Site Type Initiative:
Rock Type, Topographic and Climate Effects on Maximum Stand Density Index (SDI max)

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IFTNC Site Type Initiative (STI)

- Designed to:
  - Identify site factors driving carrying capacity and optimal productivity
  - Develop models to estimate site quality based on these factors
  - Create regional, geospatial tools that predict site quality

STI Phase I

- Developed a database of IFTNC member forest stand cruise and permanent plot growth data
- Database was merged with geospatial representation of physiography, climate, soils and geology

STI Phase I:

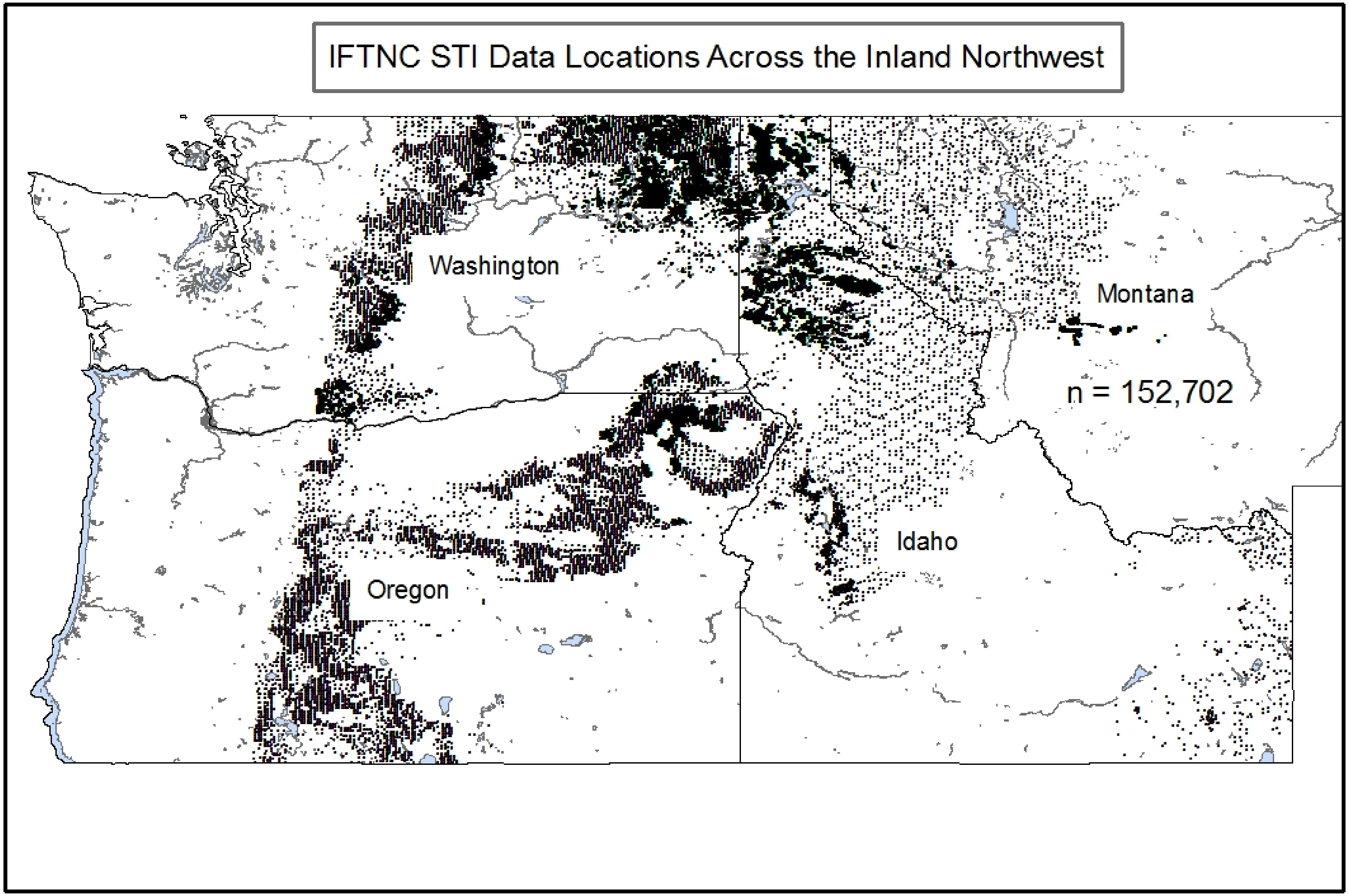
Current work

- Database is being use to identify the drivers of site quality and define site-type classes throughout the Inland Northwest
- Principal components:
  - Light
  - Moisture
  - Temperature
  - Nutrients

Objective of Present Study

- Identify the effects of Soil parent material (Rock type), Topography and Climate variables on Reineke’s (1933) Maximum Stand Density Index (SDI max)

The Settings: Inland Northwest



IFTNC- STI Dataset

- + 150,000 plots
- ~ 4,000,000 individual tree data
- 28 species
- ~ 100 variables: stand and tree level variables, climate, topography, soil parent material characteristics
- And more to come: repeated measures and longitudinal data

