



Characterizing Sierra Nevada meadow climate change vulnerability to prioritize conservation and restoration efforts

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Meadows are keystone ecosystems:

- Filtering, storage, delayed release of water from snowpack to streams
- Carbon, nitrogen storage
- Biodiversity hotspots, refugia
- Disproportionately high ecosystem services given their small footprints



Meadows are sensitive to climate change, but sensitivity varies:

- Shorter winter snow cover decreases productivity and soil carbon storage (Arnold et al. 2014)
- Meadow response to drought varies with hydrology and plant functional type (Debinski et al. 2010)
- Water table depth needs vary with soil texture, vegetation phenology, and vegetation hydrologic niche (Loheide et al. 2009, Lowry et al. 2011)
- Changes in minimum winter temperature and snowpack reduce meadow size, but depends on hydrogeology (Drexler et al. 2013)
- Sensitivity to mean annual flow, runoff timing, and periods of low flow varies regionally (Null et al. 2010)

Number of meadows studied:

2

55

1-3

7

15



Managers need regional perspective to:

- Understand relative meadow vulnerability to climate change throughout Sierra Nevada
- Understand hydrologic and geomorphic drivers of vulnerability
- Prioritize use of limited resources for conservation and restoration

Key questions:

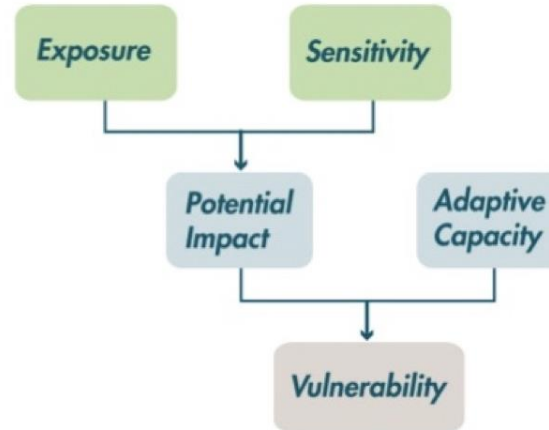
- Which degraded meadows are likely to be climate resilient if restored?
- Which climate resilient meadows may be candidates for conservation as climate refugia?
- Which meadows are vulnerable to climate change and may make less sense to invest in?





Vulnerability assessment framework:

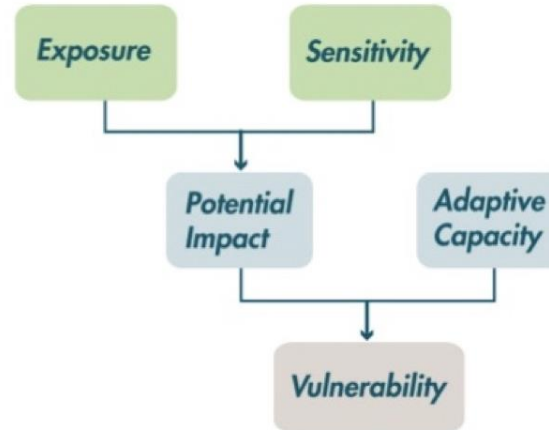
Glick et al. 2011



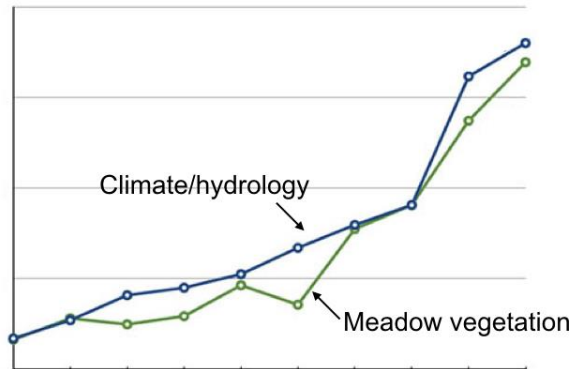


Vulnerability assessment framework:

Glick et al. 2011



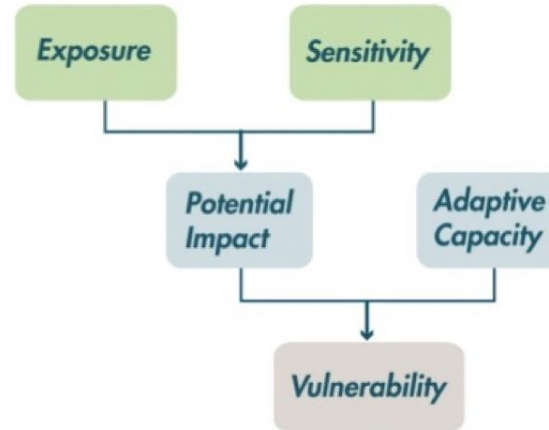
Sensitivity of meadow vegetation to climate



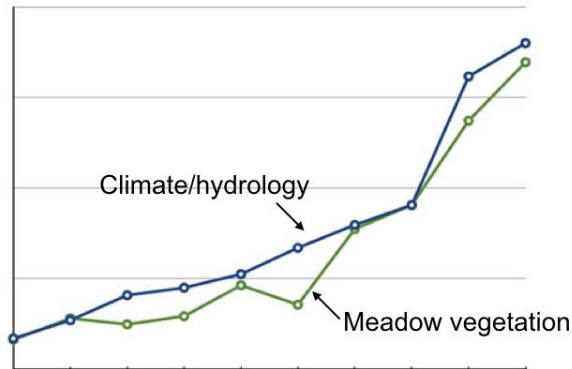


Vulnerability assessment framework:

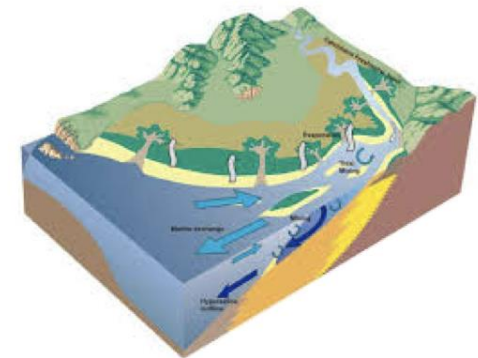
Glick et al. 2011



Sensitivity of meadow vegetation to climate



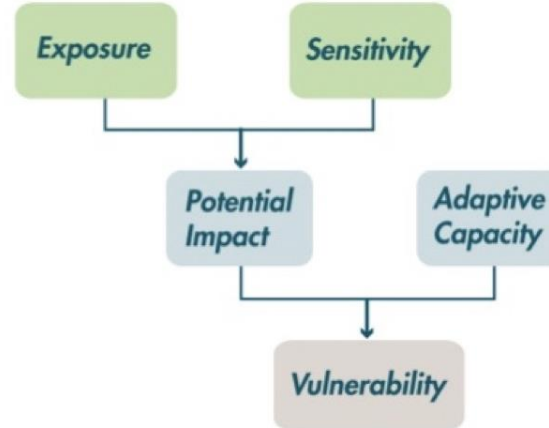
Adaptive capacity conferred by landscape setting/geomorphology



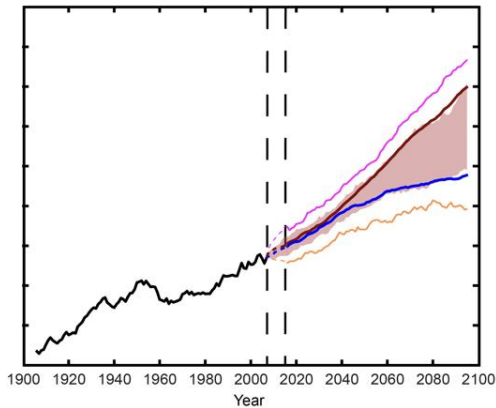


Vulnerability assessment framework:

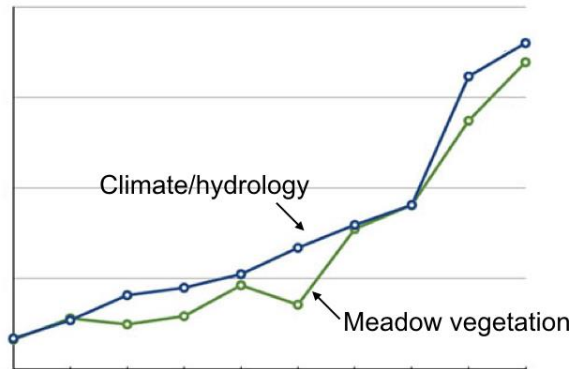
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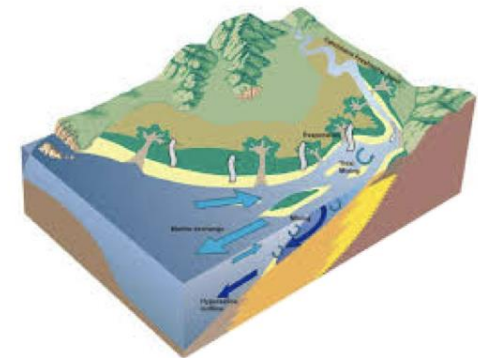
Exposure to future climate change



