Quantifying Stand Density-Growth Relationship Across Contrasting Forests Types of the Continental United States

Emmerson Chivhenge, Aaron. R. Weiskittel, Christopher. W . Woodall, David. G Ray & Anthony. W. D'Amato

Western Mensurationists
Moscow, Idaho. 15-17 June , 2025

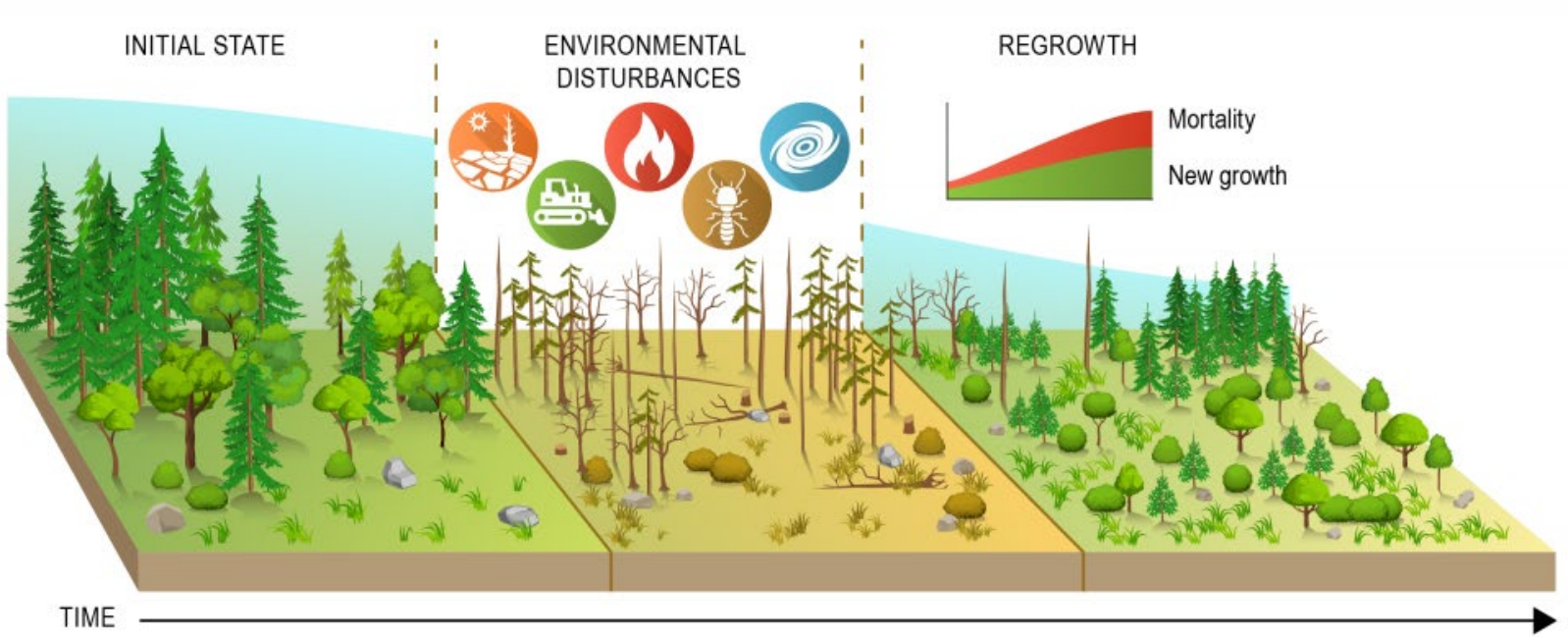
Growth, Removals and Mortality (GRM)

- Increase in size and biomass of trees in a stand over time
- Competition main driver
- Types of growth

Gross growth: all growth including mortality

Net growth: gross growth-mortality

Mortality: trees dying from natural causes



Citations: Weiskittel et al (2011); (Curtis, 1970); Nathan Johnson

Stand Density Index (SDI)

- Biologically based measure of SD

independent of site and stand age

- Maximum SDI: carrying capacity (#/ha)

- Relative Density= SDI/SDImax (0-1)

predicts phases of stand development

management decisions

Relative density	Stage of stand development
0.15	Crown closure
0.30	Lower bound of density management zone
0.55	Onset of imminent competition mortality
1	Maximum size-density

PERFECTING A STAND-DENSITY INDEX FOR EVEN-AGED FORESTS[1]

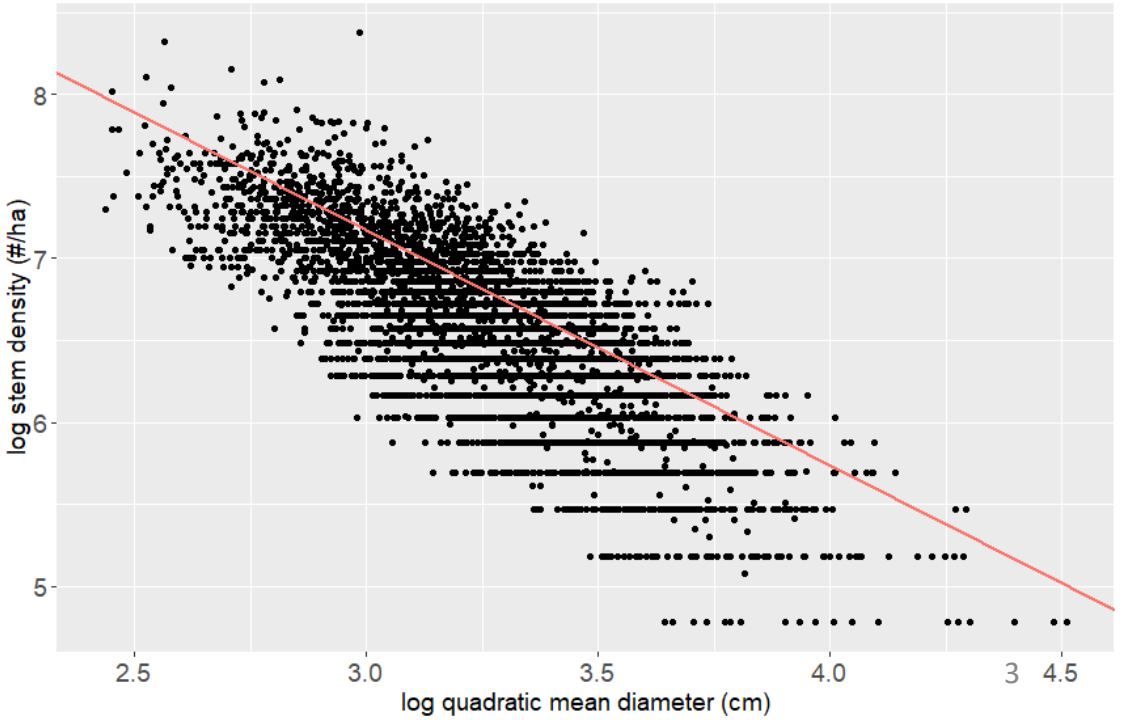
By L. H. Reineke

Associate Silviculturist, California Forest Experiment Station, Forest Service, United States Department of Agriculture