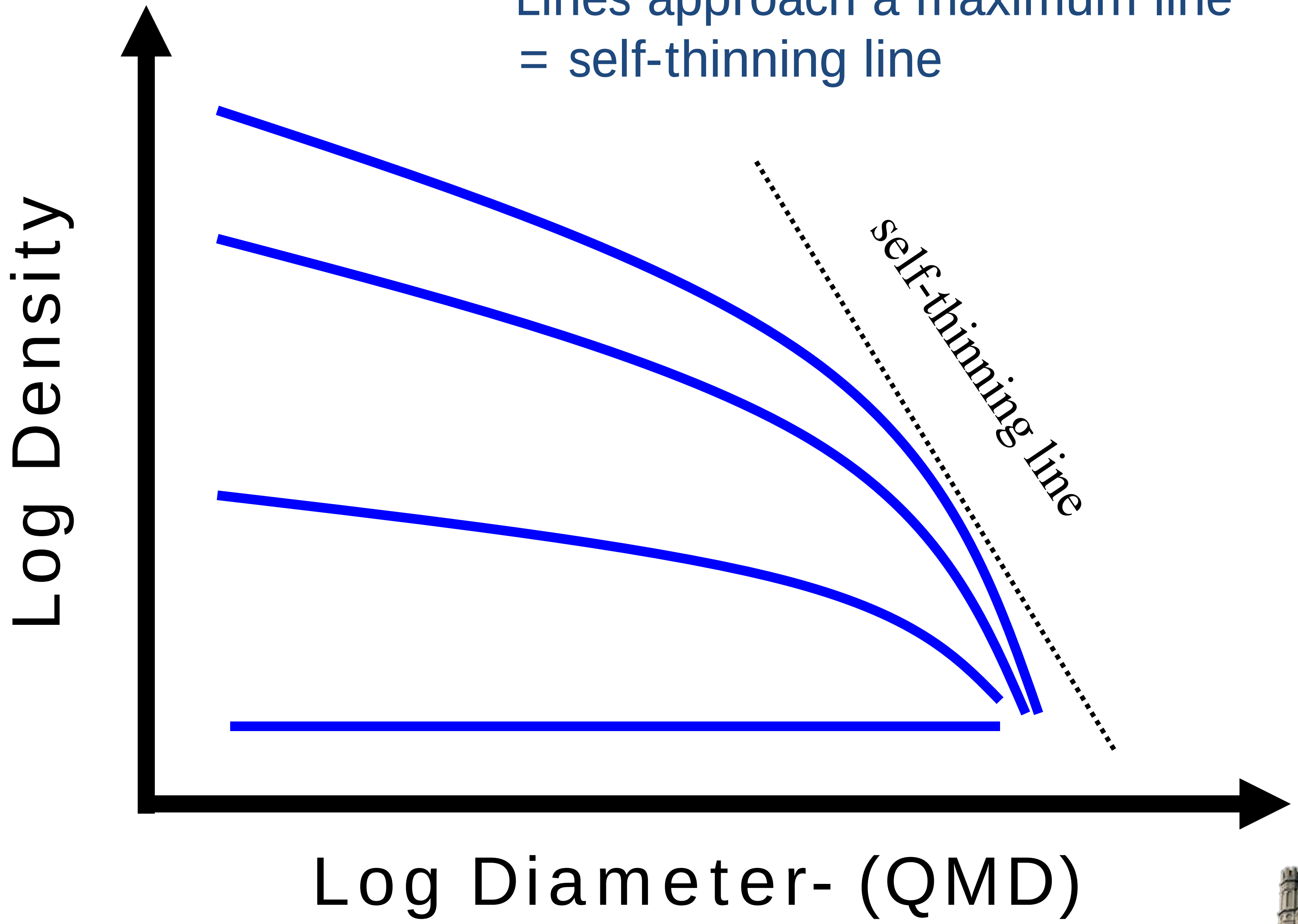
Background: Self-Thinning Line and Reineke’s SDI Max

- In the words of Boris Zeide (2005), Reineke’s stand density index “may be the most significant American contribution to forest science”
- Populations of trees growing at high densities are subject to self-thinning (density-dependent mortality)

Background: Self-Thinning Line and Reineke's Max SDI

- Reineke's Equation - for fully stocked even-aged stands of trees the relationship between quadratic mean DBH (Dq) and trees per acre (N) has a straight line form in log-log scale with a slope of -1.605 (Stand Density Index – SDI)

Lines approach a maximum line = self-thinning line



Limiting Relationship Functional Form of Reineke

$$\ln N = \ln \alpha + \beta \ln D_q$$

$$\mathrm{SDI} = e^{\alpha + \beta \,\mathrm{Ln}(Dq)}$$

Max SDI is the number of trees per unit area with a specified diameter (Dq = 10 in)

Fitting the Self-thinning line

- There are several statistical methods to estimate the boundary line.
- Arbitrarily hand fitting a line above an upper boundary (Yoda et al. 1963)
- Ordinary least squares methods (OLS) (White and Harper 1970)
- Using subjectively selected data points in a major axis analysis (principal components analysis) (Weller 1987)

Fitting the Self-thinning line

- The previous methods are subjective and result in an estimated "average boundary" as opposed to an "absolute boundary" size-density relationship.

