Chapter 12
State and Change of Forest Resources

Anne Herold, Jürgen Zell, Brigitte Rohner, Markus Didion, Esther Thürig, and Erik Rösler

Abstract In the Swiss National Forest Inventory (NFI), wood volume and changes in wood volume are estimated based on the stem volume of individual trees using various models: stem volume models and tariff models, models estimating volumes of large and small branches and growth models. Many of the models applied in the fourth NFI were described in previous publications, but some of them have subsequently been completed or adjusted based on methodological developments. This chapter mainly updates descriptions published previously.

12.1 Introduction

In the Swiss NFI (NFI), wood volume and changes in wood volume are estimated based on the stem volume of individual trees using various models. Many of the models applied currently were described by Kaufmann (2001), and this earlier text is thus referred to repeatedly below. However, some of them have subsequently been completed or adjusted based on methodological developments, and some of the descriptions provided by Kaufmann (2001) are not comprehensive. Therefore, this chapter mainly updates descriptions published previously, but also recapitulates fundamental information when necessary for readability and completeness.

Stem volume models estimate single stem volume using three measured tree dimensions: diameter at breast height ($d_{1.3}$), upper diameter at 7 m height (d_7) and tree height (h). The stem volume models currently implemented are the same as those described by Kaufmann (2001). Section 12.2 therefore provides complementary information and a summary of the essential information, such as equations and coefficients. Tariff models are the most general and estimate single stem volume as a function of $d_{1.3}$ as the only measured tree dimension. The current tariff models have

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been slightly modified from the descriptions given by Kaufmann (2001). Section 12.3 provides updated descriptions.

In addition to stem volumes, volumes of large and small branches are estimated, mainly as inputs for biomass estimation. The ratio of the volume of large branches to stem volume over bark is estimated using a logit model described by Kaufmann (2001). The corresponding model for the ratio of small branches is very similar but has not been published previously. These two models and their estimated coefficients are described in Sect. 12.4.

As the NFI is based on permanent inventory plots, changes in resources in general can be estimated as the difference between consecutive NFIs. In particular changes in standing volume such as growth, harvest and mortality can be estimated directly as the difference in tree volume. However, in some cases growth models are needed. The models and coefficients for basal area increment and volume increment are described in Sect. 12.5.

12.2 Stem Volume Models

The stem volume models map $d_{1.3}$, d_7 and tree height to total stem volume over bark of individual trees, including the tree top and the aboveground part of the stump but excluding branches. They are able to explain nearly all variance and are more precise than the tariff models (Sect. 12.3). However, d_7 and tree height are time-consuming measurements and are therefore only assessed on a subsample, namely the tariff trees.

The method for selecting tariff trees is explained in Sect. 2.3.4.5. The estimated volume of the tariff trees is used for two purposes. First, it is used as the dependent variable when fitting tariff models (Sect. 12.3). Second, it is used to improve stem volume predictions with the tariff models, which use $d_{1.3}$ as the only explanatory variable measured in the field (Sect. 12.3). For the tariff trees, stem volume can be estimated using both the more precise stem volume model and the generally applicable tariff model. The difference between the two models is scaled up (by the inverse of the selection probability) and added to the tariff volumes to correct for the difference to the stem volume. Assuming that the stem volume is known and is unbiased for the tariff trees, this procedure results in unbiased estimates of standing and total volume even in small sampling units, i.e. for rare tree species or small regions (Mandallaz 1991, 1997). A full description of this two-stage estimation procedure and the reasons to adopt it were presented by Kaufmann (2001, page 176 ff.).

The stem volume functions of the NFI were developed in 1991. Nine different functions were fitted: seven were developed for the main tree species Norway spruce (*Picea abies*), silver fir (*Abies alba*), pine (*Pinus sylvestris* and *P. nigra*), European larch (*Larix decidua*), Douglas fir (*Pseudotsuga menziesii*), European beech (*Fagus sylvatica*) and oak (*Quercus* spp.), and the remaining two were developed for coniferous and broadleaved species (Kaufmann 2001; page 162 ff.). For the sake of completeness, the equations and the coefficients (Table 12.1) are presented here.

Norway spruce (*Picea abies*):

Table 12.1 Coefficients of the stem volume models used in the NFI

	b_0	b_1	b_2	b_3	b_4	b_5
Norway spruce	0.029504	0.46756	2.43885	−5.74664	−0.0018265	–[a]
Silver fir	0.039594	0.35832	−0.39142	3.75195	−0.013314	1.62E-07
Pine	0.055349	0.40341	−0.63535	4.84573	−0.10114	–[a]
European larch	−0.0173	0.36366	2.49123	0.000107	–[a]	–[a]
Douglas fir	0.013166	0.35079	2.67531	−2.95083	0.0010962	–[a]
European beech	0.0025428	0.39446	2.56612	−3.67034	0.03567	–[a]
Oak	−0.026759	0.31686	5.01484	−7.71408	0.19704	–[a]
Coniferous (all species)	0.0084865	0.5436	2.8898	−1.94043	−4.93601	−1.33E-05
Broadleaved (all species)	−0.021786	0.39992	0.28036	2.30656	−1.20368	–[a]

[a]Variable not part of the model

$$V = b_0 + b_1 d_7^2 h + b_2 d_{1.3}^2 + b_3 d_7^3 + b_4 h \tag{12.1}$$

Silver fir (*Abies alba*):

$$V = b_0 + b_1 d_7^2 h + b_2 d_{1.3} + b_3 d_{1.3}^2 + b_4 d_{1.3}^3 h + b_5 h^4 \tag{12.2}$$

Pine (*Pinus sylvestris* and *P. nigra*):

$$V = b_0 + b_1 d_7^2 h + b_2 d_{1.3} + b_3 d_{1.3}^2 + b_4 d_{1.3}^3 h \tag{12.3}$$

European larch (*Larix decidua*):

$$V = b_0 + b_1 d_7^2 h + b_2 d_{1.3}^2 + b_3 h^2 \tag{12.4}$$

Douglas fir (*Pseudotsuga menziesii*):

$$V = b_0 + b_1 d_7^2 h + b_2 d_{1.3}^2 + b_3 d_{1.3}^3 + b_4 d_{1.3}^2 h^2 \tag{12.5}$$

European beech (*Fagus sylvatica*):

$$V = b_0 + b_1 d_7^2 h + b_2 d_{1.3}^2 + b_3 d_7^3 + b_4 d_{1.3}^3 h \tag{12.6}$$

Oak (*Quercus* spp.):

$$V = b_0 + b_1 d_7^2 h + b_2 d_{1.3}^2 + b_3 d_{1.3}^3 + b_4 d_{1.3}^3 h \tag{12.7}$$

Coniferous (all species):

$$V = b_0 + b_1 d_7^2 h + b_2 d_{1.3}^2 + b_3 d_7^2 + b_4 d_7^3 + b_5 d_{1.3} h^3 \tag{12.8}$$

Broadleaved (all species):

$$V = b_0 + b_1 d_7^2 h + b_2 d_{1.3} + b_3 d_{1.3}^2 + b_4 d_7^2 \tag{12.9}$$

where V is the stem volume over bark (in m^3), $d_{1.3}$ is the diameter at breast height (in m), d_7 is the upper diameter measured at 7 m height (in m), and h is the total tree height (in m).

As the stem volume models are fundamental to the NFI, this section includes information about their derivation and the data used to fit them.

Model fitting was based on a data set including long-term growth and yield data from approximately 38,000 tree stems from the permanent plot network of the Experimental Forest Management (EFM) trials conducted at WSL. These stems were measured (lying) in 2-m sections as the trees were harvested, between 1888 and 1974. Thus, their precise volume is known. Table 12.2 gives an overview of the number of available stem measurements for each species and the regional distribution of the measured stems in Switzerland.

The NFI tariff sample trees and the trees from the EFM trials were assessed for very different objectives: the NFI aimed to infer the state of forests representatively over the whole of Switzerland and its production regions, whilst the EFM experiments aimed to answer various research questions (e.g. Zell 2018; Peck et al. 2014) but are not representative of Switzerland's forests. In fact, the tree population from the EFM trials is clearly different from that of the corresponding species in Switzerland's forests: trees of the regions Plateau and Pre-Alps are generally overrepresented in the EFM data set, whereas trees of the Alps region are underrepresented.

The two data sets actually represent tree populations with different characteristics. For example, the stem forms of EFM and NFI sample trees are clearly different for all species and species groups. More specifically, the slenderness ratio ($h/d_{1.3}$) of trees measured in EFM plots is systematically larger than that of NFI sample trees, as shown for Norway spruce in Fig. 12.1

Stem volume models are assumed to be valid for all of Switzerland, but this is not so the tariff models, which respect regional differences. Therefore, the stem forms were shown for the regions with respect to their fitting data set (i.e. the EFM data) compared to their prediction data set (i.e. the NFI data). The stem form of trees in the Swiss Plateau is similar to that of EFM sample trees, whereas trees in the Jura and the Pre-Alps show a lower slenderness ratio compared to trees from the EFM trials. This difference even increases in the regions Alps and Southern Alps. Figures 12.2 and 12.3 show examples of these differences for Norway spruce and European beech, respectively.

