Why You Should NOT Use Site Index

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What You Need to Know

Site index systems are:

- Fuzzily-defined,
- Often used incorrectly,
- Prone to large over-estimates at young ages,
- Misapplied in many growth models to drive height growth and model treatment effects.

Site Index has out-sized leverage in financial decisions relative to its precision and accuracy.

What We Mean by "Site Index"

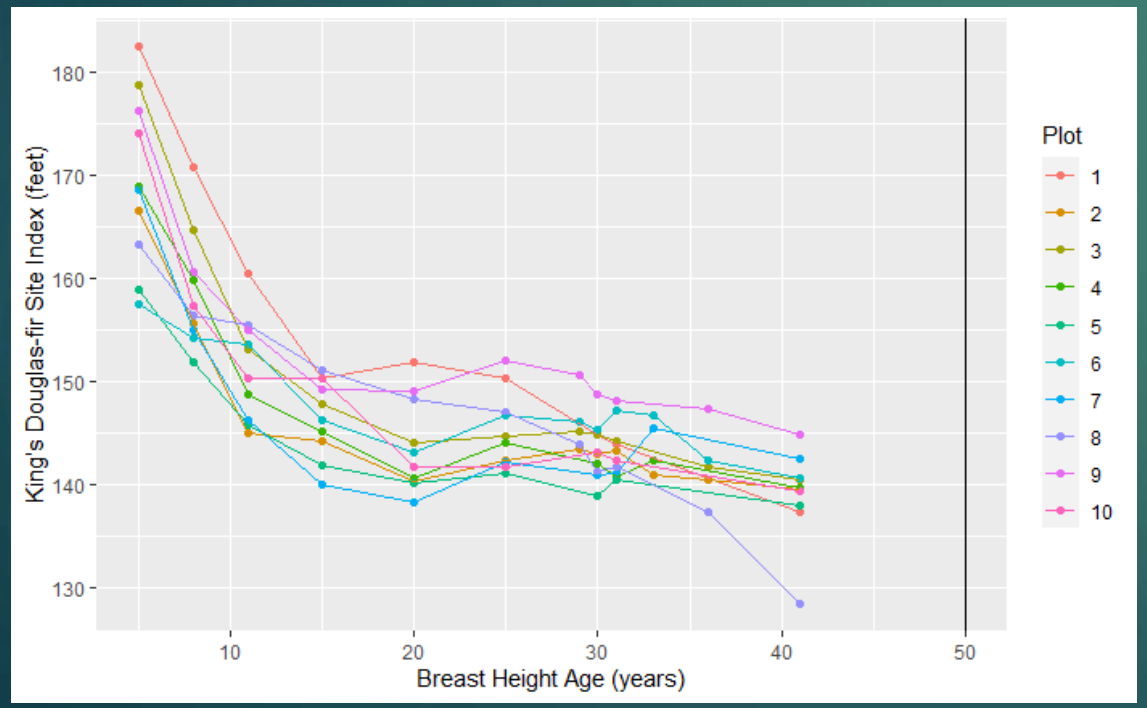
- The expected height of some set of dominant and/or co-dominant trees of a species at a fixed (base) age.
- A North American definition.
  - Chosen in the early 1900's.
  - Age and Height thought to be easy to measure.
  - Related to potential productivity.
  - Uses trees to integrate many site factors.
  - Assumed to be insensitive to management and thus an indicator of underlying productivity. It relies on three hypotheses (Skovsgaard and Vanclay, 2008):
    - Height growth correlates well with stand volume growth,
    - Total volume production at a given stand height should be identical for all site classes (Eichorn's Rule), and
    - Stand volume growth is independent of thinning.
- Intended to assign lands to a few broad Site Classes for predicting yields (*e.g.*, McArdle & Meyer (1949)).

