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# Models predicting stand level biomass for Norway spruce (*Picea* spp.), Scots pine (*Pinus* spp.) and broadleaf dominated forest in Norway

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Forest in Engerdal, Norway. Photo: Ole Martin Bollandsås

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## Preface

This report is based on Knut Ole Viken's Master Thesis "Biomass equations and biomass expansion factors (BEFs) for Scots pine (*Pinus* spp.), Norway spruce (*Picea* spp.) and broadleaf dominated stands in Norway" submitted to the Department of Ecology and Natural Resource Management, Norwegian University of Life Sciences. The development of the report is partly funded by the Bioenergy Innovation Centre (CenBio). CenBio is a cooperation between the Norwegian University of Life Sciences, Norwegian Institute of Bioeconomy Research (NIBIO), The Foundation for Scientific and Industrial Research (SINTEF), and the Norwegian University of Science and Technology (NTNU).

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Tron Eid, Knut Ole Viken, Rasmus Astrup

## Summary

Eid, T., Viken, K.O. & Astrup, R. 2016. Models predicting stand level biomass for Norway spruce (*Picea* spp.), Scots pine (*Pinus* spp.) and broadleaf dominated forest in Norway. - INA fagrapport 37, 31 pp.

This report presents models for prediction of stand level biomass in forests dominated by Norway spruce, Scots pine and broadleaves, respectively. The models cover both aboveground (stem, bark, branches, foliage) and belowground tree components. The models are based on stand level variables normally available in forest management plans and on variables that are used in relevant decision-support tools. The models can be applied for quantifying biomass for different tree components, and subsequently carbon, when data on induvial trees are not available. The models behaved reasonably well when tested over different forest conditions and regions. However, users should be aware of uncertainties related to western and northern parts of Norway, where the tests revealed underestimation of the biomass.

## Sammendrag

Eid, T., Viken, K.O. & Astrup, R. 2016. Models predicting stand level biomass for Norway spruce (*Picea* spp.), Scots pine (*Pinus* spp.) and broadleaf dominated forest in Norway. [Bestandsmodeller for bestemmelse av biomasse i gran-, furu- og lauvdominert skog i Norge]. - INA fagrapport 37, 31 pp.

Denne rapporten presenter modeller for prediksjon av bestandsbiomasse for henholdsvis gran-, furu- og lauvtredominert skog. Modellene dekker biomasse både over (stamme, bark, greiner/topper og nåler/blader) og under bakken. Modellene er basert på bestandsvariabler som normalt er tilgjengelig i skogbruksplaner og variabler som brukes i ulike prognoseverktøy. Disse modellene vil kunne være nyttige dersom informasjon om enkelttrær ikke er tilgjengelig. Tester for ulike skogforhold og ulike regioner viste at modellene stort sett gav gode resultater. Brukere av modellene bør imidlertid være klar over en viss usikkerhet knyttet til estimering av biomasse i vestlige og nordlige deler av Norge der testene viste at biomassen ble undervurdert.

# 1. Introduction

Reliable estimates of forest biomass are important both with regard to forests as source for renewable energy and for quantification of carbon stock and carbon sequestration of forests. The biomass of individual trees is usually determined by using allometric models predicting biomass based on easily measurable tree variables such as diameter at breast height (dbh) and total tree height (ht) (e.g. Marklund 1987, 1988; Petersson & Ståhl 2006; Repola 2008, 2009; Bollandsås et al. 2009). Per unit area biomass (for a stand or sample plot) may subsequently be estimated by summation of biomass of all individual trees. If information on individual trees is available, and appropriate allometric biomass models exist, this is generally the most accurate way to quantify biomass at stand or plot level.

Quite often, however, individual tree data are not available. In all forest management plans developed in Norway for example, only stand level information such as volume ha$^{-1}$, number of trees ha$^{-1}$, basal area mean diameter (Dg) and basal area weighted mean height ($H_L$) is available. Furthermore, decision-support tools such as Avvirk-2000 (Eid & Hobbelstad 2000) and Gaya (Hoen & Eid 1990; Hoen & Gobakken 1997) are both dependent on-, and produce stand level information. Several studies, however, have quantified biomass or carbon (e.g. Hobbelstad 2007; Gjølsjø & Hobbelstad 2009; Raymer et al. 2009) on stand level using biomass models for individual trees with the stand level variables Dg and $H_L$ as input. With this "average tree" approach, stand level biomass is estimated by multiplying the "average tree biomass" with the number of stems ha$^{-1}$. However, since the relationships between biomass and the independent variables (dbh or ht) in reality are non-linear (see e.g. Repola 2009), using average values (Dg and $H_L$) to predict biomass will introduce bias (e.g. Gertner 1991).

When stand level information only is available, appropriate biomass estimates can be carried out in two different ways; 1) by using stand level volume and corresponding biomass expansion factors (i.e. preferably expansion factors that are dependent on stand level variables) or 2) by predicting stand level biomass directly based on models with stand level variables. The former approach has been used for example by Rørstad et al. (2010), Bergseng et al. (2013) and Borges et al. (2015). However, they had to use expansion factors calibrated for Finland (Lehtonen et al. 2004) because expansion factors based on Norwegian conditions were not available. The latter approach has not been applied in Norway to date since no national stand level biomass models been developed for Norway.

The main objective of this report was to present models (equations) for prediction of stand level biomass (tons dry weight) based on stand level independent variables. The report is based on a master thesis submitted by Viken (2012). Tree species-specific (Norway spruce, Scots pine, and broadleaves) models that cover both aboveground (stem, bark, branches, foliage) and belowground tree components were developed. The models are based on variables that normally are available from forest management plans and variables that are used in relevant decision-support tools. The model development was based on data from the Norwegian National Forest Inventory (NFI).

## 2. Materials and methods

2.1. Data collection and preparation

The data used for modeling were collected on the permanent sample plots of the Norwegian NFI, in the period between 2006 and 2010 (Landsskogtakseringen 2011). These sample plots are distributed in a 3 x 3 km grid covering the entire forested area of Norway, except Finnmark county. Only sample plots defined as productive forest (i.e. minimum production of 1 $m^3$ $ha^{-1}$ $yr^{-1}$ inclusive bark) within the land use classes “Forestry”, “Protected areas” and “Recreation areas” in development classes III-V were included (for details on definitions, see (Landsskogtakseringen 2011). The total number of sample plots was 7004 (Table 1).

For each sample plot of 250 $m^2$ (radius 8.92 m), all trees with dbh over bark ≥ 5 cm was measured for dbh and recorded for species. Stand level variables such as site index (SI, defined as dominant height (m) at breast height age 40 years), stand age and elevation were also assessed for each plot. In addition, a subsample of 10 trees was selected within the sample plot proportional to stand basal area for height measurement. Total tree heights (ht), for the trees not measured for height within a certain plot, were computed based on the sample trees from the plot.

Stem volume of individual trees with dbh ≥ 5 cm was determined from tree volume models, with dbh and ht as independent variables, developed by Vestjordet (1967), Brantseg (1967), and Braastad (1966) for Norway spruce *(Picea abies)*, Scots pine *(Pinus silvestris)* and birch

*(Betula pubescens and Betula pendula*), respectively. For Sitka spruce *(Picea sitchensis)*, models developed by Bauger (1995) were applied. For Norway spruce and Scots pine trees growing in the western part of the country, we applied models developed by Bauger (1995).

To determine biomass for all above- and belowground tree components of individual trees, we applied Swedish models developed by Marklund (1987, 1988) and Petersson & Ståhl (2006). All these models use dbh and ht as independent variables.

Viken (2012) also tested Finish models for individual trees developed by Repola (2008, 2009) for application under Norwegian conditions. In general he found the Swedish models to perform better, probably because these models were based on larger samples, covered larger geographical areas (especially regarding the south-north dimension) and also included larger ranges in tree sizes as compared to the Finish models. Smith et al. (2014, 2016) developed individual tree biomass models for birch based on Norwegian data. These models, however, were not available when Viken (2012) developed his stand level biomass models.

For aboveground biomass of Scots pine and Norway spruce, Marklund (1987, 1988) developed models for the following components; stem, stem bark, living branches, dead branches and needles. For aboveground biomass of birch, models for stem, stem bark, living branches and dead branches were available from Marklund (1988), but not for foliage. Foliage biomass of broadleaf species was therefore determined by multiplying the stem biomass for the actual tree with a factor of 0.022 (Liski et al. 2002).

