Maximum stand-density model development and validation

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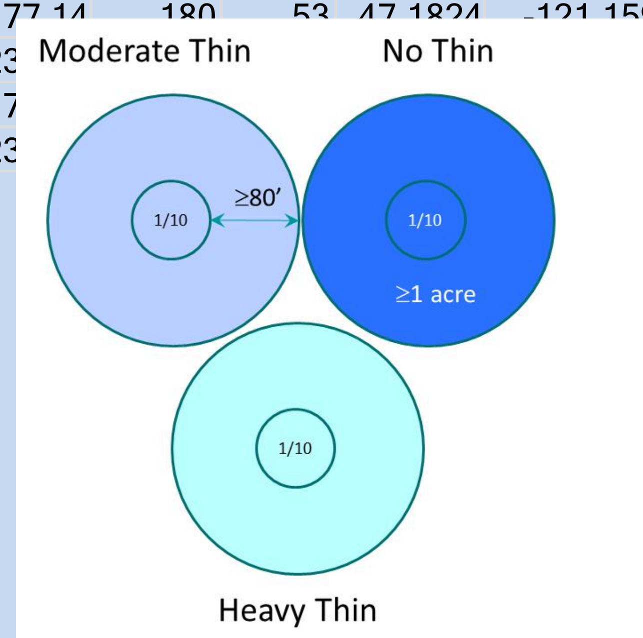
Intermountain Forest Tree Nutrition Cooperative

IFTNC Site Type Initiative

Site Type Initiative

- Phase I: Data assembly, model development, validation
- Phase II: Field studies

Stand_ID	StandQMD	StandTPA	StandBA	Aspect	Slope	Latitude	Longitude	Rock_Type	elev
11_99268	7.9762	510.52	177.14	180	53	47.1824	-121.159	Metasediment	838
12_109039	8.33	617.93	23[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Extrusive	710
12_22760	7.5427	560.86	17[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Extrusive	665
12_22780	11.1137	356.21	23[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Extrusive	574



Goal of forest stand density management studies

Accurately predict site-specific maximum stand density across the Inland Northwest to meet landowner management objectives

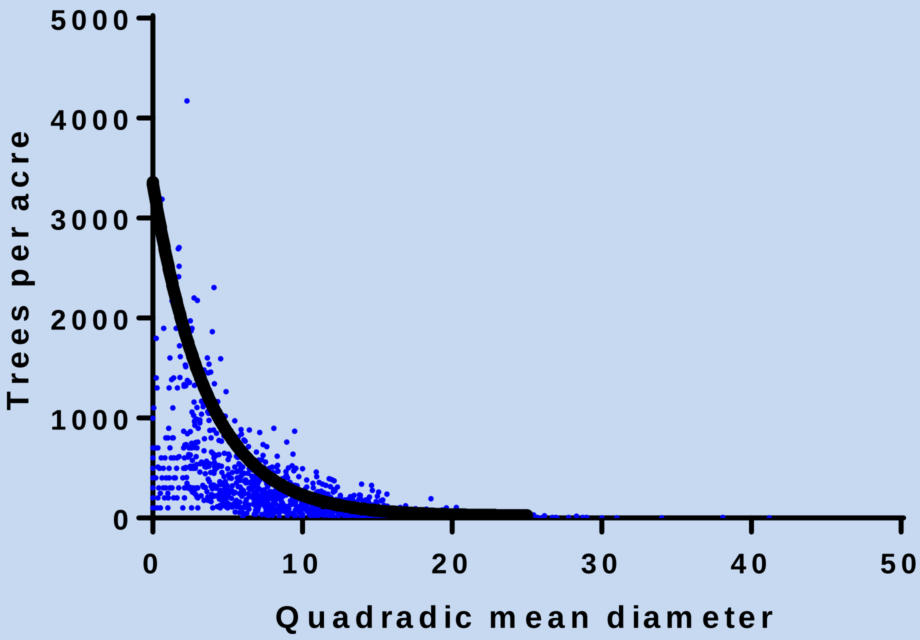
- Forest size-density: conventions, assumptions
- Modeling approach
- Factors controlling size-density functions
- Validating the unmeasurable
- Using the predictions

