Potential Forest Sector Impacts of Climate Change on Douglas-fir Forests of the United States Pacific Northwest

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Outline

1. Background
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1.1 Study Context
Productivity Measure Definition

- Potential mean annual increment (PMAI): cubic meter volume per hectare per year at time of culmination for a normally stocked stand for a given site

- Only input is site index, which is plugged into normal yield tables to provide potential PMAI

Potential Mean Annual Increment (PMAI):

- indicates the productivity of a forest stand
- aids in modeling, monitoring, and forest planning
- provides metric for timberland /non-timberland designation

Site Index (SI)

The height of a dominant tree at a reference age

1.1 Study Context (cont'd)

Overall Objective:

- Examine and identify the best practical method for assigning (a) timberland or (b) other forest land for forest inventory plots that are missing site index trees.

Four Studies Emerged:

1. Compare different methods for imputing PMAI from climatic variables

2. Use "best" model from 1. along with GCM model output for IPCC climate change scenarios to evaluate future regional potential productivity

3. Explore different model error structures for "best" model from 1. and map response and test significance of site index to changes in climatic variables (elasticities)

4. Incorporate site index equations from 3., individual tree growth and yield models, and a regional spatial equilibrium model of the log market to evaluate potential changes in regional processing capacity, log price, and financially optimal rotation ages of IPCC climate change scenarios.

2. Productivity Mapping Study

2.1. Methods - Data

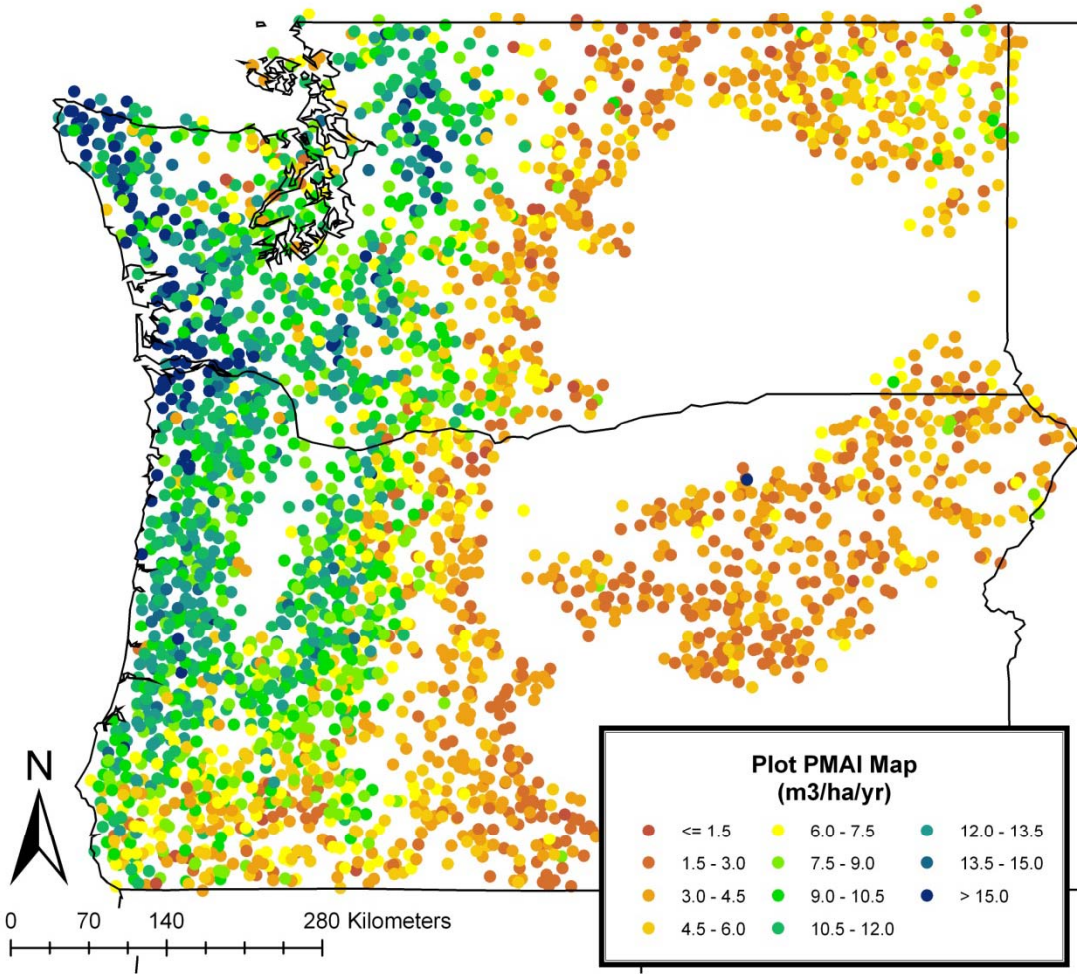
- Potential Mean Annual Increment and geographic attributes were obtained for 3356 measurement plots in Oregon and Washington.
- Monthly temperature and precipitation normal data for the period 1971-2000 was produced by the Parameter-elevation Regressions on Independent Slopes Model (PRISM).
- Short wave incoming solar radiation was calculated based on Coops et al. (2000) utilizing latitude, longitude, slope, aspect, elevation and the PRISM monthly maximum and minimum temperatures.

Data Summary

Variable	Units	Mean	Median	Maximum	Minimum	Std. Dev.
PMAI	Cubic Meters/Hectare/Year	7.4	6.8	23.8	0.2	4.08
Site Index	Meters at 50 years	28.1	27.8	54.8	9.2	8.9
Geographic Variables						
Latitude	Degrees	45.4	45.3	49.0	42.0	1.98
Longitude	Degrees	-121.6	-122.1	-116.5	-124.7	2.02
Elevation	Meters	808.2	777.4	2171.4	4.9	503.97
Climatic Variables						
Temperature	Degrees Celsius	8.4	8.5	13.7	0.8	2.16
Precipitation	Centimeters	143.7	127.0	593.9	25.7	90.62
CMI	Millimeters	-30.3	-34.2	83.8	-80.0	19.61

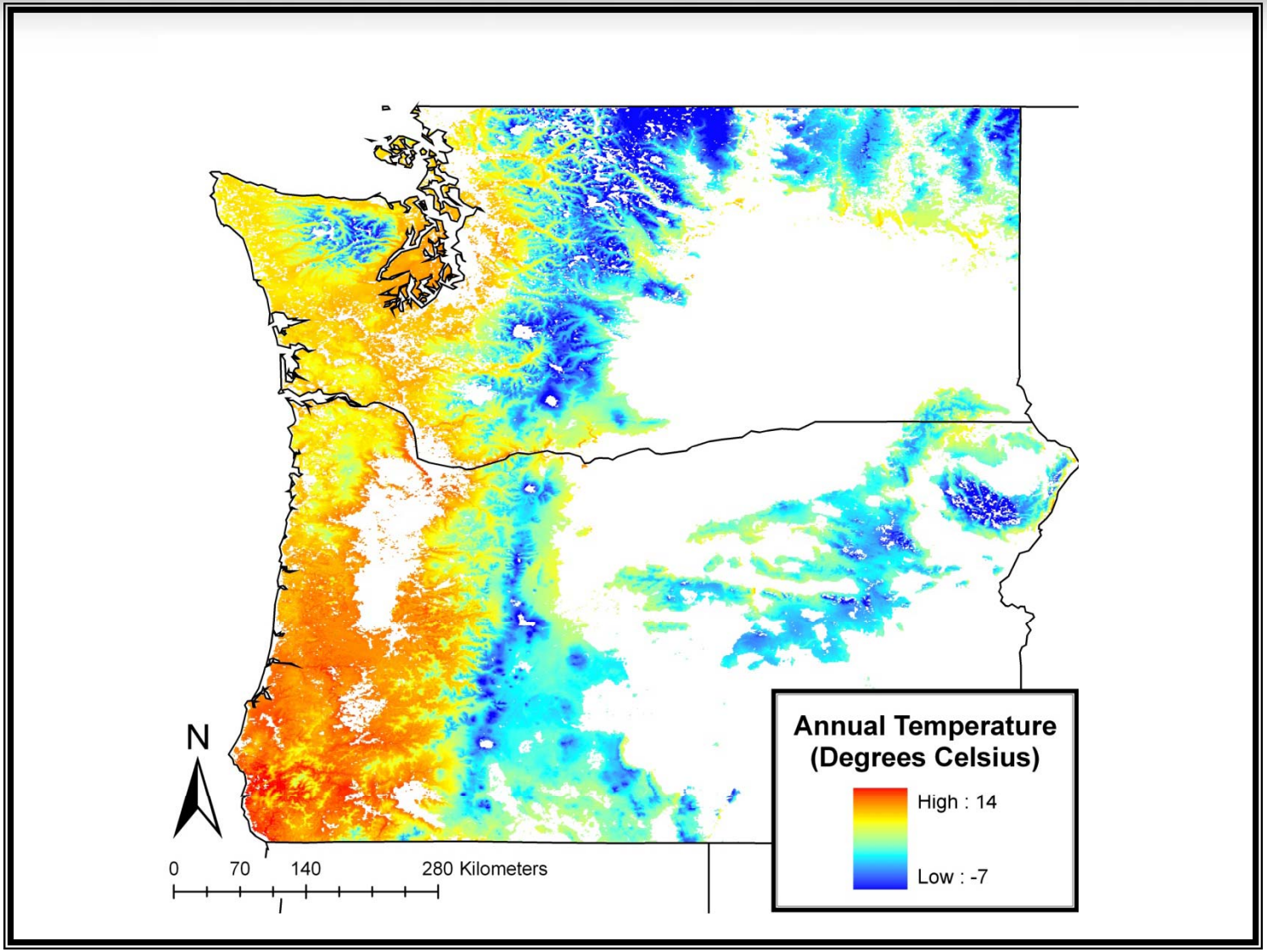
2.1. Productivity Mapping Study – Data (cont'd)