Sensitivity of meadow vegetation to climate



Adaptive capacity conferred by landscape setting/geomorphology

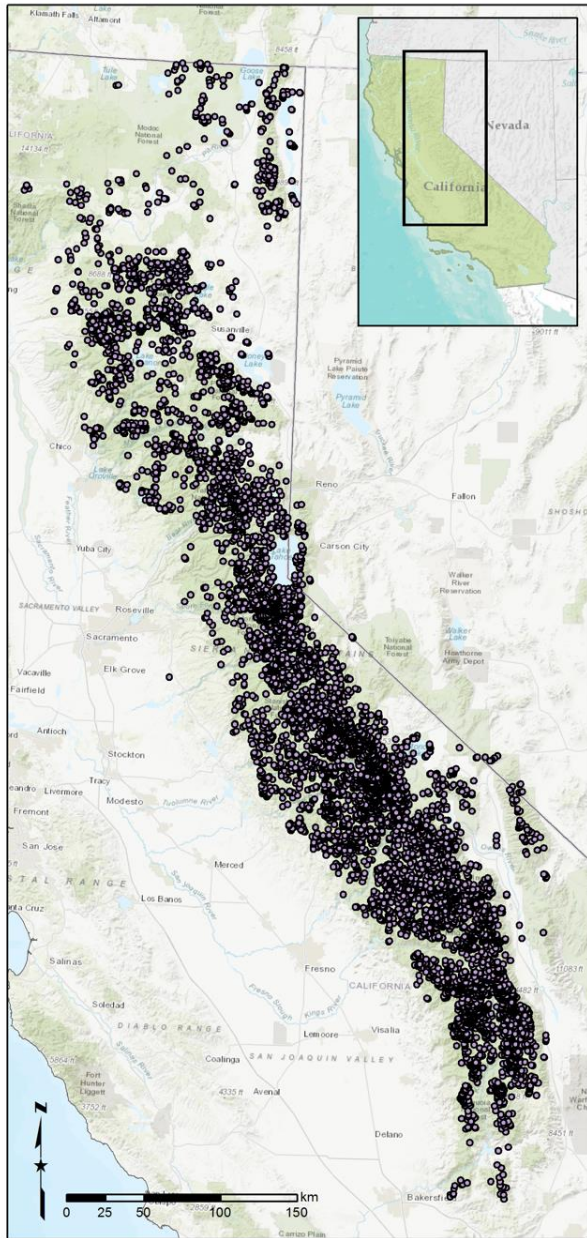




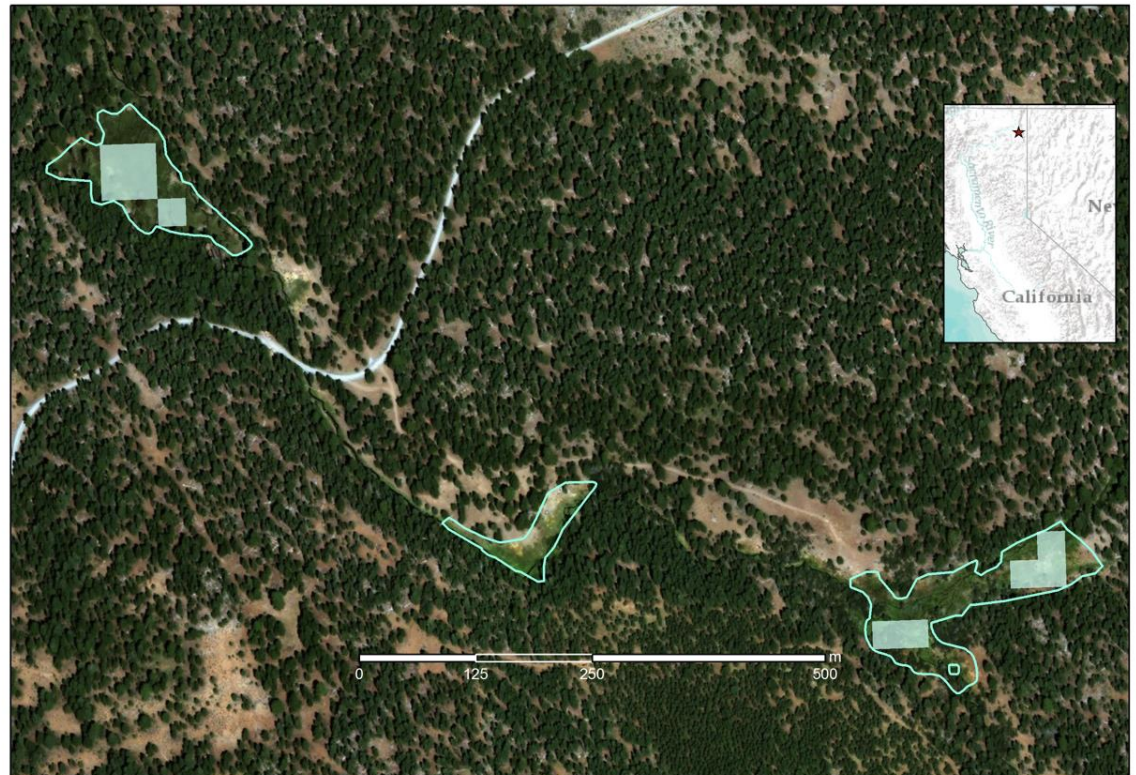
- • Quantify meadow climate sensitivities at inter annual timescales
- • Identify landscape patterns and drivers of climate sensitivity
- Incorporate results into decision support tool to guide meadow conservation and restoration priorities

Generalizable patterns that will allow managers to better anticipate meadow response to climate and site restoration accordingly





- Recently updated meadows dataset for whole Sierra Nevada, hand-delineated from aerial imagery (D. Weixelman)
- Filtered to meadows with >1 acre core area with consistent vegetation data
- Working dataset included ~8,100 meadows





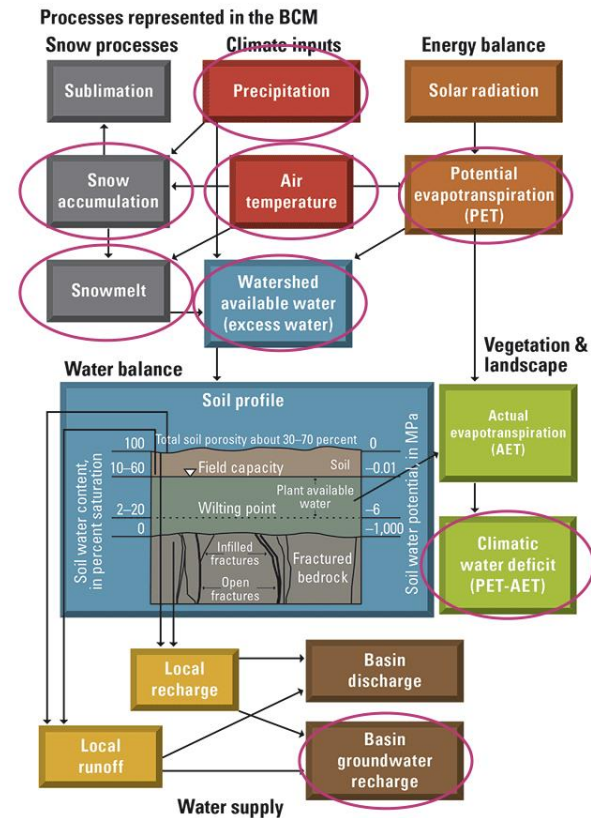
Meadow vegetation condition:



- LandSat imagery (16-day intervals)
- 31-year time series (1985-2016 water years)
- Vegetation indices:
 NDVI: vegetation greenness
 NDWI: vegetation water content

