Multiple pathways of development in northeastern forests: The role forest history plays in mature forest structure

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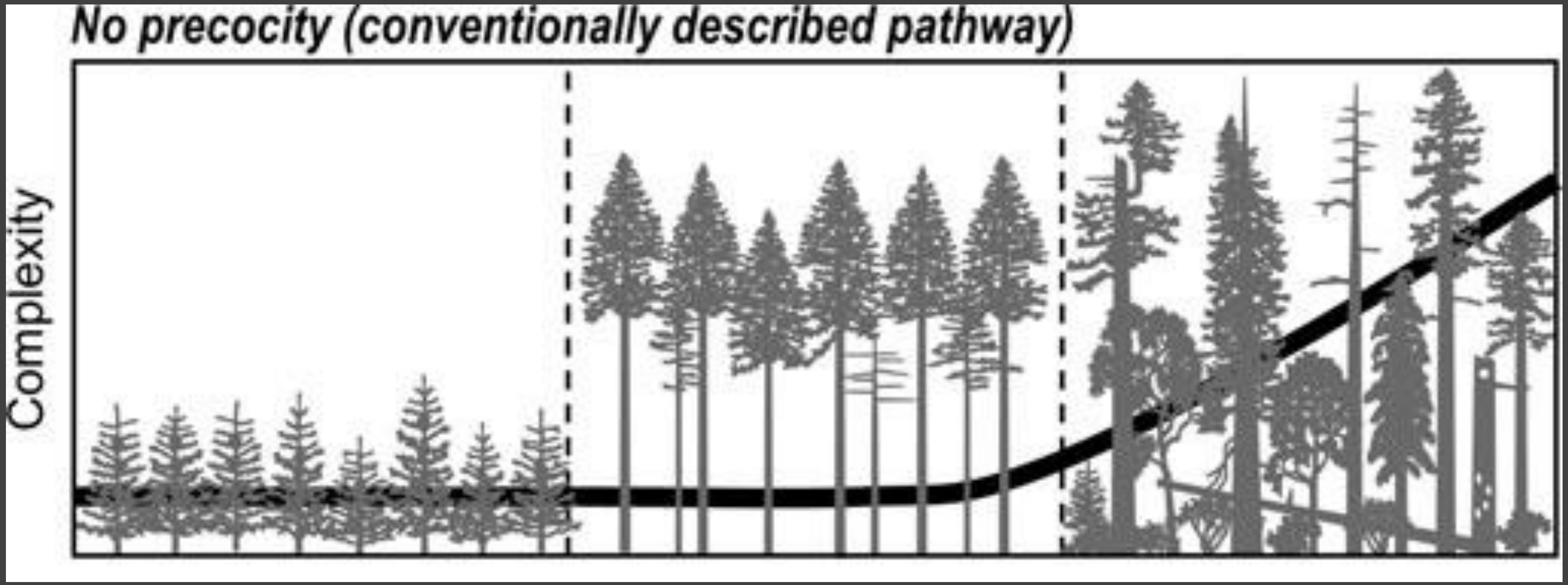
Background

- Many forests in Northeast are mature (80-150yrs) as forests recover from historic land-use
- Thus, structure and functions of mature forests are increasingly relevant regionally
- Mature forest structure of extra interest due to the USFS & BLM national inventory of mature and old-growth forests

Background



Conventional pathway of development, Donato et al. 2012

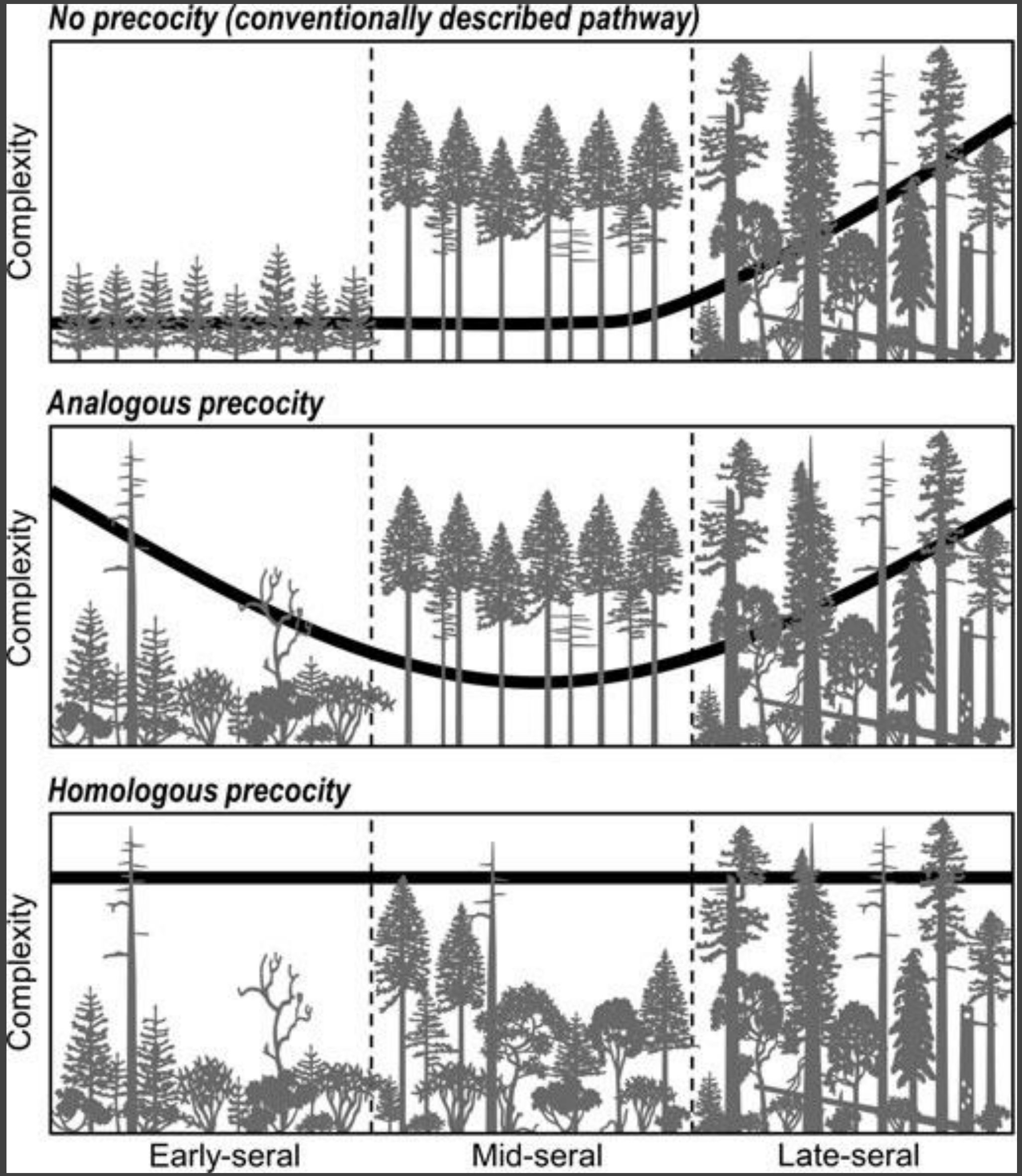
- Conventional stand development models following human land-use are based on <u>cleared</u> forests (ie. Oliver and Larson 1996)
- In these models, complexity is low until late in stand development (ie. dead trees, coarse woody debris (CWD), large trees, etc.)
- These models predict mature forests are developing complex structures, but in low quantities

Background

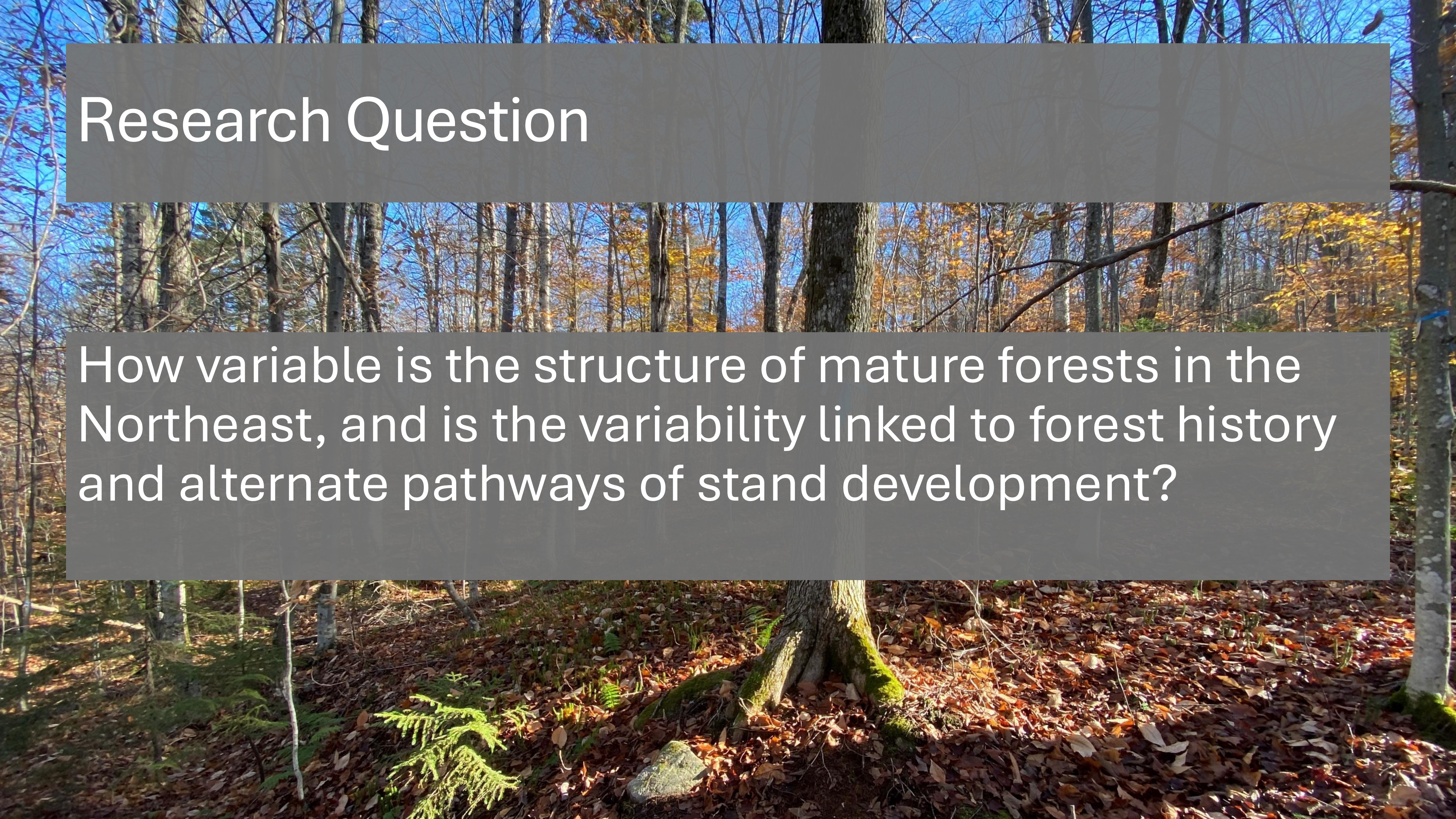
- Stand scale research shows partial disturbances can lead to alternate development pathways and differences in structure