Table 12.2 Number of measured stems from the Experimental Forest Management data set for each species corresponding to a fitted model, along with the regional distribution of the trees used for measurements

	N stems	Jura	Plateau	Pre-Alps	Alps		Southern Alps
					Under	Over	
					1500 m a.s.l.		
Coniferous (all species)	27,799	15%	39%	36%	6%	4%	0%
		(14%)	(16%)	(22%)	(19%)	(22%)	(7%)
Norway spruce (Picea abies)	15,292	15%	46%	36%	0%	3%	0%
		(12%)	(17%)	(24%)	(20%)	(22%)	(6%)
Silver fir (Abies alba)	7,222	22%	28%	49%	1%	0%	0%
		(29%)	(22%)	(33%)	(12%)	(1%)	(3%)
Pine (Pinus sylvestris and Pinus nigra)	1,751	9%	43%	2%	46%	0%	0%
		(19%)	(16%)	(3%)	(53%)	(5%)	(4%)
European larch (Larix decidua)	1,599	0%	34%	1%	41%	24%	0%
		(1%)	(3%)	(1%)	(16%)	(51%)	(28%)
Douglas fir (Pseudotsuga menziesii)	601	9%	5%	86%	0%	0%	0%
		(23%)	(71%)	(5%)	(0%)	(0%)	(1%)
Broadleaved (all species)	10,903	23%	52%	25%	0%	0%	0%
		(21%)	(22%)	(16%)	(18%)	(1%)	(22%)
European beech (Fagus sylvatica)	8,234	24%	45%	31%	0%	0%	0%
		(29%)	(25%)	(20%)	(13%)	(0%)	(14%)
Oak (Quercus spp.)	1,805	32%	68%	0%	0%	0%	0%
		(27%)	(33%)	(3%)	(14%)	(0%)	(23%)

In brackets is the corresponding regional distribution of the species in Switzerland's forests according to NFI3

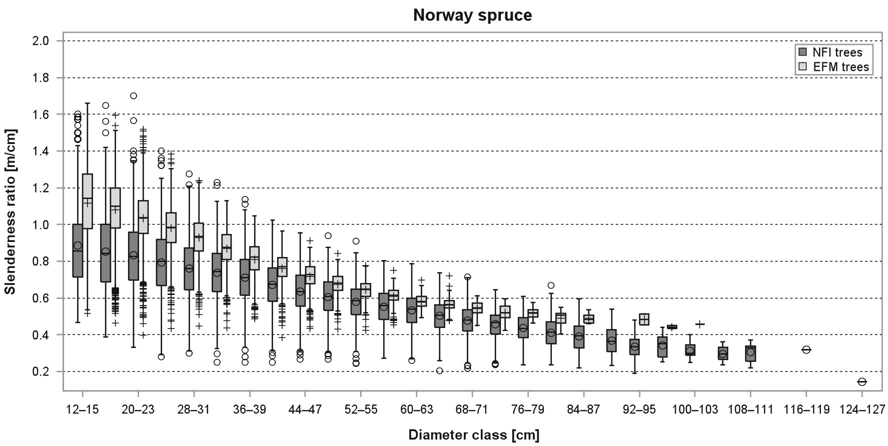

Fig. 12.1 Slenderness ratio ($h/d_{1.3}$) per diameter class of Norway spruce (*Picea abies*) sample trees measured in the NFI (measurements on standing trees) and as part of the EFM Project (measurements on lying trees) over all Switzerland

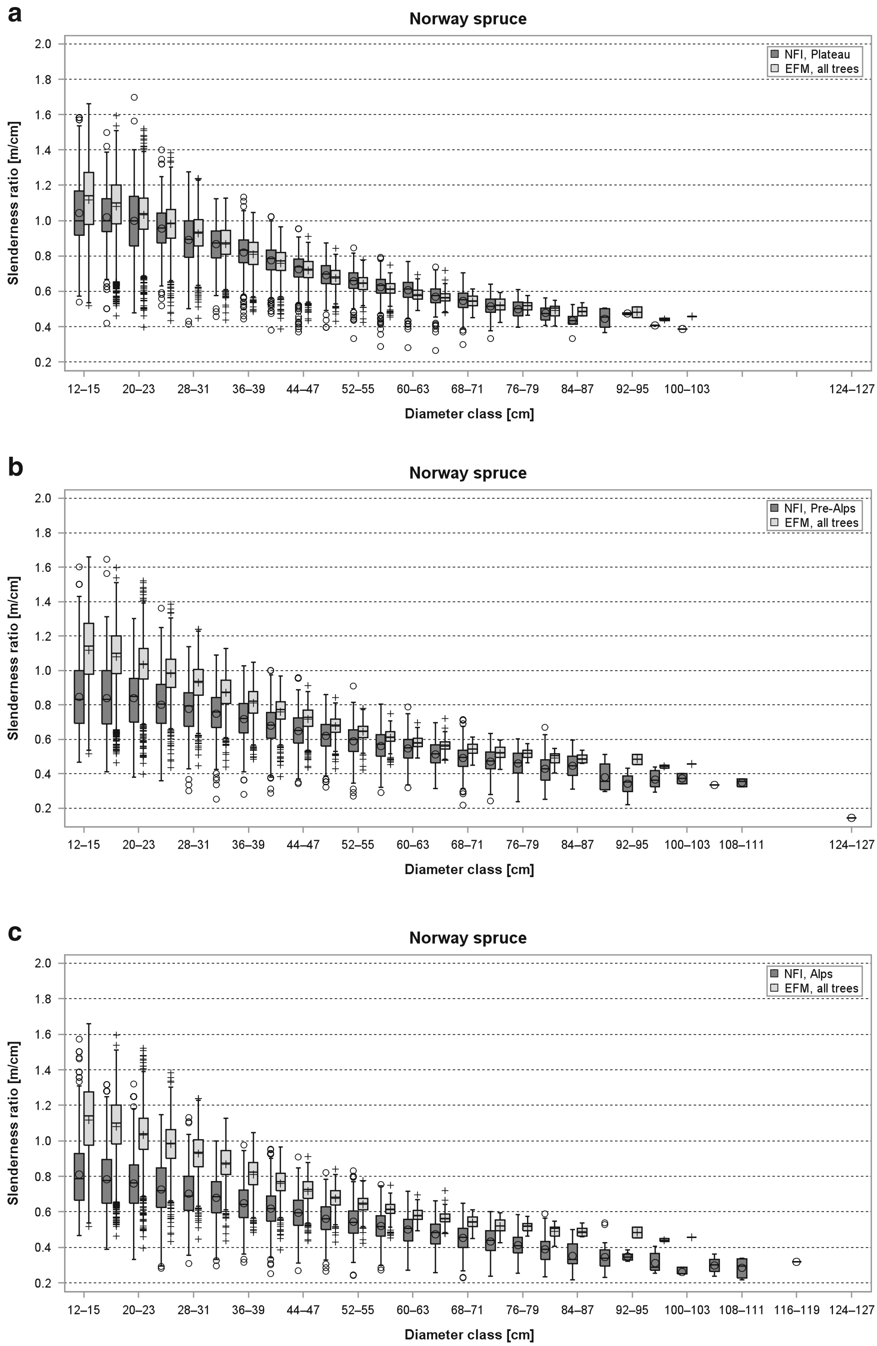

Fig. 12.2 Slenderness ratio ($h/d_{1.3}$) per diameter class of Norway spruce (*Picea abies*) sample trees measured in the NFI (measurements on standing trees) in the regions Plateau (**a**), Pre-Alps (**b**) and Alps (**c**) and as part of the EFM Project (measurements on lying trees) over all Switzerland

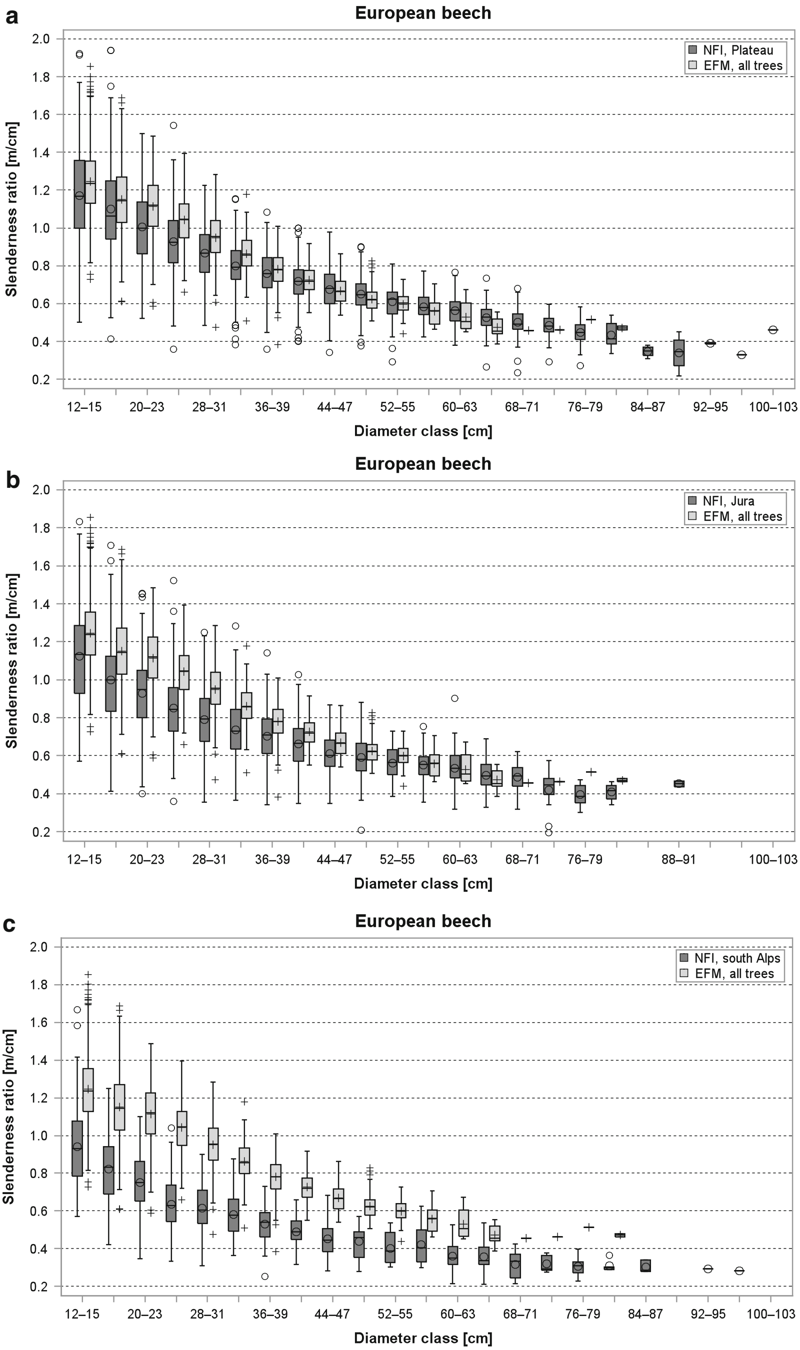

Fig. 12.3 Slenderness ratio ($h/d_{1.3}$) per diameter class of European beech (*Fagus sylvatica*) sample trees measured in the NFI (measurements on standing trees) in the regions Plateau (**a**), Jura (**b**) and Southern Alps (**c**) and as part of the EFM Project (measurements on lying trees) over all Switzerland

