**Validation of the Mixedwood Growth Model (MGM) against the 2020 Saskatchewan Provincial Permanent Sample Plot Dataset**

*MGM21 Beta VS8 2.21.39 / Rev6378*

Mike Bokalo and Phil Comeau
Department of Renewable Resources
University of Alberta

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## Introduction:

In this report, we present results from a validation of the Mixedwood Growth Model (MGM) using the Saskatchewan 2020 provincial permanent sample plot (PSP) database.

The procedures used for this validation follow the methods and evaluation metrics outlined in the published validation manuscript "*The Validation of the Mixedwood Growth Model (MGM) for Use in Forest Management Decision Making", Forests 2013, 4(1), 1-27; doi:10.3390/f4010001* (Bokalo et. al., 2013). Bokalo et al. (2013) focused on pure and mixed stands of white spruce and aspen. Follow-up validations using the same procedures were carried out for lodgepole pine (Bokalo and Comeau, 2013), jack pine (Strimbu et al., 2015), Alberta juvenile Provincial Growth and Yield (PGYI) data (Bokalo et al., 2015), black spruce (Oboite, 2018), validation of MGM18 (Bokalo et al., 2019) and the validation of MGM21 (VS8.2.21.39 / Rev6378) using the Alberta 2020 PGYI database (Comeau et al. 2021).

In this report, we evaluate MGM's performance against re-measured permanent sample plot (PSP) data and examine overall model performance. This validation also indicates where the model requires refinement, in relation to stand types and species. Model performance was evaluated for all species found in the dataset, even though MGM is parameterized only for aspen, white spruce, black spruce, lodgepole pine, and jack pine. Other species (e.g., white birch, balsam fir, Douglas-fir, balsam poplar) are modelled as surrogates of the primary species.

**The Mixedwood Growth Model:**

This validation references a new version of MGM: MGM21 (VS8.2.21.39 / Rev6378) which has been significantly modified from earlier versions and includes:

- A new climate and composition sensitive maximum size-density function for mature trees ≥ 4cm DBH (Comeau, 2021b)
- A new self-thinning system for mature trees ≥ 4cm DBH
- Revised survival functions for balsam fir, jack pine, lodgepole pine, and black spruce without a tagging limit variable (Comeau, 2021a)
- New height increment and diameter increment functions for black spruce (Oboite and Comeau, 2021)
- A new routine that solves for missing tree ages within MGM (i.e., Internal Age Solver)
- Improved tree age estimates for regenerated trees
- A modified approach to estimate white spruce tree age
- The updating of tree age estimates after stand establishment or thinning
- New site index functions for SK, MB, and BC
- Updated diameter estimates in MGM's Treelist Generator for untended deciduous trees
- Streamlined crop plans with fewer inputs
- Faster runtimes when using large Stand Workbooks
- 32-bit support for Microsoft Office 2016, Microsoft Office 2019, and local installations of Microsoft Office 365
- 64-bit support for Microsoft Office 2019 and local installations of Microsoft Office 365

**Validation Data:**

The Saskatchewan provincial dataset from June 11, 2021, containing 2048 plots, was the base dataset for this analysis. To prepare the data, missing heights were estimated using MGM's height-diameter equations for Saskatchewan. Plot volume was compiled from height and DBH information using the Saskatchewan taper equations from Gal and Bella (1994), and site index was calculated on each plot for MGM's primary species (WS, JP, TA, and BS) using age and top height measurements (thickest 100 trees/ha). Site index calculations for the Saskatchewan Site Index Curves were based on Hu and Garcia (2010), Fang (2007), Nigh et al. (2002), and Huang et al. (1997). In cases where site index could not be calculated due to missing top height information, default site index values were assigned based on the mesic-medium site indices from Bjelanovic and

Comeau (2019) for white spruce, jack pine, and trembling aspen. The default site index value for black spruce was assigned the mesic-medium value from Beckingham et al. (1996).

Of the 2048 plots, 871 plots met the minimum requirements for an MGM validation:

1. Known stand ages
2. Repeated tree-level measurements after Performance Survey Age (i.e., 12 years)
3. Treelists with more than 1 tree
4. Plot location coordinates that are required for calculating Climate Moisture Index (CMI)
5. No documented treatments after stand establishment (e.g., thinning, replanting, or site preparation)

Of the 871 plots an additional 34 plots were removed resulting in a dataset containing 847 plots. The 34 plots that were removed had dramatic and unusual changes volume (residuals > 150 $m^3$). These plots have significant leverage on the performance metrics tending to unfairly skew the results negatively. MGM is a deterministic model and does not model stochastic events such as insect attack, wind damage, or wildlife damage. Including plots with severe stochastic events has a strong negative impact on validation results. Since the validation attempts to evaluate model performance of stands undergoing normal stand dynamics, removal of these 34 plots is justified. The number of plots removed by species group were:

- 4 plots from the jack pine (JP) group were removed
- 6 plots from the aspen (TA) group were removed
- 24 plots from the spruce (WS) group were removed

This dataset represents a range of forest stand types (species mixtures and structures; including a range of stand productivities (site index), CMI, stand ages (juvenile, mid-rotation and mature), and projection lengths (Table 1).

**Table 1:** Plot characteristics for the validation dataset by primary species group (BF, TA, JP, BS, and WS). N = number of plots; BHAge = breast height age

| | | SI (m @ 50 years BHAge) | | | CMI | | | Initialization Age | | | Projection Length | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Species | N | Min | Mean | Max | Min | Mean | Max | Min | Mean | Max | Min | Mean | Max |
| BF | 2 | 13.9 | 16.9 | 19.9 | -0.64 | 2.22 | 5.09 | 56 | 64 | 71 | 15 | 30 | 44 |
| BS | 124 | 4.4 | 11.0 | 18.7 | -2.12 | 7.46 | 16.93 | 35 | 82 | 173 | 5 | 15 | 39 |
| JP | 173 | 10.7 | 16.1 | 22.5 | -4.87 | 5.50 | 14.15 | 23 | 53 | 113 | 6 | 17 | 51 |
| TA | 150 | 12.7 | 19.0 | 26.6 | -1.92 | 4.53 | 11.92 | 27 | 61 | 105 | 5 | 21 | 52 |
| WS | 264 | 9.5 | 16.6 | 27.0 | -1.52 | 4.44 | 12.96 | 25 | 77 | 187 | 5 | 21 | 44 |

**Methods:**

For this validation, the first plot measurement greater than or equal to Performance Survey Age (i.e., 12 years) was used to initialize MGM. Then, each treelist was projected to the final measurement where the observed stand conditions were evaluated against the MGM predictions. Using the final measurement for validation provided the longest possible growth interval and eliminated autocorrelation issues that arise when multiple measurements from individual plots are used. (This approach also avoids issues associated with having variable numbers of measurements between plots).

*Data Preparation*

The 2020 Saskatchewan Permanent Sample Plot dataset were filtered using the approach outlined in the *Validation Data* section. Ingress from new germinants and trees crossing PSP diameter thresholds were removed. Treefactors for individual trees were standardized over time, ensuring that treefactors from the first measurement matched treefactors from the final measurement when calculating summary statistics. Veteran trees were also retained to evaluate MGM's ability to model uneven-aged and multi-cohort stands.

Climate Moisture Index (Hogg et al., 2013) was calculated for the 30-year reference period 1981-2010 using plot coordinates, plot elevations, and ClimateNA Version 6.11

(Wang et al., 2016). Plots with missing elevations were assigned elevation values from the Canadian Digital Elevation Model (NRC 2016).

*Hierarchical Analysis*

A hierarchical approach was used to evaluate model performance. To do this, the Saskatchewan dataset was partitioned into: 1) broad cover groups, 2) species groups, and 3) broad cover groups by species. This approach enables identification of where problems with either the model or validation data are occurring. This approach also aids in defining where the model works well and where it may need further refinement.

Broad cover groups represent dominant stand types: pure conifer (C), conifer leading (CD), deciduous leading (DC), and pure deciduous (D). Pure types were defined as having 80% or greater basal area of the primary species, while mixed types had between 50% and 80% of their basal area represented by the primary type. Data were also organized into one of 13 dominant species groups: TA, BF, JP, BS, WS, and MX. (MX was used if there were no dominant leading species.) Species groups were defined as having 50% or greater basal area of the primary species, while mixed types had no single species greater than 50% basal area. The broad cover group by species category was a combination of the broad cover group (stand type) and the species groupings. Since basal area proportions vary over time and plots with long-term observations are subject to succession, plots were categorized using observed data from the final measurement.

*MGM Settings*

MGM projections used for this validation did not apply gap loss (i.e., GapArea% = 0). The maximum size-density adjustment was enabled for all species (i.e., MaxDenAdj = 1 1 1 1). No merchantability criteria were set (i.e., Stump Height = 0m, Minimum DBH = 0cm, Top Diameter Inside Bark = 0cm, and Volume Loss = 0%). MGM's Internal Age Solver was used to calculate missing tree ages relative to tree height and site index. Observed tree ages in the Saskatchewan dataset were not overwritten by MGM's Internal Age Solver. There were no removals or harvests over the projection periods. (Note: Gap

loss and the MaxDenAdj were available in MGM18 but are no longer user-selectable options).

*Validation Metrics*

The model was validated for stand volume ($m^3ha^{-1}$), basal area ($m^2ha^{-1}$), average DBH (cm), average height (m), top height (m) and density (stems $ha^{-1}$). Top height was defined as the average height of the 100 thickest (largest DBH) stems $ha^{-1}$ of each species. Basal area, density, and top height are readily measurable in the field and are useful for tracking stand performance against the model. Average height and DBH are additional metrics of tree size.

In order to assess the validity of the predictions, both graphical methods and statistical metrics were used. Plots of the observed (Y) versus predicted ($\hat{Y}$), with a $Y = \hat{Y}$ line representing the perfect fit, were used to graphically evaluate the goodness of fit and identify any model biases (Bokalo et al. 2013). All plotting was performed in R.

As statistical measures, we calculated average mean bias (AMB), relative model bias (RMB) and efficiency (EF) (Vanclay and Skovsgaard 1997). AMB, RMB, EF, and all summary statistics were prepared using R. Residuals (difference between actual and predicted) for conifer and deciduous volume were also calculated and plotted against 12 variables: Initial conifer and deciduous density, initial conifer and deciduous volume, predicted conifer and deciduous volume, initial conifer and deciduous DBH.

**Results:**

The validation results for the entire Saskatchewan dataset are shown in Table 2. The scatterplots for these are presented in Appendix A (pages 1-2). The RMB values for the conifer component (volume, basal area, DBH, average height, density and top height) range from -5.02% to 2.2% in the full dataset. Conifer volume is tending to be overpredicted (RMB=-5.02%) while DBH is underestimated (RMB=2.2). For the deciduous components (volume, basal area, DBH, average height, density and top height)

RMB ranges between -11.45% (for deciduous density) and 1.61%. Efficiency is above 0.81 for conifer and deciduous, indicating excellent model performance. Graphs (Appendix A, pages 1-2) show reasonable fit around the 1:1 line.

## Data Categorized into Broad Cover Groups

The validation results, categorized into broad cover groups (C, CD, DC, D) are shown in Table 3. The scatterplots for these are presented in Appendix A (pages 3-10).

### Conifer Broad Cover Group (C)

The RMB values for the conifer component (volume, basal area, DBH, average height, density and top height) range from -2.51 to 0.74%. Efficiency ranged between 0.82 and 0.96 for the conifer component. For the secondary deciduous component, volume, and basal area are overestimated by the model with RMB values of -14.3% and, -12.33% respectively. Deciduous DBH (RMB=-1.7%) has a small bias, while height and top height have RMB values of -2.19% and -2.41%, respectively. It is important to recognize that the average deciduous volume (20.6 $m^3$ $ha^{-1}$), basal area (2.69 $m^2$ ha-1), and density (46 sph) are all low, indicating that the deciduous component does not have a significant role in this broad cover group. Moreover, higher relative biases are not surprising, given the small absolute values that are associated with these. For example AMB for deciduous volume was -2.95 $m^3$/ha and AMB deciduous density was -5 sph. Efficiency ranged between 0.35 and .78 for the deciduous component. Scatterplots for the coniferous dominated broad cover group are shown in Appendix A (pages 3-4)

### Conifer Dominated Mixedwood (CD)

In the CD broad cover group, the performance of both conifer and deciduous are important. For the CD conifer component, the largest RMB is in volume (-6.08%). For the deciduous components, the RMB values are less than ± 5.9%. with the exception of density with a RMB of -9.43%. Scatterplots in Appendix A (pages 5-6) show small model biases for this cover group. Efficiencies for the conifer and deciduous components are quite variable, ranging from 0.16 to 0.89 depending on the variable.

**Table 2.** Summary of observed stand parameters (number of plots (N), volume ($m^3$), basal area ($m^2$), DBH (cm), height (m), density (stems/ha) and top height (m)) as well as the validation statistics (average mean bias (AMB), standard deviation of residuals (SD Resid), relative model bias (RMB), efficiency (EF) for the conifer and deciduous components for the Saskatchewan dataset. Bolded cells have RMB exceeding ±10%.

| | | | Conifer | | | | | | | | Deciduous | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Observed | | | | Validation Statistics | | | | Observed | | | | Validation Statistics | | | |
| Cover Group | N | Variable | Mean | Min | Max | SD | AMB | SD Resid | RMB | EF | Mean | Min | Max | SD | AMB | SD Resid | RMB | EF |
| ALL | 781 | Volume ($m^3$/ha) | 192.37 | 0.97 | 541.48 | 101.32 | -9.66 | 43.54 | -5.02 | 0.81 | 100.4 | 0.27 | 444.91 | 94.37 | -5.74 | 34.7 | -5.72 | 0.86 |
| | | Basal Area ($m^2$/ha) | 24.15 | 0.2 | 54.42 | 11.25 | -0.49 | 4.33 | -2.04 | 0.85 | 11.28 | 0.06 | 42.93 | 9.78 | -0.66 | 3.6 | -5.85 | 0.86 |
| | | Mean DBH (cm) | 19.65 | 10.55 | 49.28 | 5.96 | 0.44 | 1.62 | 2.22 | 0.92 | 22.31 | 7.7 | 46.7 | 6.74 | 0.36 | 2.73 | 1.61 | 0.83 |
| | | Mean Height (m) | 17.07 | 9.36 | 31.22 | 3.49 | -0.18 | 1.36 | -1.03 | 0.85 | 19.43 | 8.7 | 29.85 | 4.07 | 0.06 | 1.77 | 0.29 | 0.81 |
| | | Density (sph) | 904 | 0 | 4167 | 722 | -16 | 176.7 | -1.71 | 0.94 | 228 | 0 | 2262 | 320 | -33 | 136.9 | **-11.45** | 0.82 |
| | | Top Height (m) | 20.73 | 9.72 | 36.14 | 4.52 | -0.13 | 1.62 | -0.64 | 0.87 | 20.49 | 8.7 | 31.85 | 4.36 | -0.21 | 1.79 | -1 | 0.83 |

**Table 3.** Summary of observed stand parameters (number of plots (N),volume ($m^3$), basal area ($m^2$), DBH (cm), height (m), density (stems/ha) and top height (m)) as well as the validation statistics (average mean bias (AMB), standard deviation of residuals (SD Resid), relative model bias (RMB), efficiency (EF) for the conifer and deciduous components by broad cover group for the Saskatchewan dataset. Bolded cells have RMB exceeding ±10%.

| | | | Conifer | | | | | | | | Deciduous | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Observed | | | | Validation Statistics | | | | Observed | | | | Validation Statistics | | | |
| Cover Group | N | Variable | Mean | Min | Max | SD | AMB | SD Resid | RMB | EF | Mean | Min | Max | SD | AMB | SD Resid | RMB | EF |
| C | 425 | Volume ($m^3$/ha) | 224.55 | 18.66 | 541.48 | 96.97 | -5.64 | 40.12 | -2.51 | 0.83 | 20.6 | 0.27 | 109.67 | 19.62 | -2.95 | 15.54 | **-14.3** | 0.35 |
| | | Basal Area ($m^2$/ha) | 29.01 | 3.74 | 54.42 | 9.61 | -0.11 | 4.08 | -0.38 | 0.82 | 2.69 | 0.06 | 10.13 | 2.28 | -0.33 | 1.73 | **-12.33** | 0.41 |
| | | Mean DBH (cm) | 18.08 | 10.55 | 48.67 | 5.51 | 0.13 | 1.11 | 0.74 | 0.96 | 20.1 | 7.7 | 46.7 | 6.94 | -0.39 | 3.24 | -1.92 | 0.78 |
| | | Mean Height (m) | 16.44 | 9.36 | 31.22 | 3.44 | -0.06 | 1.2 | -0.39 | 0.88 | 17.1 | 8.7 | 27.2 | 3.81 | -0.37 | 2.07 | -2.19 | 0.69 |
| | | Density (sph) | 1265 | 37 | 4167 | 712 | 1 | 200.98 | 0.07 | 0.92 | 46 | 0 | 500 | 70 | -5 | 41.98 | -7.37 | 0.69 |
| | | Top Height (m) | 19.95 | 10.43 | 36.14 | 4.44 | -0.03 | 1.28 | -0.13 | 0.92 | 17.42 | 8.7 | 27.19 | 3.86 | -0.42 | 2.03 | -2.41 | 0.71 |
| CD | 159 | Volume ($m^3$/ha) | 204.64 | 21.09 | 387.78 | 63.28 | -12.45 | 40.97 | -6.08 | 0.54 | 108.65 | 4.03 | 240.03 | 43.82 | -5.76 | 38.22 | -5.3 | 0.22 |
| | | Basal Area ($m^2$/ha) | 23.59 | 4.32 | 39.27 | 6.48 | -0.7 | 3.88 | -2.98 | 0.63 | 12.22 | 1.09 | 26.42 | 4.29 | -0.72 | 3.86 | -5.9 | 0.16 |
| | | Mean DBH (cm) | 22.59 | 12.32 | 49.28 | 5.92 | 0.66 | 1.84 | 2.92 | 0.89 | 25.38 | 12.37 | 44.25 | 6.31 | 0.91 | 2.42 | 3.58 | 0.83 |
| | | Mean Height (m) | 18.89 | 10.51 | 28.62 | 3.11 | -0.32 | 1.44 | -1.7 | 0.78 | 21.22 | 10.08 | 27.9 | 3.13 | 0.47 | 1.58 | 2.24 | 0.72 |
| | | Density (sph) | 647 | 74 | 2125 | 383 | -39 | 137.5 | -6.09 | 0.86 | 263 | 25 | 705 | 138 | -25 | 112.85 | -9.43 | 0.3 |
| | | Top Height (m) | 24.04 | 11.94 | 31.55 | 3.06 | -0.02 | 1.79 | -0.07 | 0.66 | 22.6 | 10.08 | 29.69 | 2.94 | 0.13 | 1.64 | 0.58 | 0.69 |
| D | 72 | Volume ($m^3$/ha) | 15.48 | 0.97 | 56.19 | 14.42 | -7.72 | 31.85 | **-49.85** | -4.17 | 231.53 | 46.55 | 444.91 | 86.81 | -16.34 | 43.14 | -7.06 | 0.72 |
| | | Basal Area ($m^2$/ha) | 2.23 | 0.2 | 6.59 | 1.78 | -0.56 | 3.31 | **-25.2** | -2.57 | 26.12 | 7.99 | 42.93 | 7.02 | -1.94 | 4.7 | -7.43 | 0.47 |
| | | Mean DBH (cm) | 18.61 | 11.61 | 31.3 | 4.85 | 1.95 | 2.52 | 10.5 | 0.56 | 19.79 | 12.23 | 31.88 | 4.85 | 1.17 | 1.27 | 5.89 | 0.87 |
| | | Mean Height (m) | 14.86 | 9.56 | 22.13 | 3.26 | 0.18 | 1.53 | 1.19 | 0.78 | 20.07 | 13.45 | 29.26 | 3.59 | 0.41 | 1.03 | 2.02 | 0.9 |
| | | Density (sph) | 49 | 0 | 275 | 66 | -14 | 65.07 | **-18.14** | 0.05 | 914 | 235 | 2262 | 419 | -163 | 264.22 | **-17.84** | 0.45 |
| | | Top Height (m) | 15.07 | 9.72 | 22.13 | 3.28 | -0.16 | 1.79 | -1.09 | 0.7 | 22.2 | 14.76 | 31.85 | 3.56 | -0.12 | 1.2 | -0.53 | 0.89 |
| DC | 91 | Volume ($m^3$/ha) | 102.28 | 17.63 | 260.29 | 47.76 | -24.46 | 61.44 | **-23.92** | -0.92 | 197.04 | 36.17 | 391.59 | 70.63 | -4.83 | 52.64 | -2.45 | 0.44 |
| | | Basal Area ($m^2$/ha) | 12.51 | 3.46 | 27.17 | 4.92 | -1.88 | 6.07 | **-14.99** | -0.67 | 21.06 | 6.22 | 34.66 | 6.42 | -0.43 | 5.3 | -2.03 | 0.31 |
| | | Mean DBH (cm) | 22.33 | 12.65 | 44.49 | 5.69 | 0.76 | 2.14 | 3.41 | 0.84 | 24.89 | 13.63 | 36.38 | 5.02 | 0.77 | 2.04 | 3.08 | 0.81 |
| | | Mean Height (m) | 17.82 | 11.02 | 25.99 | 3 | -0.61 | 1.68 | -3.42 | 0.65 | 22.05 | 14.03 | 29.85 | 3.15 | 0.21 | 1.39 | 0.93 | 0.8 |
| | | Density (sph) | 346 | 62 | 952 | 209 | -55 | 141.48 | **-15.97** | 0.47 | 470 | 74 | 1675 | 248 | -26 | 157.23 | -5.46 | 0.59 |
| | | Top Height (m) | 21.2 | 12.55 | 28.86 | 3.26 | -0.82 | 2.38 | -3.85 | 0.4 | 23.69 | 15.16 | 30.15 | 2.84 | -0.28 | 1.63 | -1.19 | 0.66 |

Deciduous Broad Cover Group (D)

The RMB values for the deciduous component (volume, basal area, DBH, average height, and top height) are all less than ±7.06% while deciduous density has a RMB of -17.84%. Deciduous efficiencies range from 0.45 to 0.9. Scatterplots for the deciduous dominated broad cover group are shown in Appendix A (pages 7-8). The secondary conifer component in this cover group shows an overestimate of volume (RMB=-49.85%, AMB=-7.72 $m^3ha^{-1}$ while underestimating DBH (RMB=10.5%, AMB=2.5 cm). Several points regarding the secondary conifer results should be noted. First, this is a pure deciduous broad cover group with average conifer volumes of only 15.5 $m^3 ha^{-1}$. (Conifer volumes in this cover group range between 1.0 and 56.2 $m^3ha^{-1}$ with a standard deviation of 14.4 $m^3ha^{-1}$.) Second, AMB values are small for the conifer component. By overestimating density, there is a tendency to maintain smaller trees with this resulting in underestimates of average DBH.

Deciduous Dominated Mixedwood (DC)

In the DC broad cover group, the performance of both conifer and deciduous are important. For the dominant deciduous component, all RMB values except for density are less than ±5.46%. (Table 3). Deciduous density is overestimated by 5.46% while DBH is underestimated by 3.08%. This is similar to the trend seen in the Deciduous group. In the secondary conifer component, some RMB values are high with RMB value of -23.9% for volume and with the DBH being underestimated, likely due to an overestimate of density (RMB = -15.9%). Plots of predicted vs observed shown in Appendix A (pages 9-10) illustrate generally close relationships reflecting efficiencies above 0.42.

**Table 4.** Summary of observed stand parameters (number of plots (N), volume ($m^3$), basal area ($m^2$), DBH (cm), height (m), density (stems/ha) and top height (m)) as well as the validation statistics (average mean bias (AMB), standard deviation of residuals (SD Resid), relative model bias (RMB), efficiency (EF) for the conifer and deciduous components by species group for the Saskatchewan dataset. Bolded cells have RMB exceeding ±10%. (Species groups with fewer than 10 plots have been omitted).

| | | | Conifer | | | | | | | | Deciduous | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Observed | | | | Validation Statistics | | | | Observed | | | | Validation Statistics | | | |
| Species Group | N | Variable | Mean | Min | Max | SD | AMB | SD Resid | RMB | EF | Mean | Min | Max | SD | AMB | SD Resid | RMB | EF |
| BS | 124 | Volume ($m^3$/ha) | 193.14 | 18.66 | 437.45 | 95.57 | 15.52 | 27.91 | 8.03 | 0.89 | 17.66 | 0.34 | 98.13 | 20.5 | -0.93 | 5.14 | -5.24 | 0.94 |
| | | Basal Area ($m^2$/ha) | 28.73 | 3.74 | 54.42 | 11.71 | 1.74 | 3.58 | 6.07 | 0.88 | 2.67 | 0.09 | 11.63 | 2.7 | 0.05 | 0.72 | 1.91 | 0.93 |
| | | Mean DBH (cm) | 13.75 | 10.57 | 19.56 | 1.83 | 0.26 | 0.67 | 1.88 | 0.85 | 18.75 | 9.8 | 32.9 | 5.07 | -1.85 | 2.75 | -9.84 | 0.57 |
| | | Mean Height (m) | 13.7 | 9.36 | 18.41 | 2.25 | 0.64 | 0.7 | 4.69 | 0.82 | 15.38 | 8.7 | 21.73 | 3.1 | -1.55 | 1.62 | -10.1 | 0.47 |
| | | Density (sph) | 1849 | 297 | 4167 | 795 | 62 | 267.9 | 3.33 | 0.88 | 52 | 0 | 500 | 86 | 13 | 31.34 | **15.56** | 0.88 |
| | | Top Height (m) | 17.4 | 10.71 | 26.62 | 3.34 | 0.25 | 1.17 | 1.42 | 0.87 | 15.72 | 8.7 | 21.98 | 3.3 | -1.36 | 1.65 | -8.67 | 0.58 |
| JP | 173 | Volume ($m^3$/ha) | 191.58 | 19.88 | 448.18 | 76.02 | -15.09 | 35.48 | -7.88 | 0.74 | 8.04 | 0.27 | 44.37 | 9.21 | -2.65 | 6.72 | **-32.95** | 0.38 |
| | | Basal Area ($m^2$/ha) | 25.64 | 4.66 | 47.44 | 7.46 | -1.37 | 3.71 | -5.33 | 0.72 | 1.16 | 0.06 | 6.76 | 1.22 | -0.29 | 0.87 | **-24.76** | 0.43 |
| | | Mean DBH (cm) | 17.14 | 10.55 | 31.55 | 3.65 | -0.07 | 0.87 | -0.4 | 0.94 | 15.55 | 7.7 | 37.8 | 5.5 | -1.41 | 2.78 | -9.05 | 0.68 |
| | | Mean Height (m) | 16.12 | 9.6 | 21.92 | 2.69 | -0.22 | 1.06 | -1.36 | 0.84 | 15.14 | 10.8 | 23.7 | 3.03 | -1.31 | 1.47 | -8.64 | 0.57 |
| | | Density (sph) | 1172 | 138 | 3288 | 512 | -27 | 183.8 | -2.34 | 0.87 | 24 | 0 | 488 | 55 | -4 | 38.49 | -8.31 | 0.72 |
| | | Top Height (m) | 18.05 | 10.43 | 24.56 | 3.02 | -0.15 | 1.15 | -0.83 | 0.85 | 15.33 | 10.8 | 23.7 | 3.03 | -1.25 | 1.47 | -8.18 | 0.59 |
| MX | 34 | Volume ($m^3$/ha) | 169.03 | 35.59 | 359.61 | 71.86 | 3.32 | 46.28 | 1.96 | 0.58 | 140.22 | 31.47 | 249.5 | 55.64 | -10.09 | 47.83 | -7.19 | 0.23 |
| | | Basal Area ($m^2$/ha) | 21.05 | 5.54 | 45.91 | 8.6 | 1.16 | 4.31 | 5.52 | 0.73 | 16.14 | 4.47 | 28.35 | 5.69 | -0.79 | 5.01 | -4.87 | 0.21 |
| | | Mean DBH (cm) | 20.63 | 13.64 | 44.49 | 6.07 | 0.49 | 1.98 | 2.36 | 0.89 | 24.34 | 15.92 | 40.35 | 5.73 | 0.38 | 2.33 | 1.54 | 0.83 |
| | | Mean Height (m) | 17.09 | 13.55 | 25.99 | 2.72 | -0.42 | 2 | -2.43 | 0.43 | 20.43 | 14.24 | 26.09 | 2.97 | -0.25 | 1.47 | -1.24 | 0.75 |
| | | Density (sph) | 699 | 75 | 1625 | 439 | 20 | 115.8 | 2.81 | 0.93 | 359 | 0 | 927 | 216 | -22 | 169.7 | -5.83 | 0.33 |
| | | Top Height (m) | 22.34 | 15.23 | 27.12 | 2.81 | -0.12 | 2.31 | -0.53 | 0.32 | 22.46 | 15.16 | 29.69 | 2.97 | -0.52 | 1.64 | -2.34 | 0.66 |
| TA | 150 | Volume ($m^3$/ha) | 70.76 | 0.97 | 260.29 | 56.54 | -20.45 | 56.24 | **-28.9** | -0.12 | 217.41 | 46.55 | 444.91 | 79.65 | -9.49 | 49.2 | -4.37 | 0.6 |
| | | Basal Area ($m^2$/ha) | 8.75 | 0.2 | 27.17 | 6.34 | -1.6 | 5.58 | **-18.26** | 0.16 | 23.71 | 6.5 | 42.93 | 7.12 | -1.07 | 5.06 | -4.53 | 0.47 |
| | | Mean DBH (cm) | 20.94 | 11.61 | 35.5 | 5.31 | 1.17 | 2.3 | 5.59 | 0.76 | 22.65 | 12.23 | 36.38 | 5.58 | 1.01 | 1.72 | 4.48 | 0.87 |
| | | Mean Height (m) | 16.84 | 9.56 | 24.91 | 3.32 | -0.33 | 1.61 | -1.97 | 0.75 | 21.32 | 13.45 | 29.85 | 3.47 | 0.35 | 1.2 | 1.66 | 0.87 |
| | | Density (sph) | 199 | 0 | 952 | 213 | -45 | 125.91 | **-18.49** | 0.6 | 681 | 74 | 2262 | 408 | -90 | 218.72 | **-13.14** | 0.66 |
| | | Top Height (m) | 19.05 | 9.72 | 28.86 | 4.37 | -0.62 | 2.22 | -3.26 | 0.72 | 23.13 | 14.76 | 31.85 | 3.27 | -0.14 | 1.38 | -0.59 | 0.82 |
| WS | 264 | Volume ($m^3$/ha) | 251.42 | 32.56 | 541.48 | 86.21 | -14.73 | 42.8 | -5.86 | 0.72 | 72.42 | 0.48 | 213.38 | 50.15 | -4.37 | 29.46 | -6.04 | 0.65 |
| | | Basal Area ($m^2$/ha) | 28.48 | 4.1 | 51.29 | 8.75 | -0.7 | 3.95 | -2.45 | 0.79 | 8.27 | 0.12 | 22.02 | 5.27 | -0.62 | 3.02 | -7.46 | 0.66 |
| | | Mean DBH (cm) | 23.34 | 13.14 | 49.28 | 5.79 | 0.5 | 1.76 | 2.15 | 0.9 | 24.57 | 8.44 | 46.7 | 6.55 | 1.02 | 2.72 | 4.17 | 0.8 |
| | | Mean Height (m) | 19.37 | 12.81 | 31.22 | 2.98 | -0.42 | 1.39 | -2.16 | 0.76 | 20.41 | 10.3 | 27.9 | 3.4 | 0.74 | 1.73 | 3.62 | 0.69 |
| | | Density (sph) | 715 | 37 | 2600 | 411 | -37 | 127.9 | -5.17 | 0.9 | 170 | 0 | 705 | 142 | -20 | 72.96 | **-11.26** | 0.71 |
| | 124 | Top Height (m) | 24.61 | 15.8 | 36.14 | 2.84 | -0.06 | 1.59 | -0.24 | 0.69 | 21.33 | 10.3 | 29.05 | 3.41 | 0.41 | 1.85 | 1.94 | 0.69 |

**Data Categorized by Dominant Species**

The validation results for the Saskatchewan dataset, categorized by species are shown in Table 4. The scatterplots for these are presented in Appendix A (pages 11-22).

Balsam Fir (BF)

There are only 2 plots dominated by balsam fir. Given the small sample size no results are shown.

Black Spruce (BS)

124 black spruce plots were available for validation in this dataset. The conifer component of the black spruce group performed well with all RMB values below ±8.03%. BS density appears to be underestimated as density increases (Figure 1) and Appendix A (page 13) even though efficiency is 0.88 and RMB is 3.3%. The minor deciduous component of these black spruce stands has larger RMB values for average height (-10.1%) and density (15.6%); however, these large RMB values are associated with small AMB values (-0.93 $m^3ha^{-1}$ for volume and 13.0 sph for density). Scatter plots for the BS group are provided in Appendix A (pages 13 and 14).

Jack Pine (JP)

There are 173 plots dominated by jack pine in the dataset. The jack pine conifer component validated well with all RMB values below ±7.88%. Scatterplots do not indicate any issues (Figure 2, Appendix A, pages 15 and 16). The minor deciduous component has a RMB of -32.9% for volume, -24.7% for basal area. These biases are associated with the small volume and basal areas of the deciduous component.

Mixedwood (MX)

In this category, there are 34 plots representing stands with no single, dominant conifer or deciduous species. With respect to conifer component, all RMB values are less than ±5.52%. With respect to the deciduous component, all RMB values are less than ±7.19%. The scatterplots in Appendix A (pages 17 and 18) do not indicate any problems.

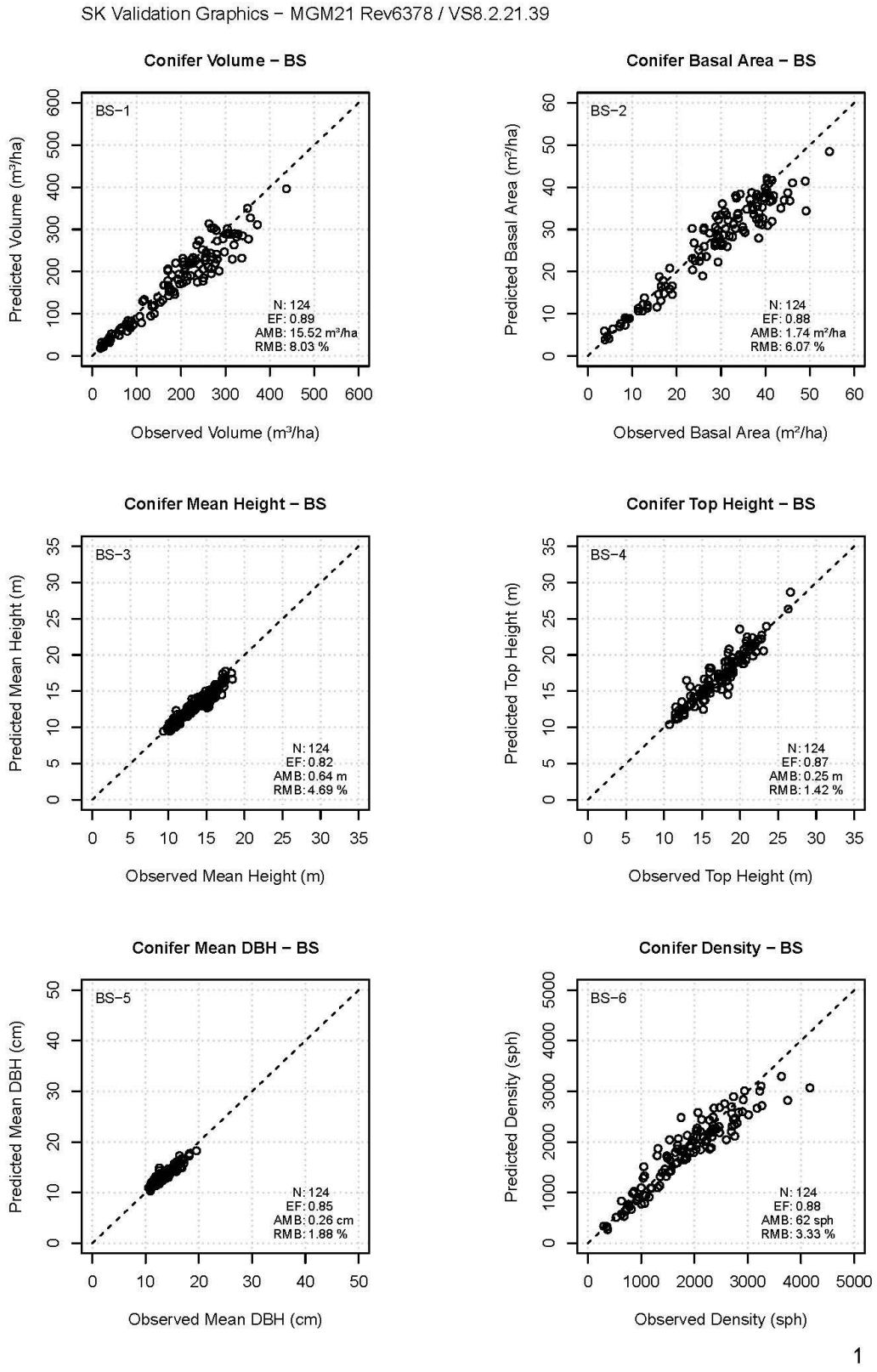


Figure 1. Scatterplots of observed and predicted stand volume, basal area, average height, top height, diameter and density for the conifer component in the black spruce (BS) species group.