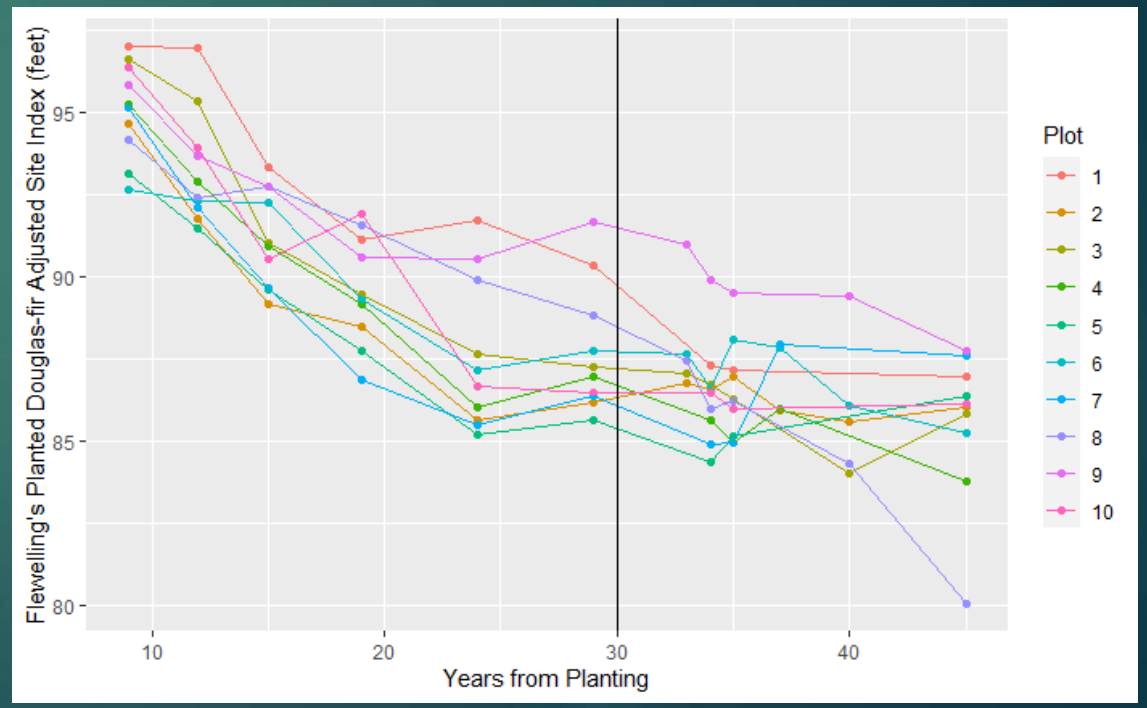
What We Mean by Age and Height

- Age:
  - Years from seed,
  - Years from planting, or
  - Years above breast height.
- Height:
  - Typically, a "dominant height", but not a standardized attribute:
    - Mean height of "dominant and co-dominant" trees (usually undamaged and disease-free),
    - Mean height of the largest X trees by height,
    - Mean height of the largest X trees by DBH,
    - Other definitions
  - All definitions result in an average height of a population of trees whose composition changes over time.
  - When solved for height, Site Index Equation systems define a height over age trajectory that is representative of a changing composite of trees and not a tree height growth curve.
  - All definitions require an appropriate sampling frame for estimation. There is a plot size effect that can lead to bias if the plot size used is different from that used to build the site equations.

The Age Problem

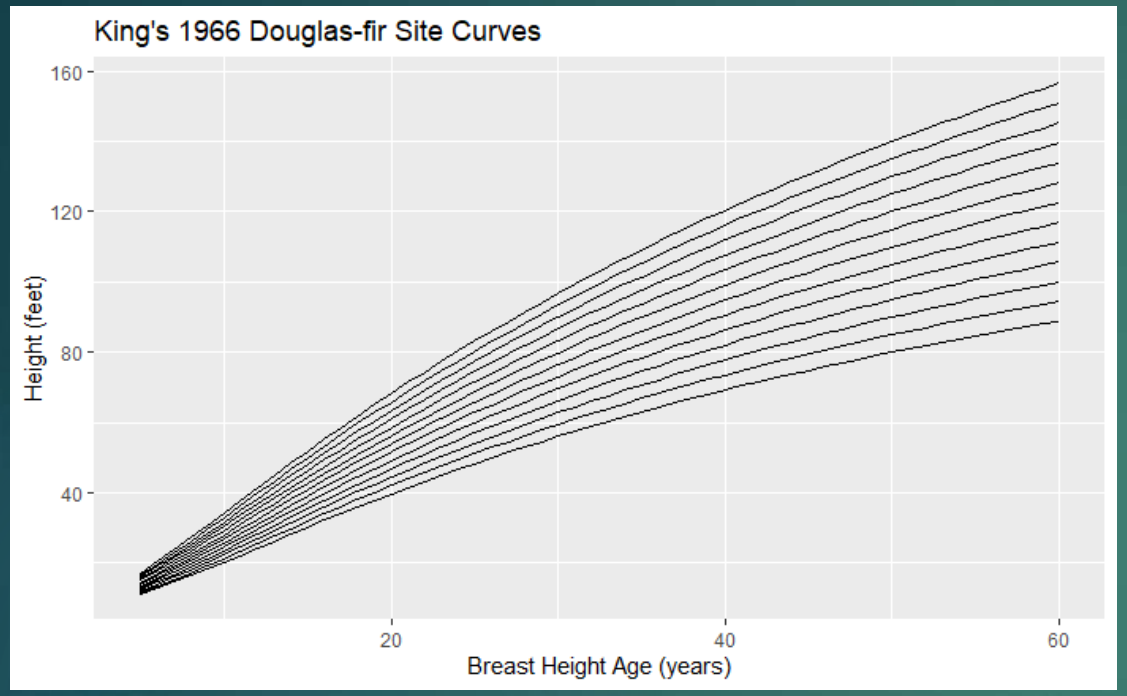
- Site Index assessed at early ages tends to overestimate stand performance at later ages.
- Example:
  - King's (left) and Flewelling's (right) Douglas-fir Site Index estimates over time from a plantation on ten 0.125-hectare plots.*
  - Both systems display a large over-estimation at young ages of eventual site index nearing the base age (black vertical line).

