Bark Biomass Estimation Using the National Volume/Biomass Estimator Library

Yingfang Wang
Forest Management Service Center
USDA Forest Service
2150 Centre Ave, Bldg A
Fort Collins CO 80526

Forest Management Service Center (FMSC)

- FMSC is a sub-unit of Forest Management Staff of the Washington Office, located in Fort Collins, Colorado.
- The Service Center provides mensuration, statistical, modeling, biometric, sampling, and analysis skills to the Forest Service and works in partnership with other government agencies, universities, forest industry, and individuals in the USA and other countries.

- The Service Center includes the following groups:
  - Forest Vegetation Simulator (FVS)
  - Forest Product Measurement

FVS and Forest Product Measurement

- FVS is the USDA Forest Service’s nationally supported framework ensuring consistency among forests in vegetation growth and yield modeling.

- The Forest Products Measurements group coordinates biometric activities for the national forests. Our primary responsibilities are developing and applying practical and efficient methods of timber cruising, scaling, volume estimation, and area determination.

- The Forest Product Measurement group maintains the National Volume Estimator Library (NVEL) and the National Biomass Estimator Library (NBEL)

National Volume Estimator Library (NVEL)

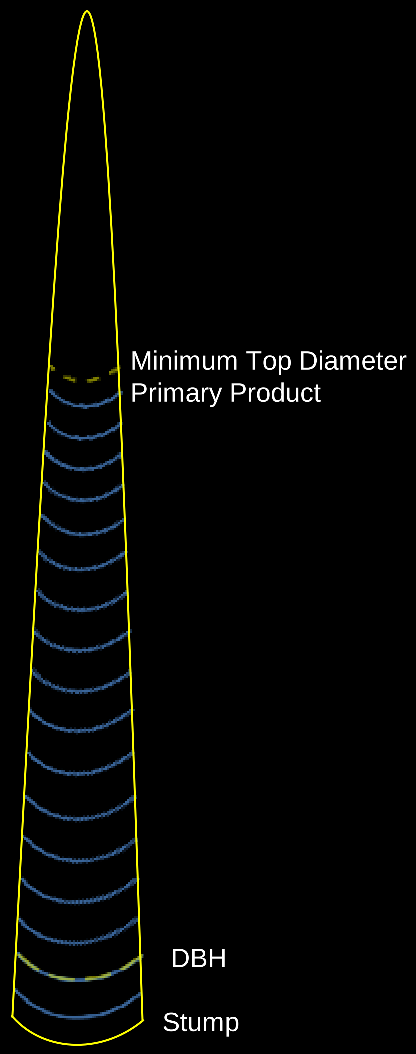
- Collection of the standing tree volume estimators used by the Forest Service.
- Contains the research publications, descriptions of the implementation process, and the computer source code.
- Written in Fortran and compiled into a DLL. It can be linked into other program, such as C#, C++, VB, Python, MS Excel, etc.
- Used by the national timber Cruise Processing, FVS, and Field Sampled Vegetation (FSVeg) database.

NVEL

- Volume Library calculates Gross Volumes
  - Net Volume is handled by calling program
- There are four types of volumes available:
  - Sawtimber
  - Pulpwood (or non-sawtimber)
  - Topwood
  - Total Cubic

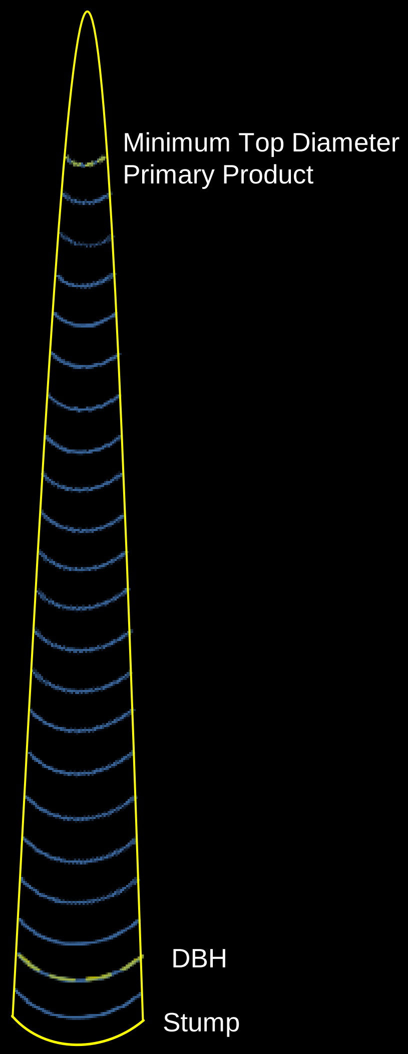
NVEL - Sawtimber

- Sawtimber is the merchantable portion of the main stem from the stump to a minimum top diameter
- There is a minimum DBH for a tree to contain sawtimber
- There is a minimum log length a tree needs to have to contain sawtimber



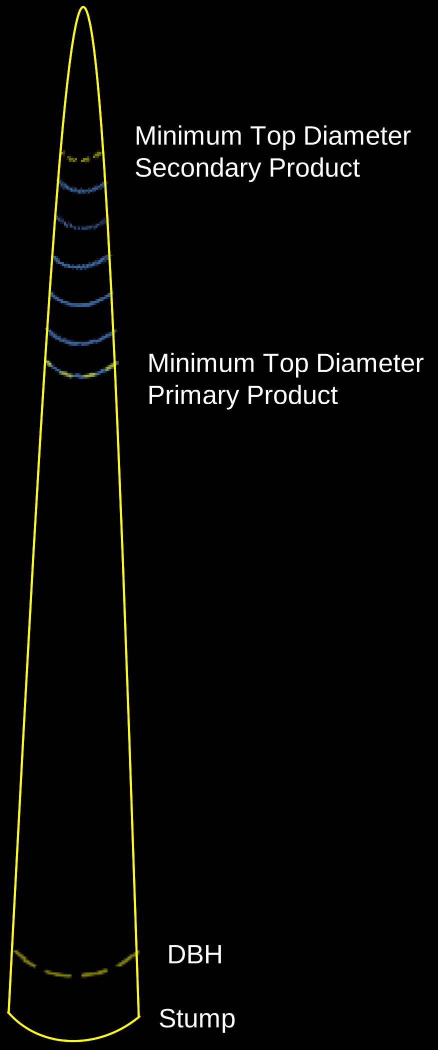
NVEL - Pulpwood (or Non-Sawtimber)

- There are lots of different non-sawtimber products, including:
  - Pulpwood
  - Roundwood
  - Post and Poles
- Non-sawtimber is the merchantable portion of the main stem from the stump to a minimum top diameter



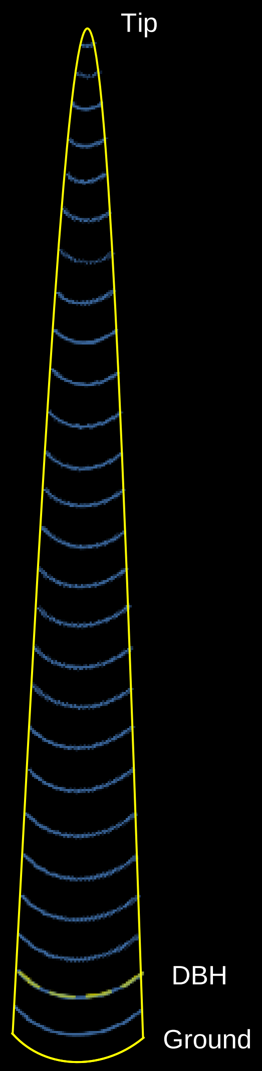
NVEL - Topwood

- Topwood only exists on sawtimber trees.
- Topwood is the portion of the main stem from the minimum top diameter primary product to the minimum top diameter secondary product.
- Topwood is an optional product.



