

Hierarchical Bayesian Small Area Estimation of Forest Attributes in the Interior Western US

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The Forest Inventory and Analysis Program (FIA)



Orcas Island, Washington

FIA Overview

- Responsible for reporting status and trends of the nation's forests.
- Collects inventory data on and computes estimates for many forest attributes to monitor the status and trends of the nation's forests.
- Sampling design is meant for sufficient precision to provide **state-level** estimates through post-stratified estimation.



The Nation's Forest Census

FIA's Sampling Design

- Overlay hexagons with area of 6000 acres across the United States. Randomly select a location in each hexagon for a FIA plot.
- A FIA crew visits each plot once every 10 years to remeasure the plot.
- A 10 year timeframe where each plot has been measured is referred to as an “evaluation”.

United States
Department of
Agriculture

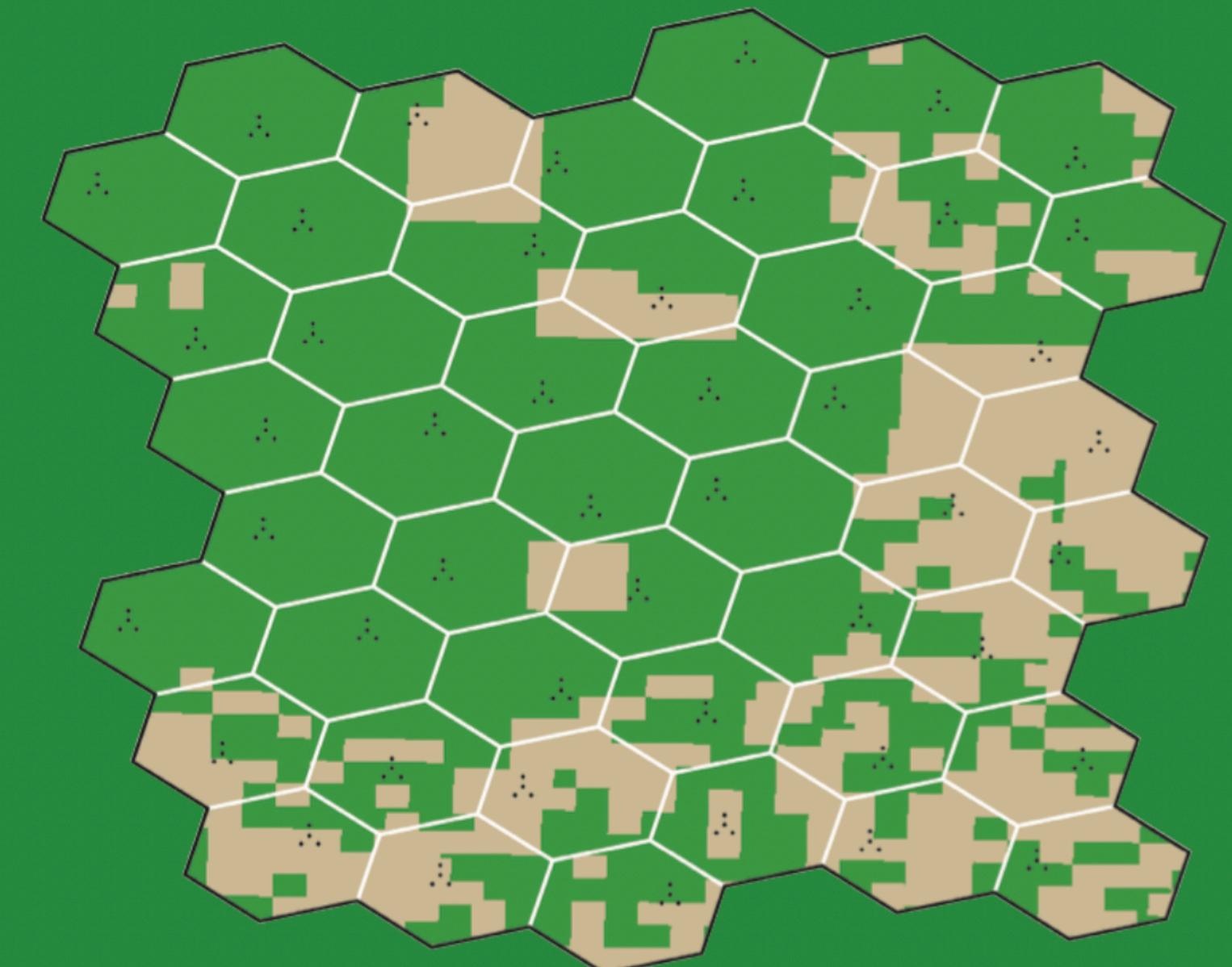
Forest Service



Southern
Research Station
General Technical
Report SRS-80

The Enhanced Forest
Inventory and Analysis
Program—National
Sampling Design and
Estimation Procedures