Potential Mean Annual Increment Plot Map



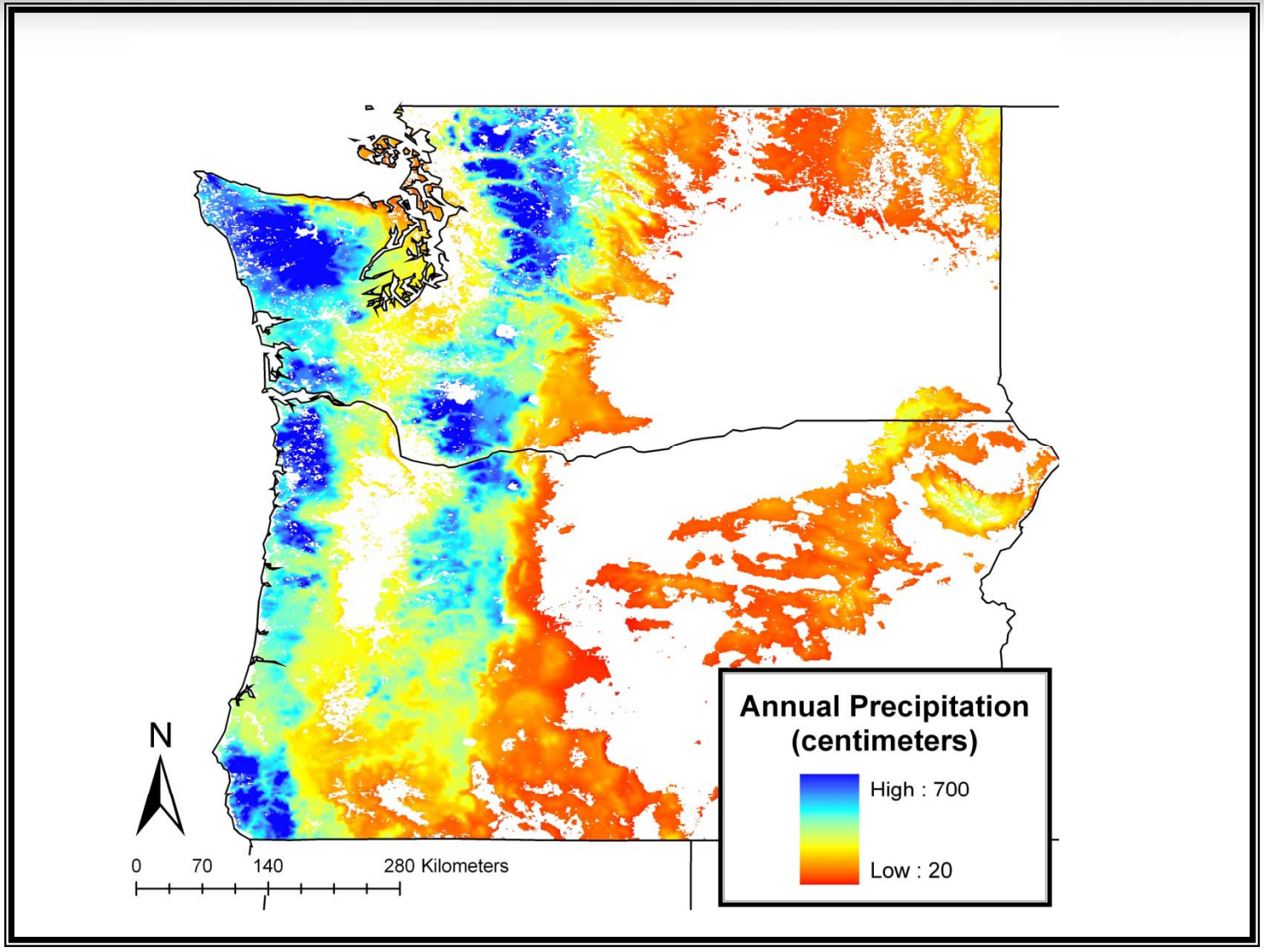
2.1. Productivity Mapping Study – Data (cont'd)

Average Annual Temperature Map



2.1. Productivity Mapping Study – Data (cont'd)

Average Annual Rainfall Map



2.1. Growing Season Climate Moisture Index

The Climate Moisture Index in this study is the millimeters of precipitation per year in excess of evaporation and plant transpiration given a location solar radiation and temperature

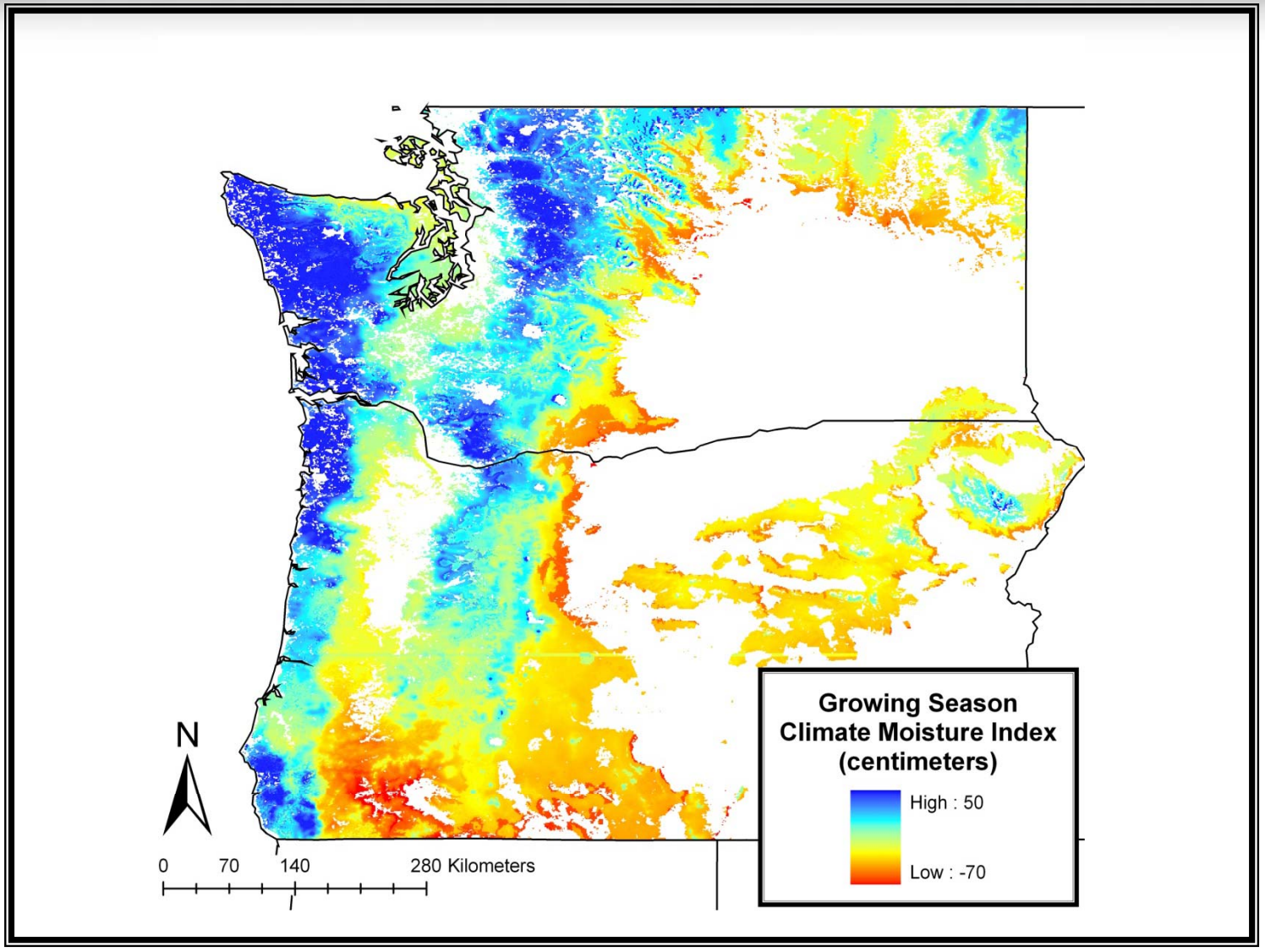
$$CMI = \sum_{months} \Pr ecipitation - (days_{Month} * Evapotranspiration / 10)$$

Where Evapotranspiration is calculated using a variant of the Hargreaves Model which given mean temperatures in ° Celsius and solar radiation in mega joules per square meter per day

$$Evapotranspiration = 0.0135 * (Temperature + 17.78) * Solar\_Radiation * \left(\frac{238.8}{595.5 - 0.55 * Temperature} \right)$$

Monthly precipitation, temperature values came from PRISM (www.prism.oregonstate.edu) and are averages over the 1971-2000 period and solar radiation was calculated utilizing latitude, longitude, slope, aspect, elevation and the PRISM monthly maximum and minimum temperatures.

2.1. Productivity Mapping Study – Data (cont'd)
Growing Season Climate Moisture Index Map



2.2. Simultaneous Autoregressive Model

$$PMAI_i = \beta_1 + \beta_2 T_i + \beta_3 CMI_i + \beta_4 T * P_i + \beta_5 T_i^2 + \beta_6 P_i^2 + \beta_7 ST + \rho U_L + e_i$$

where:

$$U_L = PMAI_L - \left(\beta_1 + \beta_2 T_L + \beta_3 CMI_L + \beta_4 T_L * P_L + \beta_5 T_L^2 + \beta_6 P_L^2 + \beta_6 ST_L\right)$$

and

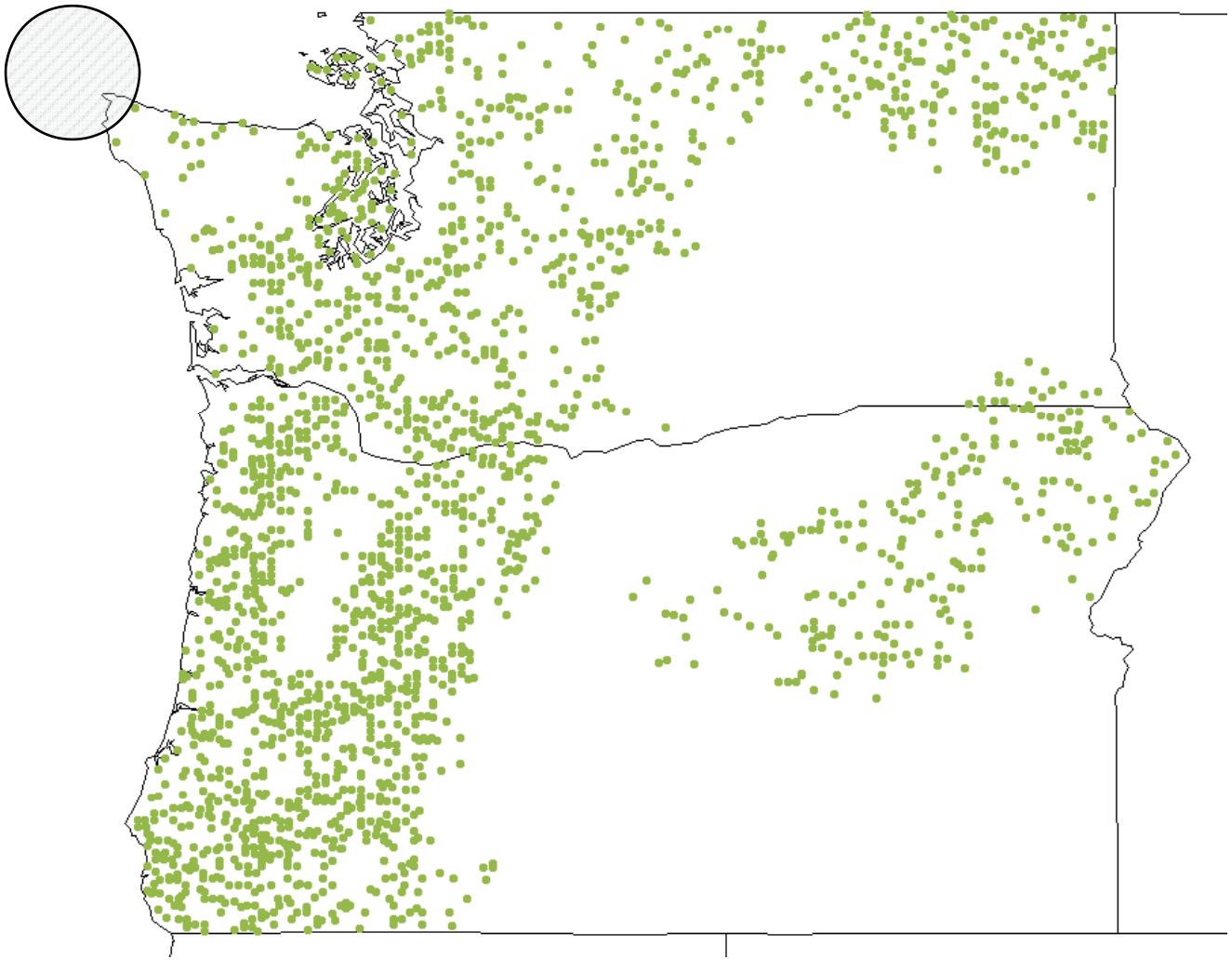
$$PMAI_L = \frac{\sum_{x \in N}^{n} w_x PMAI_x}{\sum_{x \in N}^{n} w_x} \quad and \quad i_L = \frac{\sum_{x \in N}^{n} w_x i_x}{\sum_{x \in N}^{n} w_x}$$