NVEL - Total Cubic

- Total cubic volume is the volume of the main stem from the Ground to the Tip.



NVEL - Volume Estimators

- Volume estimators fall into two classes:
  - Direct Volume Estimators
  - Profile Models (or Taper equations)
- Direct Volume Estimators are regression equations that predict tree volume directly from DBH and some height measurement.
- Profile Models model the form of the tree. Volume is estimated by either electronically scaling the tree or integrating the profile model between two heights.

Direct Volume Estimators

- Development:
  - Trees are selected in the field and felled, typically sampled from timber sales.
  - Using pre-determined merchandizing rules, the tree is bucked into logs.
  - Volume is determined for each log and summed to determine the tree volume.
  - Regression equations are developed to predict the tree volume.
  - Separate equations needed for each product and each unit of measure (sawtimber, pulpwood, cubic volume, Scribner bdft, international bdft).

Direct Volume Estimators

- Kemp Model (R1)
- Chojnacky Models (R2, R3, R4)
- Hann and Bare models (R3)
- Eager Mill Study (R3)
- Pillsbury and Kirkley models (R5)
- Lasher Model (R8)
- Gevorkiantz models (R9)
- Larson and Winterberger models(R10)
- Haack and Gregory models (R10)
- TARIFF (R5, R6, R10)

Direct Volume Estimators

- Usage in Volume Library
  - Equation numbers are assigned for groups of equations by species and publication.
  - Topwood is usually computed by subtracting calculated cubic volume to 6 inch top from calculated cubic volume to 4 inch top.

Direct Volume Equations

- Pros
  - Generally, easy to use (calculator or spreadsheet)
- Cons
  - Without the publication, merchandizing rules are unknown.
  - Cannot adapt to changing merchandizing rules.
  - Fixed products and units of measure.
  - Validation requires falling trees and scaling them using original merchandizing rules.
  - Expensive to modify

Profile Models

- Development
  - Trees are selected in the field for measurement.
    - Felled tree measurements are usually from timber sales
    - Standing tree measurements are usually taken from inventory plots
  - Diameter and bark thickness are measured up the stem at various heights.
  - From these measurements, stem profile models are developed.

Profile Models

- Flewelling profile models (R1, R2, R3, R4, R6, R10)
- Behre's Hyperbola (R1, R6)
- Rustagi and Loveless profile models (R4)
- Wensel and Olson profile models (R5)
- Clark's Profile Model (R8, R9)
- Curtis profile models (R10)
- Demars Profile Model (R10)

Profile Models

- Use in Volume Library
  - The height to a merchantable top diameter is determined.
  - The number and lengths of merchantable logs are determined, accounting for trim.
  - Log end diameters are determined.
  - Volumes are determined for individual logs.
  - Log volumes are summed to determine tree volumes.

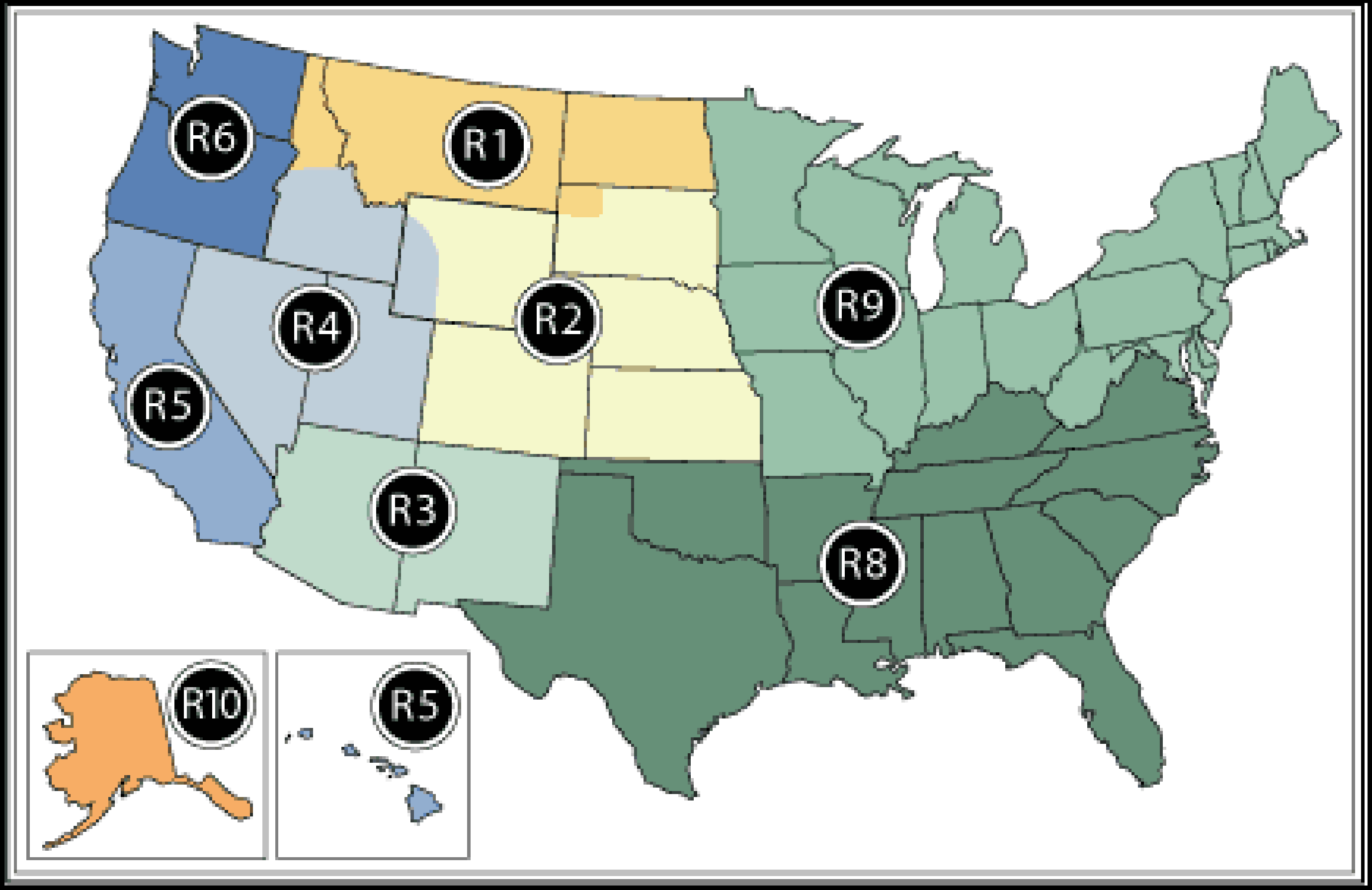
Profile Models

- Pros
  - Flexible, can easily handle changing merchandizing rules and volumes.
  - Generally work better at the extreme ends of the diameter range then Direct Volume Estimators.
  - With most profile models, additional data can be collected to get better results (bark thickness, upper stem diameters, merchantable heights).
- Cons
  - Complex. Requires computer programs to utilize.
  - Validation requires scaling felled trees.

Regional Volume Models

- Each Region utilizes their own volume models.
- To sell timber, the volume model must be approved by the Regional Forester.
- Each volume equation consists of:
  – Published documentation for the model (most cases)
  – Software necessary to use the model.
- FMSC maintains the software and houses the published works.
- Volume estimators are modified at the request of the Regional Office.

