# CARBON ESTIMATION METHODS

by

**Curtis L. VanderSchaaf**

Forestry Extension Specialist,

Central Mississippi Research and Extension Center

Mississippi State University

10-05-2023

# What Are Forest Carbon Markets/Programs/Projects?

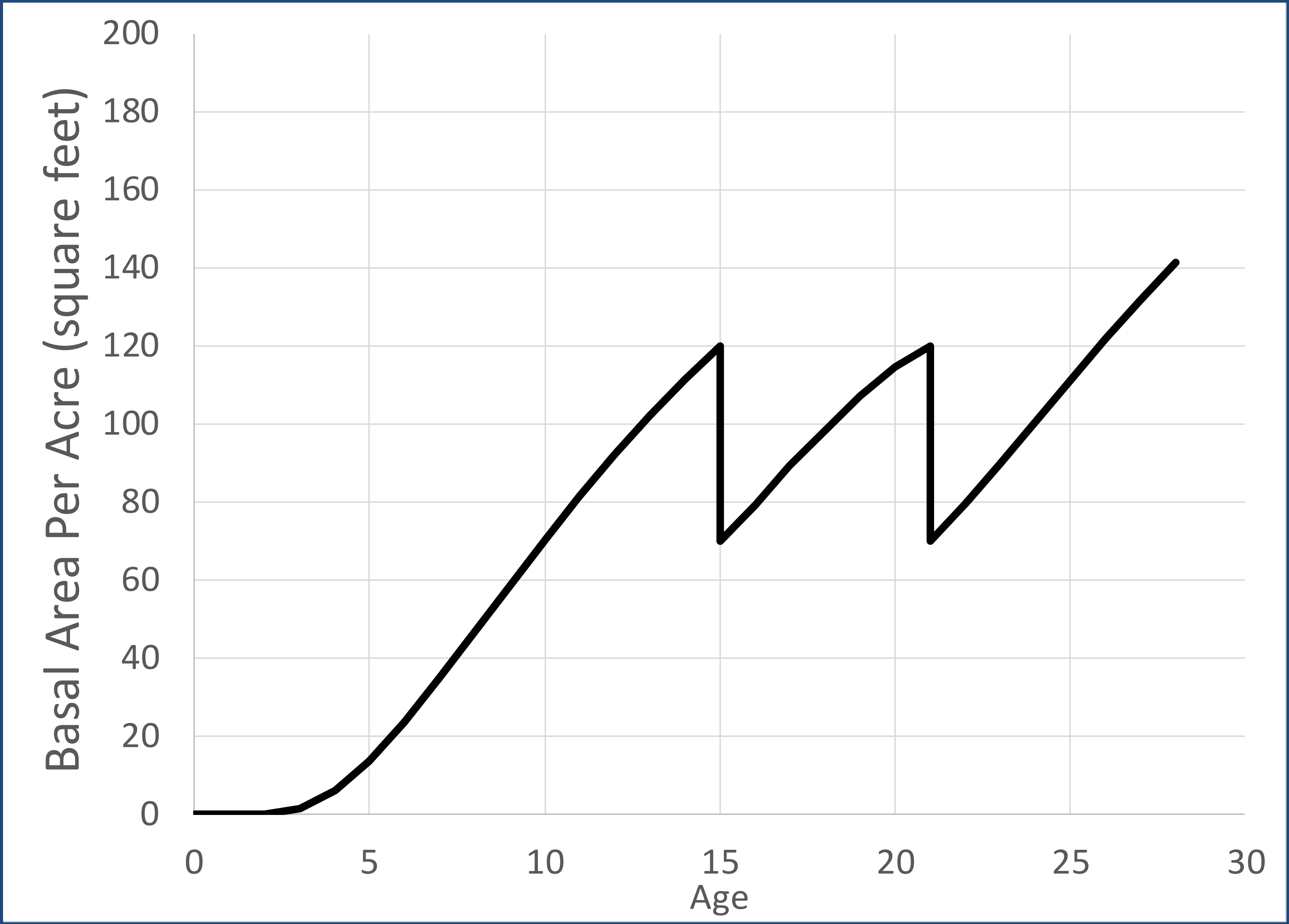
Carbon offset markets allow landowners to sell the carbon taken up by their forest to another entity to compensate for emissions made elsewhere. Forest carbon offset projects can include improved forest management practices, avoided deforestation, tree planting, and deferred harvests.

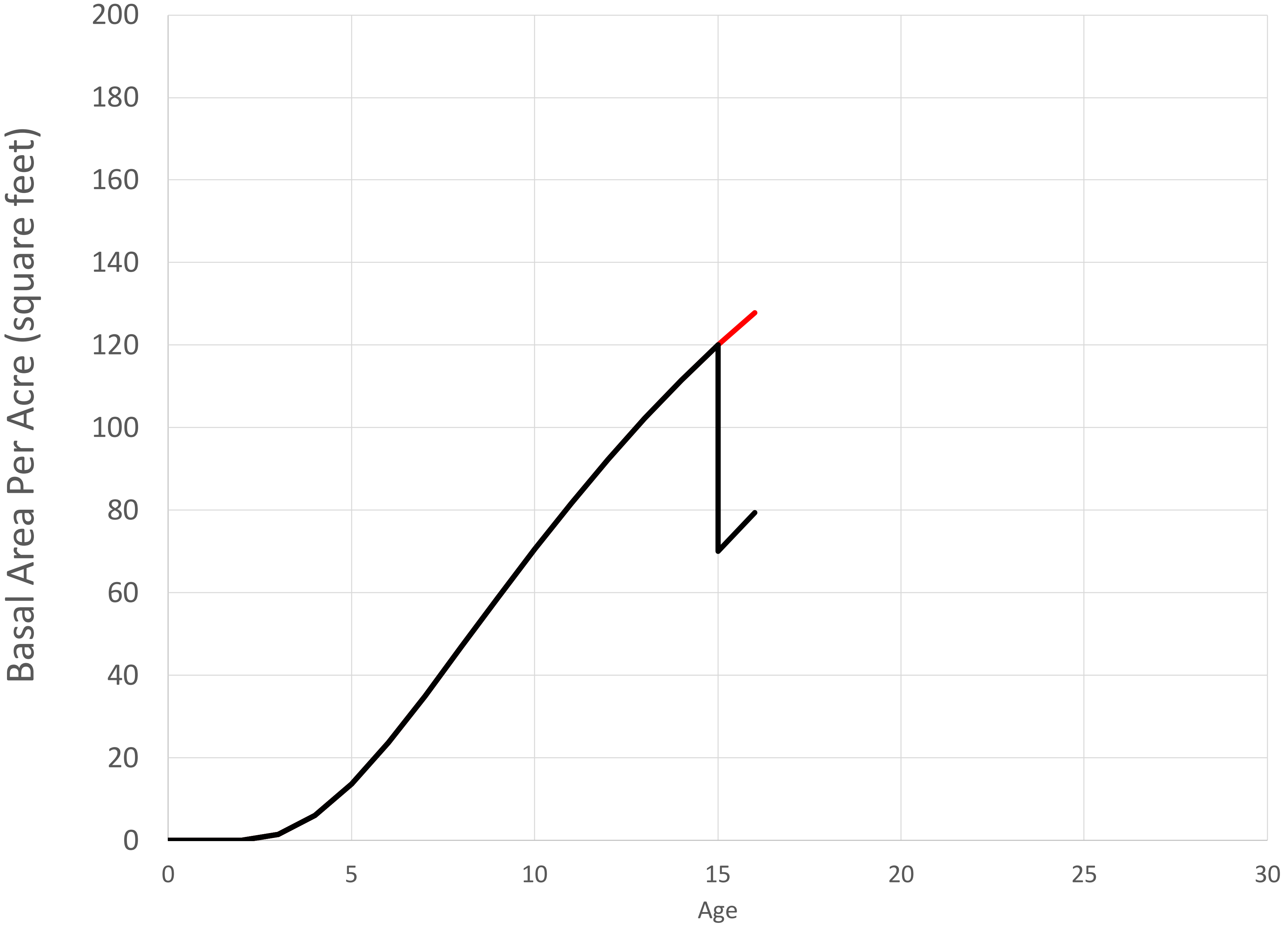
Selling forest carbon can provide an additional source of revenue to a landowner and the long-term commitment keeps forests intact

