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Douglas-fir adjustment functions for the Forest Carbon Predictor version 4.04

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REPORT INFORMATION SHEET

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EXECUTIVE SUMMARY

Background

Radiata pine comprises approximately 90% of NZ's exotic plantation forest estate area and Douglas-fir comprises 5%, with minor contributions from a range of other species including eucalypts (NEFD 2008). The Forest Carbon Predictor (FCP) was developed to predict carbon stocks in radiata pine stands, based on comprehensive biomass data from a range of tree ages, sites, and silvicultural regimes. Biomass data for species other than radiata pine are limited to a few studies per species. Carbon stock estimates obtained using the radiata pine model will therefore be applied to other species, although it is acknowledged that species differences may exist. To improve the accuracy of carbon stock estimates for Douglas-fir all available biomass data for this species were used to develop adjustment functions for use with the FCP version 4.04.

Objective

- The objective of this study was to utilize all available Douglas-fir biomass data to develop adjustment functions for the Forest Carbon Predictor version 4.04, in order to provide more accurate carbon stock estimates for this species in New Zealand.

Key Result

- Douglas-fir biomass data from 10 stands were used to develop empirically determined adjustment functions for use with the Forest Carbon Predictor.
- Douglas-fir above-ground live biomass carbon ($AGL_{D\text{-}F}$) stocks were estimated by adjusting the radiata stem wood plus bark $(X8 + X16)_{Radiata}$, the crown needle ages classes $(X3, X4, X5)_{Radiata}$, and live and dead branch $(X6 + X7)_{Radiata}$ stock estimates from the FCP. Below-ground biomass carbon ($BGL_{D\text{-}F}$) of Douglas-fir was estimated using the modelled root/shoot ratio ($BGL_{Radiata}/AGL_{Radiata}$) for radiata pine. Dead wood ($\text{Dead wood}_{D\text{-}F}$) and Litter ($\text{Litter}_{D\text{-}F}$) were estimated by adjusting the modelled Deadwood and Litter stock estimates from the FCP. Total carbon (excluding mineral soil) was obtained by summing the pools.
- The Douglas-fir adjustment functions in the Forest Carbon Predictor v 4.04 invoked when "species" is specified as PMEN are:

$$\text{Stem}_{D\text{-}F} = 1.0675 \times (X8 + X16)_{Radiata}$$

$$\text{Crown}_{D\text{-}F} = 1.4332 \times (X3 + X4 + X5 + X6 + X7)_{Radiata}$$

$$AGL_{D\text{-}F} = \text{Stem}_{D\text{-}F} + \text{Crown}_{D\text{-}F}$$

$$BGL_{D\text{-}F} = AGL_{D\text{-}F} \times (BGL_{Radiata}/ AGL_{Radiata})$$

$$\text{Dead wood}_{D\text{-}F} = 0.6077 \times \text{Dead wood}_{Radiata}$$

$$\text{Litter}_{D\text{-}F} = 1.319 \times \text{Litter}_{Radiata}$$

$$\text{Total}_{D\text{-}F} = \text{AGL}_{D\text{-}F} + \text{BGL}_{D\text{-}F} + \text{Dead wood}_{D\text{-}F} + \text{Litter}_{D\text{-}F}$$

Implications of Results/Conclusions

- The inclusion of adjustment functions for estimating carbon stocks in above-ground biomass, dead wood and litter pools using the FCP v 4.04, is expected to provide improved estimates for Douglas-fir stands. New root biomass data showed that the radiata pine root/shoot ratio can be applied to Douglas-fir.

Douglas-fir adjustment functions for the Forest Carbon Predictor version 4.04

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Table of Contents

EXECUTIVE SUMMARY **1**
INTRODUCTION **4**
METHODS **6**
Douglas-fir stands included in this study 6
Analysis 7
RESULTS **8**
Comparison of measured with modelled carbon stocks 8
Implementation 12
DISCUSSION **12**
ACKNOWLEDGEMENTS **13**
REFERENCES **15**
Appendices **18**

INTRODUCTION

Knowledge of tree carbon stocks and changes in New Zealand's intensively managed exotic forests is required to meet its reporting commitments under the Kyoto Protocol. Radiata pine comprises approximately 90% of NZ’s exotic plantation forest estate and Douglas-fir comprises 5%, with minor contributions from a range of other species (NEFD 2008). The Forest Carbon Predictor provides unbiased carbon stock estimates for radiata pine (Beets et al., 2011). Little biomass data exist for species other than radiata pine in New Zealand, nevertheless unbiased and precise estimates of carbon stocks and changes are required for forestland and land converted to forestland (IPCC 2003). To reduce bias, efficient methods are being developed to incorporate limited data from alternative species into the existing carbon modelling system (Forest Carbon Predictor) for radiata pine.