N is all plots within a distance of .5° of the *i* th plot

w is the inverse of the distance

2.2. Simultaneous Autoregressive Model

The weighting function



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$$PMAI_i = \beta_1 + \beta_2 T_i + \beta_3 CMI_i + \beta_4 T * P_i + \beta_5 T_i^2 + \beta_6 P_i^2 + \beta_7 ST + \rho U_L + e_i$$

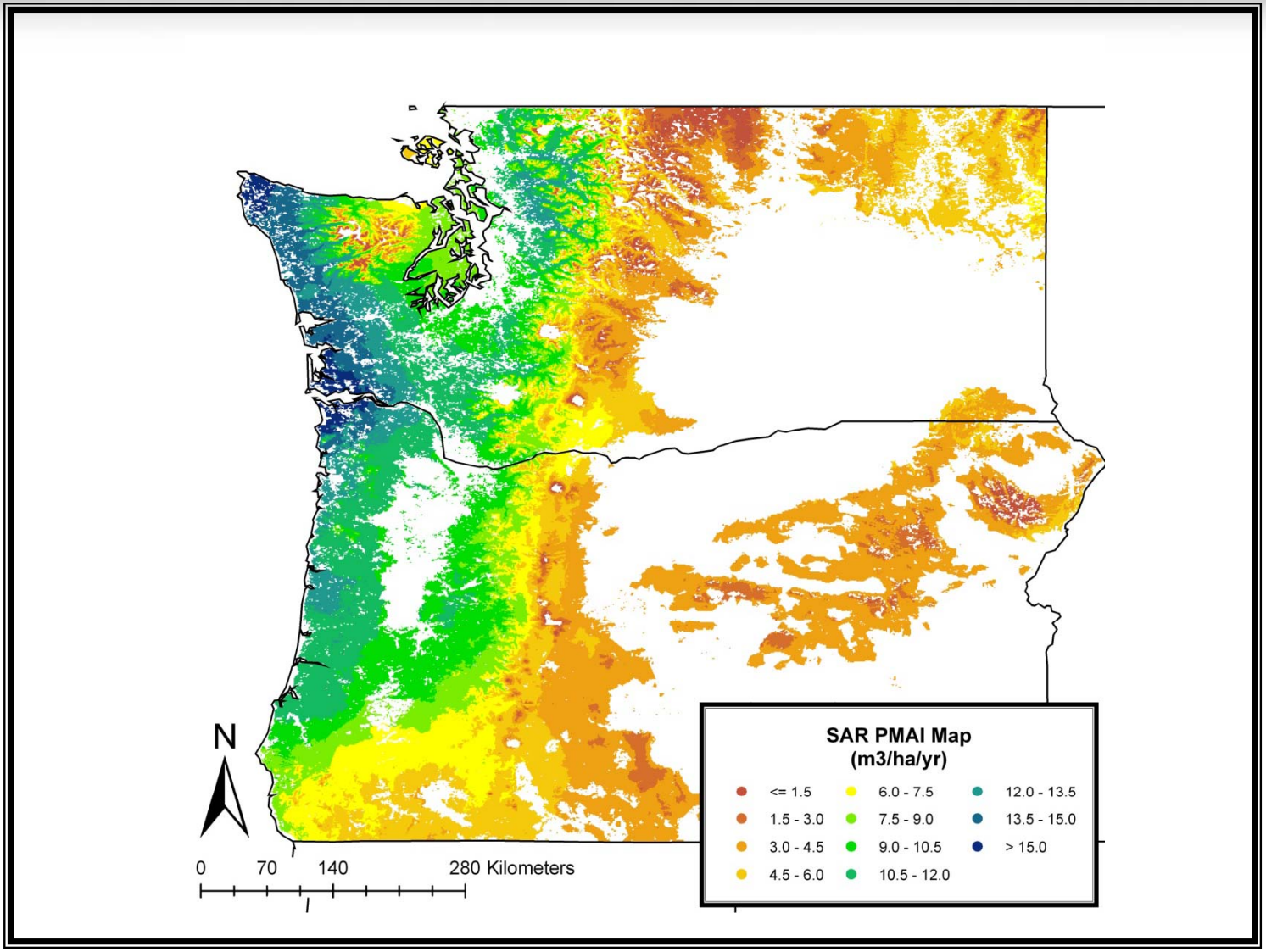
where:

$$U_L = PMAI_L - \left(\beta_1 + \beta_2 T_L + \beta_3 CMI_L + \beta_4 T_L * P_L + \beta_5 T_L^2 + \beta_6 P_L^2 + \beta_6 ST_L\right)$$

Variable	Coefficient	Std. Error	t-Statistic
β_1	-3.276	2.550	-1.28
β_2	1.029	0.157	6.55
β_3	0.017	0.005	3.58
β_4	0.002	0.000	8.68
β_5	-0.058	0.010	-5.90
β_6	0.000	0.000	-10.82
β_7	3.496	0.157	22.25
ρ	1.041	0.019	56.17
R^2	0.734		
RMSE	2.100 (m^3/ha/yr)		

2.2. Results – Simultaneous Autoregressive Model

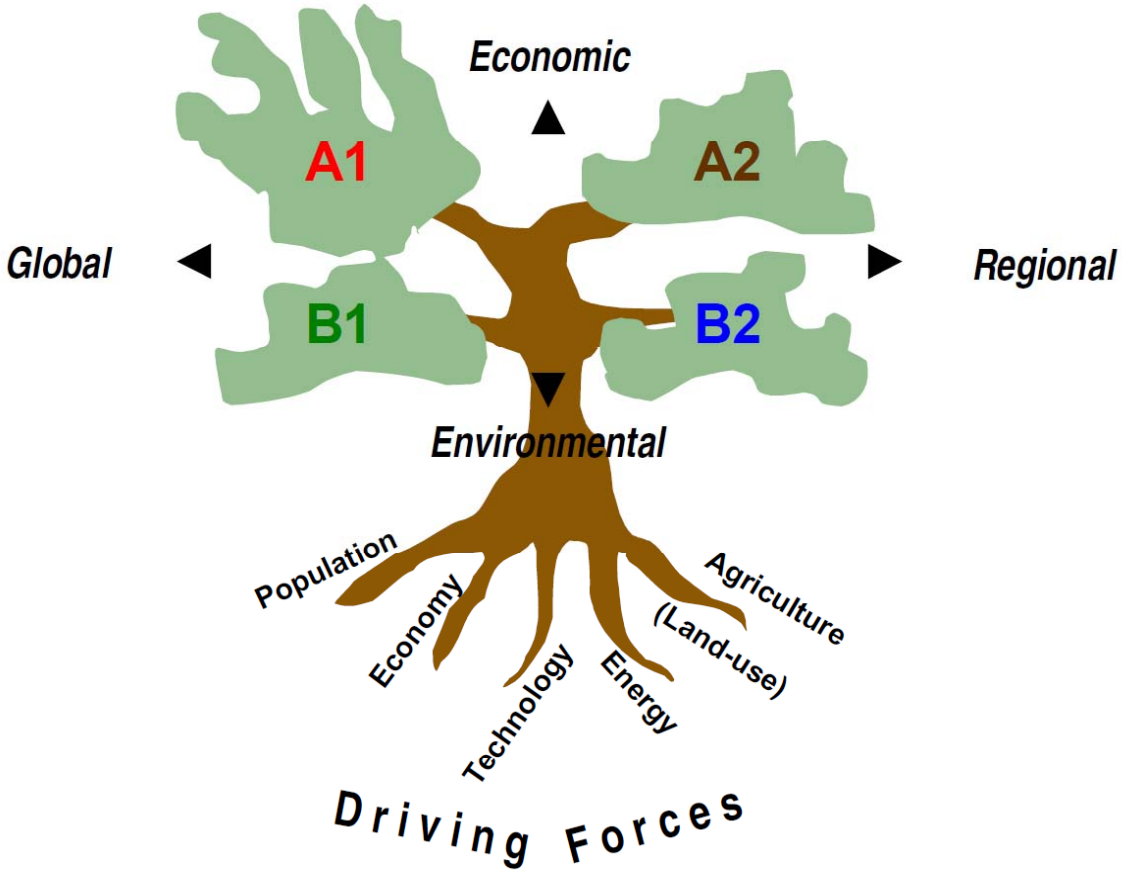
Potential Mean Annual Increment Map



3.1. Climate Change
Scenarios

IPCC Climate Change Scenarios

Special Report on Emission Scenarios (SRES)



IPCC Scenarios http://www.ipcc-data.org/guidelines/TGICA_guidance_sdciaa_v2_final.pdf

Climate Change Scenarios

Commit - greenhouse gas emissions are stabilized at year 2000 levels

SRESA1B – global economy with very rapid economic growth.

SRESA2 – regional economy with rapid economic growth.

SRESB1 – global economy with slower economic growth, environmental focus.

General Circulation Models

NCAR - The National Center for Atmospheric Research's general-circulation Community Climate System Model.

