Effects of height and live crown ratio imputation strategies on stand biomass estimation

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Background – Forest Biomass

- Increasing importance of forest biomass
    - Climate change agreements
    - Voluntary carbon markets
    - Bioenergy plants
    - Forest fire fuel loads
- Current estimation methods are mostly for large scales (> 4m ha) and cannot be reliably scaled down
- Finer-resolution estimates that are accurate and defensible are required

Background – Tree Models

- OSU and the FIA are developing species-specific, individual-tree biomass equations
  - Allow estimation of component and total biomass
  - Easily integrated into current inventory designs and estimated similar to stem volume
  - Easily scaled up to stand, sub-regional, and regional levels

- Uncertainty about the effects of inventory practices developed for volume on the accuracy of biomass estimates

Background – Imputation

- A common practice is to impute missing heights (HT) and live crown ratios (LCR) using predictive models
  - Expensive to measure relative to diameter-at-breast-height (DBH)
  - Often predicted with regional models if local models unavailable
  - If no HT or LCR measurements available, nonlinear fixed-effect models (NFEM) are often used
  - If some measurements are available, NFEMs adjusted by a correction factor or nonlinear mixed-effect models (NMEM) are used to improve accuracy

- Models are optimized for HT or LCR, not end products (volume, biomass) and may reduce the accuracy of stand-level estimates

Objectives

- To assess the effects of HT and LCR imputation methods on the accuracy of stand-level biomass estimates, a set of stand inventories were simulated

    1) *the predictive model used to impute HT and/or LCR*
    2) *the number of trees subsampled for extra measurements*
    3) *The method of selecting subsample trees (random for this presentation due to time)*

- Goal is to give initial guidance to inventory managers who need to estimate biomass at the stand-level

Methods – Data

- Collected to develop the SW Oregon variant of the ORGANON growth and yield model
- 3,454 undamaged Douglas-fir trees
- 102 stands with 4 to 25 sample points each
- Systematically sampled with random starts
- 4 subplots at each point; DBH exclusive
- DBH (7.6-44.1 in.), HT (54.5-160.1 ft), and LCR (0.03-0.92) measured for each tree
- Stands cover a wide variety of species mixes, ages, densities, and ownership types (cooperative)

Methods – Biomass Models

- NFEMs developed by Krishna Poudel using data from the OSU/FIA partnership (n = 22)

Stem wood = ƒ(DBH, HT)

Stem bark= ƒ(DBH)

Foliage = ƒ(DBH, HT, LCR)

Branch = ƒ(DBH, HT, LCR)

Total = sum of components = ƒ(DBH, HT, LCR)

Methods – HT and LCR Models

- HT predicted using a Chapman-Richards NFEM (n = 4,948):

$$HT = f(DBH, BA, CCFL)$$

- LCR predicted using a logistic NFEM (n = 8,236):

$$LCR = f(DBH, HT, PCCFL, BA, DBH5, HT5, SI)$$

where BA is stand basal area (sq. ft/ac), CCFL and PCCFL are crown competition factor in larger trees at the stand and plot level, DBH5 and HT5 is the mean DBH and HT of the stand's five tallest trees, and SI is the stand index (ft)

Methods – HT Predictive Methods

- **Method 1**: HT NFEM without any adjustment
- **Method 2**: HT NFEM with an ordinary least squares correction factor (CF); model is corrected proportionally based on a linear relationship between measured and fitted values through the origin
- **Method 3**: HT NMEM with a stand-level random intercept effect; random effects for “new” stands are estimated using linear regression (BLUP)