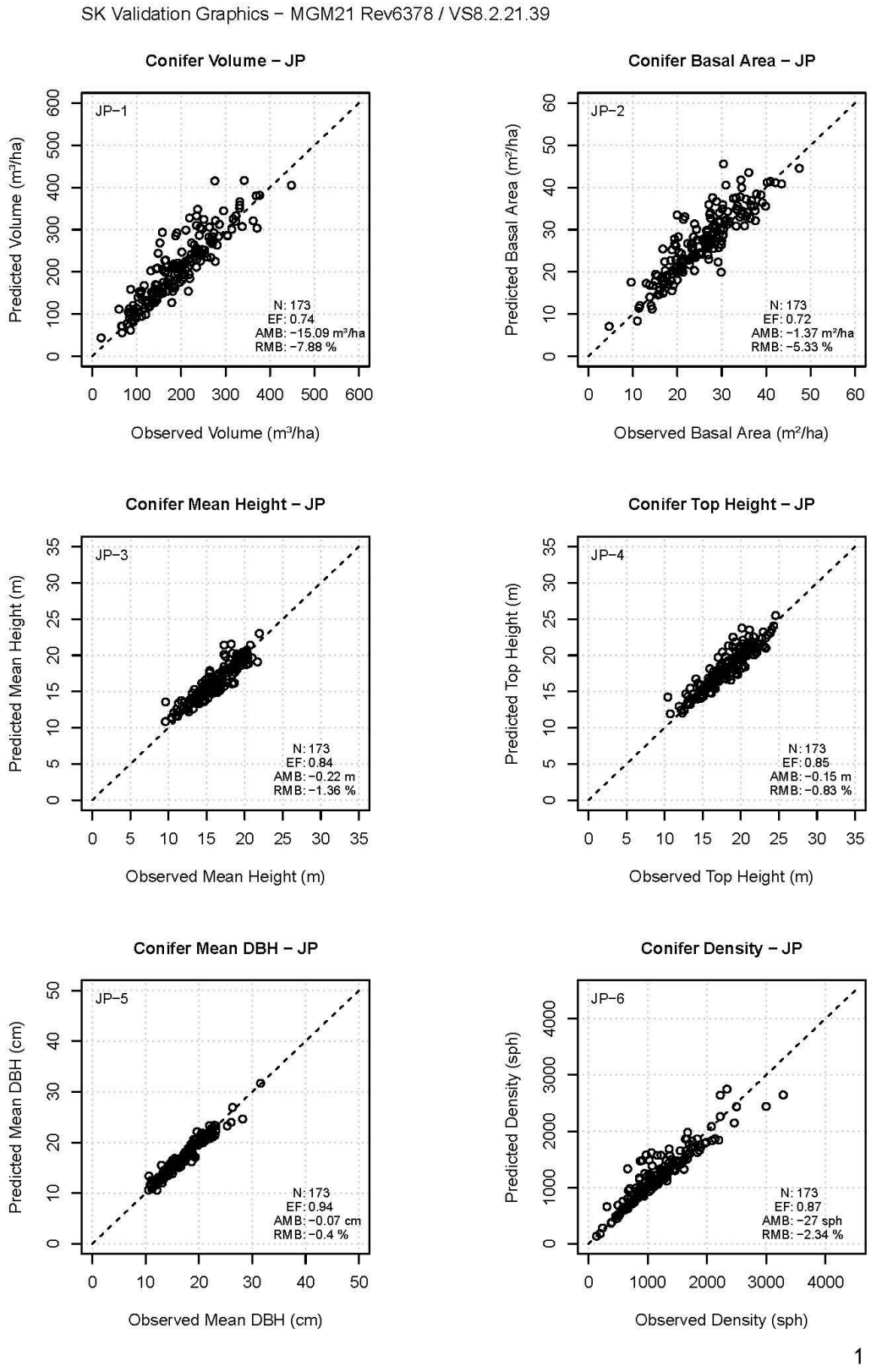


Figure 2. Scatterplots of observed and predicted stand volume, basal area, average height, top height, diameter and density for the conifer component in the jack pine (JP) species group.

Aspen (TA)

There are 150 plots categorized as aspen dominated. The RMB values for the deciduous component (volume, basal area, DBH, average height, and top height) are all less than ±4.53% while deciduous density has a RMB of -13.14%. Figure 3 shows the aspen group scatterplots of observed vs predicted for deciduous volume, basal area, average height, top height, DBH and density. Conifer volume and basal area both have RMB values of -28.9% and -18.26% while density has a RMB of -18.49%. Deciduous efficiencies range from 0.47 to 0.87 %. Scatterplots indicate a tendency to overestimate conifer volume and conifer basal area in this stratum which is likely resulting from overestimation of conifer density (Appendix A, pages 19 and 20).

White Spruce (WS)

There are 264 plots dominated by white spruce in the validation dataset. The model validated well for the majority of conifer component with RMB values less than ±5.86% (Figure 4). The deciduous component is also modelled well with RMB values below ±7.46 with the exception of density with a RMB of -11.26%. Deciduous AMB value are small (volume AMB=-4.37, density AMB=-20). The scatterplots in Figure 4 and in Appendix A (pages 21 and 22) illustrate the generally strong correspondence between MGM predictions and observed.

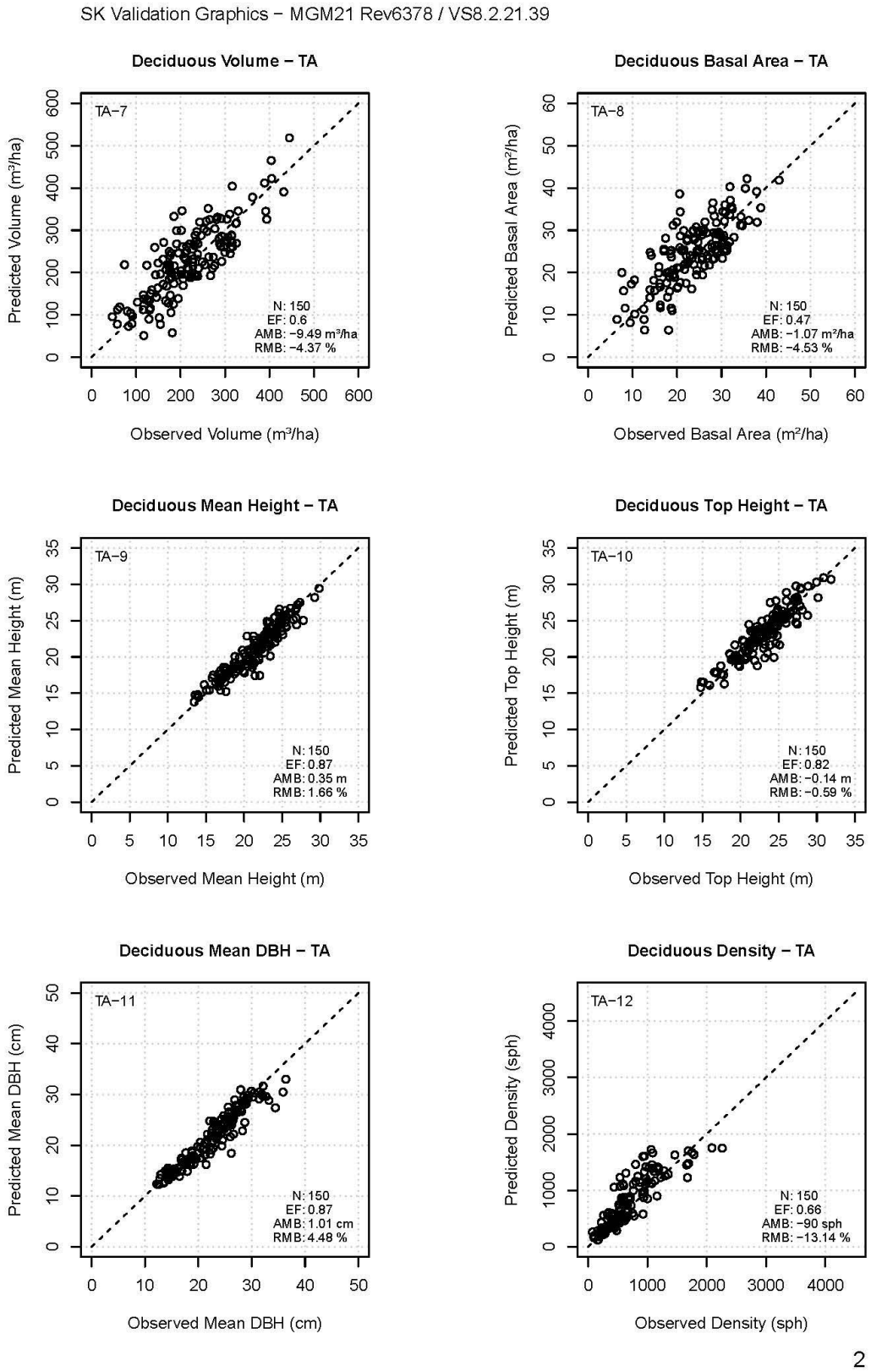


Figure 3. Scatterplots of observed and predicted stand volume, basal area, average height, top height, diameter and density for the deciduous component in the aspen (TA) species group.

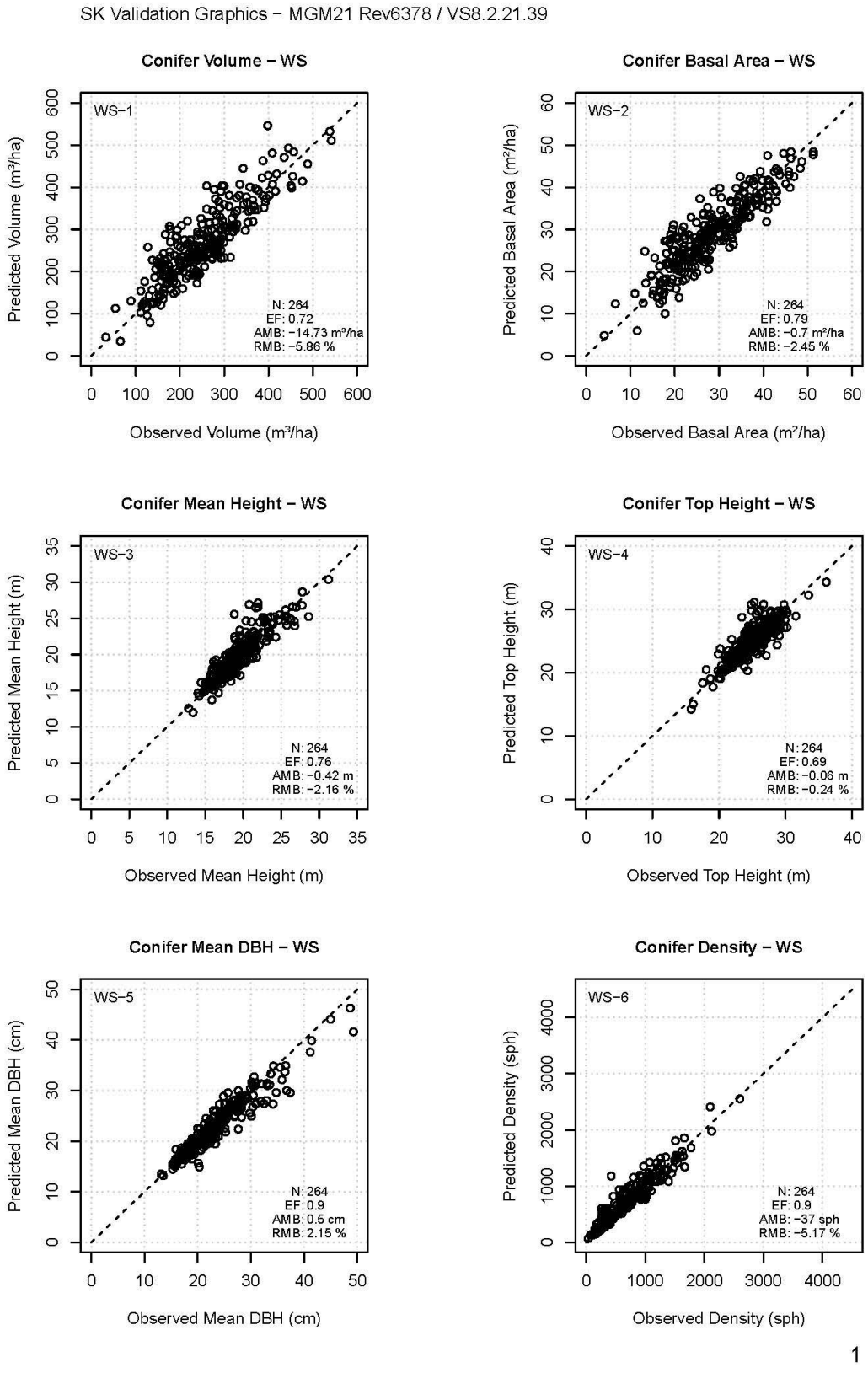


Figure 4. Scatterplots of observed and predicted stand volume, basal area, average height, top height, diameter and density for the conifer component in the white spruce (WS) species group.

**Table 5.** Summary of observed stand parameters (volume ($m^3$), basal area ($m^2$), DBH (cm), height (m), density (stems/ha) and top height (m)) as well as the validation statistics (average mean bias (AMB), standard deviation of residuals (SD Resid), relative model bias (RMB), efficiency (EF) for the conifer and deciduous components by broad cover group and species for the Saskatchewan dataset. Bolded cells have RMB exceeding ±10%. (Groups that cannot be contrasted have been omitted).

| | | | Conifer | | | | | | | | Deciduous | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Observed | | | | Validation Statistics | | | | Observed | | | | Validation Statistics | | | |
| Group | N | Variable | Mean | Min | Max | SD | AMB | SD Resid | RMB | EF | Mean | Min | Max | SD | AMB | SD Resid | RMB | EF |
| CWS | 131 | Volume ($m^3$/ha) | 263.68 | 212.16 | 359.61 | 83.16 | 32.57 | 103.72 | **12.35** | -0.79 | 33.7 | 31.47 | 35.92 | 3.15 | -9.42 | 8.7 | **-27.97** | -24.59 |
| | | Basal Area ($m^2$/ha) | 34.32 | 27.34 | 45.91 | 10.11 | 4.12 | 11.34 | **12.01** | -0.51 | 4.77 | 4.47 | 5.07 | 0.42 | -0.83 | 1.34 | **-17.44** | -16.62 |
| | | Mean DBH (cm) | 18.41 | 15.61 | 21.11 | 2.75 | 1.41 | 1.98 | 7.67 | 0.09 | 20.22 | 19.9 | 20.53 | 0.45 | -2.44 | 0.16 | **-12.05** | -58.28 |
| | | Mean Height (m) | 16.36 | 15.4 | 17.4 | 1 | 0.68 | 1.43 | 4.16 | -1.74 | 16.52 | 14.96 | 18.08 | 2.2 | -1.51 | 1.14 | -9.13 | -0.2 |
| | | Density (sph) | 1231 | 675 | 1583 | 487 | -27 | 110.49 | -2.19 | 0.94 | 92 | 0 | 150 | 80 | 10 | 22.52 | 6.96 | -1.21 |
| | | Top Height (m) | 22.34 | 21.7 | 23.32 | 0.86 | 0.48 | 2 | 2.14 | -4.9 | 18.23 | 16.49 | 19.98 | 2.47 | -0.32 | 0.66 | -1.77 | 0.89 |
| CDWS | 133 | Volume ($m^3$/ha) | 293.96 | 32.56 | 541.48 | 87.21 | -14.32 | 45.22 | -4.87 | 0.7 | 31.25 | 0.48 | 109.67 | 20.8 | -4.56 | 22.16 | **-14.6** | -0.18 |
| | | Basal Area ($m^2$/ha) | 33.23 | 4.1 | 51.29 | 8.4 | -0.35 | 4.06 | -1.04 | 0.76 | 3.79 | 0.12 | 10.13 | 2.25 | -0.61 | 2.41 | **-15.97** | -0.22 |
| | | Mean DBH (cm) | 23.38 | 13.53 | 48.67 | 5.71 | 0.26 | 1.56 | 1.12 | 0.92 | 23.54 | 8.44 | 46.7 | 6.93 | 1.06 | 3.14 | 4.51 | 0.77 |
| | | Mean Height (m) | 19.42 | 13.39 | 31.22 | 2.89 | -0.53 | 1.4 | -2.74 | 0.73 | 19.31 | 10.3 | 27.2 | 3.51 | 0.84 | 1.93 | 4.37 | 0.64 |
| | | Density (sph) | 826 | 37 | 2600 | 443 | -25 | 128.71 | -3.06 | 0.91 | 79 | 0 | 362 | 72 | -18 | 51.7 | -21.08 | 0.41 |
| | | Top Height (m) | 24.75 | 16.11 | 36.14 | 2.87 | -0.16 | 1.48 | -0.64 | 0.73 | 19.7 | 10.3 | 27.19 | 3.42 | 0.59 | 2.04 | 3.01 | 0.61 |
| DTA | 72 | Volume ($m^3$/ha) | 15.48 | 0.97 | 56.19 | 14.42 | -7.72 | 31.85 | **-49.85** | -4.17 | 231.53 | 46.55 | 444.91 | 86.81 | -16.34 | 43.14 | -7.06 | 0.72 |
| | | Basal Area ($m^2$/ha) | 2.23 | 0.2 | 6.59 | 1.78 | -0.56 | 3.31 | **-25.2** | -2.57 | 26.12 | 7.99 | 42.93 | 7.02 | -1.94 | 4.7 | -7.43 | 0.47 |
| | | Mean DBH (cm) | 18.61 | 11.61 | 31.3 | 4.85 | 1.95 | 2.52 | **10.5** | 0.56 | 19.79 | 12.23 | 31.88 | 4.85 | 1.17 | 1.27 | 5.89 | 0.87 |
| | | Mean Height (m) | 14.86 | 9.56 | 22.13 | 3.26 | 0.18 | 1.53 | 1.19 | 0.78 | 20.07 | 13.45 | 29.26 | 3.59 | 0.41 | 1.03 | 2.02 | 0.9 |
| | | Density (sph) | 49 | 0 | 275 | 66 | -14 | 65.07 | **-18.14** | 0.05 | 914 | 235 | 2262 | 419 | -163 | 264.22 | **-17.84** | 0.45 |
| | | Top Height (m) | 15.07 | 9.72 | 22.13 | 3.28 | -0.16 | 1.79 | -1.09 | 0.7 | 22.2 | 14.76 | 31.85 | 3.56 | -0.12 | 1.2 | -0.53 | 0.89 |
| DCTA | 78 | Volume ($m^3$/ha) | 100.52 | 17.63 | 260.29 | 47.61 | -27.3 | 64.9 | **-27.16** | -1.19 | 204.36 | 57.8 | 391.59 | 70.5 | -3.17 | 53.7 | -1.55 | 0.42 |
| | | Basal Area ($m^2$/ha) | 12.26 | 3.46 | 27.17 | 4.99 | -2.16 | 6.44 | **-17.58** | -0.85 | 21.48 | 6.5 | 34.66 | 6.48 | -0.27 | 5.27 | -1.27 | 0.34 |
| | | Mean DBH (cm) | 22.2 | 12.65 | 35.5 | 5.14 | 0.75 | 2.07 | 3.37 | 0.82 | 25.29 | 13.63 | 36.38 | 4.89 | 0.88 | 2.04 | 3.46 | 0.79 |
| | | Mean Height (m) | 17.9 | 11.02 | 24.91 | 2.84 | -0.61 | 1.6 | -3.38 | 0.64 | 22.47 | 14.03 | 29.85 | 2.95 | 0.31 | 1.34 | 1.36 | 0.78 |
| | | Density (sph) | 338 | 62 | 952 | 208 | -63 | 147.73 | **-18.53** | 0.4 | 467 | 74 | 1675 | 250 | -22 | 135.89 | -4.64 | 0.7 |
| | | Top Height (m) | 21.2 | 12.55 | 28.86 | 3.25 | -0.87 | 2.4 | -4.1 | 0.38 | 23.98 | 16.86 | 30.15 | 2.72 | -0.15 | 1.54 | -0.64 | 0.68 |

**Data Categorized by Broad Cover Group and Dominant Species**

The validation results for the Saskatchewan dataset, categorized into broad cover groups (C, CD, DC, D) and by species are shown in Table 5. The scatterplots for these are presented in Appendix A (pages 23-44).

The purpose of evaluating validation results within broad cover group by species is to identify differences in model behaviour between the broad cover groups. Within the Saskatchewan dataset, based on plot numbers within comparison groups, valid comparisons can only be made for white spruce and trembling aspen.

**White Spruce:**

Contrasting the Conifer Broad Cover Group (CWS) and the Conifer Dominated Mixedwood Broad Cover Group (CDWS) there is no clear difference in model performance between the two groups with respect to the conifer component. The RMB for conifer volume for the CWS group is -7.22% which is similar to the CDWS group (-4.87%). However, with respect to the deciduous component, the deciduous volume for the CWS (RMB -14.6%) compared to the CDWS group (-3.92%) indicates an overestimate of deciduous yield in pure conditions but very good model behaviour in mixtures.

**Trembling Aspen:**

Contrasting the Deciduous Dominated Broad Cover Group (DTA) and the Deciduous Dominated Mixedwood Broad Cover Group (DCTA) there is a difference in model performance between the two groups. For the DCTA group the RMB for volume is -1.55% while the RMB for the DTA is -7.06%, likely caused by an overestimate of deciduous density (RMB = -17.84% and AMB of -168 sph). The conifer volume is significantly overestimated in both the DTA (RMB = -49.85%) and DCTA (RMB = -27.16%) groups. The high RMB in the DTA is not significant as the mean conifer volume is 15.48 $m^3$. The overestimate in the DCTA is significant with an AMB of 27.3 $m^3$. In both cases the conifer densities are overestimated and are the likely cause of volume overestimates.

## Conclusions

Results from this validation indicate that MGM's overall performance is strong. MGM's primary species (i.e., white spruce, jack pine, aspen, and black spruce) generally validate well, individually or in mixture. Issues do remain 1) in modelling deciduous densities, 2) in modelling spruce density and volume in deciduous dominated mixedwoods, and 3) when modelling species that are minor components (i.e., have low density or basal area) of stands. These issues reflect the influence of small sample sizes, small plot areas sampled, and the ability to predict tree-level behavior using a non-spatial (distance independent) model. MGM's purely deterministic approach may also contribute to some of the model bias. Errors in the validation dataset, the occurrence of stochastic events (e.g., insects, wind, flooding, wildlife damage etc.), and undocumented tree removals are also suspected in some cases. Further refinements to MGM could improve model behavior. These improvements include: 1) incorporating climate into MGM's diameter and height growth models, 2) updating the diameter and height growth models jack pine, aspen and white spruce, and 3) completely modelling secondary species such as balsam poplar, white birch, and balsam fir. Modelling these secondary species would require the development and application of new height-age, mortality and growth equations. However, developing new submodels for balsam poplar, white birch, and balsam fir may be problematic, due to the limited PSP data for these species. While ingress was not modelled in MGM and PSP ingress data was not included in the validation, its presence influences stand dynamics. Ingress can also contribute to stand volumes and stand structure over extended periods. The need to model ingress is recognized and should be addressed in the future.

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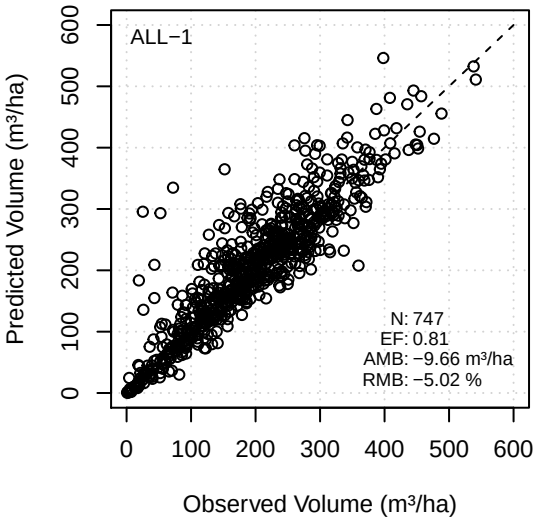
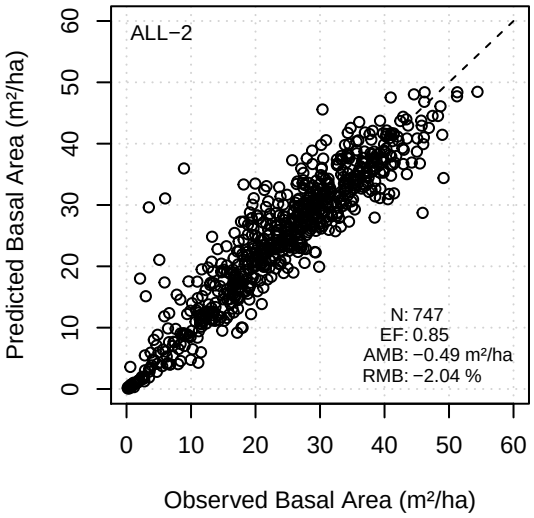
# Appendices