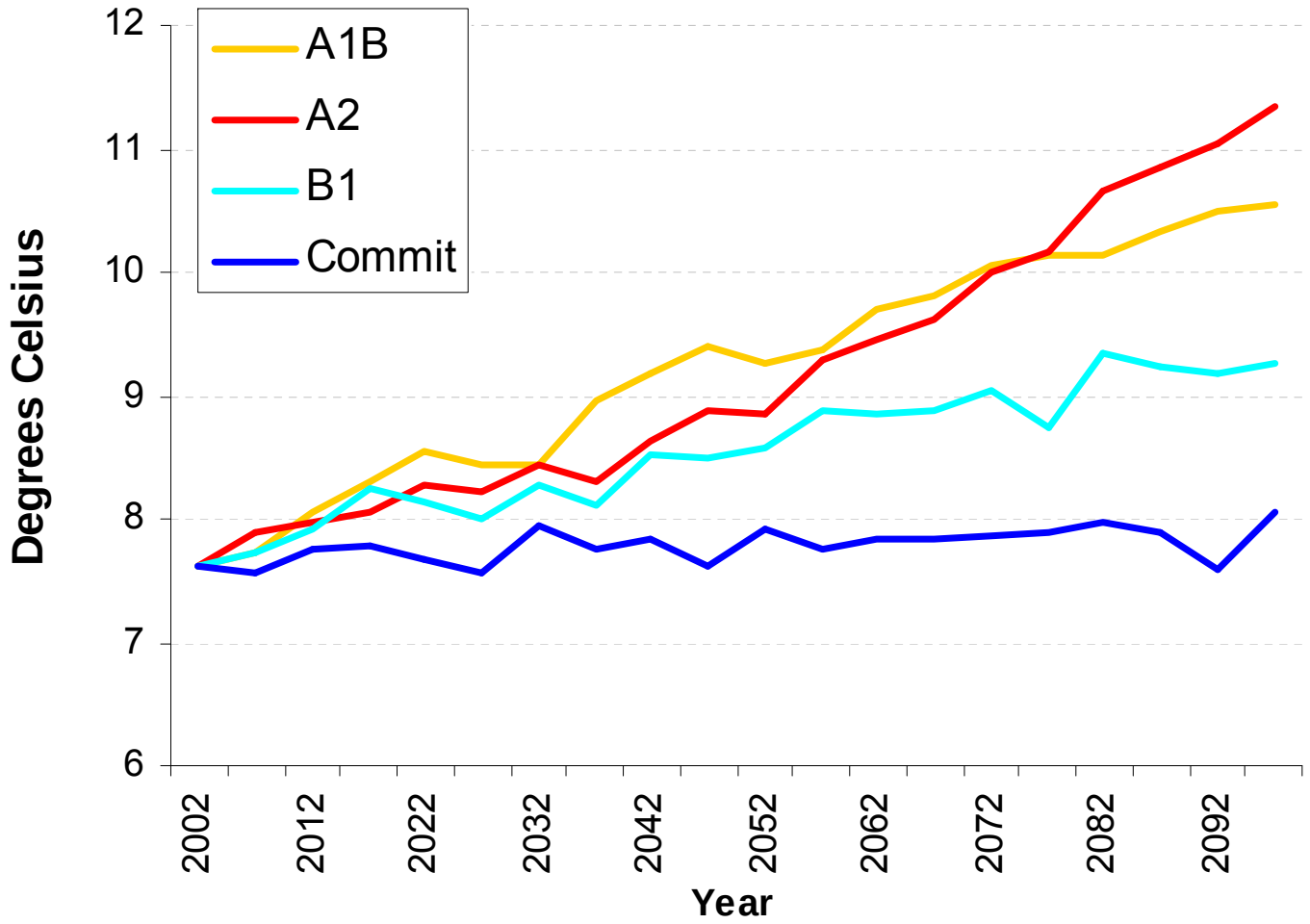
CNRM - French Centre National de Recherches Meteorologiques Coupled Global Climate Model version 3

CSIRO - Australian Commonwealth Scientific and Industrial Research Organisation's MK3

