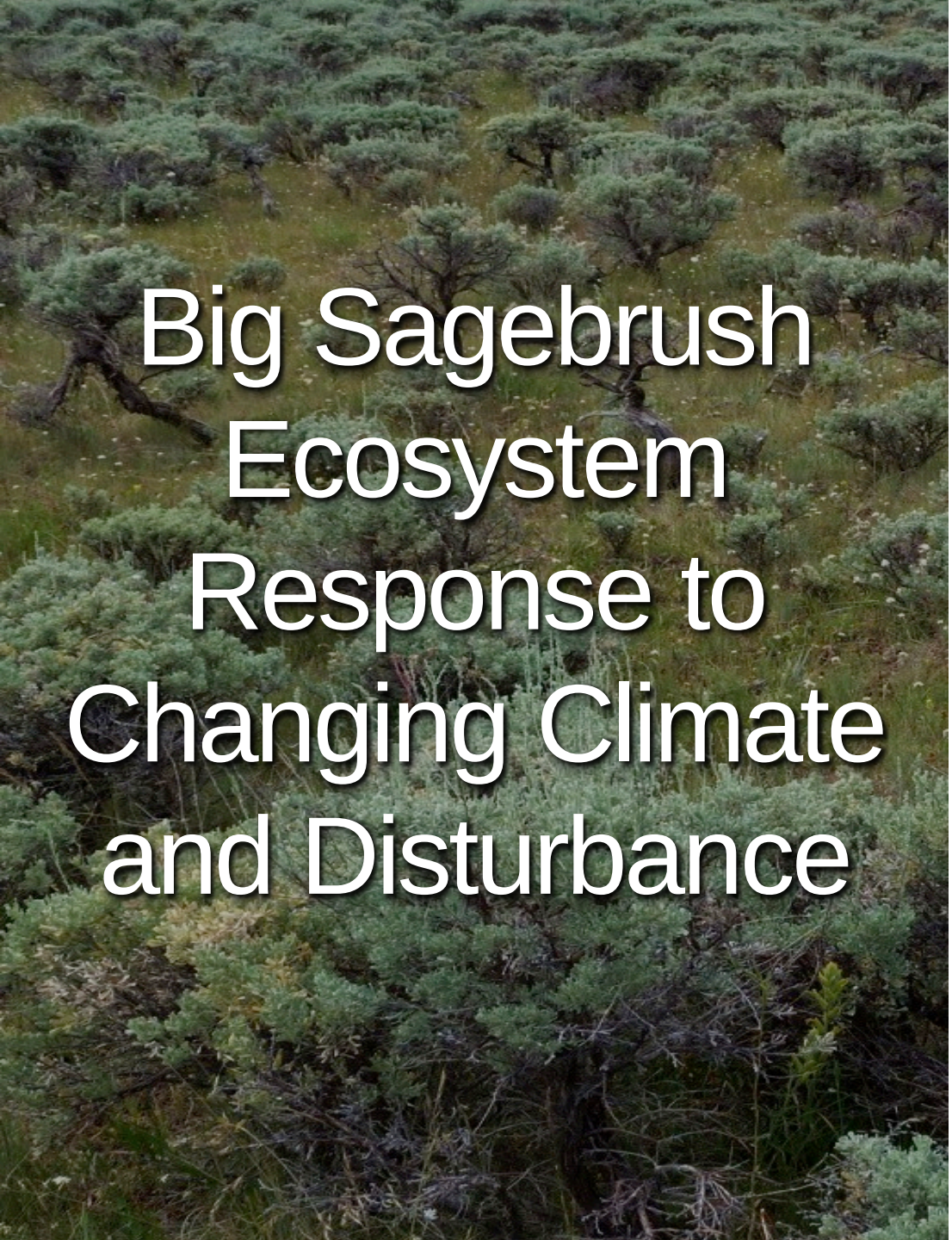


Big Sagebrush Ecosystem Response to Changing Climate and Disturbance

Dr. William Lauenroth
& **Dr. Kyle Palmquist**
University of Wyoming

Dr. John Bradford
USGS SW Biological Science Center

Dr. Daniel Schlaepfer
University of Basel

Great Northern Landscape Conservation Cooperative · Southern Rockies Landscape Conservation Cooperative · Great Basin Landscape Conservation Cooperative · Plains & Prairie Potholes Landscape Conservation Cooperative

Today:

An ecohydrological approach

Ecohydrology of sagebrush ecosystems

Climate change impacts

Sagebrush suitability and regeneration

Plant species biodiversity

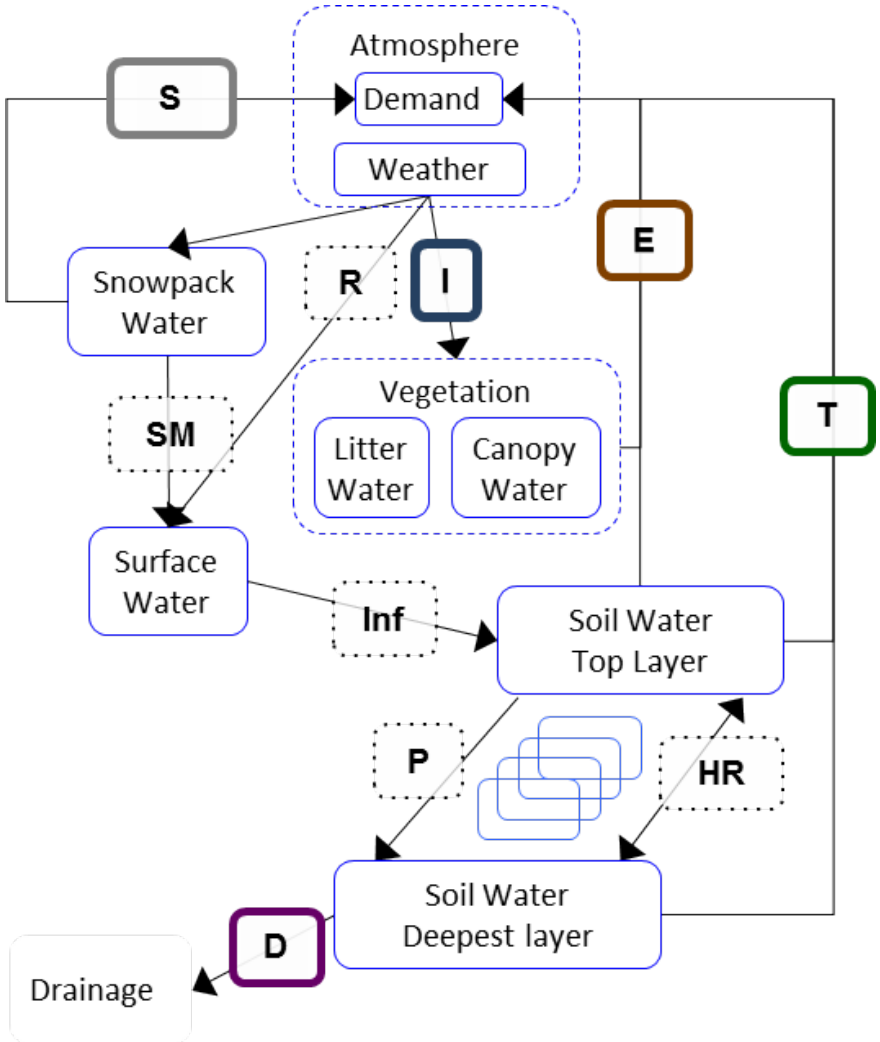
Plant community responses

Sagebrush mortality

Heterogeneous & water-limited landscapes

An ecohydrological approach: SOILWAT

- Inputs:
  - Daily weather
  - Vegetation properties
  - Soil properties
  - Ecosystem processes
- Outputs:
  - Daily, monthly, and annual values of each water balance component



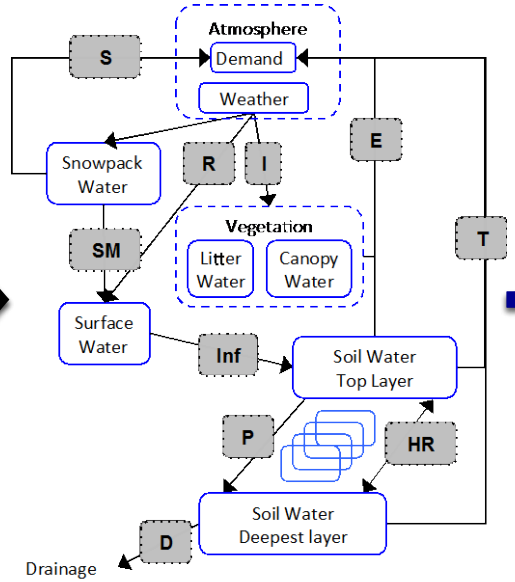
Parton 1978 ➔ Sala et al 1992 ➔ Bradford and Lauenroth 2006 ➔ Lauenroth and Bradford 2006➔ Schlaepfer et al. 2012 ➔ Bradford et al. 2014

SOILWAT:
A translation tool

Daily weather

Soil Conditions

Vegetation Structure



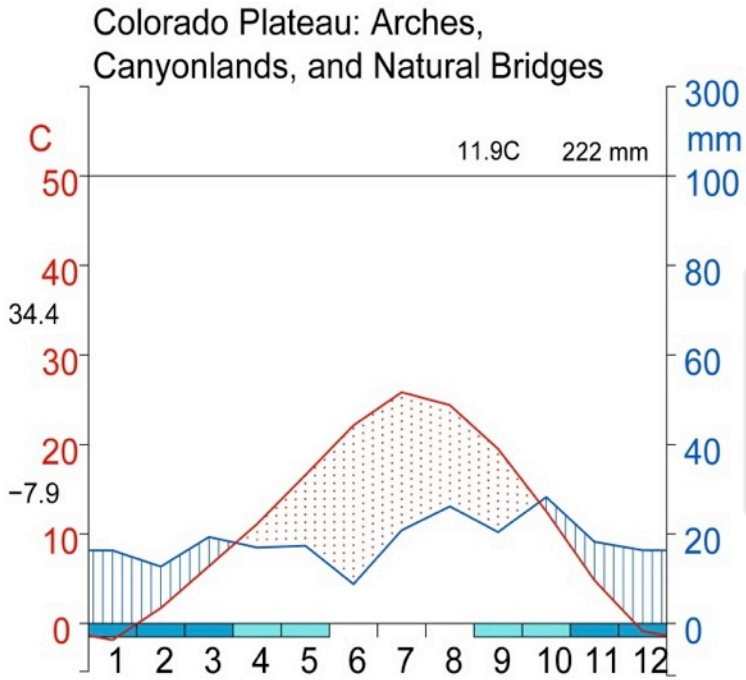
Water balance

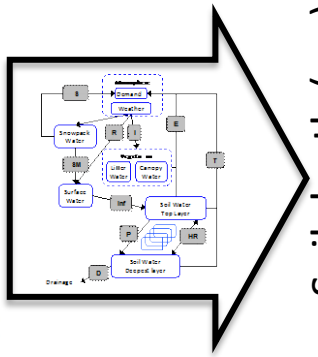
Water availability for plants

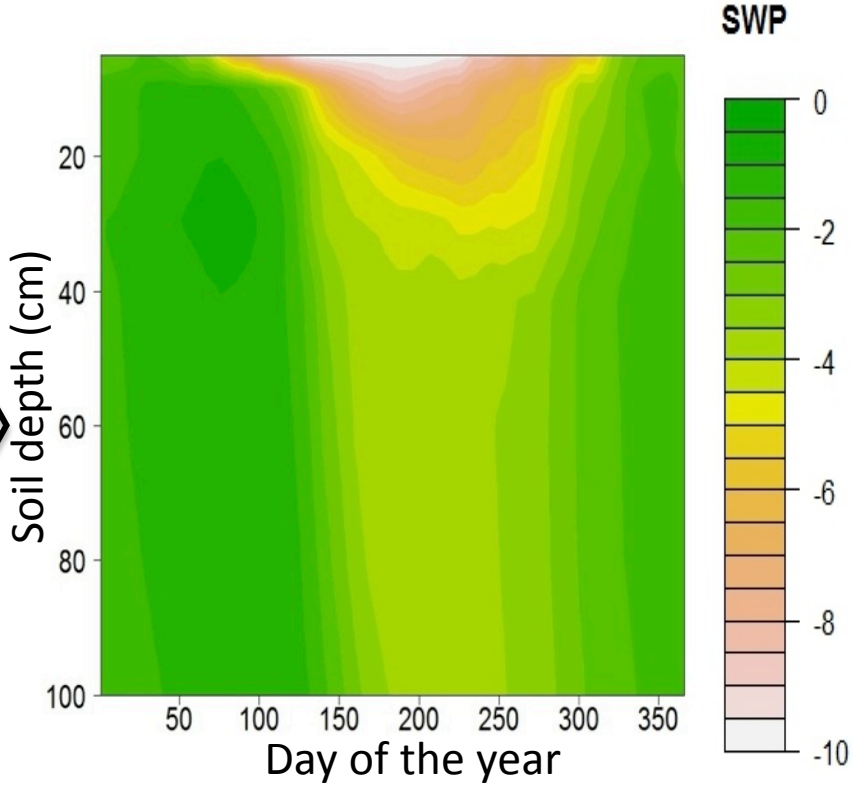
Parton 1978 → Sala et al 1992 → Bradford and Lauenroth 2006 → Lauenroth and Bradford 2006→ Schlaepfer et al. 2012 Ecohydrology

SOILWAT:

Climate & Soil -> Water availability

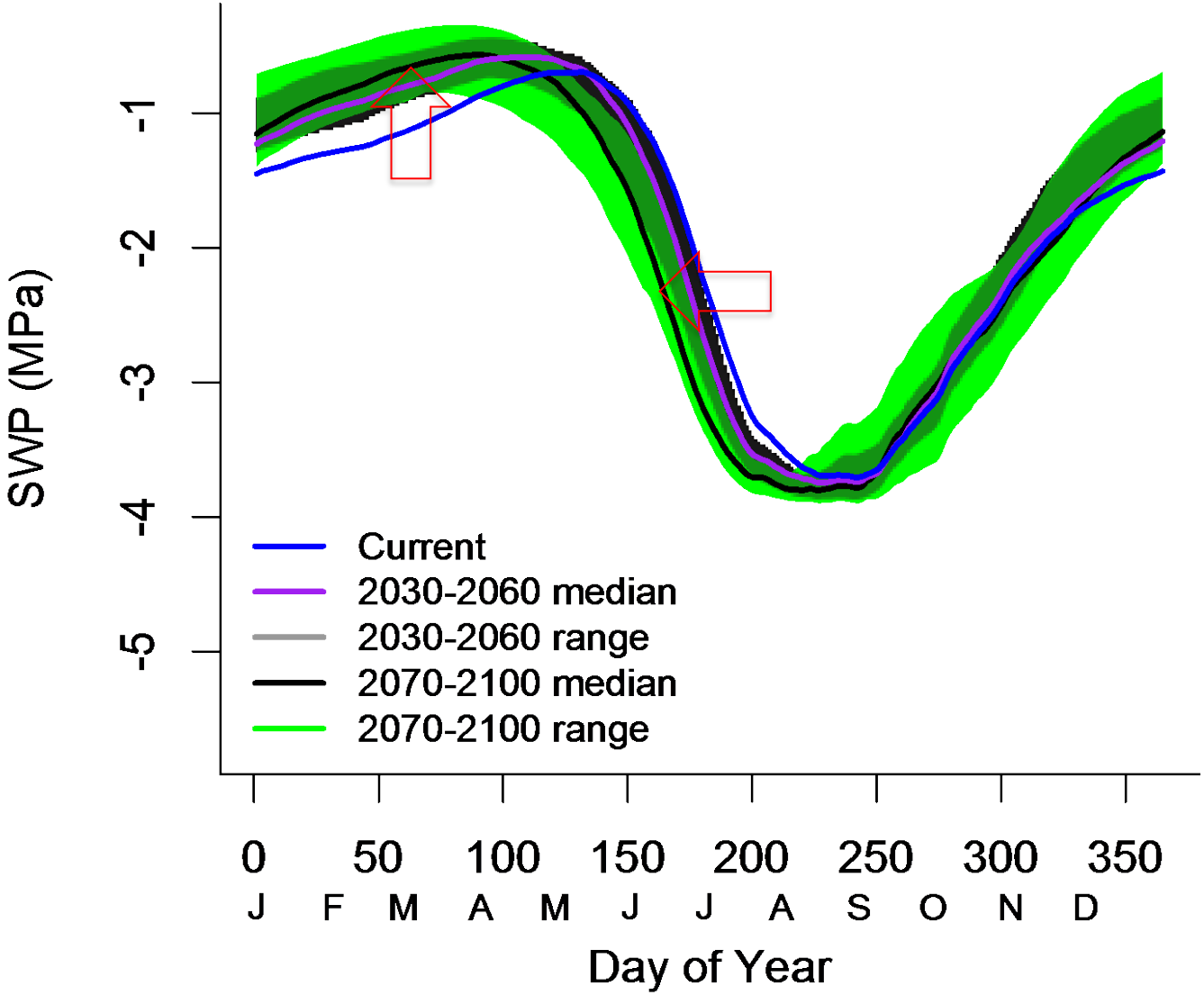






SOILWAT:

A tool for future projections



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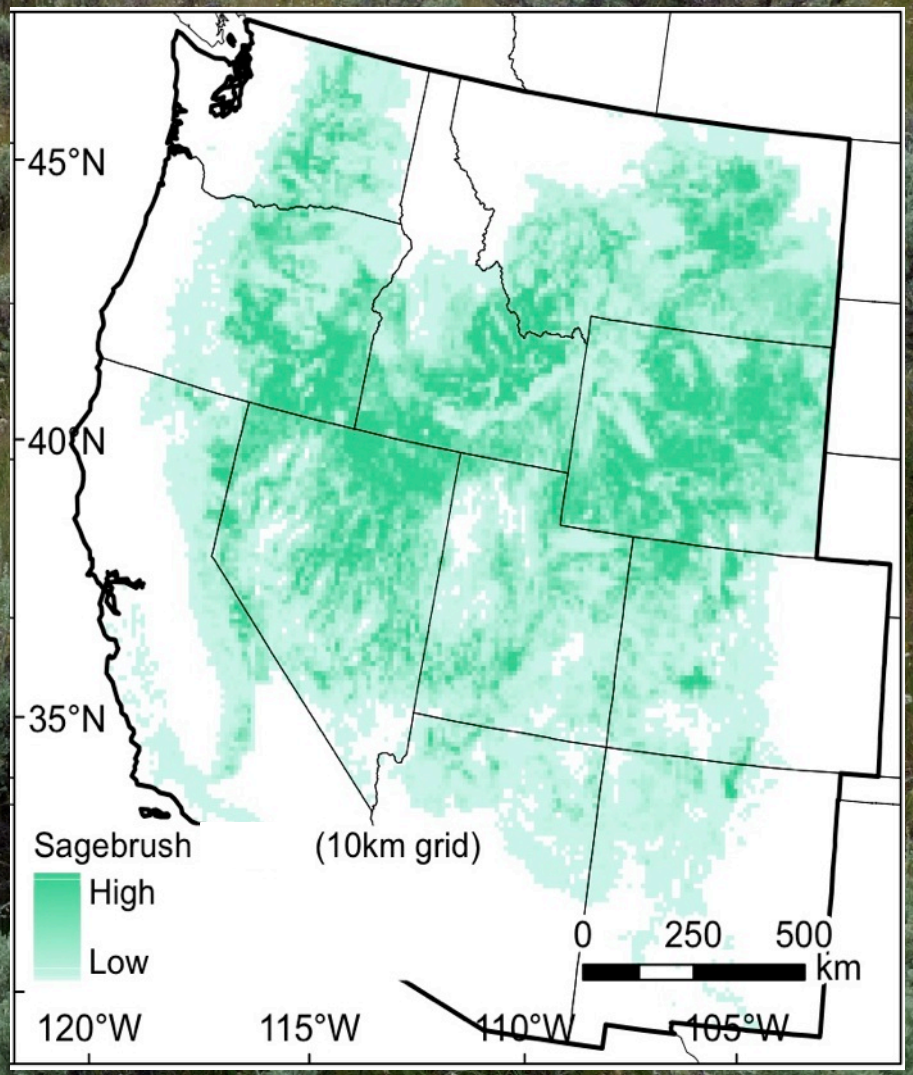
Sagebrush mortality

Big Sagebrush Ecosystems

Widespread semiarid ecosystem in western US (>470,000km^2)

Dominated by big sagebrush (*Artemisia tridentata*)

Habitat for vulnerable species (e.g., greater sage-grouse)



Schlaepfer et al. (2011) Ecohydrology

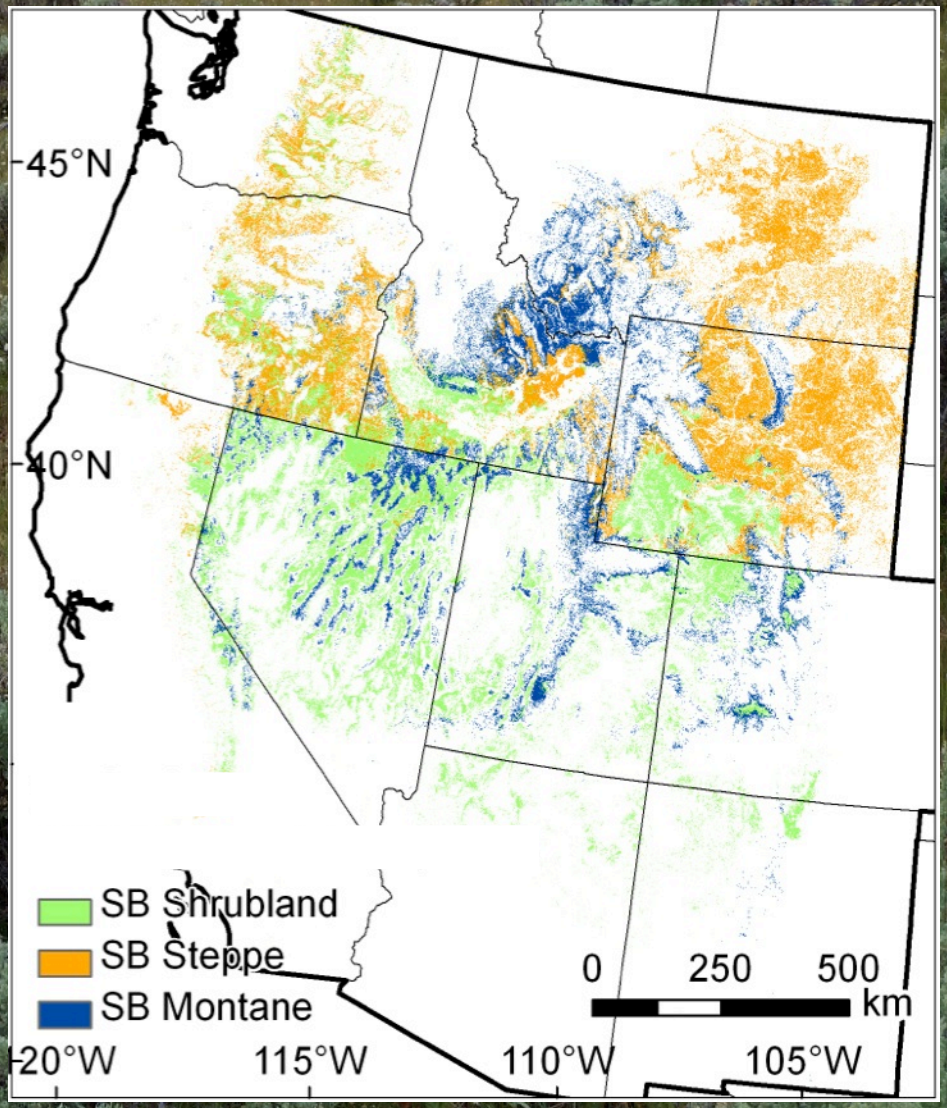
Big Sagebrush Ecosystems

SB-Shrubland
(Intermountain Basins Big Sagebrush Shrubland): *A. tridentata* ssp *tridentata* or *A. tridentata* ssp *wyomingensis*

SB-Steppe
(Intermountain Basins Big Sagebrush Steppe): *A. tridentata* ssp *tridentata* and ssp *wyomingensis* with bunchgrasses

SB-Montane
(Intermountain Basins Montane Sagebrush Steppe): *A. tridentata* ssp *vaseyana*

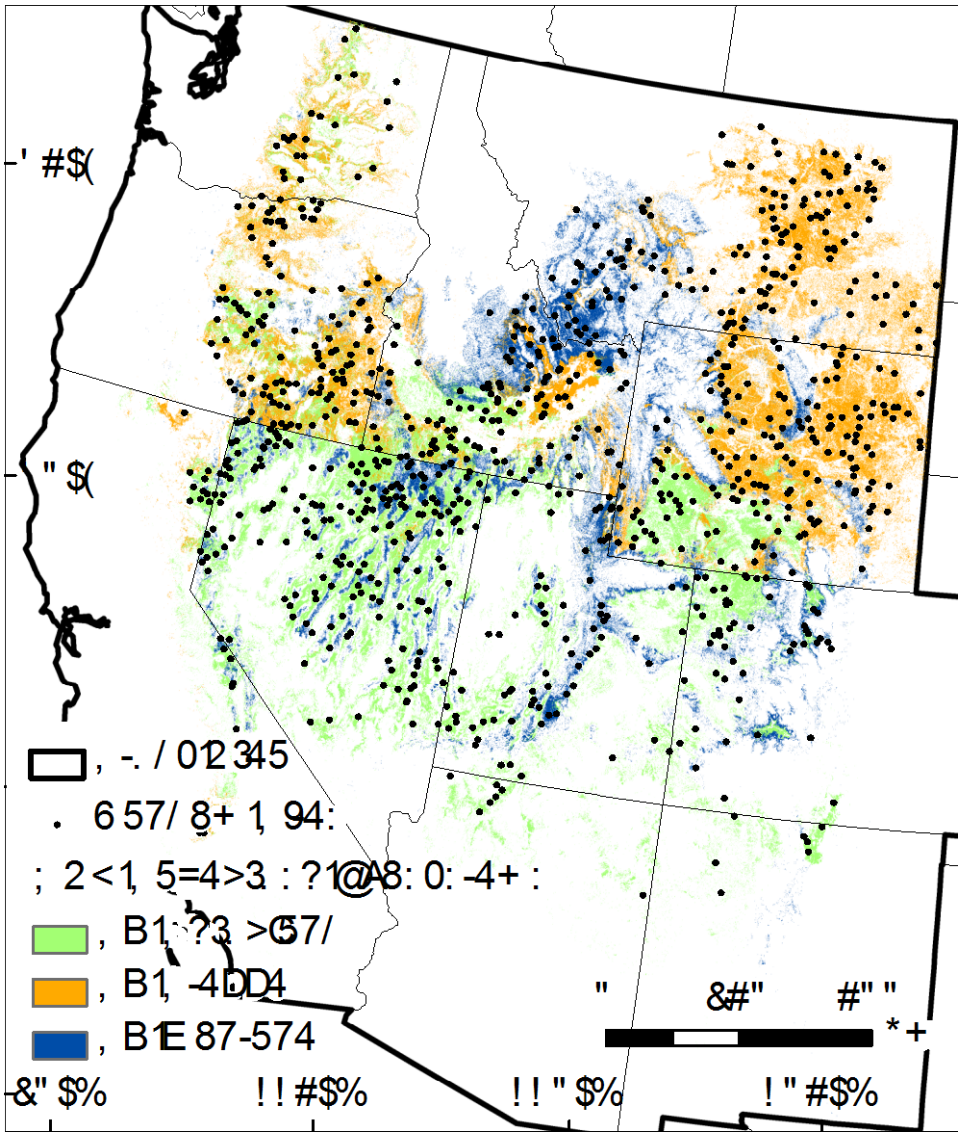
GAP cover types (US Geological Survey, 2010)