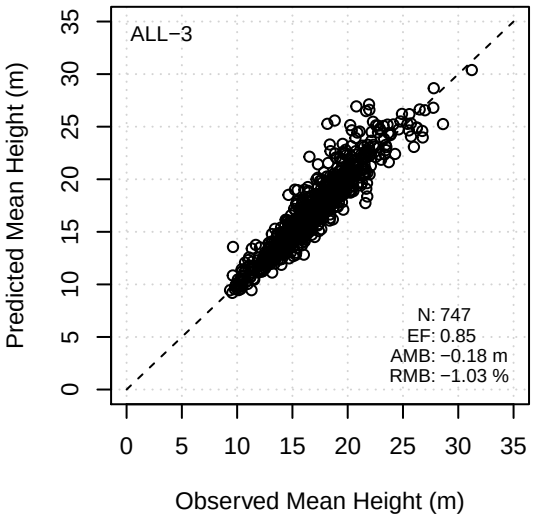
**Conifer Volume − ALL**



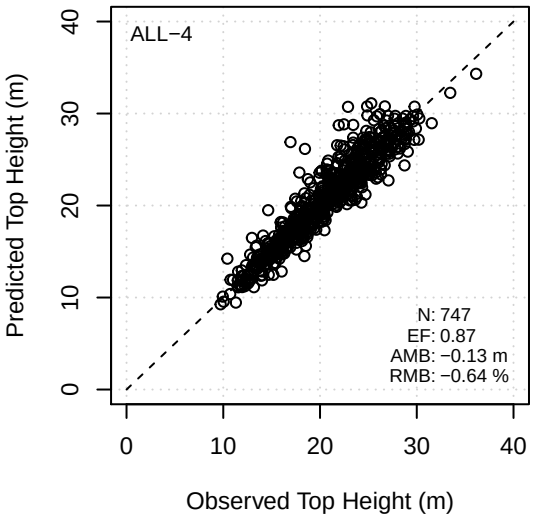

**Conifer Basal Area − ALL**



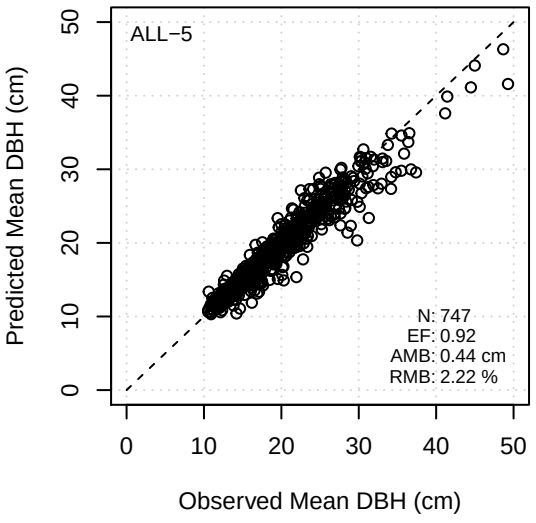

**Conifer Mean Height − ALL**



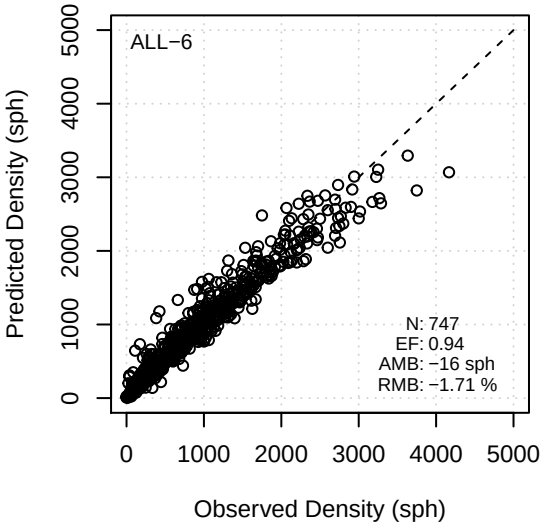

**Conifer Top Height − ALL**



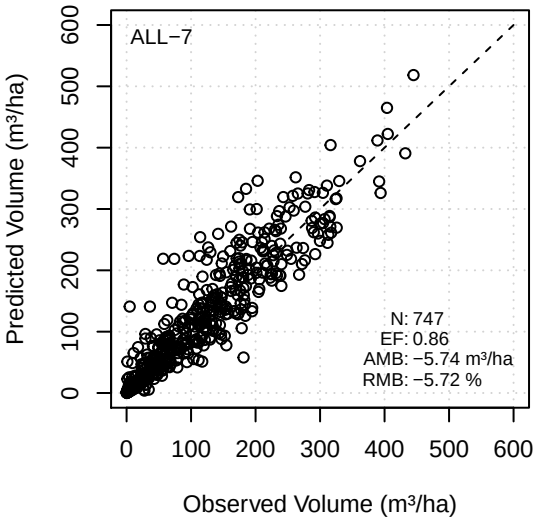

**Conifer Mean DBH − ALL**



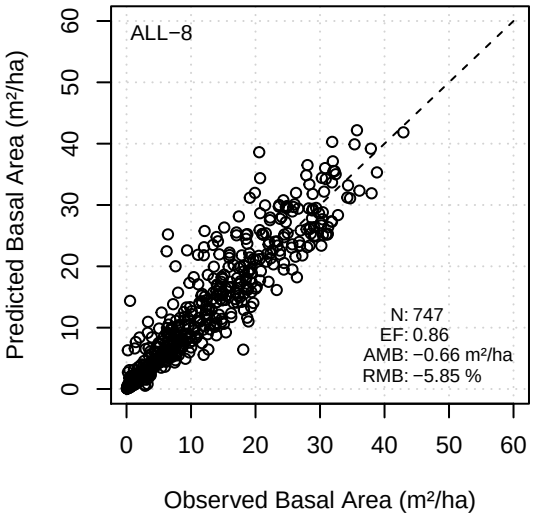

**Conifer Density − ALL**



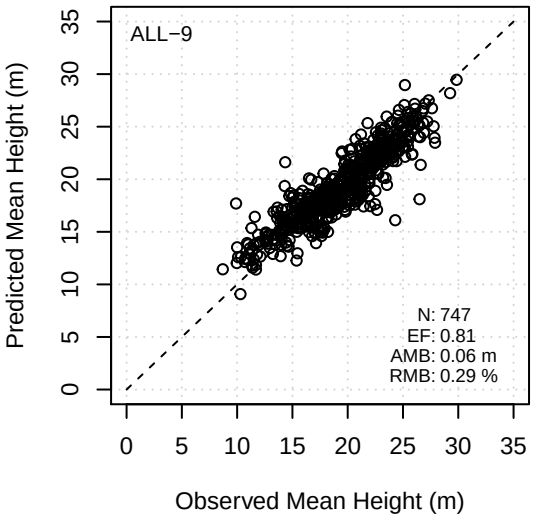
**Deciduous Volume − ALL**



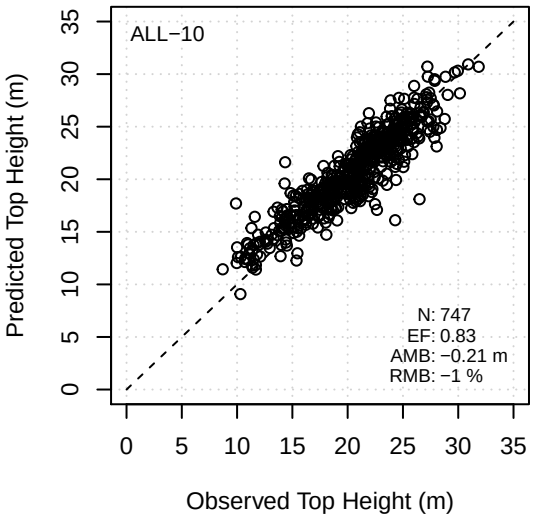

**Deciduous Basal Area − ALL**



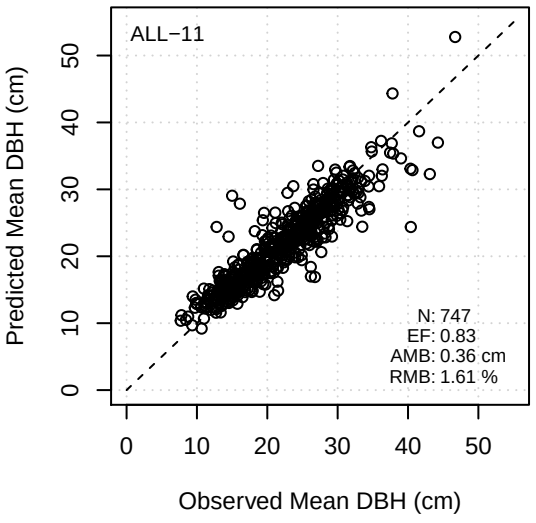

**Deciduous Mean Height − ALL**



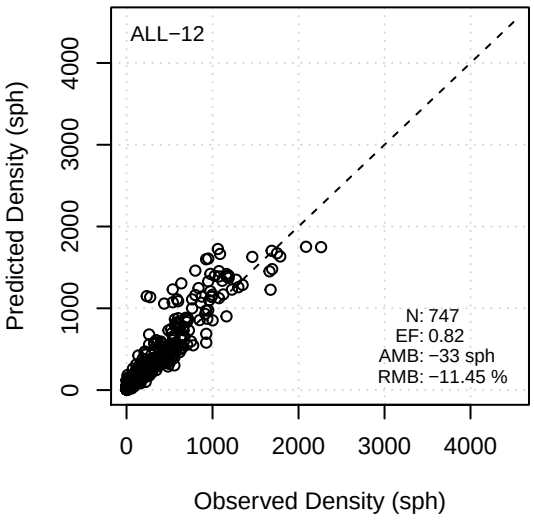

**Deciduous Top Height − ALL**



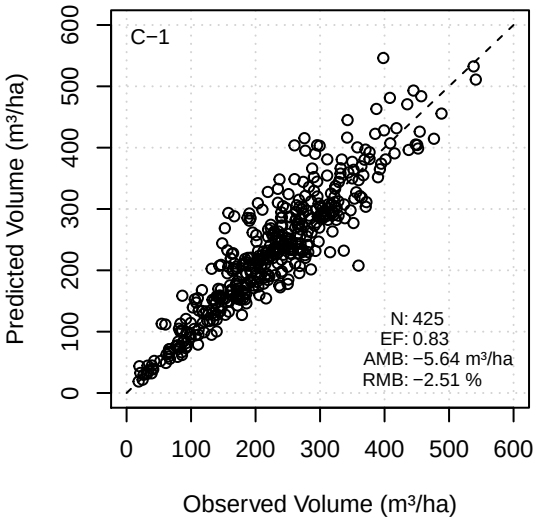

**Deciduous Mean DBH − ALL**



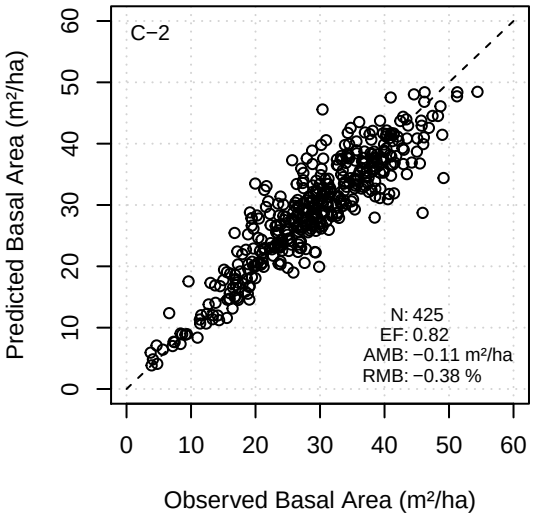

**Deciduous Density − ALL**



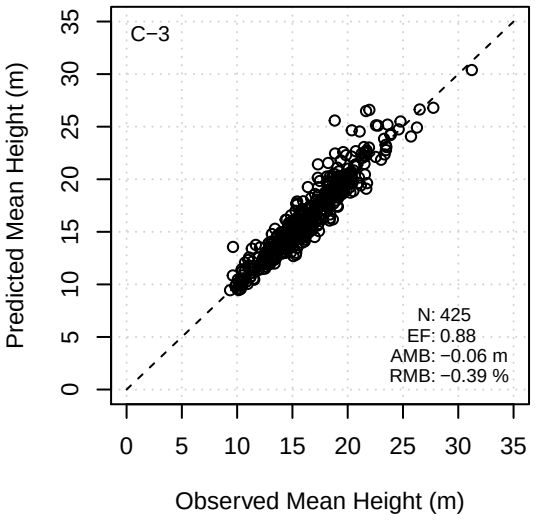
**Conifer Volume − C**



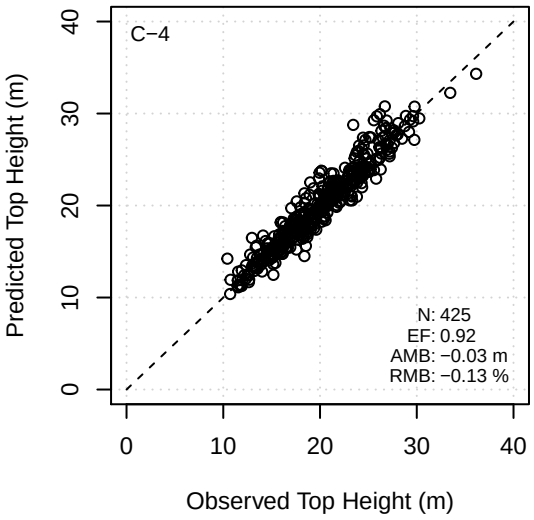

**Conifer Basal Area − C**



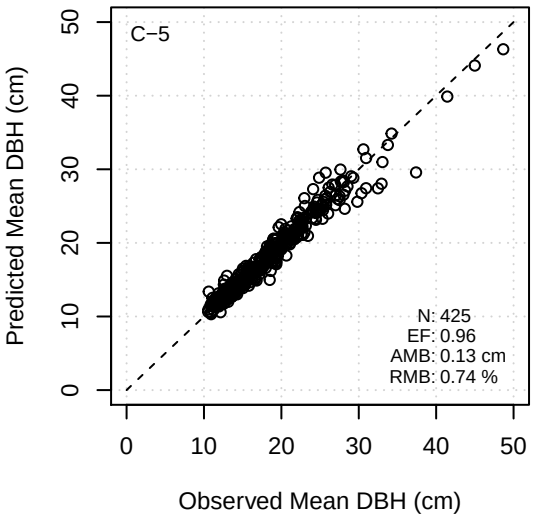

**Conifer Mean Height − C**



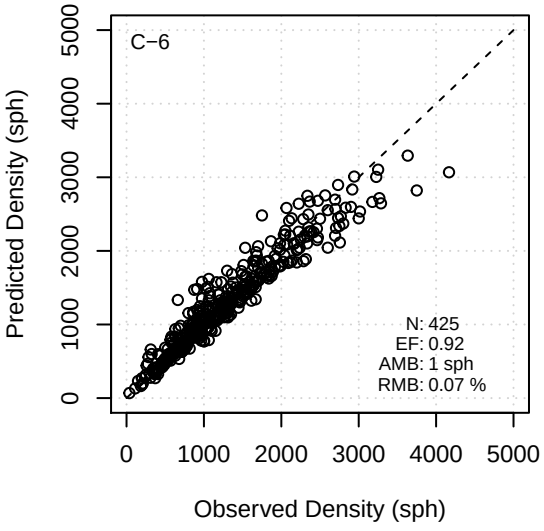

**Conifer Top Height − C**



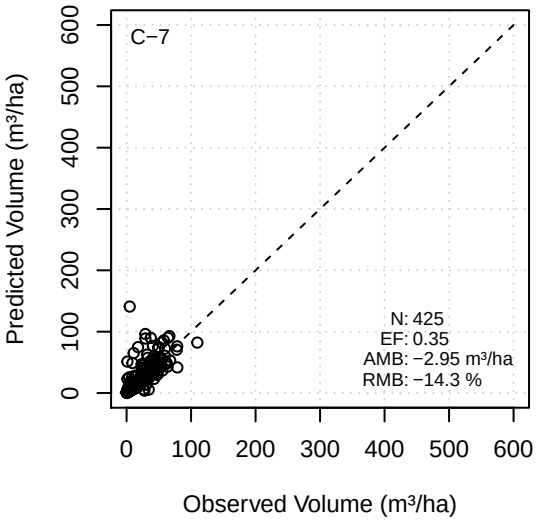

**Conifer Mean DBH − C**



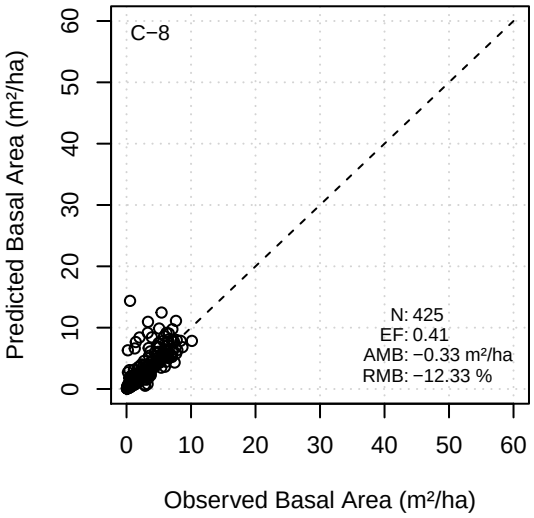

**Conifer Density − C**



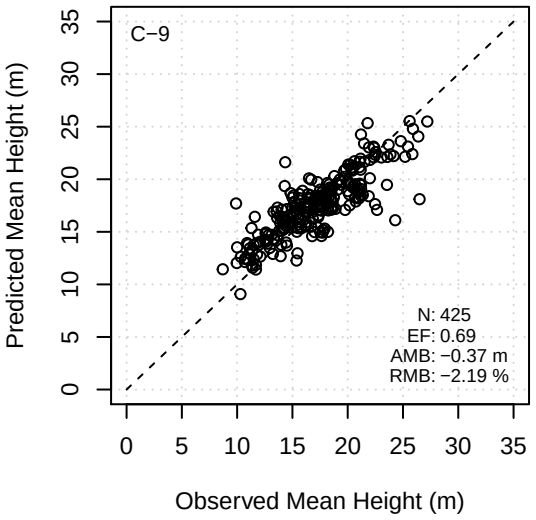
**Deciduous Volume − C**



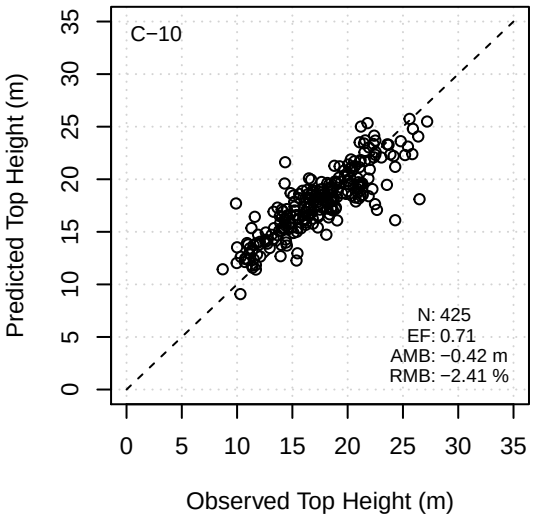

**Deciduous Basal Area − C**



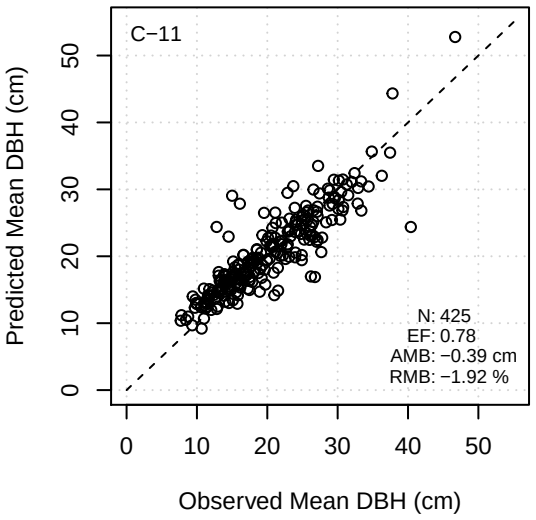

**Deciduous Mean Height − C**



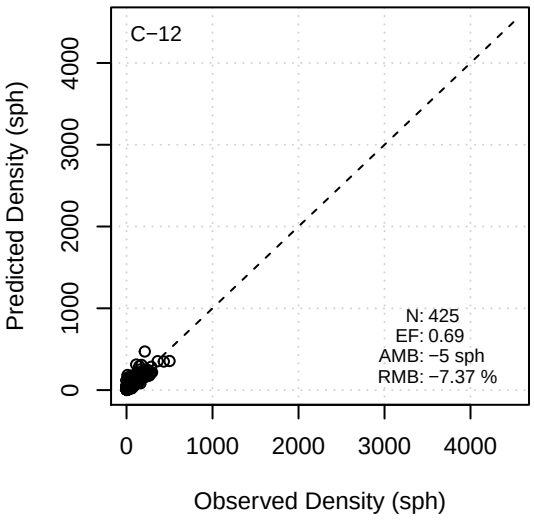

**Deciduous Top Height − C**



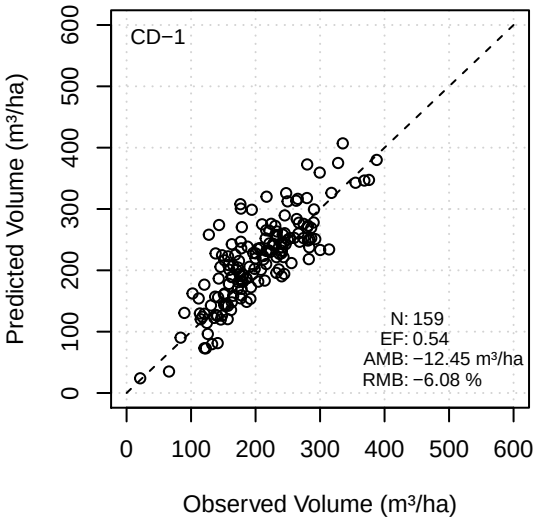

**Deciduous Mean DBH − C**



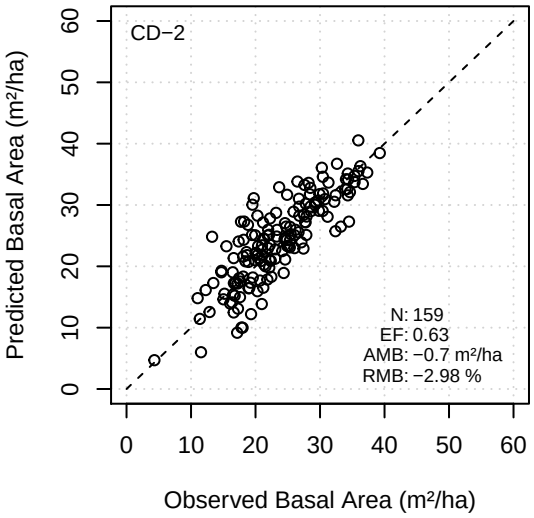

**Deciduous Density − C**



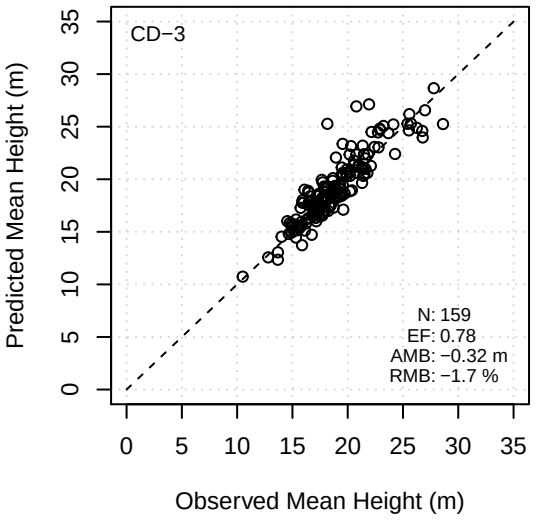
**Conifer Volume − CD**



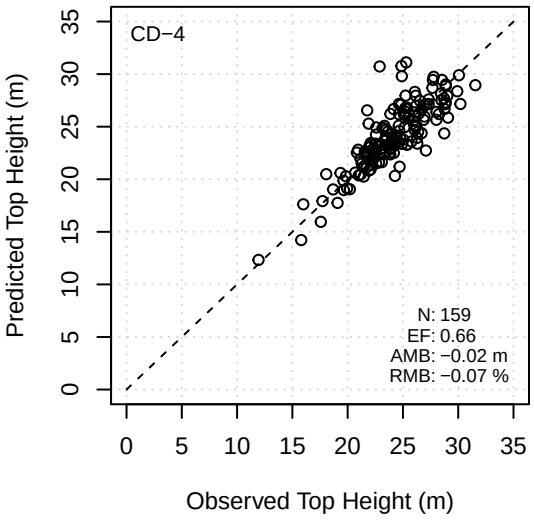

**Conifer Basal Area − CD**



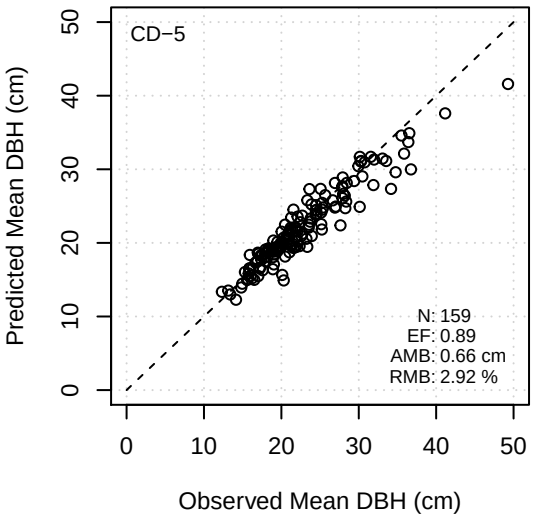

**Conifer Mean Height − CD**



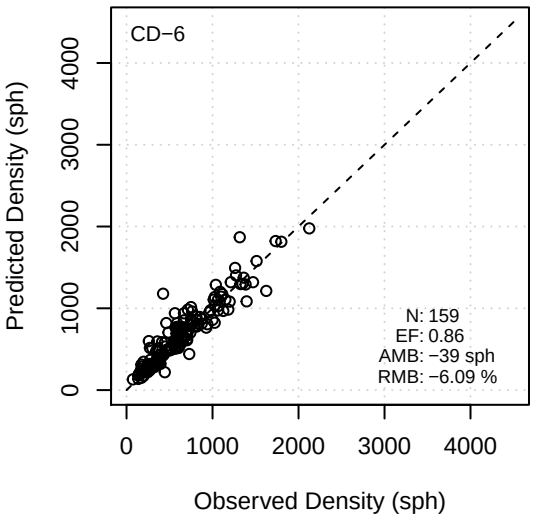

**Conifer Top Height − CD**



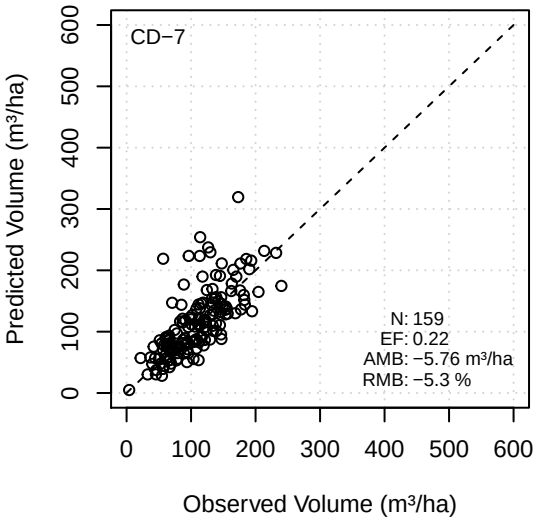

**Conifer Mean DBH − CD**



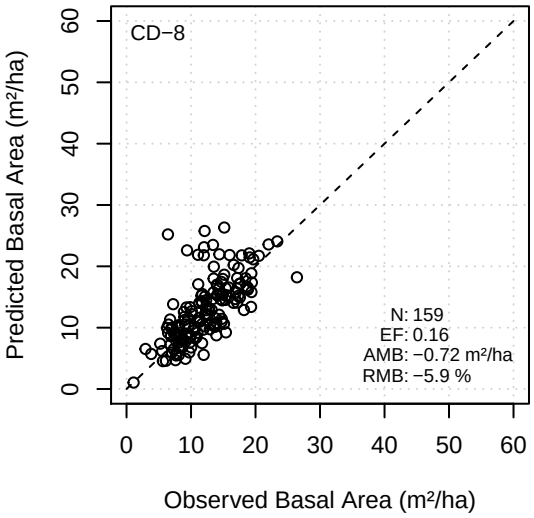

**Conifer Density − CD**



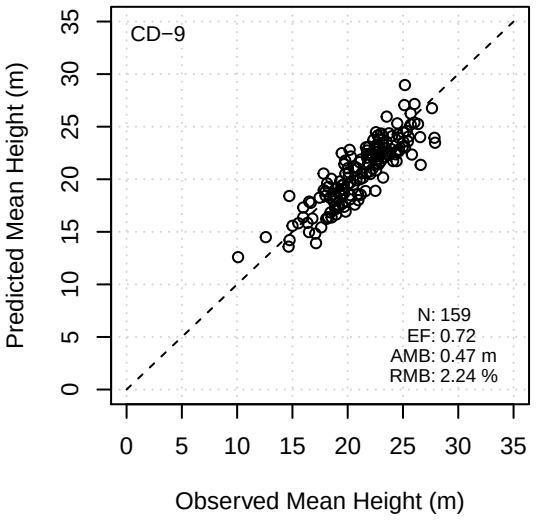
**Deciduous Volume − CD**



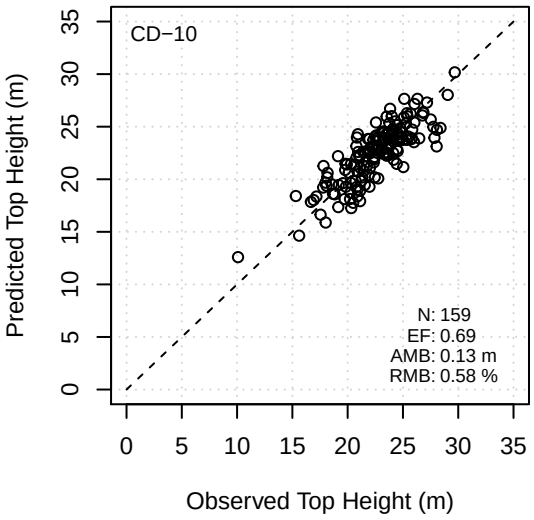

**Deciduous Basal Area − CD**



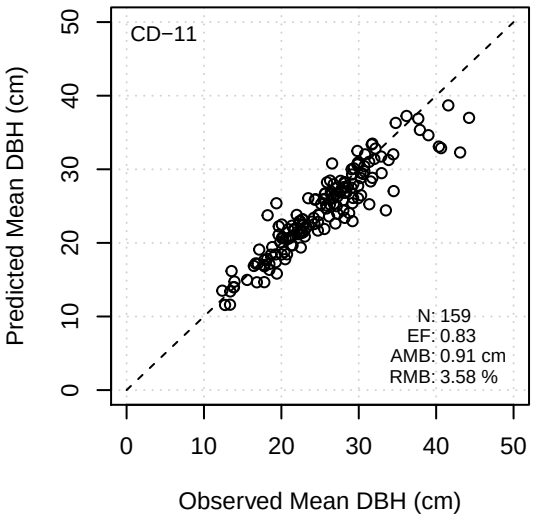

**Deciduous Mean Height − CD**



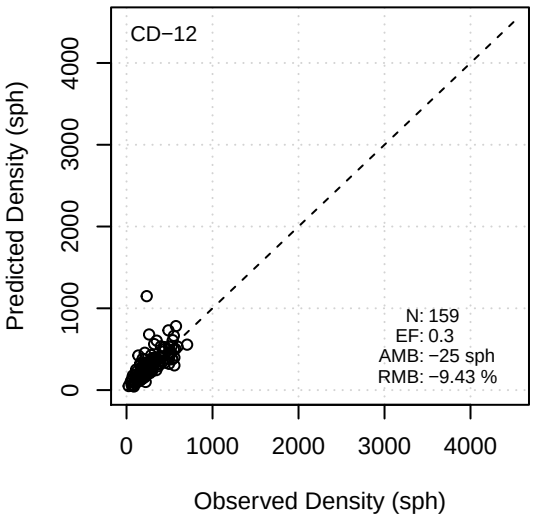

**Deciduous Top Height − CD**



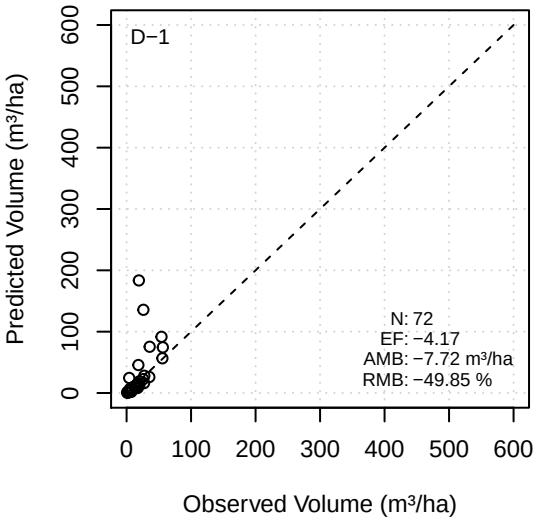

**Deciduous Mean DBH − CD**



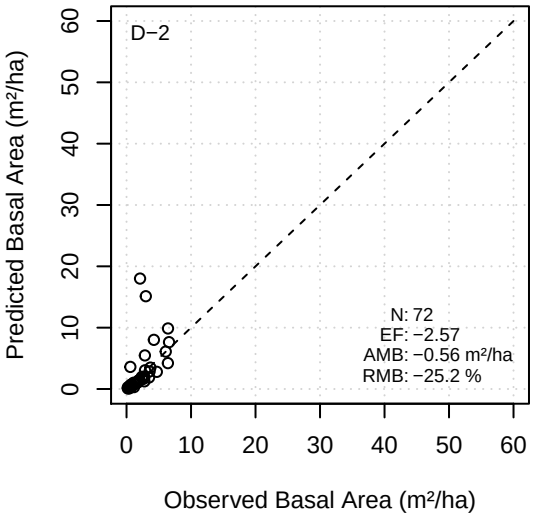

**Deciduous Density − CD**



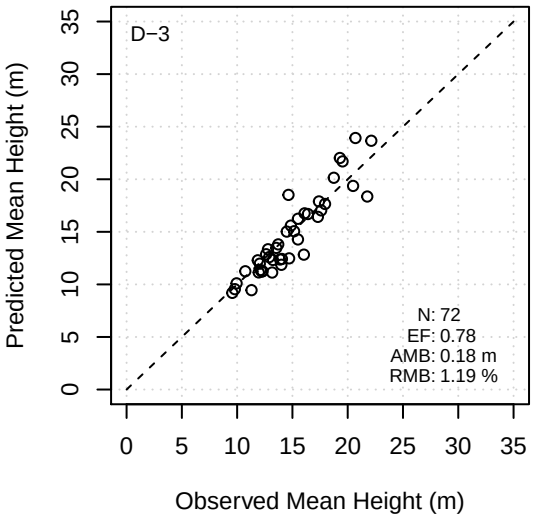
**Conifer Volume − D**



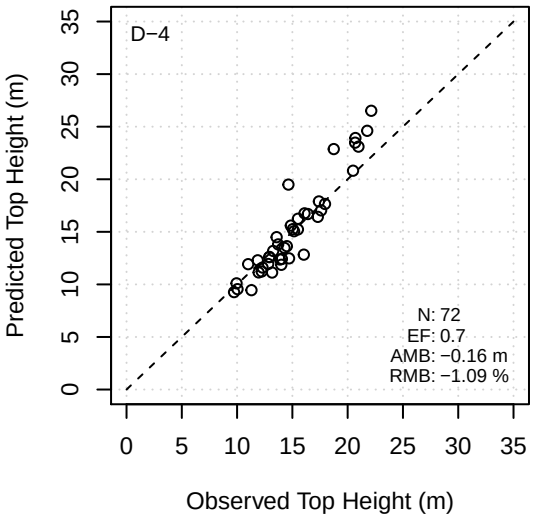

**Conifer Basal Area − D**



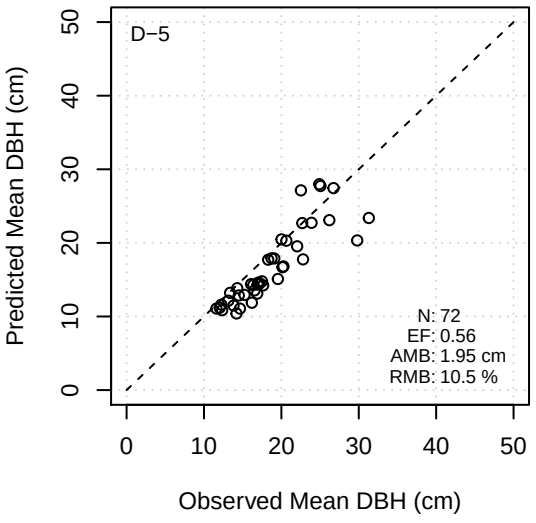

**Conifer Mean Height − D**



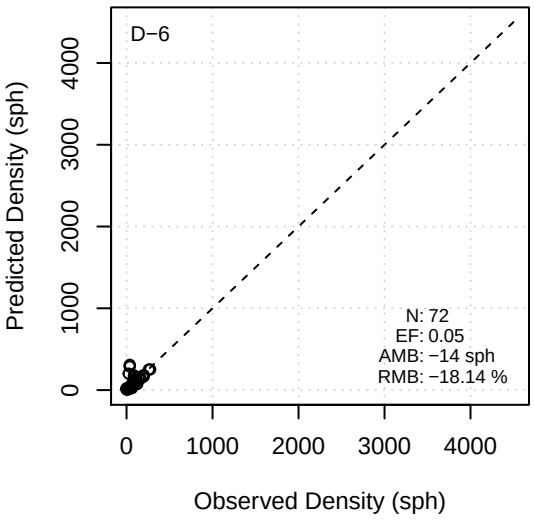

**Conifer Top Height − D**



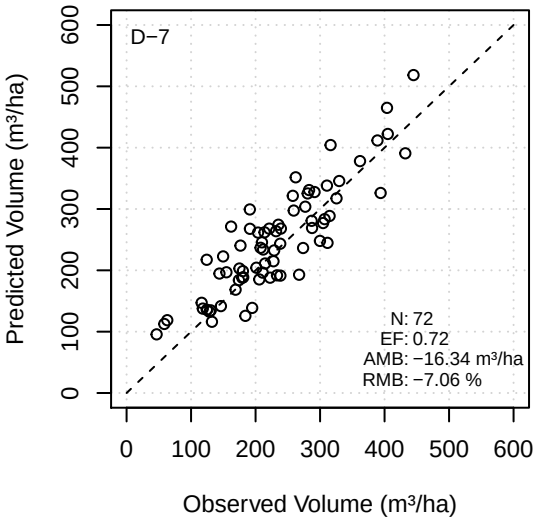

**Conifer Mean DBH − D**



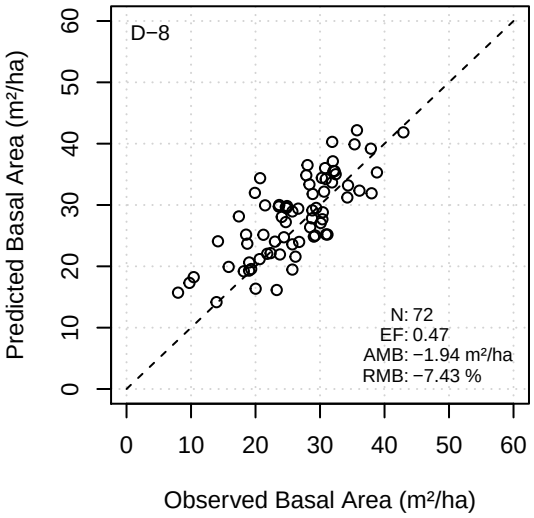

**Conifer Density − D**



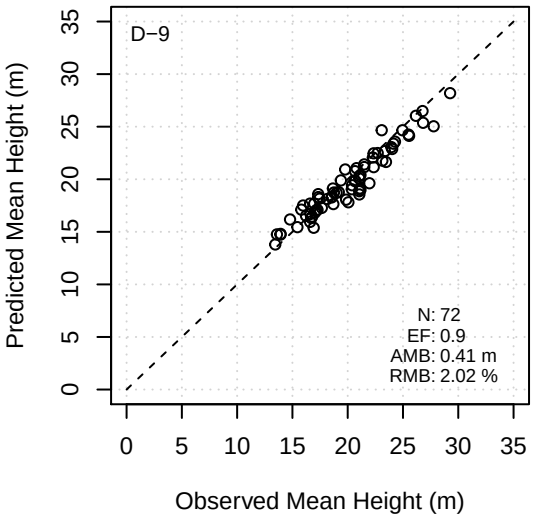
**Deciduous Volume − D**



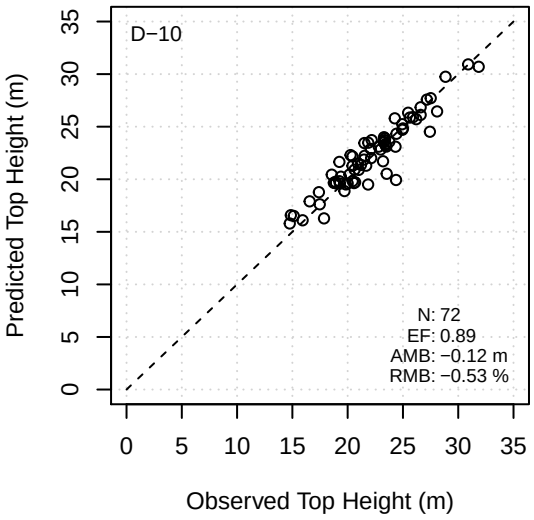

**Deciduous Basal Area − D**



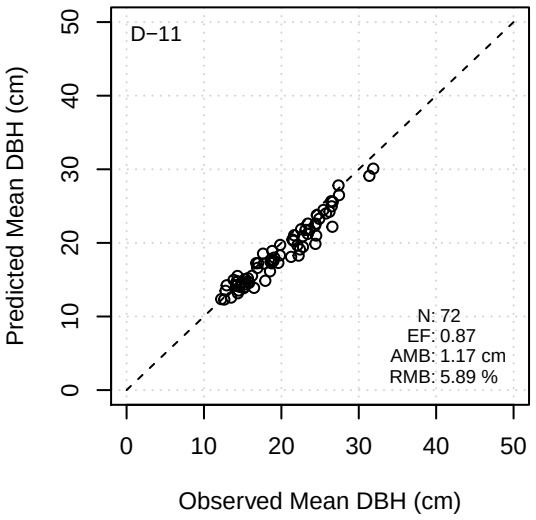