Hadley - British Hadley Centre for Climate Prediction and Research's CM3

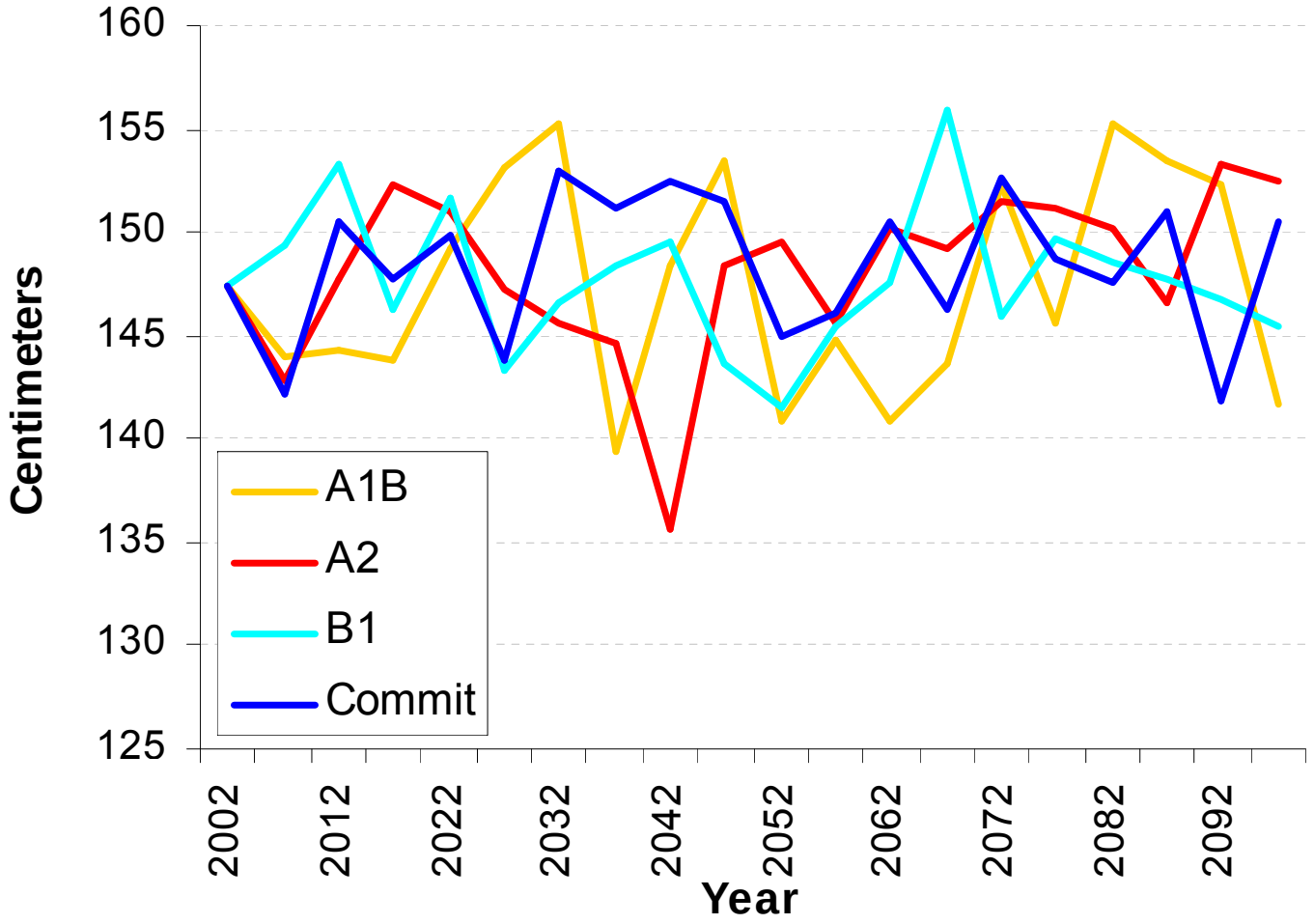
3.1. Climate Change
Temperature

Average annual temperature



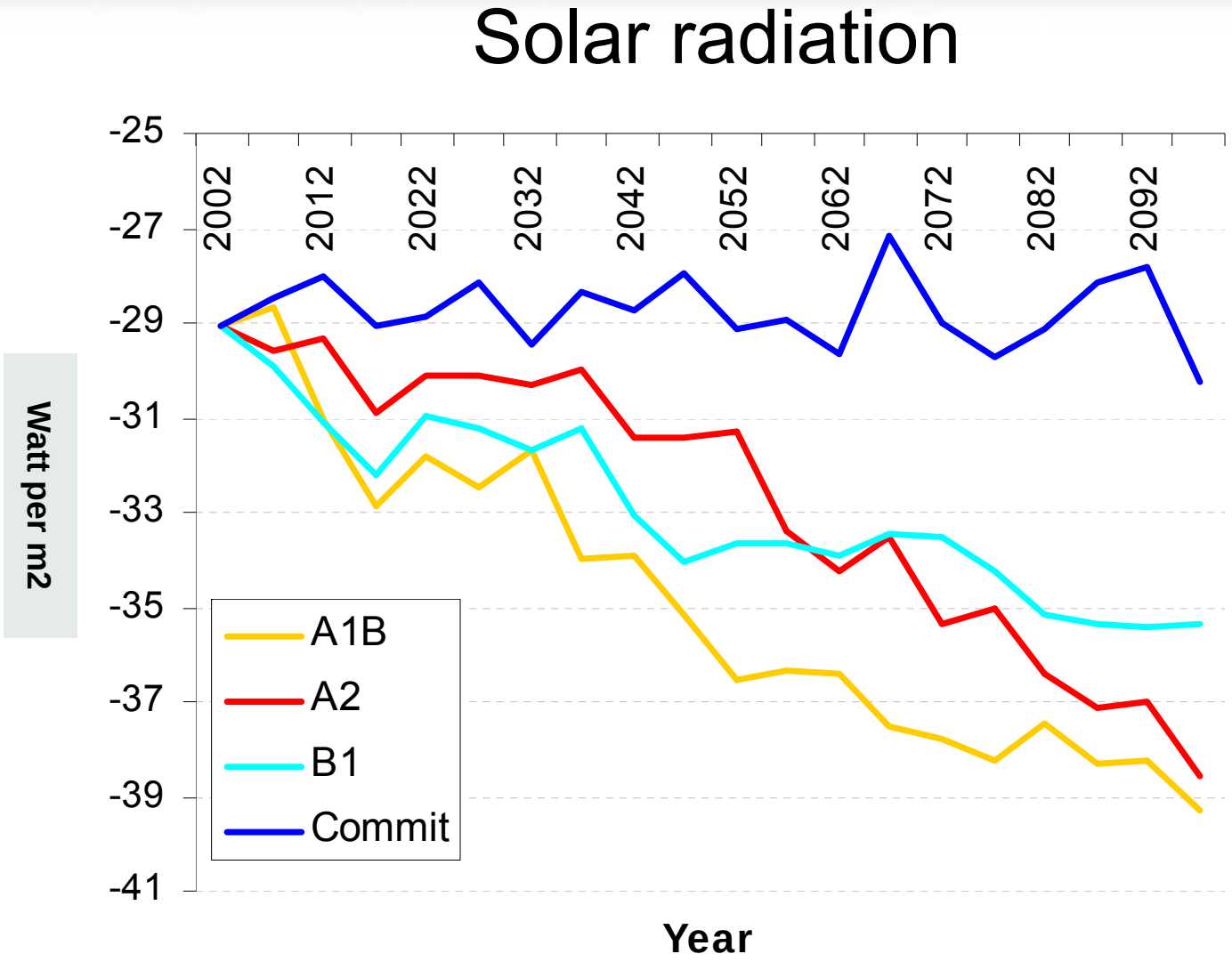
3.1. Climate Change
Precipitation

Annual precipitation flux



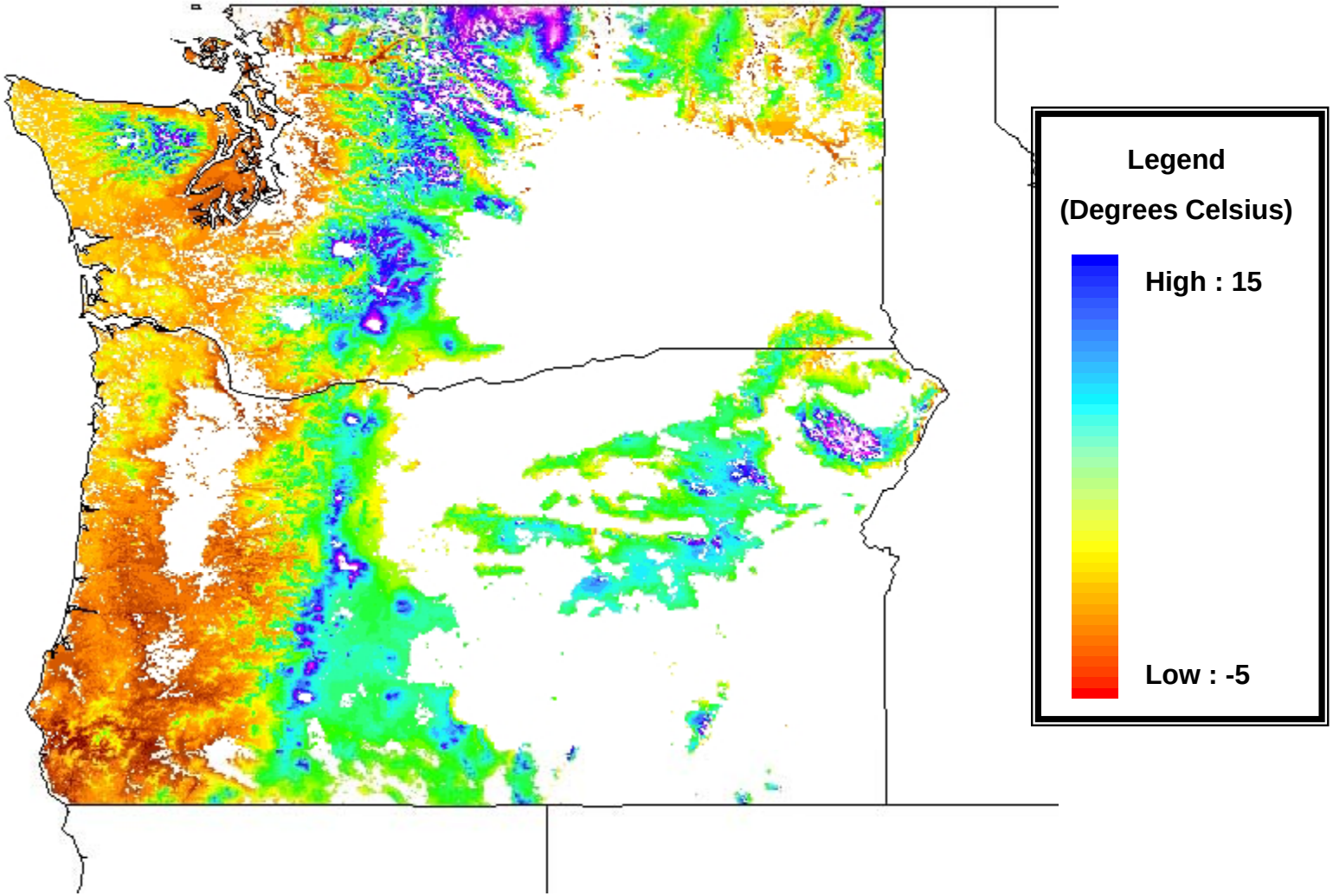
3.1. Climate Change

Solar radiation



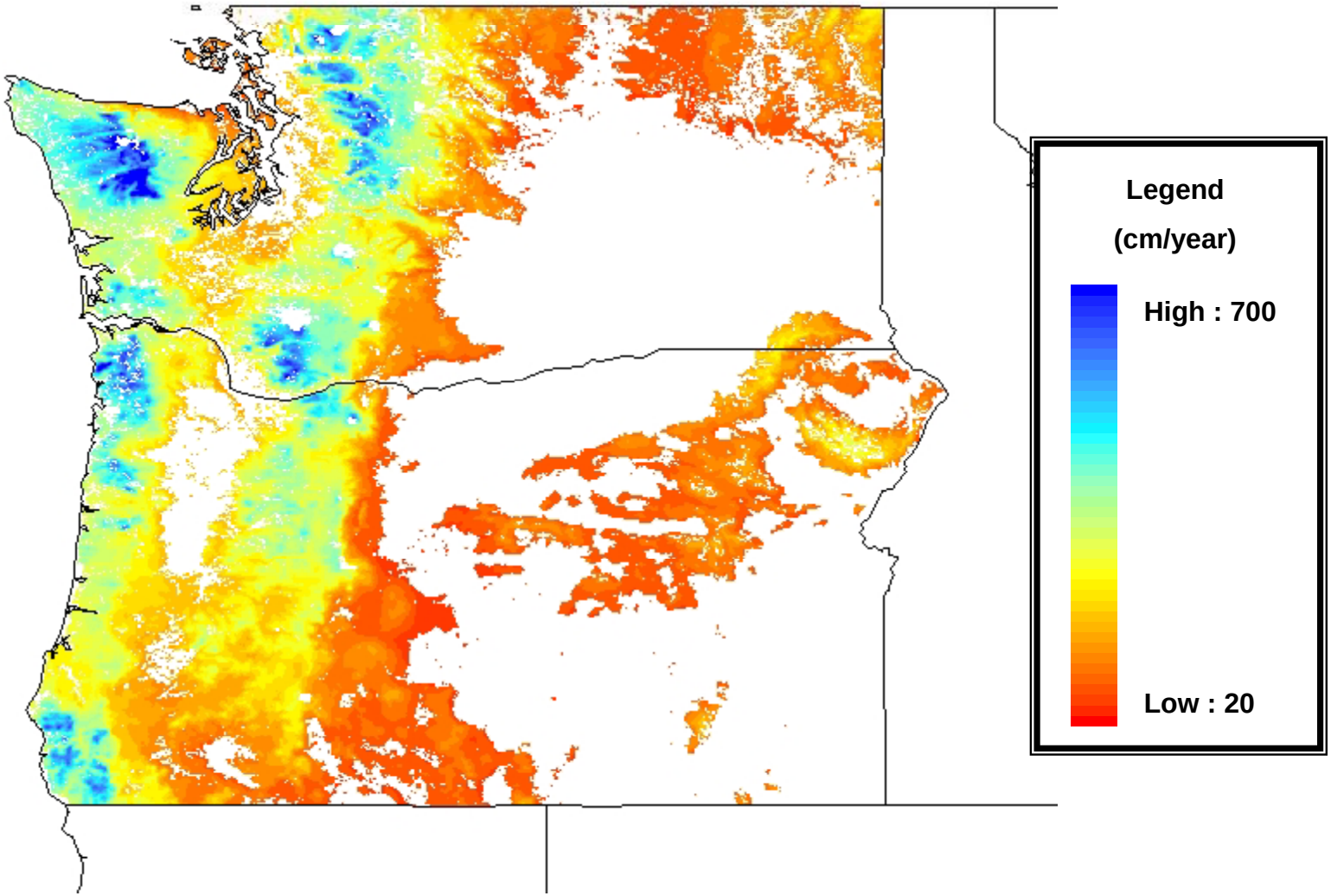
2090 Average Temperature

SRESA1B



2080 Annual Precipitation

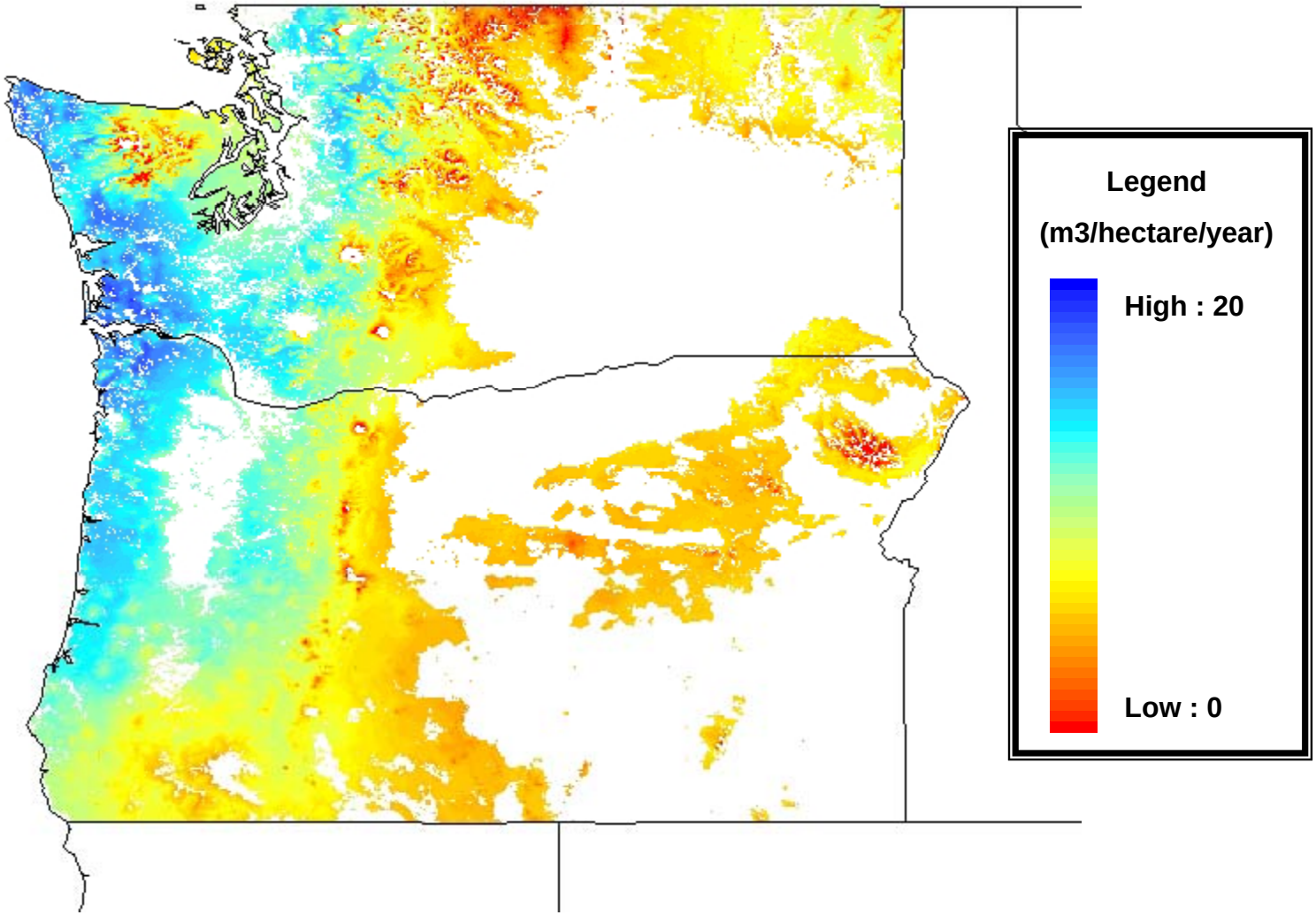
SRESA1B



2009 Forestland Productivity

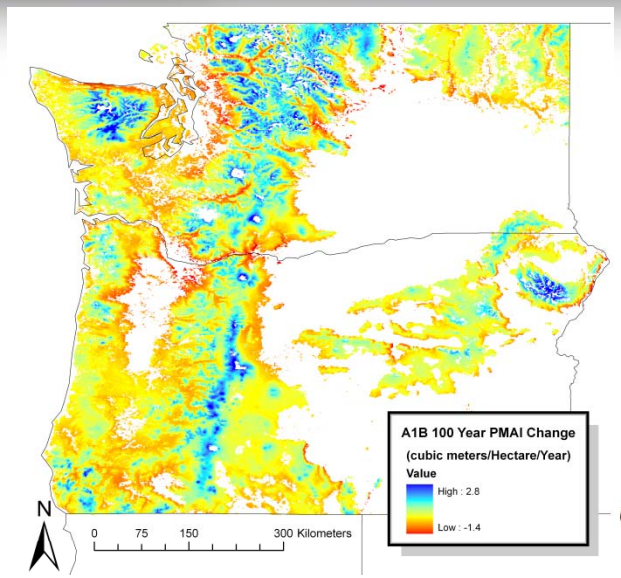
(Mean Annual Increment at Culmination)