William A. Bechtold and
Paul L. Patterson, Editors



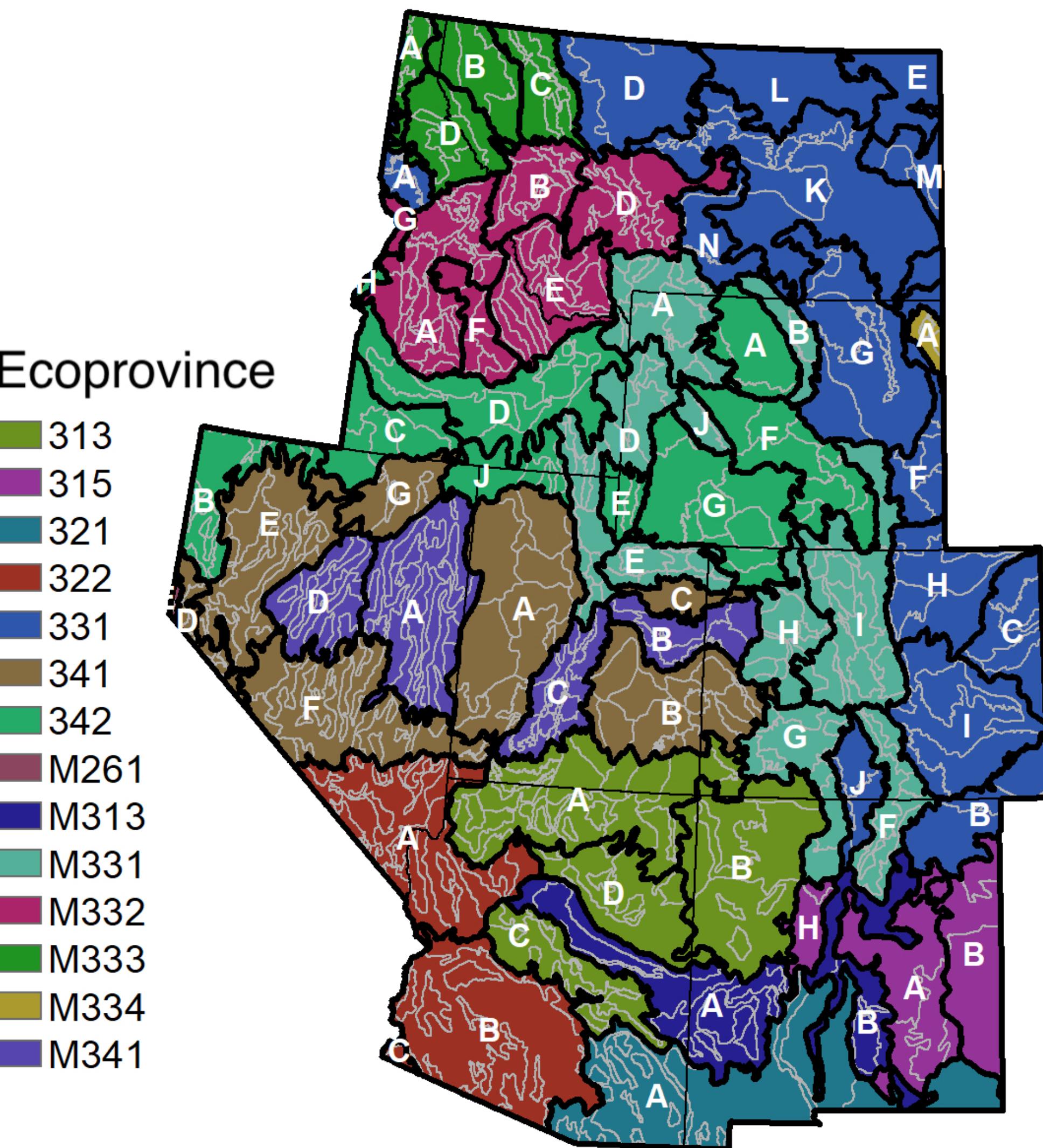
FIA's Small Area Estimation Needs

- FIA has a growing need for statistically defensible estimates over smaller geographic regions such as:
 - Counties
 - Watersheds
 - Ecologically defined regions
 - Recently burned areas
 - And more!



The Big Idea

- Combine FIA and auxiliary data to fit Fay-Herriot models to **estimate means** of four FIA variables **in ecologically defined regions called “subsections”**.
- Borrow strength from higher levels of hierarchy in these ecological regions: models that borrow out to the section level and models that borrow out to the province level.
- Assess both borrowing strategies for hierarchical Bayesian models and for EBLUPs.
- Compare estimator performance between models and with the industry-standard post-stratified estimator.