> **Forest Carbon Markets for Vermont Landowners**
>
> **Natural climate solutions**
>
> Forests are considered a natural solution to climate change because they remove carbon dioxide ($CO_2$) - a potent greenhouse gas (GHG) - from the atmosphere and store the carbon in wood and soil[1]. Increasing the amount of carbon stored in forests and harvested wood products can reduce the amount of $CO_2$ in the atmosphere while providing the other critical ecosystem services that forests provide. New carbon offset markets allow landowners to sell the carbon taken up by their forest to another entity to compensate for emissions made elsewhere. Because of the interest in forest carbon offsets from landowners and emitters, new opportunities for selling forest carbon are rapidly developing. Forest carbon offset projects can include improved forest management practices, avoided deforestation, or tree planting. Programs are open to all forestland owners, including family forests, municipalities, tribes, non-profit groups, and public entities. **Selling forest carbon can provide an additional source of revenue to a landowner and the long-term commitment keeps forests intact, but carbon projects are complex and may not be suitable for all forest parcels.**
>
> Kosiba, AM. 2021. Forest Carbon Markets for Vermont Landowners. Vermont Department of Forests, Parks and Recreation.

Types of forest carbon offset projects

# What is Business-as-Usual (BAU) – loblolly pine plantation



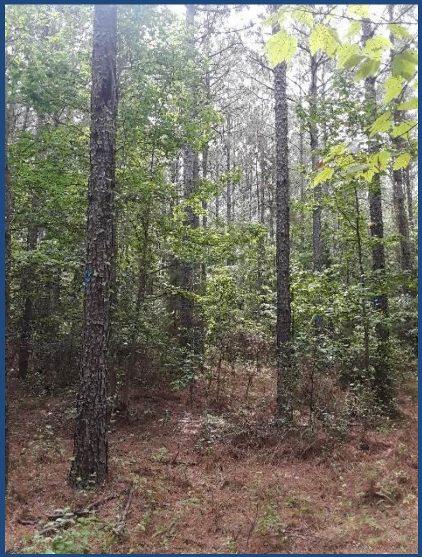


Basal Area Per Acre (square feet)
200
180
160
140
120
100
80
60
40
20
0
0
5
10
15
20
25
30
Age

# Why Conduct Inventories

Inventories help to determine the amount of a resource, plus in many cases the spatial distribution of that resource

- Helps to specify what activities need to occur to meet a management objective
- Economic value of a particular stand
- Potential restrictions when harvesting
- Landscape-level Resource Planning
- Among others …



# What is an Inventory

To me a valid inventory is anything you are willing to use when buying/selling timber or when developing management plans

- Some of you are probably more willing to “put up” money on lower intensity inventories than others
- Many foresters I talk with don’t do “traditional” square grid, one plot per acre, 10 BAF cruises
- Level of acceptable risk will vary by forester - others can’t answer this question definitively for you
- However, in some cases there are specified protocols and desired levels of precision that must be met

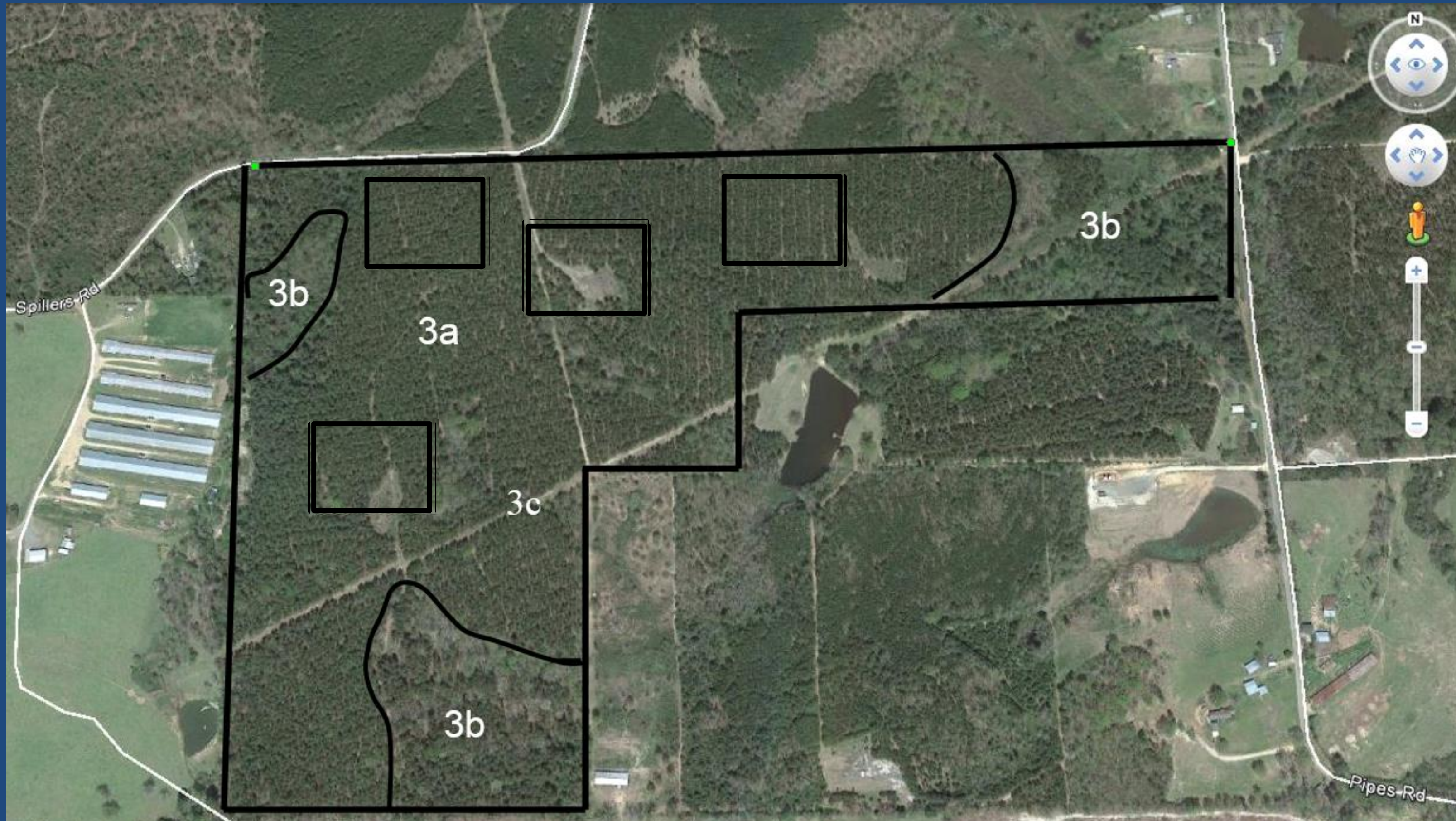
# Why Conduct Inventories

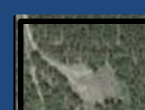
Inventories help to determine the amount of a resource, plus in many cases the spatial distribution of that resource