Schlaepfer et al. (2011) Ecohydrology

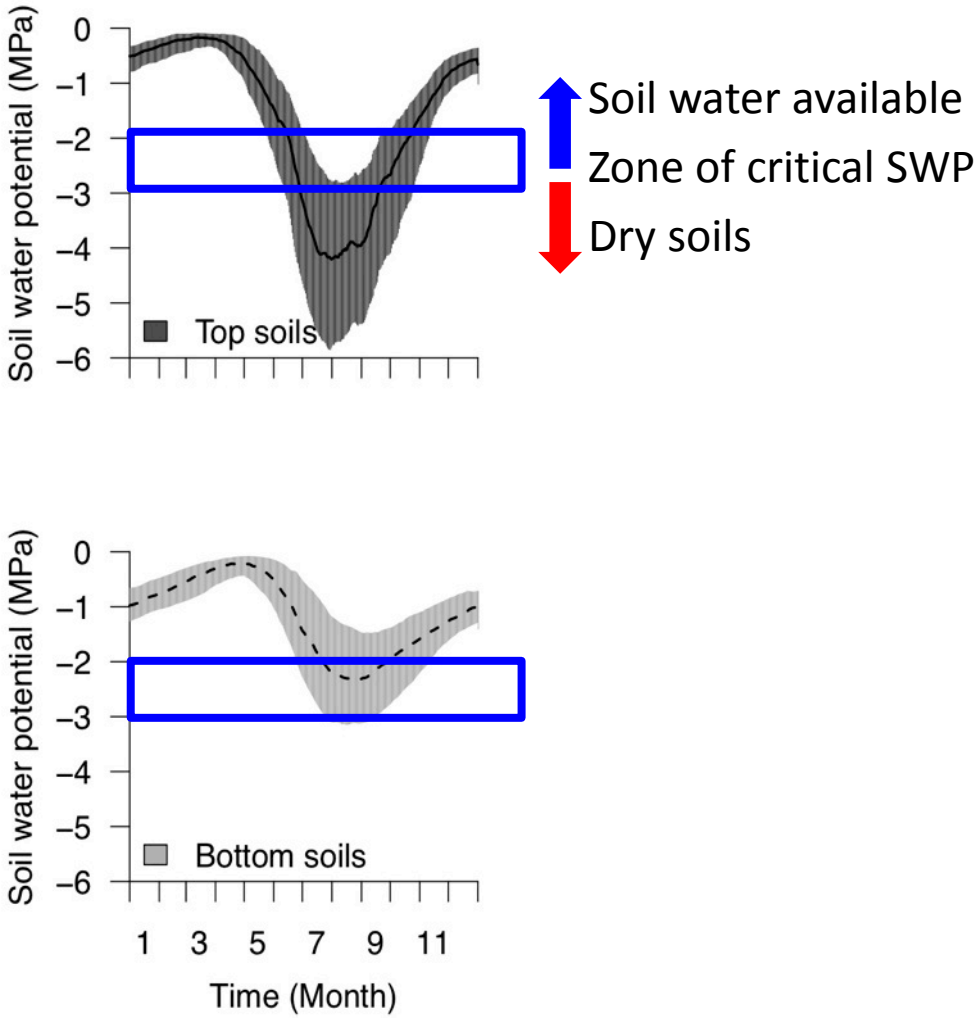
Sagebrush ecohydrology

- Simulated soil moisture dynamics (50 yrs)
- 898 Sites
- Representative of
  - climate
  - soil
  - ecosystem types



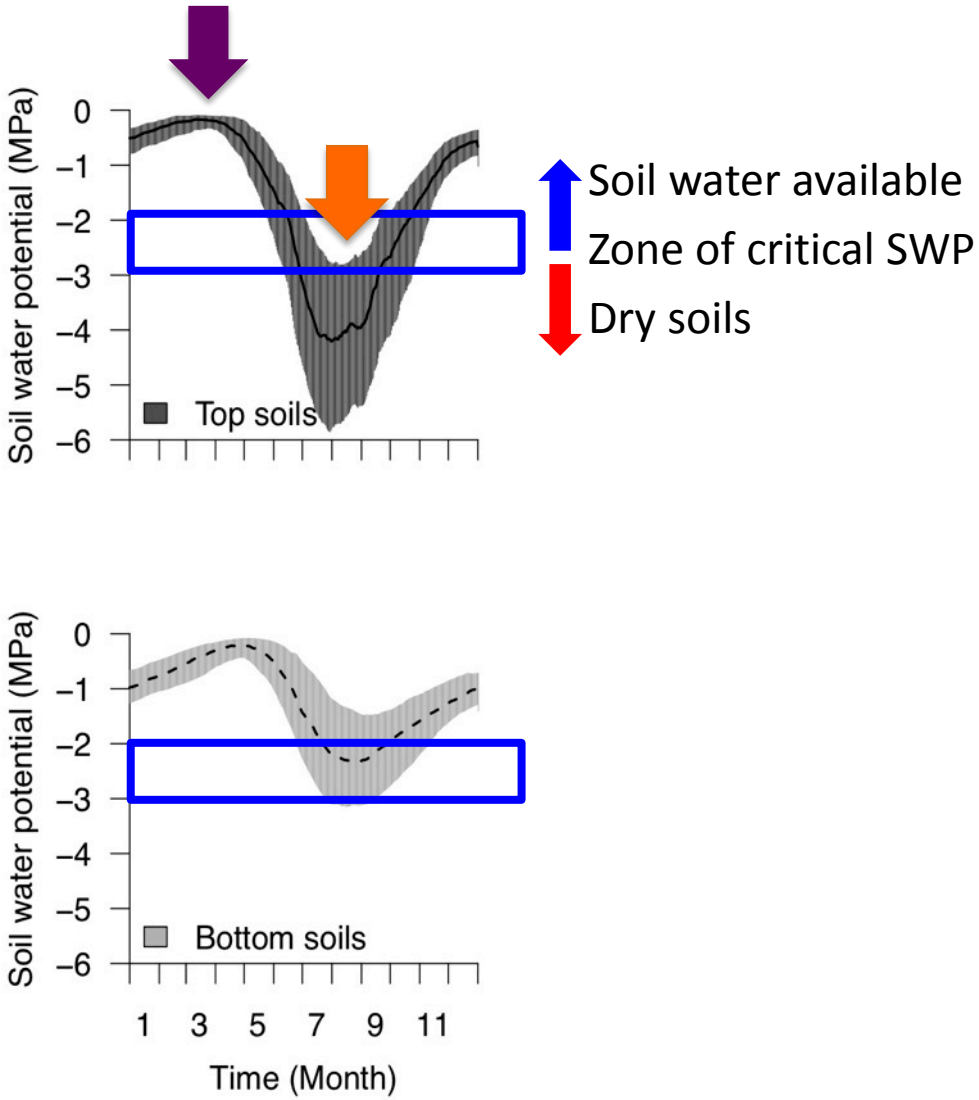
GAP land cover (USGS 2010)

Sagebrush ecohydrology



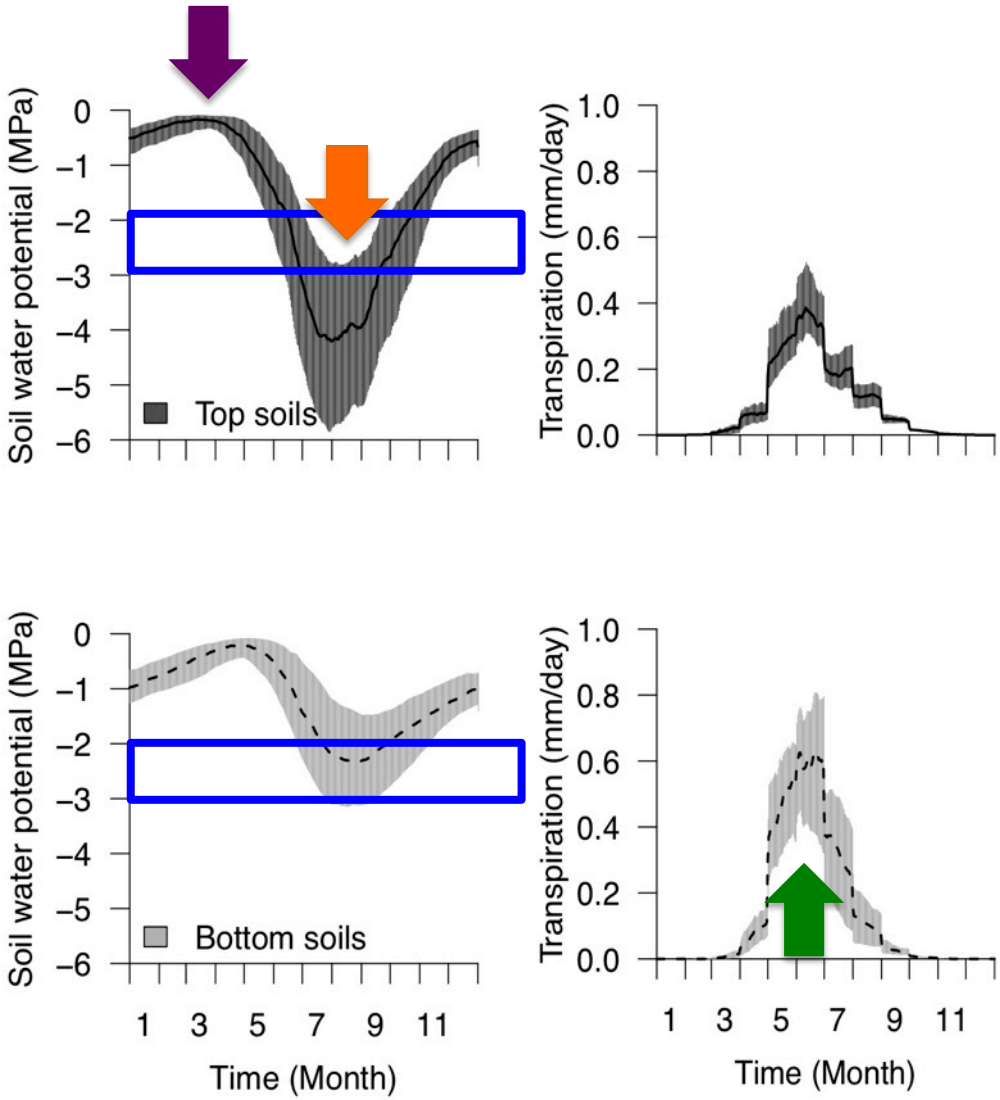
Sagebrush ecohydrology

- A storage-dominated water balance
- Cool season recharge of soil water
- Summer dry period in top soil layers



Sagebrush ecohydrology

- A storage-dominated water balance
- Cool season recharge of soil water
- Summer dry period in top soil layers
- More transpiration from bottom than top soil layers
- Sagebrush ecohydrological niche: utilization of deep, seasonally-stored water



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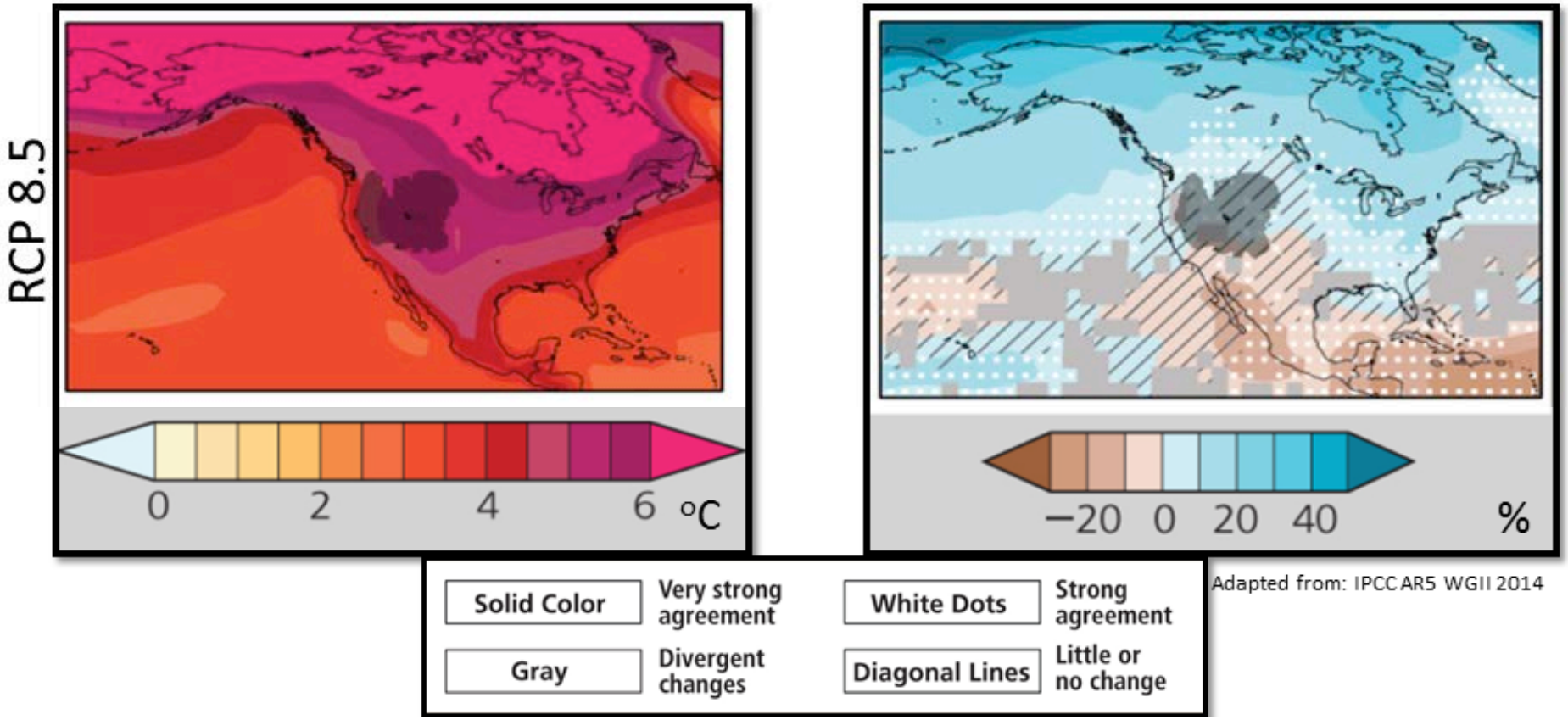
MAT

MAP



Temperature change: 4 to 5.5 °C

Precipitation change: -10 to 10 %

Predictions contingent on the General Circulation Model (GCM) chosen

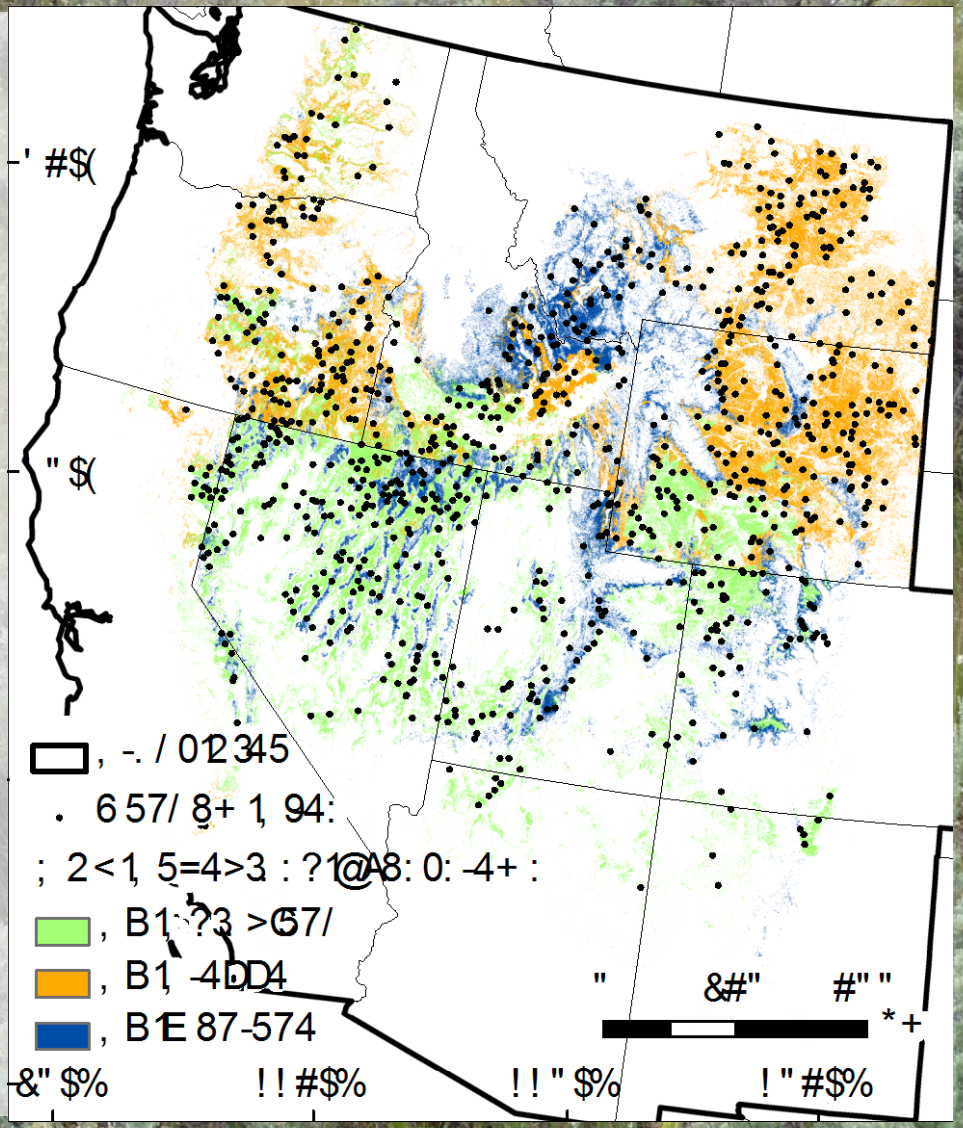
SOILWAT Simulations

1/8-degree, daily current and future weather data

Hybrid-delta downscaling

Simulations run for:

- 10 GCMs, RCP & RCP 4.5
- Current, 2030-2060, 2070-2100



Questions

1. How will altered precipitation and temperature influence key aspects of big sagebrush water balance?

2. How will climate change impacts on ecohydrology differ in magnitude and variability across sites for big sagebrush ecosystem types?

3. What is the spatial pattern of climate change impacts on sagebrush ecohydrology and what are the anticipated impacts within Sage-grouse Management Zones?

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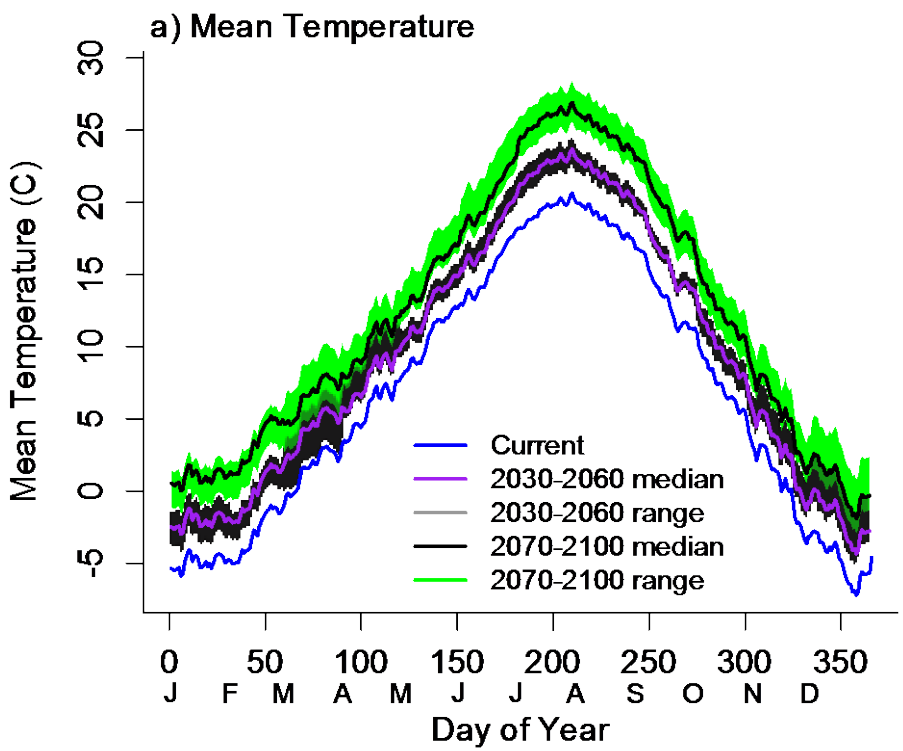
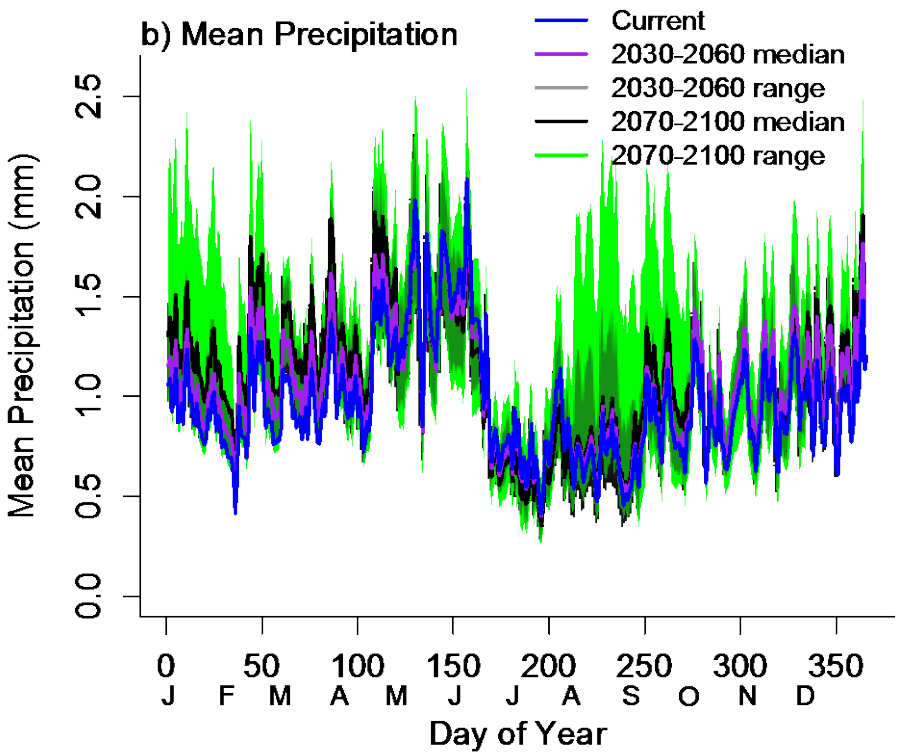
Current and future daily precipitation and temperature