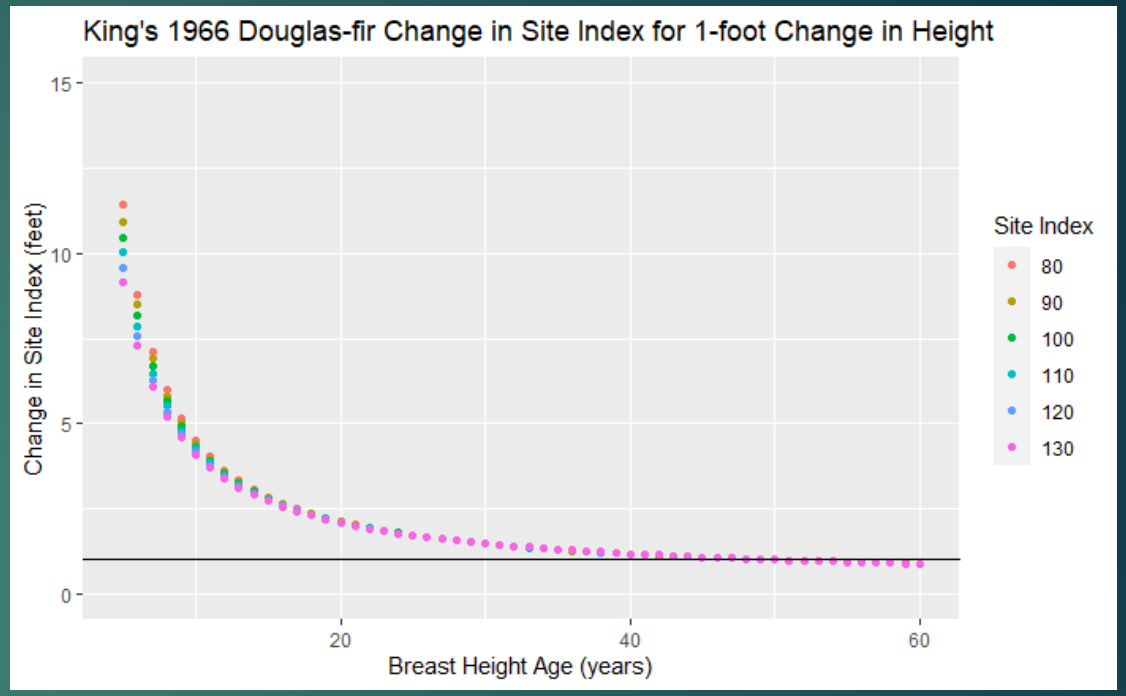




*Data provided by Weyerhaeuser Company

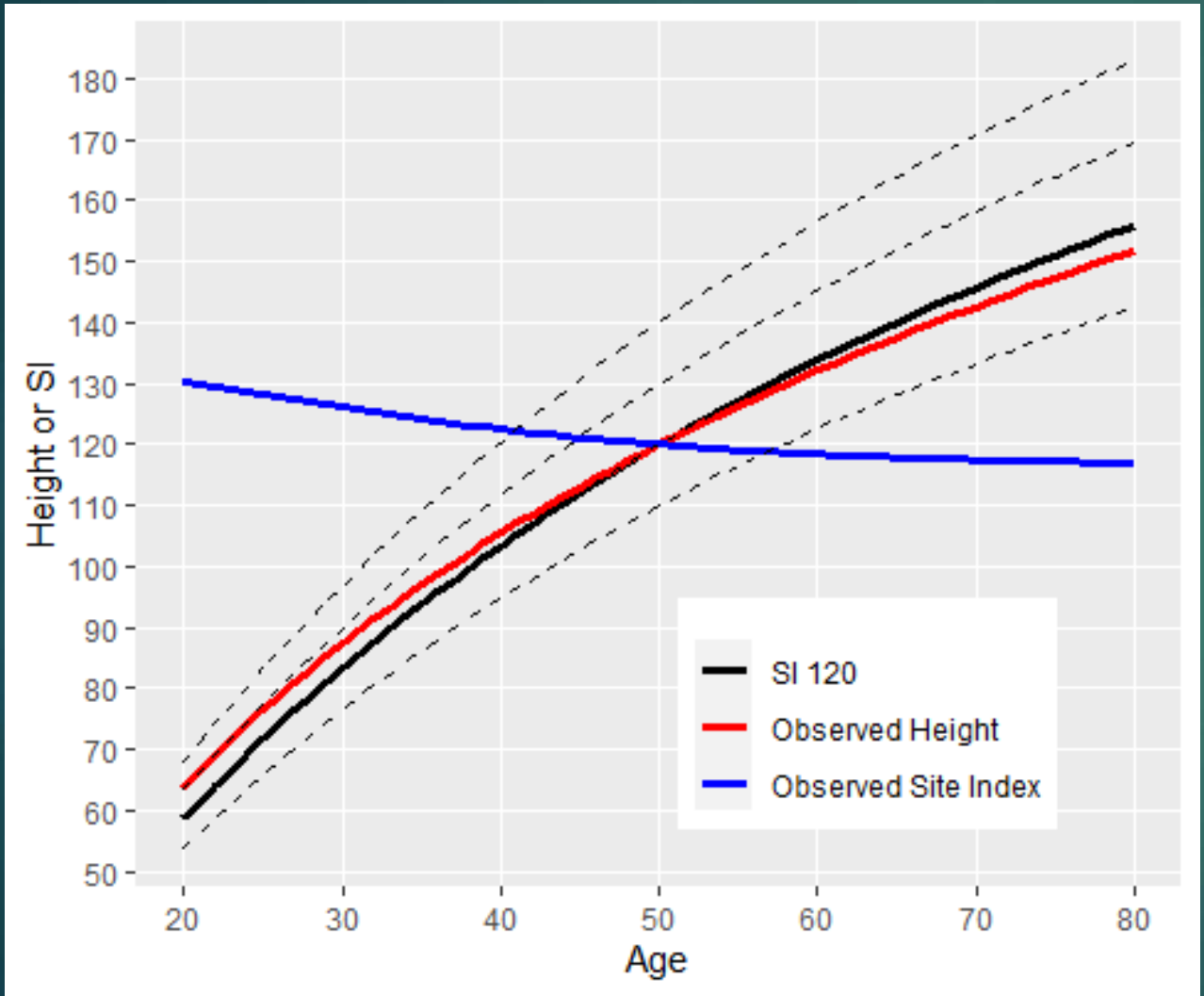
The Age Problem





- Height measurement errors or silvicultural treatment effects at early ages will magnify the apparent site index. If the treatment effect is Type B or Type C, estimated site index will decline in years following treatment.
- Entropy increases over time; thus, early height measurements are "optimistic" and can lead to an observed decrease in site index over time (this is partially dependent on the methodology used to build the site equations).