- We want to know this information at the lowest cost and using the least amount of time, given the information we want or need to know
  - Budgets….
- Depending on the value of the timber
  - 100% tally may be conducted – NO SAMPLING
  - Some type of sampling will be conducted
    - Measuring a reduced portion of the population to infer about the behavior of that population – HENCE SOME LEVEL OF RISK AND UNCERTAINTY

Using “blow-up/expansion” factors

Obviously, the portion of that stand that we directly measure and use to “blow-up” to the entire stand level is EXTREMELY IMPORTANT

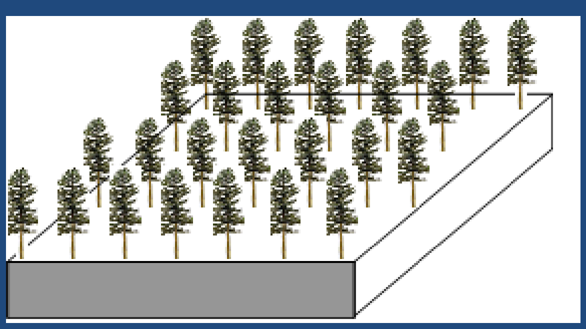

N
Spillers Rd
3b
3a
3b
3c
3b
Pipes Rd

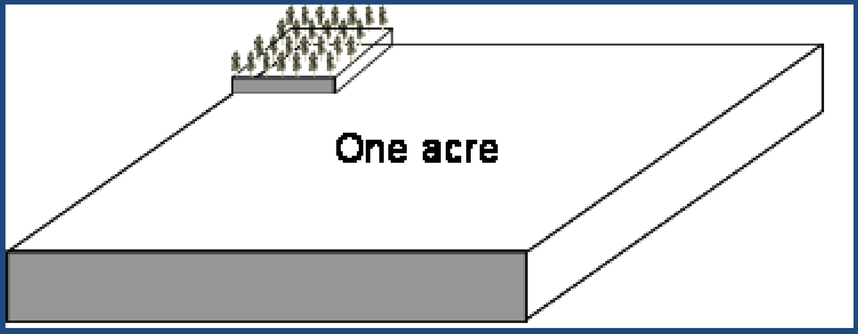


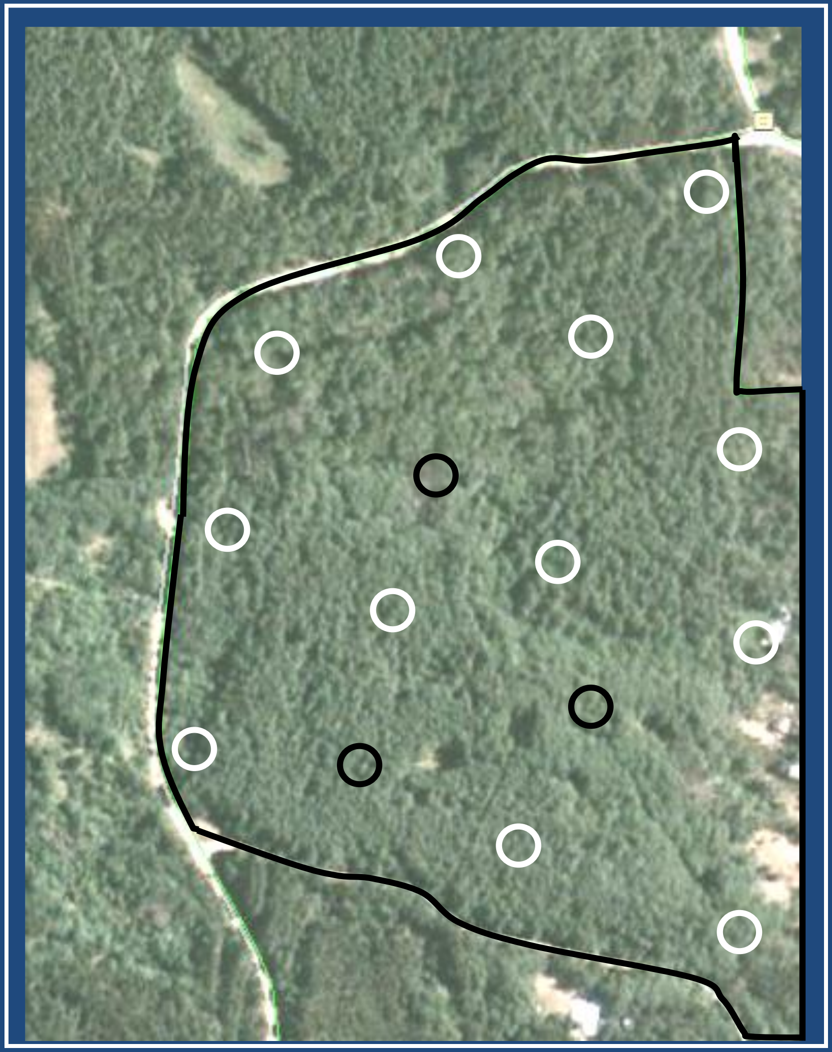
# Why Conduct Inventories

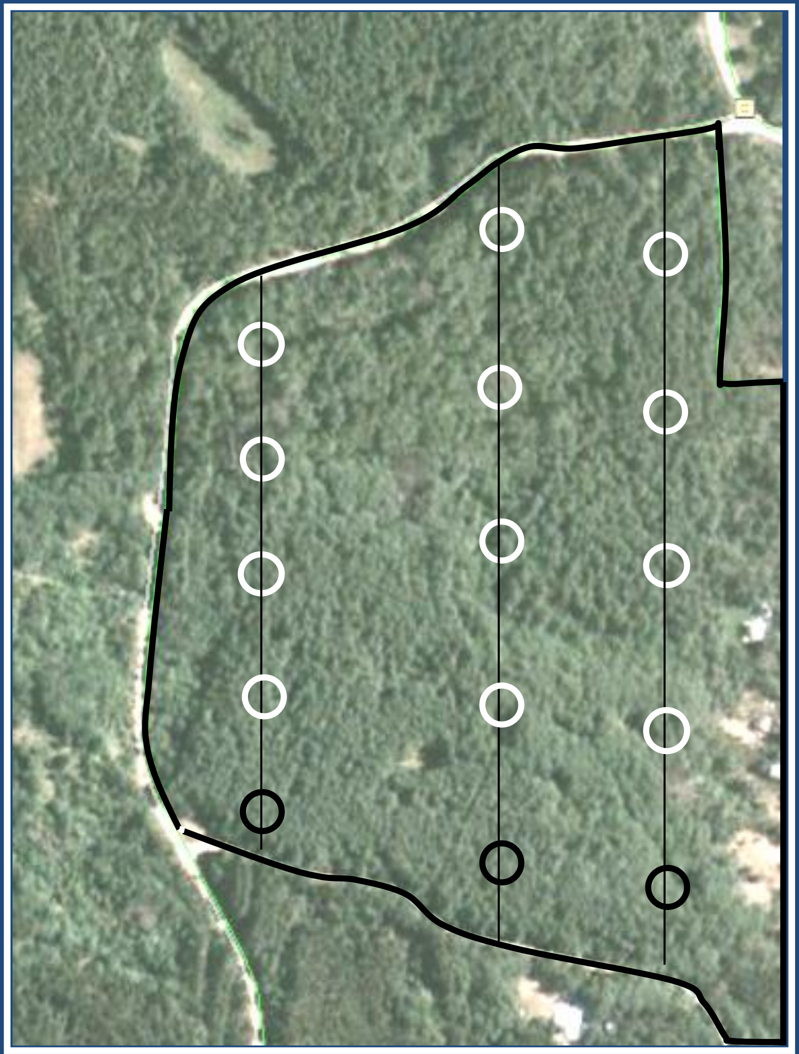
Some type of sampling will be conducted

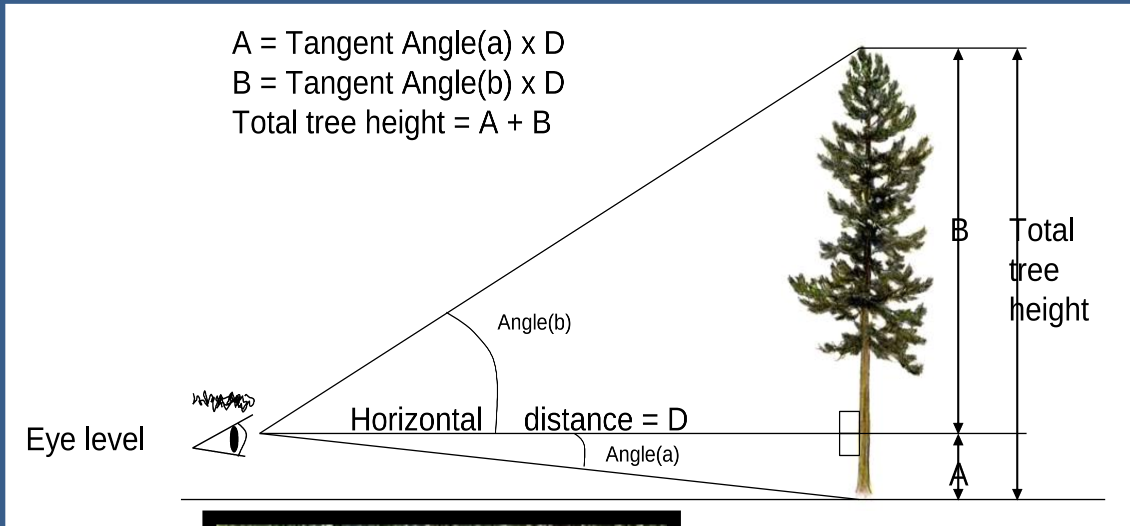
- Obviously, the greater the sample of a stand, on average, the better the inference should be to the entire stand
  - Measuring a small portion of a stand increases the possibility of measuring a below-than-average portion, or a greater-than-average portion
    - Creating substantial error when “blowing-up” to the stand level
- A greater sample size should increase the probability of obtaining a representative sample of the entire stand
  - Think about species compositions, slope, aspect, edge-effects, etc.










A = Tangent Angle(a) x D
B = Tangent Angle(b) x D
Total tree height = A + B
Eye level
Horizontal
distance = D
Angle(b)
Angle(a)
B
A
Total
tree
height

# MULTIPLE-ENTRY VOLUME EQUATIONS

Below are listed a variety of equation forms used to estimate volume/weight of various tree components:

| | | |
|---|---|---|