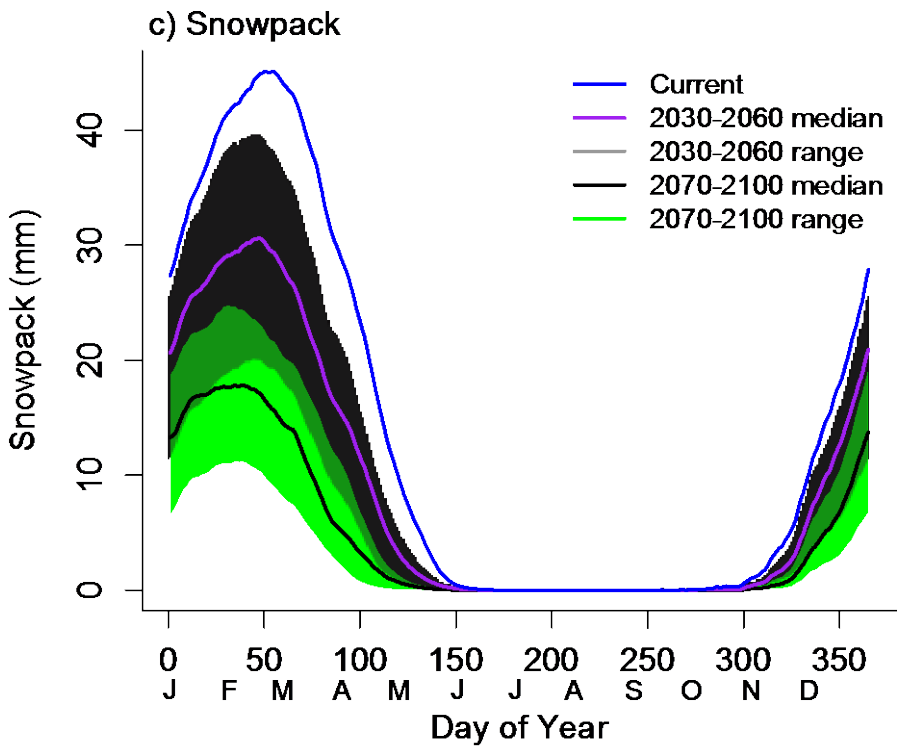


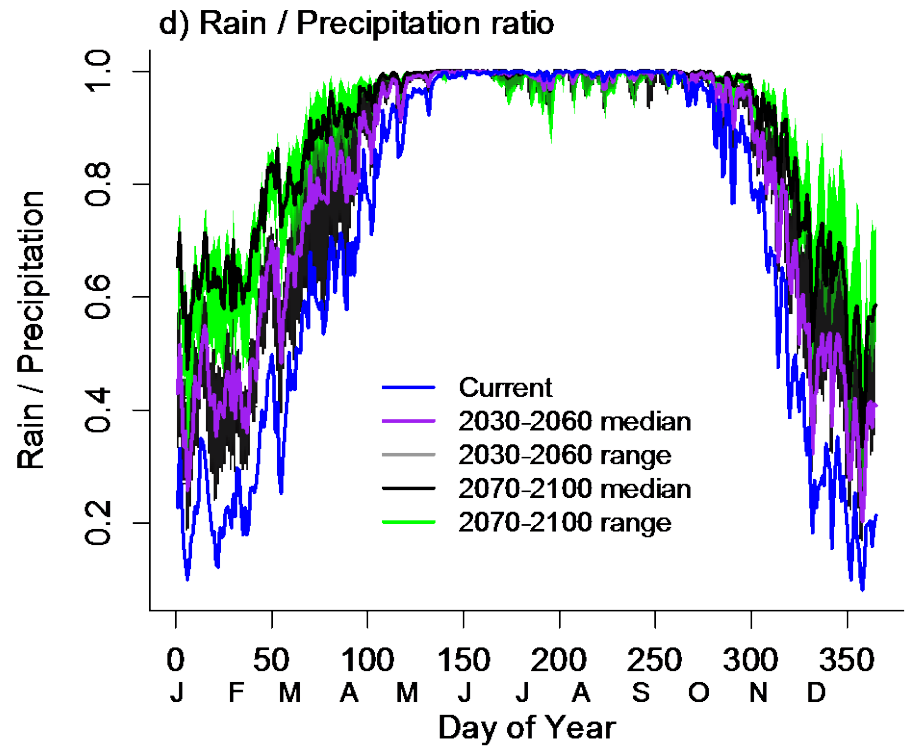
2030-2060: 2.7 °C increase
2070-2100: 5.4 °C increase

2030-2060: 27 mm increase
2070-2100: 45 mm increase

Palmquist et al. *Ecology* (accepted)

Current and future daily snowpack and rain / precipitation ratio



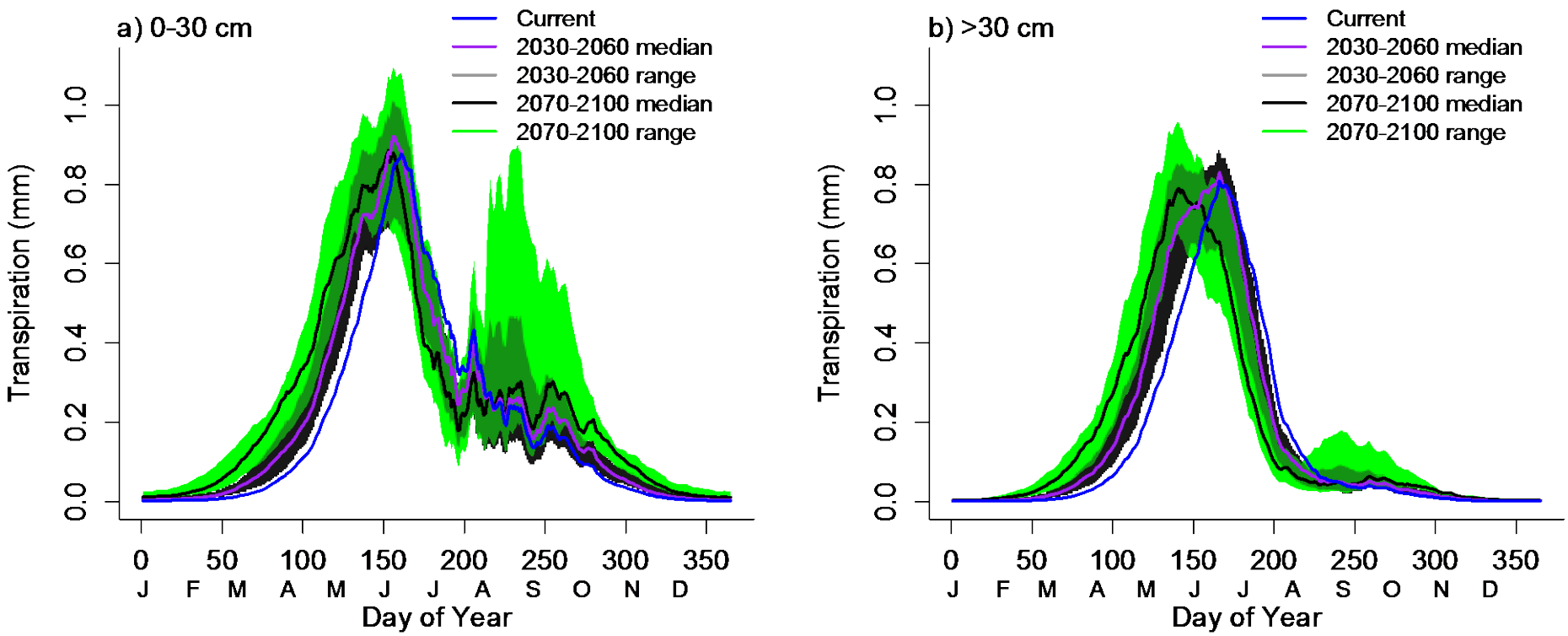


2030-2060: 14 mm decrease
2070-2100: 27 mm decrease

2030-2060: 0.08 increase
2070-2100: 0.16 increase

Palmquist et al. *Ecology* (accepted)

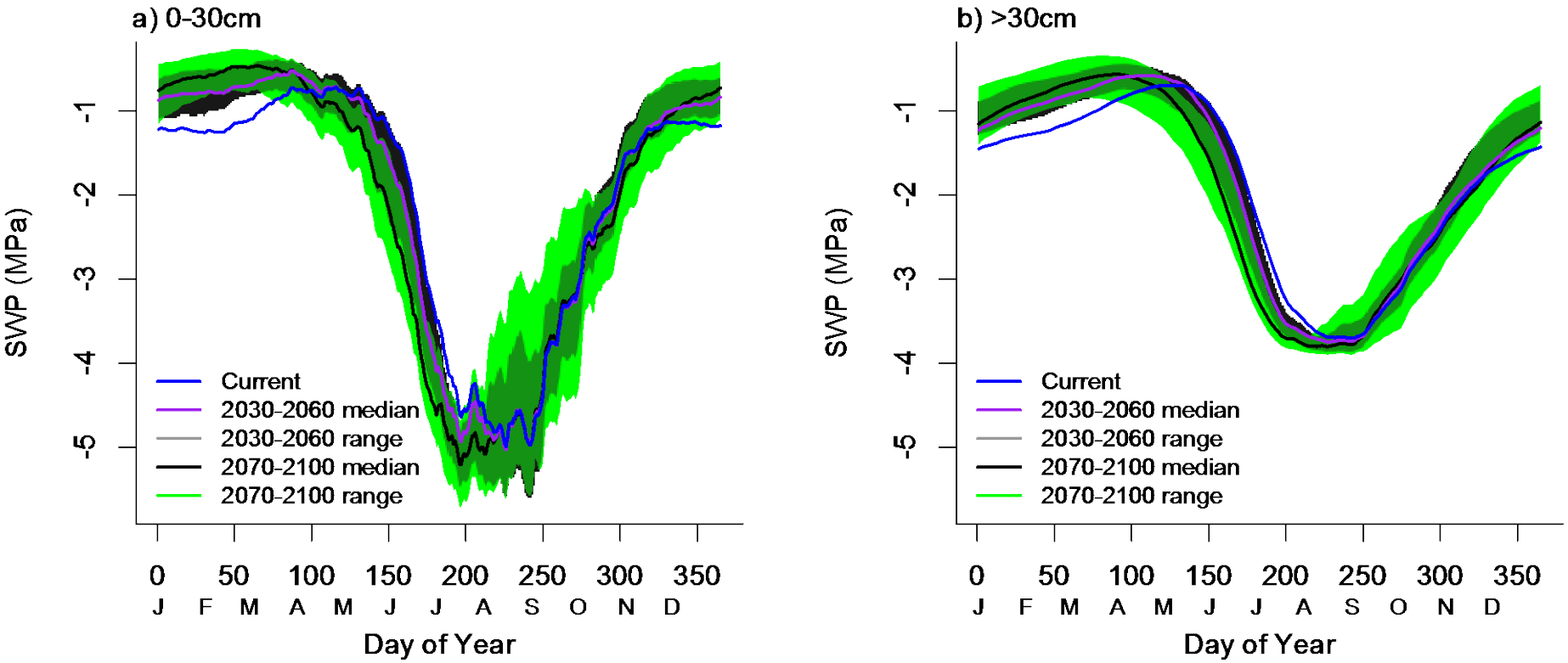
Current and future daily transpiration



2030-2060: 15 mm increase
2070-2100: 29 mm increase

Palmquist et al. *Ecology* (accepted)

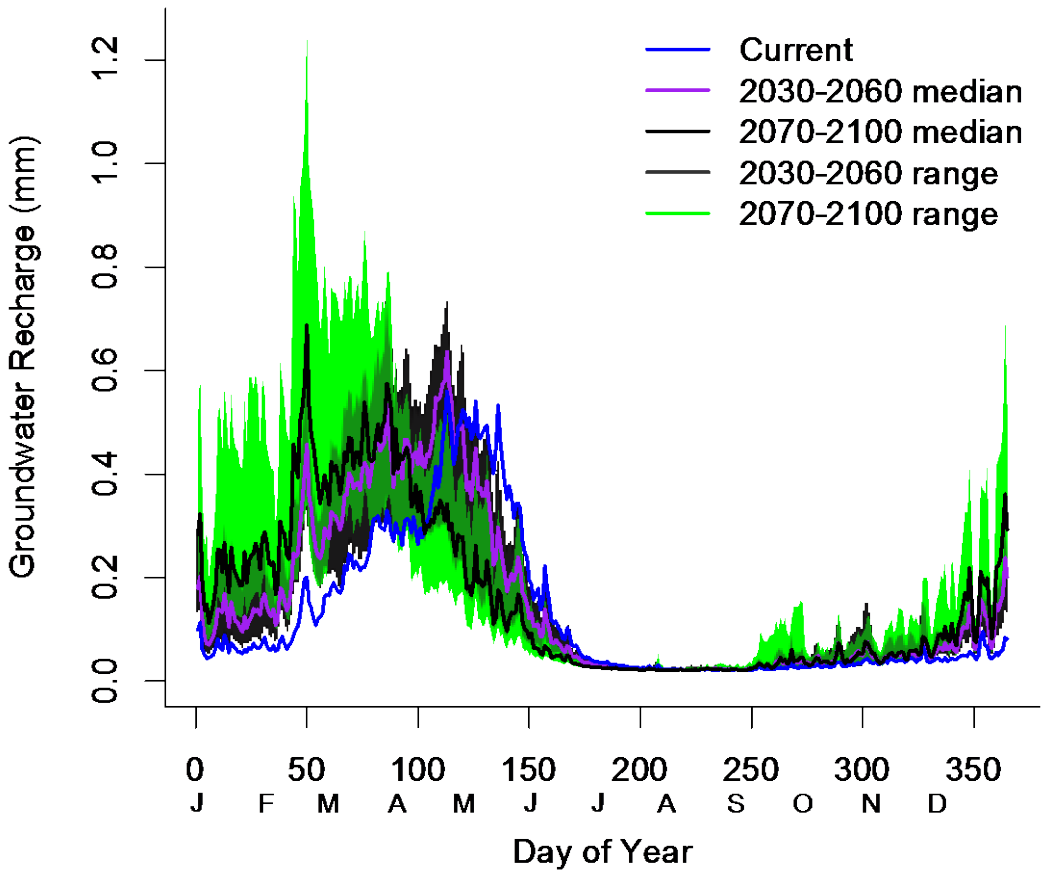
Current and future daily SWP



2030-2060: 0.05 Mpa increase
2070-2100: 0.09 Mpa decrease

Palmquist et al. *Ecology* (accepted)

Current and future daily groundwater recharge



2030-2060: 12 mm increase
2070-2100: 14 mm increase

Palmquist et al. *Ecology* (accepted)

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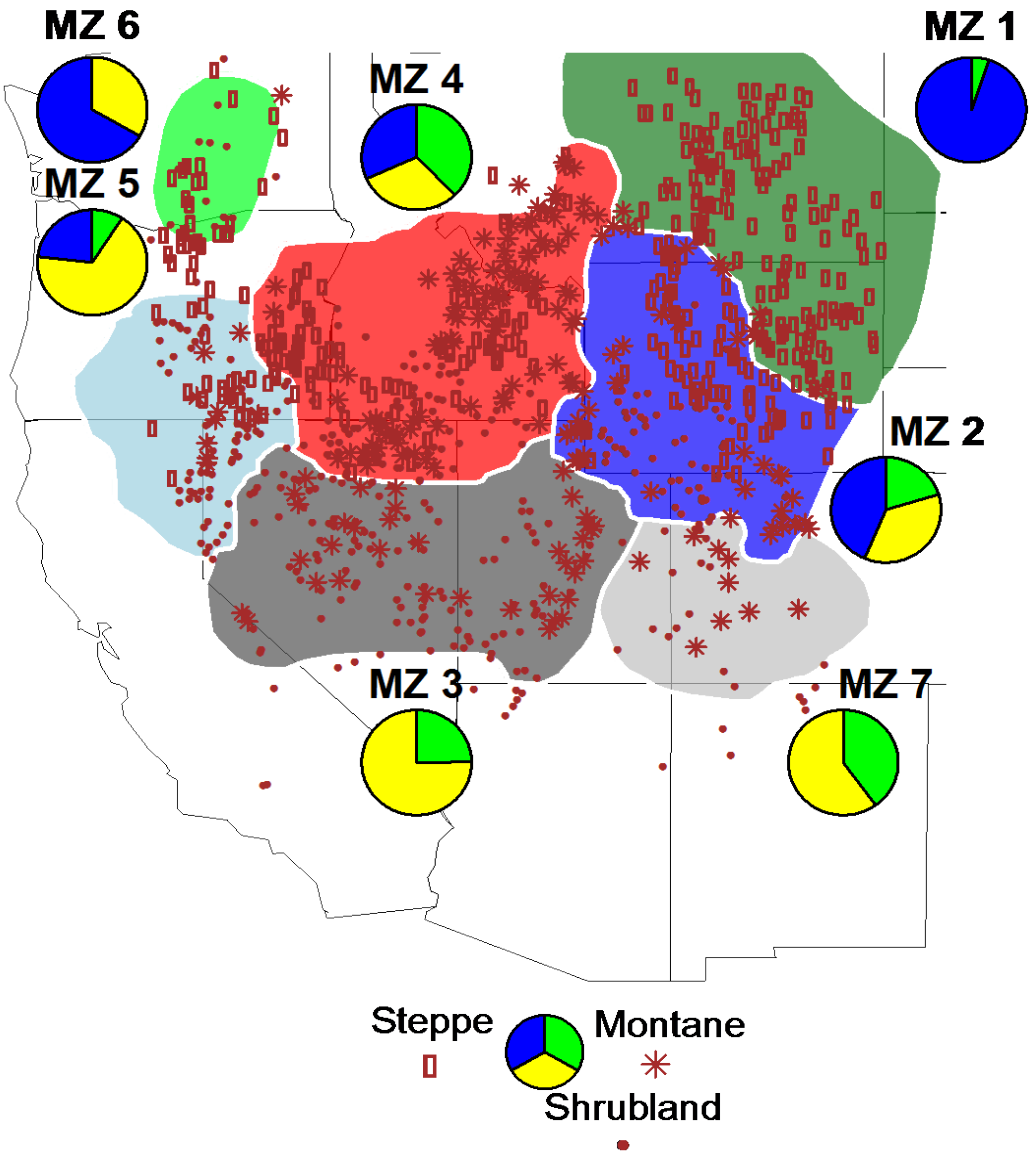
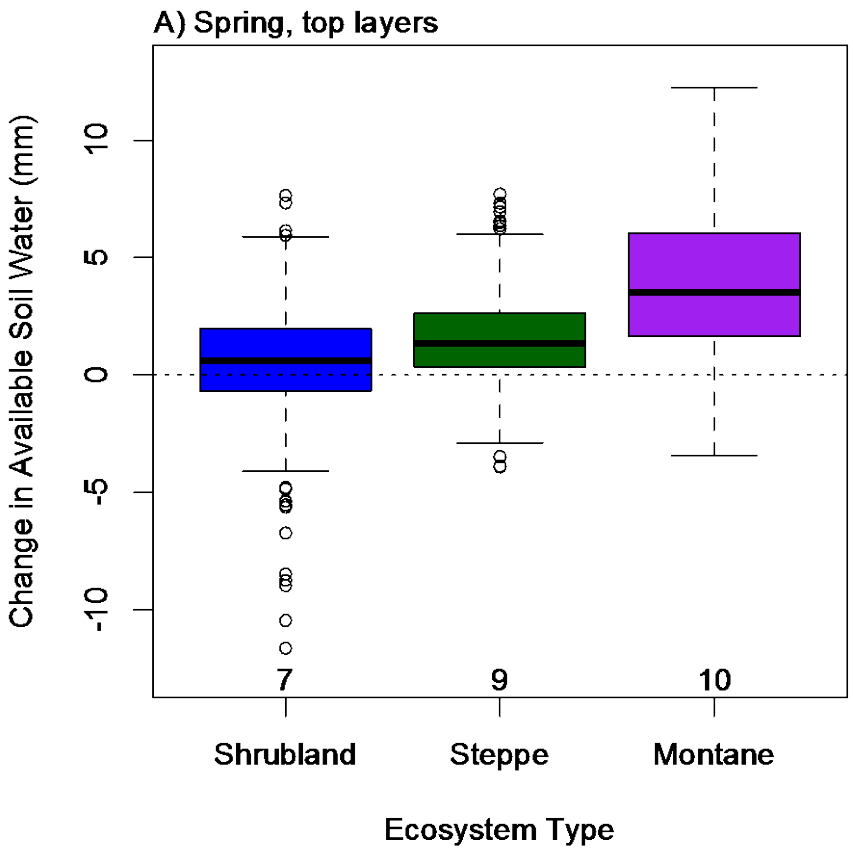
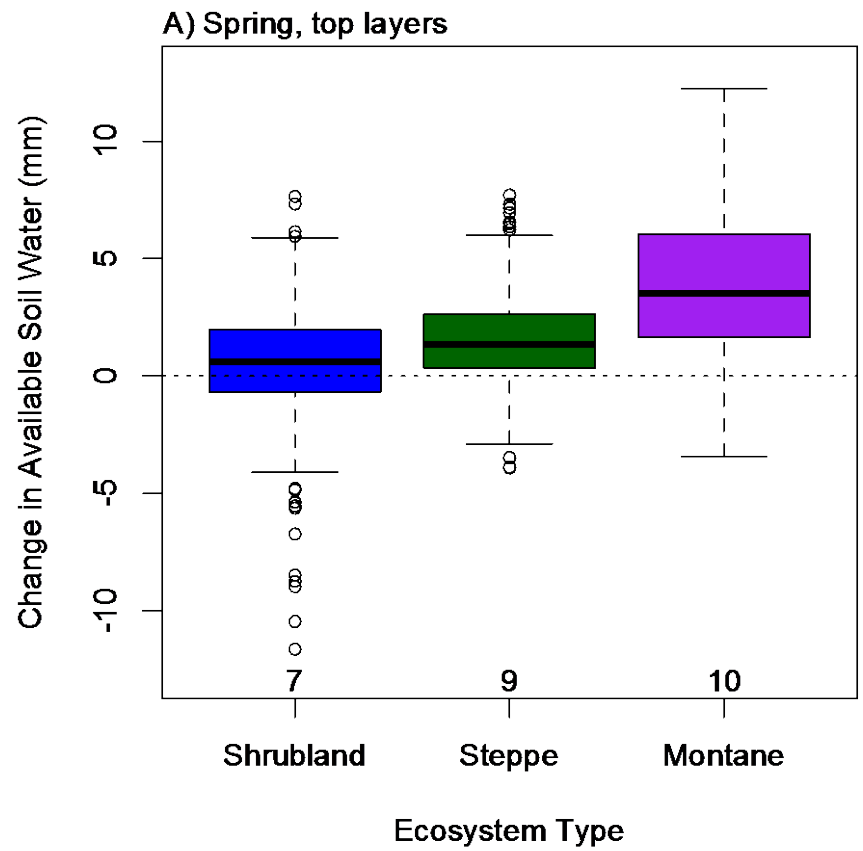


Palmquist et al. *Ecological Applications* (in review)

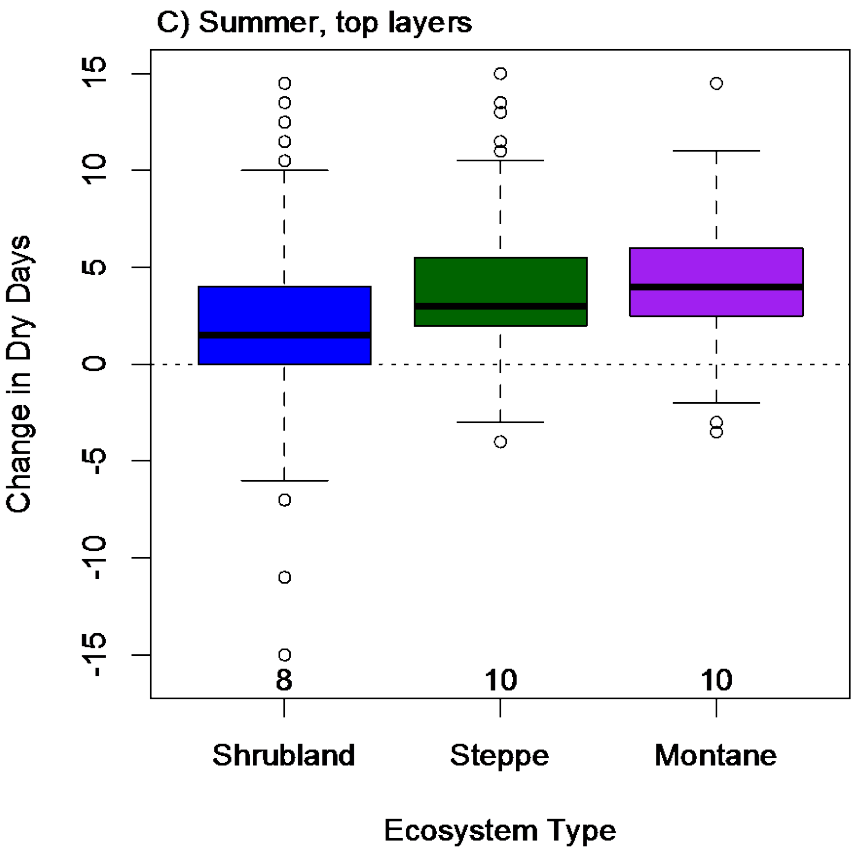
Change in Available Soil Water by 2030-2060 – Ecosystem Types

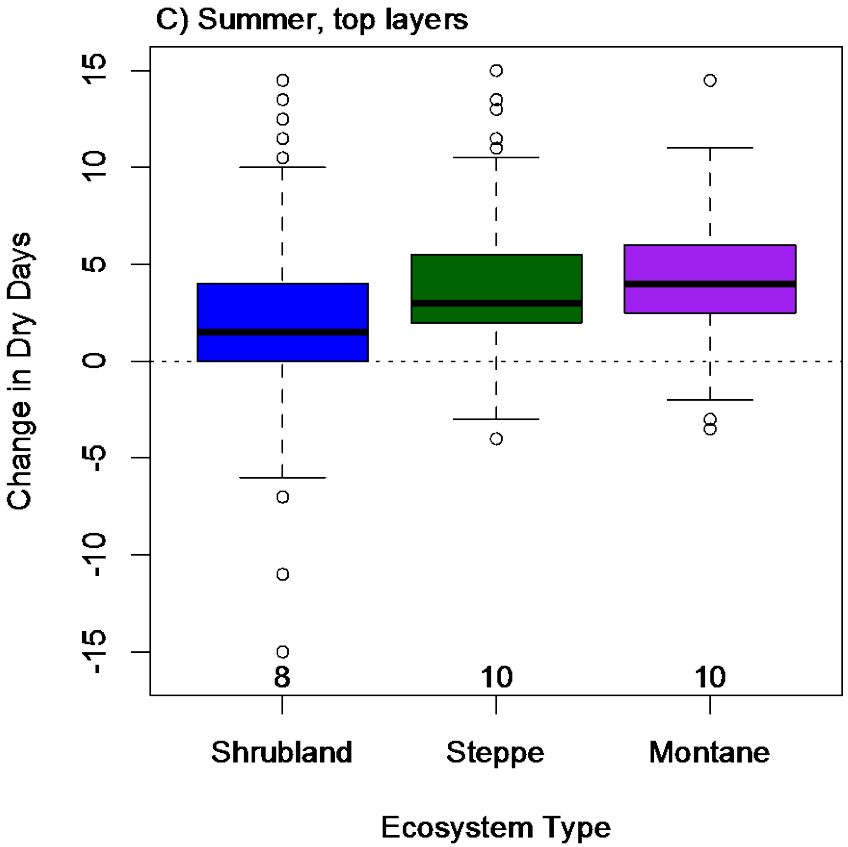




Palmquist et al. *Ecological Applications* (in review)