To compensate for these differences and to complete the EFM data set over the full range of slenderness ratios, approximately 500 additional trees were sampled in 1990 and 1992. They were selected with the criteria of a low slenderness ratio and a large diameter at breast height (spruce: 199, fir: 11, larch: 89, pine: 20, beech: 174 and oak: 10). The diameters at 10%, 30%, 50%, 70% and 90% of the total tree height, as well as the diameter at breast height ($d_{1.3}$), the upper diameter at 7 m height (d_7) and the tree height (h), were measured on these standing trees. The stem volumes were then calculated using a method similar to that described in Sect. 13.2. Cubic interpolation splines were fitted between the measured diameters to achieve continuous stem profiles (Sect. 13.2 step 2), and the stem volumes were then calculated with rotational integrals (Kaufmann 1993, unpublished internal report; Sect. 13.2 step 7). This data set was then merged with the EFM data set to fit the stem volume functions.

Another difference between the NFI and EFM sample trees is the diameter distribution. In the EFM data set, small diameters are over-represented while middle and large diameters are under-represented compared to the NFI tariff sample trees (see Fig. 12.4 for examples with Norway spruce and European beech). To increase the comparability of the data, only a subsample of the full EFM data set was used to fit the models: stems <12 cm in breast height diameter ($d_{1.3}$) were not considered and stems 12–35 cm in $d_{1.3}$ were selected randomly and proportionally to their $d_{1.3}$. Stems with diameters >35 cm were all included.

Coefficients of the Eqs. 12.1, 12.2, 12.3, 12.4, 12.5, 12.6, 12.7, 12.8 and 12.9 were estimated with weighted linear regressions. The increasing variance over predicted values (heteroscedasticity) was respected by weighting the residuals with the term $1/\left(d_7^3 h\right)$, i.e. assuming that the variance is proportional to $\left(d_7^3 h\right)$. To reduce bias, a grouped jackknife (Efron and Stein 1981) was applied instead of using only

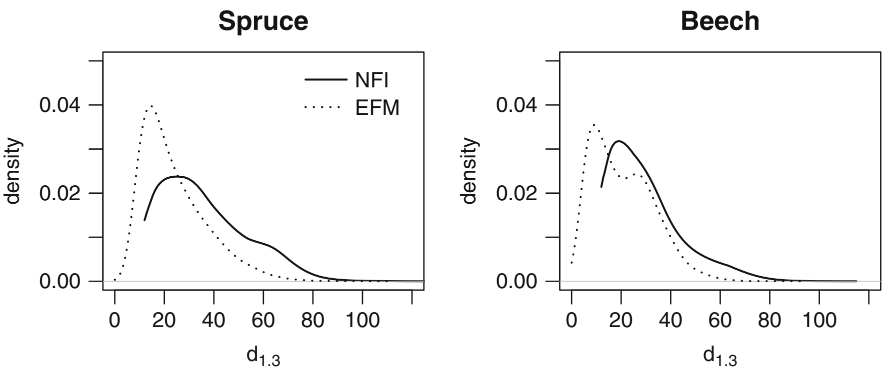

Fig. 12.4 Densities of the diameter distributions of Norway spruce (left) and European beech (right) sample trees measured in the NFI and in the EFM Project

one estimator. The data were randomly split into 20 groups. An estimator was calculated for each group, as well as for the whole data set.

This fitting methodology has the following advantages. First, the data set used to fit the coefficients is closer to observations made in the NFI, owing to subsampling and complementing of the data with extreme forms. Second, by weighting the residuals, the inherent increasing variance is incorporated into the prediction. Third, a smaller bias in the estimated coefficients can be assumed, owing to the grouped jackknife. Fourth, as the models may result in negative predictions, a simple imputation for these trees was established using geometrically reasonable volume estimates. Fifth, the standardised residuals are unbiased over $d_7/d_{1.3}$ and $h/d_{1.3}$, as illustrated in Fig. 12.5.

To analyse the predictive behaviour of the models using the NFI data, a sample from the EFM data (the source of information for volumes) was selected proportionally to the three-dimensional density of $d_{1.3}$, h and d_7 in the NFI. The stem volume models were applied to this sample data set and residuals were calculated. As the residuals are representative of the NFI data, they could be used to show over- or underestimation of the stem volume models. Figure 12.5 shows the results of this analysis for examples with Norway spruce and European beech. For the largest trees (with an estimated volume >5 m^3), an overestimation of about 5–10% was found, whereas the form factor and the slenderness showed better residual distributions.

Some critical points of the stem volume functions are: (a) the model selection was not fully described; (b) biased predictions were obtained over the size of trees (see Fig. 12.5 for examples with Norway spruce and European beech); and (c) reproduction of the coefficients was not entirely possible, and discrepancies were large for some species (see Fig. 12.6 for examples with Norway spruce and European beech).

Possible Further Developments A re-analysis of the entire system for estimating volume is planned. Special attention will be given to unbiased predictions over the range of observations. Therefore, different prediction methods will be tested. The weighted residuals technique will be compared with a model-based approach in which all explanatory variables of the stem form functions are predicted (by simple or multiple imputation). Further, the stem volume functions will be analysed with respect to model selection, model formulation and heteroscedasticity. The overall aim will be to develop a prediction system capable of reproducing the observed (i.e. the representatively resampled) volumes.

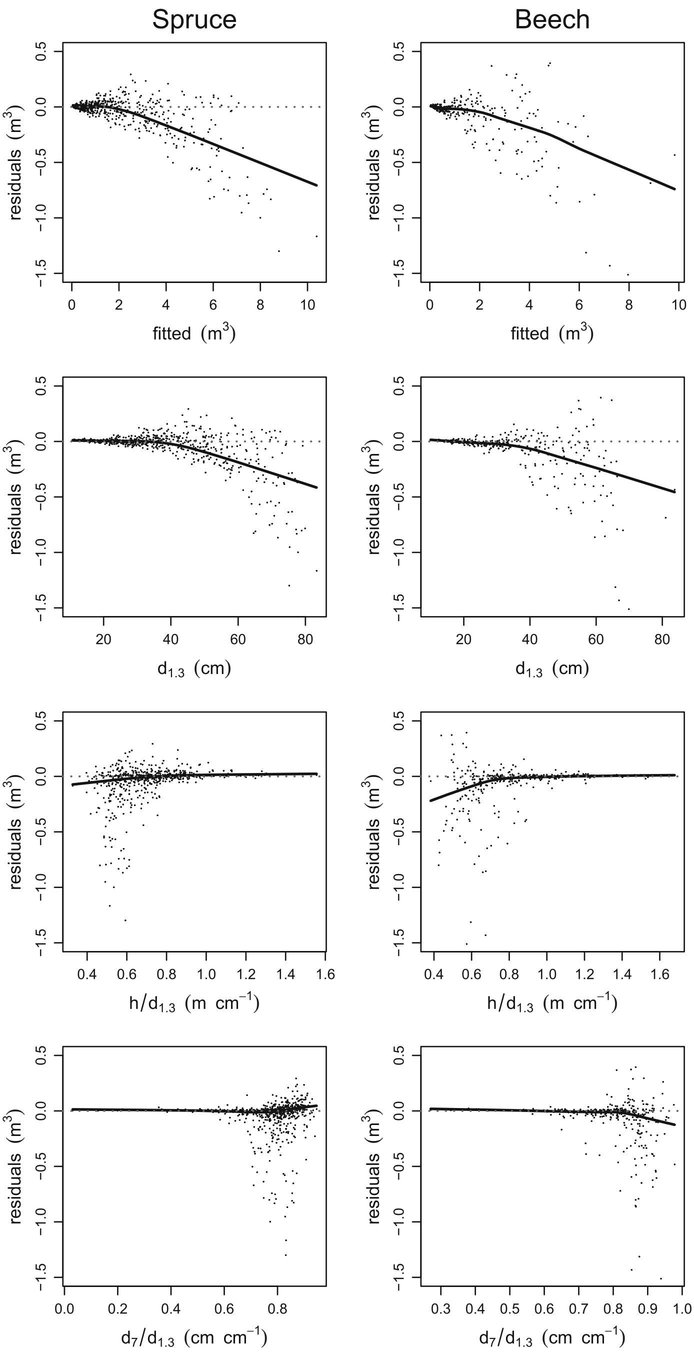

Fig. 12.5 Residual analysis of the stem volume functions for Norway spruce (*left*) and European beech (*right*)

