Ecological Drought: Concepts, Drought Metrics & Tools

Imtiaz Rangwala, *CU Boulder*
Shelley Crausbay, *Conservation Science Partners*
Wynne Moss, *Conservation Science Partners*

Mentimeter Activity

Workshop overview

Part I (9:30 – 10:25) A conceptual overview of ecological drought

- An introduction to drought and drought indicators
- Ecological drought and its manifestations
- Connecting drought metrics with ecological responses

Part II (10:35 – 11:30) Online tools for measuring ecological drought

- Introduction to the DrIP tool
- Practice with exploring drought data
- Future drought projections

Intro to drought

Imtiaz Rangwala, *CU Boulder*

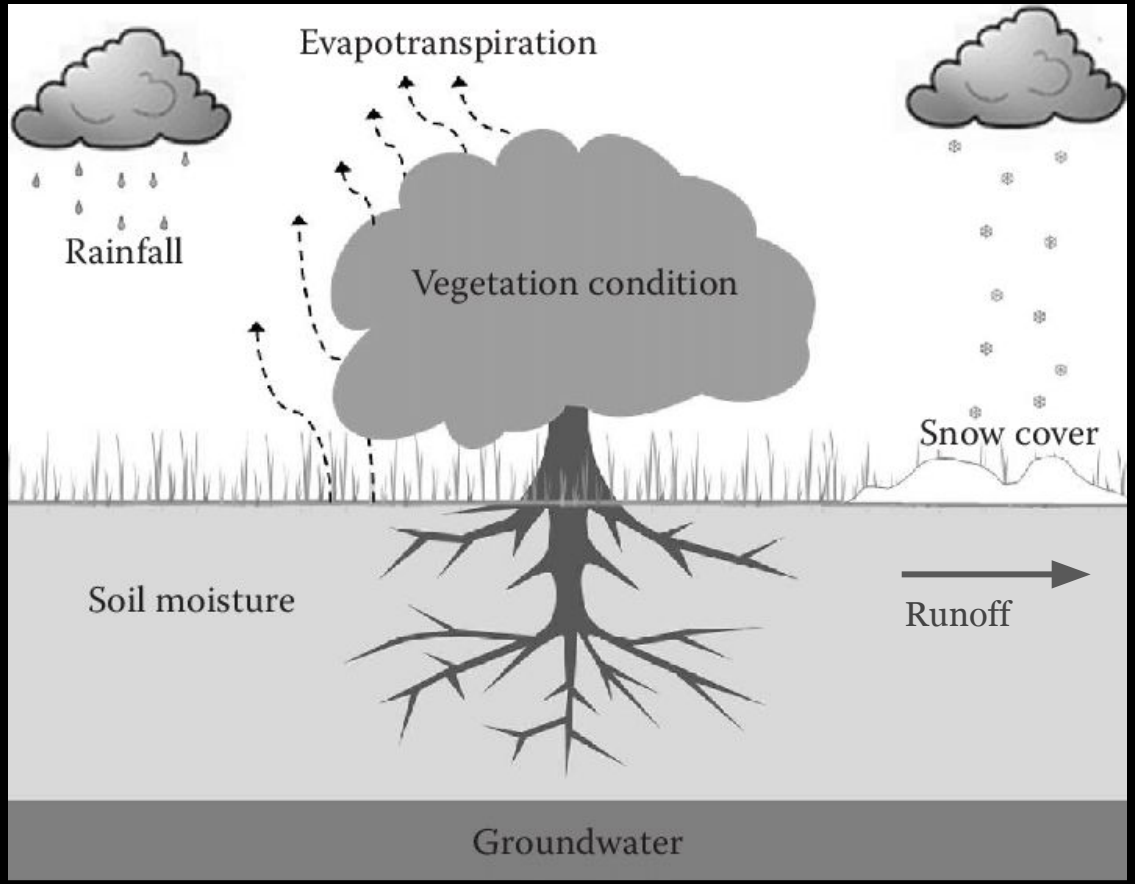
Defining Drought

"The problem of defining drought is longstanding and has never been resolved to the satisfaction of all…Drought means many different things to many different audiences"

"I have come to favor a simple definition….**insufficient water to meet needs**"

Kelly Redmond (The Depiction of Drought; BAMS, 2002)

- Deficiencies in different components of the water cycle could indicate drought and drive impacts
- Deficiency of water is influenced by both supply and demand for water



Hayes, Michael J.; Svoboda, Mark D.; Wardlow, Brian D.; Anderson, Martha C.; and Kogan, Felix, "Drought Monitoring: Historical and Current Perspectives" (2012). Drought Mitigation Center Faculty Publications. 94. http://digitalcommons.unl.edu/droughtfacpub/94

Aridity

A measure that accounts for both the water supply (precipitation) and demand (evaporative demand) elements

Quantified in various ways:
= AET/PET
= PET-AET
= PET-Precipitation

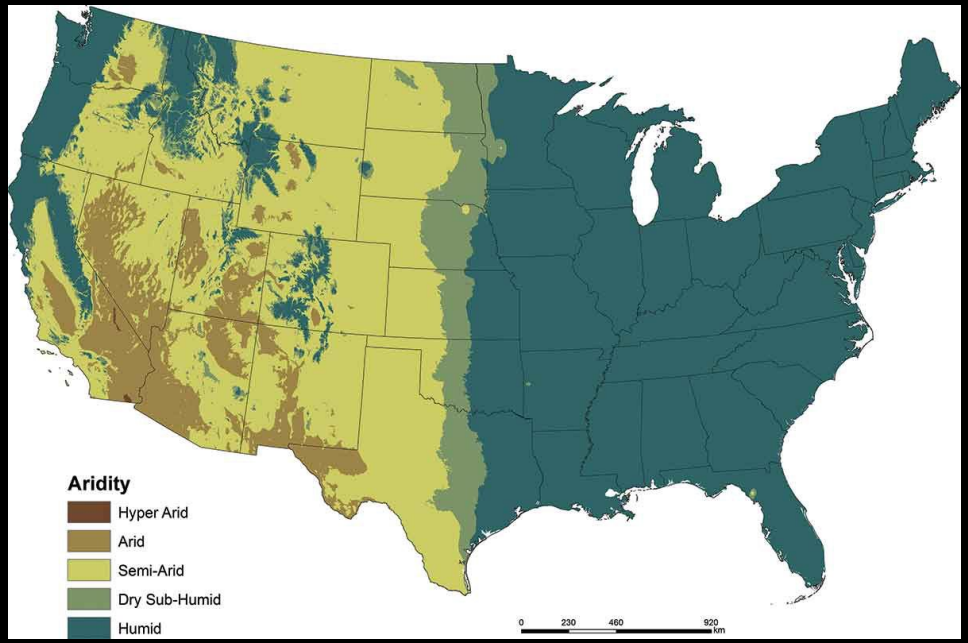
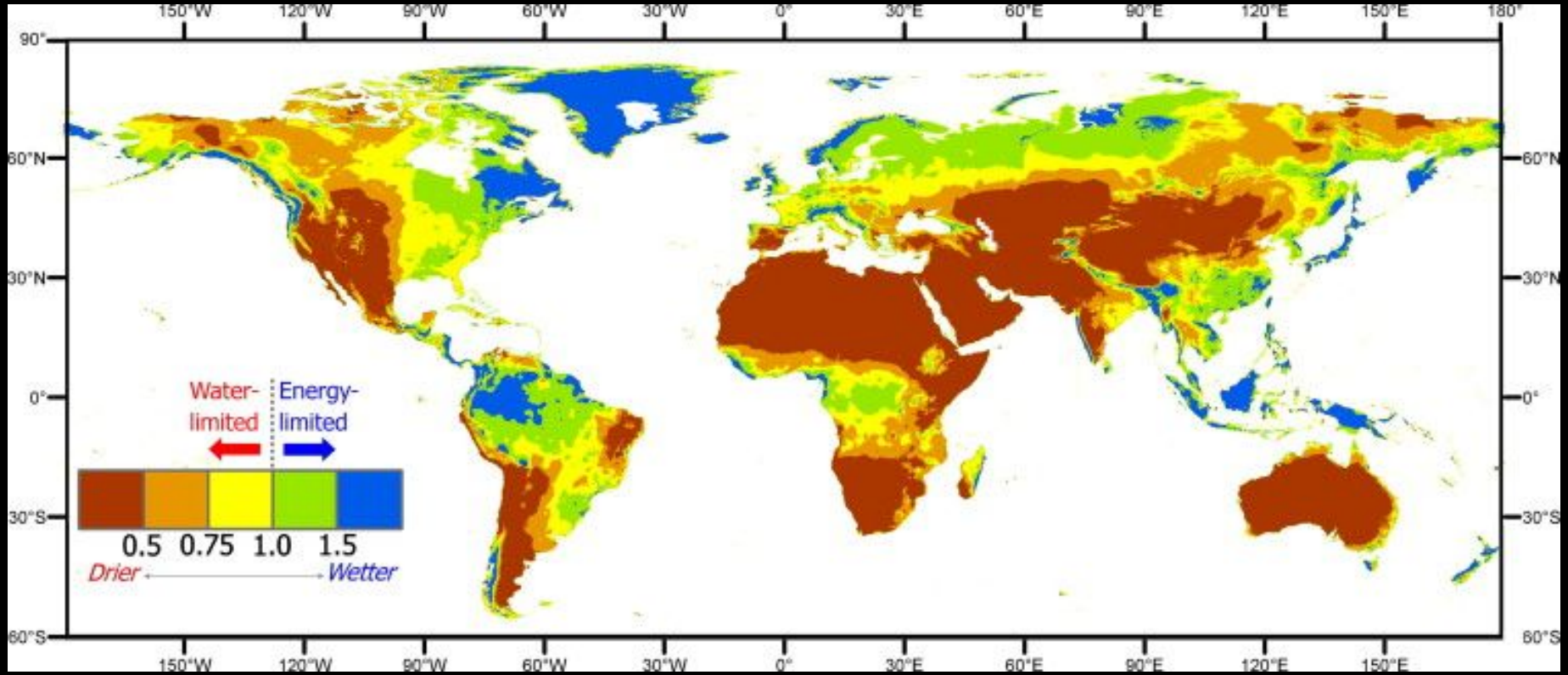