**Deciduous Mean Height − D**



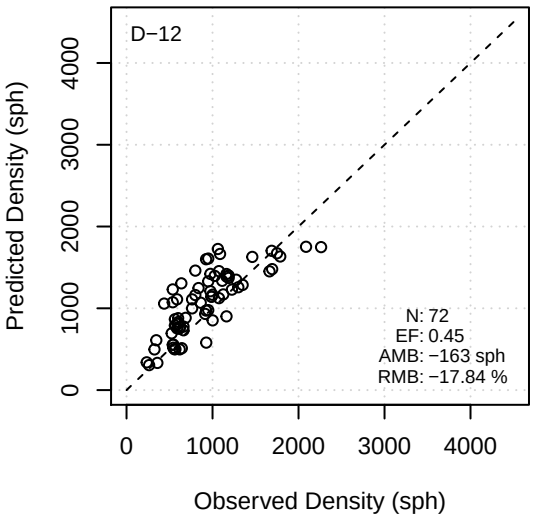

**Deciduous Top Height − D**



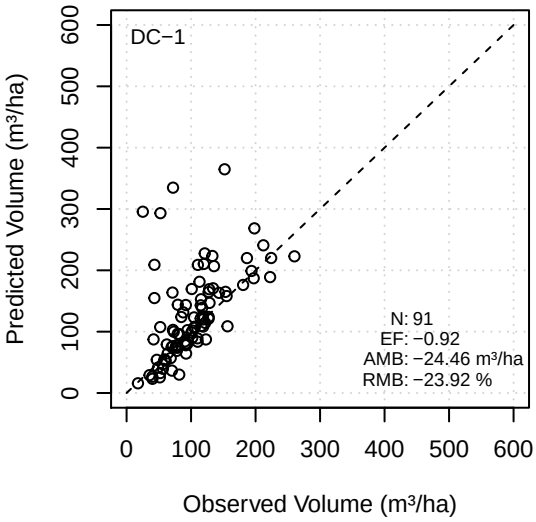

**Deciduous Mean DBH − D**



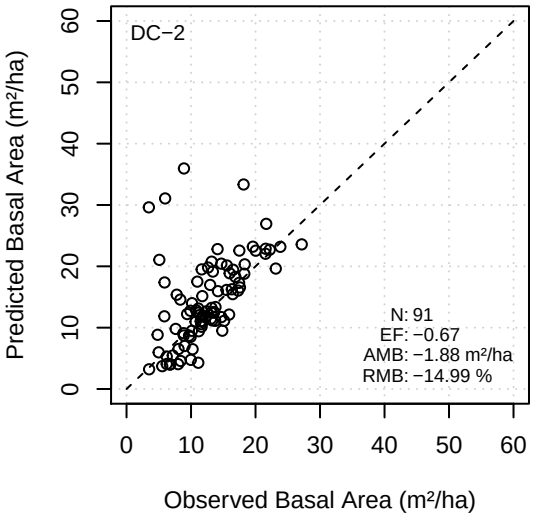

**Deciduous Density − D**



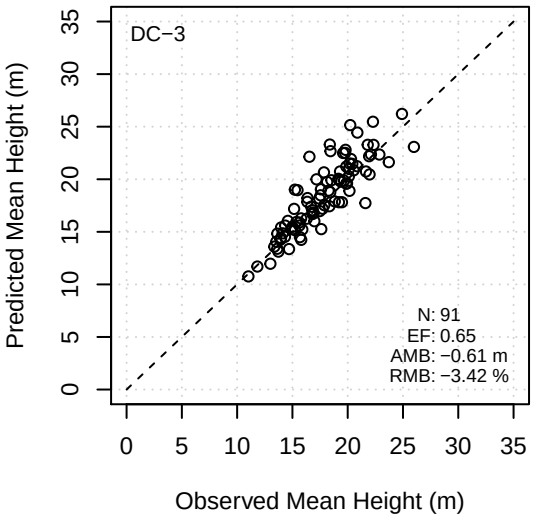
**Conifer Volume − DC**



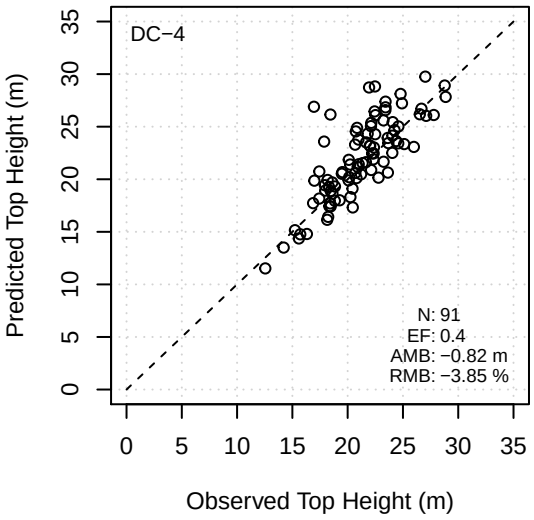

**Conifer Basal Area − DC**



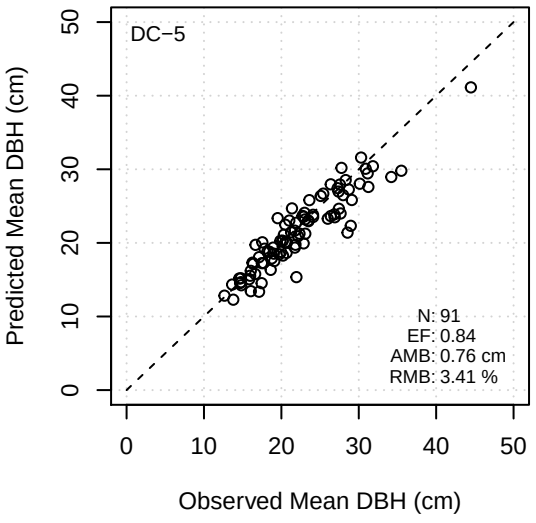

**Conifer Mean Height − DC**



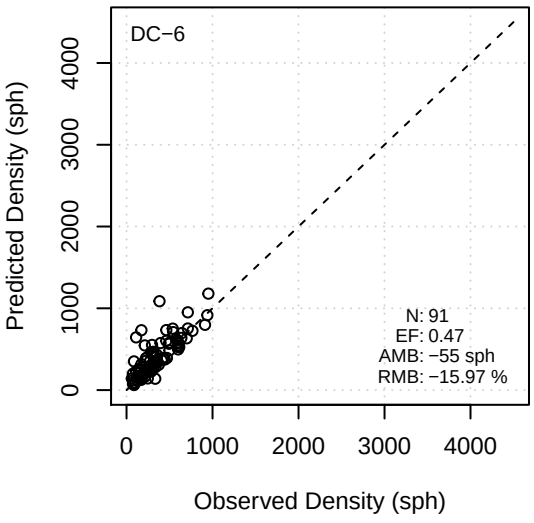

**Conifer Top Height − DC**



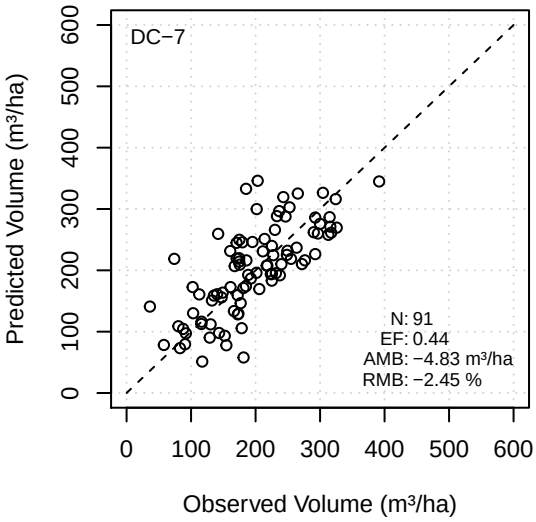

**Conifer Mean DBH − DC**



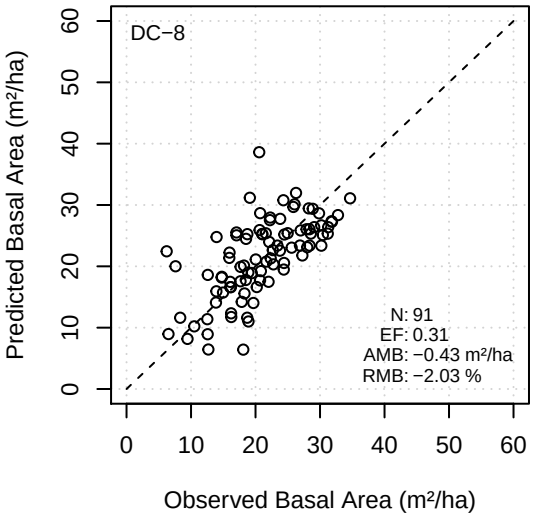

**Conifer Density − DC**



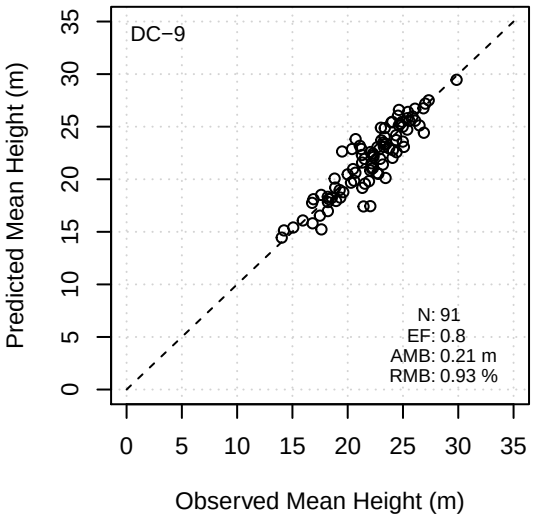
**Deciduous Volume − DC**



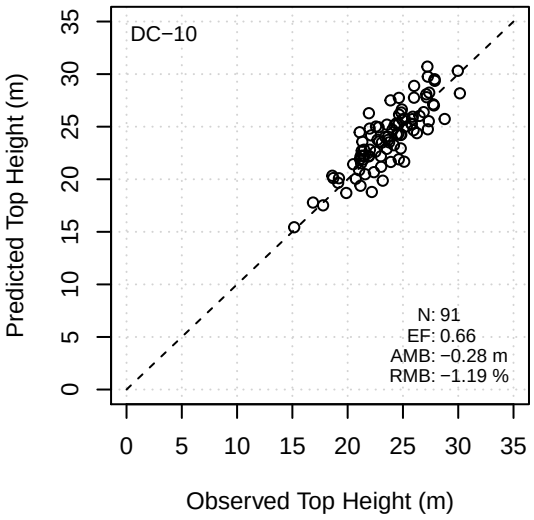

**Deciduous Basal Area − DC**



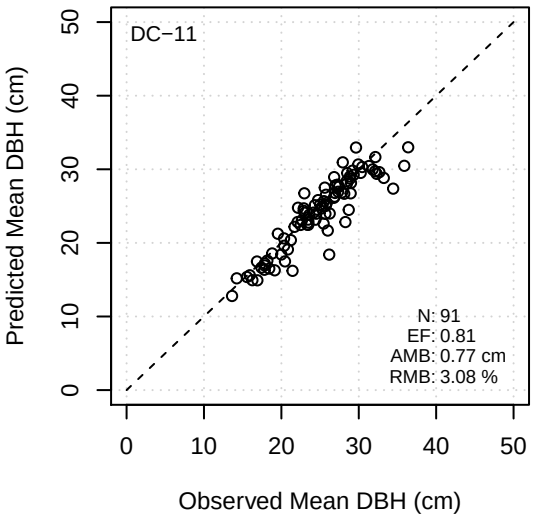

**Deciduous Mean Height − DC**



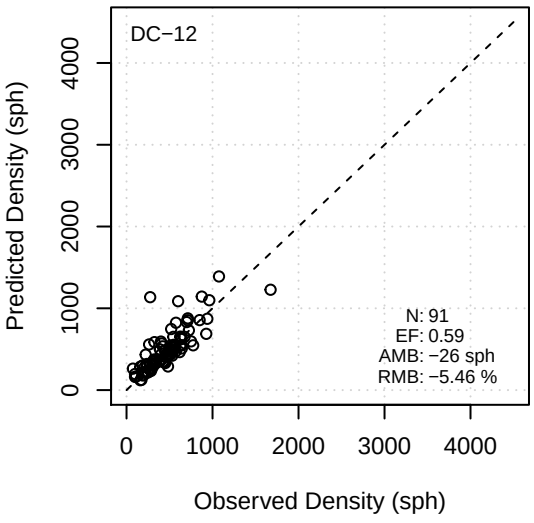

**Deciduous Top Height − DC**



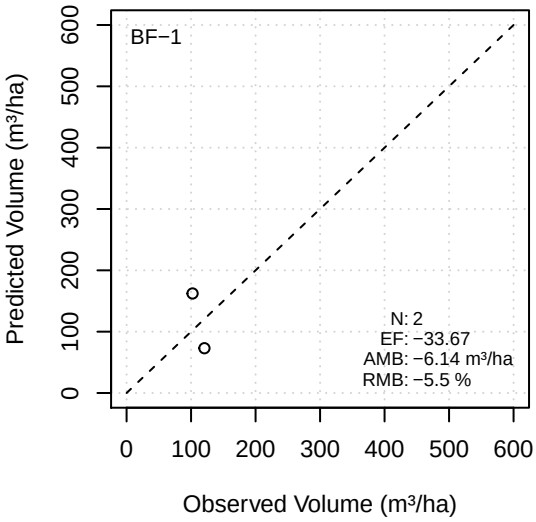

**Deciduous Mean DBH − DC**



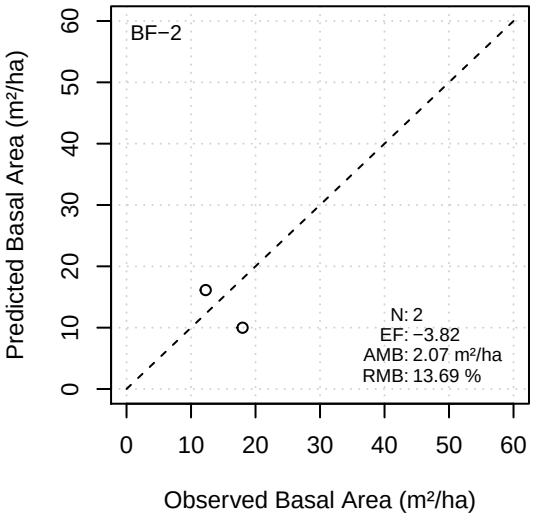

**Deciduous Density − DC**



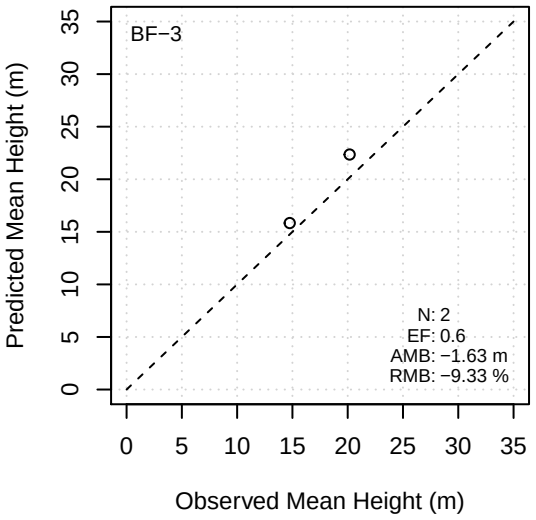
**Conifer Volume − BF**



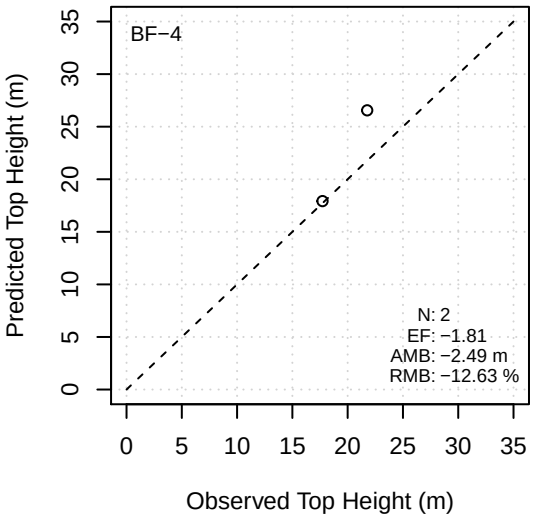

**Conifer Basal Area − BF**



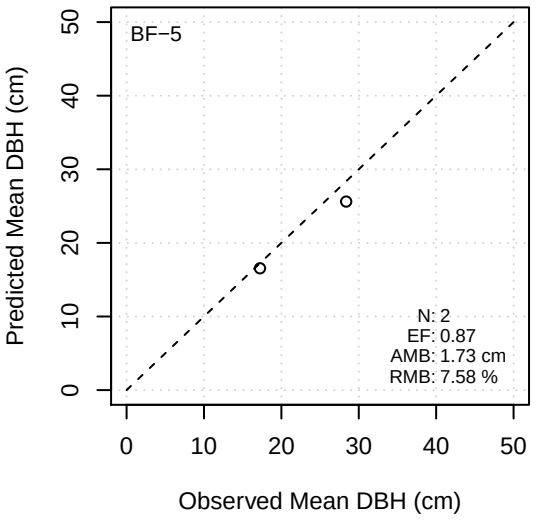

**Conifer Mean Height − BF**



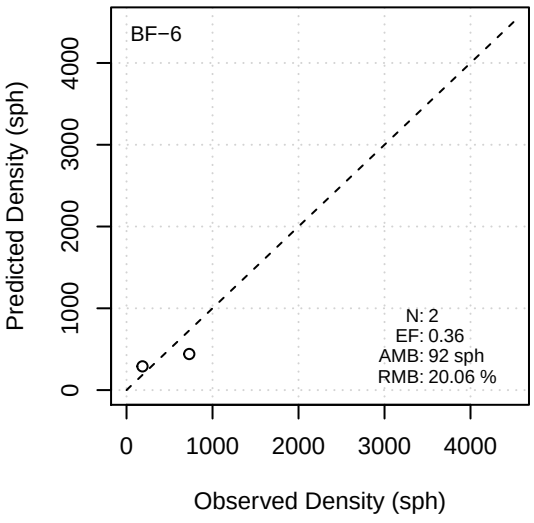

**Conifer Top Height − BF**



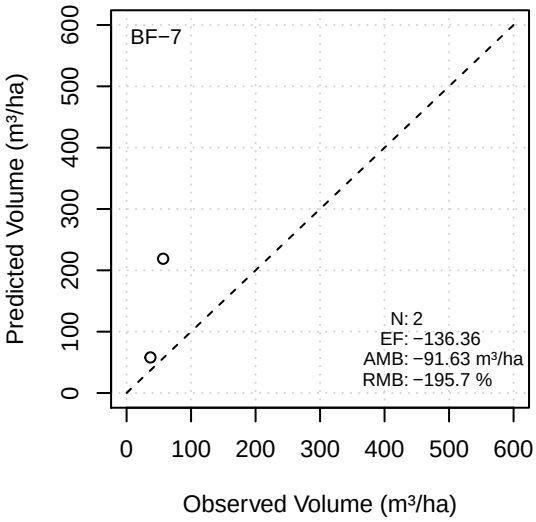

**Conifer Mean DBH − BF**



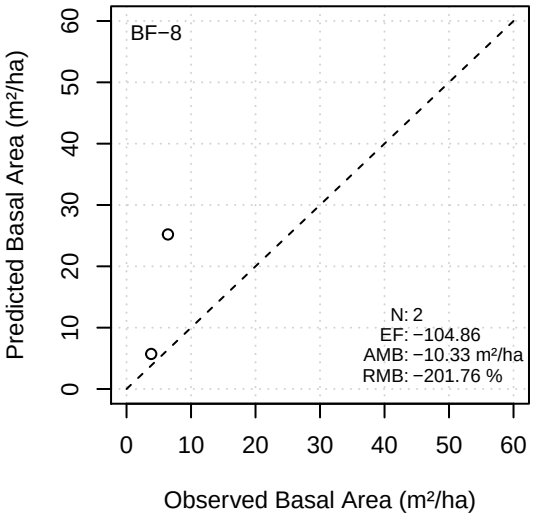

**Conifer Density − BF**



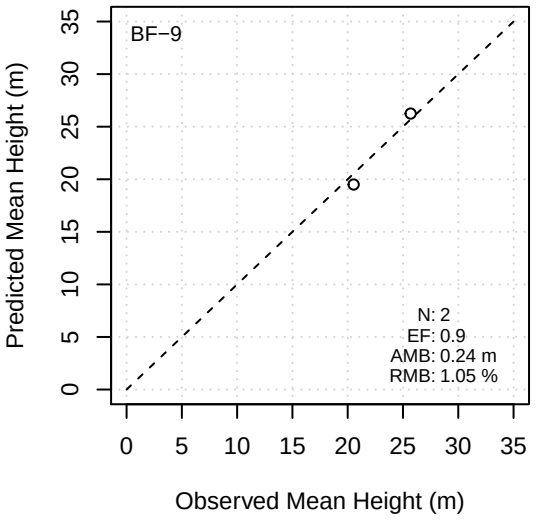
**Deciduous Volume − BF**



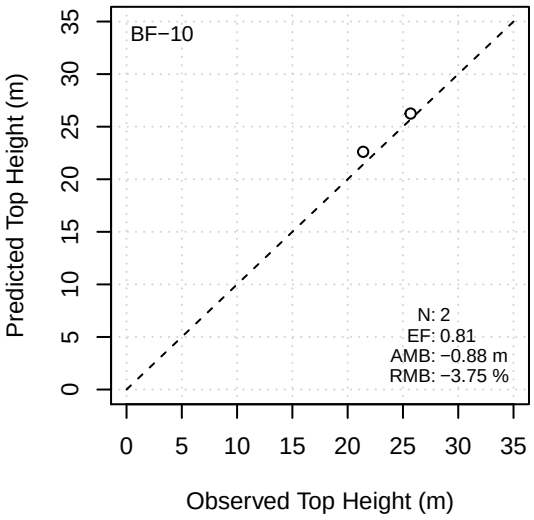

**Deciduous Basal Area − BF**



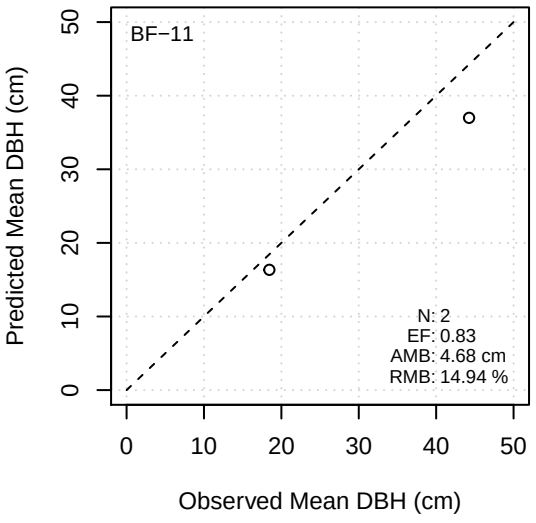

**Deciduous Mean Height − BF**



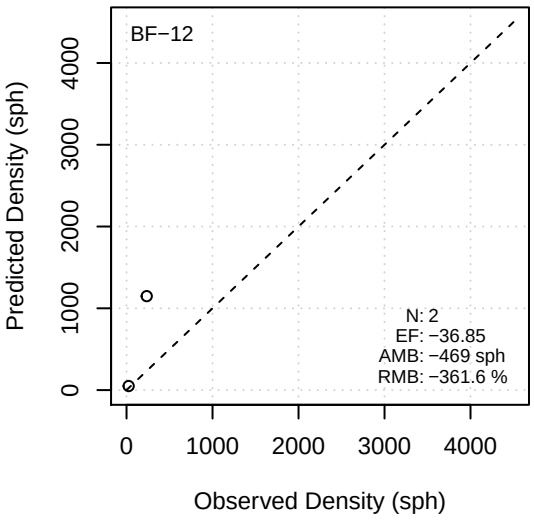

**Deciduous Top Height − BF**



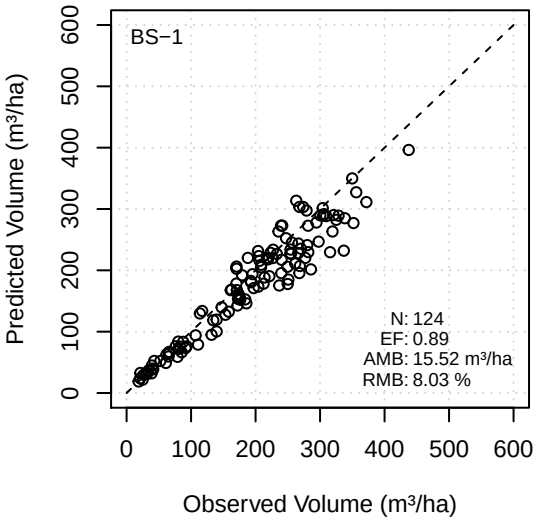

**Deciduous Mean DBH − BF**



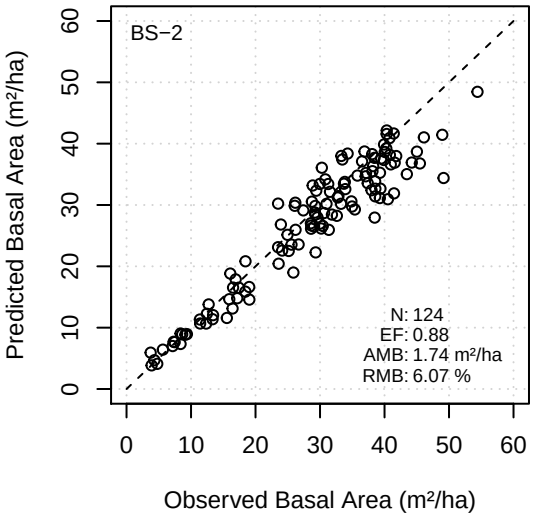

**Deciduous Density − BF**



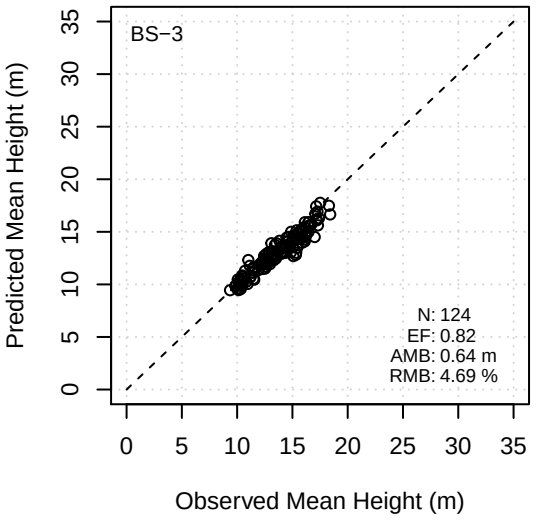
**Conifer Volume − BS**



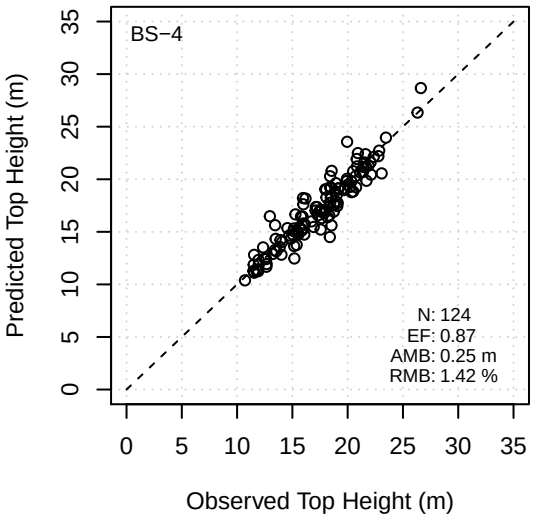

**Conifer Basal Area − BS**



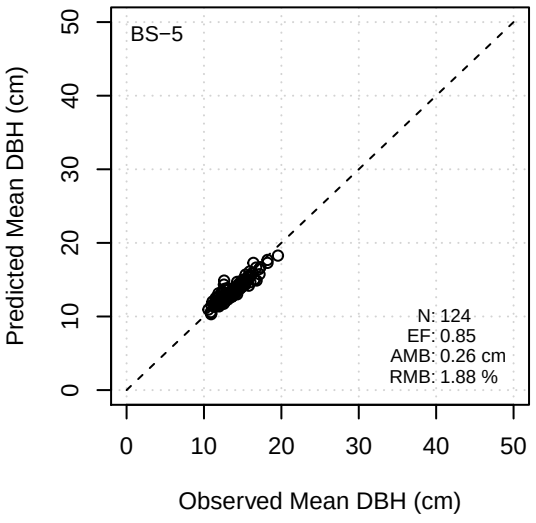

**Conifer Mean Height − BS**



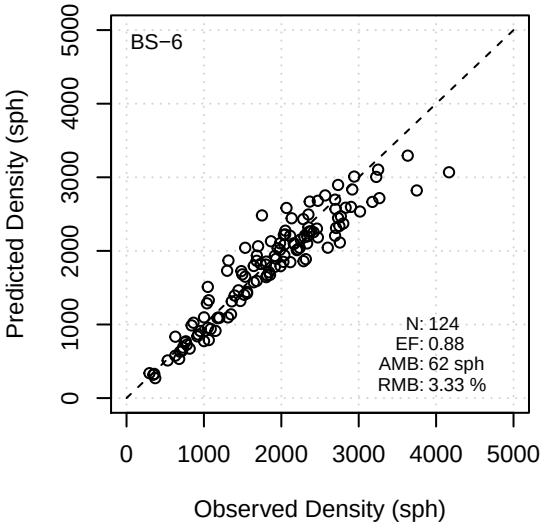

**Conifer Top Height − BS**



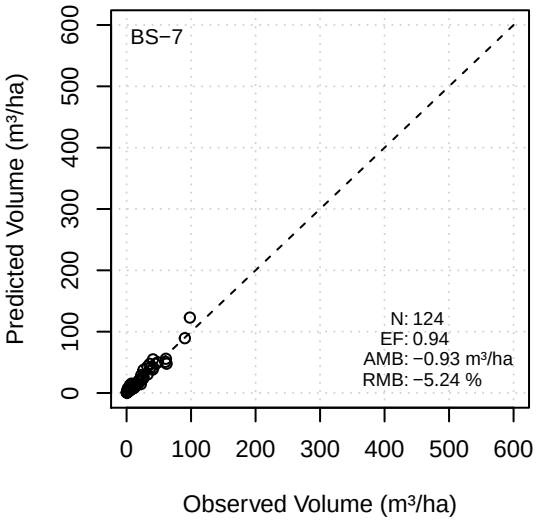

**Conifer Mean DBH − BS**



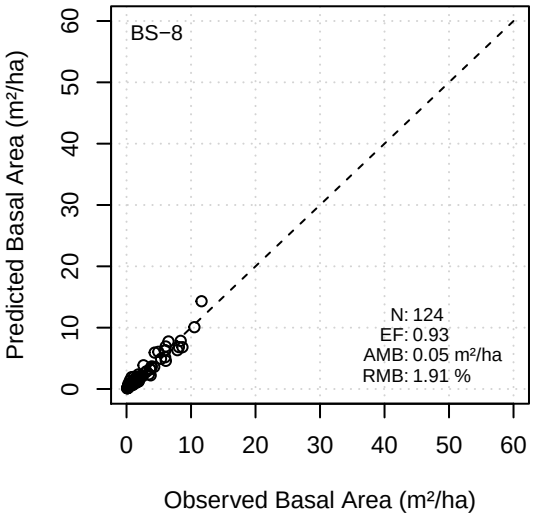

**Conifer Density − BS**



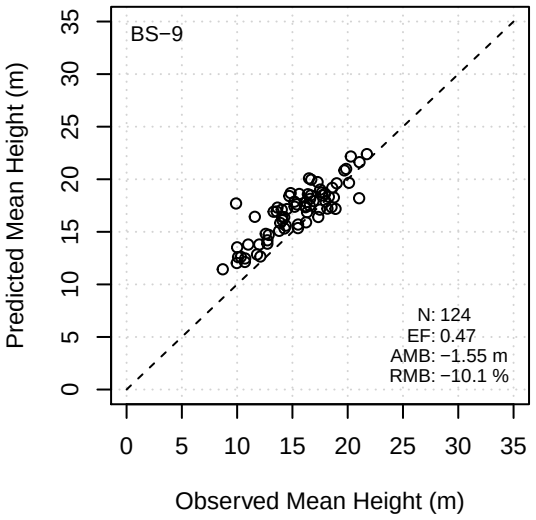
**Deciduous Volume − BS**



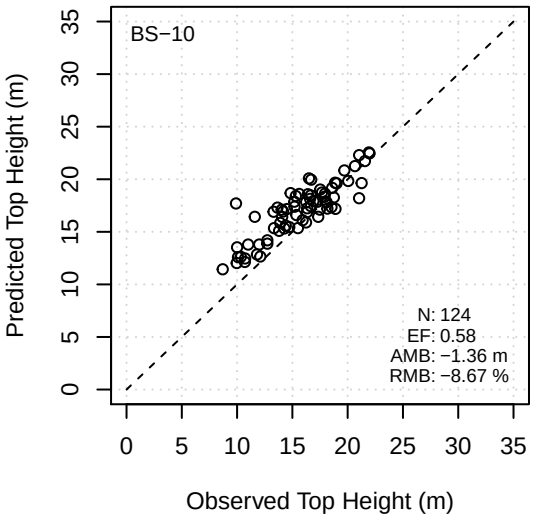

**Deciduous Basal Area − BS**



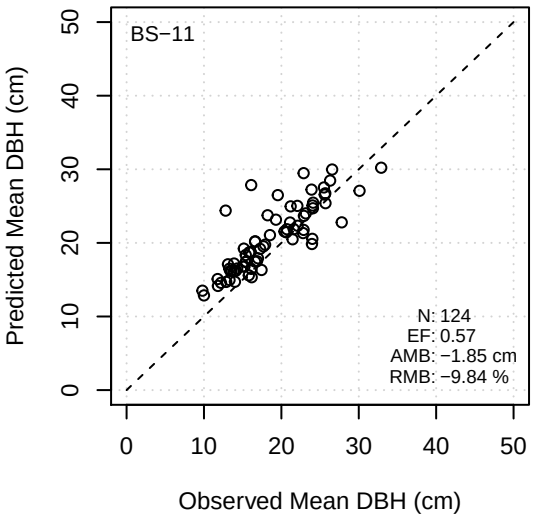

**Deciduous Mean Height − BS**



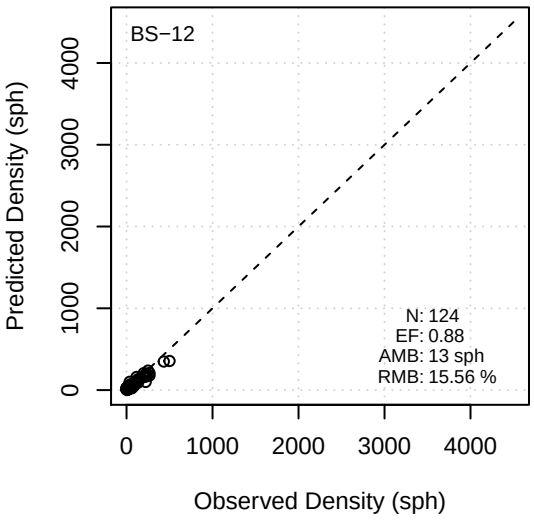

**Deciduous Top Height − BS**



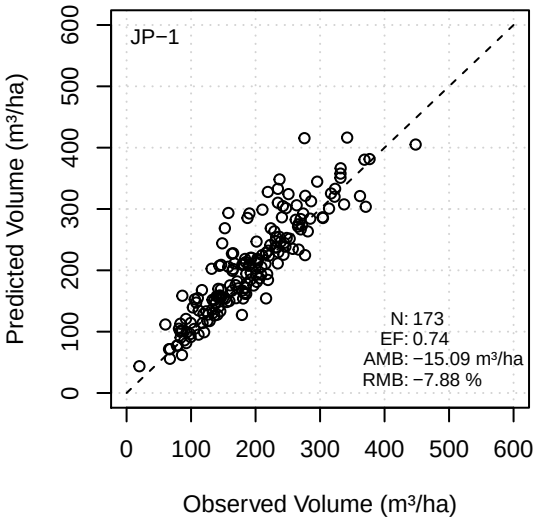

**Deciduous Mean DBH − BS**



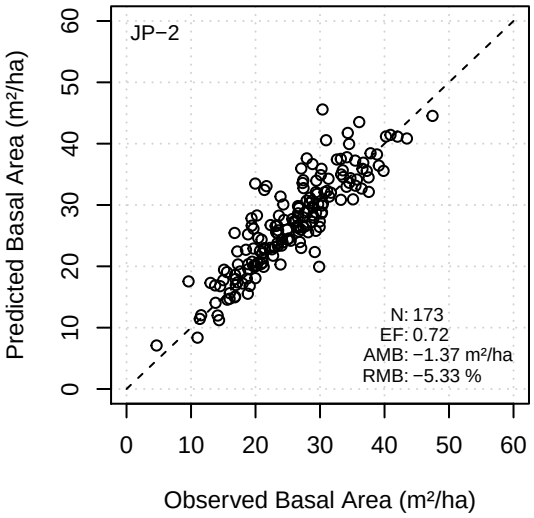

**Deciduous Density − BS**



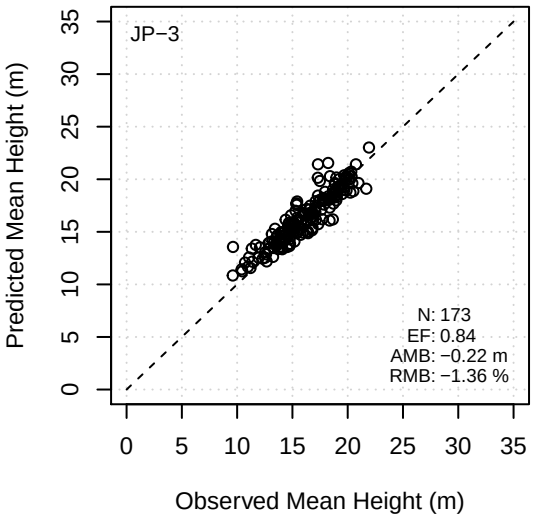
**Conifer Volume − JP**



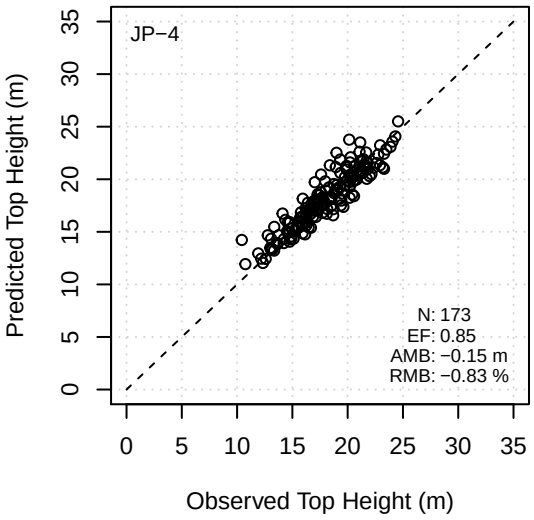

**Conifer Basal Area − JP**



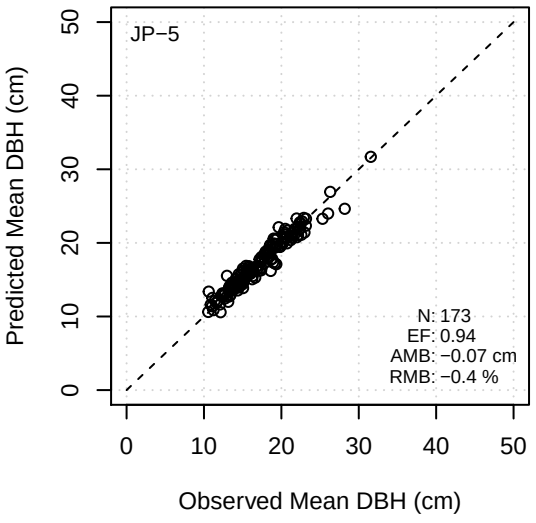

**Conifer Mean Height − JP**



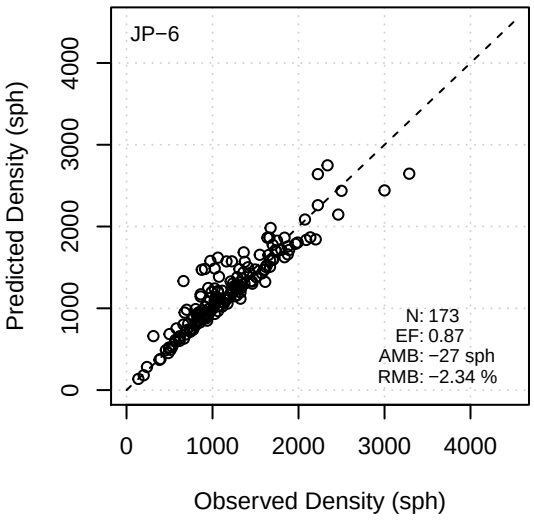

**Conifer Top Height − JP**



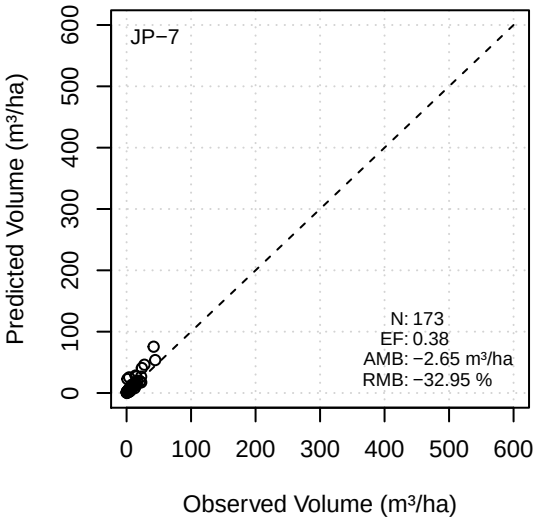