The Data



Washington Highway 410, edge of Mt. Rainier National Park

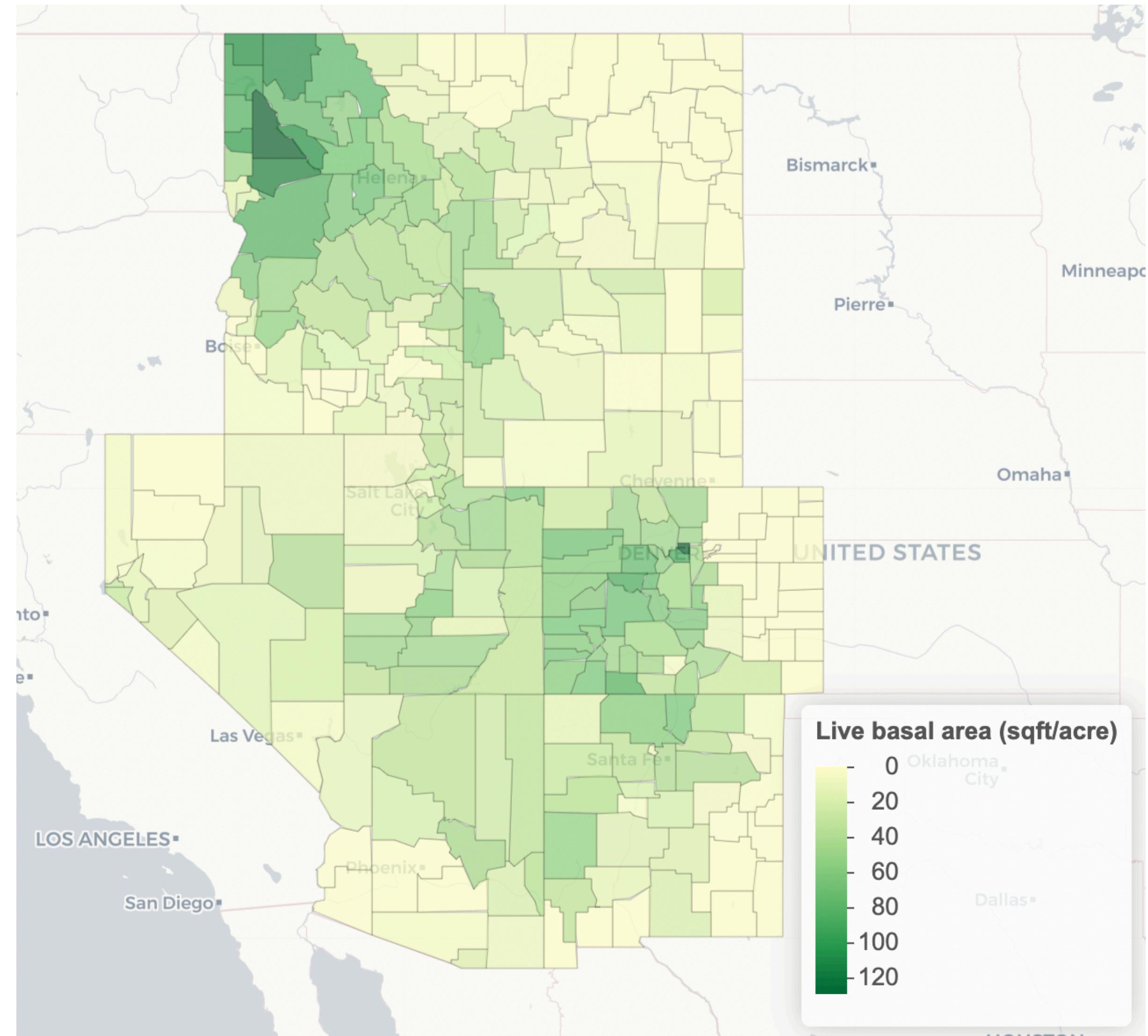
Data Acquisition

- We used FIESTA to retrieve a FIA evaluation of data from the Interior Western region of the United States from 2007 to 2017, which included 86,065 plots.
- FIESTA is FIA's custom estimation tool which allows for easy access to FIA data and many estimators, all in R.
- Available on CRAN.