The Forest Carbon Predictor version 4.04 includes the 500 Index growth model (Knowles, 2005) and a new wood density model which were developed specifically for Douglas-fir. The 500 Index growth model predicts stem volume increment per plot from one measurement of the plot basal area, mean top height, stocking, and takes into consideration information on the silvicultural history and intentions to model volume in live and dead pools. The Douglas-fir wood density model predicts growth sheath density on an annual basis from soil fertility and temperature. The volume and wood density predictions and silviculture information are used by C_Change (Beets et al. 1999) to predict carbon in live and dead biomass pools annually over a rotation. C_Change was parameterised using radiata pine biomass data, and some differences in biomass partitioning would be expected for other species. Rather than re-parameterise C_Change for other species with limited biomass data, a practical alternative approach would be to simply adjust the carbon stock estimates from the FCP using species-specific biomass data.

This is an inherently reasonable approach because the FCP incorporates the effects of age and silvicultural management activities on the size and disposition of live and dead organic matter pools, and these factors are expected to apply irrespective of species. Nevertheless, adjustment factors would need to allow for species differences in crown/stem relationships, root/shoot ratios, and dead tree component decay rates. We hypothesized previously that component- and species-specific adjustment functions could be developed using biomass measurements for species of interest, and adjustments applied to predictions from the radiata pine model (Beets et al., 1999, Beets et al., 2010).

C_Change models carbon stocks per ha in various live and dead organic matter pools as a function of initial stocking, thinning and pruning intensity and timing, stem annual volume increment, growth sheath wood density, tree component mortality and decay rates and stand age. Stem carbon is calculated by multiplying the annual volume increment from the 500 Index model by the corresponding growth sheath density from the Douglas-fir wood density model, which provides an estimate of wood density given the mean annual air temperature, soil fertility, and ring width (following Beets et al., 2007). Carbon stocks in live pools are estimated using increment expansion factors, and carbon in dead pools are estimated from component-specific mortality rates and temperature dependent decay functions (Beets et al., 1999, Garrett et al., 2012). These linked models are referred to as the Forest Carbon Predictor (FCP).

Live biomass and dead organic matter data from Douglas-fir biomass studies were used to develop empirical adjustment functions for use with the FCP.

Objectives

The objective of this study was to utilize all available Douglas-fir biomass data to develop adjustment functions for the Forest Carbon Predictor version 4.04, in order to provide more accurate carbon stock estimates for this species in New Zealand.

METHODS

Douglas-fir stands included in this study

Biomass study sites and summary statistics for each stand are given in Appendix 1. Stand attributes determined or measured at most sites included stand age, stocking, basal area, mean height, above-ground live biomass, dead wood and litter (Oliver et al. 2007, Oliver et al. 2009, Oliver et al. 2010, Oliver et al. 2011). Root biomass was measured at one site in the Central North Island and three sites in the South Island. Litter (LFH) was measured at most sites, although negligible litter was present in young stands, and in such cases was assumed to be zero. For example at the 10-year-old stand at Gowan Hill and the 9-year-old stand at Forest Creek needle litter was more-or-less absent, which was to be expected because needle retention was reasonably high in these stands (4 - 5 years retention). Dead wood was measured at several sites that had been thinned.