| Constant form factor | Y = | $b_1 D^2 H$ |
| Combined variable | Y = | $b_0 + b_1 D^2 H$ |
| Generalized combined variable | Y = | $b_0 + b_1 D^2 + b_2 H + b_3 D^2 H$ |
| Logarithmic | Y = | $b_1 D^{b_2} H^{b_3}$ |
| Generalized logarithmic | Y = | $b_0 + b_1 D^{b_2} H^{b_3}$ |
| Honer transformed variable | Y = | $\dfrac{D^2}{b_0 + b_1 H^{-1}}$ |
| Form class | Y = | $b_0 + b_1 D^2 HF$ |

Where:

Y some measure of stem/tree content,

D diameter at breast height,

H some measure of tree height,

F …ssion of tree form, and

$b_0, b_1, b_2, b_3$ are parameters to be estimated

# What is a Harvest Deferral Credit (HDC)

In my previous experience (e.g. CCX), we would estimate dry weight using an equation (say as a function of DBH and total tree height), assume 50% of the dry weight was carbon.

To get $CO_2$ Equivalent, you would take the amount of carbon as estimated above and then multiply by:

$$44/12 = 3.666667$$

Where 44 is the atomic weight of $CO_2$ (Oxygen (~16) + Oxygen (~16) + Carbon (~12) and ~12 is the atomic weight of carbon.

# MULTIPLE-ENTRY CARBON/BIOMASS/VOLUME EQUATIONS

Below are listed a variety of equation forms used to estimate volume/weight of various tree components:

| | | |
|---|---|---|
| Constant form factor | Y = | $b_1 \mathrm{D}^2 \mathrm{H}$ |
| Combined variable | Y = | $b_0 + b_1 \mathrm{D}^2 \mathrm{H}$ |
| Generalized combined variable | Y = | $b_0 + b_1 \mathrm{D}^2 + b_2 \mathrm{H} + b_3 \mathrm{D}^2 \mathrm{H}$ |
| Logarithmic | Y = | $b_1 \mathrm{D}^{b_2} \mathrm{H}^{b_3}$ |
| Generalized logarithmic | Y = | $b_0 + b_1 \mathrm{D}^{b_2} \mathrm{H}^{b_3}$ |
| Honer transformed variable | Y = | $\dfrac{\mathrm{D}^2}{b_0 + b_1 \mathrm{H}^{-1}}$ |
| Form class | Y = | $b_0 + b_1 \mathrm{D}^2 \mathrm{HF}$ |

Where:

Y some measure of stem/tree content,

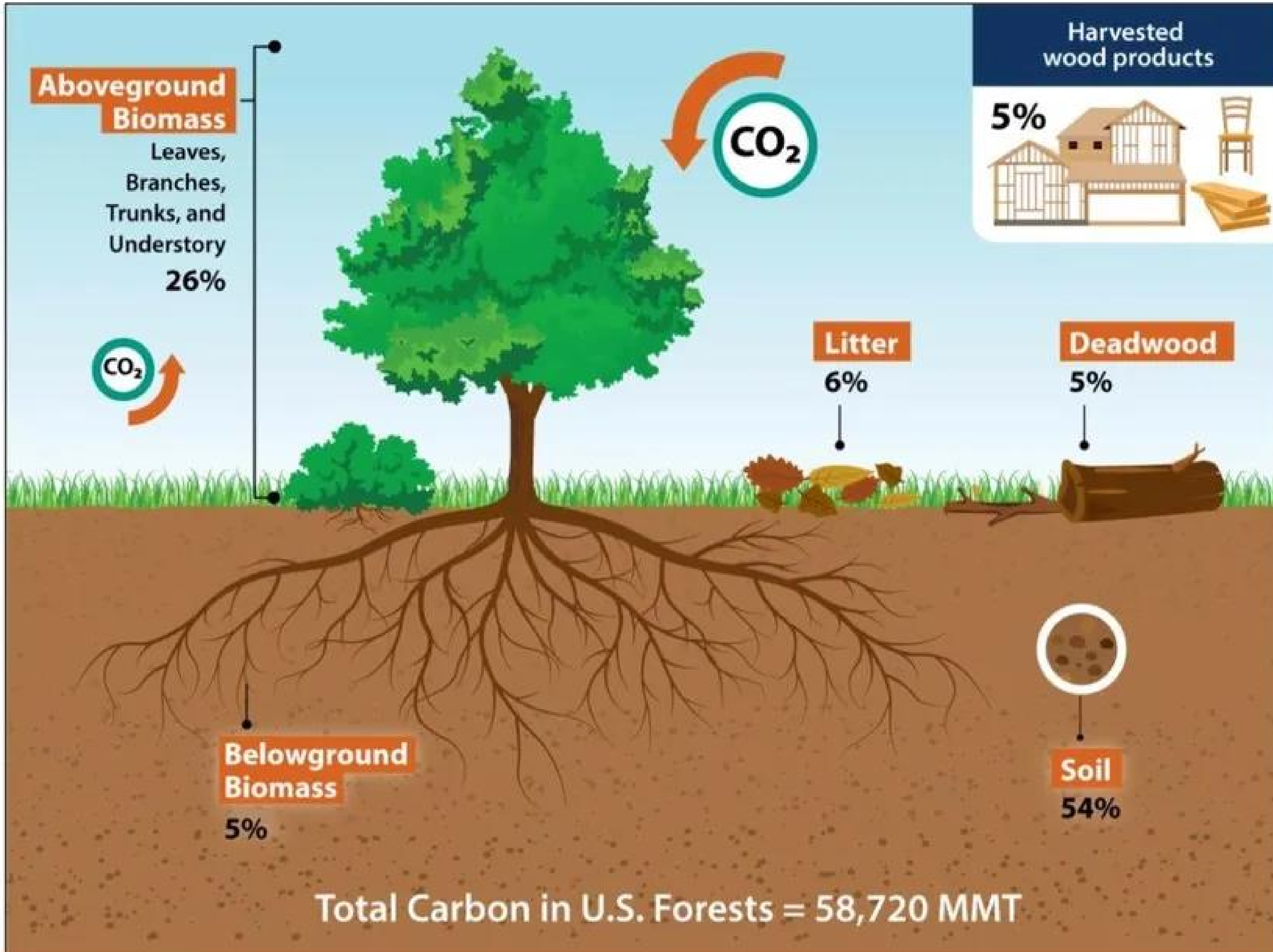
D diameter at breast height,

H some measure of tree height,

F an expression of tree form, and

$b_0, b_1, b_2, b_3$ are parameters to be estimated

**Source: Land Use, and Land-Use Change, and Forestry" in US National Greenhouse Gas Inventory, EPA 430-R-20_002, April 13, 2020**


Harvested wood products
5%
Aboveground Biomass
Leaves, Branches, Trunks, and Understory
26%
$CO_2$
$CO_2$
Litter
6%
Deadwood
5%
Belowground Biomass
5%
Soil
54%
Total Carbon in U.S. Forests = 58,720 MMT

# Remote Sensing

**How does the LandYield platform work?**

LandYield follows the requirements of ACR's methodology for small non-industrial forest owners to enroll forested parcels in carbon offset projects. LandYield has exclusive access to CORE Carbon™, Finite Carbon's online platform, to aggregate numerous small landholdings into larger projects and uses innovative technology such as remote sensing to monitor forest conditions over time.

NCX


## Reliable Data Makes Trustworthy Markets

The Basemap forest dataset serves as the foundation of the Natural Capital Exchange (NCX). The probabilistic model provides acre-by-acre intelligence on the location, diameter, and species of trees across the continental United States.

By combining Basemap forest cover and composition data with economics, timber-harvest pricing, and regional information, NCX can give an accurate assessment of timber and carbon value for every acre of land at no cost to the landowner.

Map Key

| Anew (Blue Source) Forestry Project Development |
|---|
| 1. Partner with property owners with holdings of 3,000 acres or more for carbon management |
| 2. Projects must be legally considered at risk for development or aggressive harvesting |
| 3. Verification is through regional economic assessments and interviews with local foresters and property stakeholders |
| 4. Information is reviewed via satellite imagery, LiDAR, and synthetic aperture radar data - provides a high-level assessment of the property's potential |
| 5. Once agreed, parties sign a Carbon Marketing and Development Agreement to ensure alternative uses of the land are taken off the table for the project's full lifetime |
| 6. To help more landowners get involved, Anew takes on the responsibility and costs required to bring credits to fruition |

anew

# What is Double-Sampling

Double-sampling involves estimating the relationship between two correlated variables

- Some predictable/systematic relationship must exist between the two variables
- One variable (supplementary) is more easily/less time consuming/less expensive to measure relative to the other variable (principal)
- If two variables are correlated, then knowing the value of the one variable, you “know” something about the value of the other variable
  - Measuring the less costly variable can provide some idea of the value of the more costly variable

**Table 6. Parameters and equations* for estimating component ratios of total aboveground biomass for all hardwood and softwood species in the United States.**

| Species class | Biomass component | Parameters $\beta_0$ | $\beta_1$ | Data points† | $R^2$ |
|---|---|---|---|---|---|
| Hardwood | Foliage | –4.0813 | 5.8816 | 632 | 0.256 |
| | Coarse roots | –1.6911 | 0.8160 | 121 | 0.029 |
| | Stem bark | –2.0129 | –1.6805 | 63 | 0.017 |
| | Stem wood | –0.3065 | –5.4240 | 264 | 0.247 |
| Softwood | Foliage | –2.9584 | 4.4766 | 777 | 0.133 |
| | Coarse roots | –1.5619 | 0.6614 | 137 | 0.018 |
| | Stem bark | –2.0980 | –1.1432 | 799 | 0.006 |
| | Stem wood | –0.3737 | –1.8055 | 781 | 0.155 |

* Biomass ratio equation:

$$ratio = \mathrm{Exp}(\beta_0 + \frac{\beta_1}{dbh})$$

where

*ratio* = ratio of component to total aboveground biomass for trees 2.5 cm dbh and larger

*dbh* = diameter at breast height (cm)

Exp = exponential function

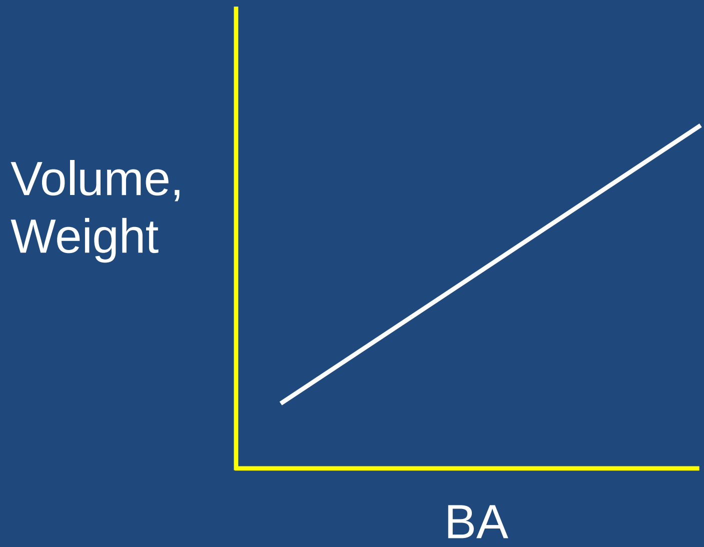
ln = log base e (2.718282)