- Many Northeast stands were only partially logged, and some were lightly managed after stand initiation

- Regional models lack multiple development pathways, and it’s unclear how such pathways have impacted mature forest structure



Hypothesized alternative stand development pathways, Donato et al. 2012



Research Question

How variable is the structure of mature forests in the Northeast, and is the variability linked to forest history and alternate pathways of stand development?

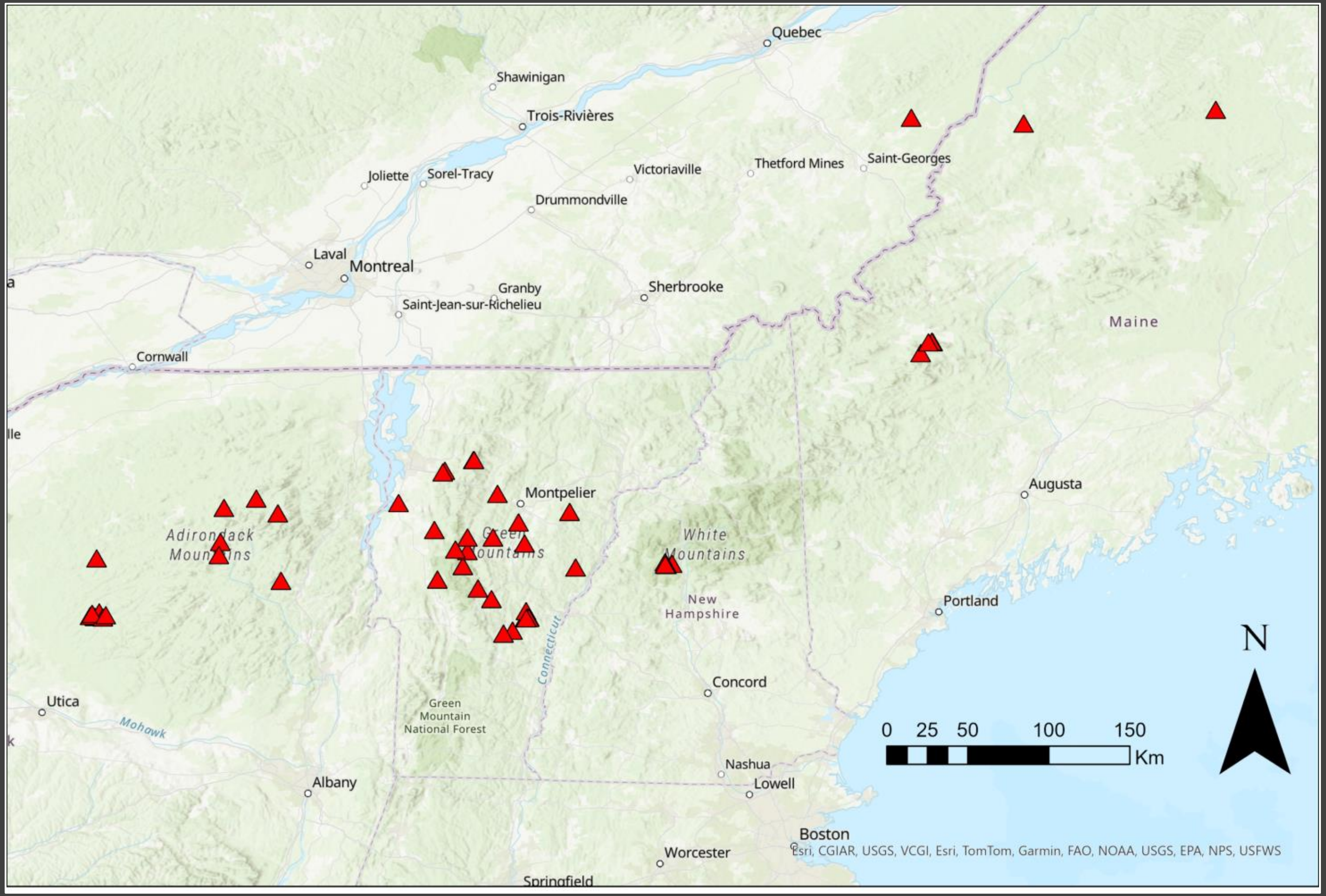
Hypotheses

- H1: The structure of mature stands in the Northeast is highly variable
- H2: Forest history explains a significant portion of this variability
- H3: The link between forest history and mature forest structure supports alternate pathways of stand development at a regional scale

Site Details

- 63 mature, northern hardwood-conifer stands with minimal natural disturbance

- <u>Four forest histories:</u>
  1. Cleared-unmanaged (conventional pathway)
  2. Cleared-managed
  3. Partially cleared-unmanaged
  4. Partially cleared-managed

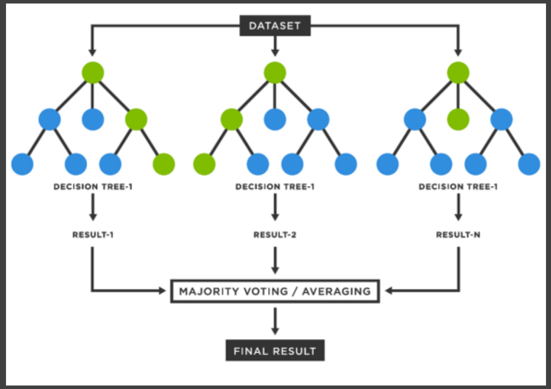


Workflow

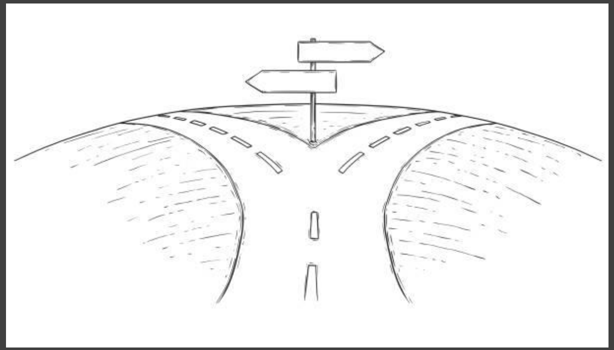
Research Q: What is the structural variability of mature forests and is this variability linked to forest history and pathways of development?

Structural Metric	First quartile	Median	Third quartile	Range
CWD Volume (m^3/ha)	36	47	79	6 - 189
Live aboveground biomass (Mg/ha)	149	195	230	82 - 391
Standing Dead Aboveground Biomass (Mg/ha)	10	18	30	0 - 74

H1: Mature forests have variable structure



H2: Forest history is linked to this structural variability



H3: There is evidence for alternate pathways of stand development

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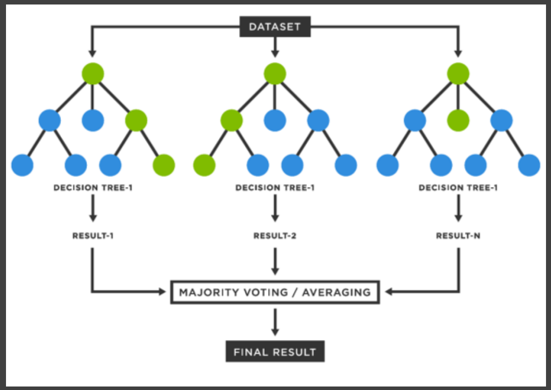

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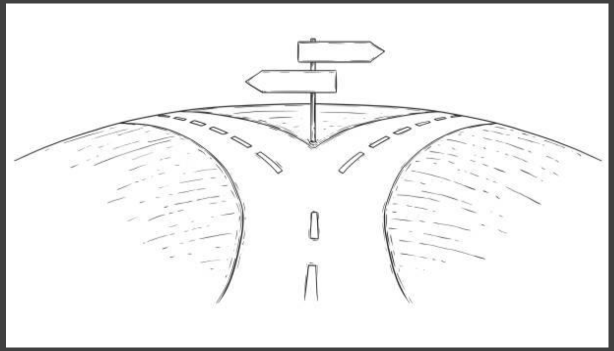