The Silviculture Problem

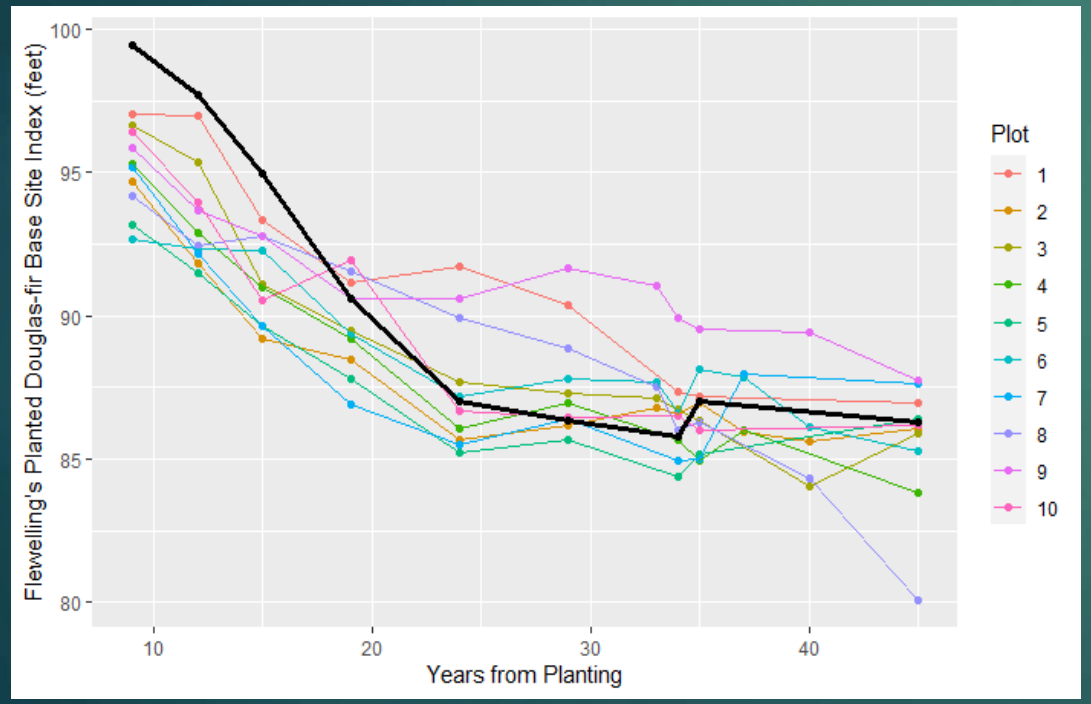


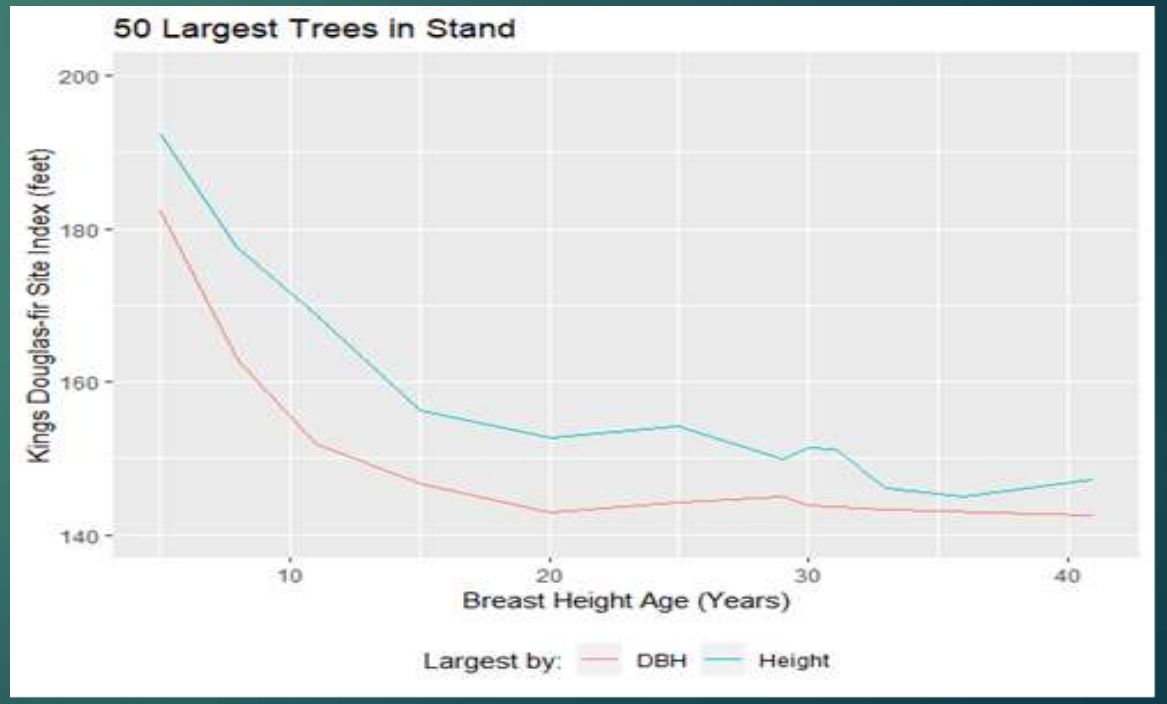
- Observed Site Index:
  - Based on Site Index Curves and the current stand.
  - Also called Expressed or Current Site Index
- Why Might Observed Site Index Decrease Over Time?
  - Tree improvement selects for fast height growth in young trees?
  - Improved Silviculture?
    - Site preparation.
    - Early fertilization.
    - Competing Vegetation Control.
