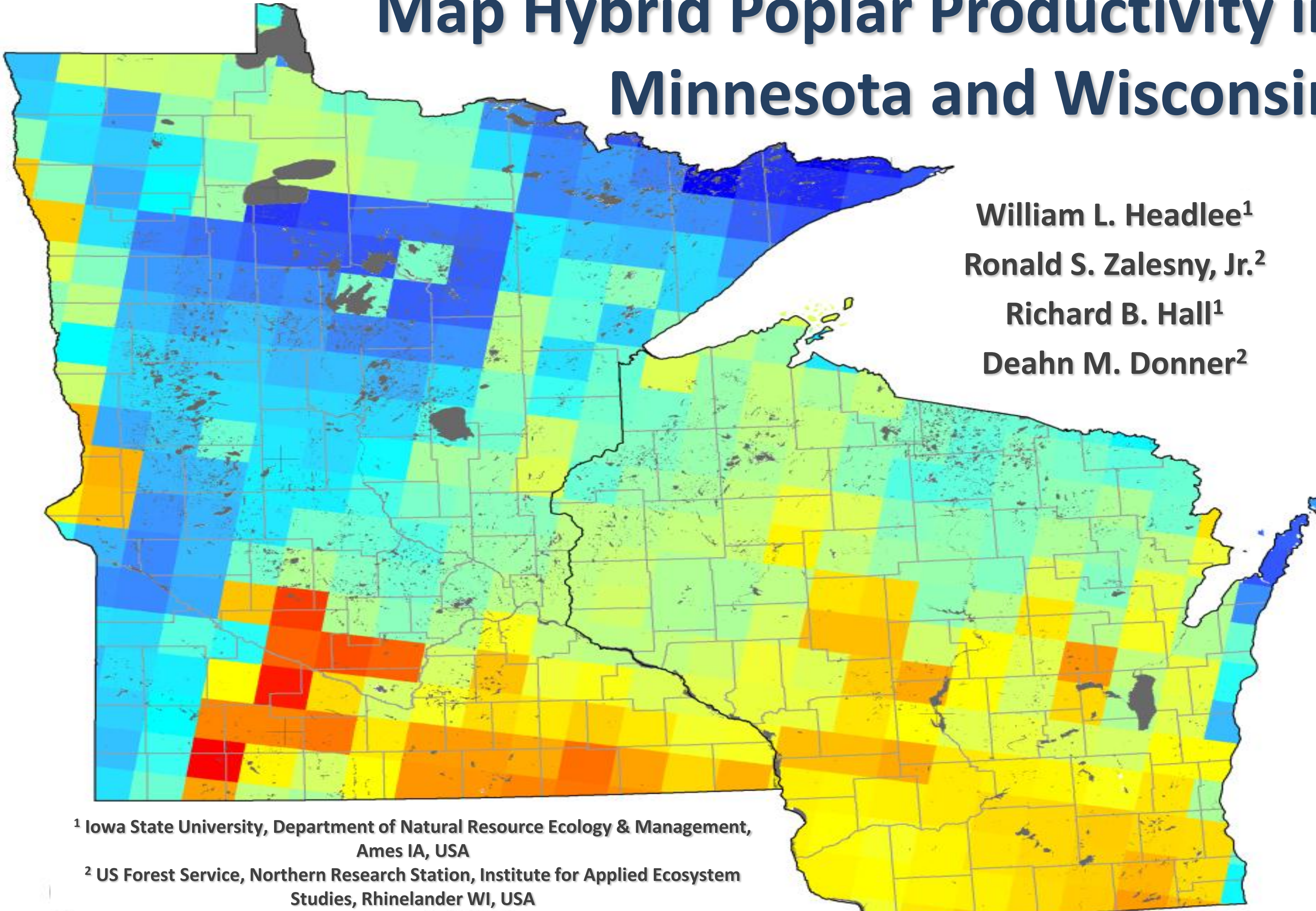
Using the 3-PG Model to Predict and Map Hybrid Poplar Productivity in Minnesota and Wisconsin



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Overview

- Purpose of Study
- Overview of 3-PG
- Modeling Procedures
  - Data acquisition
  - Parameter values
  - Calibration
  - Validation
  - Sensitivity analysis
- Mapping
- Discussion

Mature hybrid poplar plantation in Minnesota. (photo R. Zalesny)

Purpose of Study

- Inability to predict productivity is a major obstacle for hybrid poplar deployment – stakeholders don't like uncertainty about yields!