Methods – LCR Predictive Methods

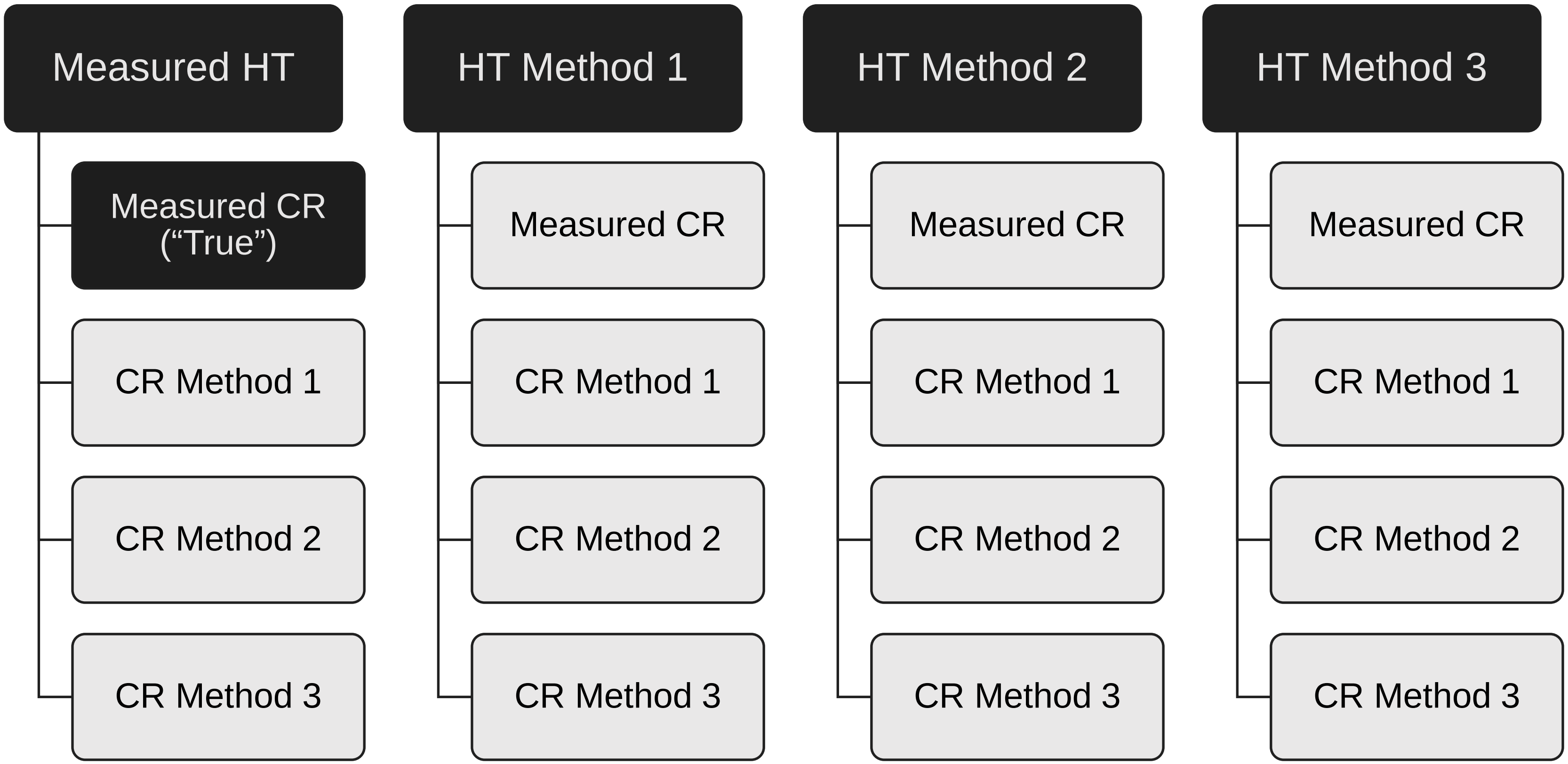
- **Method 1**: LCR NFEM without any adjustment
- **Method 2**: LCR NFEM with CF
- **Method 3**: LCR NMEM with a stand-level random intercept effect *and no stand-level fixed-effects (BA, DBH5, HT5, SI, PCCFL)*; random effects for “new” stands are estimated using linear regression (BLUP)

Methods – Simulation

- Stand inventories simulated 500 times for each subsample size (n = 1…15)
- Each iteration of the simulation is a leave-one-out cross-validation
  - Each stand is removed, or “left out”, in turn
  - All HT and LCR models are fit to the remaining stands (“region”)
  - Subsampled trees in “left out” stand used to adjust models
  - HT, LCR and all biomass components are predicted using each of the 15 HT and CR imputation combinations
  - Mean deviation (bias) and RMSE (precision) calculated for “left out” stand estimates and averaged for each subsample size

- Estimates for bole, crown (branch and foliage), and total (combination thereof) only

Methods – Simulation



Total of 15 HT/LCR predictive model combinations!