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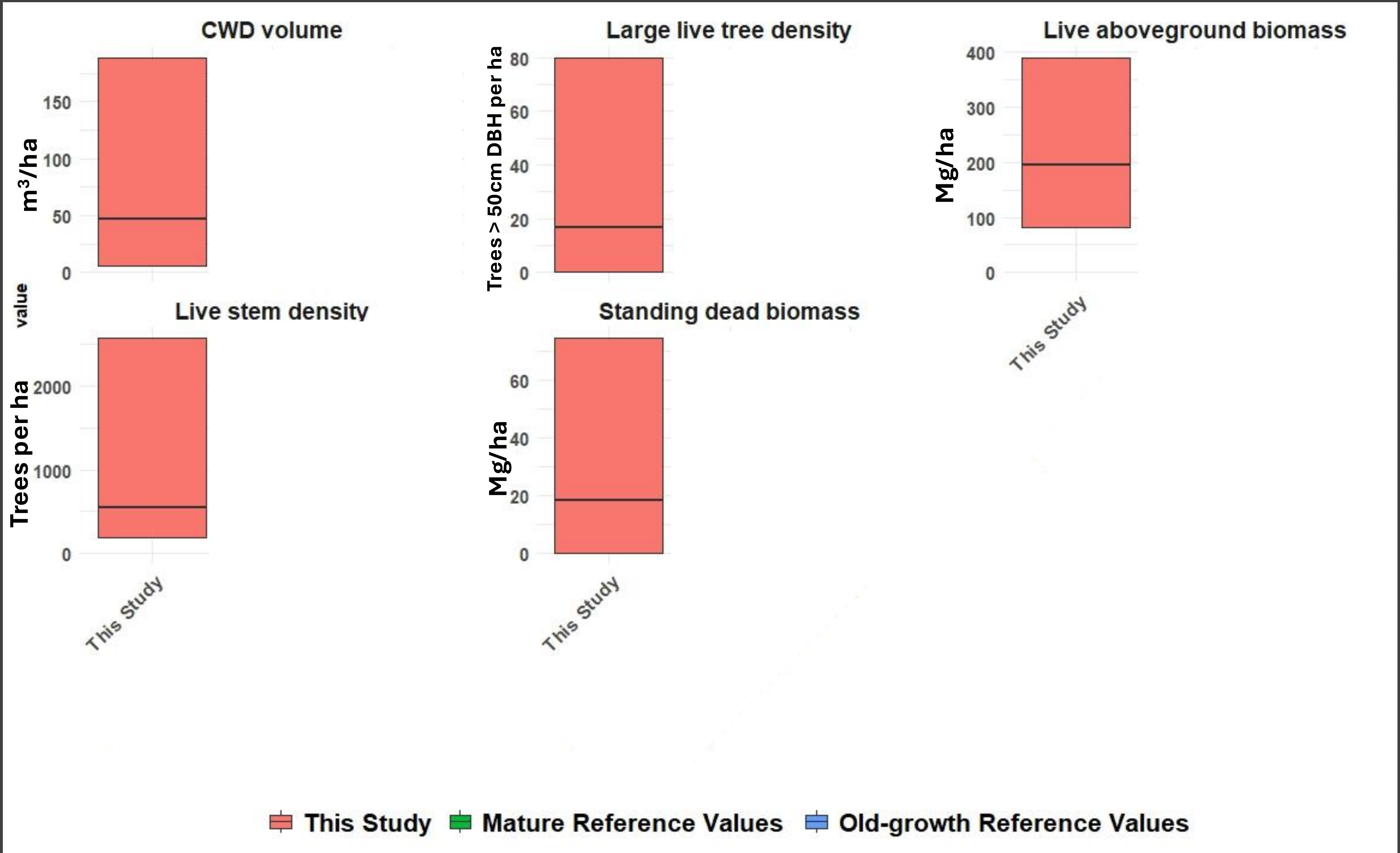
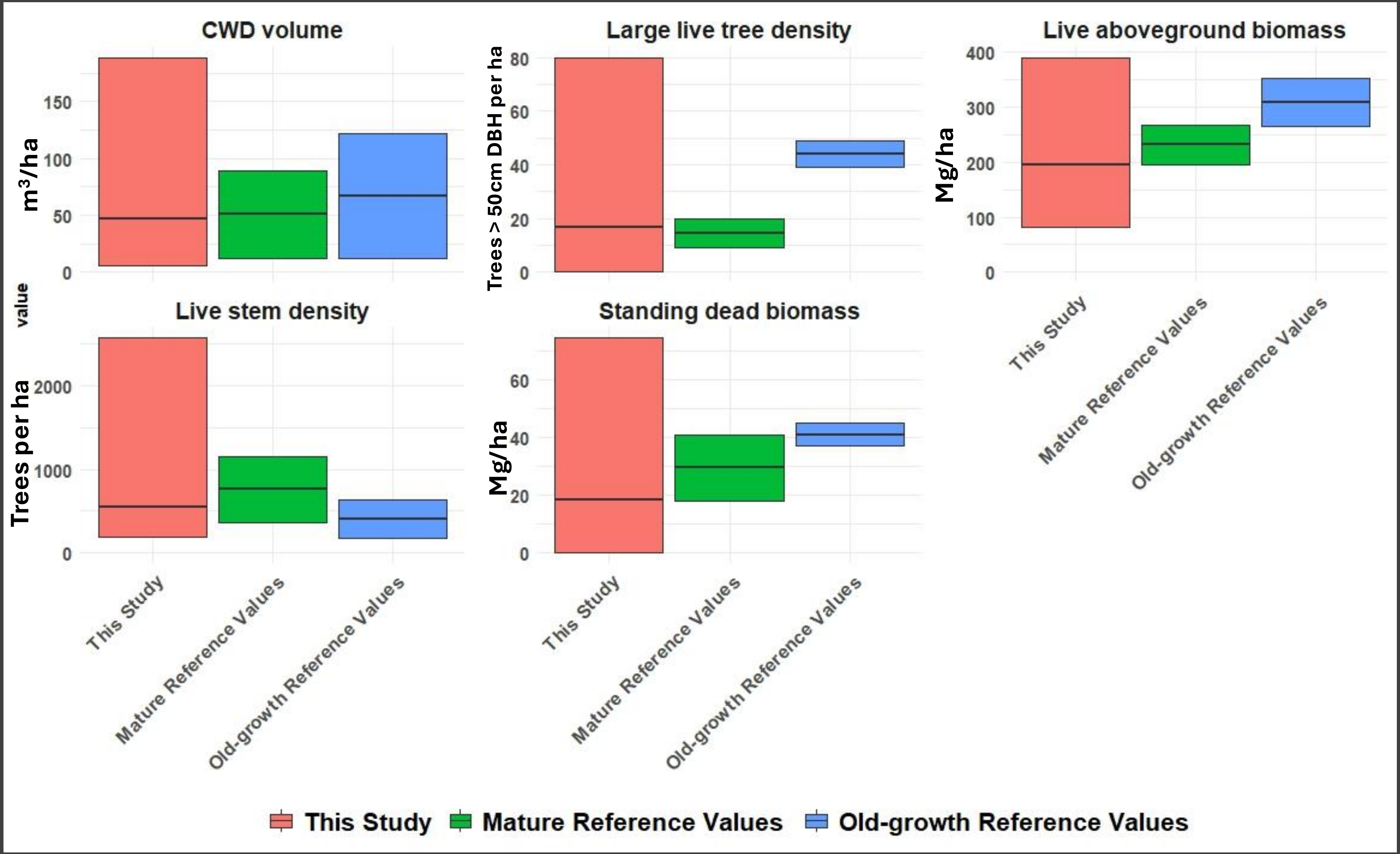


CWD volume
m³/ha
150
100
50
0
Large live tree density
Trees > 50cm DBH per ha
80
60
40
20
0
Live aboveground biomass
Mg/ha
400
300
200
100
0
This Study
value
Live stem density
Trees per ha
2000
1000
0
This Study
Standing dead biomass
Mg/ha
60
40
20
0
This Study
This Study
Mature Reference Values
Old-growth Reference Values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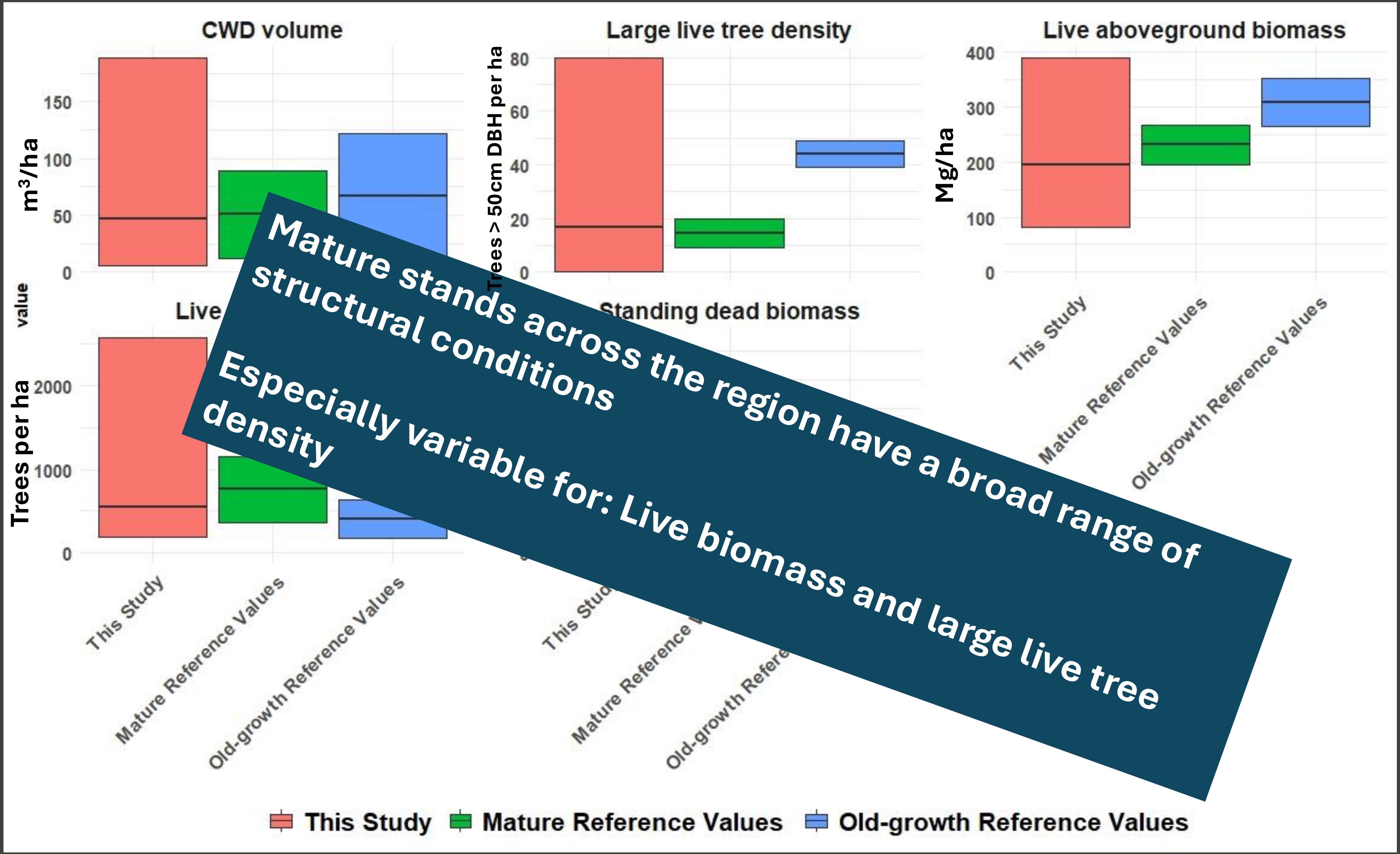