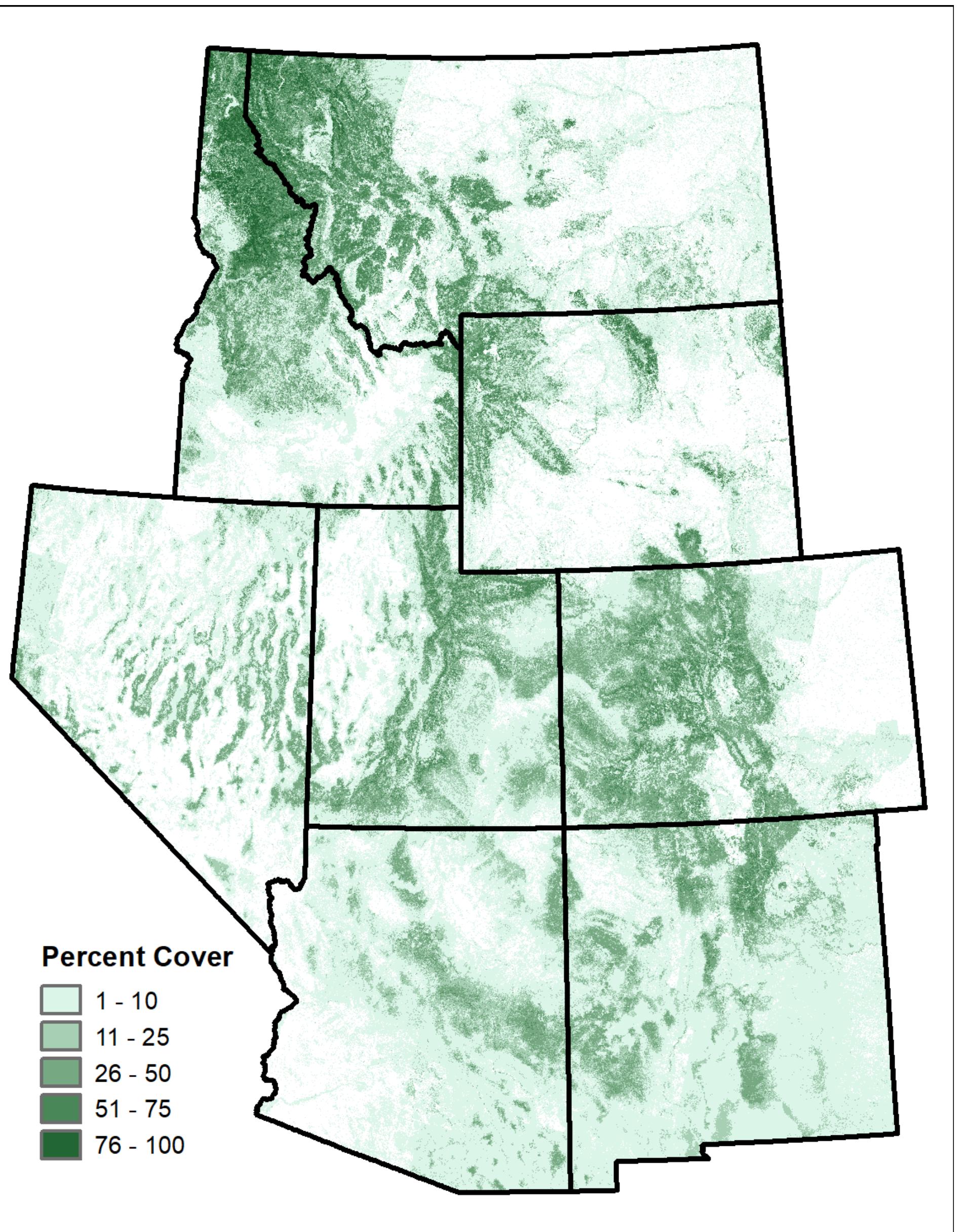
FIA Data Overview

- Four FIA variables of interest: basal area, biomass, trees per acre, and net volume.
- This data is available at the **plot level**, but we have aggregated it to the **area level**.



Auxiliary Data Overview

- Remotely-sensed explanatory variable at pixel level: tree canopy cover.
- Forest/non-forest strata indicator variable for each sampled plot.



Methods

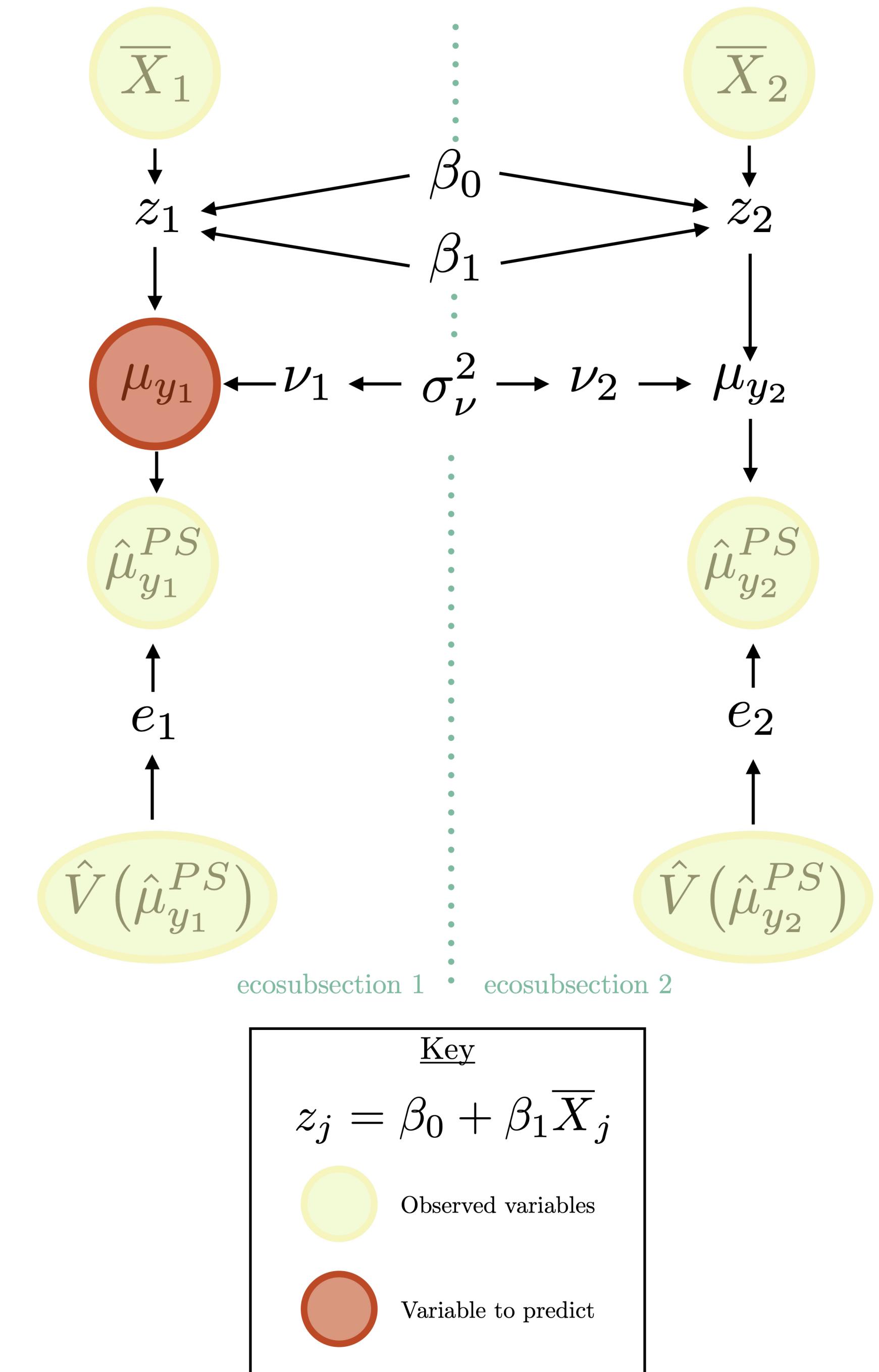


Cape Flattery, the most northwest part of the continental United States

Our Estimators

- The post-stratified estimator and six variations of the Fay-Herriot model.