  - The Population of Site Trees Changes?

The Sampling Problem

Black line illustrates combining all plots in the plantation and then selecting site trees.*

Illustrates the effect of choosing the incorrect site tree population (DBH is correct here).

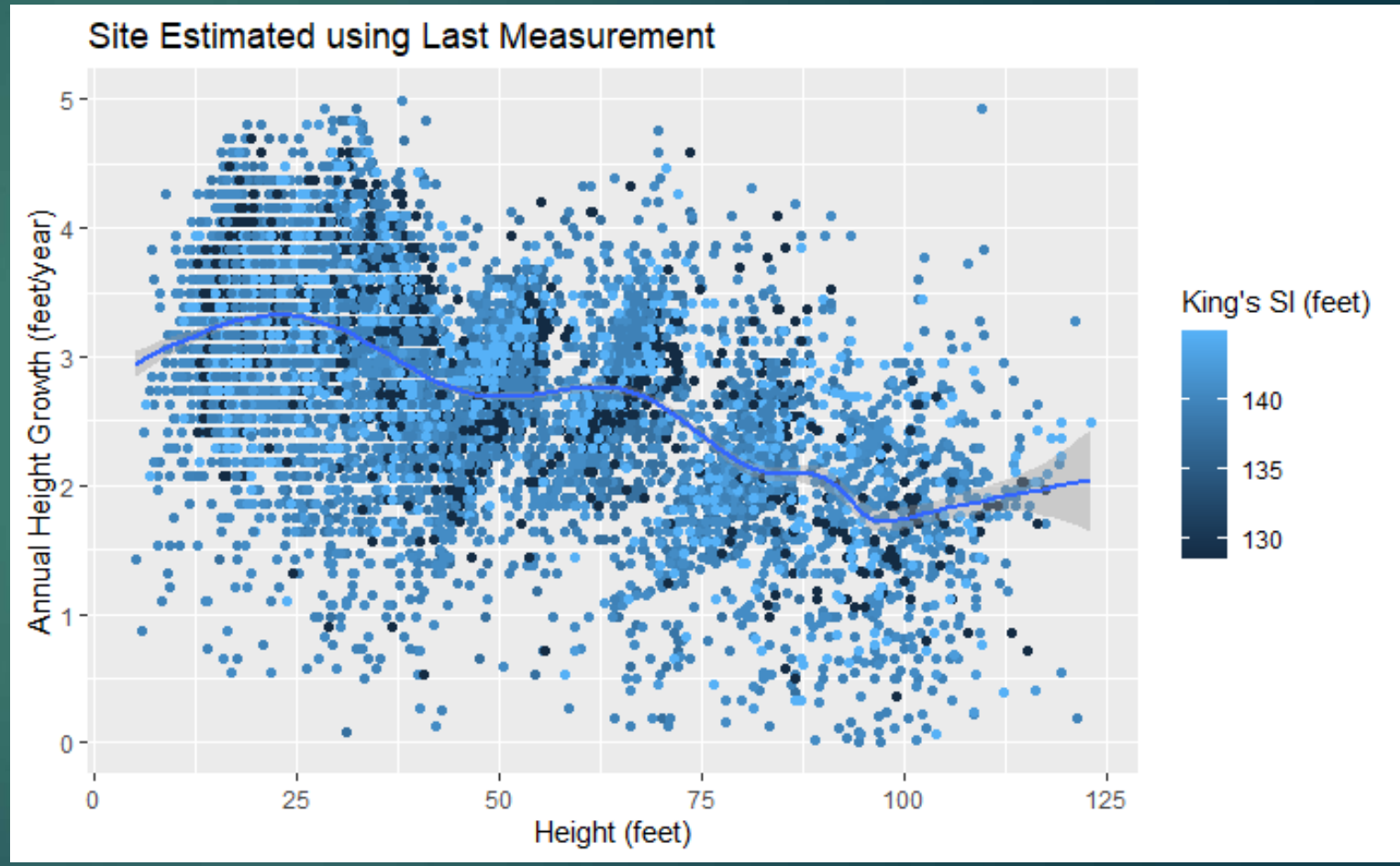




*We might expect the black line to always be above the plot-specific lines (i.e., cherry picking); however, the fact that DBH and Height are not perfectly correlated can lead to results as seen here.