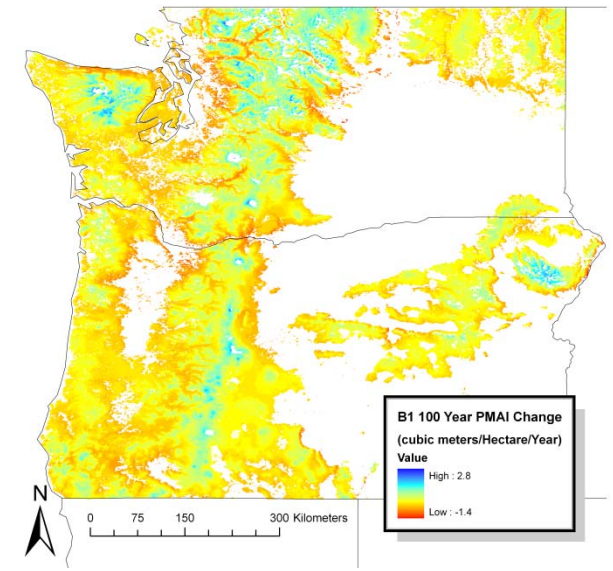
SRESA1B

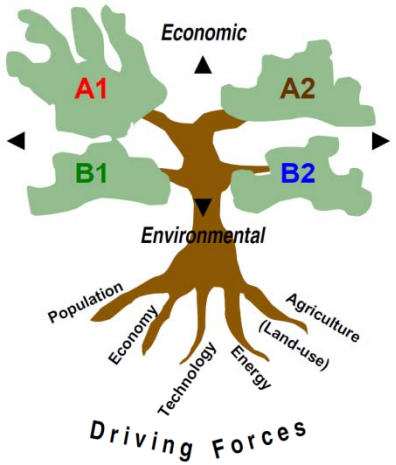


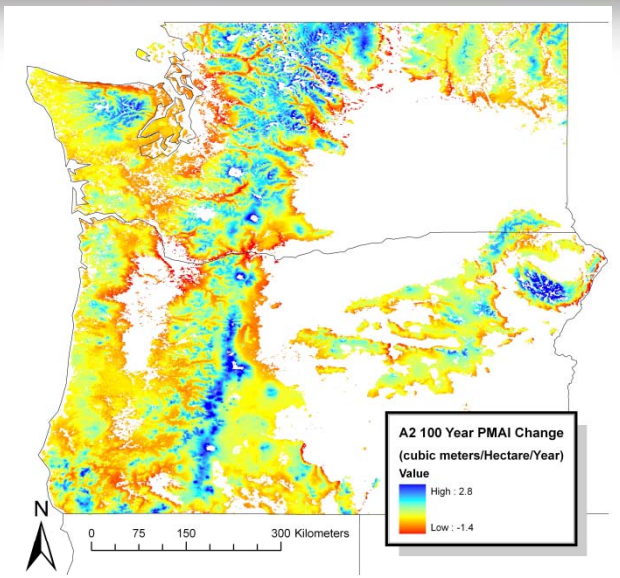
3.1. Climate Change

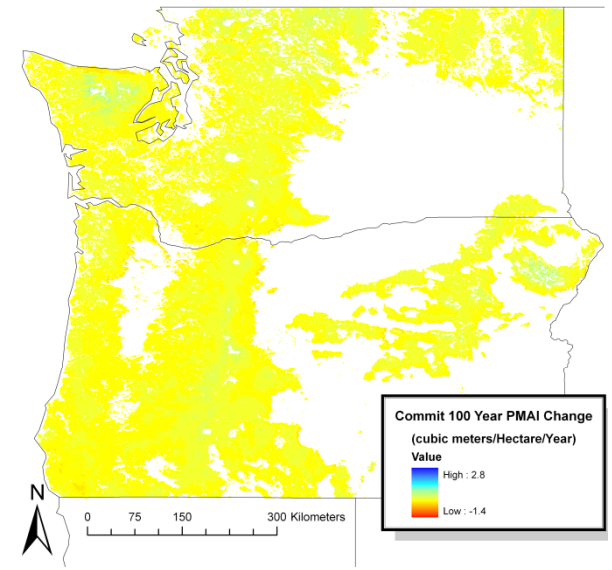
Changes in PMAI over the next century by IPCC scenario











3.1. Climate Change
Changes in future PMAI

100 Year changes in potential mean annual increment (m3/ha/yr) by IPCC scenario

	Oregon					Washington				
	0 - 500	500 - 1000	1000 - 1500	1500 - 2000	> 2000	0 - 500	500 - 1000	1000 - 1500	1500 - 2000	> 2000
	(elevation, meters)					(elevation, meters)				
Forestland hectares	2,859,072	2,352,320	3,602,688	2,937,930	324,902	2,828,096	2,666,589	2,688,275	1,010,122	58,710
Current Values										
Average PMAI	10.1	7.6	4.9	3.7	2.4	10.4	6.6	4.6	2.5	0.5
Annual Temperature	10.9	9.9	7.1	5.6	3.4	9.9	7.5	5.3	2.9	0.5
Annual Precipitation	182	170	98	83	107	198	170	154	155	139
Growning Season CMI	-25.8	-33.1	-40.2	-41.0	-31.7	-11.1	-27.7	-25.7	-19.8	-6.5
PMAI after 100 Years										
A1B	9.9	7.5	5.0	4.2	3.6	10.1	6.7	5.3	3.9	2.1
A2	9.8	7.5	5.0	4.3	4.0	10.0	6.6	5.3	4.1	2.4
B1	10.0	7.5	4.9	4.0	3.0	10.2	6.6	5.0	3.3	1.3
Commit	10.1	7.5	4.9	3.8	2.5	10.4	6.6	4.7	2.6	0.6
100 year change in PMAI										
A1B	-0.3	0.0	0.2	0.5	1.1	-0.4	0.1	0.7	1.4	1.5
A2	-0.3	-0.1	0.2	0.6	1.5	-0.4	0.0	0.7	1.6	1.9
B1	-0.1	0.0	0.1	0.3	0.5	-0.2	0.0	0.4	0.7	0.7
Commit	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.1	0.1
100 year % change in PMAI										
A1B	-2.5	-0.3	3.2	12.7	46.3	-3.4	1.4	14.3	54.7	285.9
A2	-3.1	-0.9	3.7	15.8	62.1	-4.0	-0.2	15.1	63.6	354.0
B1	-1.4	-0.4	1.5	6.8	21.8	-1.9	0.6	7.7	29.8	136.7
Commit	-0.3	-0.3	0.0	1.3	4.0	-0.4	-0.1	1.3	5.1	12.3

3.1. Climate Change
Timberland Ownership

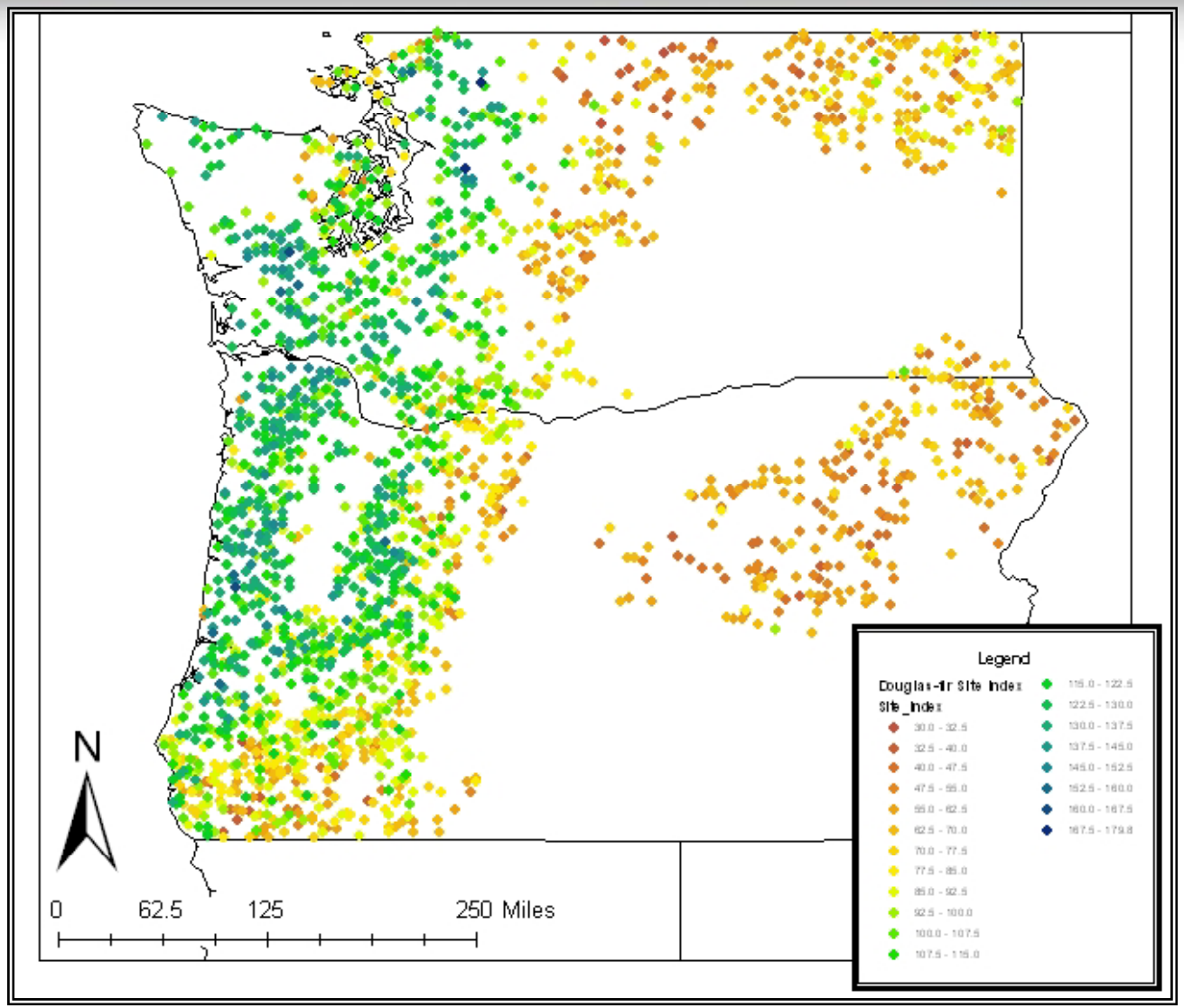
Pacific Northwest timberland ownership by elevation class