Douglas-fir above- and below-ground live biomass and litter data from Nordmeyer and Ledgard (1993) and Nordmeyer (1997, unpublished) were also compiled for analysis. These studies were in 15- and 28-year-old stands at Trig E, Craigieburn Range (elev. 1040) measured in 1980 and remeasured in 1993, a 13-year-old stand at Bridge Hill, Craigieburn Range (elev. 900m located just below the Trig E stand) measured in 1993, and a 10-year-old stand at Ribbonwood, Upper Waitaki (elev. 500m) measured in 1997. The stand at Trig E was thinned from an initial stocking of 4000 tree/ha to 2700 trees/ha and pruned to 2 m height at stand age 13 (Nordmeyer and Ledgard 1993), however the dead wood and branch residues arising from these operations were not measured. Needle litter was measured in these stands, but these data were not always usable. For example, the young 10 year-old stand at Ribbonwood had high needle retention (10 years), and the forest floor litter was predominantly of grass origin (Nordmeyer pers. comm.). In such cases, the Douglas-fir litter estimate was assumed to be zero. The Bridge Hill and Ribbonwood stands were unthinned when the biomass studies were undertaken. At Trig E whole stem wood density was reported to be 442 kg m^3, and the site mean annual temperature was 8.0°C (Nordmeyer and Ledgard 1993).

Tree stocking, basal area, mean top height, needle retention, soil C/(N -0.014) ratio, site mean annual air temperature, and silvicultural history data for the sites were entered into the Forest Carbon Predictor v 4.04, to provide carbon stock estimates in four pools (above-ground live biomass, below-ground live biomass, dead wood and litter). Other inputs included average needle retention of biomass trees, which exceeded 3 years (3+), so the maximum needle retention parameter for radiata pine (3) was used. Wood density was estimated using mineral soil C and N measurements, to 5 cm depth, or at some sites to 10 cm depth (Nordmeyer pers. comm.), and site mean annual air temperature from National Institute of Water and Atmospheric Research (NIWA) climate surfaces (Oliver et al., 2007, 2009, 2010, 2011).

Analysis

Carbon stock adjustment factors were determined empirically from the slope of the relationships between measured biomass carbon and modelled carbon. For Douglas-fir, these adjustments were applied separately to crown and stem components of above-ground live carbon, and to the dead wood and litter pool estimates.

RESULTS

Comparison of measured with modelled carbon stocks

Above-ground live biomass, below-ground live biomass , dead wood and litter carbon in Douglas-fir stands at 10 biomass sites and corresponding predictions obtained using the FCP 4.04 are given in Table 1. Douglas-fir usually had more carbon in live pools compared with radiata pine estimates at the corresponding stand age, mean top height, basal area, and stocking. When applying the FCP, Douglas-fir adjustment functions are used to “correct” for these observed differences.

Table 1. Modelled (FCP - without the adjustment functions) and measured (Meas.) carbon stocks at the given age by pool at 10 Douglas-fir biomass study sites in New Zealand.

		Above-ground (t C/ha)		Below-ground (t C/ha)		Litter (t C/ha)		Dead wood (t C/ha)	
Site	**Age**	**FCP**	**Meas.**	**FCP**	**Meas.**	**FCP**	**Meas.**	**FCP**	**Meas.**
S. Kaingaroa	21	83.1	103.2	16.9	-	5.0	7.2	0.0	0.0
Gowan Hill	10	29.3	52.8	6.6	-	2.3	0.0	0.0	0.0
Forest Creek	9	11.4	25.7	2.6	-	0.8	0.0	0.0	0.0
Forest Creek	19	50.9	80.0	10.3	-	3.5	-	0.0	0.0
Trig E	15	32.0	54.8	8.1	-	8.3	9.3	2.4	-
Trig E	28	126.0	153.6	26.9	59.0	7.8	13.0	5.2	-
Bridge Hill	13	32.5	45.5	7.1	15.0	2.7	10.3	0.0	0.0
Ribbonwood	10	25.2	44.9	5.6	15.9	2.0	0.0	0.0	0.0
N. Kaingaroa	28	155.4	159.2	34.1	28.8	6.2	5.1	11.1	4.8
Whakarewarewa	31	137.0	136.4	30.2	-	5.1	7.3	12.1	9.1

Carbon stocks adjustment functions for Douglas-fir

The relationship between measured carbon stocks and stock estimates from the FCP model are shown by component in Figure 1. Above-ground live biomass carbon is the sum of stem (wood plus bark component) and crown (foliage plus live and dead attached branches and reproductive part component) carbon. The slope coefficient for stems (1.0675) indicates that Douglas-fir stands tend to have more stem carbon than estimated using the Forest Carbon Predictor v 4.04. The slope coefficient for crowns (1.4332) indicates that Douglas-fir has almost 50% more needle and branch carbon than estimated using the model (Figure 1), which primarily reflects the high needle retention (attains around 8 years at some sites) and also the extra "branchiness" of Douglas-fir compared with radiata pine. The coefficients for litter (1.319) and dead wood (0.6077) indicate that Douglas-fir stands have more carbon in litter and less in dead wood pools relative to comparable radiata pine stands.

