (bottom figure) are related to the actual volume.

The relation between the actual volume and the *Current* model is represented by the broad dotted lines (dbh: $V_{current}$ = 1.22x – 14.17, r^2 = 97%; mid-diameter: $V_{current}$ = 0.59x + 97.34, r^2 = 77%) and for the actual volume with de *New generic* model is represented by the fine dotted lines (dbh: V_{new_gen} = 0.93x + 21.47, r^2 = 97%; mid-diameter: V_{new_gen} = 0.65x + 108.72, r^2 = 77%).

In general, mid-diameter models perform less than the dbh-based models, especially for large volume tree parts, indicated by the dotted trend lines of both models. Both the explained variance and the regression equations systematically deviate from the actual volume. The models underestimate the volume, although the Current model underestimates more than the New generic model. Comparing the performance of the two dbh based models, it is clear that the Current model overestimates the volume, and that this overestimate increases with increasing volume of the tree parts. The New generic model slightly underestimates the volume. Differences with the actual volume are however much smaller as can be seen in the figure and concluded from the explained variance and equations.

Irrespective of species, both dbh based models calculate the volume relatively accurate (total Current model r^2 = 93%, total New generic model r^2 = 97%), as can be seen in table 4. Overall, the mid-diameter based models are much less accurate, ranging in total explained variance between 39% and 55%. However, the Current volume estimate has in both cases a larger mean square error (MSE). Furthermore, in dividing this MSE in a random and systematic part it becomes clear that the Current models have a much larger systematic error in volume calculations.



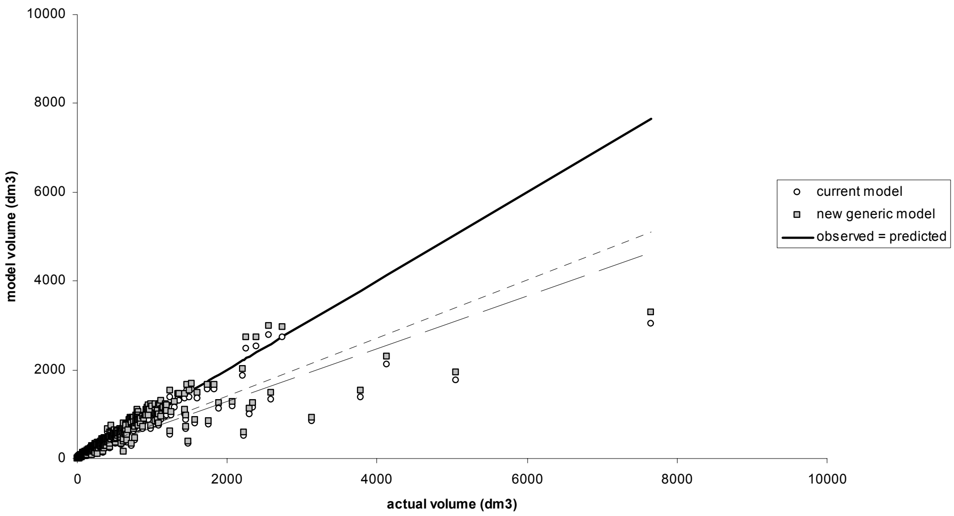


Figure 6. Comparison of Current volume model predictions and New generic volume model predictions with the actual volume (observed = predicted thick solid line) for dbh based assessments (top) and mid-diameter based assessments (bottom figure).

Table 4. Analyses of model performance and model error for the Present model and New generic model based on dbh and mid-diameter assessments.

	Current model	New generic model
Dbh based models		
Total explained variance	92.9%	96.6%
Mean square error (MSE)	36875.34	10160.89
MSE % systematic	57.9%	18.4%
Mid-diameter based models		
Total explained variance	39.2%	54.8%
Mean square error (MSE)	94382.68	83919.49
MSE % systematic	62.9%	50.2%