National Forest Regions

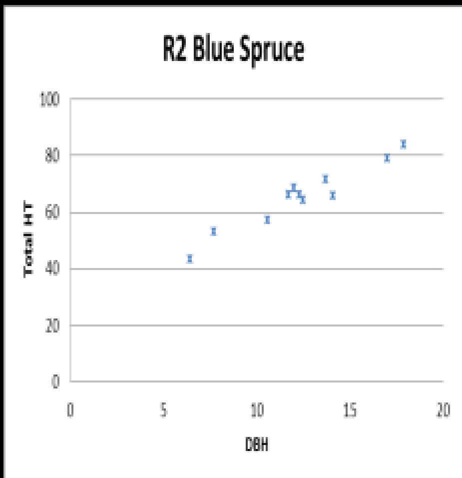


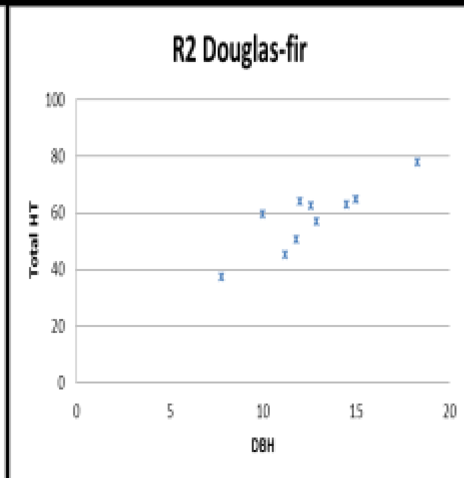
Bark Biomass Estimation from NVEL – Method I

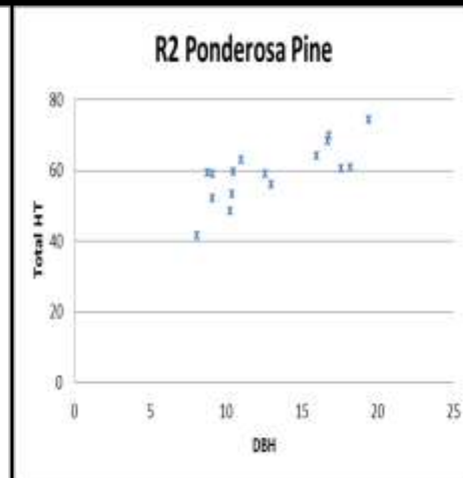
- Publication: H. A. Meyer 1946. Bark volume determination in trees. J. of Forestry, Vol. 44, No. 12, pp1067-1070
- Bark ratio: $k = \frac{DIB}{DOB}$
- For a given species and site, *k* remains the same for measurements taken at different height (?).
- Bark volume: $V_{bark} = V_{wood} * (\frac{1}{k^2} - 1)$
- Bark biomass = V_{bark} * barkDensity