- More recently, Stochastic Frontier Regression (SFR) has been successfully used to model the self-thinning boundary line (Comeau et al. 2010, Weiskittel et al. 2009, Bi 2001).

Stochastic Frontier Regression (SFR)

- Econometrics fitting technique used to study production efficiency, cost and profit frontiers.

SFR Model:

- $Ln(TPA) = a + \beta{*}Ln(QMD) + v - u$
- v = two-sided random error
- u = non-negative random error
- Maximum likelihood techniques are used to estimate the frontier

Fitting the Self-thinning line: Stochastic Frontier Regression

- Fitting performed using FRONTIER 4.1 (Coelli 1996)
- Data analysis using SAS 9.2

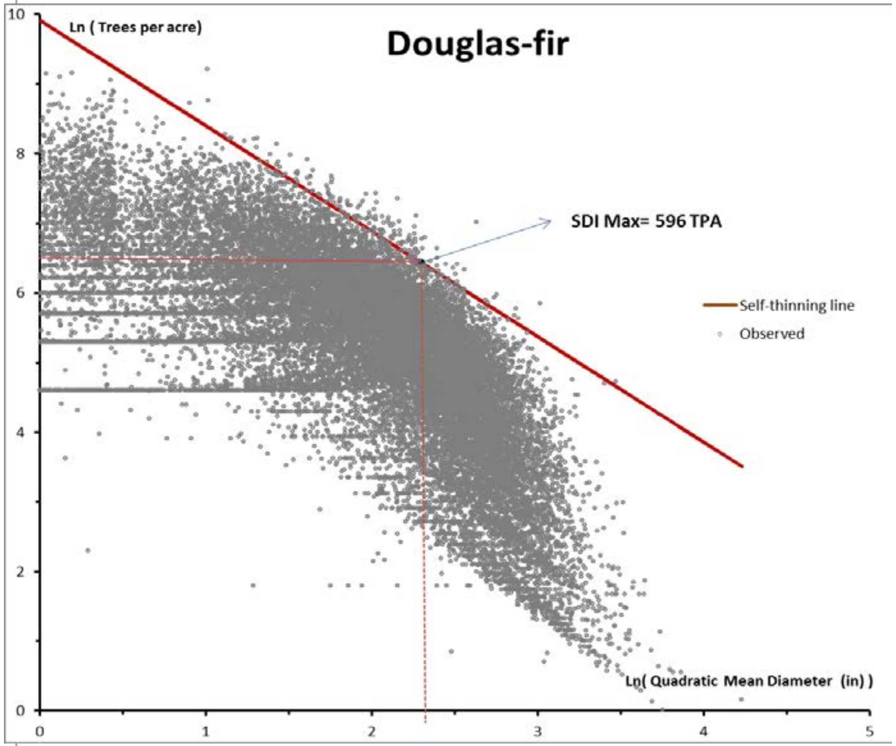
Analysis - IFTNC – STI Dataset

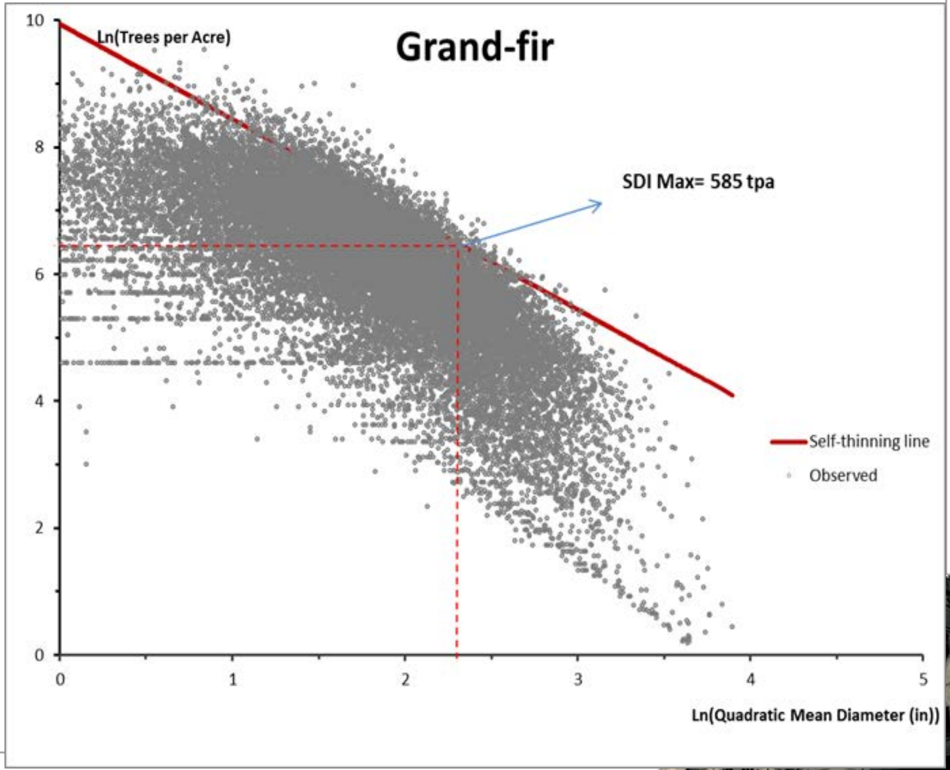
- We analyzed the effect of rock type, climate and topography on the species self-thinning relationship and Reineke’s SDI Max for:
    - Douglas-fir
    - Grand-fir
    - Ponderosa pine
    - Western larch