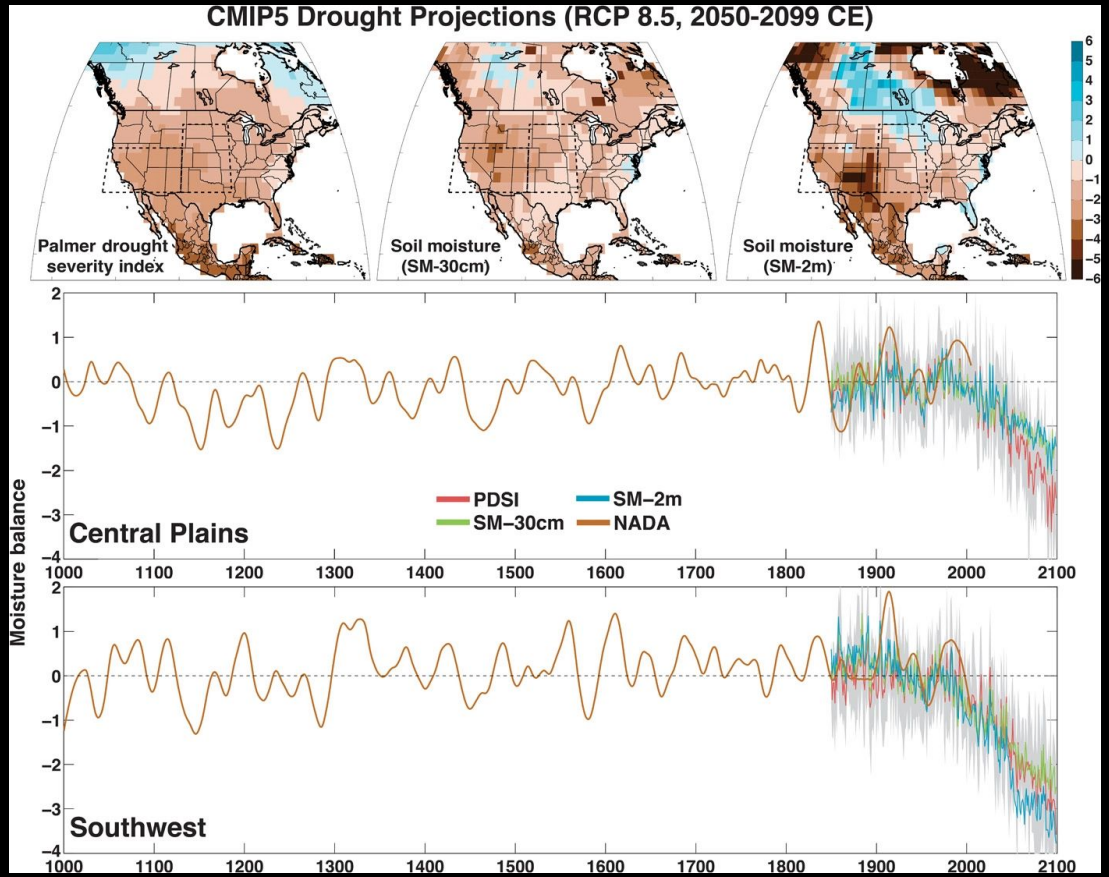
Image: Basche & Edelson 2017

AET = actual evapotranspiration; PET = potential evapotranspiration

Water Limited vs. Energy Limited Regions



Climate Change: Drought vs. Aridification



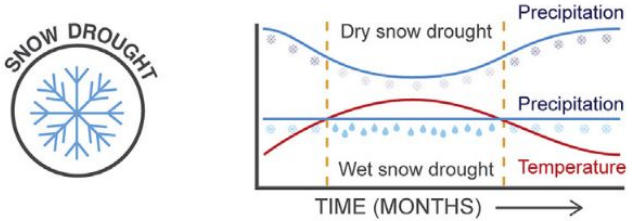
What's an appropriate qualification as we look at future trends in water balance metrics or drought indices?

- Changes in intensity and frequency of drought

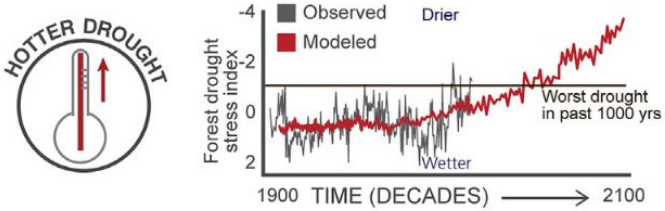
OR

- Extent of Aridification

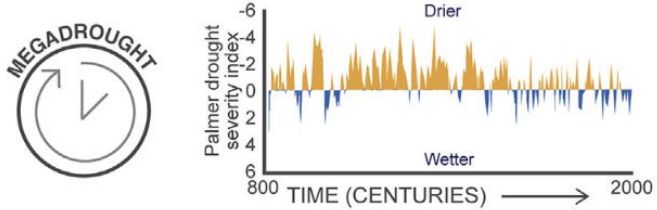
Novel droughts emerging during the 21st century from climate heating



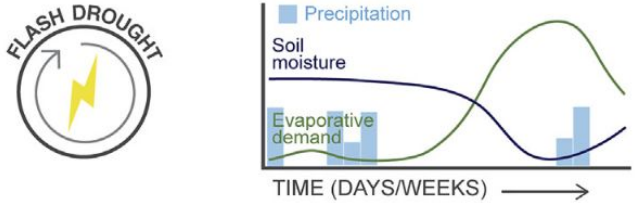
A drought due to low winter precipitation (dry snow drought), or as a result of warm winter temperatures that reduce the ability of winter precipitation to accumulate as snowpack (warm snow drought) (Mote et al., 2016).



A drought occurring under warming temperatures, a modification of earlier terminology of global-change-type drought (after Breshears et al., 2005). Figure adapted from Williams et. al., 2013.



A prolonged drought lasting two decades or longer (Woodhouse and Overpeck, 1998). Figure adapted from Cook et. al., 2016.

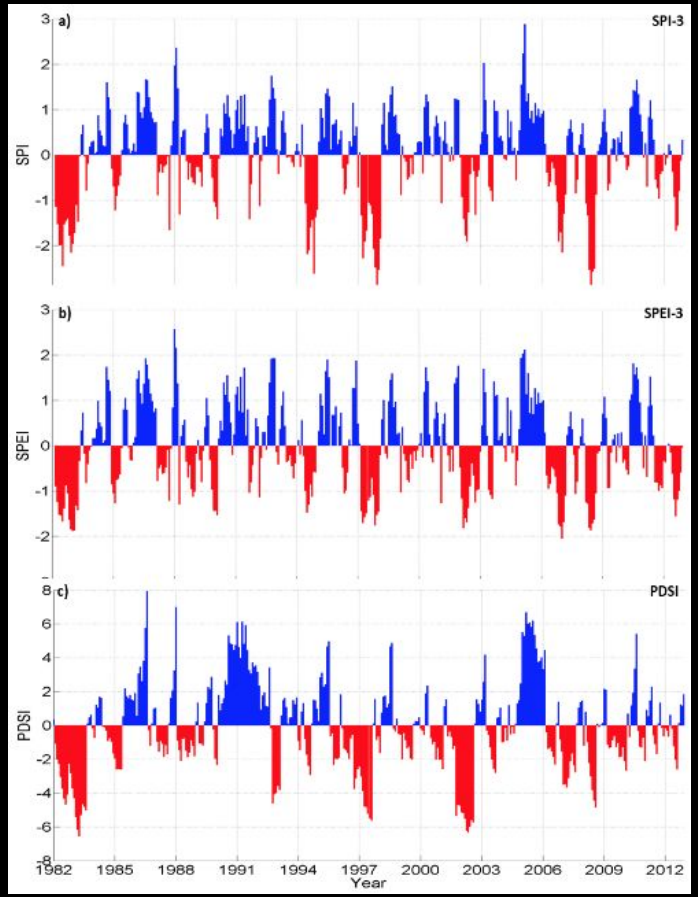


A severe drought that arises rapidly, within weeks-to-months, and is characterized by moisture deficits and abnormally high evaporative demand (Otkin et. al., 2018).