Mature stands across the region have a broad range of structural conditions

Especially variable for: Live biomass and large live tree density

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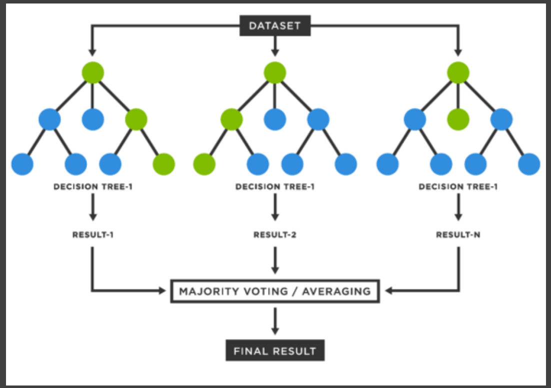
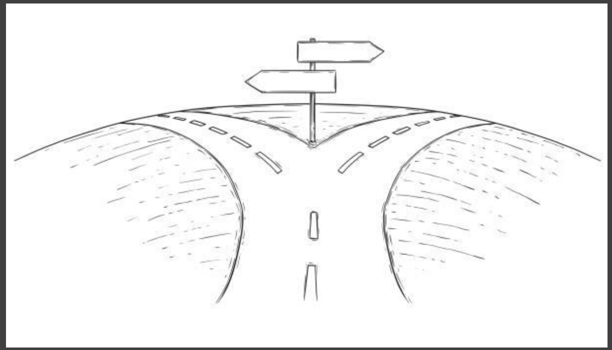


H2: Forest history is linked to this structural variability



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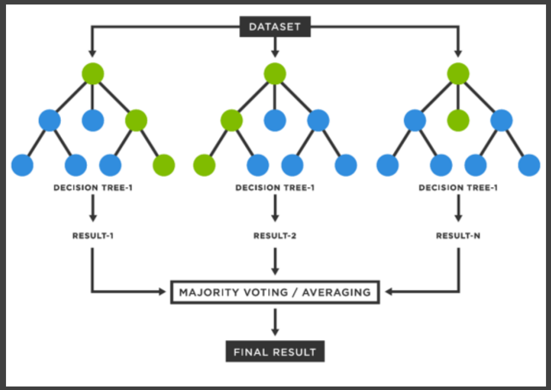

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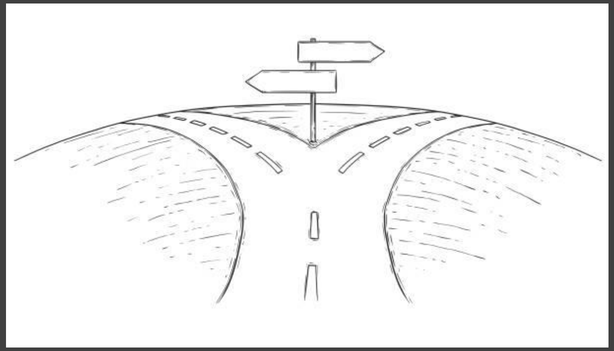


H3: There is evidence for alternate pathways of stand development

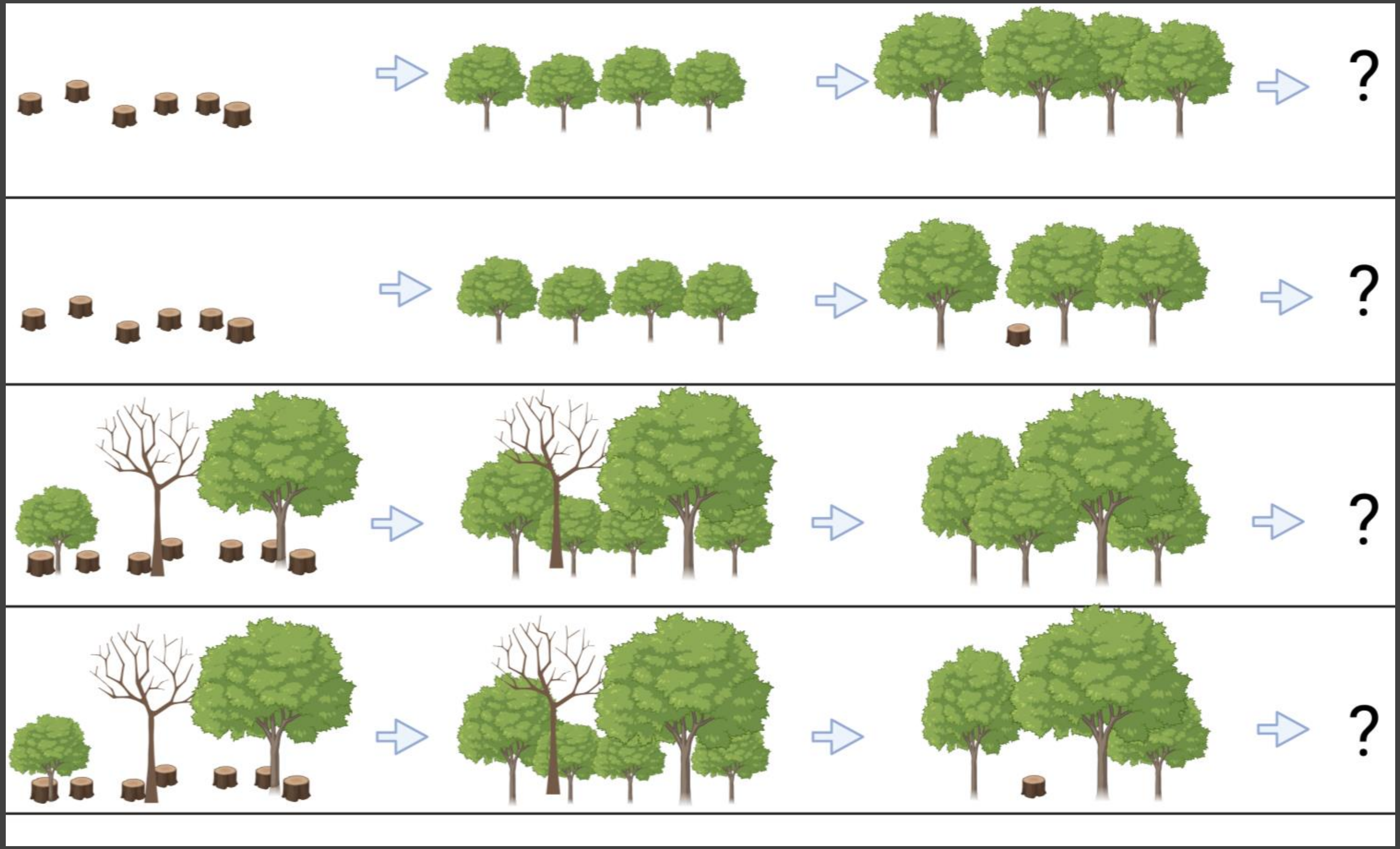
2: Is mature forest structure related to forest history?