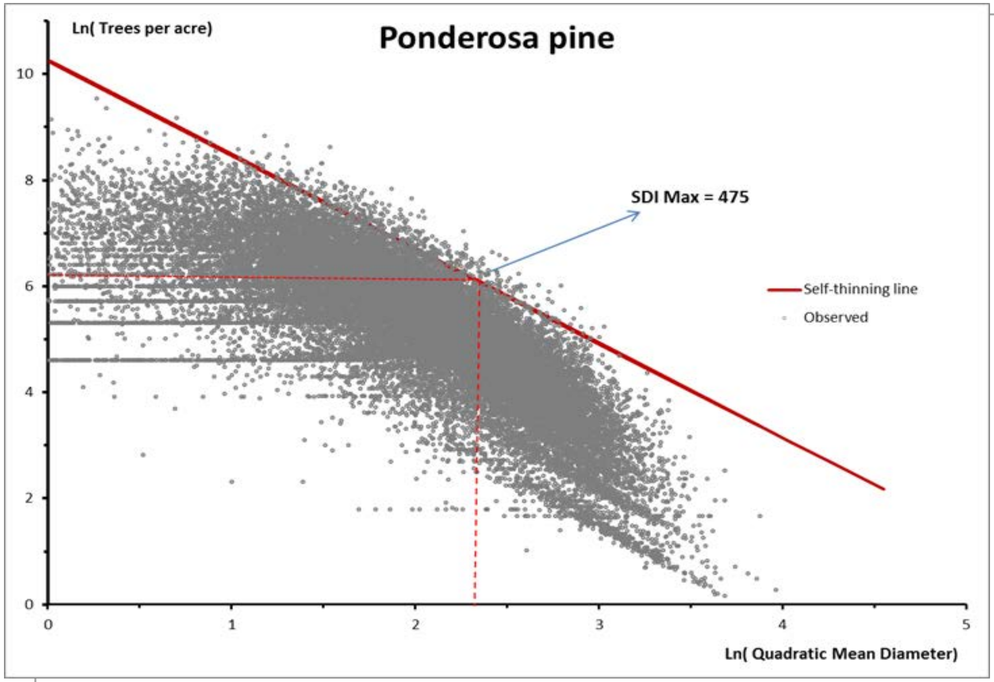
Results: Self-thinning boundary line

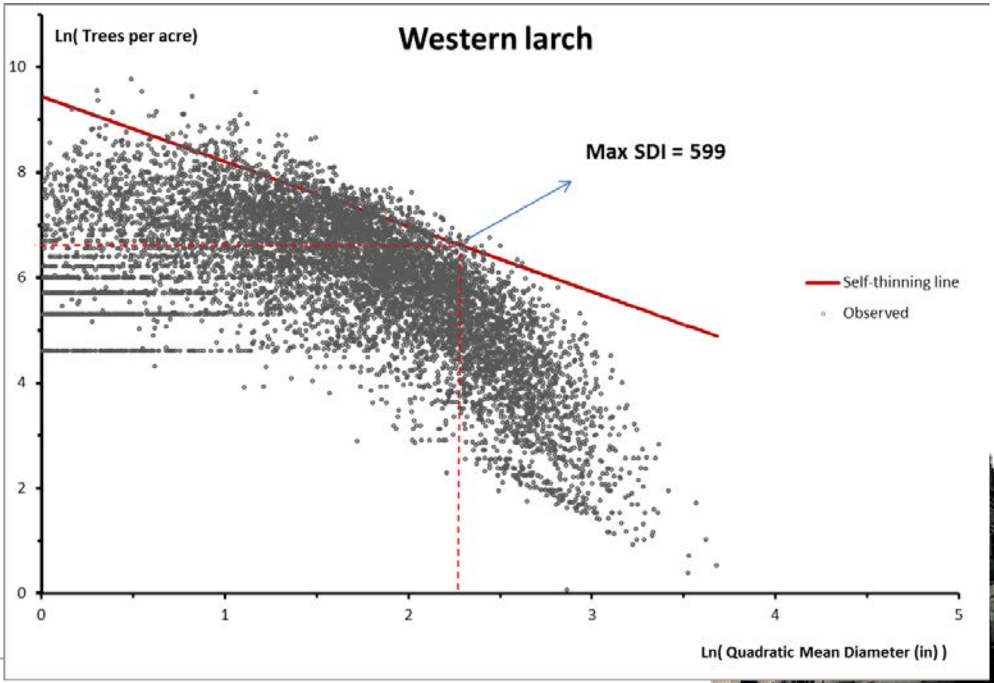
Species	Intercept	Slope	SDI MAX
Douglas-fir	**9.878** (0.0106)	**-1.515** (0.0239)	**596**
Grand-fir	**9.852** (0.0195)	**-1.511** (0.0094)	**585**
Ponderosa pine	**10.256** (0.03022)	**-1.777** (0.0123)	**475**
Western larch	9.24421 (0.03550)	**-1.237** (0.01761)	**599**