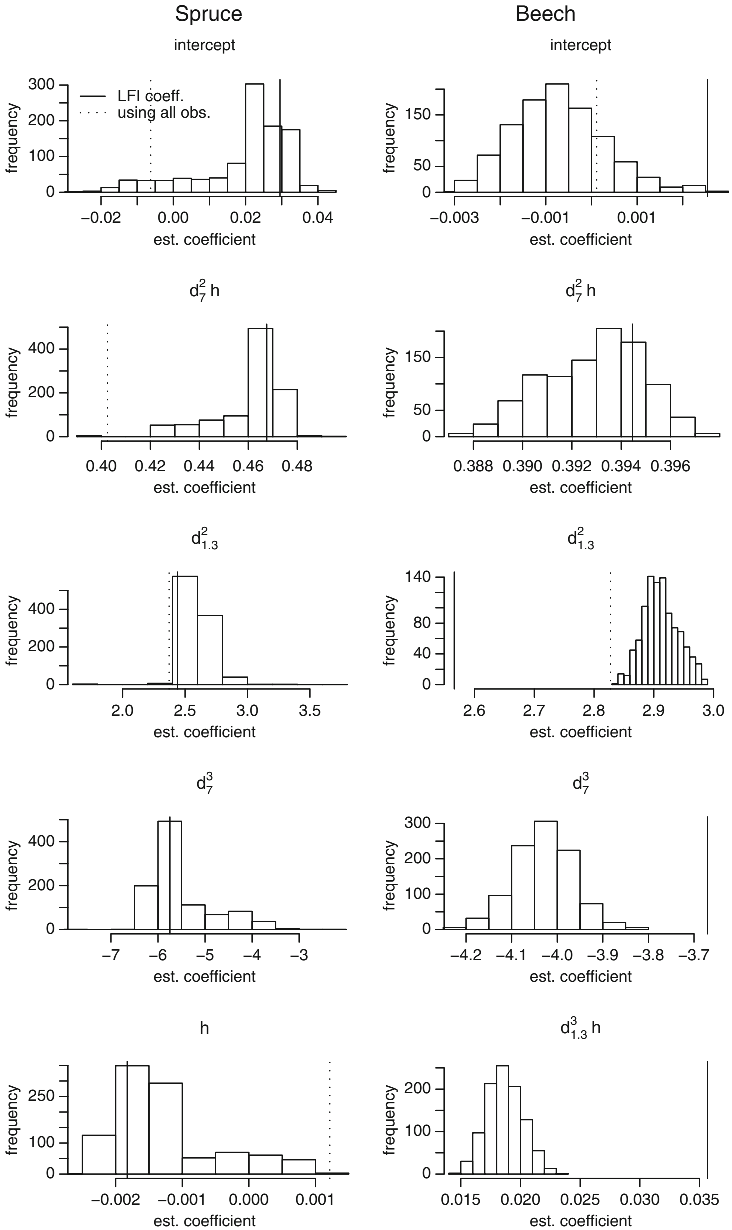

Fig. 12.6 Distribution of 1000 refitted coefficients for Norway spruce (*left*) and European beech (*right*), based on the fitting procedure described in this section (subsampling proportional to $d_{1.3}$, grouped jackknife). Continuous lines indicate the coefficients reported in the NFI and the dotted lines indicate coefficients based on all observations and jackknifing)

12.3 Tariff Models

The stem volume models described in Sect. 12.2 can only be applied to trees with measured $d_{1.3}$, d_7 and h, namely the tariff trees (Sect. 2.3.4). However, for the majority of NFI sample trees only $d_{1.3}$ is measured. For these trees, stem volume over bark, including the tree top and the aboveground part of the stump, is estimated with a tariff model that only depends on measured $d_{1.3}$ and on stand and site attributes as auxiliary variables. A total of 30 different tariff models were fitted for different combinations of tree species and production regions (Table 12.3).

The tariff models have largely remained the same since 1992, and the model descriptions and analysis documented by Kaufmann (2001; pages 166–169) are mostly still valid. This section therefore focuses on minor changes.

Tariff models were fitted based on the stem volume of the tariff sample trees (Sect. 12.2). The models that were described by Kaufmann (2001) had an independent set of coefficients for each inventory cycle. However, this caused artificial jumps in the volume prediction between inventories and therefore resulted in implausible estimations of growth in some cases, for example in small sampling units or for rare tree species. For this reason, the tariff models were refitted in a slightly different form so that all information from NFI1–3 was used simultaneously. The different inventories were considered through two additional coefficients (b_8 and b_9). Table 12.3 shows the number of observations used to fit each model. Stem volumes in NFI4 are currently estimated using coefficients fitted for NFI3.

$$\hat{Y} = exp\left(b_0 + b_1 \ln(d_{1.3}) + b_2 \ln^4(d_{1.3}) + \sum_{i=3}^{9} b_i B_i \right) \tag{12.10}$$

where $\hat{Y}$ is the tariff volume over bark fitted for each tariff number (201, 202, . . ., 230; Table 12.3). The index i corresponds to the additional single tree and sample-plot attributes (3,. . ., 9), and $d_{1.3}$is the measured diameter at breast height. B_3 to B_9 are the following additional single tree and sample-plot attributes:

- B_3 TMI: site quality expressed as the maximum of the total mean increment from stand establishment until the age of 50 years, in kg dry weight ha^{-1} year^{-1} (Sect. 15.5)
- B_4 d_{dom}: dominant diameter, i.e. mean diameter of the 100 thickest trees per hectare (derived from the diameters of the sample trees in the plot)
- B_5 bifurcation of the stem (0 = no bifurcation, 1 = bifurcation) based on field observations
- B_6 elevation (m a.s.l.), taken from the digital elevation model with a 25 m grid
- B_7 stand layer to which the single tree belongs (0 = upper layer, 1 = understorey) based on field observations

B_8 *(inv2)* and B_9 *(inv3)* together indicate the inventory cycle(s) in which the tree was measured:

inv2=0 and inv3=0: tree measured in NFI1
inv2=1 and inv3=0: tree measured in NFI2
inv2=0 and inv3=1: tree measured in NFI3

Table 12.3 Combinations of tree species and production regions along with the number of stems used to fit each tariff model

Tariff number	Tree species	Production region	N of stems
201	Norway spruce (Picea abies)	Jura	3509
202		Plateau	5854
203		Pre-Alps	8230
204		Alps	10,774
205		Southern Alps	1476
206	Silver fir (Abies alba)	Jura	2374
207		Plateau	2247
208		Pre-Alps	3149
209		Alps/Southern Alps	1227
210	Pine (Pinus sylvestris, P. nigra, P. mugo arborea)	Jura	423
211		Plateau	591
212		Pre-Alps/Alps/Southern Alps	1287
213	Larch (Larix decidua, L. kaempferi)	Jura/Plateau/Pre-Alps/Alps	2836
214		Southern Alps	744
215	Other conifers	All	595
216	European beech (Fagus sylvatica)	Jura	3751
217		Plateau	3303
218		Pre-Alps	2101
219		Alps	1219
220		Southern Alps	874
221	Oak (all species) (Quercus spp.)	Plateau	721
222		Jura/Pre-Alps/Alps/Southern Alps	607
223	Sycamore and Norway maple (Acer pseudoplatanus, A. platanoides)	Jura/Plateau	899
224		Pre-Alps/Alps/Southern Alps	821
225	Ash (Fraxinus excelsior, F. ornus)	Plateau	786
226		Jura/Pre-Alps/Alps/Southern Alps	1099
227	Chestnut (Castanea sativa)	All	802
228	Other broadleaved	Jura/Plateau	1043
229		Pre-Alps/Alps	762
230		Southern Alps	721

The model coefficients b_0 to b_9 are presented in Table 12.7.

Depending on the tariff, some explanatory variables of the general model do not contribute substantially to improving the model. Variables with a p-value >0.05 were sequentially deleted using a backward model selection procedure. These deleted variables are marked with a hyphen in Table 12.7.

Discussion of the Tariff Models The tariff models are used to predict single tree volumes, where the only measured biometric variable is $d_{1.3}$. All other variables represent auxiliary information and reflect changes in growth conditions that influence tree height and stem form. In this sense, the tariff models use information beyond $d_{1.3}$. However, it is unclear how precise volumes predicted by tariff models are compared to observed volumes. Since stem volumes are not measured in the NFI, such a comparison is not straight forward. Furthermore, the regression models ignore the inherent heteroscedasticity of the data, and thus the largest trees have the most impact on the coefficient estimations. The resulting p-values are potentially overoptimistic, which in turn influences model selection. Overall, the tariff models shown in Figs. 12.7 and 12.8 show unbiased behaviour over all Switzerland and only minor biases within some production regions.

12.4 Volume Models for Large and Small Branches

The volumes of large branches (≥7 cm in diameter) and of twigs and small branches (<7 cm in diameter) are predicted as fractions of the stem volume (i.e. tariff volume (Sect. 12.3)).

$$branch\ volume_i = stem\ volume * pa_i \tag{12.11}$$

where i indicates large or small branches and pa_i is volume of branches as a fraction of stem volume.

The proportion pa_i is estimated with a logit model:

$$pa_i = exp(lga_i)/(1 + exp(lga_i)) \tag{12.12}$$

$$lga_i = b_{0i} + b_{1i}d_{1.3} + b_{2i}h_1 + b_{3i}h_2 \tag{12.13}$$

where b_{0i} to b_{3i} are species- and region-specific regression coefficients for large and small branches, $d_{1.3}$ is the measured diameter at breast height, and h_1 and h_2 are indicator variables (used for spruce and beech only) for elevation (m a.s.l.) in combination with production region, as indicated in Table 12.4.

The models were fitted to data collected on the permanent plot network of the Experimental Forest Management (EFM) trials conducted at WSL (N = 14,712).