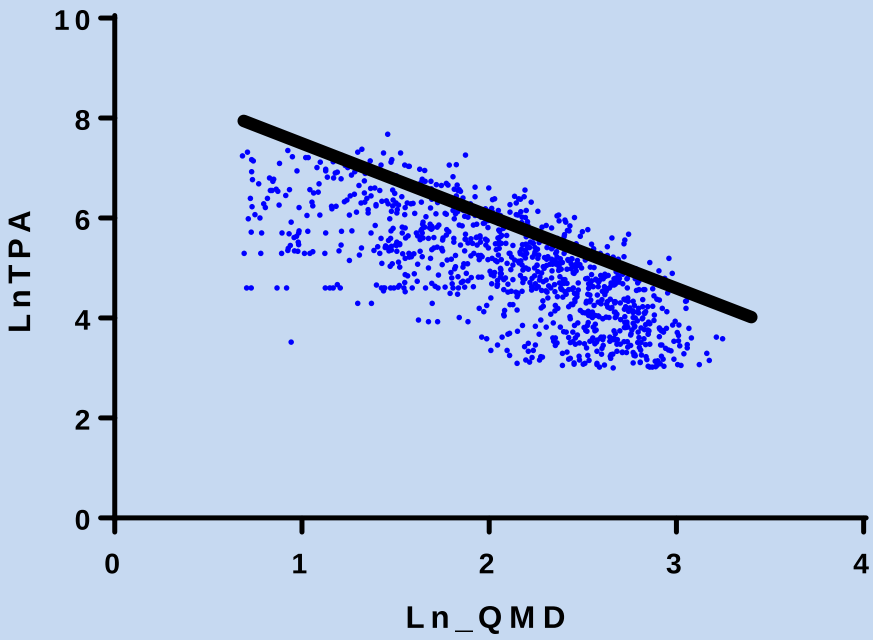
The size-density function

- Non-linear exponential function
- Log transformed into linear function

$$y = \beta_0 e^{\beta_1 x}$$

$$\ln(TPH) = \beta_0 + \beta_1 \ln(QMD)$$



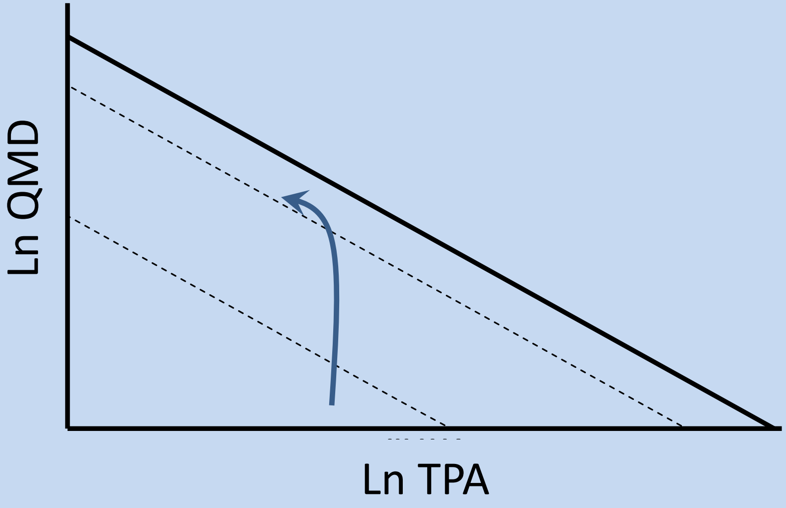


Upper boundary defines maximum stand density

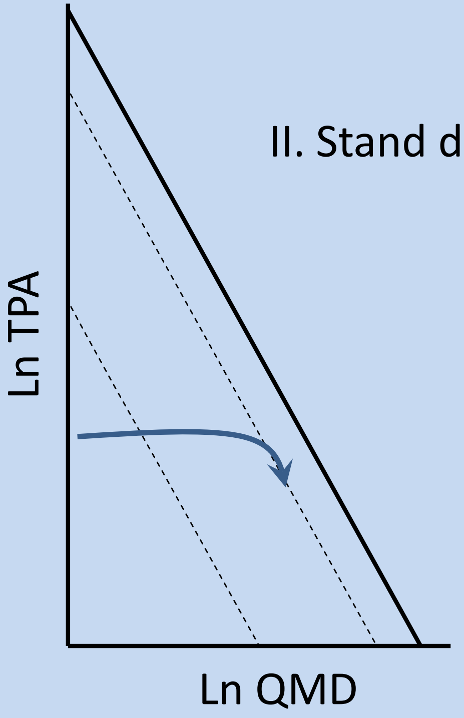
The self-thinning line

- Two conventions for tracking stand development
- Diameter increases until stand nears maximum stand density
  i.e. imminent mortality growth phase

I. Density Management Diagrams



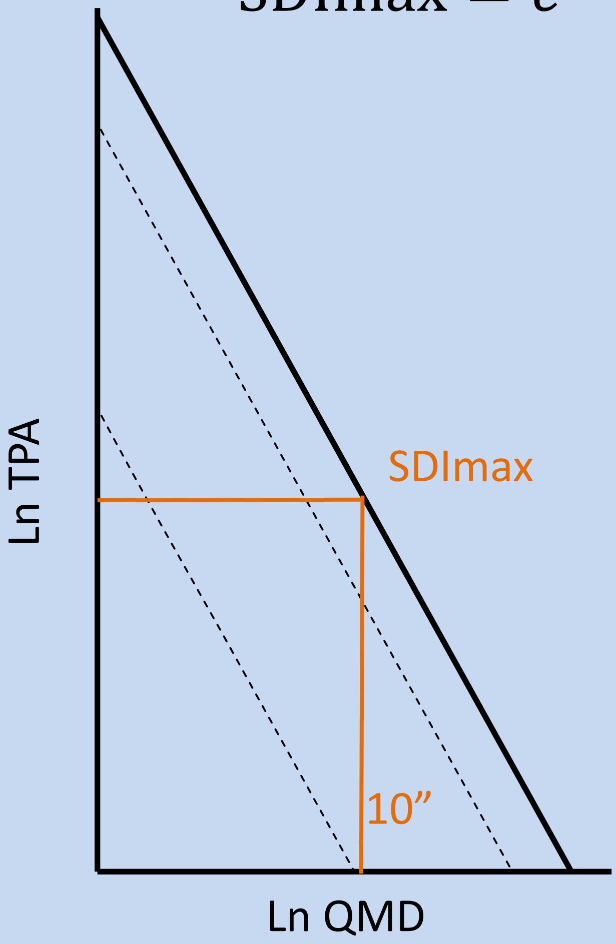
II. Stand density index



SDImax

Reineke (1933)

$$\text{SDImax} = e^{(\beta_0 + \beta_1 \cdot \ln 10)}$$

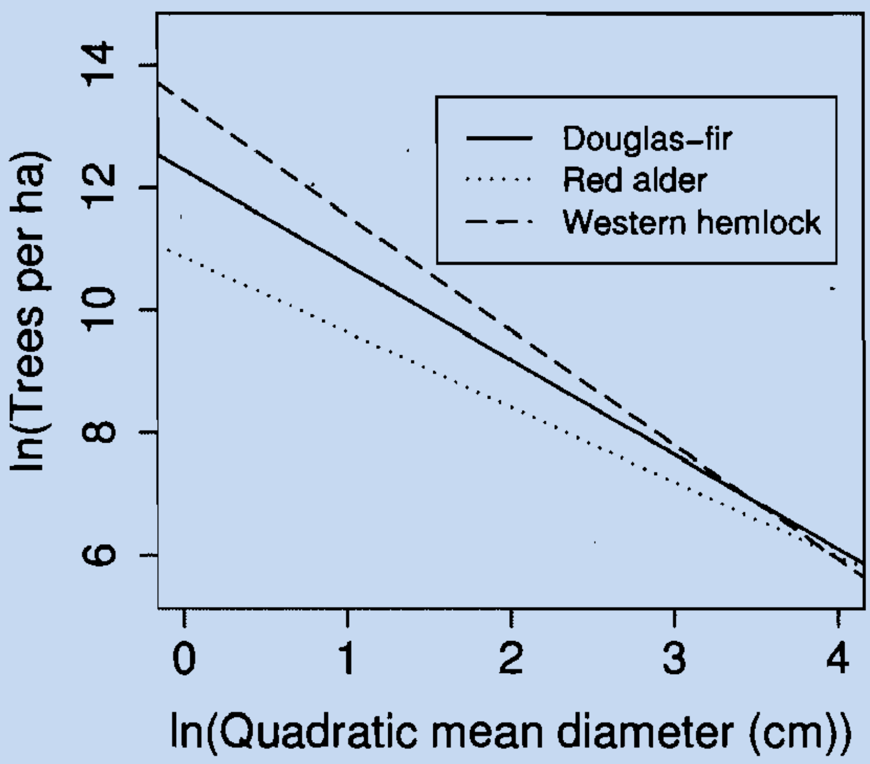


Assumes:

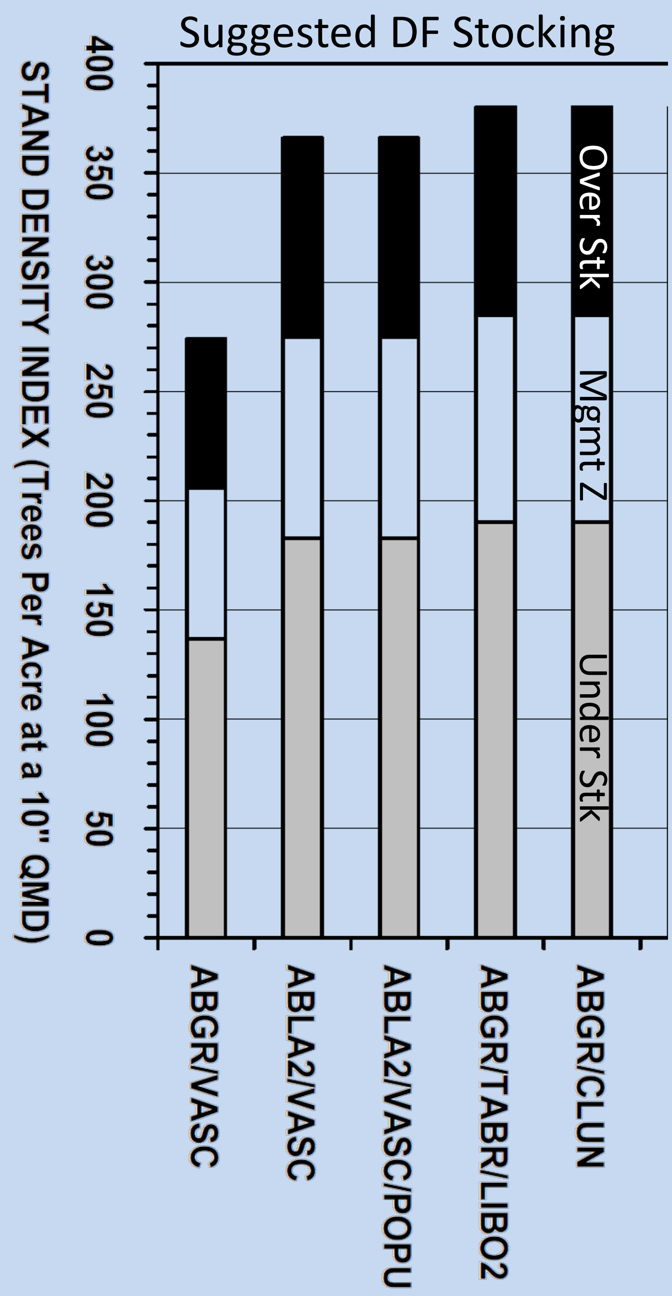
- Slope is universal (-1.605)
- Intercept is constant for a given species and region
  - i.e. not affected by site factors

Are the assumption valid?

- Slope is not universally -1.605
- Site does affect the intercept



Weiskittel et al 2009

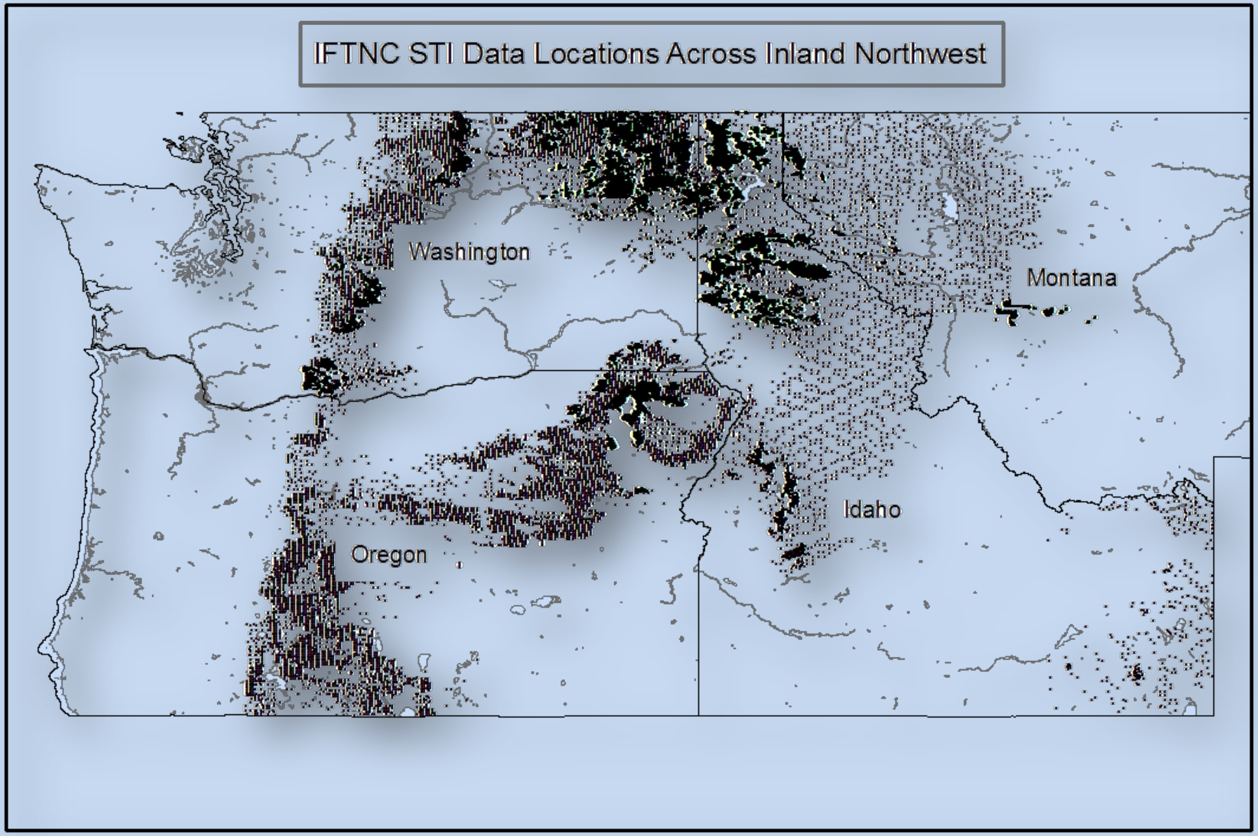


Powell 1999

Objective of modeling approach:

Identify and employ the most effective approach to define the principal factors that control the size-density function

Data assembly



Dataset:
>110,000 plots
4+ million trees
28 tree species

Associated Input:
Sand/tree level, climate, geology, topography

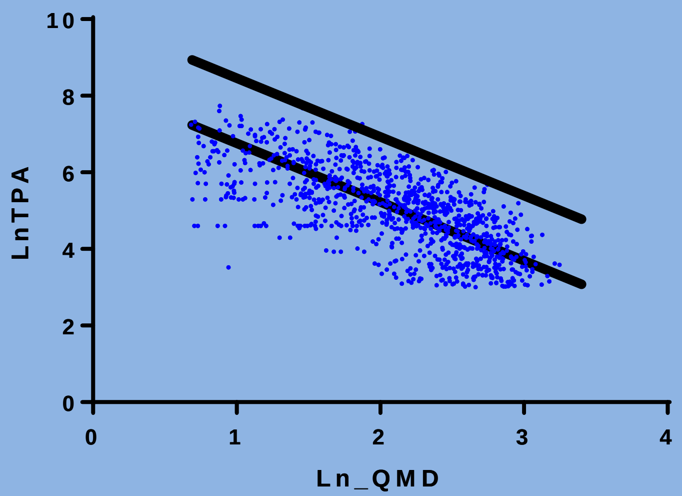
Cooperator Data Suppliers:
Bennett Lumber, BLM, Forest Capital, Hancock, IDL, Inland Empire Paper, Stimson, USFS-FIA/CVS, WA DNR