**Conifer Mean DBH − JP**



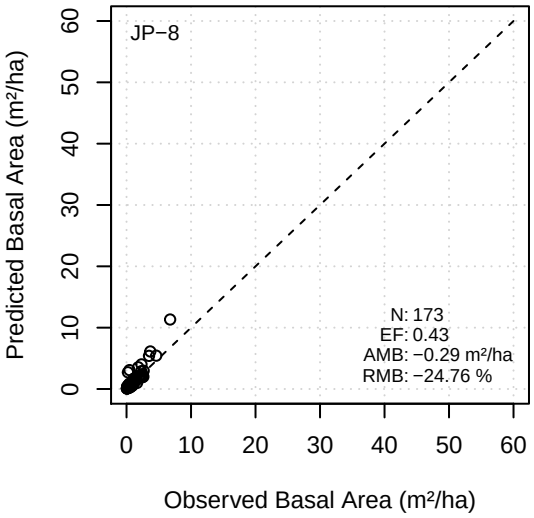

**Conifer Density − JP**



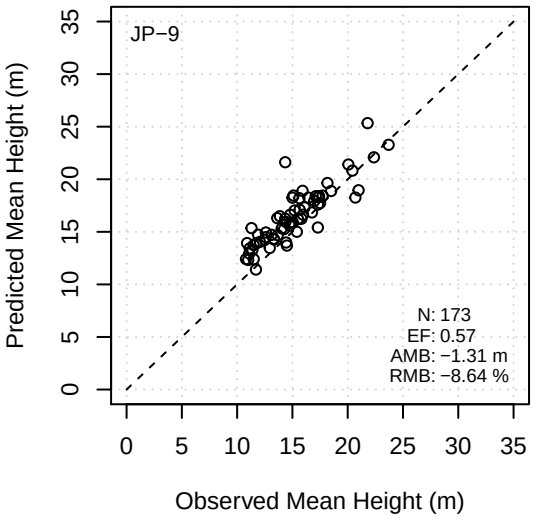
**Deciduous Volume − JP**



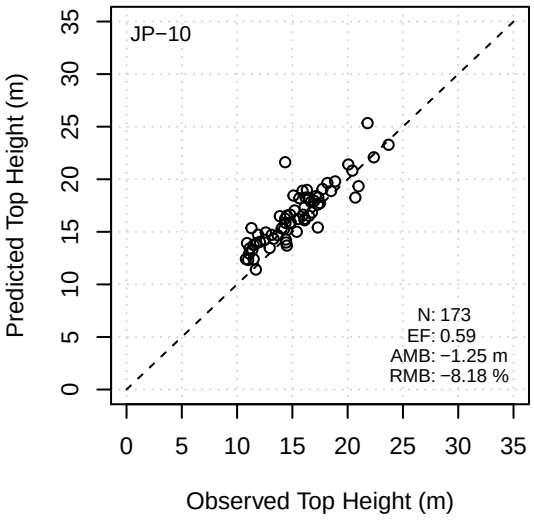

**Deciduous Basal Area − JP**



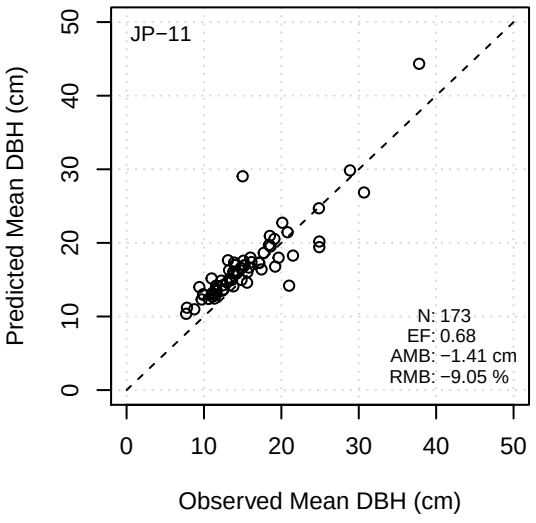

**Deciduous Mean Height − JP**



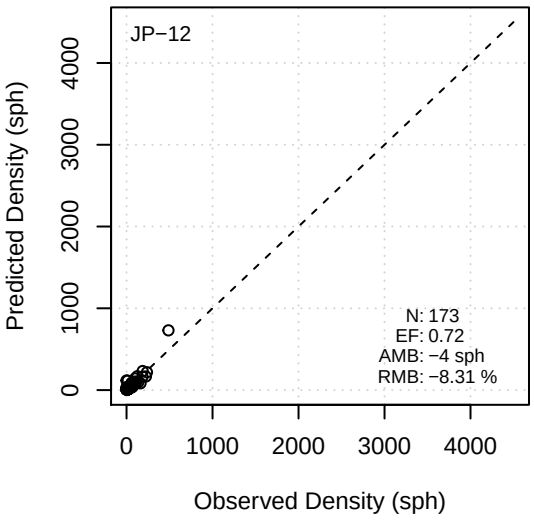

**Deciduous Top Height − JP**



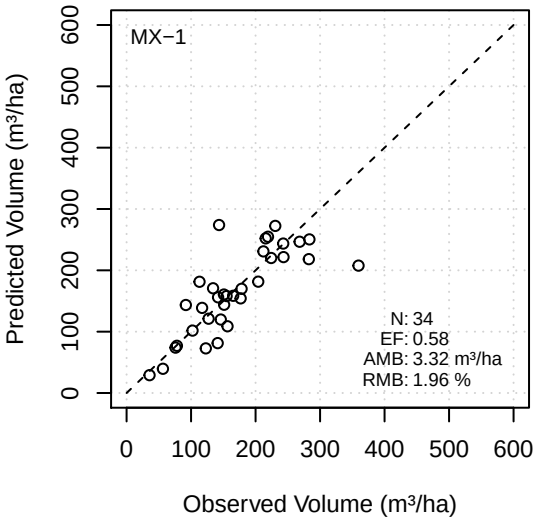

**Deciduous Mean DBH − JP**



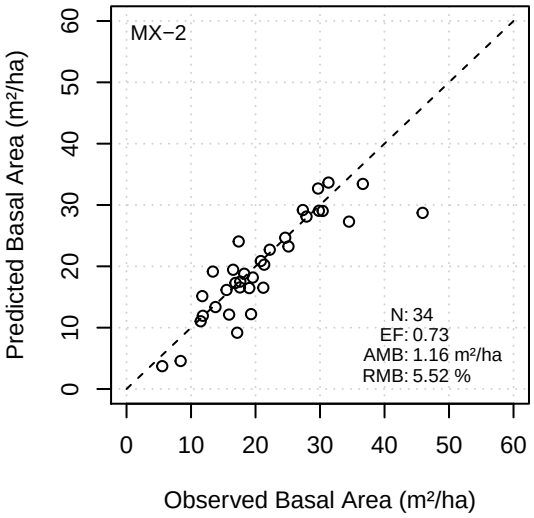

**Deciduous Density − JP**



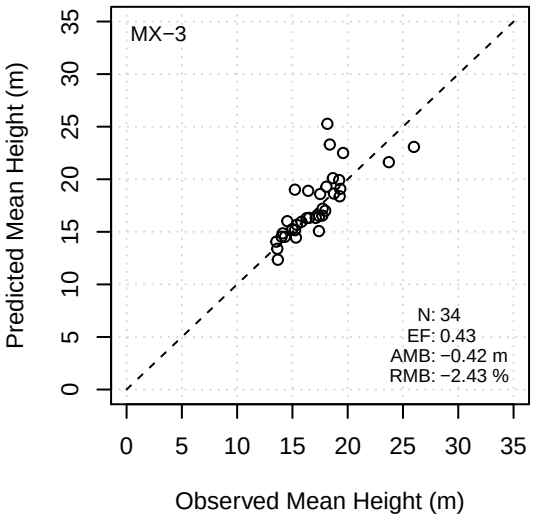
**Conifer Volume − MX**



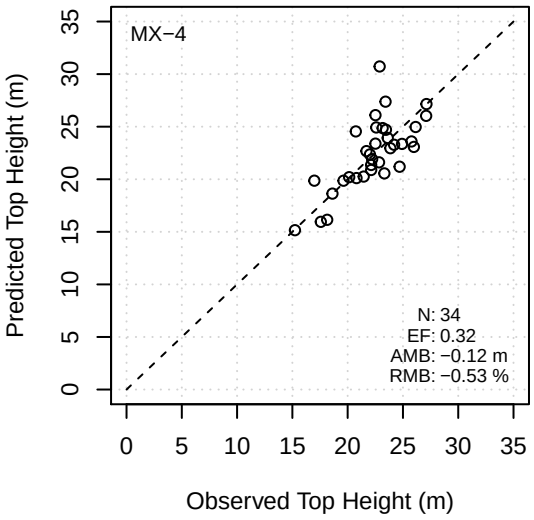

**Conifer Basal Area − MX**



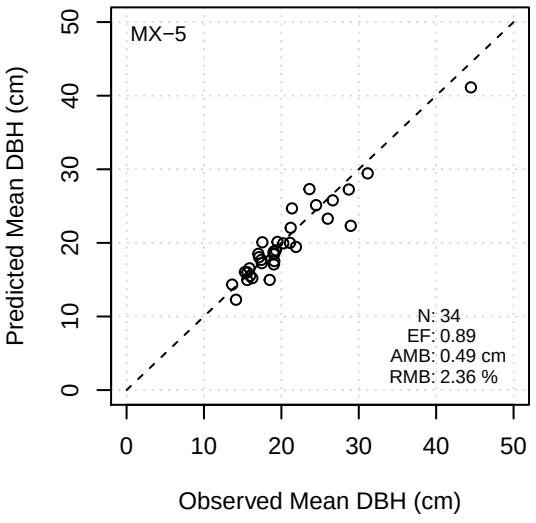

**Conifer Mean Height − MX**



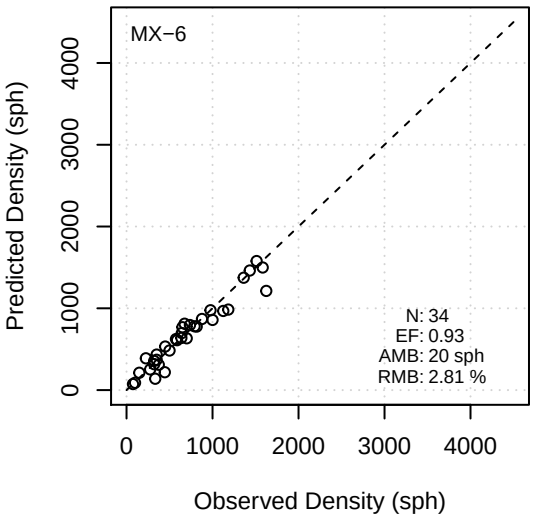

**Conifer Top Height − MX**



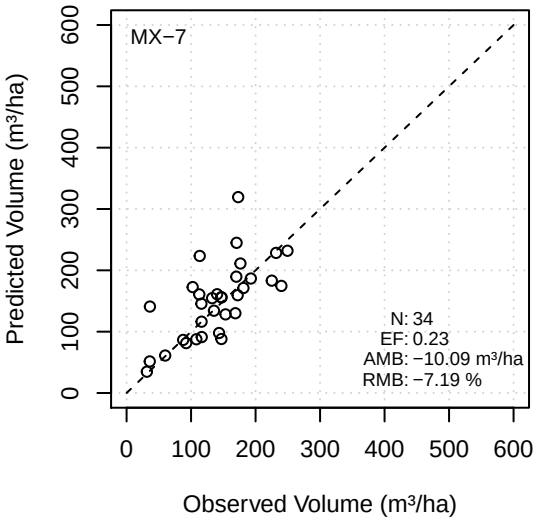

**Conifer Mean DBH − MX**



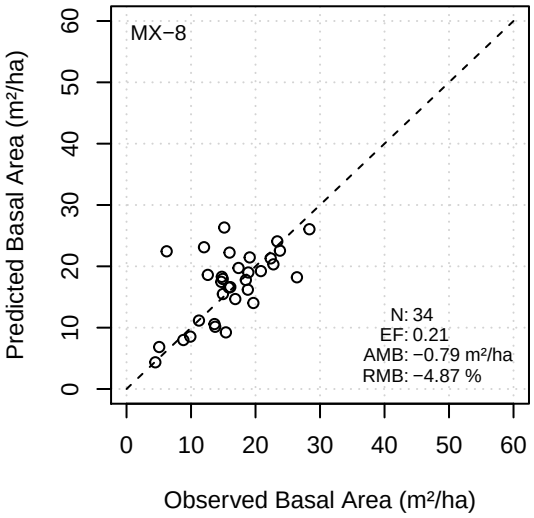

**Conifer Density − MX**



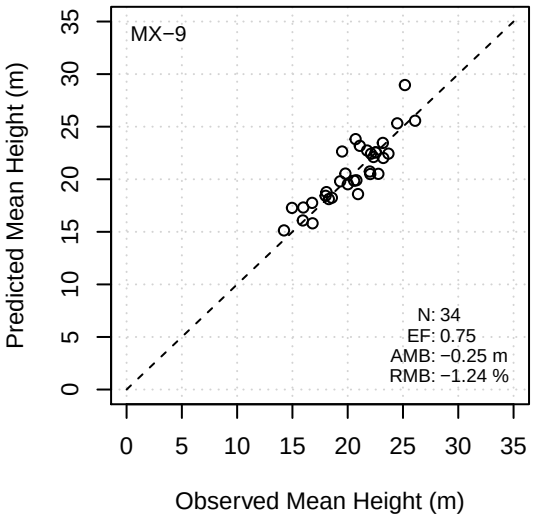
**Deciduous Volume − MX**



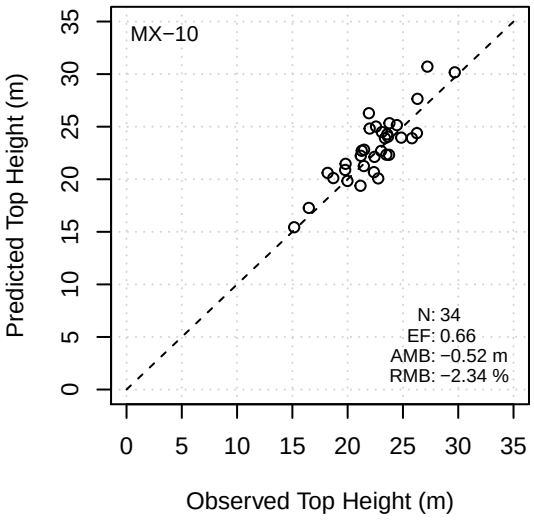

**Deciduous Basal Area − MX**



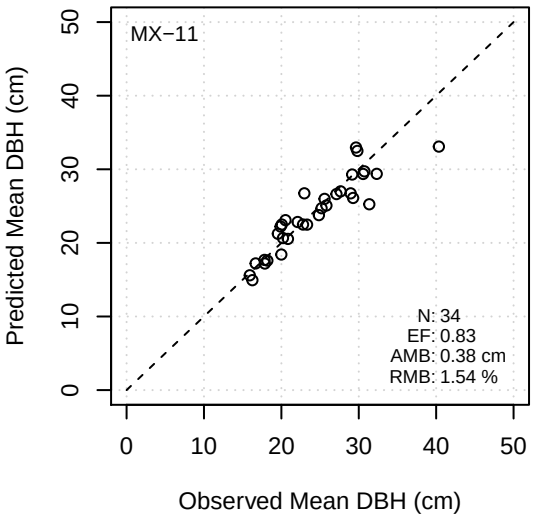

**Deciduous Mean Height − MX**



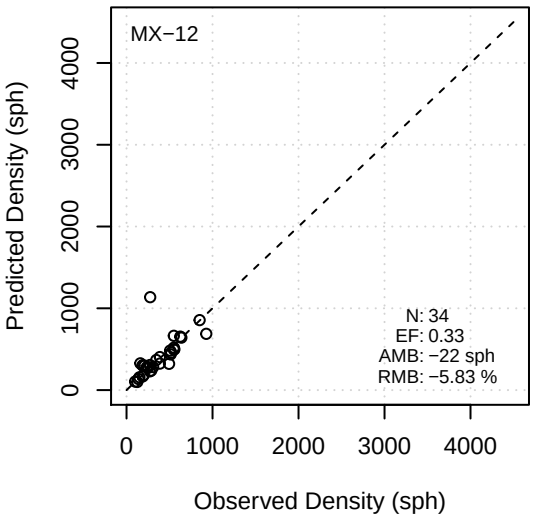

**Deciduous Top Height − MX**



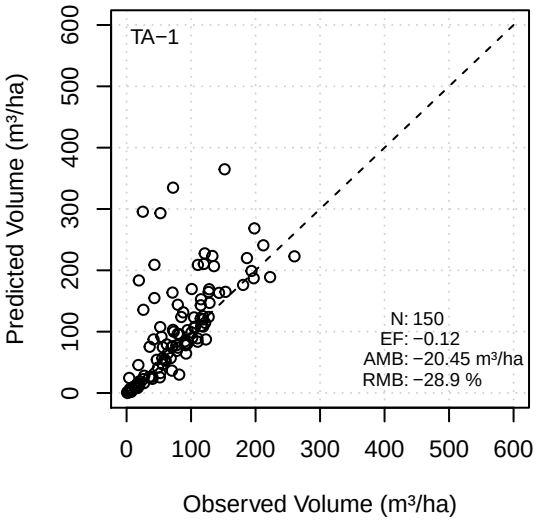

**Deciduous Mean DBH − MX**



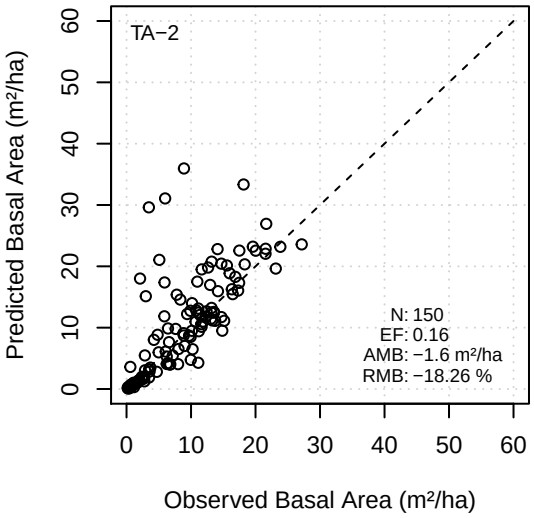

**Deciduous Density − MX**



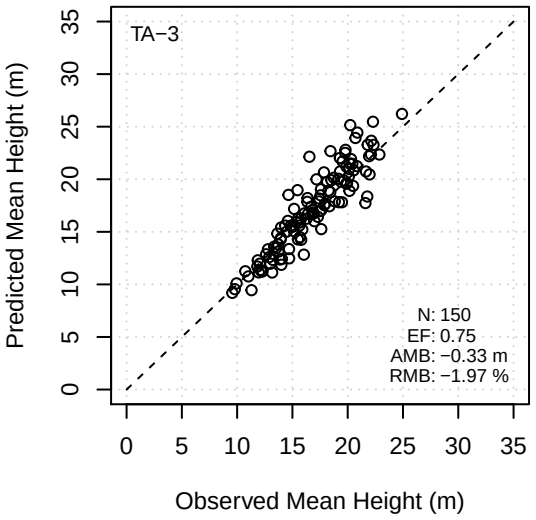
**Conifer Volume − TA**



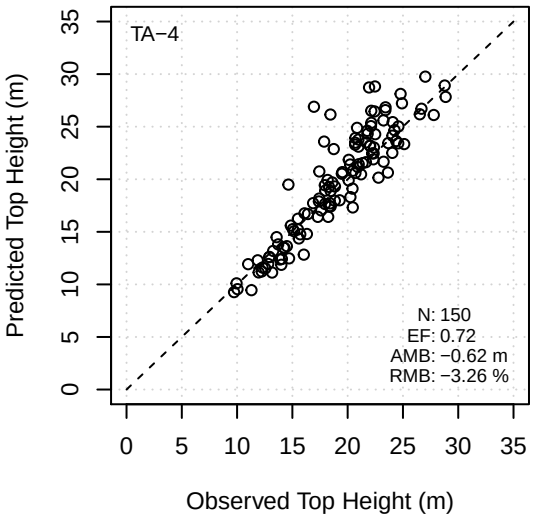

**Conifer Basal Area − TA**



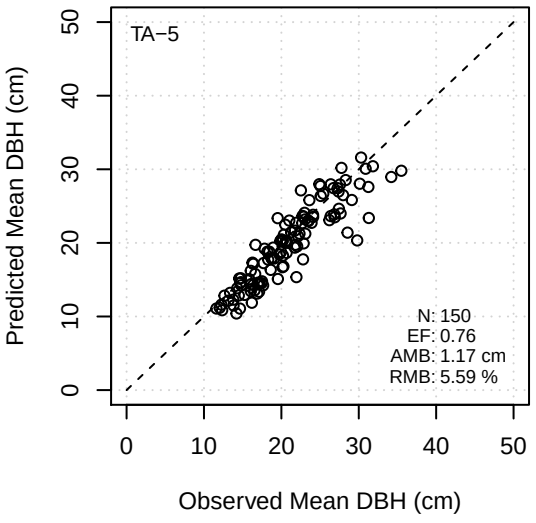

**Conifer Mean Height − TA**



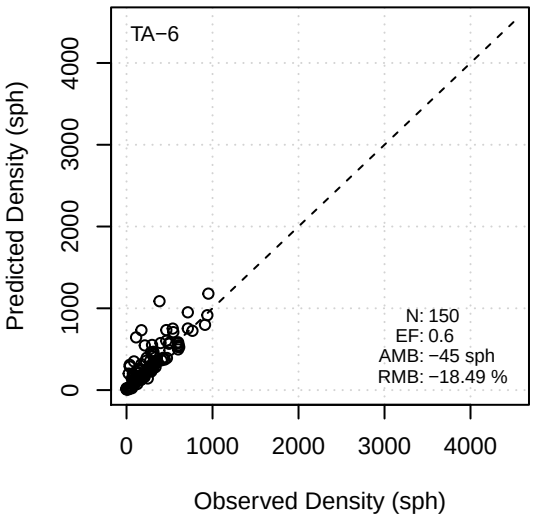

**Conifer Top Height − TA**



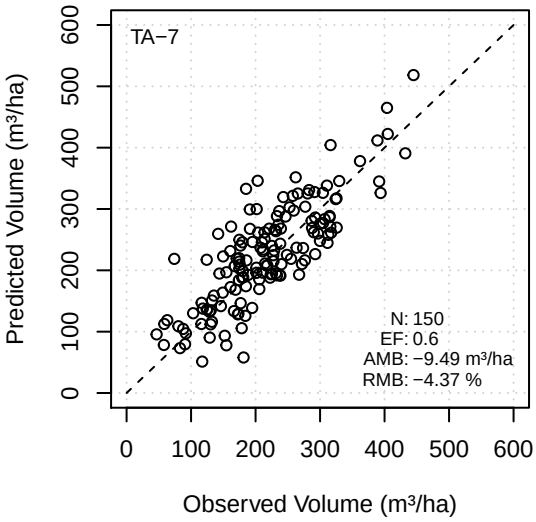

**Conifer Mean DBH − TA**



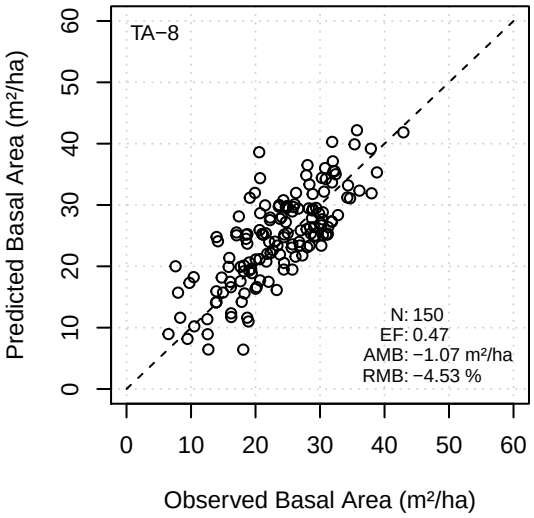

**Conifer Density − TA**



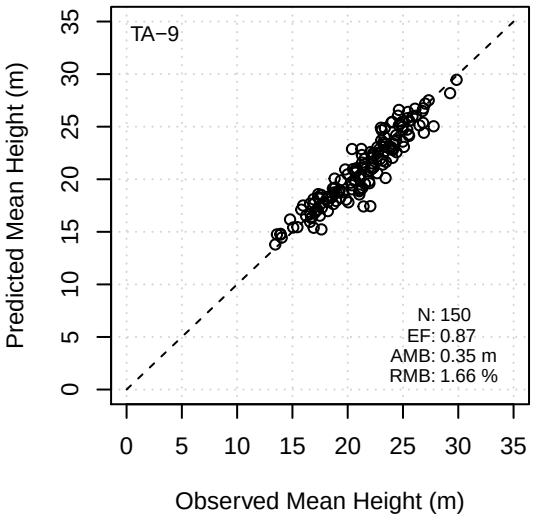
**Deciduous Volume − TA**



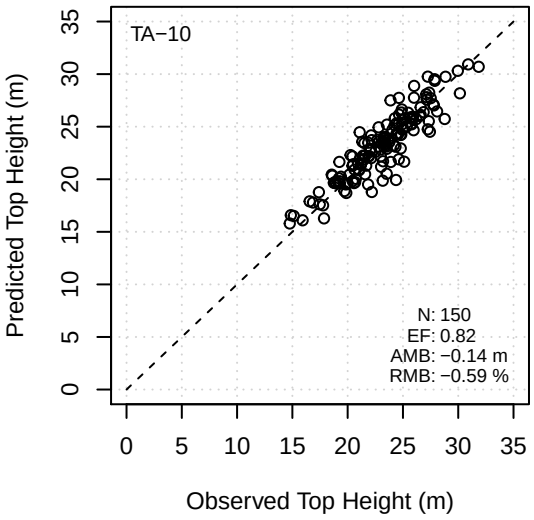

**Deciduous Basal Area − TA**



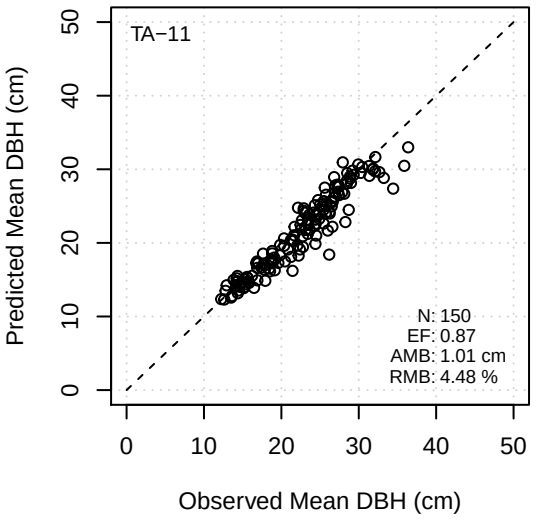

**Deciduous Mean Height − TA**



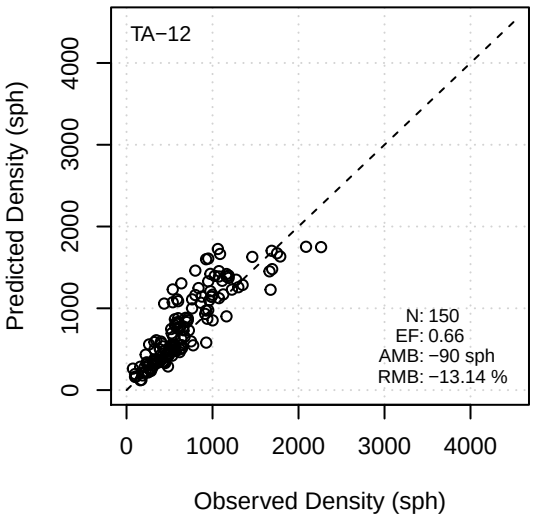

**Deciduous Top Height − TA**



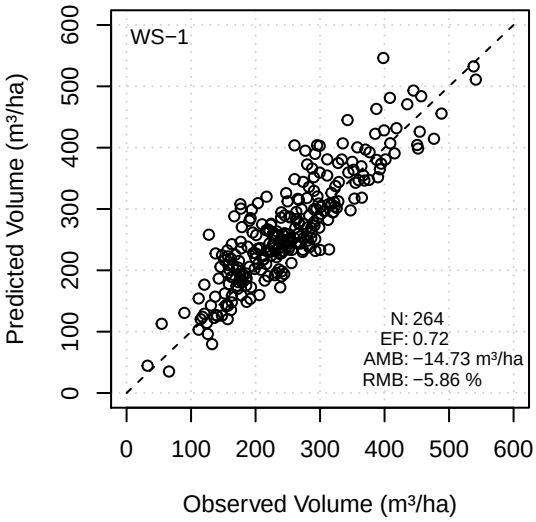

**Deciduous Mean DBH − TA**



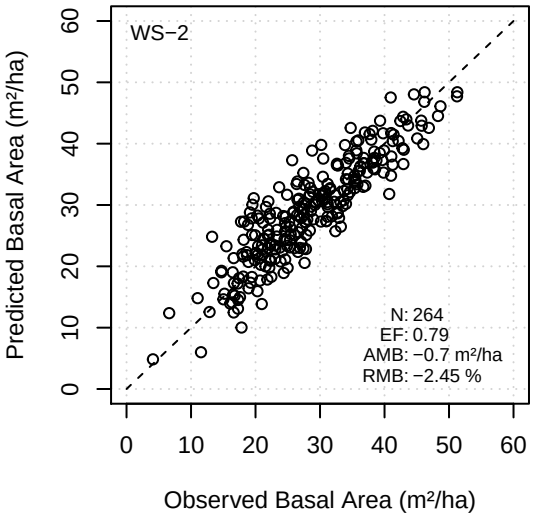

**Deciduous Density − TA**



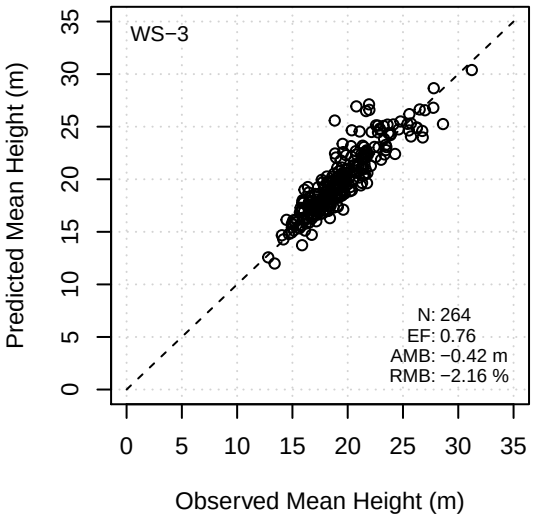
**Conifer Volume − WS**



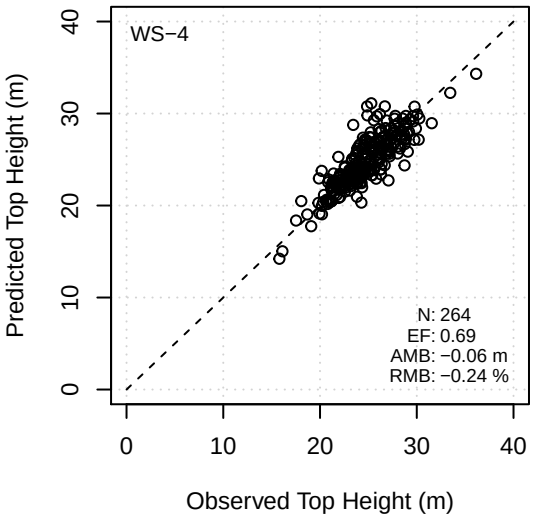

**Conifer Basal Area − WS**



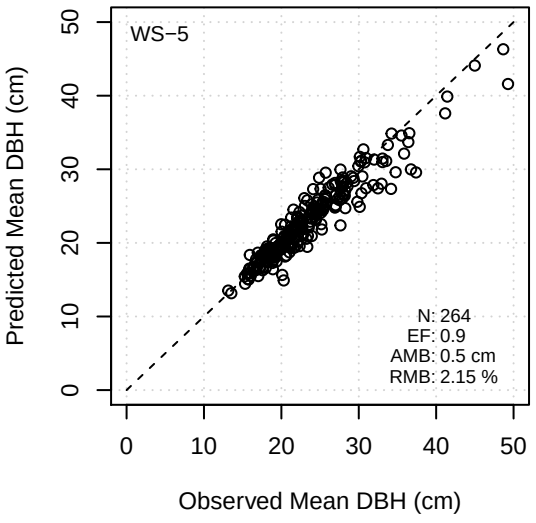

**Conifer Mean Height − WS**



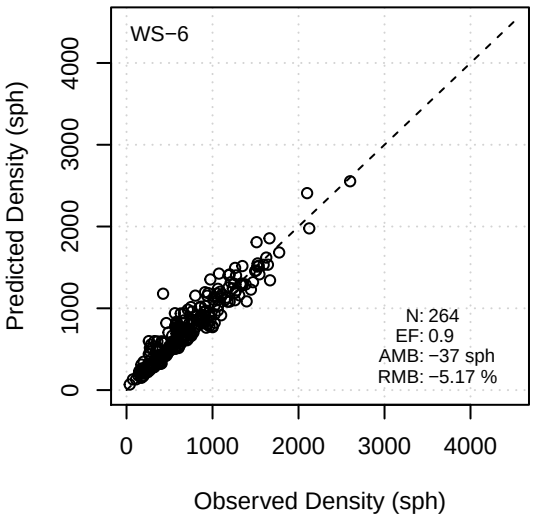

**Conifer Top Height − WS**



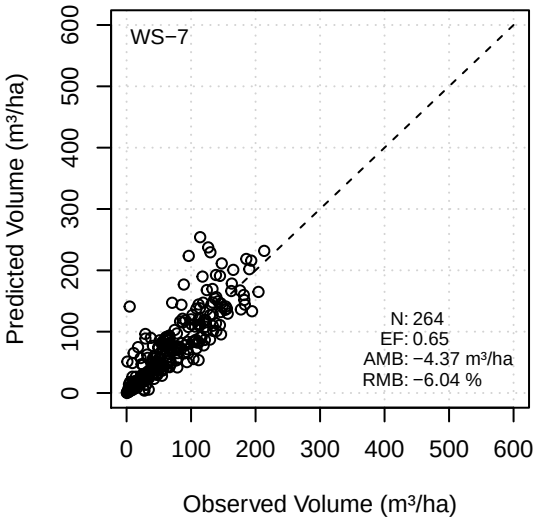

**Conifer Mean DBH − WS**



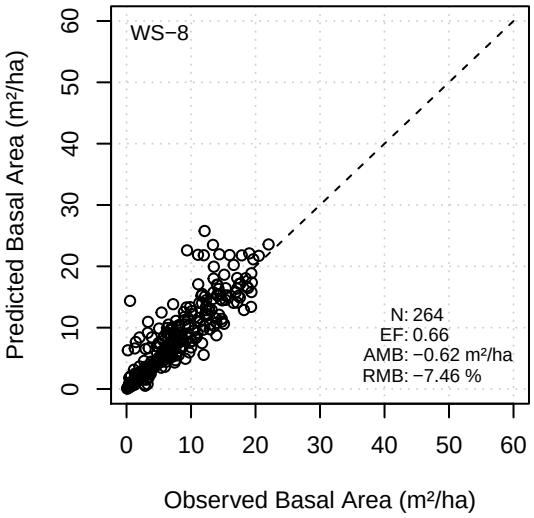

**Conifer Density − WS**



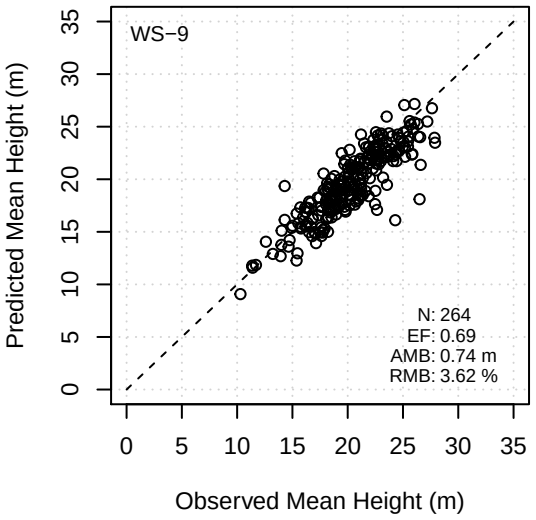
**Deciduous Volume − WS**



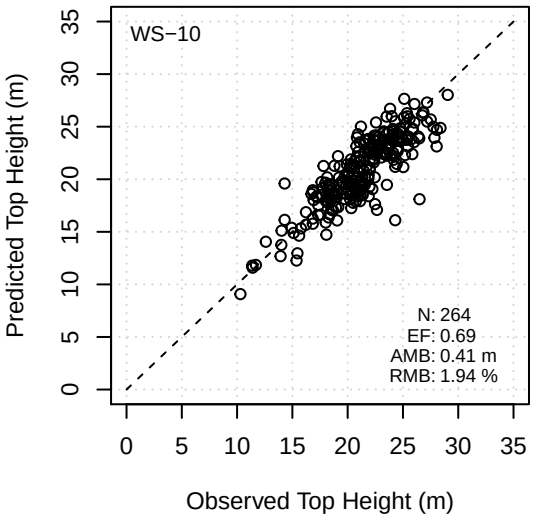

**Deciduous Basal Area − WS**



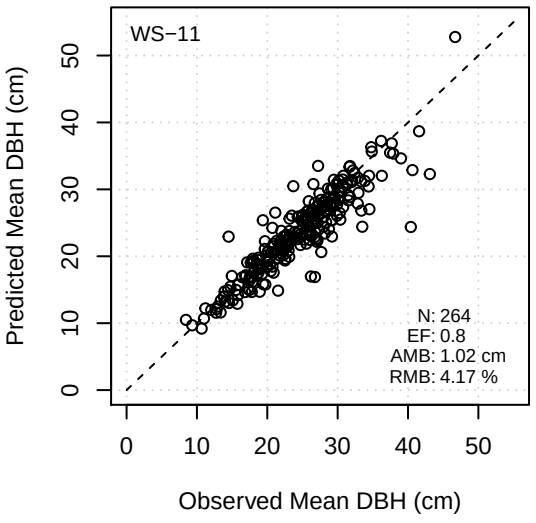

**Deciduous Mean Height − WS**



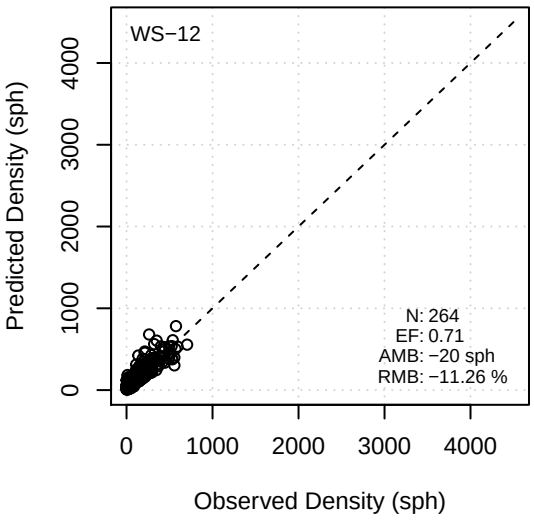

**Deciduous Top Height − WS**



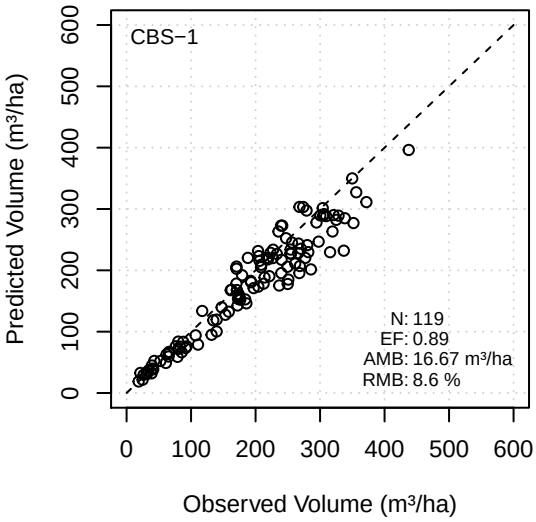

**Deciduous Mean DBH − WS**



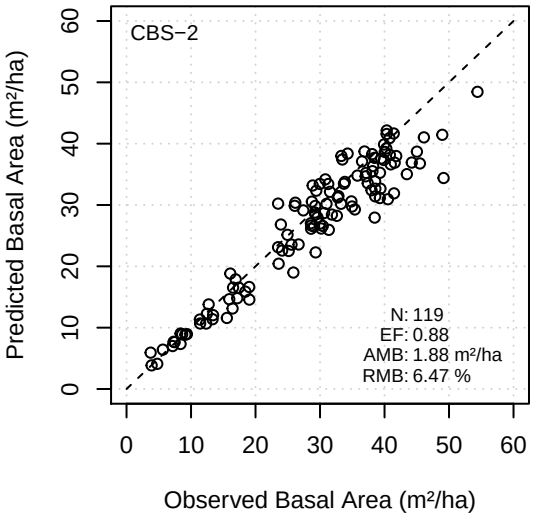

**Deciduous Density − WS**



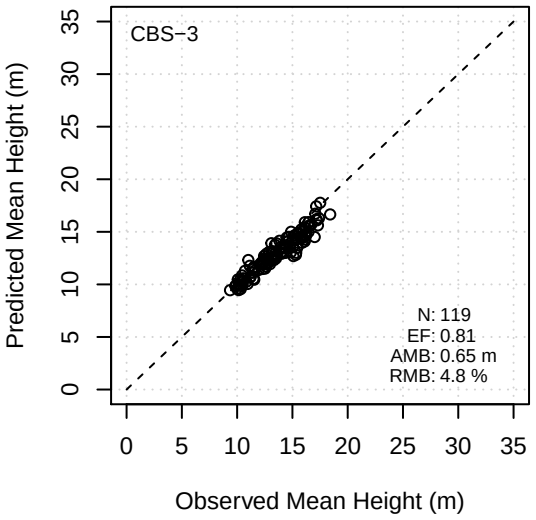