The belowground biomass models for Norway spruce and Scots pine developed by Marklund (1987, 1988) are meant for biomass determination of roots obtained in operational root extraction for bioenergy purposes. Since all root extractions, when developing these models, were based on machines, no specific minimum diameter for the roots included exists. We assume, however, that the biomass quantities predicted from these models reflect the quantities derived from practical operational root extraction procedures.

The belowground biomass models for Norway spruce and Scots pine developed by Marklund (1987, 1988) predict biomass for the following belowground components; stumps, roots $\geq 5$ cm in diameter, and roots $< 5$ cm in diameter. According to Marklund (1988), the models for roots with diameter $\geq 5$ cm should not be applied for trees with dbh $< 10$ cm because such large roots have not yet been formed for trees of this size. Biomass for roots ≥ 5 cm were therefore only determined for trees with dbh ≥ 10 cm.

The belowground models for Norway spruce, Scots pine and birch developed by Petersson & Ståhl (2006) determine biomass for all roots down to 2 mm in diameter. These models are therefore suitable for quantification of belowground carbon in trees. Since the belowground models developed by Marklund (1987, 1988) and Petersson & Ståhl (2006) serve different purposes (i.e. assessment of biomass for energy and carbon, respectively), both sets of models were applied to provide two options for belowground biomass quantification.

Marklund (1987, 1988) did not develop belowground models for birch. To determine belowground biomass for energy purposes, we therefore applied the birch models developed by Petersson & Ståhl (2006) and subsequently applied a reduction factor of 0.87 (i.e. 13% reduction). This reduction factor was based on the ratio of belowground biomass determined from the Norway spruce and Scots pine models developed by Marklund (1988) and Petersson & Ståhl (2006), respectively.

Finally, volume and biomass of individual trees were summed for all plots and converted to $ha^{-1}$ values.

## 2.2. Development and evaluation of models

The dataset comprising 7004 sample plots were first split randomly into a modelling dataset (approximately 80% of the plots) and a test dataset (remaining plots). Table 1 shows the distribution of the total number of sample plots distributed by dominating species (≥70% of a certain species according to volume $ha^{-1}$) species. Plots with volume $ha^{-1}$ <70% of either species were classified as “mixed”.

In the variable selection phase, a Pearson correlation coefficient analysis of total biomass (tons dry weight) and candidate independent variables (Table 2) was carried out based on data from all plots in order to aid the selection of variables to be included in the models.

Table 1. Number of sample plots distributed by different datasets and dominating tree species.

| Dominating species* | All | Modelling dataset | Test dataset |
|---|---|---|---|
| Norway spruce | 2043 | 1639 | 404 |
| Scots pine | 1758 | 1405 | 353 |
| Broadleaves | 1927 | 1549 | 378 |
| Mixed | 1276 | 1021 | 255 |
| Total | 7004 | 5614 | 1390 |

* defined as plots with percentage volume $ha^{-1}$ ≥70% of a specific species. Plots with percentage volume $ha^{-1}$ <70% of either species are defined as “mixed”

Table 2. Pearson correlation coefficients between total biomass $ha^{-1}$ and different stand level variables.

| | Biomass | Dg | BA | SI | V | Stand age | $H_L$ | Trees | Ele-vation |
|---|---|---|---|---|---|---|---|---|---|
| Biomass | 1 | | | | | | | | |
| Dg | 0.421 | 1 | | | | | | | |
| BA | 0.974 | 0.385 | 1 | | | | | | |
| SI | 0.551 | 0.023 | 0.506 | 1 | | | | | |
| V | 0.977 | 0.452 | 0.945 | 0.554 | 1 | | | | |
| Stand age | 0.014 | 0.585 | 0.005 | -0.530 | 0.035 | 1 | | | |
| $H_L$ | 0.700 | 0.697 | 0.623 | 0.473 | 0.753 | 0.254 | 1 | | |
| N | 0,330 | -0,456 | 0,423 | 0,321 | 0,263 | -0,437 | -0,096 | 1 | |
| Elevation | -0.155 | 0.047 | -0.158 | -0.343 | -0.159 | 0.246 | -0.109 | -0.141 | 1 |

Dg = basal area mean diameter (cm), BA = basal area ($m^2$ $ha^{-1}$), SI = site index, i.e. dominant height (m) at breast height age 40 years, V = volume ($m^3$ $ha^{-1}$), $H_L$ = mean height by basal area (Lorey mean height) (m), N = number of trees $ha^{-1}$

The correlation analysis showed that biomass was strongly correlated with BA (r = 0.973) and V (r = 0.977). Other variables with relatively high correlation coefficients were $H_L$ (r = 0.700) and SI (r = 0.551). Basal area $ha^{-1}$ and V were highly inter-correlated (r = 0.945) suggesting that simultaneous use of them as independent variables in a model will lead to multi-collinearity. Since V always is available in Norwegian forest management plans, while BA sometimes is missing, the selection of V as independent variable in the models therefor was obvious. The variable selection phase also revealed that inclusion of SI as an independent variable, in addition to volume, was important for explaining variation biomass.

The variable selection phase also highlighted two additional important issues; (1) the regression residuals clearly displayed heteroscedasticity (i.e. increasing variance in residuals over increasing predicted biomass $ha^{-1}$, see e.g. Parresol (1999)) and (2) the relationships between volume $ha^{-1}$ and biomass $ha^{-1}$ were nonlinear. To account for this we decided to fit nonlinear models. The selected model form was therefore:

$$Y = \beta_0 + \beta_1 \times V^{\beta_2} + \beta_3 \times SI + \varepsilon$$

where $Y$ is the biomass (tons), $V$ is volume ha$^{-1}$, $SI$ is site index (m), while $\beta_0, \beta_1, \beta_2, \beta_3$ are the estimated regression parameters and $\varepsilon$ is the error term assumed to be normally distributed with mean 0 and variance $\sigma^2$.

To account for the heteroscedasticity we followed the example of Lilles & Astrup (2012) who fitted models assuming the error distribution to be normal with a variance that increased proportionally to the predicted value. Hence, the error ($\varepsilon_i$) for the $i$th observation was modelled as:

$$\varepsilon_i = \alpha_1 \times X_i$$

where $X_i$ is the predicted value and $\alpha_i$ is a parameter estimated with maximum likelihood simultaneously with all the parameters in the selected model form. The models were fitted with the NLMIXED procedure in SAS. To ensure that global optima were reached, several search algorithms and initial start values were tested for each model.

Biomass models were fitted for the following tree components; stem, bark, living branches, dead branches, needles/foliage, total aboveground, stump and large roots (biomass for energy purposes), total belowground (biomass for carbon assessment) and total tree. Separate models were developed for Norway spruce, Scots pine and broadleaf dominated forest and for mixed species forest (see Table 1 for definitions).

The models were evaluated by comparison of model predicted and observed biomass ha$^{-1}$ on the test dataset. Here we tested whether the differences between predicted and observed values were significantly different from zero by means of paired $t$-tests for different groups of the material such as dominating tree species, site index classes, volume classes and geographical regions.

## 3. Results

Tables 3, 4, 5 and 6 show the stand level models for predicting biomass of different tree components for Norway spruce dominated, Scots pine dominated, broadleaf dominated and mixed species, respectively.

Generally, the models predicted increasing biomass with increasing volume and decreasing site index. For some of the tree component models, however, predicted biomass increased also when the site index increased (e.g. model for dead branches in Norway spruce dominated forest, Table 3). A few models had non-significant parameter estimates for site index (e.g. model for stem biomass in Norway spruce dominated forest, Table 3). However, as long as the sign of the parameter estimates conform with the other tree component models, this is not considered as a serious problem.

The coefficients of determination ($R^2$) ranged from 0.9749 to 0.9913 for the total tree models, from 0.9229 to 0.9494 for the total belowground models and from 0.9845 to 0.9932 for the total aboveground models. Generally, $R^2$ for branches and foliage models were lower ranging from 0.5745 to 0.9412. Tables displaying stand level biomass (tons $ha^{-1}$) over volume $ha^{-1}$ and site index based on some selected tree component models are presented in the Appendix Tables A1-A9.