Fitting the size-density function limit

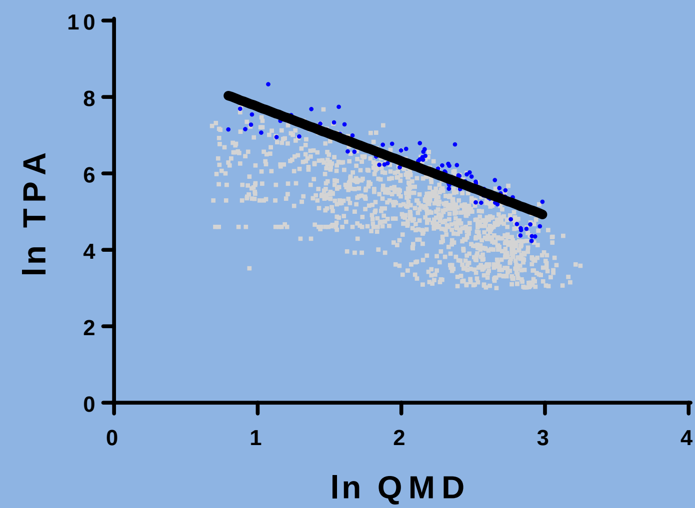
The self-thinning line

Ordinary least squares regression (OLS)

Fit a line through all points, then shift to the top edge



Select stands with highest SDI, then fit a line through those points



Fitting the size-density line with Stochastic Frontier Regression (SFR)

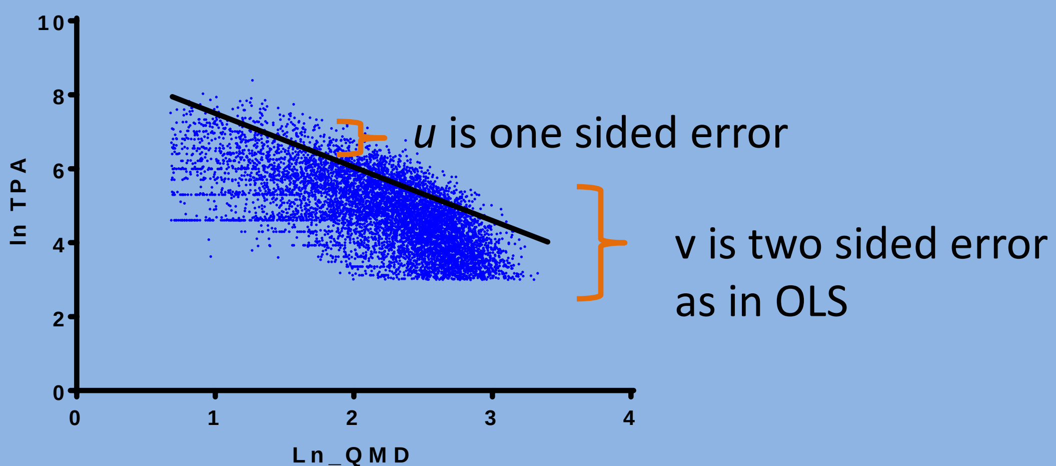
The SFR Model:

$$Ln(TPA) = \beta_0 + \beta_1 * Ln(QMD) + v - u$$

v = two-sided random error

u = non-negative random error

Maximum likelihood techniques are used to estimate the frontier



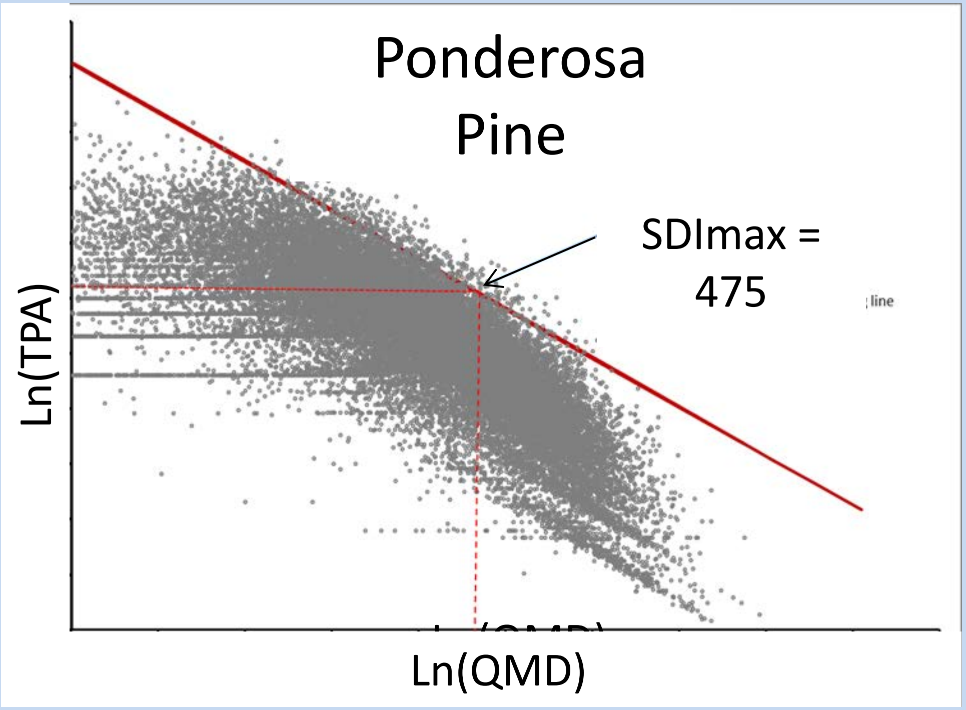
- Combined error defines the frontier
- Multi-vairate analysis possible
- Describes variability above the size-density line

SFR detects species differences in max SDI

Basic model applied to each of four species:

$$Ln(TPA) = b_0 + b_1 \cdot Ln(QMD) + v + u$$

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**



Select when target species is more than 20% of plot basal area
So, includes abundant mixed species stands

Testing site factors:

Are the self-thinning lines affected by soil parent material ?