Cleared and unmanaged (conventional pathway)

Cleared and lightly managed

Partially cleared and unmanaged

Partially cleared and lightly managed



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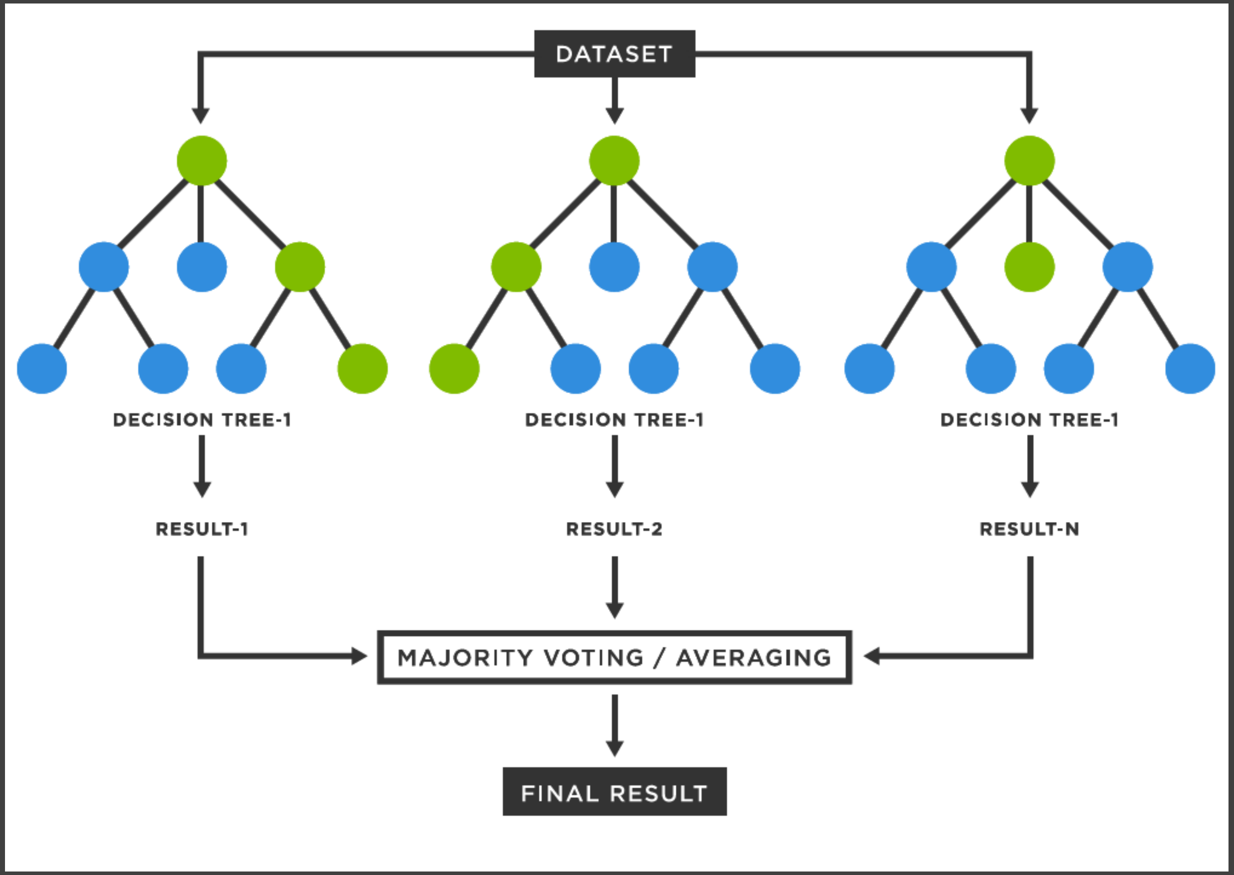
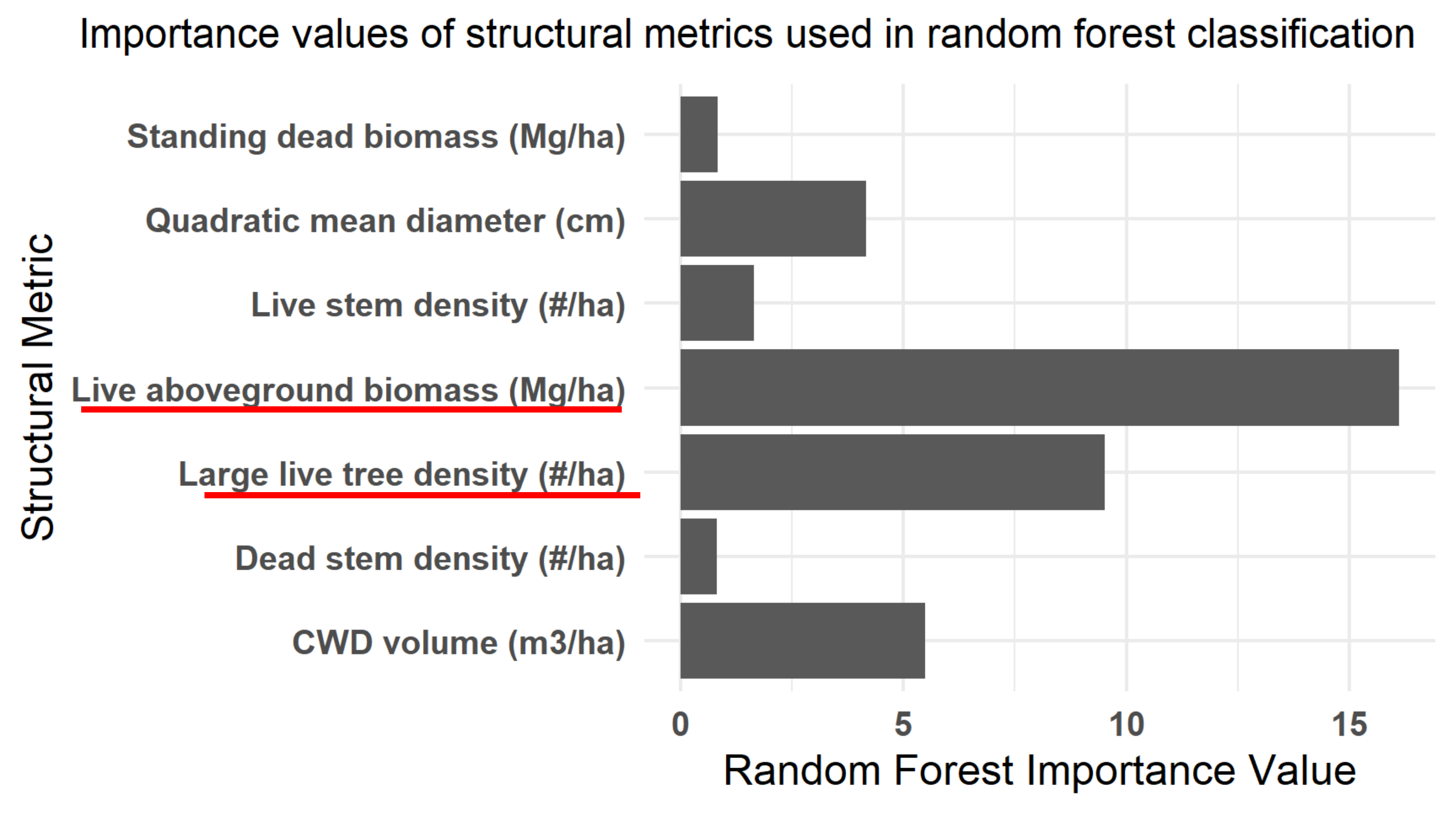
2: Is mature forest structure related to forest history?

- Forest history explained more variation in structural metrics than climate, topography or geography

- Used Random Forest to identify most important structural metrics for predicting a stand's forest history



2: Random Forest Results



Live biomass and large tree density most predictive of forest history

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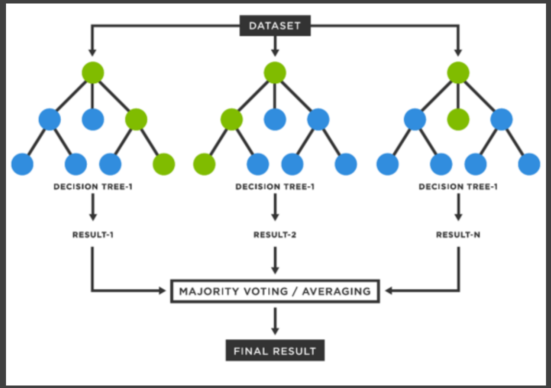

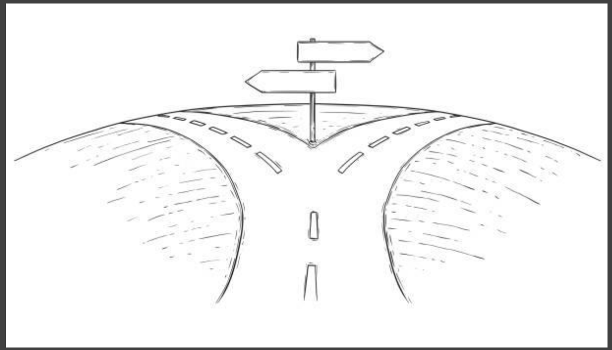

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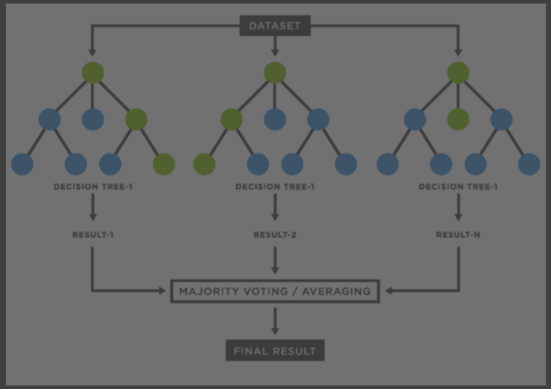

