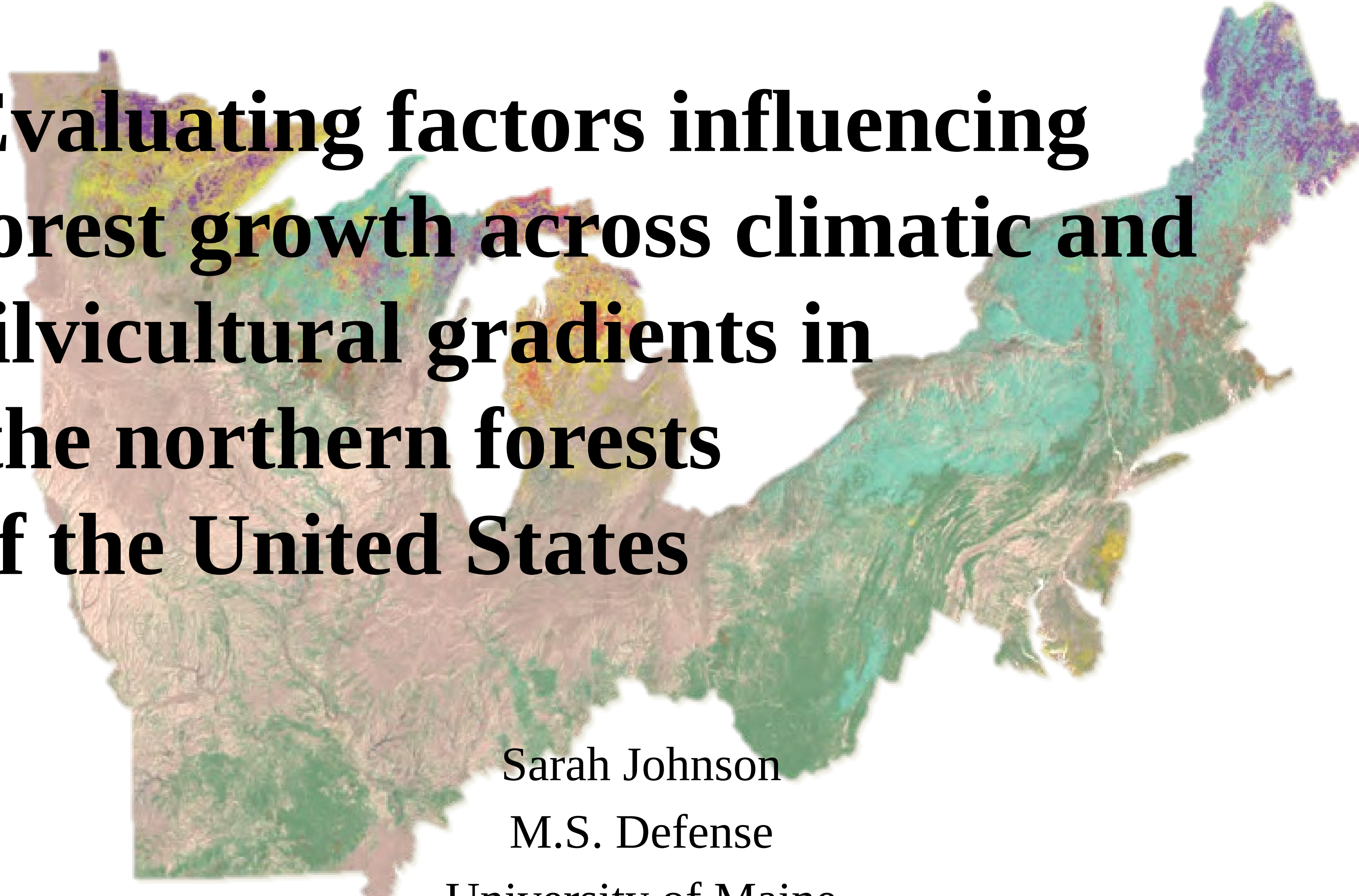

Evaluating factors influencing forest growth across climatic and silvicultural gradients in the northern forests of the United States

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M.S. Defense

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August 2 2012

Forest Growth & Yield

- Foundation of forest management
  - Many assumptions
  - Confounding factors
  - Multiple metrics
- Complex systems
  - Highly dynamic
  - Limited scope of inference
  - Differing spatial and temporal gradients
- Long-term growth and yield data is invaluable, but relatively rare

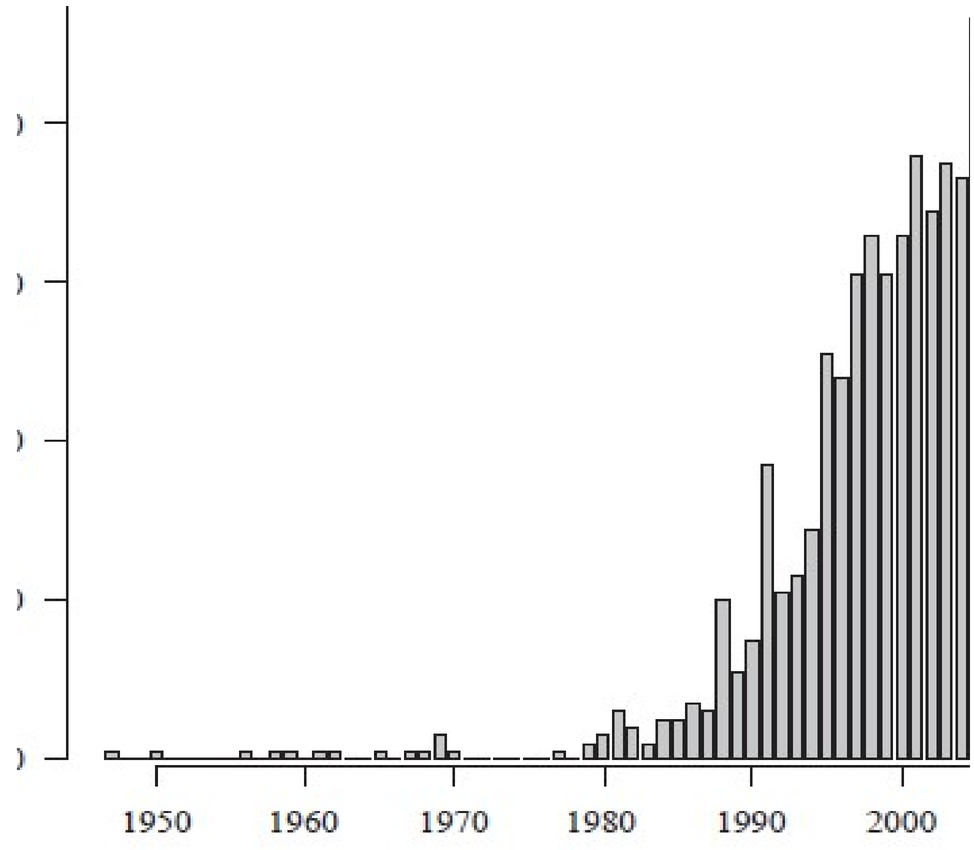
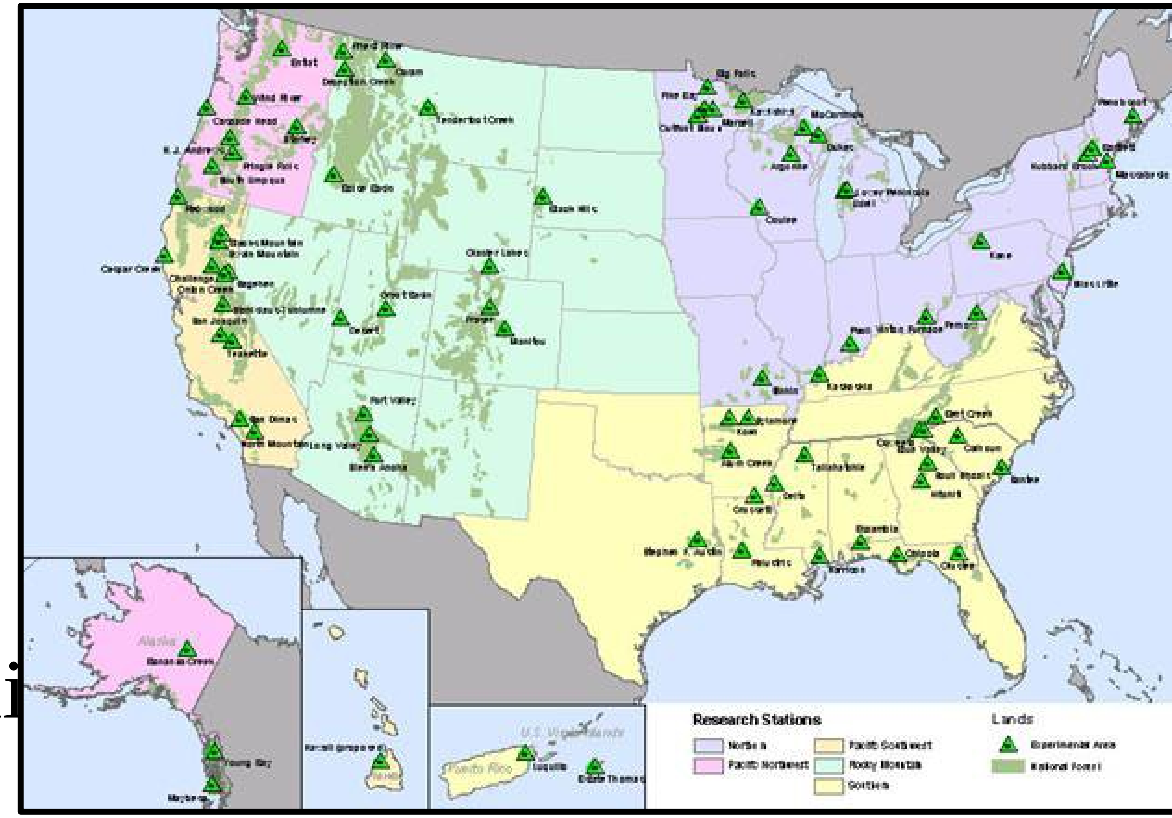


Figure 1.1. Number of publications on growth and yield, by publication year, based on a keyword search the CAB Direct Database(www.cabdirect.org, accessed December 21, 2010).