**Conifer Volume − CBS**



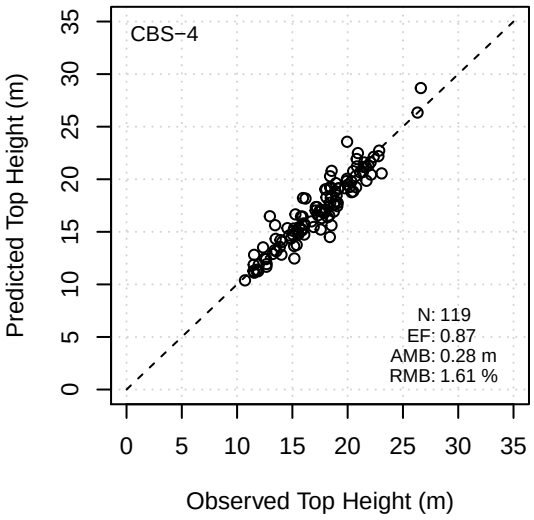

**Conifer Basal Area − CBS**



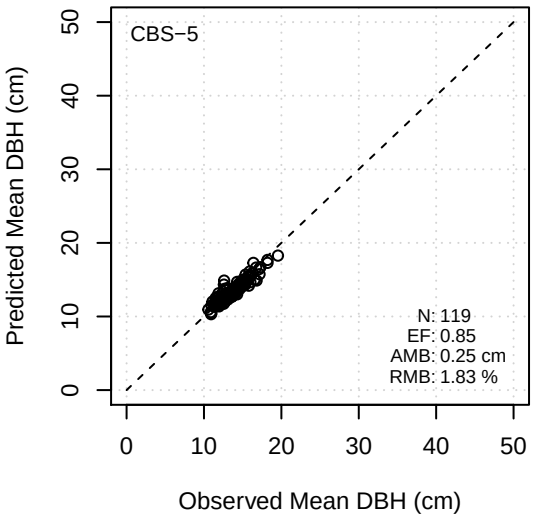

**Conifer Mean Height − CBS**



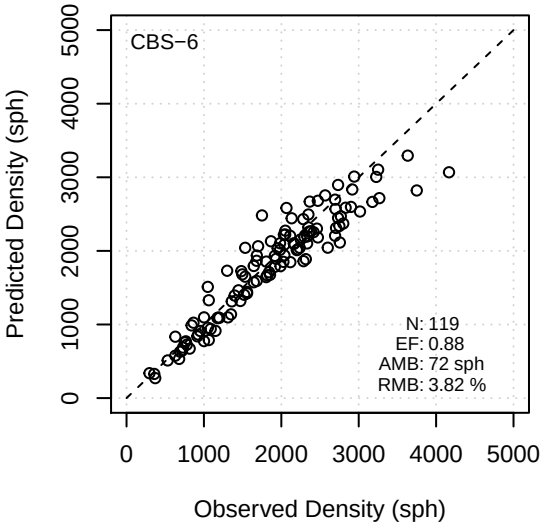

**Conifer Top Height − CBS**



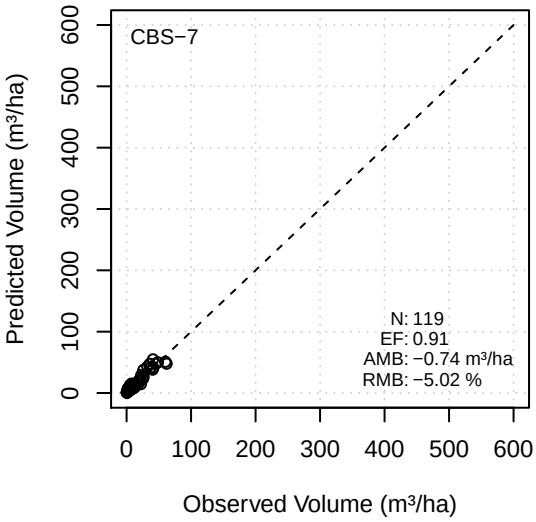

**Conifer Mean DBH − CBS**



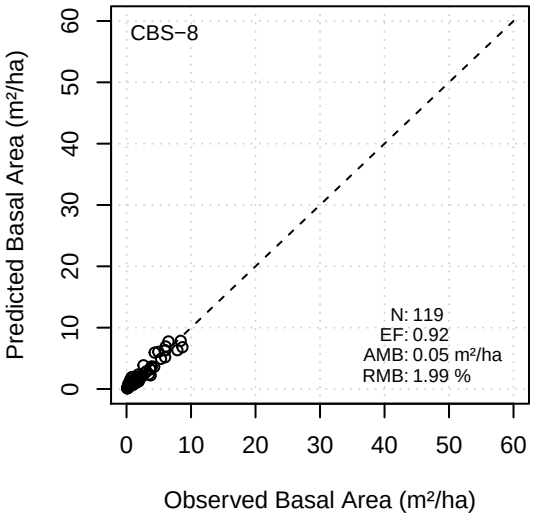

**Conifer Density − CBS**



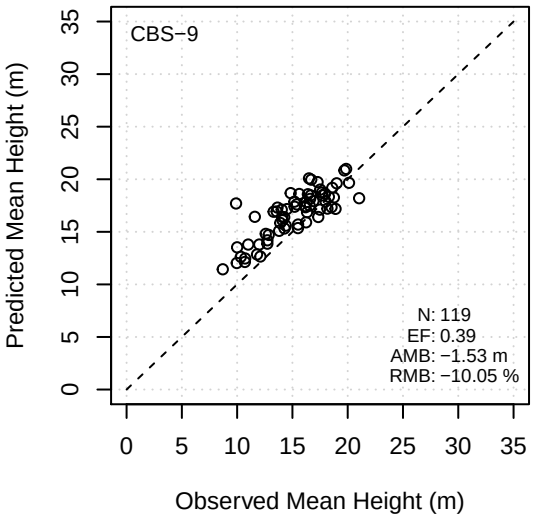
**Deciduous Volume − CBS**



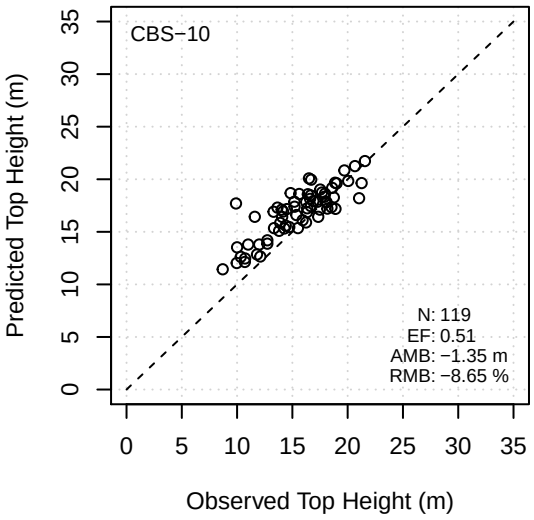

**Deciduous Basal Area − CBS**



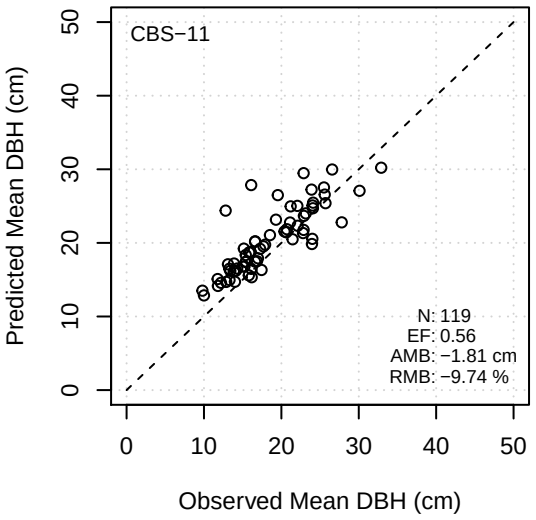

**Deciduous Mean Height − CBS**



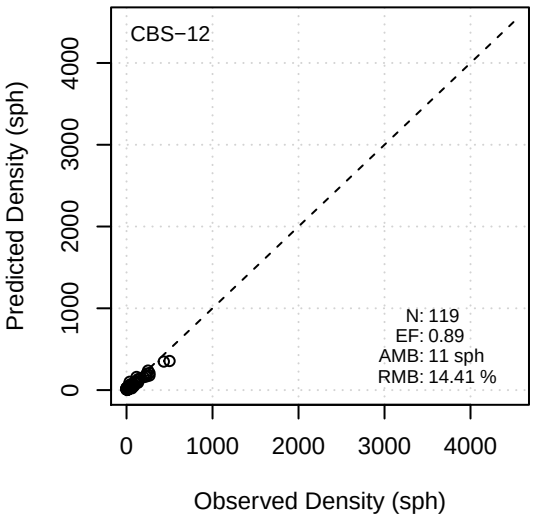

**Deciduous Top Height − CBS**



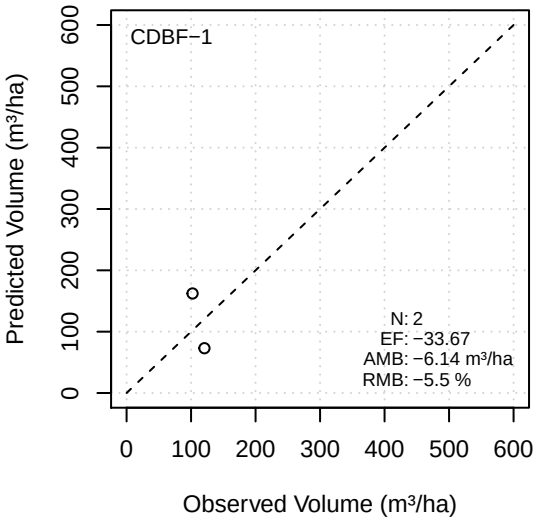

**Deciduous Mean DBH − CBS**



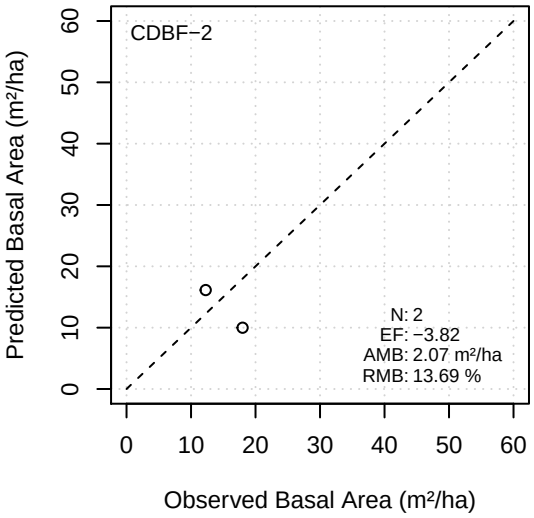

**Deciduous Density − CBS**



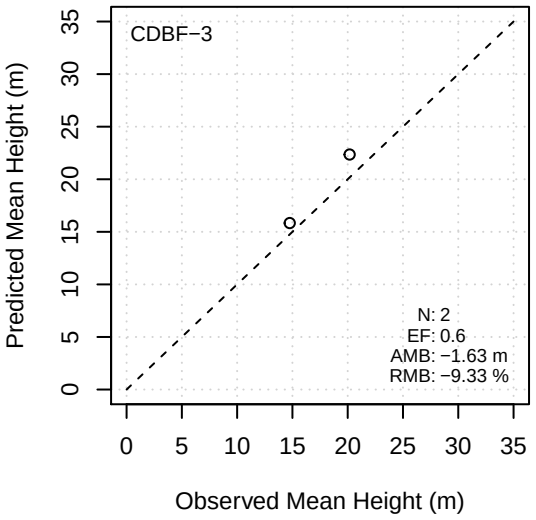
**Conifer Volume − CDBF**



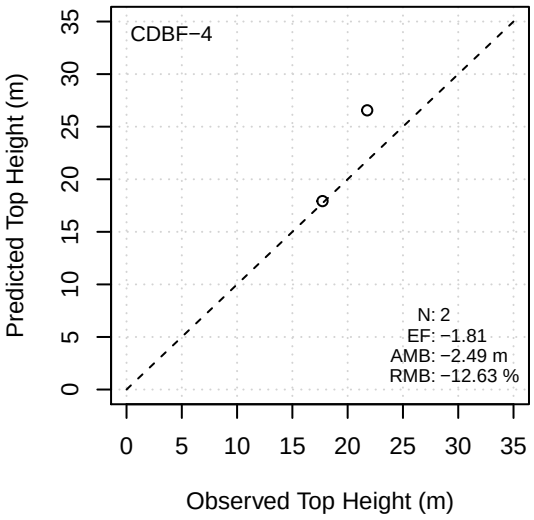

**Conifer Basal Area − CDBF**



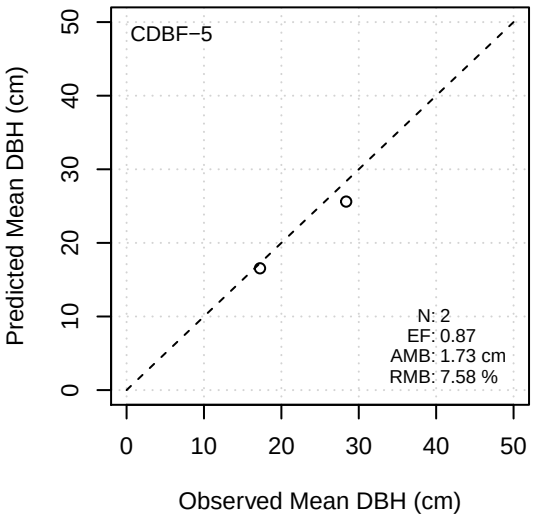

**Conifer Mean Height − CDBF**



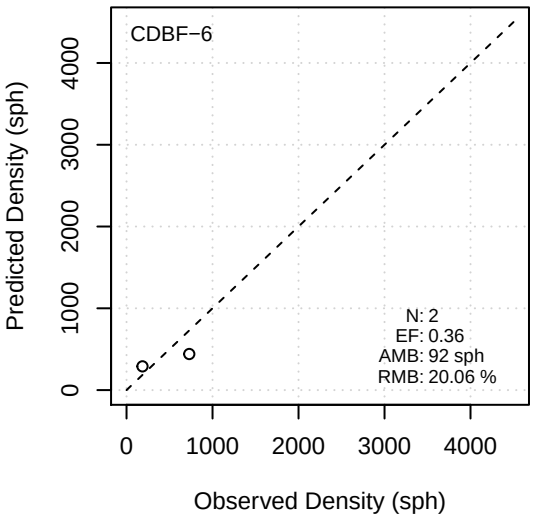

**Conifer Top Height − CDBF**



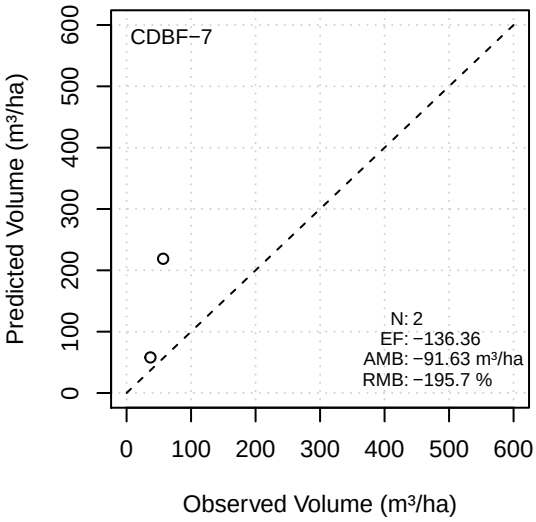

**Conifer Mean DBH − CDBF**



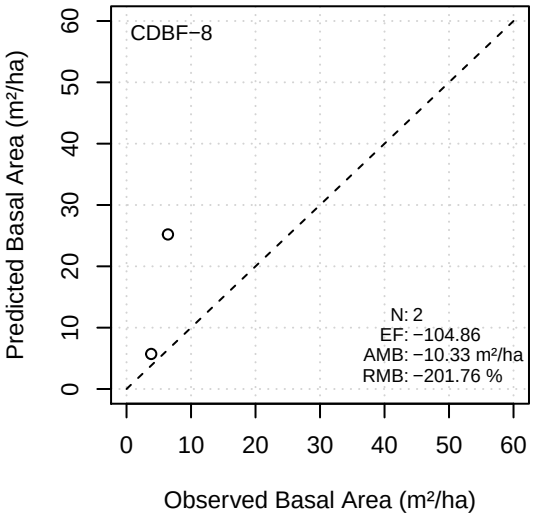

**Conifer Density − CDBF**



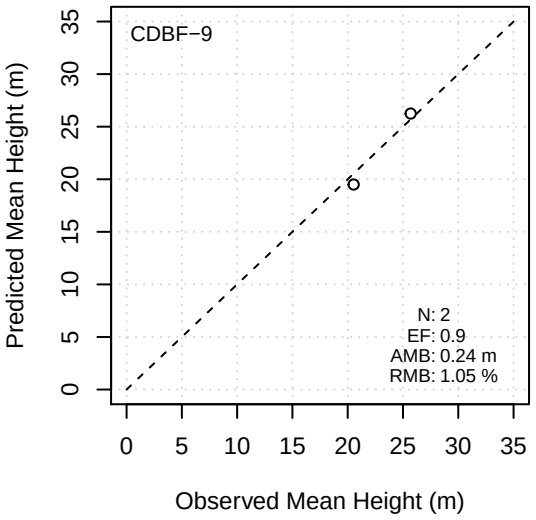
**Deciduous Volume − CDBF**



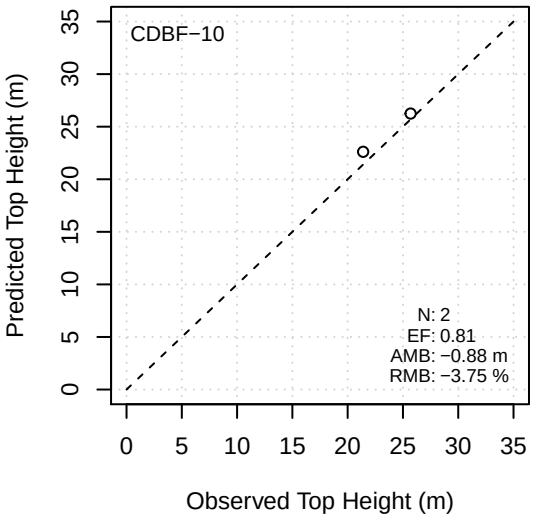

**Deciduous Basal Area − CDBF**



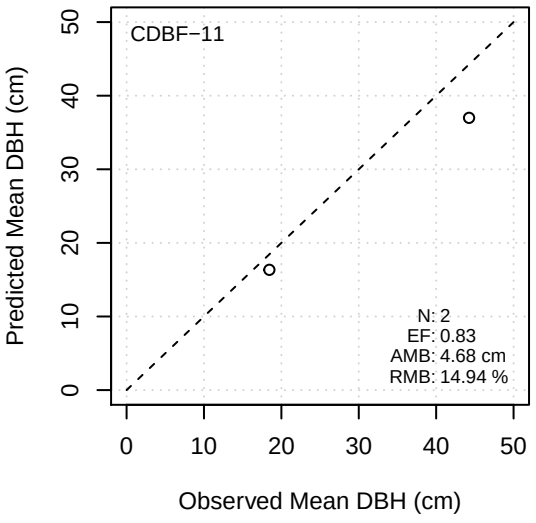

**Deciduous Mean Height − CDBF**



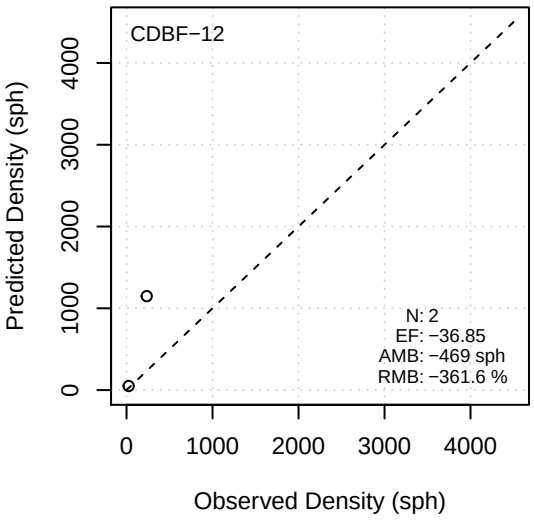

**Deciduous Top Height − CDBF**



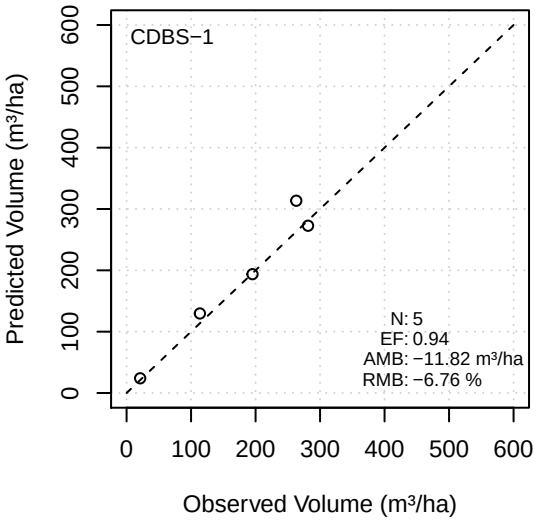

**Deciduous Mean DBH − CDBF**



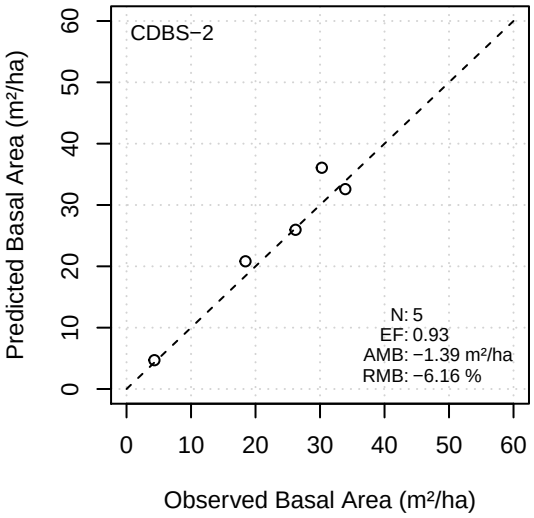

**Deciduous Density − CDBF**



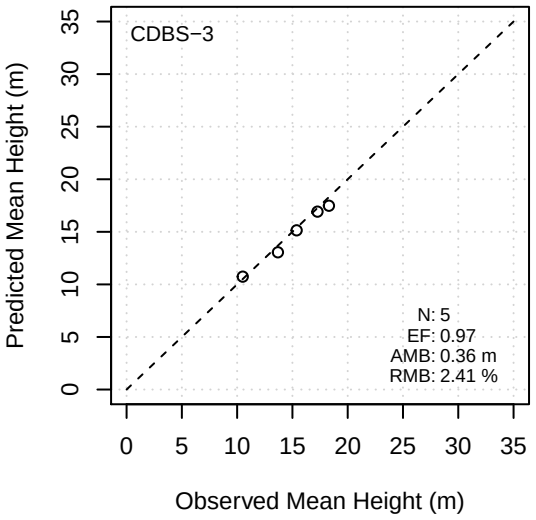
**Conifer Volume − CDBS**



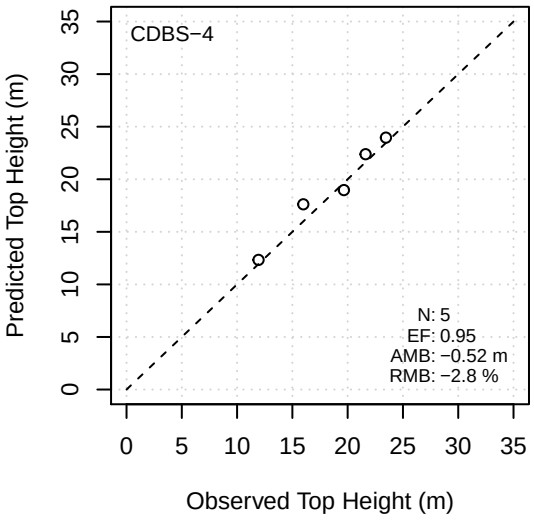

**Conifer Basal Area − CDBS**



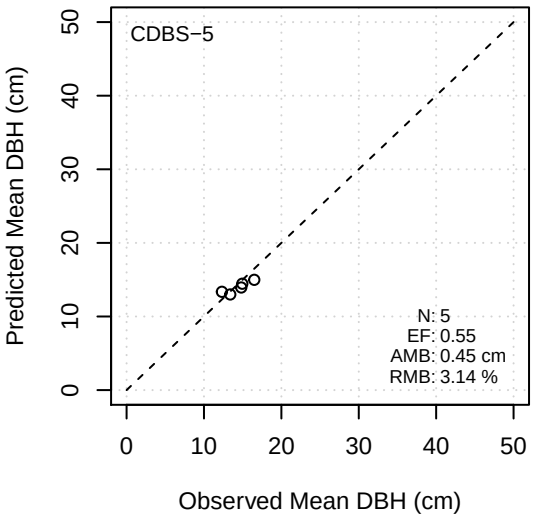

**Conifer Mean Height − CDBS**



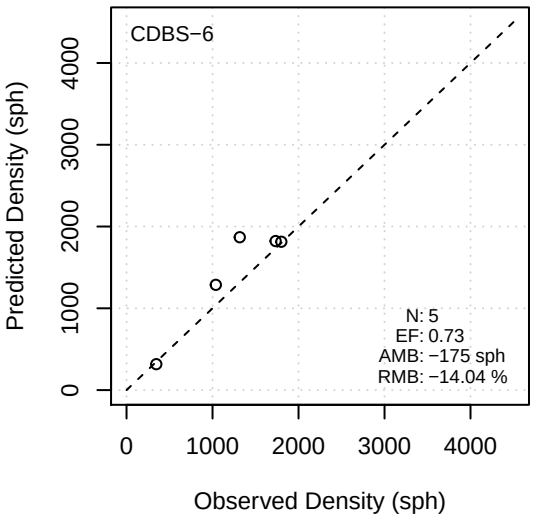

**Conifer Top Height − CDBS**



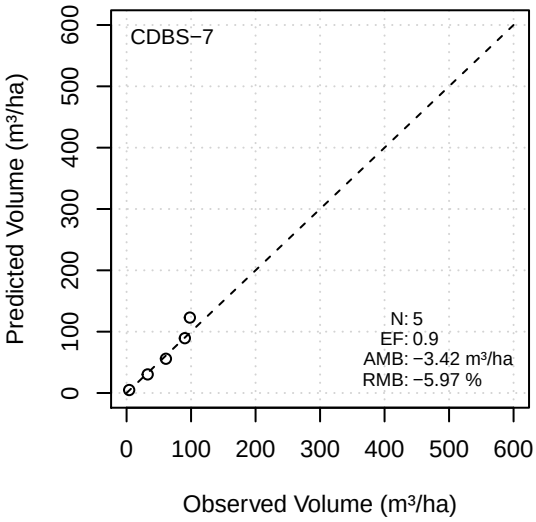

**Conifer Mean DBH − CDBS**



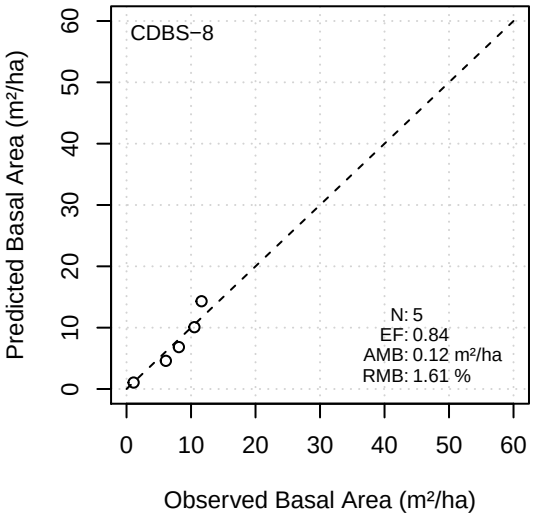

**Conifer Density − CDBS**



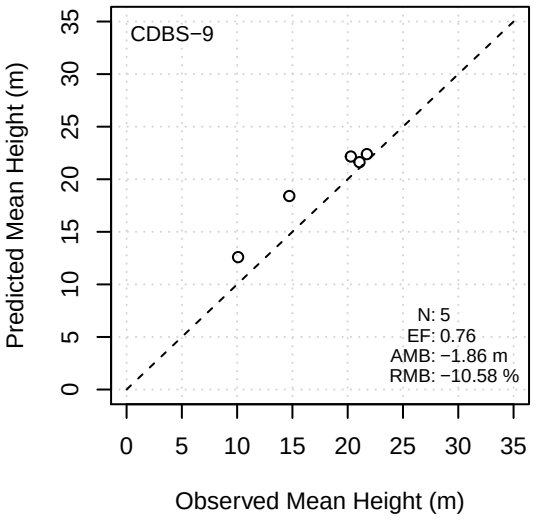
**Deciduous Volume − CDBS**



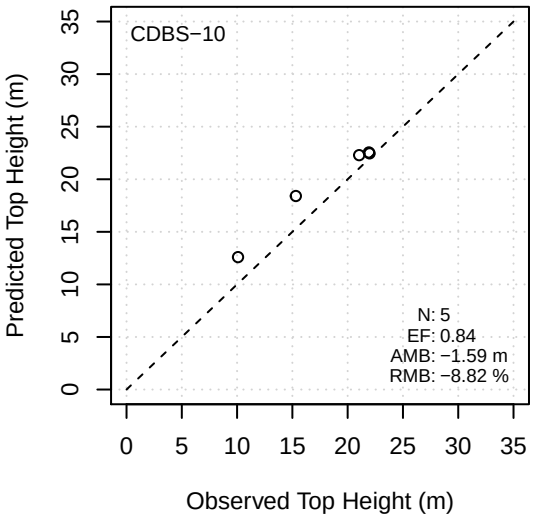

**Deciduous Basal Area − CDBS**



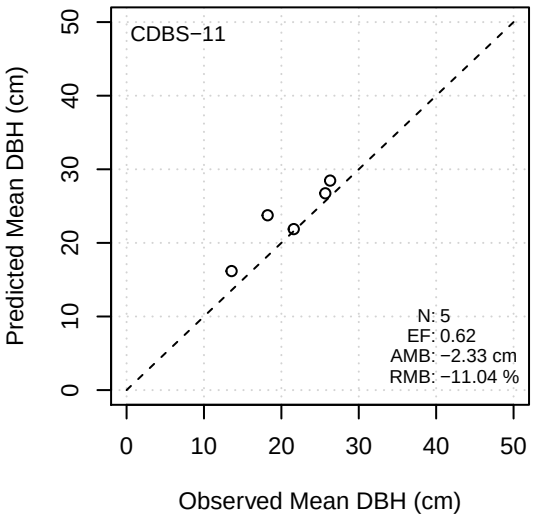

**Deciduous Mean Height − CDBS**



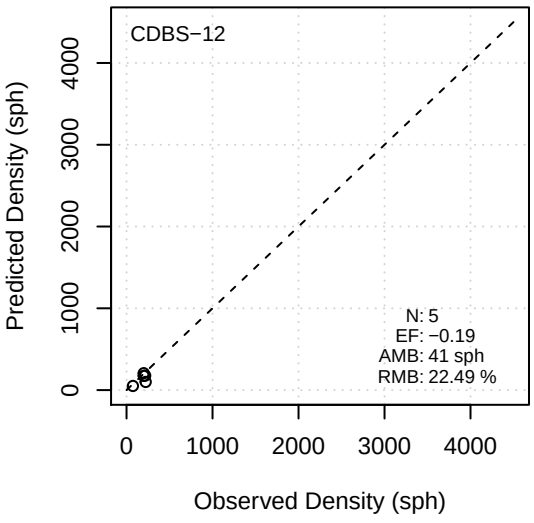

**Deciduous Top Height − CDBS**



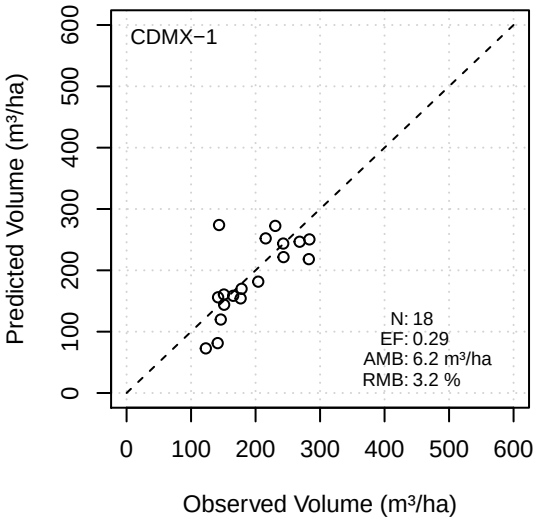

**Deciduous Mean DBH − CDBS**



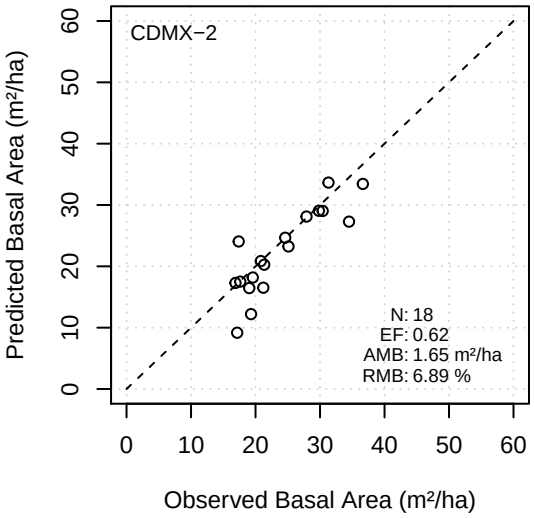

**Deciduous Density − CDBS**



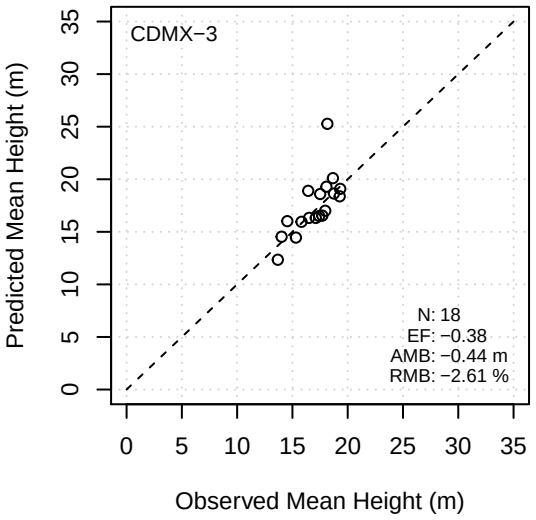
**Conifer Volume − CDMX**



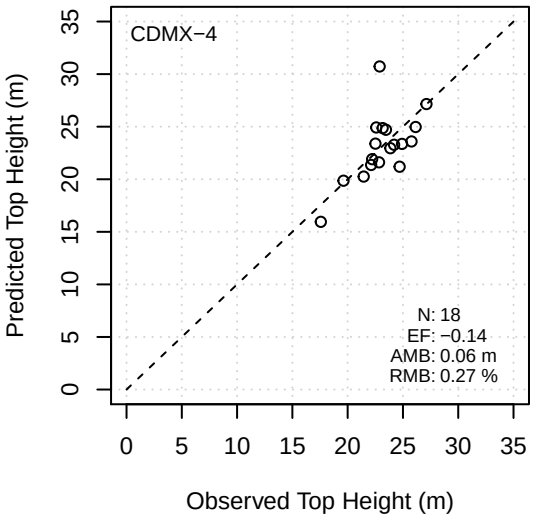

**Conifer Basal Area − CDMX**



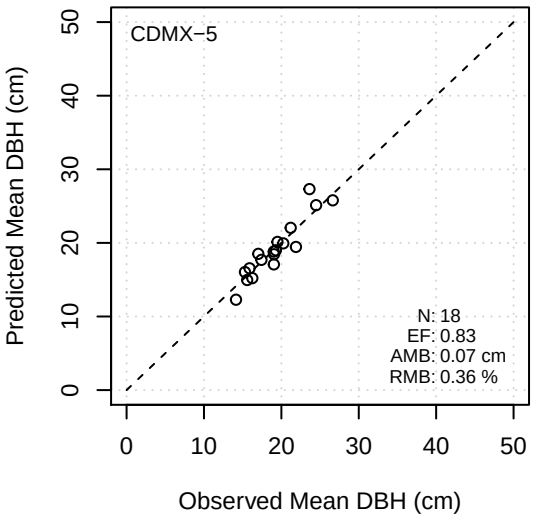

**Conifer Mean Height − CDMX**



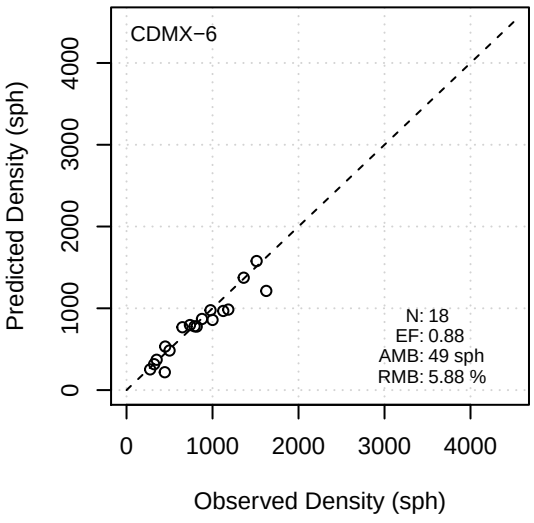

**Conifer Top Height − CDMX**



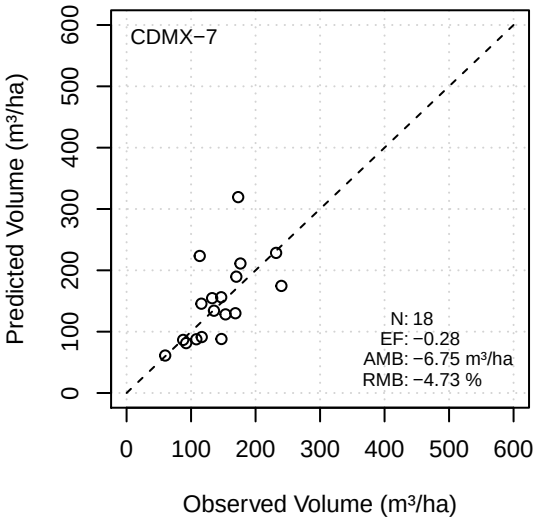

**Conifer Mean DBH − CDMX**



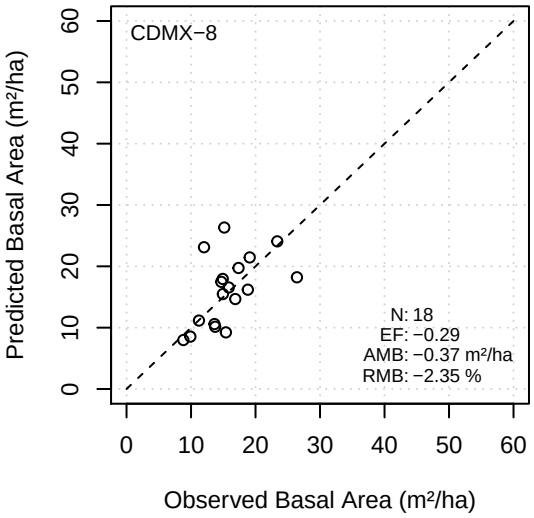

**Conifer Density − CDMX**



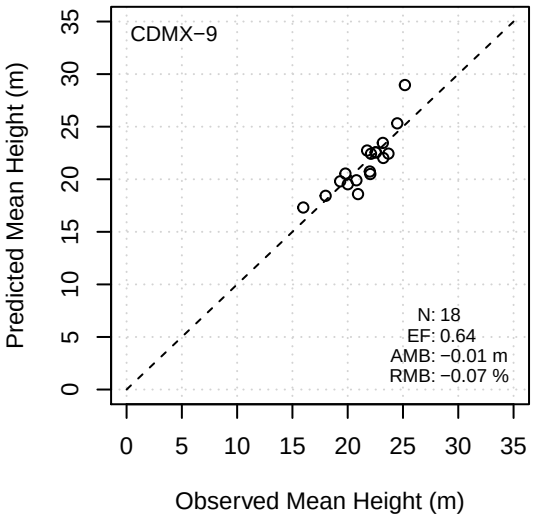
**Deciduous Volume − CDMX**



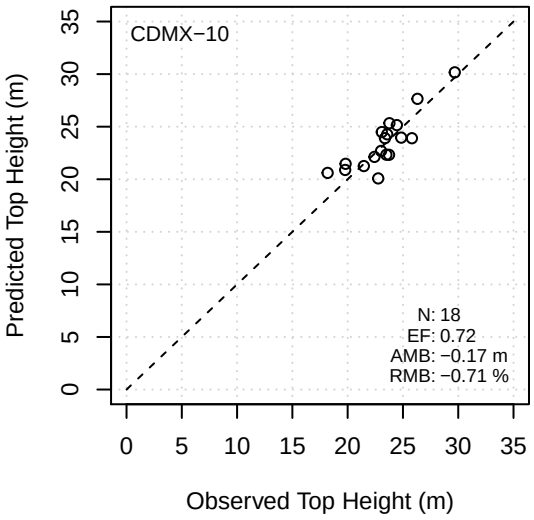

