Presentation given the TransLinks workshop:

Modeling and Managing Watersheds

September 13-16, 2011

Kigali, Rwanda
Umubano Hotel, Boulevard de l'umuganda

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The Use of Modeling in Watershed Management and Valuation

Steven McNulty, Ge Sun and Erika Cohen
USDA Forest Service

Purpose of this Session

- Discuss the reasons for using models for managing and valuing watersheds

- Give examples of how models are used in other countries

- Discuss appropriate use of models

What is model?

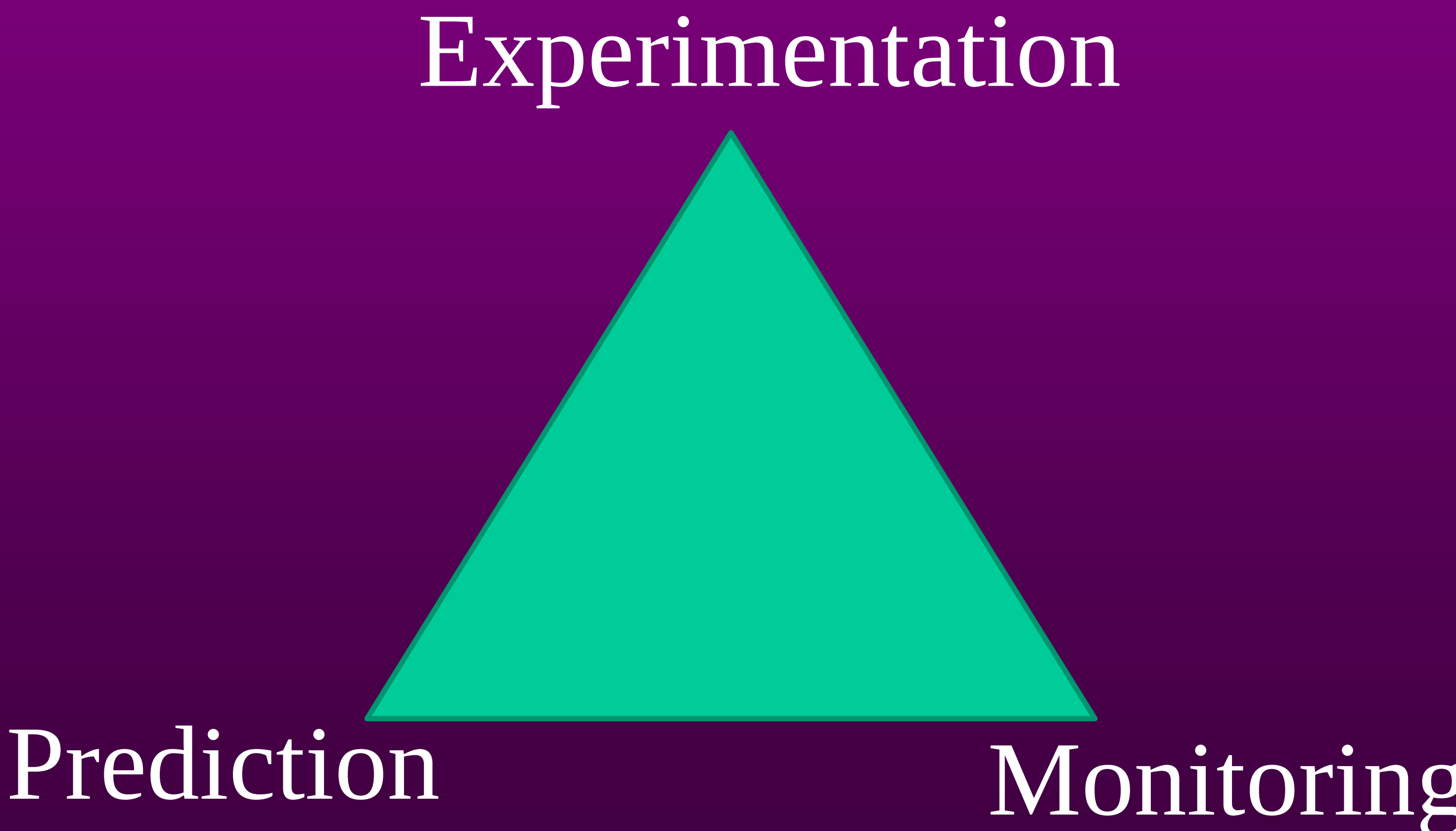
A model is a representation containing the essential structure of some object or event in the real world

Why use a Model?

Because "all models are wrong, but some are useful"

George P. Box

The Three Roles of Modeling



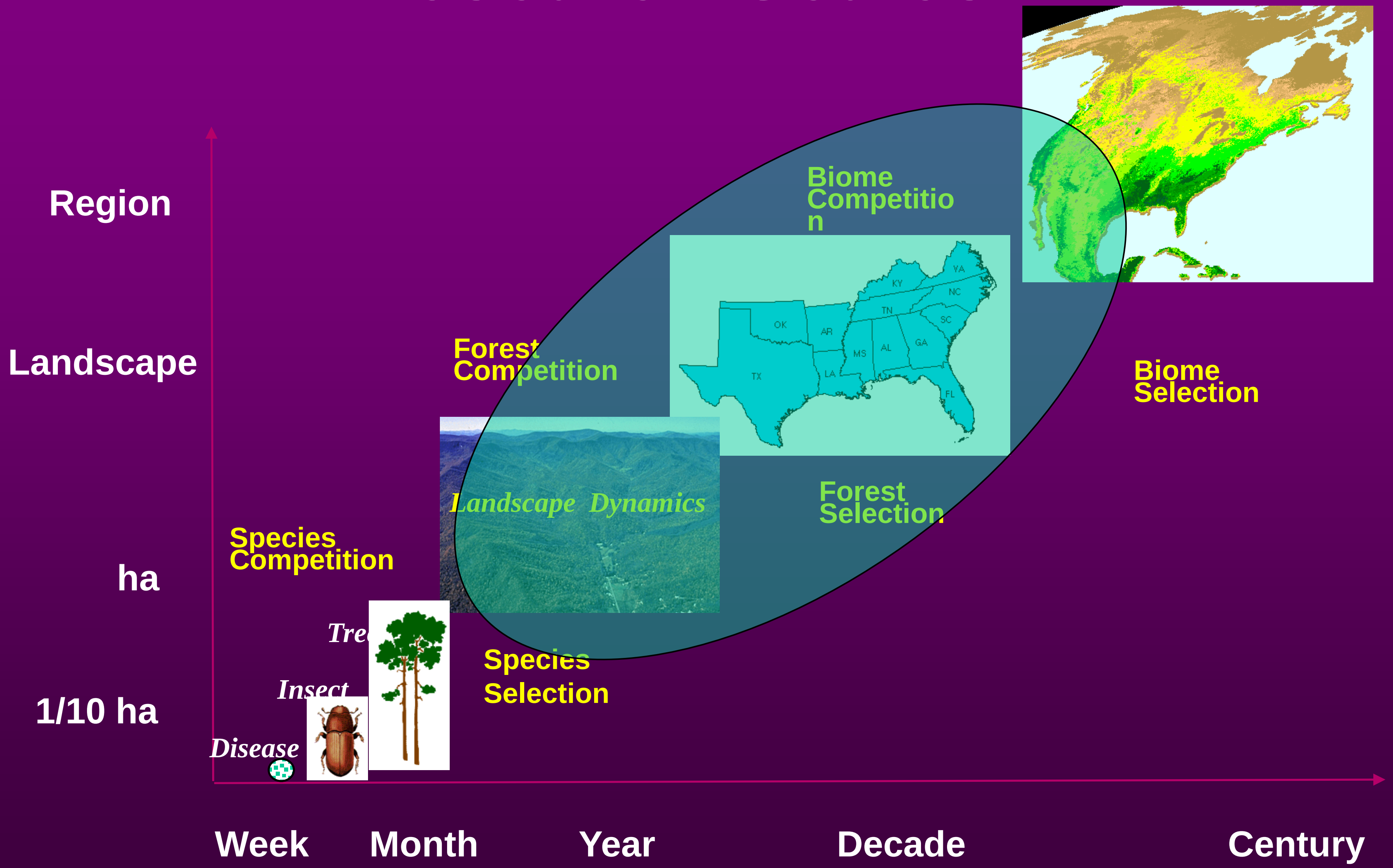
Examples of Model Application

- Is water availability, soil erosion, sedimentation, biodiversity or productivity increasing or decreasing? Why?
- How will water availability, soil erosion, sedimentation, biodiversity or productivity change in the future? Why?
- How can we better manage our watersheds to improve their condition?
- What will be the economic cost and benefit?

Five Major Considerations For Modeling Watersheds

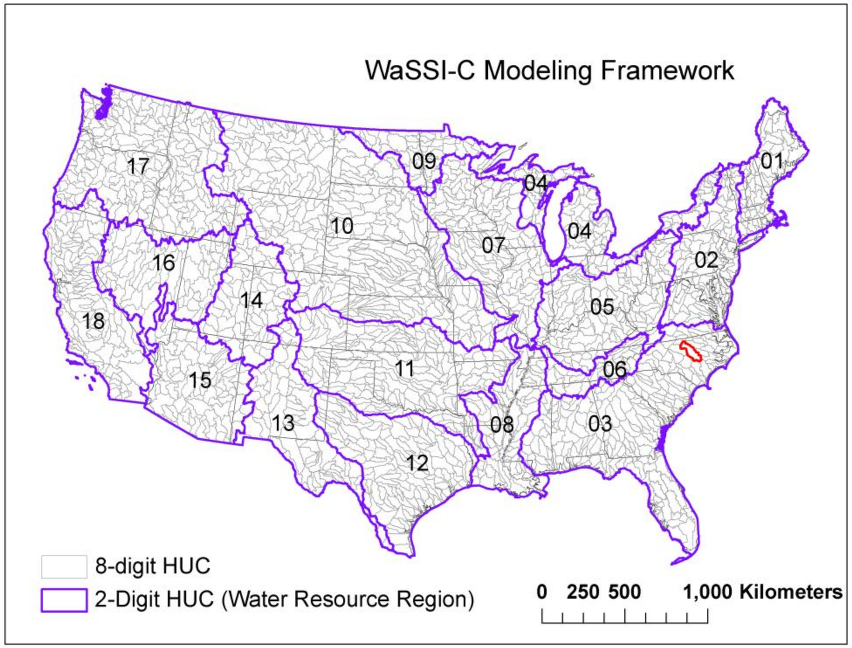
1. Question Dependent
2. Knowledge Limitations
3. Data Limitations
4. Time and Cost Limitations
5. Precision Dependent

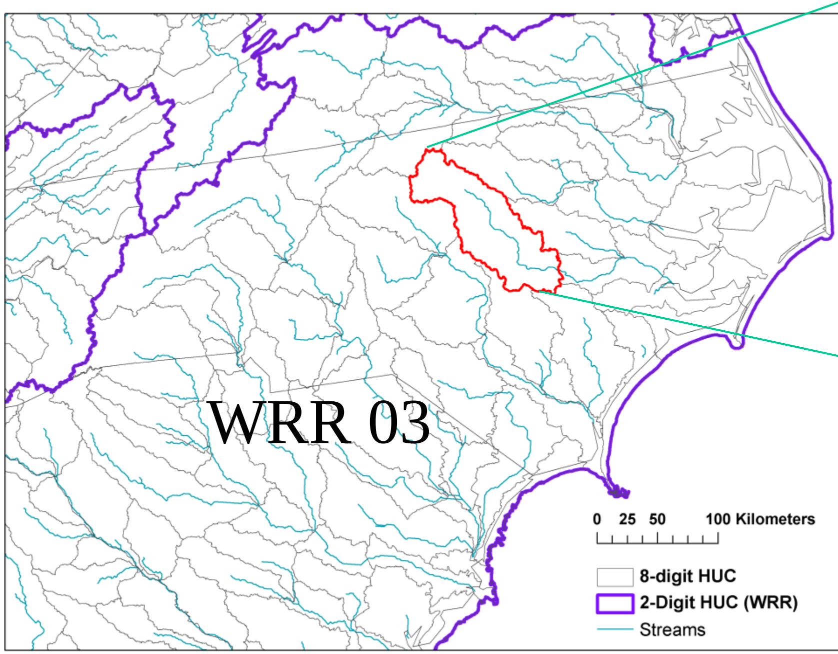
Research Scales

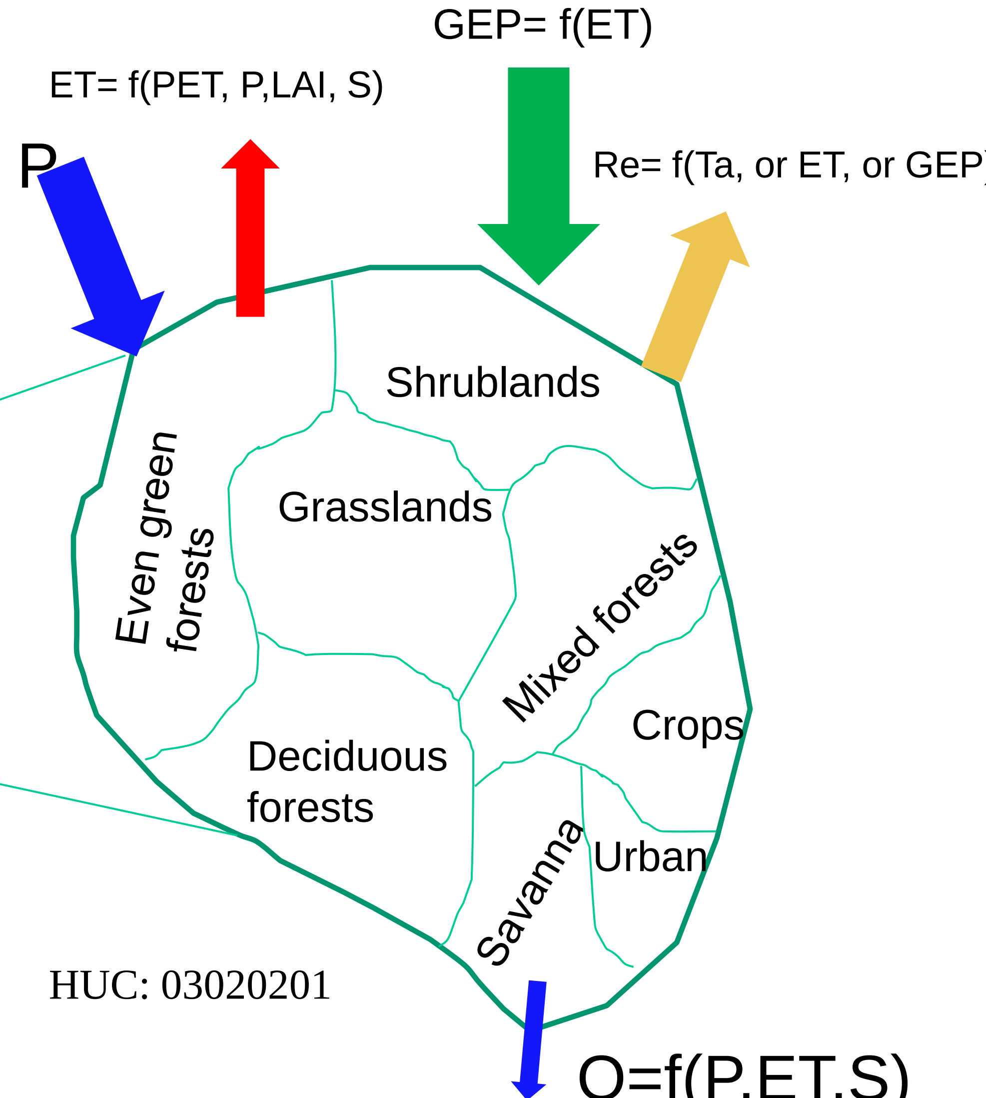


Water balance Carbon balance

ΔS = P- Q - ET NEE = - (GEP – Re)