Results: Self-thinning line by species






Ponderosa pine
Ln(Trees per acre)
SDI Max = 475
Self-thinning line
Observed
Ln(Quadratic Mean Diameter)
0
2
4
6
8
10
0
1
2
3
4
5


Western larch
Ln(Trees per acre)
Max SDI = 599
Self-thinning line
Observed
Ln(Quadratic Mean Diameter (in))
0
2
4
6
8
10
0
1
2
3
4
5

Results: Species self-thinning by Rock Type

- Are the self-thinning lines (and the corresponding SDI Max) affected by soil parent material ?

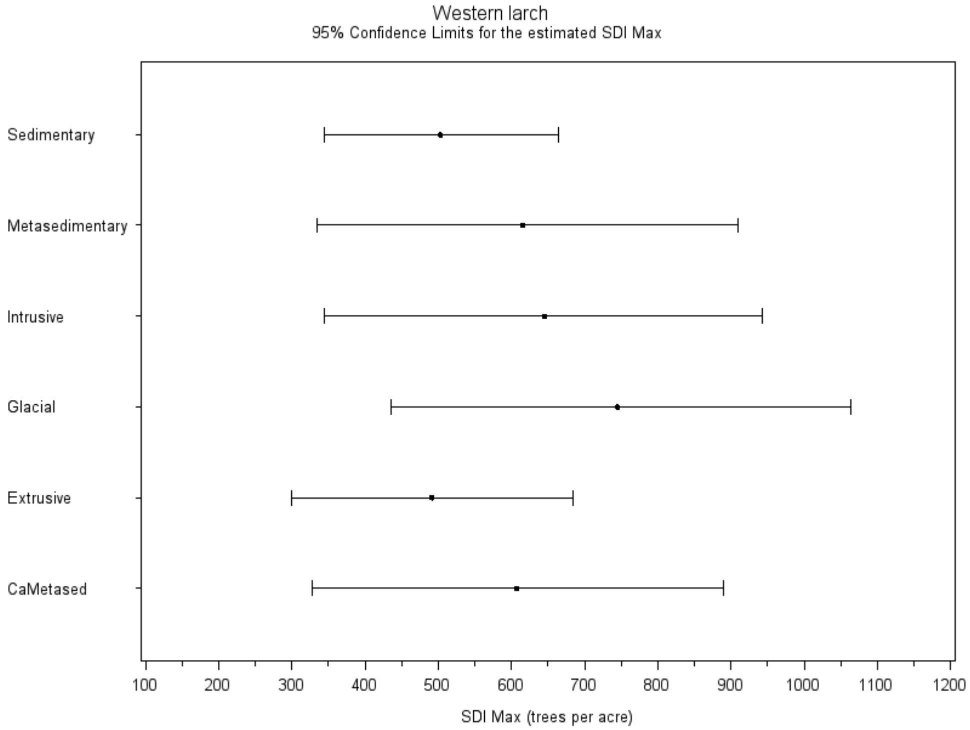
Results by Rock type

Rock Type	**Douglas-fir**			**Grand-fir**			**Ponderosa pine**			**Western larch**		
	Intercept	**Slope**	**SDI Max**	**Inter.**	**Slope**	**SDI Max**	**Inter.**	**Slope**	**SDI Max**	**Inter.**	**Slope**	**SDI Max**
CaMetased	9.96	-1.55	**596**	9.75	-1.48	**568**	9.61	-1.66	**325**	9.15	-1.23	**607**
Extrusive	10.22	-1.66	**606**	9.8	-1.55	**511**	10.57	-1.91	**484**	9.93	-1.66	**491**
Glacial	9.84	-1.53	**557**	9.57	-1.37	**610**	9.42	-1.47	**415**	9.30	-1.21	**745**
Intrusive	9.85	-1.53	**568**	9.44	-1.31	**617**	9.37	-1.49	**377**	9.46	-1.34	**646**
Metasedimentary	9.78	-1.48	**588**	9.49	-1.36	**569**	9.69	-1.57	**433**	9.16	-1.23	**616**
Sedimentary	9.88	-1.52	**585**	9.73	-1.40	**665**	10.21	-1.68	**562**	8.86	-1.19	**503**