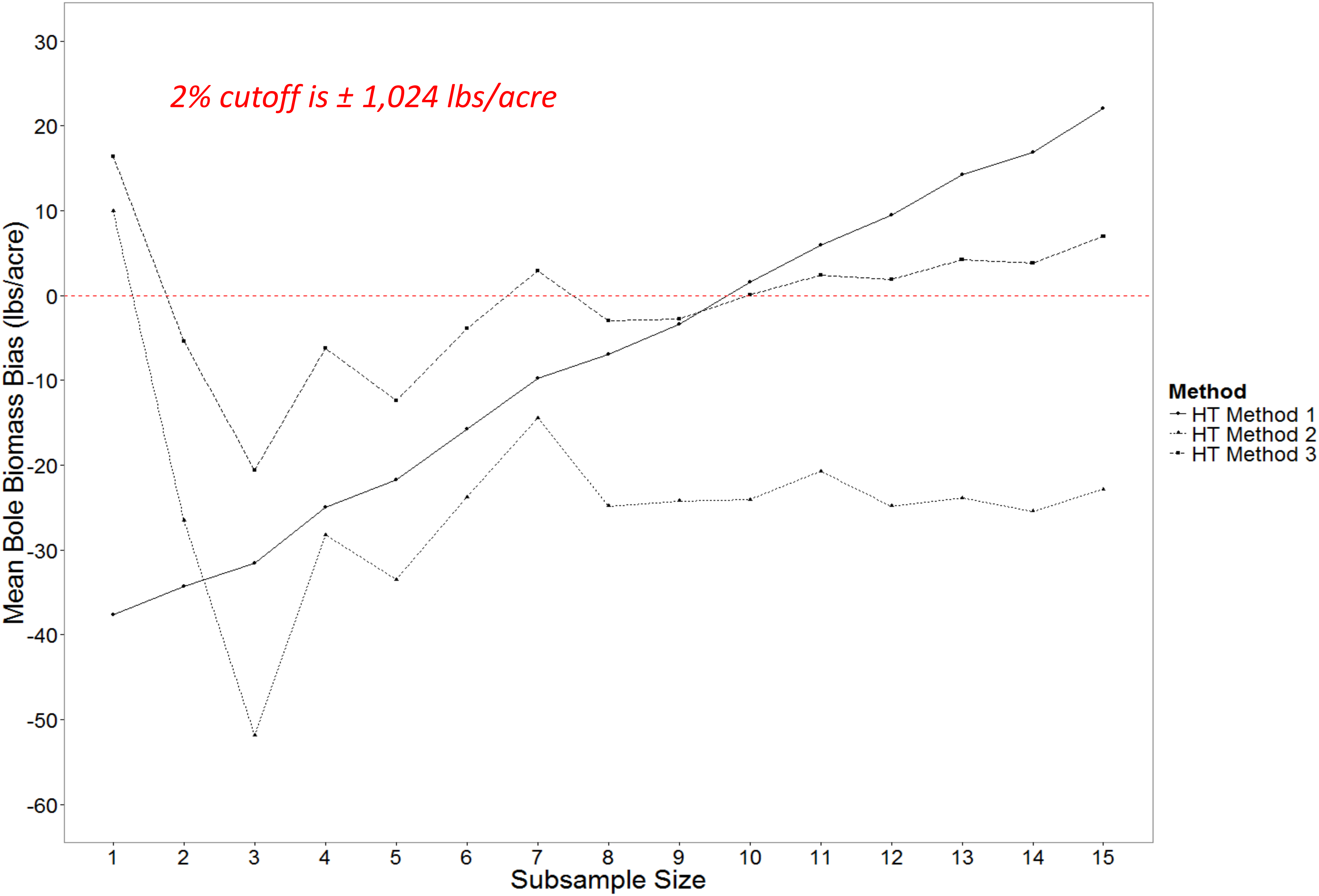
Methods – Interpretation

- Imputation strategy is "best" if it
  1) is negligibly biased (< 2% of mean biomass estimate)
  2) Has the smallest RMSE and *thus the lowest potential bias*

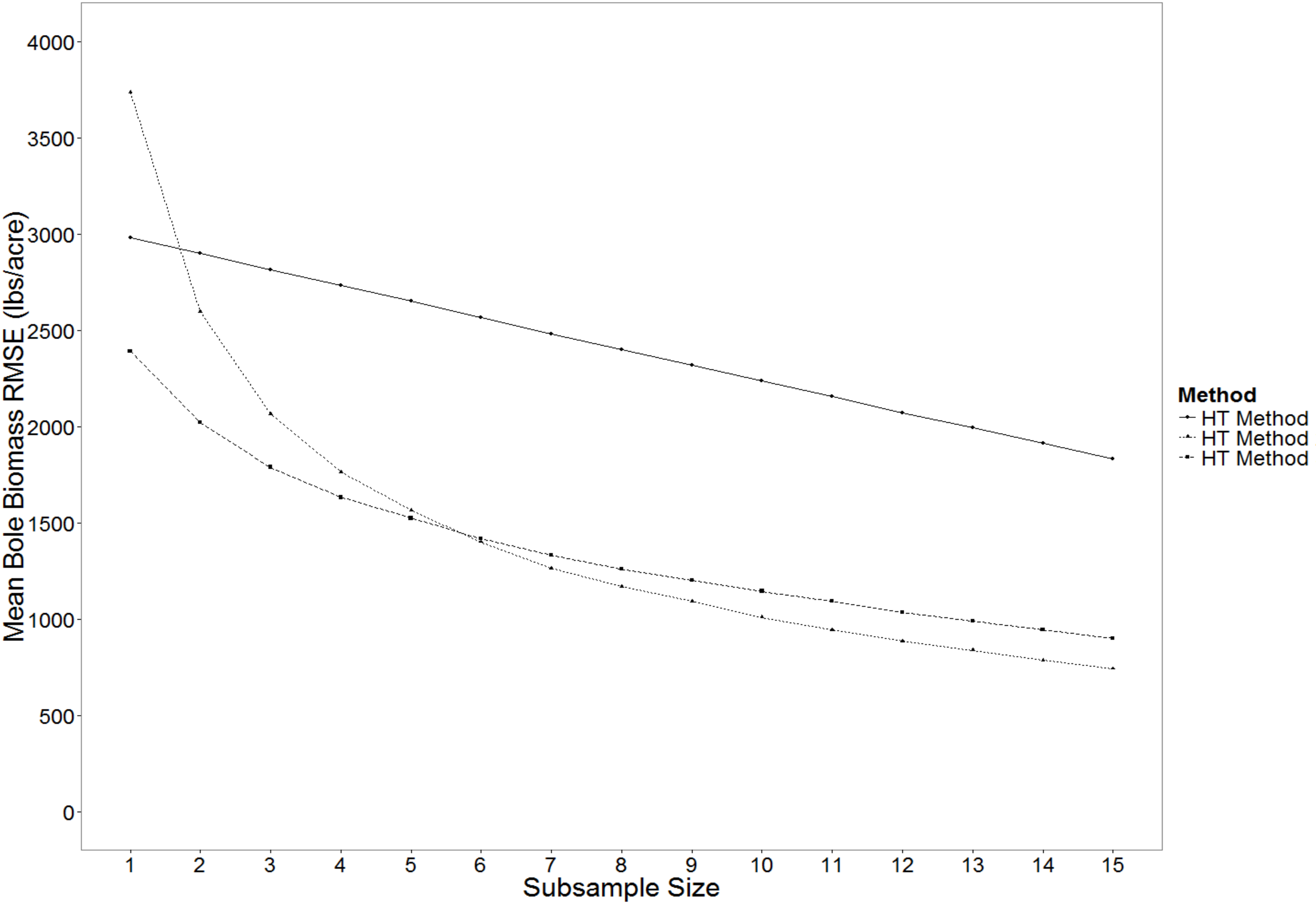
- Recommended subsample size determined as all sizes between two points
  1) minimum number of subsampled trees where > 50% of the total possible cumulative precision gain (reduction in RMSE from n = 1 to n = 15 using "best" methods); *majority of precision gains achieved*
  2) maximum number of trees where the average cumulative precision gain per subsampled tree is < 8%; *precision gains level off*