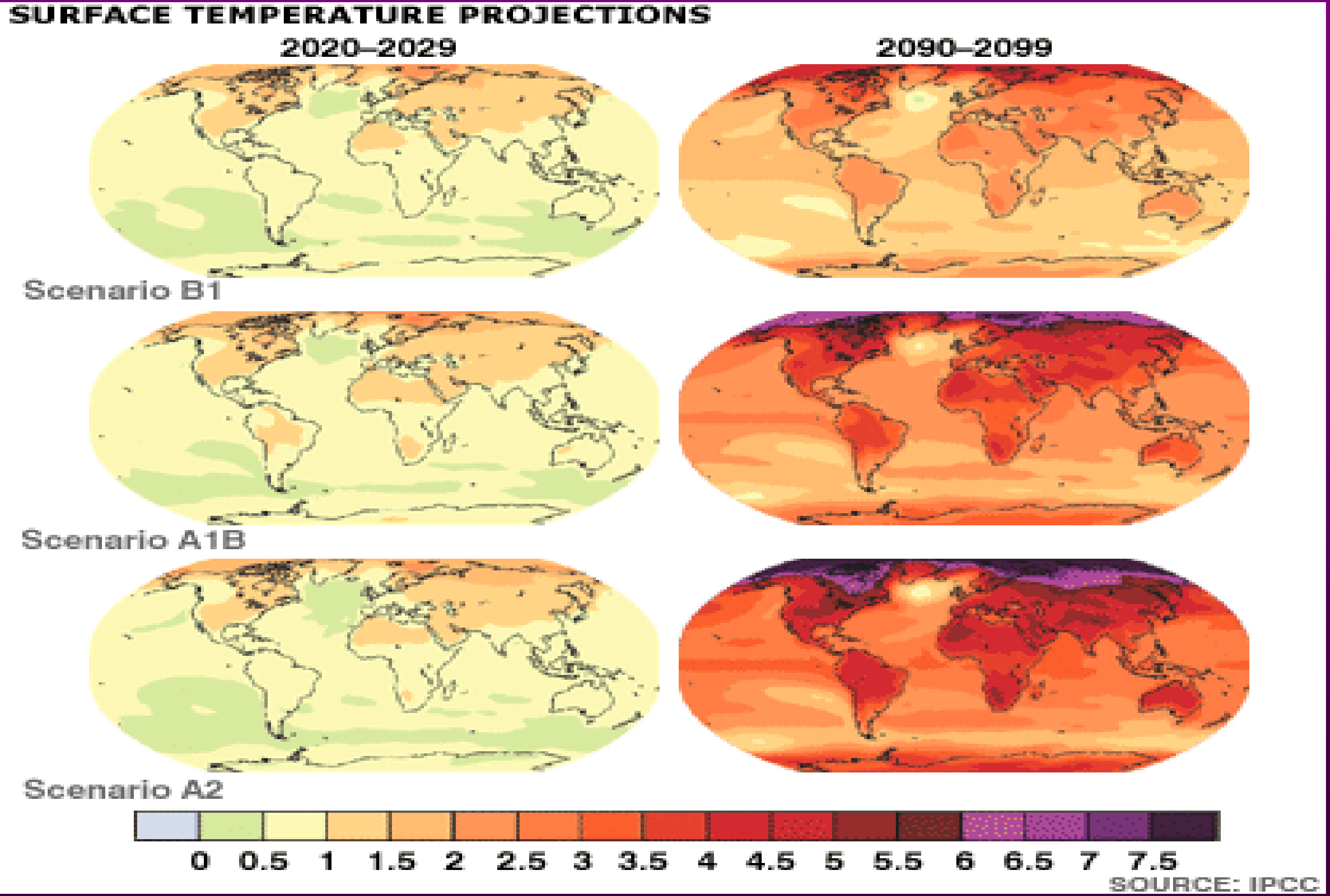
Good Predictions Start with Good Data

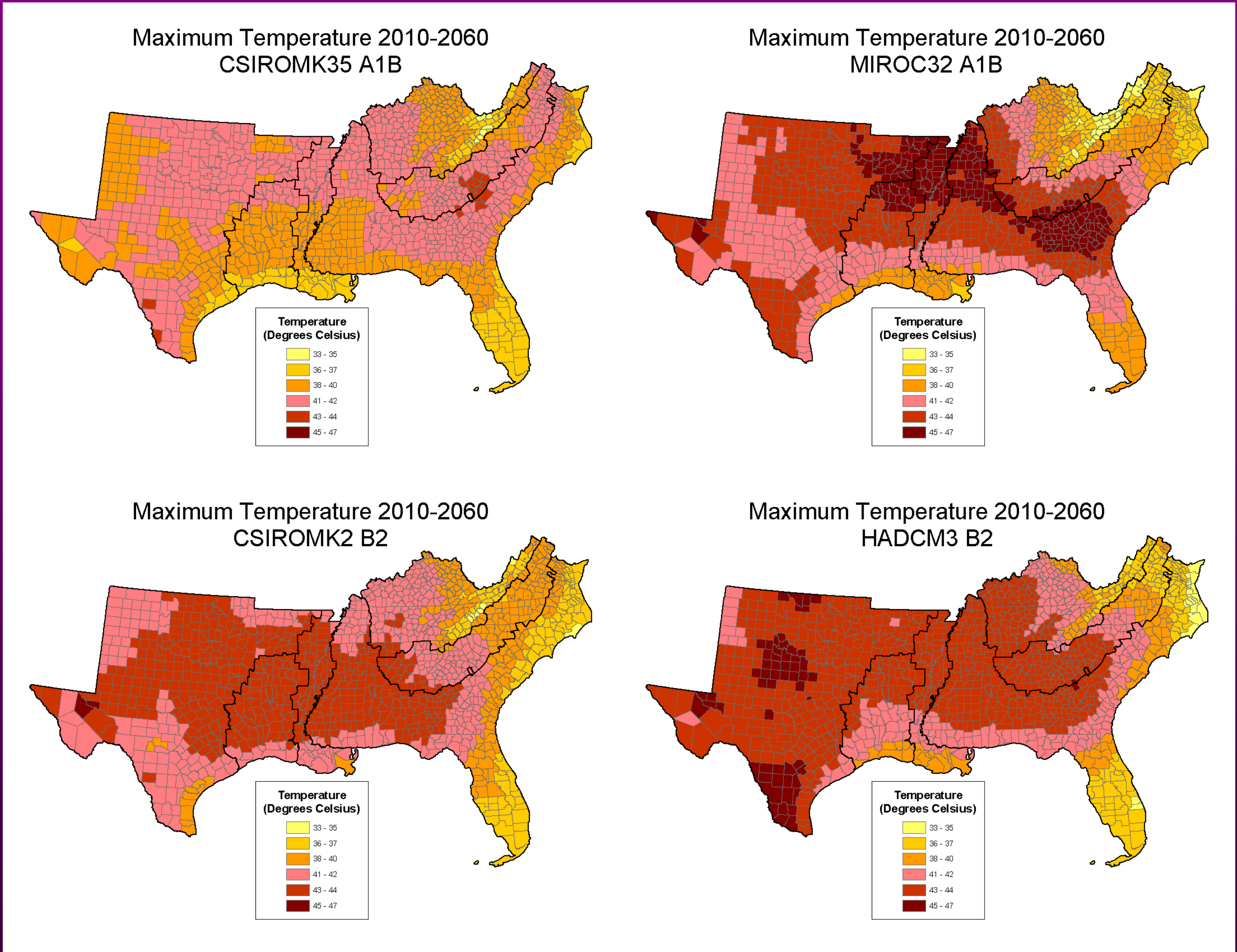
(Garbage in – Garbage out)

Data is needed for

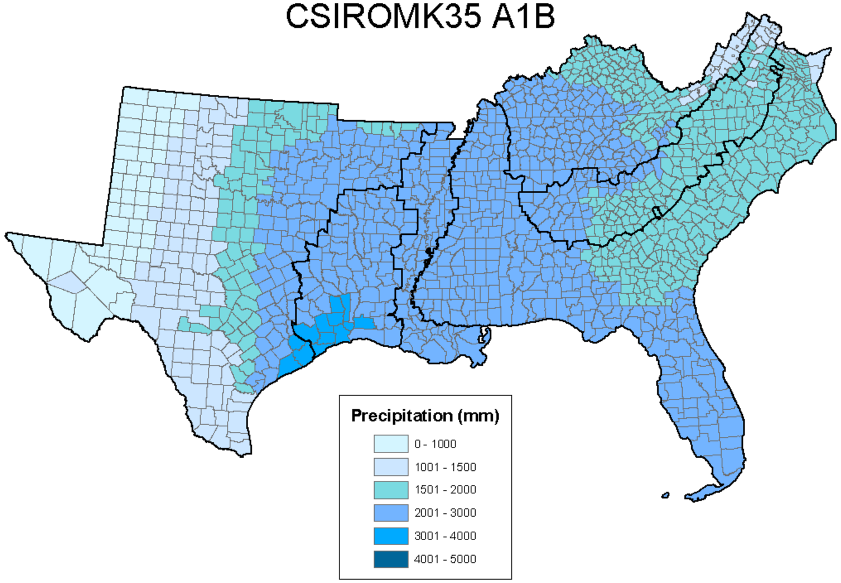
- developing equations
- parameterizing the model
- Validating the model outputs
- Projecting model outputs forward in time and space

IPCC world CC map

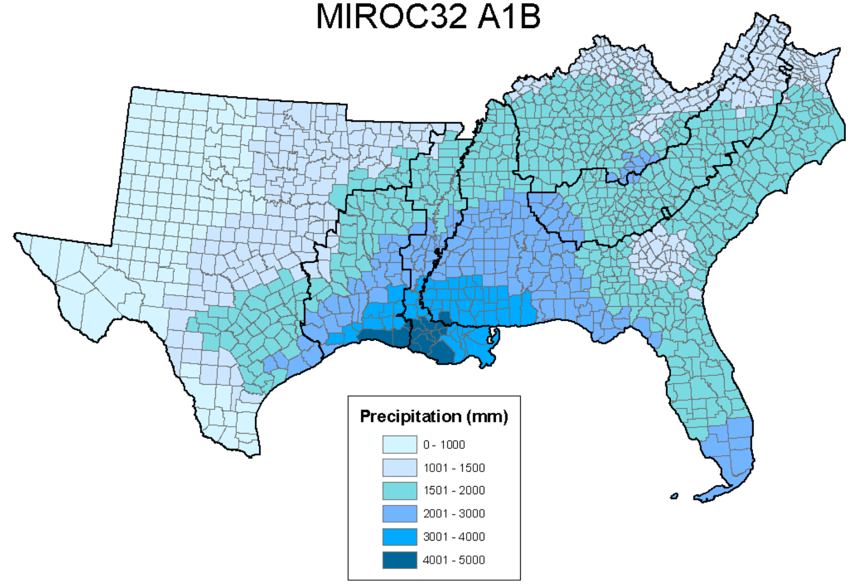



Maximum Temperature 2010-2060
CSIROMK35 A1B
Temperature (Degrees Celsius)
33 - 35
36 - 37
38 - 40
41 - 42
43 - 44
45 - 47
Maximum Temperature 2010-2060
MIROC32 A1B
Temperature (Degrees Celsius)
33 - 35
36 - 37
38 - 40
41 - 42
43 - 44
45 - 47
Maximum Temperature 2010-2060
CSIROMK2 B2
Temperature (Degrees Celsius)
33 - 35
36 - 37
38 - 40
41 - 42
43 - 44
45 - 47
Maximum Temperature 2010-2060
HADCM3 B2
Temperature (Degrees Celsius)
33 - 35
36 - 37
38 - 40
41 - 42
43 - 44
45 - 47

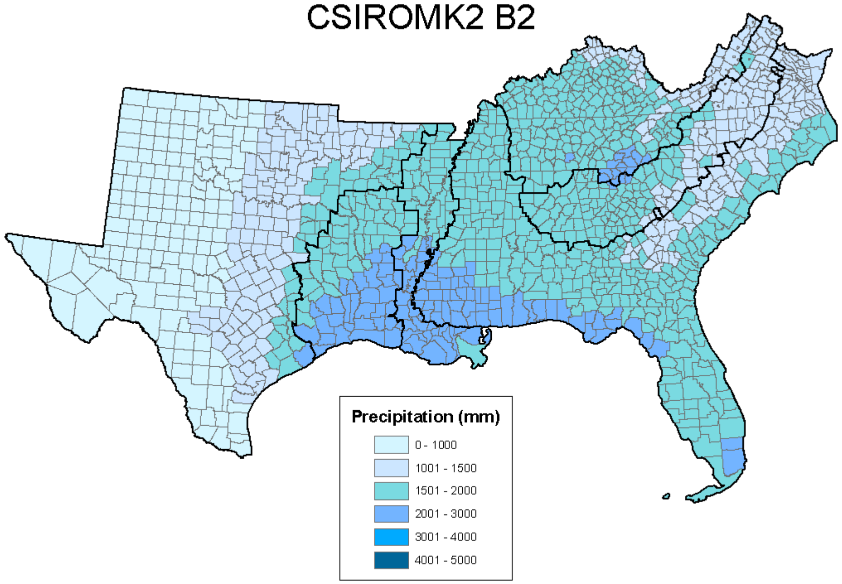
Maximum Precipitation 2010-2060
CSIROMK35 A1B



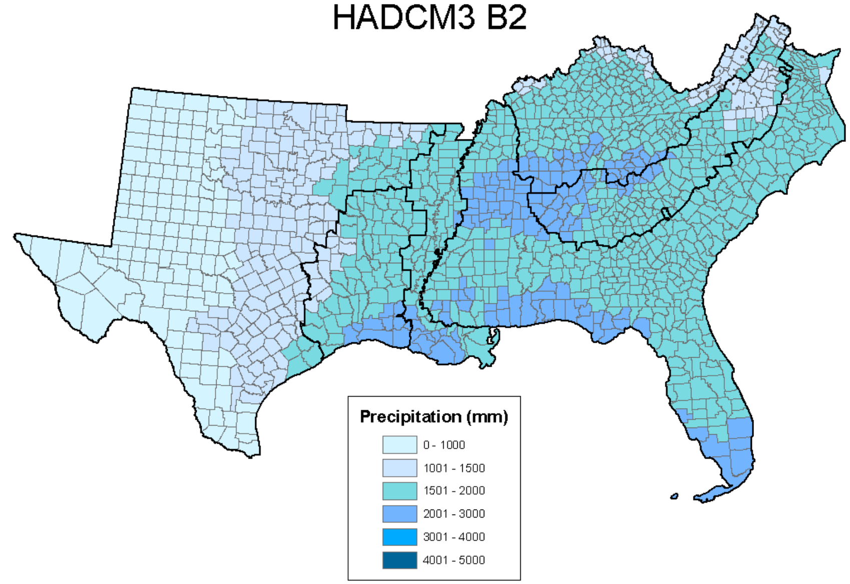
Maximum Precipitation 2010-2060
MIROC32 A1B



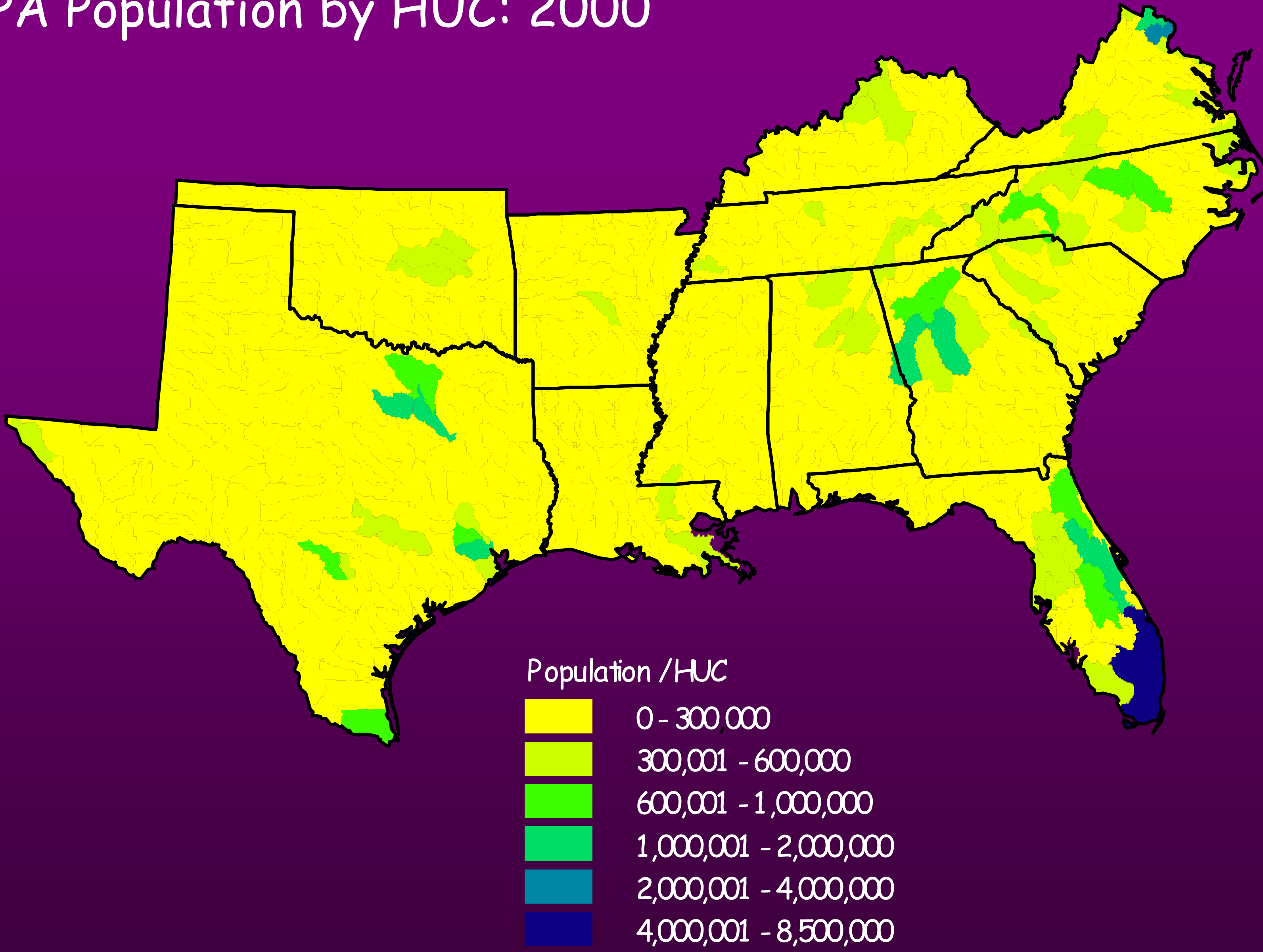
Maximum Precipitation 2010-2060
CSIROMK2 B2