**Deciduous Basal Area − CDMX**



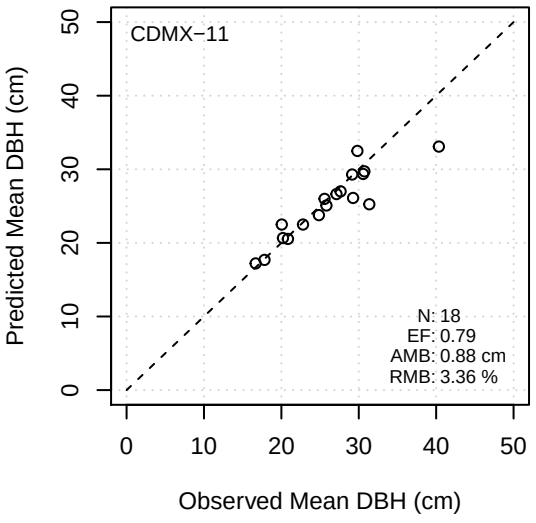

**Deciduous Mean Height − CDMX**



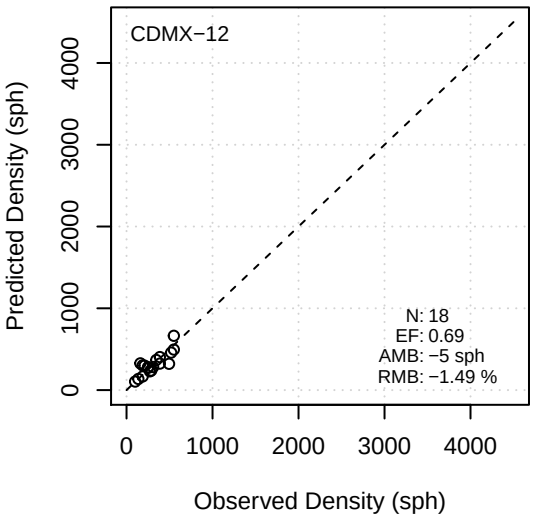

**Deciduous Top Height − CDMX**



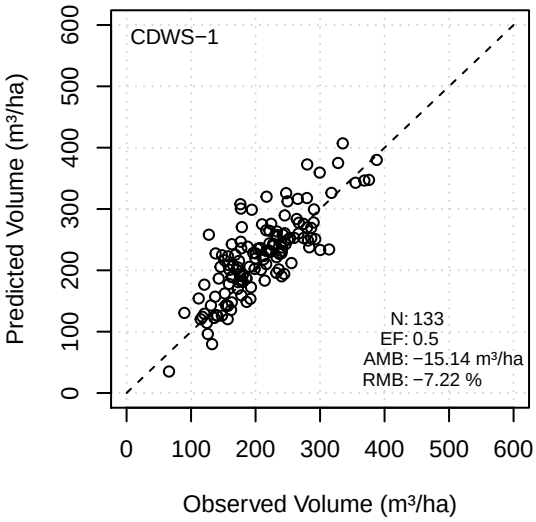

**Deciduous Mean DBH − CDMX**



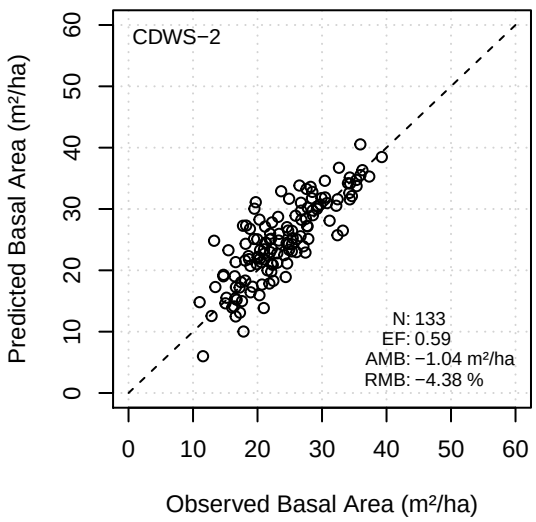

**Deciduous Density − CDMX**



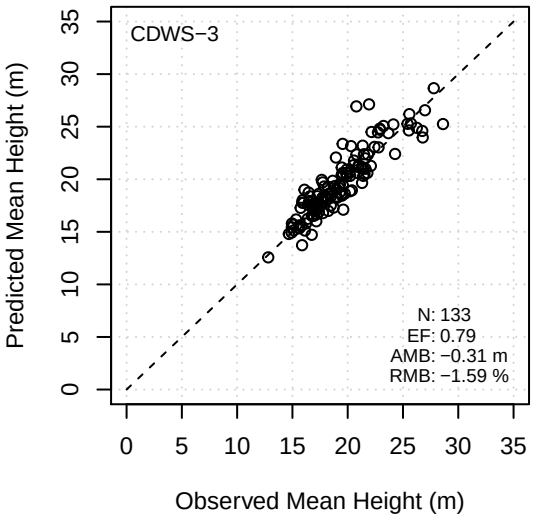
**Conifer Volume − CDWS**



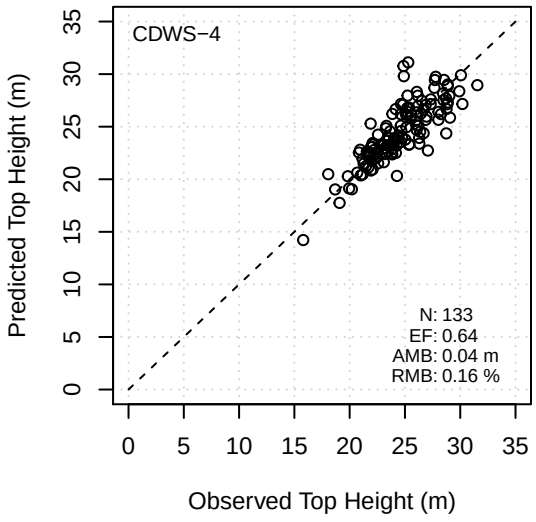

**Conifer Basal Area − CDWS**



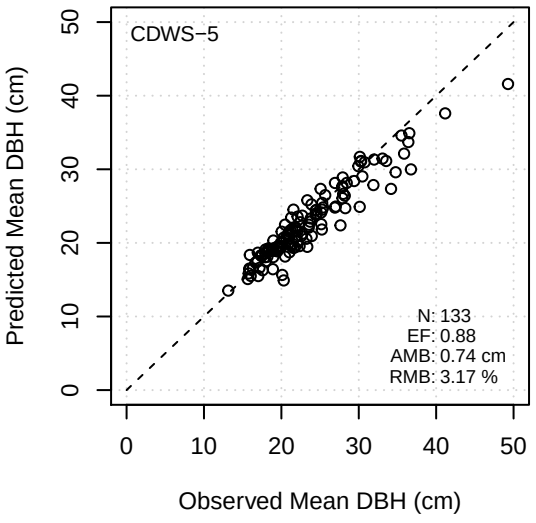

**Conifer Mean Height − CDWS**



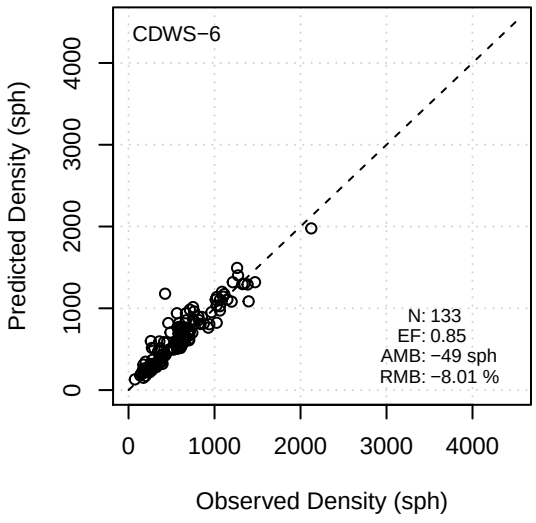

**Conifer Top Height − CDWS**



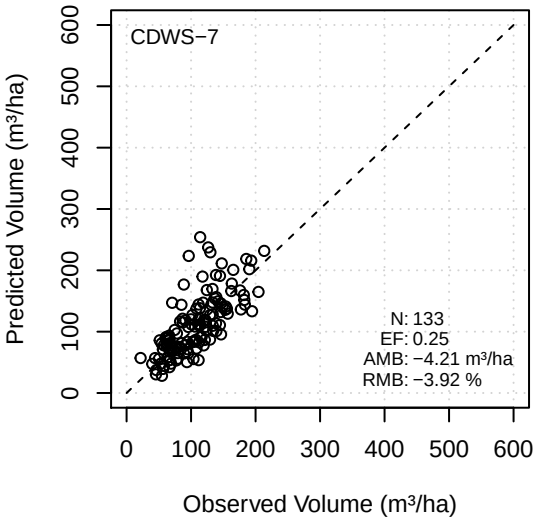

**Conifer Mean DBH − CDWS**



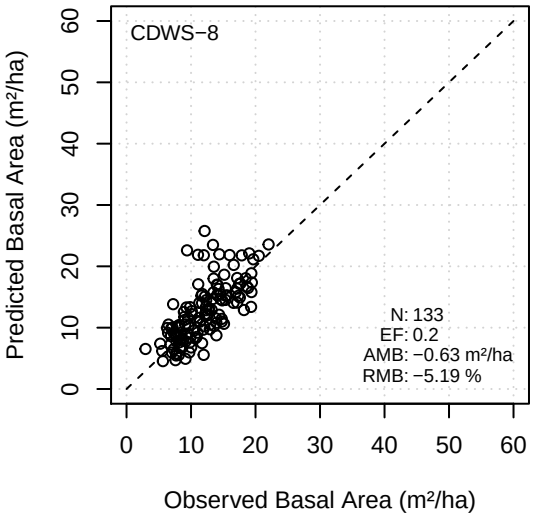

**Conifer Density − CDWS**



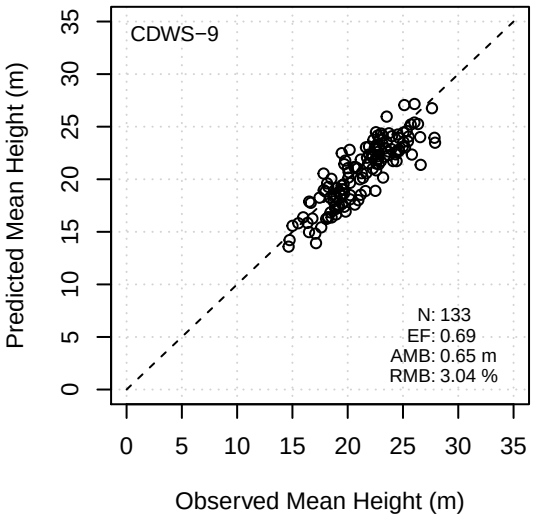
**Deciduous Volume − CDWS**



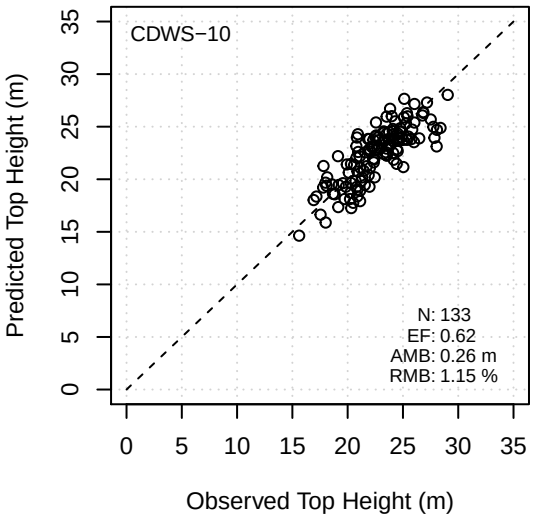

**Deciduous Basal Area − CDWS**



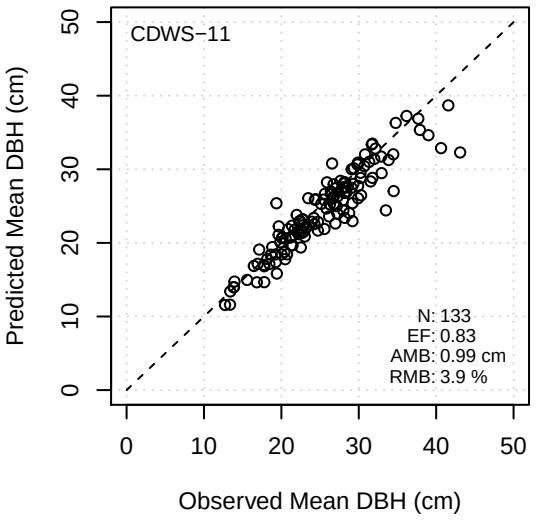

**Deciduous Mean Height − CDWS**



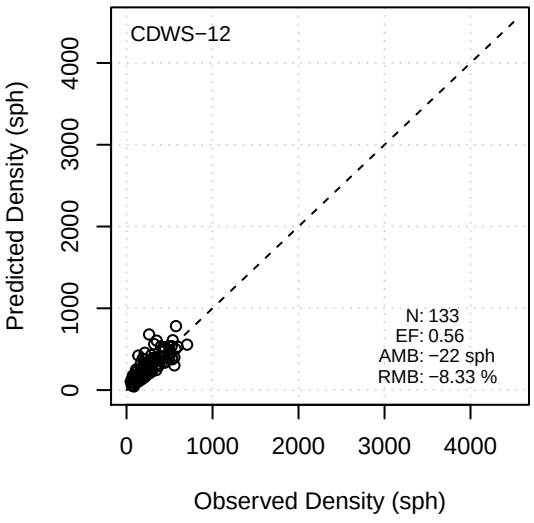

**Deciduous Top Height − CDWS**



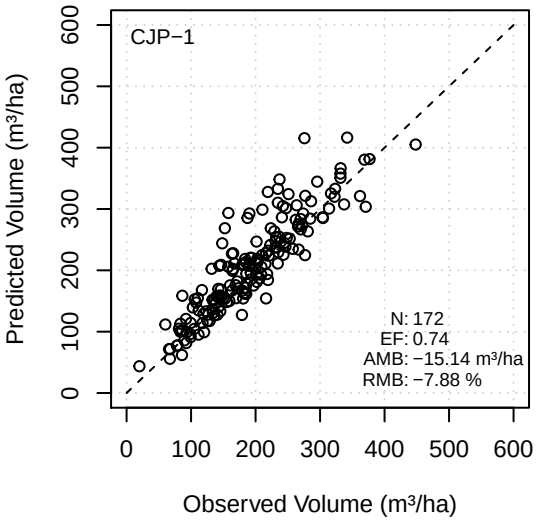

**Deciduous Mean DBH − CDWS**



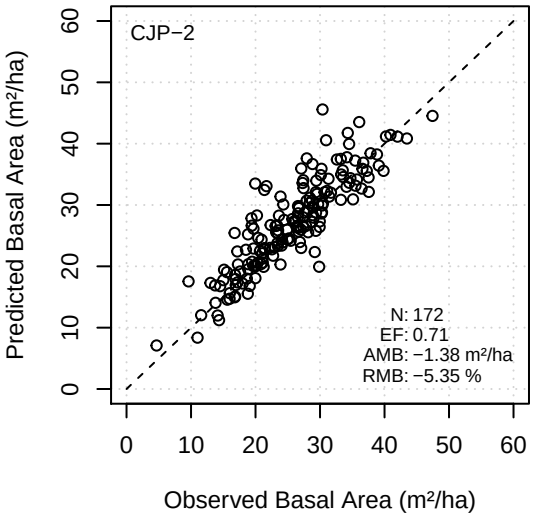

**Deciduous Density − CDWS**



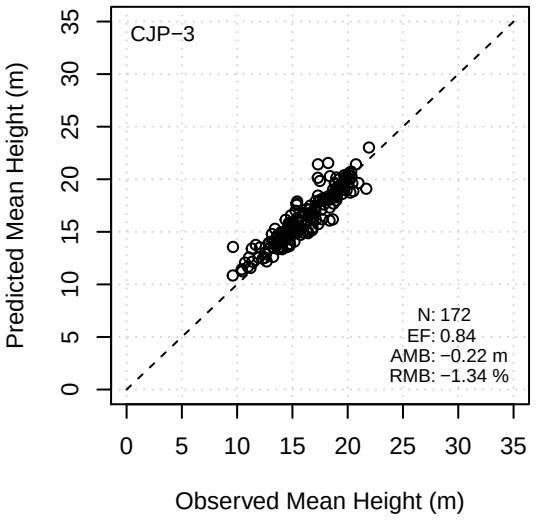
**Conifer Volume − CJP**



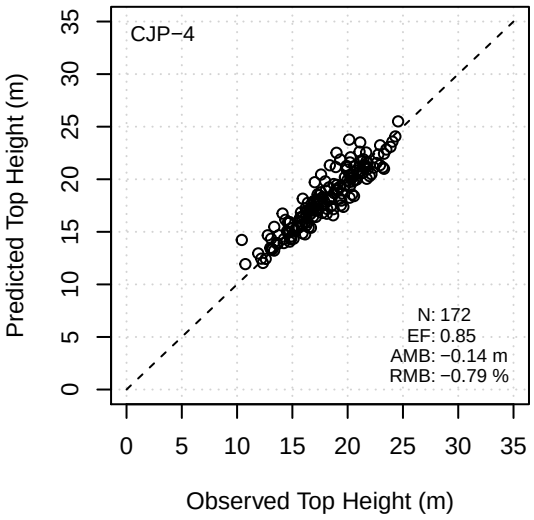

**Conifer Basal Area − CJP**



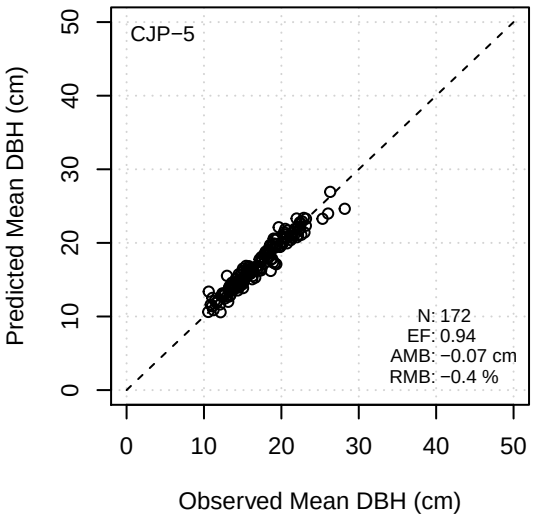

**Conifer Mean Height − CJP**



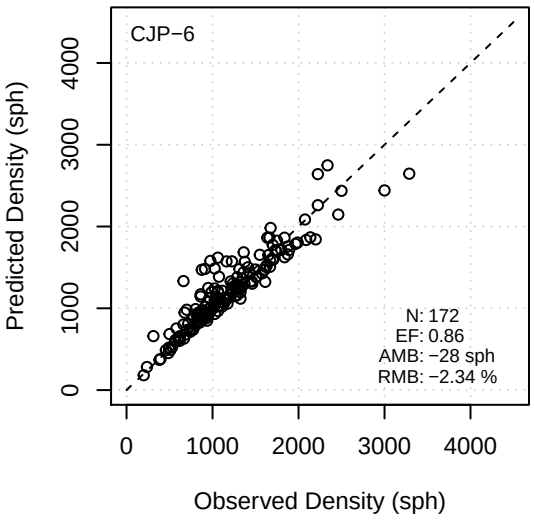

**Conifer Top Height − CJP**



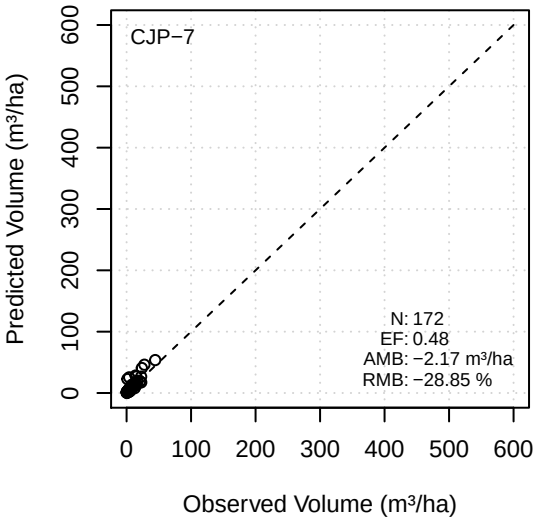

**Conifer Mean DBH − CJP**



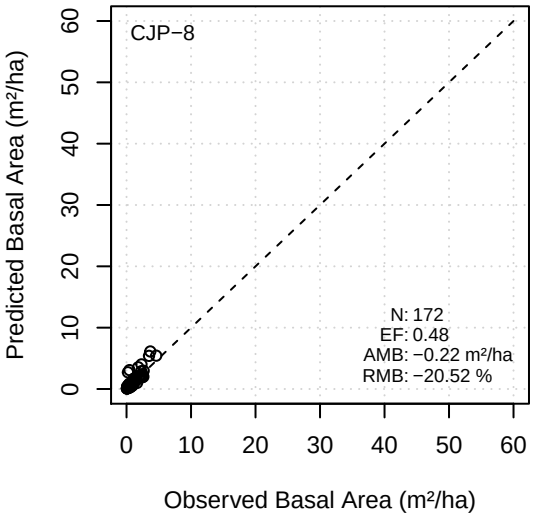

**Conifer Density − CJP**



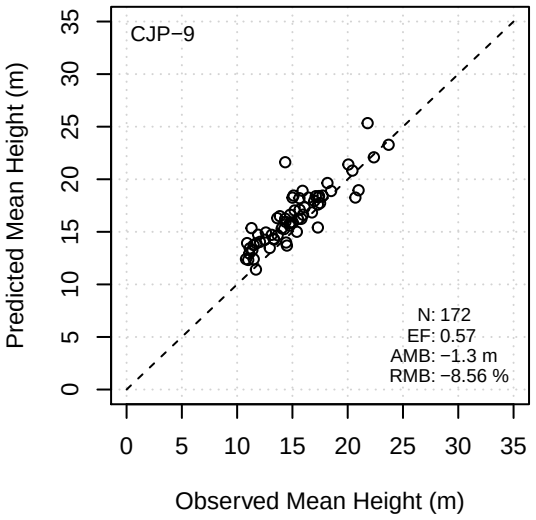
**Deciduous Volume − CJP**



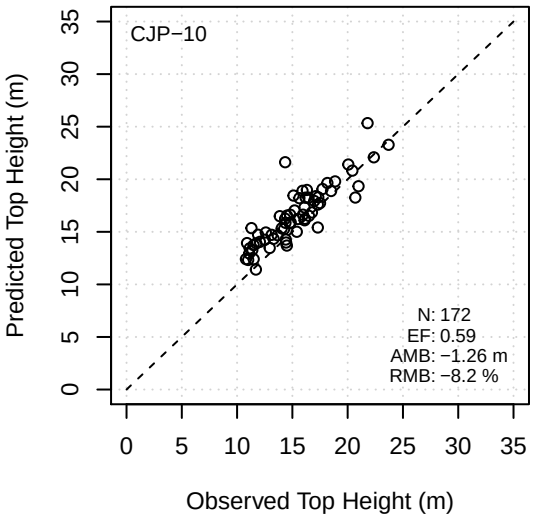

**Deciduous Basal Area − CJP**



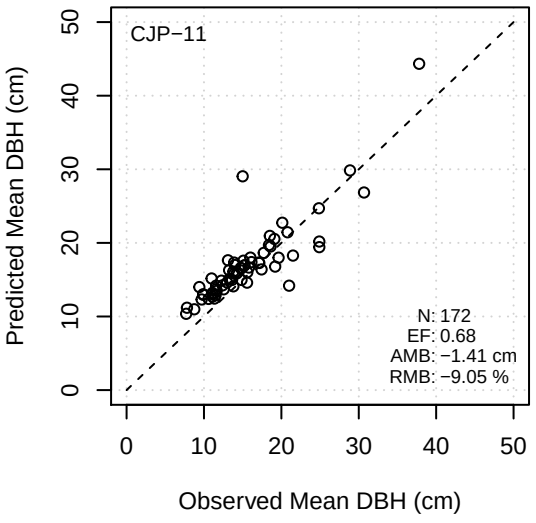

**Deciduous Mean Height − CJP**



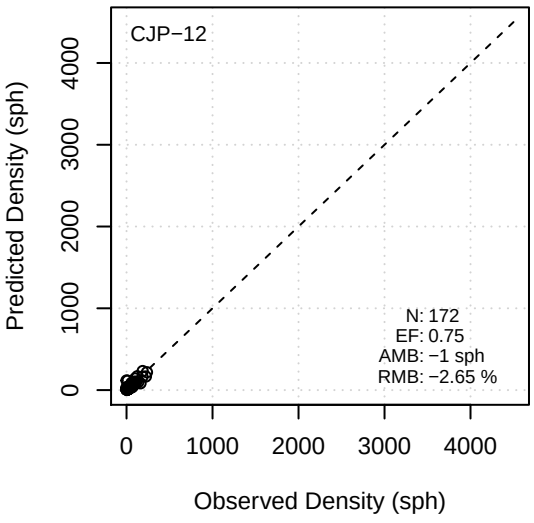

**Deciduous Top Height − CJP**



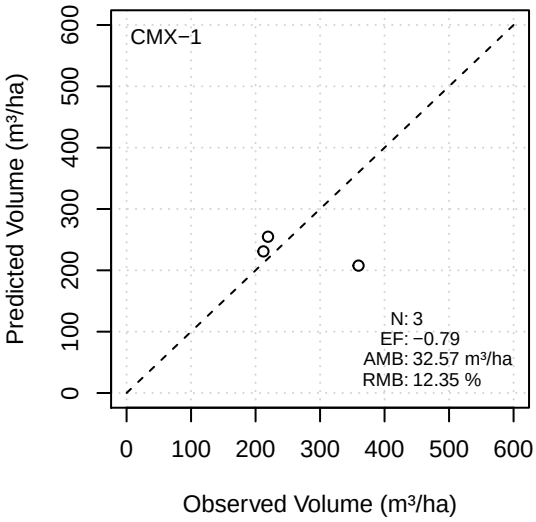

**Deciduous Mean DBH − CJP**



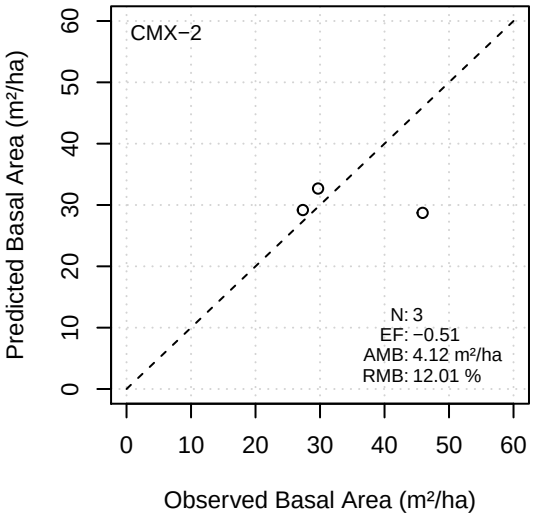

**Deciduous Density − CJP**



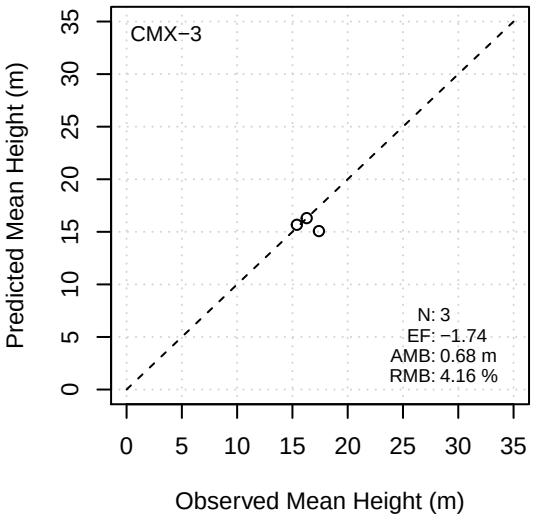
**Conifer Volume − CMX**



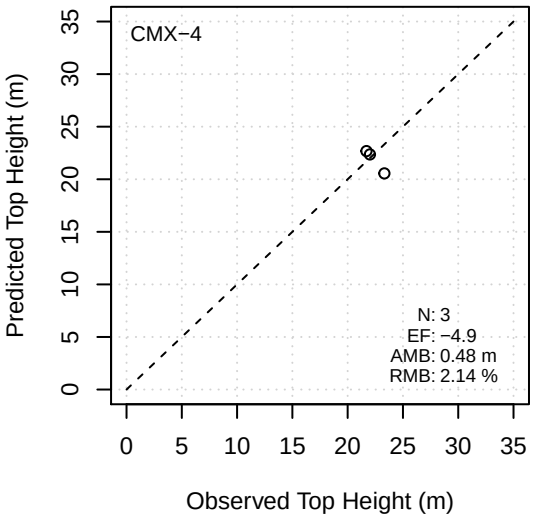

**Conifer Basal Area − CMX**



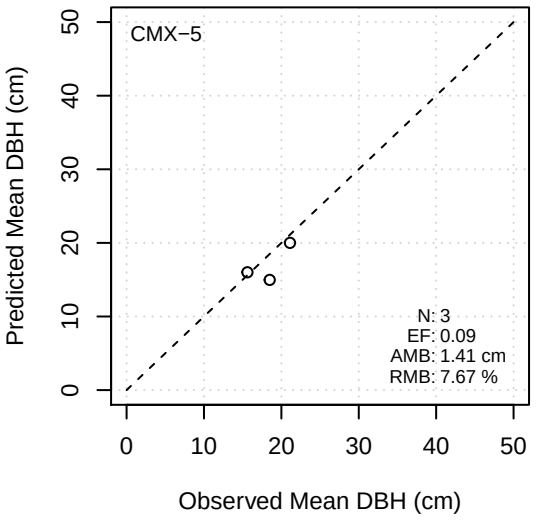

**Conifer Mean Height − CMX**



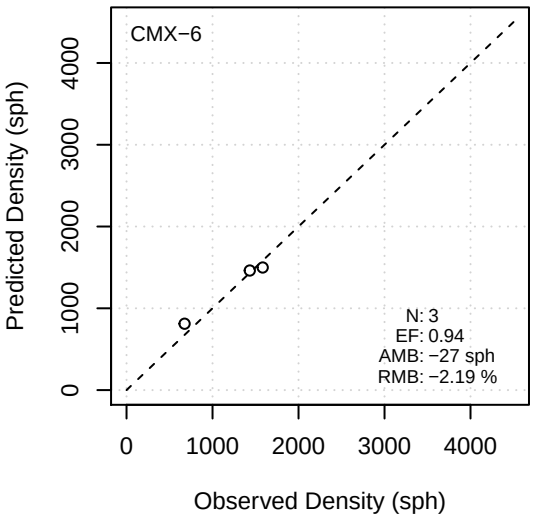

**Conifer Top Height − CMX**



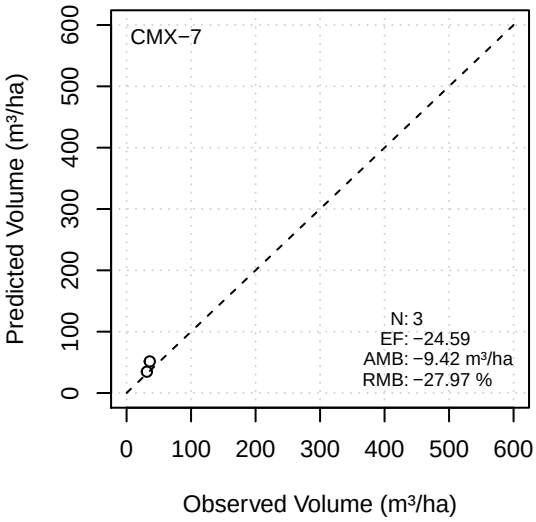

**Conifer Mean DBH − CMX**



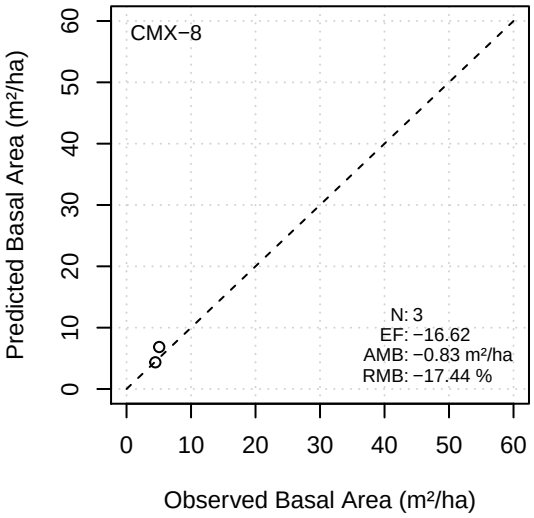

**Conifer Density − CMX**



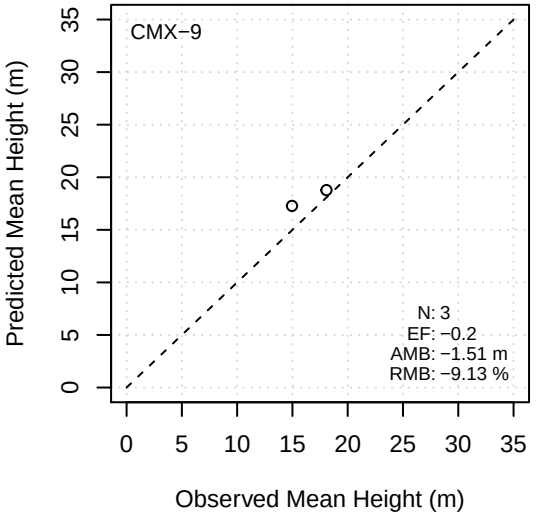
**Deciduous Volume − CMX**



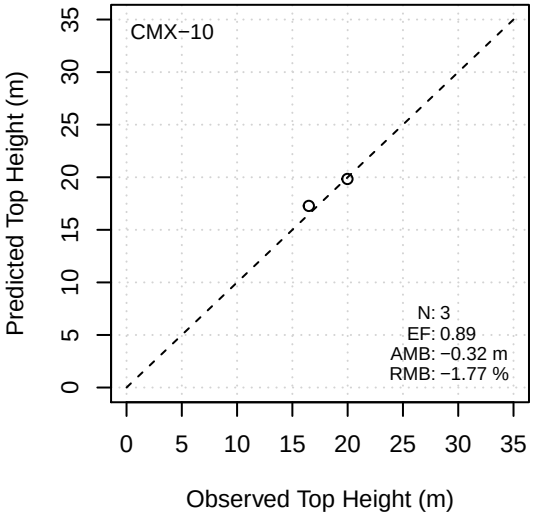

**Deciduous Basal Area − CMX**



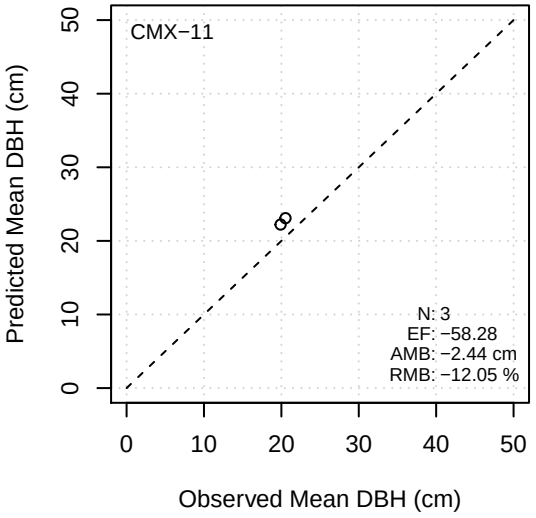

**Deciduous Mean Height − CMX**



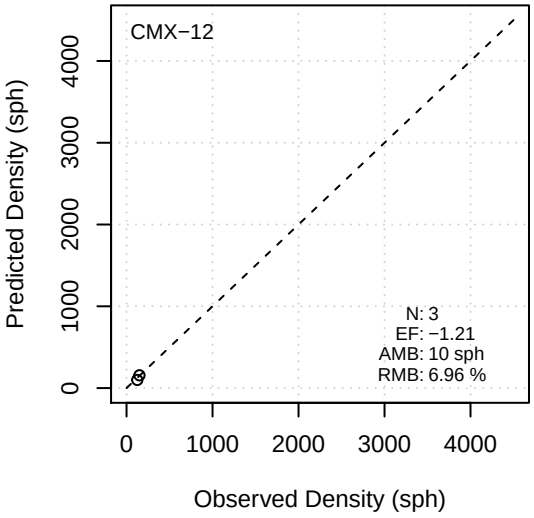

**Deciduous Top Height − CMX**



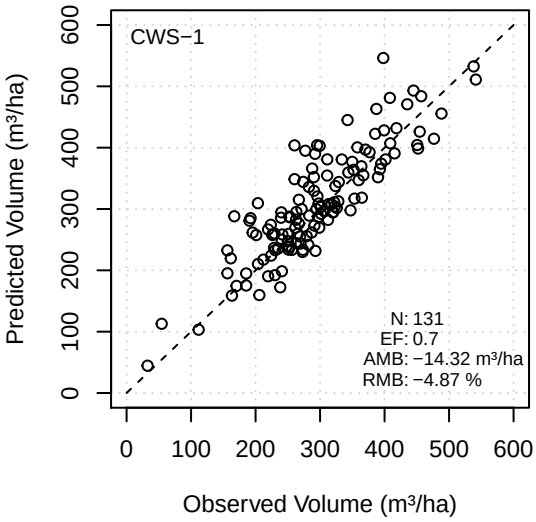

**Deciduous Mean DBH − CMX**



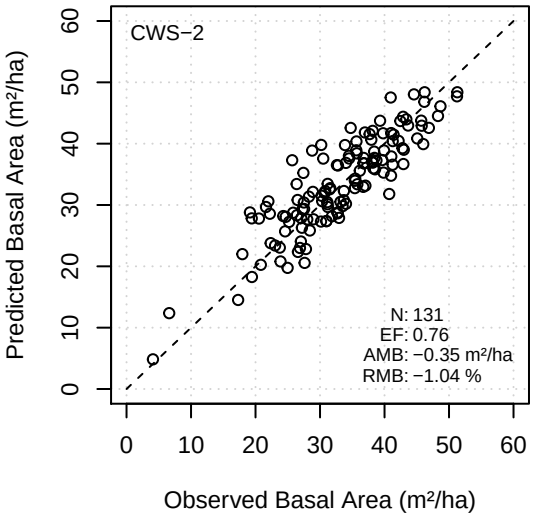

**Deciduous Density − CMX**



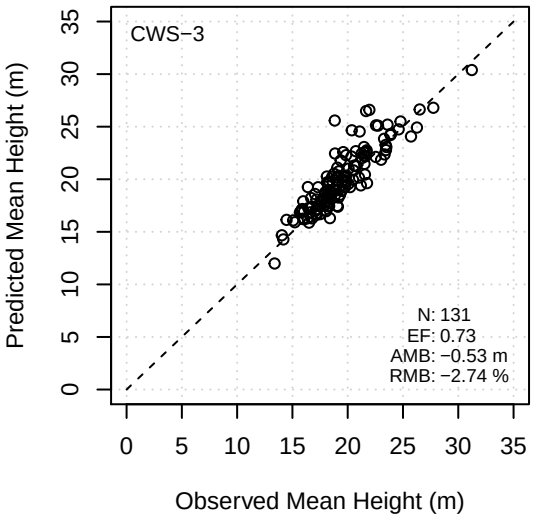
**Conifer Volume − CWS**



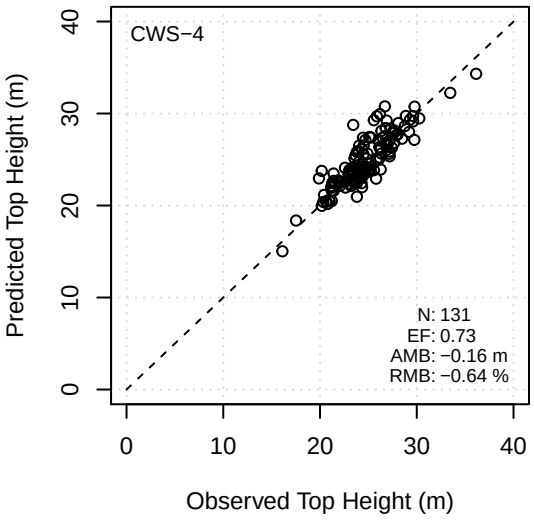

**Conifer Basal Area − CWS**



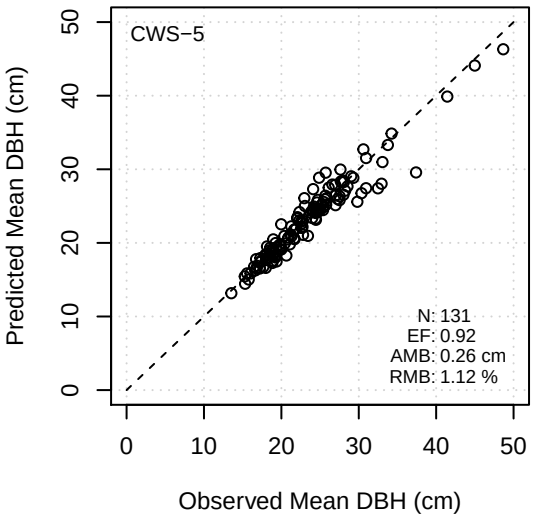

**Conifer Mean Height − CWS**



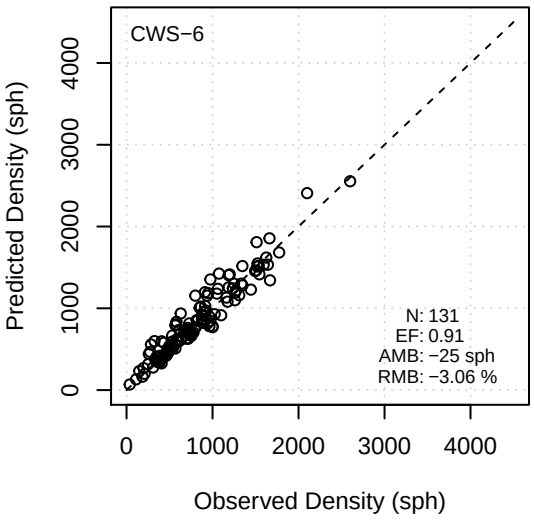