Species-specific logit regression models were fitted to large and small branches for spruce, fir, larch, pine and oak. For beech, three different models were fitted based on region (Tables 12.5 and 12.6). For Norway spruce, the proportion of large

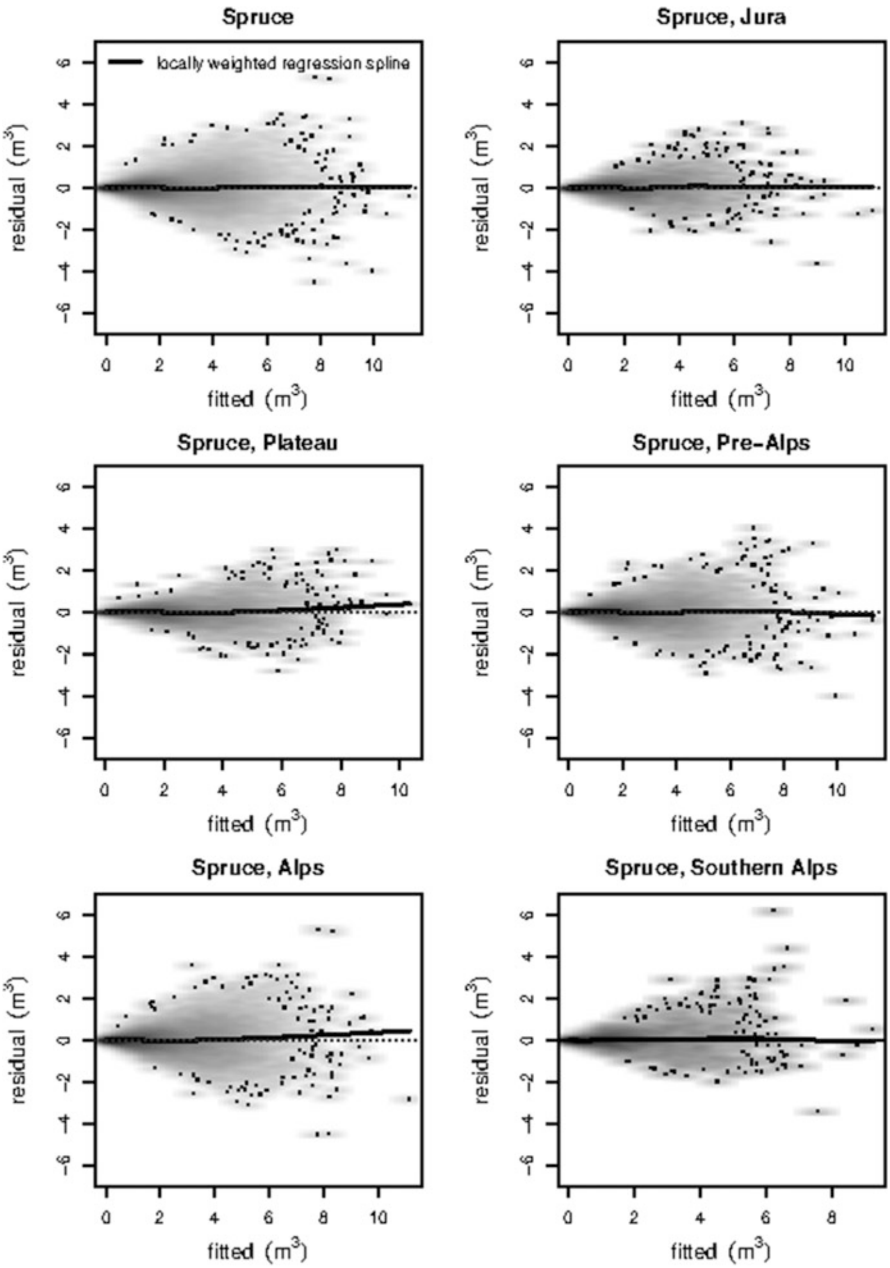

Fig. 12.7 Residual analysis of the tariff models for Norway spruce, shown for all regions together and for each region separately. The grey background is the two-dimensional density of observations (the darker the background the more observations) and the black line is a locally weighted regression spline

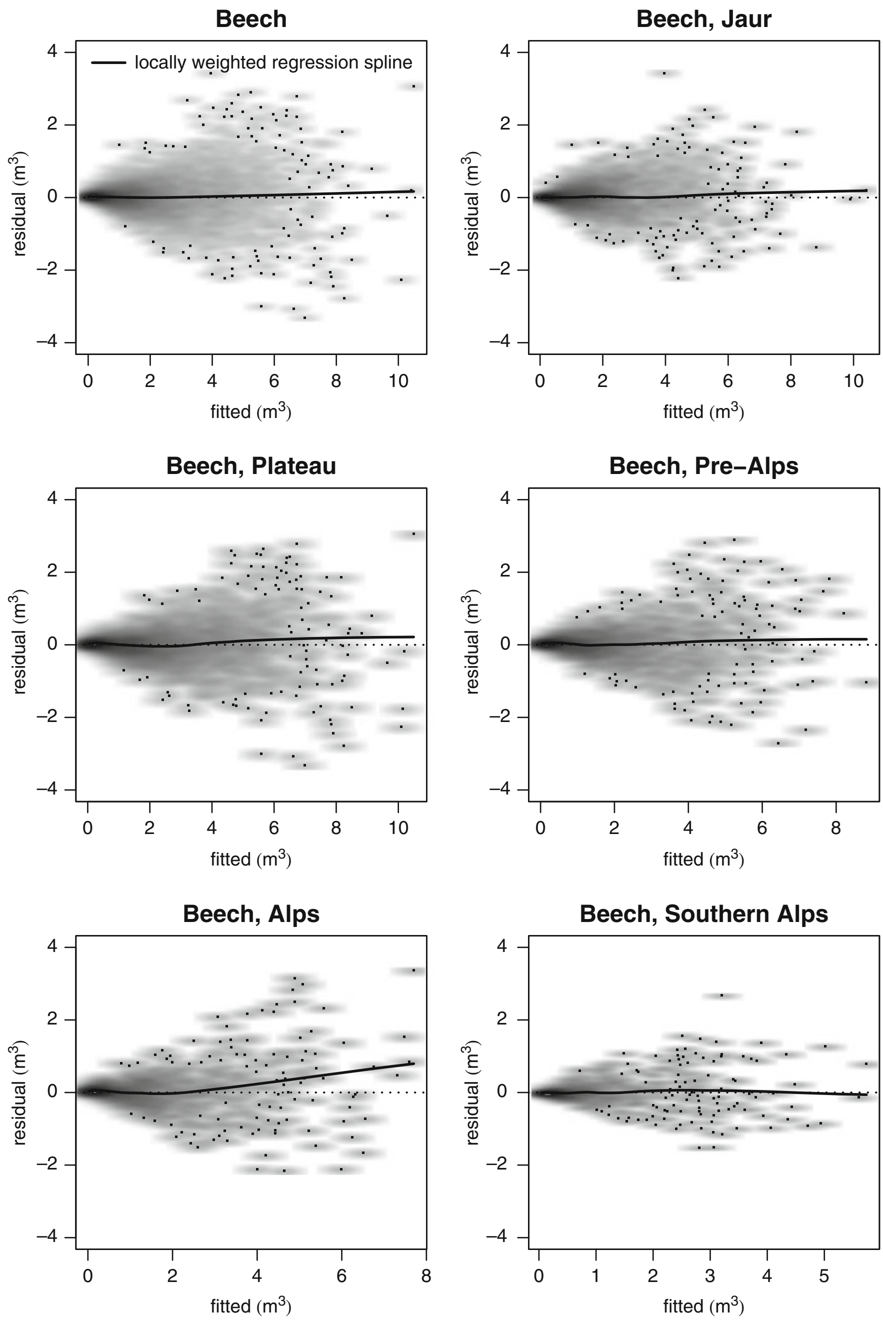

Fig. 12.8 Residual analysis of the tariff models for European beech, shown for all regions together and for each region separately. The grey background is the two-dimensional density of observations (the darker the background the more observations) and the black line is a locally weighted regression spline

Table 12.4 Indicator variables for production region and elevation (m a.s.l.), used in models to predict the volume of branches for Norway spruce and European beech

Indicator value	Production region	Elevation (m a.s.l.)
$h_1 = 1$	Alps	1000–1500
$h_1 = 0$	Alps	$\leq$1000 and >1500
$h_1 = 1$	All other regions	600–1250
$h_1 = 0$	All other regions	$\leq$600 and >1250
$h_2 = 1$	Alps	>1500
$h_2 = 0$	Alps	$\leq$1500
$h_2 = 1$	All other regions	>1250
$h_2 = 0$	All other regions	$\leq$1250

Table 12.5 Coefficients of the volume models for large branches

Tree species	Region	b_0	b_1	b_2	b_3
Silver fir	All regions	−8.7330758	0.059208154	–[a]	–[a]
Larch[b]	All regions	−5.8871184	0.010812163	–[a]	–[a]
Pine[c]	All regions	−7.7147742	0.072285665	–[a]	–[a]
European beech	Jura	−4.8322966	0.056314711	–[a]	–[a]
European beech	Plateau	−5.9903924	0.101889094	–[a]	–[a]
European beech	Pre-Alps, Alps and Southern Alps	−4.9853383	0.073941728	−0.7056977	–[a]
Other broadleaved	All regions	−4.9398872	0.061619224	–[a]	–[a]

[a]Variable not part of the model
[b]Larix decidua, L. kaempferi
[c]Pinus sylvestris, P. nigra, P. strobus, P. mugo arborea

Table 12.6 Coefficients of the volume models for small branches

Tree species	Region	b_0	b_1	b_2	b_3
Norway spruce and other conifers	All regions	−1.2064133	−0.01918645	–[a]	0.44297
Silver fir	All regions	−1.9411075	0.010967741	–[a]	–[a]
Larch[b]	All regions	−2.2772934	−0.00672607	–[a]	–[a]
Pine[c]	All regions	−1.7152468	−0.01391604	–[a]	–[a]
European beech	Jura	−0.84755833	−0.03342084	–[a]	–[a]
European beech	Plateau	−0.75961939	−0.03355523	–[a]	–[a]
European beech	Pre-Alps, Alps and Southern Alps	−2.2772572	−0.03117276	1.21051434	–[a]
Other broadleaved	All regions	−1.9339502	−0.01698668	–[a]	–[a]

[a]Variable not part of the model
[b]Larix decidua, L. kaempferi
[c]Pinus sylvestris, P. nigra, P. strobus, P. mugo arborea

branches is negligibly small, so trees of this species are assumed to have no large branches at all. Development of the volume models for large branches was documented by Kaufmann (2001). A similar procedure was used to develop volume models for small branches.

12.5 Changes in Forest Resources

As the NFI is based on permanent plots, changes such as growth, harvest and mortality are estimated by re-measuring single trees in these plots. Single-tree estimates of gains and losses per year can be directly estimated as the difference in tree volume between subsequent NFIs. Additionally, specific growth models for basal area increment (BAI) and – in the case of tariff trees – for stem volume increment (SVI) are applied to estimate the growth of trees that were cut, died, or reached the calliper threshold between two inventories.