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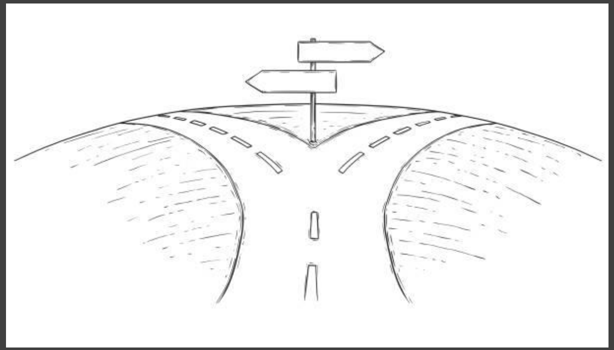
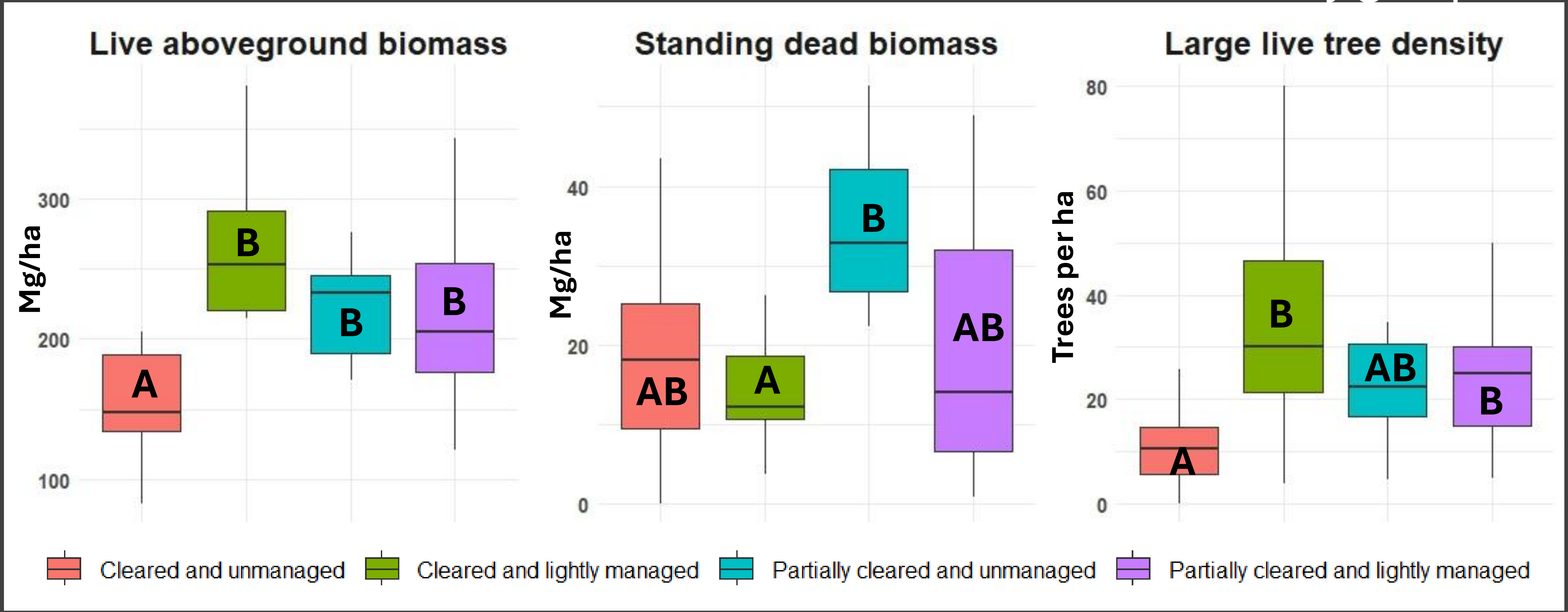


H3: There is evidence for alternate pathways of stand development

3: Differences in mature forest structure across forest history groups



- All alternative pathways had elevated live biomass (Kruskall-Wallis test)
- Differences in dead biomass. Partially cleared-unmanaged had most dead biomass
- Two alternative pathways had more large trees than conventional pathway

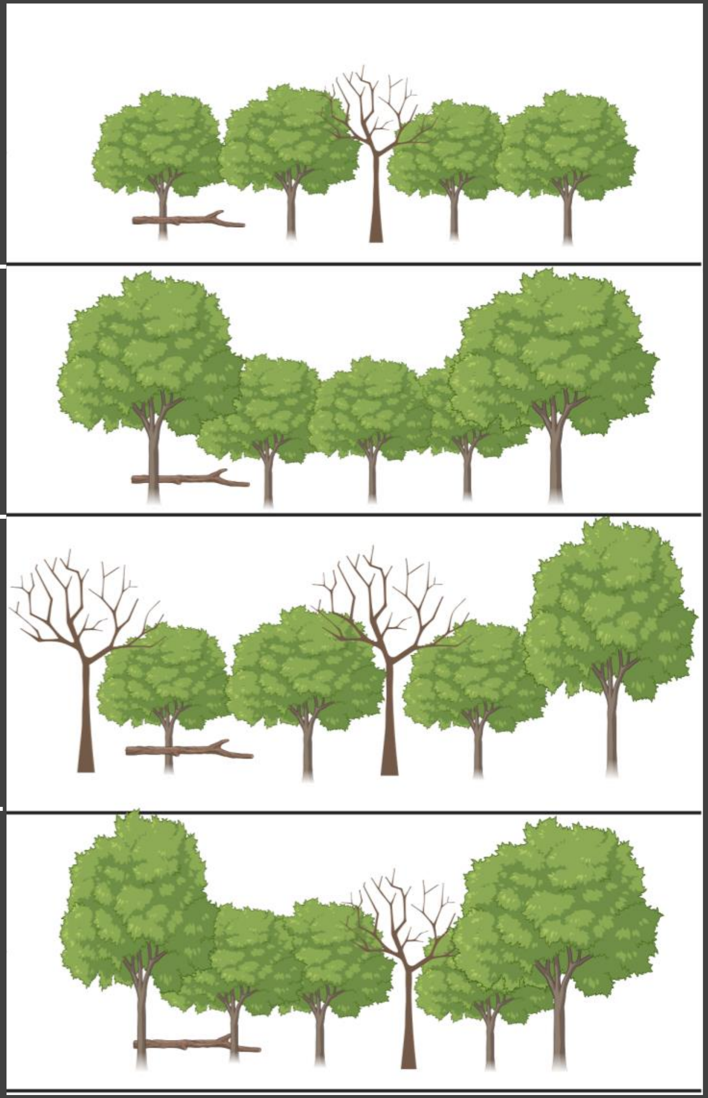
3: Alternate pathways of stand development

Cleared and then unmanaged (conventional pathway)

Cleared and then managed

Partially cleared and then unmanaged

Partially cleared and then managed



↑ large trees than cleared-unmanaged

↑ dead biomass than cleared-managed

↑ large trees than cleared-unmanaged

↑ live biomass

Forest History

Mature Stand Structure

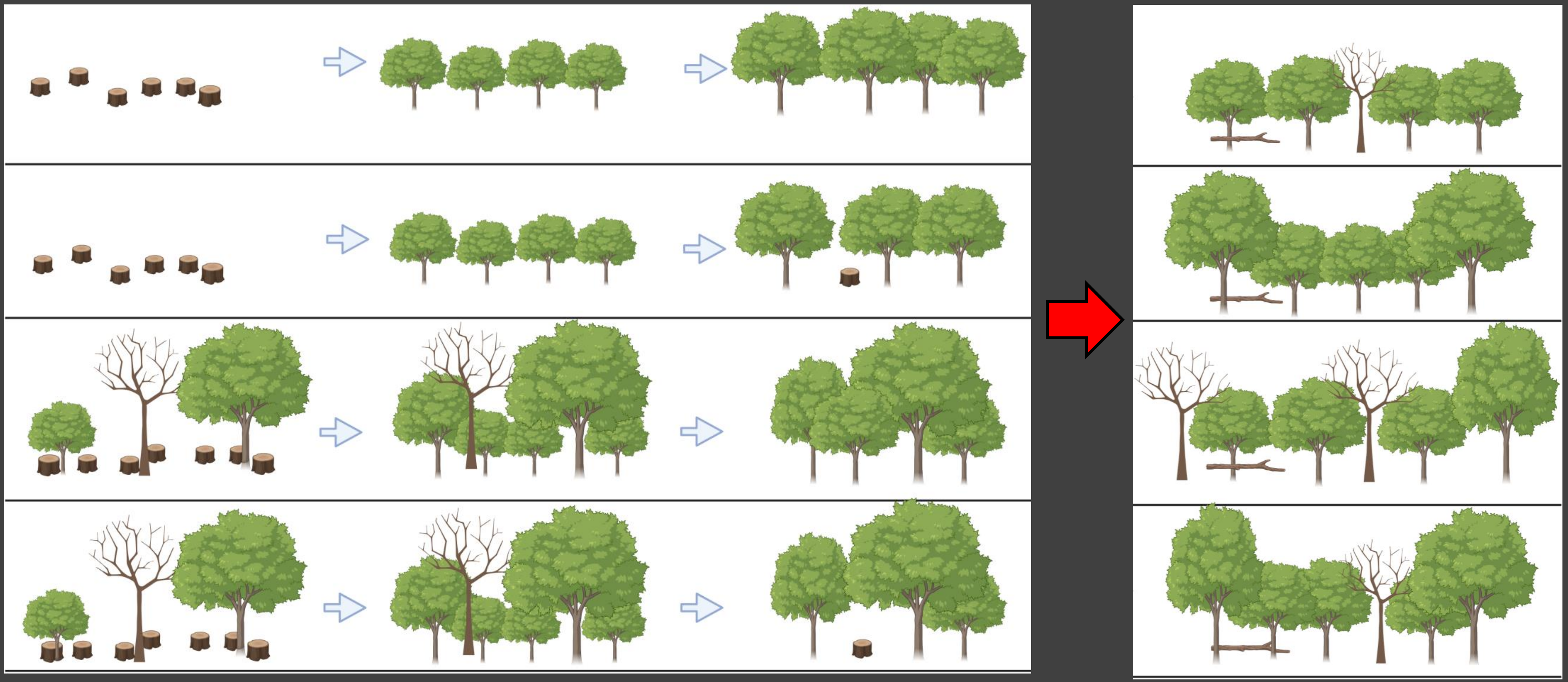
3: Alternate pathways of stand development