	Elevation class (meters)					
	0 - 499	500 - 1000	1000 - 1500	1500 - 2000	>2000	Total
	Thousand hectares					
Oregon						
Federal	638	1,135	2,166	1,661	90	5,689
Other public	240	115	44	7	-	407
Private	1,750	800	1,043	263	10	3,866
Total	2,629	2,049	3,253	1,931	100	9,962
Washington						
Federal	152	851	1,143	309	11	2,467
Other public	551	293	182	20	-	1,046
Private	1,850	1,278	692	44	-	3,865
Total	2,554	2,422	2,017	372	11	7,377
Pacific Northwest						
Federal	791	1,986	3,309	1,970	101	8,156
Other public	791	407	226	27	-	1,452
Private	3,600	2,079	1,735	306	10	7,730
Total	5,183	4,472	5,270	2,303	111	17,339

Estimates produced from 2001-2007 Forest Inventory and Analysis data (http://fiatools.fs.fed.us/fiadb-downloads/datamart.html)

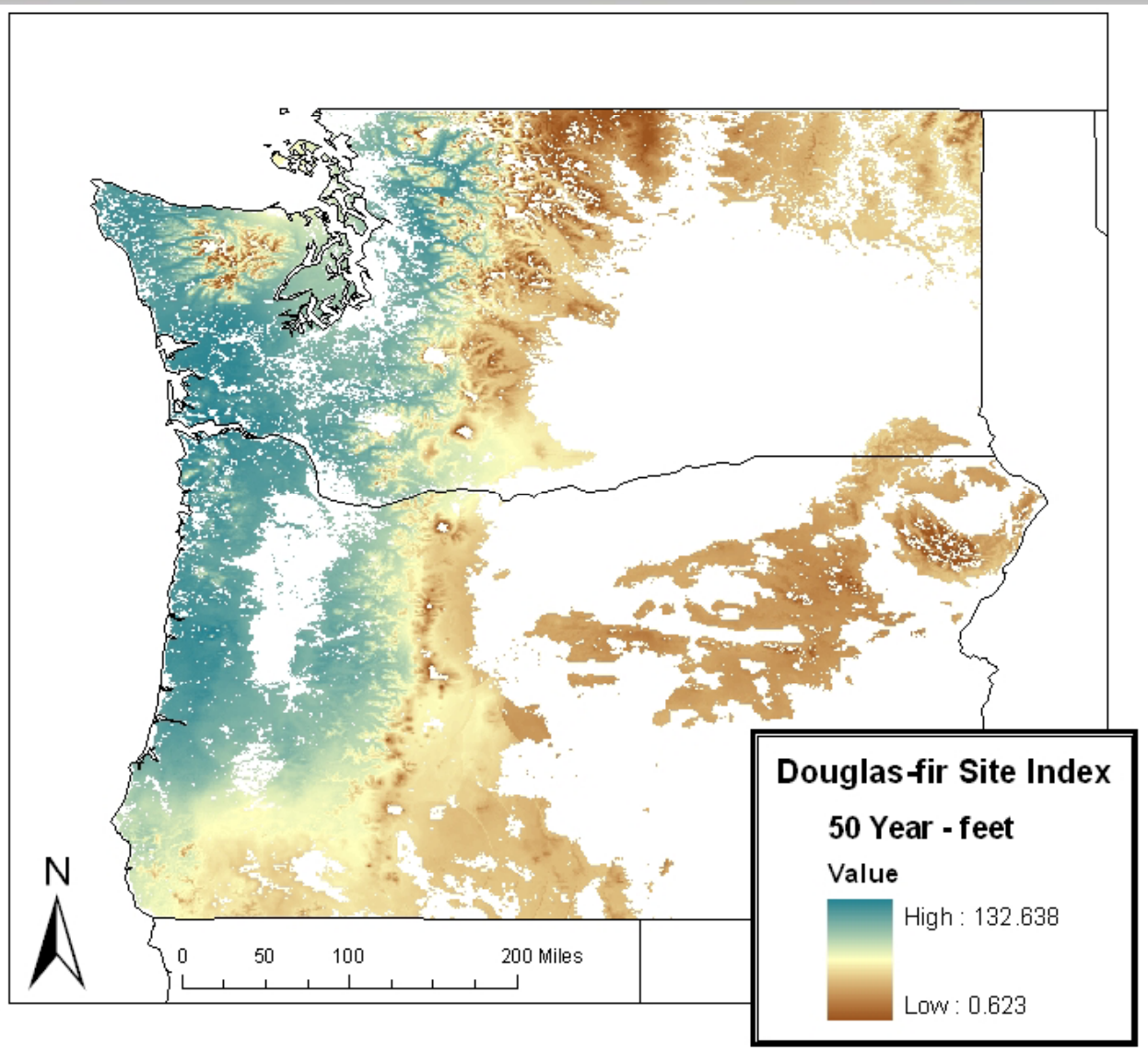
4.1. Productivity Mapping Study – Data (cont'd)

Site Index Plot Map



4.2. Results – Simultaneous Autoregressive Model

Douglas-fir 50 year Site Index Map



4. Individual Tree Growth and Yield Model ORGANON

5 year diameter growth

$$\Delta D_5 = e^{b_0 + b_1 \ln(D_s + k) + b_2 D_s + b_3 \ln\left[(CR_s + 0.2)/1.2\right] + b_4 \ln(\mathbf{SI} - 4.5) + b_5 \left[SBAL_s / \ln(D_s + 2.7)\right] + b_6 SBA_s^{0.5}} + e_{\Delta D}$$

5 year height growth

$$\Delta H_5 = \left(f_B\left[\mathbf{SI}_B, (GEA + 5)\right] - H_s\right) c_0 \left[c_1 e^{c_2 CCH_s + \left(e^{c_3\sqrt{CCH_s}} - c_1 e^{c_2 CCH_s}\right) e^{-c_4 (1.0 - CR_s)^2} e^{c_5\sqrt{CCH_s}}}\right] + e_{\Delta H}$$

Changes in live crown

$$HCB = \frac{H}{1 + e^{d_0 + d_1 H + d_2 CCFL + d_3 \ln(SBA) + d_4 D/H + d_5 \mathbf{SI}}} + e_{HCB}$$

Tree Mortality

$$PM_5 = \left[1 + e^{-a_0 + a_1 D_s + a_2 CR_s + a_3 \mathbf{SI} + a_4 SBAL_s}\right]^{-1} + e_{PM}$$

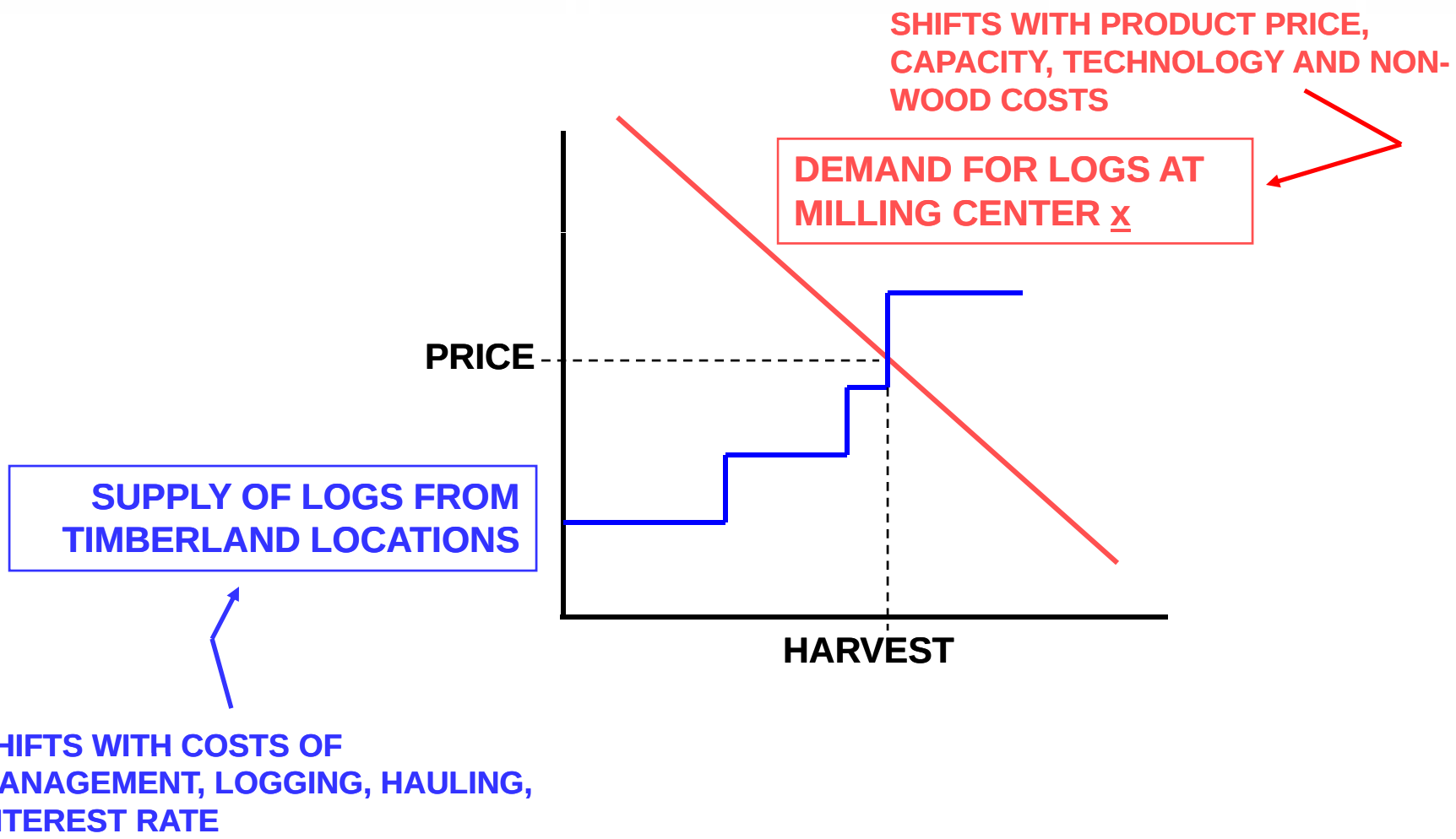
4. Individual Tree Growth and Yield Model

