Assessing the future of sagebrush ecosystems to inform climate adaptation

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Assess future ecological drought in drylands

Inform long-term planning under climate change

Reduce uncertainty in adaptation strategies

Assessing the future of sagebrush ecosystems to inform climate adaptation

Future ecological drought in sagebrush ecosystems (Daniel)

- Soil moisture modeling approach
- Changes in soil moisture patterns
- Future shifts in ecological resistance & resilience

Implications for sagebrush plant communities (Martin)

- Plant community modeling approach
- Changes in plant functional types
- Implications for sagebrush habitat

Coping with uncertainty to support adaptation investments (John)

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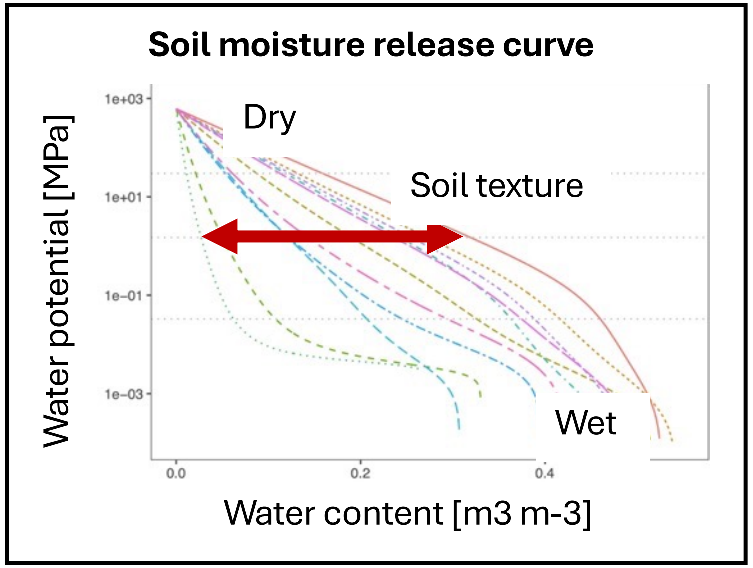
Simulation modeling approach — SOILWAT2

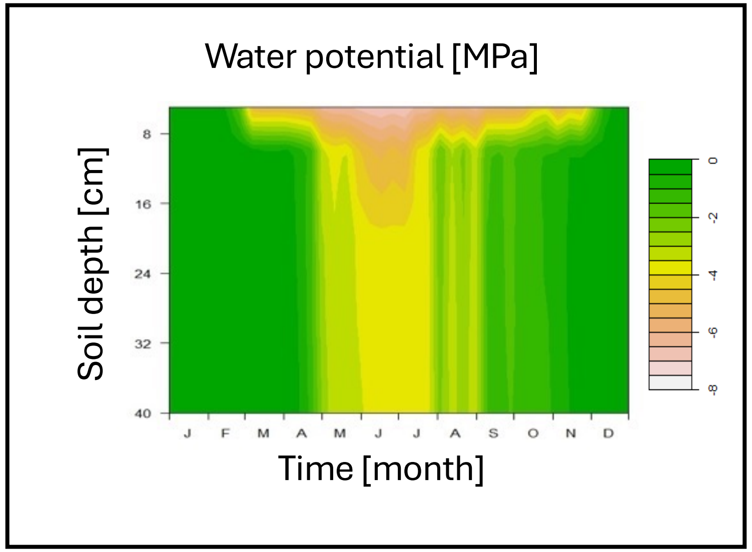
- Complex interactions between weather, vegetation, and soils in drylands
- Tight links between moisture availability and ecosystems, e.g., wildfire, biomass production, grazing
- Ecological drought through lens of soil moisture

Simulation modeling approach — SOILWAT2

- Elevation and precipitation can be useful but do often not sufficiently capture full range of ecological drought

- Model criteria for soil moisture simulations
    1. Frequent temporal resolution: flash drought; moisture storage
    2. Site-specific soil conditions: moisture vs. tension; plant available moisture
    3. High resolution across soil profile: seasonal & spatial dynamics
    4. Vegetation structure and physiology, roots
    5. Responses to climate change: CO2-fertilization; shifts in structure and physiology of vegetation



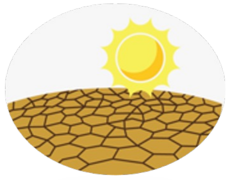


Simulation modeling approach — SOILWAT2

Daily Weather → SOILWAT2

Soil Properties → SOILWAT2

Biomass, Root depth → SOILWAT2

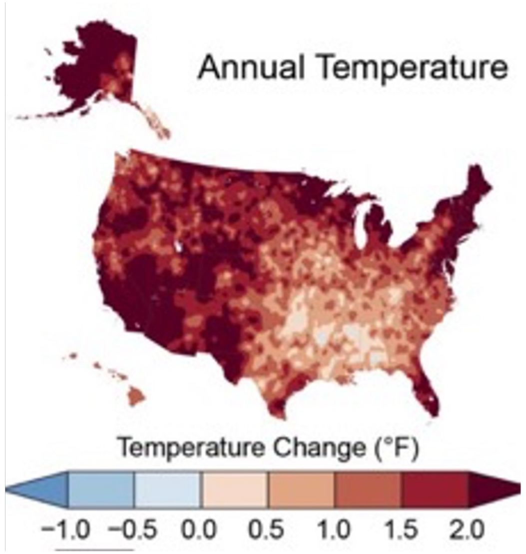


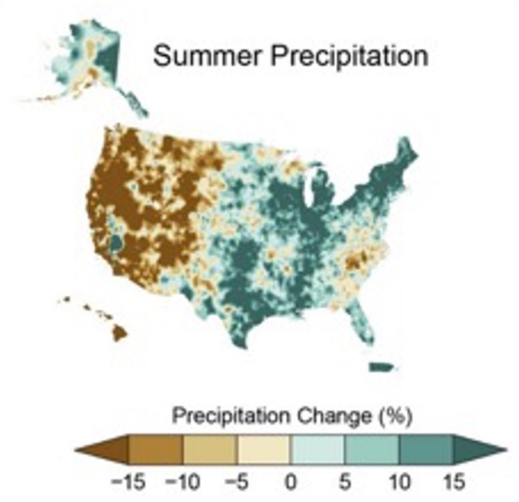
SOILWAT2

SOILWAT2 → Daily water balance & plant available water

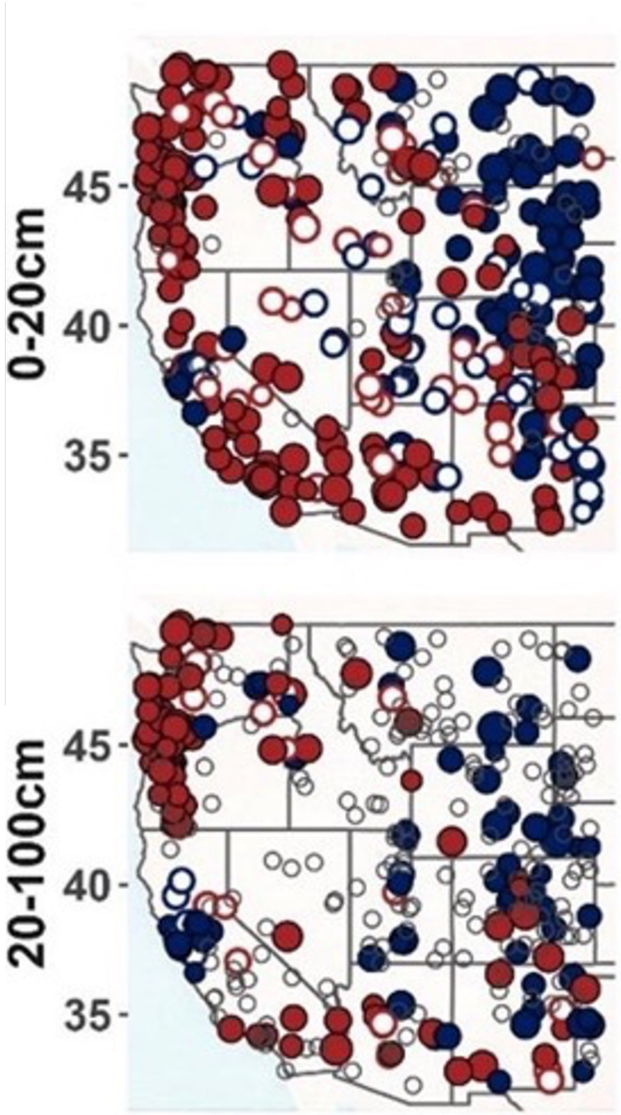
Sagebrush ecohydrological niche & future drought

Historical trends in ecological drought





- Climate trends
  (last 20 years vs. early 20th century; NCA5)
- Trends of soil moisture over 1976-2019
  - Increases in soil moisture in NC
  - Widespread decrease in soil moisture (matches overall trends in T & PPT)
  - Stronger decreases in shallow soil moisture (matches shift of PPT towards cool season)



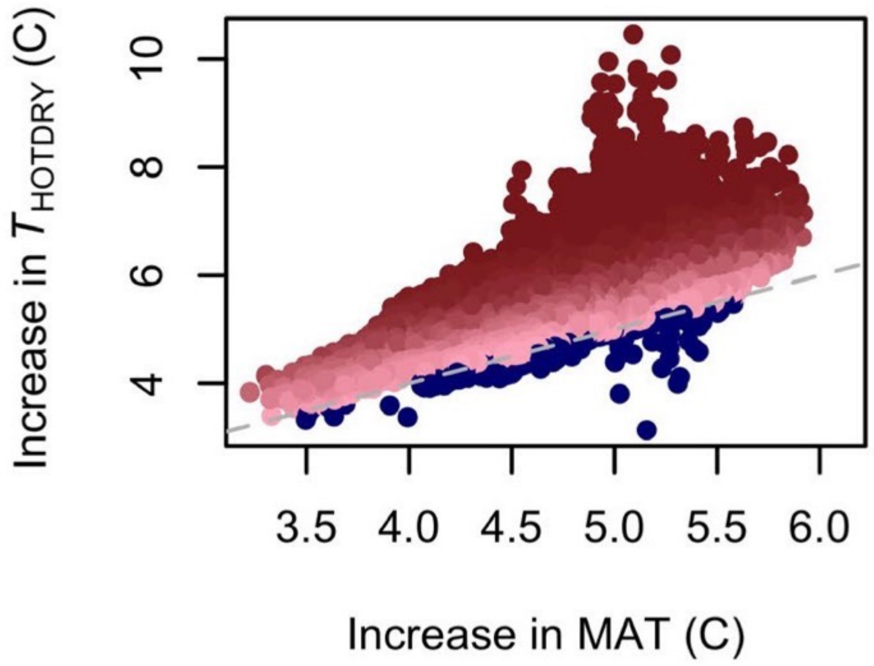
NCA5 (2023) ch. 2

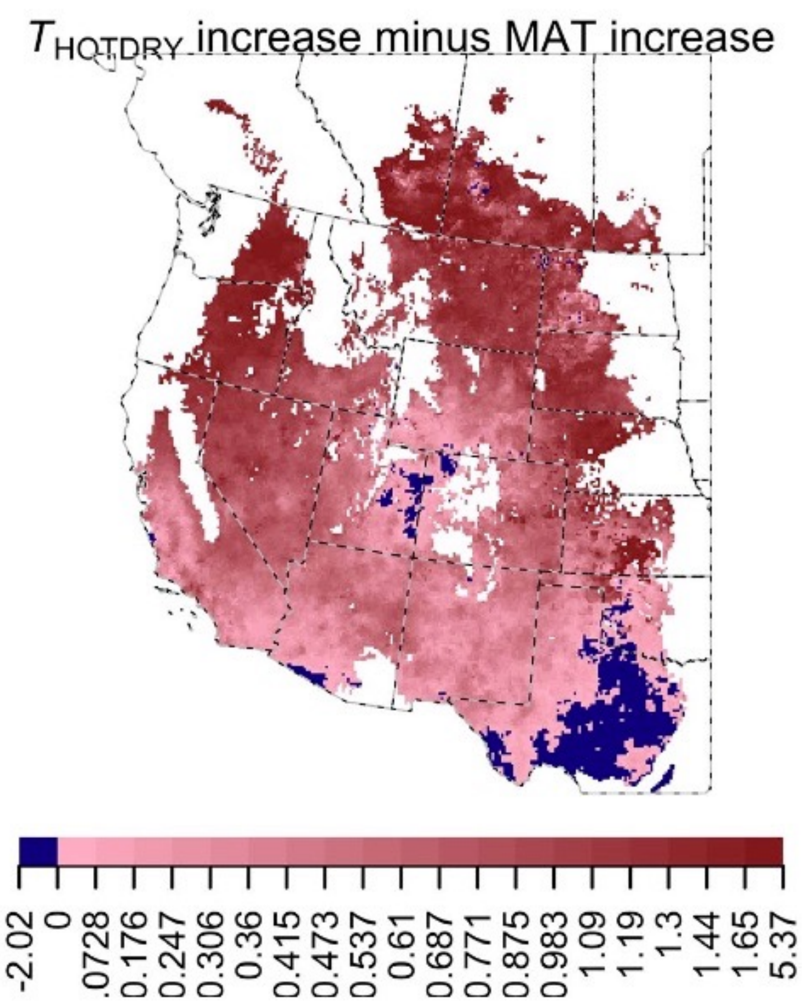
Zhang et al. (2025) Ecohydrology

Future changes in ecological drought

Rising temperature → Greater demand

And larger increase of temperature when soils are dry (particularly in northern Great Plains) → Greater stress