Short Name	Fitting Method	Borrow Strength to...	Prior on σ_ν^2
Post-Strat	Analytical	NA	NA
EBLUP Section	REML	Section	NA
EBLUP Province	REML	Province	NA
HB Section Flat Prior	MCMC	Section	$f(\sigma_\nu^2) \propto 1$
HB Province Flat Prior	MCMC	Province	$f(\sigma_\nu^2) \propto 1$
HB Section half Cauchy Prior	MCMC	Section	$\sigma_\nu \sim \text{half-Cauchy}(\text{scale} = 1)$
HB Province half Cauchy	MCMC	Province	$\sigma_\nu \sim \text{half-Cauchy}(\text{scale} = 1)$



Results

Note: All results shown are for the basal area response variable

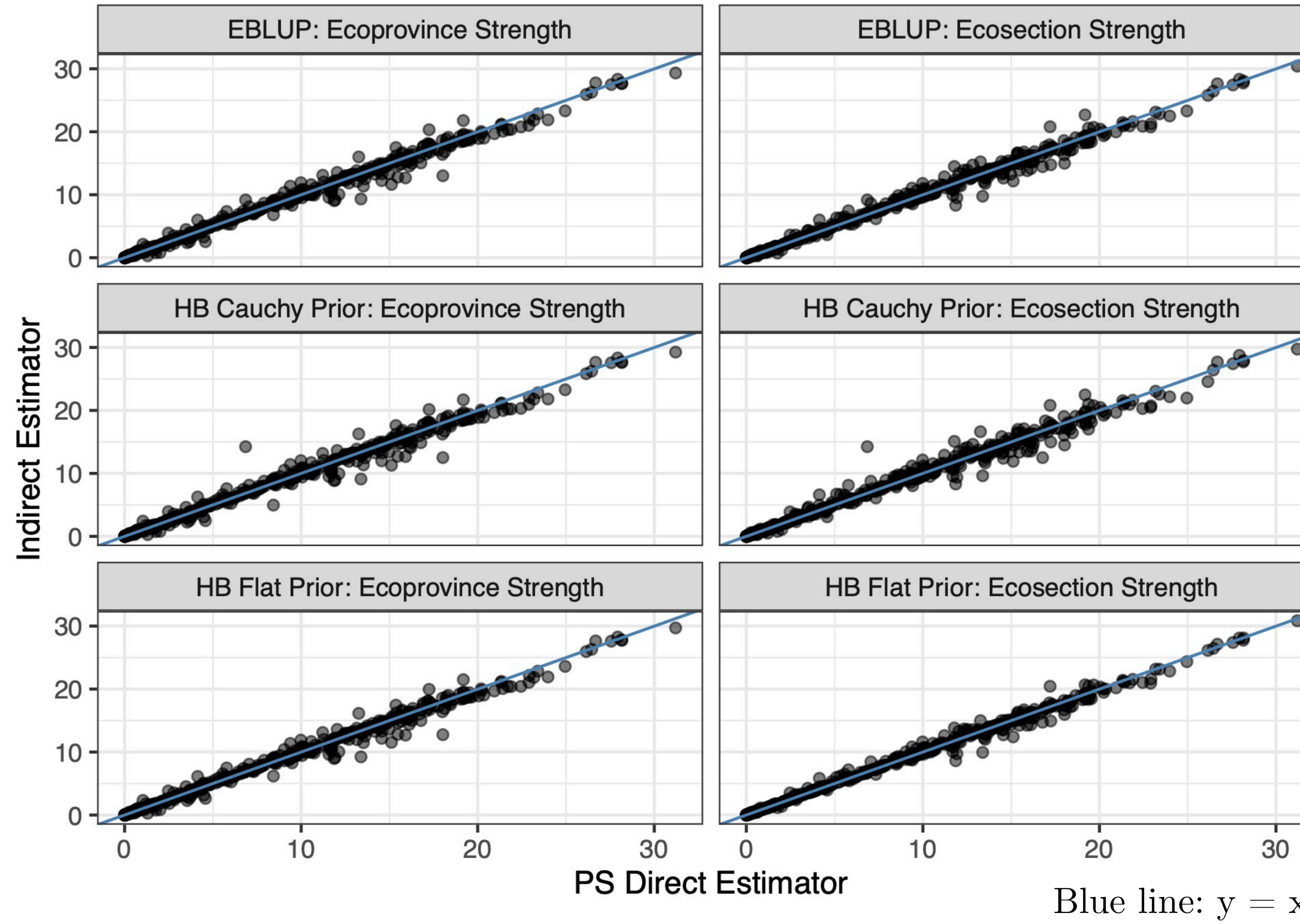


Mt. Hood, Oregon