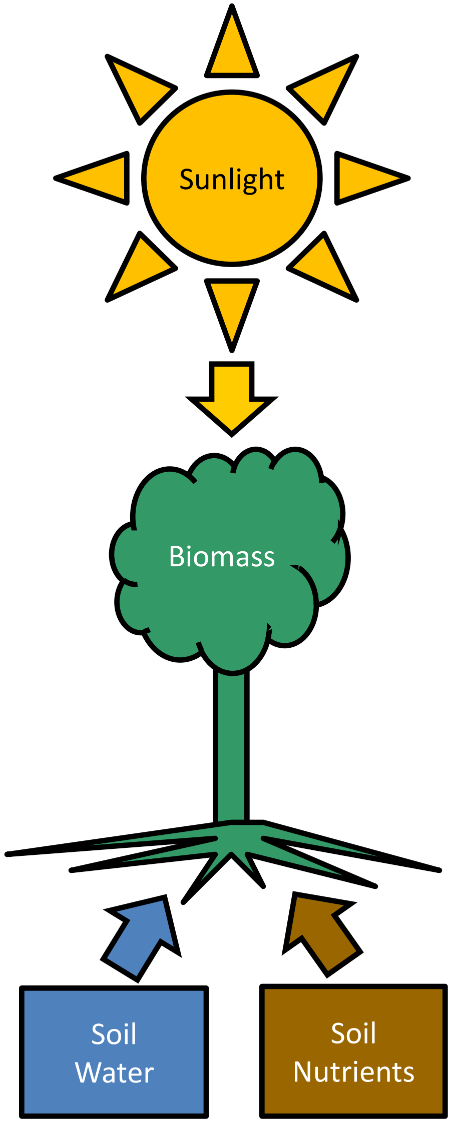
- Productivity for a given hybrid poplar genotype depends on site quality (e.g. climate and soils), and physiological processes governing growth

- Physiological Processes Predicting Growth (3-PG) model predicts tree growth with site-specific climate and soils data, and species-specific physiology data
  - Available free as an add-in for Microsoft Excel
  - Developed for eucalypts in Australia by Landsberg & Waring [1], and has been adapted for eucalypts and other species around the globe [2-10]

Overview of 3-PG

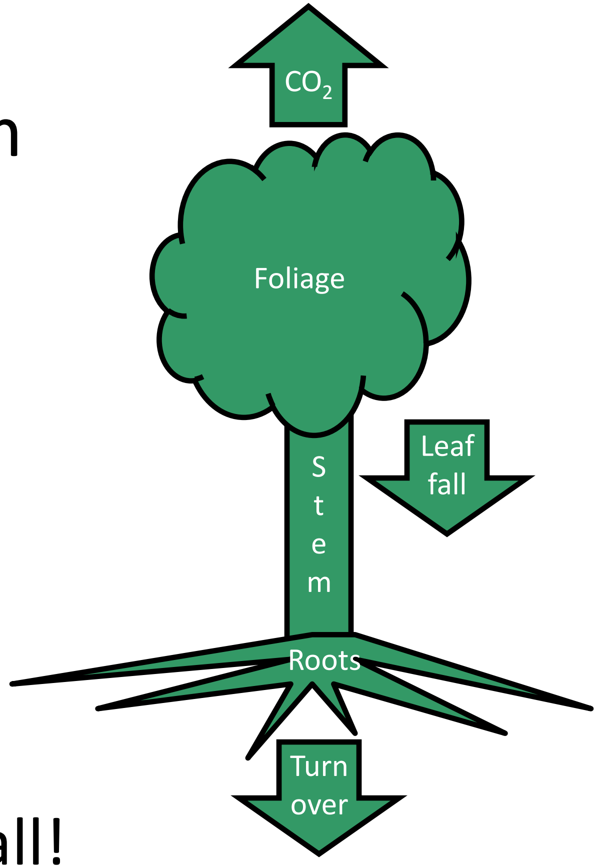
- So how does 3-PG work?

- “Process-based” model: uses site-specific **inputs** for climate and soils to estimate available pools of key resources for needed tree growth
  - Sunlight (**solar radiation**)
  - Soil water (**precipitation**, **temperature**, **soil water holding capacity**, **water table depth**, and **texture**)
  - Soil nutrients (**site fertility**)



Overview of 3-PG (cont.)