12.5.1 Model for Basal Area Increment

For sample trees for which $d_{1.3}$ is only measured once in two consecutive NFIs, BAI is estimated based on a regression model fitted to data from NFI1 and NFI2. This model is used to predict BAI for trees that were cut or died between two inventories, using the $d_{1.3}$ value measured before this event took place. Analogously, the model is used to back-estimate BAI if $d_{1.3}$ was only measured at the end of the inventory interval, such as for trees that reached the calliper threshold of 36 cm in the outer circle (*nongrowth trees*; Sect. 2.9.2). No BAI is predicted for trees that reached the calliper threshold of 12 cm in the inner circle.

As done in the previous NFIs (Kaufmann 2001; pages 174–175), BAI was modelled as a function of several tree- and plot-specific variables separately for every tariff number (Table 12.3) according to Eq. 12.14 which is based on Teck and Hilt (1991) and Quicke et al. (1994):

$$\widehat{BAI} = AS\exp\Big(b_0 + \sum_{i=1}^{6} b_i B_i + b_7(AS+1)(1-\exp(b_8 d_{1.3})) + b_9(AS-1)(1-\exp(b_{10} d_{1.3}))\Big) \tag{12.14}$$

where BAI is the basal area increment to be estimated (in m^2 per 10 years); *AS* indicates whether BAI is predicted forwards (+1, for trees that were cut or died) or backwards (–1, for nongrowth trees); the index *i* corresponds to the additional single tree and sample-plot attributes (1,. . ., 6), and $d_{1.3}$ is the measured diameter at breast height. The following additional attributes (B_1–B_6) are included:

- B_1 stand basal area (m^2 ha^{-1}), calculated based on all standing trees in the plot that are living
- B_2 basal area of larger trees (m^2 ha^{-1}), calculated based on all standing trees in the plot that are living and have a $d_{1.3}$ greater than the target tree
- B_3 TMI: site quality expressed as the maximum of the total mean increment from stand establishment until the age of 50 years, in kg dry weight ha^{-1} $year^{-1}$ (Sect. 15.5)
- B_4 elevation (m a.s.l.), taken from the digital elevation model with a 25 m grid
- B_5 for even-aged forests: stand age (years), estimated according to a regression model based on tree-ring counts from stumps in the sample plots, as described in detail by Kaufmann (2001; pages 175–176)

  for uneven-aged forests: dominant diameter d_{dom} (cm), calculated as the mean diameter of the 100 thickest trees per hectare (derived from the diameters of the sample trees in the plot)
- B_6 stand layer to which the single tree belongs (0 = upper layer, 1 = understorey), based on field observations

The coefficients b_0 to b_{10} of the BAI model are presented in Table 12.8 for the case of even-aged forests and in Table 12.9 for the case of uneven-aged forests.

Based on the single measurement of $d_{1.3}$, either at the beginning (trees that died or were cut) or at the end (nongrowth trees) of the inventory interval, and on the predicted BAI, the $d_{1.3}$ that was not measured is estimated. Changes in individual-tree volumes are then calculated by applying the tariff models introduced in Sect. 12.3.

A similar BAI model is included in the forest development model MASSIMO (Chap. 17) but with some application-specific differences (e.g. growth boost). An alternative climate-sensitive BAI model was recently developed for MASSIMO (Rohner et al. 2017), but its potential future use in NAFIDAS for estimating changes in resources still needs to be evaluated.

12.5.2 Model for Stem Volume Increment

For the particular case of tariff trees (Sect. 2.3.4) with only one $d_{1.3}$ measurement in consecutive NFIs, a regression model for stem volume increment is applied in order to enable application of the two-stage volume prediction described in Sect. 12.2 and by Kaufmann (2001; page 176 ff.). Stem volume increment over bark is modelled according to the same nonlinear equation as presented for BAI (Eq. 12.14) including the same explanatory variables. The coefficients $b_0$to b_{10} of the stem volume increment model are presented in Table 12.10 for the case of even-aged forests and in Table 12.11 for the case of uneven-aged forests.

Appendix

Table 12.7 Coefficients of the tariff models for stem volume used in the NFI

Tariff number	b_0	b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8	b_9
201	−10.724153	3.256051	−0.0048393	1.8651E-05	0.0040682	−0.3614274	−0.0002185	–[a]	0.0223077	–[a]
202	−11.433229	3.5068775	−0.0061792	1.0366E-05	0.0052032	−0.2891386	−0.0001455	–[a]	0.0189578	–[a]
203	−11.557717	3.5567913	−0.0061486	2.6217E-05	0.0046213	−0.3471568	−0.0002382	−0.0681614	0.0176758	0.0103627
204	−11.128711	3.3859389	−0.0055547	3.8636E-05	0.0051585	−0.3029449	−0.0002215	−0.1157142	0.0218381	0.0214087
205	−11.216898	3.3166269	−0.0052951	7.3452E-05	0.004947	−0.2670809	−0.0001311	−0.1669029	0.0355638	–[a]
206	−12.645729	3.8521689	−0.0069649	1.996E-05	0.0036076	−0.0871577	−5.843E-05	–[a]	0.0213972	–[a]
207	−9.1920196	2.7776135	−0.0033026	1.1998E-05	0.0032396	−0.0954103	−9.42E-05	−0.0799185	–[a]	−0.0223729
208	−9.8212454	2.9689983	−0.0034168	2.2427E-05	0.0011562	−0.2396824	−6.907E-05	−0.0863353	–[a]	–[a]
209	−12.826018	3.9526722	−0.0066614	1.5048E-05	0.00504	−0.3413568	−0.000326	–[a]	–[a]	−0.0302187
210	−8.0864786	2.2899357	–[a]	2.2655E-05	0.0029153	−0.3086679	−0.0004536	–[a]	–[a]	–[a]
211	−10.94328	3.2717589	−0.0047869	2.6183E-05	0.0020279	–[a]	–[a]	–[a]	–[a]	0.0344802
212	−9.9217344	2.7309205	−0.0030583	6.5052E-05	0.0111059	−0.1667086	−4.188E-05	−0.135107	–[a]	–[a]
213	−11.820115	3.6012538	−0.0064718	3.8231E-05	0.003826	−0.1613262	−0.0001787	–[a]	–[a]	−0.0205343
214	−12.212199	3.7878699	−0.006457	–[a]	0.0017183	−0.578801	−0.0003175	–[a]	–[a]	–[a]
215	−11.669887	3.6109797	−0.0060115	–[a]	0.0052156	−0.1916867	−0.000475	–[a]	0.0556036	0.0540687

216	−9.9675636	2.9523813	−0.0035209	3.4071E-05	0.0046608	−0.2036949	−0.0001971	−0.0509308	0.0394829	−0.0187623
217	−11.08317	3.3529562	−0.0048976	2.3704E-05	0.0011135	−0.1103548	–[a]	−0.3674877	–[a]	–[a]
218	−11.901232	3.6164971	−0.0065386	2.4967E-05	0.0076413	−0.2283382	−0.0002516	−0.2855698	0.0352969	0.026345
219	−11.503753	3.4431726	−0.0058677	4.4736E-05	0.0095763	−0.1703535	−0.0003692	−0.4949966	–[a]	–[a]
220	−8.9986338	2.4789923	−0.0022845	–[a]	0.0082187	−0.2235004	–[a]	−0.1700668	0.0500578	0.13778
221	−11.240067	3.3752972	−0.0053652	–[a]	0.004923	−0.1366446	–[a]	–[a]	–[a]	–[a]
222	−9.8165892	2.8318847	−0.0036649	7.7658E-05	0.007115	−0.1737069	−0.0004692	−0.1952119	–[a]	–[a]
223	−7.8080883	2.1328846	–[a]	4.0574E-05	0.0067504	−0.1411788	−0.000194	−0.2800938	–[a]	–[a]
224	−10.532248	3.2857015	−0.0066407	–[a]	0.0054376	−0.2015521	−0.0003639	−0.0926404	0.0606351	0.0816757
225	−14.796222	4.7069939	−0.0110384	–[a]	–[a]	−0.1001387	–[a]	–[a]	–[a]	0.0509466
226	−8.9489701	2.5317642	−0.0019888	5.1401E-05	0.0072292	−0.2289778	−0.000182	−0.1746187	–[a]	–[a]
227	−6.4107181	1.7651895	–[a]	–[a]	–[a]	–[a]	−0.0004751	−0.2959489	0.1125232	0.0614846
228	−9.9483742	2.9543902	−0.00362	–[a]	0.0012139	−0.1706129	–[a]	−0.1849696	–[a]	0.0381569
229	−7.6634052	1.8681238	0.00181239	3.1734E-05	0.0118121	−0.1876773	–[a]	−0.2573701	–[a]	–[a]
230	−11.417793	3.3083886	−0.0058817	0.00012111	–[a]	−0.3370369	−9.689E-05	–[a]	0.0505664	0.0983005

[a]Variable not part of the model

Table 12.8 Coefficients of the model for basal area increment in even-aged forests