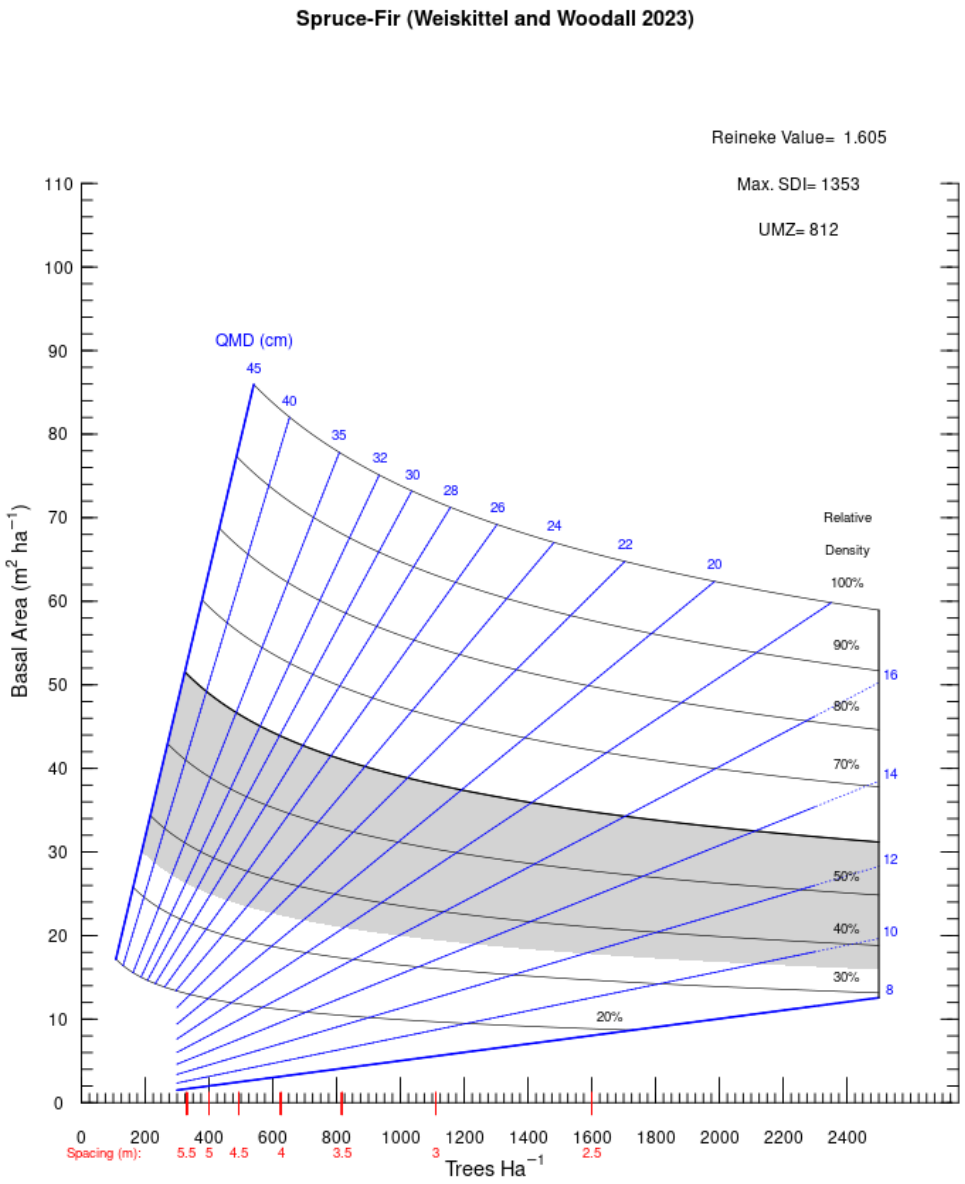
perfecting a stand-density index for even- aged forests

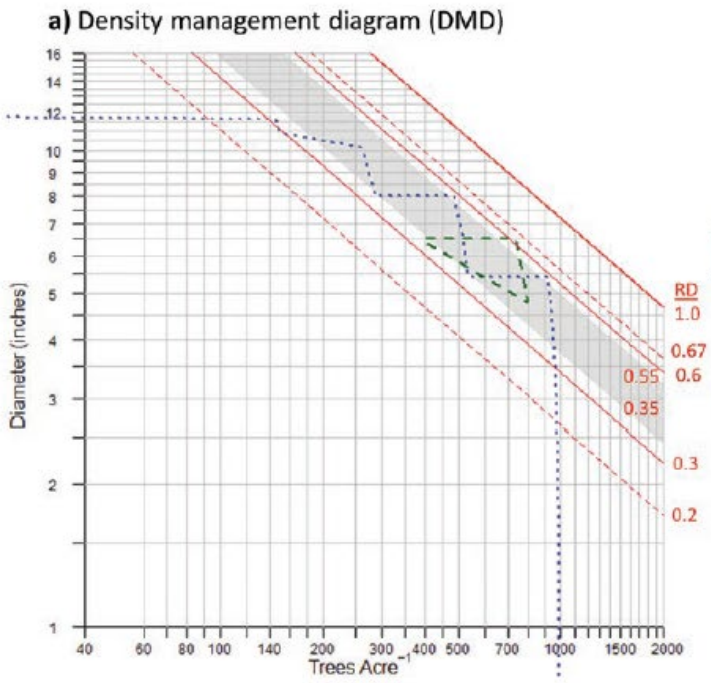
by LH REINEKE · Cited by 2481 — It is the purpose of this paper to present a **stand-density index** which does not require a yield table and which is not affected by possible errors in shap...