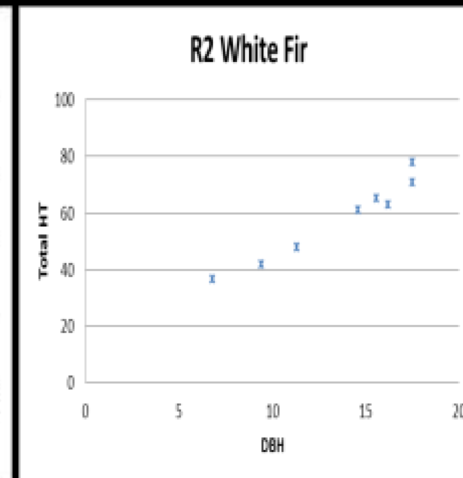
Bark ratio from volume validation

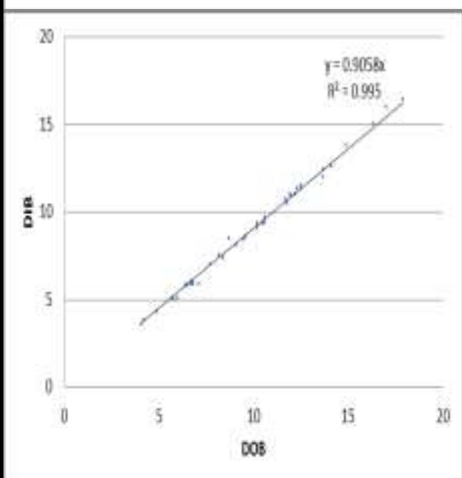
R2 - DIB/DOB

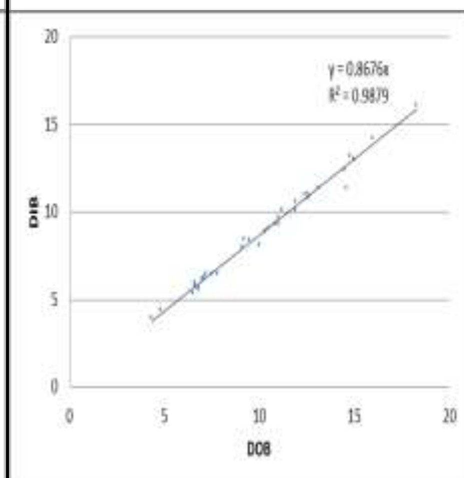

R2 Blue Spruce
Total HT
DBH

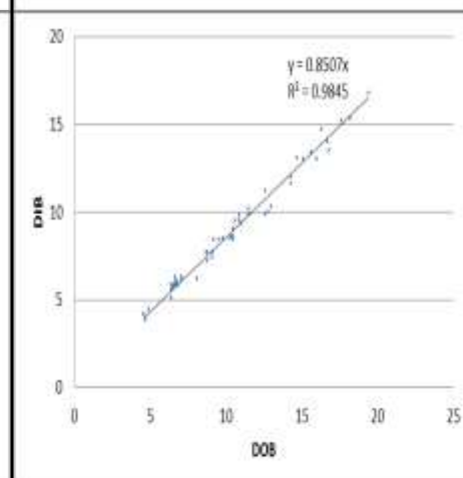

R2 Douglas-fir
Total HT
DBH

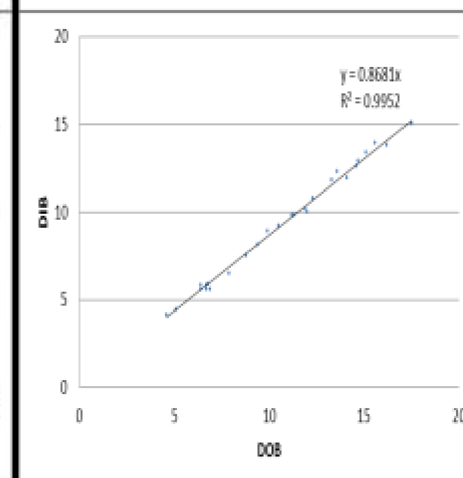

R2 Ponderosa Pine
Total HT
DBH


R2 White Fir
Total HT
DBH

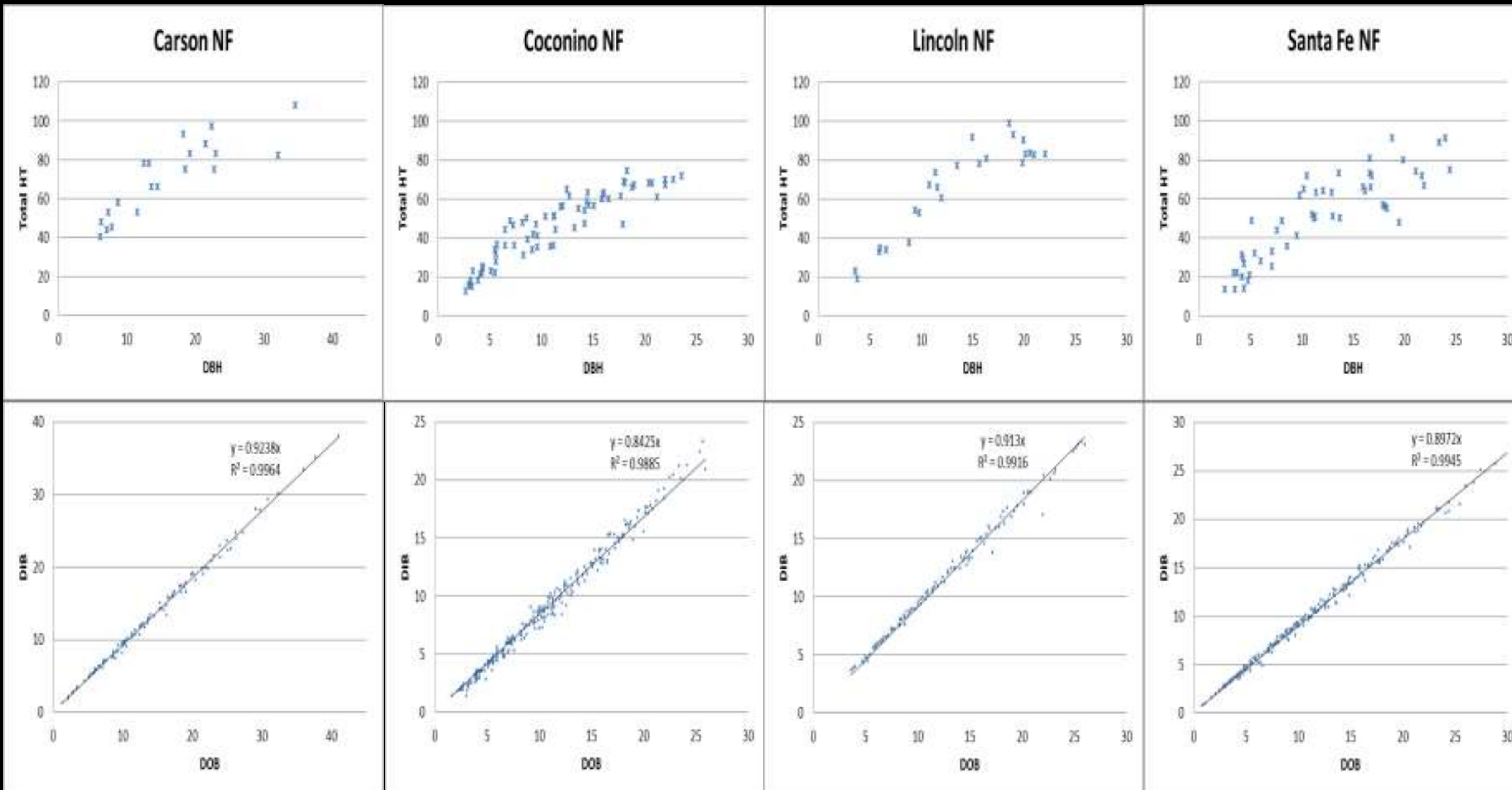

y = 0.9058x
R² = 0.995
DIB