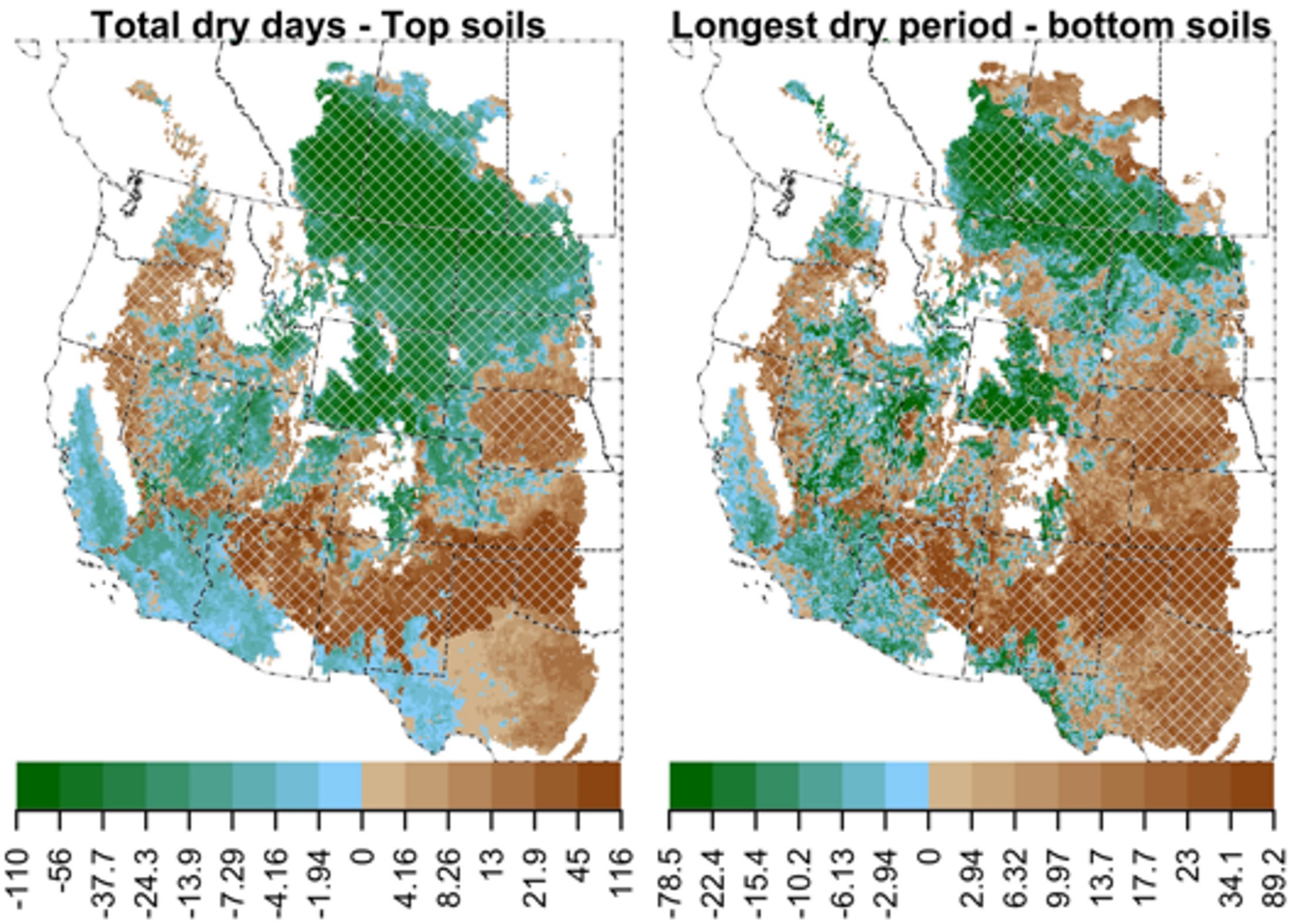


Bradford et al. (2020) GCB

Future changes in ecological drought

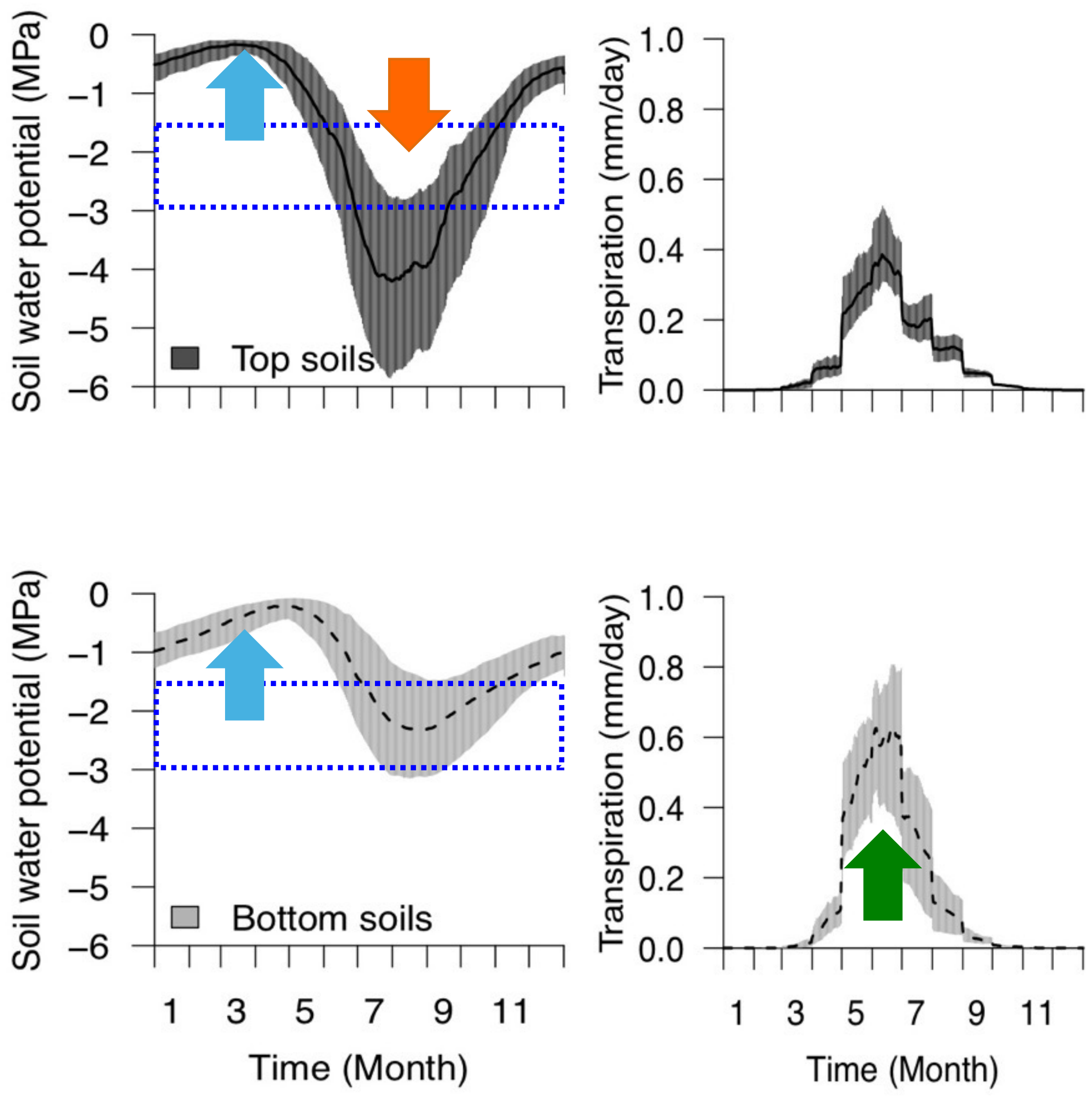
Robust signals in changes of dry soils

→ Some areas of increase, some areas of decrease (including NC)



Bradford et al. (2020) GCB

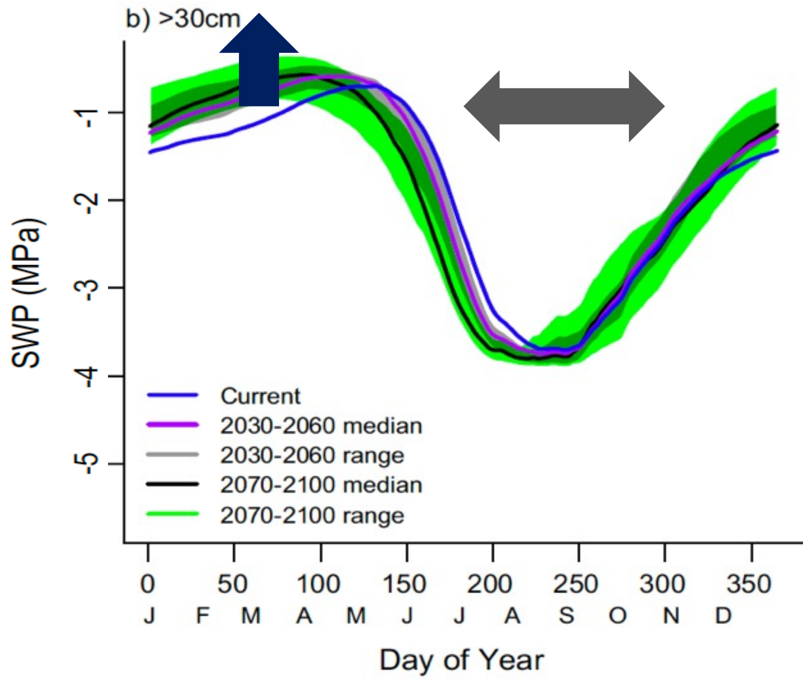
Sagebrush ecohydrological niche

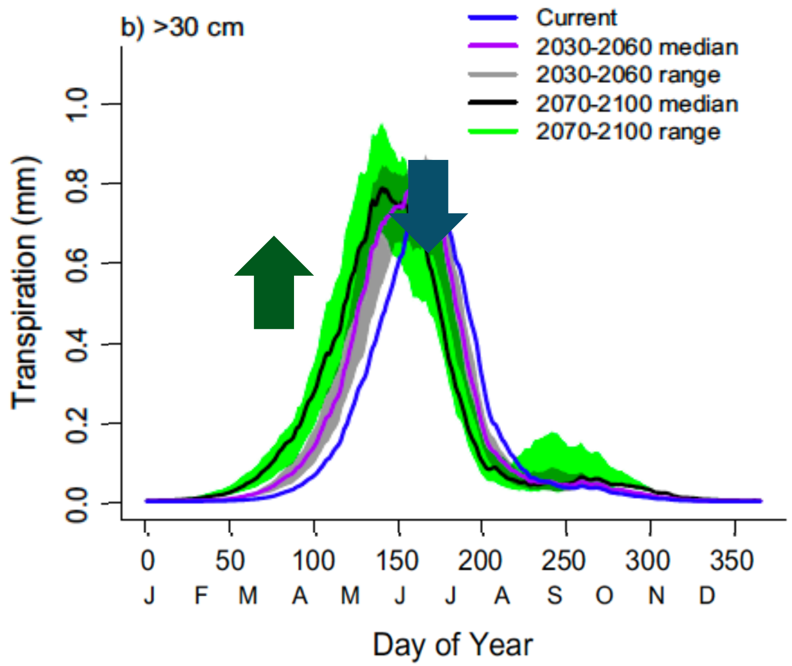


- Seasonal water dynamics defined by cool season recharge of soil water
- Summer dry period in shallow soil layers
- More transpiration from deep than shallow soil layers
- Sagebrush ecohydrological niche: utilization of deep, seasonally-stored water

Schlaepfer et al. (2012) Ecohydrology

Insights about future drought in sagebrush





Wetter winters

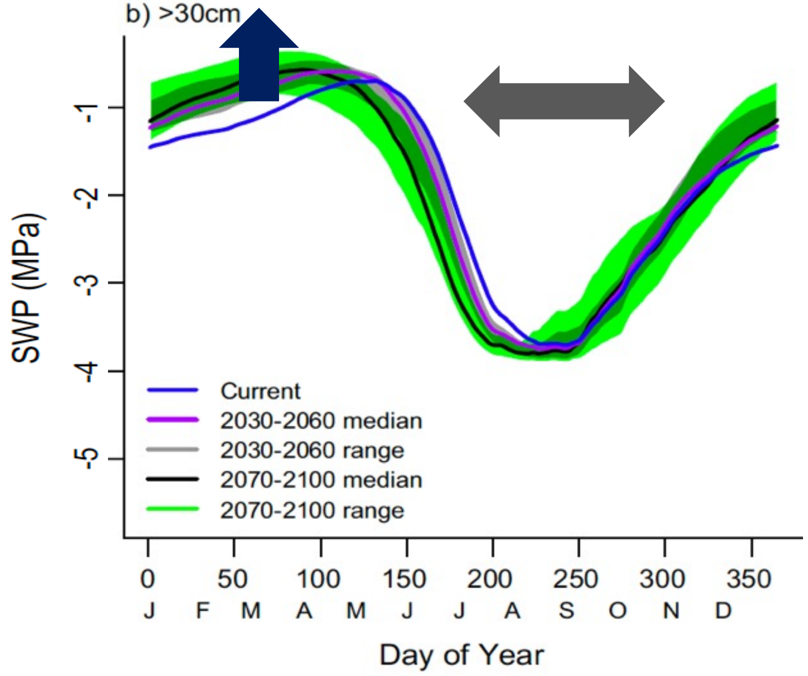
Earlier spring green-up

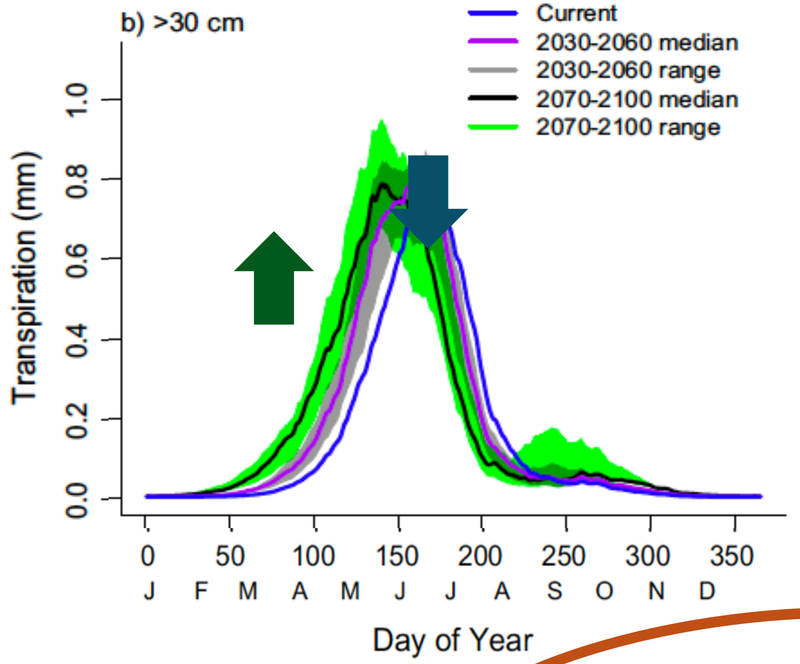
Longer (& hotter) summer dry soil periods