Tables 7, 8, 9 and 10 display the results from the comparisons of predicted biomass $ha^{-1}$ with observed biomass $ha^{-1}$. A few cases of differences significantly different from zero appear over the site index and volume classes, but any particulars patterns can hardly be seen. Over the regions, however, there are some cases of significant over- and underestimations made by the stand level models that might be more severe. Generally, this relates to western and northern Norway where the models seem to underestimate biomass.

Table 3. Stand level biomass models for Norway spruce dominated forest (forest with at least 70% volume of Norway spruce).

| Tree component | Model | $R^2$ |
| --- | --- | --- |
| Stem | $B = 0.2541 + 0.3098 \times V^{1.0277} - 0.0077 \times SI^{NS}$ | 0.9983 |
| Bark | $B = 0.0338 + 0.1058 \times V^{0.8225} - 0.0076 \times SI$ | 0.9596 |
| Living branches | $B = 0.3139 + 1.1503 \times V^{0.6069} - 0.0926 \times SI$ | 0.7522 |
| Dead branches | $B = -0.0717 + 0.0087 \times V^{1.0097} + 0.0108 \times SI$ | 0.9618 |
| Foliage | $B = -0.0570 + 0.5830 \times V^{0.6164} - 0.0262 \times SI$ | 0.7799 |
| Total aboveground | $B = 2.1234 + 1.2073 \times V^{0.8764} - 0.1533 \times SI$ | 0.9845 |
| Stumps and large roots* | $B = 0.4470 + 0.6145 \times V^{0.7832} - 0.0702 \times SI$ | 0.9239 |
| Total belowground** | $B = 0.5267 + 0.7422 \times V^{0.7771} - 0.0823 \times SI$ | 0.9229 |
| Total tree | $B = 3.0419 + 1.8851 \times V^{0.8507} - 0.2550 \times SI$ | 0.9749 |

B = biomass $ha^{-1}$ (tons), V = stem volume $ha^{-1}$, SI = site index defined as dominant height in meter at breast height age of 40 years for Norway spruce

* Stump and large roots as potential for bioenergy use based on Marklund (1988), ** Total belowground based on Petersson & Ståhl (2006), NS non-significant parameter estimate (p > 0.05)

Table 4. Stand level biomass models for Scots pine dominated forest (forest with at least 70% volume of Scots pine).

| Tree component | Model | $R^2$ |
| --- | --- | --- |
| Stem | $B = -2.0138 + 0.2409 \times V^{1.0666} + 0.3276 \times SI$ | 0.9928 |
| Bark | $B = 0.0386 + 0.0647 \times V^{0.8614} - 0.0063 \times SI^{NS}$ | 0.9401 |
| Living branches | $B = 5.3423 + 0.4992 \times V^{0.6884} - 0.4954 \times SI$ | 0.6277 |
| Dead branches | $B = -0.0143 + 0.0273 \times V^{0.8328} + 0.0011 \times SI^{NS}$ | 0.9031 |
| Foliage | $B = 0.7274 + 0.2514 \times V^{0.6108} - 0.1007 \times SI$ | 0.6117 |
| Total aboveground | $B = 3.6217 + 0.8303 \times V^{0.9150} - 0.4651 \times SI$ | 0.9866 |
| Stumps and large roots* | $B = 2.0571 + 0.4228 \times V^{0.8344} - 0.2684 \times SI$ | 0.9191 |
| Total belowground** | $B = 2.3114 + 0.4868 \times V^{0.8256} - 0.3019 \times SI$ | 0.9230 |
| Total tree | $B = 6.2616 + 1.2918 \times V^{0.8905} - 0.8079 \times SI$ | 0.9791 |

B = biomass $ha^{-1}$ (tons), V = stem volume $ha^{-1}$, SI = site index defined as dominant height in meter at breast height age of 40 years for Scots pine

* Stump and large roots as potential for bioenergy use based on Marklund (1988), ** Total belowground based on Petersson & Ståhl (2006), NS non-significant parameter estimate (p > 0.05)

Table 5. Stand level biomass models for broadleaf dominated forest (forest with at least 70% volume of broadleaves).

| Tree component | Model | $R^2$ |
|---|---|---|
| Stem | $B = -1.0821 + 0.2998 \times V^{1.0670} + 0.1512 \times SI$ | 0.9918 |
| Bark | $B = -0.0895 + 0.0743 \times V^{1.0024} + 0.0078 \times SI$ | 0.9916 |
| Living branches | $B = \quad 0.1738 + 0.3615 \times V^{0.8445} - 0.0596 \times SI$ | 0.9412 |
| Dead branches | $B = -0.0190 + 0.0452 \times V^{0.7227} - 0.0036 \times SI$ | 0.6584 |
| Foliage | $B = -0.0003 + 0.0041 \times V^{1.2403} - 0.0006 \times SI$ | 0.5745 |
| Total aboveground | $B = -0.7097 + 0.7187 \times V^{0.9915} + 0.0375 \times SI$ | 0.9932 |
| Stumps and large roots* | $B = \quad 0.4838 + 0.5379 \times V^{0.8628} - 0.1035 \times SI$ | 0.9489 |
| Total belowground** | $B = \quad 0.5444 + 0.6189 \times V^{0.8628} - 0.1180 \times SI$ | 0.9494 |
| Total tree | $B = -0.0430 + 1.3110 \times V^{0.9463} - 0.1150 \times SI$ | 0.9913 |

B = biomass $ha^{-1}$ (tons), V = stem volume $ha^{-1}$, SI = site index defined as dominant height in meter at breast height age of 40 years for birch

* Stump and large roots as potential for bioenergy use based on Petersson & Ståhl (2006) with correction factor, ** Total belowground based on Petersson & Ståhl (2006), [NS] non-significant parameter estimate (p > 0.05)

Table 6. Stand level biomass models for mixed species forest (forest with less than 70% of volume for Scots pine, Norway spruce or broadleaves).

| Tree component | Model | $R^2$ |
|---|---|---|
| Stem | $B = -0.8754 + 0.3269 \times Vs^{1.0175} + 0.2905 \times Vp^{1.0467} + 0.3354 \times Vb^{1.0633} + 0.1062 \times SI$ | 0.9961 |
| Bark | $B = 0.1219 + 0.0756 \times Vs^{0.8685} + 0.0325 \times Vp^{0.9021} + 0.0707 \times Vb^{1.0305} - 0.0055 \times SI$ | 0.9861 |
| Living branches | $B = 3.6458 + 0.4708 \times Vs^{0.7474} + 0.1591 \times Vp^{0.7935} + 0.1363 \times Vb^{1.0139} - 0.1783 \times SI$ | 0.7961 |
| Dead branches | $B = -0.2932 + 0.0034 \times Vs^{1.1458} + 0.0199 \times Vp^{0.3648} + 0.0102 \times Vb^{0.8181} + 0.0320 \times SI$ | 0.8399 |
| Foliage | $B = -1.3949 + 0.3126 \times Vs^{0.7235} + 0.0665 \times Vp^{0.6198} + 0.1169 \times Vb^{0.0519} + 0.0729 \times SI$ | 0.8855 |
| Total aboveground | $B = 2.5836 + 1.0721 \times Vs^{0.8947} + 0.6374 \times Vp^{0.9470} + 0.6067 \times Vb^{1.0241} - 0.1664 \times SI$ | 0.9883 |
| Stumps and large roots* | $B = 2.7840 + 0.3339 \times Vs^{0.8772} + 0.1775 \times Vp^{0.9573} + 0.3157 \times Vb^{0.9430} - 0.1389 \times SI$ | 0.9305 |
| Total belowground** | $B = 3.2949 + 0.4105 \times Vs^{0.8685} + 0.1954 \times Vp^{0.9534} + 0.3631 \times Vb^{0.9448} - 0.1643 \times SI$ | 0.9332 |
| Total tree | $B = 5.8227 + 1.4894 \times Vs^{0.8872} + 0.8659 \times Vp^{0.9469} + 0.9854 \times Vb^{0.9964} - 0.3433 \times SI$ | 0.9811 |

B = biomass $ha^{-1}$ (tons), Vs, Vp, Vb = stem volume $ha^{-1}$ for Norway spruce, Scots pine and broadleaves, SI = site index defined as dominant height in meter at breast height age of 40 years for the species with the largest volume proportion