Maximum Precipitation 2010-2060
HADCM3 B2



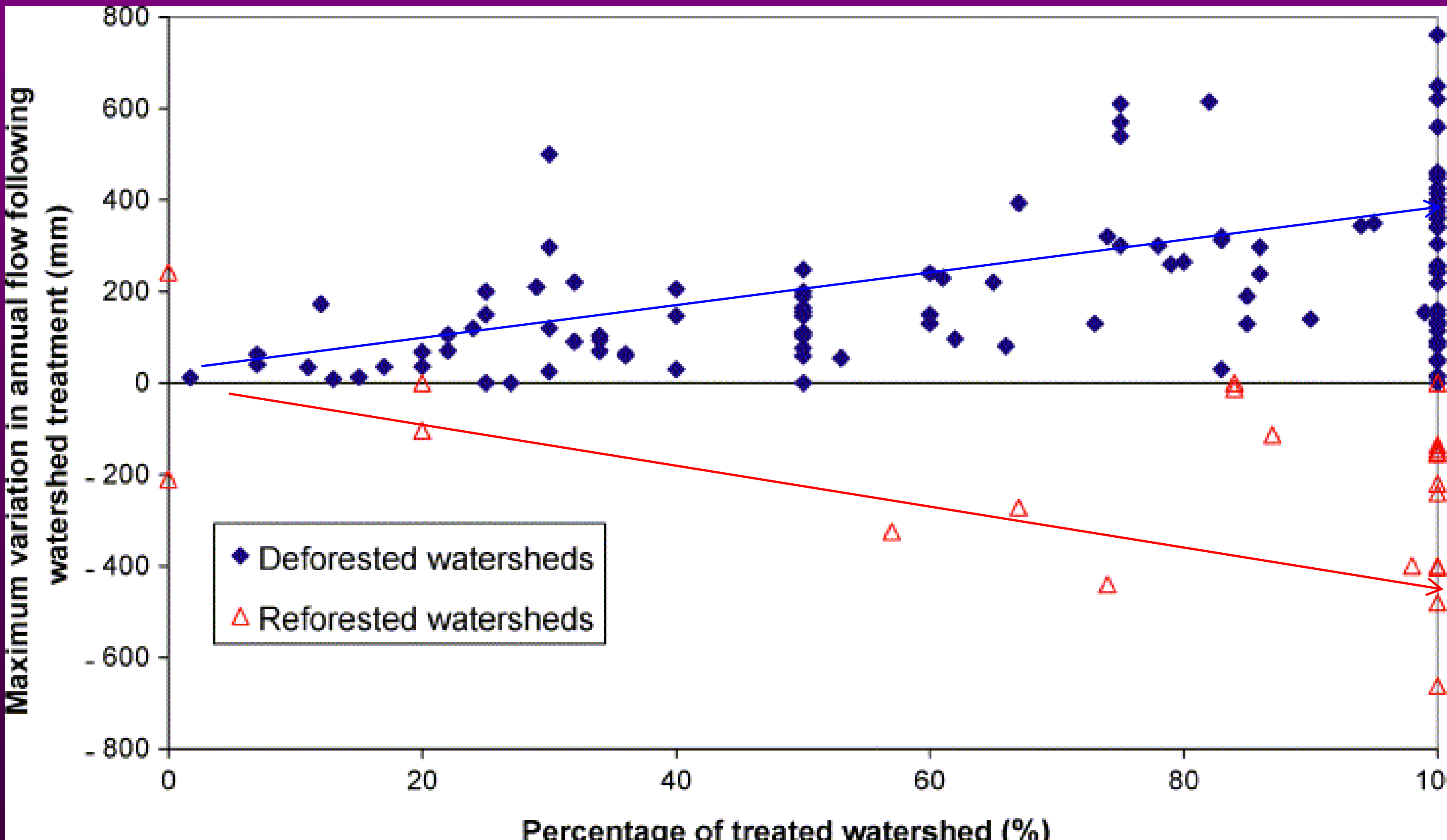
NPA Population by HUC: 2000



Sensitivity of Forest Water Yield

Streamflow Flow Response to Watershed Manipulation

(Andreassian, Journal of Hydrology 2004 (291):1-27)



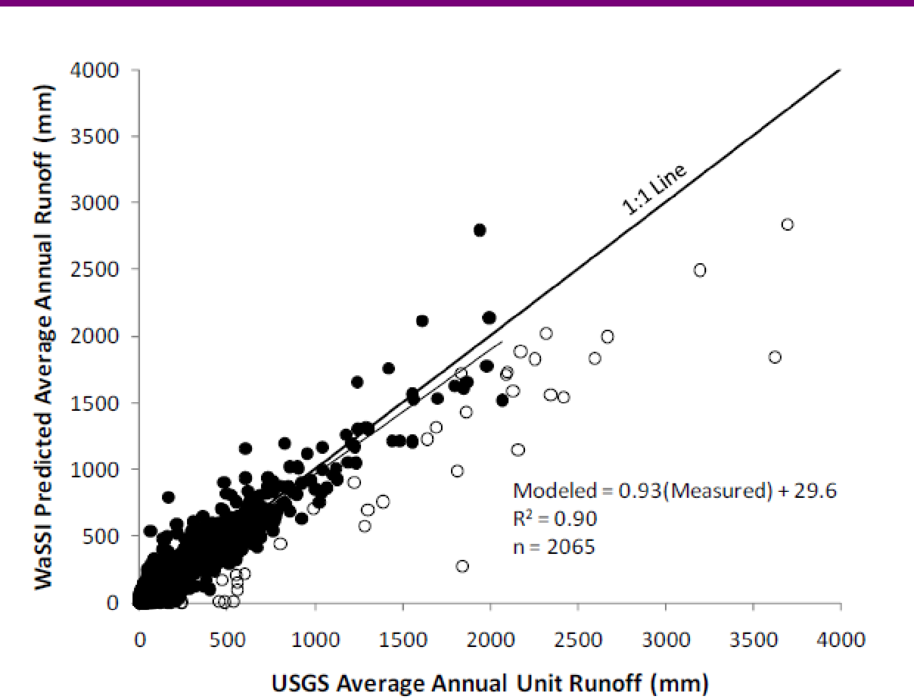
An Example of Watershed Modeling using

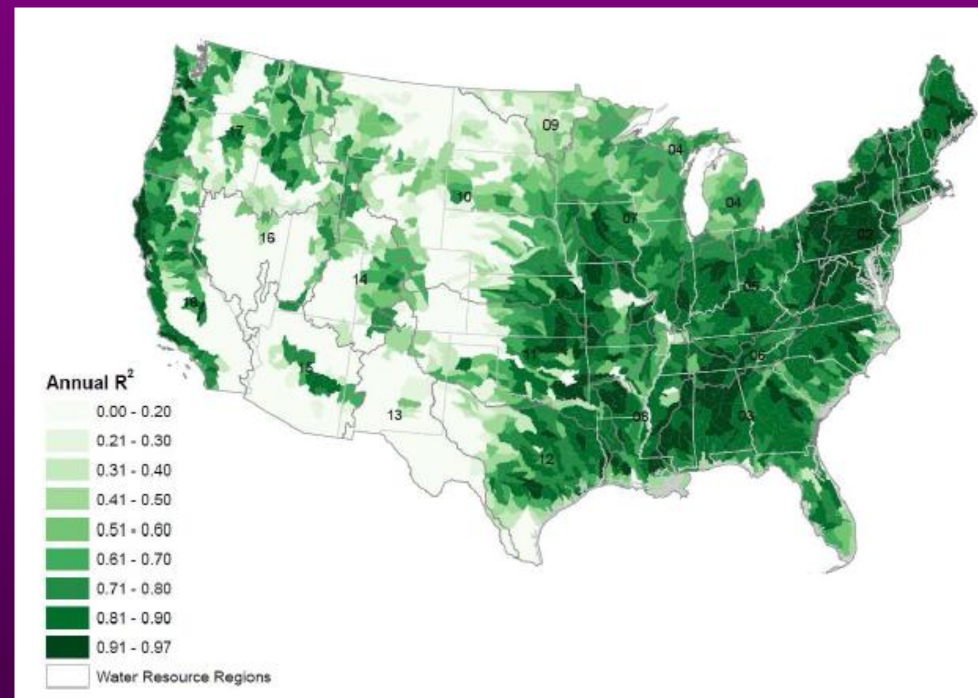
WaSSI (Water Supply Stress Index)

Can we Trust Model Outputs?

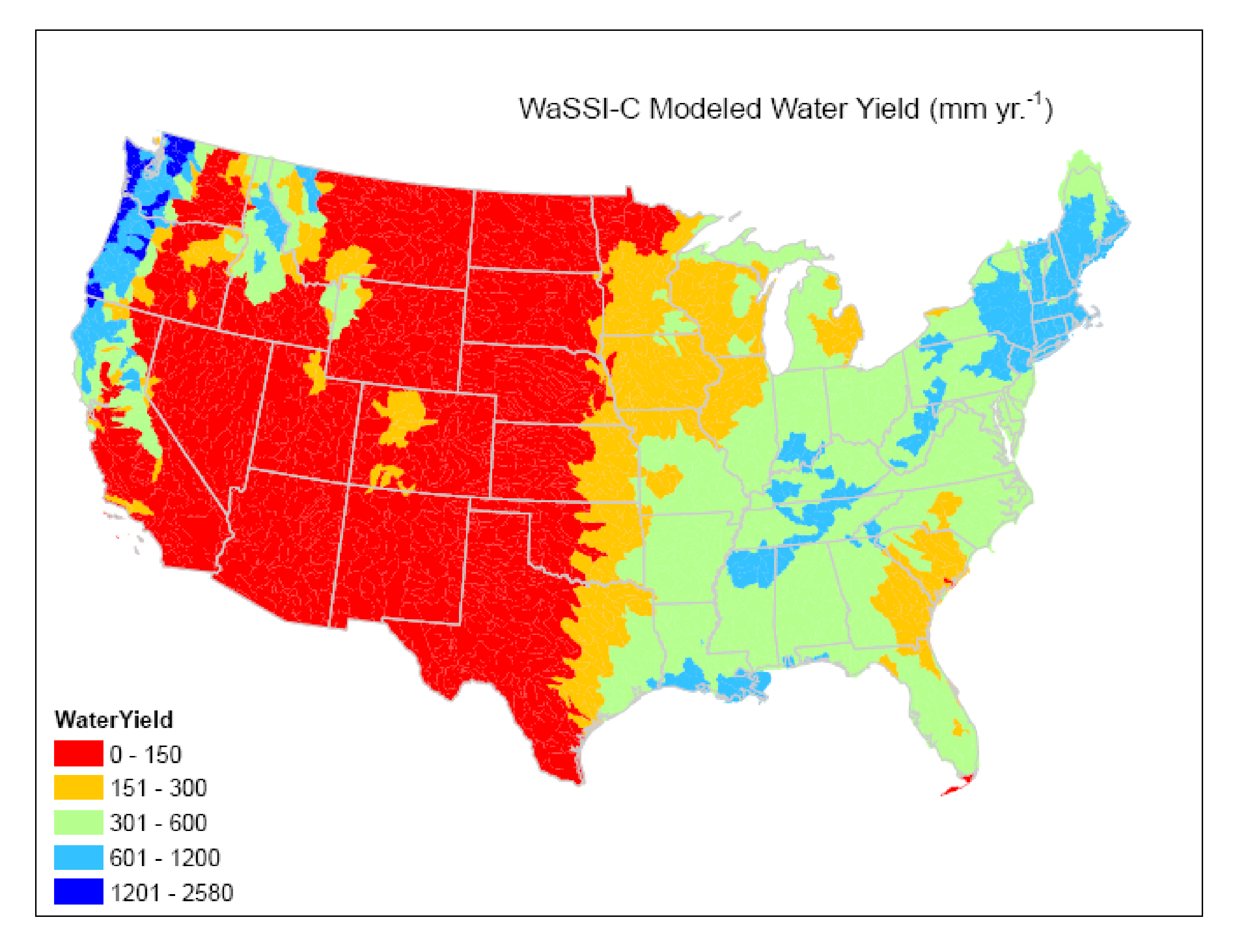
Can we use Outputs for Decision Making?

Model Validation (Runoff)

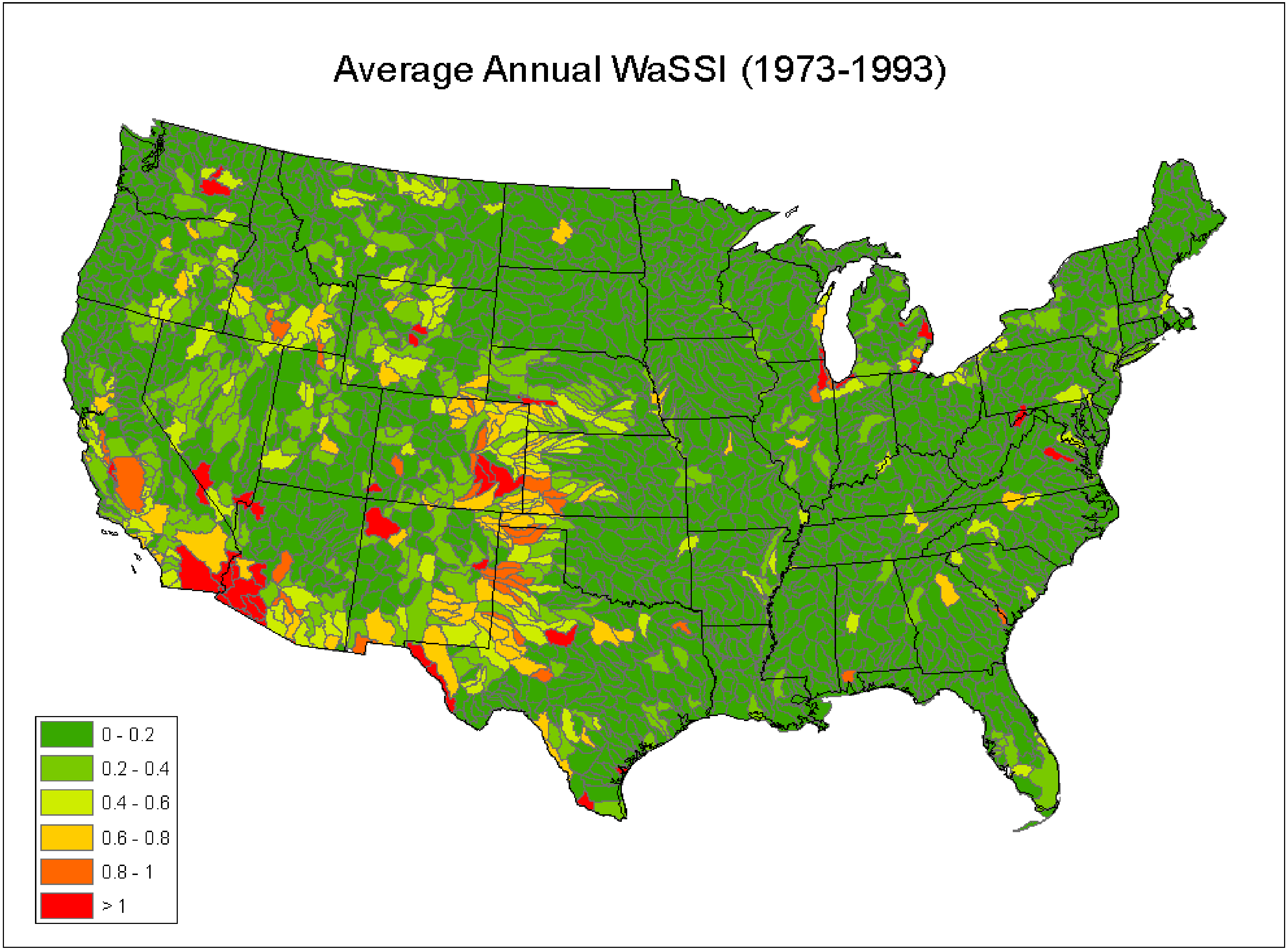


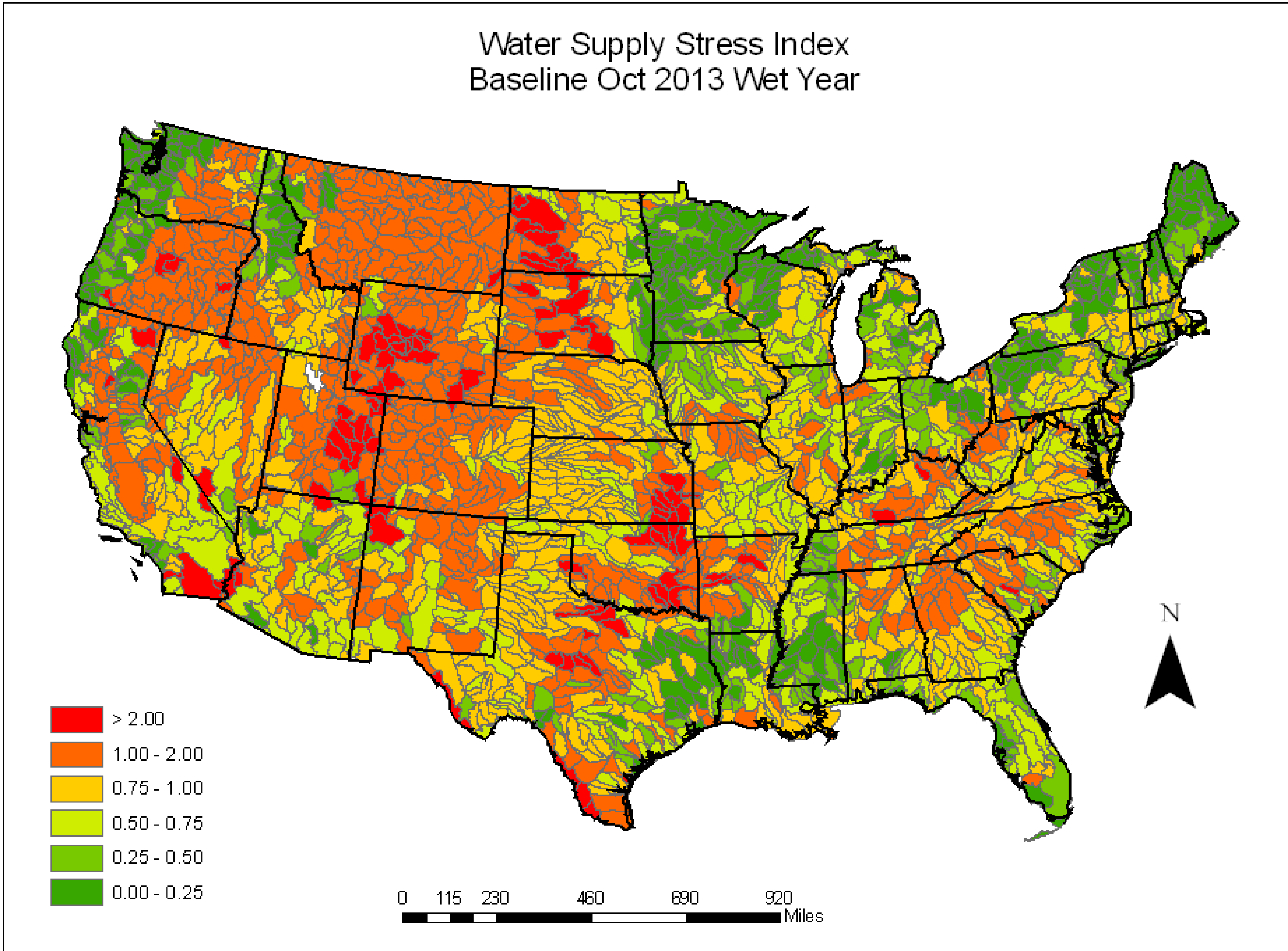


Water Yield



Sun et al., JGR-Biogeoscience, (In press)