Change in Dry Days by 2030-2060 – Ecosystem Types





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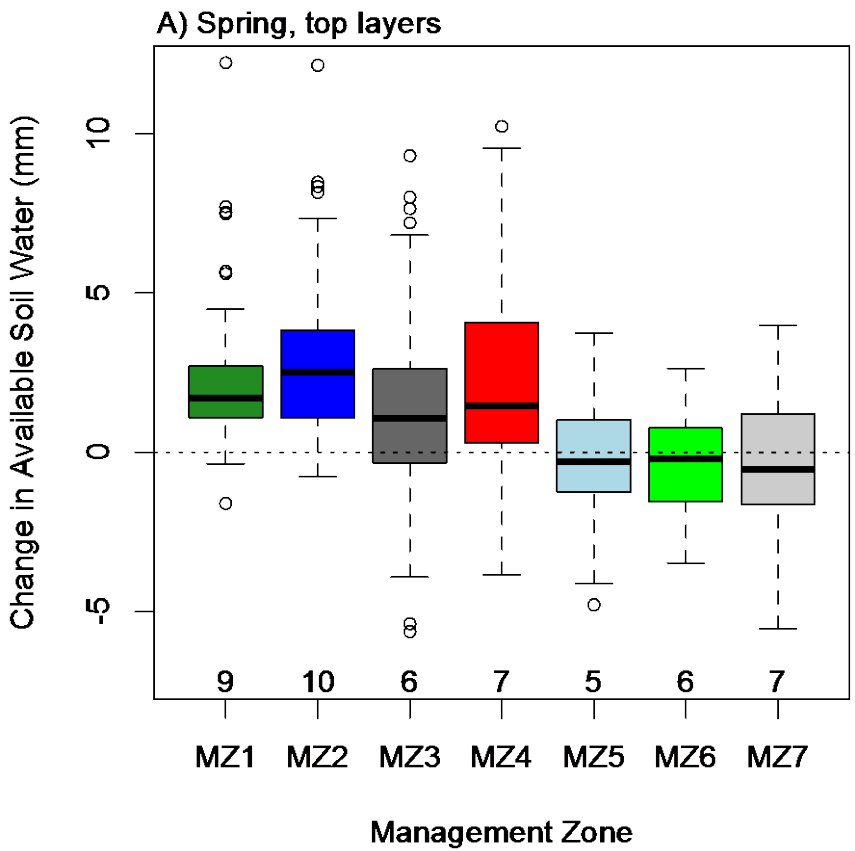
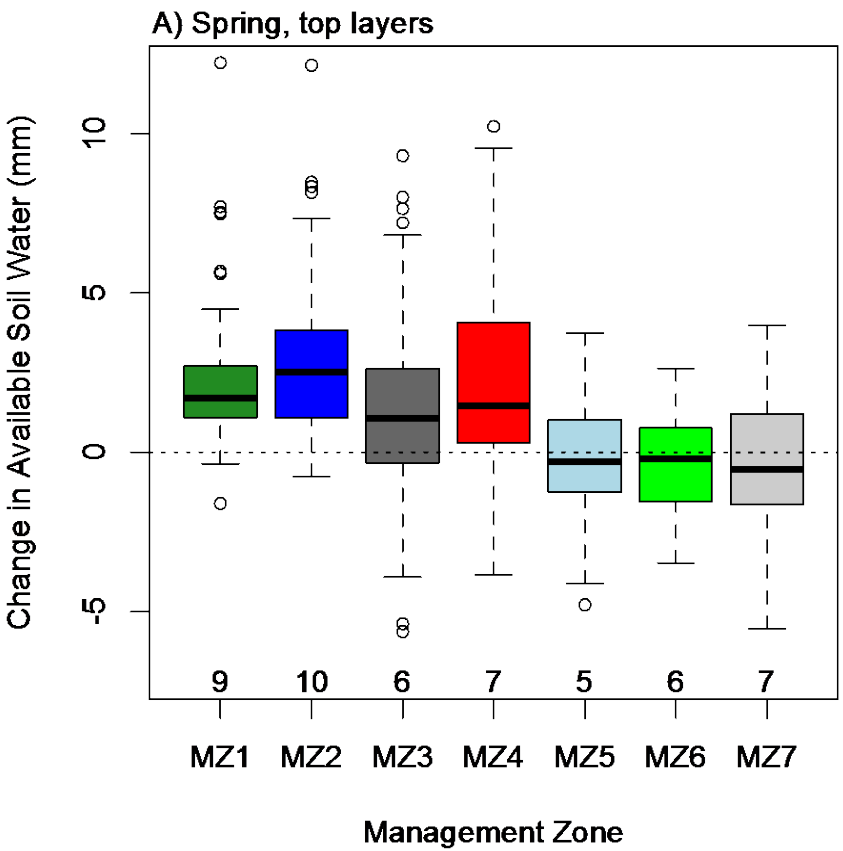
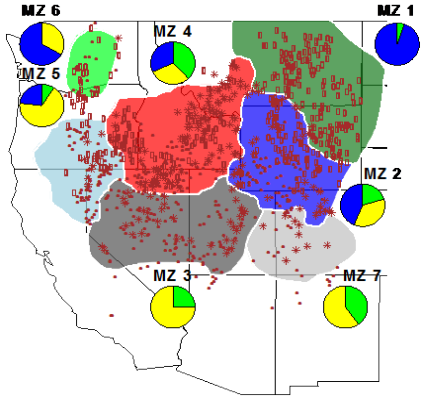
Change in Available Soil Water by 2030-2060 – MZs







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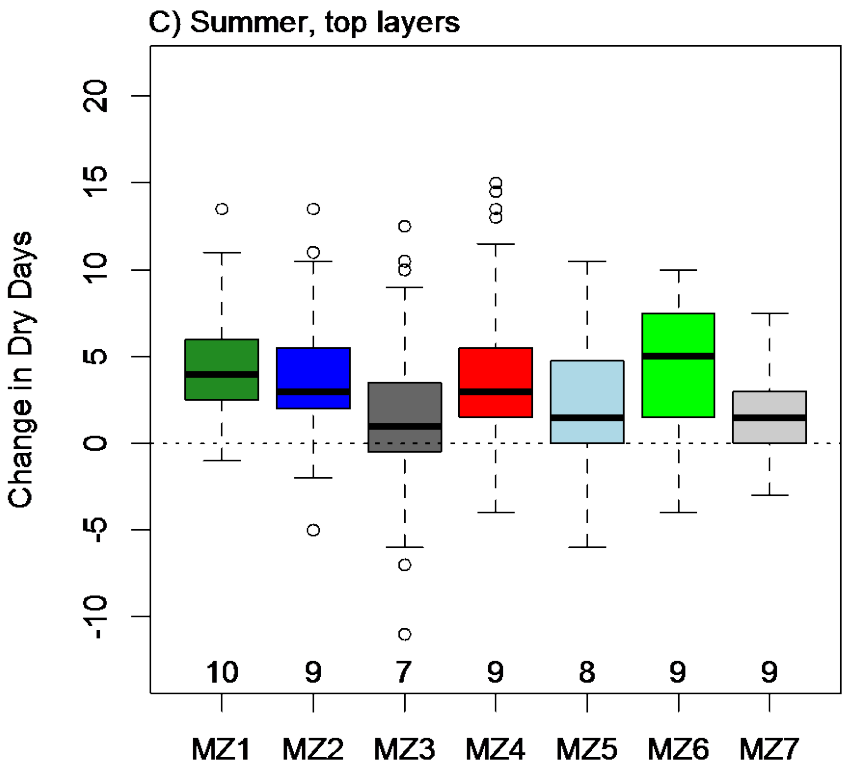

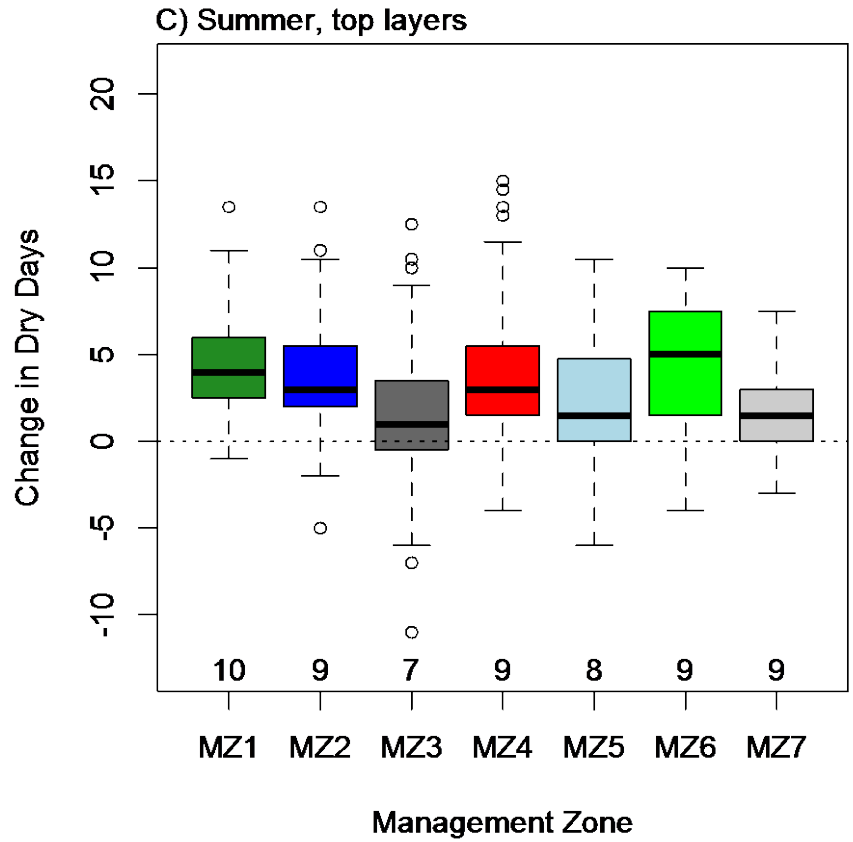

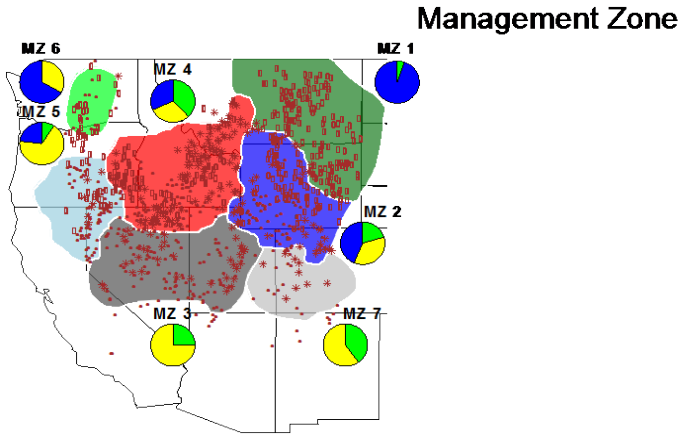

Palmquist et al. *Ecological Applications* (in review)

Summary: Climate Change Impacts on Ecohydrology

- Warmer temperatures, increases in winter precipitation
- Reduced snowpack and more precipitation falling as rain
- Increased transpiration and groundwater recharge earlier in the year
- Wetter winters, extended drier summers
- Ecohydrological response varied across GCMs
- Changes will vary geographical and ecologically:
  - Drier conditions in the southwest and at low elevations
  - Increased habitat suitability at high latitudes and high elevation sites

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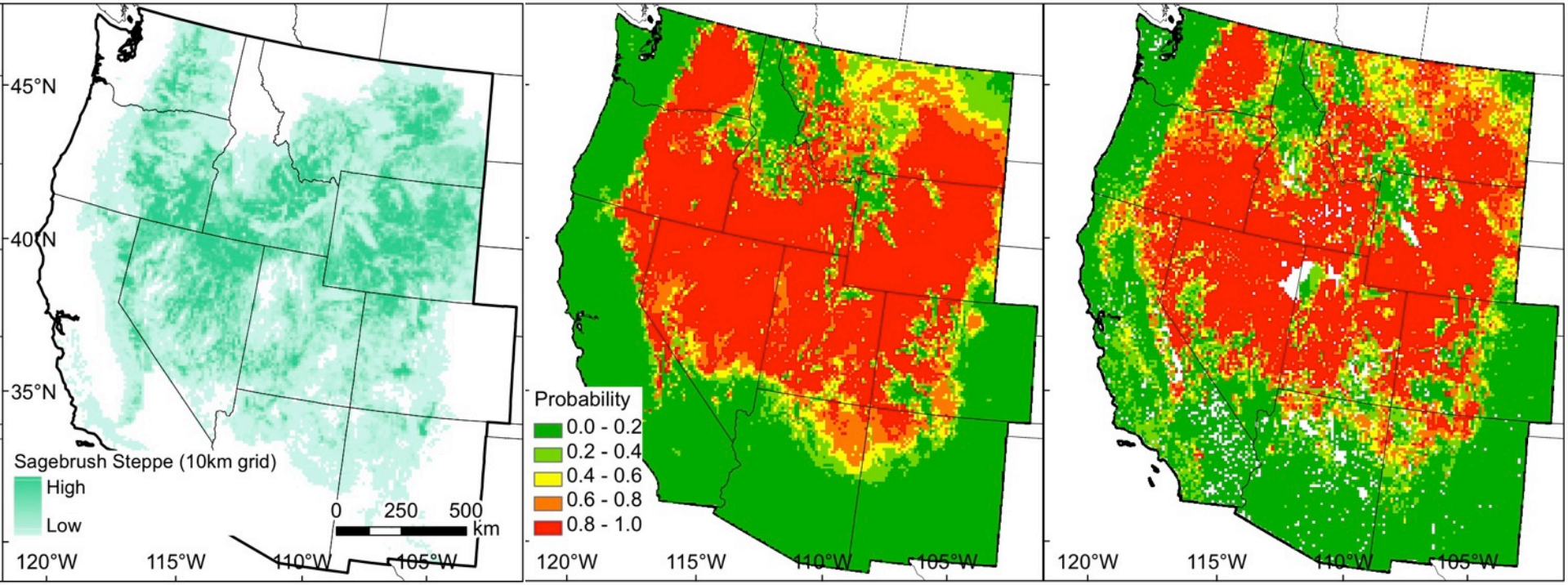
Sagebrush Ecohydrological Suitability

Species distribution modeling….based on soil moisture

GAP data | Climate - SDM | Soil water – SDM

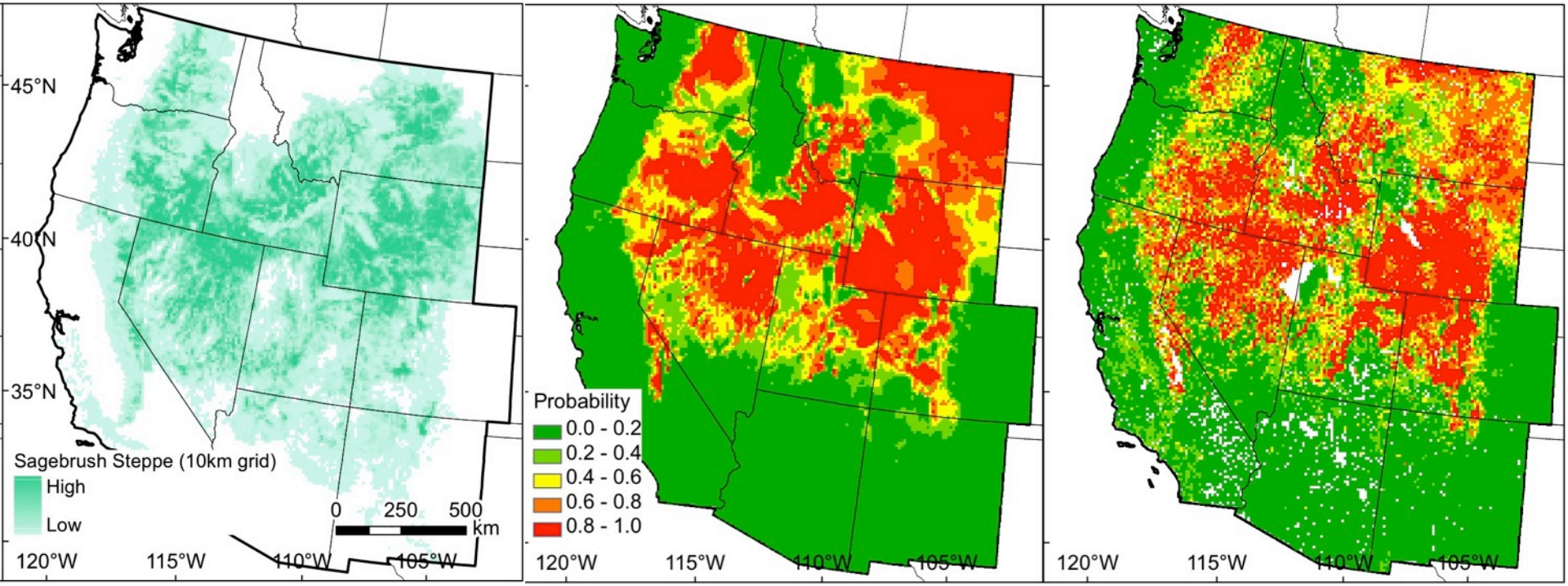


Schlaepfer et al. (2012) Ecography

Sagebrush Ecohydrological Suitability

Future (2070-2099, A2 scenario)

GAP data | Future Climate | Future Soil water

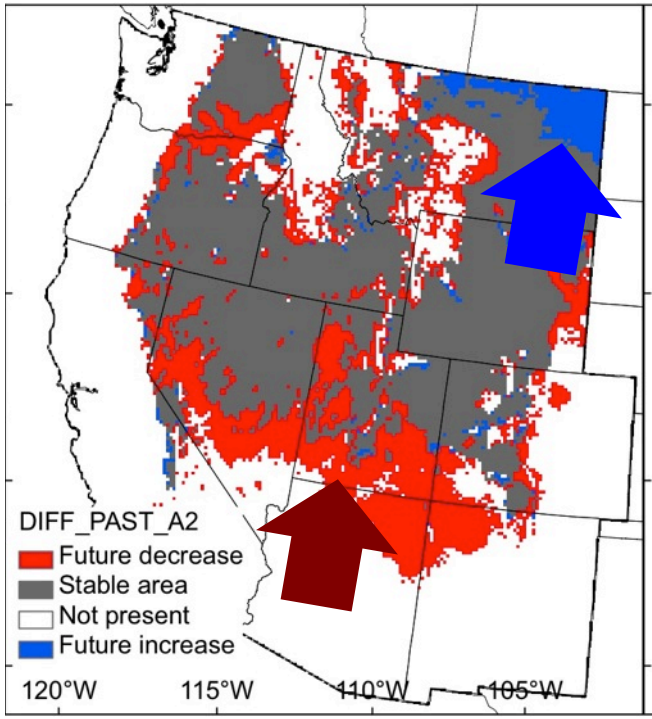


Schlaepfer et al. (2012) Ecography

Sagebrush Ecohydrological Suitability

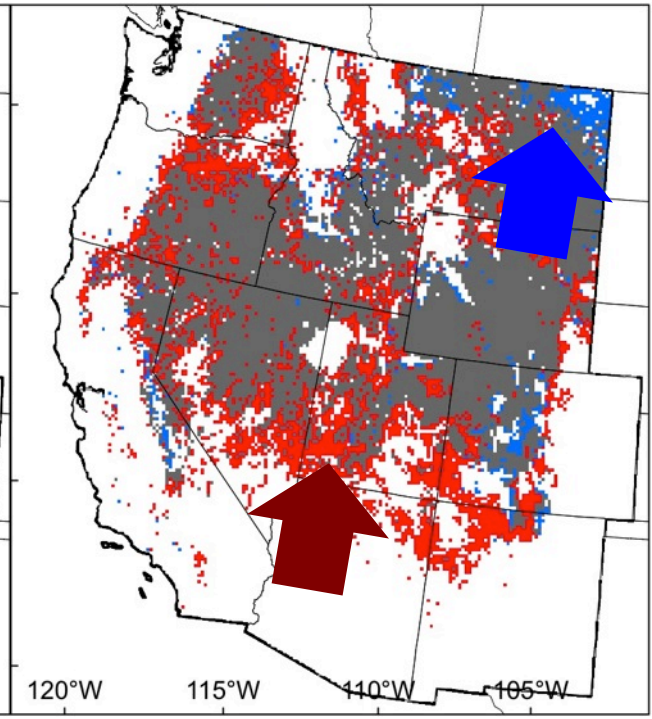
Climate vs. soil water SDM: similar regional patterns….

Climate - SDM



Loss: 32%, Gain: 5%
Total change: -27%
$CI_{90\%}$ = (-52, -18)%

Soil water - SDM



Loss: 31%, Gain: 5%
Total change: -26%
$CI_{90\%}$ = (-59, -23)%

1970-2000 vs. 2070-2100 (A2 Emissions scenario)

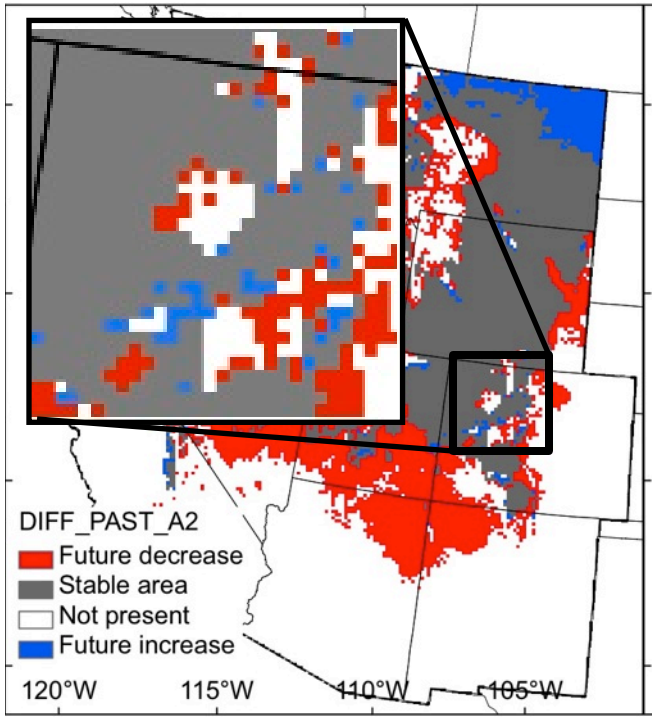
Schlaepfer et al. (2012) Ecography

Sagebrush Ecohydrological Suitability

Climate vs. soil water SDM: similar regional patterns….

..but soil water approach represents fine grain patches driven by soil.

Climate - SDM



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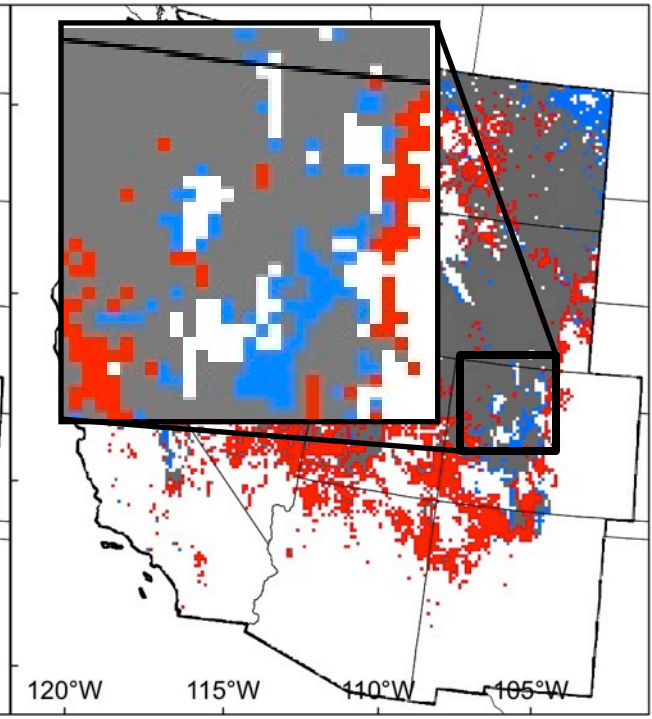

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1970-2000 vs. 2070-2100 (A2 Emissions scenario)

Schlaepfer et al. (2012) Ecography

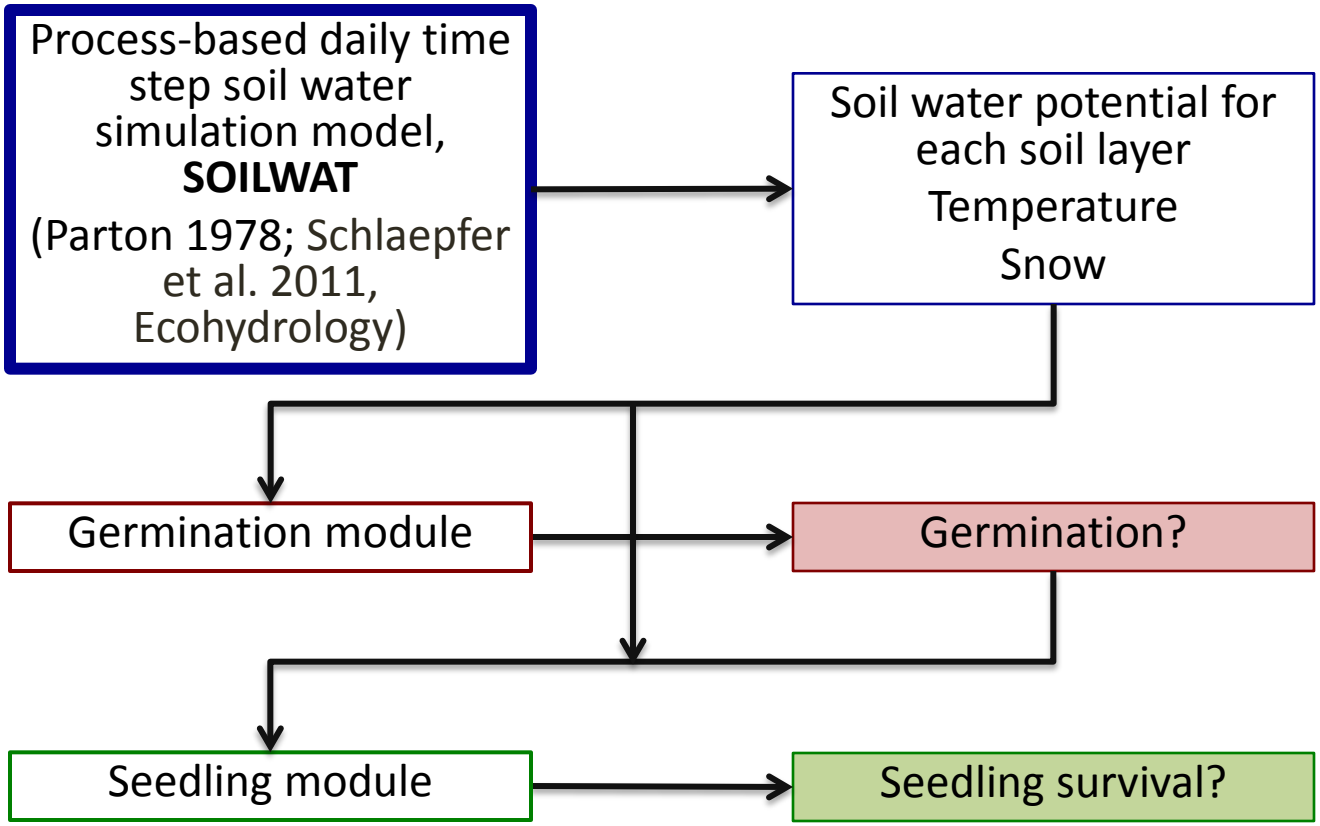
Sagebrush regeneration

Sagebrush regeneration: Literature Review

- Regeneration is episodic
- Seed availability is seldom limiting
- The three most important environmental controls are vulnerable to climate change
  - Available soil water
  - Temperature
  - Snow

Schlaepfer, D. R., Lauenroth, W. K., and Bradford, J. B. 2014. Natural regeneration processes in big sagebrush (Artemisia tridentata). Rangeland Ecology and Management 67:344–357.