Crausbay et al., 2020

Standardized Indices

- Great at indicating departures from normal conditions
- Departures are in standardized units (std. deviations)
- Allows for comparability across regions (e.g., of different aridity)
- Important to understand their sensitivities to physical and biological processes — in order to relate deviations in an index to impacts
- Several indices (e.g., SPI, SPEI, EDDI) operate at multiple timescales (weeks to years)



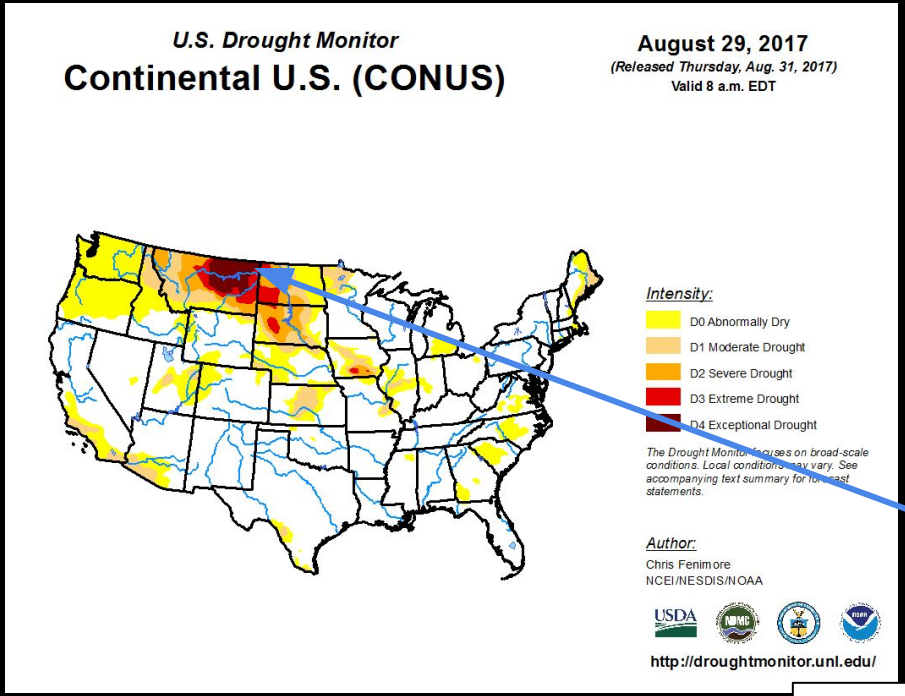
https://iopscience.iop.org/article/10.1088/1755-1315/303/1/012012/pdf

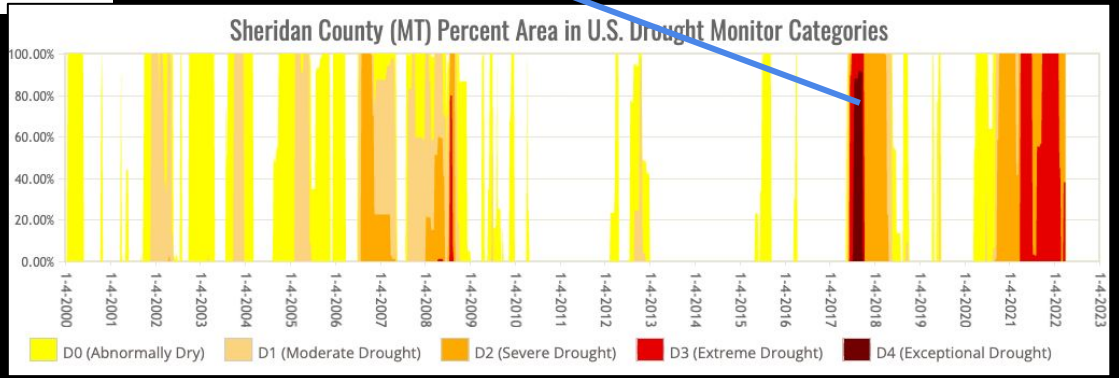
Standardized Drought Indices

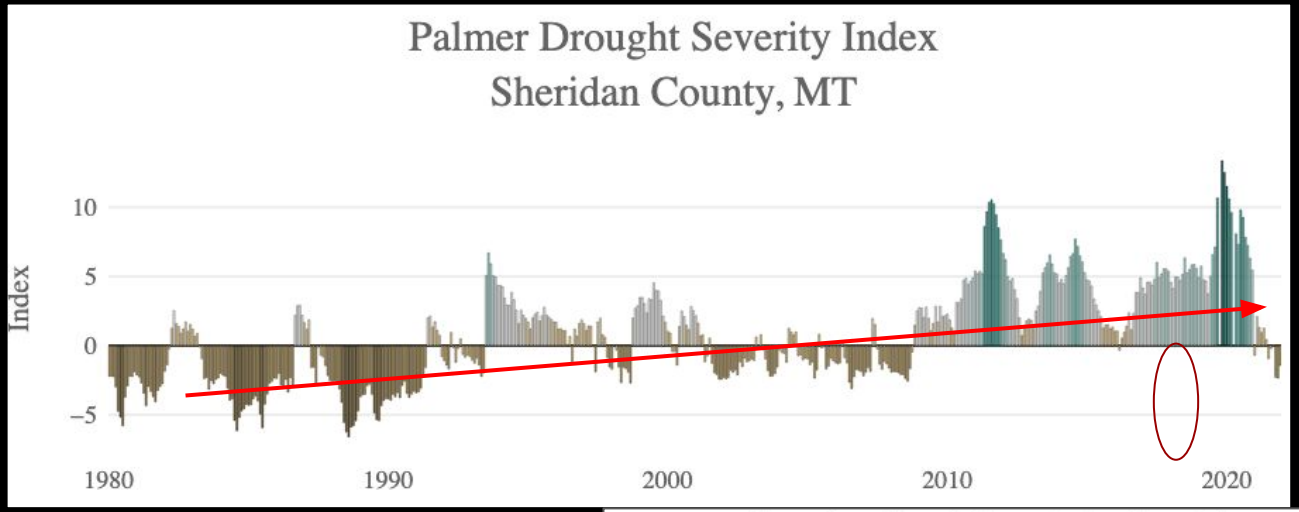
Drought Index	Timescale	Input Variables	Proxy for
Palmer Drought Severity Index (PDSI)	Single	Precipitation, Temperature	Long-term soil moisture conditions
Standardized Precipitation Index (SPI)	Multiple	Precipitation	Precipitation
Standardized Precipitation & Evapotranspiration Index (SPEI)	Multiple	Precipitation, PET*	Soil Moisture, Runoff
Evaporative Demand Drought Index (EDDI)	Multiple	PET	Atmospheric Thirst
Forest Drought Stress Index (FDSI)	Single (water year)	Cold season precipitation, Warm season VPD**	Water year drought stress in the western US