Weiskittel et al. 2011. *Forest Growth and Yield Modeling*. Wiley. p. 415

Silvicultural Research

- Long-term and large-scale
- Open-ended questions
- Unique opportuni
- Diverse challenges



MS Context

Can we use historical silvicultural experiments to better understand variability of growth across regional scales and multiple gradients?

How?

Challenges?

Opportunities?

Importance?

Project Significance

- Multiple gradients present & influential in NE
  - First effort to compare net growth of EFRs across multiple gradients
  - 80 years of ind. tree-level net growth to study
  - Increase accessibility and highlight importance of these LT studies
  - Explain local variation in silvicultural outcome based on multiple factors

Thesis Goals

- Increase scientific collaboration within NE

- Use historical data for silvicultural synthesis
  - What is needed?
  - What is available?
  - Does silvicultural outcome vary across NE?

Research Questions

- How can we reuse previously collected data from complex historical studies?
- What are minimum data requirements?
- What can we do in future to better store and utilize these data?
- What types of comparison can we make with these data?

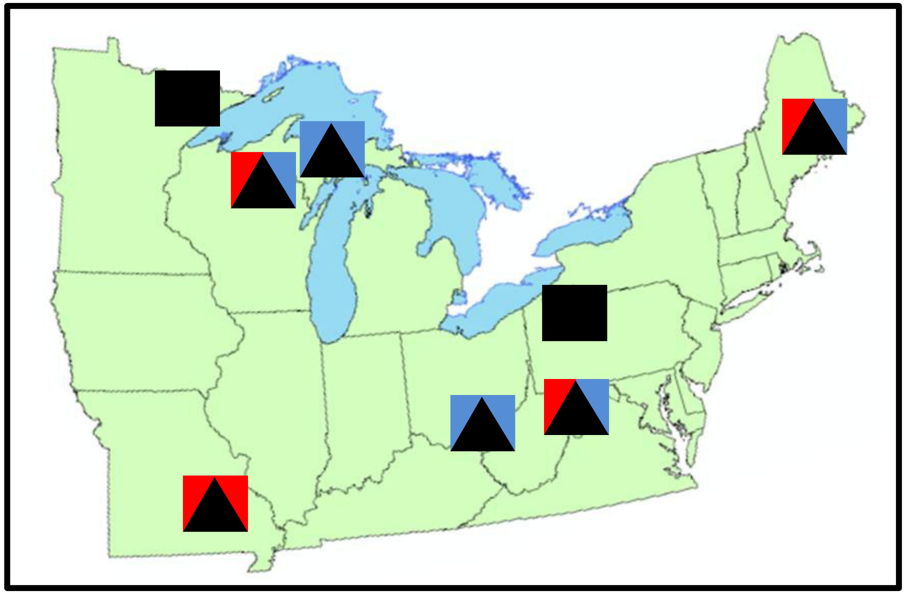
Objectives

- Increase data quality and accessibility with creation of relational database
  - Provide simple guidelines for future standardization of silvicultural data

- Contrast stand-level growth rates across long-term silvicultural studies
  - Showcase the importance of cataloguing long-term forest growth records

Forest Data

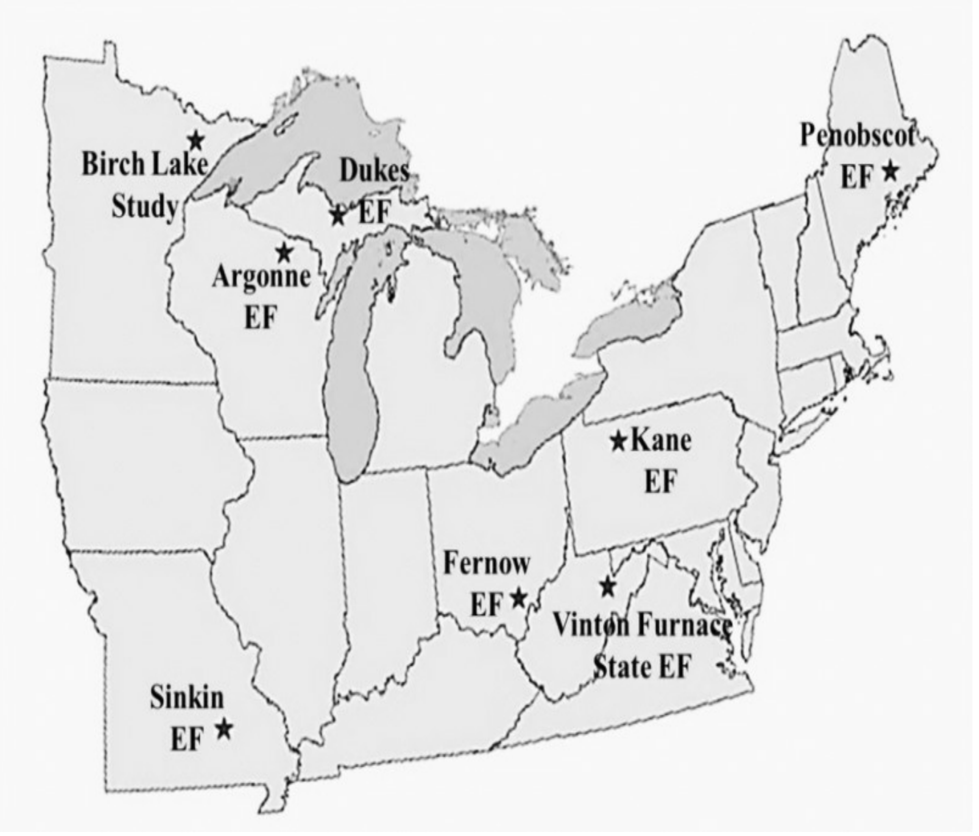
- 8 long-term experiments
- 28 unique treatments
  - Control
  - EA
  - UEA
- Multiple data formats
  - Aggregated vs. individual
  - txt, xls, dat, accbd
  - Long vs. wide



Long-term Data

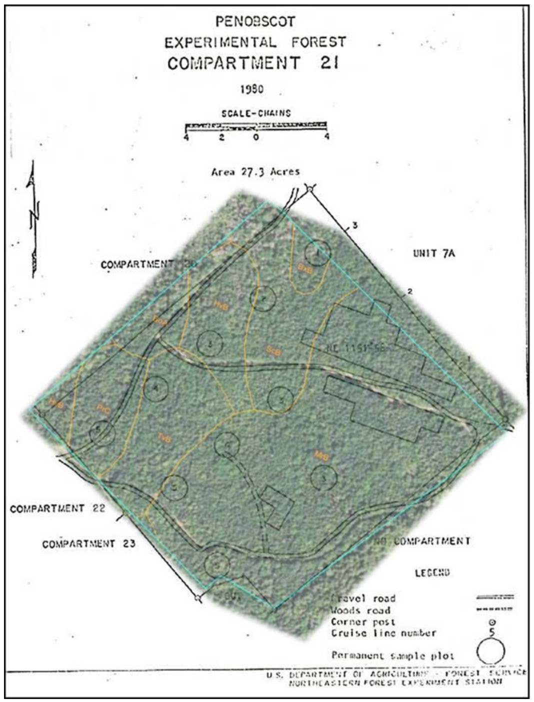
- All plot- and tree-level data previously collected
  - 1927 – 2010

- 3 categories and sources
  - Forest growth data:
    - USFS NRS
  - Soils data:
    - NRCS soil surveys
  - Climatic data:
    - PRISM Climate Group (OSU)



Soil Data

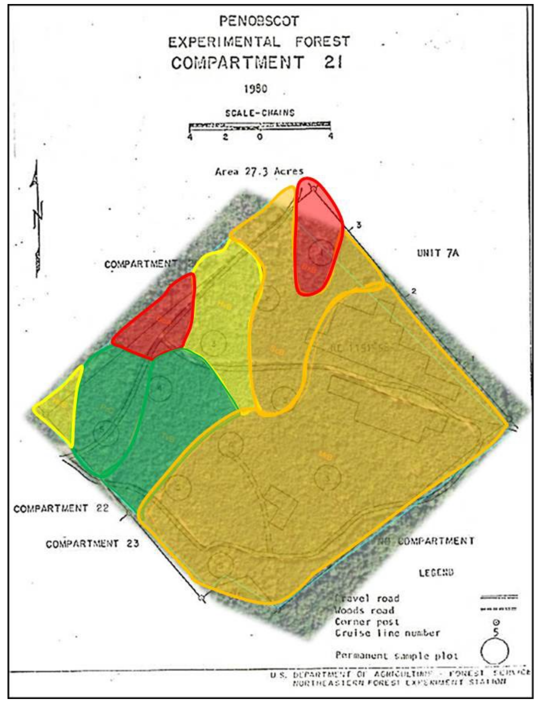
Type



USDA United States Department of Agriculture

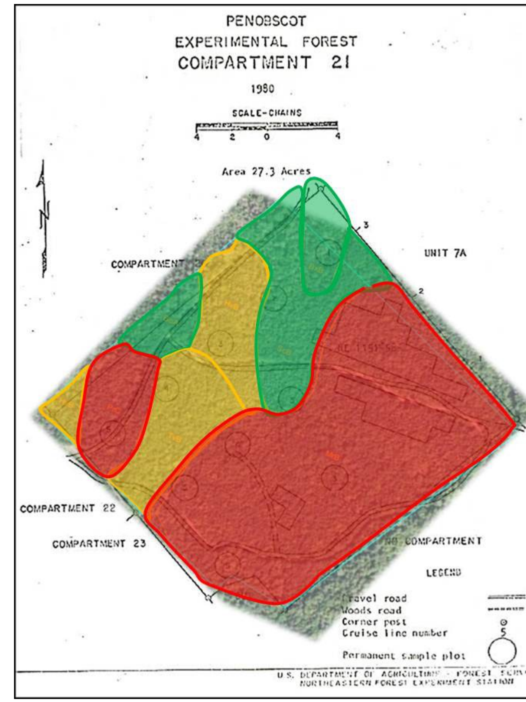
NRCS Natural Resources Conservation Service