Rock-type covariates added to individual species models:

$Ln(TPA) = b_0 + b_1 \cdot Ln(QMD) + b_{2i} \cdot Rock\ Type_i + v + u$

Rock Type	Douglas-fir		
	Intercept	**Slope**	**SDI Max**
CaMetased	9.96	-1.55	**596**
Extrusive	10.22	-1.66	**606**
Glacial	9.84	-1.53	**557**
Intrusive	9.85	-1.53	**568**
Metasedimentary	9.78	-1.48	**588**
Sedimentary	9.88	-1.52	**585**

Soil parent material affects both slope and intercept of self-thinning line

Testing site factors:

Are the self-thinning lines affected by physiography and climate?

$$Ln(TPA) = b_0 + b_1 \cdot Ln(QMD) + b_{2i} \cdot Rock\ Type_i + b_{3j} \cdot Physiography_j + b_{4k} \cdot Climate_k + v + u$$

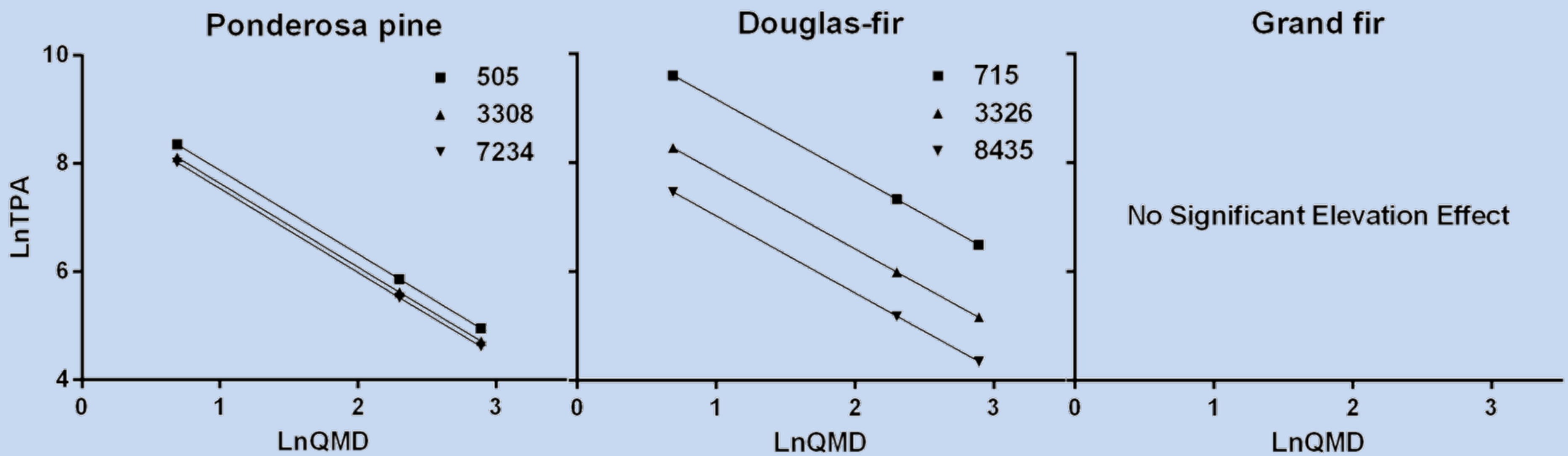
Physiography:

- Elevation
- Slope
- Aspect

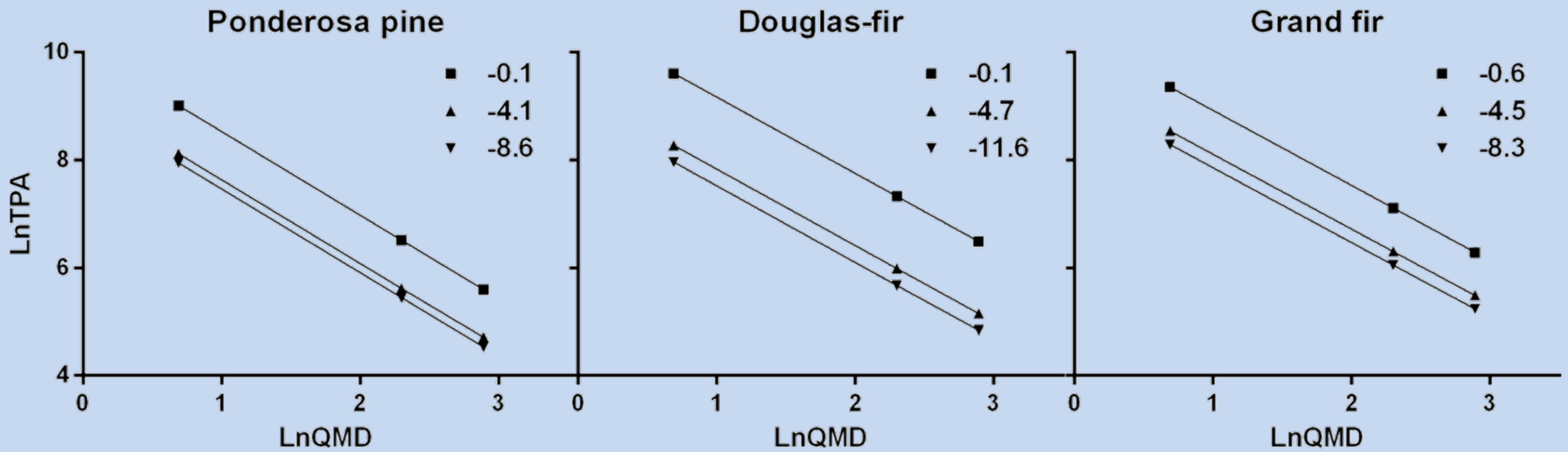
Climate:

- Clusters of variables represented by:
  - Annual degree-days >5 °C: dd5
  - frost-free period: ffp
  - Mean temp coldest month: mtcm
  - Annual Dryness Index: adi
  - (temp/precip)
  - Sumer/Spring precip balance : sspb

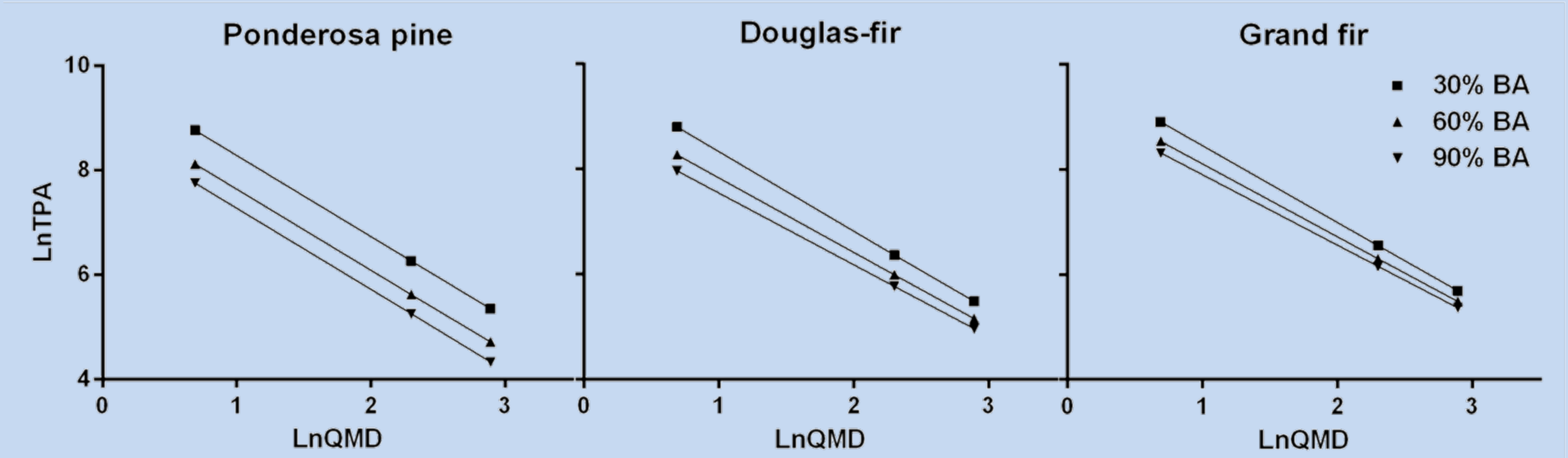
Elevation



Mean temperature of coldest month, mtcm



Percent basal area influences individual species models



- Implies that occurrence of other species increases maximum density over that in pure stands
- Must account for the influence of other species when present