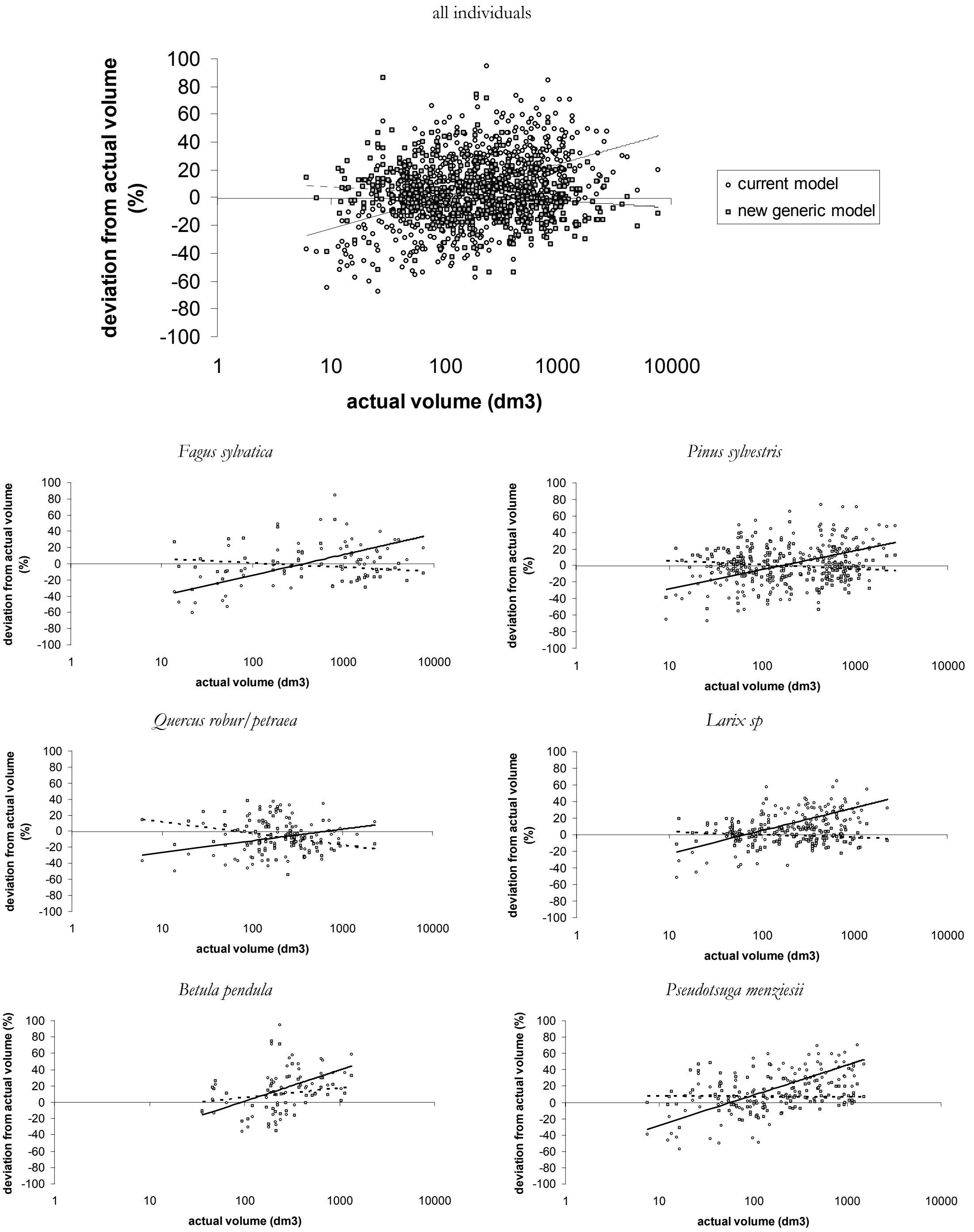


Figure 7. Relative deviation from the actual volume, based on the dbh-based Current model (open circles) and New generic model (grey squares) for all individuals (top figure) and most abundant tree species (small figures) in the three study sites. Solid line indicates linear regression of Current model, fine dotted line New generic model (equations and goodness of fit presented in Annex 4).

Plotting the relative deviation from actual volume for both models reveals the nature of the systematic error (figure 7). For all individuals and all species separately, the Current model generally underestimates small volumes (approximately <100 dm^3)

and overestimates large volumes (approximately >100 dm^3). Deviations on individual tree part estimates vary from -65% up to 95% (average 7%), while the general trend based on the regression deviates between -22% and 47%. The New generic model shows for most species a much weaker and opposite trend, with individual tree part deviations between -55 and 85% (average 2%). The general trend in deviation (based on the regression) from the actual volume is much smaller and ranges between -7% and 8%.

> Based on the analyses and comparisons of the different models and measured variables, the ***New generic model***, based on length and dbh, is regarded as the most appropriate, accurate and applicable model.

3.5 Consequences on stand scale

The consequences of the Current and New generic dbh based models on the stand scale are calculated for the three study sites. In all cases, the Current model overestimates the volume per site and in total (table 5), although estimates of individual species can vary. Regarding the total volume of cwd studied, the New generic model deviates less than 2%. The Current model however deviates more than 18%.

Table 5. Total cwd volume (in dm³) according the actual measurements, the Current model and the New generic model, for dbh bases calculations, on the inventoried transects in the three study sites.

location	species	actual volume	Current volume	New generic volume
Galgenberg	red oak	465	444	395
	birch	14753	19032	16935
	beech	1422	1683	1445
	oak	6494	5998	5312
	Scots pine	45903	55065	45572
	larch	7240	8093	7094
	unknown	614	612	569
	Sitka spruce	4066	5125	4709
	Pine (nigra)	5404	6182	5639
Galgenberg Total		86360	102234	87669
difference (%)			18.4 %	1.5 %
Het Leesten	birch	647	715	714
	beech	27	23	29
	Douglas fir	31525	43207	33945
	Scots pine	19561	21810	19840
	larch	12909	16163	13109
Het Leesten Total		64669	81918	67638
difference (%)			26.7 %	4.6 %
Pijpebrandje	red oak	1050	1173	1113
	birch	278	225	260
	beech	58274	67248	53348
	Douglas fir	3253	3961	3407
	oak	17503	17152	15823
	Scots pine	9166	8771	7694
	larch	22879	28956	21845
	unknown	58	37	47
Pijpebrandje Total		112461	127525	103537
difference (%)			13.4 %	-7.9 %
Grand Total		263491	311677	258844
difference (%)			18.3 %	-1.8 %

3.6 Differences in forest reserve total cwd volume

In the preceding paragraphs the Current and New models were compared with actual volume estimates. It became clear that the New generic model predicts the volumes more accurate and with less (systematic) bias than the Current model. From this point onward, the New generic model will be regarded as the model with the most accurate cwd volume estimates.