Drainage



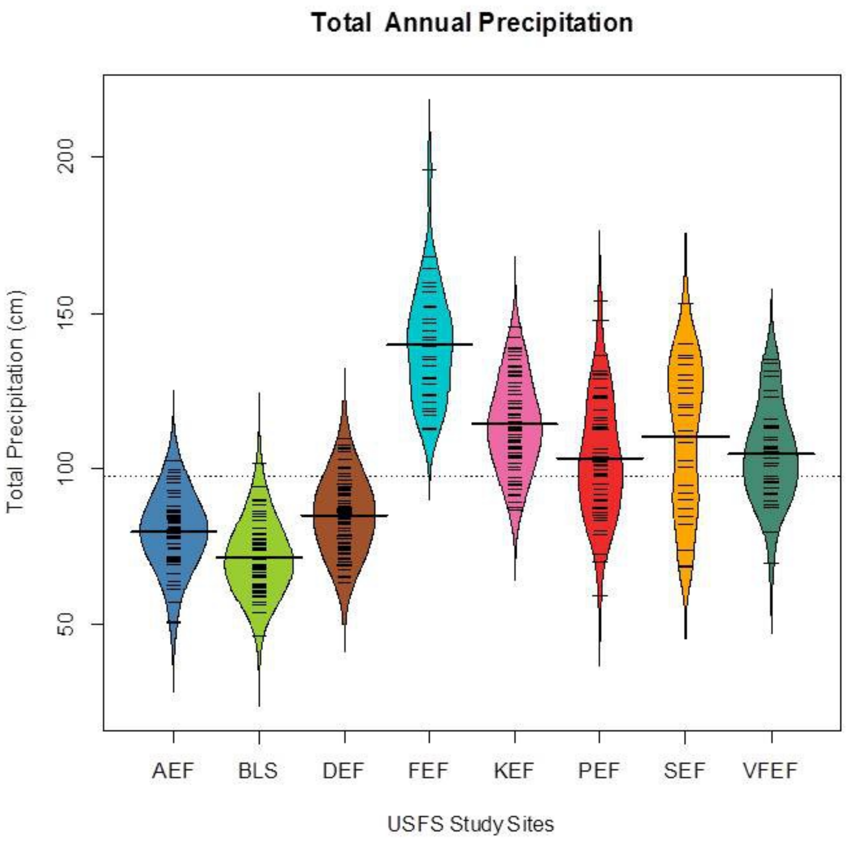
- Very Poorly Drained
- Poorly Drained
- Moderately Well Drained
- Well Drained
- Very Well Drained

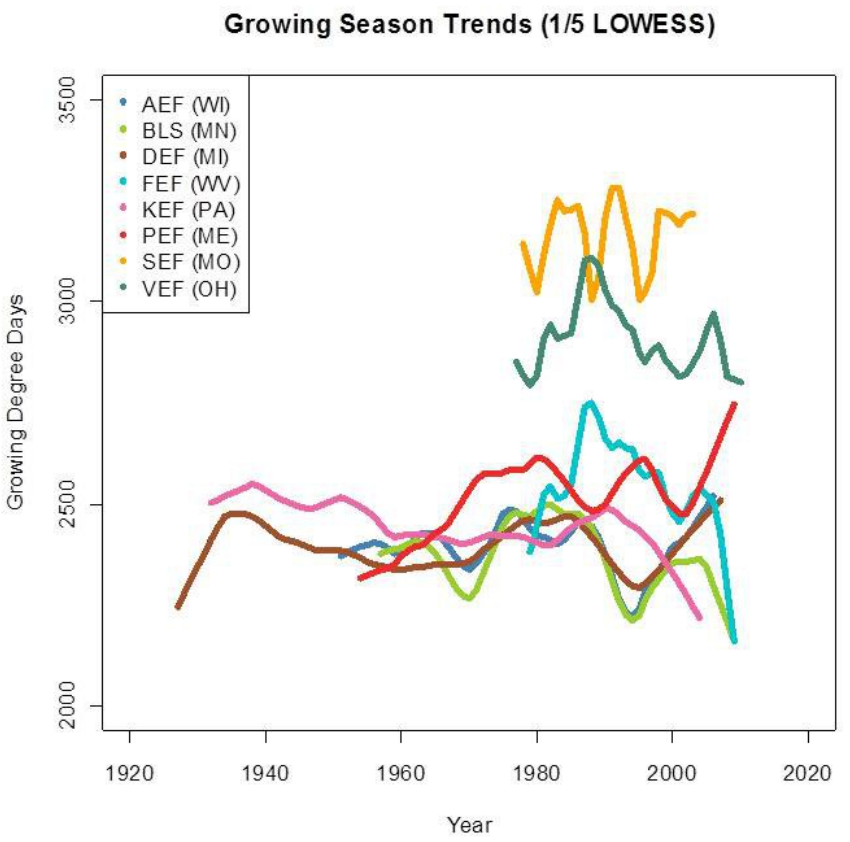
WHC



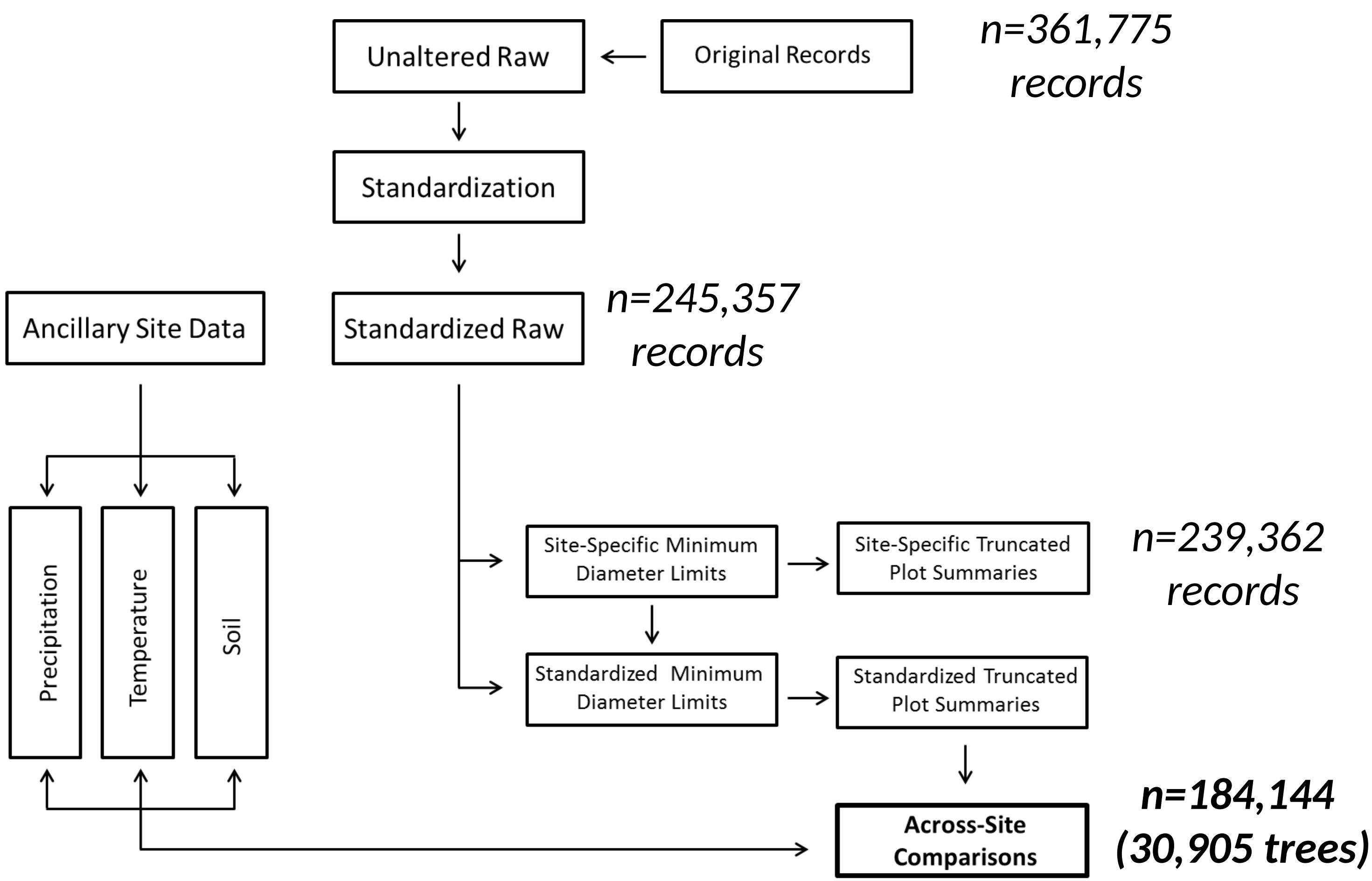
- Very Low
- Low
- Moderate
- High
- Very High