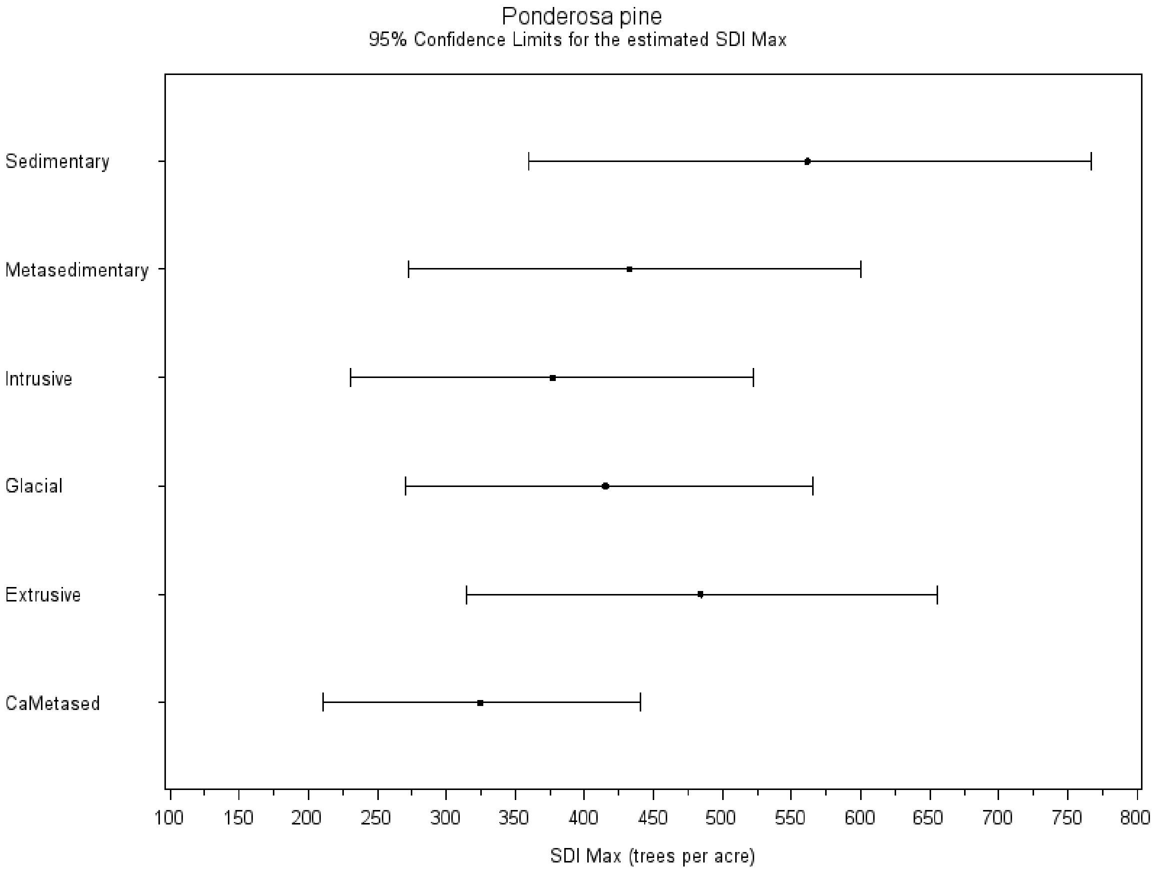
Rock Type
Bootsrap 95% Confidence Intervals for SDI MAX

- Stochastic frontier models introduce skewed error terms
- Assumption of normality of errors is not valid
- Traditional statistical tests cannot be applied
- Bootsrapping provides approximate Confidence Limits for estimation.

Bootsrap 95% Confidence Intervals for SDI MAX



Bootsrap 95% Confidence Intervals for SDI MAX



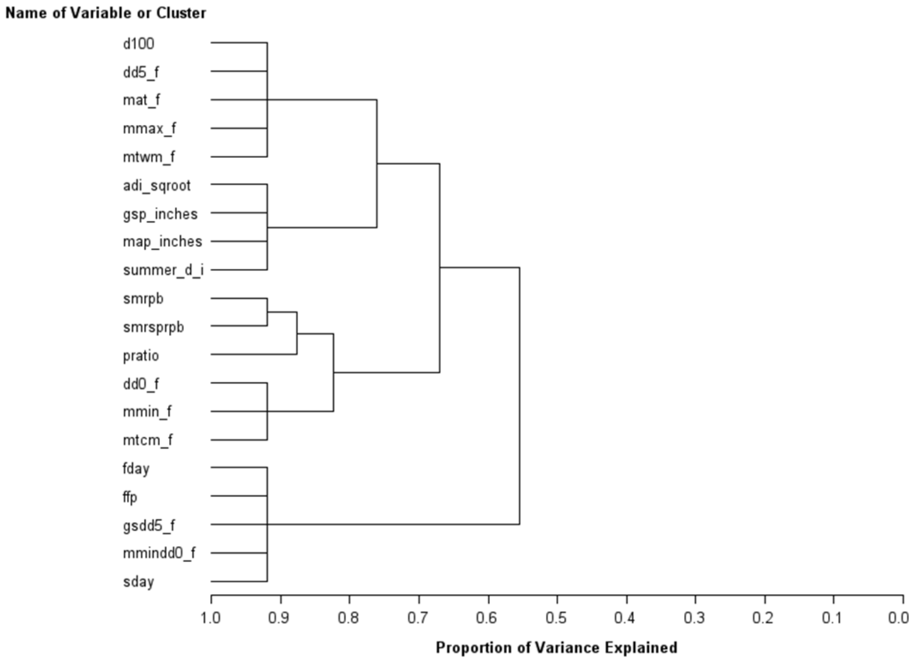
Effect of Climate Variables on the self-thinning line. Climate variables from the US Forest Service Moscow Laboratory