Summary of Growth Model Equation Abbreviations

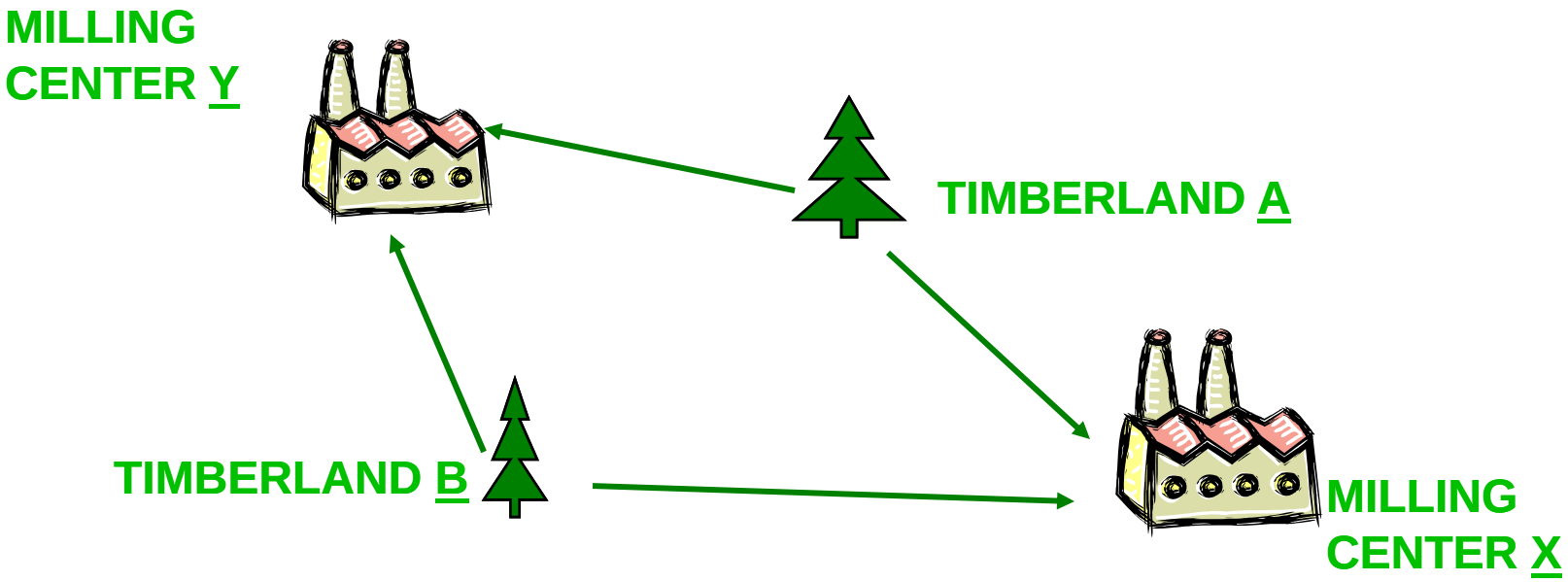
Abbrevition	units	Description
CCFL	ft2/ac	Plot crown competition factorin trees with a d > that of the subject tree
CCH	%	Percent crown closure at the top of the tree for the plot
CR	none	Live crown ratio (CL:H)
D	in.	Diameter at 4.5 ft above ground level (breast height)
GEA	years	Growth equivalent age: age of a dominant tree with the same height on the same site as subject tree
H	ft	Total tree height from ground level to the top of the tree
SI	ft at 50-yr BHA	Site index
SBA	ft2/ac	Basal area of the plot
SBAL	ft2/ac	Plot basal area in trees with D > that of the subject tree

5.1. Regional Log Market Model

Model of Log Market at Milling Center x



5.1. Regional Log Market Model

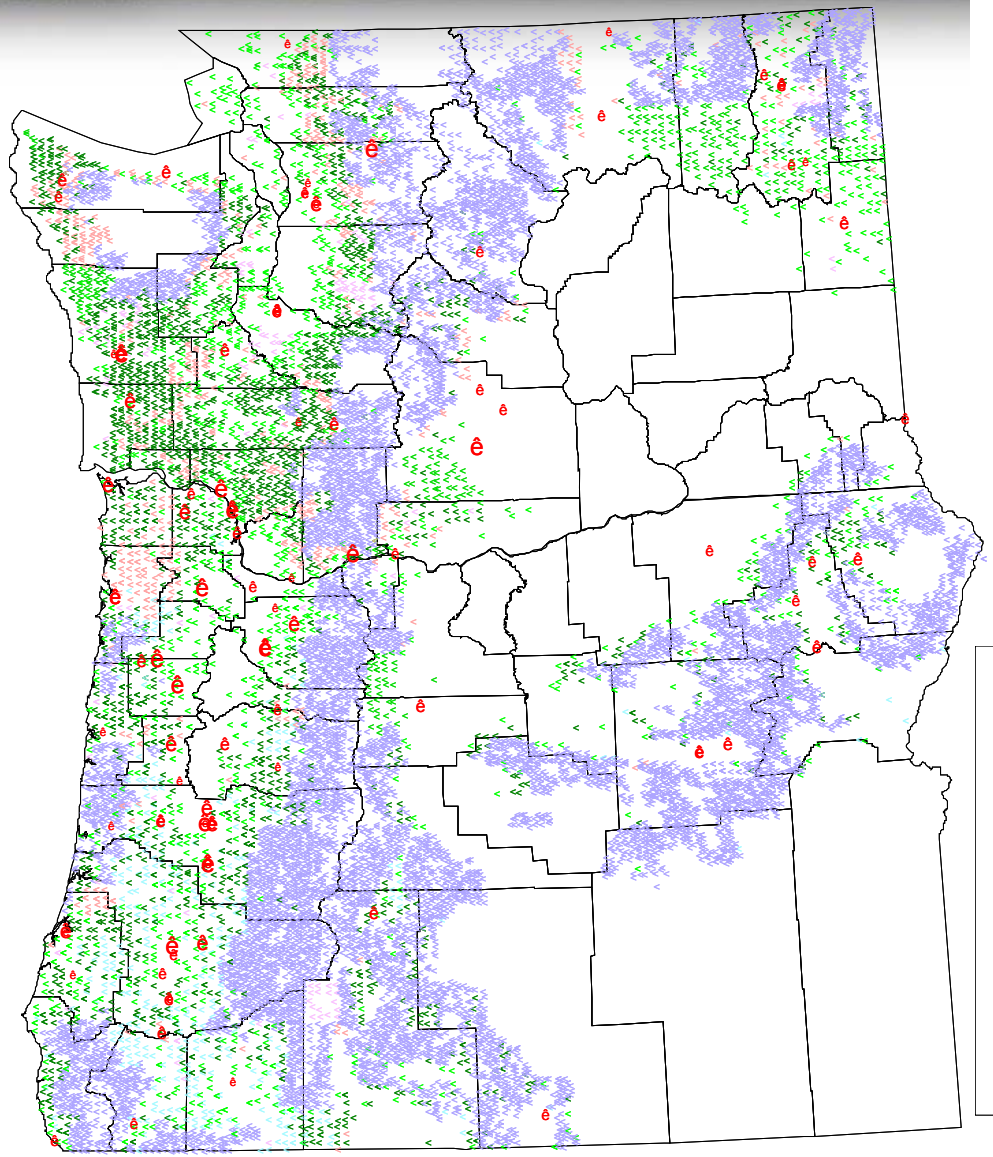


MARKET BALANCE MUST BE FOUND ACROSS ALL MILLING CENTERS AND LOG SOURCES

LOG BUYERS TRADE-OFF SOURCES TO MINIMIZE COSTS

LOG SELLERS TRADE-OFF DESTINATIONS TO MAXIMIZE NET RETURNS

5.1. Regional Log Market Model



Plot and Milling Center Layout for Regional Log Market Model

SWPI Model Setup

Lumber 8 hr Capacity	
ê	0 - 100
ê	100 - 180
ê	180 - 260
ê	260 - 350
ê	350 - 500

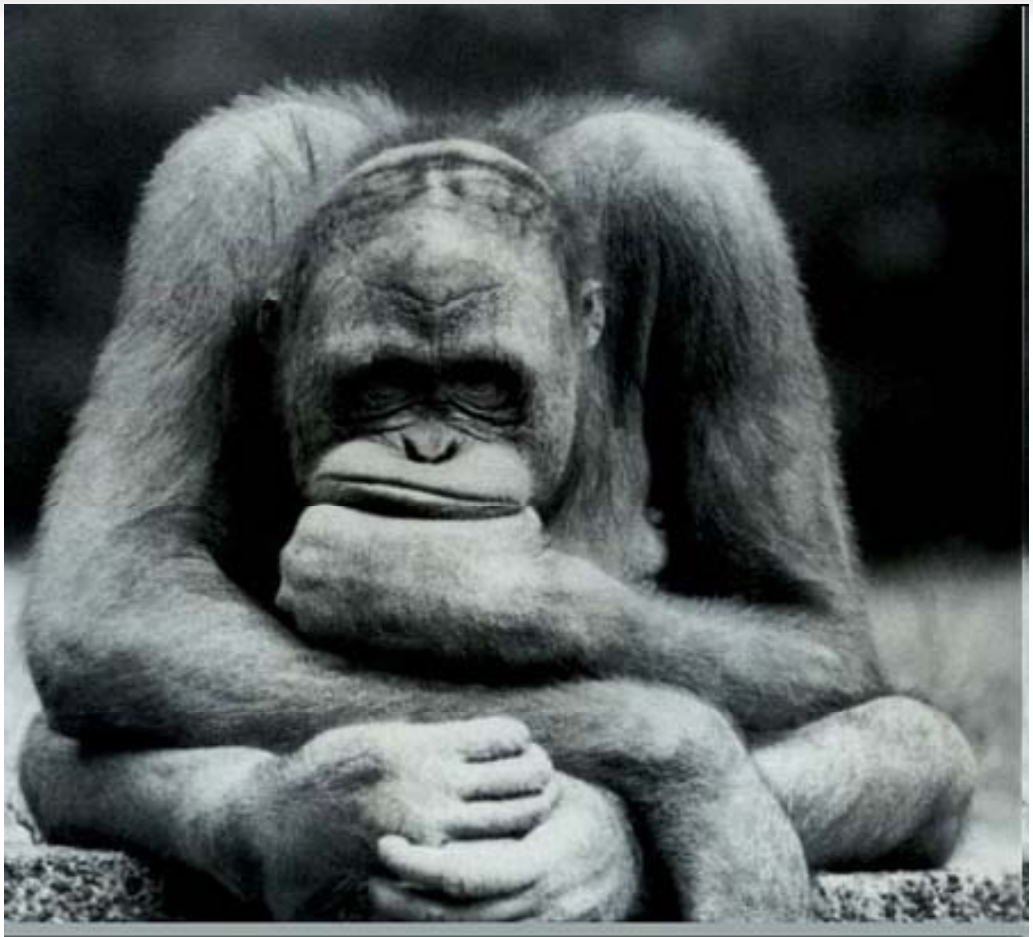
Forested Plot Ownership	
<	BLM
<	Forest Industry
<	Native American
<	Other Private
<	Other Public
<	State
<	USFS

5.2. Regional Log Market Model
Even Flow

Percentage Change in Maximum Even Flow Harvest Levels

IPCC Scenario	Western Washington	Western Oregon
A1B	-0.32%	-0.44%
A2	-0.31%	-0.44%
B1	-0.31%	-0.36%
Com	-0.29%	-0.24%

6. Concluding remarks



Oh what to do, What to do

6. References

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Thank You

Questions??

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