- Species-specific physiological parameters determine the amount and type of biomass produced from available resource pools
  - Quantum canopy (photosynthetic) efficiency
  - Biomass partitioning (foliage, stem, roots)
  - Ratio of NPP to GPP
  - Leaf litterfall rate
  - Root turnover rate
  - The list goes on… 60 parameters in all!



Overview of 3-PG (cont.)

- Simplified mathematical structure:

$$NPP_{Total} = PAR \times CC \times LAI \times Q_{max} \times R \times M$$

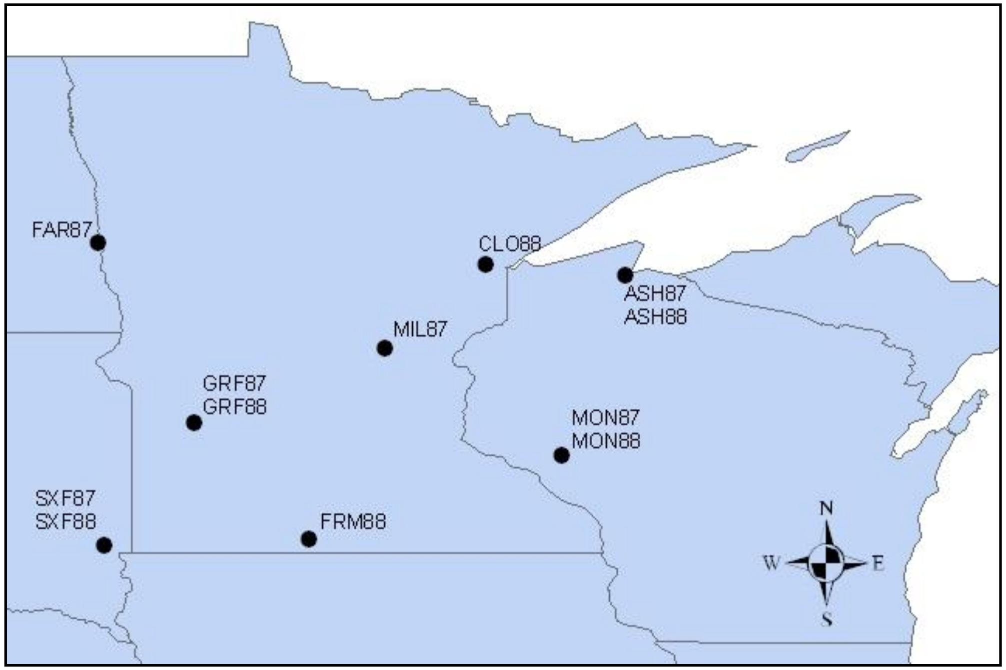
where

NPP_{Total} = net biomass production (NPP_{Stem} + $NPP_{Foliage}$ + NPP_{Roots})
PAR = photosynthetically active radiation
CC = canopy cover (fraction of ground area)
LAI = leaf area index (leaf area per unit ground area)
Q_{max} = maximum quantum canopy efficiency
R = ratio of NPP to GPP
M = growth modifiers (available water, soil fertility, temperature, etc.)

(Adapted from Sands [11])

Modeling Procedure: Data

- Used previously published productivity data from 12 sites in Minnesota, Wisconsin, and eastern edge of the Dakotas planted in 1987 and 1988 (Netzer et al. [12])
  - –*Populus deltoides* × *P. nigra* (DN) hybrids
  - –Planted at 2.4m × 2.4m spacing (1,735 trees ha^{-1})
  - –Measured multiple times from age 3 to 11 years
  - –Selected 8 sites for calibration (56 datapoints) and 4 sites for validation (25 datapoints)



Data (cont.)

- Summary of climate and soils data gathered for all 12 sites (red = highest, blue = lowest)