Results – Bole Biomass

- Mean stand bole biomass is 50,182 lbs/ac (92.39% of total)
- Bias is negligible; maximum observed bias was -51.8 lbs/ac (0.10% of mean)
- NMEM (Method 3) is most precise for 1-5 subsampled trees (4.76% to 3.04%)
- NFEM w/CF (Method 2) is most precise for 6-15 trees subsampled trees (2.79% to 1.48%)
- Majority (> 50% cumulative) of precision gains with 4 or more subsampled trees
- Precision gains level off (< 8% cumulative per tree) after 12 subsampled trees
- Estimates driven by HT (LCR unused)

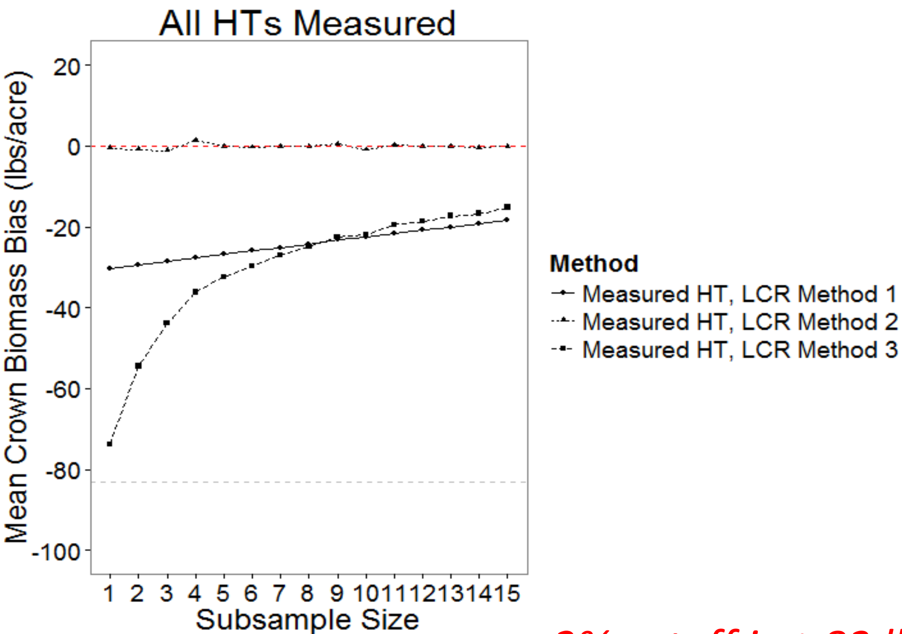


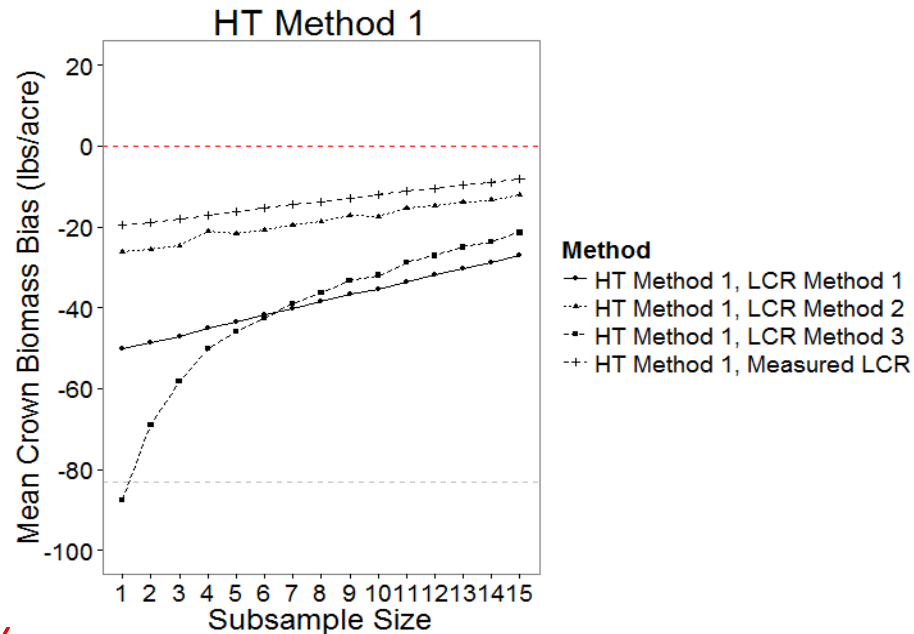
2% cutoff is ± 1,024 lbs/acre
Mean Bole Biomass Bias (lbs/acre)
30
20
10
0
-10
-20
-30
-40
-50
-60
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Subsample Size
Method
HT Method 1
HT Method 2
HT Method 3


Mean Bole Biomass RMSE (lbs/acre)
4000
3500
3000
2500
2000
1500
1000
500
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Subsample Size
Method
HT Method 1
HT Method 2
HT Method 3