In this paragraph total forest reserve volumes are calculated according to the Current model and differences are compared with the New generic model. In the forest reserve monitoring program, fallen coarse woody debris is measured by dbh and length. However, around the year 2001 in four reserves (nr 10, 46, 53, 56) mid-diameter and length are measured. For standing coarse woody debris, dbh and length remains the standard method. Current volume estimates are based on equation 2 (fallen coarse woody debris for all dbh-based reserves, all standing coarse woody debris) and equation 3 (fallen coarse woody debris for the four mid-diameter reserves). New generic volume estimates are based on equation 7 (fallen coarse woody debris for all dbh-based reserves, all standing coarse woody debris) and equation 8 (fallen coarse woody debris for the four mid-diameter reserves).

Comparing the Current model estimates with the New generic model estimates on tree parts indicates that volume estimates differ ($V_{new} = 0.81V_{current} + 29.47$, $r^2 = 97\%$). These differences are irrespective whether all dead tree parts are included or only fallen tree parts are included.

When total coarse woody debris volumes per reserve and measurement dates are calculated, differences between the Current and New generic volume model can be compared. In figure 8, the deviation of the estimated Current total volume is plotted, compared to the New generic model. Negative values indicate overestimates of the Current model, and positive values indicate underestimates of the Current model.

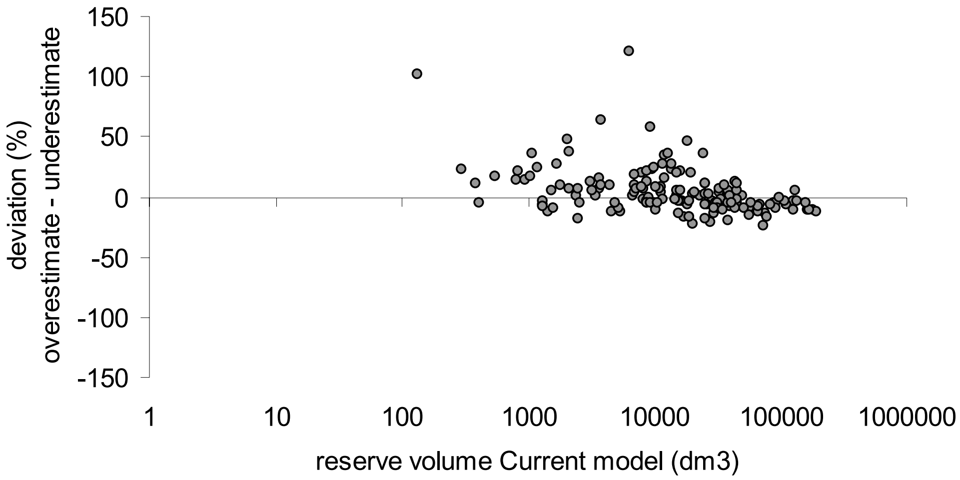


Figure 8. Total volume deviation for all forest reserves from the Current model compared to the New generic model estimates, in relation to volume size. Negative values indicate overestimates of the Current volume and positive values underestimates of the Current model.

No clear trend is apparent with total present reserve volume, nor with time of measurement (not presented). Both over- and underestimates occur over the entire range. In general, more underestimates than overestimates can be observed in figure 8.

In Annex 5 all Current and New generic total reserve volume estimates are presented, together with the deviation from volumes calculated with the Current model. In figure 9, the frequency and extend of over- and underestimates of these differences are plotted.

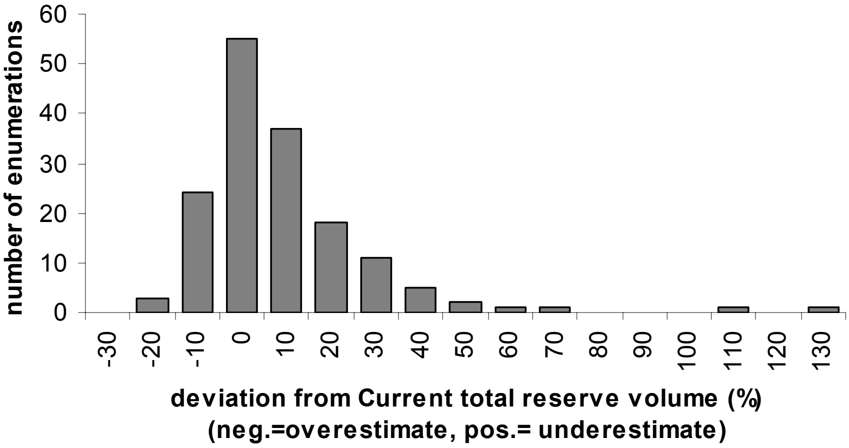


Figure 10. The number and extent of deviations of the Current total reserve volume estimates compared to the New generic volume model estimates.

In all enumerations, total estimated volume according to the Current model is 4896 m^3, of which with 1523 m^3 is standing dead and 3373 m^3 is fallen coarse woody debris. The New generic model predicts a total coarse woody debris volume of 4701 m^3, consisting of 1515 m^3 standing and 3186 m^3 fallen. The absolute and relative differences of all enumerations are presented in table 6.

Table 6. Deviation in absolute volume (in m^3!), and relative deviation, of all reserve enumerations, from the Current model compared to the New generic model. Negative values are overestimates of the Current model.