Climatic Data





Methodology



Relational Database

Site

- Precipitation
- Temperature
- Geological attributes

Replicate

- Soil attributes
- Time since study initiation

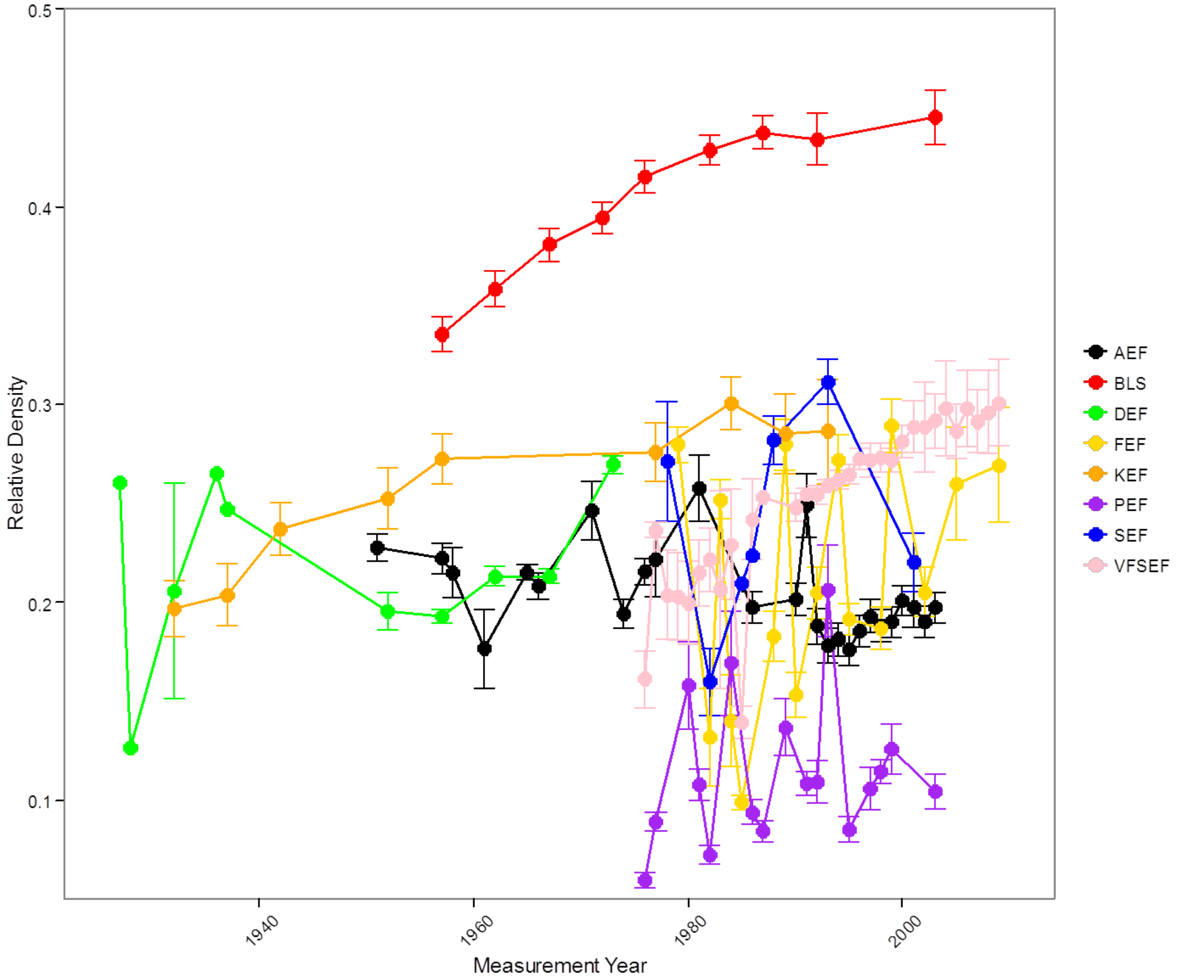
Plot

- Treatment type
- Time since stand entry
- Summarized stand attributes
- Plot size

Tree

- Tree number
- Species
- Diameter
- Status code
- Additional notes

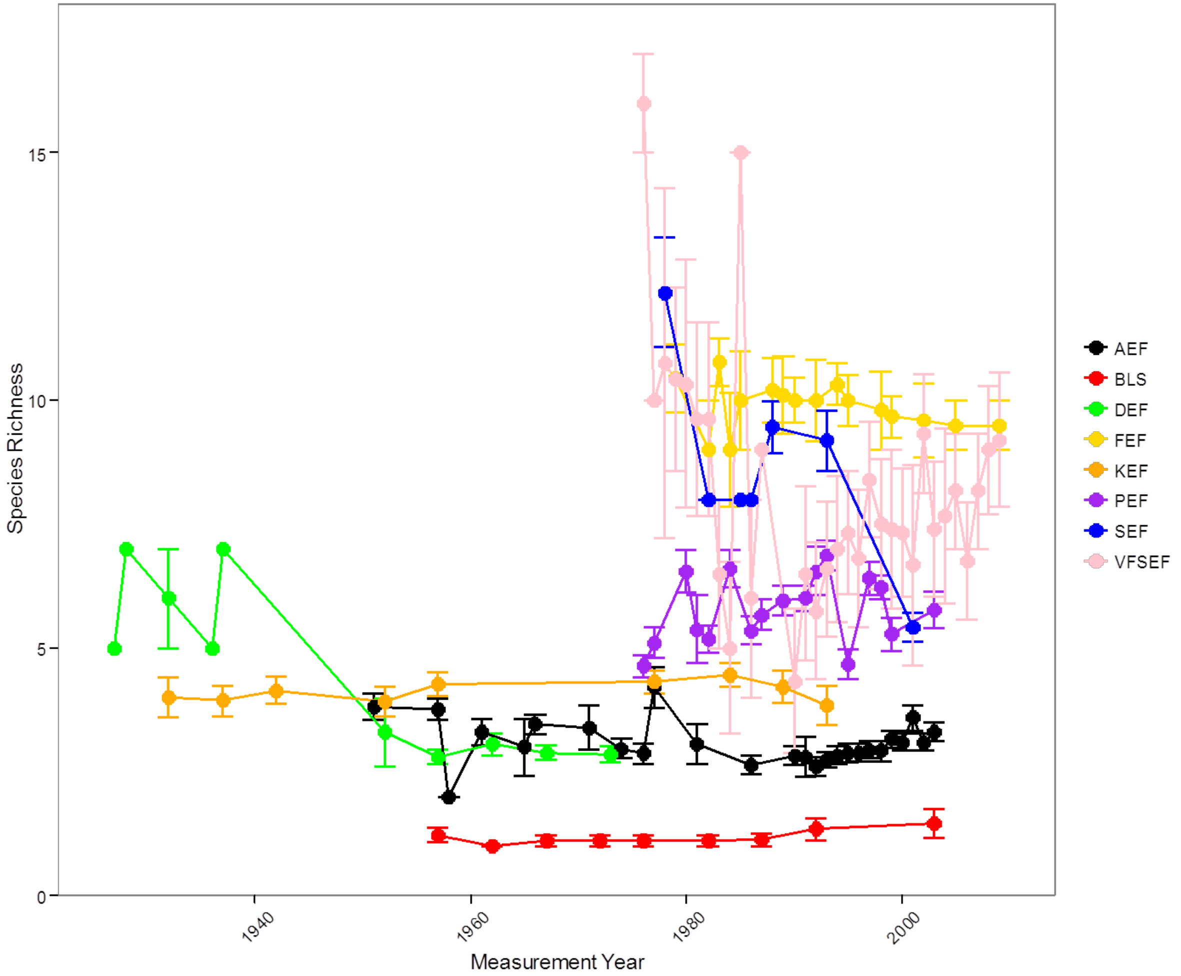
Initial Trends – Relative Density



Regional RD = 0.20 ± 0.001

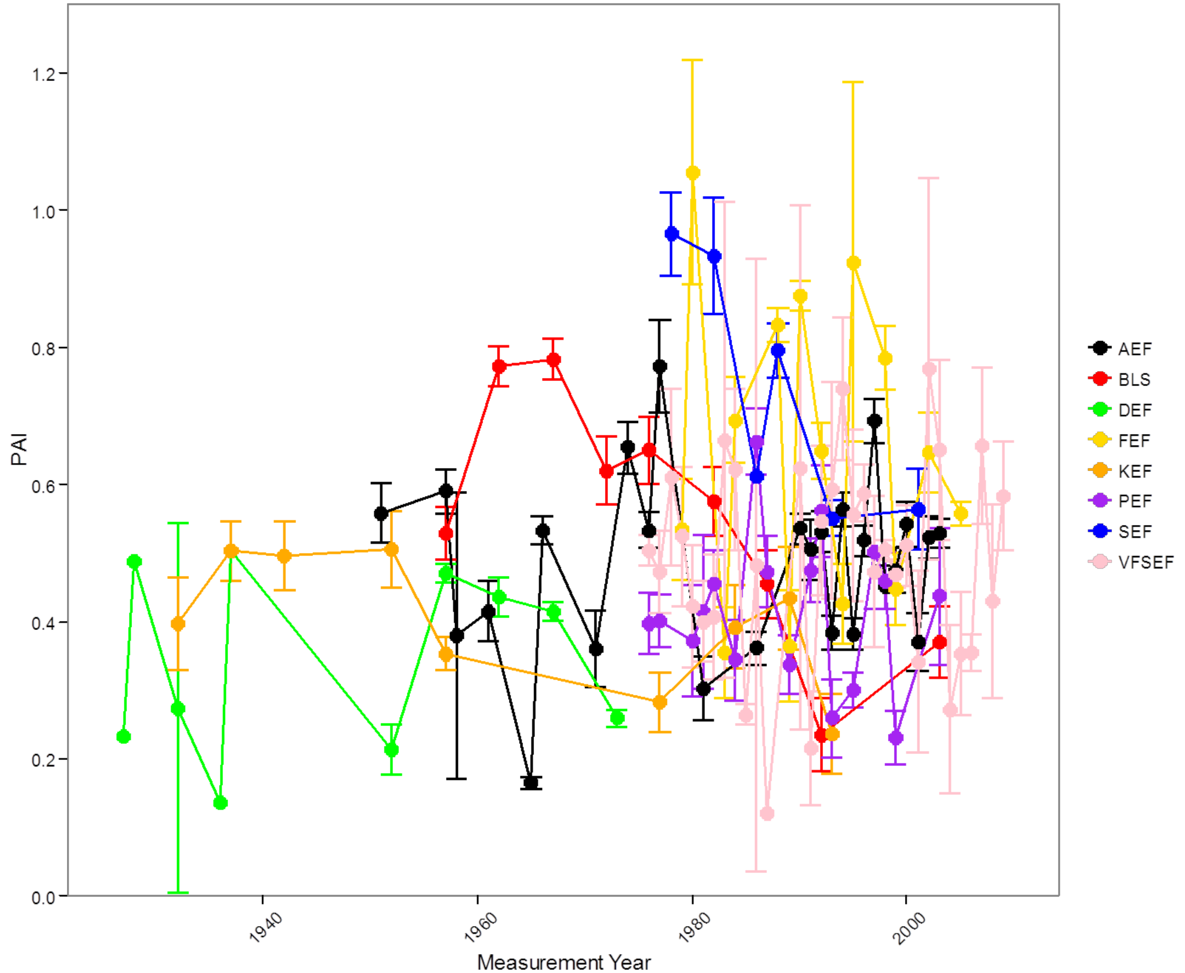
(using additive SDI and specific gravity)