Dataset	Site	High Temp[a] (°C; Apr-Oct)	Low Temp[a] (°C; Apr-Oct)	Precipitation[b] (mm; Annual)	Solar[a] (MJ/m²/d)	Soil Texture[c]	Water Table Depth[c] (cm)	Max Avail Water[c] (mm)	Min Avail Water (mm)
Calibration	ASH87	**17.7**	**6.1**	807	13.0	silt loam	30	**131**	92
	ASH88	17.9	6.4	815	13.0	silt loam	30	131	92
	FRM88	20.8	9.7	837	13.8	clay loam	**>100**	182	**0**
	GRF87	20.8	**9.8**	662	**14.0**	loam	75	164	41
	GRF88	20.7	9.8	670	13.9	loam	>100	192	0
	MIL87	20.4	7.7	**660**	13.2	silty clay loam	**0**	196	**196**
	MON87	21.3	9.1	839	**12.9**	silt loam	>100	**215**	0
	MON88	**21.4**	9.2	**843**	13.0	silt loam	>100	211	0
Validation	CLO88	**17.5**	**6.9**	**826**	**12.9**	loam	**>100**	163	**0**
	FAR87	21.2	8.6	**496**	13.3	silty clay	**23**	**158**	**122**
	SXF87	**22.5**	**9.8**	605	**14.0**	silty clay loam	>100	**190**	0
	SXF88	22.3	9.8	634	13.9	silty clay loam	>100	181	0

[a] Temperature and solar radiation data obtained from National Renewable Energy Laboratory
[b] Precipitation data obtained from NOAA National Climatic Data Center monthly summaries
[c] Soils data obtained from existing soil maps (Web Soil Survey)

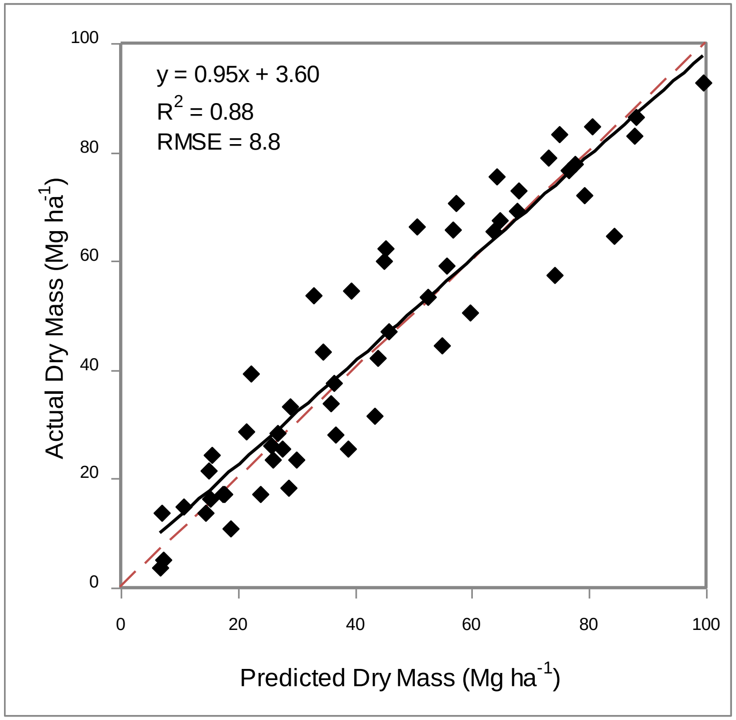
Modeling Procedure: Parameters

- Of the 60 physiological parameters in the model…
  - 40 parameter values found in the literature
  - 13 parameters assigned default 3-PG values (mainly conversion factors and low-sensitivity parameters)
  - 7 parameters assigned "other" values (6 based on expert knowledge, 1 based on best-fit of model)

- For all parameter values, see article in BioEnergy Research:
  - Headlee, WL, Zalesny Jr, RS, Donner, DM, Hall, RB. Using a process-based model (3-PG) to predict and map hybrid poplar biomass productivity in Minnesota and Wisconsin, USA. BioEnergy Research. Accepted 8/27/2012. DOI 10.1007/s12155-012-9251

Modeling Procedure: Calibration

- Manipulated unknown physiological parameter (age at full canopy; fullCanAge) along with unknown site variable (fertility rating; FR) to produce best-fit model for calibration sites