	Standing		Fallen		Total	
	Absolute deviation from Current model [m^3]	Relative deviation from Current model [%]	Absolute deviation from Current model [m^3]	Relative deviation from Current model [%]	Absolute deviation from Current model [m^3]	Relative deviation from Current model [%]
total	-8.18	-0.5	-187.32	-5.6	-195.50	-4.0
average	-0.05	17.7	-1.18	3.9	-1.23	4.0
min	-9.80	-24.8	-25.78	-26.3	-23.67	-23.6
max	6.13	183.2	6.37	101.9	8.57	120.8
sd	2.32	39.6	4.34	17.7	4.75	19.5
n	159		159		159	

For all reserves and enumerations combined, differences between the models are small. In total, the Current model predicts an overestimate of 196 m^3, which is approximately 4% of the total coarse woody debris volume (according to the New generic model estimates). However, differences between enumeration estimates can vary. In 77 cases an underestimate of the Current model was found and in 82 cases an overestimate. On average for each enumeration, the total volume is underestimated by 4%, the fallen volume by 4% and the standing volume by 18%. Largest differences in relative terms are an overestimate of the fallen volume by 26% and an underestimate by 183% of the standing volume. In absolute amounts these differences are less dramatic; a maximum overestimate for an enumeration of 26 m^3 and an underestimate of 6 m^3 in fallen cwd volume. Total deviation range from an underestimate of 9 m^3 to an overestimate of 24 m^3.

4 Discussion

In this study coarse woody debris (cwd) volume models were designed, tested and evaluated. The basis for cwd volume estimates are diameter and length of the dead tree parts. Difficulties in cwd estimates are the various ways cwd can be encountered in forests; standing or fallen cwd, whole trees, stems, crowns, branches or parts of it. Accurate measurements and estimates are thus complicated and simplifications necessary in order to have a practical means of cwd estimates.

In this study we firstly compared various statistical models (***New models***), from detailed to more simple ones. These models were fitted by means of multiple linear regression on actual volume measurements. Of these models we selected the most appropriate New model. Then we compared the selected New model with the ***Current models*** and evaluate whether the New model more accurately estimates coarse woody debris volumes.

In the New models, factor which have a significant effect were diameter, length and species. The decay state of the coarse woody debris did not have a large enough effect to justify its inclusion in the model. It is unclear if the not meaningful effect of the decay state on volume estimates is due to a lack of tree parts in the more decayed classes or simply because its effect is negligible. More information is needed to explore the effects of decay state on coarse woody debris volume. Although the factor species did have a significant effect on the model, the species effect was however small. Apparently, the different species have a similar effect on the volume estimates, given the non-significant differences between almost all species. Therefore, New species based models produce similar volume estimates, goodness of fit, and MSE compared to the New generic models, including only diameter and length. The New generic model is thus chosen as the most appropriate New model.

Also in comparison with the Current model it seems justified to choose the ***New (dbh based) generic model*** as the most appropriate of the models as:

- dbh based models (Current and New) produce better estimates than mid-diameter based models,
- the Current model has a lower goodness of fit, a larger mean square error, and a larger systematic error, resulting in underestimates of small volumes and overestimates of larger volumes,
- the New generic model predicts coarse woody debris volumes more accurately and is generally applicable.

However, the number of larger coarse woody debris parts was small in the analyzed dataset, hampering adequate volume estimates for larger trees. Unfortunately, large dead wood is rare in the Dutch forest and it is thus a very difficult task to collect data on large dead trees. Therefore, at the moment the New generic model greatly improves dead volume estimates and can be considered the best available alternative. Nevertheless, estimates should be used with care regarding large trees. When sufficient larger dead wood tree parts become readily available a reanalyzes of volume models is advised.

Consequences of using the improved New generic model over the Current model are apparent. In the three studied sites, total cwd volume is estimated with a 2% deviation compared to an 18% deviation. Considering total Forest Reserve volumes, consequences vary per enumeration. Differences can range from a maximum overestimate of 24 m^3 and underestimate of 9 m^3. The great variability in differences is mainly due to the variability in cwd composition in the Forest Reserves. Many small cwd parts will result in (relatively small) underestimates, while few large cwd parts will result in relatively large overestimates. The composition of cwd parts varies between reserves and enumeration dates.

Total dead wood volume is even larger than the estimated coarse woody debris by the models. Dead wood can also be found attached in living trees or as tree stumps. Norden et al (2004) for example, found estimated proportions of 6% of the total dead wood volume for each these elements. Dead wood elements smaller than 10cm diameter at the base are not included in our study. Christensen et al. (2004) calculated the dead wood with a lower limit of 5cm by: $V_{5cm} = V_{10cm} * (0.0297 * diameter_{10cm} + 0.8301)$. According to this equation, the total volume in this study would thus approximately be 1.13 times larger for a lower limit of 5cm. The total dead wood volumes can even be more precise. Norden et al. (2004) measured all dead wood in 25 broadleaved stands in southern Sweden, with a diameter larger than 1cm. They indicate that smaller dead wood (between 1-10cm diameter) can amount op to 45% of the total dead wood volume. They did however find no clear relation between the total coarse and total fine dead wood.

Nevertheless, the New generic dbh based volume model accurately estimates total cwd volumes, within the used range. The New generic model ($Ln(vol) = -2.2845 + 2.0349*Ln(dbh) + 0.6594*Ln(length)$) is generally applicable, based on only dbh and length only. It produces higher estimates than traditional wood production based stem volume calculations. The estimates are approximately 22% higher (see Jagers op Akkerhuis, 2005, Wijdeven unpublished), due to the implicit inclusion of all tree parts including branches, and not only the stem volume.