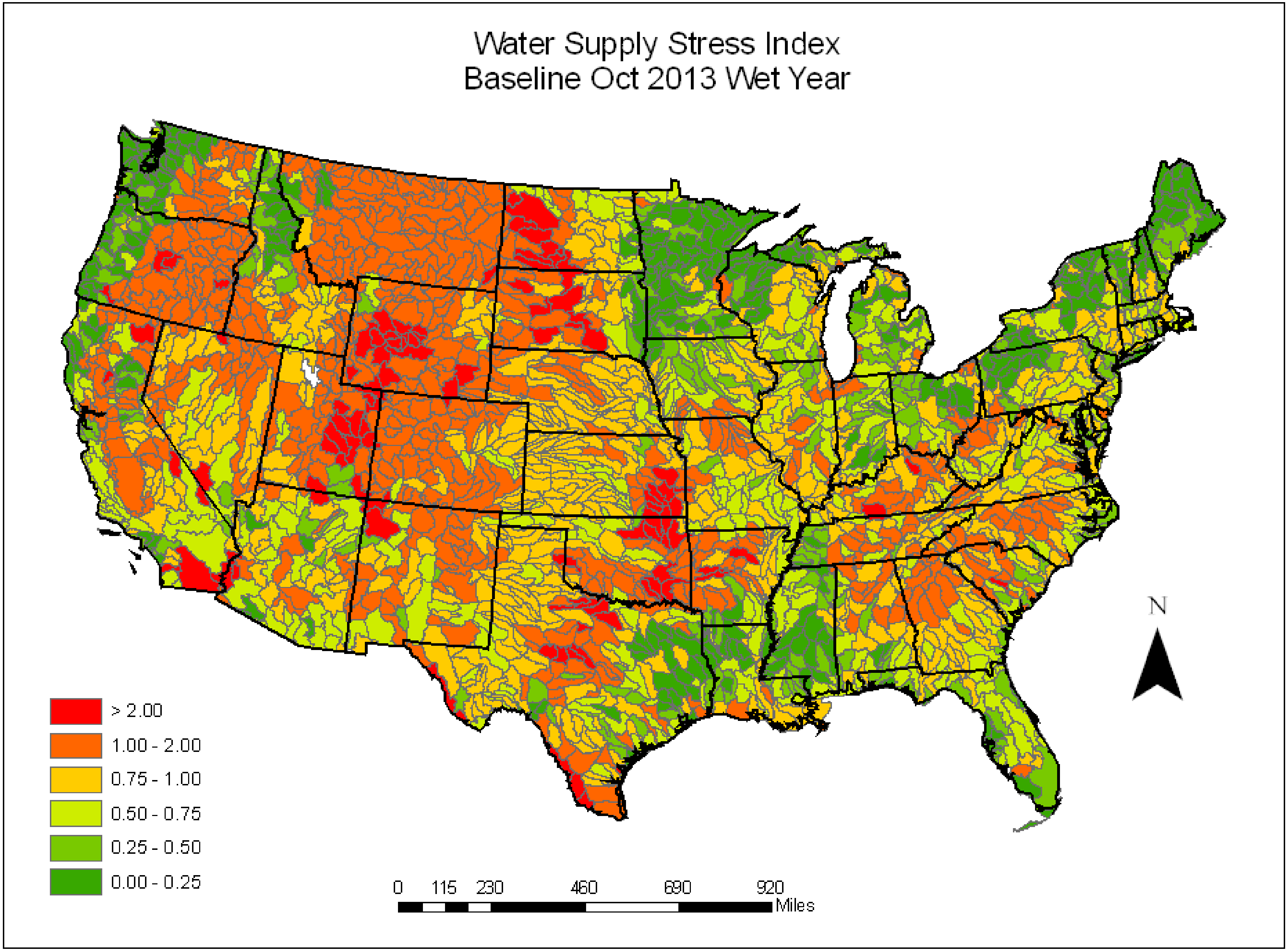

Average Annual WaSSI (1973-1993)
0 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8
0.8 - 1
> 1

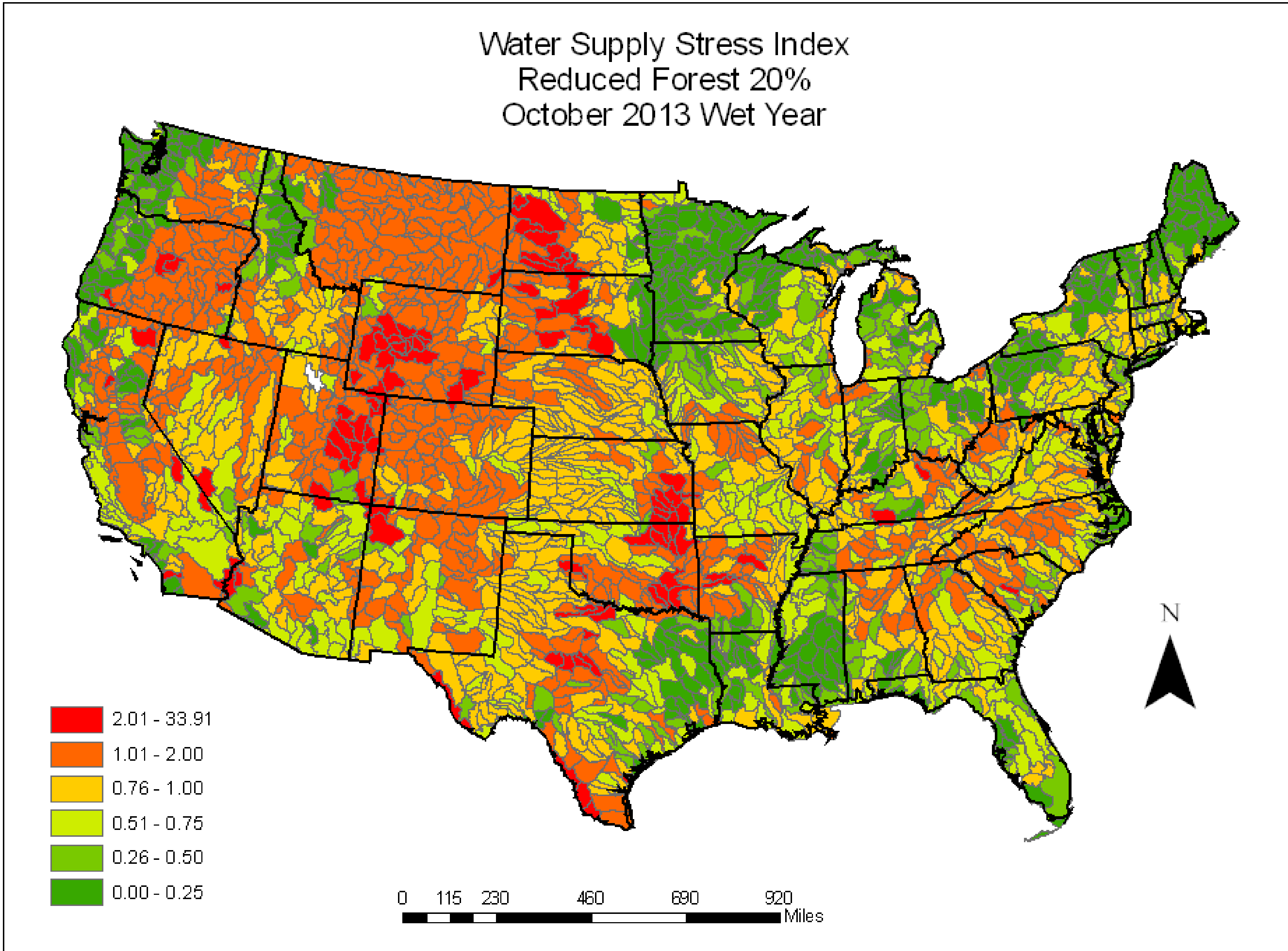


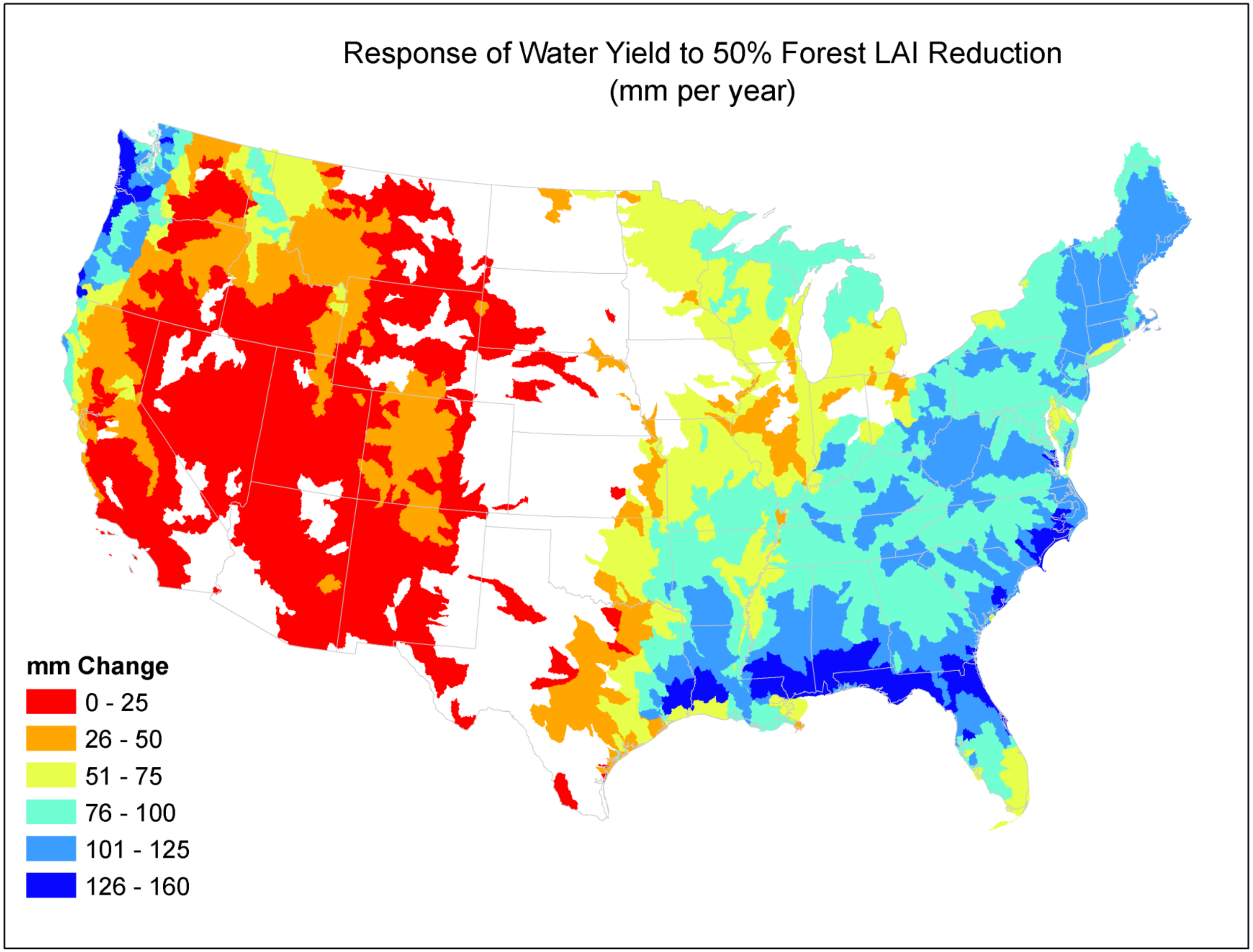
Water Supply Stress Index
Baseline Oct 2013 Wet Year
> 2.00
1.00 - 2.00
0.75 - 1.00
0.50 - 0.75
0.25 - 0.50
0.00 - 0.25
N
0
115
230
460
690
920
Miles

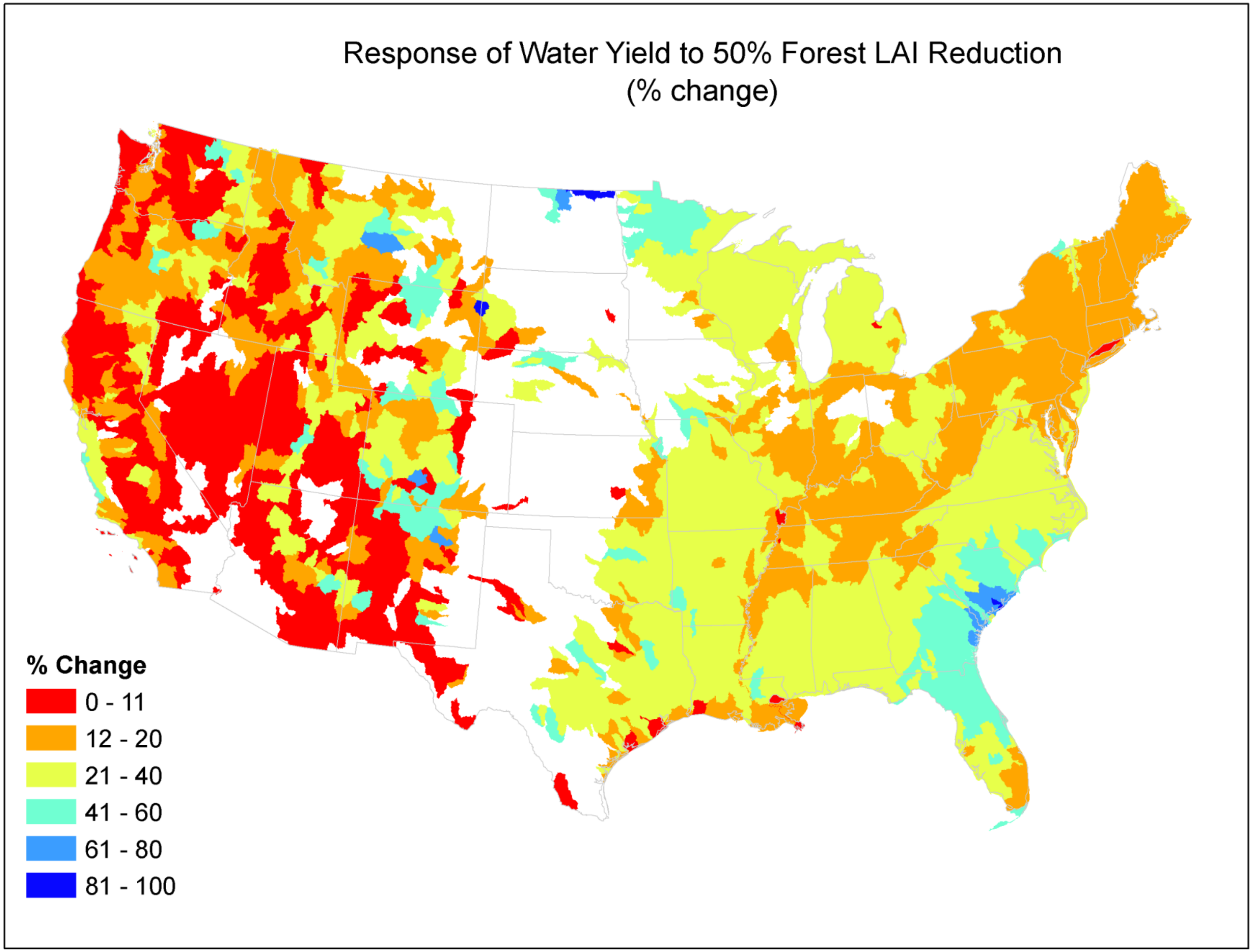
Changes in Current Conditions

Deforestation


Water Supply Stress Index
Baseline Oct 2013 Wet Year
> 2.00
1.00 - 2.00
0.75 - 1.00
0.50 - 0.75
0.25 - 0.50
0.00 - 0.25
0 115 230 460 690 920
Miles
N

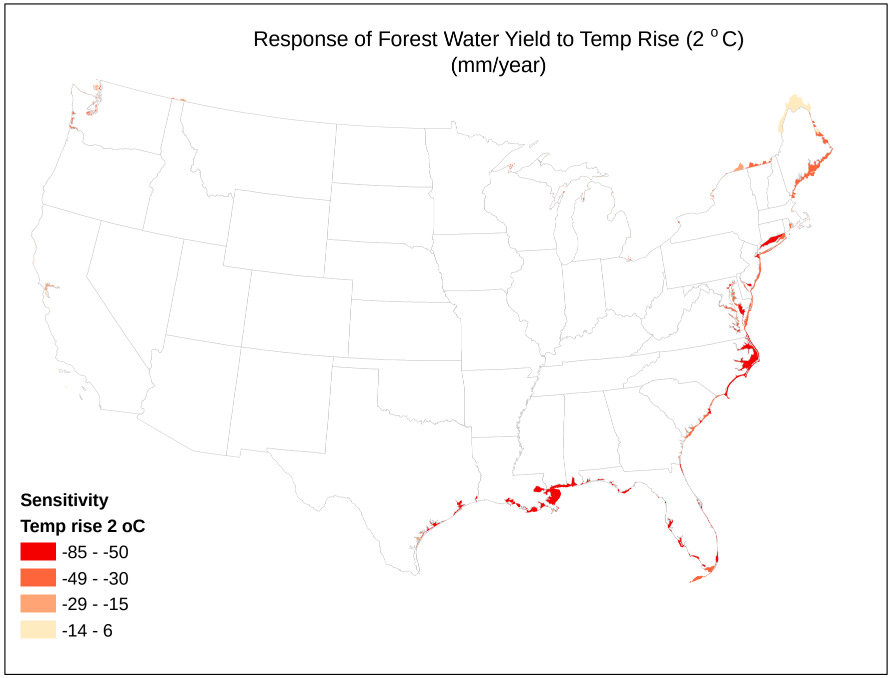

Water Supply Stress Index
Reduced Forest 20%
October 2013 Wet Year
2.01 - 33.91
1.01 - 2.00
0.76 - 1.00
0.51 - 0.75
0.26 - 0.50
0.00 - 0.25
0
115
230
460
690
920
Miles
N