Cleared and unmanaged

Cleared and managed

Partially cleared and unmanaged

Partially cleared and managed

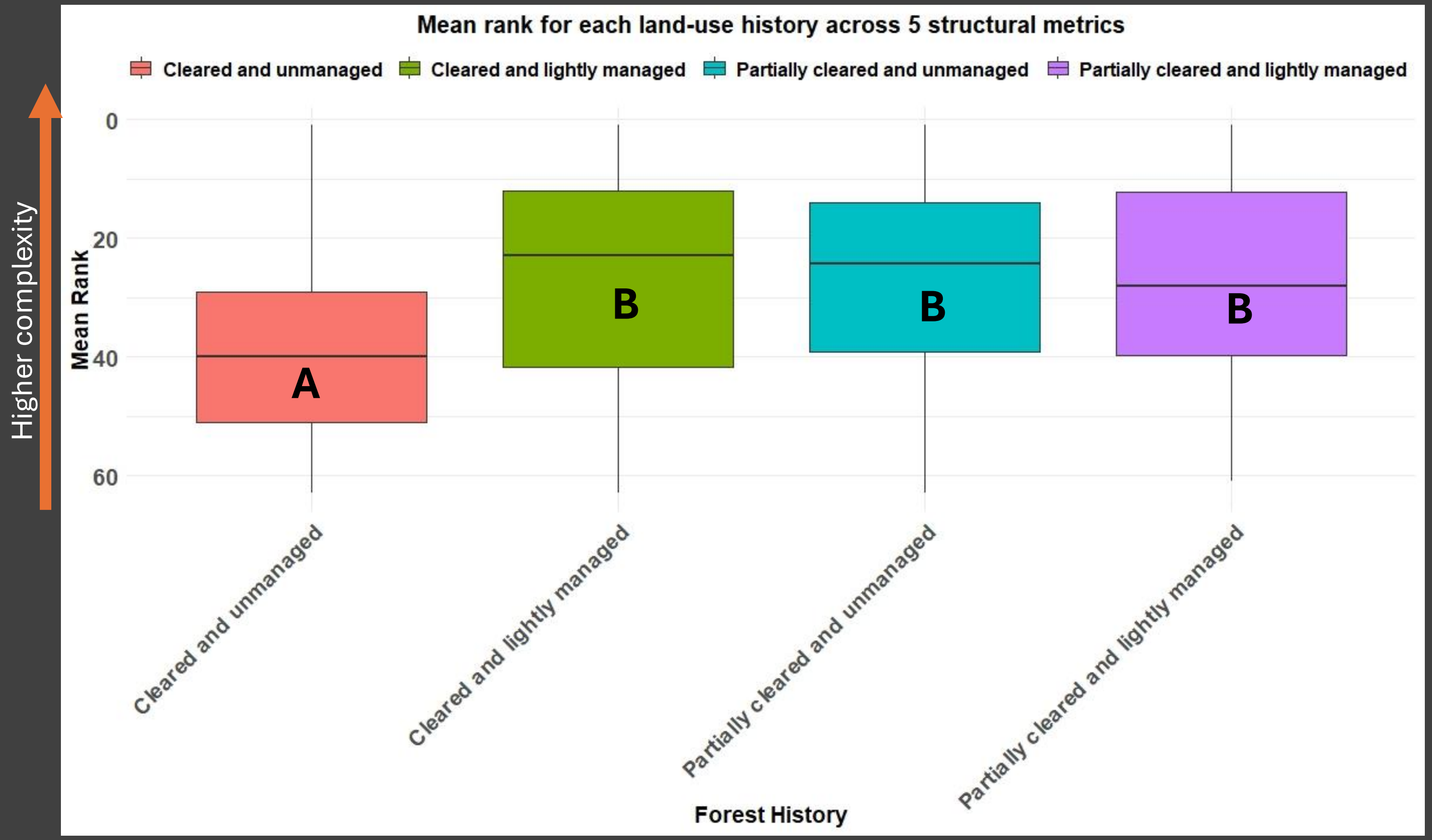


Forest history

Mature Stand Structure

Assessing broad differences in complex structure

- Ranked sites based on CWD volume, live biomass, standing dead biomass, QMD and big live tree density. Compared ranks across groups
- Non-conventional pathways had significantly more complex characteristics on average (ANOVA)
- Suggests complex characteristics can develop earlier in non-conventional pathways



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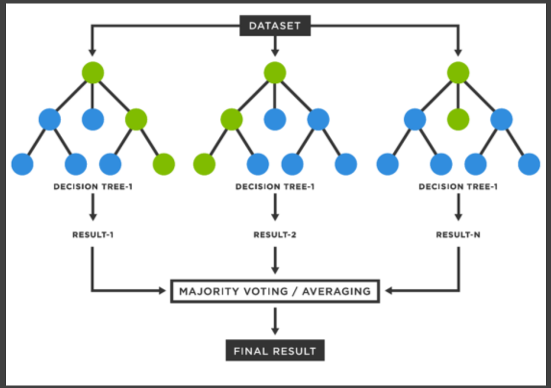

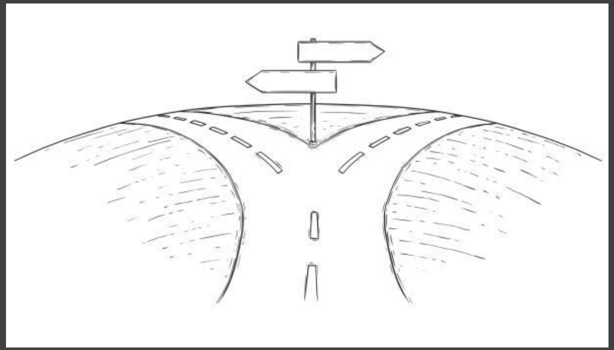

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H2: Forest history is linked to this structural variability

H3: There is evidence for alternate pathways of stand development

Takeaways

- Alternate pathways are prevalent across the Northeast and altering mature forest structure
- Alternate pathways can develop complex structures like large trees and deadwood earlier across the region
- This can alter mature forest functions such as habitat provisioning, carbon storage, resilience, improve stream function

Acknowledgements

USDA McIntire-Stennis Forest Research Program
NSF Graduate Research Fellowship Program
University of Vermont Field Crews


Questions?

Assessing broad differences in complex structure between pathways

- Sites were ranked 1-63 based on 6 structural metrics indicative of old forest structure
- Rankings were averaged across all metrics to develop a mean complexity ranking

Stand	forest history	CWD Rank	Live Biomass Rank	Standing Dead Biomass Rank	QMD Rank	Large Live Tree Density Rank	Mean Rank
Arbutus Outlet	Intermediate-unmanaged	39	31	17	53	57	39.4
Bagley	Intermediate-unmanaged	46	9	9	26	28	23.6
Beth's Brook	Cleared-unmanaged	15	52	57	46	44	42.8

Randomly selected stands to provide an example of ranking system

1: Range of structural conditions

Structural Metric	Min	Max	Mature Reference Values	Citation	Old-growth Reference Values	Citation
CWD Volume (m^3 /ha)	6	189	12 - 89	Hale et al. 1999; Keeton et al. 2011	12-122	Stewart et al. 2011; Hale et al. 1999; Keeton et al. 2011
Live aboveground biomass (Mg/ha)	82	391	196 - 267	Rutkowski and Stottlemyer 1993; Forrester et al. 2003; Keeton et al. 2011	266-352	Keeton et al. 2011; Woods and Kern, 2022
Standing Dead Aboveground Biomass (Mg/ha)	0	74	18 - 41	Forrester et al. 2003; Keeton et al. 2011	39	Keeton et al. 2011
Live Stem Density (#/ha)	192	2572	357 - 1156	Rutkowski and Stottlemyer 1993; Forrester et al. 2003; Keeton et al. 2011; Hale et al. 1999	175 - 627	Stewart et al. 2011; Hale et al. 1999; Keeton et al. 2011
Dead Stem Density (#/ha)	0	317	0 - 90	Keeton et al. 2011; Hale et al. 1999	0 - 100	Stewart et al. 2011; Hale et al. 1999; Keeton et al. 2011
Quadratic Mean Diameter (cm)	13	36	28	Keeton et al. 2011	27 - 34	Stewart et al. 2011; Keeton et al. 2011
Large Live Tree Density (# > 50cm dbh /ha)	0	80	9	Keeton et al. 2011	39 - 49	Stewart et al. 2011; Keeton et al. 2011