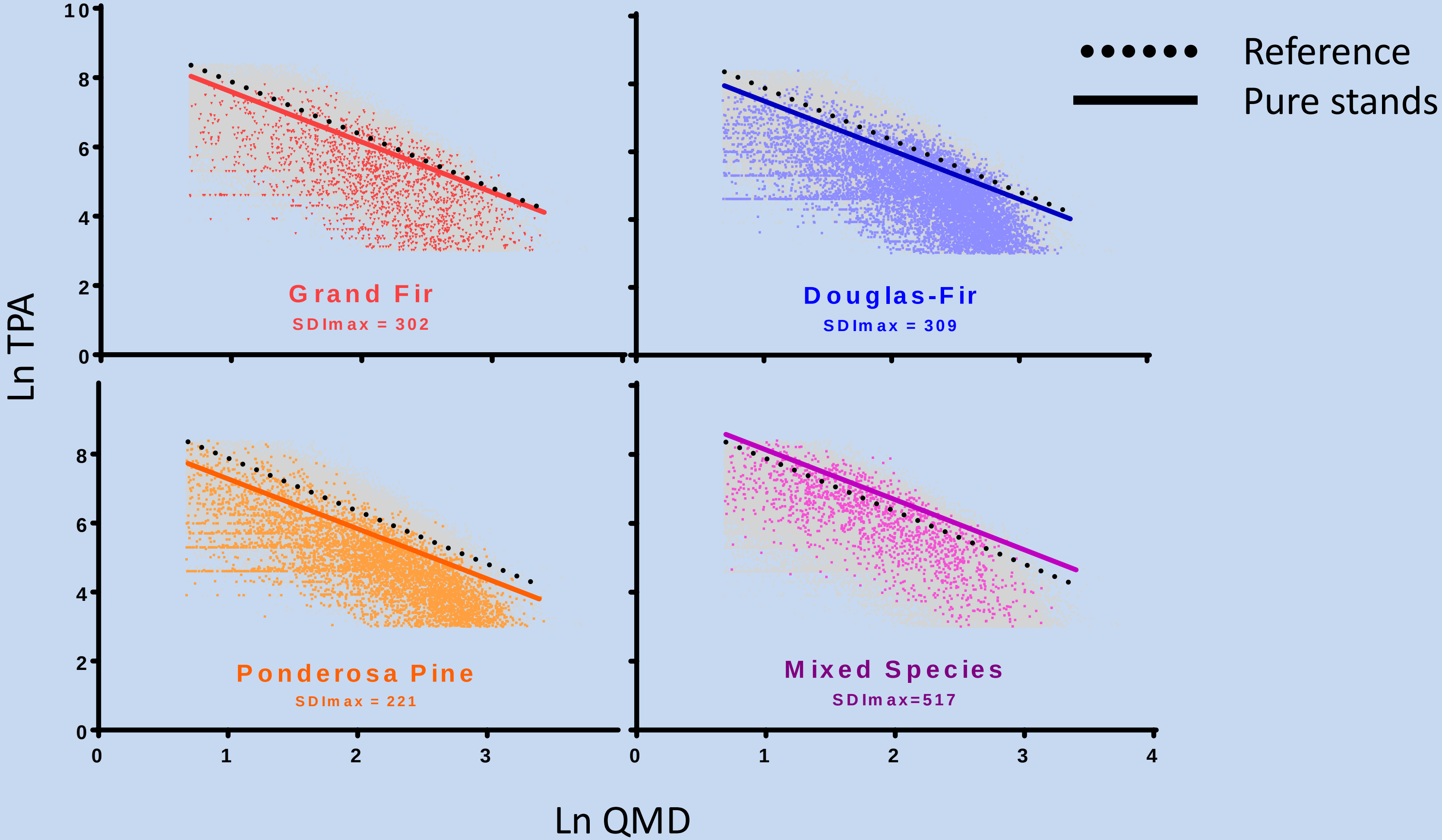
Mixed species model

- Full model includes rocks, physiography, climate and species

$$
\begin{aligned}
&\mathit{Ln(TPA)} = \\
&b_0 + \\
&b_1 \cdot \mathit{Ln(QMD)} + \\
&b_{2i} \cdot \mathit{Rock\ Type}_i + \\
&b_{3j} \cdot \mathit{Physiography}_j + \\
&b_{4k} \cdot \mathit{Climate}_k + \\
&b_{5m} \cdot \mathit{Species\ BA}_m + \\
&v + u
\end{aligned}
$$

- 10% of data reserved for validation

Individual species estimates obtained by specifying pure stands



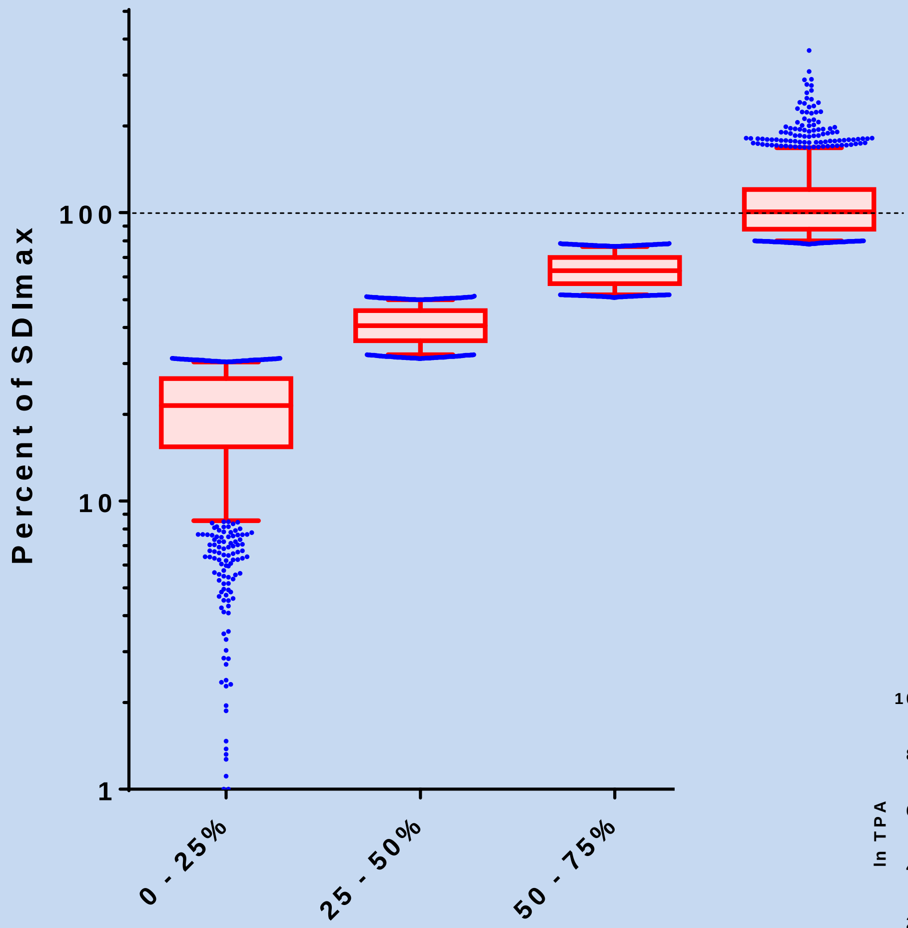
- Greater stocking is possible in mixed species stands