Sagebrush regeneration: Modeling



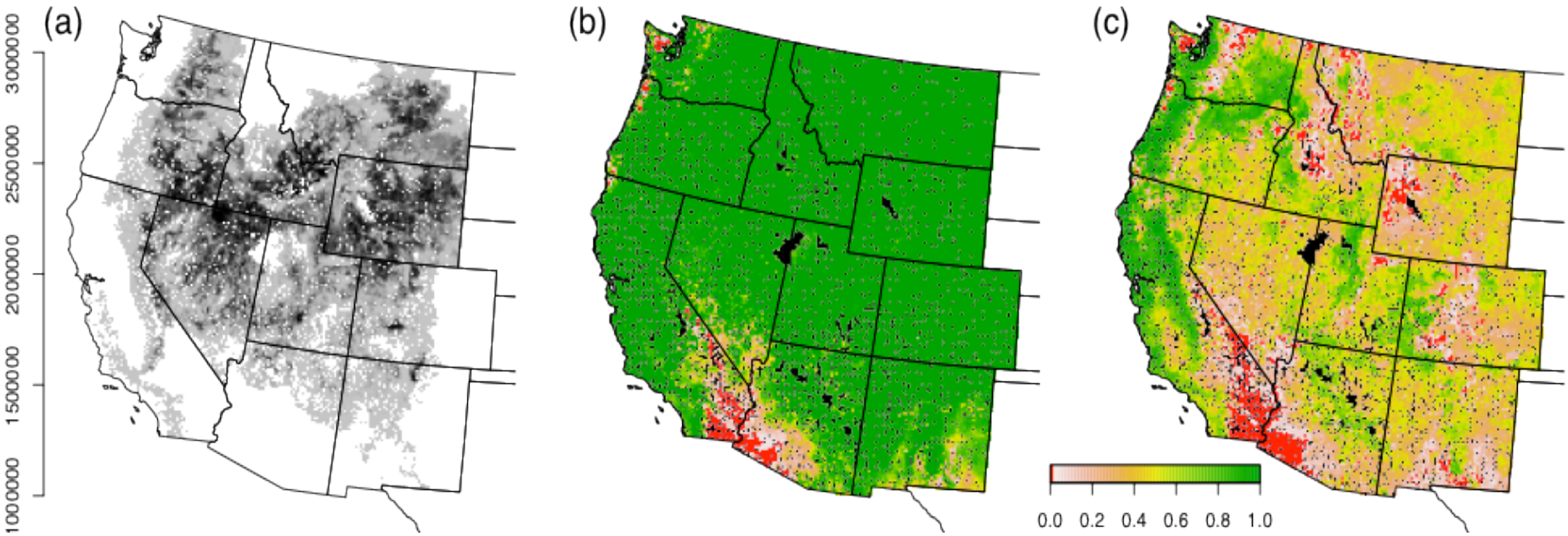
Schlaepfer, D. R., Lauenroth, W. K., and Bradford, J. B. 2014. Modeling regeneration responses of big sagebrush (*Artemisia tridentata*) to abiotic conditions. Ecological Modeling 286: 66-77.

Sagebrush regeneration: Modeling

Sagebrush abundance

Probability of germination

Probability of establishment

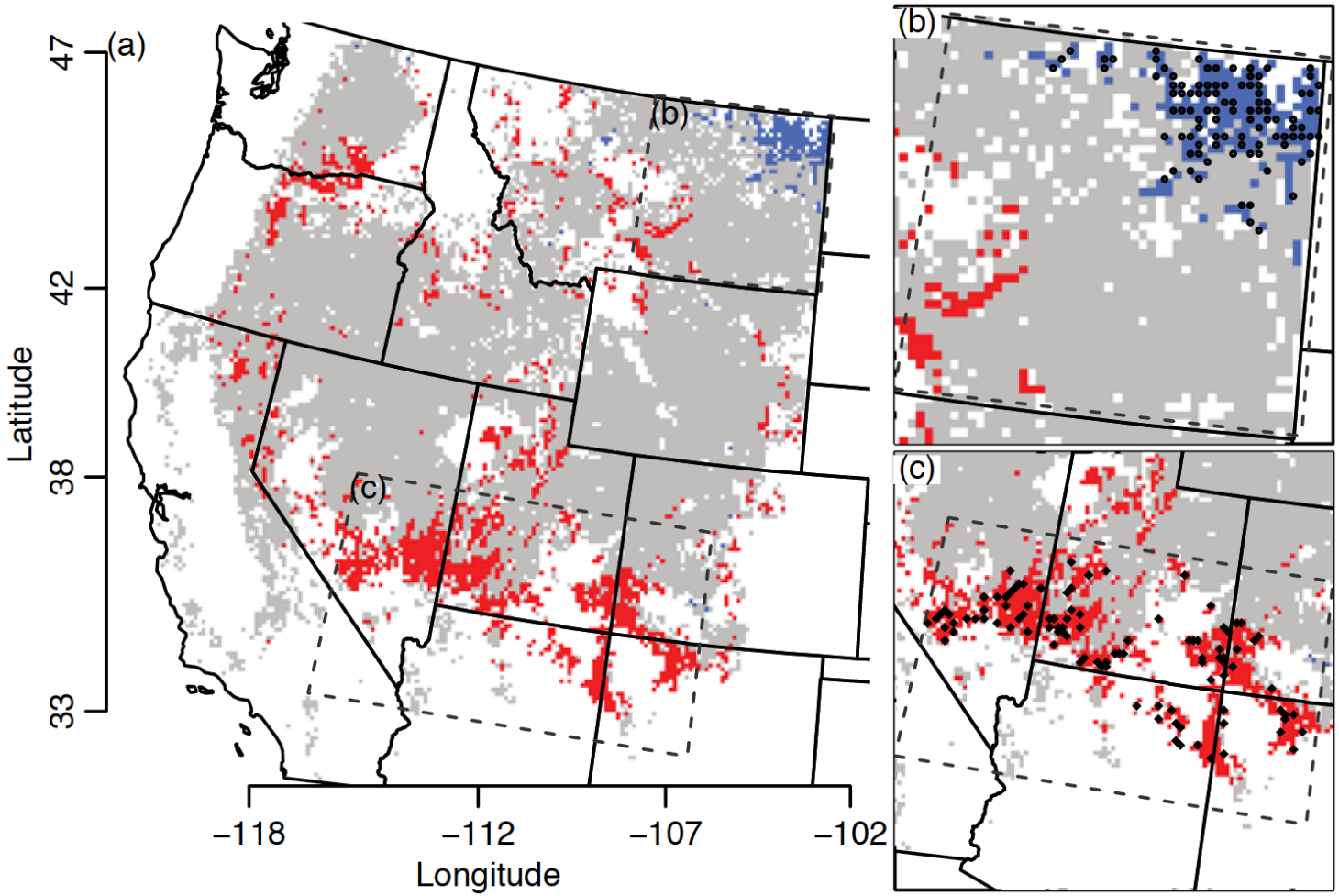


Result: Establishment is limiting (germination isn't)

Schlaepfer, D. R., Lauenroth, W. K., and Bradford, J. B. 2014. Modeling regeneration responses of big sagebrush (*Artemisia tridentata*) to abiotic conditions. Ecological Modeling 286: 66-77.

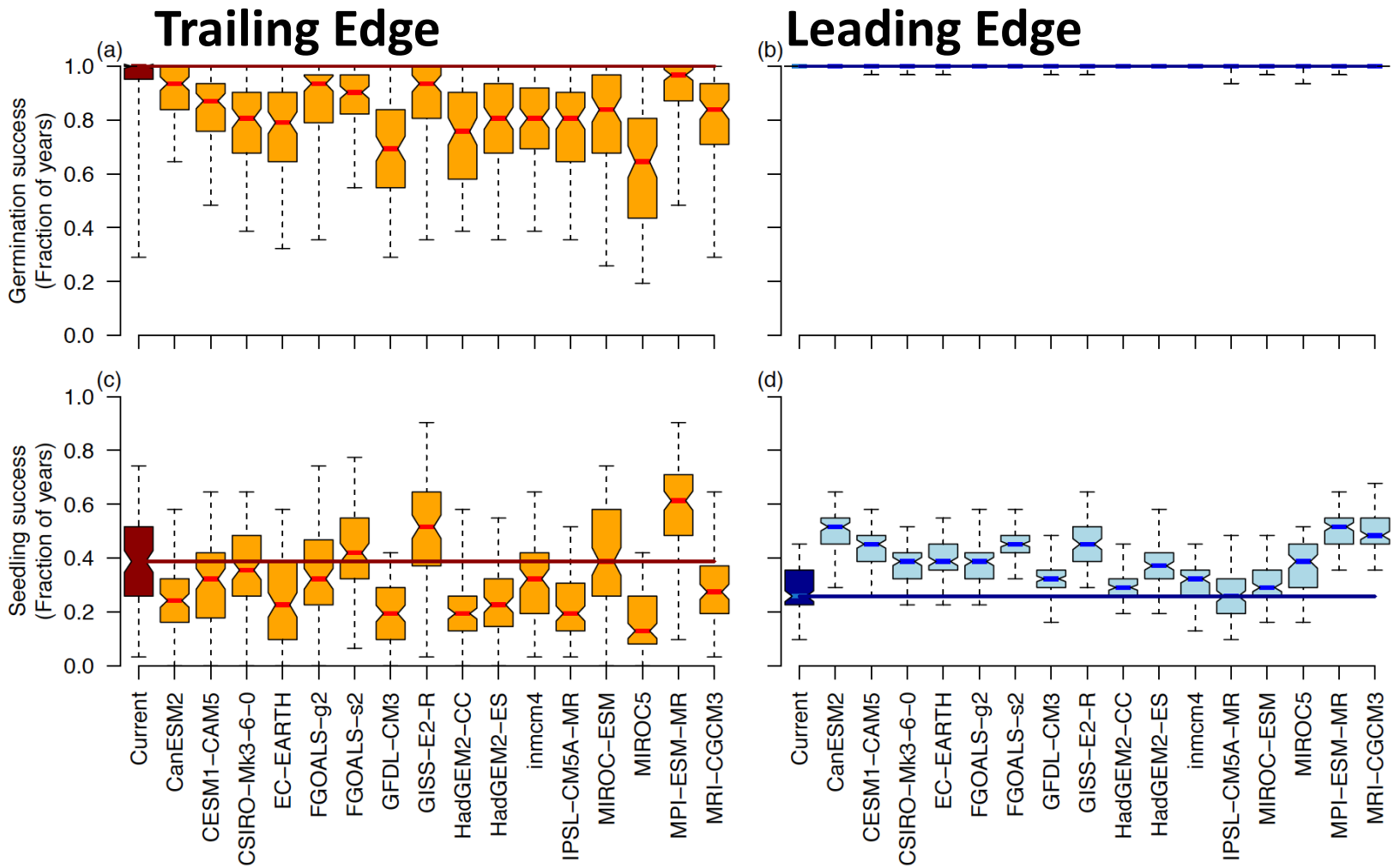
Sagebrush Regeneration: Forecasting

Leading & Trailing Edges of Sagebrush Distribution



Schlapefer, D.R., Taylor, K.A., Pennington, V. E., Nelson, K. N., Martyn, T. E., Rottler, C. M., Lauenroth, W. K., Bradford, J. B. 2015. Future regeneration of big sagebrush support predicted changes in habitat suitability at trailing and leading edges. Ecosphere

Sagebrush Regeneration: Forecasting



1970-2000 vs. 2070-2100 (RCP8.5)

Schlapefer, D.R., Taylor, K.A., Pennington, V. E., Nelson, K. N., Martyn, T. E., Rottler, C. M., Lauenroth, W. K., Bradford, J. B. 2015. Ecosphere

In progress: updated regeneration & suitability analysis

- 10km grid across western North America
- Two representative concentration pathways (4.5 & 8.5)
- 13 general circulation models
- Three time periods: current, 2031-2060, 2071-2100
- (Also quantify soil temperature & moisture regimes)

Today:

An ecohydrological approach

Ecohydrology of sagebrush ecosystems

Climate change impacts

Sagebrush suitability and regeneration

Plant species biodiversity

Plant community responses

Sagebrush mortality

Plant species richness in big sagebrush ecosystems

Roadmap

- State of knowledge about forbs in sage-grouse habitat
- Contrast plant community structure and plant species richness
- Forbs as the major source of species richness

State of Knowledge about Forbs

- UW Libraries & Google Scholar
  - Journal articles
  - Agency reports
  - Conference proceedings
  - Books
  - M.S. theses/Ph.D. dissertations

What Information is Available?

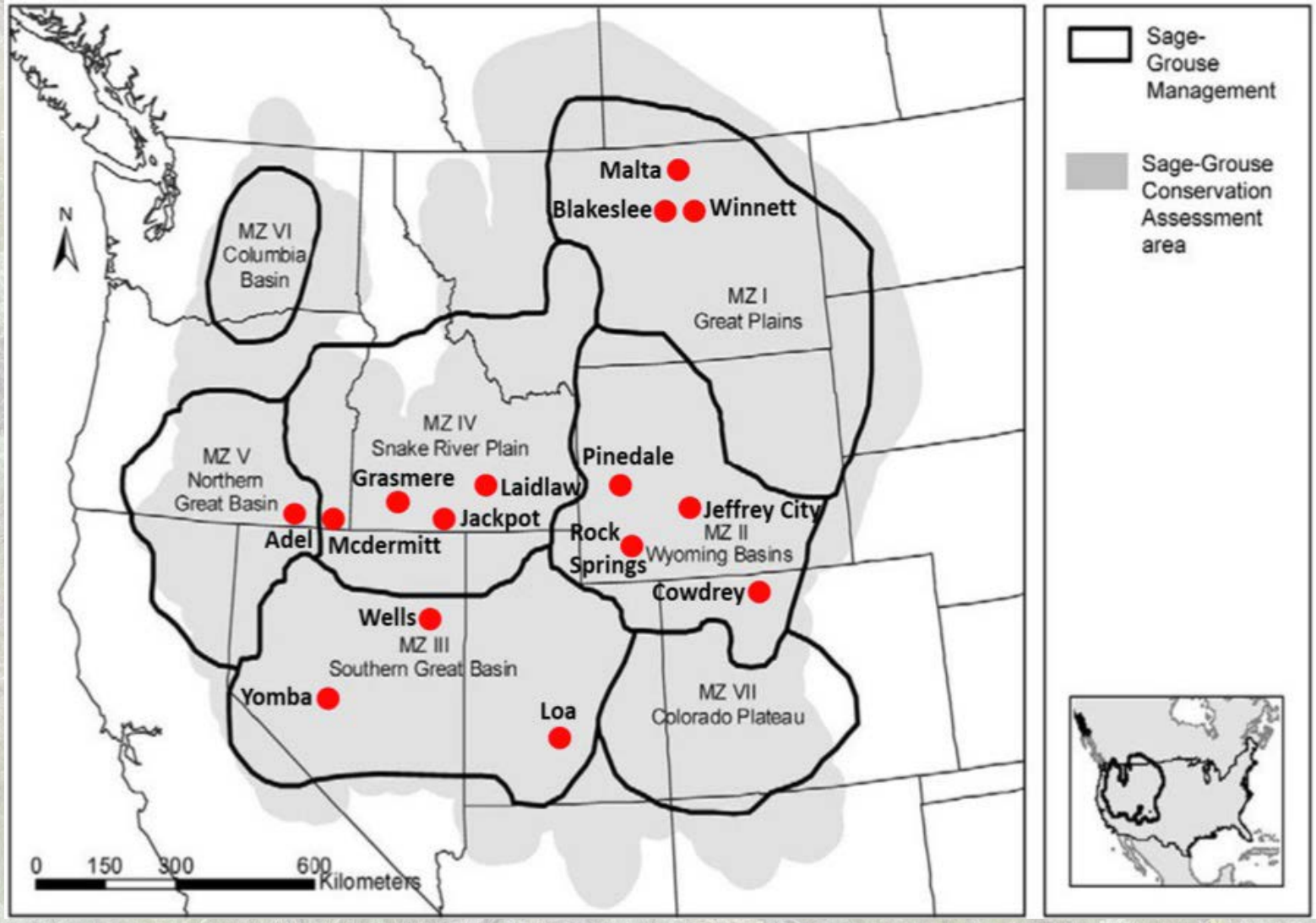
- 68 articles
  1. Diet (13)
  2. Habitat (23)
  3. Vegetation Management (24)
  4. Climate (8)

Knowledge Gaps & Research Needs

- Limited information about forbs
  - Most information is not species specific
  - Sampling inadequate for forbs

Pennington et al. 2016. Sagebrush, Greater Sage-Grouse, and the Occurrence and Importance of Forbs. ***Western North American Naturalist*** **(**revision**).**

Field Sites

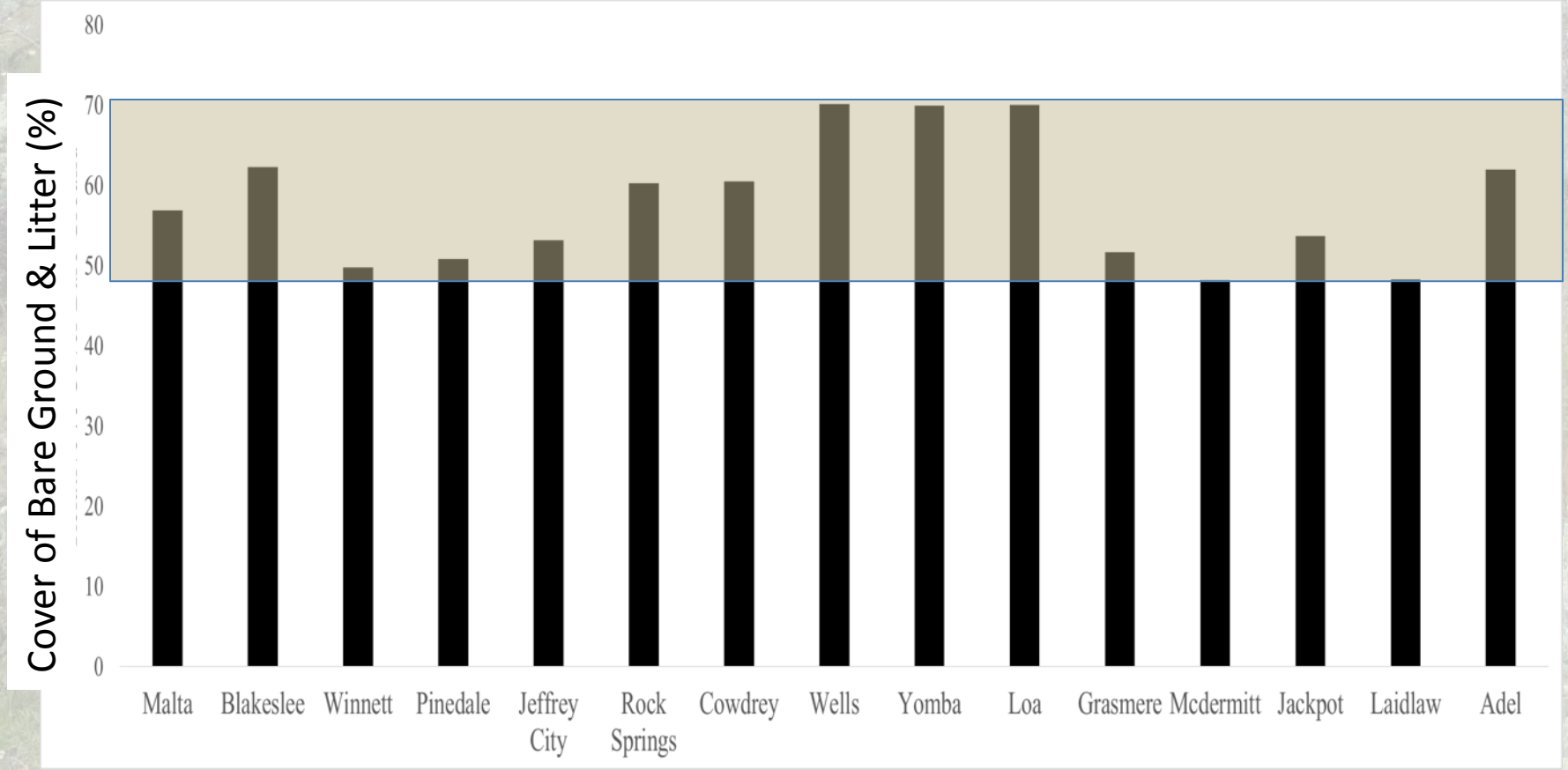

Sage-Grouse Management
Sage-Grouse Conservation Assessment area
N
MZ VI Columbia Basin
MZ I Great Plains
MZ IV Snake River Plain
MZ V Northern Great Basin
MZ II Wyoming Basins
MZ III Southern Great Basin
MZ VII Colorado Plateau
Malta
Blakeslee
Winnett
Pinedale
Grasmere
Laidlaw
Jackpot
Jeffrey City
Adel
Mcdermitt
Rock Springs
Cowdrey
Wells
Yomba
Loa
0 150 300 600 Kilometers

Field Methods

- 3 – 10 x 10m plots at each site
  - counted and measured shrubs within each plot.
  - estimated cover of all understory species in 30 – 20 x 50 cm quadrats in each plot.
- 3 – 100 x 2.4 m belt transects
  - counted number of different forbs and identified each to species

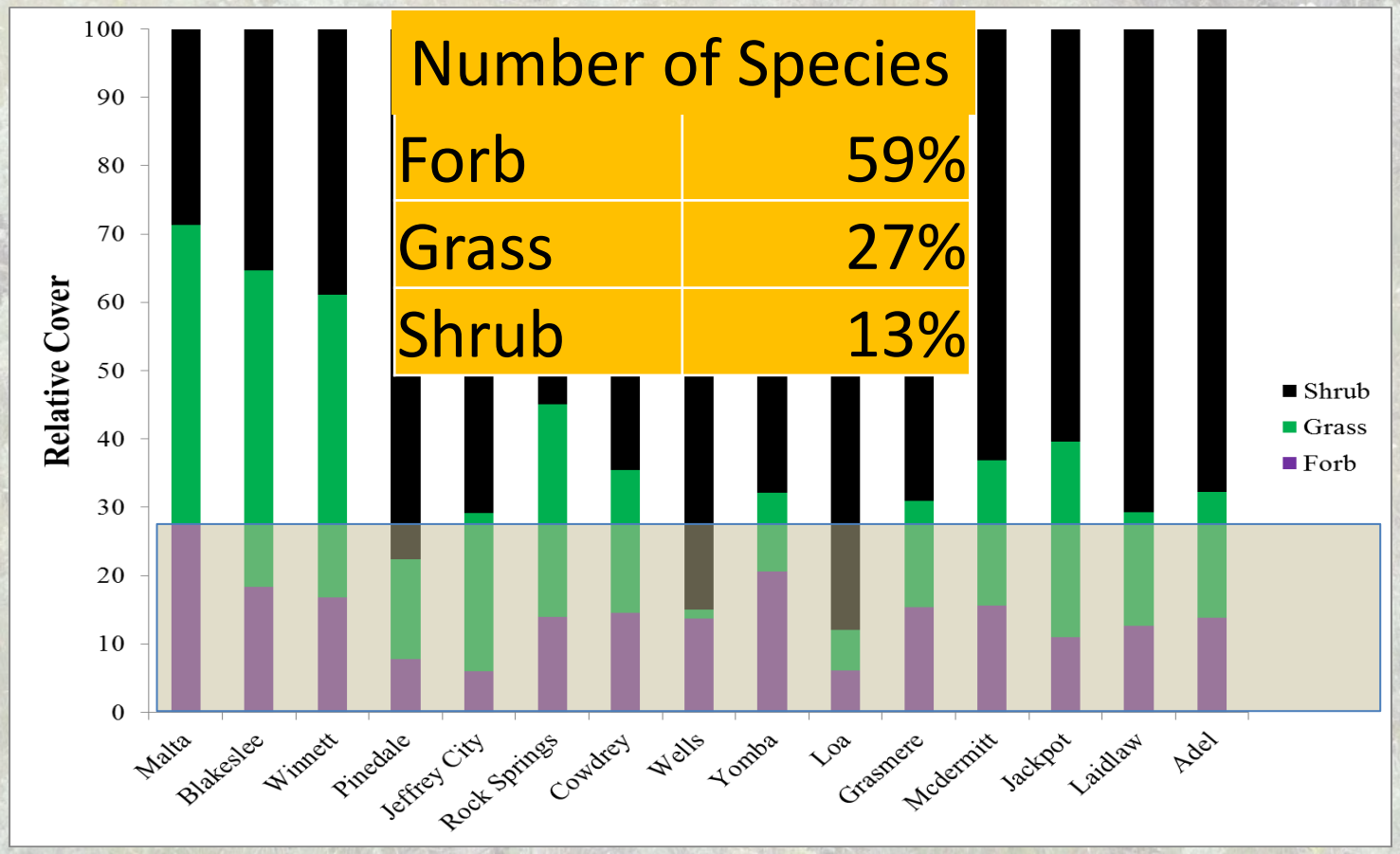
Plant Community Structure

Bare ground and litter account for 50-70% of surface cover.