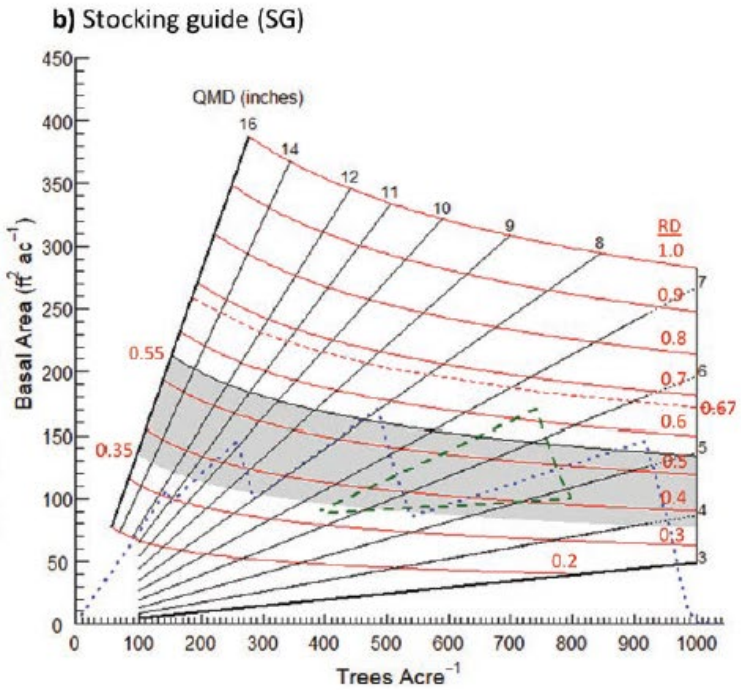
12 pages



Integration of relative density



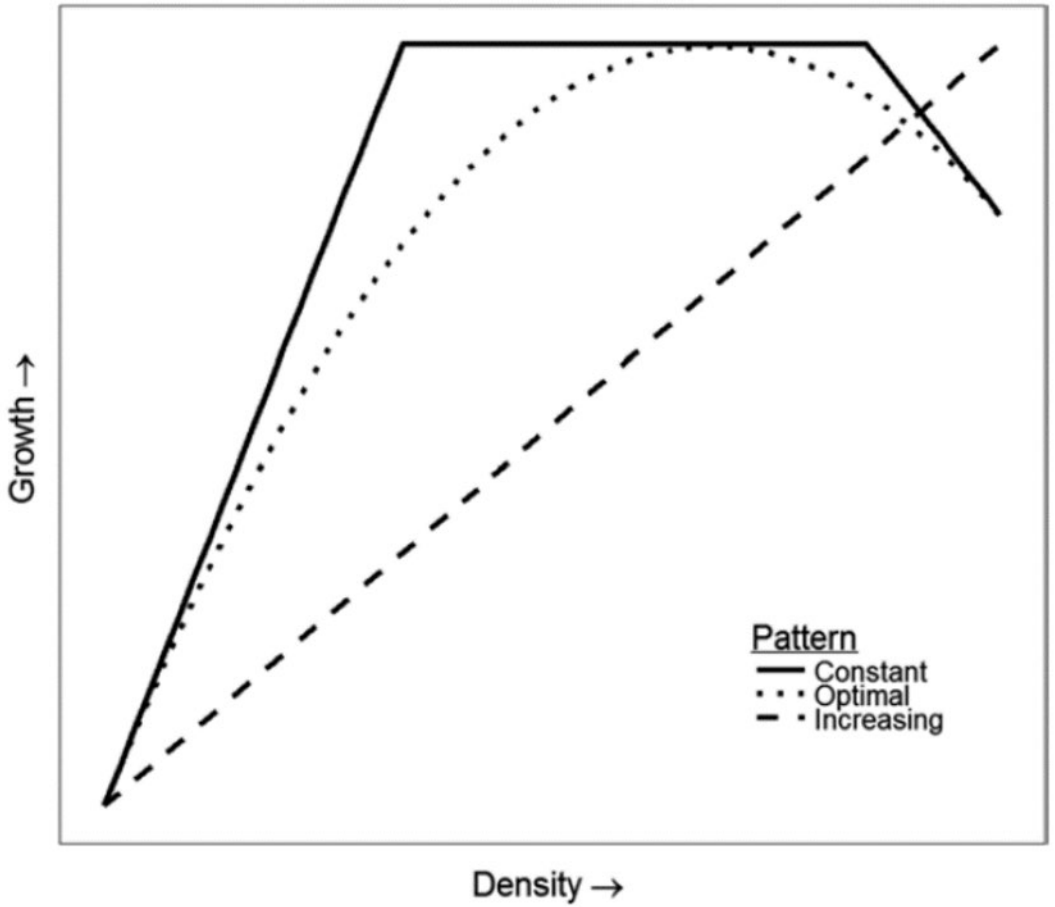




Citation: Jang 2025 https://bcgov-env.shinyapps.io/SDMD/ , Ray et al 2023

Theoretical density relationships

- Production forestry aims at identifying a density where trees to sustainably maximize growth
- No consensus on the density-growth relationships and definitions
- Better quantitative models to represent density-growth relationships



Theoretical relationships between volume growth and stand density

Citation: Allen II and Burkhart (2019); Zeide (2004); Long, (1985); Jang (2021); Pretzsch, (2009)

Site → Regional → National Scale

Natural Resource Modeling

RESEARCH ARTICLE | Open Access

Pacific Northwest conifer forest stand carrying capacity under future climate scenarios

Ryan R. Heiderman, Mark J. Kimsey Jr.

Hindawi Publishing Corporation
International Journal of Forestry Research
Volume 2010, Article ID 212068, 8 pages
doi:10.1155/2010/212068

Research Article

Rapid Assessment of Relative Density in Mixed-Species Stands of the Northeastern United States

M. J. Ducey and R. A. Knapp

ELSEVIER

Forest Ecology and Management
Volume 417, 15 May 2018, Pages 90-102

Variation in the maximum stand density index and its linkage to climate in mixed species forests of the North American Acadian Region

Caitlin Andrews [a b], Aaron Weiskittel [a], Anthony W. D'Amato [c], Erin Simons-Legaard [a]

ELSEVIER

Forest Ecology and Management
Volume 433, 15 February 2019, Pages 396-404

Site sensitive maximum stand density index models for mixed conifer stands across the Inland Northwest, USA

Mark J. Kimsey Jr., Terry M. Shaw, Mark D. Coleman

Journal of Forestry, 2023, 121, 443–456
https://doi.org/10.1093/jofore/fvad029
Advance access publication 21 July 2023
Research Article - silviculture

OXFORD

Relative Density as a Standardizing Metric for the Development of Size-Density Management Charts

David Ray,[1,*] Robert Seymour,[1] Shawn Fraver,[1] John-Pascal Berrill,[2] Laura Kenefic,[3] Nicole Rogers,[1] and Aaron Weiskittel[2]

[1]University of Maine, Orono, ME, USA.
[2]California Polytechnic State University, Humboldt, Arcata, CA, USA.
[3]USDA Forest Service, Northeastern Research Station, Bradley, ME, USA.

sustainability

MDPI

Article

Evaluating Stand Density Measures for Regulating Mid-Rotation Loblolly Pine Plantation Density in the Western Gulf, USA

Yuhui Weng [1,*], Dean Coble [2], Jason Grogan [1], Chen Ding [3] and Xiongwei Lou [4]

ELSEVIER

Forest Ecology and Management
Volume 566, 15 August 2024, 122057

USA

hina

Quantifying minimum site occupancy requirements of common forest tree species in northern New England, USA: Implications for stocking assessment

David Ray [a 1], Robert Seymour [a], Shawn Fraver [a], John-Pascal Berrill [b], Laura Kenefic [c], Nicole Rogers [a], Aaron Weiskittel [d]

1166

Canadian Science Publishing

ARTICLE

A species-specific, site-sensitive maximum stand density index model for Pacific Northwest conifer forests[1]

Ryan R. Heiderman and Mark J. Kimsey, Jr.

ELSEVIER

Forest Ecology and Management
Volume 260, Issue 9, 30 September 2010, Pages 1613-1622

A stand density index for complex mixed species forests in the northeastern United States

Mark J. Ducey, Rachel A. Knapp

ELSEVIER

Available online at www.sciencedirect.com
ScienceDirect
Forest Ecology and Management 244 (2007) 50–59

Forest Ecology and Management
www.elsevier.com/locate/foreco

Effect of stand densities on stand dynamics in white fir (*Abies concolor*) forests in northeast California, USA

Jianwei Zhang *, William W. Oliver, Martin W. Ritchie

USDA Forest Service, Pacific Southwest Research Station, 3644 Avtech Parkway, Redding, CA 96002, United States
Received 18 January 2007; received in revised form 21 March 2007; accepted 23 March 2007

scientific reports

Check for updates

OPEN

Relative density of United States forests has shifted to higher levels over last two decades with important implications for future dynamics

scientific reports

Check for updates

OPEN

Denser forests across the USA experience more damage from insects and pathogens

Christopher Asaro [1,4], Frank H. Koch [3,4] & Kevin M. Potter [2,3]

ELSEVIER

Forest Ecology and Management
Volume 226, Issues 1–3, 1 May 2006, Pages 368-372

Short communication

The relative density of forests in the United States

Christopher W. Woodall, Charles H. Perry, Patrick D. Miles

ELSEVIER

Forest Ecology and Management
Volume 216, Issues 1–3, 12 September 2005, Pages 367-377

Determining maximum stand density index in mixed species stands for strategic-scale stocking assessments

Chris W. Woodall, Patrick D. Miles, John S. Vissage

Introduction

Growth	Density
Volume (total vs merchantable)	Basal area
Biomass	Relative density (SDI, Standardized SDI, RD, Relative spacing)
Carbon (total carbon vs annual average)	Trees per hectare

- Gross=live + removal+ mortality (tC/ha/yr)
- Net=live + removal (tC/ha/yr)
- RD=SDI/SDImax

Overarching questions

1. Is there a breakpoint/ change point in the relationship between gross and net growth?

2. If there is a change point, what is the sign and magnitude of the breakpoint?

a) Does growth increase after the breakpoint?