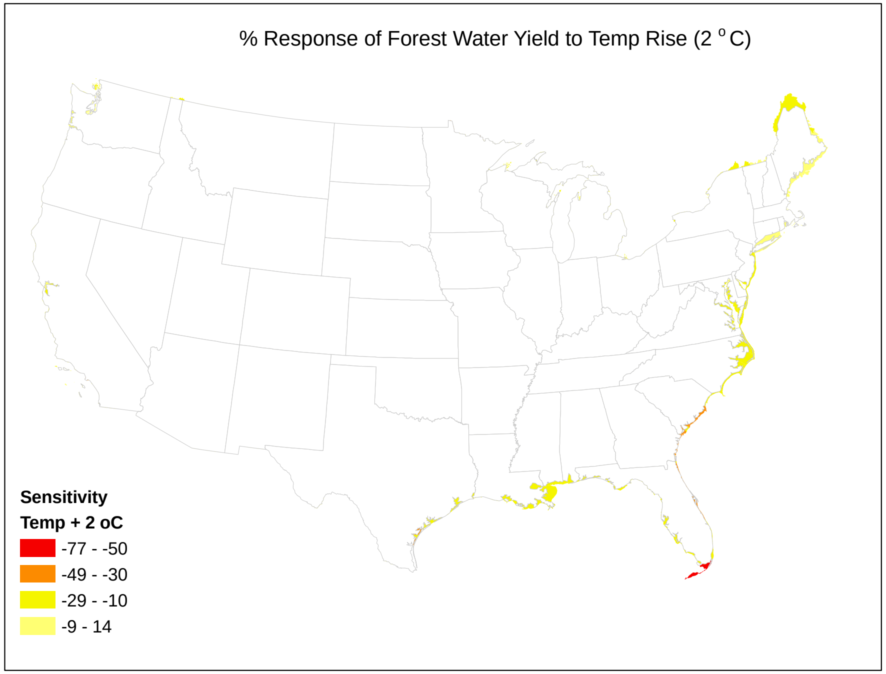

Response of Water Yield to 50% Forest LAI Reduction
(mm per year)
mm Change
0 - 25
26 - 50
51 - 75
76 - 100
101 - 125
126 - 160


Response of Water Yield to 50% Forest LAI Reduction
(% change)
% Change
0 - 11
12 - 20
21 - 40
41 - 60
61 - 80
81 - 100

Climate Change

Temp + 2 ºC

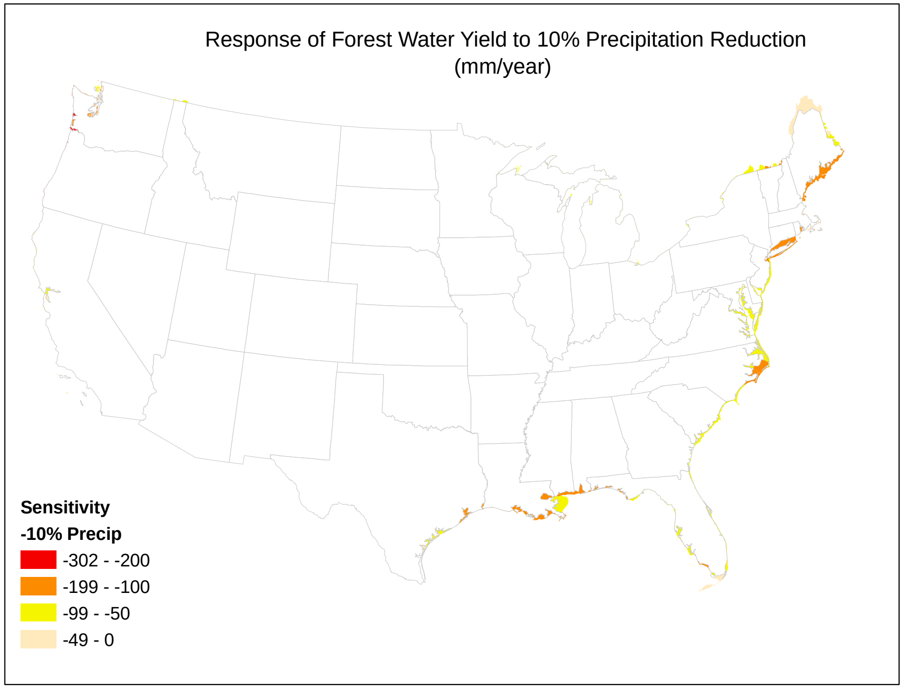




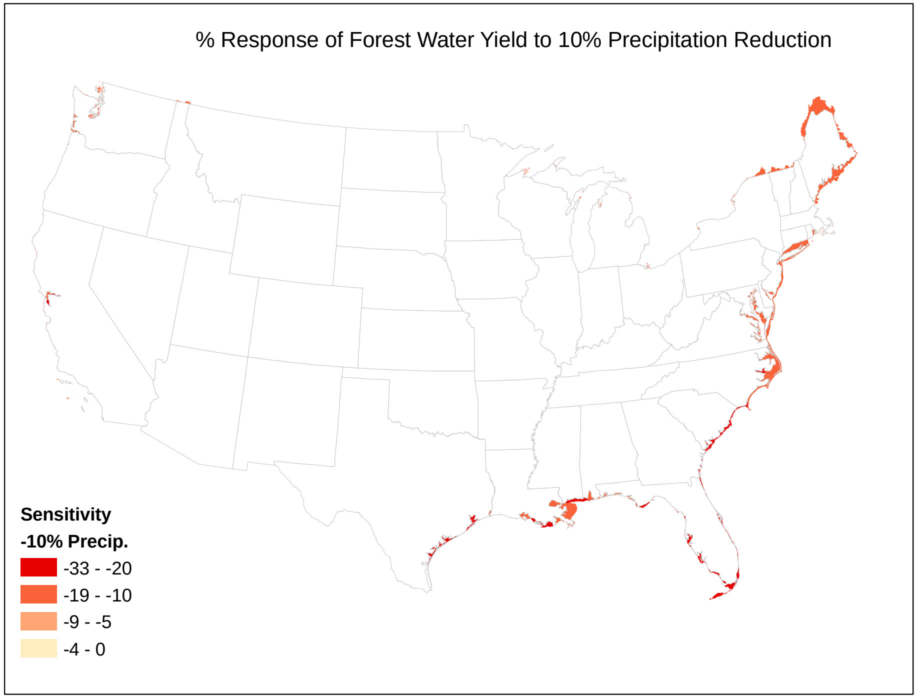
mm/yr.

%

Precip -10%

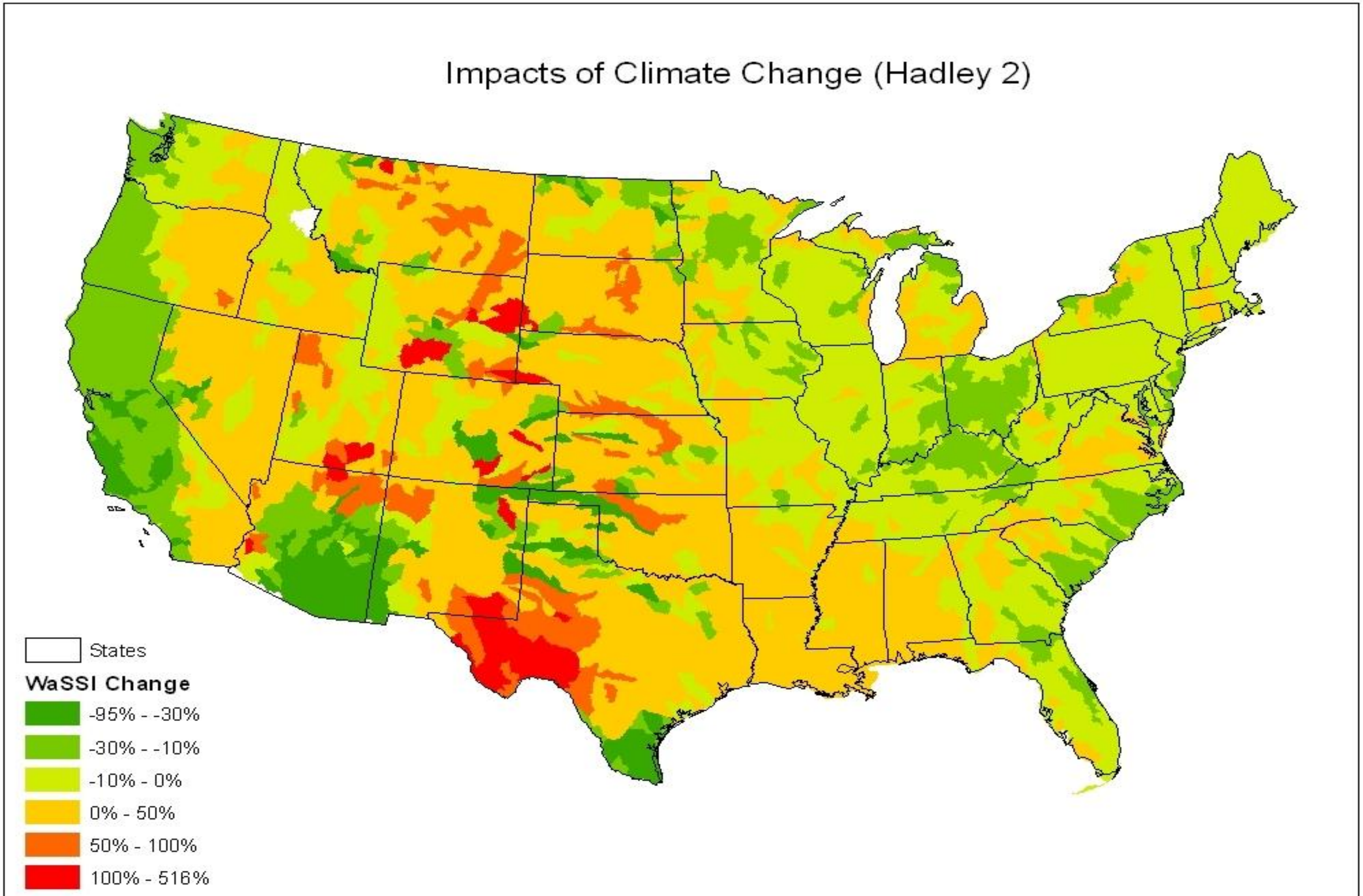


mm/yr.