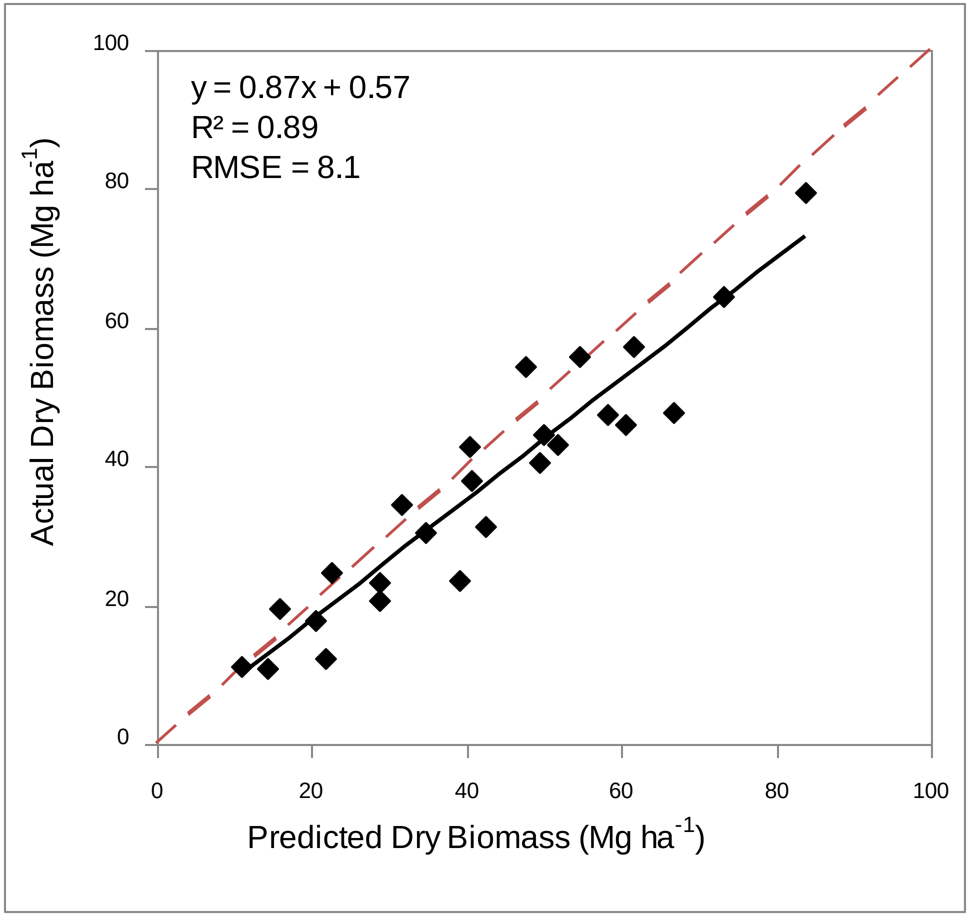
- Best-fit model selected based on lowest root mean square error (RMSE; Mg ha^{-1})

FR	fullCanAge	RMSE
1.00	**5**	**8.77**
0.95	4	8.94
0.90	3	9.69

Modeling Procedure: Validation

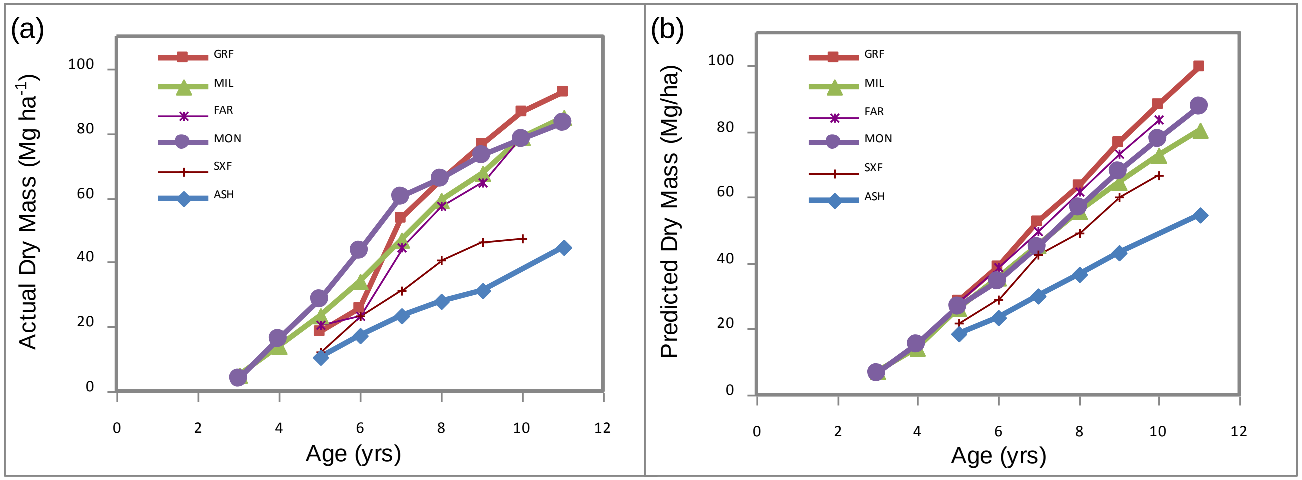
- Used calibration settings to predict yields at the remaining 4 sites from Netzer et al. (2002)