5 Conclusions

In this study coarse woody debris (cwd) volume models were designed, tested and evaluated. A cwd volume model should be generally applicable, using variables commonly used in most monitoring schemes and accurately estimating volumes for all possible tree parts (whole trees, stems, branches). The basis for coarse woody debris volume estimates are diameter and length of the dead tree parts and possible additional variables are species and decay state. We compared New statistical models (by means of multiple linear regression) and Current simple mathematical models with actual volume measurements.

Two New models were regarded as most accurate; the New species specific model containing species, diameter and length, and the New generic model, containing only diameter and length. Comparing the performance of the New models (New species specific and New generic) and Current models indicates the following:

1. of the New models, the New generic model is evaluated as the most appropriate one, since (a) the decay state not significantly affects the volume estimates, (b) most species not significantly differ in volume calculations, and (c) the more simple New generic model produces comparable volume estimates with a similar goodness of fit and means square error than the New species specific model,
2. dbh based models (Current and New) produce better estimates than mid-diameter based models,
3. of the Current and New generic dbh-based models, the Current model has a lower goodness of fit, a larger mean square error, and a larger systematic error, resulting in underestimates of small volumes and overestimates of larger volumes, while the New generic model predicts coarse woody debris volumes more accurately and is generally applicable.

Therefore the New generic coarse woody debris (dbh-based) volume model is chosen as the most appropriate model:

Ln(vol) = -2.2845 + 2.0349*Ln(dbh) + 0.6594*Ln(length)
with dbh in cm, length in m and volume in dm^3.

However, larger tree parts were underrepresented in the dataset, hampering volume estimates of larger trees. When sufficient larger dead wood tree parts become readily available a reanalyzes of volume models is advised. Nevertheless, the New generic model greatly improves coarse woody debris volume estimates. Consequences for coarse woody debris estimates in forest reserves vary with differences between 9 m3 (121%) to 24 m3 (24%) per reserve. The great variability in differences is mainly due to the variability in cwd composition in the Forest Reserves.

The New generic model generally produces 22% higher estimates compared to traditional wood production based stem volume calculations, due to the implicit inclusion of branches (Wijdeven unpublished). However, total dead wood volume can be significantly larger, since dead wood in stumps and attached on living trees can be substantial (6% of total volume each) while fine woody debris can even amount up to 45% of the total dead wood volume (Norden et al., 2004).

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Appendix 1 Dbh based New species specific volume model

$$Ln(vol) = c1 + c2*Ln(dbh) + c3*Ln(length)$$

With volume in dm^3, Dbh in cm and length in m.

Species specific estimates of the coefficients of the Dbh-based fitted New volume model and related standard errors.

	Estimate	Standard error
C1 values		
Quercus rubra	-2.2698	0.0723
Betula pendula	-2.2847	0.0541
Fagus sylvatica	-2.1546	0.0568
Pseudotsuga menzisii	-2.2753	0.0467
Quercus robur/petraea	-2.1220	0.0492
Pinus sylvestris	-2.1878	0.0473
Larix sp.	-2.2081	0.0463
Picea sitchensis	-2.3608	0.0481
Pinus nigra sp.	-2.2250	0.0489
C2 value	1.9914	0.0194
C3 value	0.6796	0.0133

Appendix 2 Mid Diameter based New species specific volume model

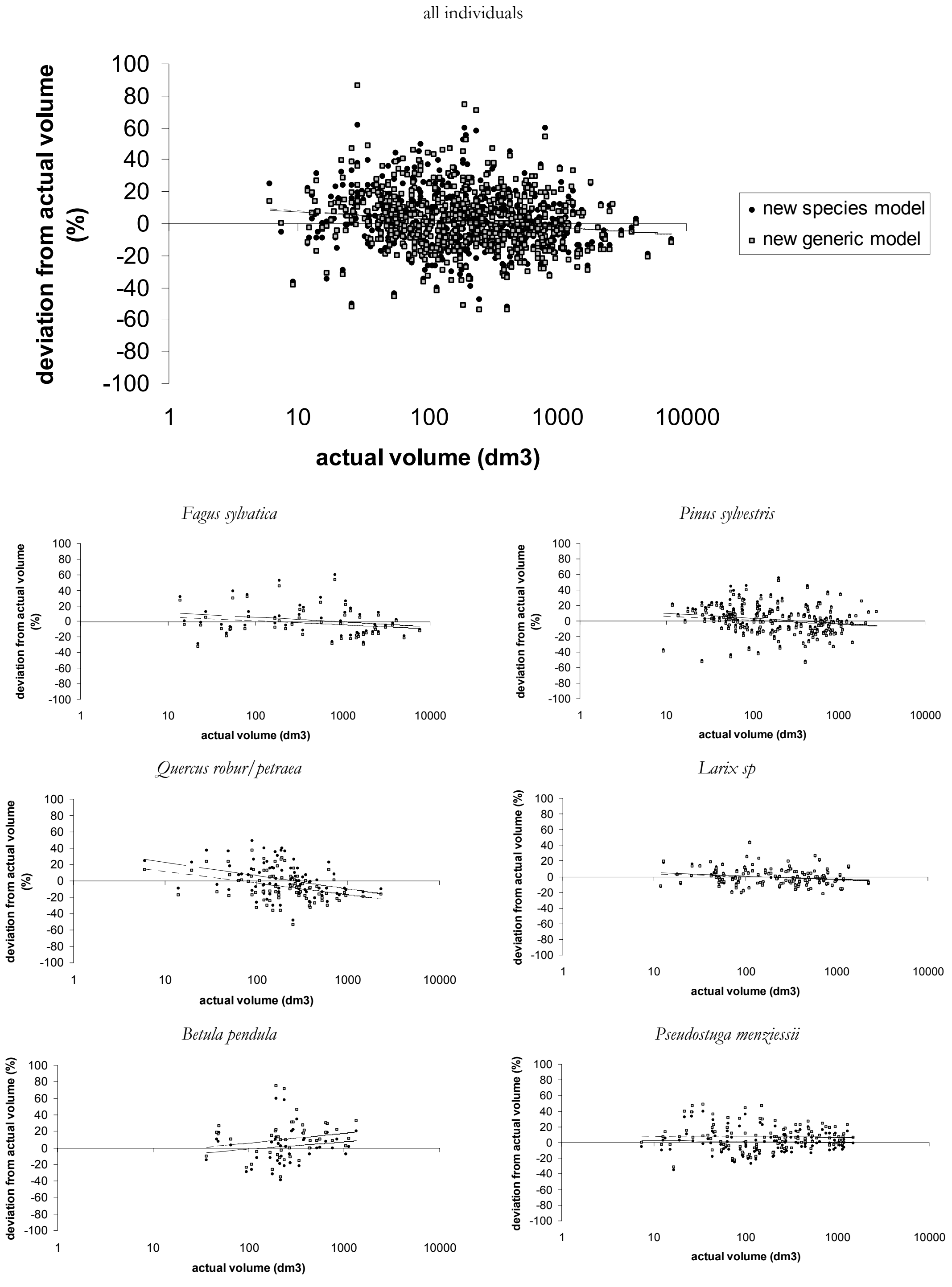
$$Ln(vol) = c1 + c2*Ln(md) + c3*Ln(length)$$