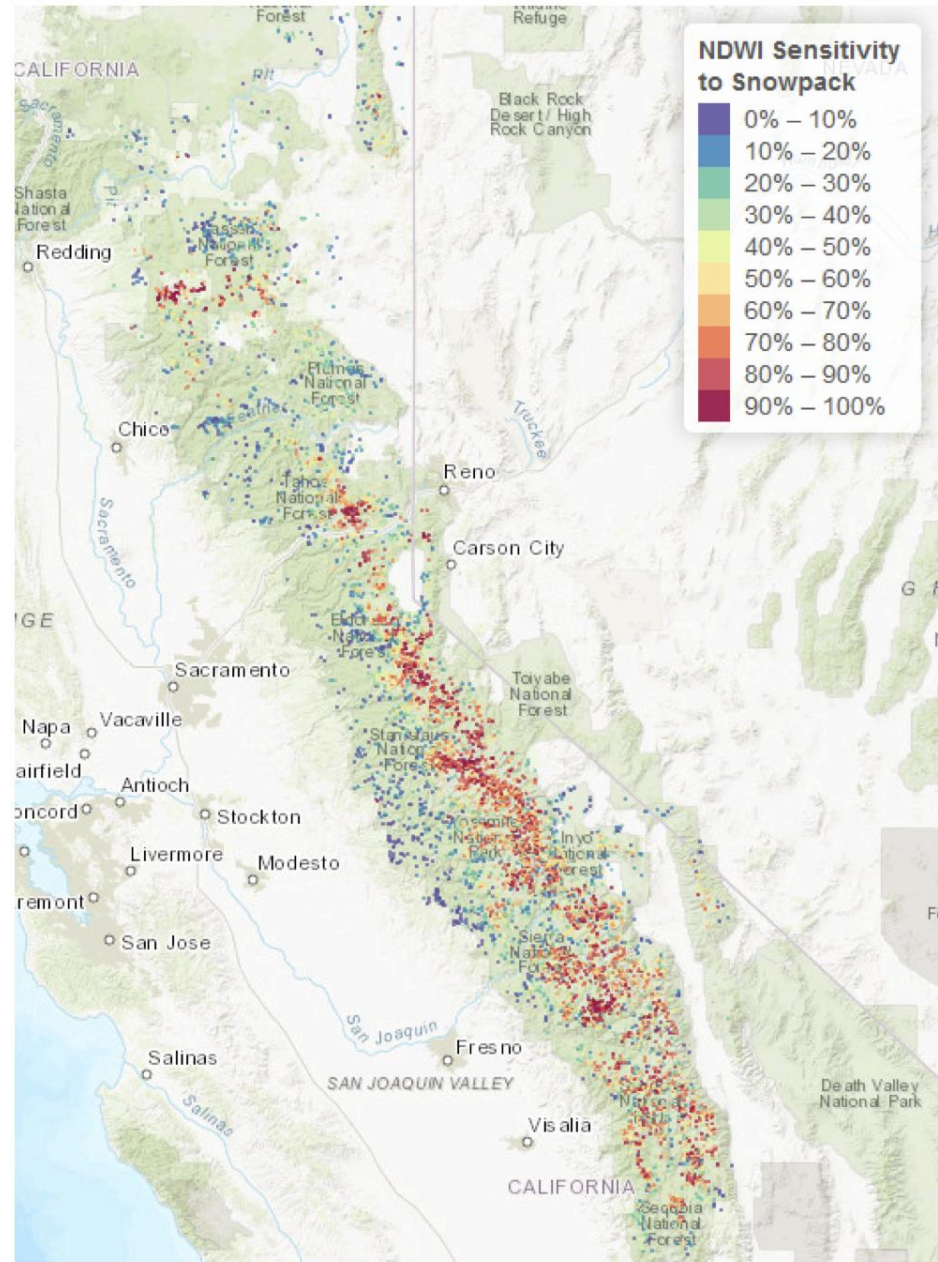
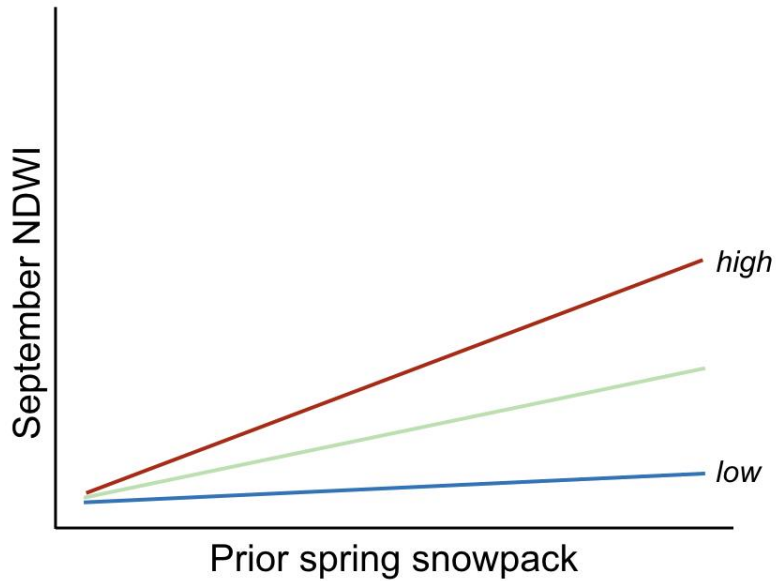
Meadow climate conditions:

- Basin Characterization Model (Flint et al. 2013)
- Climate & hydrology data + processes ecologically-relevant climate metrics
- Past estimates and future projections





Measuring sensitivity of meadow vegetation to climate:





35 measured landscape attributes:

Meadow-scale		Watershed-scale	
Impact	Mean human modification	Impact	Mean human modification
	Centroid longitude		Percent cool slope
Position/size/shape	Centroid latitude	Shape	Percent low slope
	Mean elevation		Percent steep slope
	Standard deviation of elevation		Curvature (integral)
	Acreage		Curvature (moment I)
	Perimeter:area ratio		Percent area of geologic types with high aquifer potential
Soil	Soil clay content	Soil/geology	Percent area of geologic types with low aquifer potential
	Root zone available water storage		Root zone available water storage
	0-150cm available water storage		0-150cm available water storage
Climatology	30-year mean timing of maximum greenness	Land cover	Maximum greenness
	30-year mean annual potential evapotranspiration		Percent herbaceous cover
	30-year mean annual precipitation		Percent barren cover
	30-year mean annual climatic water deficit		Percent forested cover
	30-year mean annual April snowpack		Percent cover classified as dense forest
	30-year standard deviation of annual potential evapotranspiration		
	30-year standard deviation of annual precipitation		
	30-year standard deviation of annual climatic water deficit		
	30-year standard deviation of annual snowpack		
	30-year mean September greenness		



Factor analysis: condense a lot of related measured variables into a few independent factors
(also: measure the unmeasurable)

OVER THE LAST WEEK, HOW HAVE YOU BEEN "ON AVERAGE" OR "USUALLY" REGARDING THE FOLLOWING

- Low mood, sadness, feeling blah or down, depressed, just can't be bothered.