* Stump and large roots as potential for bioenergy use based on Marklund (1988) for Norway spruce and Scots pine and Petersson & Ståhl (2006) with correction factor for broadleaves, ** Total belowground based on Petersson & Ståhl (2006), [NS] non-significant parameter estimate ($p > 0.05$)

Table 7. Differences between predicted total biomass based on the stand level models and observed total biomass from individual trees for Norway spruce dominated sample plots.

| Site index class (m) | n | Observed biomass (tons $ha^{-1}$) | Difference between predicted and observed biomass | | |
|---|---|---|---|---|---|
| | | | (tons $ha^{-1}$) | (%) | SE (tons $ha^{-1}$) |
| 6 | 38 | 91.14 | -6.83* | -7.50 | 2.15 |
| 8 | 83 | 120.55 | -2.28 | -1.89 | 1.39 |
| 11 | 83 | 137.76 | 1.52 | 1.11 | 1.28 |
| 14 | 62 | 165.13 | 3.48 | 2.11 | 1.94 |
| 17 | 65 | 197.55 | 4.95* | 2.51 | 1.91 |
| 20 | 50 | 246.50 | -0.05 | -0.02 | 3.15 |
| 23 | 21 | 317.47 | 2.39 | 0.75 | 3.57 |
| 26 - | 2 | 234.92 | -5.73 | -2.44 | 6.37 |
| Volume class [1)] | | | | | |
| 25 | 32 | 33.79 | 3.36* | 9.95 | 0.48 |
| 75 | 87 | 75.48 | 0.59 | 0.78 | 0.85 |
| 125 | 64 | 114.81 | -1.17 | -1.02 | 1.64 |
| 175 | 61 | 149.52 | 0.59 | 0.40 | 1.96 |
| 225 | 37 | 190.45 | -2.68 | -1.40 | 2.74 |
| 275 | 33 | 221.22 | 1.67 | 0.76 | 3.25 |
| 325 | 31 | 248.85 | 7.11* | 2.86 | 2.65 |
| 375 | 16 | 286.30 | 3.93 | 1.37 | 6.91 |
| 425 | 15 | 322.09 | -2.62 | -0.81 | 5.90 |
| 475 | 6 | 348.20 | 0.29 | 0.08 | 8.13 |
| 625 | 20 | 430.58 | -1.45 | -0.34 | 4.84 |
| ≥750 | 2 | 603.47 | -51.00 | -8.45 | 23.03 |
| Region | | | | | |
| Southern Norway | 274 | 166.06 | 3.78* | 2.28 | 0.84 |
| Elevation (m): | | | | | |
| 0 – 249 | 58 | 204.73 | 13.46* | 6.57 | 1.46 |
| 250 – 499 | 75 | 187.54 | 7.00* | 3.73 | 1.54 |
| 500 – 749 | 102 | 143.08 | 0.76 | 0.53 | 1.03 |
| 750 - | 39 | 129.80 | -8.38* | -6.46 | 2.41 |
| Middle Norway | 77 | 133.50 | -2.58 | -1.93 | 1.48 |
| Western Norway | 29 | 296.79 | -18.00* | -6.06 | 4.01 |
| Northern Norway | 24 | 134.03 | -5.59* | -4.17 | 2.36 |
| All plots | 404 | 166.53 | 0.56 | 0.34 | 0.76 |

* significantly different from zero ($p < 0.05$), [1)] mean values ($m^3$ $ha^{-1}$) for classes

Table 8. Differences between predicted total biomass based on the stand level models and observed total biomass from individual trees for Scots pine dominated sample plots.

| Site index class (m) | N | Observed biomass (tons ha$^{-1}$) | Difference between predicted and observed biomass | | |
|---|---|---|---|---|---|
| | | | (tons ha$^{-1}$) | (%) | SE (tons ha$^{-1}$) |
| 6 | 64 | 64.85 | -3.49* | -5.37 | 1.00 |
| 8 | 148 | 86.44 | -0.08 | -0.09 | 0.83 |
| 11 | 83 | 106.83 | 0.64 | 0.60 | 0.98 |
| 14 | 37 | 147.86 | 1.79 | 1.21 | 1.97 |
| 17 | 20 | 155.27 | 0.25 | 0.16 | 2.85 |
| 20 | 1 | 159.59 | 2.05 | 1.29 | --- |
| Volume class [1)] | | | | | |
| 25 | 57 | 28.19 | 0.57 | 2.01 | 0.47 |
| 75 | 89 | 60.07 | -0.89 | -1.48 | 0.82 |
| 125 | 90 | 93.62 | -0.86 | -0.92 | 0.94 |
| 175 | 46 | 121.48 | 3.12* | 2.57 | 1.34 |
| 225 | 27 | 155.12 | 0.42 | 0.27 | 2.29 |
| 275 | 22 | 188.63 | 0.24 | 0.13 | 3.02 |
| 325 | 9 | 224.45 | -3.61 | -1.61 | 3.27 |
| 375 | 5 | 257.55 | -4.48 | -1.74 | 10.41 |
| 425 | 4 | 308.56 | -24.00 | -7.78 | 16.54 |
| 475 | 1 | 317.09 | -1.93 | -0.61 | --- |
| ≥ 625 | 3 | 359.31 | -6.65 | -1.85 | 20.56 |
| Region | | | | | |
| Southern Norway | 248 | 99.52 | 2.16* | 2.17 | 0.57 |
| Elevation (m): | | | | | |
| 0 – 249 | 71 | 122.78 | 2.69* | 2.19 | 1.20 |
| 250 – 499 | 86 | 114.52 | 3.07* | 2.68 | 1.12 |
| 500 – 749 | 69 | 71.99 | 1.58* | 2.19 | 0.75 |
| 750 - | 22 | 65.45 | -0.68 | -1.04 | 1.39 |
| Middle Norway | 24 | 70.31 | -1.77 | -2.52 | 1.25 |
| Western Norway | 67 | 106.92 | -8.84* | -8.27 | 1.29 |
| Northern Norway | 14 | 68.67 | -1.46 | -2.12 | 1.25 |
| All plots | 353 | 97.72 | -0.32 | -0.33 | 0.53 |

* significantly different from zero ($p < 0.05$), [1)] mean values (m$^3$ ha$^{-1}$) for classes

Table 9. Differences between predicted total biomass based on the stand level models and observed total biomass from individual trees for broadleaf dominated sample plots.

| Site index class (m) | n | Observed biomass (tons $ha^{-1}$) | Difference between predicted and observed biomass | | |
|---|---|---|---|---|---|
| | | | (tons $ha^{-1}$) | (%) | SE (tons $ha^{-1}$) |
| 6 | 62 | 35.09 | 0.24 | 0.68 | 0.16 |
| 8 | 149 | 60.13 | -0.84* | -1.39 | 0.30 |
| 11 | 96 | 100.13 | -1.37* | -1.37 | 0.63 |
| 14 | 46 | 133.03 | -1.21 | -0.91 | 1.19 |
| 17 | 20 | 134.74 | 0.80 | 0.60 | 2.48 |
| 20 | 3 | 196.37 | 8.64 | 4.40 | 2.25 |
| 23 - | 2 | 193.96 | 14.35* | 7.40 | 1.09 |
| Volume class [1)] | | | | | |
| 25 | 140 | 28.96 | 0.37* | 1.29 | 0.09 |
| 75 | 141 | 74.12 | -0.58* | -0.79 | 0.26 |
| 125 | 45 | 124.24 | -1.62 | -1.31 | 0.90 |
| 175 | 29 | 170.14 | -3.09 | -1.81 | 2.01 |
| 225 | 12 | 218.70 | -1.44 | -0.66 | 3.06 |
| 275 | 5 | 248.86 | 5.29 | 2.12 | 5.30 |
| 325 | 2 | 334.36 | -23.66* | -7.07 | 0.46 |
| 375 | 2 | 373.52 | -35.59 | -9.53 | 8.23 |
| ≥ 425- | 2 | 406.65 | -7.05 | -1.73 | 22.80 |
| Region | | | | | |
| Southern Norway | 113 | 89.42 | 0.67 | 0.74 | 0.54 |
| Elevation (m): | | | | | |
| 0 – 249 | 35 | 171.49 | 0.97 | 0.57 | 1.63 |
| 250 – 499 | 21 | 102.45 | 1.50 | 1.47 | 1.46 |
| 500 – 749 | 20 | 83.19 | 0.04 | 0.05 | 0.92 |
| 750 - | 37 | 42.38 | 0.45 | 1.07 | 0.23 |
| Middle Norway | 30 | 87.17 | -3.34 | -3.84 | 1.63 |
| Western Norway | 88 | 84.32 | -1.70* | -2.01 | 0.55 |
| Northern Norway | 147 | 56.75 | -0.39 | -0.70 | 0.27 |
| All plots | 378 | 75.18 | -0.59* | -0.78 | 0.27 |