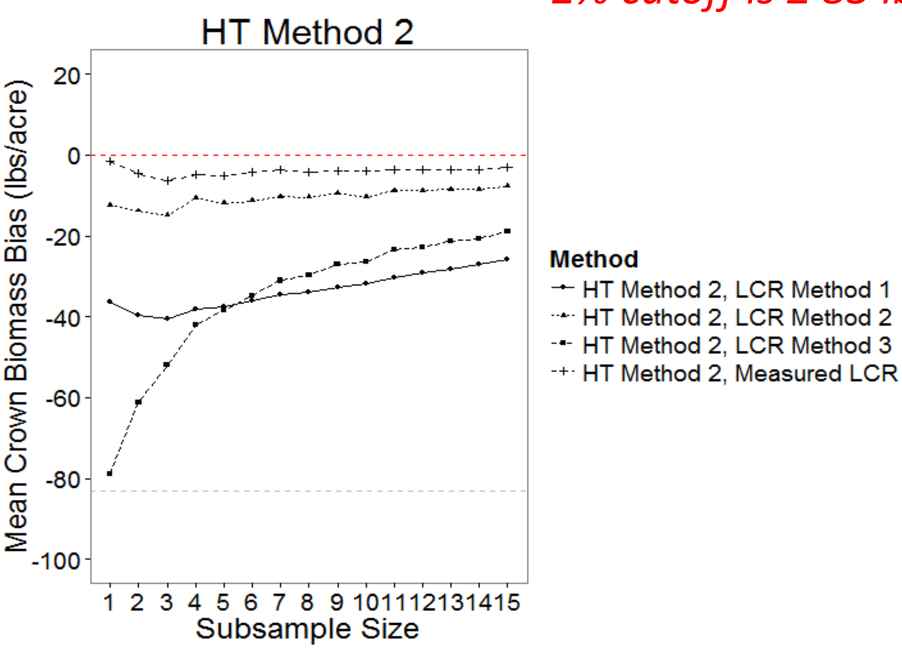
Results – Crown Biomass

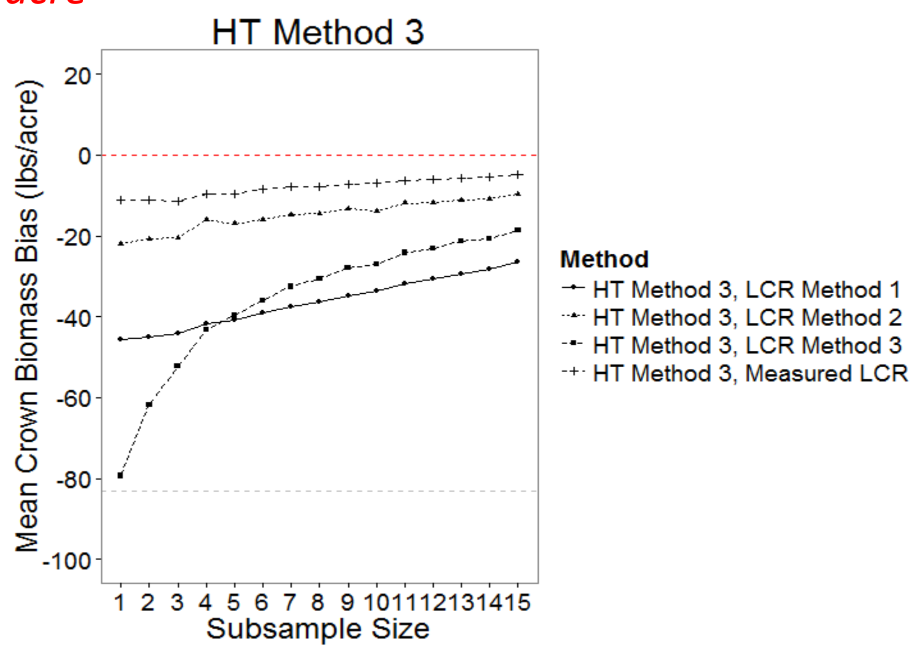
- Mean stand crown biomass is 4,136 lbs/ac (7.61% of total)
- Bias is mostly negligible; maximum observed bias was -87.5 lbs/ac (2.12% of mean)
- HT and LCR NMEMs (Method 3) are most precise for 1-14 subsampled trees (9.76% to 3.43%)
- HT NMEM and LCR NFEM w/CF (Method 2) are most precise for 15 trees subsampled trees (3.24%)
- Majority of precision gains with 4 or more subsampled trees
- Precision gains level off after 11 subsampled trees
- Estimates driven primarily by LCR, not HT