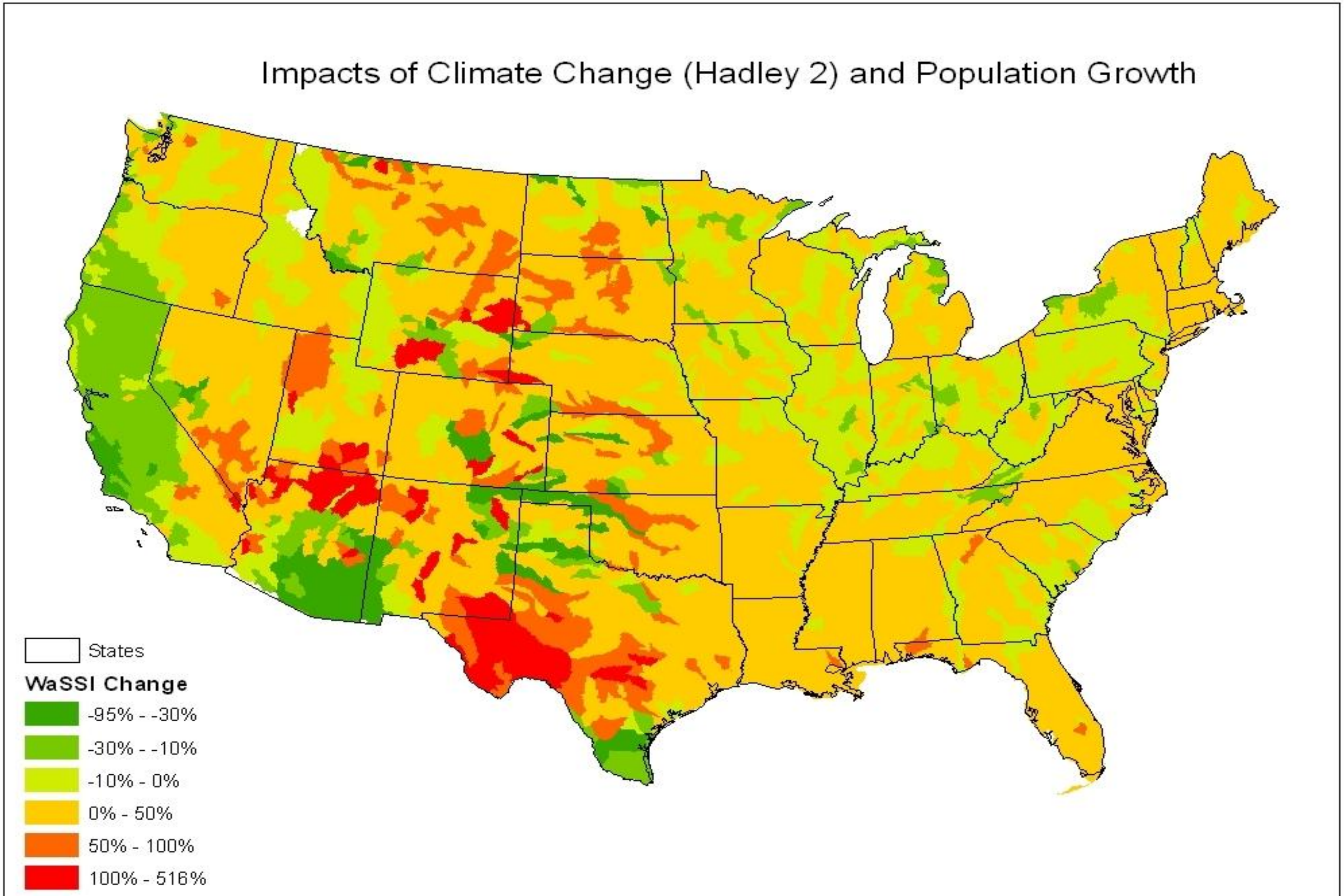
%

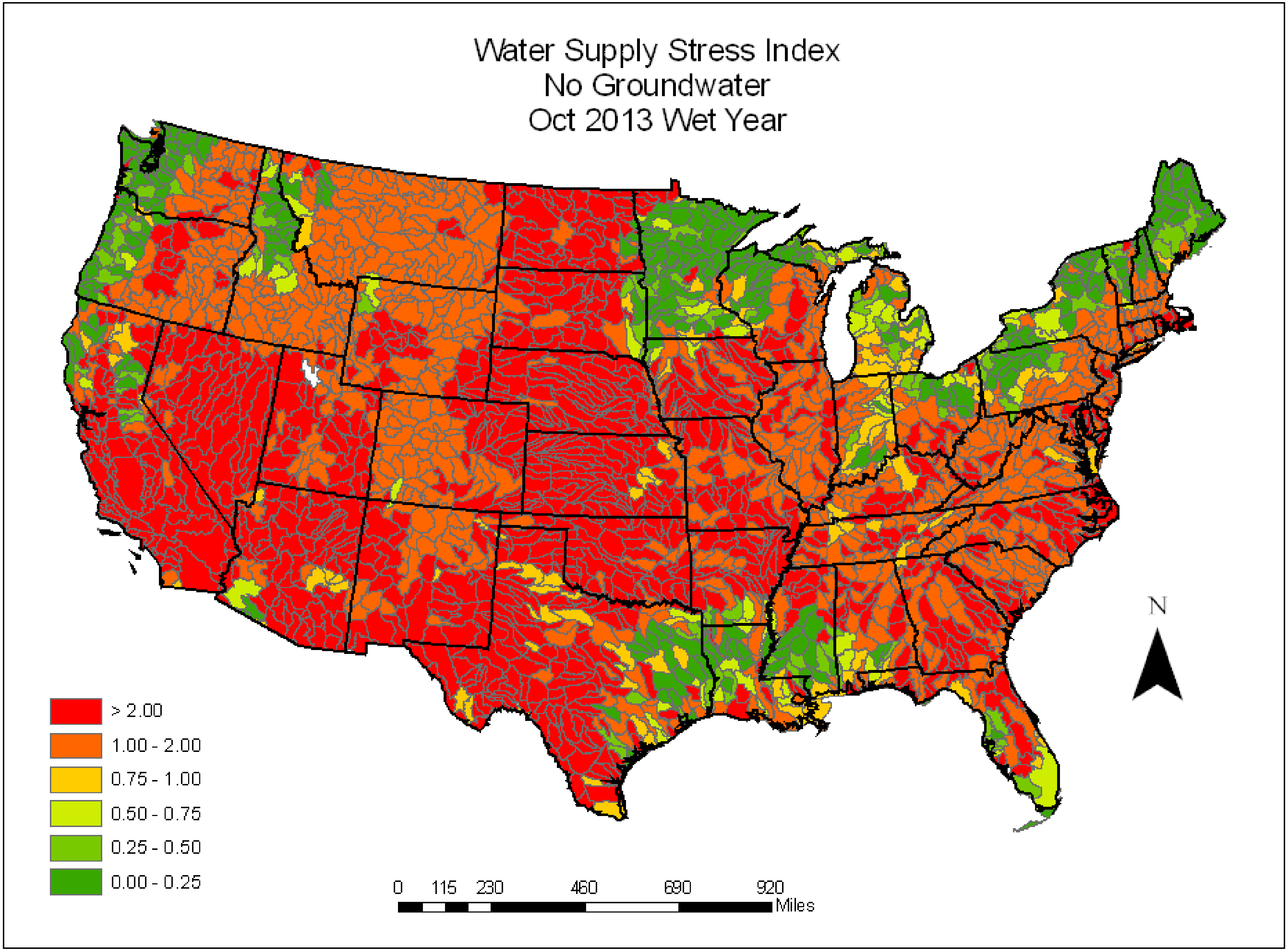
Climate Change Impacts on Water Supply



Climate Change and Groundwater Loss

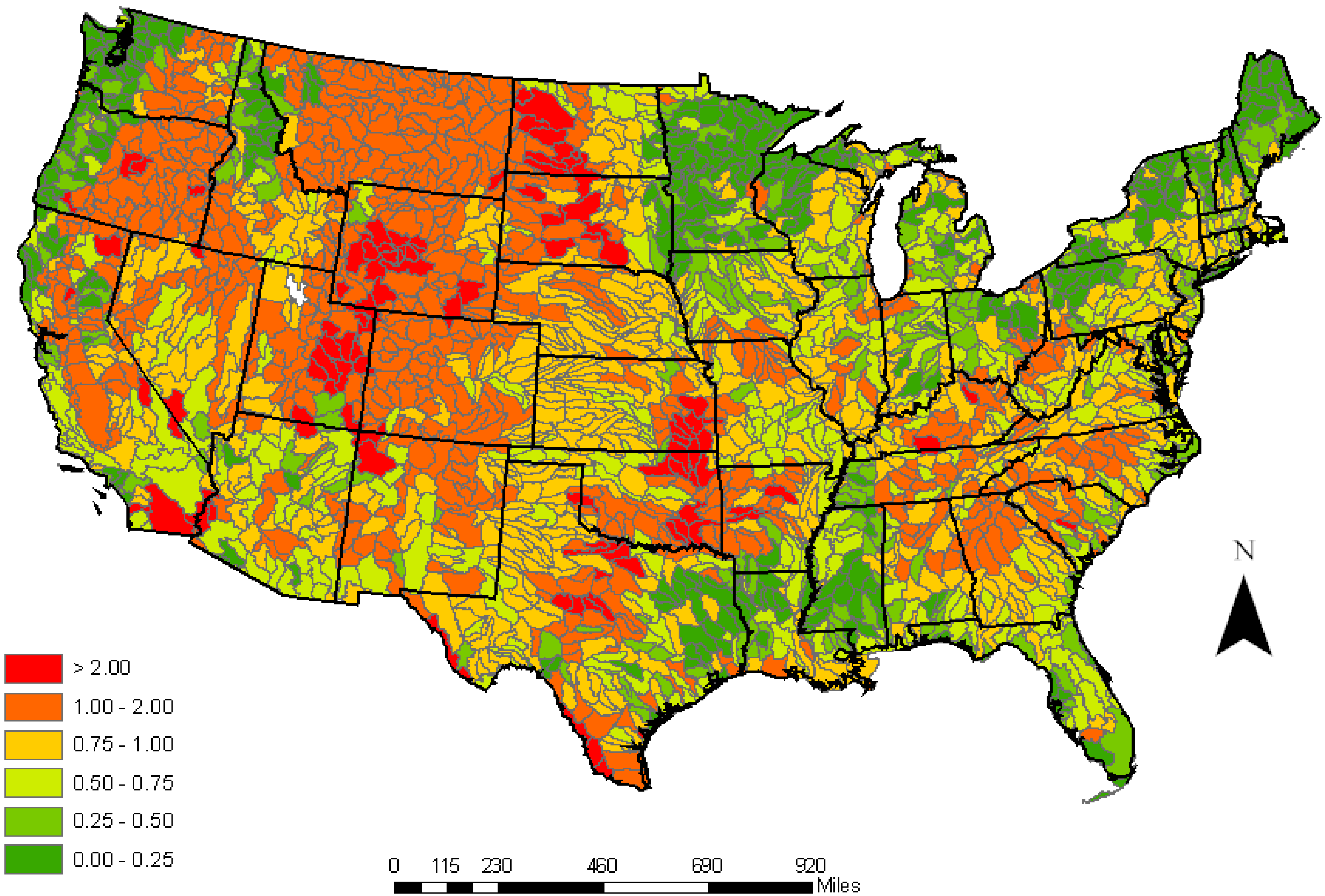
Climate and Population Change Impacts on Water

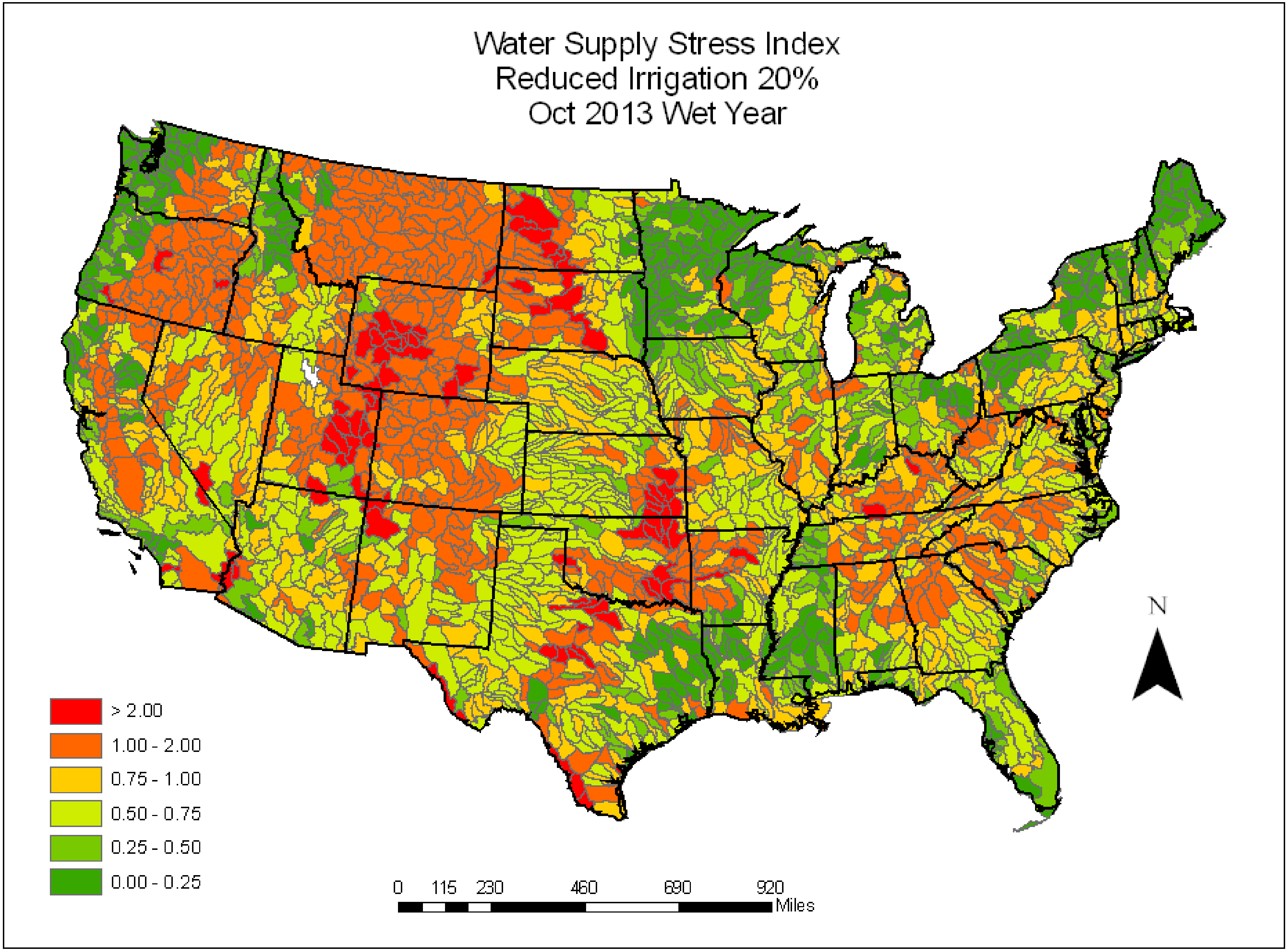


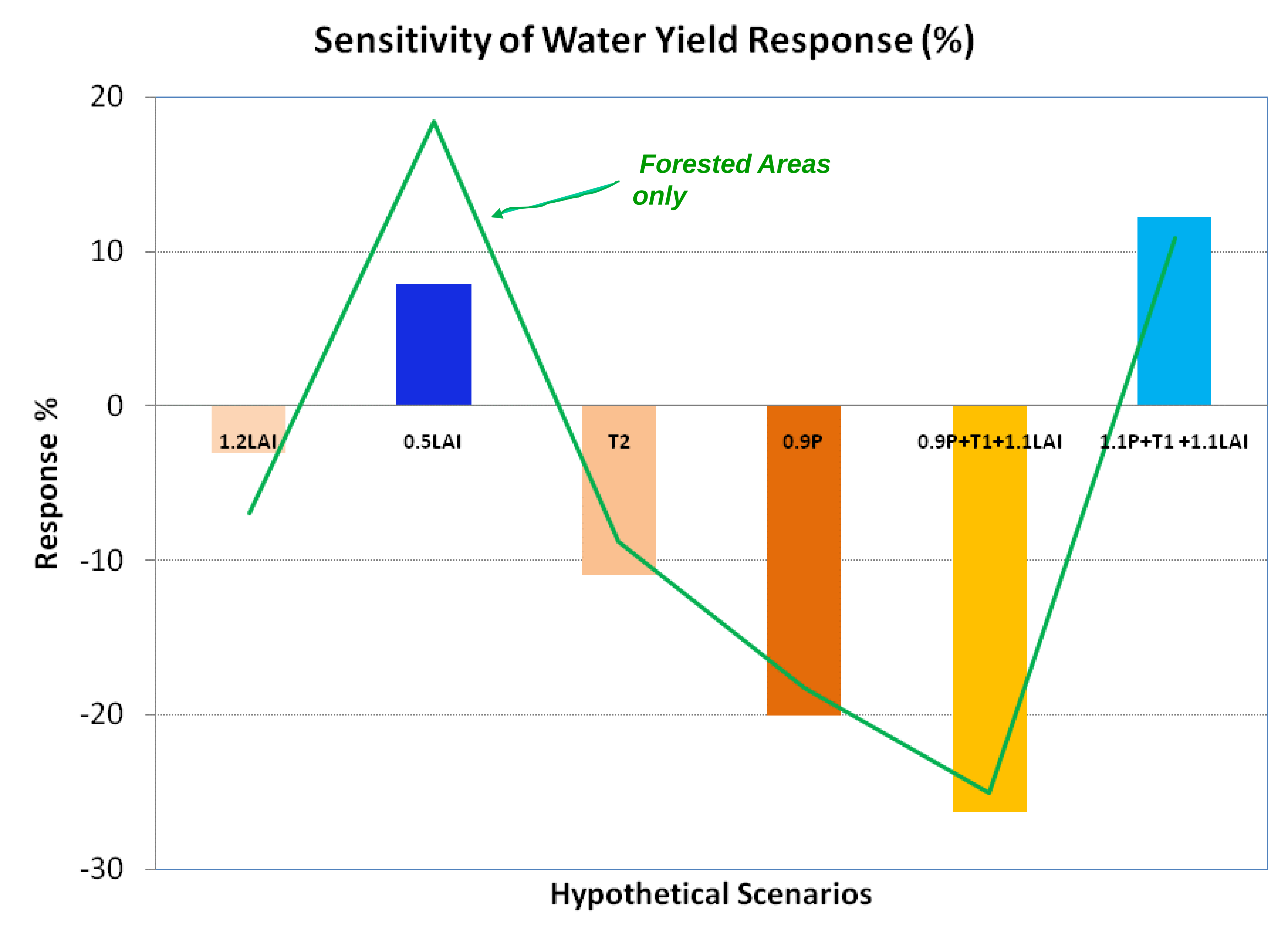

Water Supply Stress Index
No Groundwater
Oct 2013 Wet Year
> 2.00
1.00 - 2.00
0.75 - 1.00
0.50 - 0.75
0.25 - 0.50
0.00 - 0.25
0 115 230 460 690 920
Miles
N

Irrigation

Water Supply Stress Index
Baseline Oct 2013 Wet Year




Water Supply Stress Index
Reduced Irrigation 20%
Oct 2013 Wet Year
> 2.00
1.00 - 2.00
0.75 - 1.00
0.50 - 0.75
0.25 - 0.50
0.00 - 0.25
N
0 115 230 460 690 920
Miles


Sensitivity of Water Yield Response (%)
20
10
0
-10
-20
-30
Response %
Forested Areas only
1.2LAI
0.5LAI
T2
0.9P
0.9P+T1+1.1LAI
1.1P+T1 +1.1LAI
Hypothetical Scenarios

Water Trade-offs

Linking Models Together
Another Level of Complexity

Three Basic Forms of Model Integration

Integration of Model inputs (stresses)

Integration of Disciplines

Integration of time and space

Integrated Forest Modeling

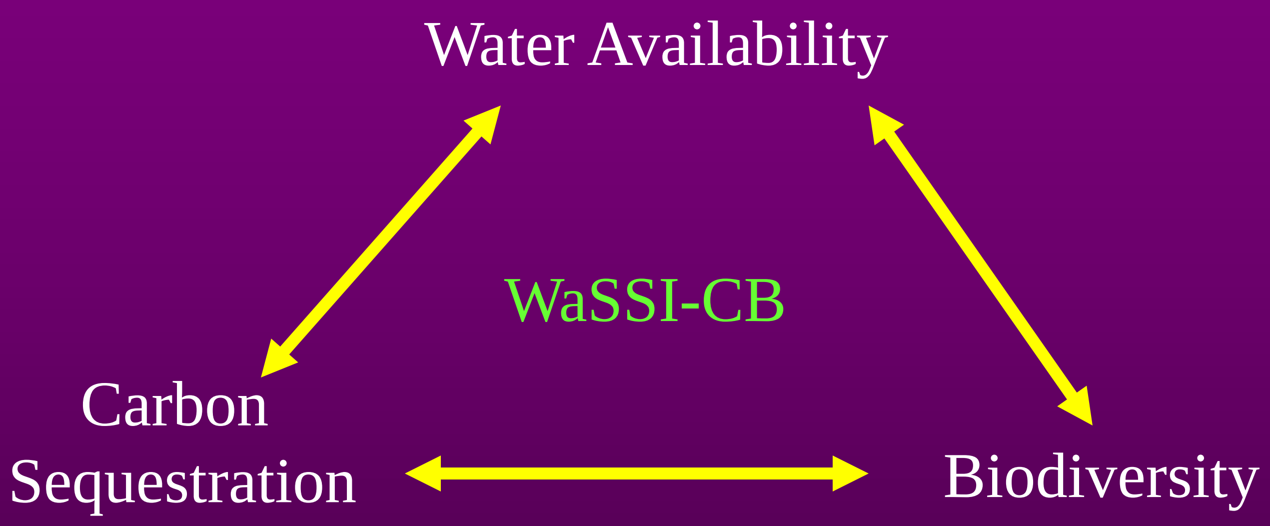
Model Inputs
Soil data (2)
Tree physiology (20)
Climate (5)
Atmospheric CO_2 (1)
Ozone (1)
N Deposition (1)
Insect (1)

Integrated Models
Physiology
hydrologic
Biodiversity
Economic

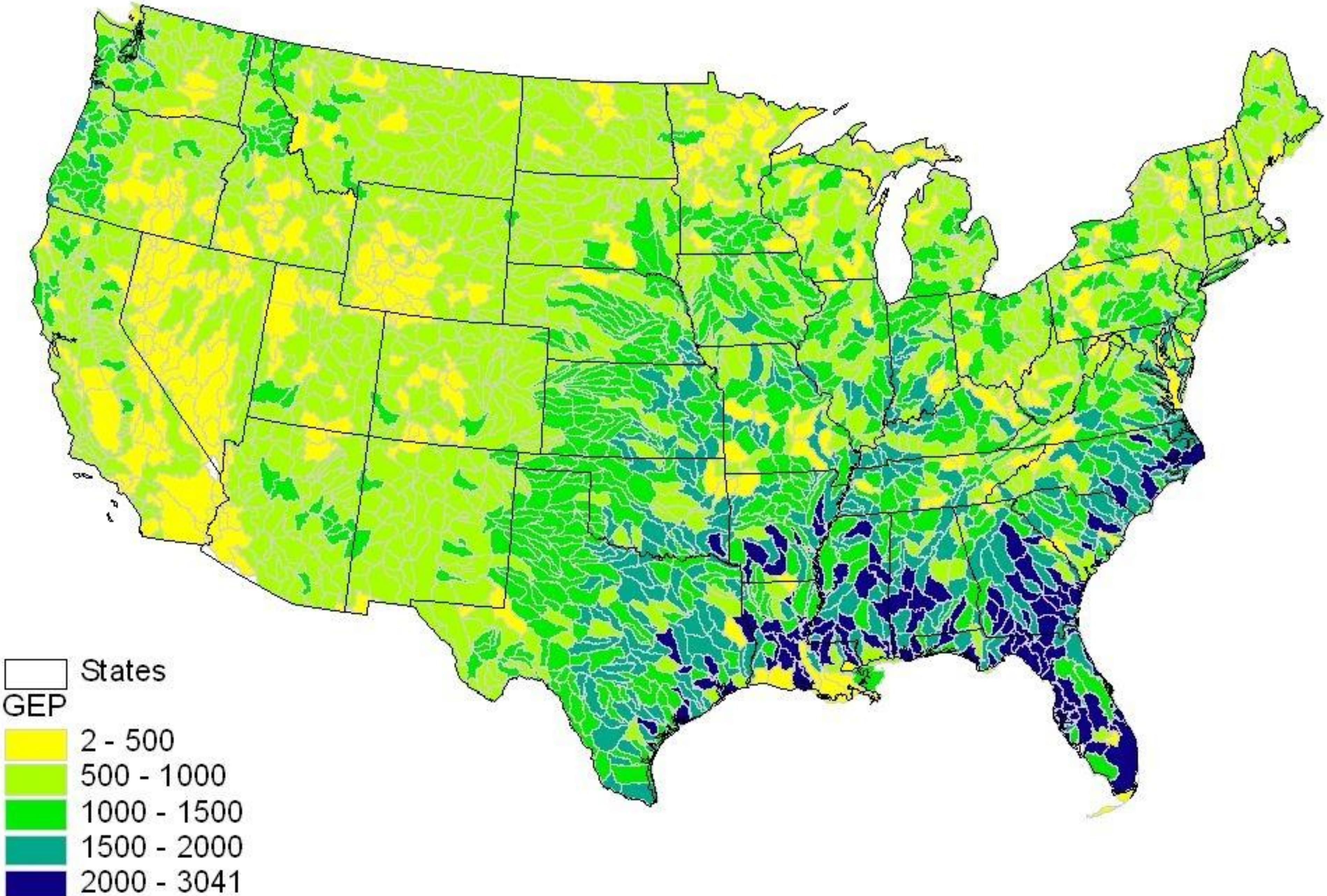
Model Outputs
Growth
Mortality
Biodiversity
Harvest
Economic value
Water use
Water yield
Land use change
Insect pop.
Fire Risk