Tariff number	b_0	b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8	b_9	b_{10}
201	−5.9725569915	–[a]	−0.0141177298	0.0001238032	−0.0001432649	–[a]	−0.4419050465	1.2188805463	−0.0412665308	−1.5231641275	−0.0237900579
202	−5.3576716248	−0.0025350447	−0.0111731296	0.0001268912	−0.0001237766	−0.0080959830	–[a]	1.6531399040	−0.0309199696	−2.1006858679	−0.0193730741
203	−5.5999909162	−0.0043099417	−0.0031308013	0.0000464691	–[a]	−0.0061571625	−0.2207767935	2.0016539661	−0.0268785619	−2.5092794008	−0.0175886468
204	−5.9825581961	−0.0037218221	–[a]	0.0000380153	−0.0003578998	–[a]	−0.1401817972	1.7800081812	−0.0335025138	−2.1295719027	−0.0220781723
206	−6.8444118394	–[a]	−0.0093693450	0.0000595320	−0.0002954498	–[a]	–[a]	1.9166289572	−0.0524099113	−2.2333832935	−0.0318386482
207	−5.4476670286	−0.0059109694	–[a]	–[a]	0.0002315729	−0.0105309248	–[a]	2.2800097417	−0.0312465564	−3.0428097110	−0.0173548649
208	−6.4408829679	−0.0028410743	–[a]	–[a]	–[a]	−0.0060645499	–[a]	2.3633048416	−0.0390392191	−2.8302169872	−0.0244004409
209	−6.5055494813	–[a]	–[a]	–[a]	–[a]	−0.0101625094	–[a]	2.5696306474	−0.0389299081	−2.7872422289	−0.0309975118
210	−5.8575937635	–[a]	−0.0121997004	–[a]	−0.0009879144	0.0111109659	–[a]	0.7814336607	−0.0303123174	−10.0000000000	−0.0012457366
211	−6.9563871462	0.0070660957	−0.0320973525	0.0005112433	–[a]	0.0060150484	–[a]	−0.0197114881	−0.0985273172	0.0866565286	–[a]
212	−6.4261569817	−0.0074148414	–[a]	–[a]	–[a]	–[a]	−0.0001000000	1.6505499690	−0.0277870666	−2.2765817737	−0.0163653810
213	−6.7953609789	−0.0052489981	−0.0103129849	0.0001334874	–[a]	–[a]	–[a]	1.6772472515	−0.0509718006	−1.8539023598	−0.0353850006
215	−6.2673072979	–[a]	–[a]	–[a]	–[a]	–[a]	–[a]	1.2754456244	−0.0664971420	−3.1697298624	−0.0109958381
216	−6.0035754188	−0.0100298195	–[a]	0.0000592003	–[a]	−0.0060826314	–[a]	1.9892347814	−0.0361807091	−2.3349153659	−0.0252764159
217	−7.5435469469	–[a]	−0.0054871223	0.0001363784	−0.0003236908	–[a]	–[a]	2.1763432732	−0.0558397384	−2.3437735594	−0.0391380136
218	−6.9790127094	−0.0032962563	–[a]	0.0000421386	−0.0005080777	–[a]	–[a]	2.2032171585	−0.0487511502	−2.5636204245	−0.0305965922
219	−6.5431541989	–[a]	−0.0124751526	0.0000735144	−0.0007074670	0.0031207677	−0.5452301129	1.5517003191	−0.0753173816	−1.5899547937	−0.0556268702
221	−6.9921993719	0.0086011546	−0.0095388228	0.0001775024	–[a]	–[a]	–[a]	1.3732159062	−0.0471328782	−1.5589308056	−0.0304159108
222	−6.1045742673	–[a]	–[a]	–[a]	–[a]	–[a]	–[a]	3.6041963410	−0.0083661657	−7.0902276154	−0.0035660288
223	−6.5274474562	–[a]	−0.0172270729	0.0000907116	–[a]	–[a]	–[a]	1.3172166568	−0.0751507507	−1.4562757256	−0.0519940718
224	−5.8086525351	−0.0088521730	–[a]	0.0001087008	–[a]	–[a]	–[a]	3.1033997441	−0.0075478492	−10.0000000000	−0.0020843691
225	−5.7187214188	–[a]	–[a]	–[a]	–[a]	–[a]	–[a]	1.5401536430	−0.0363248815	−3.9809955692	−0.0077976708
226	−6.4276148516	–[a]	–[a]	0.0000520548	–[a]	−0.0080900070	–[a]	2.2956149040	−0.0351685160	−2.5650228462	−0.0268937547
227	−23.1177575591	–[a]	–[a]	–[a]	–[a]	–[a]	–[a]	9.4072550257	−0.1770963558	−10.0000000000	−0.0964787963
228	−6.3296482034	–[a]	–[a]	–[a]	–[a]	–[a]	–[a]	3.8433016946	−0.0116393351	−4.6639497862	−0.0082584971
229	−7.8887806029	−0.0189361901	–[a]	–[a]	−0.0004978637	–[a]	–[a]	2.8269973959	−0.0650354461	−3.0844060725	−0.0493176443

[a]Variable not part of the model

Table 12.9 Coefficients of the model for basal area increment in uneven-aged forests

Tariff number	b_0	b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8	b_9	b_{10}
201	−5.3463805127	–[a]	−0.0187785258	0.0000612228	–[a]	–[a]	0.0000000000	1.0287447250	−0.0405496467	−1.4472917416	−0.0179297677
202	−5.5534990481	−0.0094775685	–[a]	0.0001577019	0.0003495484	–[a]	−0.3370856275	1.9508277783	−0.0124437409	−3.0000000000	−0.0065142676
203	−5.0806115871	–[a]	−0.0095143248	0.0000690710	−0.0004799371	−0.0071544352	–[a]	1.3988472729	−0.0429638638	−1.7621742218	−0.0234704010
204	−5.4839564382	−0.0081505463	0.0049078212	0.0000292479	−0.0003921279	−0.0086835713	–[a]	1.7616296143	−0.0388817765	−2.4059857603	−0.0197084468
205	−4.5893146522	−0.0048346137	−0.0075398644	–[a]	−0.0005286772	0.0061500581	−0.5338777078	0.8454519540	−0.0519822681	−1.3600685185	−0.0174306781
206	−6.6103943593	−0.0098281726	0.0232563626	–[a]	–[a]	−0.0272062833	–[a]	2.8393884519	−0.0384469463	−3.2414553206	−0.0263771512
207	−6.9649489993	−0.0103624688	0.0109648412	–[a]	–[a]	–[a]	–[a]	2.3845980246	−0.0517128958	−2.6351473376	−0.0325415511
208	−5.9266305124	−0.0038519207	−0.0077257158	0.0001212667	–[a]	–[a]	−0.1737349481	1.5810843113	−0.0354557708	−1.8668678522	−0.0220897328
209	−6.9496764153	−0.0128876735	−0.0117087149	–[a]	−0.0003281241	0.0093460154	—[1]	2.0265882649	−0.0785205061	−2.1951196082	−0.0478887002
210	−4.7818446774	–[a]	–[a]	–[a]	–[a]	–[a]	–[a]	3.0000000000	−0.0011047318	−1.4187520167	−0.0015373376
211	−7.6402540921	–[a]	−0.0603585232	–[a]	–[a]	–[a]	–[a]	2.3109864961	−0.0487407286	−2.6139668701	−0.0310590012
212	−6.1058114909	–[a]	–[a]	−0.0001396340	−0.0005150931	–[a]	–[a]	1.5661264182	−0.0469866377	−1.6950020250	−0.0369951807
213	−5.5974573086	−0.0060007067	–[a]	0.0002170699	–[a]	–[a]	−0.2295110226	1.2305966730	−0.0191139809	−1.8379144009	−0.0103019105
214	−2.4512135510	−0.0076731853	−0.0174007601	−0.0003088548	−0.0009886755	–[a]	−0.3732842363	3.0000000000	−0.0039490260	−3.0000000000	−0.0040601338
215	−7.4889257646	–[a]	0.0203299522	–[a]	–[a]	–[a]	−0.6240826952	2.6758859496	−0.0219906826	−3.0951606559	−0.0161881377
216	−5.7690764286	–[a]	−0.0081976076	0.0000747968	0.0001565503	–[a]	–[a]	2.2241620640	−0.0120551377	−3.5527130438	−0.0062496692
217	−8.3686218200	–[a]	–[a]	0.0000948696	–[a]	–[a]	–[a]	2.5139879450	−0.0693457269	−2.7597035071	−0.0426371964
218	−6.3477822588	−0.0111179450	–[a]	–[a]	−0.0003807825	–[a]	–[a]	1.9096330293	−0.0552630020	−2.2694431841	−0.0339515038
219	−7.4164536583	–[a]	−0.0055648313	0.0000658307	–[a]	−0.0130392315	–[a]	2.3054479091	−0.0567858332	−2.5086384861	−0.0426036766
220	−7.1084697111	–[a]	−0.0001000000	–[a]	−0.0004985165	−0.0105495330	−0.2859337889	2.4993334571	−0.0524799097	−2.6250223977	−0.0431105050
221	−8.4022899987	0.0060541954	−0.0170831458	0.0001659352	–[a]	−0.0148269842	–[a]	2.4911454919	−0.0641389440	−2.6073997562	−0.0506235362
222	−7.8634955822	–[a]	–[a]	–[a]	–[a]	–[a]	–[a]	2.4026041833	−0.0483820806	−2.6279871204	−0.0369619186
223	−8.6963947922	–[a]	–[a]	0.0000708614	–[a]	−0.0120053170	–[a]	2.7697490346	−0.0672622887	−2.8371679713	−0.0583405991
224	−5.7467716000	–[a]	–[a]	–[a]	–[a]	–[a]	–[a]	1.8660330453	−0.0232199659	−3.0000000000	−0.0127560652
225	−5.2530765582	−0.0116087796	–[a]	–[a]	–[a]	–[a]	–[a]	3.3945739049	−0.0101681782	−2.8739321287	−0.0112585186
226	−7.2541434628	–[a]	–[a]	0.0000854853	–[a]	−0.0142416440	–[a]	2.3645807882	−0.0485700539	−2.5967763172	−0.0363075794
227	−10.5072740585	–[a]	–[a]	–[a]	–[a]	–[a]	–[a]	3.5396869228	−0.0964343943	−3.6228742135	−0.0755542458
228	−9.6558982180	−0.0218944051	–[a]	0.0001231541	–[a]	–[a]	–[a]	3.9363251304	−0.0447726900	−4.3240409439	−0.0321211317
229	−8.5346866377	−0.0160221363	–[a]	0.0000756011	−0.0013503759	−0.0071350973	–[a]	3.5559417470	−0.0720972566	−3.7935484613	−0.0528753369
230	−8.5012101613	−0.0125758616	0.0271552129	−0.0004131241	−0.0006962986	−0.0491419974	–[a]	4.2184520047	−0.0953190451	−4.7074136058	−0.0649524942