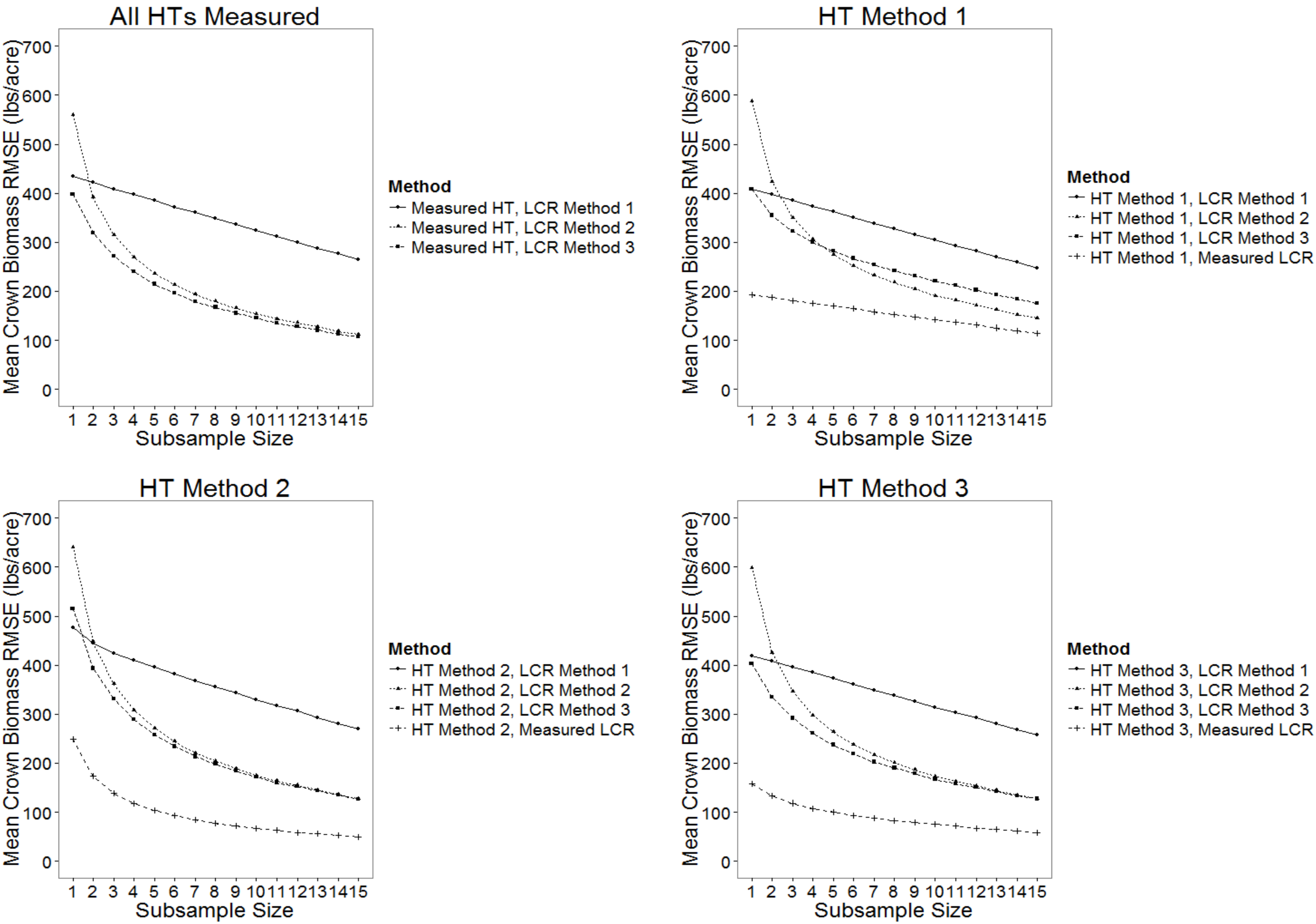




2% cutoff is ± 83 lbs/acre

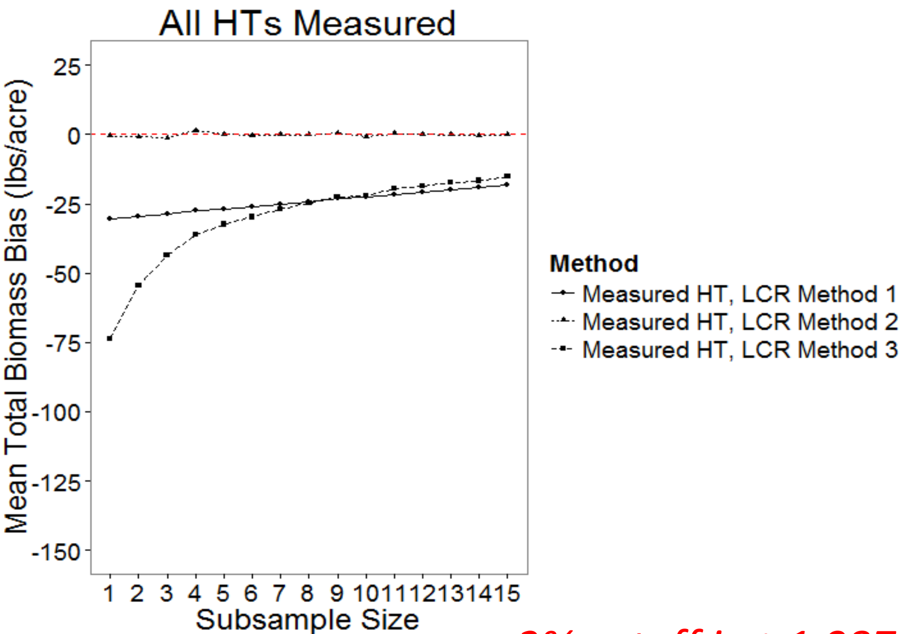


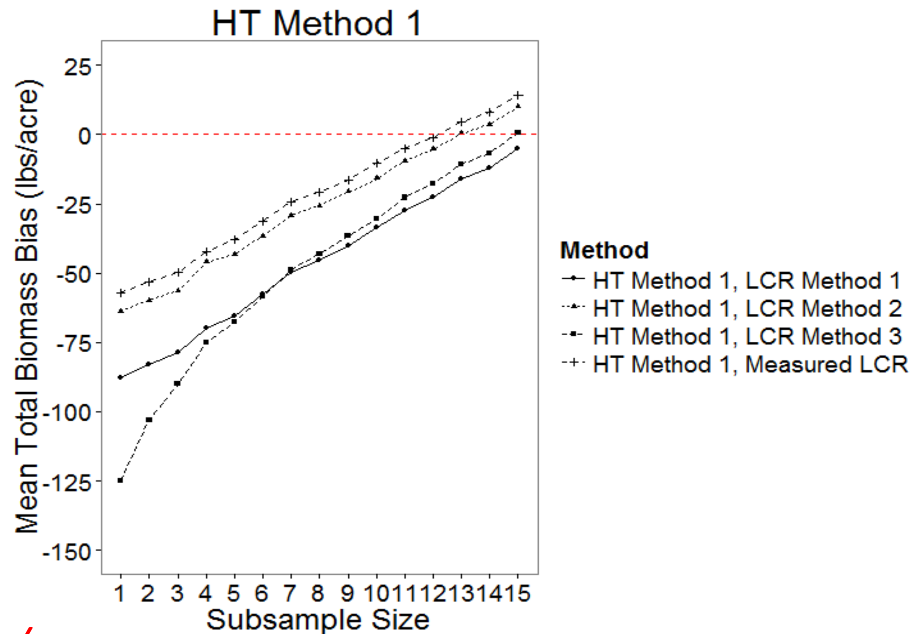



All HTs Measured
Mean Crown Biomass RMSE (lbs/acre)
0
100
200
300
400
500
600
700
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Subsample Size
Method
Measured HT, LCR Method 1
Measured HT, LCR Method 2
Measured HT, LCR Method 3
HT Method 1
Method
HT Method 1, LCR Method 1
HT Method 1, LCR Method 2
HT Method 1, LCR Method 3
HT Method 1, Measured LCR
HT Method 2
Method
HT Method 2, LCR Method 1
HT Method 2, LCR Method 2
HT Method 2, LCR Method 3
HT Method 2, Measured LCR
HT Method 3
Method
HT Method 3, LCR Method 1
HT Method 3, LCR Method 2