Variable	Definition	Mean	Std Dev
ADI	Annual Dryness Index: sqrt(dd5)/map	0.05	0.02
d100	Julian date the sum of degree-days >5 °C reaches 100 °C	127.9	13.4
dd0	Annual degree-days <32 °F (based on monthly mean temperatures)	1,157.0	326.6
dd5	Annual degree-days >5 °C (based on monthly mean temperatures)	2,678.0	510.6
fday	Julian date of the first freezing date of autumn	255.8	8.1
ffp	Length of the frost-free period	96.4	19.4
gsdd5	Degree-days >5 °C accumulating within the frost-free period	1,843.0	498.3
gsp	Growing season precipitation, April–September	10.64	2.47
map	Mean annual precipitation	30.3	8.5
mat	Mean annual temperature	42.1	2.57
mmax	Maximum temperature in the warmest month	77.7	4.15
mmin	Minimum temperature in the coldest month	16.3	2.50
mmindd0	Annual degree-days <0 °C based on monthly minimum temperatures	2,449.0	456
mtcm	Mean temperature in the coldest month	23.2	2.52
mtwm	Mean temperature in the warmest month	62.1	2.68
pratio	Ratio os Summer precipitation to total precipitation: gsp/map	0.36	0.05
sday	Julian date of the last freezing date of spring	159.4	12.95
smrpb	Summer precipitation balance: (jul+aug+sep)/(apr+may+jun)	0.63	0.07
smrsprpb	Summer/Spring precipitation balance (jul+aug)/(apr+may)	0.56	0.10
SDI	Summer dryness index = sqrt(gsdd5)/gsp	0.12	0.04

Climate Variable Reduction for Modeling using Clustering

- Variable clustering (proc varclus SAS 9.2) was used to reduce the number of redundant (highly correlated) climate variables to input in the self-thinning model.

Clusters of climate variables



We select one representative from each cluster, reducing the number of climate variable to include in the self-thinning model from 20 to 5

Effects of Climate Variables

- We select one representative from each cluster, reducing the number of climate variable to include in the self-thinning model from 20 to 5:
- Annual degree-days >5 °C (based on monthly mean temperatures: dd5
- Length of the frost-free period: ffp
- Mean temperature in the coldest month: mtcm
- Annual Dryness Index: ADI
- Summer/Spring precipitation balance (jul+aug)/(apr+may): smrsprpb

Effect of Topographic Variables

- Elevation (radiation, temperature, wind, snow, relative humidity)
- Slope (soil moisture, wind, snow, radiation, and temperature)
- Aspect (radiation, temperature, moisture, snow)
- Cosine-transformed Aspect (North-South-Contrast: radiation, temperature, snow)
- Sine-transformed Aspect (East-West-Contrast: radiation, precipitation, snow)
- The joint effect of Slope and Aspect was modeled using the cosine and sine transformation suggested by Stage (1976)

Testing the significance and impact of climate, topographic and stand variables in the boundary relationship

- Self-thinning relationship as a multidimensional surface (Weiskittel et al . 2009)
- After selecting the previous 5 climate variables, topographic and stand factors (Skewness of DBH^1.5 distribution: SK, proportion of basal area in the primary species, PBA) were tested for relevance in the boundary function.
- Significance of final covariates was tested using log-likelihood ratio test.

- The following variables showed a significant effect on the multidimensional self-thinning boundary surface:
- Rock Type
- Elevation (ft)
- Cosine Aspect
- Proportion of basal area of the main species
- Annual Dryness Index