With vol in dm^3, Dm (mid-diameter) in cm and length in m.

Species specific estimates of the coefficients of the Dm-based fitted New volume model and related standard errors.

	Estimate	Standard error
C1 values		
Quercus rubra	-2.2249	0.0930
Betula pendula	-2.1446	0.0689
Fagus sylvatica	-2.0017	0.0724
Pseudotsuga menziesii	-2.2894	0.0608
Quercus robur/petraea	-2.1925	0.0648
Pinus sylvestris	-2.2636	0.0624
Larix Sp.	-2.3547	0.0616
Picea sitchensis	-2.3705	0.0624
Pinus nigra sp.	-2.3451	0.0644
C2 value	1.8675	0.0238
C3 value	1.0713	0.0146

Appendix 3 Comparison of New species specific and New generic volume model



Relative deviation from the actual volume, based on the dbh-based New species model (closed circles) and New generic model (grey squares) for all individuals (top figure) and most abundant tree species (small figures) in the three study sites. Broad dotted lines indicate linear regression of New species model and fine dotted lines of New generic model (equations and goodness of fit presented in table below).

Analyses of the relative deviation of model estimates from actual volume for the different species, based on linear regression on Ln transformed volumes (see figure above).

	New species model		New generic model	
	equation	r^2	equation	r^2
All individuals	y = -2.069Ln(x) + 12.014	2.3	y = -2.2098Ln(x) + 13.146	2.4
Fagus sylvatica	y = -2.6742Ln(x) + 17.928	5.6	y = -2.2716Ln(x) + 11.393	4.4
Pinus sylvestris	y = -2.8487Ln(x) + 16.793	4.0	y = -2.2489Ln(x) + 11.402	2.7
Quercus robur/petraea	y = -7.1014Ln(x) + 39.317	12.8	y = -6.2235Ln(x) + 26.223	11.8
Larix sp.	y = -1.9221Ln(x) + 9.5441	4.0	y = -1.4251Ln(x) + 6.7829	2.2
Betula pendula	y = -0.5656Ln(x) + 3.9304	0.3	y = 5.1011Ln(x) - 17.69	3.8
Pseudostuga menziessii	y = 3.8128Ln(x) - 19.155	2.5	y = -0.2337Ln(x) + 8.2452	0.0

Appendix 4 Linear regression of deviation estimates

Analyses of the relative deviation of model estimates from actual volume for the different species, based on linear regression on Ln transformed volumes.

	Current model		New generic model	
	equation	r^2	equation	r^2
All individuals	y = 9.9768Ln(x) - 44.849	20.7	y = -2.2098Ln(x) + 13.146	2.4
Fagus sylvatica	y = 11.076Ln(x) - 65.406	39.8	y = -2.2716Ln(x) + 11.393	4.4
Pinus sylvestris	y = 9.9152Ln(x) - 50.546	21.8	y = -2.2489Ln(x) + 11.402	2.7
Quercus robur/petraea	y = 6.2795Ln(x) - 40.748	8.4	y = -6.2235Ln(x) + 26.223	11.8
Larix sp.	y = 12.004Ln(x) - 50.405	39.5	y = -1.4251Ln(x) + 6.7829	2.2
Betula pendula	y = 16.58 Ln(x) - 75.011	22.3	y = 5.1011Ln(x) - 17.69	3.8
Pseudostuga menziessii	y = 16.1 Ln(x) - 65.368	52.1	y = -0.2337Ln(x) + 8.2452	0.0