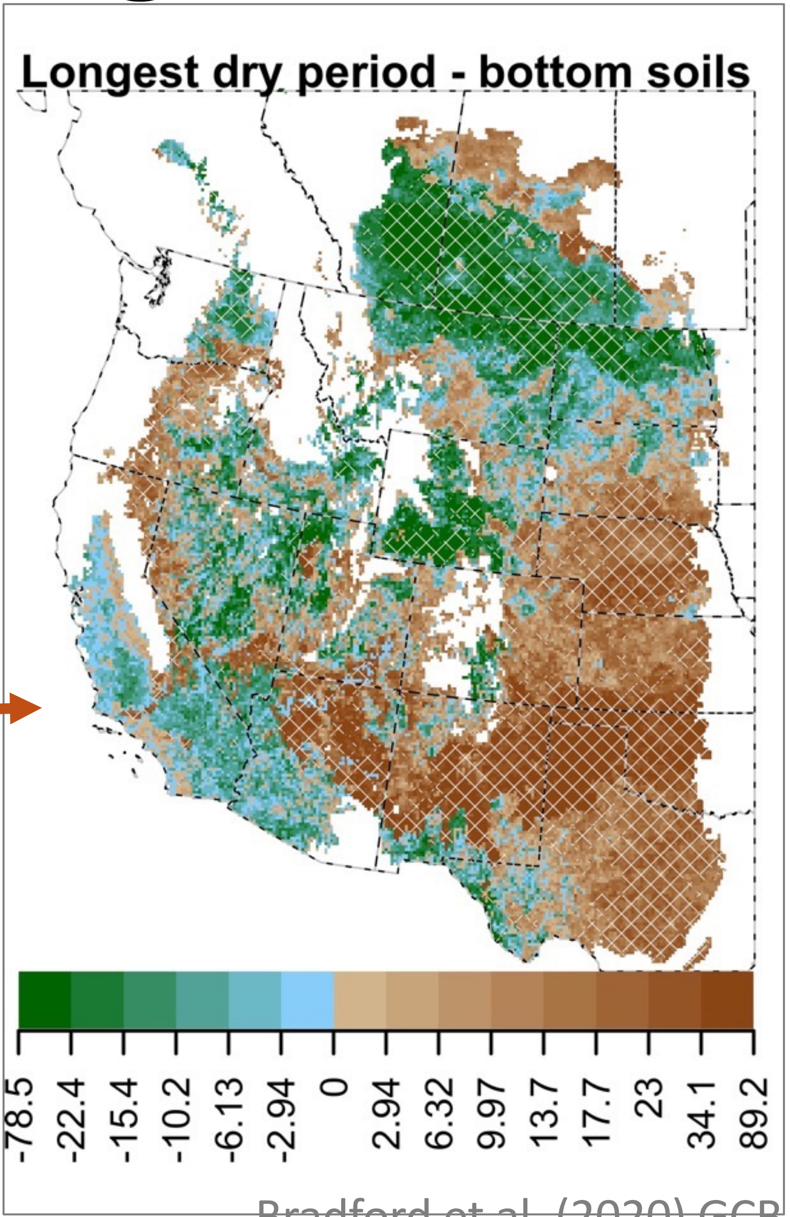
Earlier senescence

Palmquist et al. (2016) Ecology

Insights about future drought in sagebrush







Wetter winters

Earlier spring green-up

Longer (& hotter) summer dry soil periods

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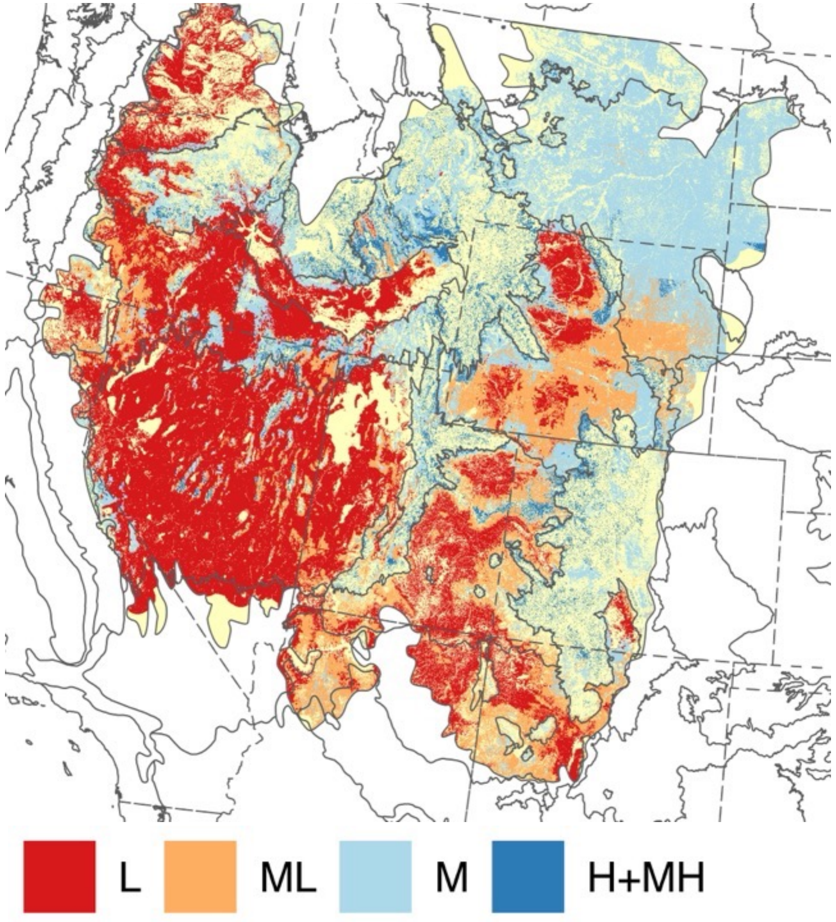
Palmquist et al. (2016) Ecology

Bradford et al. (2020) GCB

Ecological resilience & resistance to cheatgrass (R&R indicators)

Ecological resilience & resistance to cheatgrass

Resilience (historical)



- R&R indicators (Chambers et al.)
  - Resistance to cheatgrass invasion
  - Resilience to recover from stress (e.g., drought, fire)
  - Categories: L, ML, M, H+MH

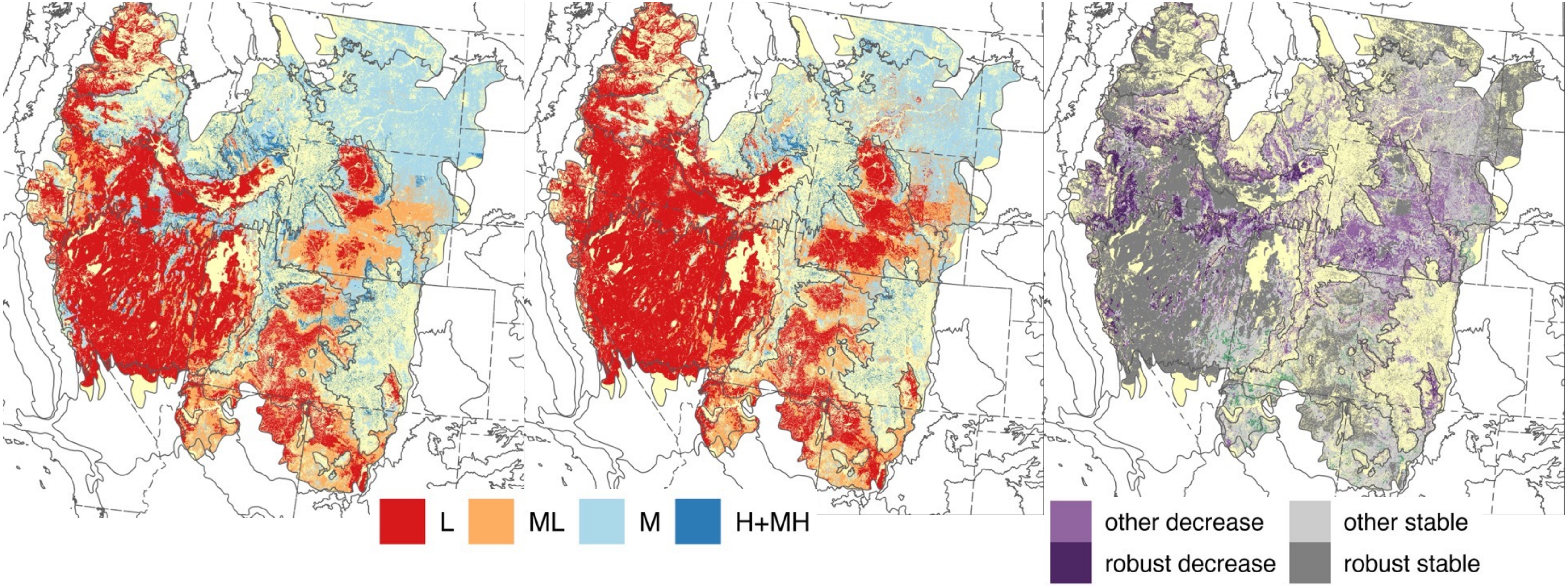
- Defined set of metrics
  - Ecological drought
  - Responsive to climate change
- Developed predictive models of ecological resistance and resilience indicators

- Future projections based on climate models

Schlaepfer et al. (2025) Ecological Applications

Ecological resilience & resistance to cheatgrass

Resilience (historical) **Future** (end 21st; RCP4.5) **Projected change**



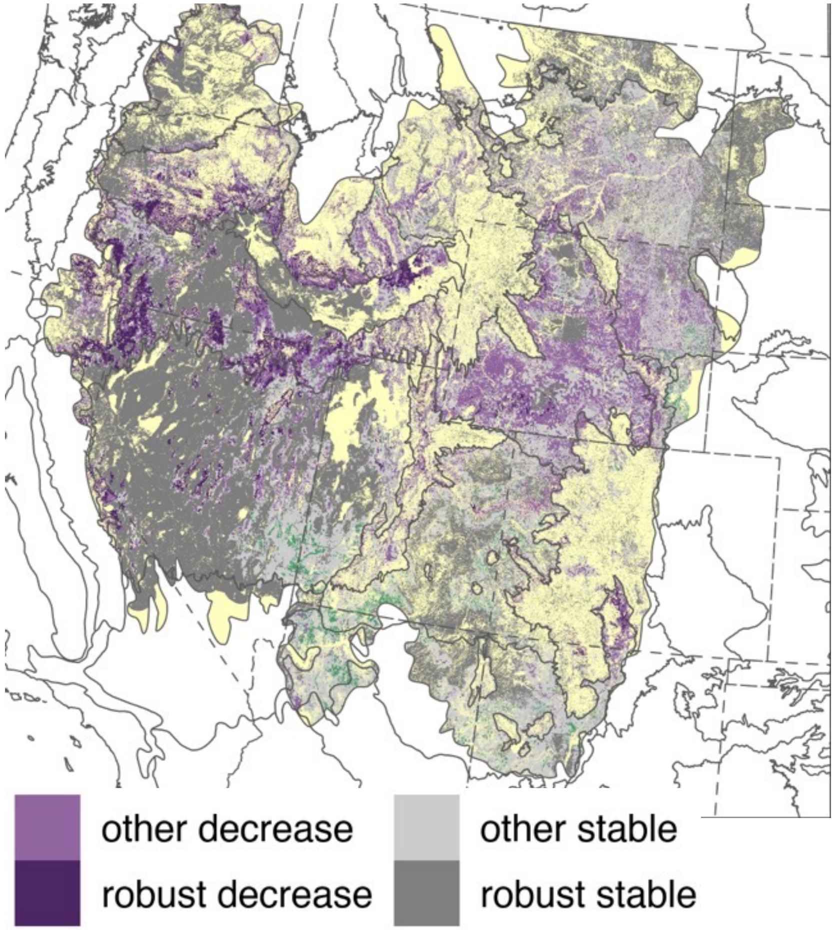
Schlaepfer et al. (2025) Ecological Applications

Ecological resilience & resistance to cheatgrass

- Most of the area that is historically Low remains Low (gray)
- Other categories either decreased (purple) or remained the same (gray)
- The Moderate R&R category had the most widespread decreases (particularly WY & MT)

→ Climate change amplifies restoration challenge

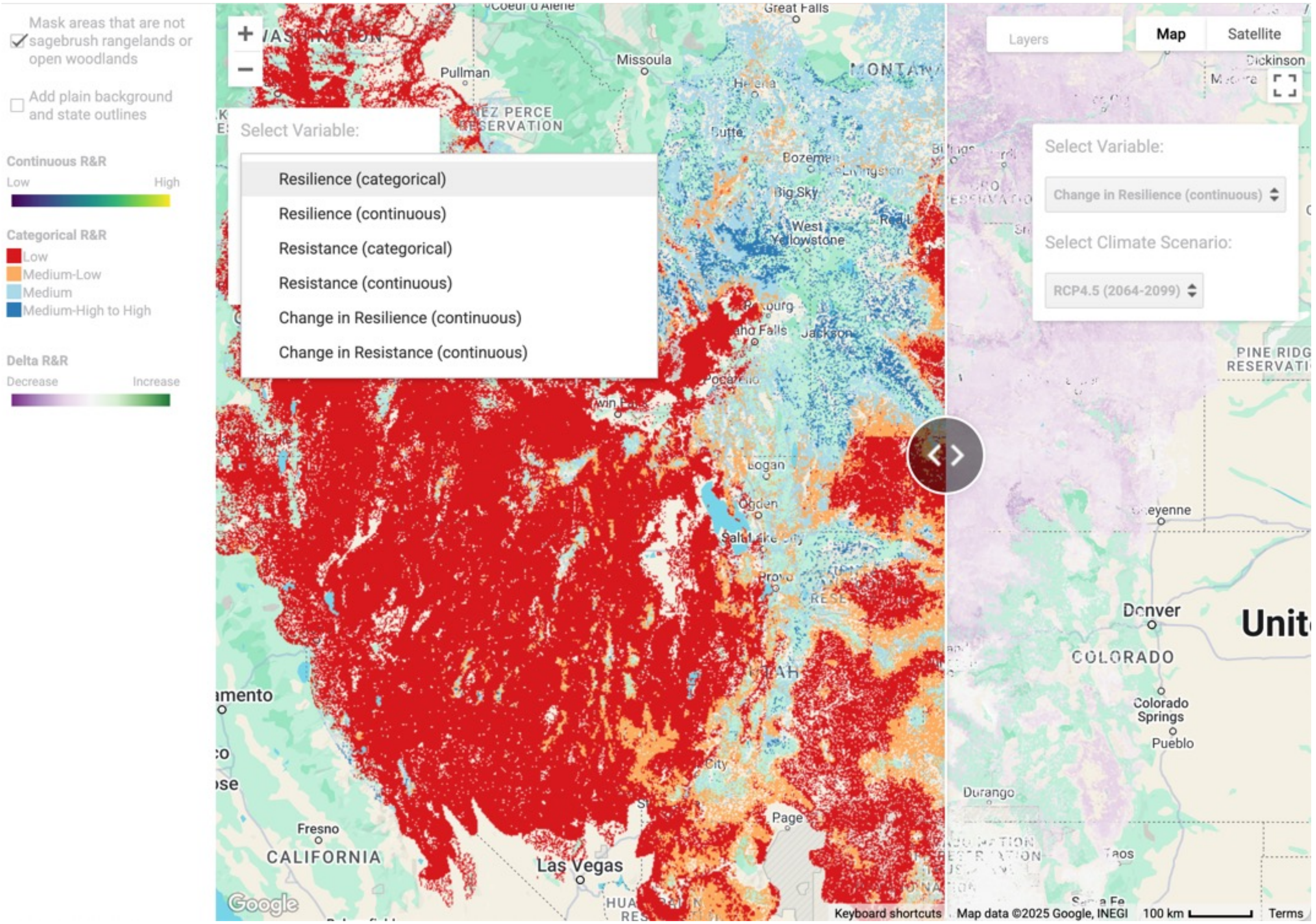
Projected change



Schlaepfer et al. (2025) Ecological Applications

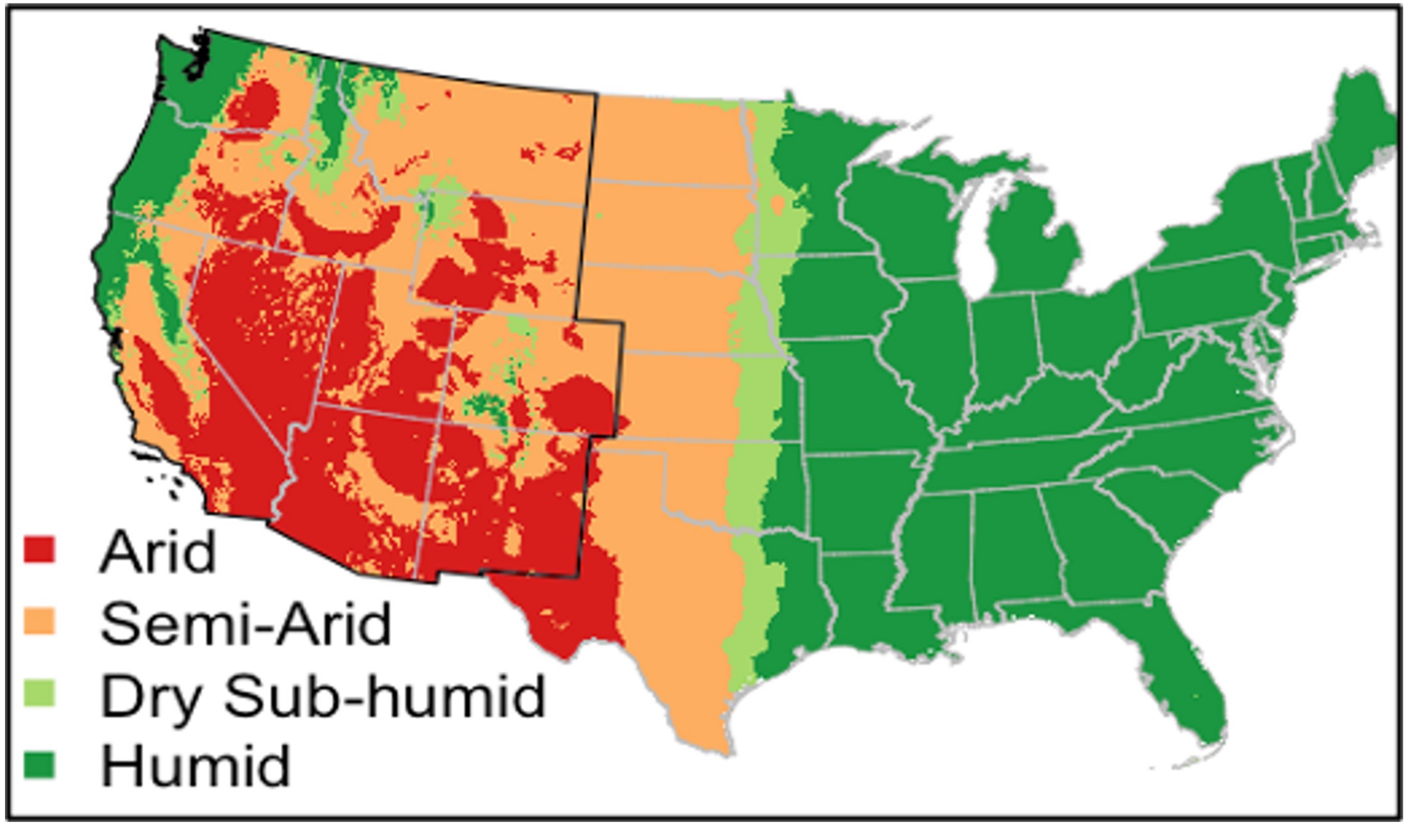
Ecological resilience & resistance to cheatgrass