*Potential Evapotranspiration, **Vapor Pressure Deficit

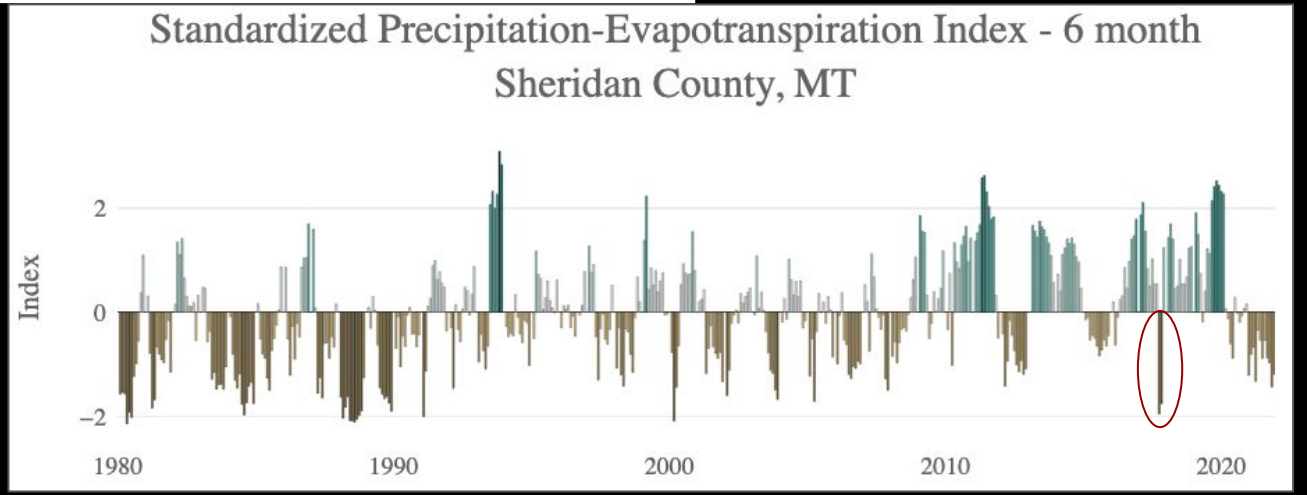
2017 Northern Plains Drought



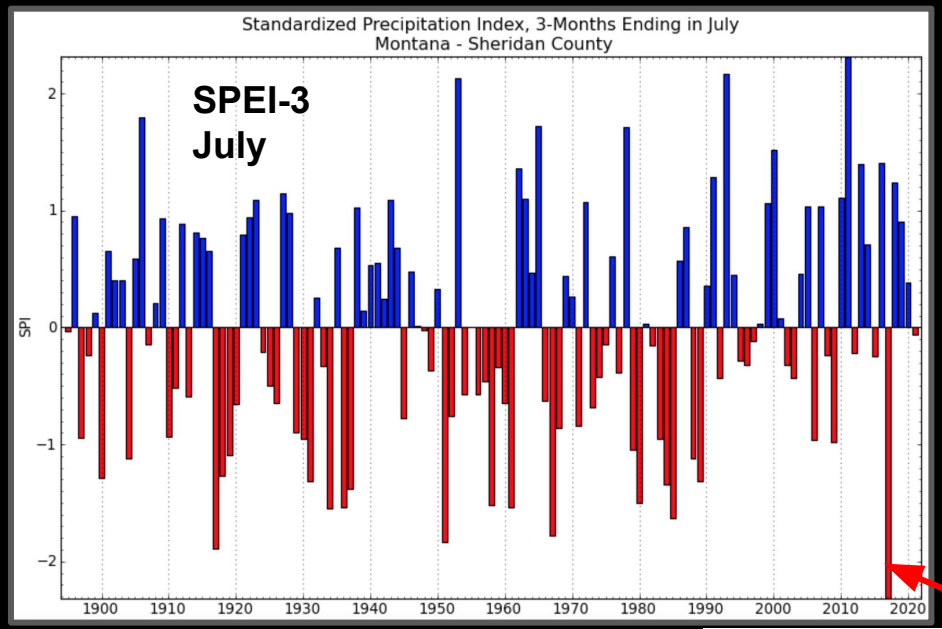




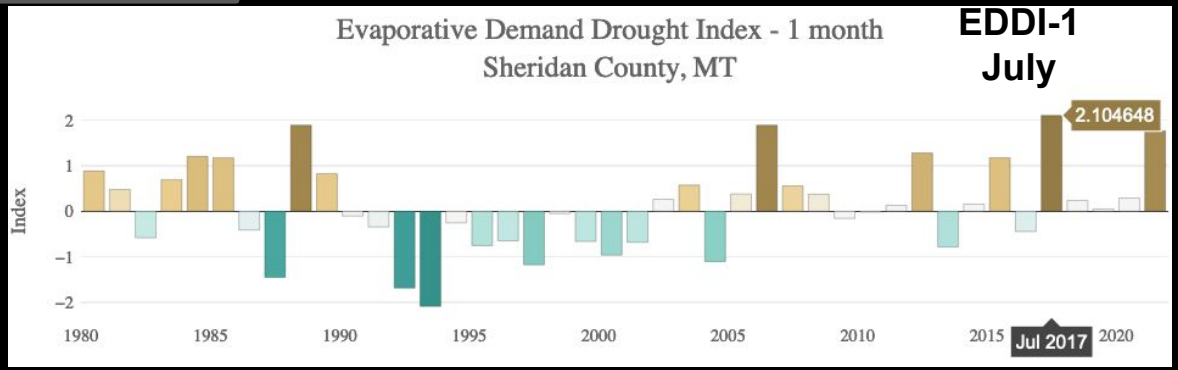
2017 Northern Plains Drought



https://droughtindexportal.colorado.edu/



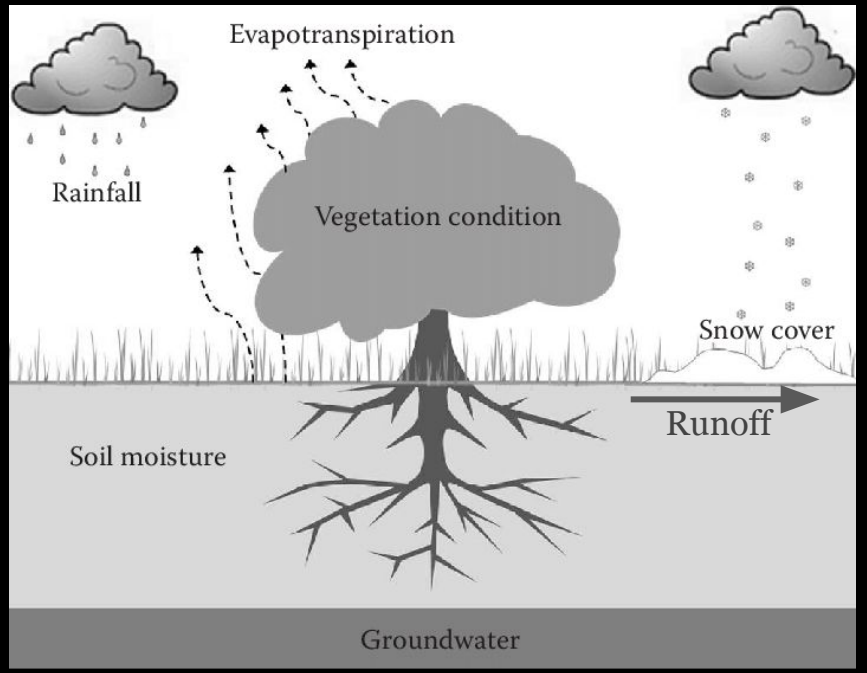
2017 Northern Plains Drought



https://droughtindexportal.colorado.edu/

On using drought indices to assess/project impacts

- Work with multiple indices. Don't rely on a single index to capture drought stress to your system
- Evaluate sensitivities of different indices (incl. timescales) to impacts
- Understand where the (biophysical) sensitivities are coming from between impacts and the index



Hayes, Michael J.; Svoboda, Mark D.; Wardlow, Brian D.; Anderson, Martha C.; and Kogan, Felix, "Drought Monitoring: Historical and Current Perspectives" (2012). Drought Mitigation Center Faculty Publications. 94. http://digitalcommons.unl.edu/droughtfacpub/94

Imtiaz Rangwala
inra0720@colorado.edu

Intro to ecological drought

Wynne Moss, *Conservation Science Partners*

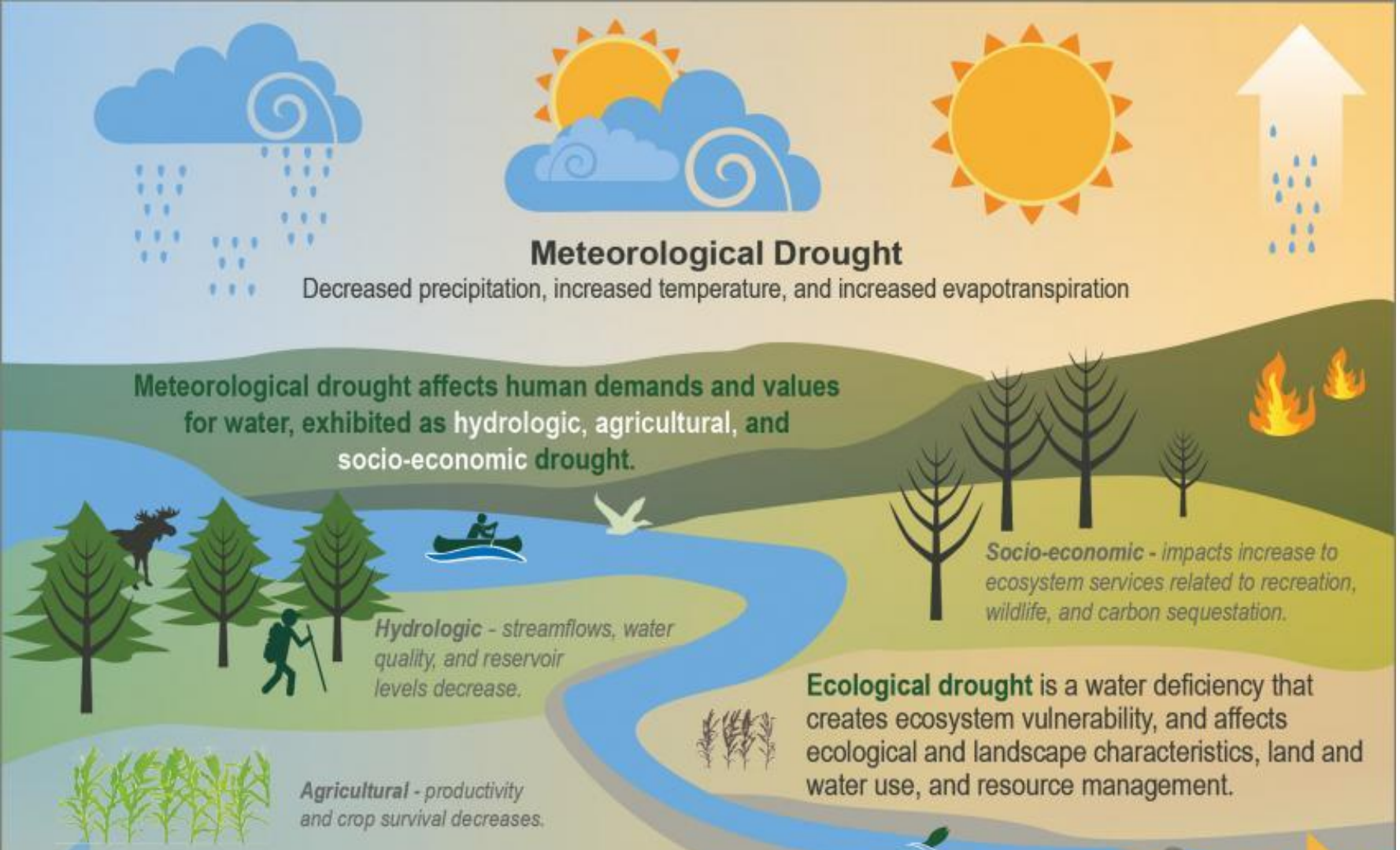

Meteorological Drought
Decreased precipitation, increased temperature, and increased evapotranspiration
Meteorological drought affects human demands and values for water, exhibited as hydrologic, agricultural, and socio-economic drought.
Socio-economic - impacts increase to ecosystem services related to recreation, wildlife, and carbon sequestation.
Hydrologic - streamflows, water quality, and reservoir levels decrease.
Ecological drought is a water deficiency that creates ecosystem vulnerability, and affects ecological and landscape characteristics, land and water use, and resource management.
Agricultural - productivity and crop survival decreases.