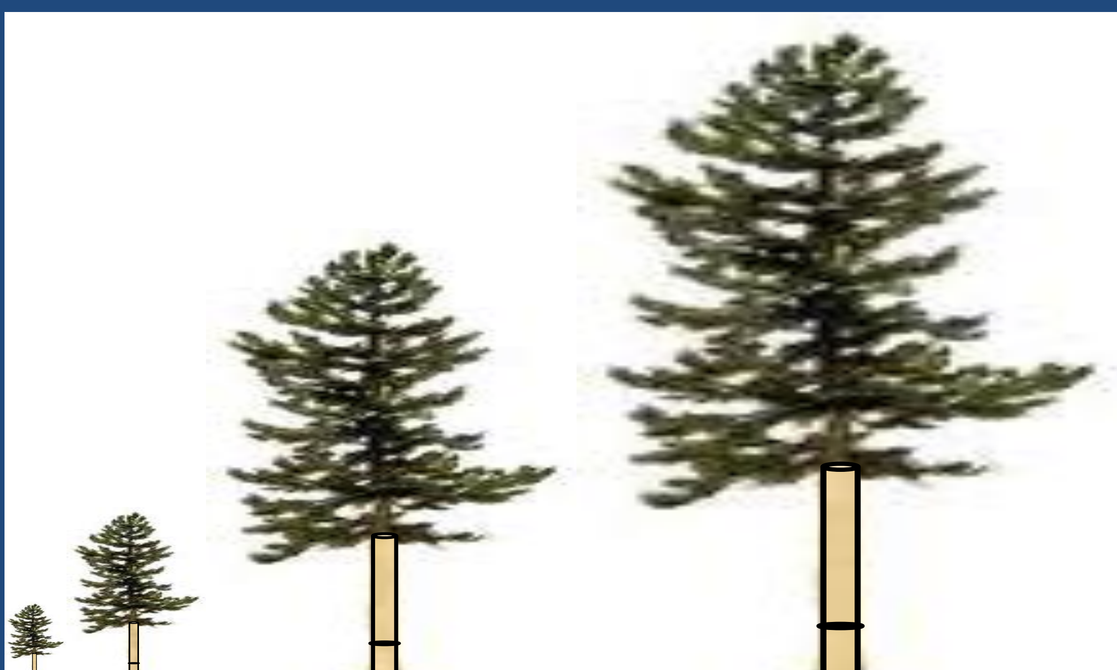
† Number of data points generated from published equations (generally at 5 cm dbh intervals) for parameter estimation.

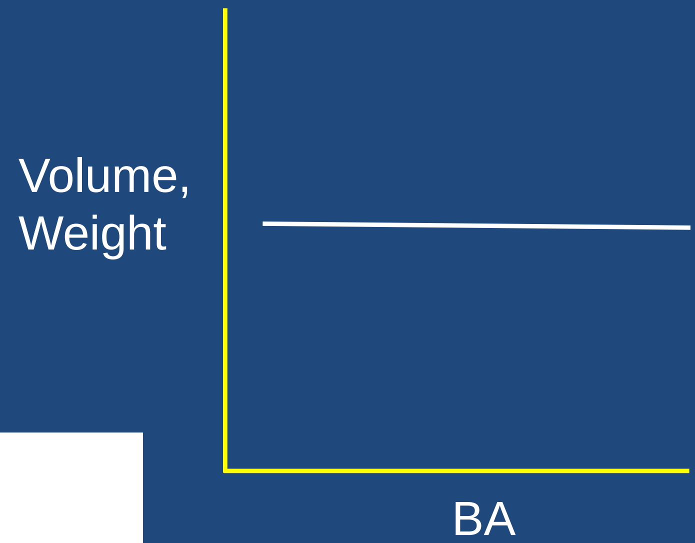
National-Scale Biomass Estimators for United States Tree Species

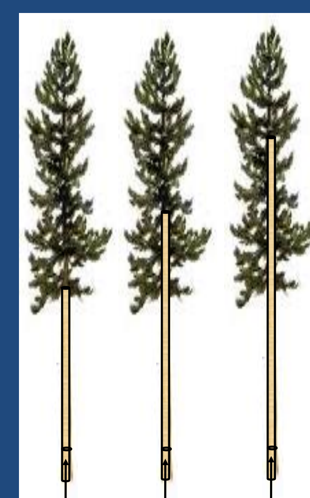
Jennifer C. Jenkins, David C. Chojnacky, Linda S. Heath, and Richard A. Birdsey