- Schlaepfer et al. 2024 ScienceBase (DOI: 10.5066/P928Y2GF)
- https://ee-martinholdrege.projects.earthengine.app/view/futurerr



Next steps: Projection of long-term soil moisture and ecological drought

- Extent and time
    - CONUS (4/10-km gridMET/MACA grid)
    - Historical and future 1980-2100
- Dataset
    - Daily soil moisture for multiple soil depths
    - Ecological drought metrics
- Data dissemination via Climate Toolbox
- Funded by USGS CASC



- Ecological metrics to inform long-term management decisions (e.g., Chenoweth et al. 2023)
    - Sensitive to climate change
    - Overall conditions
    - Seasonal variability
    - Seasonal timing
    - Drought characteristics

- What information related to future ecological drought would be useful for you?

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Implications for sagebrush plant communities (Martin)

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Coping with uncertainty to support adaptation investments (John)

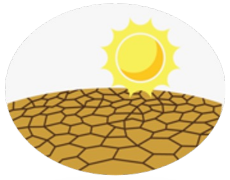
Modeling Framework

Soil Moisture

Daily Weather

Soil Properties

Biomass
Root depth

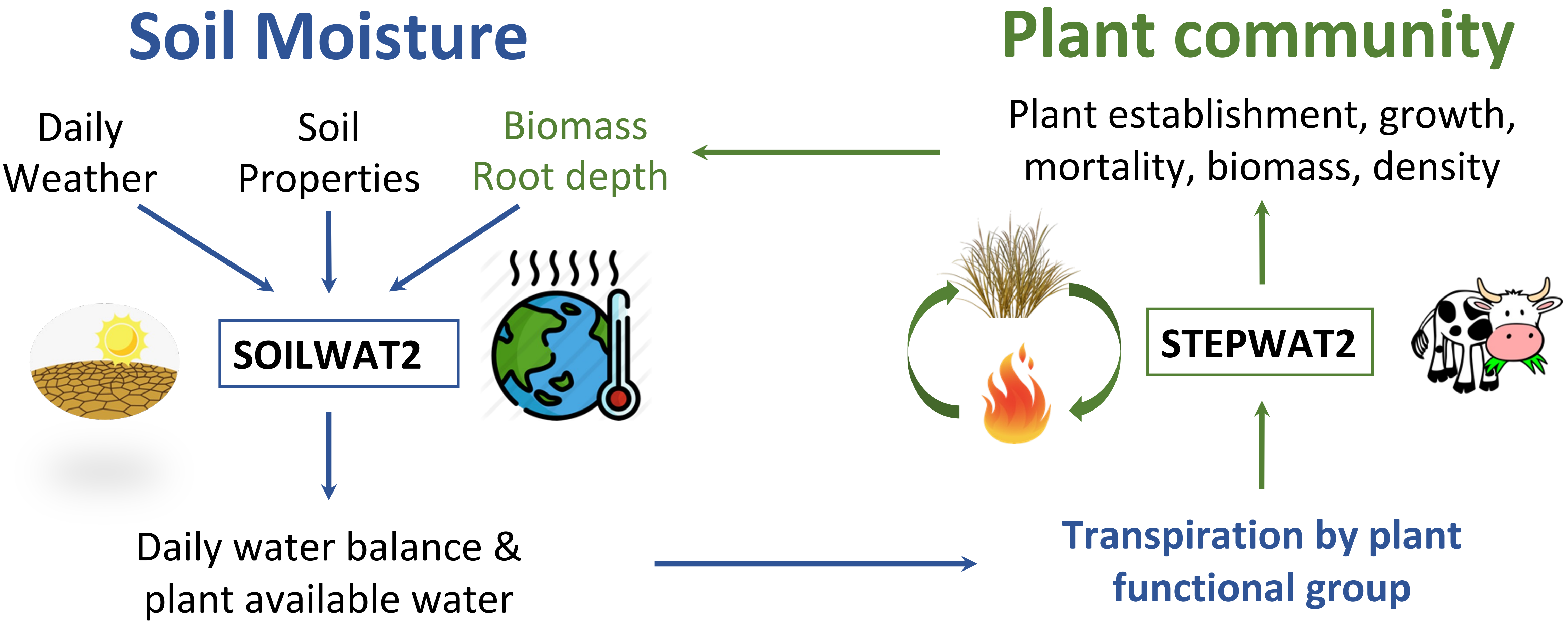


SOILWAT2

Daily water balance &
plant available water

Bradford et al. 2014, Bradford et al. 2020

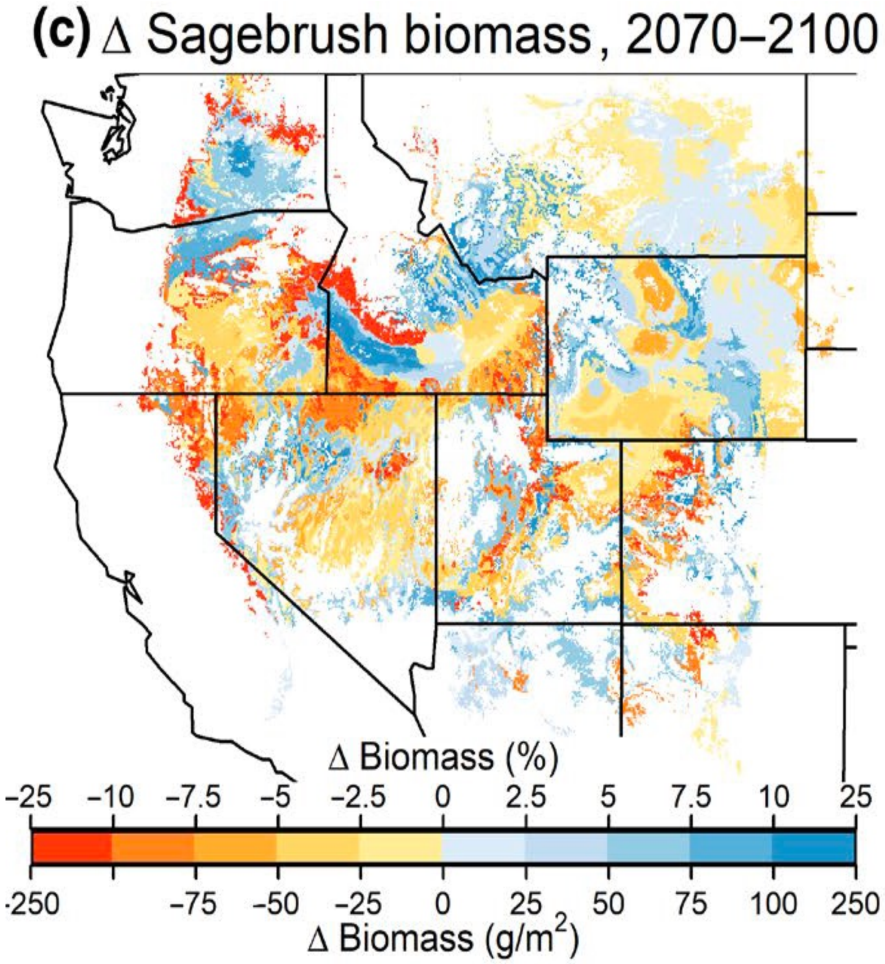
Modeling Framework



Bradford et al. 2014, Bradford et al. 2020

Palmquist et al. 2018, Holdrege et al. 2024a

Climate change implications for **Sagebrush**

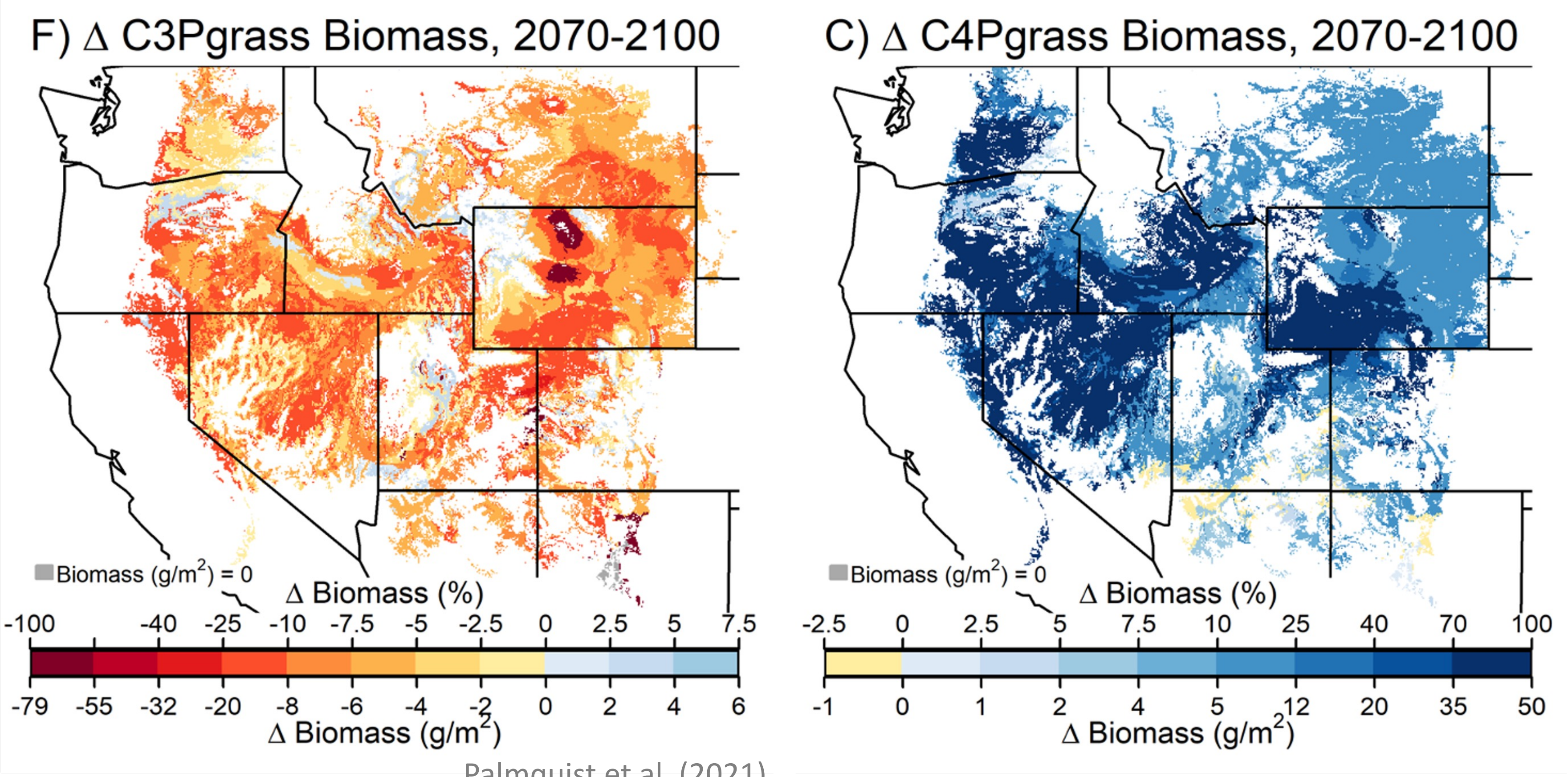


Palmquist et al. (2021)

- Big sagebrush likely to remain climatically viable within much of the biome
- Potential declines in some areas

(Schlaepfer et al 2011, Still & Richardson 2015, Renwick et al. 2018)

Climate change implications for **Perennial Grasses**



Palmquist et al. (2021)

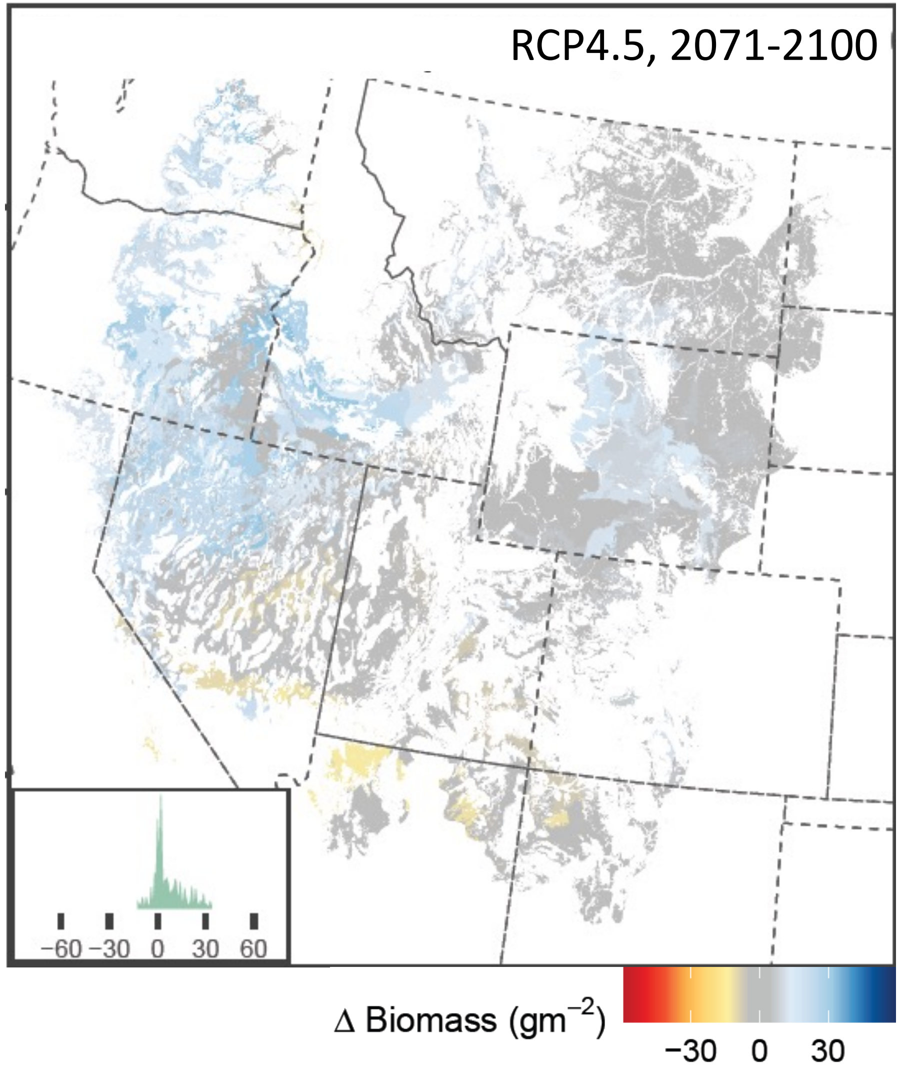
Future temperatures more consistent with warm-season (C4) perennial grasses than cool season (C3) perennials (Havrilla et al. 2023)