- Model fit (R^2=0.89, RMSE = 8.1 Mg ha^{-1}) is similar as for calibration (R^2=0.88, RMSE = 8.8 Mg ha^{-1})

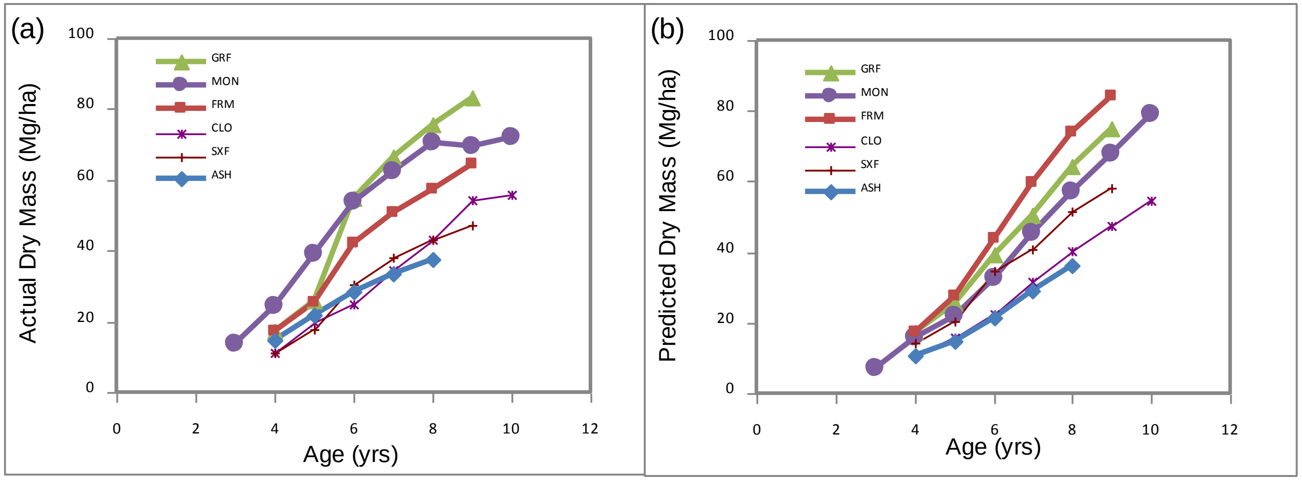


Validation (cont.)