* significantly different from zero ($p < 0.05$), [1)] mean values ($m^3$ $ha^{-1}$) for classes

Table 10. Differences between predicted total biomass based on the stand level models and observed total biomass from individual trees for mixed species sample plots.

| Site index class (m) | n | Observed biomass (tons ha$^{-1}$) | Difference between predicted and observed biomass | | |
|---|---|---|---|---|---|
| | | | (tons ha$^{-1}$) | (%) | SE (tons ha$^{-1}$) |
| 6 | 25 | 64.54 | -5.71* | -8.85 | 1.78 |
| 8 | 69 | 85.93 | -5.25* | -6.11 | 1.22 |
| 11 | 68 | 115.78 | -3.06* | -2.64 | 1.35 |
| 14 | 67 | 132.15 | 0.52 | 0.39 | 1.60 |
| 17 | 16 | 186.48 | 3.33 | 1.78 | 5.29 |
| 20 | 7 | 182.49 | 9.24 | 5.06 | 7.37 |
| 23 - | 3 | 254.77 | -5.00 | -1.96 | 13.20 |
| Volume class 1) | | | | | |
| 25 | 37 | 34.12 | -1.16 | -3.41 | 0.78 |
| 75 | 67 | 69.64 | -2.65* | -3.80 | 0.98 |
| 125 | 54 | 105.96 | -5.22* | -4.93 | 1.56 |
| 175 | 41 | 140.77 | -2.47 | -1.75 | 2.25 |
| 225 | 20 | 175.93 | 1.30 | 0.74 | 3.83 |
| 275 | 21 | 205.56 | -0.35 | -0.17 | 4.48 |
| 325 | 6 | 251.98 | -2.89 | -1.15 | 10.28 |
| 375 | 6 | 271.45 | 5.43 | 2.00 | 8.11 |
| 425 | 2 | 325.62 | -17.27* | -5.30 | 1.76 |
| ≥ 475 | 1 | 347.61 | 21.96 | 6.32 | - |
| Region | | | | | |
| Southern Norway | 187 | 120.65 | -0.57 | -0.48 | 0.92 |
| Elevation (m): | | | | | |
| 0 – 249 | 63 | 156.74 | -0.98 | -0.62 | 1.86 |
| 250 – 499 | 60 | 123.30 | 1.86 | 1.51 | 1.73 |
| 500 – 749 | 45 | 86.51 | -1.69 | -1.95 | 1.33 |
| 750 - | 19 | 77.17 | -3.97 | -5.14 | 2.14 |
| Middle Norway | 37 | 105.94 | -5.54* | -5.23 | 1.89 |
| Western Norway | 19 | 86.73 | -7.99* | -9.21 | 2.99 |
| Northern Norway | 12 | 87.62 | -9.21* | -10.52 | 3.54 |
| All plots | 255 | 114.25 | -2.29* | -2.00 | 0.80 |

* significantly different from zero ($p < 0.05$), 1) mean values (m$^3$ ha$^{-1}$) for classes

## 4. Concluding remarks

We have presented models for prediction of stand level biomass for Norway spruce, Scots pine and broadleaf dominated forests, respectively. The models are based on stand level independent variables normally available in forest management plans and on variables used in decision-support tools. The models may be useful for quantifying biomass for different tree components, and subsequently carbon, when data on induvial trees are not available. The models behaved reasonably well when tested over different forest conditions and regions. However, users should be aware of uncertainties related to western and northern parts of Norway, where the tests revealed underestimation of the biomass.

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## Appendix. Tables displaying stand level biomass

Table A1. Total tree biomass (tons $ha^{-1}$) for Norway spruce dominated forest (forest with at least 70% volume of Norway spruce) distributed on volume and site index classes.

| Volume | Site index (m) | | | | | | |
|---|---|---|---|---|---|---|---|
| ($m^3$ $ha^{-1}$) | 6 | 8 | 11 | 14 | 17 | 20 | 23 |
| 25 | 30.66 | 30.15 | 29.38 | 28.62 | 27.85 | 27.09 | 26.32 |
| 50 | 54.07 | 53.56 | 52.80 | 52.03 | 51.27 | 50.5 | 49.74 |
| 75 | 75.72 | 75.21 | 74.44 | 73.68 | 72.91 | 72.15 | 71.38 |
| 100 | 96.30 | 95.79 | 95.02 | 94.26 | 93.49 | 92.73 | 91.96 |
| 125 | 116.11 | 115.6 | 114.83 | 114.07 | 113.3 | 112.54 | 111.77 |
| 150 | 135.34 | 134.83 | 134.06 | 133.30 | 132.53 | 131.77 | 131.00 |
| 175 | 154.09 | 153.58 | 152.81 | 152.05 | 151.28 | 150.52 | 149.75 |
| 200 | 172.44 | 171.93 | 171.17 | 170.40 | 169.64 | 168.87 | 168.11 |
| 225 | 190.46 | 189.95 | 189.18 | 188.42 | 187.65 | 186.89 | 186.12 |
| 250 | 208.17 | 207.66 | 206.90 | 206.13 | 205.37 | 204.60 | 203.84 |
| 275 | 225.63 | 225.12 | 224.35 | 223.59 | 222.82 | 222.06 | 221.29 |
| 300 | 242.85 | 242.34 | 241.57 | 240.81 | 240.04 | 239.28 | 238.51 |
| 325 | 259.85 | 259.34 | 258.58 | 257.81 | 257.05 | 256.28 | 255.52 |
| 350 | 276.66 | 276.15 | 275.39 | 274.62 | 273.86 | 273.09 | 272.33 |
| 375 | 293.30 | 292.79 | 292.02 | 291.26 | 290.49 | 289.73 | 288.96 |
| 400 | 309.76 | 309.25 | 308.49 | 307.72 | 306.96 | 306.19 | 305.43 |
| 425 | 326.08 | 325.57 | 324.80 | 324.04 | 323.27 | 322.51 | 321.74 |
| 450 | 342.25 | 341.74 | 340.98 | 340.21 | 339.45 | 338.68 | 337.92 |
| 475 | 358.29 | 357.78 | 357.01 | 356.25 | 355.48 | 354.72 | 353.95 |
| 500 | 374.20 | 373.69 | 372.93 | 372.16 | 371.40 | 370.63 | 369.87 |
| 525 | 390.00 | 389.49 | 388.72 | 387.96 | 387.19 | 386.43 | 385.66 |
| 550 | 405.68 | 405.17 | 404.40 | 403.64 | 402.87 | 402.11 | 401.34 |
| 575 | 421.26 | 420.75 | 419.98 | 419.22 | 418.45 | 417.69 | 416.92 |
| 600 | 436.73 | 436.22 | 435.46 | 434.69 | 433.93 | 433.16 | 432.40 |

Grey: outside data range

Table A2. Total aboveground biomass (tons $ha^{-1}$) for Norway spruce dominated forest (forest with at least 70% volume of Norway spruce) distributed on volume and site index classes.