Cool season grasses may decline and warm season grasses *might* increase (Palmquist 2021)

Climate change implications for **Cheatgrass**

- Historical trend of cheatgrass invasion is very likely to continue
- Projected increases wildfire frequency (at least in many areas) likely to exacerbate cheatgrass invasion problems

Change in Cheatgrass biomass

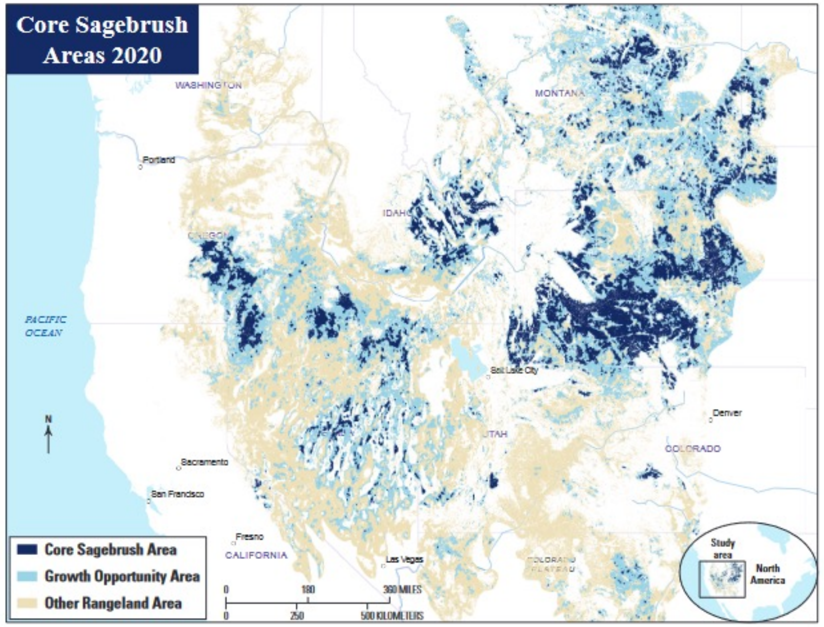


Sagebrush Ecological Integrity

USGS
science for a changing world

Prepared in cooperation with the Western Association of Fish and Wildlife Agencies and the U.S. Fish and Wildlife Service

A Sagebrush Conservation Design to Proactively Restore America's Sagebrush Biome



Open-File Report 2022–1081

U.S. Department of the Interior
U.S. Geological Survey

Doherty et al. (2022)

The Sagebrush Conservation Design helps identify intact sagebrush areas, and primary threats to the ecosystem

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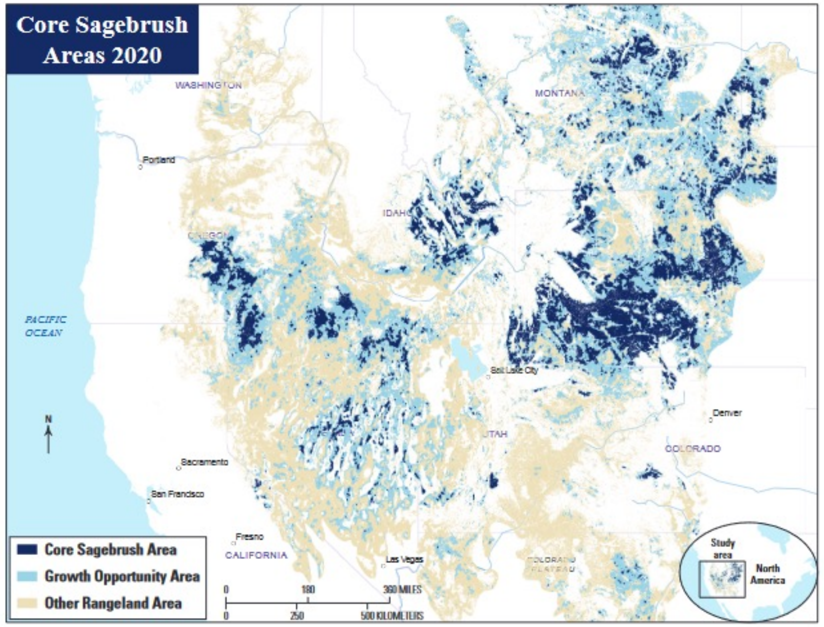


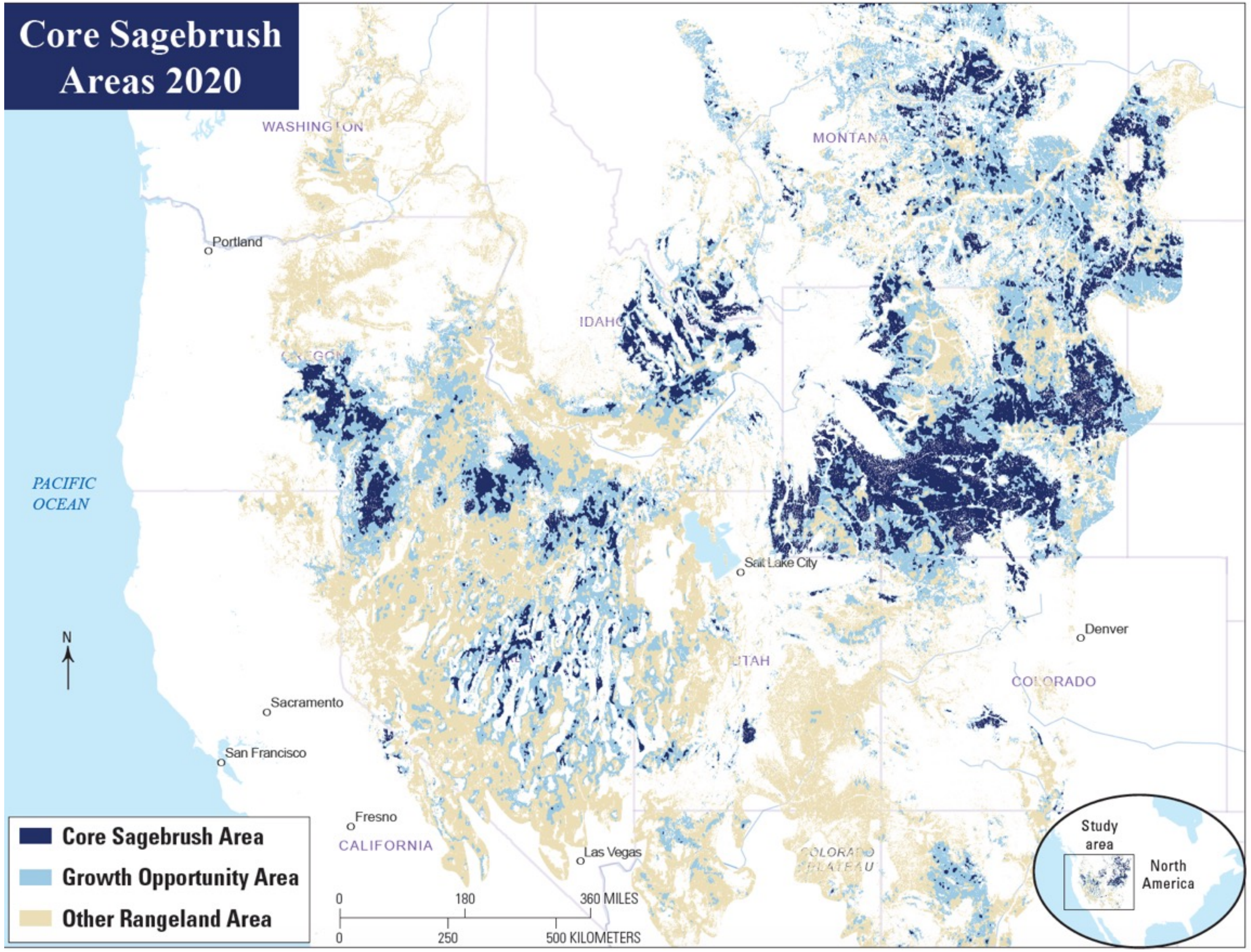
Open-File Report 2022–1081

U.S. Department of the Interior
U.S. Geological Survey

Doherty et al. (2022)

SEI ~ Sagebrush (+), Perennial grasses (+), Annual grasses (-), Conifers (-), Human modification (-)

Sagebrush Ecological Integrity



Doherty et al. (2022)

High SEI: Core Sagebrush Area (CSA)

Intermediate SEI: Growth Opportunity Area (GOA)

Low SEI: Other Rangeland Area (ORA)

Sagebrush Ecological Integrity

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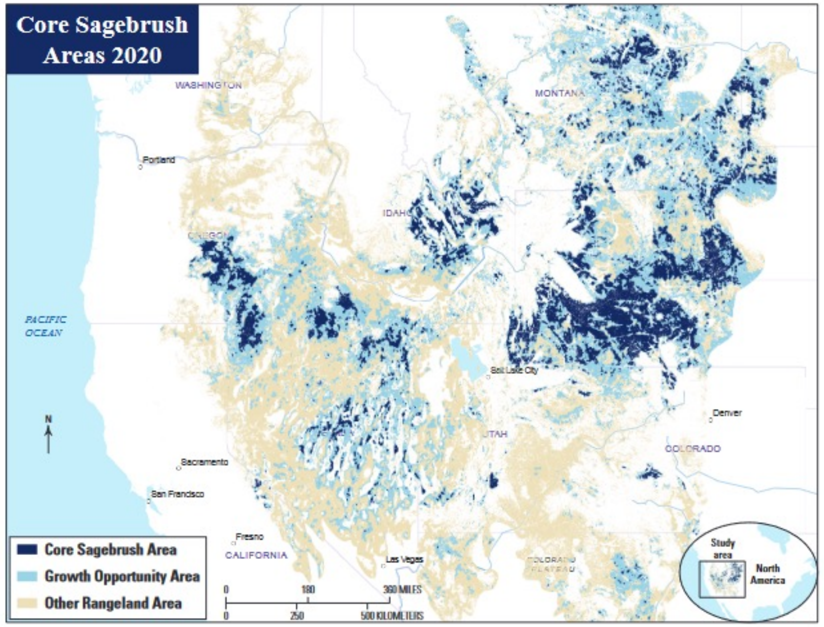

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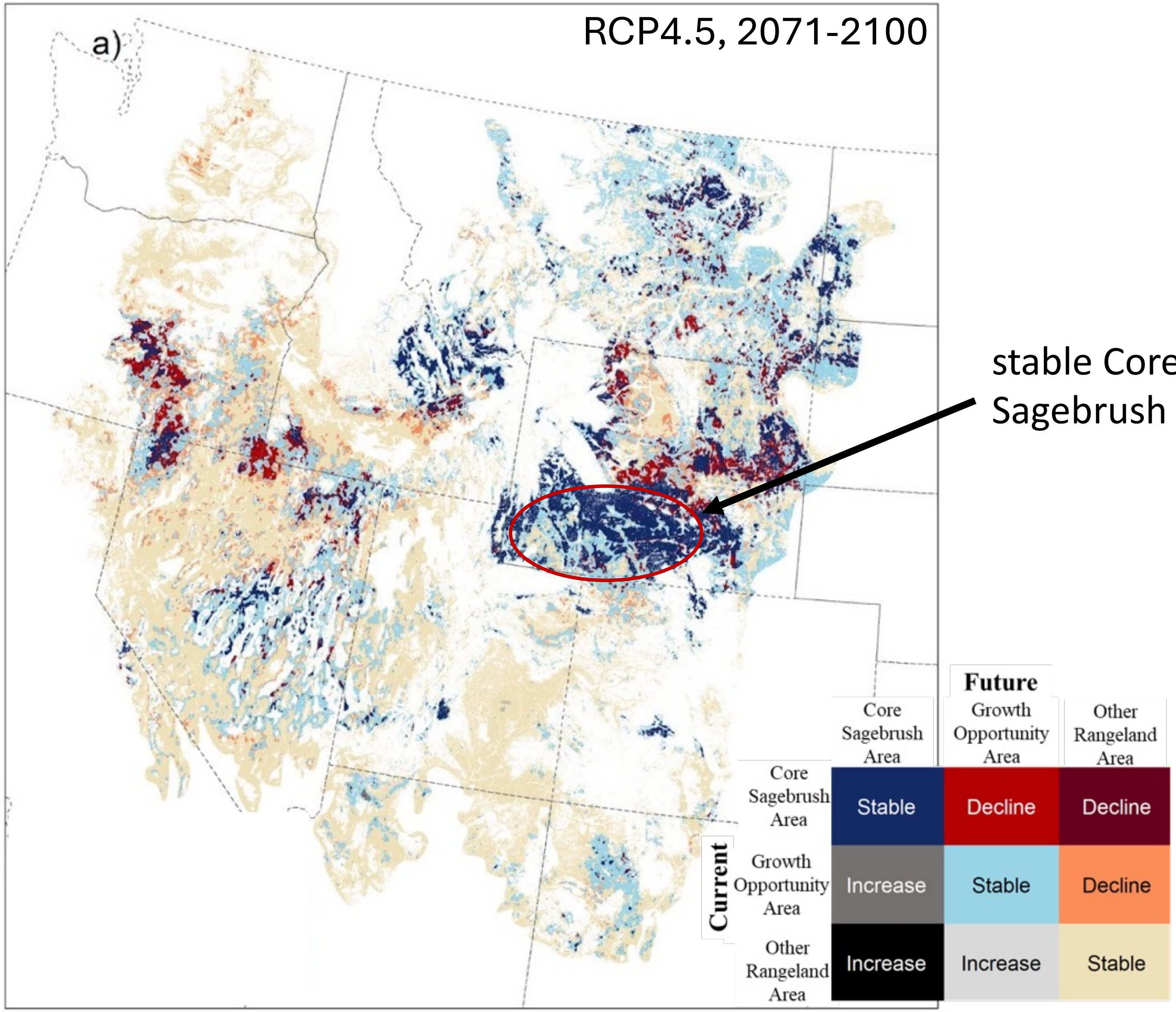
Future SEI ~ Sagebrush * Δ (+), Perennial grasses * Δ (+), Annual grasses * Δ (-), Conifers (-), Human modification (-)

(Δ = simulated change in cover from STEPWAT2)