# Double-Sampling Within a Forest Inventory





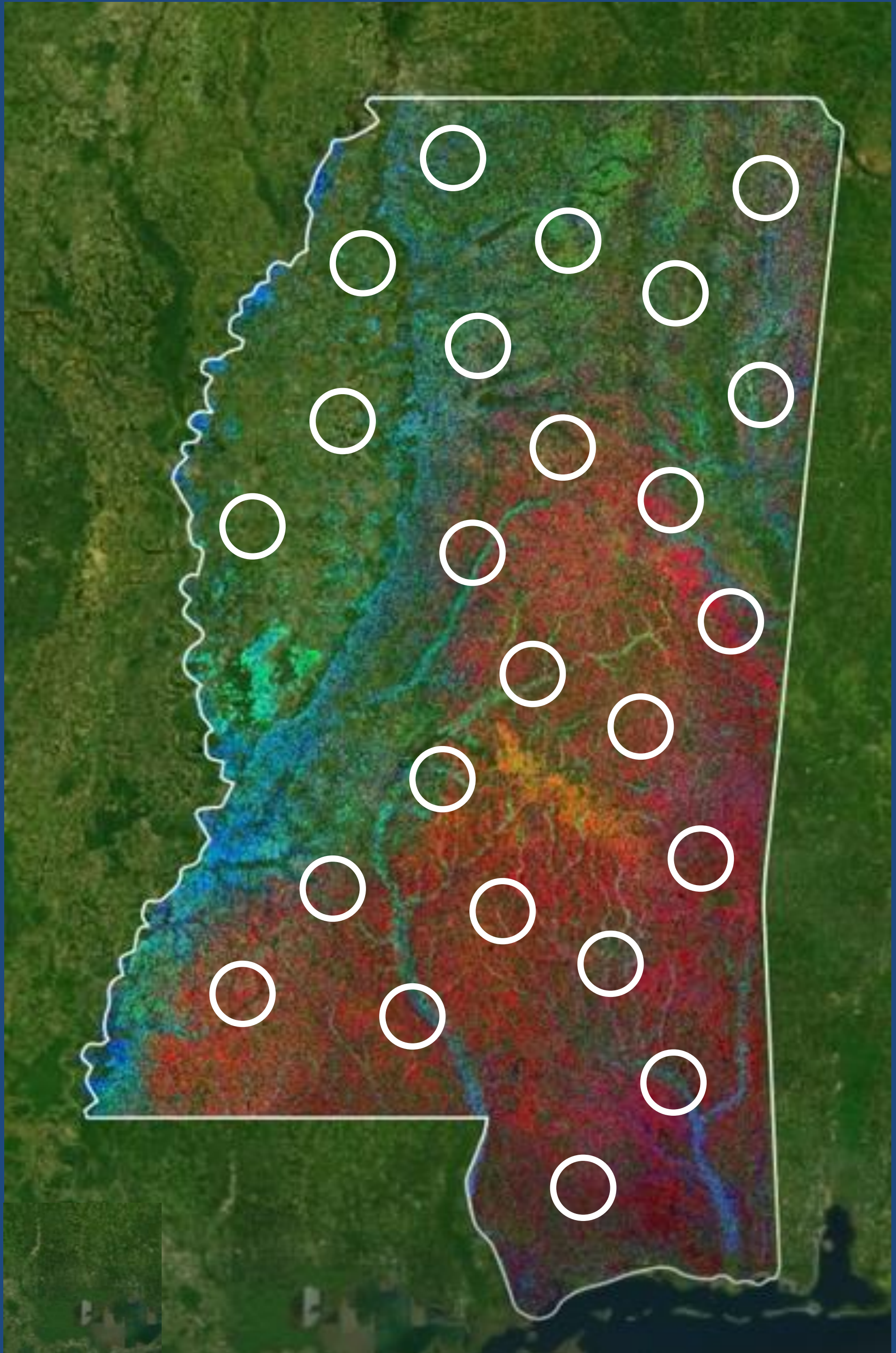



## Ratio

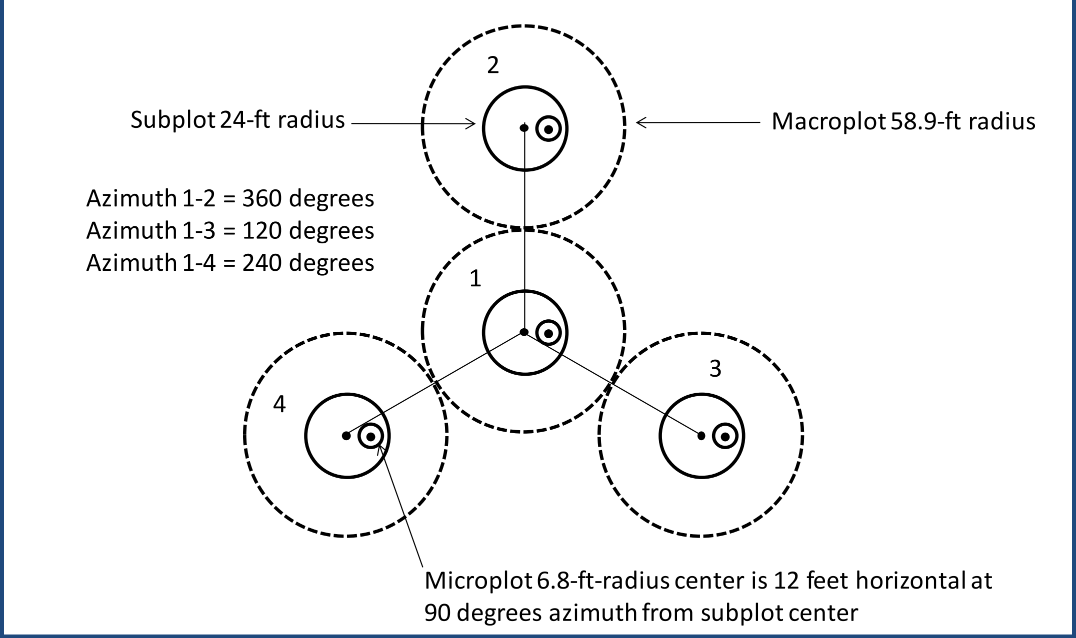
Between "boots-on-ground" plot estimate

And the satellite estimate for those same plots

You then estimate the non-sampled area using the satellite, and "correct" them using the ratio from above



# Forest Inventory and Analysis

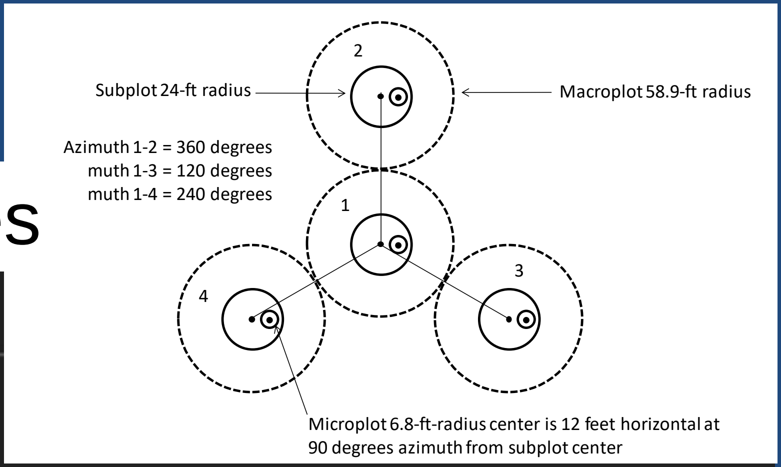



Currently, all plots are measured over a 5-year period (a cycle)

- Basically 1/5th of all plots are measured annually (a panel)

# NCX

## Aboveground carbon of live trees



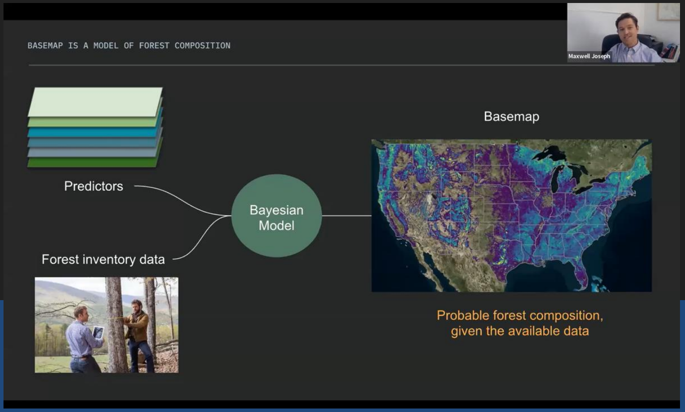

WE INTEGRATE FOREST INVENTORIES WITH REMOTELY SENSED DATA

### Predictors

- Sentinel 2 imagery
- Land cover
- Climate
- Ecoregion boundaries

### Measurements

- Forest inventories
  - Forest type
  - Tree counts
  - Stem sizes
  - Species identity