Grand-fir

Parameter Estimates

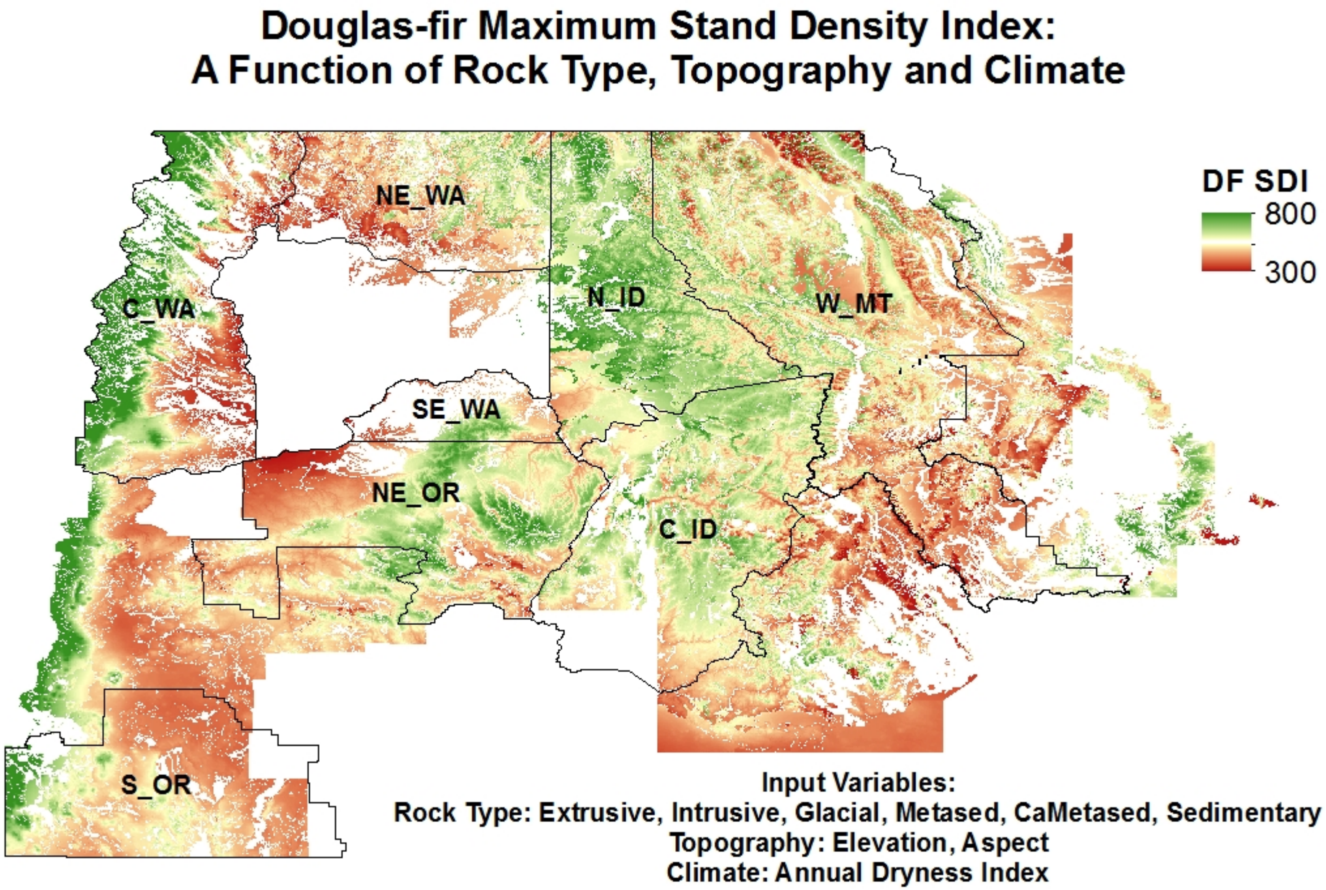
Parameter		Estimate	Standard Error	Approx Pr > |t|
Intercept		13.910174	0.370689	<.0001
QMD		-1.028163	0.009794	<.0001
Aspect		0.060336	0.008771	<.0001
Annual Dryness Index		-0.677151	0.031307	<.0001
Elevation		-0.720136	0.049429	<.0001
Rock_type	CaMetased	-0.026175	0.054491	0.6310
Rock_type	Extrusive	-0.067840	0.052488	0.1962
Rock_type	Glacial	-0.105916	0.055670	0.0571
Rock_type	Intrusive	-0.144987	0.054298	0.0076
Rock_type	Metasedimentary	-0.072869	0.053261	0.1713
Rock_type	Sedimentary	Baseline	.	.
BasalArea proportion		-0.539306	0.018857	<.0001

Douglas-fir

Parameter Estimates

Parameter		Estimate	Standard Error	Approx Pr > |t|
Intercept		12.544202	0.304119	<.0001
QMD		-1.181450	0.011162	<.0001
Aspect		-0.064699	0.011176	<.0001
Annual Dryness Index		-0.240721	0.031451	<.0001
Elevation		-0.636242	0.040794	<.0001
Rock_type	CaMetased	-0.033190	0.050024	0.5070
Rock_type	Extrusive	0.230092	0.036172	<.0001
Rock_type	Glacial	-0.077457	0.037671	0.0398
Rock_type	Intrusive	-0.102470	0.036742	0.0053
Rock_type	Metasedimentary	-0.062823	0.038038	0.0986
Rock_type	Sedimentary	-Baseline-	.	.
BasalArea prop		-0.700997	0.026065	<.0001

: Douglas-fir: Regional geospetial map


Douglas-fir Maximum Stand Density Index:
A Function of Rock Type, Topography and Climate

Input Variables:
Rock Type: Extrusive, Intrusive, Glacial, Metased, CaMetased, Sedimentary
Topography: Elevation, Aspect
Climate: Annual Dryness Index

Next Steps

- Continue identifying site factors driving carrying capacity
- Developing models to estimate site quality and productivity based on these identified factors
- Develop regional geospatial tools that predict site quality

- Phase II Site Type Initiative: utilize the defined site-type classes as a foundation for management activities prescriptions based on empirical studies