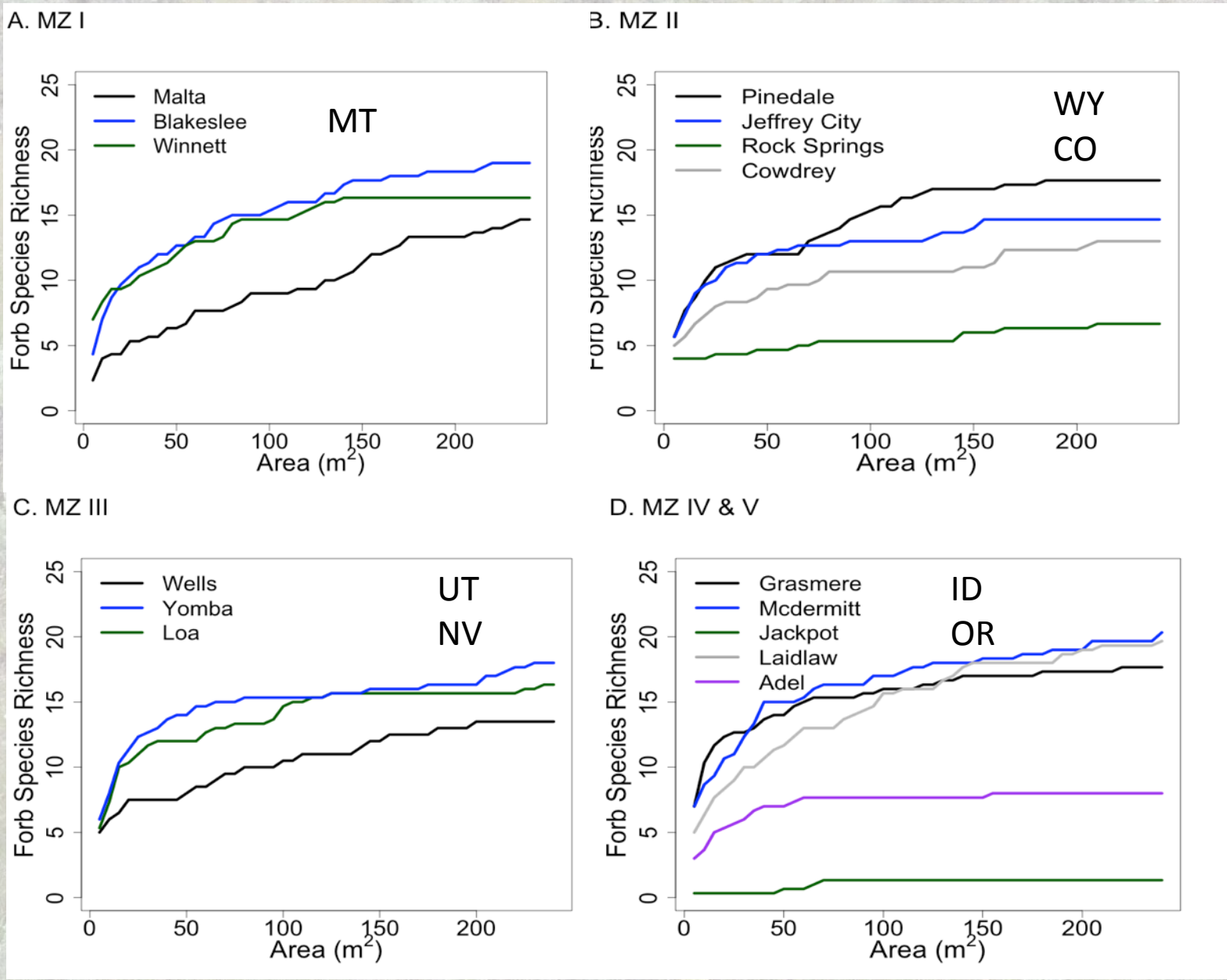
Plant community structure

Forbs account for 5-30% of surface cover.

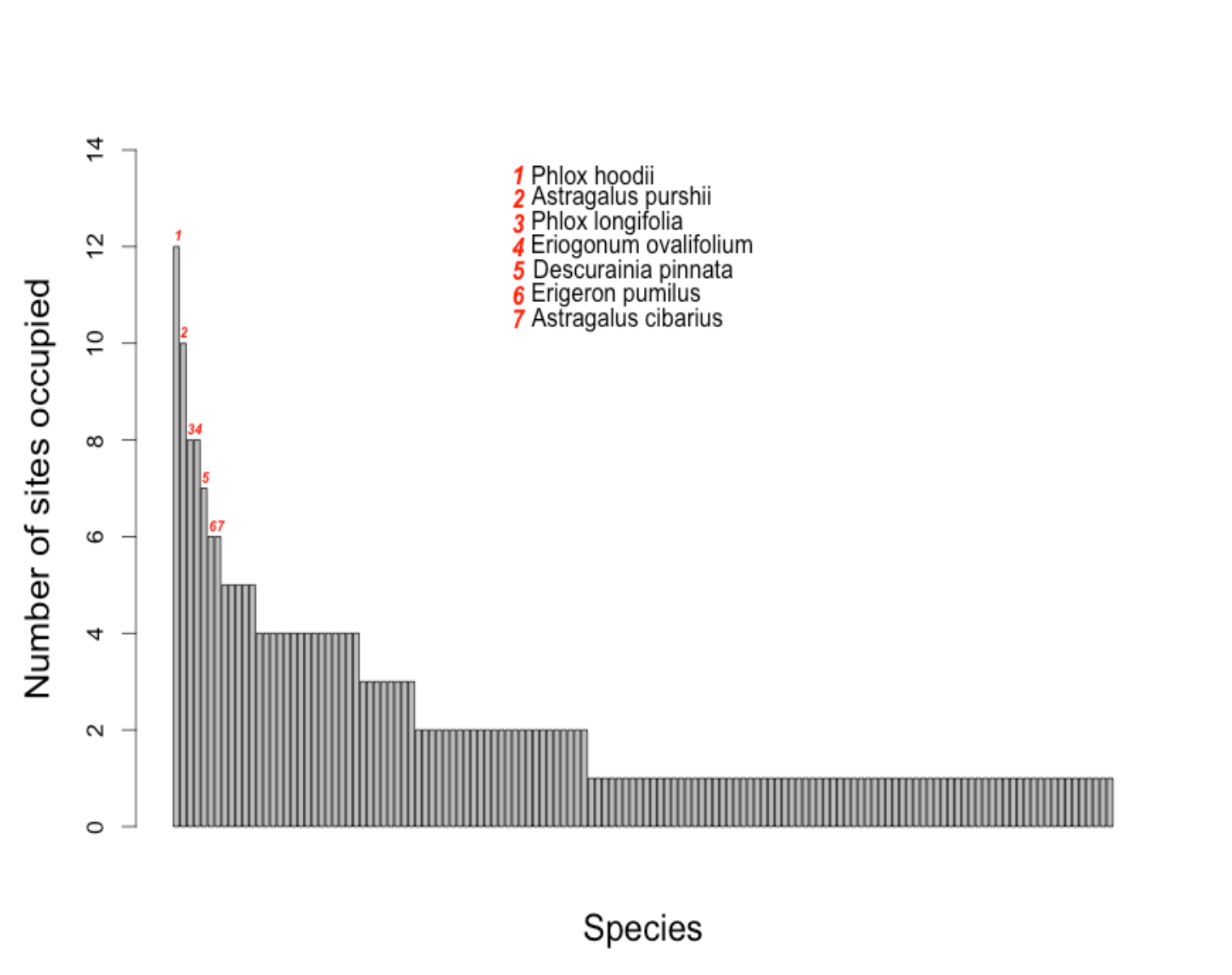


Number of Species	
Forb	59%
Grass	27%
Shrub	13%

Area Sampled and Forb Species Detected



An Important Difficulty in Dealing with Forbs

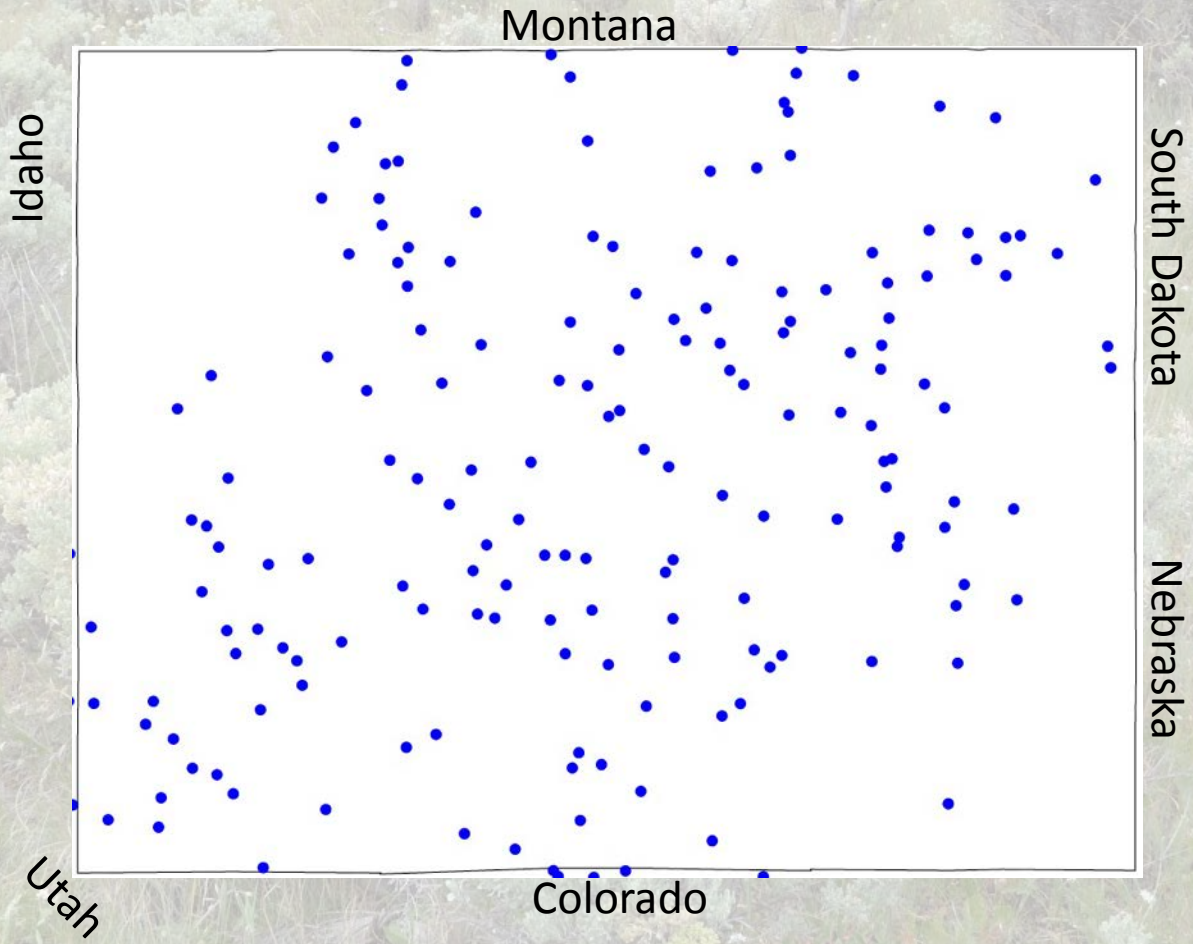


Forbs in Big Sagebrush Ecosystems

- Mentioned by grouse biologists, but very little specific information.
- Poorly sampled by vegetation ecologists.
- Small component of vegetation structure, but largest component of plant species richness in big sagebrush ecosystems.
- Our analyses suggest that precipitation and soil texture were the most important explanatory variables for both numbers and composition of forbs.

Next Step in Our Forb Work

We have a project with the University of Wyoming Biodiversity Institute to sample up to 50 big sagebrush sites in Wyoming during Summer 2016.



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Plant species biodiversity

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Sagebrush mortality

Questions

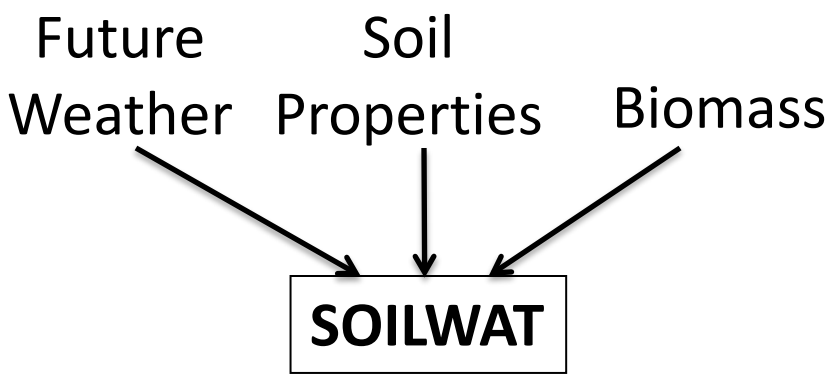
1. How will big sagebrush vegetation response to altered ecohydrology?
2. Will core sage-grouse habitat continue to be high quality?
3. How will disturbance interact with climate change to influence big sagebrush vegetation dynamics?

STEPWAT: Individual-based Plant Model

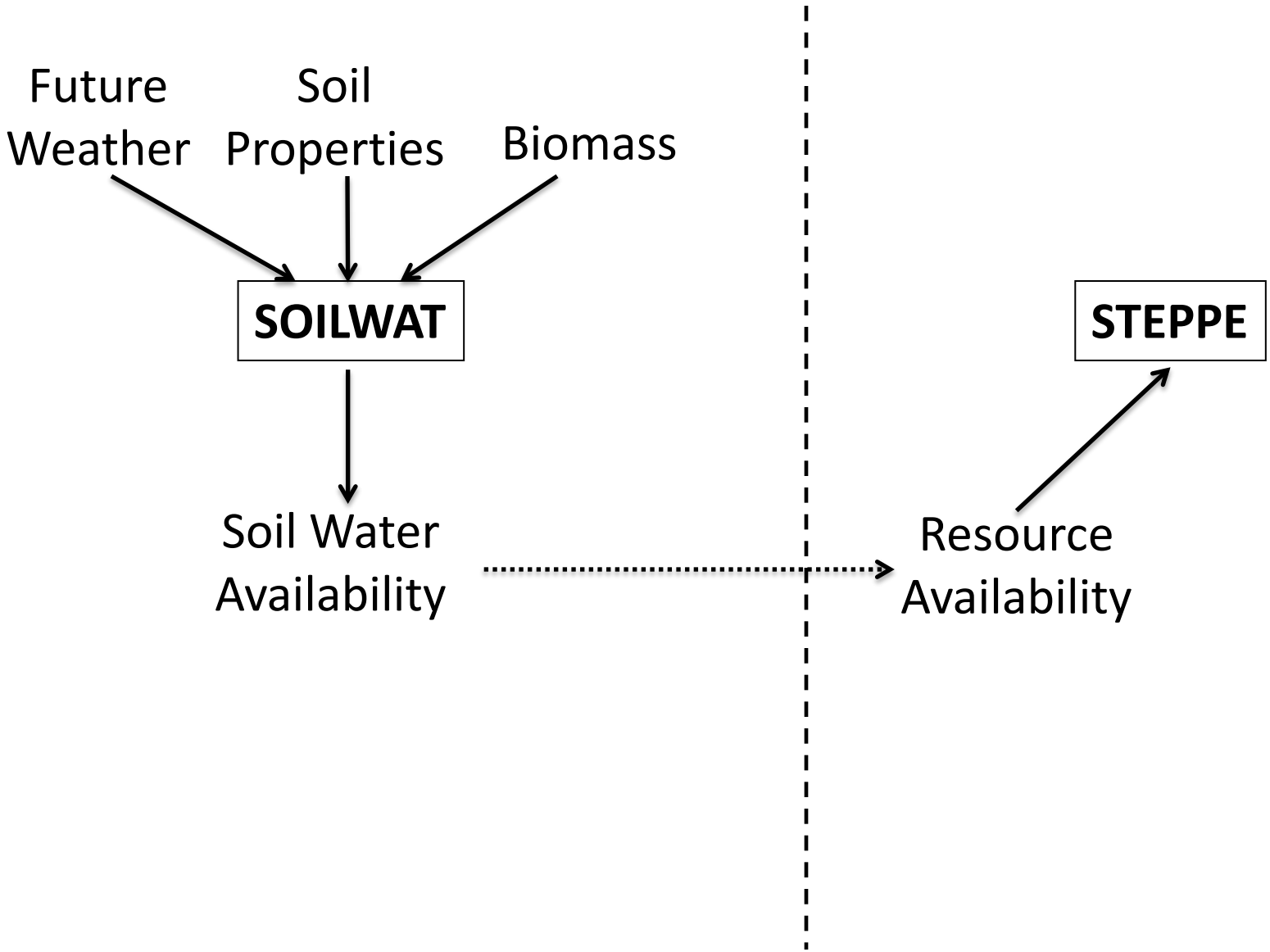
SOILWAT

STEPPE

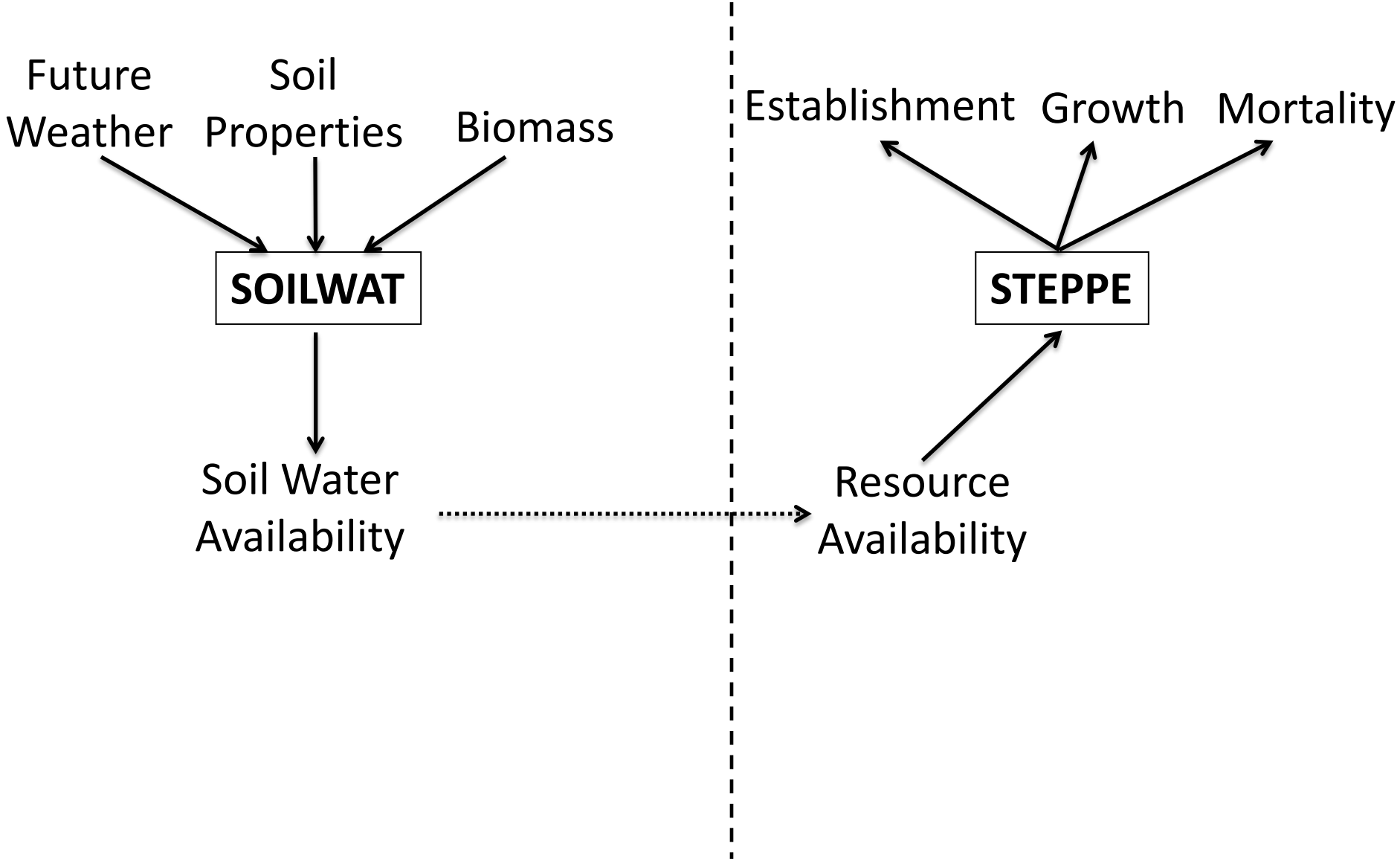
STEPWAT: Individual-based Plant Model



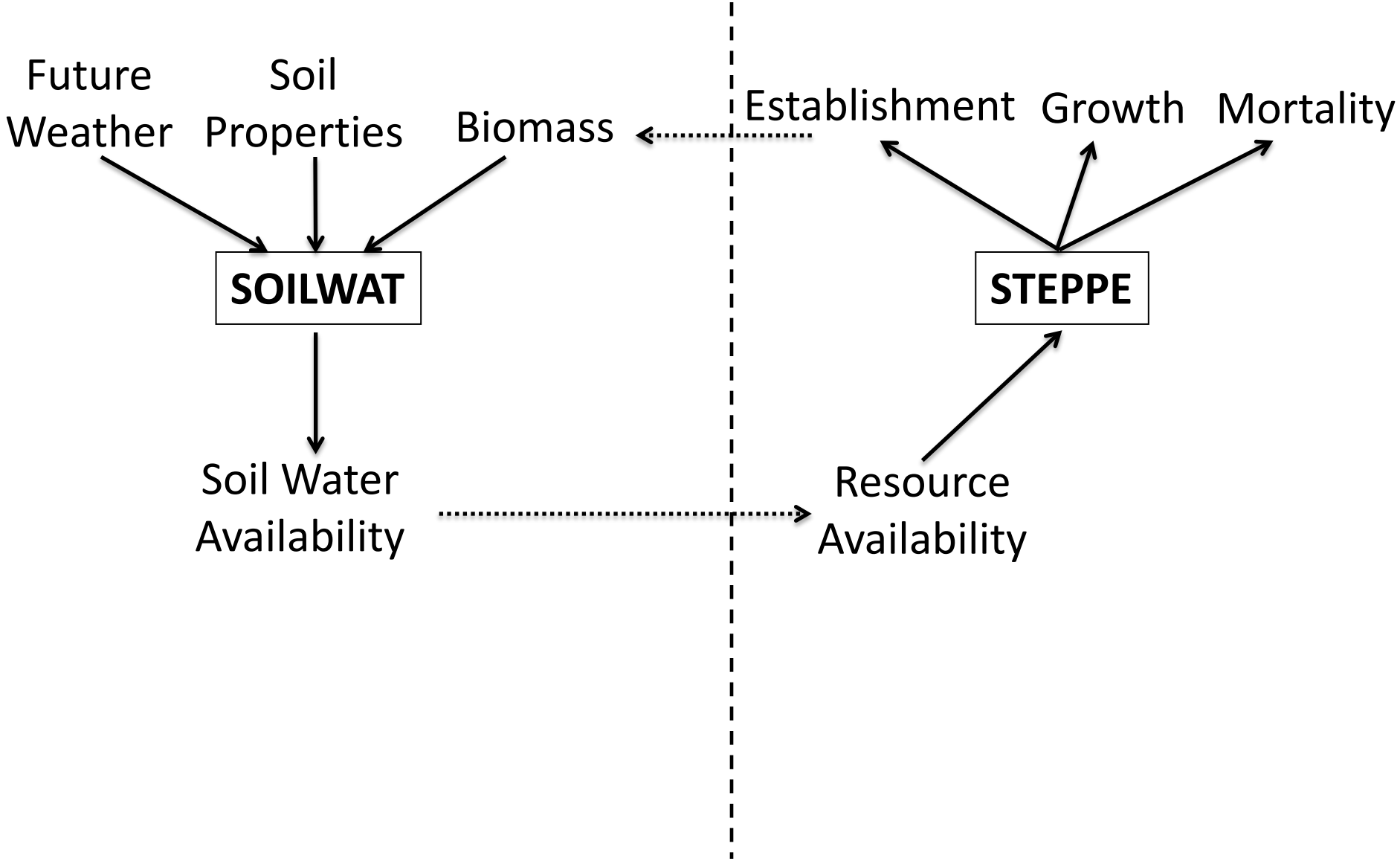
STEPWAT: Individual-based Plant Model



STEPWAT: Individual-based Plant Model



STEPWAT: Individual-based Plant Model



STEPWAT Simulations

- Fire frequency: 2, 10, 50 years
- Grazing: annual basis; low, moderate, high intensities
- Multiple soil types (sand loam, loam, silt loam, clay loam)
- 10 GCMs, RCP8.5, 2030-2060, 2070-2100