# THANK YOU

Curtis VanderSchaaf
Central Mississippi Research & Extension Center

(601) 857-2284

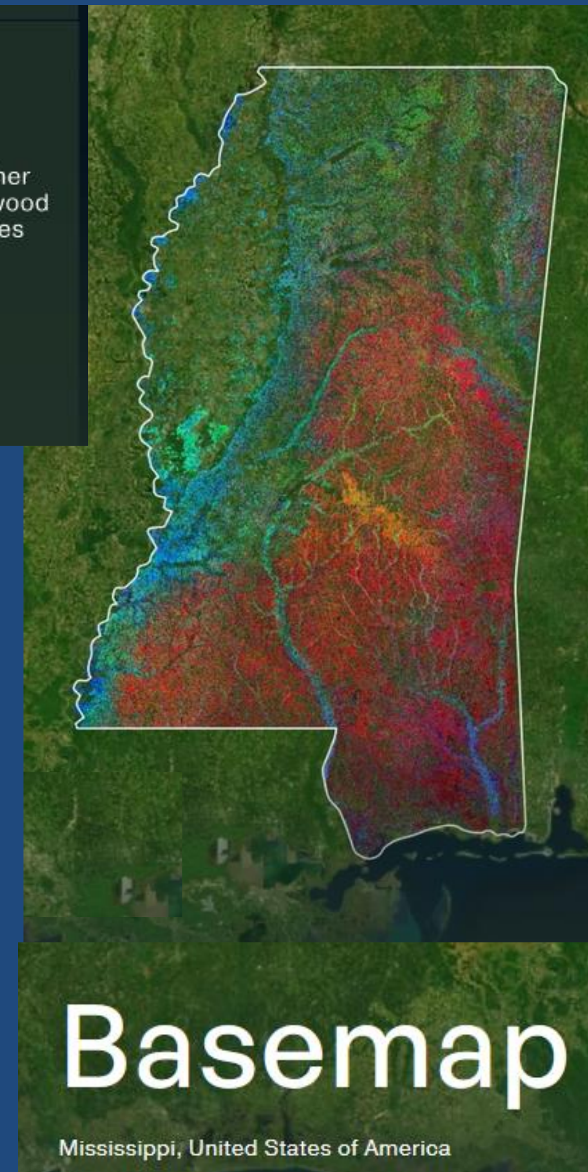
clv127@msstate.edu

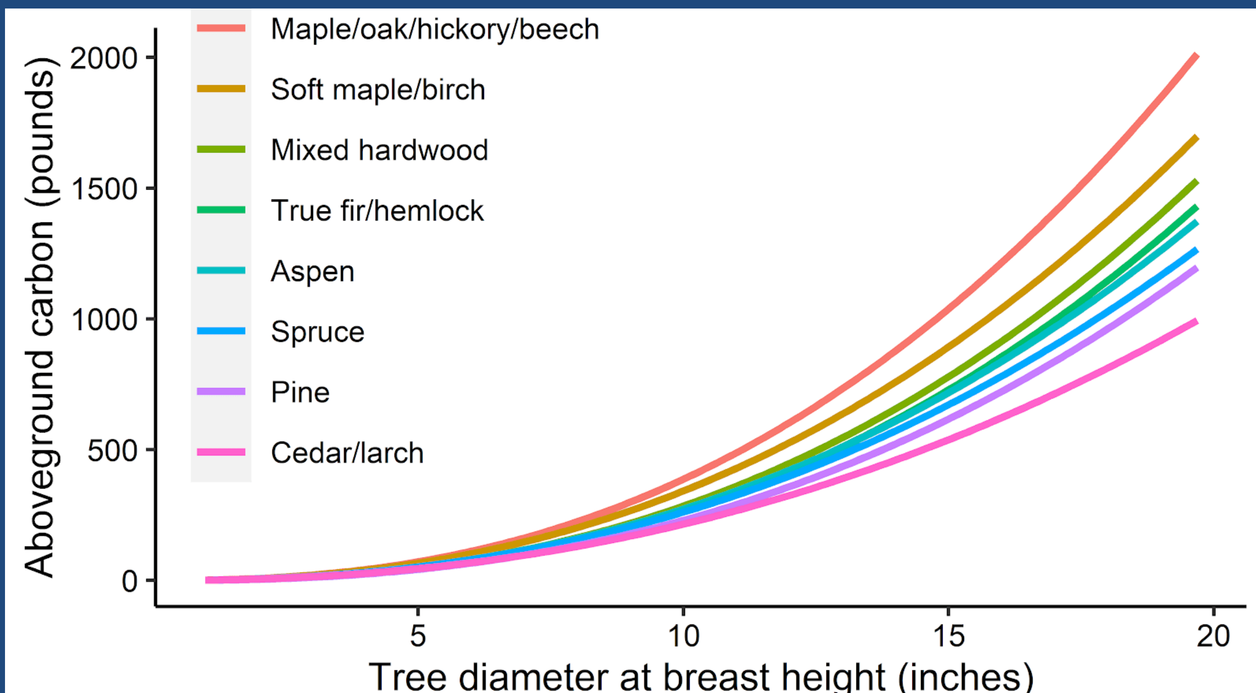
MISSISSIPPI STATE UNIVERSITY
EXTENSION
Forestry

# Species contain different amounts of carbon

Depends on:

- Tree size
- Specific gravity
- Bark ratio


Source: Jenkins et al. 2004; US Forest Service Gen. Tech. Rep. NE-319

# What is a Harvest Deferral Credit (HDC)

**29. How are carbon credits created in this program?**

This program pays landowners to increase carbon stocks on their property by deferring BAU (or business-as-usual) harvest activity. This creates carbon removal credits, which in the NCX Seller Agreement are called "Harvest Deferral Credits."

**36. How do I translate merchantable tons of timber to Harvest Deferral Credits?**

Since all trees store carbon, Harvest Deferral Credits are simply units that express the carbon content of the trees instead of, for example, their weight (like green tons). NCX estimates that 1 Harvest Deferral Credit represents the standing carbon that is stored in approximately 25 tons of softwood/pine timber.

To me, a HDC within this market is a calculated measure of carbon, I believe carbon is carbon – whether loblolly or Douglas-fir, a HDC is a HDC.

Now, per acre, the amount of HDC likely depends on site quality, stand density, age, species composition, previous silvicultural activities – "traditional growth and yield"

## 2.10 Weight Table for Various Woods

| | Weight Per Standard Cord (Pounds) | Tons Per Standard Cord Ratio | Weight Per 1000 B.F. of Green Lumber (Pounds) | Weight Per Cubic Foot Green (Pounds) | Weight Per Cubic Foot Air Dry 128 Moisture Content |
|---|---|---|---|---|---|
| Ash, white | 4300 | 2.2 | 4000 | 48 | 41 |
| Aspen | 3900 | 2.0 | 3600 | 42 | 27 |
| Basswood | 3800 | 1.9 | 3500 | 41 | 26 |
| Beech | 4900 | 2.5 | 4500 | 55 | 44 |
| Birch, yellow | 5100 | 2.6 | 4800 | 58 | 43 |
| Birch, white | 4500 | 2.3 | 4200 | 50 | 39 |
| Cedar, red | 3300 | 1.7 | 3100 | 37 | 33 |
| Cedar, n. white | 2500 | 1.3 | 2300 | 28 | 22 |
| Cherry, black | 4000 | 2.0 | 3800 | 46 | 35 |
| Cottonwood | 4400 | 2.2 | 4100 | 49 | 29 |
| Elm | 5000 | 2.5 | 4600 | 56 | 37 |
| Gum, sweet/ black | 4500 | 2.3 | 4200 | 45/50 | 35/34 |
| Hackberry | 4500 | 2.3 | 4200 | 50 | 37 |
| Hemlock | 4500 | 2.3 | 4200 | 49 | 28 |
| Hickory | 5700 | 2.9 | 5300 | 64 | 51 |
| Locust, black | 5200 | 2.6 | 4800 | 58 | 49 |
| Maple, hard | 5300 | 2.7 | 4600 | 56 | 44 |
| Maple, soft | 4300 | 2.2 | 3900 | 50 | 38 |
| Oak, red | 5700 | 2.9 | 5200 | 63 | 44 |
| Oak, white | 5600 | 2.8 | 5200 | 62 | 48 |
| Pine, red | 3800 | 1.9 | 3500 | 42 | 33 |
| Pine, shortleaf | 4700 | 2.4 | 4300 | 51 | 38 |
| Pine, white | 3200 | 1.6 | 3000 | 36 | 25 |
| Poplar, yellow | 3400 | 1.7 | 3200 | 38 | 28 |
| Spruce | 3000 | 1.5 | 2800 | 34 | 28 |
| Sycamore | 4700 | 2.4 | 4300 | 52 | 35 |
| Tamarack | 4200 | 2.1 | 3900 | 47 | 37 |
| Walnut, black | 5200 | 2.6 | 4800 | 58 | 39 |

2.10

| Species | Specific Gravity | Weight per $ft^3$ |
|---|---|---|
| Mixed Oak | 0.68 | 44.7 |
| Mixed Southern pine | 0.51 | 34.2 |
| Red Maple | 0.58 | 38.6 |
| Red Oak | 0.67 | 44.1 |
| Southern Pine | 0.55 | 36.7 |
| White Oak | 0.73 | 47.7 |
| Yellow Poplar | 0.43 | 29.2 |

https://www.engineersedge.com/civil_engineering/specific_gravity_and_weight_of_wood__15394.htm?fbclid=IwAR19urFq_ASMWAQOINAQnGYYbktLJZyK0O1i-ySaG6xxTrY-MQjV3gXDKpE

**Timber Management Field Book**

2008 Edition

United States
Department of Agriculture
Forest Service
Northeastern Area
State and Private Forestry
11 Campus Boulevard, Suite 200
Newtown Square, PA 19073
NA–MR–02–08
August 2008
www.na.fs.fed.us

# NCX

## Aboveground carbon of live trees