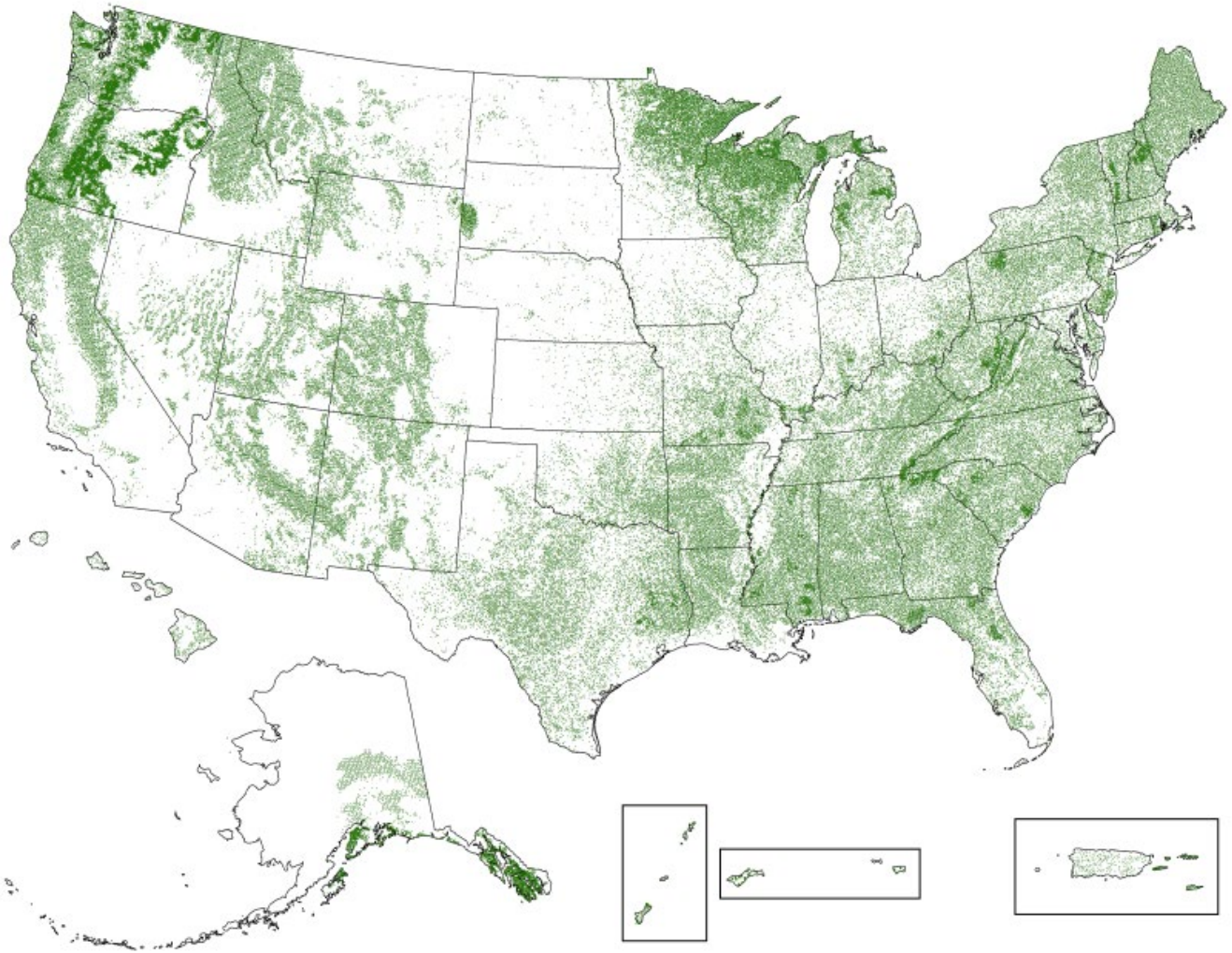
b) Does growth show an optimal level after the breakpoint?

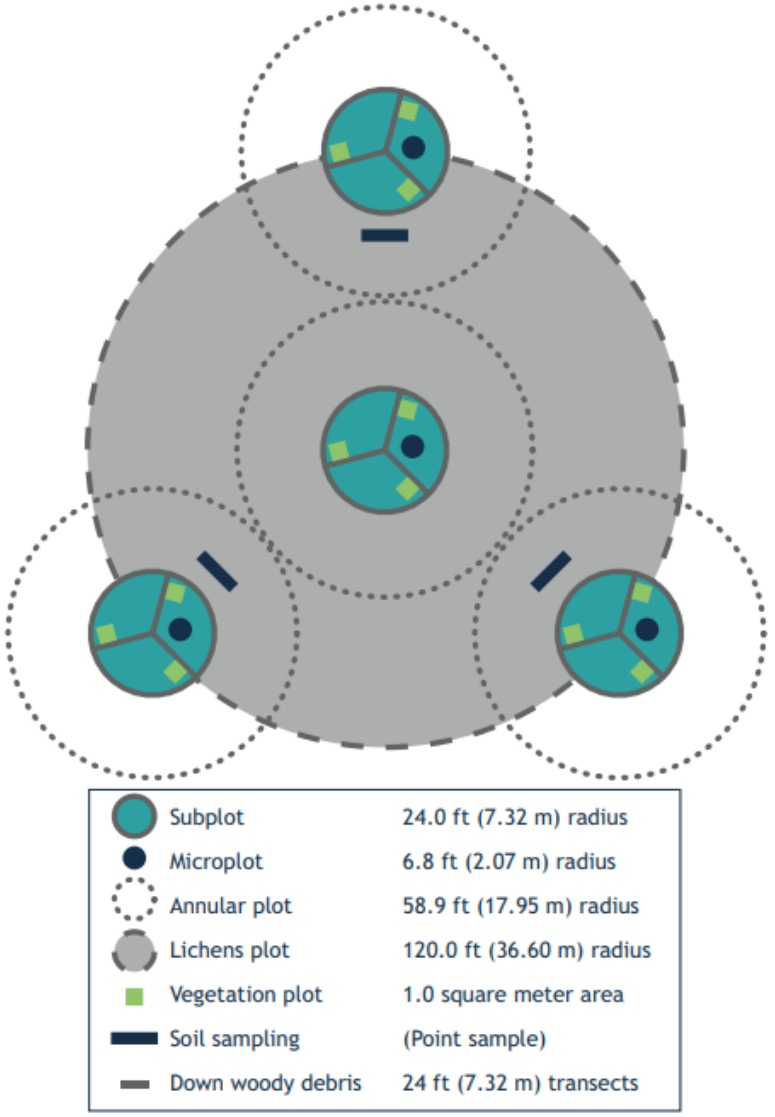
c) Does growth decline after the breakpoint?

3. Do we have breakpoints of the same forest types/ecoregions in the same clusters?

4. What are the potential drivers of the different density-growth relationships?

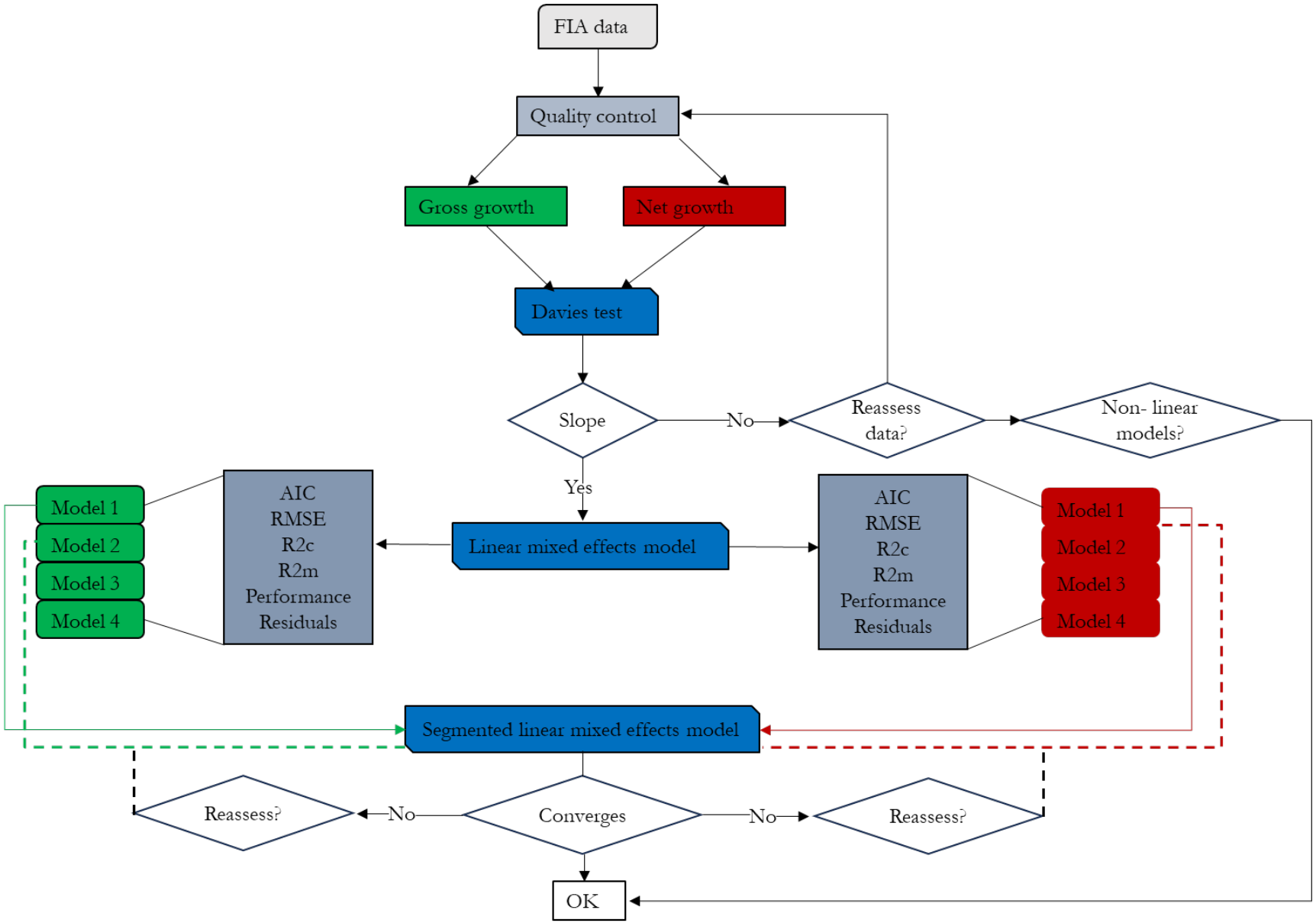
Forest Inventory and Analysis (FIA) data