Image: USFS

What is ecological drought?

"An episodic deficit in water availability that drives ecosystems beyond thresholds of vulnerability, impacts ecosystem services, and triggers feedbacks in natural and/or human systems"

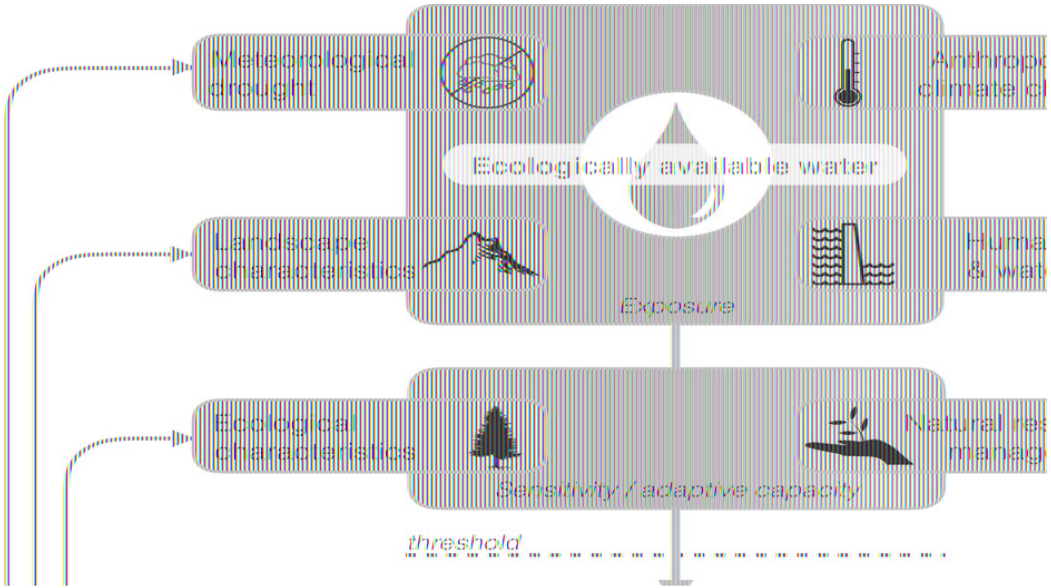
Crausbay et al. 2017, *BAMS*

Ecological drought

"An episodic deficit in water availability…"

Crausbay et al. 2017, *BAMS*

Ecological drought

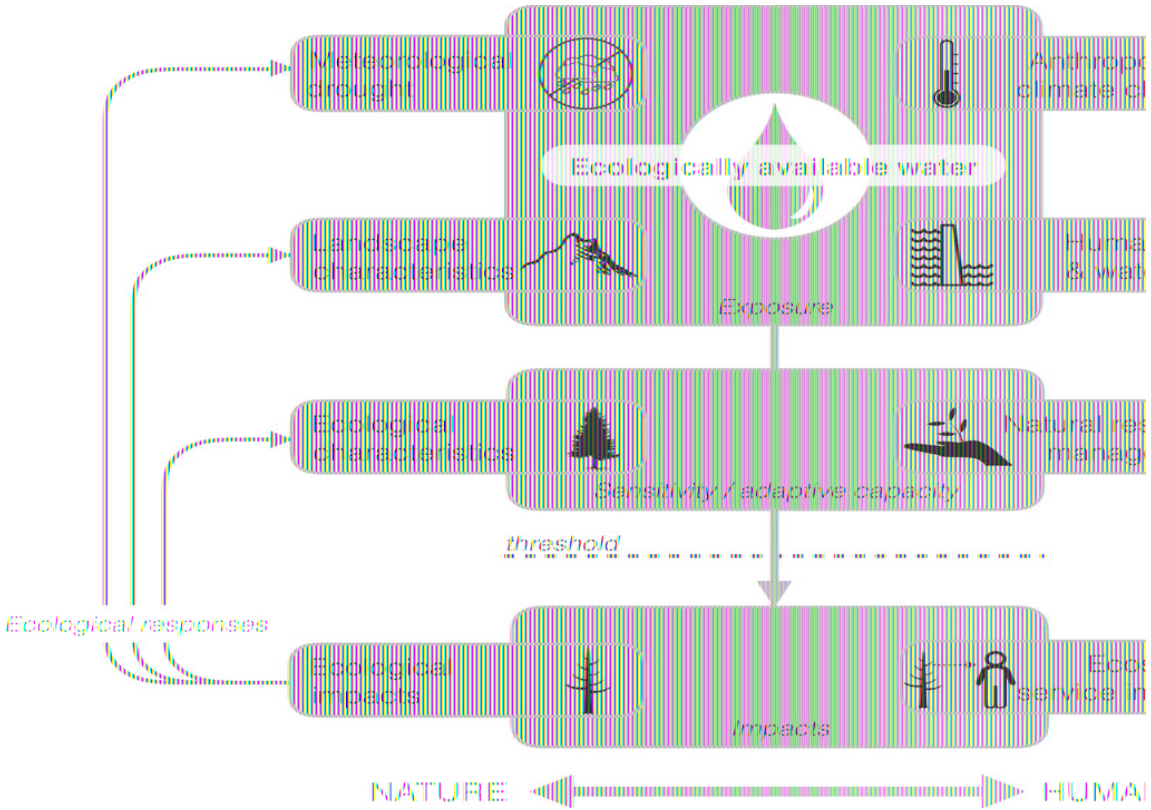


"An episodic deficit in water availability…"

"...that drives ecosystems beyond thresholds of vulnerability…"

Crausbay et al. 2017, *BAMS*

Ecological drought



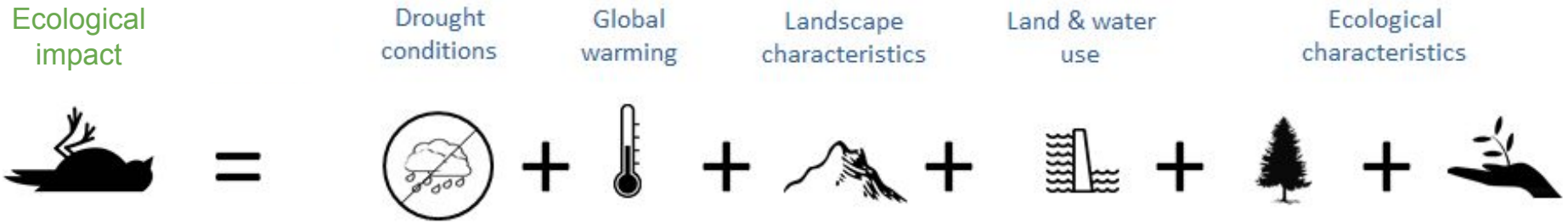
"An episodic deficit in water availability…"

"...that drives ecosystems beyond thresholds of vulnerability…"

"...impacting ecosystem services and triggering feedbacks in natural and/or human systems."