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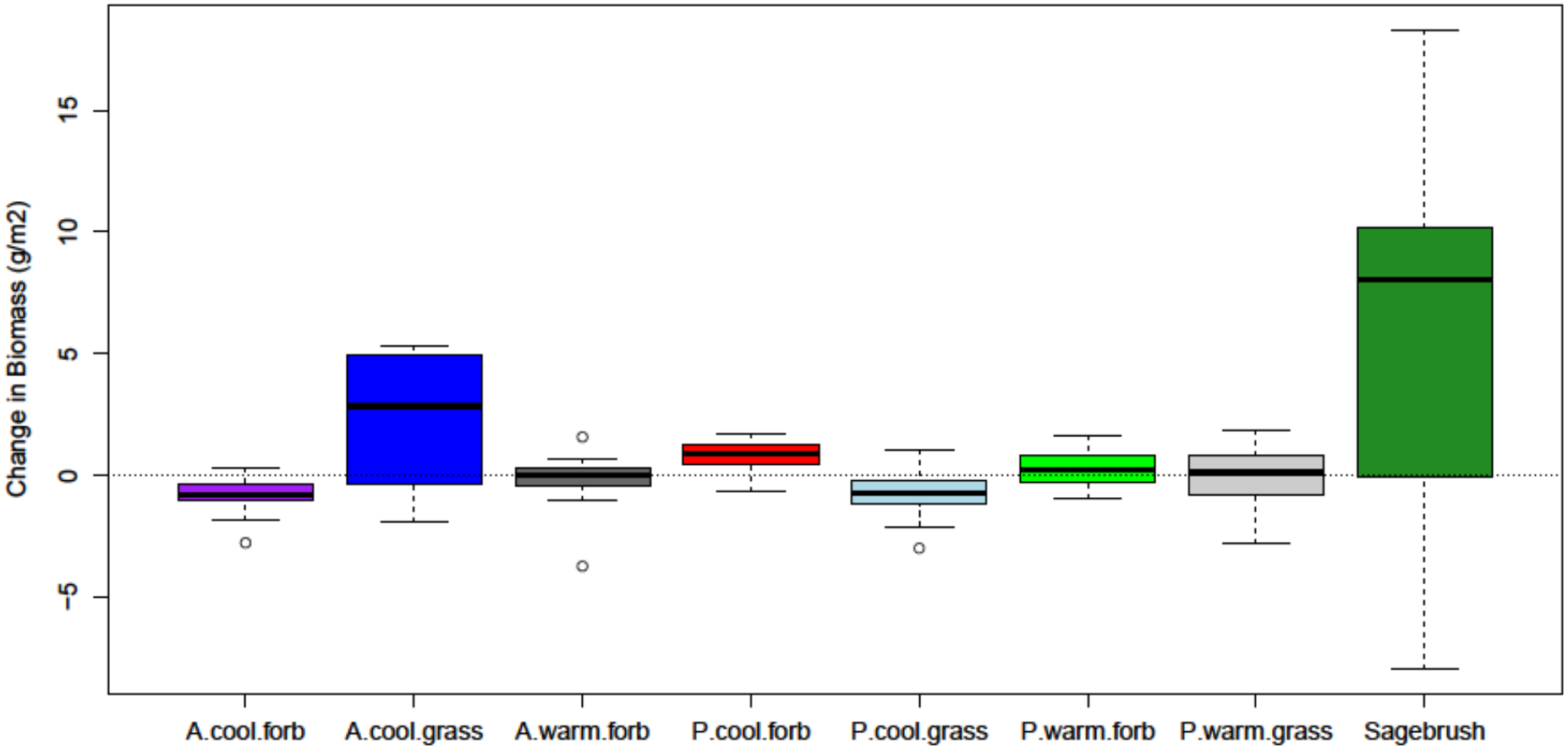
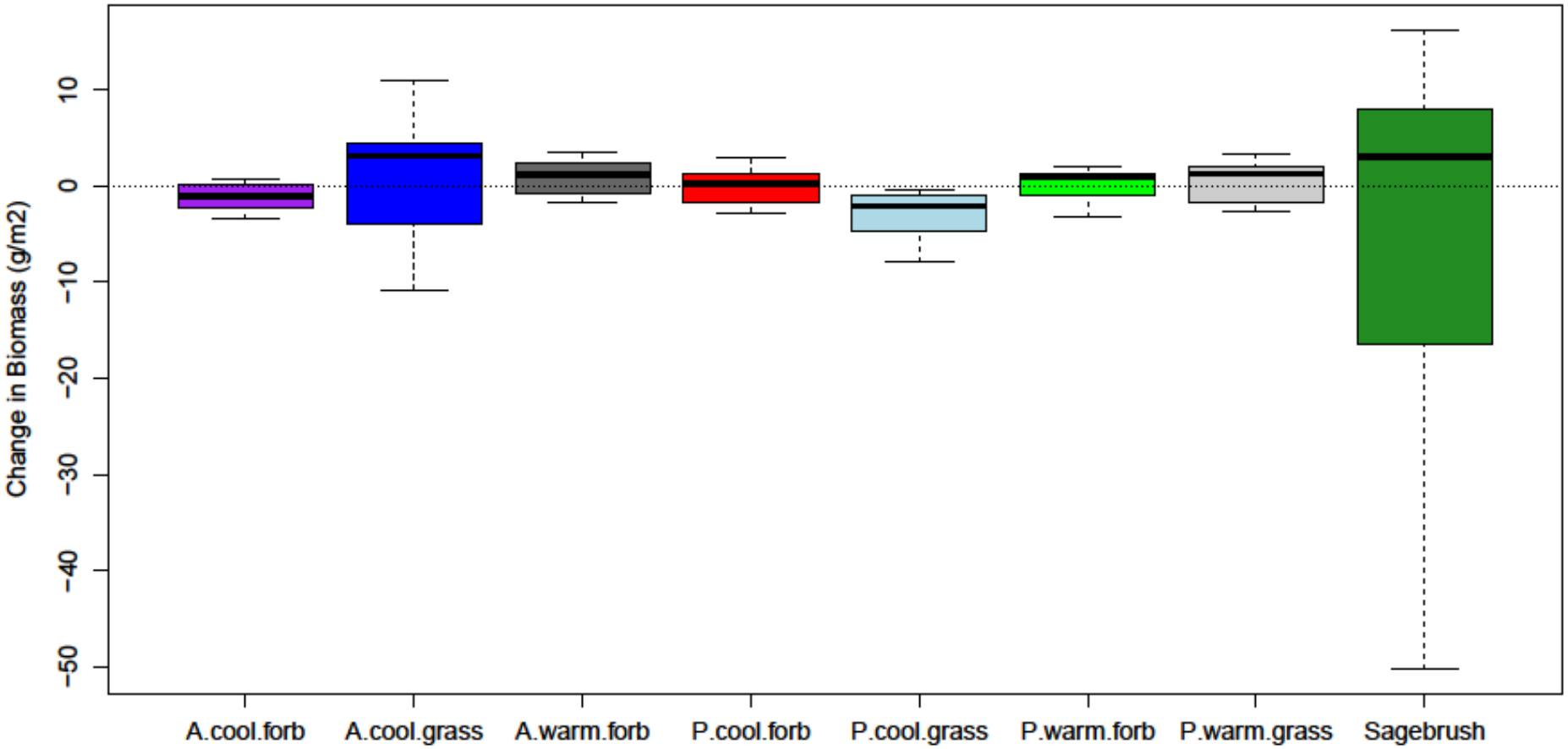
- 5 sites from MZ 2

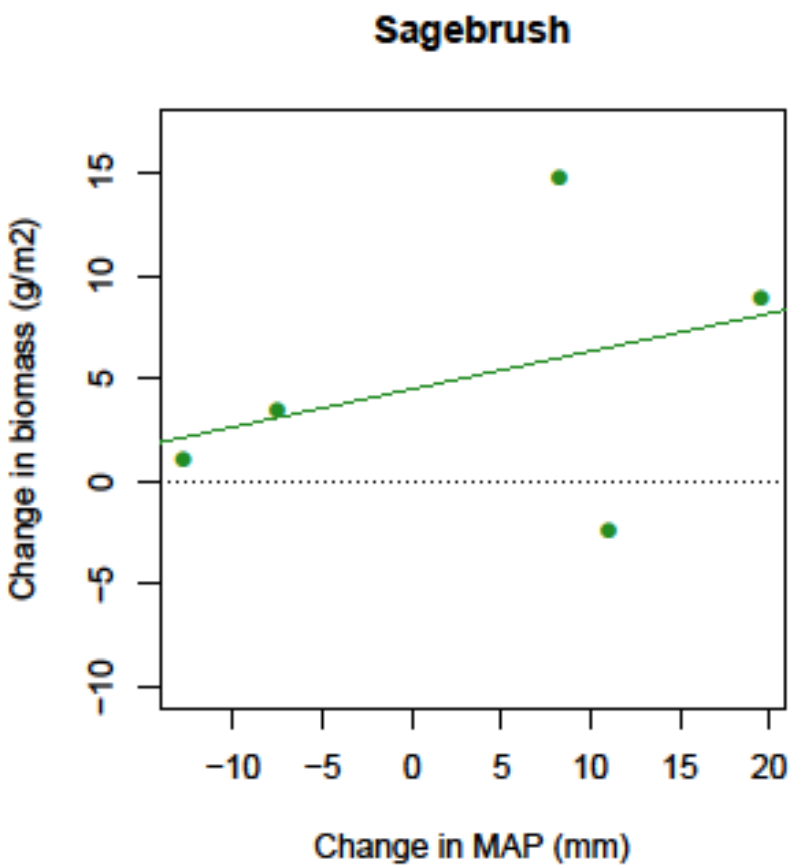
Change in Functional Group Biomass by 2030-2060

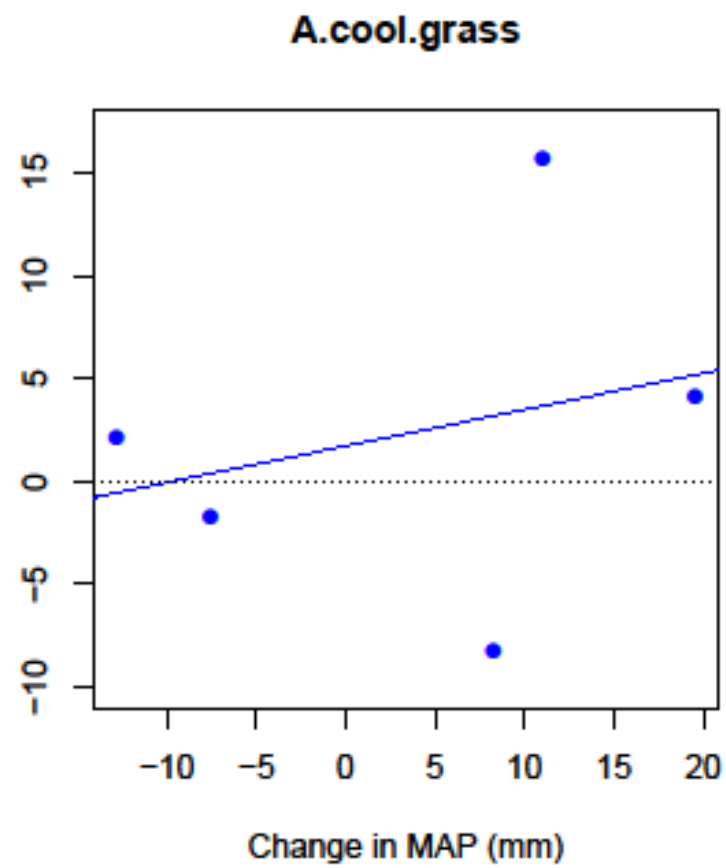


Change in Functional Group Biomass by 2070-2100

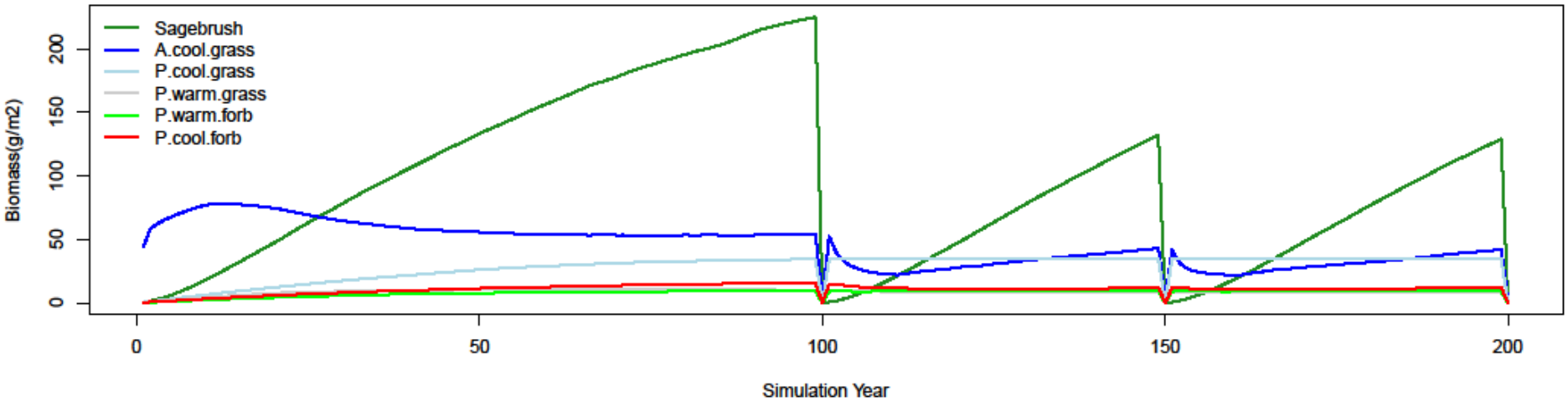


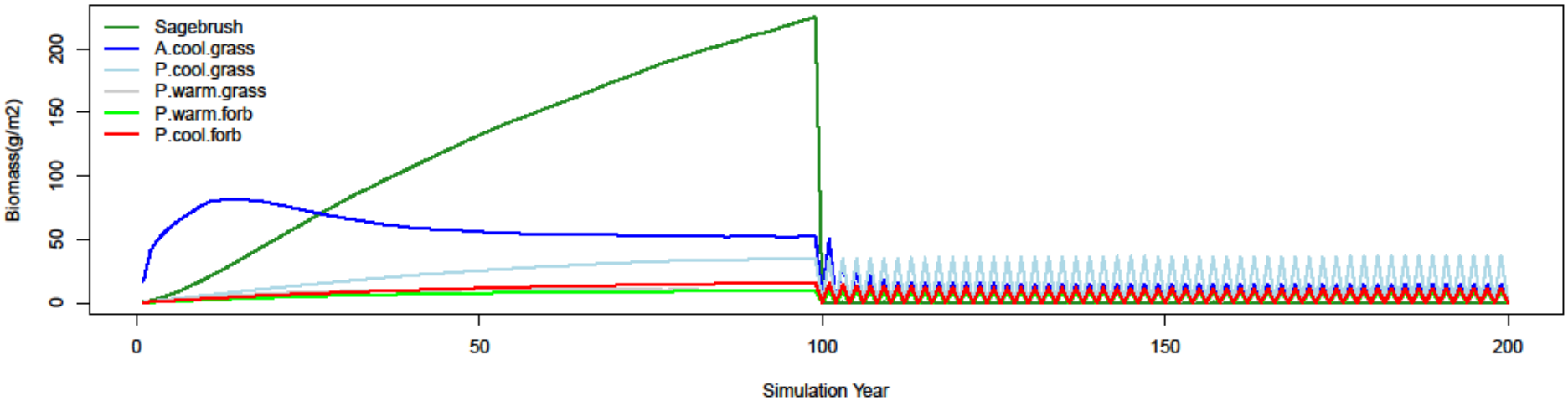
Change in Biomass vs. Change in MAP by 2030-2060





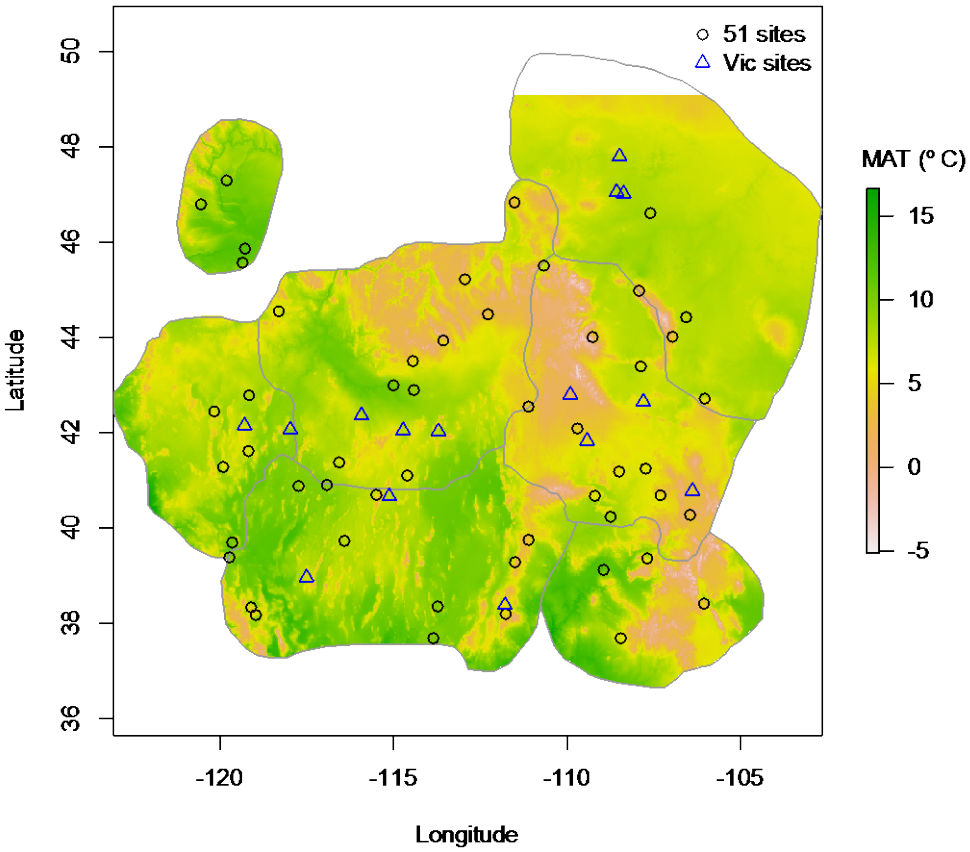
Fire Frequency Impacts on Plant Biomass by 2030-2060

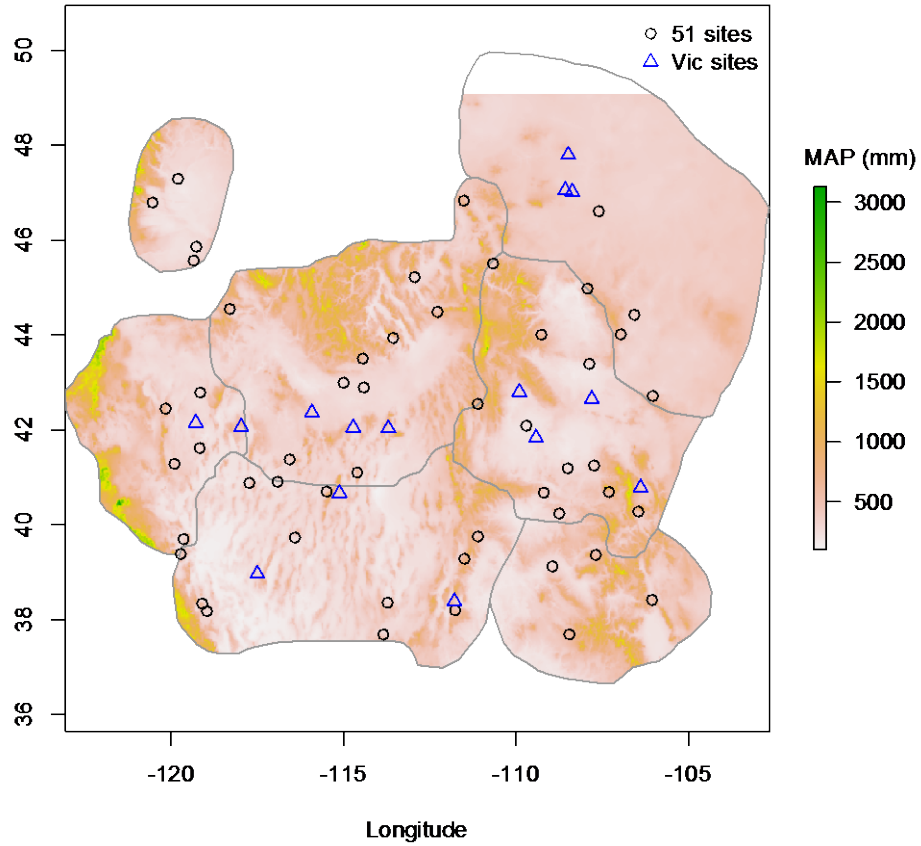




Next Steps

51 SOILWAT sites and 15 Field Sites across the western US





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Ecohydrology of sagebrush ecosystems

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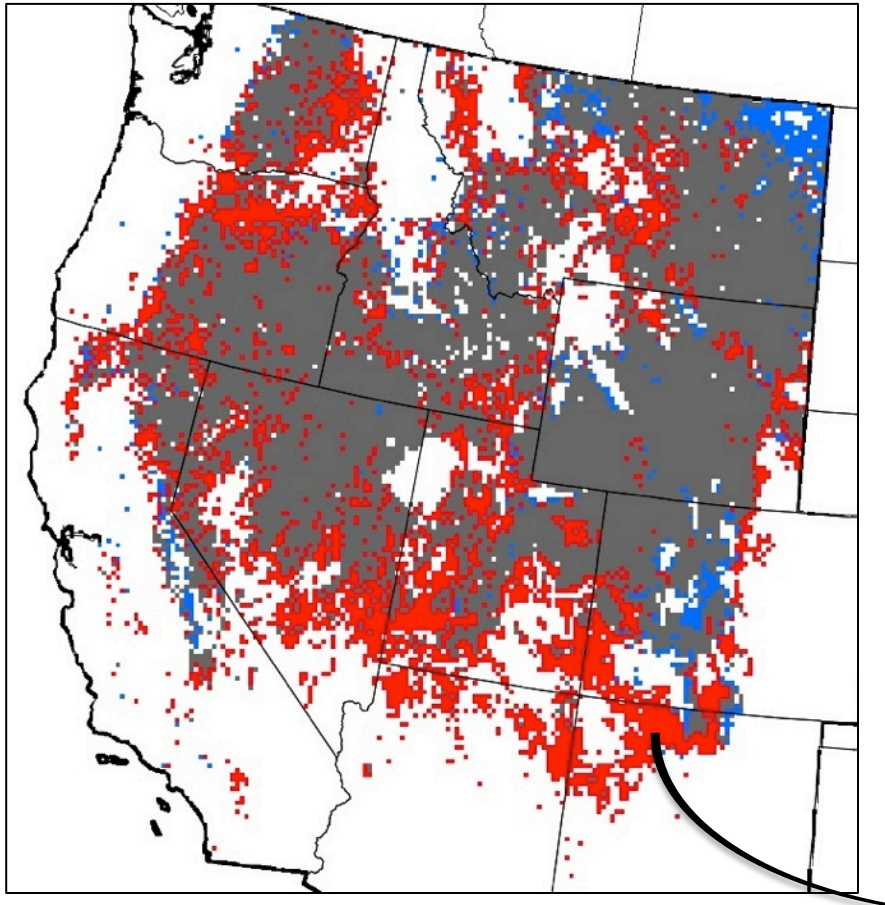
Plant species biodiversity

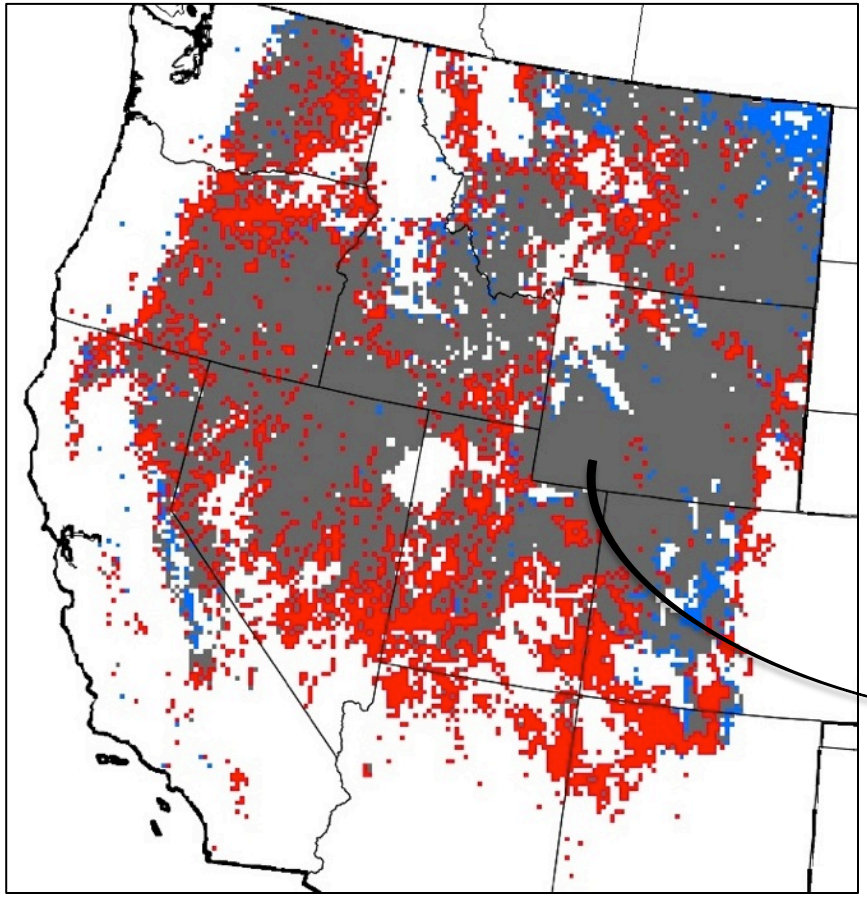
Plant community responses

Sagebrush mortality

Sagebrush mortality



Sagebrush mortality

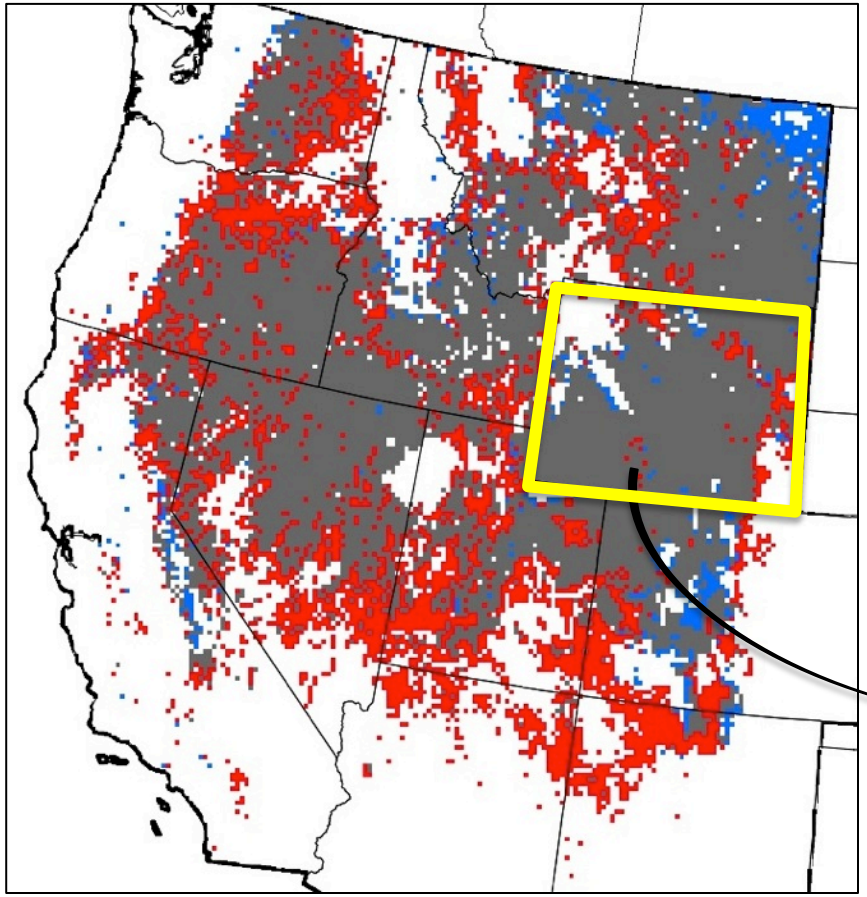


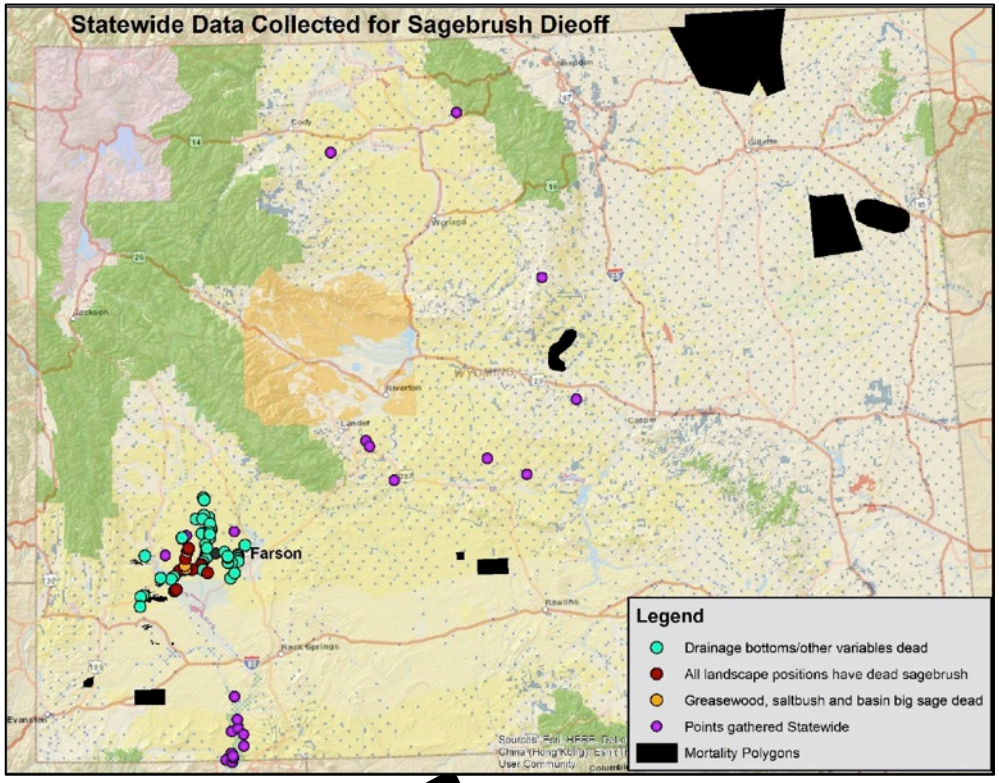
Clause, K. J., and J. Randall. 2014. Sagebrush die-off report 2014. Wyoming Game and Fish Department.