Citations: USDA, (2005); Janowiak et al, (2017); Domke, (2023)

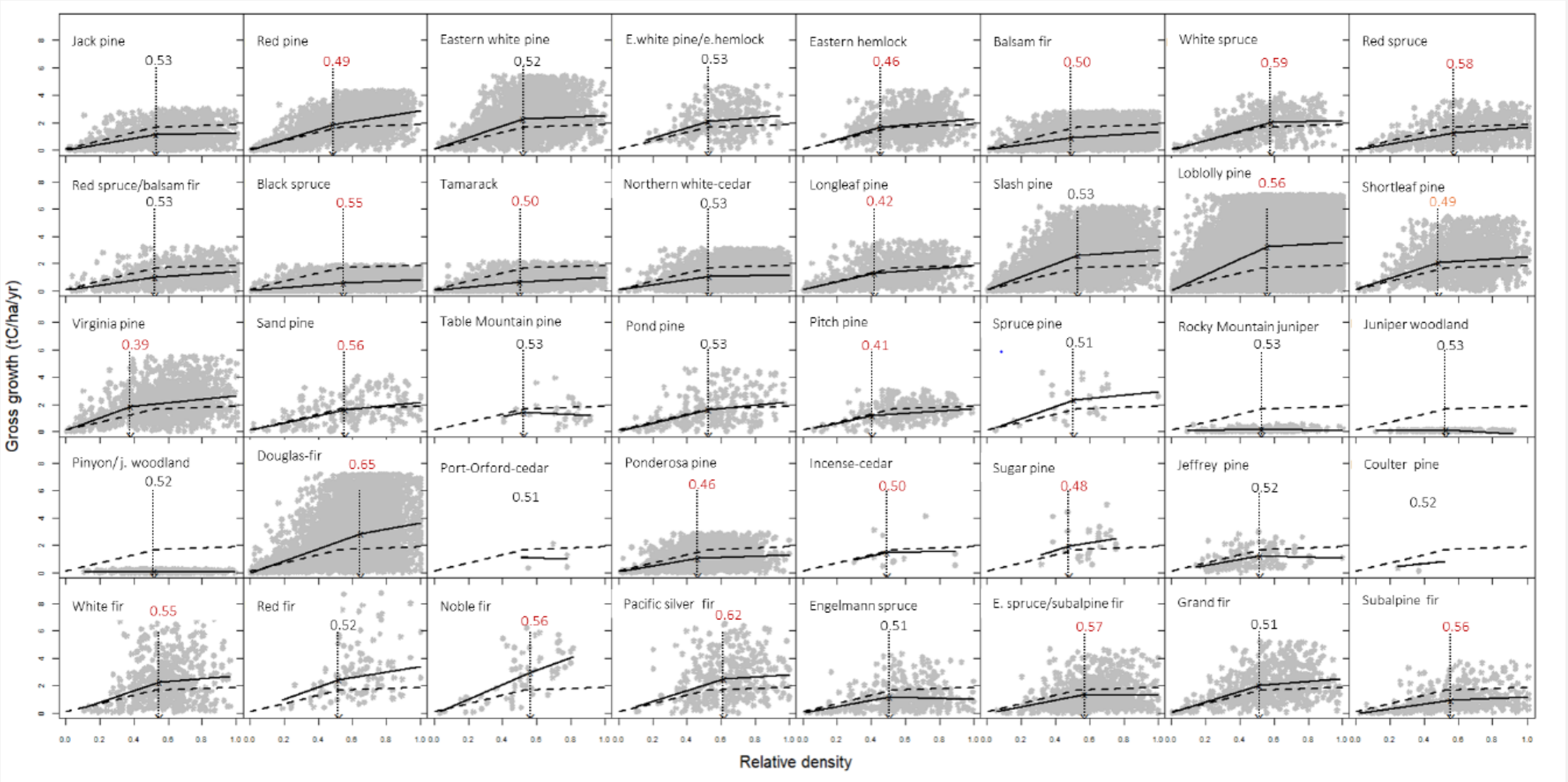
Workflow


FIA data
Quality control
Gross growth
Net growth
Davies test
Slope
No
Reassess data?
Non- linear models?
Yes
Model 1
Model 2
Model 3
Model 4
AIC
RMSE
R2c
R2m
Performance
Residuals
Linear mixed effects model
AIC
RMSE
R2c
R2m
Performance
Residuals
Model 1
Model 2
Model 3
Model 4
Segmented linear mixed effects model
Reassess?
No
Converges
No
Reassess?
OK

RESULTS: Test for slope differences

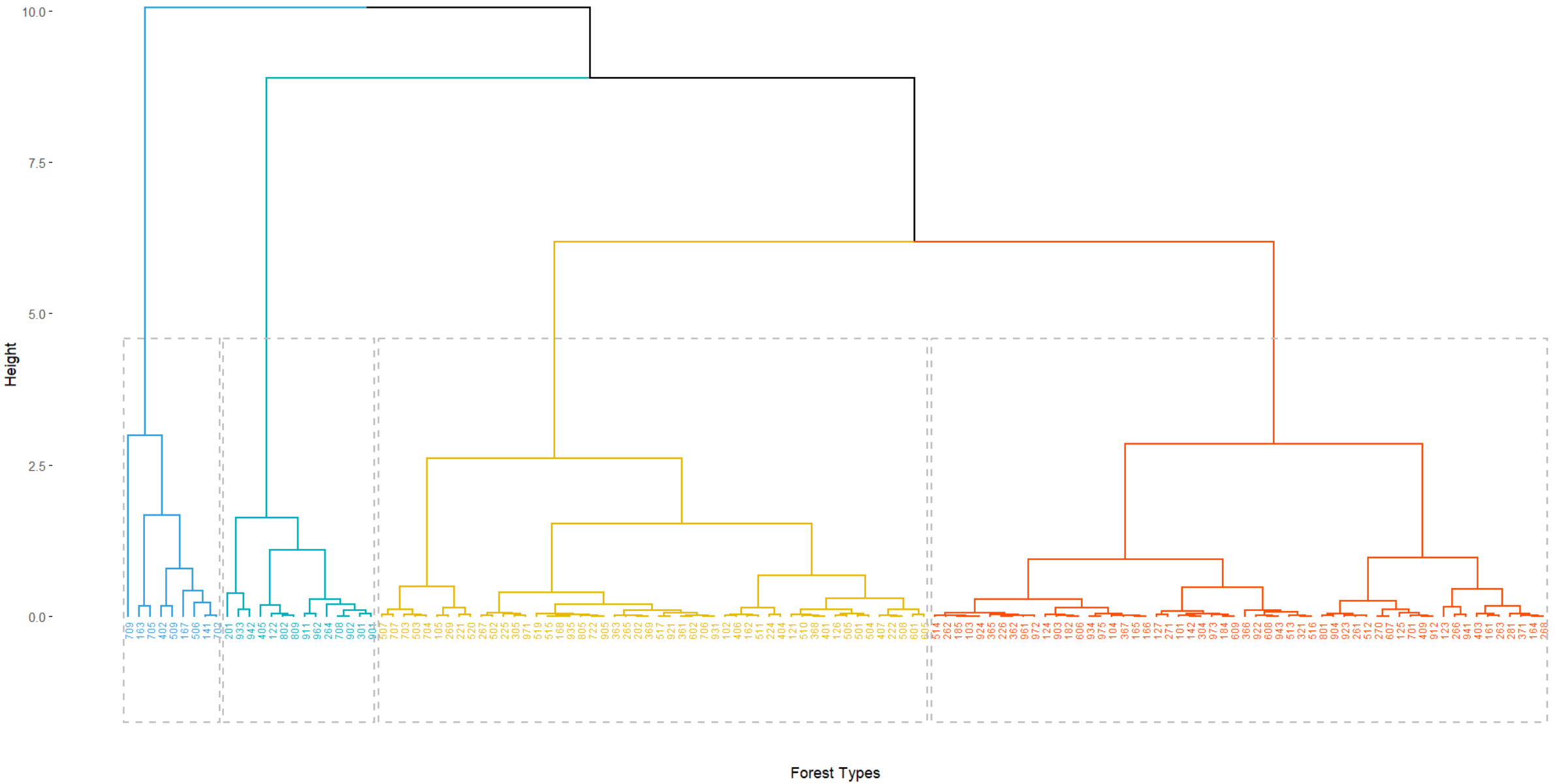
Growth metric	'Best' at estimate	Adjusted p-value
Gross growth	0.56	2.2e-16
Net growth	0.56	2.2e-16