Initial Trends – Species Richness



Regional Richness= 4.02 ± 0.05

Initial Trends – Growth Rates



Regional PAI = 0.48 ± 0.25 m2ha-1yr-1

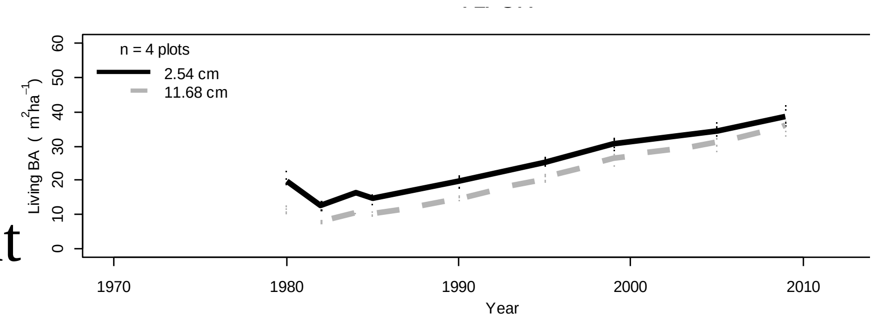
(2.09 ± 1.09 ft2ac-1yr-1)

Argonne

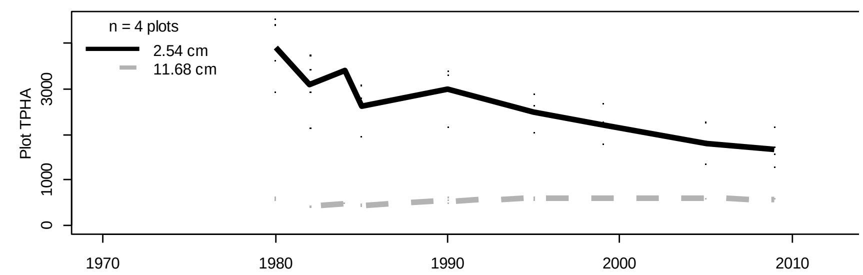
Penobscot

Limitations

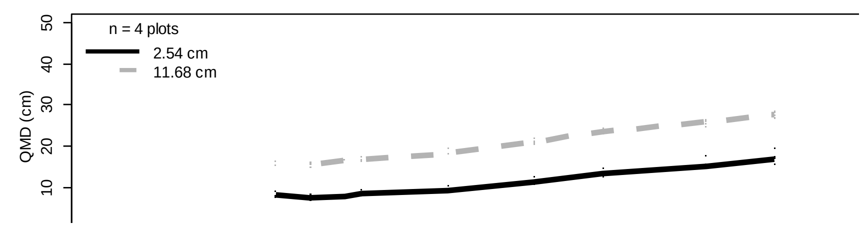
- Volume
  - Not all site had tree height measurements



- Inherent species differences
  - 72 species present



- Understory dynamics
  - Diameter truncations



Challenges

- Scientist general aversion to data sharing

- Data accessibility

- Clear, effective communication of complex experiments

Looking Forward

Increasing ease of collaboration

- Know what types of data are available at your site
- Identify missing information or unclear records that can be immediately fixed
- Prepare documents that are associated with silvicultural experiment
- Begin metadata compilation
- Design data use policies

LT Data Opportunities

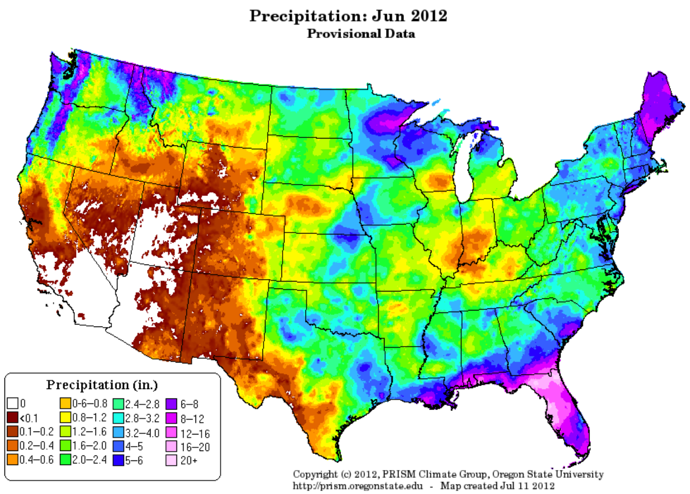
- Increase record robustness by compiling descriptive data
- Increase the strength of data storage by begging metadata
- Standardize raw data as part of metadata compilation
- Continue to use database for future comparisons
- Flexible multi-scale analysis with future collaboration

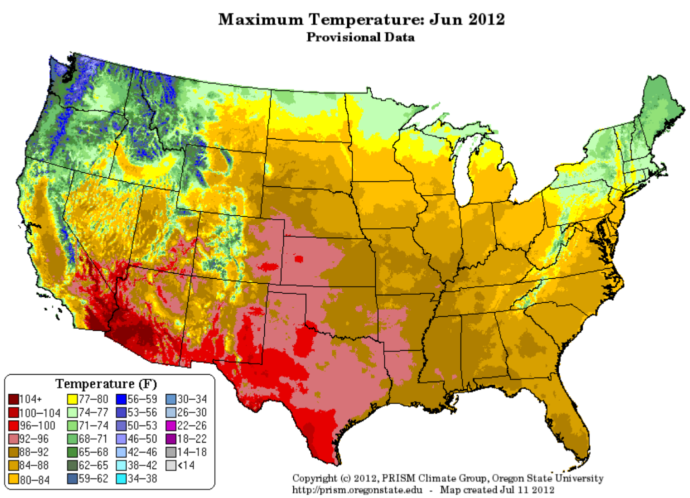
Summary

- Data standardization can facilitate large-scale comparisons of silvicultural studies
- Additional site-level data management needed
- Database is a flexible approach to increase future use of standardized silvicultural data records

Research Questions

- What is influencing NE forest growth?
- Which factors are most important?
- Are there differences across multiple gradients?
  - Climatic gradients?
  - Silvicultural gradients?
  - Other gradients?