| Volume | Site index (m) | | | | | | |
|---|---|---|---|---|---|---|---|
| ($m^3$ $ha^{-1}$) | 6 | 8 | 11 | 14 | 17 | 20 | 23 |
| 25 | 21.48 | 21.17 | 20.71 | 20.25 | 19.79 | 19.33 | 18.87 |
| 50 | 38.42 | 38.12 | 37.66 | 37.20 | 36.74 | 36.28 | 35.82 |
| 75 | 54.31 | 54.00 | 53.54 | 53.08 | 52.62 | 52.16 | 51.70 |
| 100 | 69.53 | 69.23 | 68.77 | 68.31 | 67.85 | 67.39 | 66.93 |
| 125 | 84.29 | 83.99 | 83.53 | 83.07 | 82.61 | 82.15 | 81.69 |
| 150 | 98.69 | 98.38 | 97.92 | 97.46 | 97.00 | 96.54 | 96.08 |
| 175 | 112.79 | 112.48 | 112.02 | 111.56 | 111.10 | 110.64 | 110.18 |
| 200 | 126.64 | 126.34 | 125.88 | 125.42 | 124.96 | 124.50 | 124.04 |
| 225 | 140.28 | 139.98 | 139.52 | 139.06 | 138.60 | 138.14 | 137.68 |
| 250 | 153.74 | 153.43 | 152.97 | 152.51 | 152.05 | 151.59 | 151.13 |
| 275 | 167.03 | 166.72 | 166.26 | 165.80 | 165.34 | 164.88 | 164.42 |
| 300 | 180.17 | 179.86 | 179.40 | 178.94 | 178.48 | 178.02 | 177.56 |
| 325 | 193.17 | 192.87 | 192.41 | 191.95 | 191.49 | 191.03 | 190.57 |
| 350 | 206.05 | 205.75 | 205.29 | 204.83 | 204.37 | 203.91 | 203.45 |
| 375 | 218.82 | 218.52 | 218.06 | 217.60 | 217.14 | 216.68 | 216.22 |
| 400 | 231.49 | 231.18 | 230.72 | 230.26 | 229.80 | 229.34 | 228.88 |
| 425 | 244.05 | 243.75 | 243.29 | 242.83 | 242.37 | 241.91 | 241.45 |
| 450 | 256.53 | 256.22 | 255.76 | 255.30 | 254.84 | 254.38 | 253.92 |
| 475 | 268.92 | 268.61 | 268.15 | 267.69 | 267.23 | 266.77 | 266.31 |
| 500 | 281.23 | 280.92 | 280.46 | 280.00 | 279.54 | 279.08 | 278.62 |
| 525 | 293.46 | 293.15 | 292.69 | 292.23 | 291.77 | 291.31 | 290.85 |
| 550 | 305.62 | 305.31 | 304.85 | 304.39 | 303.93 | 303.47 | 303.01 |
| 575 | 317.71 | 317.41 | 316.95 | 316.49 | 316.03 | 315.57 | 315.11 |
| 600 | 329.74 | 329.44 | 328.98 | 328.52 | 328.06 | 327.60 | 327.14 |

Grey: outside data range

Table A3. Total belowground biomass (tons ha$^{-1}$) for Norway spruce dominated forest (forest with at least 70% volume of Norway spruce) distributed on volume and site index classes.

| Volume | Site index (m) | | | | | | |
|---|---|---|---|---|---|---|---|
| (m$^3$ ha$^{-1}$) | 6 | 8 | 11 | 14 | 17 | 20 | 23 |
| 25 | 9.09 | 8.92 | 8.68 | 8.43 | 8.18 | 7.94 | 7.69 |
| 50 | 15.55 | 15.38 | 15.14 | 14.89 | 14.64 | 14.4 | 14.15 |
| 75 | 21.30 | 21.13 | 20.88 | 20.64 | 20.39 | 20.14 | 19.90 |
| 100 | 26.62 | 26.46 | 26.21 | 25.96 | 25.72 | 25.47 | 25.22 |
| 125 | 31.66 | 31.49 | 31.25 | 31.00 | 30.75 | 30.51 | 30.26 |
| 150 | 36.47 | 36.31 | 36.06 | 35.81 | 35.57 | 35.32 | 35.07 |
| 175 | 41.11 | 40.94 | 40.70 | 40.45 | 40.20 | 39.96 | 39.71 |
| 200 | 45.60 | 45.44 | 45.19 | 44.94 | 44.69 | 44.45 | 44.20 |
| 225 | 49.97 | 49.80 | 49.56 | 49.31 | 49.06 | 48.82 | 48.57 |
| 250 | 54.23 | 54.06 | 53.82 | 53.57 | 53.32 | 53.08 | 52.83 |
| 275 | 58.39 | 58.23 | 57.98 | 57.74 | 57.49 | 57.24 | 57.00 |
| 300 | 62.48 | 62.31 | 62.07 | 61.82 | 61.57 | 61.32 | 61.08 |
| 325 | 66.48 | 66.32 | 66.07 | 65.83 | 65.58 | 65.33 | 65.09 |
| 350 | 70.42 | 70.26 | 70.01 | 69.77 | 69.52 | 69.27 | 69.02 |
| 375 | 74.30 | 74.14 | 73.89 | 73.64 | 73.40 | 73.15 | 72.90 |
| 400 | 78.12 | 77.96 | 77.71 | 77.46 | 77.22 | 76.97 | 76.72 |
| 425 | 81.89 | 81.72 | 81.48 | 81.23 | 80.98 | 80.74 | 80.49 |
| 450 | 85.61 | 85.44 | 85.19 | 84.95 | 84.70 | 84.45 | 84.21 |
| 475 | 89.28 | 89.11 | 88.87 | 88.62 | 88.37 | 88.12 | 87.88 |
| 500 | 92.91 | 92.74 | 92.49 | 92.25 | 92.00 | 91.75 | 91.51 |
| 525 | 96.50 | 96.33 | 96.08 | 95.84 | 95.59 | 95.34 | 95.10 |
| 550 | 100.05 | 99.88 | 99.63 | 99.39 | 99.14 | 98.89 | 98.65 |
| 575 | 103.56 | 103.40 | 103.15 | 102.90 | 102.66 | 102.41 | 102.16 |
| 600 | 107.04 | 106.88 | 106.63 | 106.38 | 106.14 | 105.89 | 105.64 |

Grey: outside data range

Table A4. Total tree biomass (tons $ha^{-1}$) for Scots pine dominated forest (forest with at least 70% volume of Scots pine) distributed on volume and site index classes.

| Volume | Site index (m) | | | | | | |
|---|---|---|---|---|---|---|---|
| ($m^3$ $ha^{-1}$) | 6 | 8 | 11 | 14 | 17 | 20 | 23 |
| 25 | 24.12 | 22.50 | 20.08 | 17.65 | 15.23 | 12.81 | 10.38 |
| 50 | 43.50 | 41.88 | 39.46 | 37.04 | 34.61 | 32.19 | 29.76 |
| 75 | 61.80 | 60.18 | 57.76 | 55.34 | 52.91 | 50.49 | 48.07 |
| 100 | 79.43 | 77.82 | 75.39 | 72.97 | 70.55 | 68.12 | 65.70 |
| 125 | 96.58 | 94.97 | 92.54 | 90.12 | 87.70 | 85.27 | 82.85 |
| 150 | 113.36 | 111.74 | 109.32 | 106.9 | 104.47 | 102.05 | 99.62 |
| 175 | 129.83 | 128.21 | 125.79 | 123.37 | 120.94 | 118.52 | 116.10 |
| 200 | 146.05 | 144.43 | 142.01 | 139.58 | 137.16 | 134.73 | 132.31 |
| 225 | 162.04 | 160.42 | 158.00 | 155.58 | 153.15 | 150.73 | 148.31 |
| 250 | 177.84 | 176.22 | 173.80 | 171.38 | 168.95 | 166.53 | 164.11 |
| 275 | 193.47 | 191.85 | 189.43 | 187.00 | 184.58 | 182.16 | 179.73 |
| 300 | 208.94 | 207.32 | 204.90 | 202.48 | 200.05 | 197.63 | 195.21 |
| 325 | 224.27 | 222.66 | 220.23 | 217.81 | 215.38 | 212.96 | 210.54 |
| 350 | 239.47 | 237.86 | 235.44 | 233.01 | 230.59 | 228.16 | 225.74 |
| 375 | 254.56 | 252.94 | 250.52 | 248.10 | 245.67 | 243.25 | 240.83 |
| 400 | 269.53 | 267.92 | 265.50 | 263.07 | 260.65 | 258.22 | 255.80 |
| 425 | 284.41 | 282.79 | 280.37 | 277.94 | 275.52 | 273.10 | 270.67 |
| 450 | 299.18 | 297.57 | 295.14 | 292.72 | 290.30 | 287.87 | 285.45 |
| 475 | 313.87 | 312.26 | 309.83 | 307.41 | 304.98 | 302.56 | 300.14 |
| 500 | 328.47 | 326.86 | 324.44 | 322.01 | 319.59 | 317.16 | 314.74 |
| 525 | 343.00 | 341.38 | 338.96 | 336.53 | 334.11 | 331.69 | 329.26 |
| 550 | 357.45 | 355.83 | 353.41 | 350.98 | 348.56 | 346.13 | 343.71 |
| 575 | 371.82 | 370.21 | 367.78 | 365.36 | 362.93 | 360.51 | 358.09 |
| 600 | 386.13 | 384.51 | 382.09 | 379.67 | 377.24 | 374.82 | 372.39 |