DOB


y = 0.8676x
R² = 0.9879
DIB
DOB

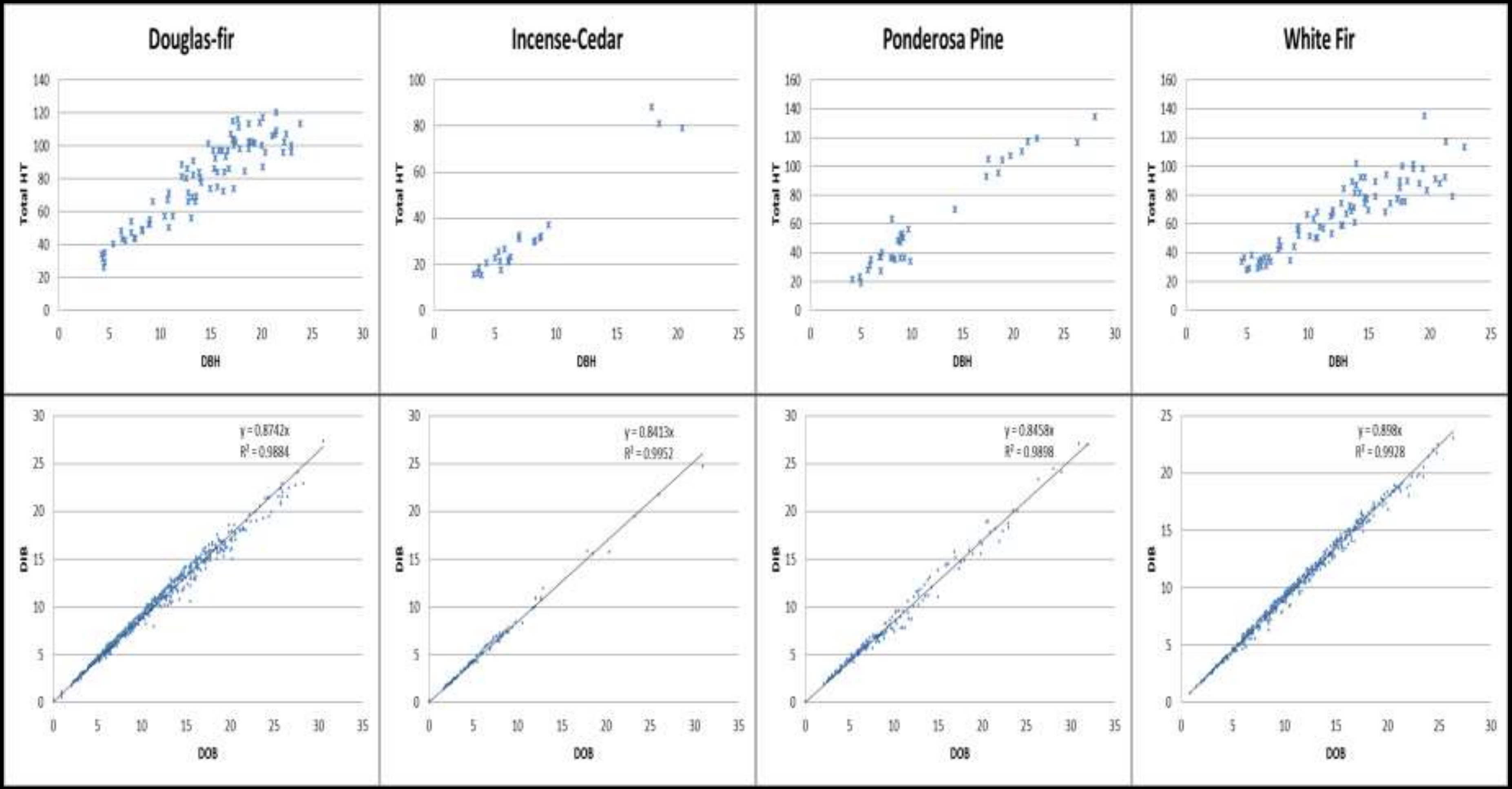

y = 0.8507x
R² = 0.9845
DIB
DOB


y = 0.8681x
R² = 0.9952
DIB
DOB

R3 Ponderosa Pine – DIB/DOB

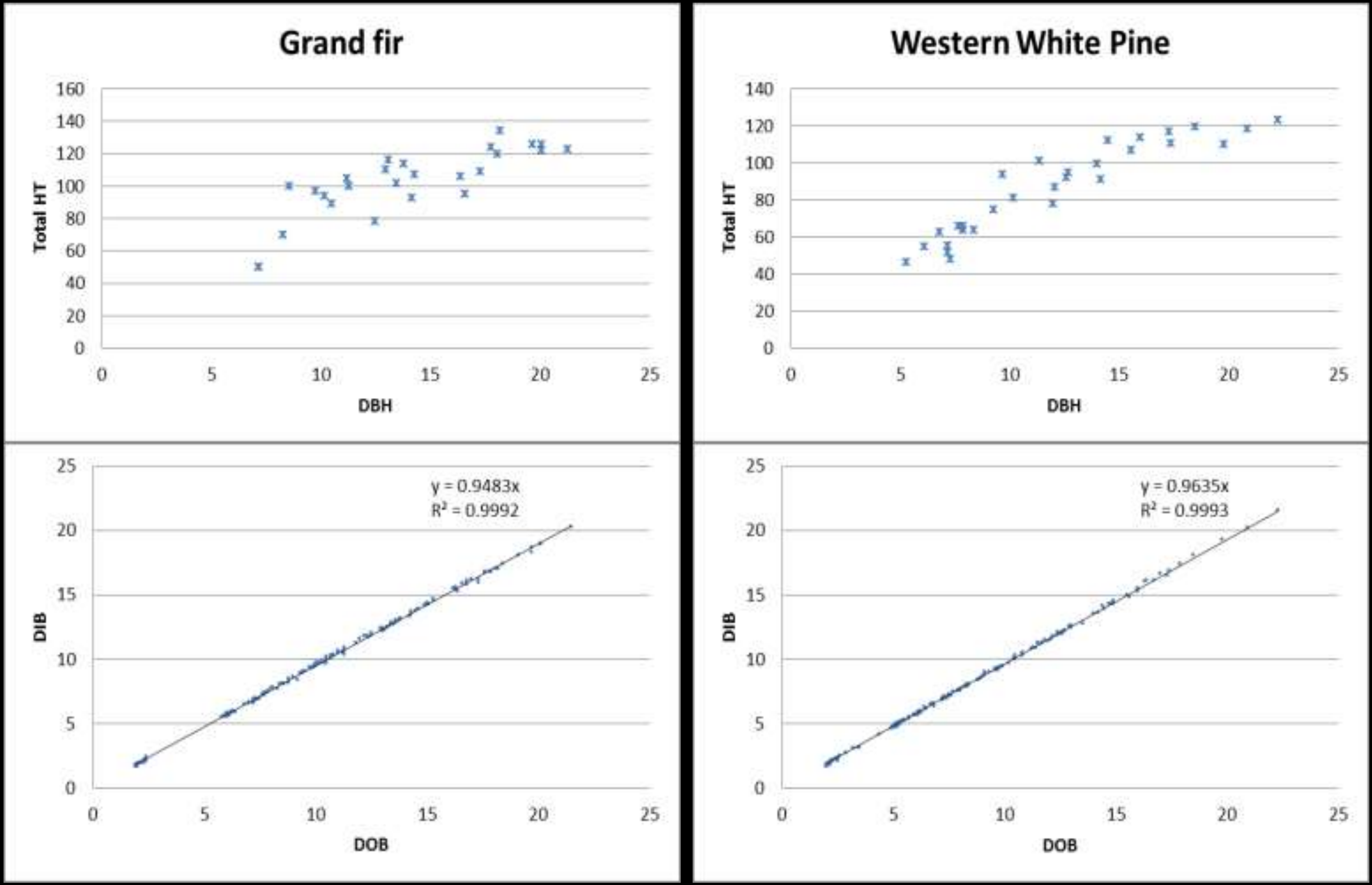


R5 – DIB/DOB



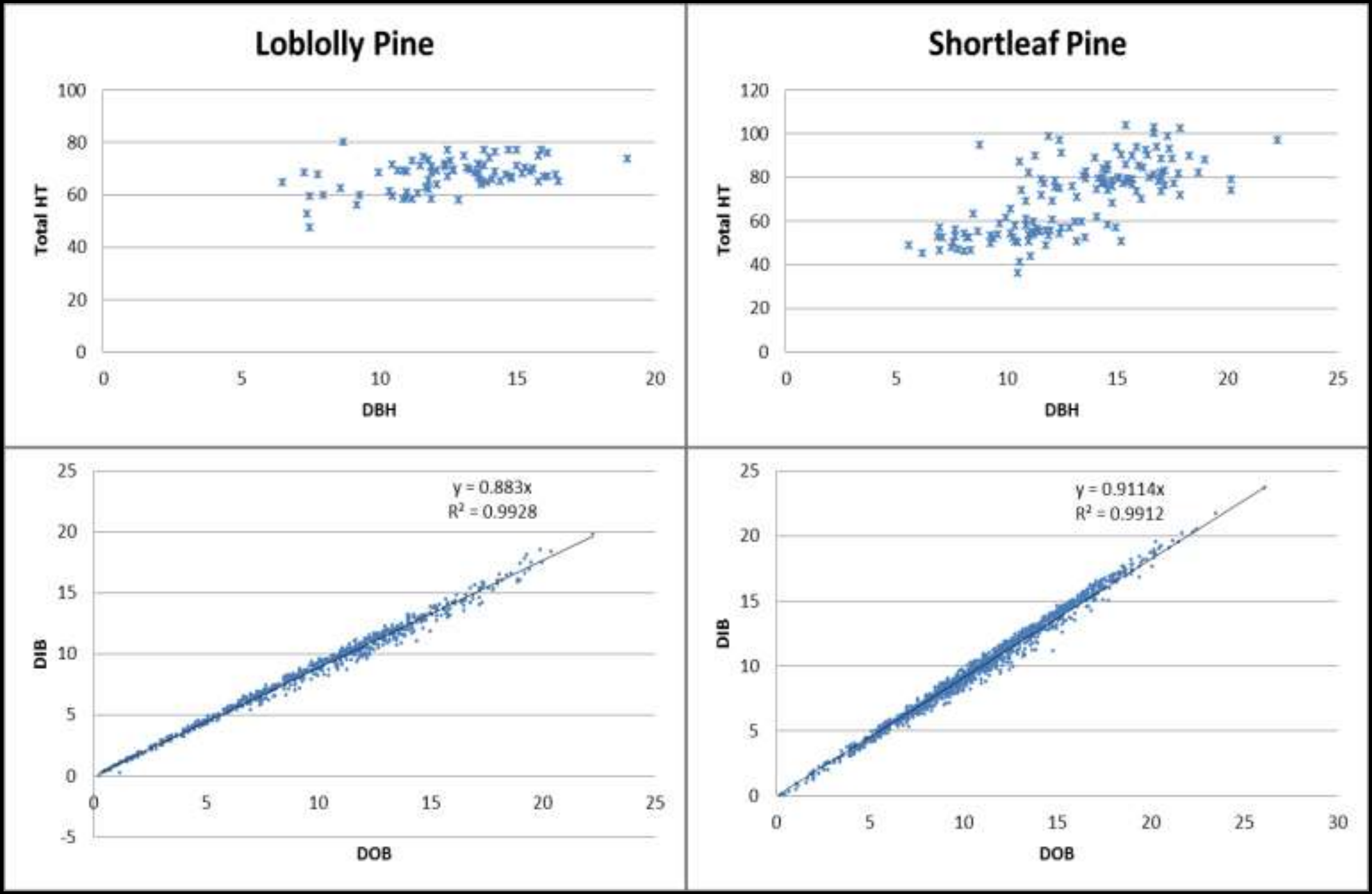
Douglas-fir
Incense-Cedar
Ponderosa Pine
White Fir
Total HT
DBH
DIB
DOB
y = 0.8742x
R² = 0.9884
y = 0.8413x
R² = 0.9952
y = 0.8458x
R² = 0.9898
y = 0.898x
R² = 0.9928