- 1987 plantings
  - (a) Actual biomass
  - (b) Predicted biomass

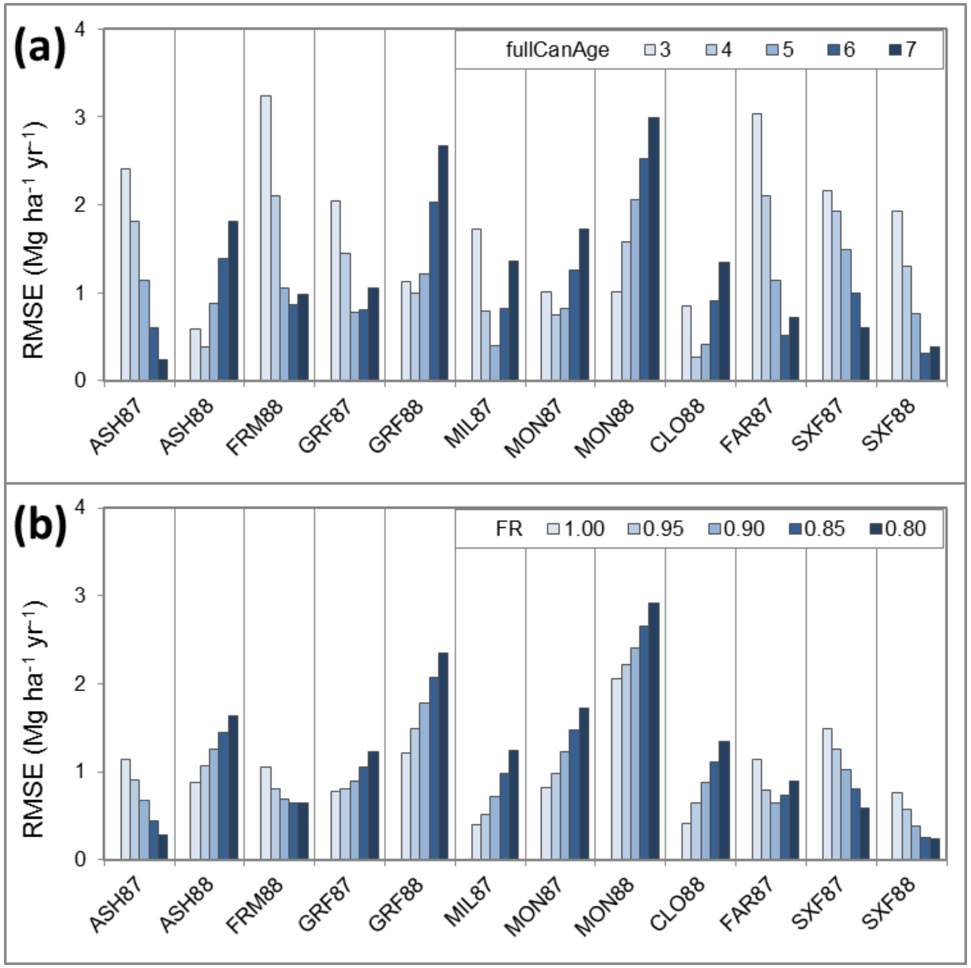


- 1988 plantings
  - (a) Actual biomass
  - (b) Predicted biomass



Sensitivity Analysis

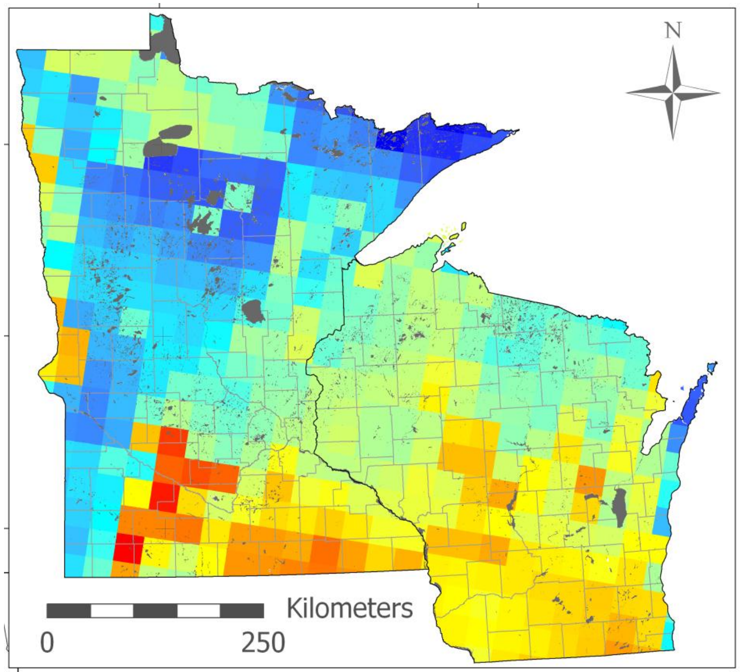
- Independently manipulated fullCanAge and FR to gauge model sensitivity
  - fullCanAge: 3, 4, 5, 6, 7
  - FR: 0.80, 0.85, 0.90, 0.95, 1.00
- Different sites achieved minimum RMSE at different values of fullCanAge and FR
- In reality, fullCanAge likely increases as FR decreases (hypothesized values: FR=0.85-1.00; fullCanAge=3-6)

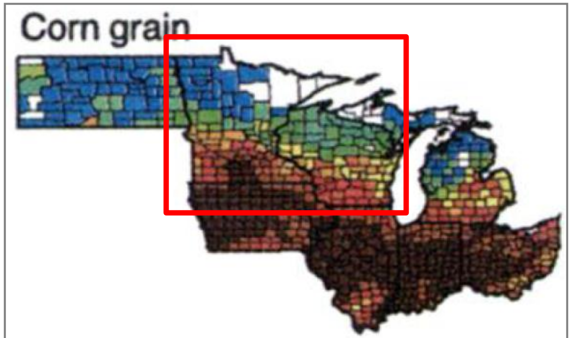


RMSE for individual sites by (a) full canopy age, and (b) fertility rating.