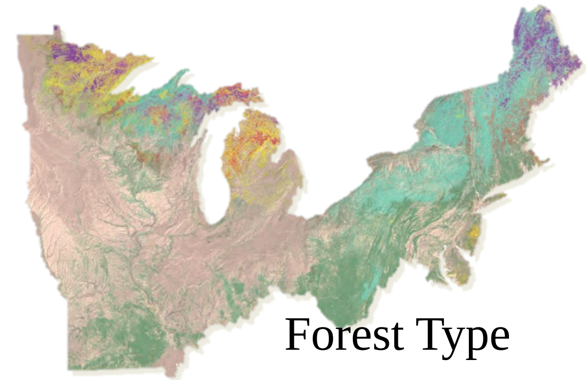


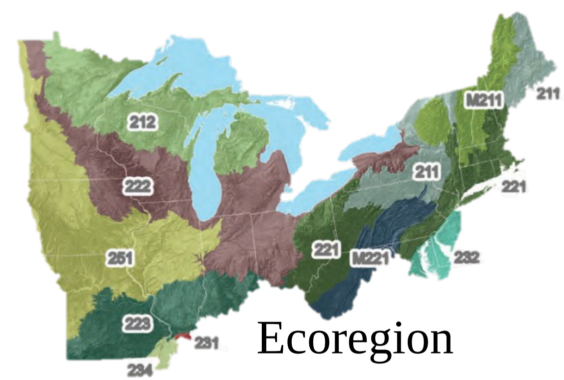


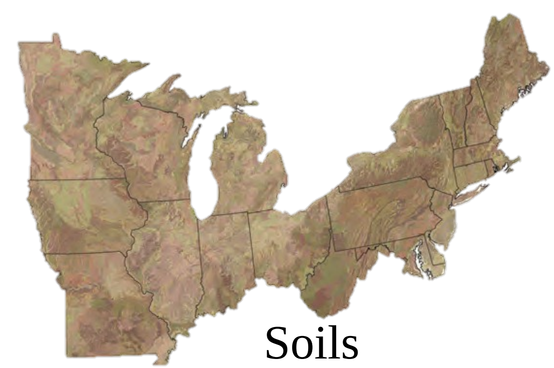
Goals

- Use standardized data for large scale comparisons

- Better understand influential factor variability associated multiple gradients







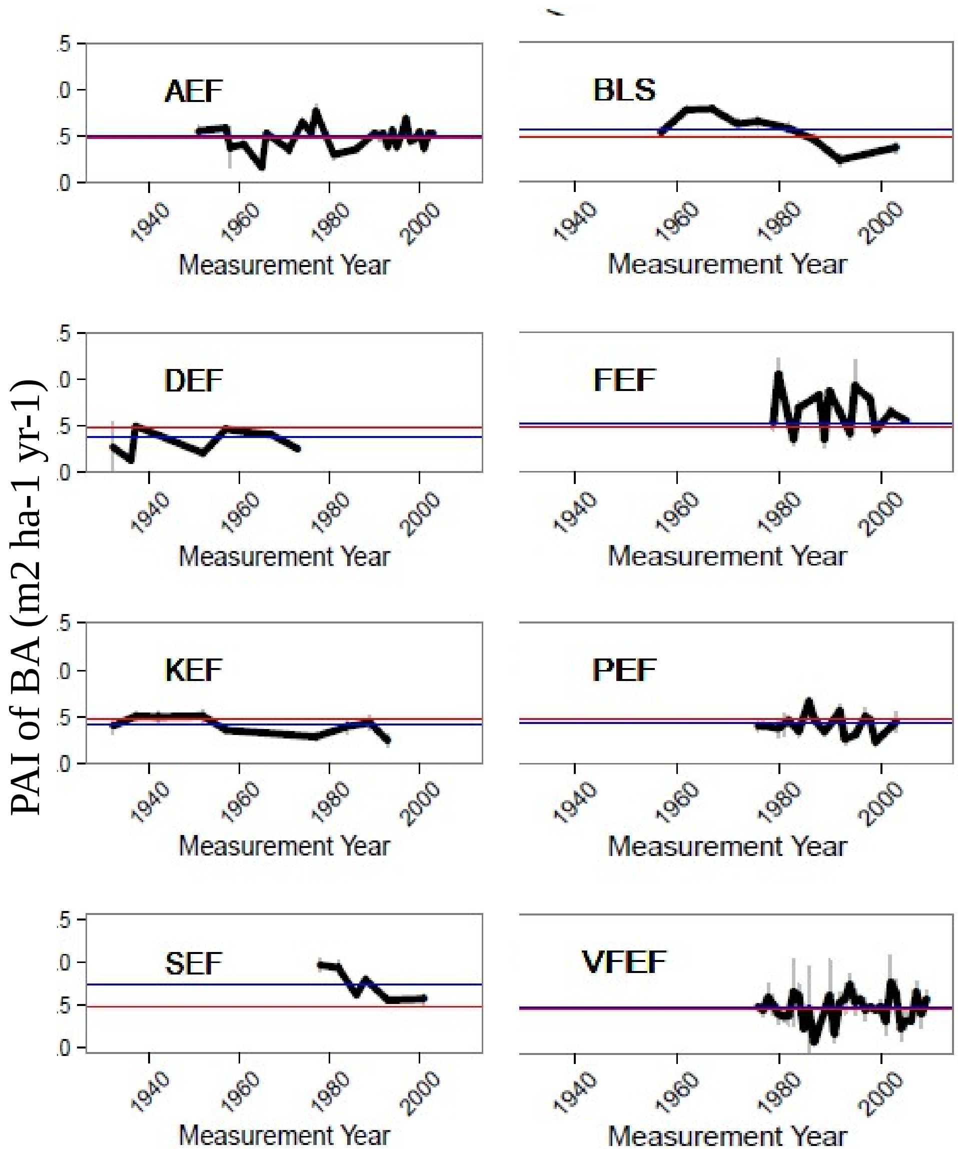
Shifley et al. 2011. *Forests of the Northern United States*. NRS GTR-90. USDA Forest Service. p 218.

Objectives

- Highlight general trends and variability of stand-level basal area periodic annual increment
- Identify the relative ranking of factors influencing growth
- Explore the influence of specific factors on stand growth response

Data Synthesis

- Site data
  - Soils
    - Depth
    - Drainage
  - Parent Material
- Interval data
  - PAI (ba)
  - Climatic
    - Temperature
    - Precipitation
  - Stand characteristics
    - Composition
    - Size

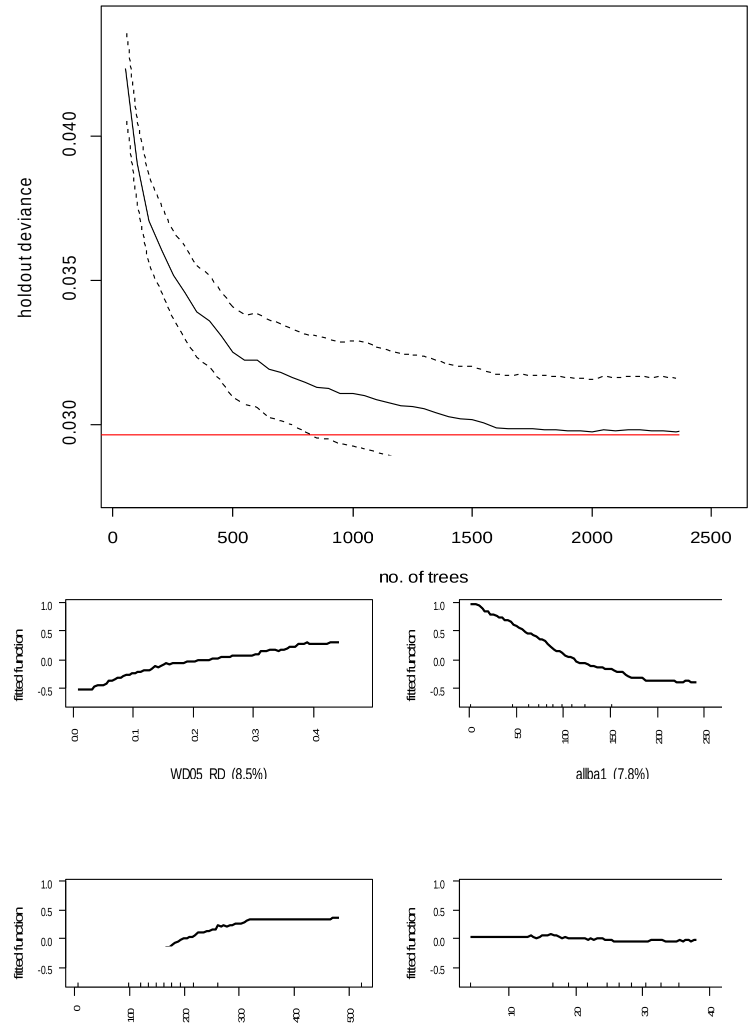


Statistical Approaches

Method	Advantages	Disadvantages
Linear models	-Simple approach -Easy to interpret	-Not appropriate for complex ecological relationships -Required assumptions
Additive Models	-Flexible functional forms -Good for complex relationships	-May be difficult to interpret -Complicated to fit
Mixed-effect models	-Account for data hierarchy -Linear or nonlinear -Repeated measures	-Assumptions of data importance and relationships across area
Meta-analysis	-Multiple large scale comparisons	-Multiple biases -Low transparency
Regression Trees	-No assumptions on data structure required -Multiple data types	-Low level of prediction strength -May be difficult to interpret
Boosted Regression Trees	- 2 ML techniques to increase prediction strength of RT -Iterative model fitting (CV) -Automatically model interactions	-Sensitive to data inputs -Model structure -May be difficult to interpret standard fit statistics

Boosted Regression Trees

- Regression Trees
  - Multiple data formats
  - Partitions data
- Boosting
  - Several iterations
  - Cross-validated
- Output
  - Influential factors
  - Relative ranking
  - Observed relationship



Model Covariates

Soils

Composition

Diameter

Silviculture

Density*

Climate

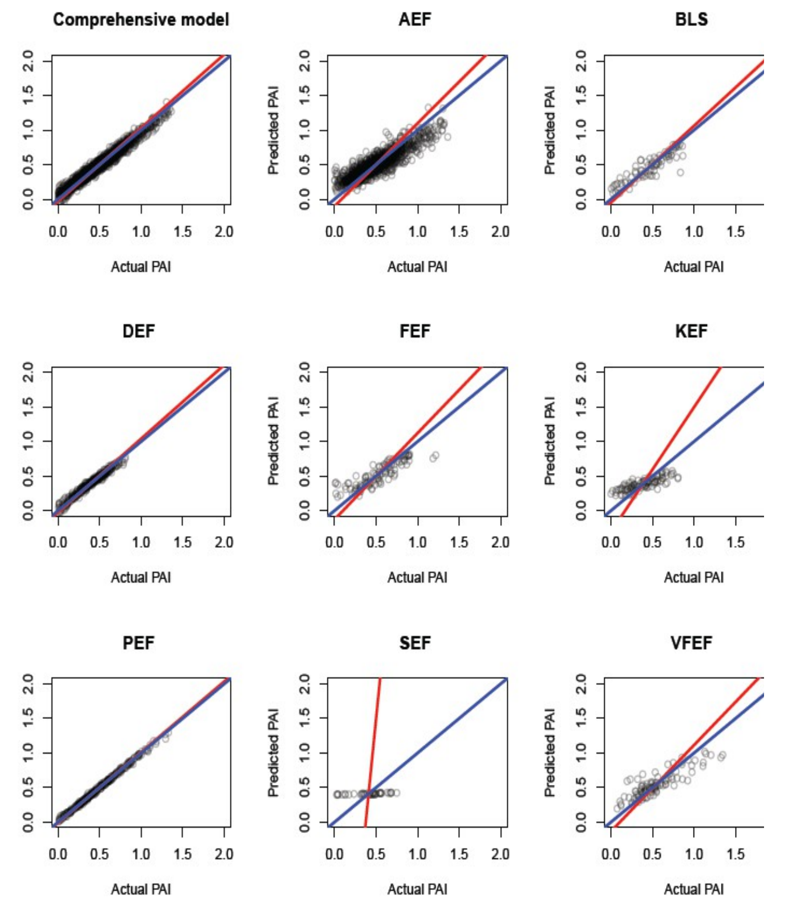
Diversity

*maximum RD based on Woodall et al. 2005

Models

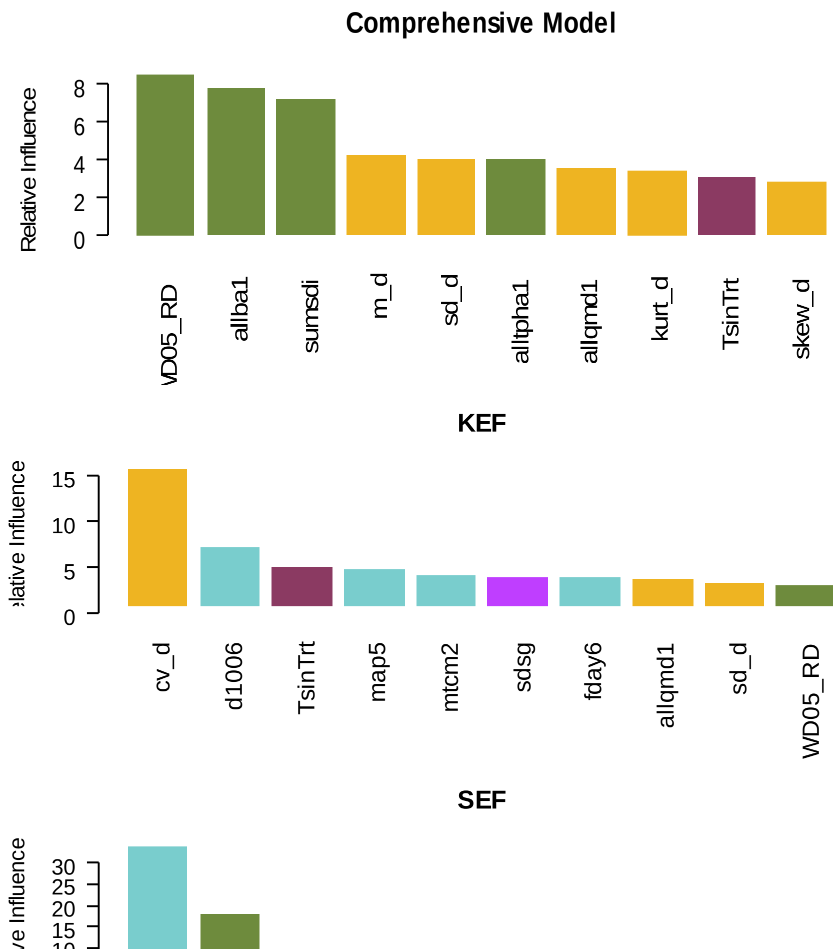
- Good fit for regional model
  - 3-way interactions
- Variable fits for site models
  - Small sample sizes