Douglas-fir above-ground live biomass carbon ($AGL_{D\text{-}F}$) was estimated from radiata pine stem carbon and crown carbon using the following functions:

$$Stem_{D\text{-}F} = 1.0675 \times (X8 + X16)_{Radiata}$$

$$Crown_{D\text{-}F} = 1.4332 \times (X3 + X4 + X5 + X6 + X7)_{Radiata}$$

$$AGL_{D\text{-}F} = Stem_{D\text{-}F} + Crown_{D\text{-}F}$$

Douglas-fir below-ground live biomass carbon ($BGL_{D\text{-}F}$) was estimated using the modelled root/shoot ratio for radiata pine, which was assumed to apply to Douglas-fir:

$$BGL_{D\text{-}F} = AGL_{D\text{-}F} \times (BGL_{Radiata} / AGL_{Radiata})$$

Where

$BGL_{Radiata}$ = modelled below-ground biomass carbon for radiata pine

$AGL_{Radiata}$ = modelled above-ground biomass carbon for radiata pine

Dead wood and litter pools were estimated using the following functions:

$$\text{Dead wood}_{D\text{-}F} = 0.6077 \times \text{Dead wood}_{Radiata}$$

$$\text{Litter}_{D\text{-}F} = 1.319 \times \text{Litter}_{Radiata}$$

Total carbon (excluding mineral soil C) was estimated by summing the four pools:

$$\text{Total}_{D\text{-}F} = \text{AGL}_{D\text{-}F} + \text{BGL}_{D\text{-}F} + \text{Dead wood}_{D\text{-}F} + \text{Litter}_{D\text{-}F}$$

The C_Change model was used to estimate stocks (t dry matter/ha) in:

X8 = stem wood dry matter

X16 = stem bark dry matter

X3 – X5 = 1 – 3+ year-old needles

X6 = live branch and cone dry matter

X7 = dead attached branch dry matter

The FCP v 4.04 was used to estimate carbon stocks (t C/ha) in:

$\text{Dead wood}_{Radiata}$ = dead wood estimate from unadjusted FCP run

$\text{Litter}_{Radiata}$ = litter estimate from unadjusted FCP run

The subscript $_{Radiata}$ indicates that estimates for Douglas-fir were derived from C_Change for radiata pine.

Note that the root/shoot ratio from Nordmeyer (1997) averaged approximately 40%, which is considerably higher than Douglas-fir at Northern Kaingaroa (19%) and radiata pine (20%). The Douglas-fir data collected by Nordmeyer were obtained using a variable area pit method (Nordmeyer pers. comm.), which appears to overestimate root biomass relative to shoot biomass. The root/shoot ratio for radiata was therefore used in our analysis, in order to be consistent with the results at the Northern Kaingaroa site (where tree root systems were individually excavated in total) and with Douglas-fir data from international studies (Ranger & Gelhaye 2001).