Mapping

- Same physiological parameters and settings as before
- Used existing spatial layers for climate data (NARR; from NOAA) and soils data (STATSGO; from NRCS)
- Generated biomass estimates for each 32-km climate grid (Mg ha^{-1} yr^{-1} at end of 10-year rotation)
- Productivity similar to that previously reported (4.8-9.0 Mg ha^{-1} yr^{-1}) for DN34 (Zalesny et al. [13])
- Spatial pattern similar to that observed for corn grain productivity (Prince et al. [14])



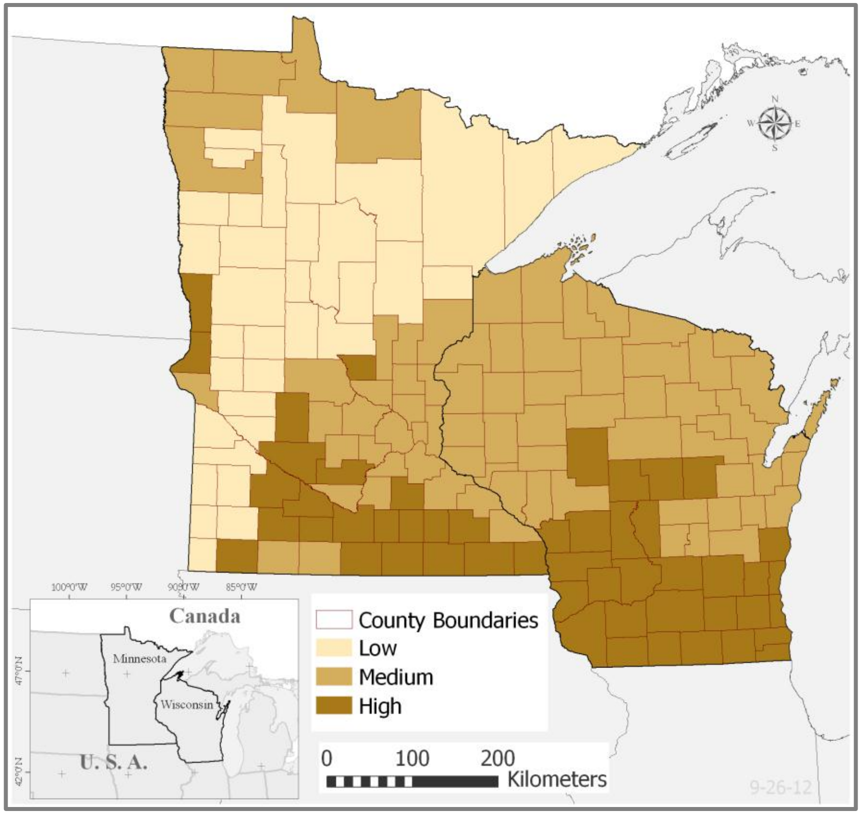


Source: *Ecological Applications* 11: 1194-1205

Mapping (cont.)

- Also have recently generated county-level estimates, for ease of comparison with agricultural data

- Higher-resolution (within-county) maps may be produced with finer-scale soils data (i.e. SSURGO)



Discussion

- Overall model fit is good, but it varies by site
  - Likely due to differences between sites in actual values of fullCanAge and FR
  - Also disease was known to be an issue at some of the most over-predicted sites (FRM88, SXF87, SXF88)
- Only calibrated and validated for selected DN hybrids; other genotypes may perform differently
- Only evaluated aboveground biomass production; still needs to be calibrated & validated for height, DBH, root biomass, etc.
- Due to averaging, map should only be used at coarse (i.e. regional) scale rather than fine (i.e. landowner) scale
- Questions?

Stem canker on hybrid poplar stem. (photo R. Zalesny)

Northern States Power plant at Granite Falls, MN. (photo R. Zalesny)

Acknowledgements

- 3-PG software provided by the Commonwealth Scientific and Industrial Research Organization (CSIRO)
- Funding provided by
  – U.S. Forest Service, Institute for Applied Ecosystem Studies (IAES)
  – Wisconsin FOCUS ON ENERGY Program
- Co-authors
  – Richard Hall (ISU)
  – Ronald S. Zalesny, Jr. (IAES)
  – Deahn Donner (IAES)
- Review and technical support
  – David Coyle (University of Georgia)
  – Steven Jungst (ISU)
  – Philip Dixon (ISU)
  – Sue Lietz (IAES)
  – Tina Baumann (IAES)

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