Grey: outside data range

Table A5. Total aboveground biomass (tons ha$^{-1}$) for Scots pine dominated forest (forest with at least 70% volume of Scots pine) distributed on volume and site index classes.

| Volume | Site index (m) | | | | | | |
|---|---|---|---|---|---|---|---|
| (m$^3$ ha$^{-1}$) | 6 | 8 | 11 | 14 | 17 | 20 | 23 |
| 25 | 16.62 | 15.69 | 14.29 | 12.90 | 11.50 | 10.11 | 8.71 |
| 50 | 30.60 | 29.67 | 28.28 | 26.88 | 25.49 | 24.09 | 22.70 |
| 75 | 43.97 | 43.04 | 41.65 | 40.25 | 38.86 | 37.46 | 36.07 |
| 100 | 56.97 | 56.04 | 54.64 | 53.25 | 51.85 | 50.45 | 49.06 |
| 125 | 69.68 | 68.75 | 67.36 | 65.96 | 64.57 | 63.17 | 61.77 |
| 150 | 82.18 | 81.25 | 79.86 | 78.46 | 77.07 | 75.67 | 74.27 |
| 175 | 94.50 | 93.57 | 92.18 | 90.78 | 89.39 | 87.99 | 86.60 |
| 200 | 106.68 | 105.75 | 104.35 | 102.96 | 101.56 | 100.17 | 98.77 |
| 225 | 118.72 | 117.79 | 116.40 | 115.00 | 113.61 | 112.21 | 110.82 |
| 250 | 130.65 | 129.72 | 128.33 | 126.93 | 125.54 | 124.14 | 122.75 |
| 275 | 142.48 | 141.55 | 140.16 | 138.76 | 137.37 | 135.97 | 134.58 |
| 300 | 154.22 | 153.29 | 151.9 | 150.50 | 149.11 | 147.71 | 146.32 |
| 325 | 165.88 | 164.95 | 163.55 | 162.16 | 160.76 | 159.37 | 157.97 |
| 350 | 177.46 | 176.53 | 175.13 | 173.74 | 172.34 | 170.95 | 169.55 |
| 375 | 188.97 | 188.04 | 186.64 | 185.25 | 183.85 | 182.46 | 181.06 |
| 400 | 200.41 | 199.48 | 198.09 | 196.69 | 195.30 | 193.90 | 192.51 |
| 425 | 211.80 | 210.87 | 209.47 | 208.08 | 206.68 | 205.28 | 203.89 |
| 450 | 223.12 | 222.19 | 220.80 | 219.40 | 218.01 | 216.61 | 215.22 |
| 475 | 234.40 | 233.47 | 232.07 | 230.68 | 229.28 | 227.89 | 226.49 |
| 500 | 245.62 | 244.69 | 243.29 | 241.90 | 240.50 | 239.11 | 237.71 |
| 525 | 256.80 | 255.87 | 254.47 | 253.08 | 251.68 | 250.28 | 248.89 |
| 550 | 267.93 | 267.00 | 265.60 | 264.21 | 262.81 | 261.42 | 260.02 |
| 575 | 279.01 | 278.08 | 276.69 | 275.29 | 273.90 | 272.50 | 271.11 |
| 600 | 290.06 | 289.13 | 287.74 | 286.34 | 284.95 | 283.55 | 282.15 |

Grey: outside data range

Table A6. Total belowground biomass (tons ha$^{-1}$) for Scots pine dominated forest (forest with at least 70% volume of Scots pine) distributed on volume and site index classes.

| Volume | Site index (m) | | | | | | |
|---|---|---|---|---|---|---|---|
| (m$^3$ ha$^{-1}$) | 6 | 8 | 11 | 14 | 17 | 20 | 23 |
| 25 | 7.44 | 6.84 | 5.93 | 5.03 | 4.12 | 3.22 | 2.31 |
| 50 | 12.80 | 12.20 | 11.29 | 10.39 | 9.48 | 8.58 | 7.67 |
| 75 | 17.69 | 17.09 | 16.19 | 15.28 | 14.37 | 13.47 | 12.56 |
| 100 | 22.30 | 21.70 | 20.8 | 19.89 | 18.98 | 18.08 | 17.17 |
| 125 | 26.72 | 26.11 | 25.21 | 24.30 | 23.39 | 22.49 | 21.58 |
| 150 | 30.97 | 30.37 | 29.46 | 28.56 | 27.65 | 26.75 | 25.84 |
| 175 | 35.11 | 34.51 | 33.60 | 32.69 | 31.79 | 30.88 | 29.98 |
| 200 | 39.14 | 38.54 | 37.63 | 36.73 | 35.82 | 34.92 | 34.01 |
| 225 | 43.09 | 42.49 | 41.58 | 40.68 | 39.77 | 38.86 | 37.96 |
| 250 | 46.96 | 46.36 | 45.45 | 44.55 | 43.64 | 42.73 | 41.83 |
| 275 | 50.76 | 50.16 | 49.26 | 48.35 | 47.44 | 46.54 | 45.63 |
| 300 | 54.51 | 53.90 | 53.00 | 52.09 | 51.19 | 50.28 | 49.38 |
| 325 | 58.20 | 57.59 | 56.69 | 55.78 | 54.88 | 53.97 | 53.07 |
| 350 | 61.84 | 61.23 | 60.33 | 59.42 | 58.52 | 57.61 | 56.71 |
| 375 | 65.43 | 64.83 | 63.92 | 63.02 | 62.11 | 61.21 | 60.30 |
| 400 | 68.99 | 68.38 | 67.48 | 66.57 | 65.67 | 64.76 | 63.86 |
| 425 | 72.50 | 71.90 | 70.99 | 70.09 | 69.18 | 68.28 | 67.37 |
| 450 | 75.98 | 75.38 | 74.47 | 73.57 | 72.66 | 71.76 | 70.85 |
| 475 | 79.43 | 78.82 | 77.92 | 77.01 | 76.11 | 75.20 | 74.30 |
| 500 | 82.84 | 82.24 | 81.33 | 80.43 | 79.52 | 78.62 | 77.71 |
| 525 | 86.23 | 85.62 | 84.72 | 83.81 | 82.91 | 82.00 | 81.09 |
| 550 | 89.58 | 88.98 | 88.07 | 87.17 | 86.26 | 85.36 | 84.45 |
| 575 | 92.91 | 92.31 | 91.40 | 90.50 | 89.59 | 88.69 | 87.78 |
| 600 | 96.22 | 95.61 | 94.71 | 93.80 | 92.90 | 91.99 | 91.09 |

Grey: outside data range

Table A7. Total tree biomass (tons $ha^{-1}$) for broadleaf dominated forest (forest with at least 70% volume of broadleaves) distributed on volume and site index classes.