Modeling with Site Index

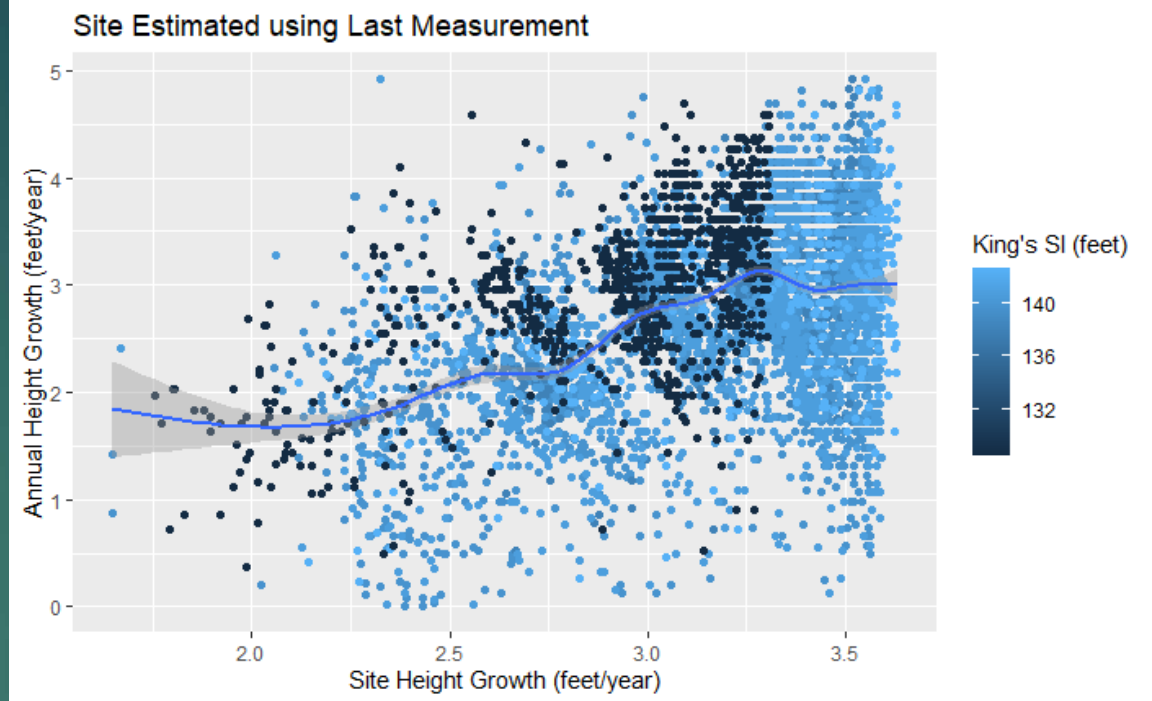
- Height growth is highly variable and not obviously related to Site Index.
- Commonly site index is estimated for a plot or installation at the measurement closest to base age in the time series, creating the situation where the future performance is assumed to be known before the growth prediction occurs.