Crausbay et al. 2017, *BAMS*

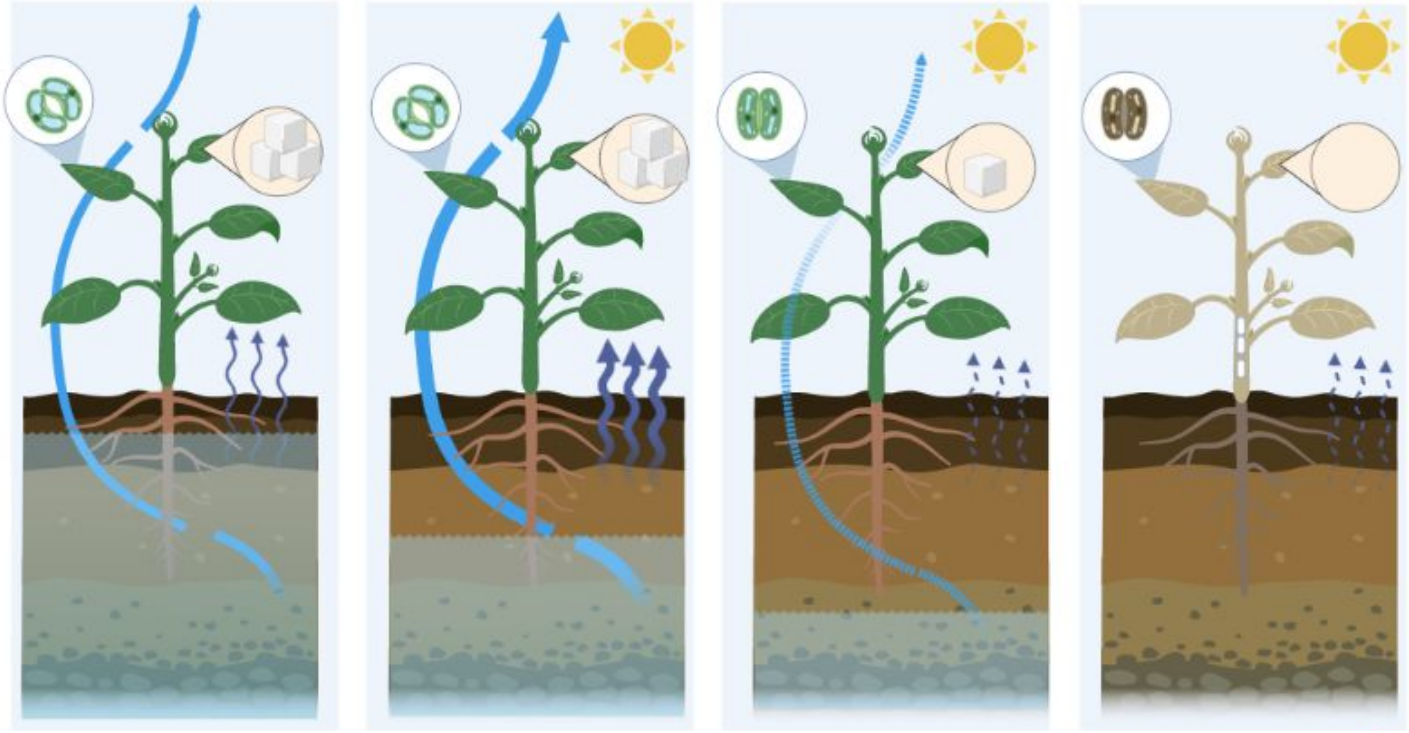
Ecological drought



Impacts of ecological drought - plant physiological stress

Typical conditions

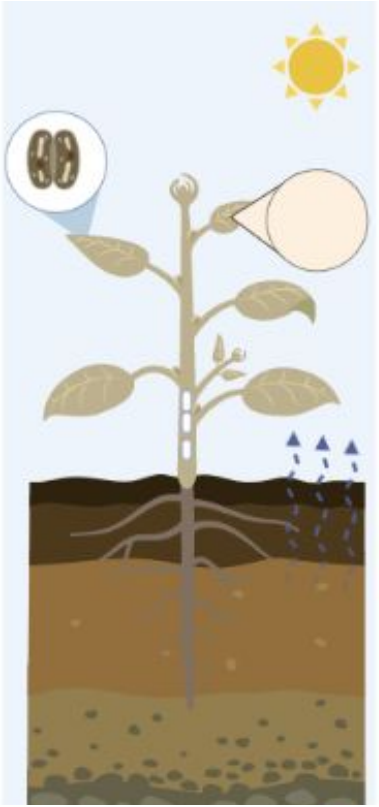
Drought progression



Depleted energy stores

Lack of water transport

Impacts of ecological drought - plant physiological stress



Depleted energy stores

Lack of water transport

- Reduced growth
- Changes in seed production
- Germination failure
- Dieback
- Seedling mortality
- Adult mortality

Indirect impacts of ecological drought

Fire

Hubbard Gap Fire
(McGrew, Nebraska)

Pests/pathogens

Bark beetle outbreak
(Rocky Mountain National Park, Colorado)

Invasions

Cheatgrass invasion
(Westcliffe, Colorado)

Impacts of ecological drought - animal

- Habitat loss or degradation
- Loss of food resources
- Heat/water stress
- Behavioral shifts
- Pathogens/disease
- Mortality/reproductive failure

Poor forage quality leads to pronghorn declines (Wyoming)

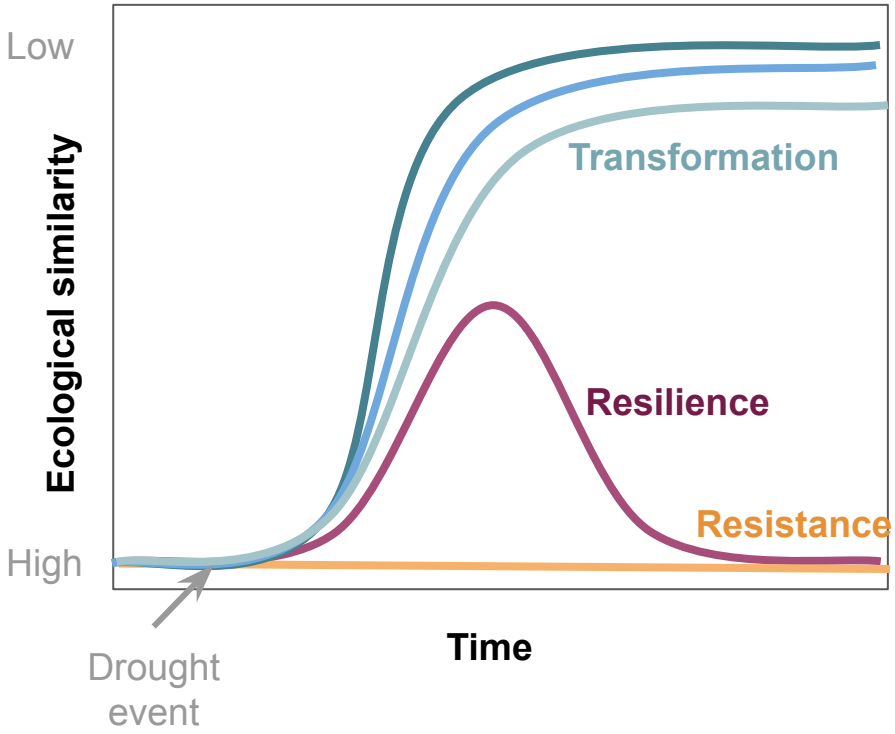
Toxic algal blooms threaten wetland birds (North Dakota)

Trout die-offs during reduced stream flow (Montana)

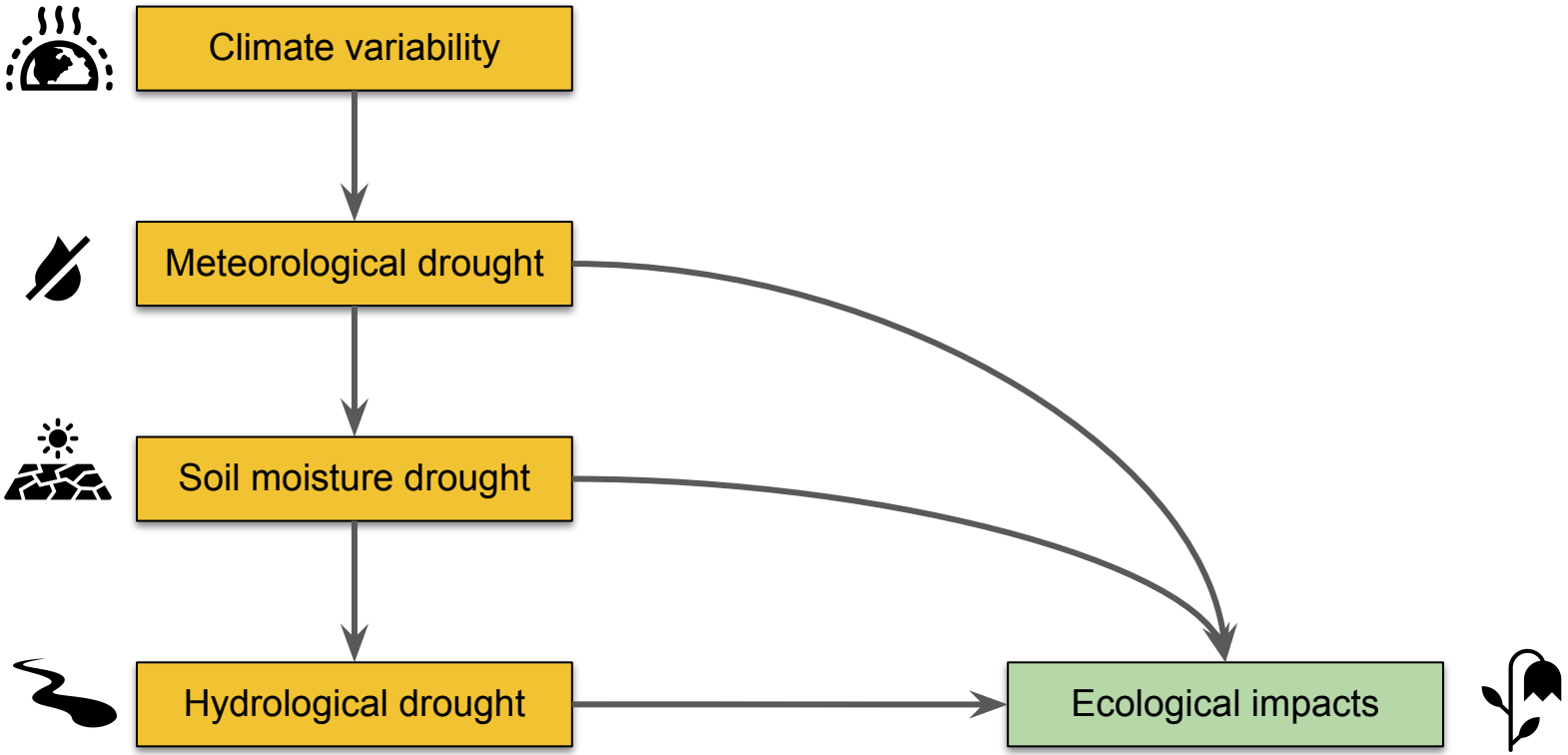
Wetland drying causes amphibian declines (Wyoming)