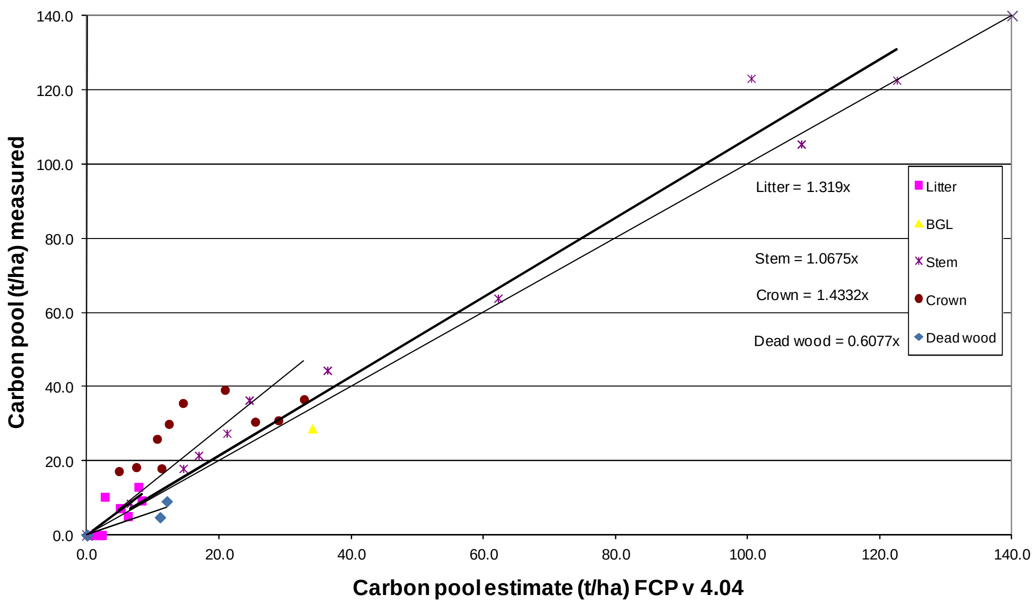

Figure 1. Relationship between measured carbon in ten Douglas-fir stands and estimated carbon in radiata pine stands of the same age, mean top height, basal area and stocking, based on the Forest Carbon Predictor.

The Douglas-fir adjustment functions appear to perform adequately with respect to above-ground live biomass and dead organic matter pools (Figure 2). However in young stands there was a tendency for the adjusted above-ground live pool to be underestimated by the model. Conversely, in old stands, the model overestimated above-ground live carbon in two stands and underestimated carbon in one stand. These tendencies reflected tree health differences – young Douglas-fir stands all had high needle retention (6-8 years retention), while two of the older stands tended to have low retention (approximately 3 years needle retention was observed at Northern Kaingaroa and Whakarewarewa). If more young stands with low needle retention (in the North Island) and older stands with high needle retention (in the South Island) had been sampled, the measured biomass carbon would be expected to straddle the y=x line better.

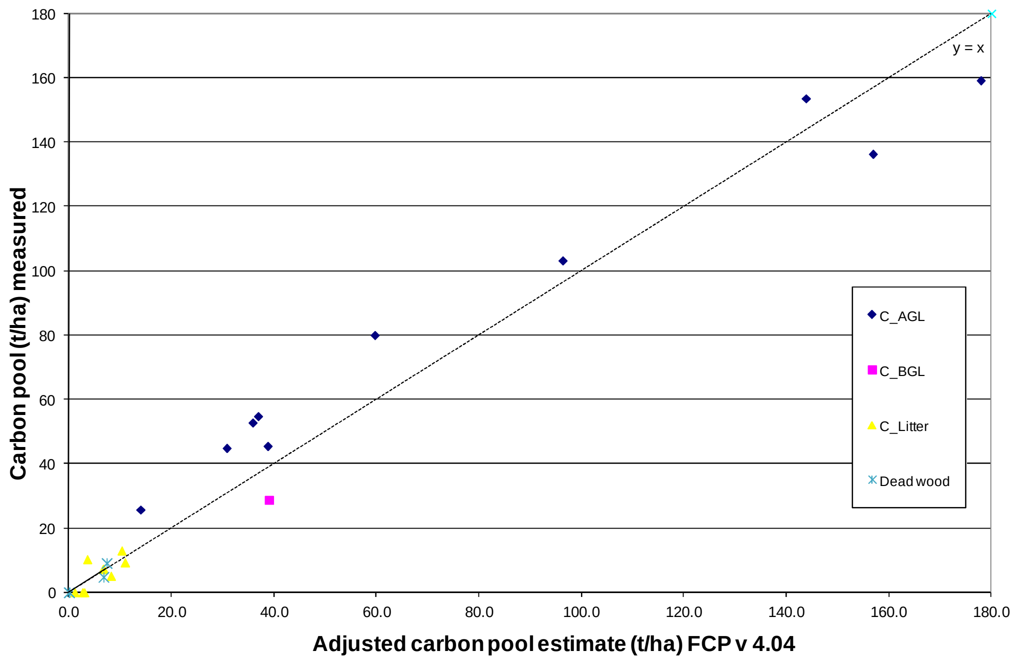

Figure 2. Relationship between measured carbon stocks in Douglas-fir stands and adjusted carbon stock estimates obtained using the Forest Carbon Predictor.