Projected changes in SEI class

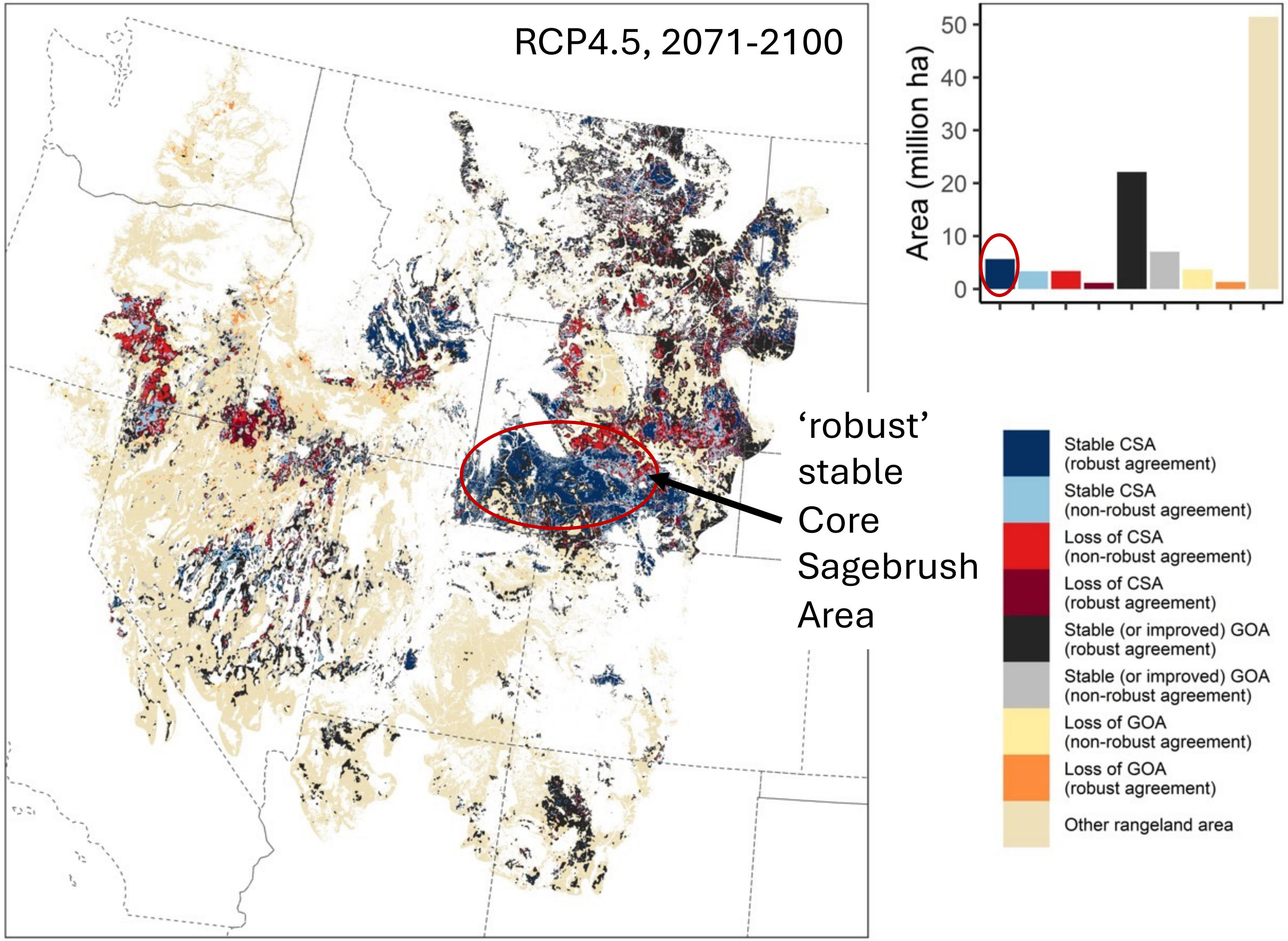


stable Core Sagebrush Area

Holdrege et al. (2024)

How will the abundance of sagebrush ecological integrity classes change in the future?

Climate uncertainty in our projections



How consistent are these changes across climate scenarios?

Holdrege et al. (2024)

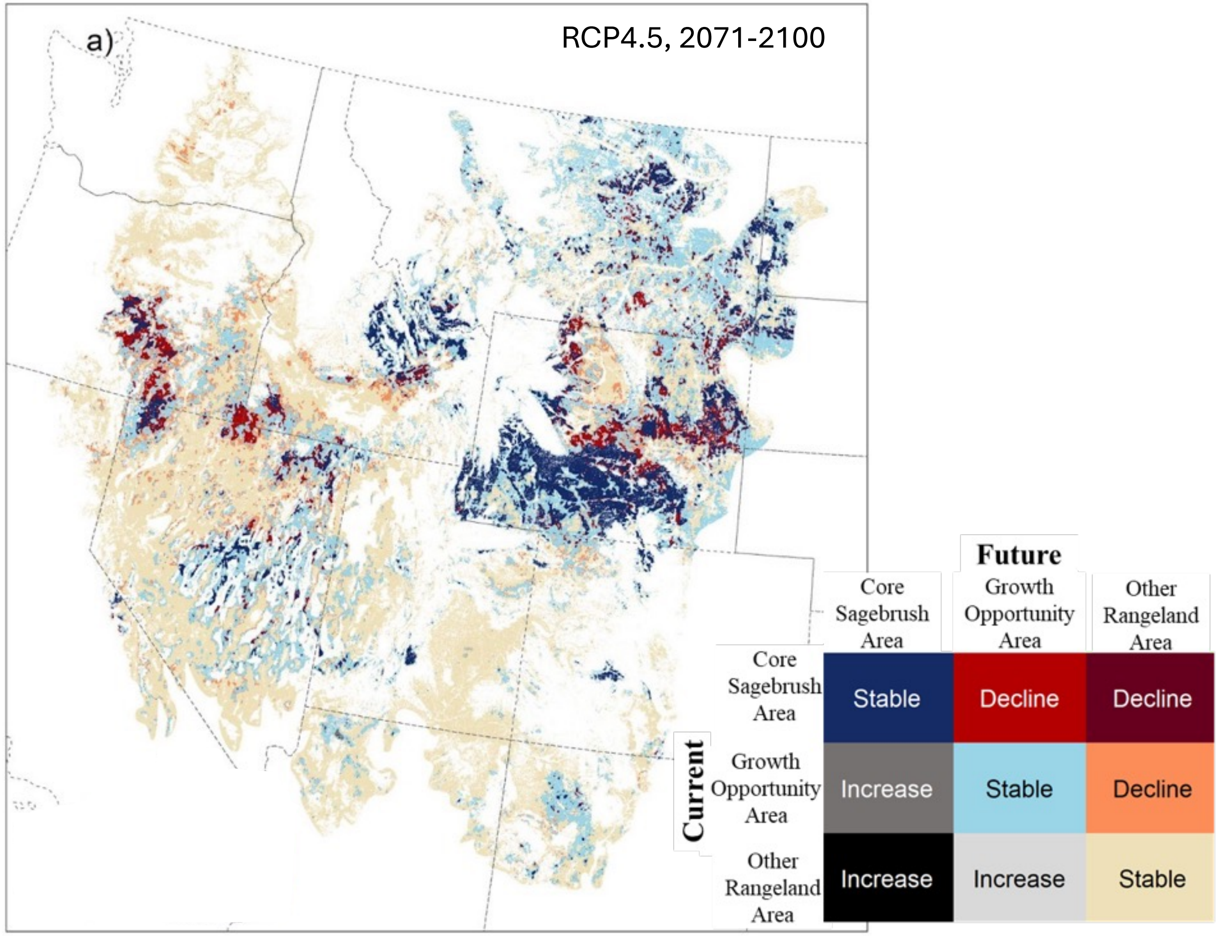
Main findings: Climate impacts on sagebrush ecological integrity

- ~2/3 of Core Sagebrush Areas are projected to **remain climatically suitable** to stay Core (RCP4.5, 2071-2100)

- **Loss of Core** driven by projected decreases in sagebrush and/or increases in annuals

- Substantial **variability among climate scenarios**, time-periods, and global climate models, but general trends are similar

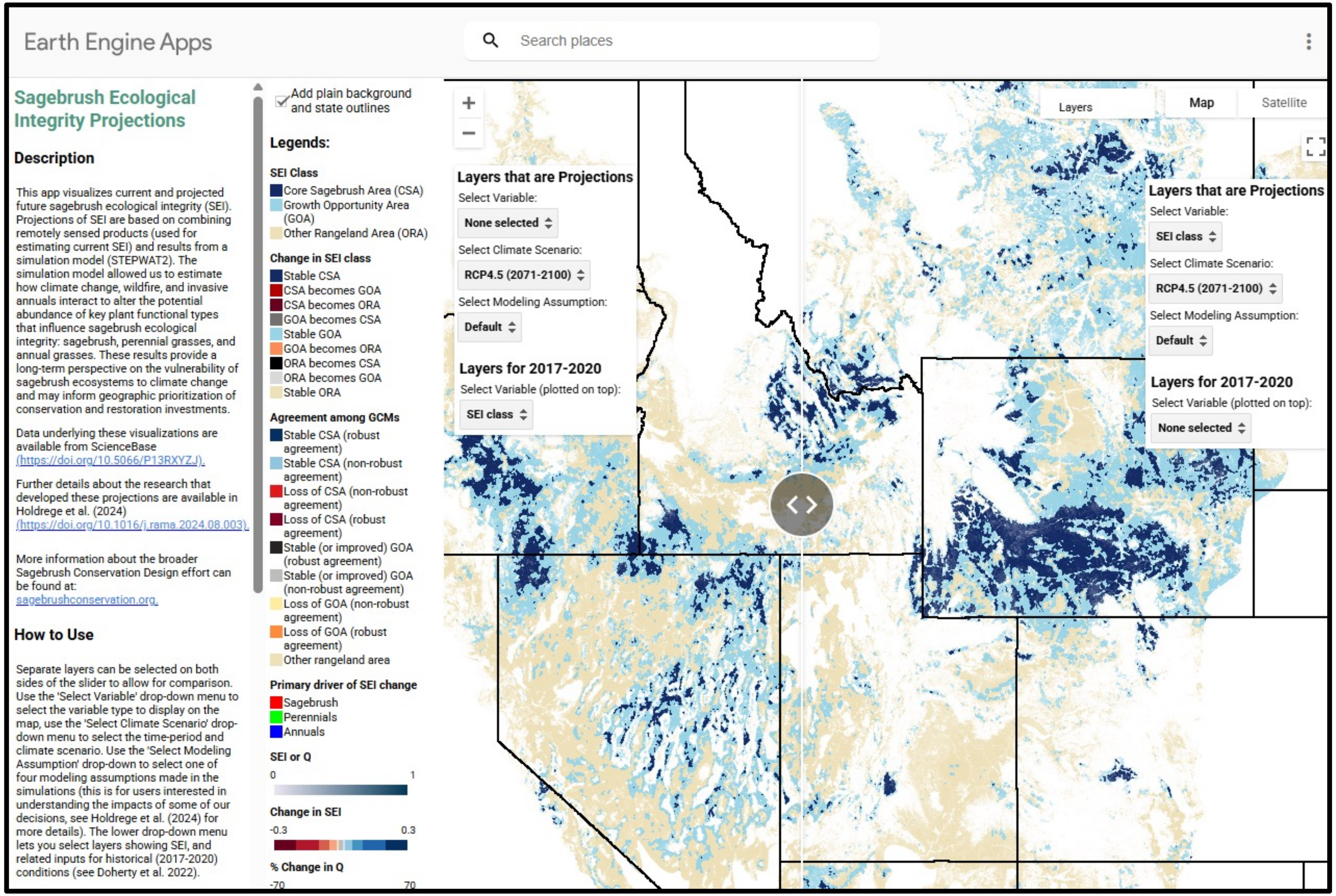
Projected Change



Publication: Holdrege et al. 2024, Rangeland Ecology & Management (https://doi.org/10.1016/j.rama.2024.08.003)
Data Release: https://doi.org/10.5066/P13RXYZJ

Web-app for visualizing these results

https://ee-martinholdrege.projects.earthengine.app/view/futuresei

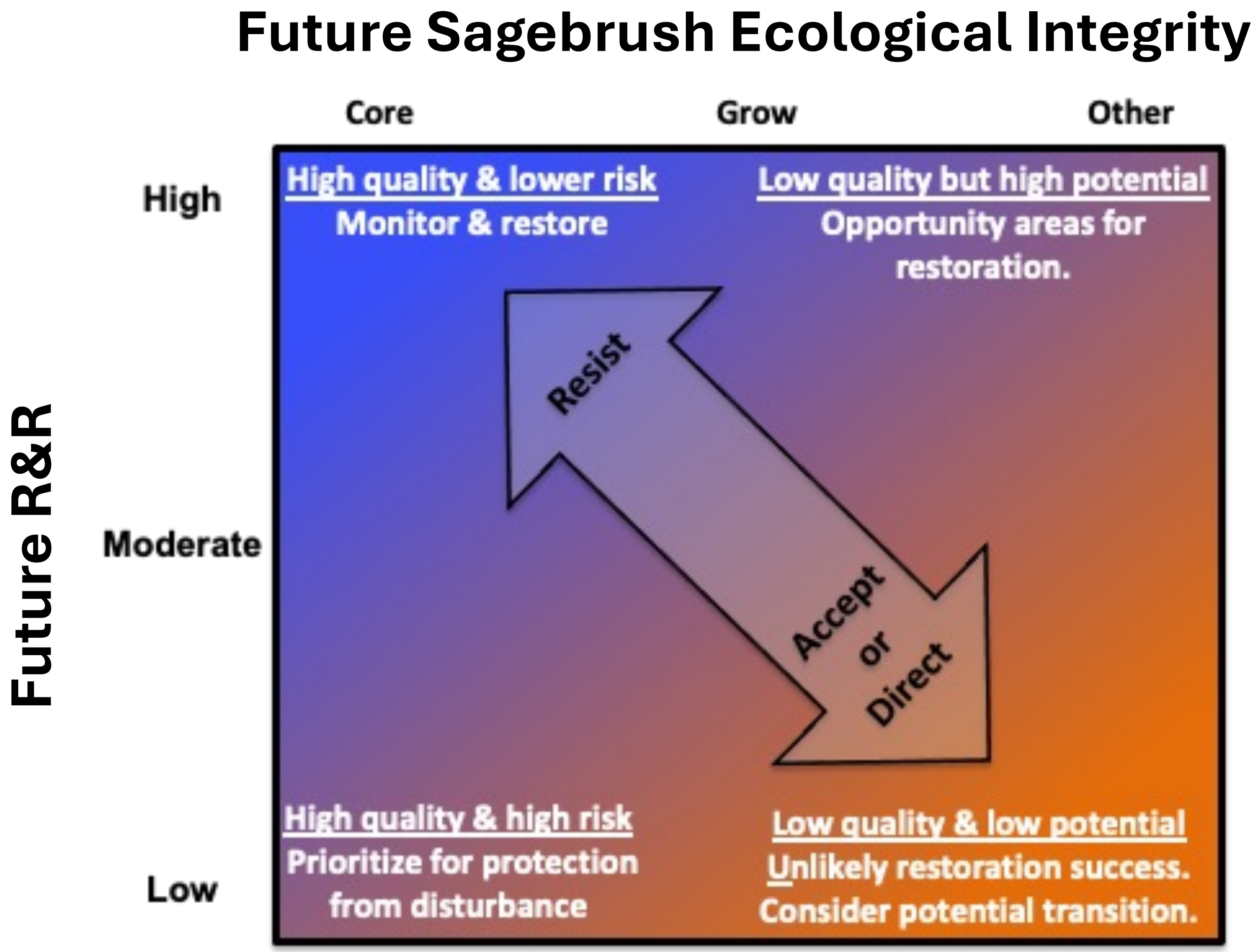


Compare:

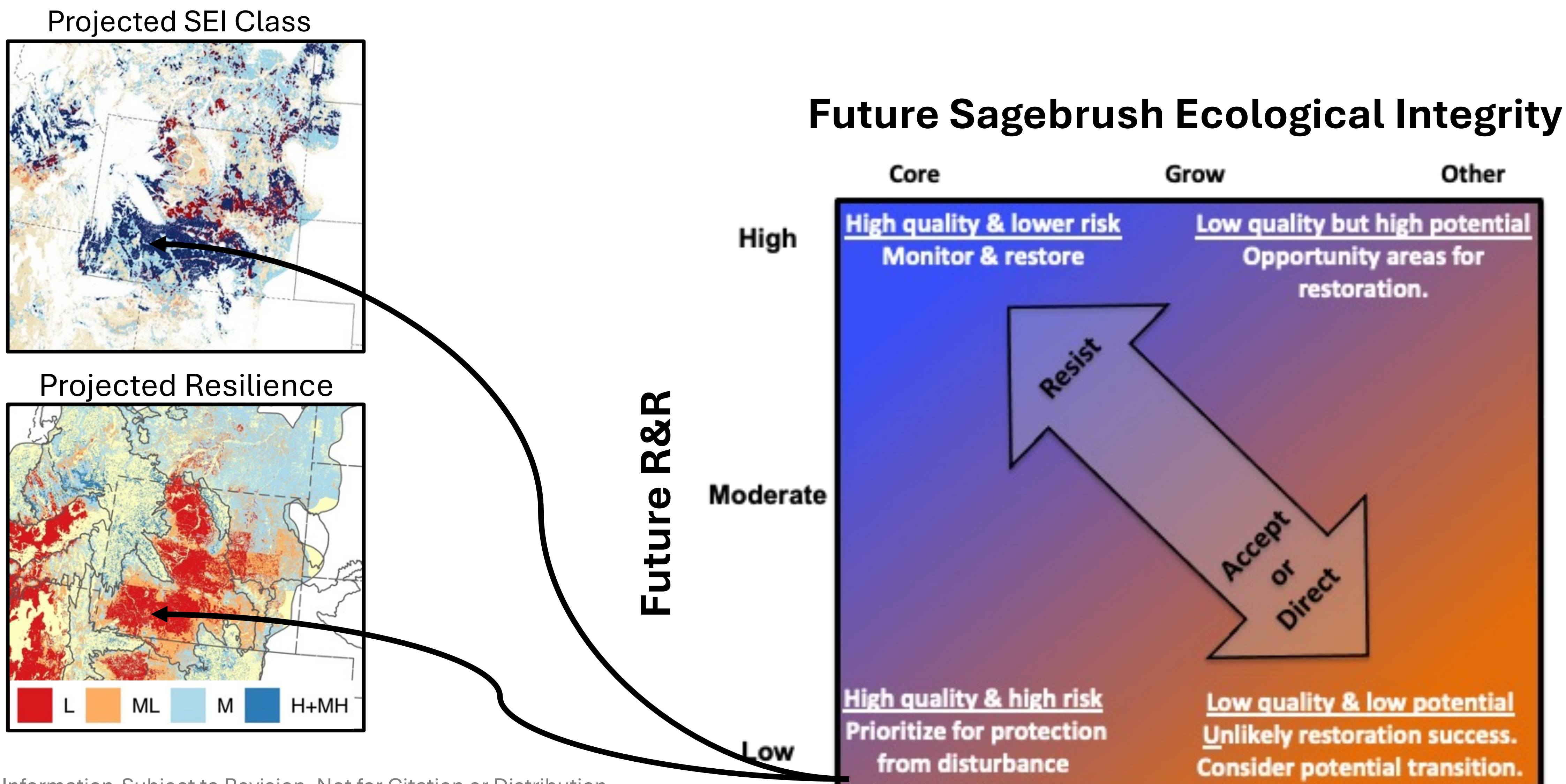
- Response variables
- Climate-scenarios
- Modeling assumptions

Next steps: Combining SCD & R&R datasets

Combining future Sagebrush Ecological Integrity and R&R to inform prioritization of conservation and restoration actions



Next steps: Combining SCD & R&R datasets



Next steps: Interactions between grazing intensity, wildfire and climate change

Grazing sustainability

- How will the **sustainability of grazing** change with climate change?
- Can altering grazing intensity **mitigate climate induced vegetation changes and wildfire**?

Targeted grazing to minimize cheatgrass

- What do we know about the **effectiveness of targeted grazing** of cheatgrass?
- Can grazing be used as a tool to mitigate **cheatgrass-fire-cycle under climate change**

(Project lead by Kyle Palmquist, Marshall U.)

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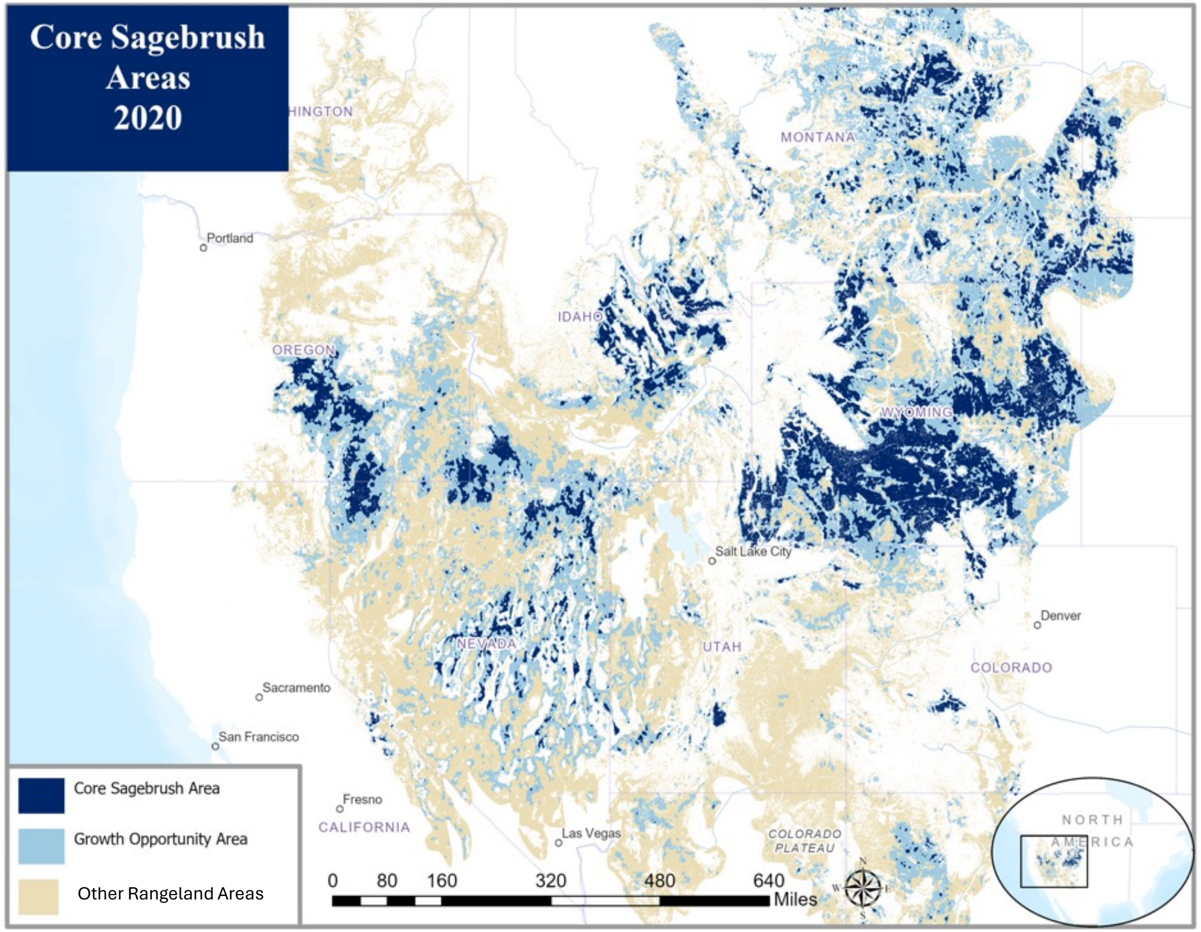
Coping with uncertainty to support adaptation investments (John)

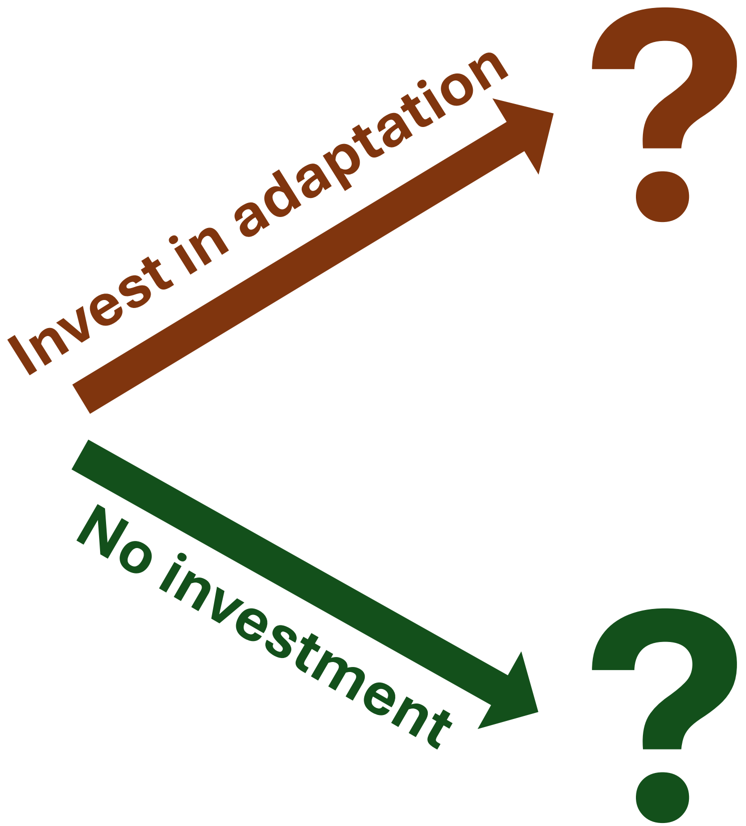
A looming challenge: assess the wholistic impacts of climate adaptation investments

Current



Doherty et al. (2022)

Future



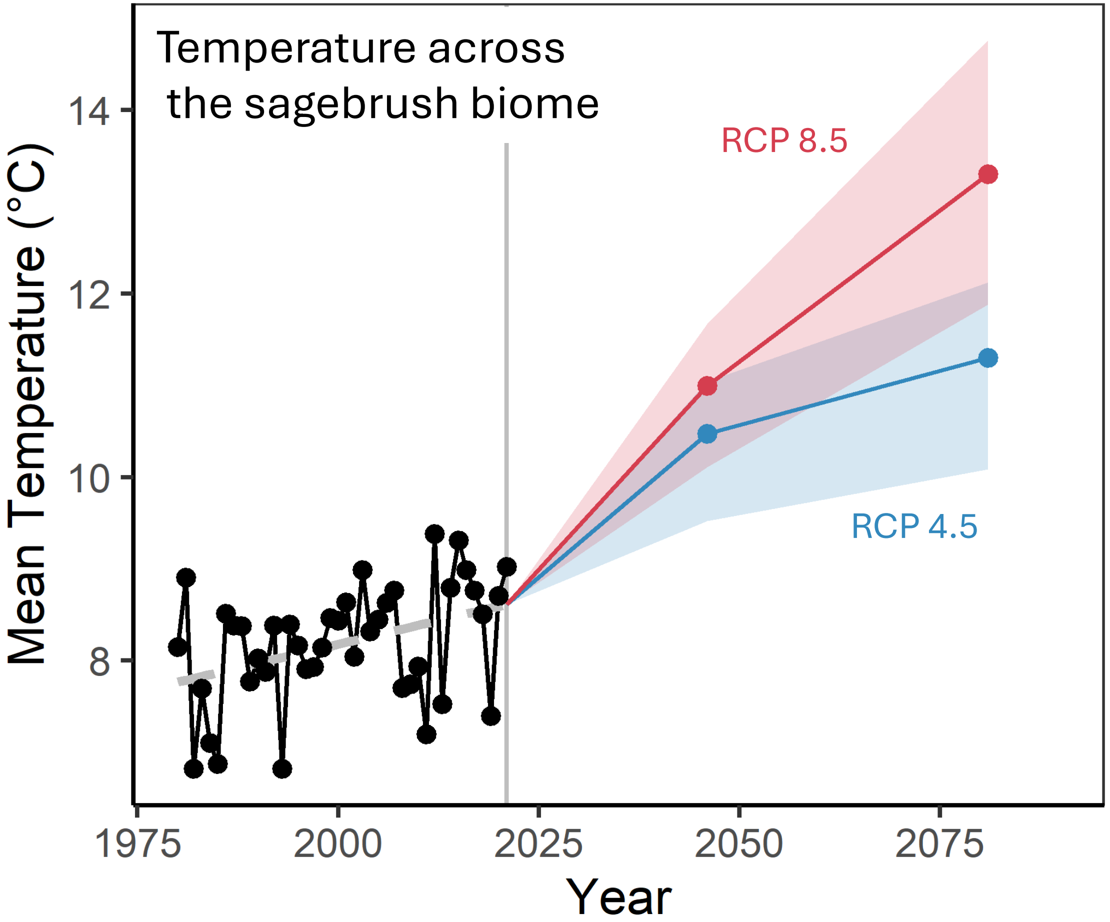
Sources of uncertainty in climate adaptation

Climate uncertainty → **Ecological uncertainty** → **Management effectiveness uncertainty**

Photo: John Gordon Ross, USGS

Photo: Bureau of Land Management

Climate uncertainty → Ecological uncertainty → Management effectiveness uncertainty



Based on data from Abatzoglou (2013) and Abatzoglou and Brown (2012)

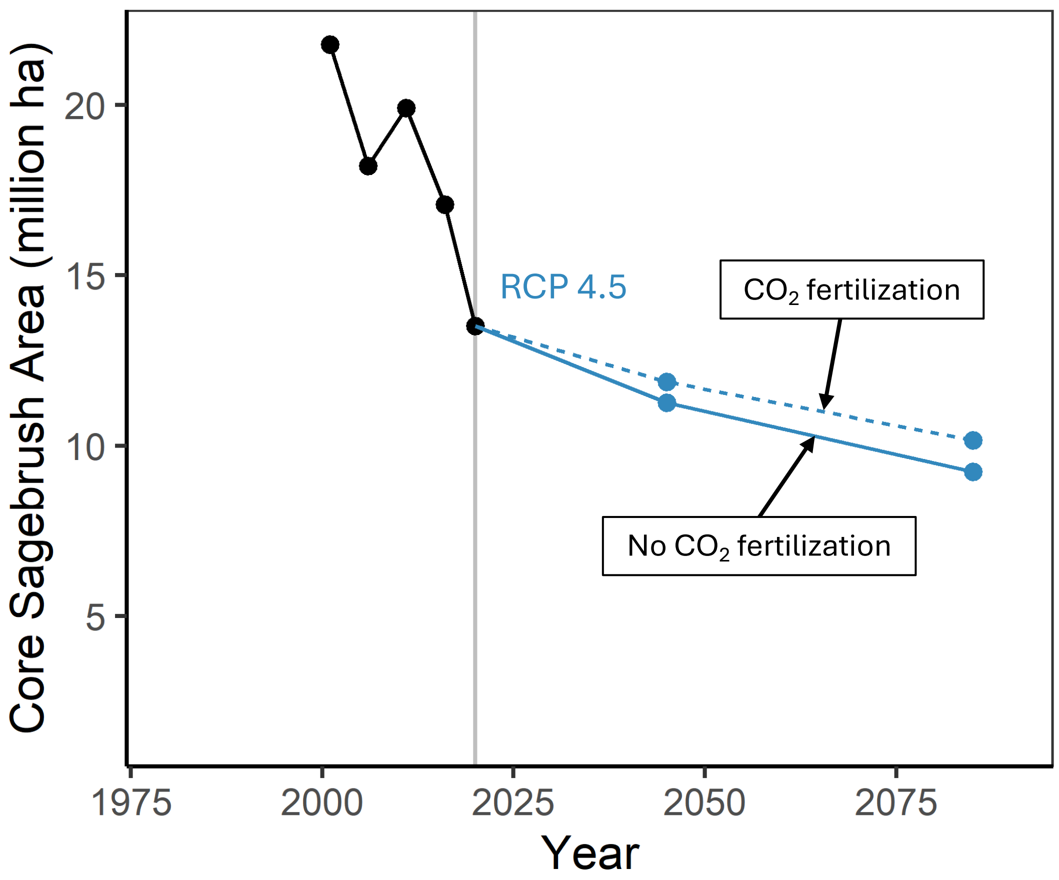
Uncertainty in how the <u>climate</u> will respond to a given amount of forcing

Partially captured by comparing scenarios & climate models

Relatively well recognized and often well addressed

Climate uncertainty → **Ecological uncertainty** → **Management effectiveness uncertainty**

Historical and projected Core Sagebrush Area



Based on data from Holdrege et al. (2024) and Doherty et al. (2022)

Uncertainty in how <u>ecosystem</u> will response to altered climate.