HT Method 3, LCR Method 3
HT Method 3, Measured LCR

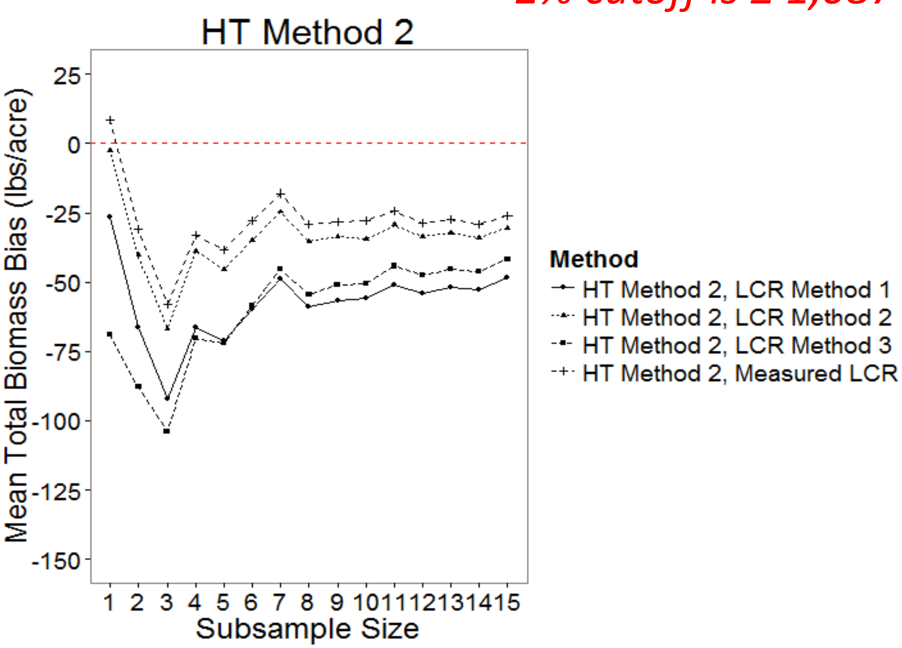
Results – Total Biomass

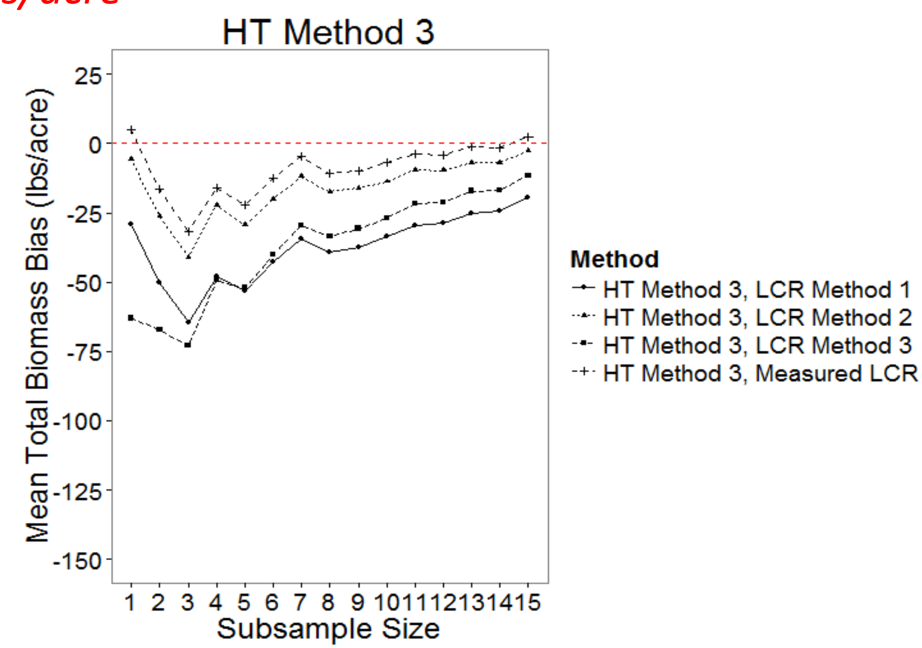
- Mean stand total biomass is 54,318 lbs/ac
- Bias is negligible; maximum observed bias was -125.10 lbs/ac (0.23% of mean)
- HT NMEMs (Method 3) and LCR NFEMs (Method 1) are most precise for 1-8 subsampled trees (4.49% to 2.36%)
- HT NFEMs w/ CF (Method 2) and LCR NMEMs are most precise for 9-14 subsampled trees (2.21% to 1.59%)
- HT and LCR NFEMs w/CF are most precise for 15 subsampled trees (1.51%)
- Majority of precision gains with 4 or more subsampled trees
- Precision gains level off after 12 subsampled trees
- Estimates driven primarily by HT, not LCR