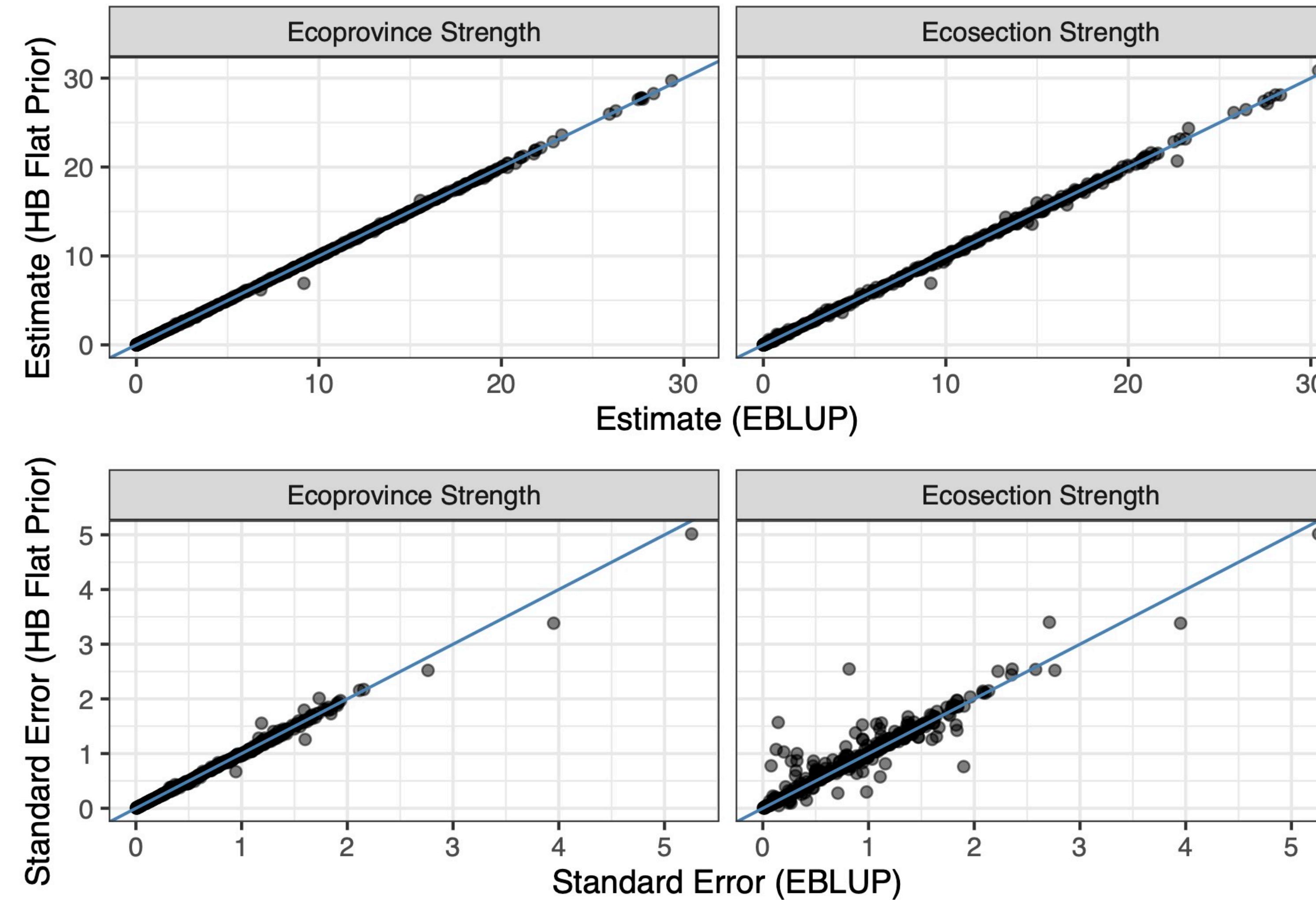


Valley of the Giants, Oregon

Assessing Bias via Agreement with Post-Stratified Estimator

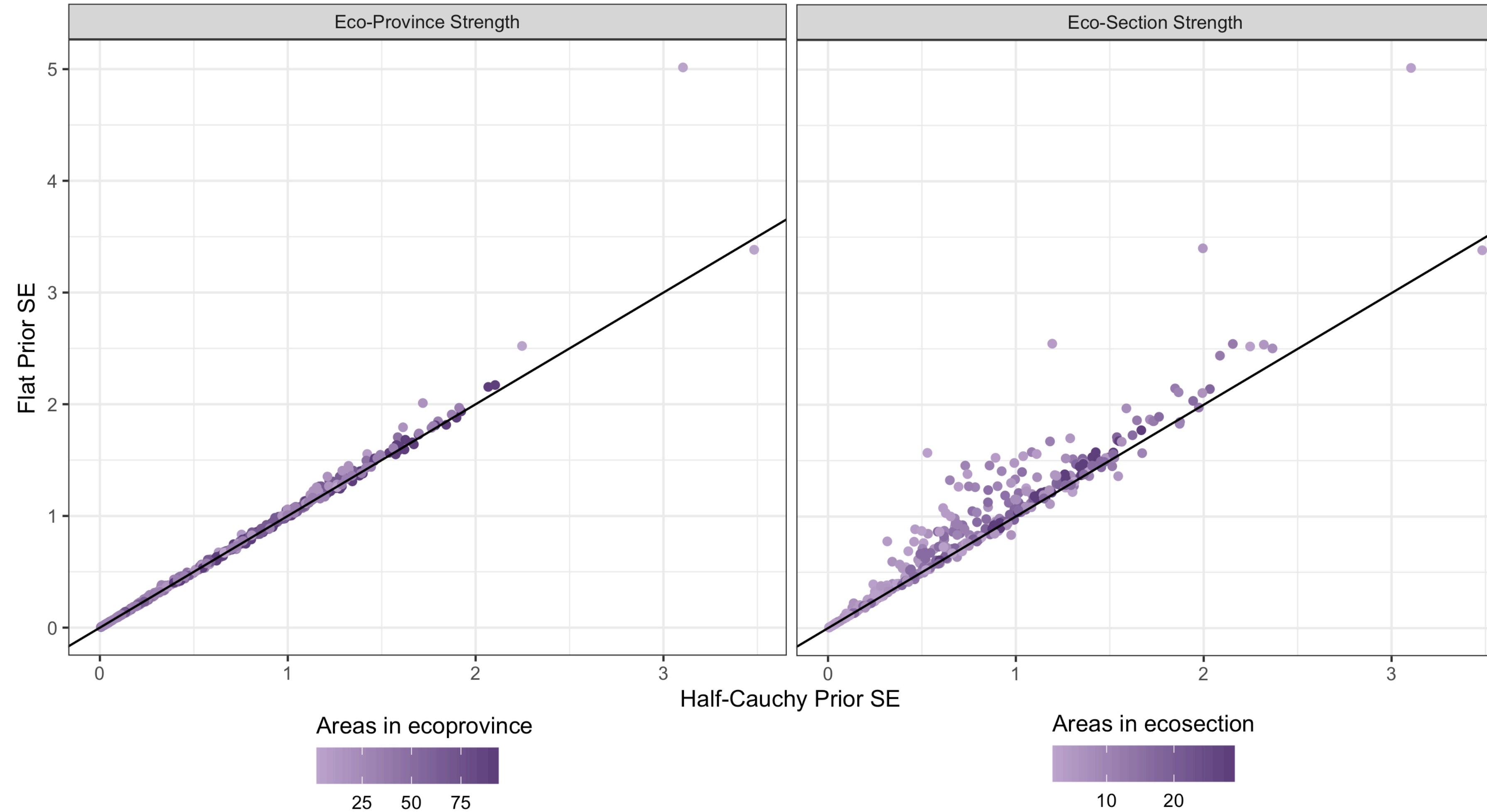


Comparing the HB Flat Prior and EBLUP Estimates (top) and Standard Errors (bottom)



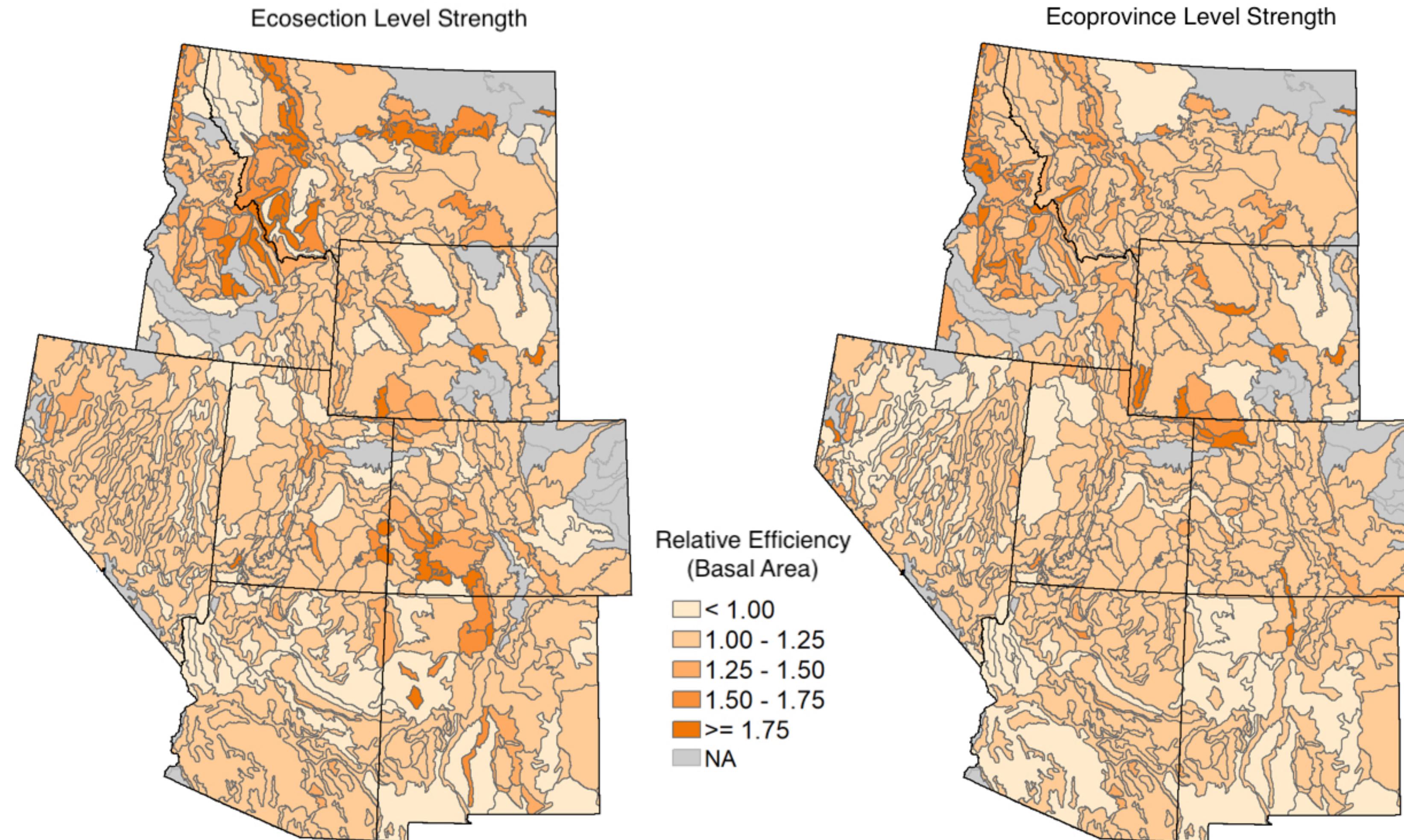
Blue line: $y = x$.