| Volume | Site index (m) | | | | | | |
|---|---|---|---|---|---|---|---|
| ($m^3$ $ha^{-1}$) | 6 | 8 | 11 | 14 | 17 | 20 | 23 |
| 25 | 26.84 | 26.61 | 26.26 | 25.92 | 25.57 | 25.23 | 24.88 |
| 50 | 52.40 | 52.17 | 51.82 | 51.48 | 51.13 | 50.79 | 50.44 |
| 75 | 77.25 | 77.02 | 76.67 | 76.33 | 75.98 | 75.64 | 75.29 |
| 100 | 101.64 | 101.41 | 101.07 | 100.72 | 100.38 | 100.03 | 99.69 |
| 125 | 125.71 | 125.48 | 125.14 | 124.79 | 124.45 | 124.10 | 123.76 |
| 150 | 149.53 | 149.30 | 148.95 | 148.61 | 148.26 | 147.92 | 147.57 |
| 175 | 173.12 | 172.89 | 172.55 | 172.20 | 171.86 | 171.51 | 171.17 |
| 200 | 196.54 | 196.31 | 195.96 | 195.62 | 195.27 | 194.93 | 194.58 |
| 225 | 219.80 | 219.57 | 219.22 | 218.88 | 218.53 | 218.19 | 217.84 |
| 250 | 242.92 | 242.69 | 242.35 | 242.00 | 241.66 | 241.31 | 240.97 |
| 275 | 265.92 | 265.69 | 265.34 | 265.00 | 264.65 | 264.31 | 263.96 |
| 300 | 288.80 | 288.57 | 288.23 | 287.88 | 287.54 | 287.19 | 286.85 |
| 325 | 311.59 | 311.36 | 311.01 | 310.67 | 310.32 | 309.98 | 309.63 |
| 350 | 334.27 | 334.04 | 333.70 | 333.35 | 333.01 | 332.66 | 332.32 |
| 375 | 356.88 | 356.65 | 356.3 | 355.96 | 355.61 | 355.27 | 354.92 |
| 400 | 379.40 | 379.17 | 378.82 | 378.48 | 378.13 | 377.79 | 377.44 |
| 425 | 401.84 | 401.61 | 401.27 | 400.92 | 400.58 | 400.23 | 399.89 |
| 450 | 424.22 | 423.99 | 423.64 | 423.30 | 422.95 | 422.61 | 422.26 |
| 475 | 446.52 | 446.29 | 445.95 | 445.60 | 445.26 | 444.91 | 444.57 |
| 500 | 468.77 | 468.54 | 468.19 | 467.85 | 467.50 | 467.16 | 466.81 |
| 525 | 490.95 | 490.72 | 490.38 | 490.03 | 489.69 | 489.34 | 489.00 |
| 550 | 513.08 | 512.85 | 512.51 | 512.16 | 511.82 | 511.47 | 511.13 |
| 575 | 535.16 | 534.93 | 534.58 | 534.24 | 533.89 | 533.55 | 533.2 |
| 600 | 557.18 | 556.95 | 556.61 | 556.26 | 555.92 | 555.57 | 555.23 |

Grey: outside data range

Table A8. Total aboveground biomass (tons ha$^{-1}$) for broadleaf dominated forest (forest with at least 70% volume of broadleaves) distributed on volume and site index classes.

| Volume | Site index (m) | | | | | | |
|---|---|---|---|---|---|---|---|
| (m$^3$ ha$^{-1}$) | 6 | 8 | 11 | 14 | 17 | 20 | 23 |
| 25 | 17.00 | 17.07 | 17.19 | 17.30 | 17.41 | 17.52 | 17.64 |
| 50 | 34.28 | 34.35 | 34.46 | 34.58 | 34.69 | 34.8 | 34.91 |
| 75 | 51.48 | 51.55 | 51.66 | 51.78 | 51.89 | 52.00 | 52.11 |
| 100 | 68.63 | 68.7 | 68.81 | 68.93 | 69.04 | 69.15 | 69.26 |
| 125 | 85.74 | 85.82 | 85.93 | 86.04 | 86.15 | 86.27 | 86.38 |
| 150 | 102.83 | 102.9 | 103.01 | 103.13 | 103.24 | 103.35 | 103.46 |
| 175 | 119.89 | 119.96 | 120.07 | 120.19 | 120.30 | 120.41 | 120.52 |
| 200 | 136.93 | 137.00 | 137.11 | 137.23 | 137.34 | 137.45 | 137.56 |
| 225 | 153.95 | 154.02 | 154.13 | 154.25 | 154.36 | 154.47 | 154.58 |
| 250 | 170.95 | 171.03 | 171.14 | 171.25 | 171.37 | 171.48 | 171.59 |
| 275 | 187.94 | 188.02 | 188.13 | 188.24 | 188.36 | 188.47 | 188.58 |
| 300 | 204.92 | 205.00 | 205.11 | 205.22 | 205.33 | 205.45 | 205.56 |
| 325 | 221.89 | 221.96 | 222.07 | 222.19 | 222.30 | 222.41 | 222.52 |
| 350 | 238.84 | 238.92 | 239.03 | 239.14 | 239.25 | 239.37 | 239.48 |
| 375 | 255.79 | 255.86 | 255.97 | 256.09 | 256.20 | 256.31 | 256.42 |
| 400 | 272.72 | 272.80 | 272.91 | 273.02 | 273.13 | 273.25 | 273.36 |
| 425 | 289.65 | 289.72 | 289.83 | 289.95 | 290.06 | 290.17 | 290.28 |
| 450 | 306.56 | 306.64 | 306.75 | 306.86 | 306.98 | 307.09 | 307.20 |
| 475 | 323.47 | 323.55 | 323.66 | 323.77 | 323.89 | 324.00 | 324.11 |
| 500 | 340.38 | 340.45 | 340.56 | 340.68 | 340.79 | 340.90 | 341.01 |
| 525 | 357.27 | 357.35 | 357.46 | 357.57 | 357.68 | 357.80 | 357.91 |
| 550 | 374.16 | 374.23 | 374.35 | 374.46 | 374.57 | 374.68 | 374.80 |
| 575 | 391.04 | 391.11 | 391.23 | 391.34 | 391.45 | 391.56 | 391.68 |
| 600 | 407.91 | 407.99 | 408.10 | 408.21 | 408.33 | 408.44 | 408.55 |

Grey: outside data range

Table A9. Total belowground biomass (tons $ha^{-1}$) for broadleaf dominated forest (forest with at least 70% volume of broadleaves) distributed on volume and site index classes.

| Volume | Site index (m) | | | | | | |
|---|---|---|---|---|---|---|---|
| ($m^3$ $ha^{-1}$) | 6 | 8 | 11 | 14 | 17 | 20 | 23 |
| 25 | 9.79 | 9.55 | 9.20 | 8.84 | 8.49 | 8.13 | 7.78 |
| 50 | 17.93 | 17.69 | 17.34 | 16.98 | 16.63 | 16.28 | 15.92 |
| 75 | 25.51 | 25.27 | 24.92 | 24.56 | 24.21 | 23.85 | 23.50 |
| 100 | 32.74 | 32.50 | 32.15 | 31.79 | 31.44 | 31.09 | 30.73 |
| 125 | 39.72 | 39.49 | 39.13 | 38.78 | 38.43 | 38.07 | 37.72 |
| 150 | 46.52 | 46.28 | 45.93 | 45.57 | 45.22 | 44.87 | 44.51 |
| 175 | 53.16 | 52.92 | 52.57 | 52.22 | 51.86 | 51.51 | 51.15 |
| 200 | 59.67 | 59.43 | 59.08 | 58.73 | 58.37 | 58.02 | 57.66 |
| 225 | 66.07 | 65.83 | 65.48 | 65.13 | 64.77 | 64.42 | 64.06 |
| 250 | 72.37 | 72.14 | 71.78 | 71.43 | 71.08 | 70.72 | 70.37 |
| 275 | 78.59 | 78.36 | 78.00 | 77.65 | 77.29 | 76.94 | 76.59 |
| 300 | 84.73 | 84.50 | 84.14 | 83.79 | 83.43 | 83.08 | 82.73 |
| 325 | 90.80 | 90.57 | 90.21 | 89.86 | 89.50 | 89.15 | 88.80 |
| 350 | 96.81 | 96.57 | 96.22 | 95.86 | 95.51 | 95.16 | 94.80 |
| 375 | 102.76 | 102.52 | 102.17 | 101.81 | 101.46 | 101.10 | 100.75 |
| 400 | 108.65 | 108.41 | 108.06 | 107.70 | 107.35 | 107.00 | 106.64 |
| 425 | 114.49 | 114.26 | 113.90 | 113.55 | 113.19 | 112.84 | 112.49 |
| 450 | 120.29 | 120.05 | 119.70 | 119.34 | 118.99 | 118.64 | 118.28 |
| 475 | 126.04 | 125.80 | 125.45 | 125.10 | 124.74 | 124.39 | 124.03 |
| 500 | 131.75 | 131.51 | 131.16 | 130.81 | 130.45 | 130.10 | 129.74 |
| 525 | 137.42 | 137.19 | 136.83 | 136.48 | 136.12 | 135.77 | 135.42 |
| 550 | 143.06 | 142.82 | 142.47 | 142.11 | 141.76 | 141.40 | 141.05 |
| 575 | 148.66 | 148.42 | 148.07 | 147.71 | 147.36 | 147.00 | 146.65 |
| 600 | 154.22 | 153.99 | 153.63 | 153.28 | 152.92 | 152.57 | 152.22 |

Grey: outside data range