Carbon

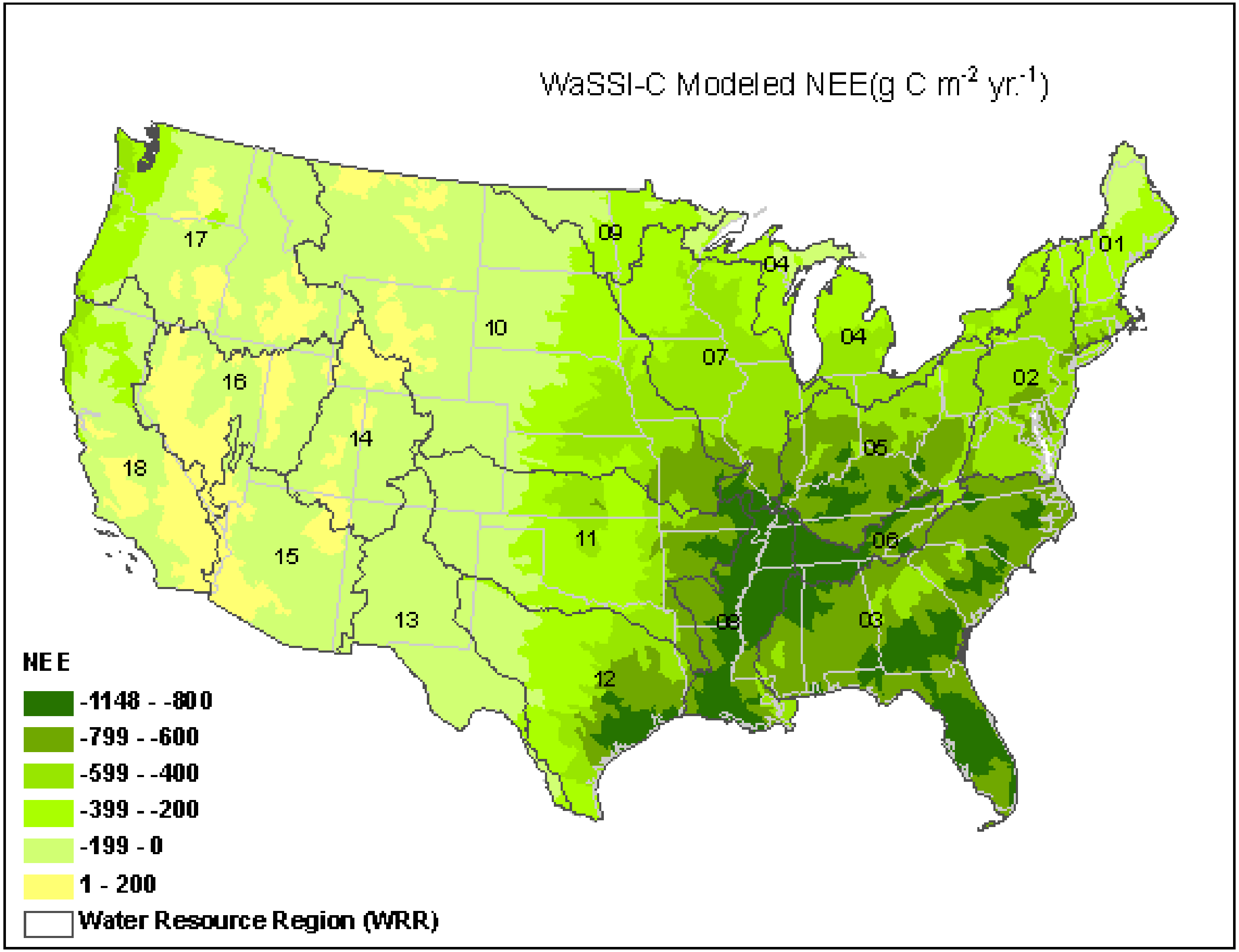
Relationships Between Ecosystem Services



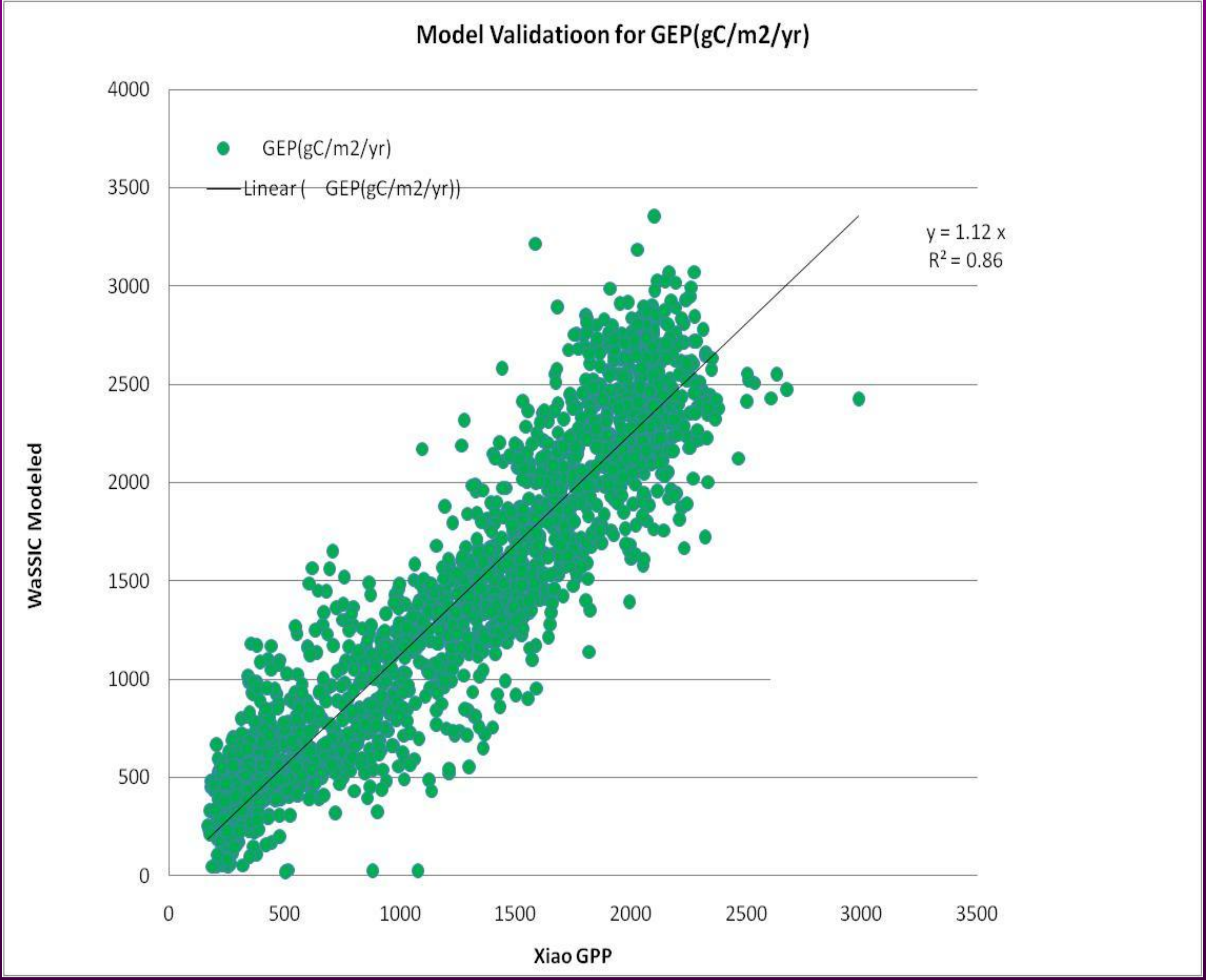
Average GEP (g C /m2/yr.) (1974-1993)



Net Ecosystem Exchange (Carbon Sequestration)

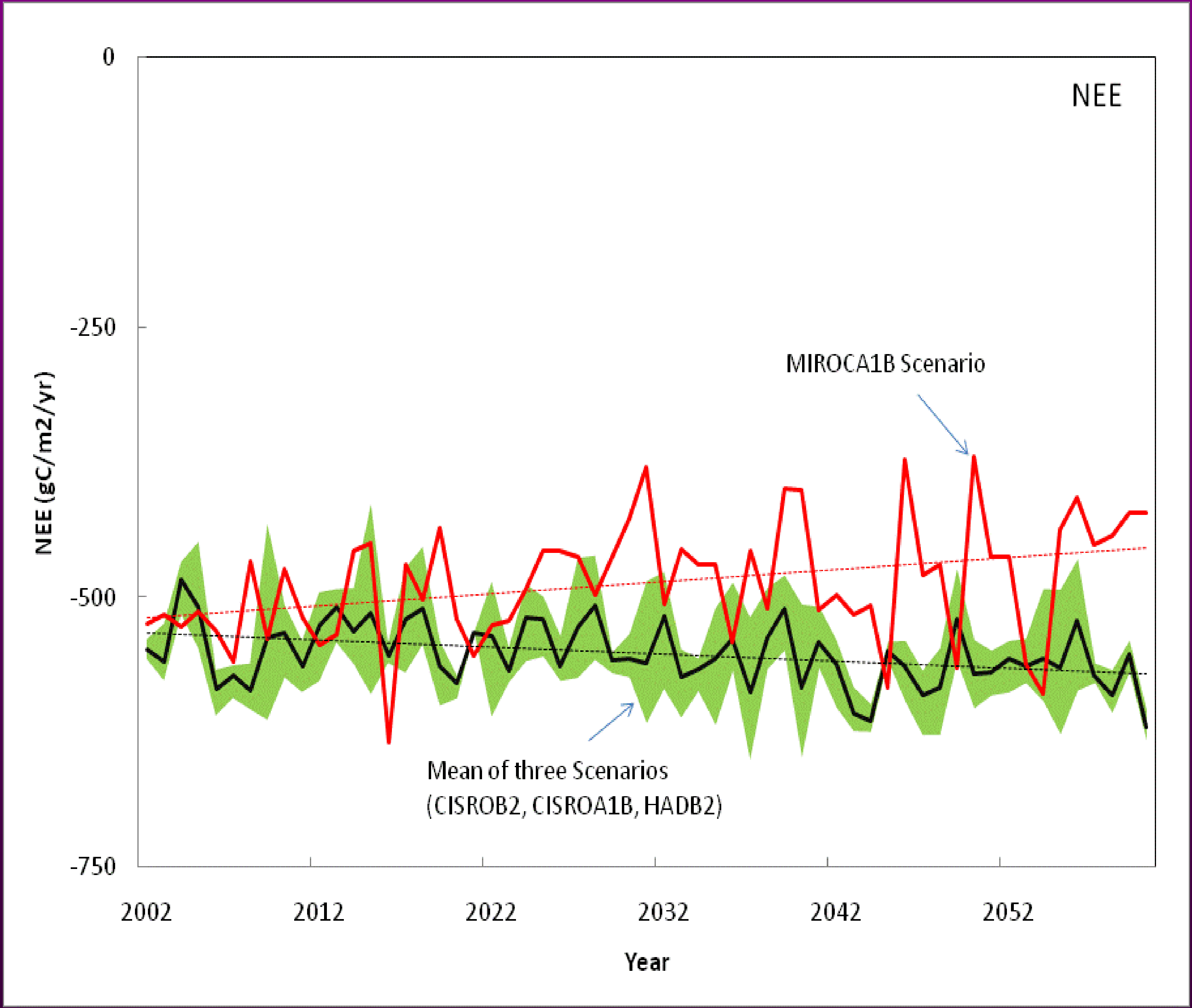


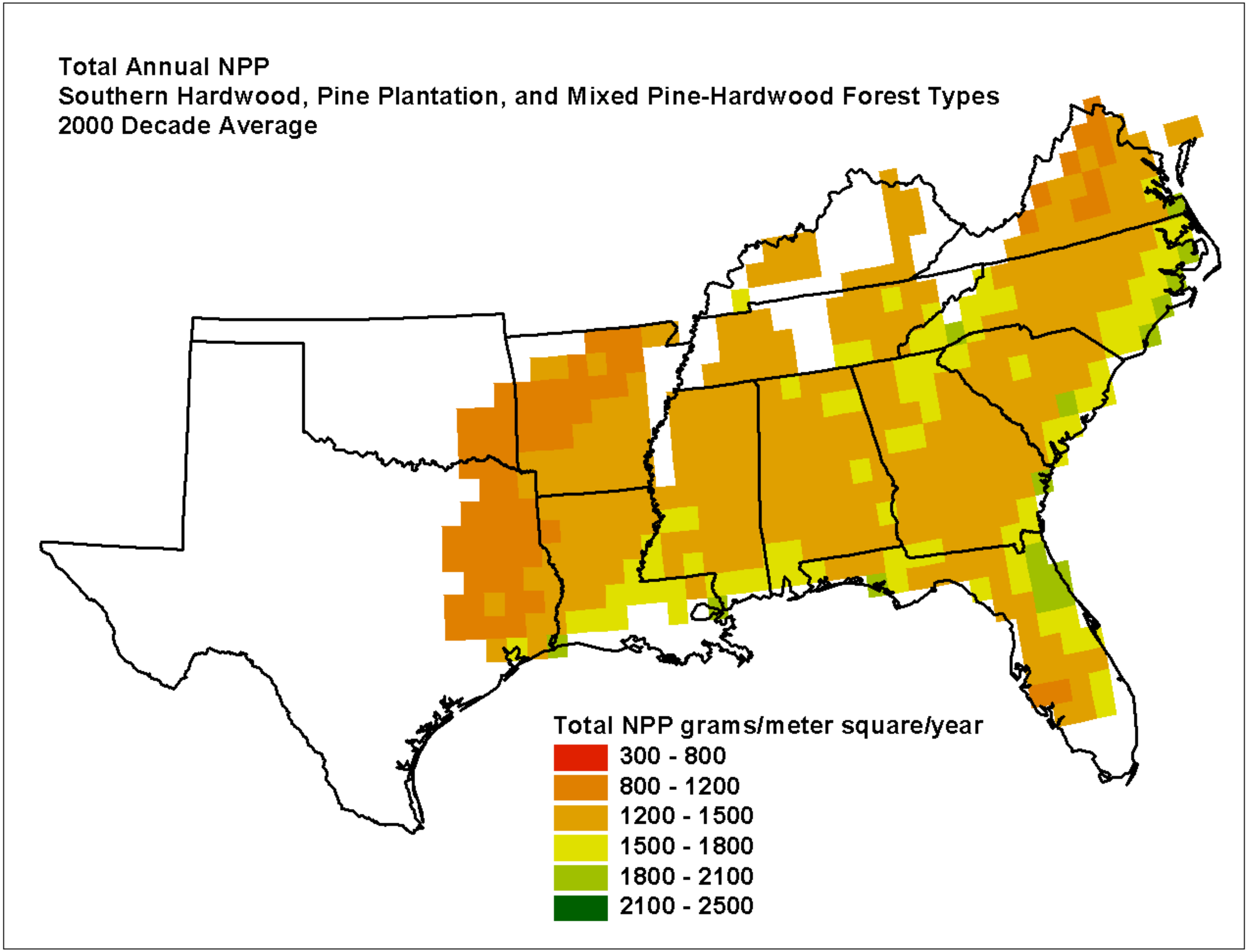
Sun et al., JGR-Biogeoscience, (In press)