R6 – DIB/DOB



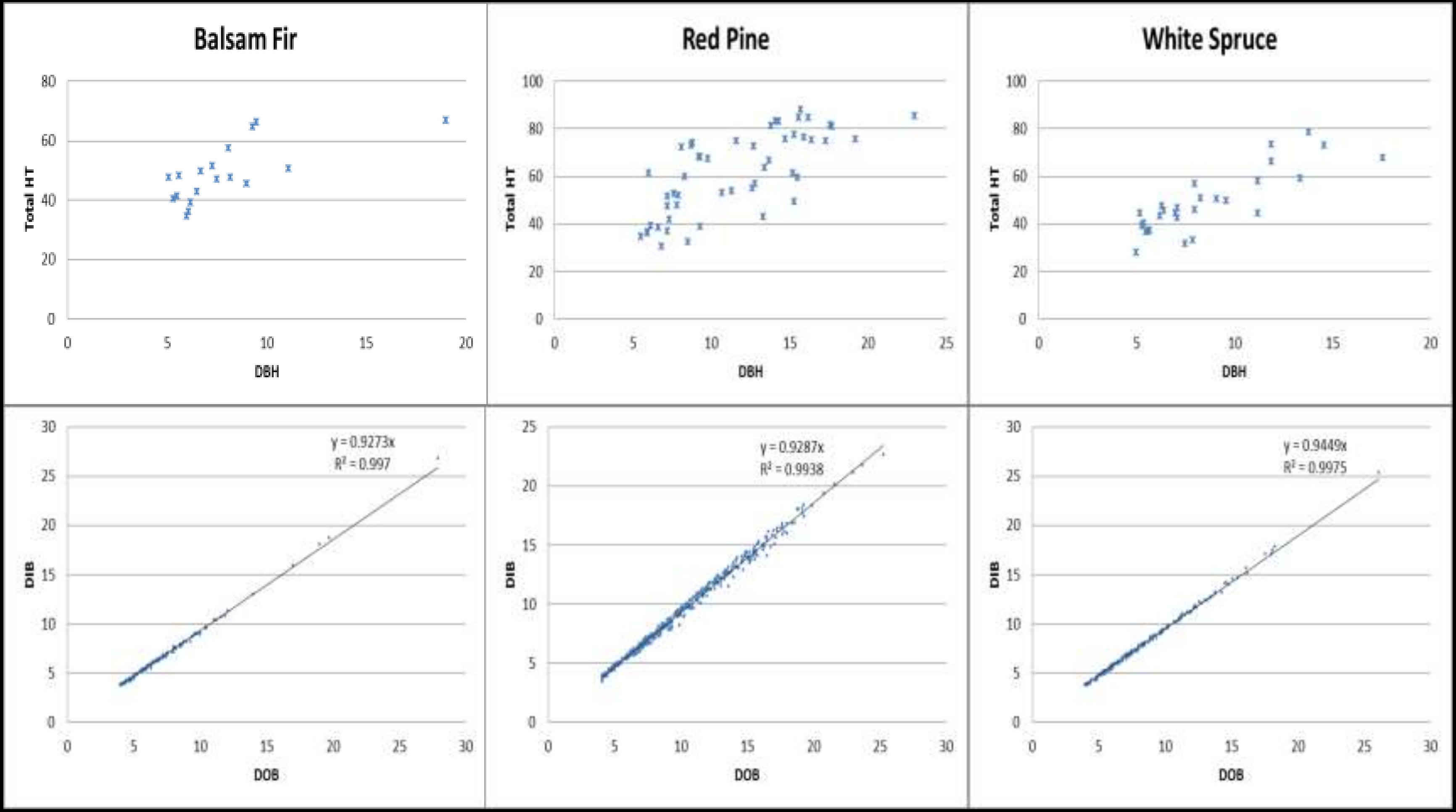
Grand fir
Total HT
DBH
Western White Pine
Total HT
DBH
y = 0.9483x
R² = 0.9992
DIB
DOB
y = 0.9635x
R² = 0.9993
DIB
DOB

R8 – DIB/DOB

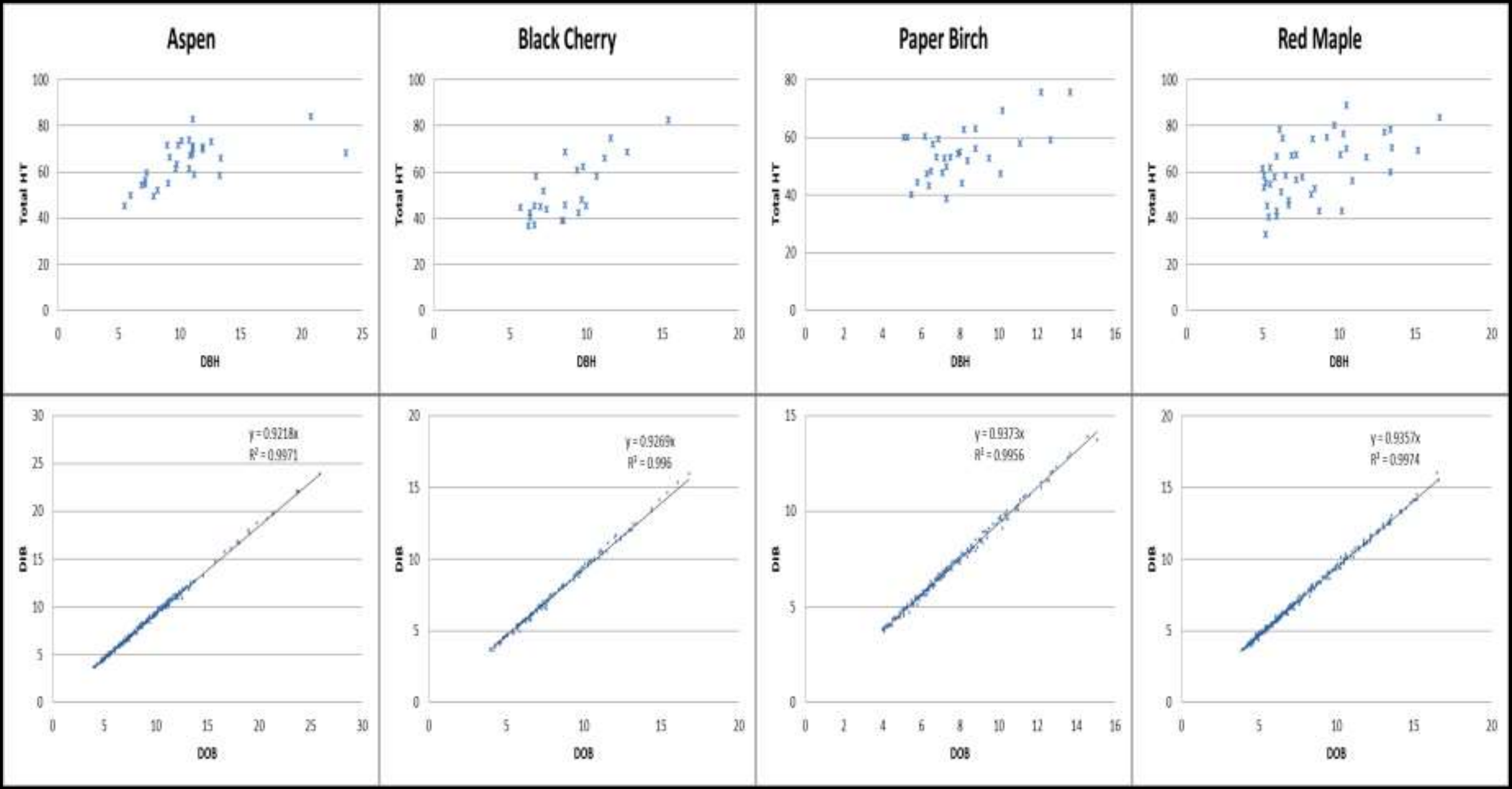


Loblolly Pine
Total HT
DBH
Shortleaf Pine
Total HT
DBH
y = 0.883x
R^2 = 0.9928
DIB
DOB
y = 0.9114x
R^2 = 0.9912
DIB
DOB