Often not well estimated

We considered uncertainty from some ecological processes (e.g., CO_2 fertilization might moderate ~ 15% of core losses).

We really need multiple ecological models!

Climate uncertainty → Ecological uncertainty → **Management effectiveness uncertainty**

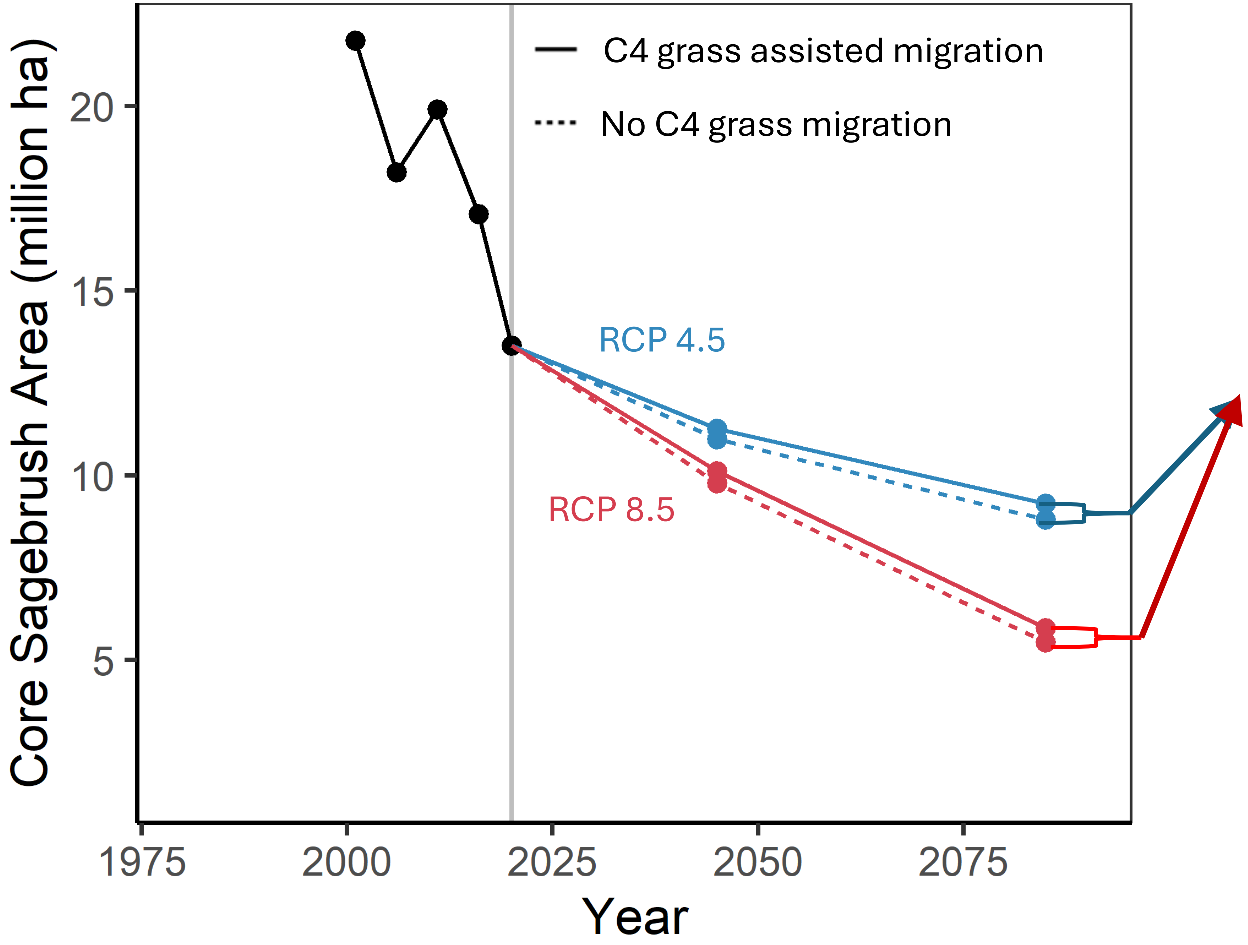

Photo: Bureau of Land Management

Uncertainty about how ecosystem services will respond to management actions.

Rarely considered

In sagebrush ecosystems, these management actions might be fire suppression, post-fire restoration, invasive treatments, etc.

Climate uncertainty → Ecological uncertainty → **Management effectiveness uncertainty**



Based on data from Holdrege et al. (2024) and Doherty et al. (2022)

One example of management action might be assisted relocation of plant species.

Loss of Core Sagebrush is reduced by ~9% if we enable C_4 grass expansion (regardless of climate uncertainty)

These results could be integrated into a cost-benefit analysis of climate adaptation investments

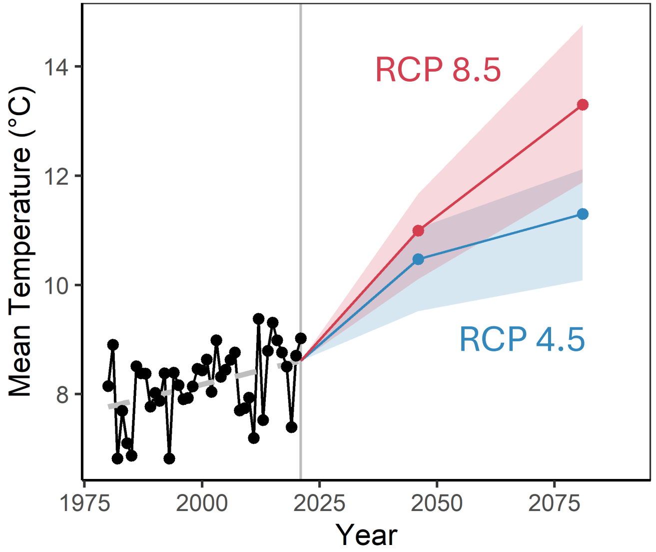
- **Costs of C_4 grass assisted migration**

  vs.

- **Benefits of protecting that Core habitat**

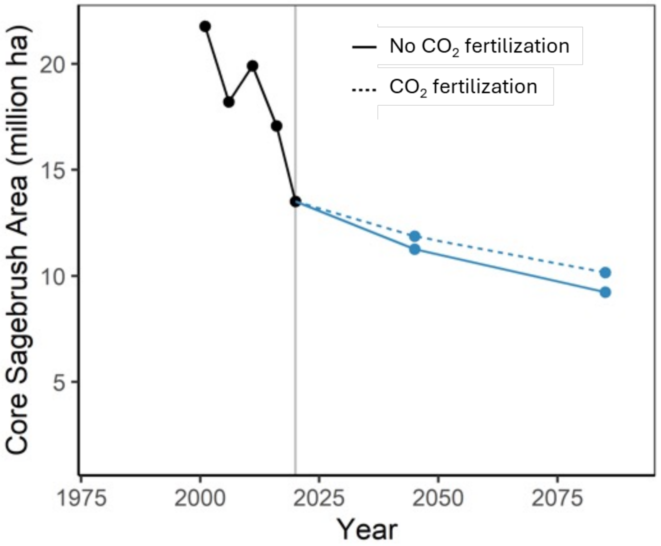
Informing adaptation decisions requires understanding all these sources of uncertainty

Climate uncertainty



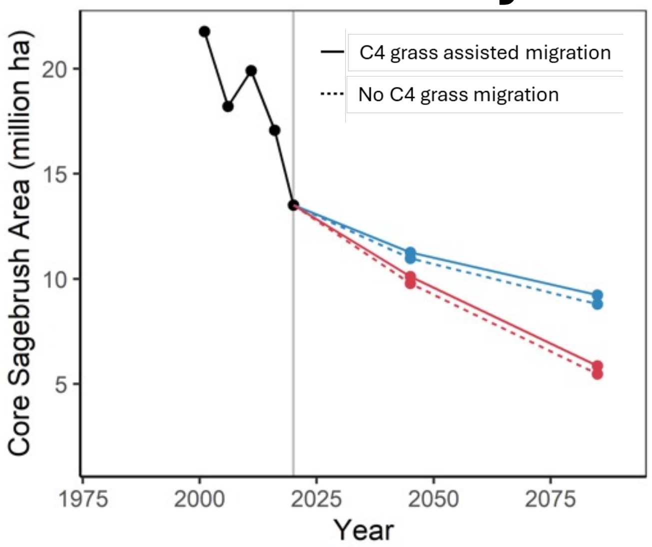
Based on data from Abatzoglou (2013) and Abatzoglou and Brown (2012)

Ecological uncertainty



Based on data from Holdrege et al. (2024) and Doherty et al. (2022)

Management effectiveness uncertainty



Based on data from Holdrege et al. (2024) and Doherty et al. (2022)

Take-home messages

Drought impacts in the northcentral region:

- NC may be relatively well positioned to maintain seasonal soil moisture patterns
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- NC region supports some of the most climate resilient high quality sagebrush habitat
- However, rising temperatures are also expected to decrease R&R in most of the NC region

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Considering uncertainty in climate, ecology and management effectiveness may help build the case for sustained adaptation investments

More information in upcoming document:

Climate change impacts on big sagebrush vegetation: a science synthesis to inform BLM resource management.

Climate projections for the sagebrush region

- Increases in annual temperatures and CO_2 along with seasonal shifts in precipitation
- Higher probability of extreme weather events (for example, droughts, heat waves, and storms)

Synthesis of climate change impacts on sagebrush plant communities

Data sources	Individual plants	Plant communities
Field studies	**1. Species and functional type responses** • Big sagebrush is resistant to most shifts in temperature and precipitation • Drought will have immediate effects on bunchgrasses and high-intensity drought could induce sagebrush mortality	**3. Plant community responses** • Identified five potential respontial response types • Intermountain communities may become more stable under projected shifts • Low elevation and southern communities at risk for invasion and increasing bare ground
Modeling	**2. Species distribution models** • Big sagebrush models show potential range expansion in north and contraction in the south • C_4 grasses are likely to expand north with increased temperatures • Little information about forb responses	**4. Region-wide effects** • Core areas identified by Doherty and others (2022) are relatively stable. • Forage species including C_3 and C_4 bunchgrasses are likely to experience compositional shifts

Key insights

- Relative stability for big sagebrush plant communities in the intermountain part of the region
- Increased threat of invasion in the southern part of the range
- Potential migration into higher elevations as snowmelt occurs earlier in the year

Implications for decisions and land management

Forage, wildfire, habitat management, recreation, and reclamation

Additional resources

Adaptation frameworks, visualizations and data products

Questions?

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Simulation modeling approach — SOILWAT2

- Daily weather
- Soil properties
- Vegetation

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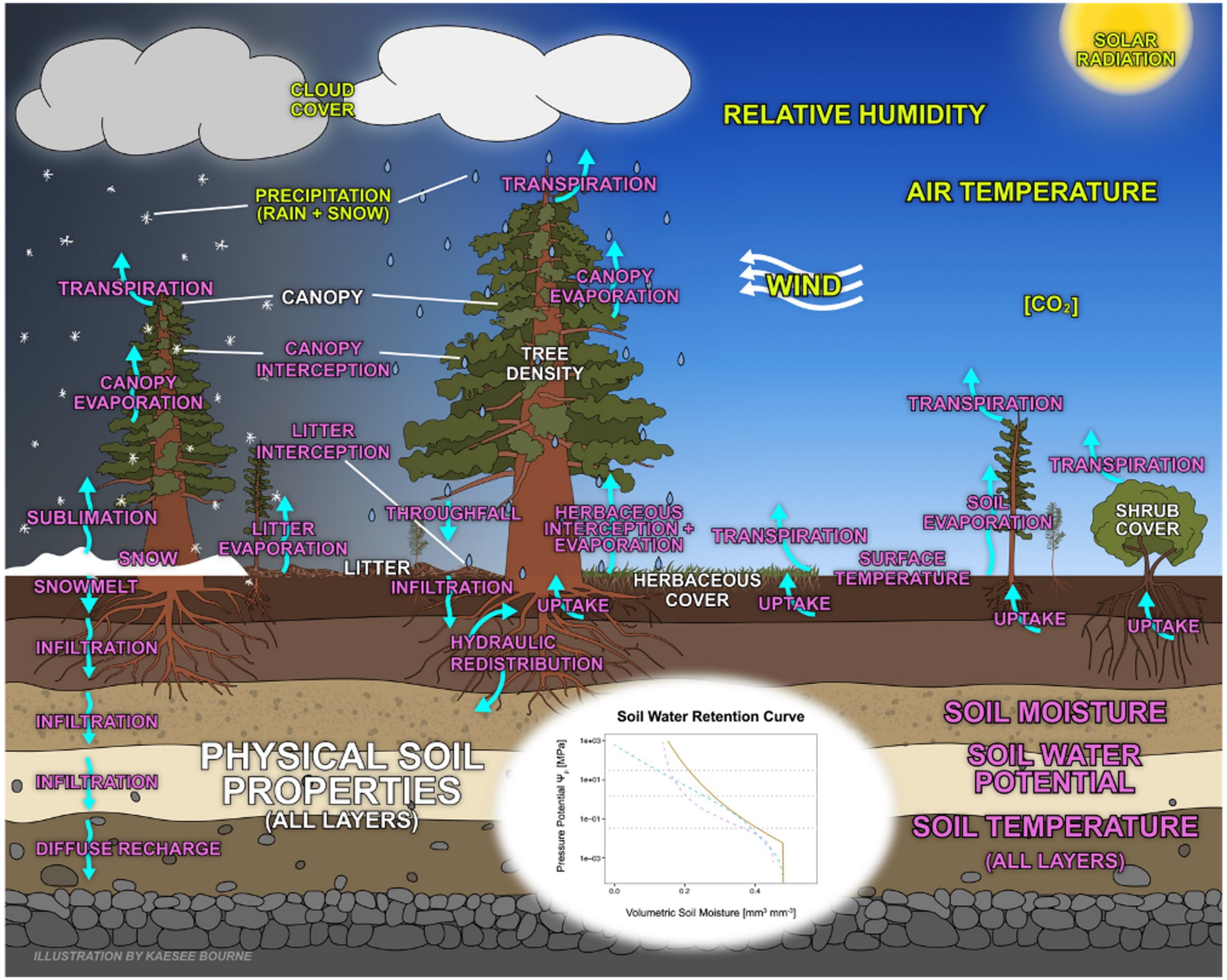

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- Water balance
- Soil moisture
- Ecological drought