Appendix 5 Estimates of coarse woody debris volume in forest reserves

Reserve number and year of enumeration [nr.year]	Current model volume [dm³]	New generic model volume [dm³]	Absolute deviation from Current model (Vnew - Vcurrent) [dm³]	Relative deviation from Current model ((Vnew-Vcurrent)/Vcurrent) [%]
1.1986	39207.7	38540.2	-667.6	-1.7
1.1996	45872.7	43587.4	-2285.3	-5.0
2.1987	7908.5	9422.3	1513.8	19.1
2.1999	8296.4	8061.8	-234.6	-2.8
3.1986	25750.6	28574.0	2823.4	11.0
3.1995	49602.1	49951.6	349.5	0.7
4.1987	11418.1	11893.4	475.4	4.2
4.1996	23437.3	23571.1	133.9	0.6
5.1987	32664.0	33672.0	1008.0	3.1
5.1996	32734.4	34990.4	2256.0	6.9
6.1986	69061.0	64140.3	-4920.7	-7.1
6.2000	38267.5	38656.1	388.6	1.0
7.1986	16601.1	15922.5	-678.7	-4.1
7.2000	18647.0	17331.1	-1315.9	-7.1
8.1985	39907.5	36841.8	-3065.7	-7.7
8.1999	34090.9	33047.0	-1043.9	-3.1
9.1987	33888.2	33084.4	-803.7	-2.4
9.1999	38610.7	40542.2	1931.4	5.0
10.1986	1531.6	1609.1	77.6	5.1
10.2001	3690.3	3942.3	252.0	6.8
11.1991	2083.6	3088.8	1005.2	48.2
12.1995	25822.8	26523.1	700.3	2.7
13.1993	301.1	369.7	68.6	22.8
14.1988	4687.2	4074.5	-612.6	-13.1
14.2000	27672.1	21664.5	-6007.6	-21.7
15.1991	7106.6	7751.1	644.5	9.1
16.1993	4537.4	4948.0	410.6	9.0
17.2001	9332.3	14781.3	5449.0	58.4
18.1993	5470.0	4795.4	-674.6	-12.3
19.1991	834.0	1016.8	182.8	21.9
20.1992	8353.8	8921.8	568.0	6.8
21.1992	6796.8	6879.6	82.8	1.2
22.1991	11835.9	11638.0	-197.9	-1.7
23.1992	135.6	273.7	138.1	101.9
24.1983	43533.6	39140.6	-4393.0	-10.1
24.1996	39181.8	37356.2	-1825.6	-4.7
25.1992	45729.4	44978.7	-750.7	-1.6
26.1986	24401.6	32973.4	8571.8	35.1
26.1993	38112.8	36200.5	-1912.3	-5.0
27.1993	9718.8	11871.5	2152.7	22.1

Reserve number and year of enumeration [nr.year]	Current model volume [dm³]	New generic model volume [dm³]	Absolute deviation from Current model (Vnew - Vcurrent) [dm³]	Relative deviation from Current model ((Vnew-Vcurrent)/Vcurrent) [%]
28.1983	1724.4	2202.9	478.5	27.7
28.1993	20443.5	21003.1	559.6	2.7
29.1997	40133.7	40314.7	181.0	0.5
30.1981	817.8	928.8	111.1	13.6
30.1991	2389.0	2397.7	8.7	0.4
30.1995	19780.6	23635.0	3854.4	19.5
31.1993	8651.0	8379.3	-271.7	-3.1
31.1996	9122.5	9011.5	-111.0	-1.2
32.1997	28889.8	27795.8	-1093.9	-3.8
33.1996	25454.8	20896.2	-4558.6	-17.9
34.1983	13856.4	17100.3	3244.0	23.4
34.1993	126995.1	122654.8	-4340.3	-3.4
35.1996	20613.5	16054.3	-4559.2	-22.1
38.1997	26534.2	24848.6	-1685.6	-6.4
39.1998	38753.7	31362.1	-7391.6	-19.1
41.1999	59850.8	53913.9	-5936.9	-9.9
42.1998	57796.4	52129.7	-5666.7	-9.8
43.1983	88659.2	84344.1	-4315.1	-4.9
43.1993	111855.9	104154.6	-7701.3	-6.9
43.2001	30090.9	26036.6	-4054.3	-13.5
44.1998	76272.3	65665.0	-10607.3	-13.9
45.1998	15111.1	15201.6	90.5	0.6
46.1982	15112.2	15812.1	699.9	4.6
46.1992	30430.0	28958.3	-1471.7	-4.8
46.2002	66139.8	57696.1	-8443.6	-12.8
47.2000	3646.1	4207.3	561.2	15.4
48.1999	27470.8	27904.3	433.5	1.6
49.1998	16061.8	19407.8	3346.0	20.8
51.1997	90953.4	86098.2	-4855.2	-5.3
52.2001	20869.2	21640.4	771.2	3.7
53.2002	132258.1	138686.1	6428.0	4.9
56.2000	25748.6	28609.4	2860.7	11.1
57.1999	66700.3	61248.3	-5452.0	-8.2
101.1981	1207.5	1496.8	289.3	24.0
101.1985	8803.6	8372.5	-431.1	-4.9
101.1990	8884.1	8434.5	-449.6	-5.1
101.1995	9915.9	9356.8	-559.1	-5.6
101.2000	73087.9	55837.9	-17250.0	-23.6
102.1985	1083.3	1465.1	381.8	35.2
102.2000	5194.7	4716.5	-478.2	-9.2
103.1982	8867.7	10701.4	1833.7	20.7
103.1992	31946.7	30352.6	-1594.1	-5.0
103.2002	40982.5	38817.6	-2164.8	-5.3
104.1983	43643.9	49239.6	5595.8	12.8
104.1993	45921.1	48236.2	2315.1	5.0