<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
a) Hardly Ever	b) Much of the time	c) Most of the time	d) All of the time
- Feelings of worthlessness, hopelessness, letting people down, not being a good person.

<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
a) Hardly Ever	b) Much of the time	c) Most of the time	d) All of the time
- Feeling tired, feeling fatigued, low in energy, hard to get motivated, have to push to get things done, want to rest or lie down a lot

<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
a) Hardly Ever	b) Much of the time	c) Most of the time	d) All of the time
- Feeling that life is not very much fun, not feeling good when usually would feel good, not getting as much pleasure from fun things as usual.

<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
a) Hardly Ever	b) Much of the time	c) Most of the time	d) All of the time
- Feeling worried, nervous, panicky, tense, keyed up, anxious.

<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
a) Hardly Ever	b) Much of the time	c) Most of the time	d) All of the time
- Thoughts, plans or actions about suicide or self-harm.

<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
a) Hardly Ever	b) Much of the time	c) Most of the time	d) All of the time

TOTAL SCORE: _____



Depression Score





35 measured variables → **8 factors**

Meadow latitude
Meadow longitude
Meadow elevation

**Landscape
position**

Watershed average max greenness
Watershed percent forest cover
Watershed percent barren cover

**Watershed
forestedness**

Meadow 30-yr precipitation
Meadow 30-yr precipitation SD
Meadow 30-yr snowpack SD

**Water
availability**

Meadow 30-yr potential evapotransp
Meadow 30-yr climatic water deficit

**Evaporative
demand**

Watershed curvature (integral)
Watershed curvature (1st moment)

**Watershed
curvature**

Watershed % hi aquifer potential
Watershed % lo aquifer potential

**Aquifer
potential**

Watershed root zone aws
Watershed 0-150cm aws

**Watershed
water storage**

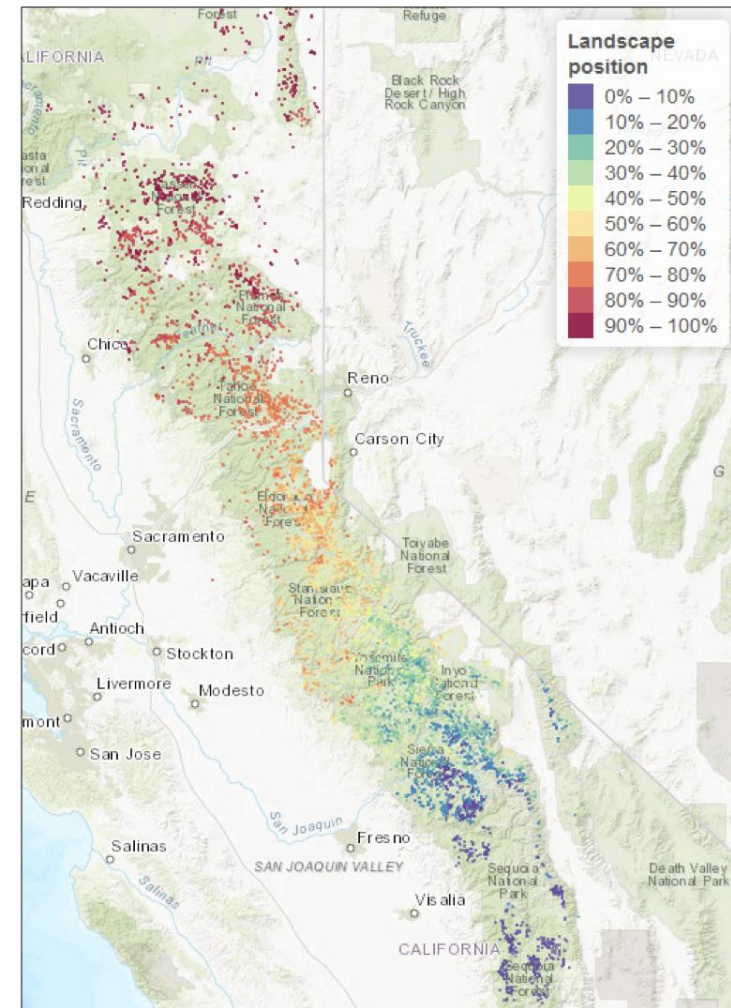
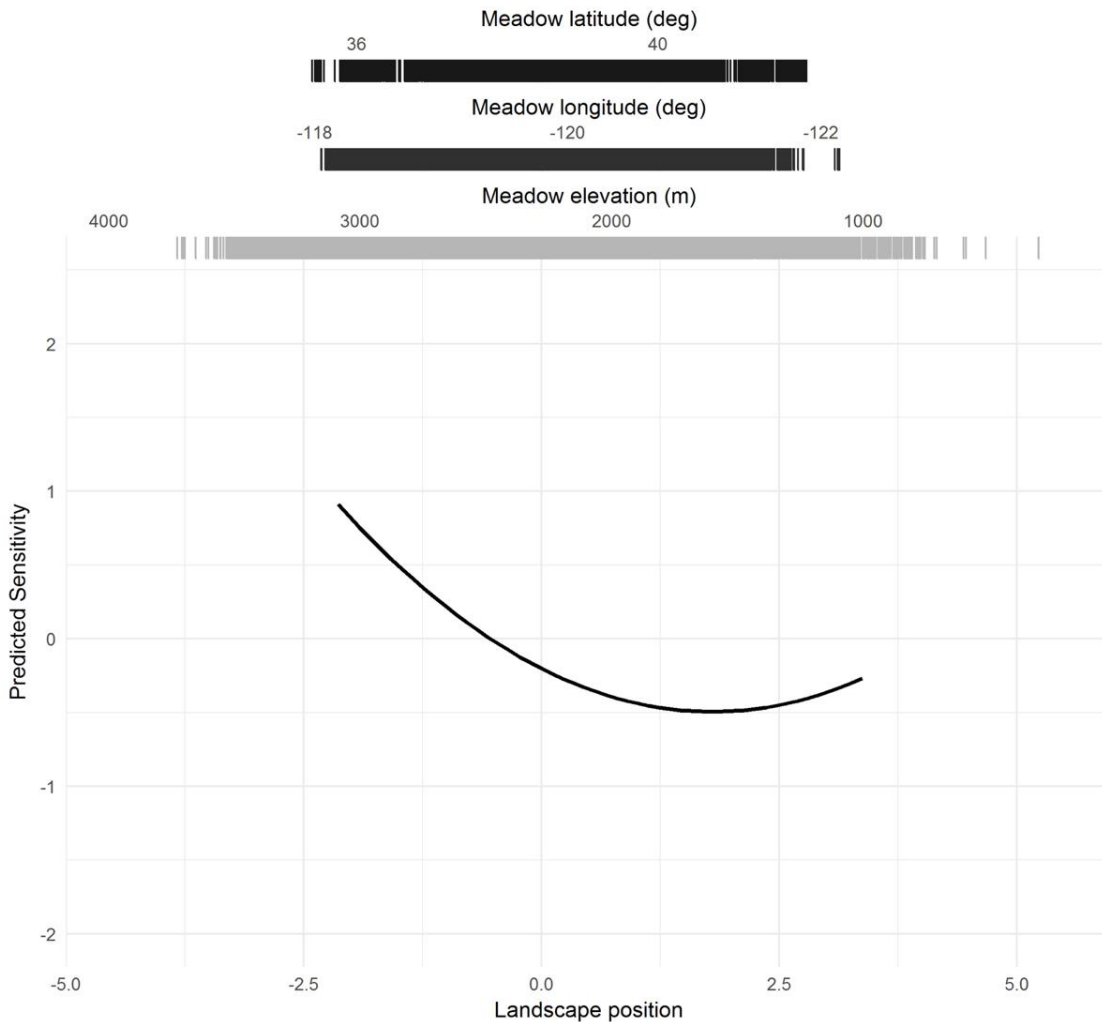
Meadow root zone aws
Meadow 0-150cm aws