del	Data	TC	LR	Optimal trees	No. Obs.	R^2	*RMSE*	*Mean Abs. Bias*	*Mean % Bias*
]	All	4	0.10	2650	2613	0.98	0.04	0.03	6.61
]	All	4	0.05	5200	2613	0.97	0.05	0.04	7.70
]	All	3	0.10	3900	2613	0.96	0.05	0.04	8.16
]	All	3	0.05	5800	2613	0.95	0.06	0.05	9.76
]	AEF	4	0.01	3750	1417	0.79	0.12	0.09	18.25
]	BLS	4	0.01	350	80	0.79	0.11	0.08	18.11
]	DEF	4	0.01	3650	424	0.97	0.03	0.03	6.47
]	FEF	4	0.01	500	107	0.78	0.12	0.09	17.43
]	KEF	4	0.001	1450	105	0.65	0.14	0.11	29.03
)]	PEF	4	0.01	5500	334	0.99	0.02	0.02	3.14
]	SEF	4	0.0001	3100	45	0.53	0.17	0.13	32.62
2]	VFSEF	4	0.001	3450	101	0.74	0.15	0.11	19.60

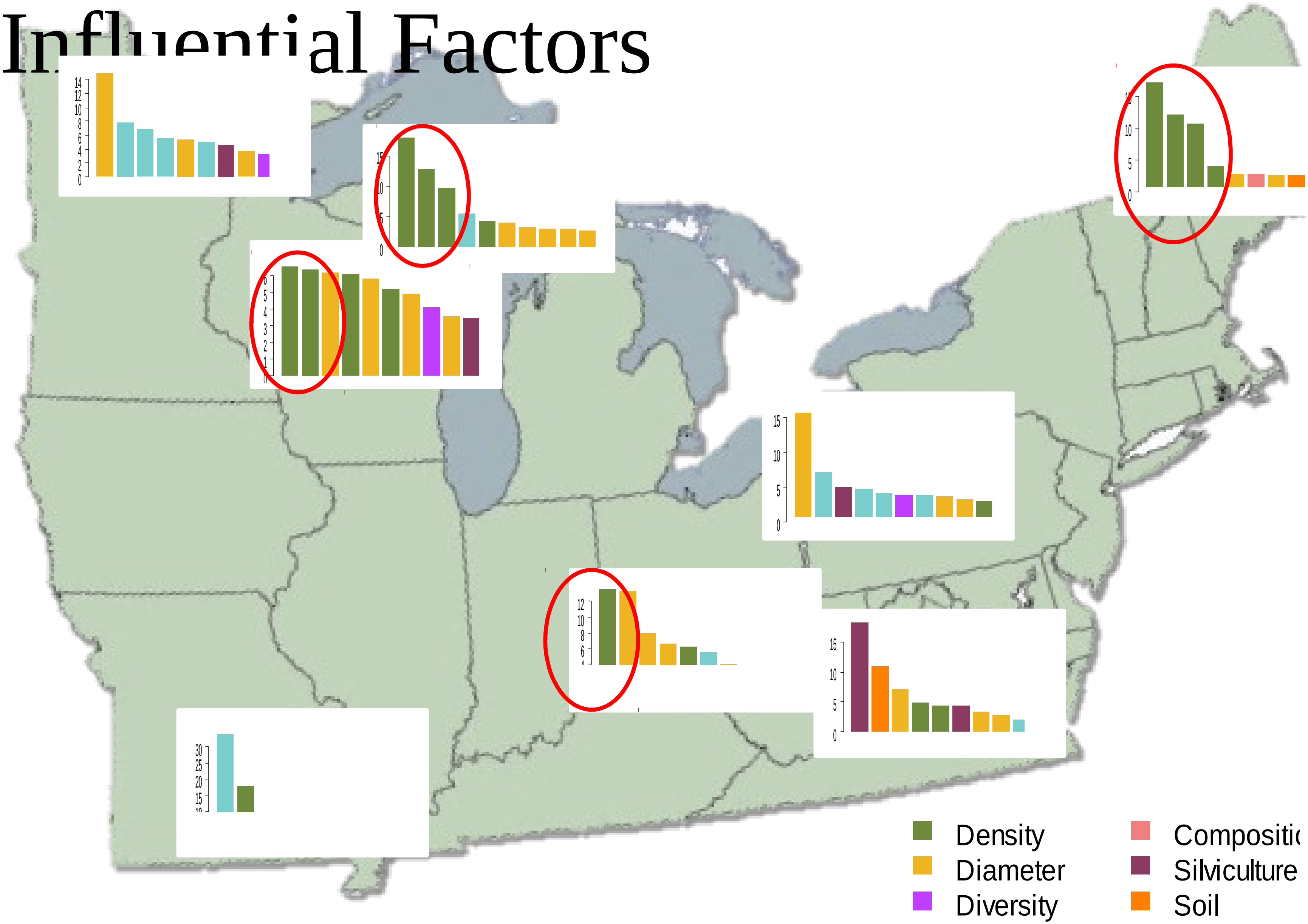


Influential Factors

- Comprehensive model
  - Density and diameter most influential
- Site models
  - Mixed species RD
  - Climate
    - Variable influential factors



Influential Factors



Influential Factors

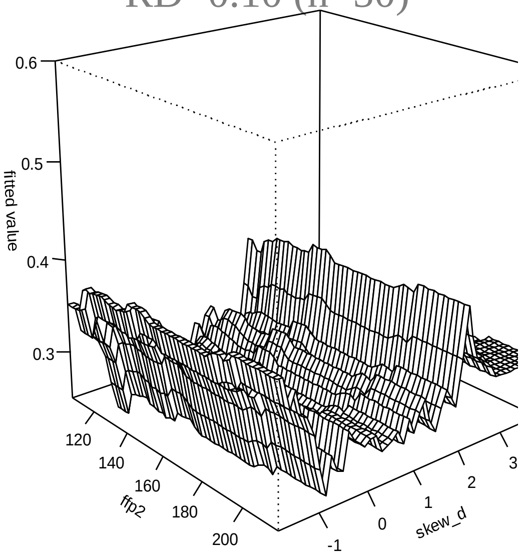
Regional Model

Site Models

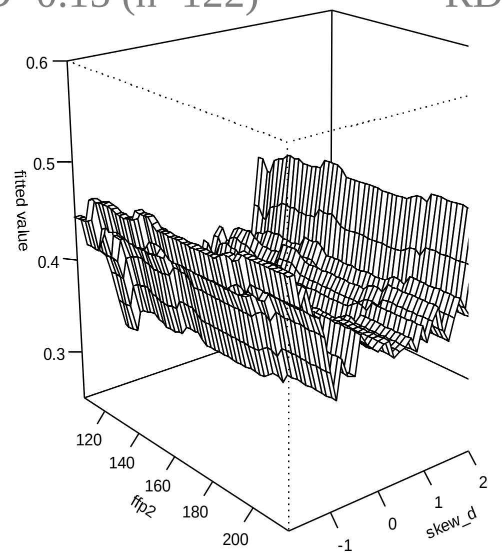
Rank	Relative Influence	Variable Name	AEF	BLS	DEF	FEF	KEF	PEF	SEF	VFSEF
1	8.46	WD05_RD*	6.07 (4)	-	9.73 (3)	1.57 (15)	3.14 (10)	16.96 (1)	18.11 (1)	0.50 (39)
2	7.84	allba1	6.4 (2)	0.74 (29)	17.74 (1)	4.41 (5)	1.53 (23)	12.17 (2)	0.10 (36)	6.33 (5)
3	7.27	addSDI	6.53 (1)	0.75 (28)	12.77 (2)	1.01 (24)	2.19 (14)	10.78 (3)	6.98 (2)	2.72 (10)
4	4.31	m_d	4.92 (7)	3.68 (8)	2.77 (12)	1.62 (14)	2.92 (11)	1.75 (17)	0.30 (28)	0.51 (38)
5	4	sd_d	5.86 (5)	0.91 (22)	2.92 (8)	3.21 (7)	3.22 (9)	2.93 (5)	2.69 (6)	13.44 (2)

Climate x Stand x Growth

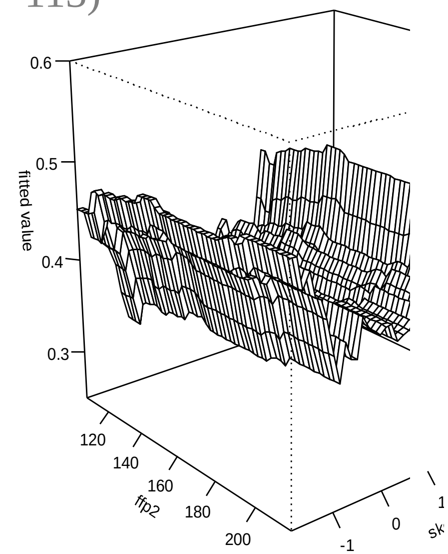
RD=0.10 (n=50)