Implementation

These new adjustment factors for Douglas-fir have been incorporated in the FCP v 4.04. To invoke these adjustment functions, it is necessary to specify species as "PMEN".

DISCUSSION

Functions were developed to adjust carbon stock estimates from the Forest Carbon Predictor version 4.04, based on the 500 Index model and the new wood density model for Douglas-fir, when linked to C_Change for radiata pine. Data from 10 Douglas-fir sites were used to develop the adjustment functions. These functions provide less biased carbon stock estimates for Douglas-fir using the FCP version 4.04. These functions should be applied in future when estimating carbon stocks in Douglas-fir stands.

Root biomass data for Douglas-fir acquired by Nordmeyer (unpubl.) suggest a higher root/shoot ratio than in radiata pine. However, the use of variable area pit methods for excavating root systems can lead to large errors and appears to be biased. Root and shoot biomass data collected for Douglas-fir growing in New Zealand and overseas suggest that the radiata pine root/shoot ratios apply to this species as well. Dead wood and litter pools were measured in several Douglas-fir stands, so it was possible to develop adjustment factors for these pools as well.

When developing the Douglas-fir adjustment functions, a new wood density model for Douglas-fir was used to predict annual growth sheath densities over a rotation. This new model is based on new national wood density survey data that showed that breast height outer wood density of Douglas-fir is influenced by both temperature and site fertility. A previous survey of breast height outer wood density did not find a relationship with temperature (Harris, 1966). However, outer wood density was shown to decrease with increasing nitrogen fertility in Douglas-fir in NZ and overseas (Brix 1993, Oliver et al. 2010). The new wood density model for Douglas-fir is very similar to that for radiata pine, with breast height outer wood density modelled as a function of mean annual temperature and nitrogen fertility. As in radiata pine, diameter growth rate significantly influenced density however this effect was much smaller in Douglas-fir compared with radiata pine. Hence, the effect of diameter growth rate was not included in the new wood density model for Douglas-fir.

C_Change could be modified to allow a wider range of needle retention levels to be modelled, to improve the accuracy of stand-specific estimates. Needle retention varies spatially owing to variation in the severity of Swiss Needle Cast disease, which is more prevalent at warm sites. In future, spatial variation in needle retention will need to be measured and mapped, as input to C_Change.

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Appendices

Appendix 1. Douglas-fir stand variables and biomass (dry matter) data used to develop adjustment functions for the Forest Carbon Predictor v 4.04.										
Site name	Gowan Hill	Southern Kaingaroa	Forest Creek	Forest Creek	Trig E	Trig E	Bridge Hill	Ribbon-wood	Northern Kaingaroa	Whaka-rewarewa
Year planted	1998	1985	2000	1990	1965	1965	1980	1983	1982	1979
Species	D-fir	D-fir	D-fir	D-fir	D-fir	D-fir	D-fir	D-fir	D-fir	D-fir
Age (yrs)	10	21	9	19	15	28	13	10	28	31
Trees/ha	1186	1250	1419	1051	2700	2700	4350	1838	800	717
BA (m2/ha)	24.8	52.6	12.0	37.9	39.8	100.0	40.0	21.6	55.5	46.7
MTH (m)	8.4	15.5	6.5	14.5	7.7	12.6	7.5	8.4	25.6	26.2
Vol_{ib} (m^3/ha)	92.6	305	35.6	215	-	-	-	-	503	479
Foliage (t/ha)	18.0	12.8	15.3	17.6	16.2	24.7	17.7	17.8	12	8.6
LiveBr (t/ha)	35.0	25.6	19.1	31.8	20.4	36.4	18.3	34.1	32.8	32.1
DeadBr (t/ha)	6.9	39.9	0.1	21.8					28.4	21.3
Reprod. parts (t/ha)	-	-	-	-	-	-	-	-	-	-
Wood (t/ha)	35.3	111.6	14.2	75.2	64.0	211.9	46.6	31.2	221.2	188.6
Bark (t/ha)	6.7	16.1	2.9	13.6	8.7	34.3	8.3	4.7	24.0	22.2
AGB (t/ha)	101.9	205.9	51.5	160.0	109.6	307.2	90.9	87.8	318.4	272.7
BGB (t/ha)						118	29.9	31.8	57.5	