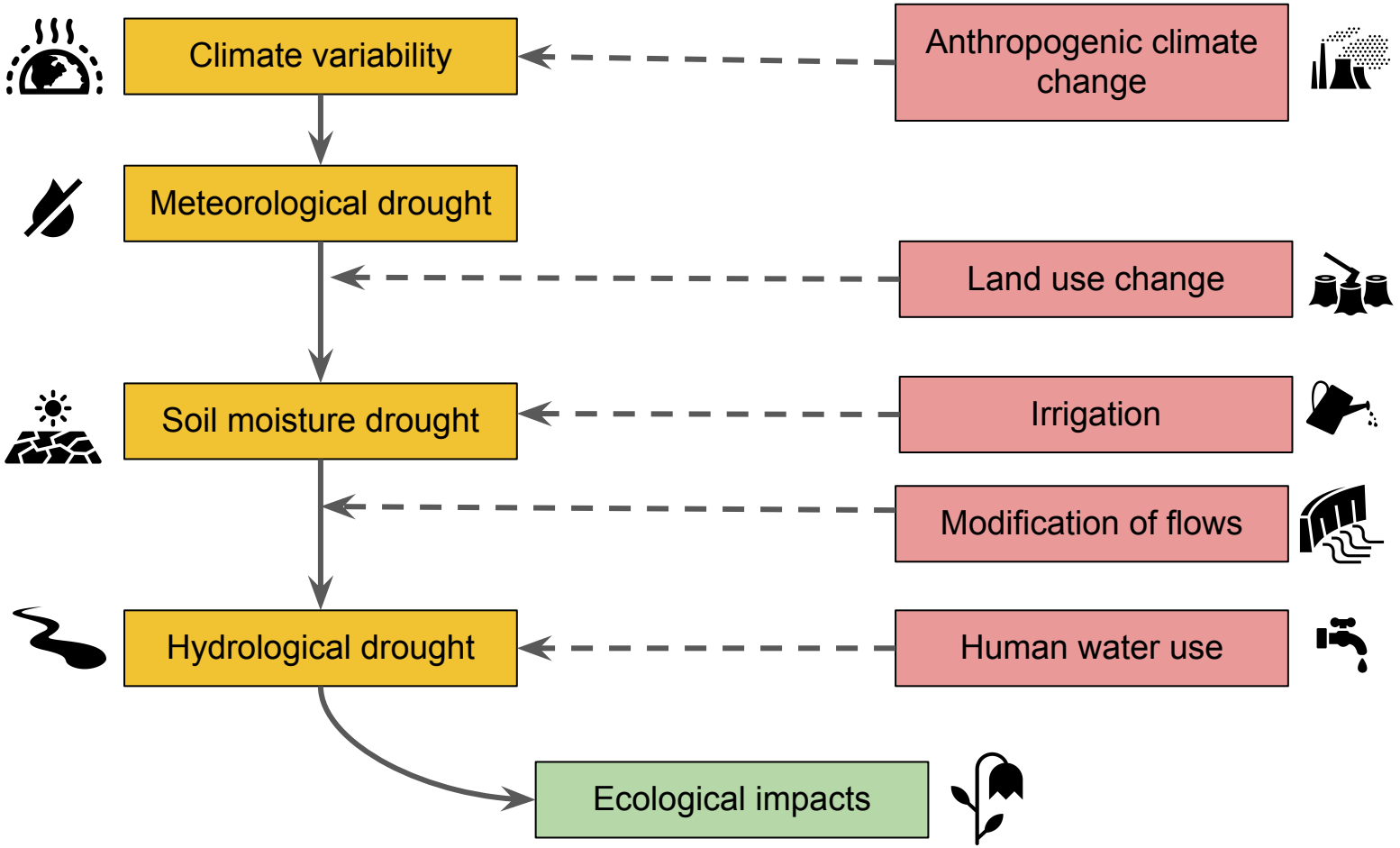
Pikas threatened by snow drought (Colorado)

Impacts of ecological drought - transformation



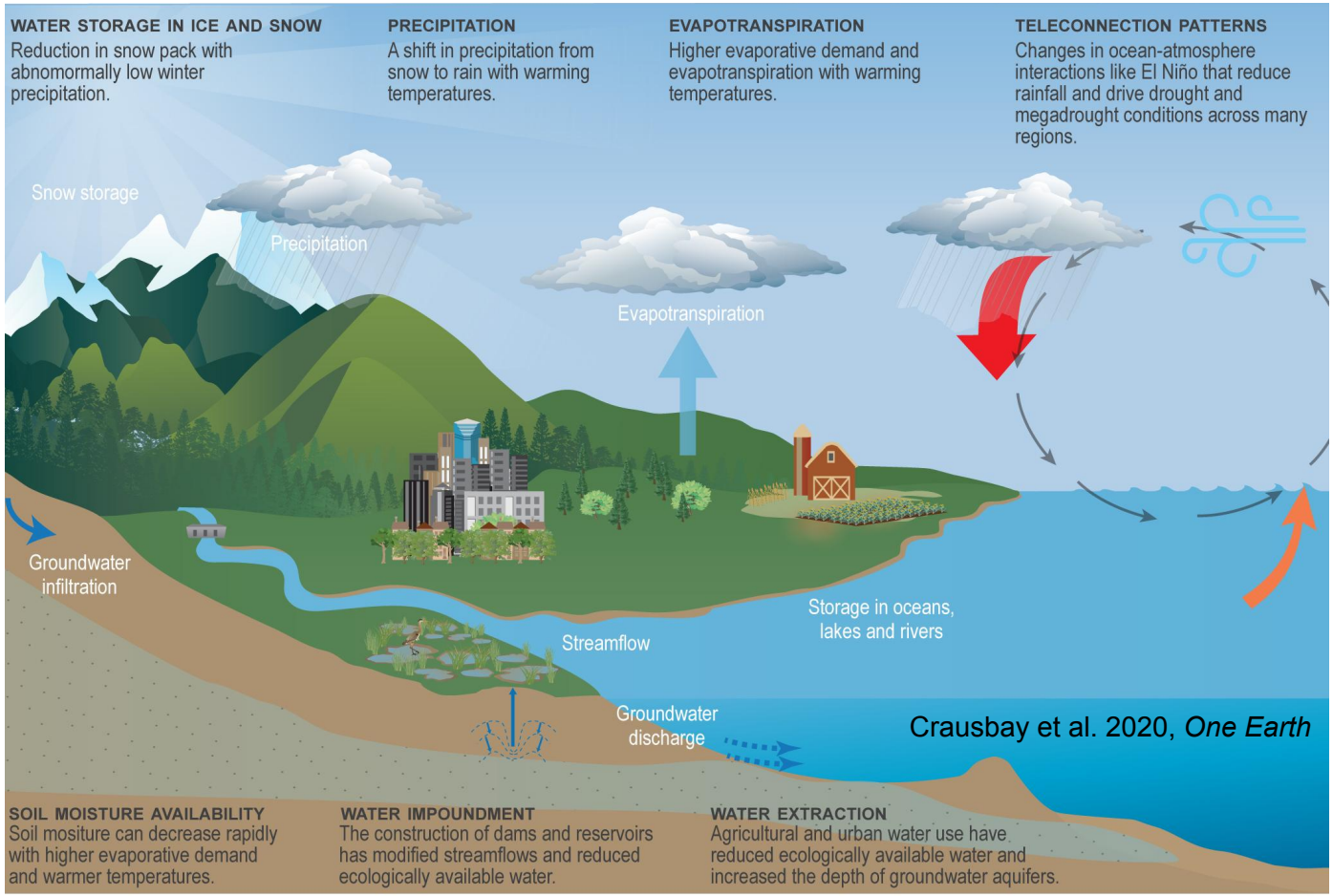
Chaparral conversion to annual grassland following drought and fire (Keeley et al. 2011, Jacobsen and Pratt 2018)


Climate variability
Meteorological drought
Soil moisture drought
Hydrological drought
Ecological impacts