Validating model estimates

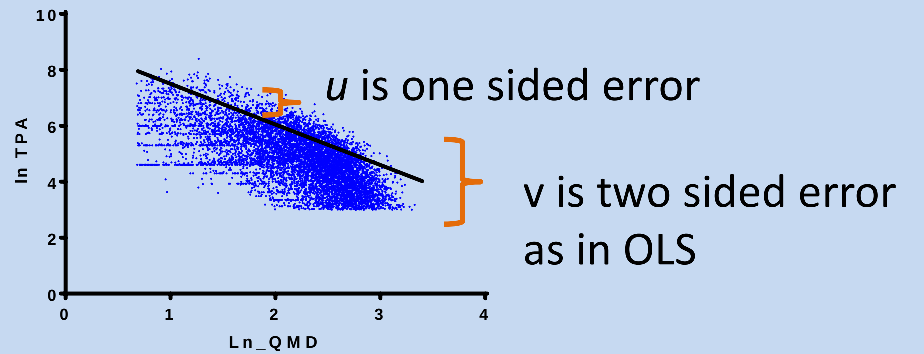
- Measuring maximum density is difficult
- Must be observed in stands that are naturally self-thinning
- Repeated measurements are most helpful
- Even then, differentiating stands may not be at 100% stocking

Validation

Compare 10% reserved data to model estimates

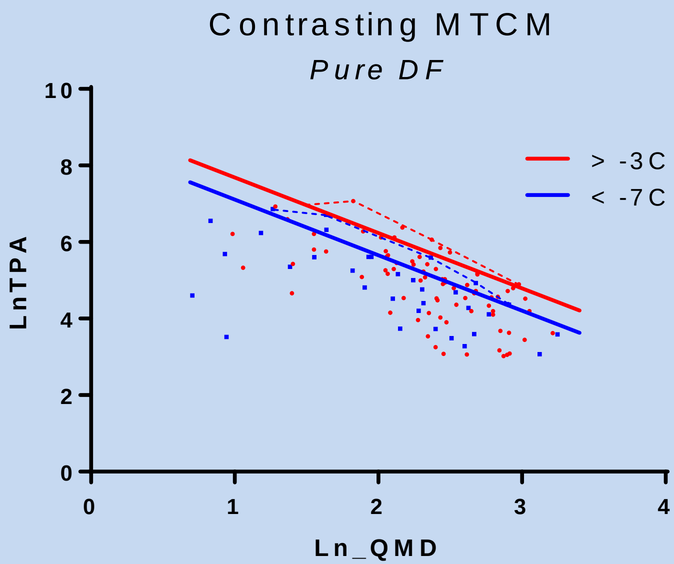


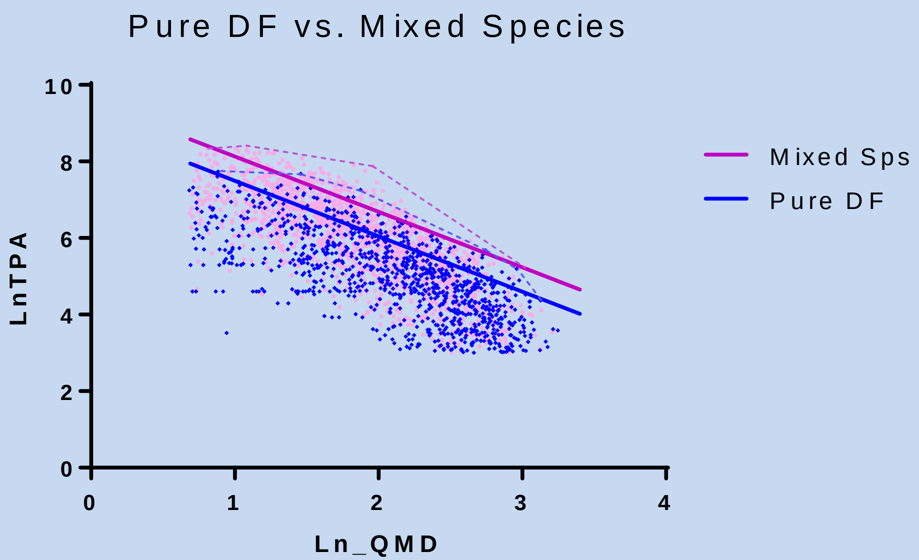
- Mean of upper quartile is 100% SDI max
- Or, 12.5% of plots have stocking levels above SDImax
- Consequence of SFR error terms