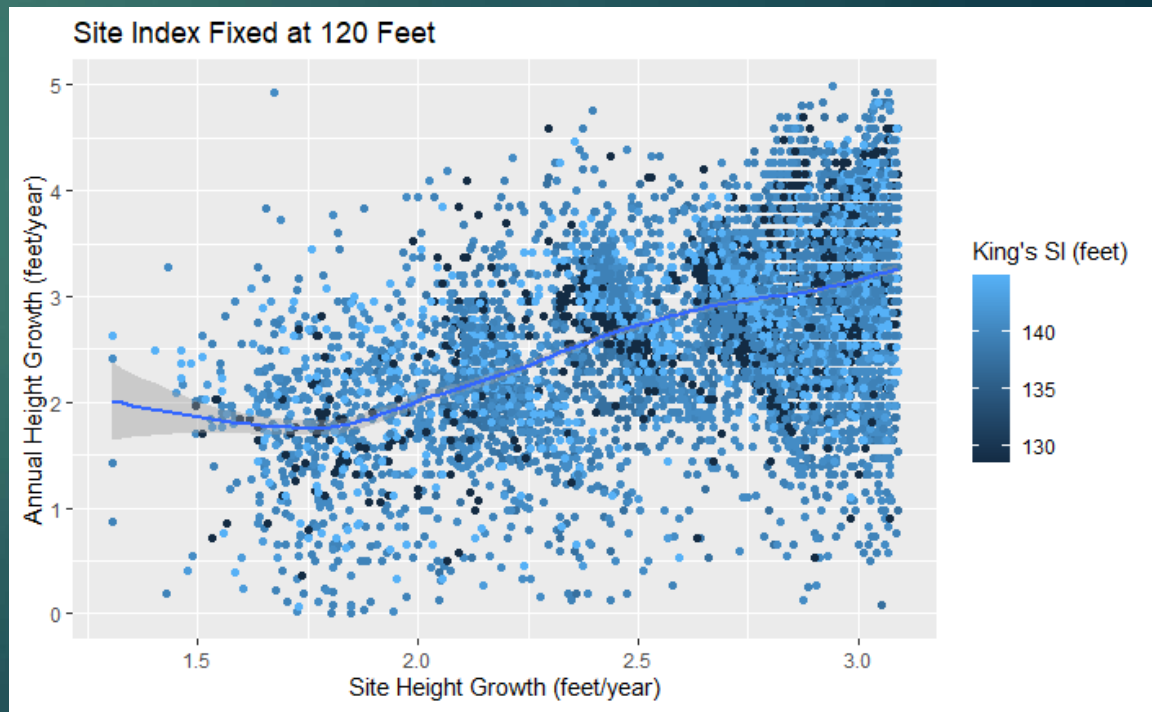


Height Growth Modeling

- Using Growth-Effective Age* site height growth is related to observed height growth, but still highly variable. (Used in ORGANON and like models)
- Ignoring *measured* Site Index by using a fixed Site Index guide curve works well and does not suffer from biased site index estimate issues – do we need site index, or do we need the shape of the site curve?

*Age at which the height of the tree matches the site height for a given site index.





Other Problems with Site Index

- Verifying Site Index is Difficult.
  - Field procedures for tree selection frequently differ from the procedures used in constructing site curves. This leads to biases.
  - Two observers may not use the same sampling procedure, leading to differing estimates and clouding the comparison.
- Many commonly used site index equations have poorly defined sampling frames and top height definitions.
- DBH-based site tree population definitions are problematic in inventory systems that subsample for height, or impute DBH (e.g., lidar) because they force a monotonic relationship between DBH and height that probably did not exist in the site index system data set.
- Site Curves are not Height Growth Curves*, but they are used to drive height growth in models (e.g., Prognosis descendants, ORGANON).
- In modeling, we are using the answer to drive the prediction.
- Estimating Site Index for afforestation or conversion is a challenge.

*Bruce, D. 1981. Consistent height-growth and growth-rate estimates for remeasured plots.

Site Index Curves v. Height-Age Curves

Site Index:

- SI = f(A,H)
  - Given current age and height, what is our best estimate of height at a fixed age?

Height-Age:

- H = f(A,SI)
  - Given an age and an assumption about SI, what is our best estimate of current height?

Just because we can algebraically manipulate one to get the other does not make them mathematical or biological inverses.

- The regression of y on x is the same as the equation obtained by solving the regression of x on y for y only if x and y are perfectly correlated.
- The data most appropriate to developing Site Index curves is not necessarily the same as that need to develop Height-Age curves, depending on the definition of SI.
- This is nothing new: Curtis, R. O., et al. , 1974 Which Dependent Variable in Site Index-Height-Age Regressions, For Sci 20:74-78.