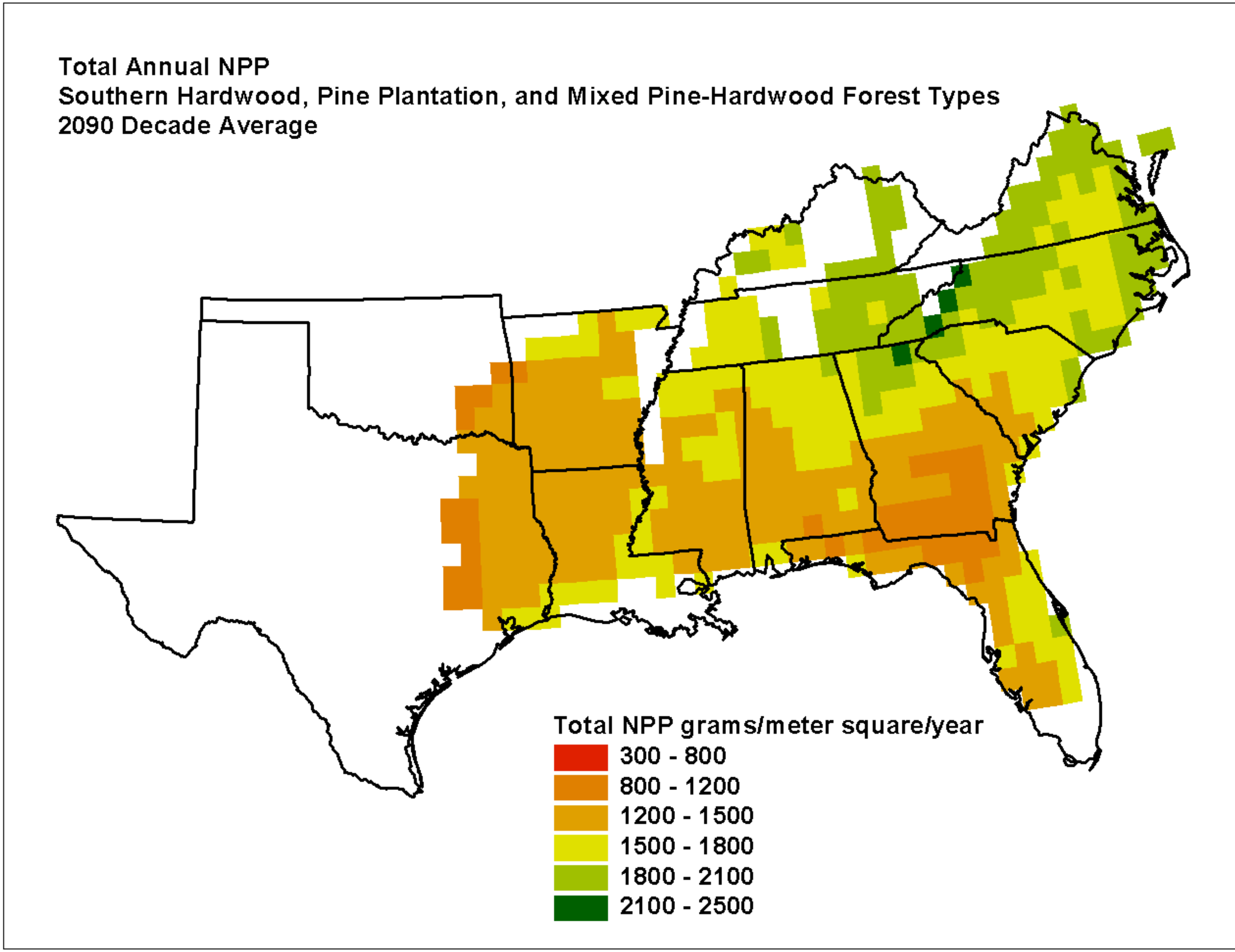


Model Validatioon for GEP(gC/m2/yr)
GEP(gC/m2/yr)
Linear (GEP(gC/m2/yr))
y = 1.12 x
R² = 0.86
4000
3500
3000
2500
2000
1500
1000
500
0
0
500
1000
1500
2000
2500
3000
3500
WaSSIC Modeled
Xiao GPP

Changes in Carbon Sequestration across the Southern US

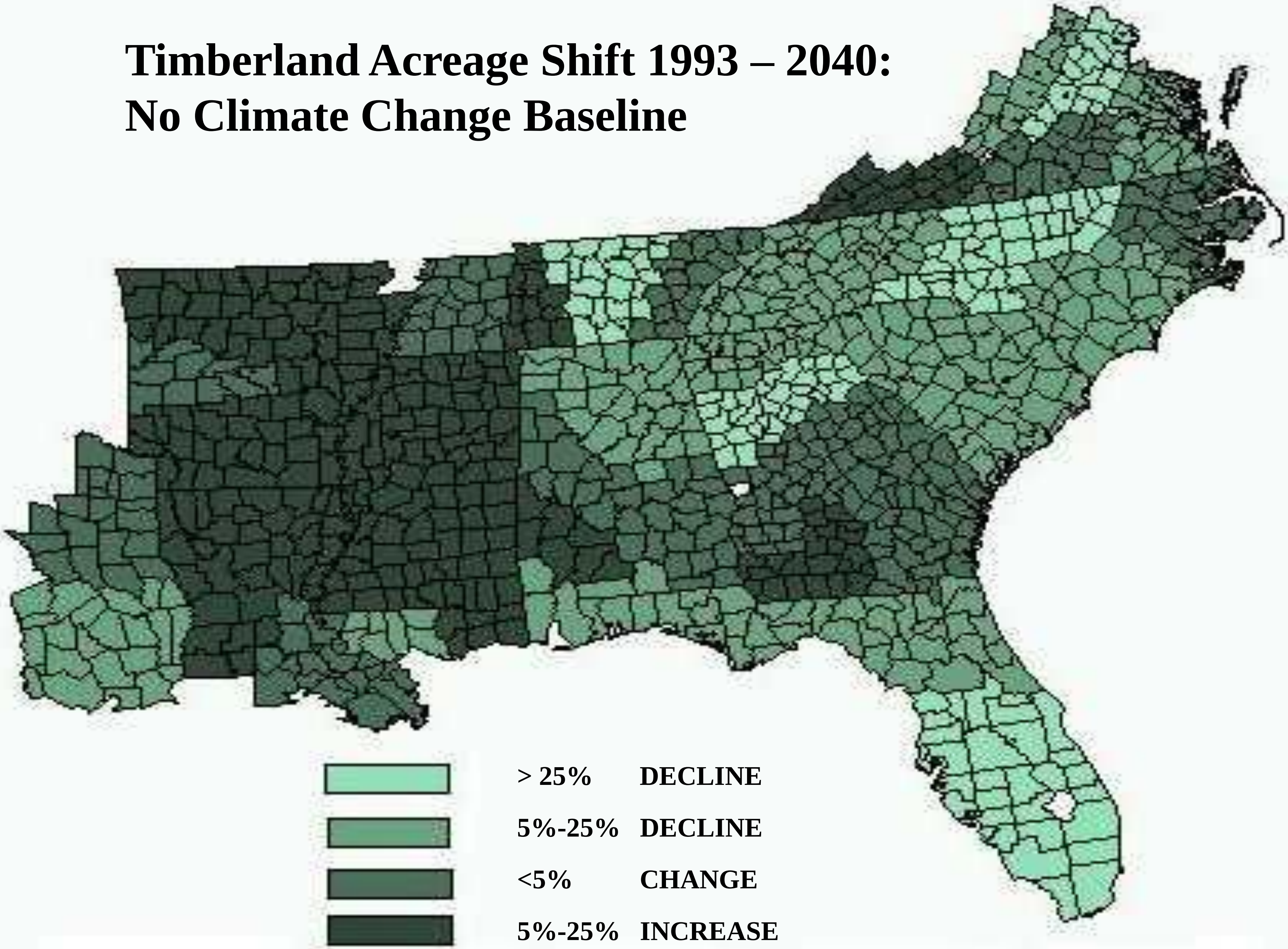



Total Annual NPP
Southern Hardwood, Pine Plantation, and Mixed Pine-Hardwood Forest Types
2000 Decade Average
Total NPP grams/meter square/year
300 - 800
800 - 1200
1200 - 1500
1500 - 1800
1800 - 2100
2100 - 2500

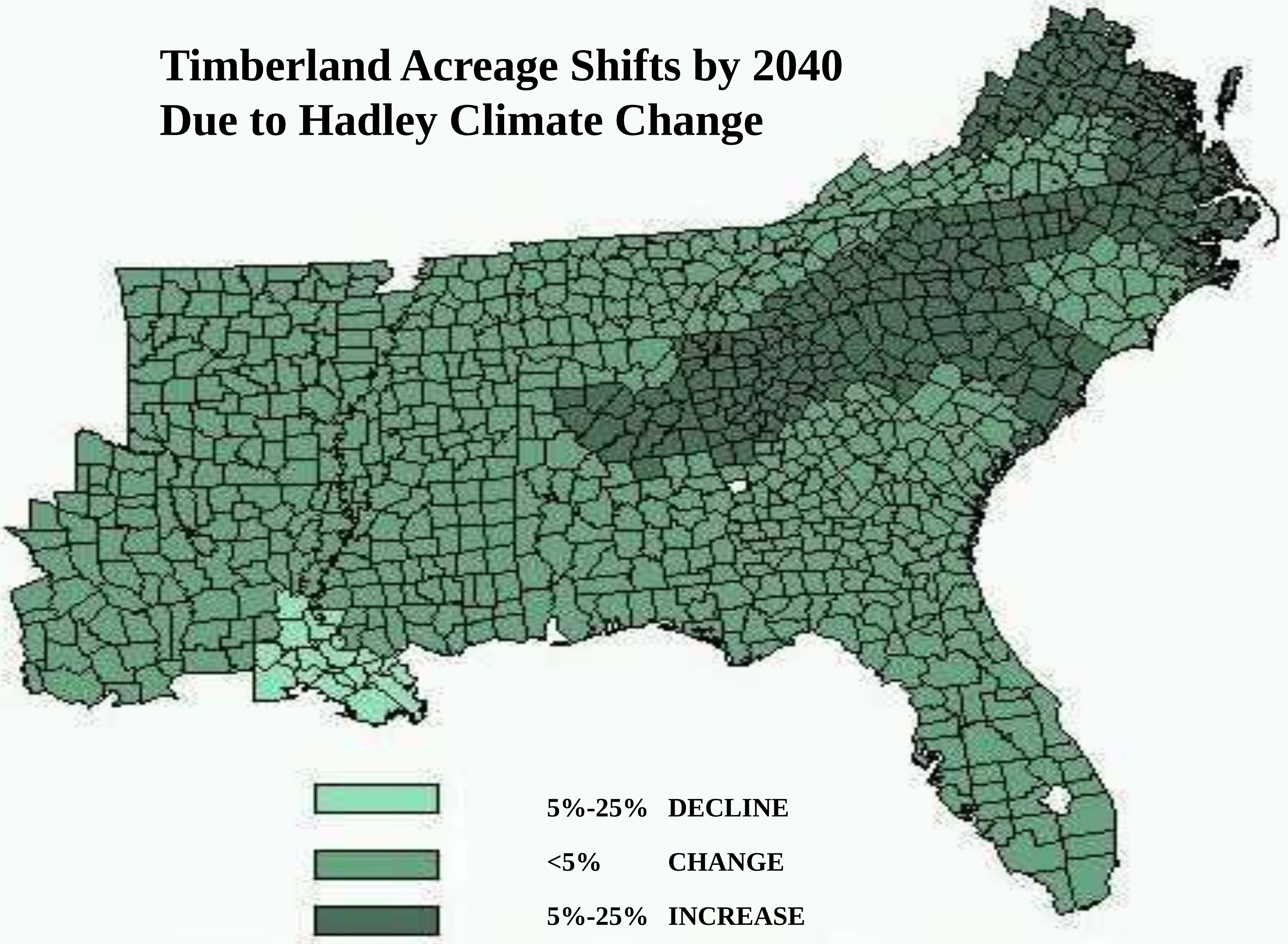

Total Annual NPP
Southern Hardwood, Pine Plantation, and Mixed Pine-Hardwood Forest Types
2090 Decade Average
Total NPP grams/meter square/year
300 - 800
800 - 1200
1200 - 1500
1500 - 1800
1800 - 2100
2100 - 2500

Links to Economic Models

Timberland Acreage Shift 1993 – 2040: No Climate Change Baseline

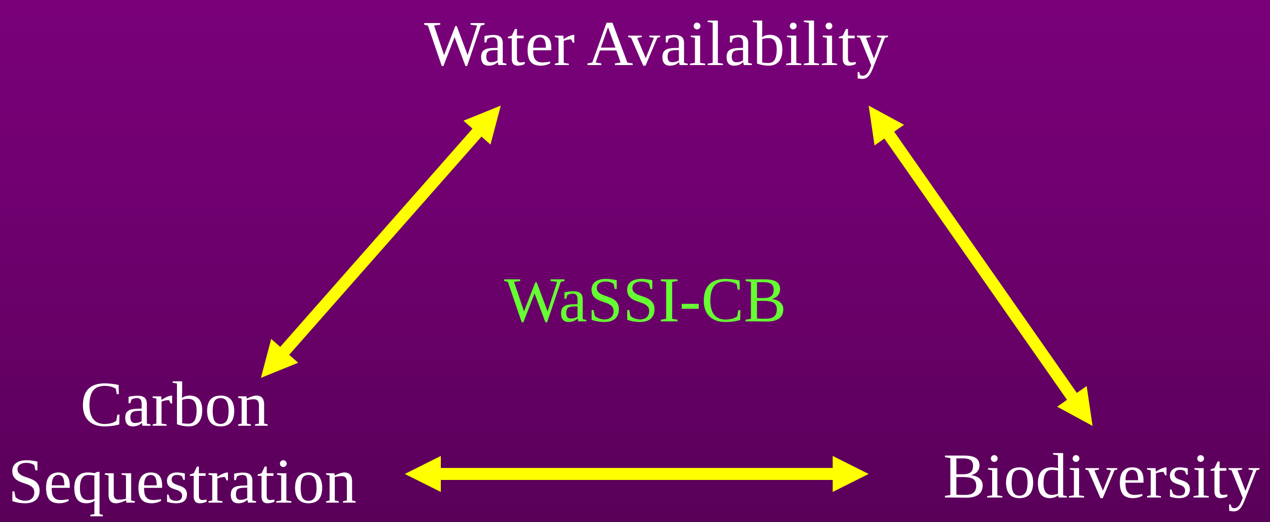


Timberland Acreage Shifts by 2040 Due to Hadley Climate Change

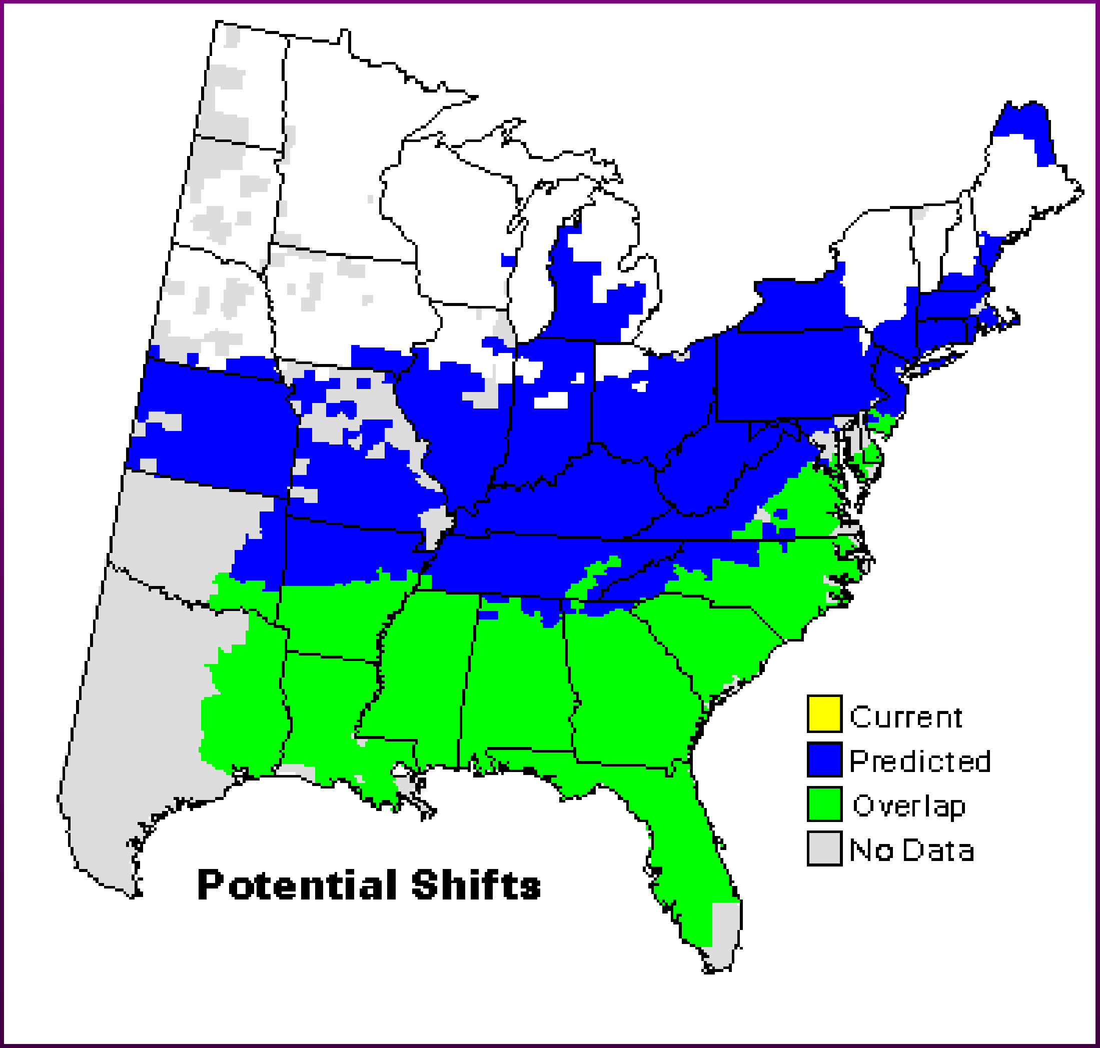


Biodiversity

Relationships Between Ecosystem Services



Loblolly pine



Iverson et. al GTR NE265

Conclusions

A model can be a useful tool for understanding complex current conditions and how watersheds could change over time

A models predictive capacity is only as good as the data used to develop, parameterize and validate the model

Increases in computer capacity and speed can greatly improve the access and application of models

By better understanding watershed condition, we can better manage watersheds for ecosystem sustainability and value

No model prediction is absolutely correct but some are useful

One last thought on modeling

I wanted a perfect ending. Now I've learned, the hard way, that some poems don't rhyme, and some stories don't have a clear beginning, middle, and end. Life is about not knowing, having to change, taking the moment and making the best of it, without knowing what's going to happen next.

-- Gilda Radner