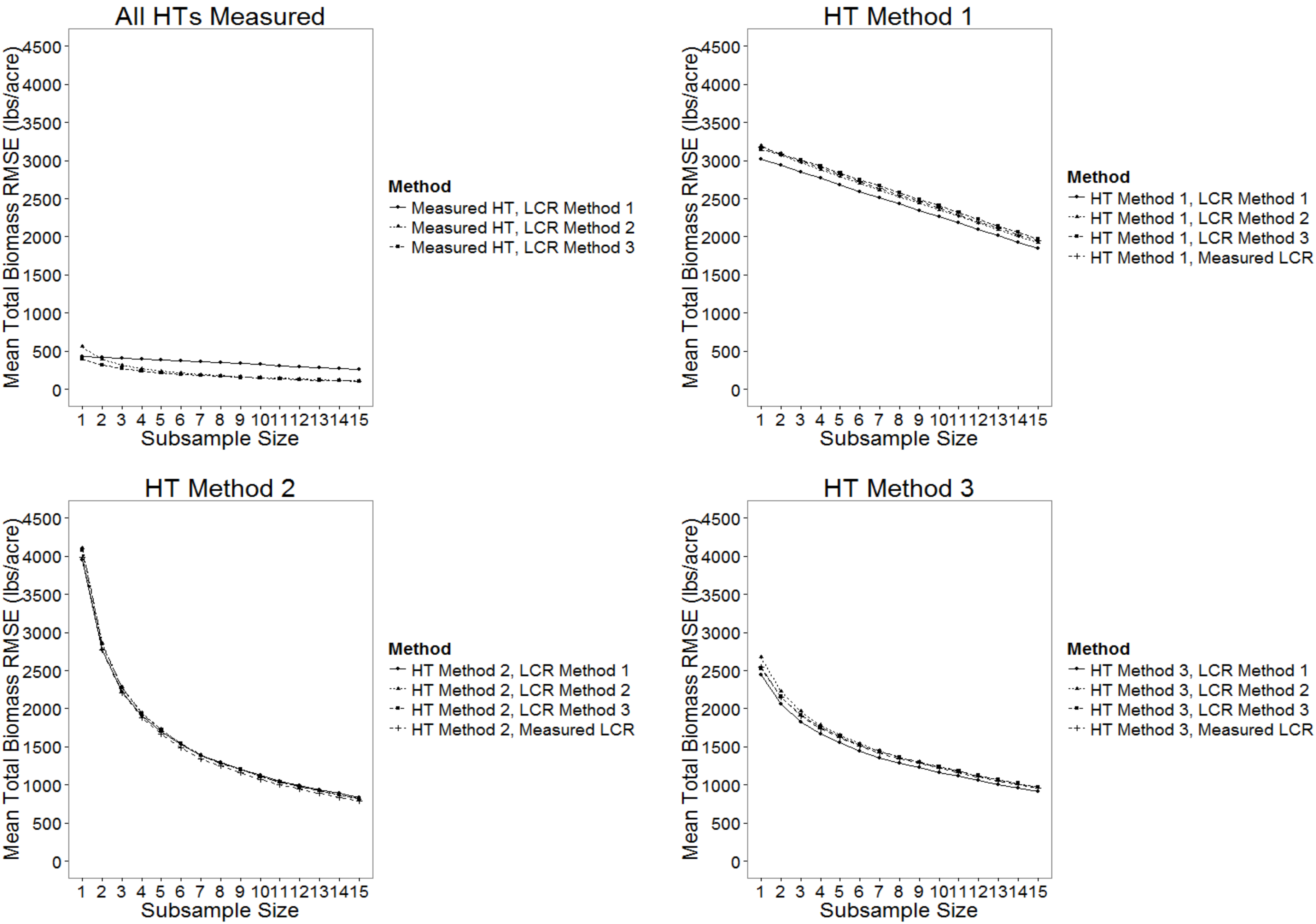




2% cutoff is ± 1,087 lbs/acre






All HTs Measured
Mean Total Biomass RMSE (lbs/acre)
Subsample Size
Method
Measured HT, LCR Method 1
Measured HT, LCR Method 2
Measured HT, LCR Method 3
HT Method 1
Mean Total Biomass RMSE (lbs/acre)
Subsample Size
Method
HT Method 1, LCR Method 1
HT Method 1, LCR Method 2
HT Method 1, LCR Method 3
HT Method 1, Measured LCR
HT Method 2
Mean Total Biomass RMSE (lbs/acre)
Subsample Size
Method
HT Method 2, LCR Method 1
HT Method 2, LCR Method 2
HT Method 2, LCR Method 3
HT Method 2, Measured LCR
HT Method 3
Mean Total Biomass RMSE (lbs/acre)
Subsample Size
Method
HT Method 3, LCR Method 1
HT Method 3, LCR Method 2
HT Method 3, LCR Method 3
HT Method 3, Measured LCR

Conclusions

- Imputation Method:
  - NMEMs generally improve precision most for small subsamples (1-5 trees) at the cost of slight increases in bias
  - NFEMs improve precision at larger subsamples (6-15 trees) with very little bias
- Subsample Size:
  - if imputing HT or LCR using adjusted models, subsample 4 trees at least and 12 trees at most
  - to achieve same relative (%) precision with crown biomass as with bole or total biomass, ~2 times as many subsampled trees needed
- HT most important for bole and total biomass, LCR most important for crown biomass

Questions?

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Thank you for your time!