Structural Metric	Range of Stand Values	Mature Reference Values	Old-growth Reference Values
CWD Volume (m^3 /ha)	6 – 189	12 - 89	12-122
Live aboveground biomass (Mg/ha)	82 – 391	196 - 267	266-352
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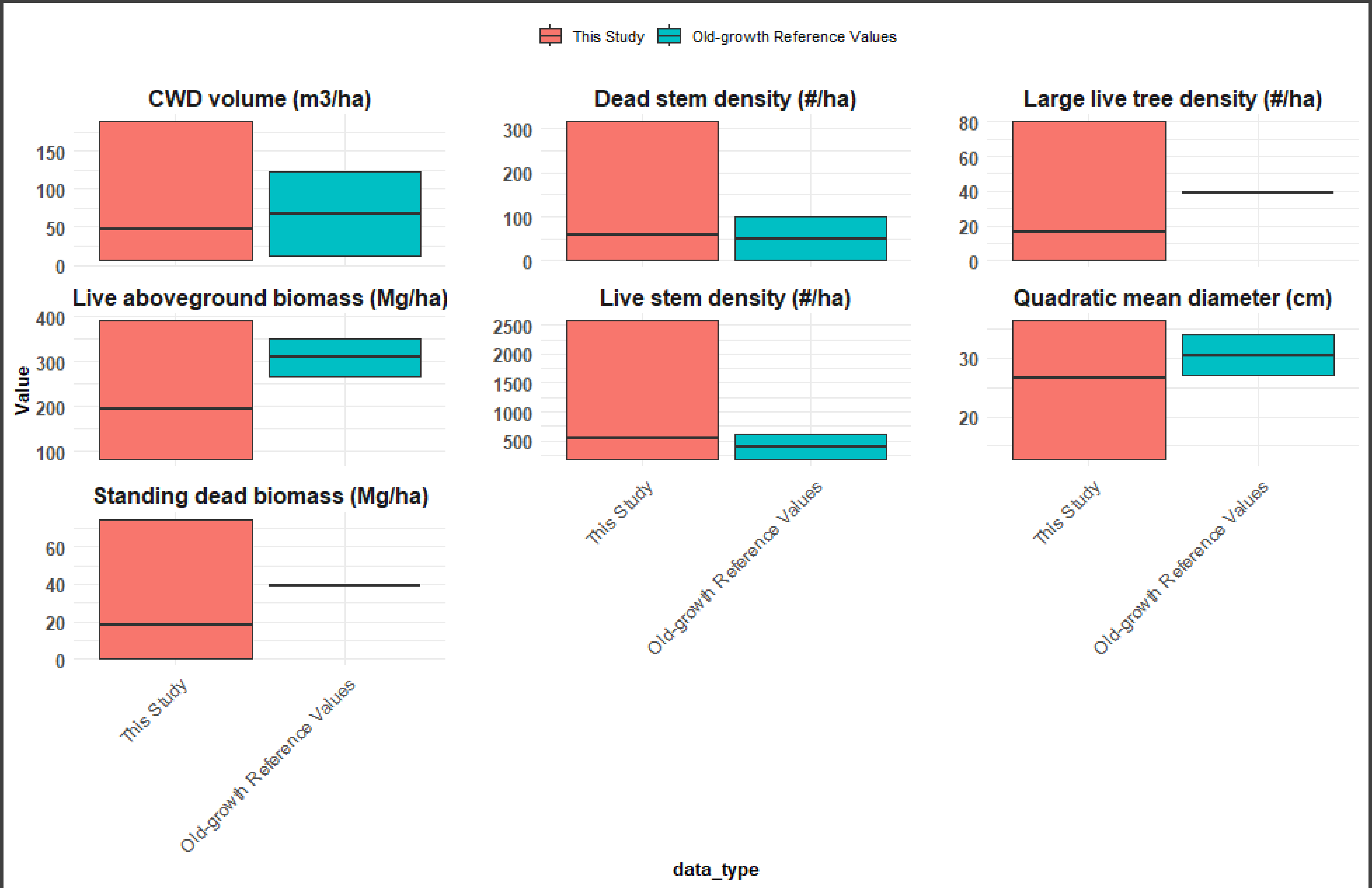
Live Stem Density (#/ha)	192 – 2572	357 - 1156	175 - 627
Dead Stem Density (#/ha)	0 – 317	0 - 90	0 - 100
Quadratic Mean Diameter (cm)	13 – 36	28	27 - 34
Large Live Tree Density (# > 50cm dbh /ha)	0 - 80	9	39 - 49



This Study
Old-growth Reference Values
CWD volume (m3/ha)
Dead stem density (#/ha)
Large live tree density (#/ha)
Live aboveground biomass (Mg/ha)
Live stem density (#/ha)
Quadratic mean diameter (cm)
Standing dead biomass (Mg/ha)
Value
data_type

1: Range of structural conditions

Structural Metric	First quartile	Median	Third quartile	Range of values	Mature Reference Values	Citation	Old-growth Reference Values	Citation
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Standing Dead Aboveground Biomass (Mg/ha)	10	18	30	0 - 74	18 - 41	Forrester et al. 2003; Keeton et al. 2011	39	Keeton et al. 2011
Live Stem Density (#/ha)	442	553	670	192 – 2572	357 - 1156	Rutkowski and Stottlemyer 1993; Forrester et al. 2003; Keeton et al. 2011; Hale et al. 1999	175 - 627	Stewart et al. 2011; Hale et al. 1999; Keeton et al. 2011
Dead Stem Density (#/ha)	33	60	95	0 – 317	0 - 90	Keeton et al. 2011; Hale et al. 1999	0 - 100	Stewart et al. 2011; Hale et al. 1999; Keeton et al. 2011
Quadratic Mean Diameter (cm)	23	27	29	13 – 36	28	Keeton et al. 2011	27 - 34	Stewart et al. 2011; Keeton et al. 2011
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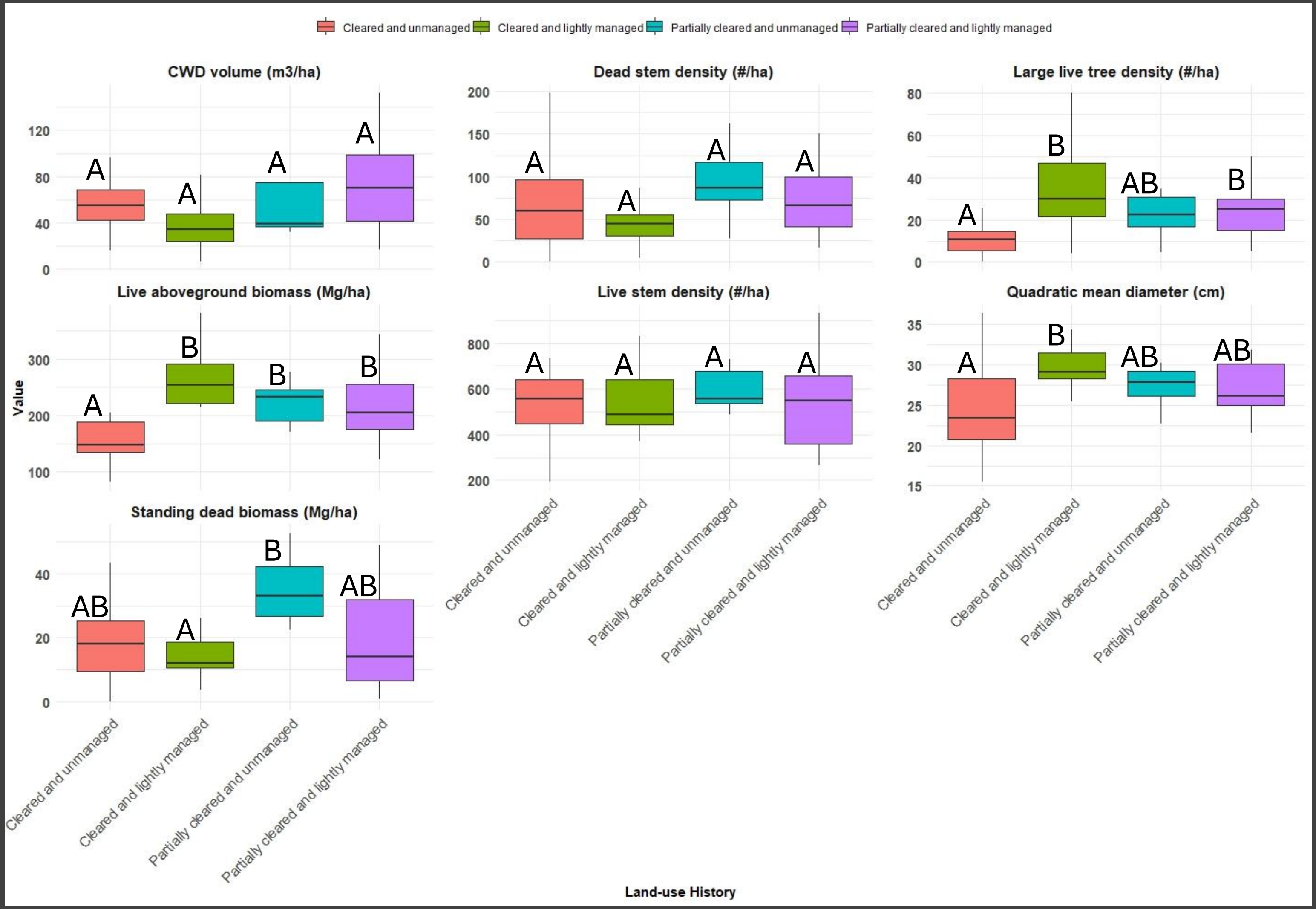
Differences in mature forest structure across forest history groups

- Statistical comparisons with Kruskall-Wallis test as data were not normal



Is mature forest structure related to forest history? – Linear Models

- Built models assessing the importance of forest history, climate, topography and geography for four unique structural metrics

- Compared partial r^2 of predictors to assess their relative importance to structural variability

Dependent Variable	Independent Variables in Final model
Live Aboveground Biomass	forest history, Mean Temperature, Total Precipitation, Elevation, Latitude
Coarse Woody Debris (CWD) Volume	forest history, Mean Temperature, Total Precipitation, Longitude, Latitude
Standing Dead Biomass	forest history, Mean Temperature, Total Precipitation, Elevation, Latitude
Large Live Tree Density	forest history, Mean Temperature, Total Precipitation, Elevation, Latitude

Is mature forest structure related to forest history? – Model Results

- forest history explained highest percentage of the variability for 3 of 4 models and was a close second in the 4th.
- Explained between 12% and 57% of variability, suggesting forest history is critical to describing the variation in mature forest structure

Dependent variable	Independent variable with highest partial r^2	Independent variable with second highest partial r^2
Live aboveground biomass	**Forest history (partial r^2 =0.57)**	Latitude (partial r^2 = 0.07)
Coarse woody debris (CWD) volume	Longitude (partial r^2 = 0.27)	**Forest history (partial r^2 = 0.21)**
Standing dead biomass	**Forest history (partial r^2 = 0.12)**	Latitude (partial r^2 = 0.007)
Large live tree density	**Forest history (partial r^2 = 0.38)**	Total precipitation (partial r^2 = 0.06)