Site Index Today

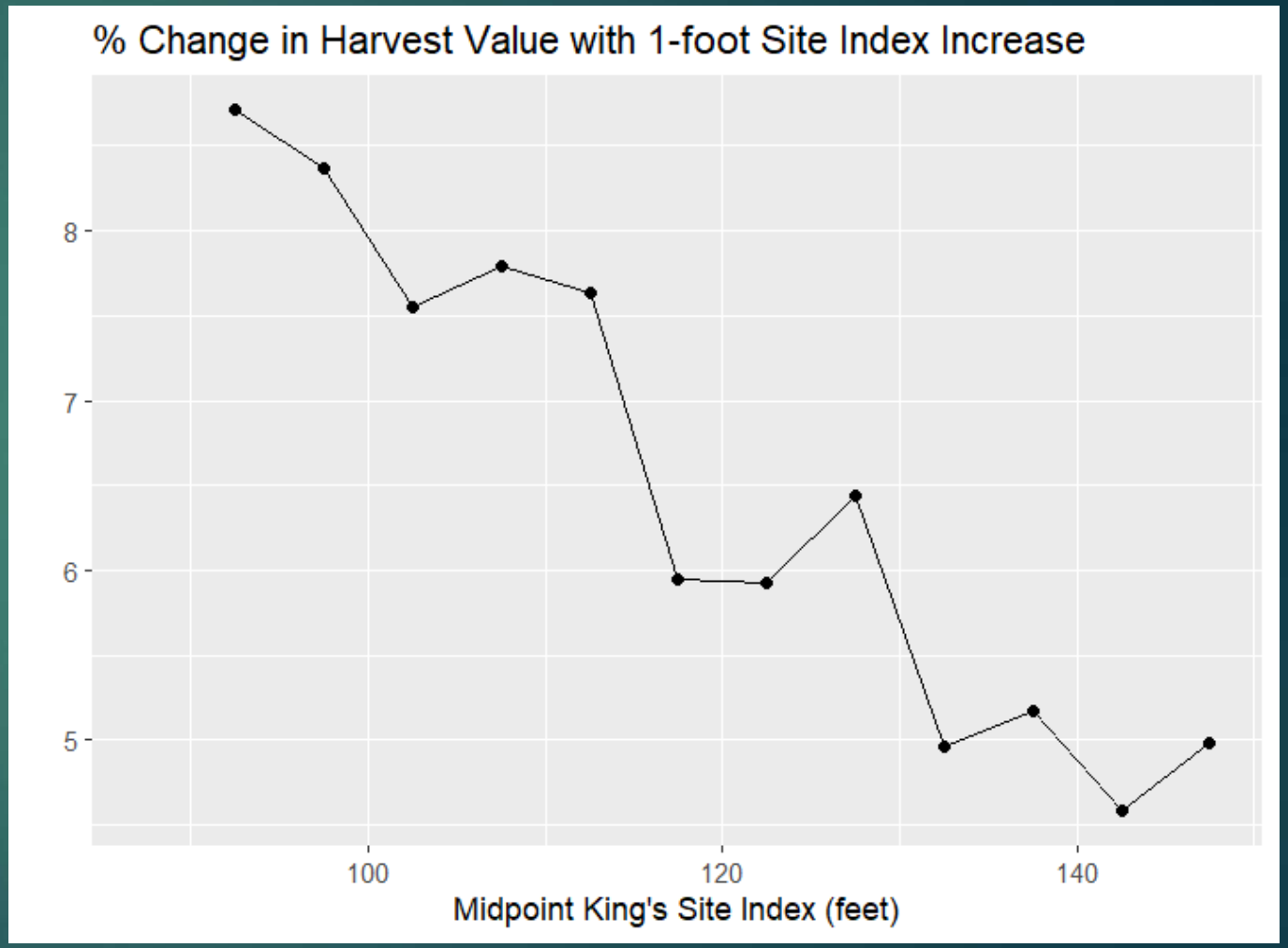
- An Input to Growth and Yield Models.
- Consequently, Changes in Site Index:
  - Affect projected or predicted yields at harvest.
  - Affect discounted cash flows and valuations.
- Uncertainty Around Site Index Complicates Investment Decisions.
- What is the right Site Index for modeling and decision-making?

What is the Right Site Index for Modeling?

- Observed Site Index:
  - Changes over time because stands do not follow site curves.
  - Tends to decrease from early age estimates.
  - Includes treatment effects that may be separately estimated by the model.
- Site Index from the Previous Rotation:
  - Includes treatments and genetics different from current stand.
- Base Site Index:
  - Site index from previous rotation with treatment and genetics subtracted.
  - Often difficult to remove treatment effects and rarely observed directly.

The Conundrum

- Site Index was an appropriate and useful tool as conceived in the early 20th century.
- Site Index is proving less useful, and even counterproductive, as we develop more sophisticated growth and yield models.
- Site Index was conceived as a broad brush, and we are trying to use it to paint fine portraits.
- "This appears to be an unhealthy situation; what began as an interim solution (site index) to a difficult problem ([the] geocentric approach [to assessing forest producing power of a site]) should not now be called the solution to the original problem."*
- How much confidence should you place in valuation differences driven by small changes in site index?



*Leary's "Interaction Theory…" (1985) p47

Possible Solutions: Modeling

- Growth Intercept:
  - Height growth in a short period above a given height.
    - *e.g.*, Alban, 1979. Feet of height growth in the five years above eight feet.
  - Jim Arney's 10-meter Site Index.
    - Height growth in the second 10 meters of the stem.
  - Gets past some complexities of early stand development.
  - Has been used to predict Site Index but that does not overcome problems of Site Index.

Possible Solutions: Modeling

- Reframe the question: "How does this treatment affect site index?"
- Ask instead: "How does this treatment affect stand dynamics?"
- Which leads to dynamical systems*:

$$\frac{dH}{dt} = q\left(48.76 / H^{0.07860} - 0.9271H\right)$$

$$\frac{dN}{dH} = -1.754 \cdot 10^{-11} H^{3.642} N^{2.518} / p^{3.037}$$

$$\frac{d\Omega}{dH} = 0.1344\, pH\left(1-\Omega\right)$$

$$\frac{dW}{dH} = 0.2474\, p\Omega H N^{0.4} + 0.4\frac{W}{N}\frac{dN}{dH}$$

Where:

H is top height
N is trees per hectare
Ω is an occupancy factor
W is BA * *H*
p is the proportion of pine BA
q is a site quality parameter

*Garcia, O. 2013 "Forest Stands as Dynamical Systems: An Introduction" In Modern Applied Science 2013, 7(5) 32 - 38.

Possible Solutions: Modeling

- State-space models:

$$\frac{dH}{dt} = f(H, G, x_i)$$

$$\frac{dG}{dt} = f(G, H, x_i)$$

$$\frac{dN}{dt} = f(N, H, x_i)$$

Where:

H is top height
G is basal area
N is trees per unit area
x_i is a vector of environmental variables.

e.g., Nord-Larsen, T., Johannsen, V.K. (2007) A state-space approach to stand growth modelling of European beech. Ann. For. Sci. 64 365-374.

Conclusion

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