Gross growth-RD relationships across forest types

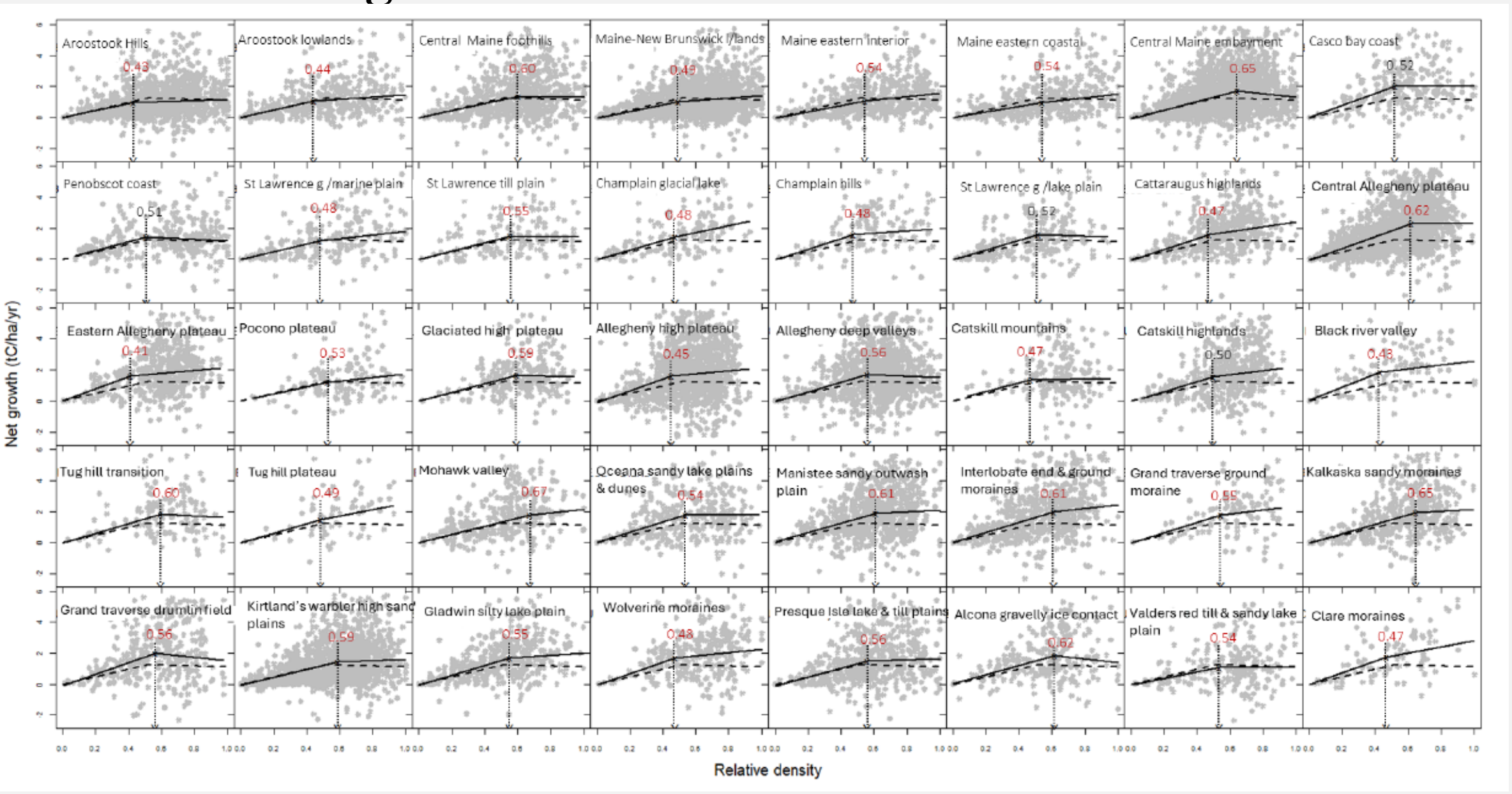


Breakpoint: 0.52 (CI: 0.51-0.54)