Validation

Compare 10% reserved data to model estimates



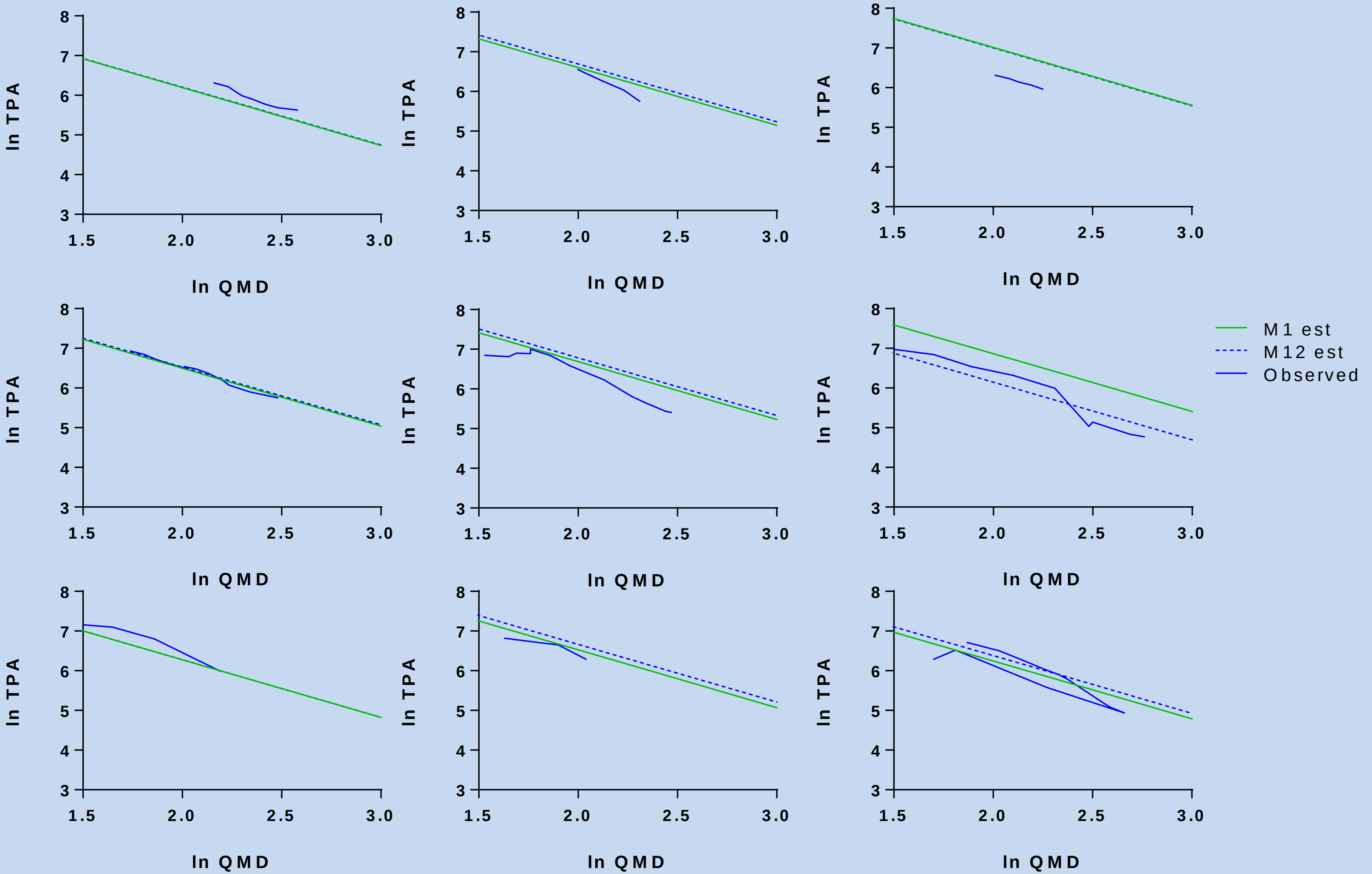


Select stands with highest or lowest MTCM

Select pure Douglas-fir for comparison with mixed stands

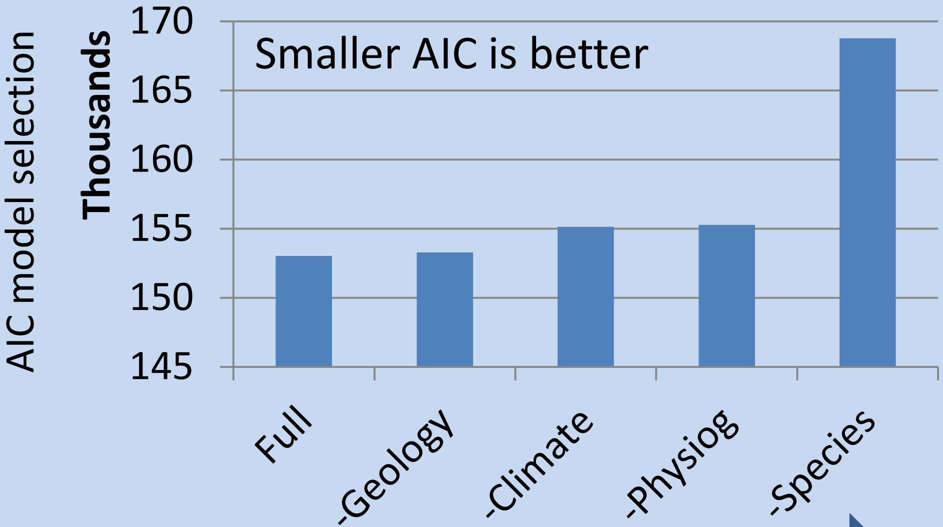
Validation with long-term measurement plots

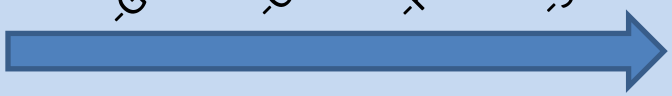
Forest Service 100-yr data



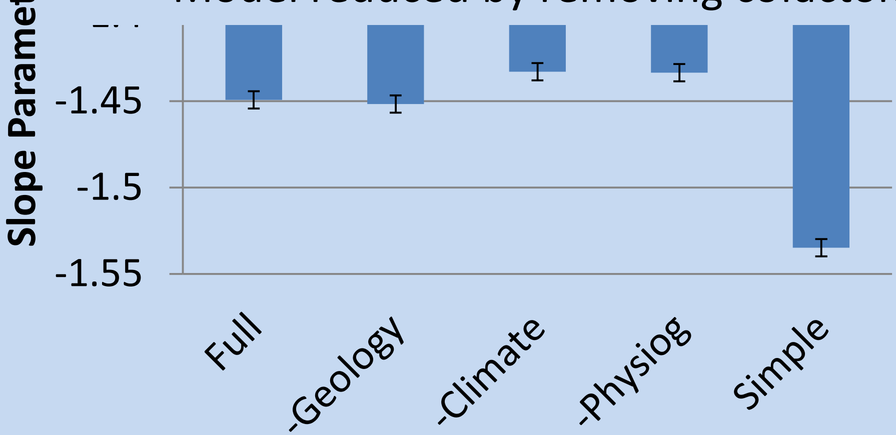
Testing the assumptions

What precision is required?





Model reduced by removing cofactors



- Species predominately controls maximum density models
- Site has some influence

- The slope is not universally -1.605

Implications from maximum density predictions

- Known factors control stocking, and therefore productivity rates and yields
- Species mix alters stocking more than site factors
- Accounting for other species becomes important
  - Especially when it's hard to maintain pure stands
- Density management diagrams
  - Slope adjustments necessary
  - Intercept differences among sites are more subtle
- Temperature and elevation do define stocking; therefore:
  - Climate change will affect stocking
  - IFTNC maximum density models predict climate change effect for a give species mix

Next steps

- Model and data adjustments to improve validation
  - Adjust SFR parameters to push estimates closer to frontier
  - Screen dataset for outlier plots
- Potential long-term datasets are important for validation
  - BC Ministry
  - Updated IDL Continuous Inventory Plots
  - Others?