Sagebrush mortality

SAGEBRUSH DIE-OFF REPORT 2014

Karen J. Clause, NRCS
Jill Randall, WGFD

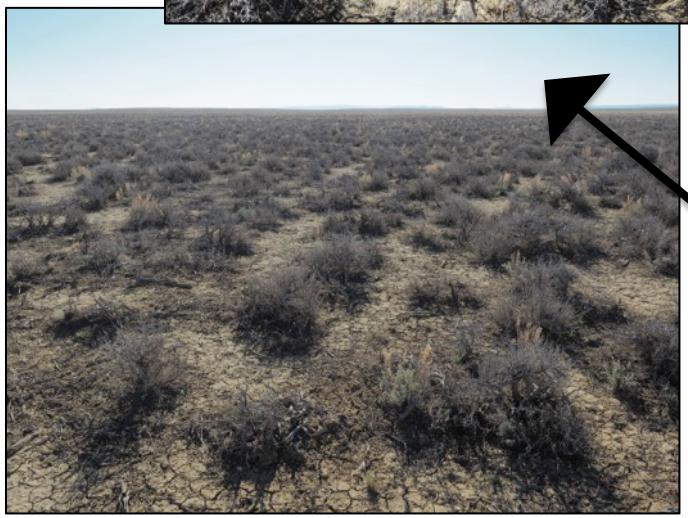


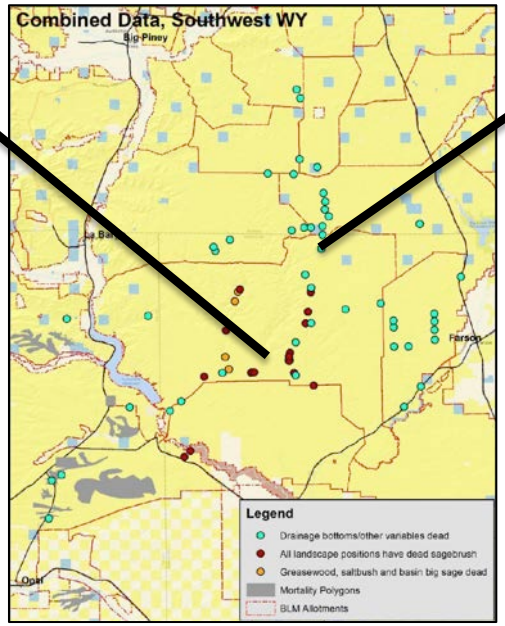


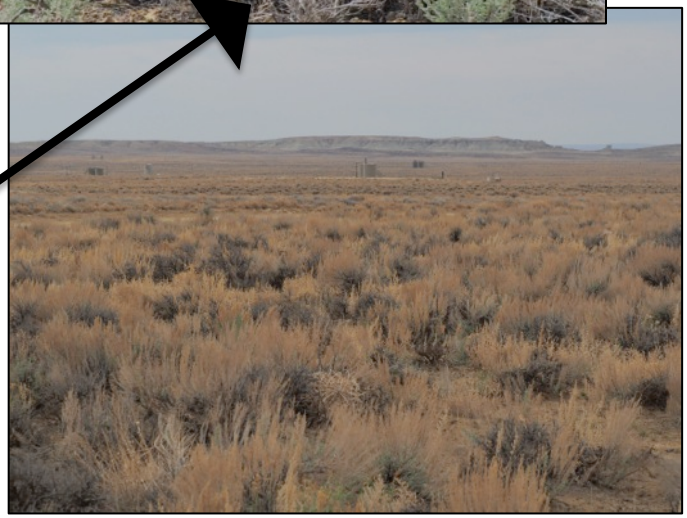
2012: Extreme drought
2013: Fall flooding

Clause, K. J., and J. Randall. 2014. Sagebrush die-off report 2014. Wyoming Game and Fish Department.

Sagebrush mortality

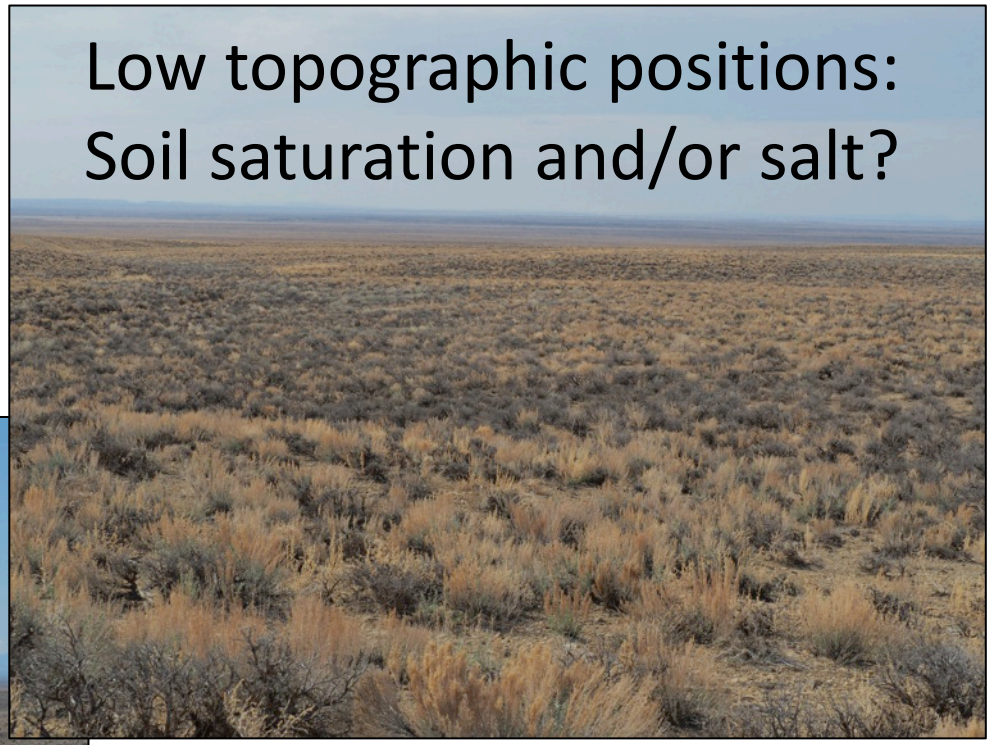


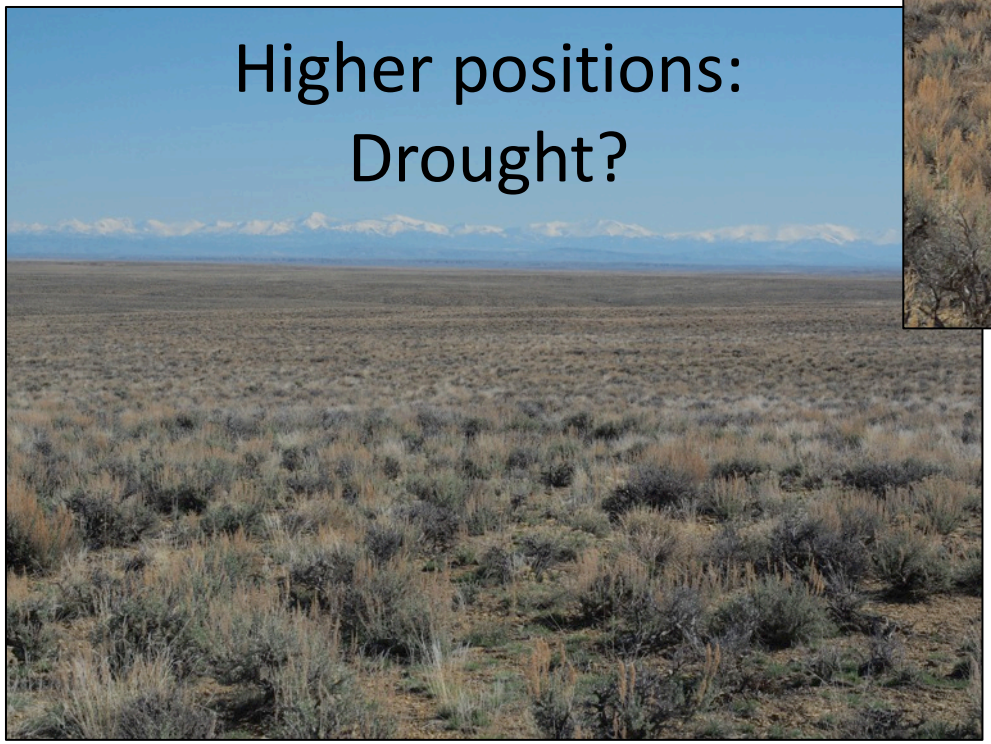




Clause, K. J., and J. Randall. 2014. Sagebrush die-off report 2014. Wyoming Game and Fish Department.

Sagebrush mortality: Multiple mechanisms?





Mortality

Objectives:

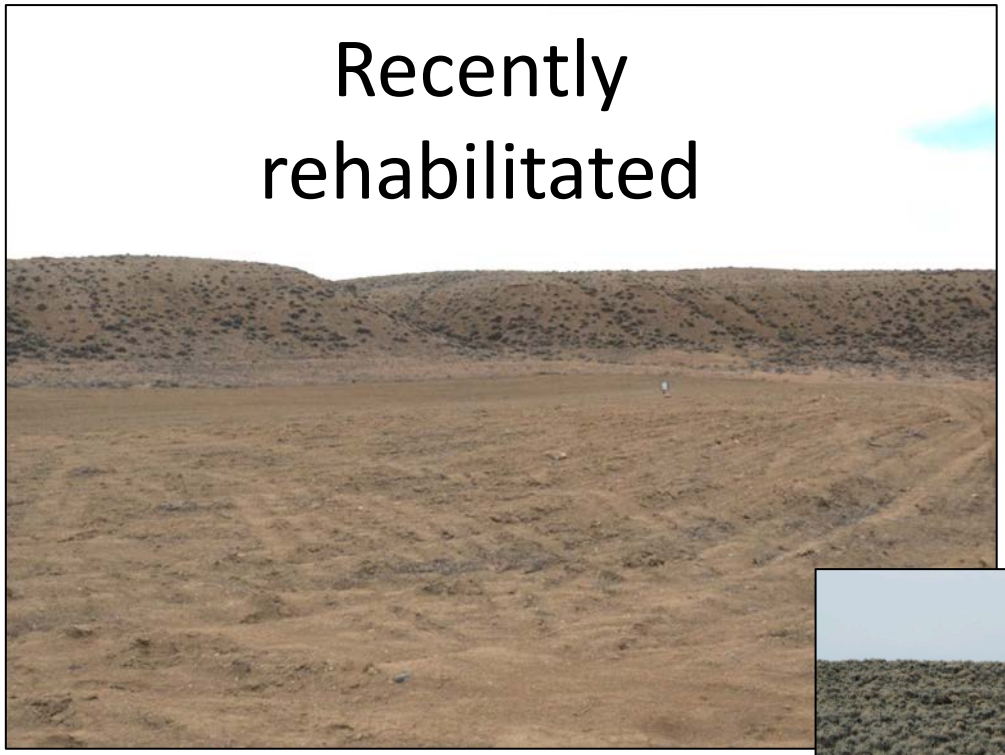
- Characterize soil moisture conditions that caused recent mortality
- Quantify the historical and potential future frequency of such conditions

- Sampling 2016 & 2017
- Including upland and lowland areas inside and outside of core mortality area
- Relate soil water conditions

Sagebush mortality:
Contribute to biological invasions?

Sagebrush mortality: Interact with other disturbances at landscape scales?

Jonah Field, WY, (Ecoflight)


Recently
rehabilitated

After 26 years

Ecohydrology of sagebrush ecosystems

Ecohydrological niche: utilization of deep, stored, cool-season moisture

Climate change impacts

Wetter winters; earlier springs; longer, drier, hotter summers

Sagebrush suitability and regeneration

Declines in south and low elevation areas – potential range shift

Plant species biodiversity

Forbs are a key habitat component, but represent a key knowledge gap

Plant community responses

In progress: climate and disturbances likely to interact; vary across range

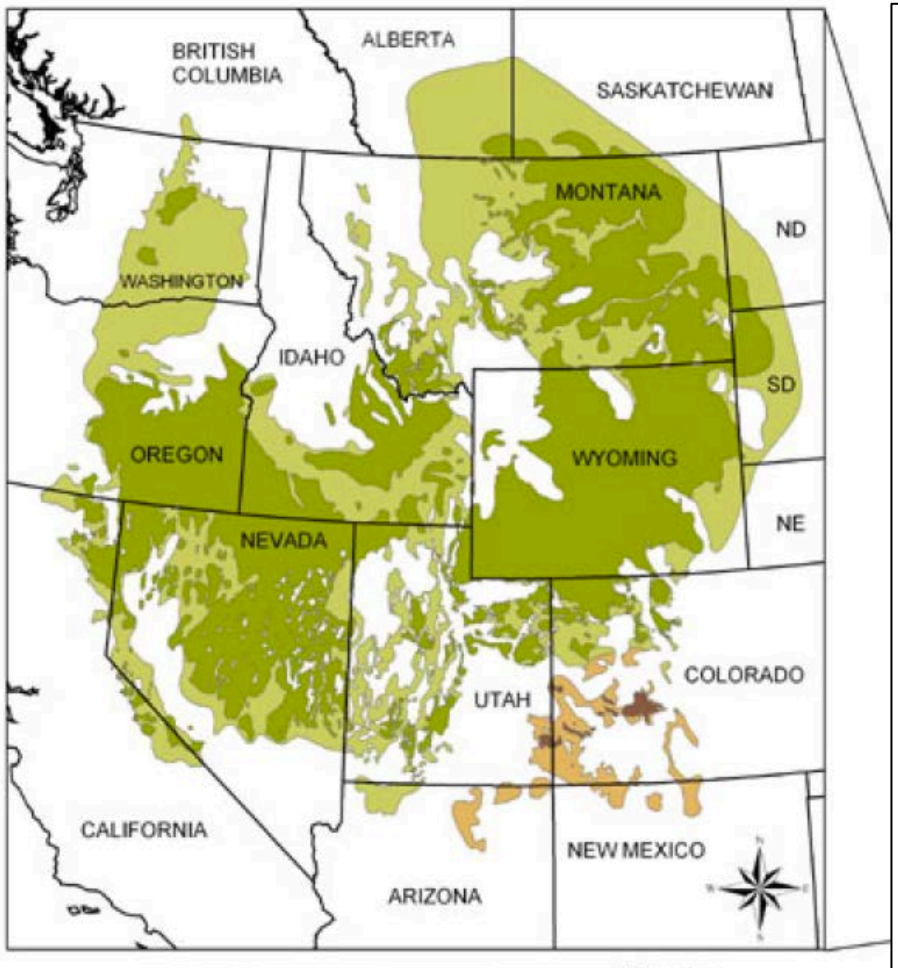
Sagebrush mortality

Starting: Potential long-term consequences; multiple mechanisms possible

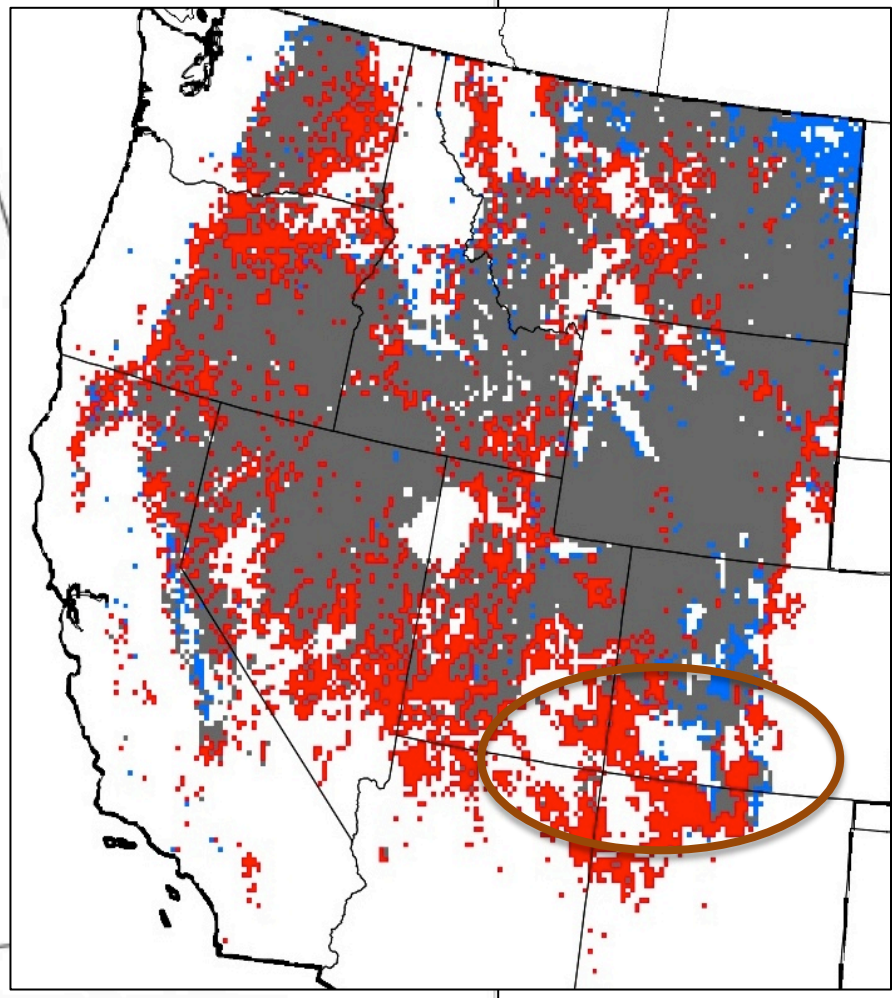
Knowledge gaps

- Range-wide sagebrush mortality/decline
- Sagebrush dispersal & migration potential (seedbanks)
- Field measurements of long-term disturbance recovery
  - Well-pads, fire, mortality
- Geographic patterns of vulnerability to annual grass invasion
- Weather extreme impacts on suitability, regeneration, and mortality
- Nearer-term forecasting
- Future of high quality habitat for other species
  - Gunnison sage grouse?

Gunnison sage grouse

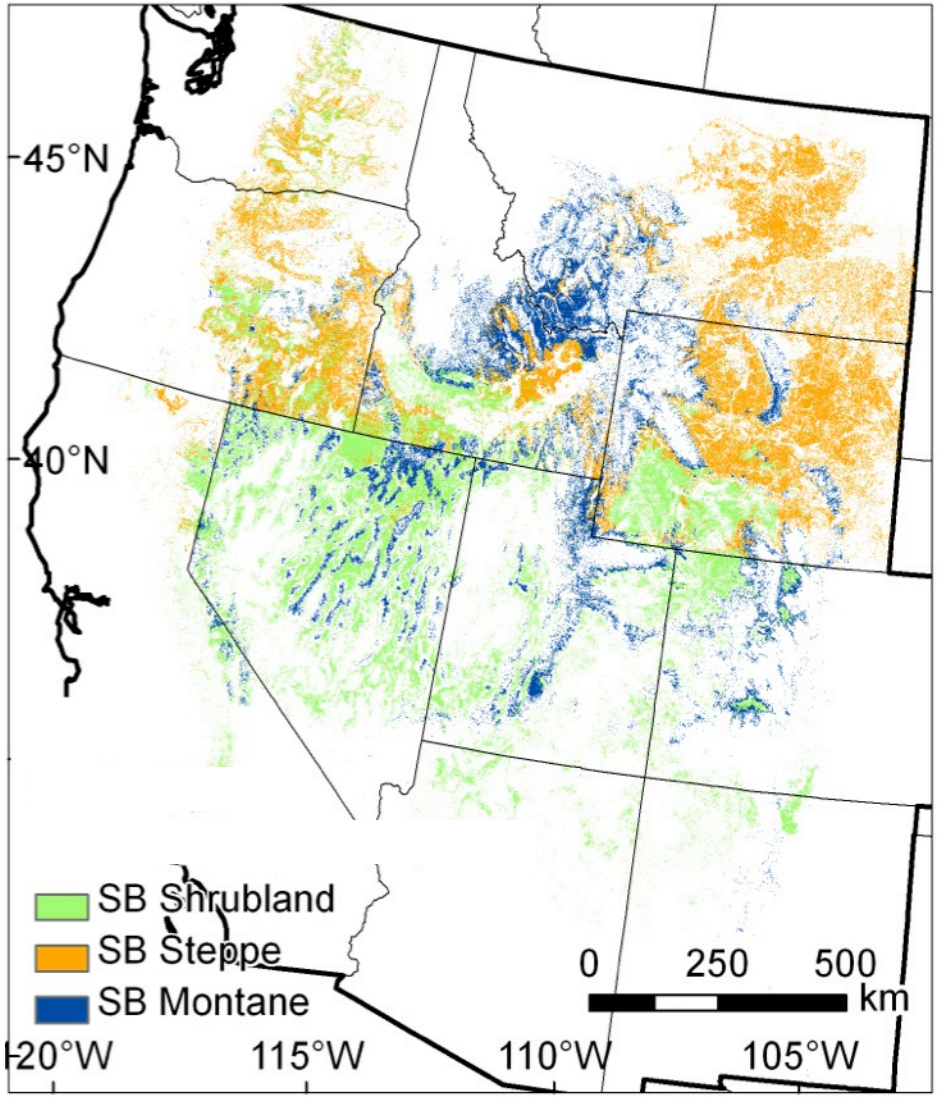


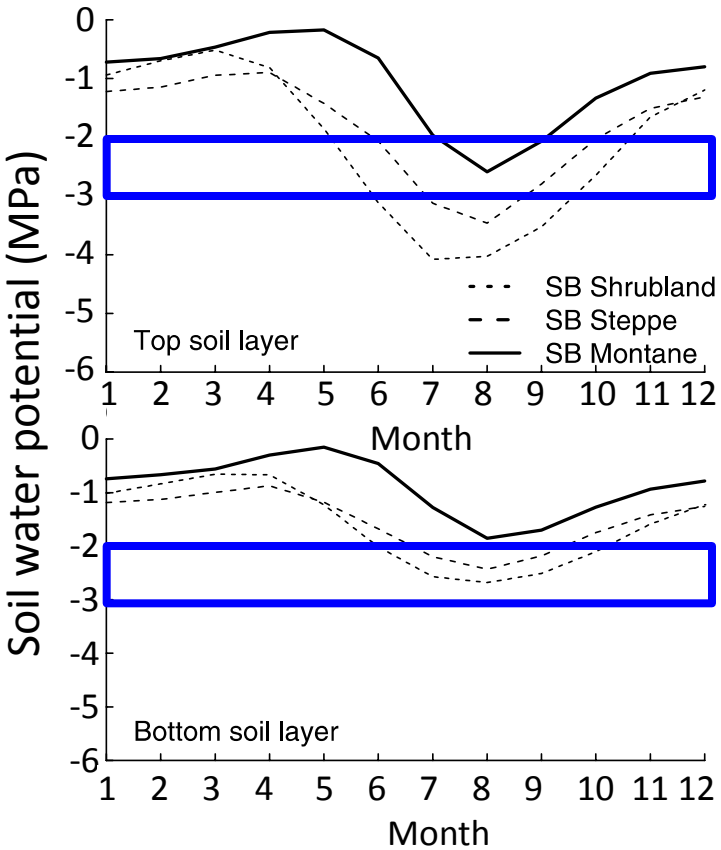
Map after Schroeder et al. 2004, Condor 106:363-376



Thank you

Sagebrush ecohydrology





Schlaepfer et al. (2012) Ecohydrology