**Meadow
water storage**



Meadows at high landscape positions tend to be less sensitive to climate.

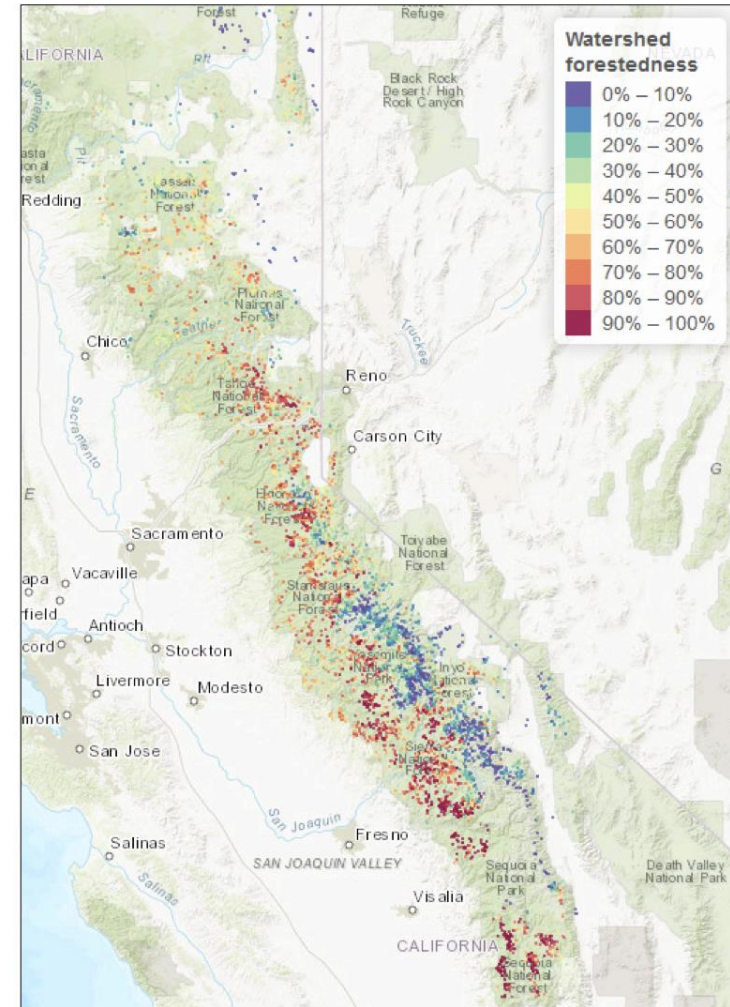
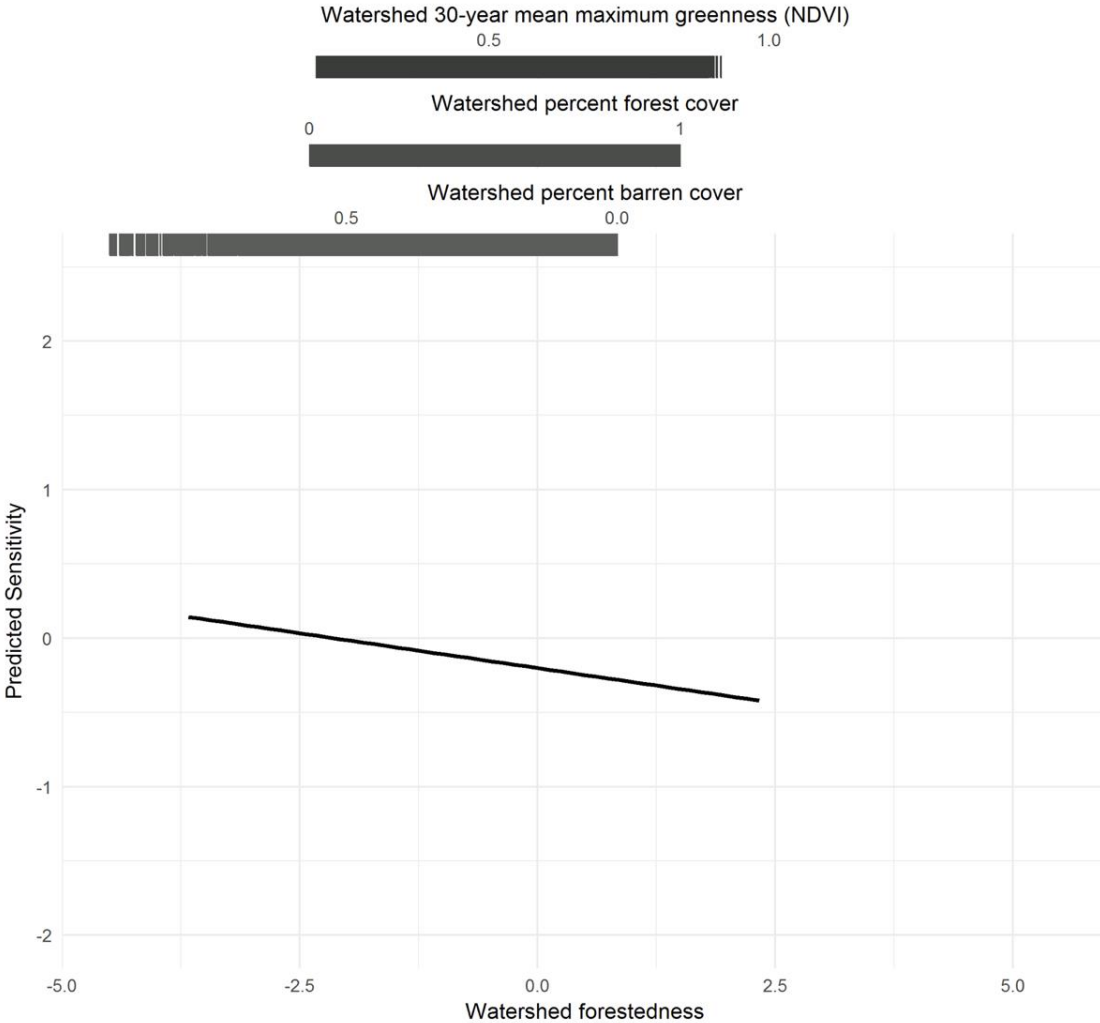
These meadows are in the northwest and at lower elevations.





Meadows in more forested watersheds tend to be less sensitive to climate.