R9 Softwood – DIB/DOB



R9 Hardwood – DIB/DOB



How to get *k* (*DIB/DOB*)

- Individual tree measurement: DBHob, DBT

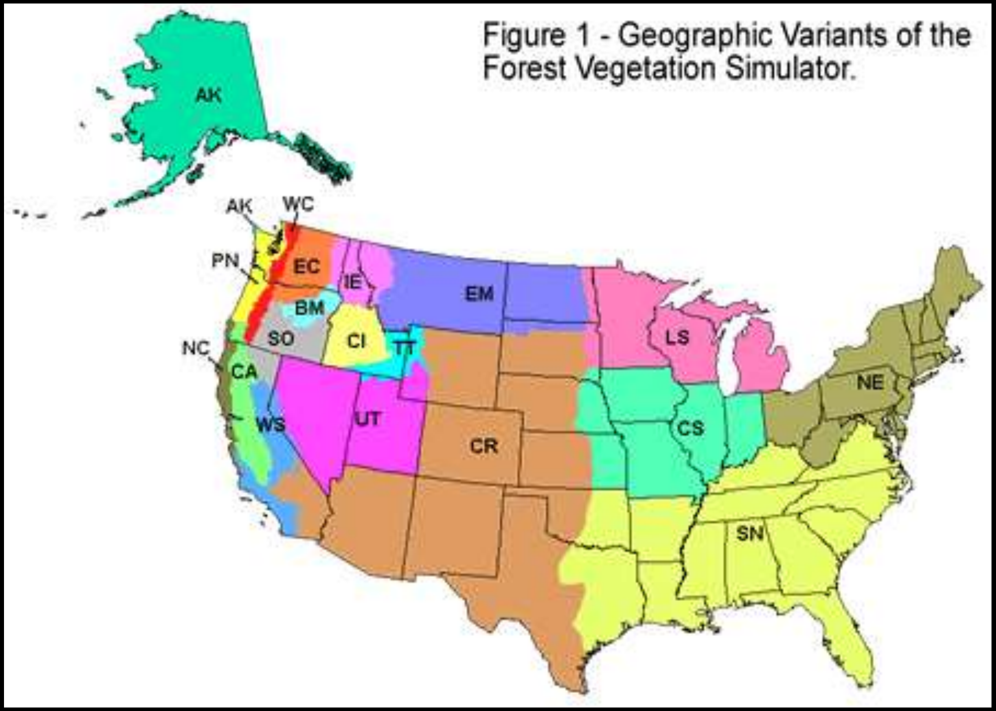
  $k = \frac{DBHob - DBT}{DBHob}$

- If there is no measurement for DBT/DIB, the species average bark ratio (*k*) can be calculated from FVS variant species bark equation.

- Input parameter for NVEL: BTR

FVS Variants

- Each variant has a list of species.
- Each species has a default bark ratio equation

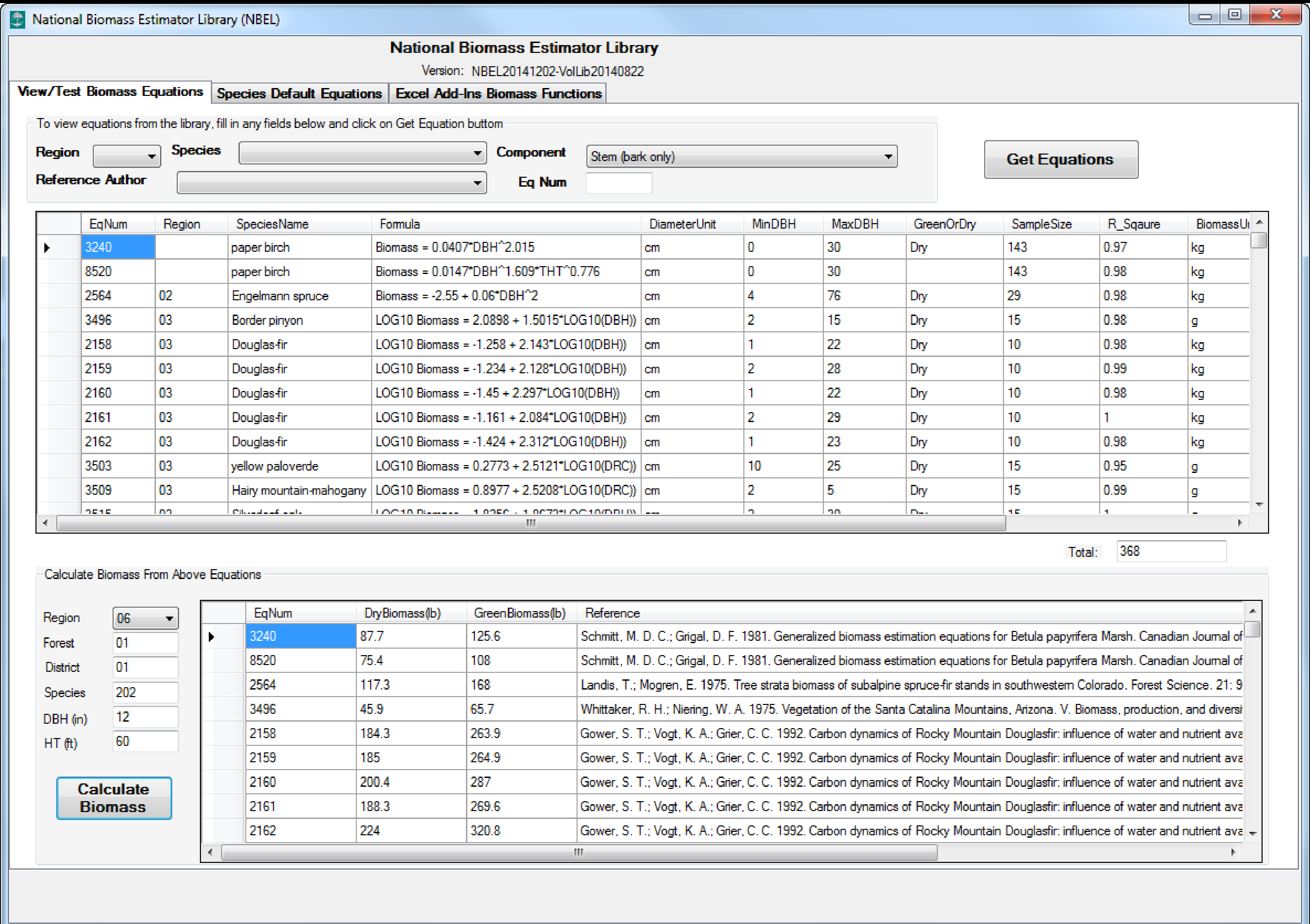


Bark Biomass Estimation from NVEL – Method II

- Needs two calls to NVEL for each tree
- First: NVEL(DBH, Height, VolEq, DBTBH…) → Vol(wood)
- Second: NVEL((DBH+DBTBH), Height, VolEq, DBTBH…) → Vol(wood+bark)
- barkVol = Vol(wood+bark) – Vol(wood)
- barkBiomass = barkVol * barkDensity

National Biomass Estimator Library (NBEL)

- Collection of published biomass equations for USA and unpublished equations by Forest Service.
- Equations and their associated metadata are stored in SQLite database.
- Written in C# and built into a Dynamic Link Library (DLL).
- Graphic user interface to query biomass equation, test/compare different equations, view species regional/forest default equation setup and library functions.