RD=0.15 (n=122)

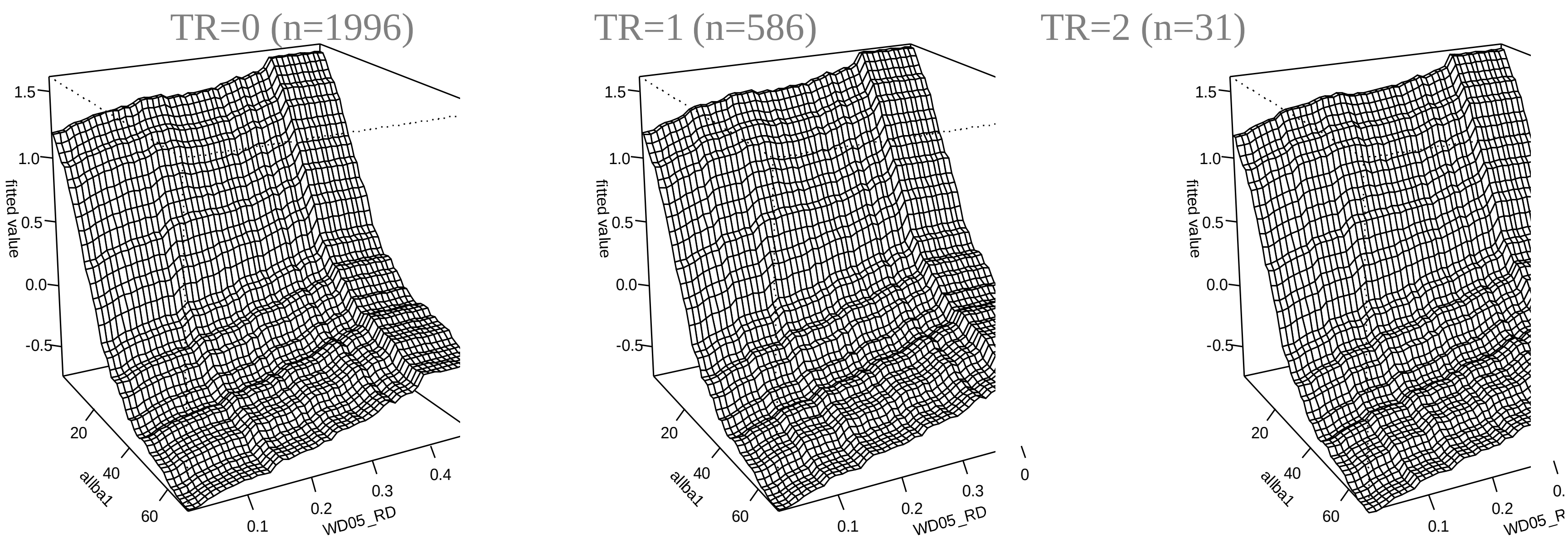


RD=0.20 (n=113)



Three-way interactions across multiple gradients present

Stand x Stand x Growth



Not all factors exhibit complex interactions at regional level

Future Implications?

- Climate predictions1
  - More precipitation in NE
  - Longer growing seasons
  - Changes in productivity

?

?

Regional Model			Site Models							
Rank	Relative Influence	Variable Name	AEF	BLS	DEF	FEF	KEF	PEF	SEF	VFSEF
1	8.46	WD05_RD*	6.07 (4)	-	9.73 (3)	1.57 (15)	3.14 (10)	16.96 (1)	18.11 (1)	0.50 (39)
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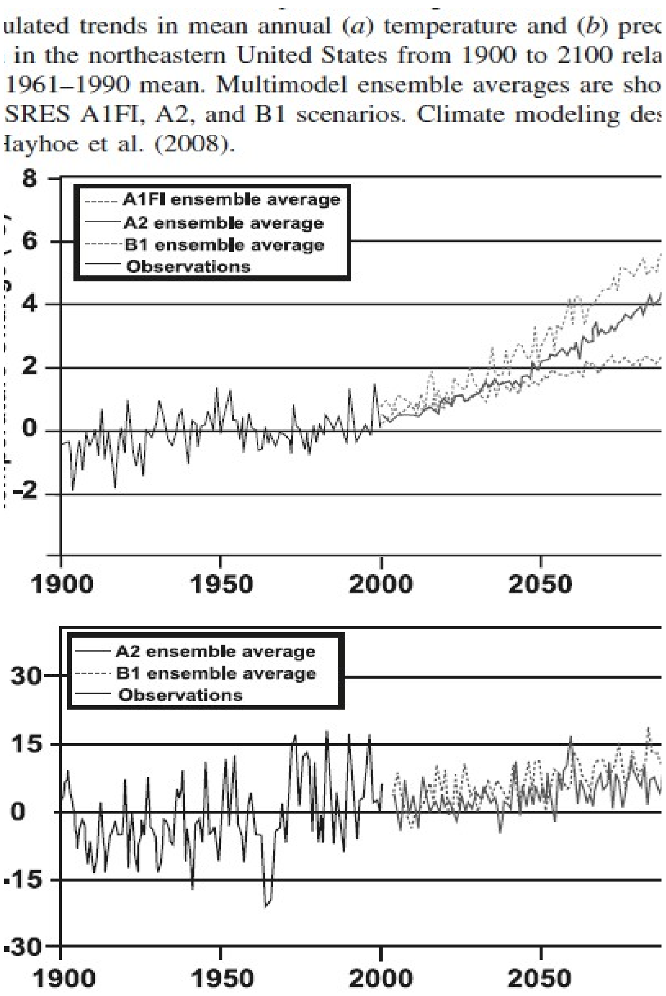
5	4	sd_d	5.86 (5)	0.91 (22)	2.92 (8)	3.21 (7)	3.22 (9)	2.93 (5)	2.69 (6)	13.44 (2)
6	4	alltpha1	5.18 (6)	-	4.32 (5)	4.75 (4)	2.79 (12)	3.96 (4)	0.23 (31)	13.50 (1)
7	3.58	[illegible]	6.21	2.59	2.88	2.06	3.75	2.20	0.68	6.57

1Rustad et al. 2012 *Changing Climate, Changing Forests: The impact of climate change on forest of the northeastern United States and Eastern Canada*

Climate Influencing Growth

- Precipitation
  - DEF, FEF
- Temperature
  - BLS, VFSEF
- Both
  - KEF, SEF
- Neither*
  - Region
  - AEF, PEF
- Importance of short-term weather events?



* In ten- most influential factors

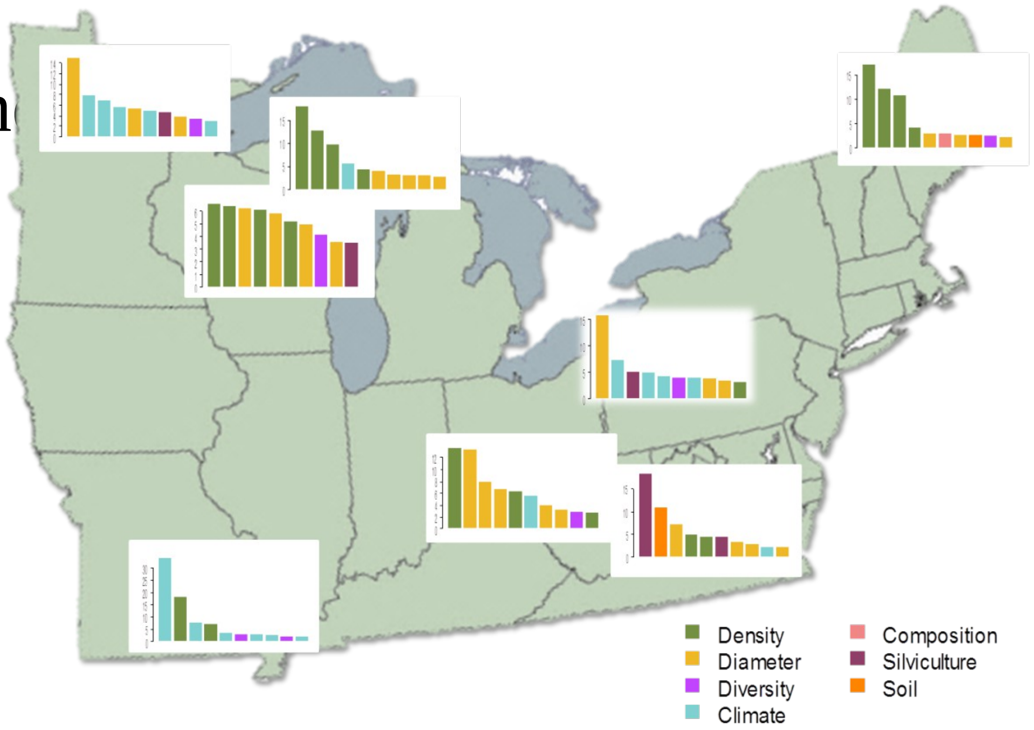
Huntington et al. 2009. *Climate and hydrological changes in the northeastern United States: r recent trends and implications for forested and aquatic ecosystems.* CJRF

Limitations

- Nonparametric results are dependent on the size, quality, and scope
- Measures of time used in the analysis may not be ecologically important
  - Unknown stand histories
- Confounding of silviculture and stand structural attributes
  - Direct vs. indirect results of silviculture

Influential Factors Summary

- Local and regional trends vary
  - Climatic factors
  - Interactions
- Multiple gradients influential in NE
- Additional study is required



Regional model

Synthesis Conclusions

- BRT are one possible framework for large scale synthesis
  - Provide influential factor tabulations
  - Dependent on data inputs

- Future additions possible
  - Treatment comparisons
  - Temporal comparisons

Overall Conclusions

Current needs for data management and record archival are high

Large scale conclusions can be drawn from raw data using independent analyses

LT data can be flexible tool for future analyses

Future Efforts

- Additional sites
- Additional data
- Additional responses
  - DWD
  - Tree recruitment
  - Mortality
  - Volume accretion
  - Carbon storage

Acknowledgements

Funding provided by NRS internal funding and additional USFS funding sources