[a]Variable not part of the model

Table 12.10 Coefficients of the model for stem volume increment over bark in even-aged forests

Tariff number	b_0	b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8	b_9	b_{10}
201	−3.1862466089	0.0092009270	−0.0104988952	0.0001252450	–[a]	–[a]	–[a]	0.9683287000	−0.9044855329	−1.0481471252	−0.5427115359
202	−2.1200720881	–[a]	−0.0112944191	0.0001991331	0.0004150566	−0.0055370394	–[a]	0.8083285112	−0.5085677616	−1.1504208788	−0.2282178919
203	−2.4611717658	–[a]	–[a]	0.0001402713	0.0003199561	−0.0078657264	–[a]	1.2050726520	−0.6208337920	−1.5688057932	−0.3058353870
204	−2.6199517463	–[a]	–[a]	0.0000604492	–[a]	−0.0032551748	–[a]	1.1550063951	−0.9695188572	−1.3614255829	−0.5095657377
206	−2.5565347223	–[a]	–[a]	0.0000613960	–[a]	–[a]	–[a]	1.0539046744	−0.8374063743	−1.2890794184	−0.3905131862
207	−1.1180929299	–[a]	−0.0106346084	–[a]	–[a]	−0.0033177239	–[a]	0.7989323198	−0.7454273985	−1.1299642471	−0.2687610008
208	−1.9907008089	–[a]	–[a]	–[a]	–[a]	–[a]	–[a]	0.9828681521	−0.7973529551	−1.1202195523	−0.4123545657
209	−1.3565978491	–[a]	–[a]	−0.0002200785	0.0019210974	−0.0195913048	–[a]	3.3157999681	−0.0765474435	−2.4865301428	−0.1137584799
210	−1.2024720699	–[a]	−0.0335570979	–[a]	–[a]	–[a]	–[a]	–[a]	–[a]	–[a]	–[a]
211	−1.2024720699	–[a]	−0.0335570979	–[a]	–[a]	–[a]	–[a]	–[a]	–[a]	–[a]	–[a]
212	−1.2024720699	–[a]	−0.0335570979	–[a]	–[a]	–[a]	–[a]	–[a]	–[a]	–[a]	–[a]
213	−1.7514629101	–[a]	–[a]	0.0002349951	–[a]	–[a]	–[a]	–[a]	–[a]	–[a]	–[a]
215	−2.8517604971	–[a]	–[a]	0.0002846672	–[a]	–[a]	–[a]	1.0770804205	−0.6155649028	−1.1034269508	−0.4424810951
216	−1.3627608379	–[a]	−0.0087780685	–[a]	−0.0004140575	–[a]	–[a]	1.0163218373	−0.2975669315	−1.5137152541	−0.1410574199
217	−1.1511612691	0.0089813279	−0.0275305914	–[a]	–[a]	0.0071095059	–[a]	–[a]	–[a]	–[a]	–[a]
218	−1.0177571596	0.0106110357	−0.0376676477	0.0000984640	−0.0008842311	0.0050014278	–[a]	–[a]	–[a]	–[a]	–[a]
219	−1.0177571596	0.0106110357	−0.0376676477	0.0000984640	−0.0008842311	0.0050014278	–[a]	–[a]	–[a]	–[a]	–[a]
221	−4.1379287044	–[a]	–[a]	–[a]	0.0013509352	–[a]	–[a]	1.5250218847	−1.0000000000	−1.5827319160	−0.7451050074
222	−4.1379287044	–[a]	–[a]	–[a]	0.0013509352	–[a]	–[a]	1.5250218847	−1.0000000000	−1.5827319160	−0.7451050074
223	−0.5074755445	0.0273985148	−0.0625244058	–[a]	−0.0013493028	–[a]	–[a]	–[a]	–[a]	–[a]	–[a]
224	−0.5074755445	0.0273985148	−0.0625244058	–[a]	−0.0013493028	–[a]	–[a]	–[a]	–[a]	–[a]	–[a]
225	−1.3860688164	–[a]	–[a]	–[a]	–[a]	−0.0136376126	–[a]	1.3095281025	−0.8761970272	−1.5488068988	−0.5077292923
226	−1.3860688164	–[a]	–[a]	–[a]	–[a]	−0.0136376126	–[a]	1.3095281025	−0.8761970272	−1.5488068988	−0.5077292923
228	−1.1389097735	–[a]	–[a]	–[a]	–[a]	–[a]	–[a]	–[a]	–[a]	–[a]	–[a]
229	−1.1389097735	–[a]	–[a]	–[a]	–[a]	–[a]	–[a]	–[a]	–[a]	–[a]	–[a]

[a]Variable not part of the model

Table 12.11 Coefficients of the model for stem volume increment over bark in uneven-aged forests

Tariff number	b_0	b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8	b_9	b_{10}
201	−1.5402394206	–[a]	−0.0266740921	0.0000904223	−0.0004624973	0.0253903975	–[a]	–[a]	–[a]	–[a]	–[a]
202	−1.5402394206	–[a]	−0.0266740921	0.0000904223	−0.0004624973	0.0253903975	–[a]	–[a]	–[a]	–[a]	–[a]
203	−0.7116806330	−0.0042516658	−0.0286035731	–[a]	−0.0007156974	0.0277742594	–[a]	–[a]	–[a]	–[a]	–[a]
204	−1.0781841206	–[a]	−0.0348577102	0.0001031825	−0.0005051668	0.0185036077	–[a]	–[a]	–[a]	–[a]	–[a]
205	−3.7529887064	–[a]	–[a]	0.0002227484	–[a]	0.0168171038	–[a]	1.2796770363	−0.2456921716	−1.5582603792	−0.1536427575
206	−2.4402823250	–[a]	–[a]	0.0001466875	–[a]	–[a]	–[a]	0.9764040338	−0.7228907526	−1.0524134975	−0.4050528784
207	−2.4402823250	–[a]	–[a]	0.0001466875	–[a]	–[a]	–[a]	0.9764040338	−0.7228907526	−1.0524134975	−0.4050528784
208	−2.4402823250	–[a]	–[a]	0.0001466875	–[a]	–[a]	–[a]	0.9764040338	−0.7228907526	−1.0524134975	−0.4050528784
209	−2.4402823250	–[a]	–[a]	0.0001466875	–[a]	–[a]	–[a]	0.9764040338	−0.7228907526	−1.0524134975	−0.4050528784
210	−8.0535623547	−0.0256603607	−0.0886705485	0.0005046373	–[a]	0.1362866029	–[a]	–[a]	–[a]	–[a]	–[a]
211	−8.0535623547	−0.0256603607	−0.0886705485	0.0005046373	–[a]	0.1362866029	–[a]	–[a]	–[a]	–[a]	–[a]
212	−8.0535623547	−0.0256603607	−0.0886705485	0.0005046373	–[a]	0.1362866029	–[a]	–[a]	–[a]	–[a]	–[a]
213	−0.9493173384	–[a]	−0.0470198952	–[a]	–[a]	–[a]	–[a]	–[a]	–[a]	–[a]	–[a]
214	5.9199620429	–[a]	−0.0360266946	−0.0012222347	−0.0028575072	–[a]	–[a]	–[a]	–[a]	–[a]	–[a]
215	−8.0535623547	−0.0256603607	−0.0886705485	0.0005046373	–[a]	0.1362866029	–[a]	–[a]	–[a]	–[a]	–[a]
216	−1.7562023261	–[a]	–[a]	0.0002519269	–[a]	–[a]	–[a]	–[a]	–[a]	–[a]	–[a]
217	−1.7562023261	–[a]	–[a]	0.0002519269	–[a]	–[a]	–[a]	–[a]	–[a]	–[a]	–[a]
218	−2.1392803217	–[a]	–[a]	–[a]	–[a]	–[a]	–[a]	1.3675043273	−0.2973194495	−1.9407441561	−0.1705210706
219	−2.1392803217	–[a]	–[a]	–[a]	–[a]	–[a]	–[a]	1.3675043273	−0.2973194495	−1.9407441561	−0.1705210706
220	−1.5646451103	–[a]	–[a]	–[a]	–[a]	–[a]	–[a]	0.5013682402	−1.0000000000	−0.3578996563	–[a]
221	−2.7840727237	–[a]	–[a]	0.0004985905	−0.0030113676	–[a]	−0.9274380417	1.2519176398	−0.3458881151	−1.0326722733	−0.3929053333
222	−2.7840727237	–[a]	–[a]	0.0004985905	−0.0030113676	–[a]	−0.9274380417	1.2519176398	−0.3458881151	−1.0326722733	−0.3929053333
223	−2.0189165870	–[a]	–[a]	–[a]	–[a]	–[a]	–[a]	0.0168947458	–[a]	−10.0000000000	−0.0350066134
224	−2.0189165870	–[a]	–[a]	–[a]	–[a]	–[a]	–[a]	0.0168947458	–[a]	−10.0000000000	−0.0350066134
225	−1.6275582101	−0.0075711735	−0.0611526559	–[a]	–[a]	0.0389005799	–[a]	–[a]	–[a]	–[a]	–[a]
226	−1.6275582101	−0.0075711735	−0.0611526559	–[a]	–[a]	0.0389005799	–[a]	–[a]	–[a]	–[a]	–[a]
227	4.4583421722	–[a]	0.0091428195	−0.0012773259	−0.0030621450	–[a]	–[a]	1.3057925325	−0.3540028056	−1.2923499953	−0.3054081810
228	−2.5260783910	–[a]	–[a]	–[a]	–[a]	–[a]	–[a]	1.8153016379	−0.6458499180	−1.9470412312	−0.3820039239
229	−2.5260783910	–[a]	–[a]	–[a]	–[a]	–[a]	–[a]	1.8153016379	−0.6458499180	−1.9470412312	−0.3820039239
230	−0.6357439915	–[a]	–[a]	−0.0006260031	–[a]	–[a]	–[a]	2.7170453600	−0.2915851985	−1.5436936798	−0.5754856630

[a]Variable not part of the model

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