National Biomass Estimator Library (NBEL)
National Biomass Estimator Library
Version: NBEL20141202-VolLib20140822
View/Test Biomass Equations
Species Default Equations
Excel Add-Ins Biomass Functions
To view equations from the library, fill in any fields below and click on Get Equation buttom
Region
Species
Component
Stem (bark only)
Reference Author
Eq Num
Get Equations

	EqNum	Region	SpeciesName	Formula	DiameterUnit	MinDBH	MaxDBH	GreenOrDry	SampleSize	R_Sqaure	BiomassUı
▶	3240		paper birch	Biomass = 0.0407*DBH^2.015	cm	0	30	Dry	143	0.97	kg
	8520		paper birch	Biomass = 0.0147*DBH^1.609*THT^0.776	cm	0	30		143	0.98	kg
	2564	02	Engelmann spruce	Biomass = -2.55 + 0.06*DBH^2	cm	4	76	Dry	29	0.98	kg
	3496	03	Border pinyon	LOG10 Biomass = 2.0898 + 1.5015*LOG10(DBH))	cm	2	15	Dry	15	0.98	g
	2158	03	Douglas-fir	LOG10 Biomass = -1.258 + 2.143*LOG10(DBH))	cm	1	22	Dry	10	0.98	kg
	2159	03	Douglas-fir	LOG10 Biomass = -1.234 + 2.128*LOG10(DBH))	cm	2	28	Dry	10	0.99	kg
	2160	03	Douglas-fir	LOG10 Biomass = -1.45 + 2.297*LOG10(DBH))	cm	1	22	Dry	10	0.98	kg
	2161	03	Douglas-fir	LOG10 Biomass = -1.161 + 2.084*LOG10(DBH))	cm	2	29	Dry	10	1	kg
	2162	03	Douglas-fir	LOG10 Biomass = -1.424 + 2.312*LOG10(DBH))	cm	1	23	Dry	10	0.98	kg
	3503	03	yellow paloverde	LOG10 Biomass = 0.2773 + 2.5121*LOG10(DRC))	cm	10	25	Dry	15	0.95	g
	3509	03	Hairy mountain-mahogany	LOG10 Biomass = 0.8977 + 2.5208*LOG10(DRC))	cm	2	5	Dry	15	0.99	g

Total: 368
Calculate Biomass From Above Equations
Region 06
Forest 01
District 01
Species 202
DBH (in) 12
HT (ft) 60
Calculate Biomass

	EqNum	DryBiomass(lb)	GreenBiomass(lb)	Reference
▶	3240	87.7	125.6	Schmitt, M. D. C.; Grigal, D. F. 1981. Generalized biomass estimation equations for Betula papyrifera Marsh. Canadian Journal of
	8520	75.4	108	Schmitt, M. D. C.; Grigal, D. F. 1981. Generalized biomass estimation equations for Betula papyrifera Marsh. Canadian Journal of
	2564	117.3	168	Landis, T.; Mogren, E. 1975. Tree strata biomass of subalpine spruce-fir stands in southwestern Colorado. Forest Science. 21: 9
	3496	45.9	65.7	Whittaker, R. H.; Niering, W. A. 1975. Vegetation of the Santa Catalina Mountains, Arizona. V. Biomass, production, and diversi
	2158	184.3	263.9	Gower, S. T.; Vogt, K. A.; Grier, C. C. 1992. Carbon dynamics of Rocky Mountain Douglasfir: influence of water and nutrient ava
	2159	185	264.9	Gower, S. T.; Vogt, K. A.; Grier, C. C. 1992. Carbon dynamics of Rocky Mountain Douglasfir: influence of water and nutrient ava
	2160	200.4	287	Gower, S. T.; Vogt, K. A.; Grier, C. C. 1992. Carbon dynamics of Rocky Mountain Douglasfir: influence of water and nutrient ava
	2161	188.3	269.6	Gower, S. T.; Vogt, K. A.; Grier, C. C. 1992. Carbon dynamics of Rocky Mountain Douglasfir: influence of water and nutrient ava
	2162	224	320.8	Gower, S. T.; Vogt, K. A.; Grier, C. C. 1992. Carbon dynamics of Rocky Mountain Douglasfir: influence of water and nutrient ava

Bark Biomass Estimation Using NBEL

- Using a particular bark equation.
  - bmGetBiomassFromEqn(EqNum, Species, DBH, THT)
- Using generic biomass equation.
  - Jenkins equation

Jenkins' equation

- A set of national-scale aboveground biomass equation based on the published equations for U. S. species.
- Equation for predicting biomass of tree components were developed as proportions of total aboveground biomass for hardwood and softwood groups.

Jenkins aboveground biomass equation

	Species group[b]	Parameter β_0	Parameter β_1	Data points[c]	Max d.b.h.[d]	RMSE[e]	R^2
					cm	*log units*	
Hardwood	Aspen/alder/ cottonwood/ willow	-2.2094	2.3867	230	70	0.507441	0.953
	Soft maple/birch	-1.9123	2.3651	316	66	0.491685	0.958
	Mixed hardwood	-2.4800	2.4835	289	56	0.360458	0.980
	Hard maple/oak/ hickory/ beech	-2.0127	2.4342	485	73	0.236483	0.988
Softwood	Cedar/larch	-2.0336	2.2592	196	250	0.294574	0.981
	Douglas-fir	-2.2304	2.4435	165	210	0.218712	0.992
	True fir/hemlock	-2.5384	2.4814	395	230	0.182329	0.992
	Pine	-2.5356	2.4349	331	180	0.253781	0.987
	Spruce	-2.0773	2.3323	212	250	0.250424	0.988
Woodland[f]	Juniper/oak/ mesquite	-0.7152	1.7029	61	78	0.384331	0.938

[a]Biomass equation:

$$bm = \text{Exp}(\beta_0 + \beta_1 \ln dbh)$$

where

bm = total aboveground biomass (kg) for trees 2.5 cm and larger in d.b.h.

dbh = diameter at breast height (cm)

Exp = exponential function

ln = natural log base "e" (2.718282)

Bark biomass ratio from Jenkins' equation

Biomass component	Parameter α_0	α_1	Data points[b]	R^2
		Hardwood		
Foliage	-4.0813	5.8816	632	0.256
Coarse roots	-1.6911	0.8160	121	0.029
Stem bark	-2.0129	-1.6805	63	0.017
Stem wood	-0.3065	-5.4240	264	0.247
		Softwood		
Foliage	-2.9584	4.4766	777	0.133
Coarse roots	-1.5619	0.6614	137	0.018
Stem bark	-2.0980	-1.1432	799	0.006
Stem wood	-0.3737	-1.8055	781	0.155

[a]Biomass ratio equation:

$$ratio = \mathrm{Exp}(\alpha_0 + \frac{\alpha_1}{dbh})$$

where

ratio = ratio of component to total aboveground biomass for trees 2.5 cm and larger in d.b.h.

dbh = diameter at breast height (cm)

Exp = exponential function

ln = log base e (2.718282)

Bark Biomass Estimation from NVEL and NBEL

- NVEL
  - Two ways to get BarkVol
    - BarkVol from bark ratio (WoodVol * ($\frac{1}{k^2}$ - 1))
    - BarkVol from two calls to NVEL using DBH and DBH+DBTBH (as DBH)
  - BarkBiomass = BarkVol * BarkDensity
- NBEL
  - Specific bark equation
  - Jenkins' equation
    - AGT = EXP(B_0 + B_1 * LN(DBH))
    - ratio = EXP(a_0 + a_1 / DBH)
    - BarkBiomass = AGT * ratio

Questions?

http://www.fs.fed.us/fmsc/measure/

Yingfang Wang
Forester

Forest Service
Forest Management Service Center

p: 970-295-5771
f: 970-295-5755
yingfangwang@fs.fed.us

2150 Centre Ave, Bldg A, Suite 341A
Fort Collins, CO 80526
www.fs.fed.us

Caring for the land and serving people