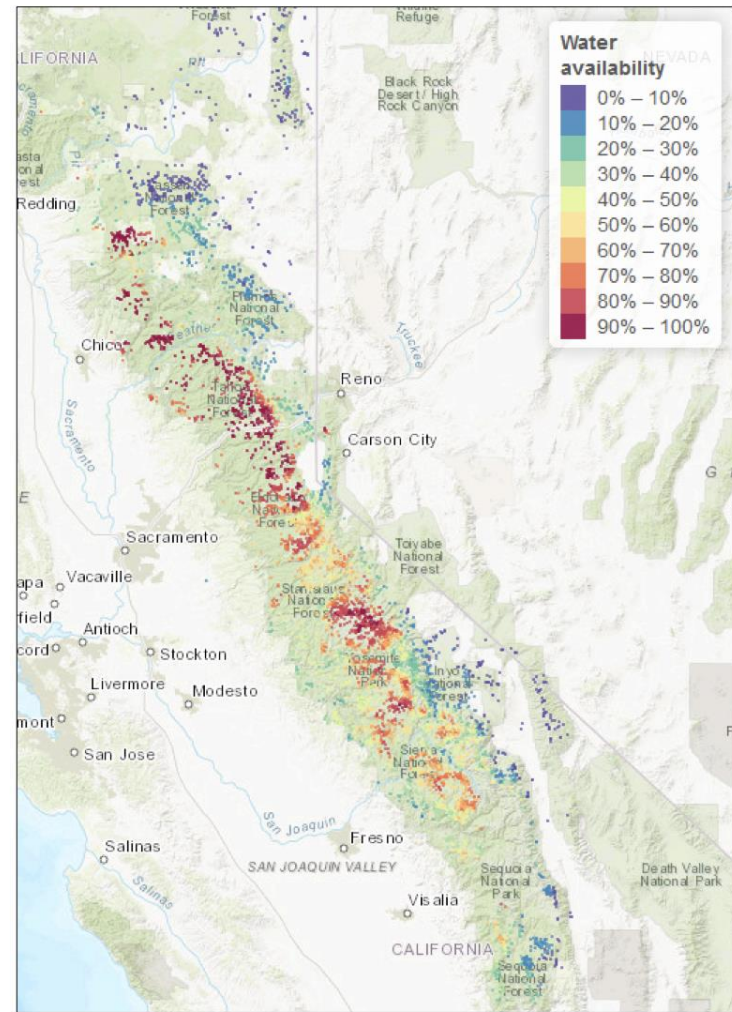
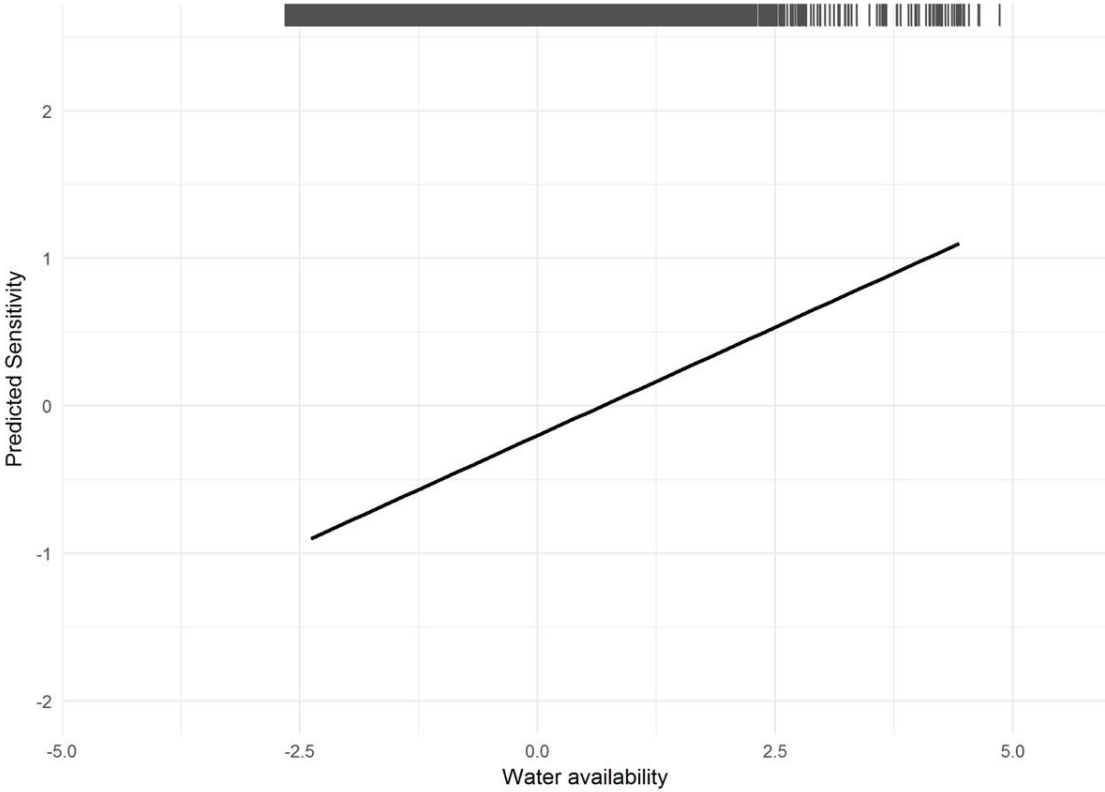
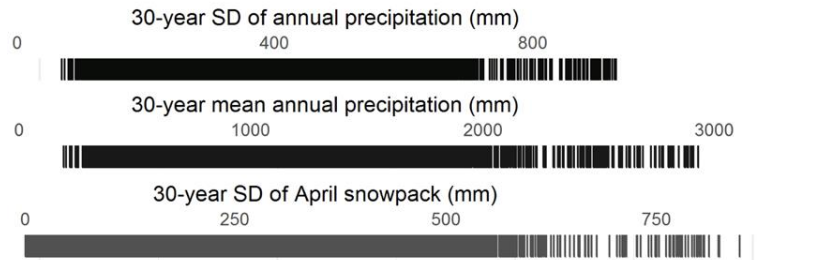
These watersheds have less barren cover, more forest cover, and are greener at peak greenness.





Meadows with higher water availability tend to be more sensitive to climate.

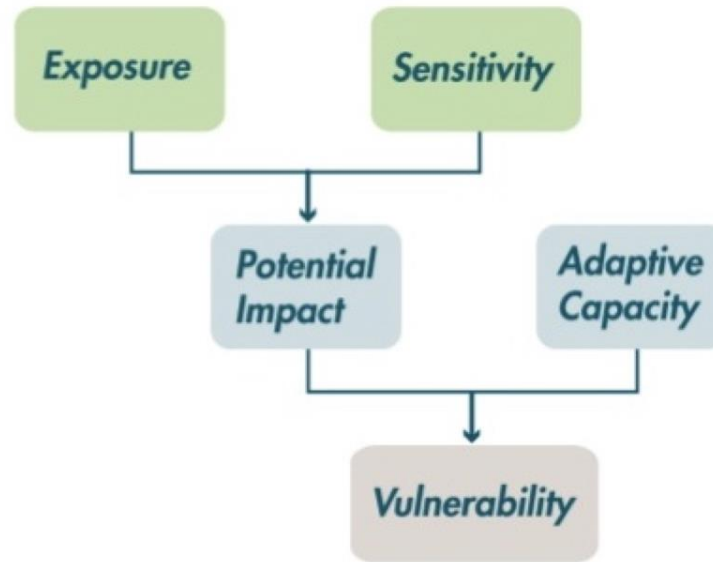
These meadows get more precipitation and more snowpack, but precipitation is more variable.





- Meadow sensitivity to climate varies considerably across the Sierras
- Meadows were more sensitive to derived hydrologic climate variables (BCM snowpack) than to atmospheric variables (e.g., ppt, pet)
- Readily available landscape-scale datasets can provide insight on meadow response to changing climate

- More sensitive meadows tend to:
 - Be in the southeast portion of the Sierras
 - Be at higher elevations
 - Be in less forested watersheds
 - Rely on higher precipitation and snowpack
 - Have lower evaporative demand *
 - Have low soil water storage capacity
 - Be in watersheds with low soil water storage capacity



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