Standard Error differences in HB models



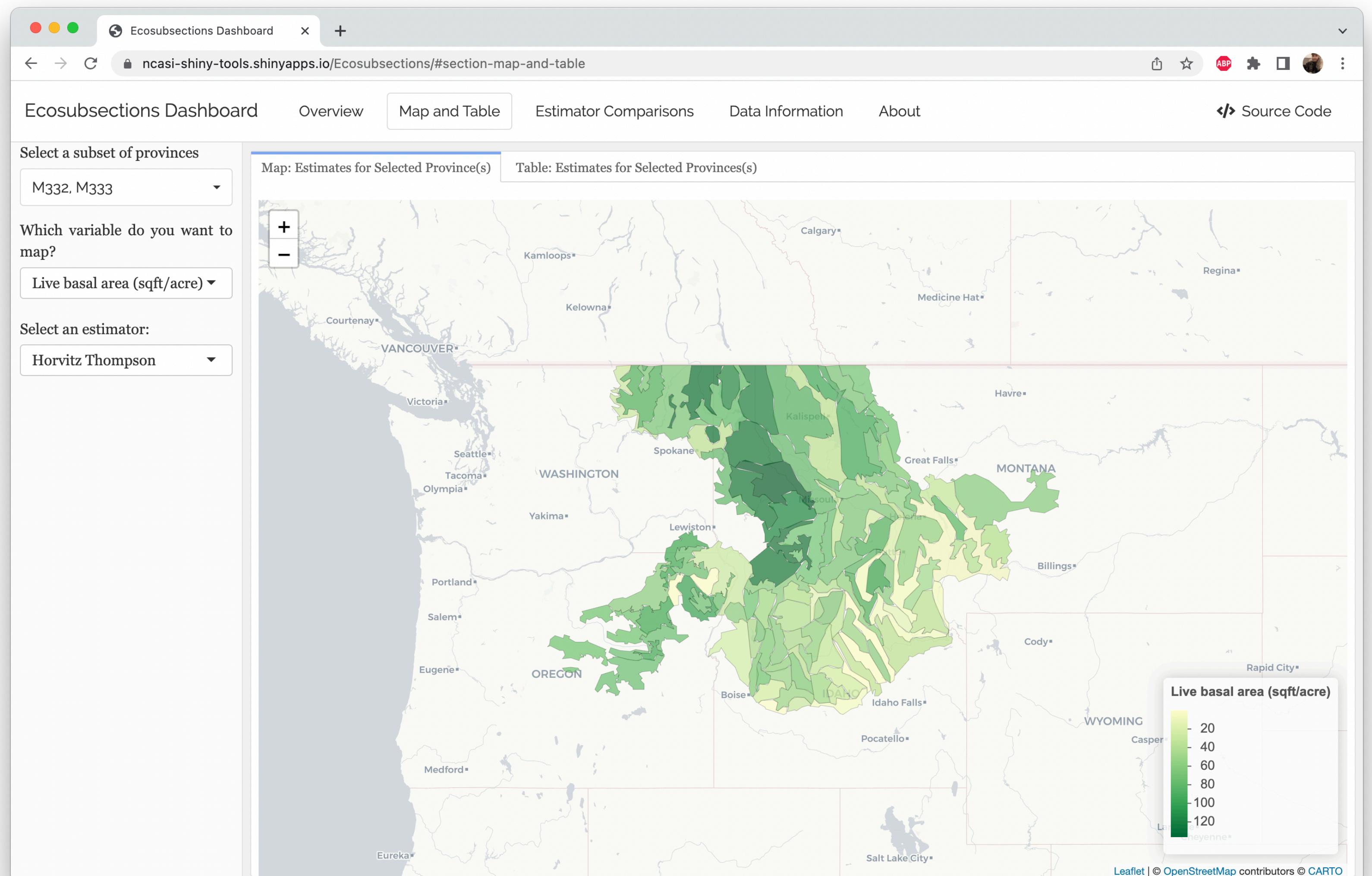
- Black line: $y = x$.
- Purple hue:
amount of areas
strength is
borrowed from.

Relative Efficiency of HB half Cauchy Prior Estimators and Post-Stratified Estimator



Impact

- These hierarchical Bayesian small area models have been added to FIESTA, for more wide use in FIA.
- The models are now part of a national portfolio of estimates available via shiny dashboards.



Future Work



Death Valley, California

- Unit-level small area models: zero-inflated models.
- A simulation study to understand potential bias.
- Further explorations of prior distributions on between-area variation.
- Multivariate small area models for many FIA variables of interest.

Thank you!

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