Clustering of gross growth RD across forest types

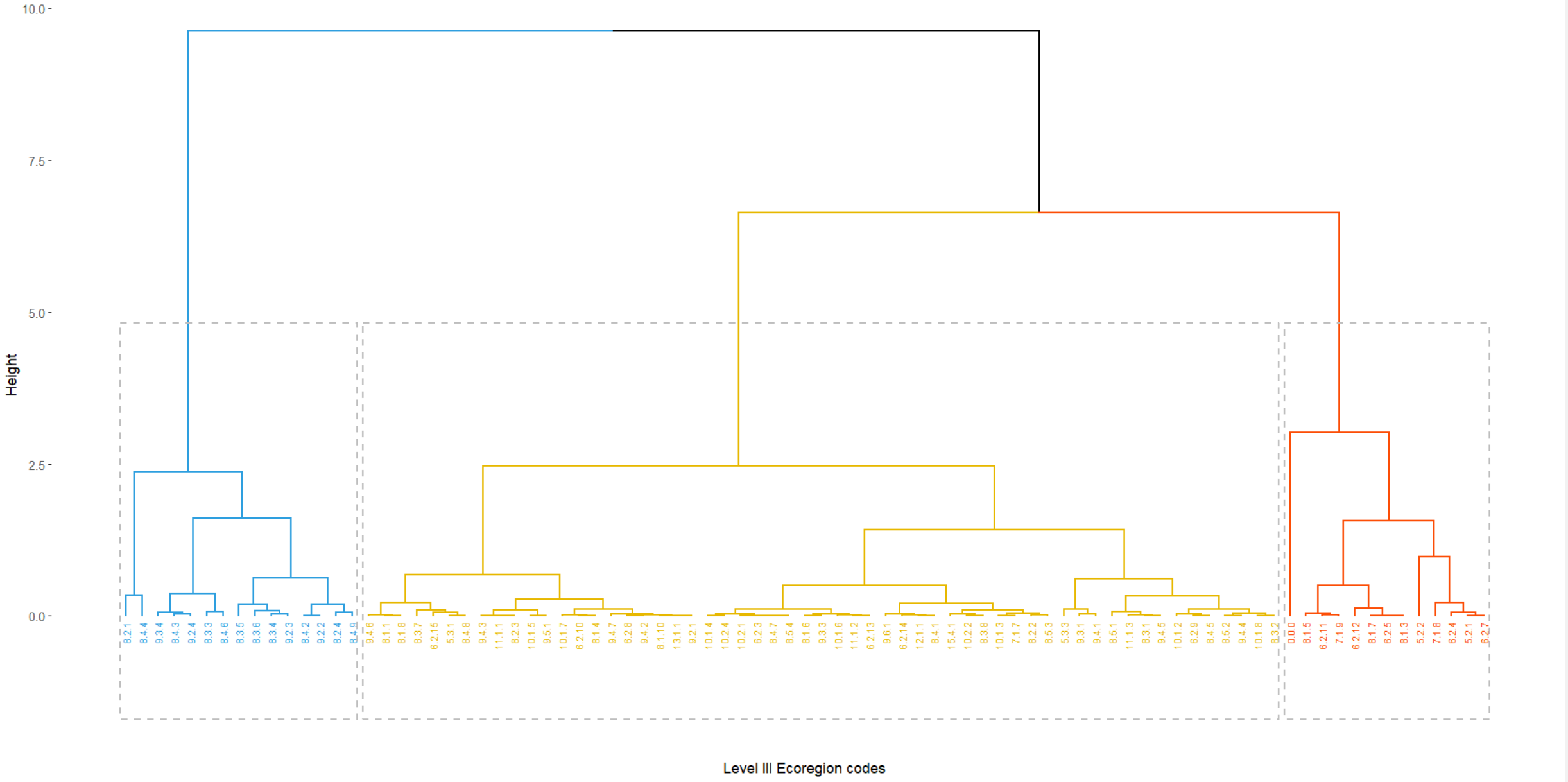


Results: Net growth-RD across ecosubsections

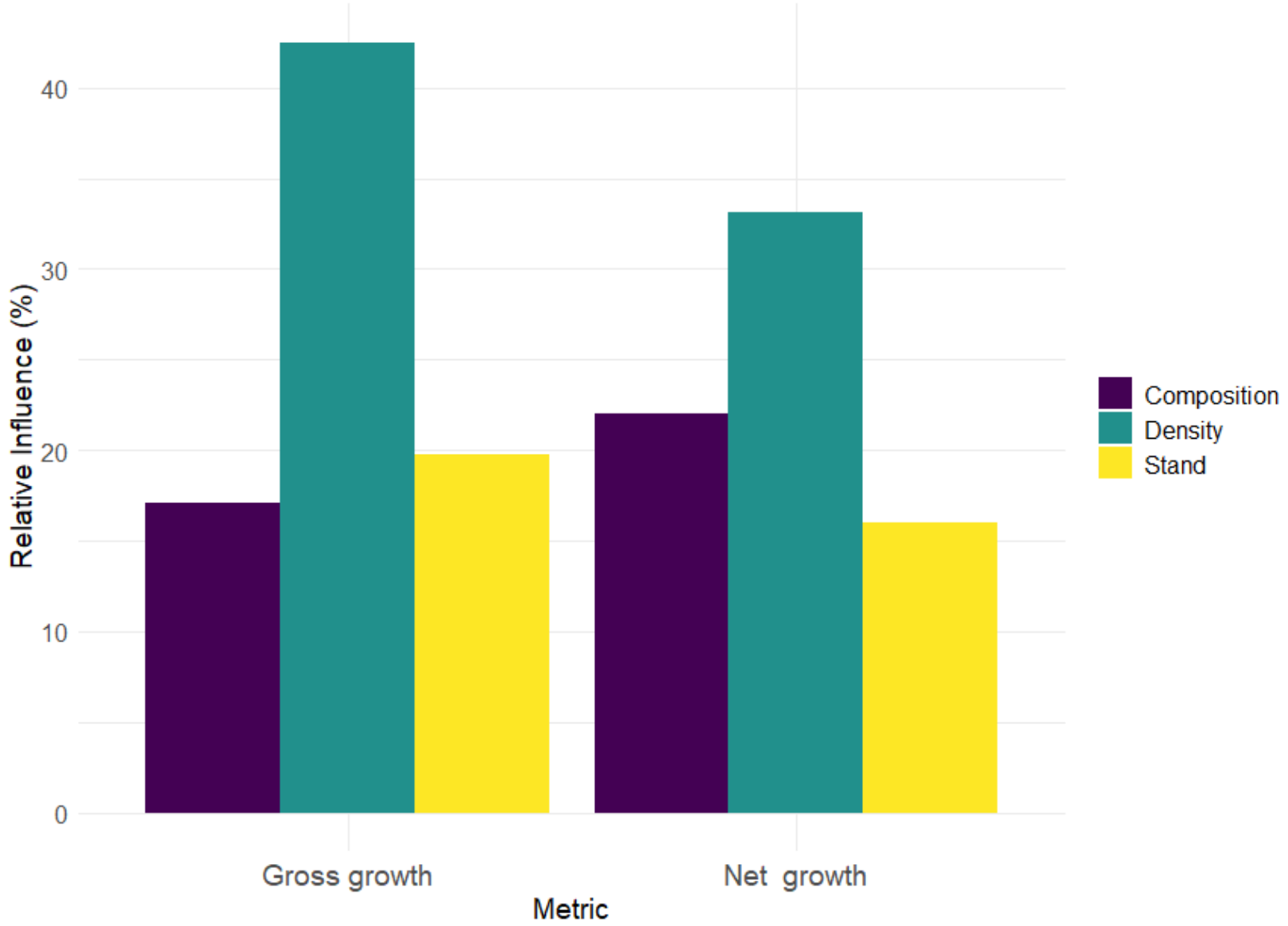


Breakpoint: 0.51 (CI: 0.50-0.52)

Clusters of RD breakpoints across ecosubsections



Potential drivers of density growth relationships



Conclusions

- Gross and net growth linearly increased with RD up to a breakpoint of 0.51-0.55 beyond which the relationship became more asymptotic

- Asymptotic nature of the relationship supports the Langsaeter hypothesis.

- Limited number of clusters optimally determined from the identified breakpoints

Conclusions

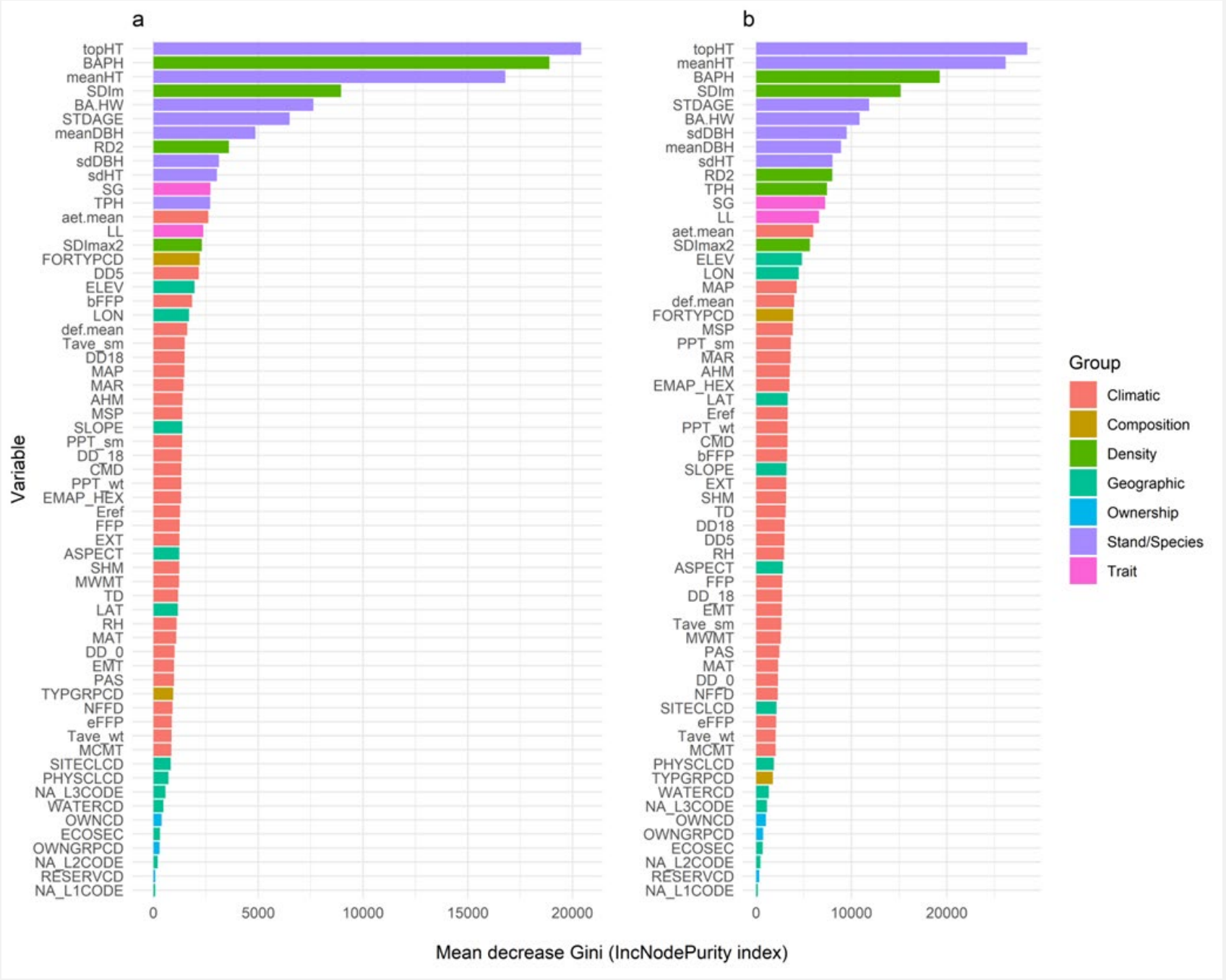
- RD is a reliable predictor of gross and net growth exhibiting logical behavior across a range of conditions, yet a substantial amount of unexplained variation remained