**Conifer Top Height − CWS**



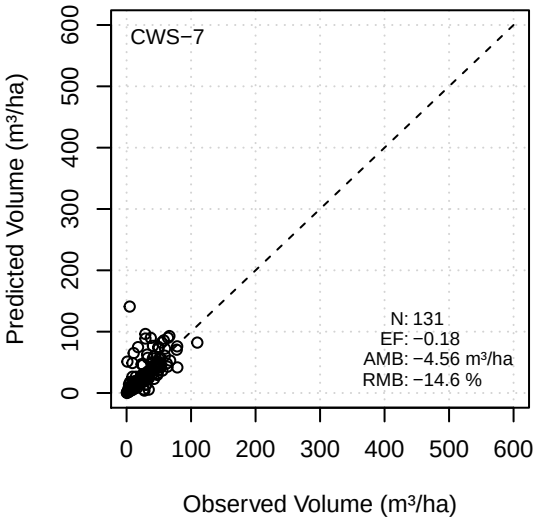

**Conifer Mean DBH − CWS**



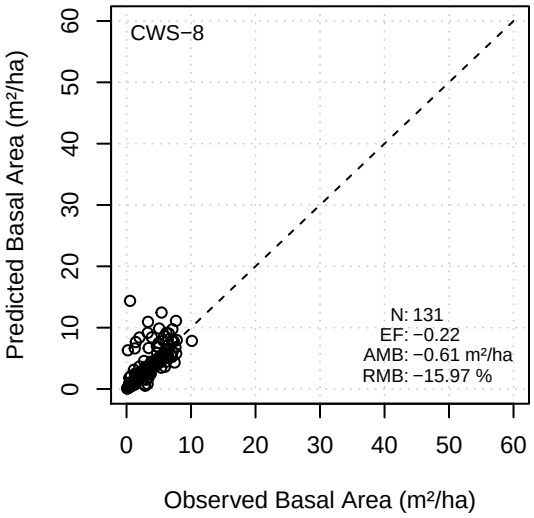

**Conifer Density − CWS**



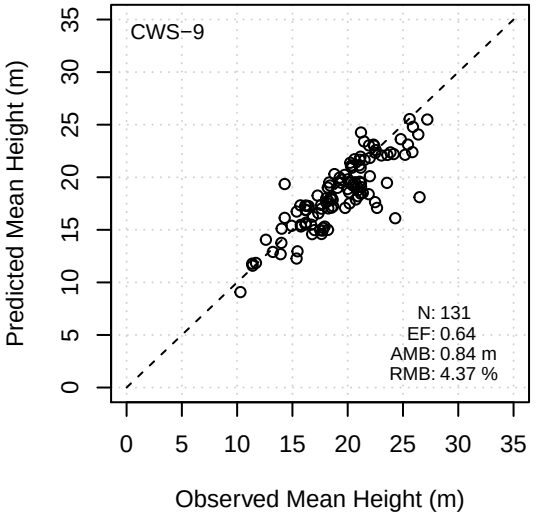
**Deciduous Volume − CWS**



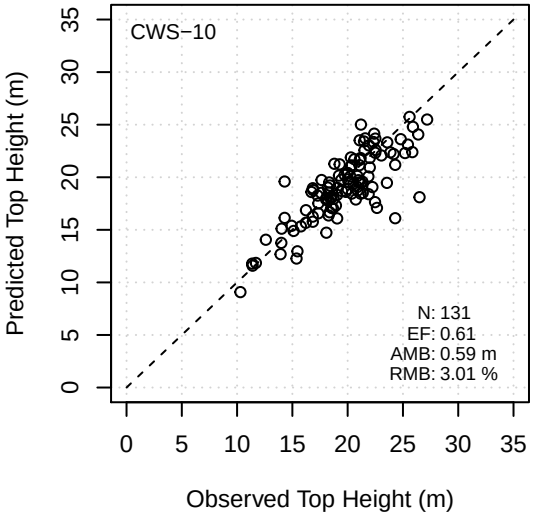

**Deciduous Basal Area − CWS**



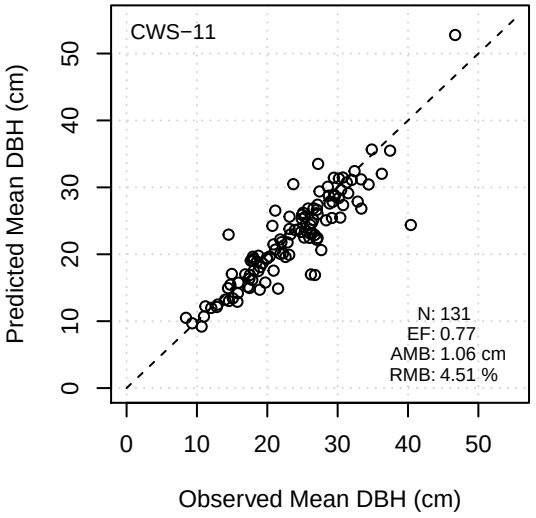

**Deciduous Mean Height − CWS**



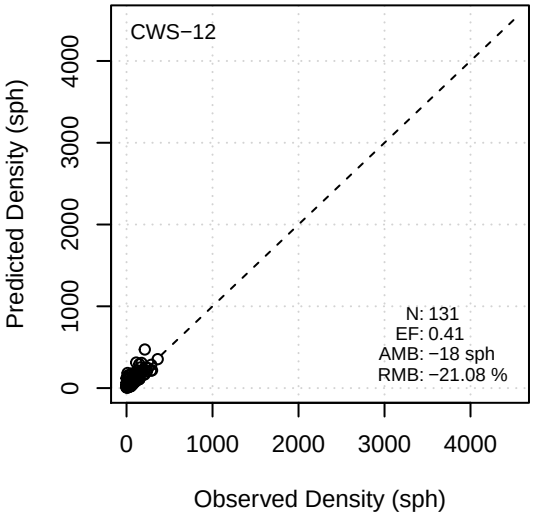

**Deciduous Top Height − CWS**



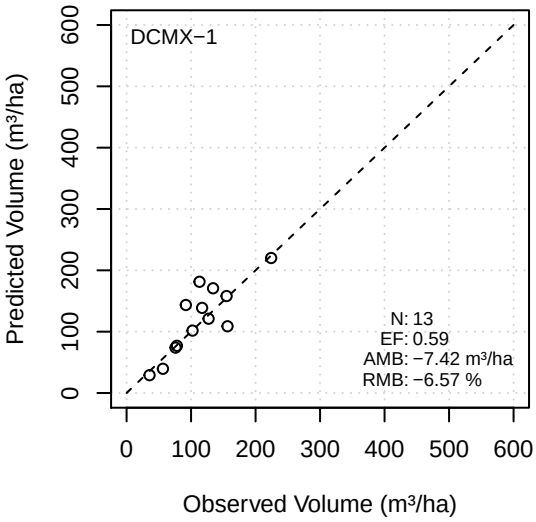

**Deciduous Mean DBH − CWS**



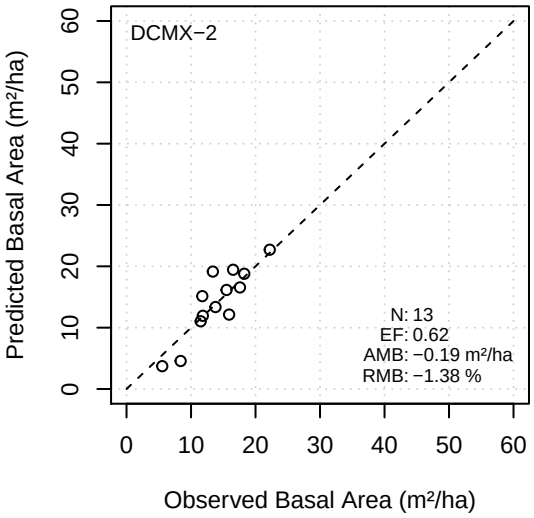

**Deciduous Density − CWS**



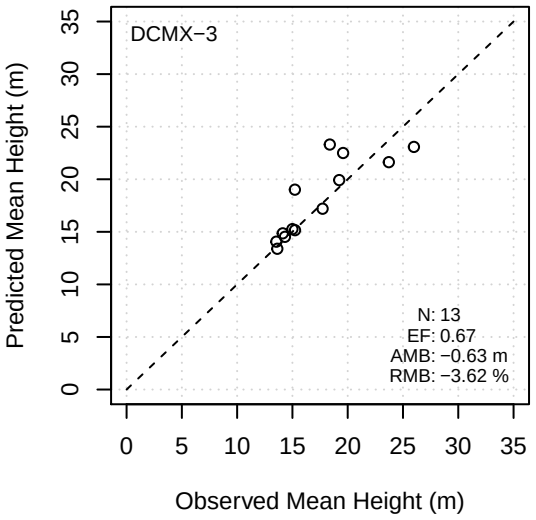
**Conifer Volume − DCMX**



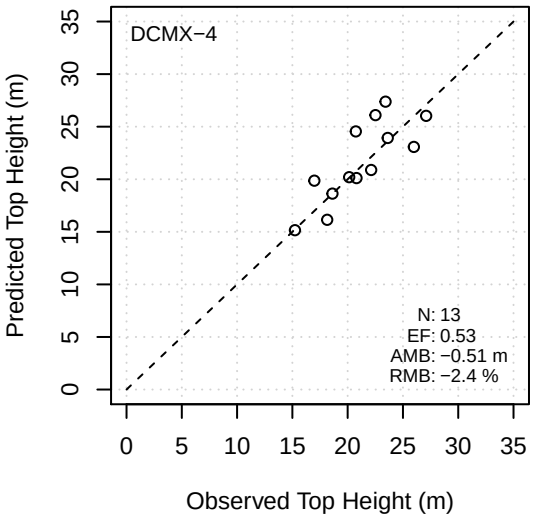

**Conifer Basal Area − DCMX**



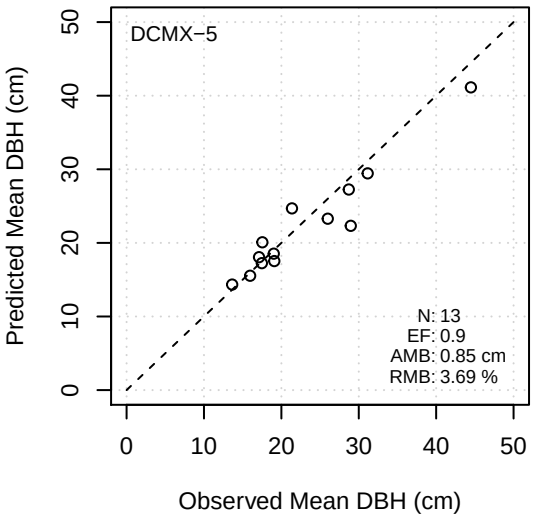

**Conifer Mean Height − DCMX**



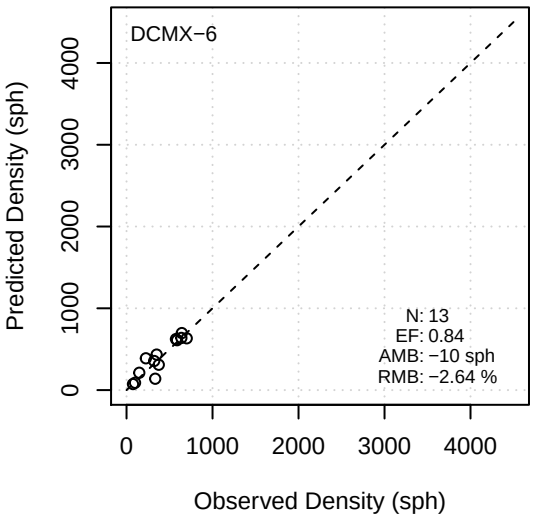

**Conifer Top Height − DCMX**



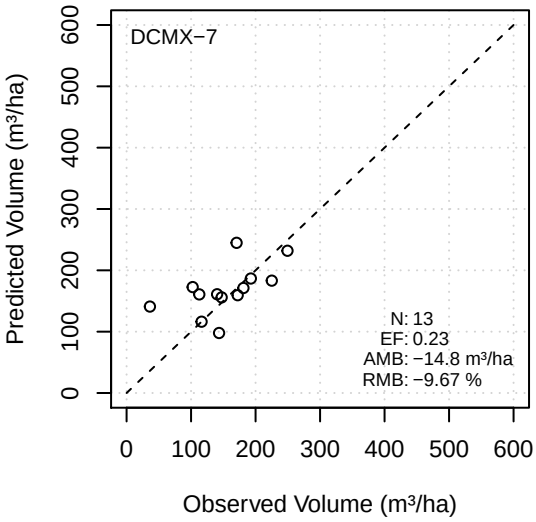

**Conifer Mean DBH − DCMX**



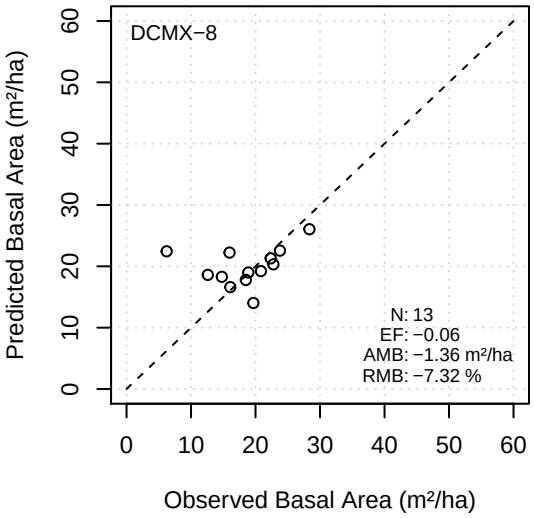

**Conifer Density − DCMX**



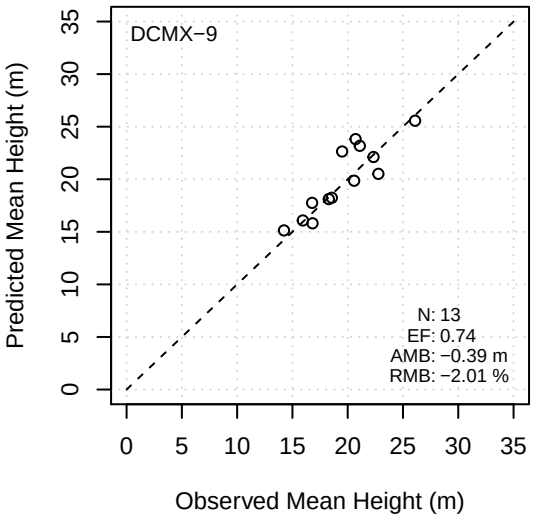
**Deciduous Volume − DCMX**



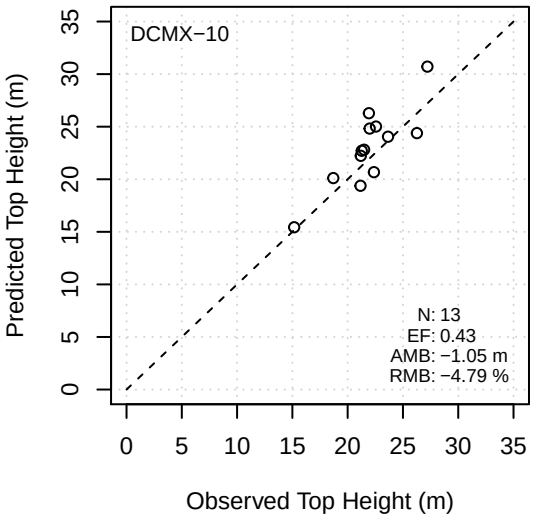

**Deciduous Basal Area − DCMX**



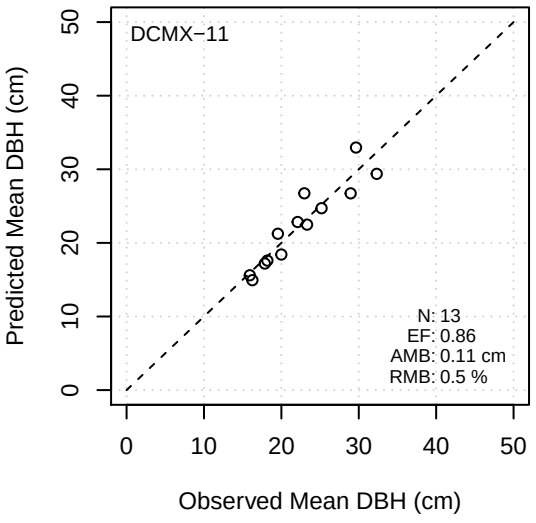

**Deciduous Mean Height − DCMX**



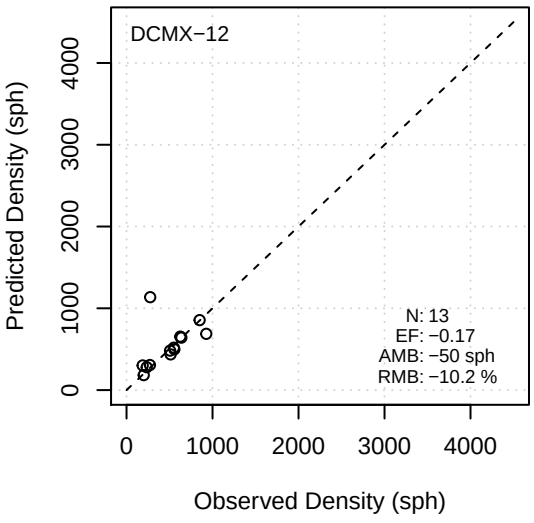

**Deciduous Top Height − DCMX**



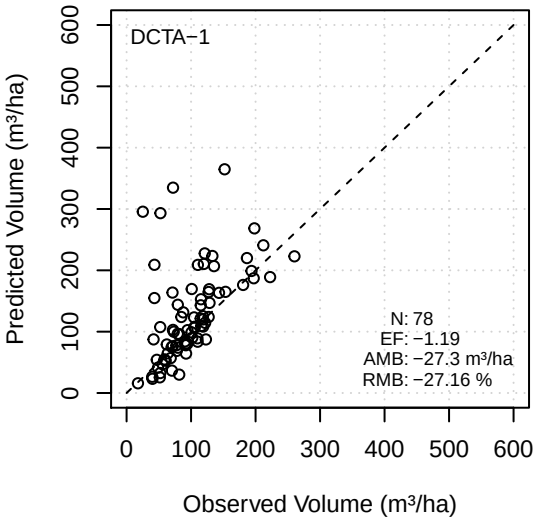

**Deciduous Mean DBH − DCMX**



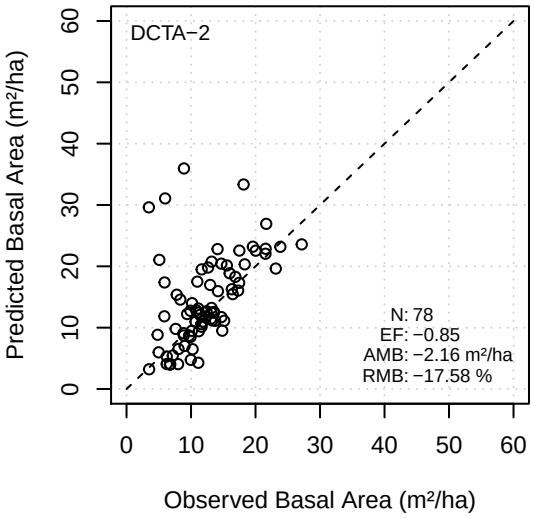

**Deciduous Density − DCMX**



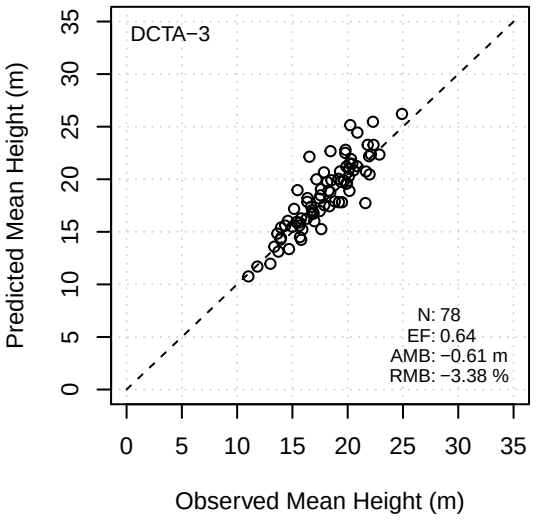
**Conifer Volume − DCTA**



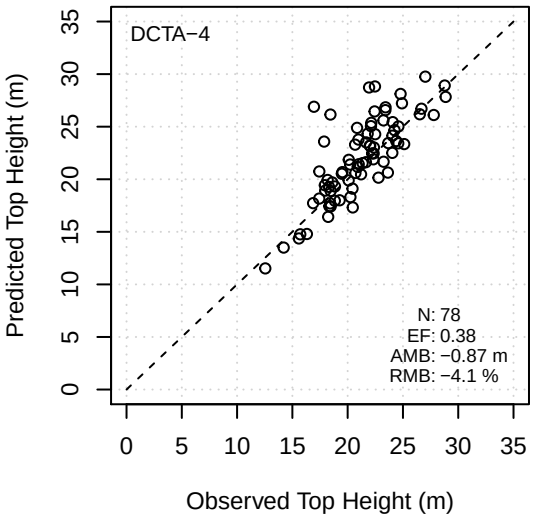

**Conifer Basal Area − DCTA**



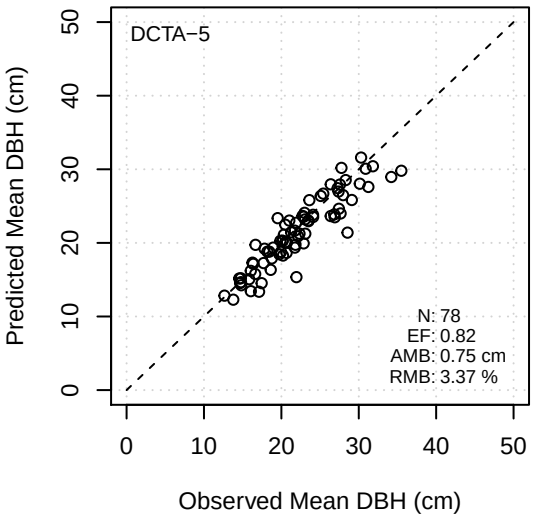

**Conifer Mean Height − DCTA**



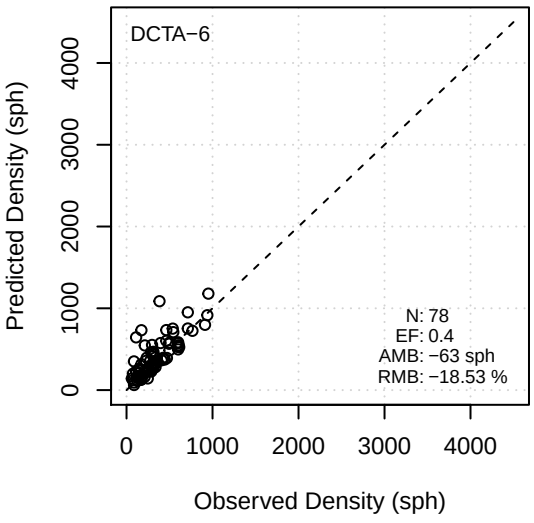

**Conifer Top Height − DCTA**



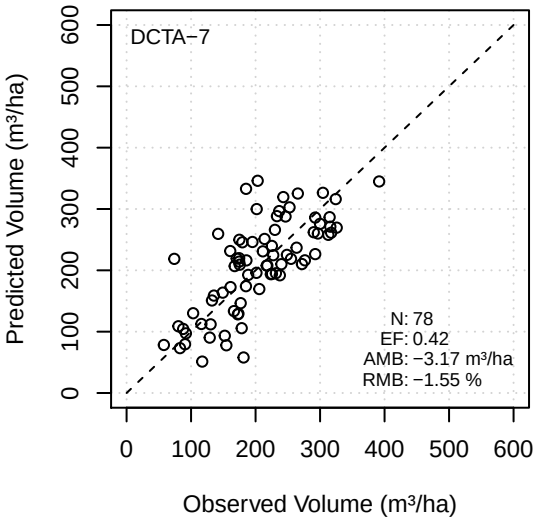

**Conifer Mean DBH − DCTA**



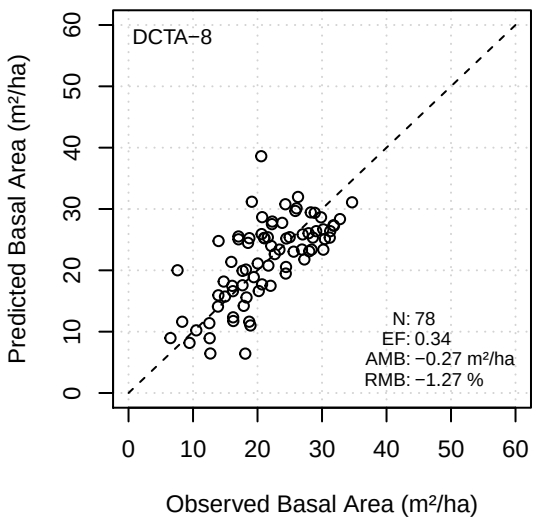

**Conifer Density − DCTA**



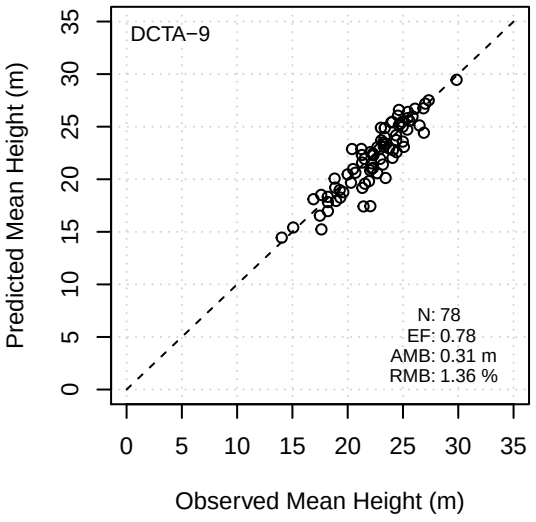
**Deciduous Volume − DCTA**



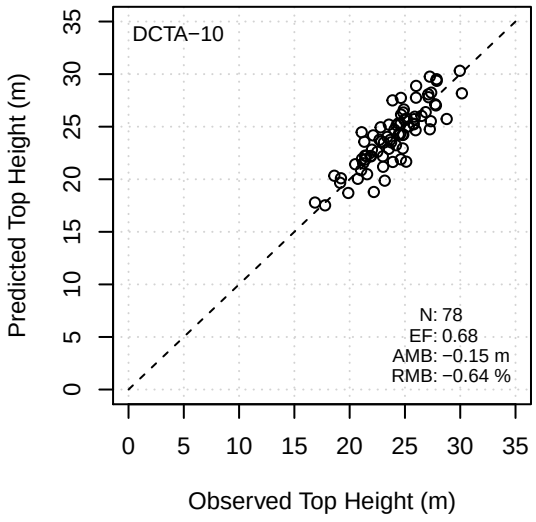

**Deciduous Basal Area − DCTA**



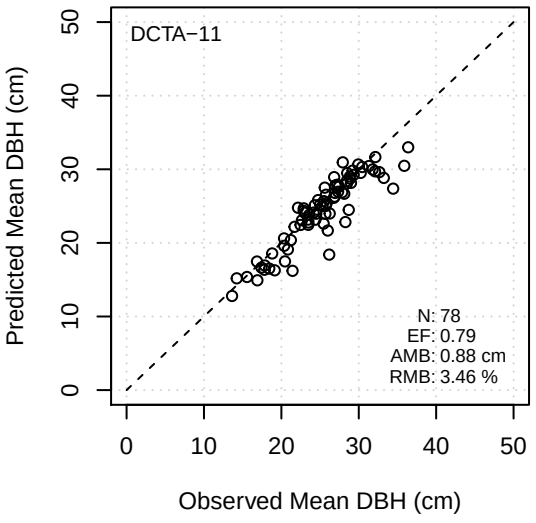

**Deciduous Mean Height − DCTA**



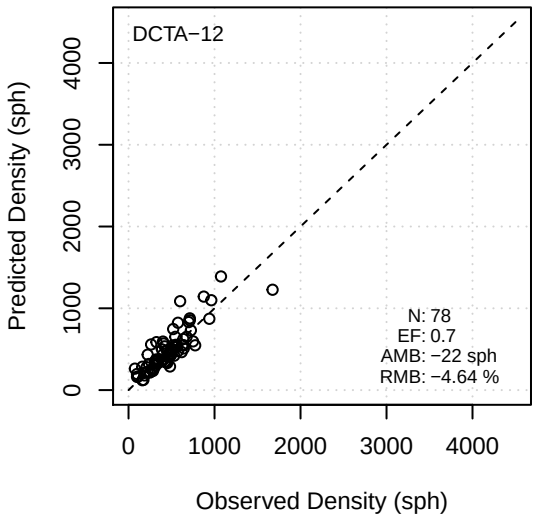

**Deciduous Top Height − DCTA**



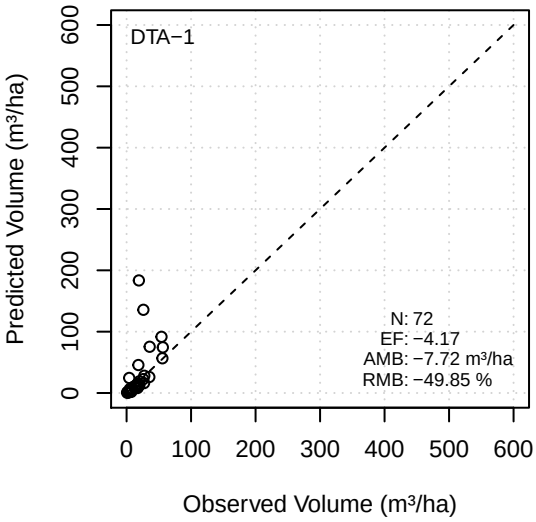

**Deciduous Mean DBH − DCTA**



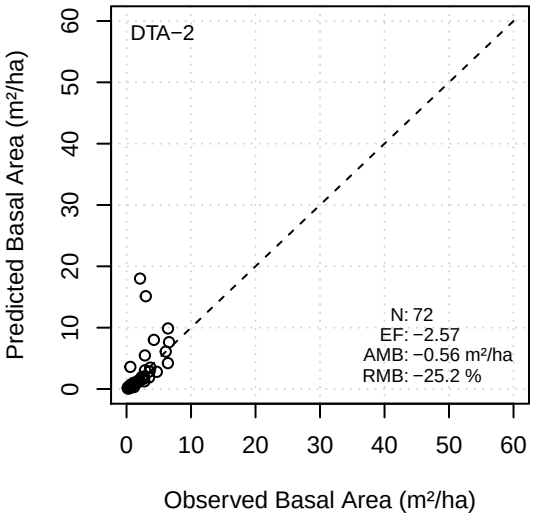

**Deciduous Density − DCTA**



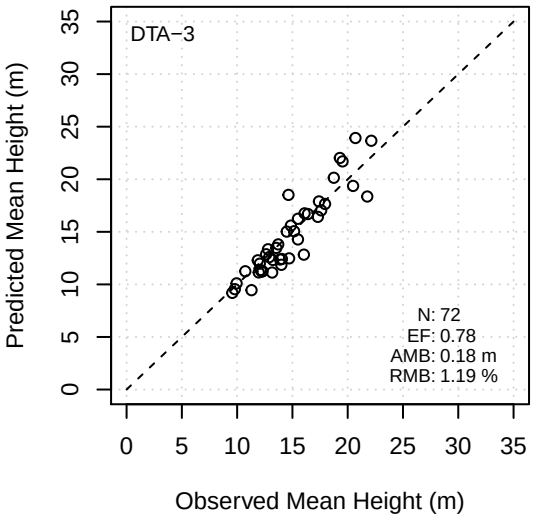
**Conifer Volume − DTA**



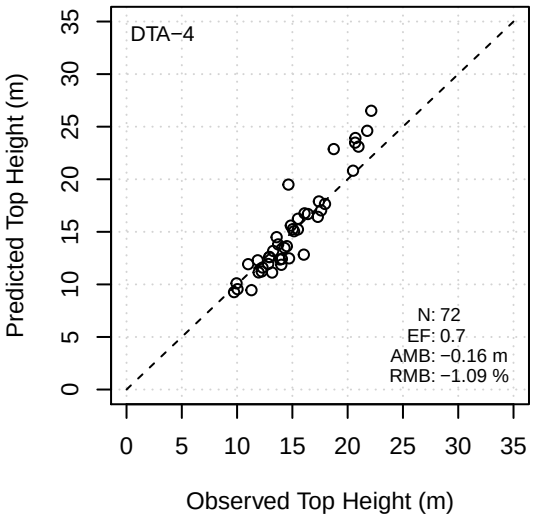

**Conifer Basal Area − DTA**



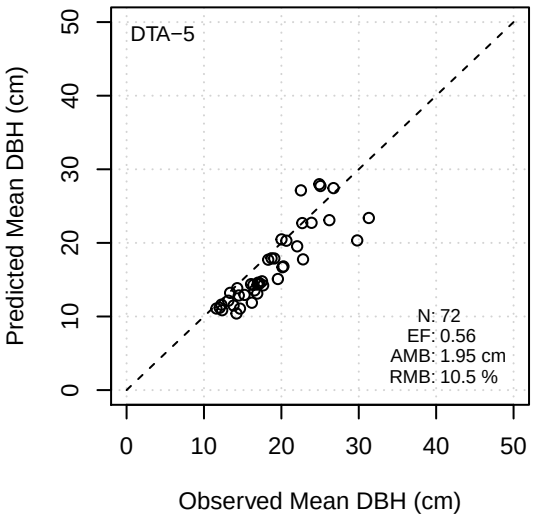

**Conifer Mean Height − DTA**



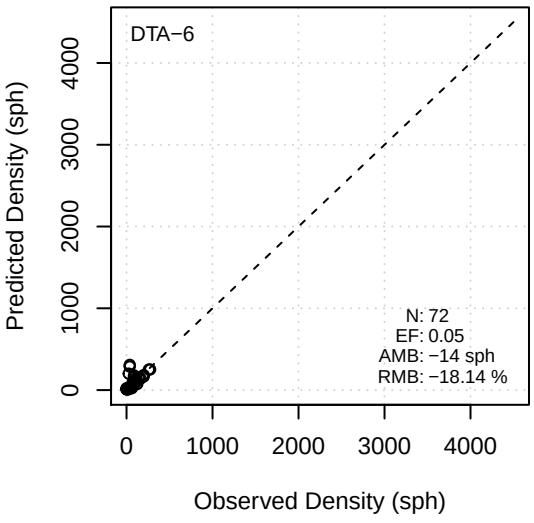

**Conifer Top Height − DTA**



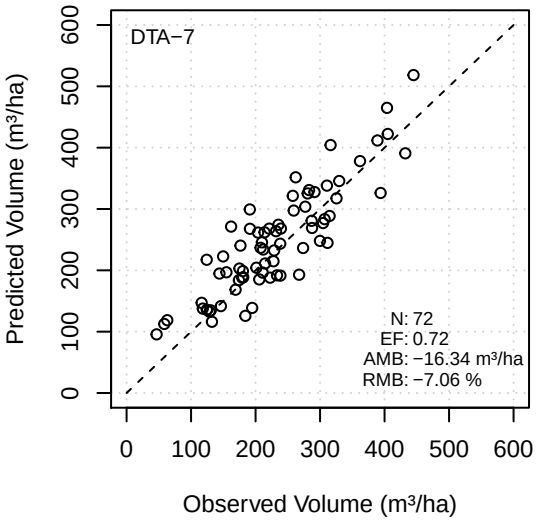

**Conifer Mean DBH − DTA**



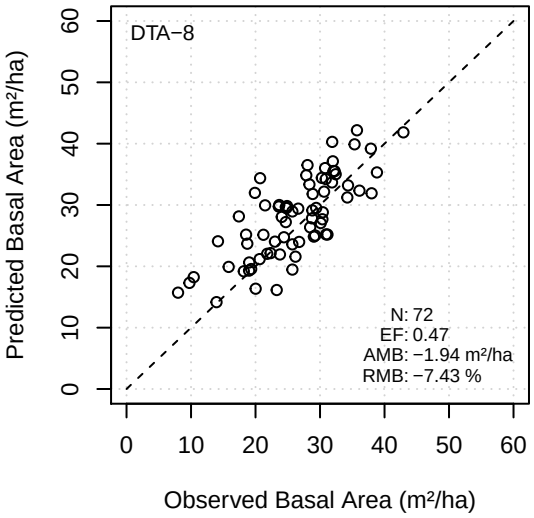

**Conifer Density − DTA**



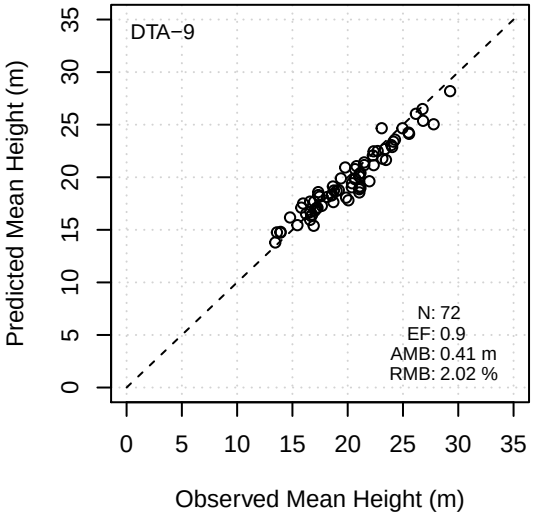
**Deciduous Volume − DTA**



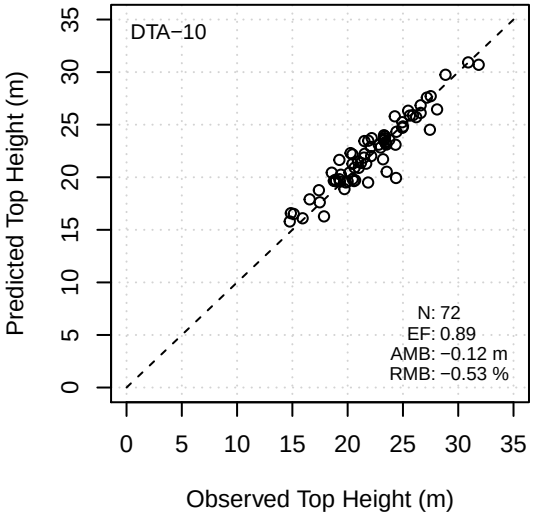

**Deciduous Basal Area − DTA**



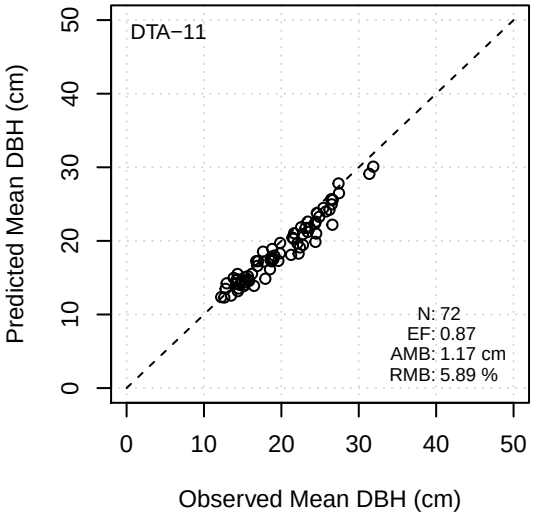

**Deciduous Mean Height − DTA**




**Deciduous Top Height − DTA**




**Deciduous Mean DBH − DTA**




**Deciduous Density − DTA**