Reserve number and year of enumeration [nr.year]	Current model volume [dm³]	New generic model volume [dm³]	Absolute deviation from Current model (Vnew - Vcurrent) [dm³]	Relative deviation from Current model ((Vnew-Vcurrent)/Vcurrent) [%]
105.1982	166524.7	148869.9	-17654.7	-10.6
105.1992	184260.2	164601.9	-19658.2	-10.7
107.1982	12254.7	16430.9	4176.2	34.1
107.1992	13792.6	17563.7	3771.0	27.3
107.2001	11593.4	14755.4	3162.0	27.3
114.1984	25431.4	23774.2	-1657.2	-6.5
114.1995	78227.1	65439.4	-12787.7	-16.3
116.1982	91652.2	82933.9	-8718.3	-9.5
117.1984	10082.4	12470.9	2388.5	23.7
117.1989	10395.7	9282.0	-1113.7	-10.7
117.1994	19232.5	18581.8	-650.8	-3.4
118.1978	59406.9	56164.7	-3242.2	-5.5
118.1990	82495.8	76948.1	-5547.7	-6.7
118.1999	134303.6	128665.2	-5638.4	-4.2
119.1977	19109.9	15873.7	-3236.2	-16.9
119.1981	17364.1	14473.5	-2890.6	-16.6
119.1985	1316.5	1232.4	-84.1	-6.4
119.1990	16002.1	15355.6	-646.5	-4.0
119.1999	50865.0	45861.9	-5003.1	-9.8
120.1981	18818.2	15739.3	-3078.8	-16.4
120.1985	1454.0	1265.8	-188.2	-12.9
120.1990	15536.8	14893.3	-643.5	-4.1
120.1999	31458.8	28338.2	-3120.6	-9.9
121.1983	107015.6	103504.3	-3511.4	-3.3
121.1991	97957.9	97141.6	-816.3	-0.8
121.1996	57574.8	48912.3	-8662.5	-15.0
121.2000	192339.2	168665.8	-23673.4	-12.3
122.1983	171880.7	153917.1	-17963.5	-10.5
122.1991	159621.3	150566.3	-9055.0	-5.7
122.1996	15964.6	16786.1	821.5	5.1
122.2000	129236.5	115491.6	-13744.8	-10.6
123.1992	36575.4	40289.0	3713.6	10.2
127.1980	2500.9	2681.4	180.5	7.2
127.1991	4992.5	4749.1	-243.4	-4.9
128.1980	557.5	654.3	96.8	17.4
128.1992	3438.7	3485.2	46.4	1.3
131.1991	14581.5	14262.1	-319.4	-2.2
132.1985	14740.4	14443.0	-297.4	-2.0
132.1991	9315.3	8892.0	-423.3	-4.5
134.1982	1305.5	1262.6	-42.9	-3.3
134.1992	1791.0	1965.4	174.4	9.7
137.1984	3247.9	3399.5	151.6	4.7
137.1991	6945.0	7173.8	228.8	3.3
138.1985	2157.5	2293.2	135.7	6.3
138.1991	3805.4	4173.6	368.1	9.7

Reserve number and year of enumeration [nr.year]	Current model volume [dm³]	New generic model volume [dm³]	Absolute deviation from Current model (Vnew - Vcurrent) [dm³]	Relative deviation from Current model ((Vnew-Vcurrent)/Vcurrent) [%]
146.1980	416.4	395.9	-20.5	-4.9
146.1991	383.9	426.2	42.3	11.0
147.1983	6911.3	8191.4	1280.0	18.5
147.1993	11495.9	12504.5	1008.6	8.8
148.1983	3865.4	6344.7	2479.3	64.1
148.1991	13135.9	17803.8	4667.9	35.5
149.1983	3125.1	3530.8	405.7	13.0
149.1992	44780.1	49674.4	4894.3	10.9
150.1983	7341.2	7813.7	472.5	6.4
150.1993	8881.5	9938.9	1057.4	11.9
151.1983	6407.6	14150.2	7742.6	120.8
151.1993	29637.9	26607.6	-3030.3	-10.2
152.1983	18666.8	27157.6	8490.9	45.5
152.1993	35193.3	31372.3	-3821.1	-10.9
154.1983	12131.7	13930.3	1798.6	14.8
154.1993	16007.5	16875.3	867.8	5.4
155.1981	8087.4	8686.1	598.7	7.4
155.1993	15286.1	18312.4	3026.4	19.8
156.1981	1573.1	1422.7	-150.4	-9.6
156.1993	2624.8	2485.7	-139.1	-5.3
157.1981	2143.7	2949.7	806.1	37.6
157.1993	11156.0	11824.5	668.5	6.0
202.1994	10445.9	11287.0	841.1	8.1
203.1994	15670.8	13415.4	-2255.3	-14.4
204.1994	1314.7	1205.1	-109.6	-8.3
712.1986	960.7	1096.7	136.0	14.2
712.1993	2494.5	2048.4	-446.2	-17.9
720.1986	10573.8	10086.1	-487.7	-4.6
720.1993	1060.4	1236.8	176.4	16.6
TOTAL	4896457.6	4700954.4	-195503.1	-4.0
		total	-195503.1	-
		average	-1229.6	4.0
		min	-23673.4	-23.6
		max	8571.8	120.8
		sd	4752.5	19.5
		n	159.0	159.0
		overestimate		82.0
		underestimate		77.0
		equal		0.0