- Stand structure and density are the potential dominant drivers for density-growth relationships

THANK YOU

???QUESTIONS???

- email: emmerson.chivhenge@maine.edu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ECOSEC
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Group
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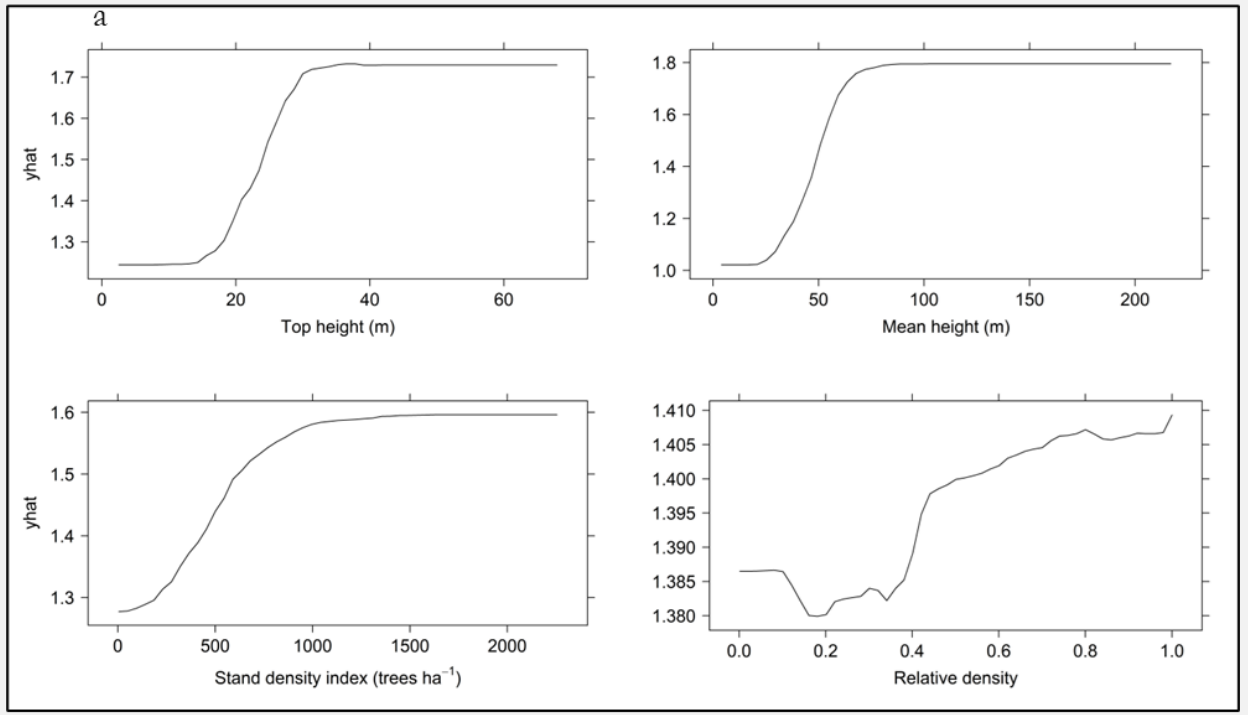
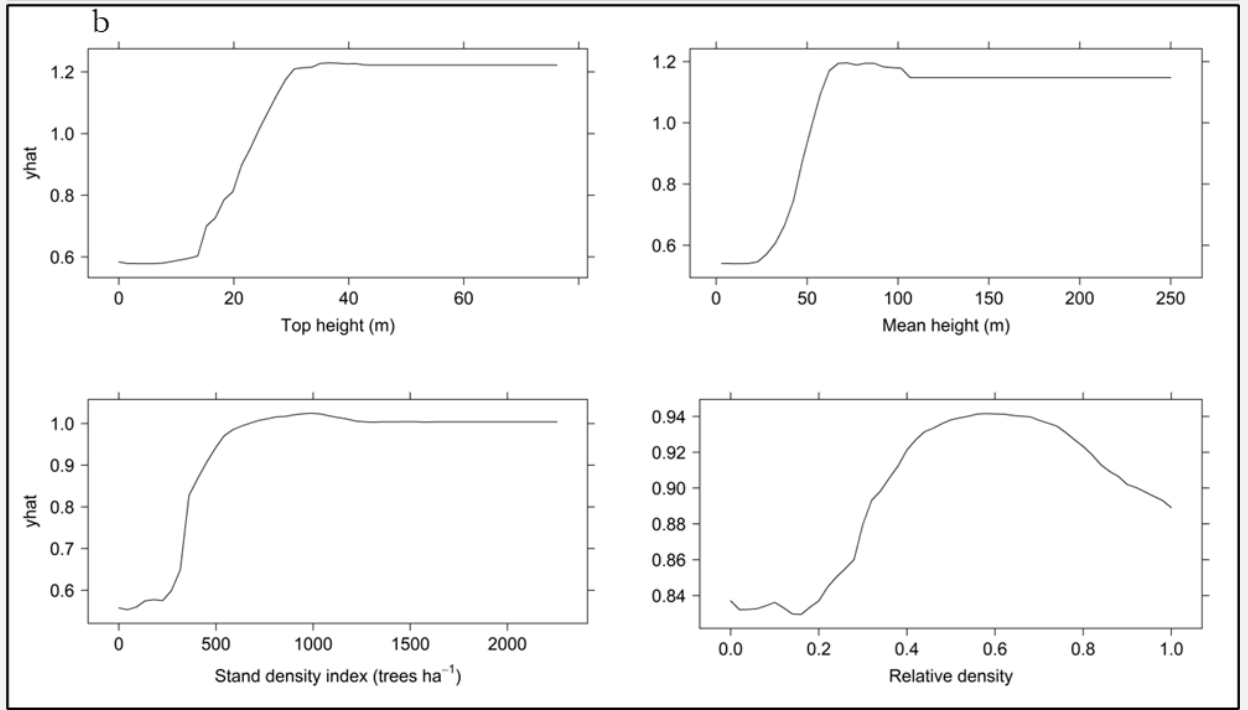
Mean decrease Gini (IncNodePurity index)


a
yhat
Top height (m)
Mean height (m)
Stand density index (trees ha^{-1})
Relative density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Top height (m)
Mean height (m)
Stand density index (trees ha^{-1})
Relative density