Modified from Van Loon et al. 2016, *Nature Geoscience*

Shifting hydrological drought conditions



Take home points

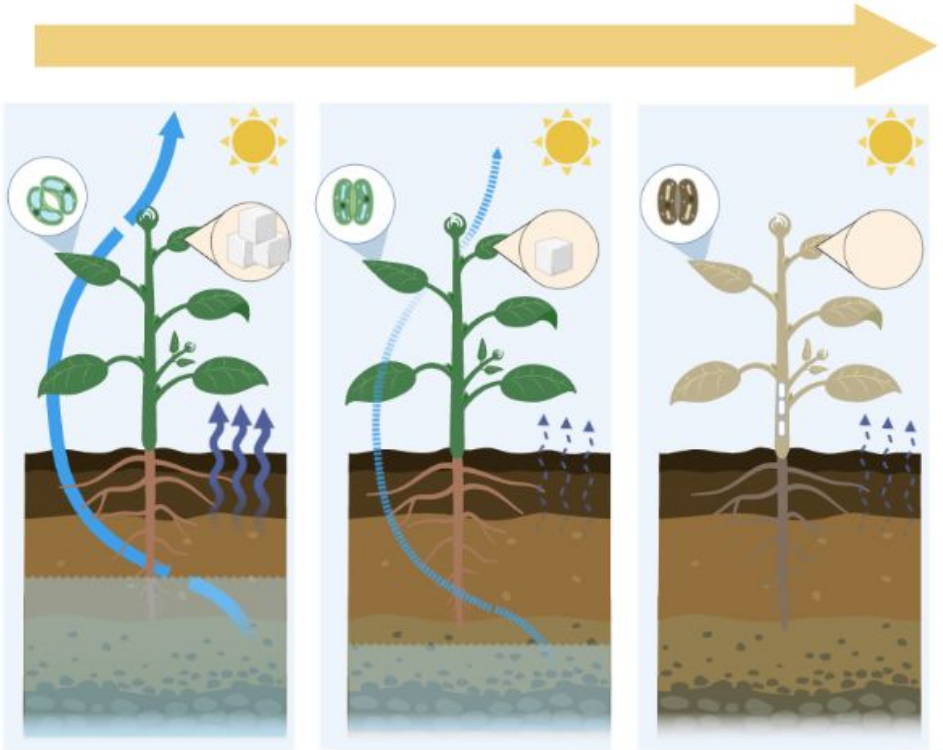
1. Ecological drought is expected to worsen under hotter climates
2. Both climatic and anthropogenic factors influence the severity of ecological drought
3. Drought impacts ecosystems everywhere – not just in arid climates

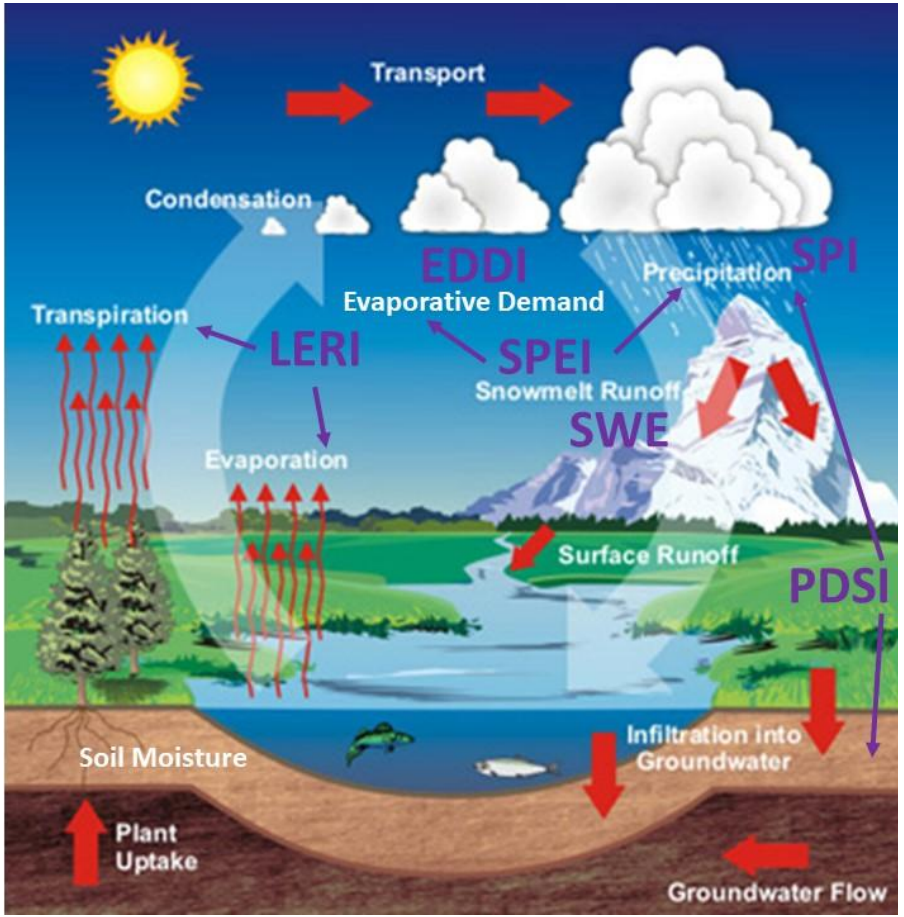
Wynne Moss
wynne@csp-inc.org

Linking ecodrought impacts to drought indices

Shelley Crausbay, *Conservation Science Partners*

Ecologically available water

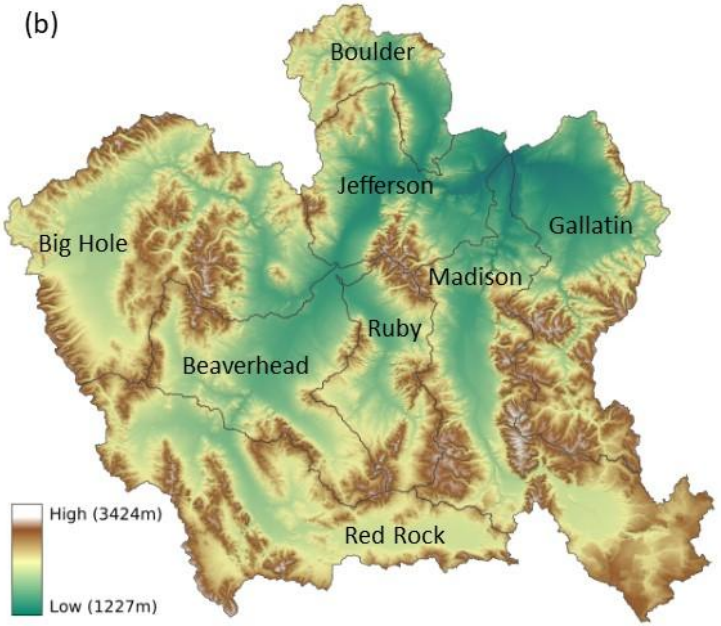




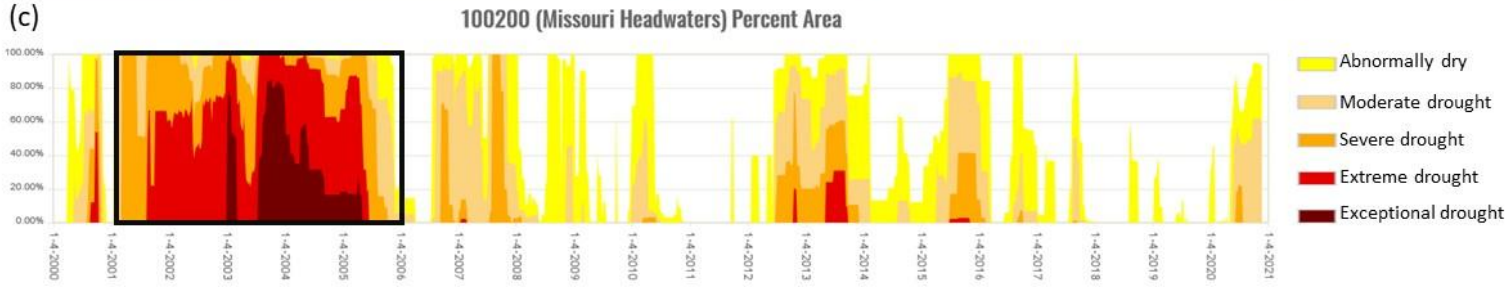
Ecological drought vulnerability

(a)

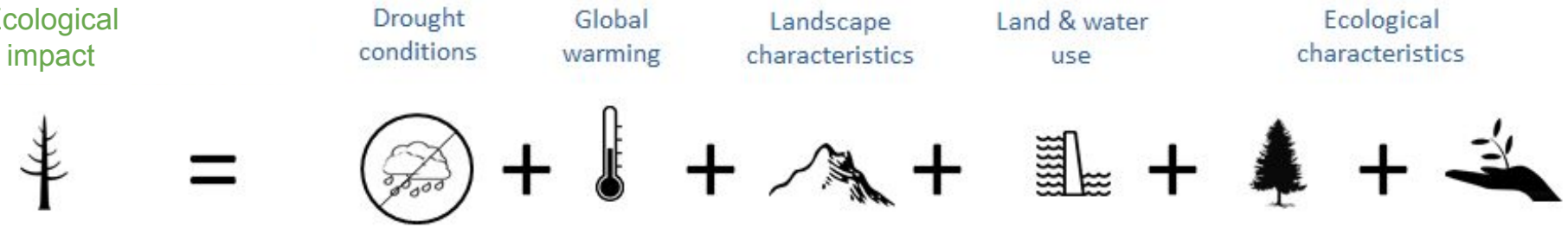
(b)



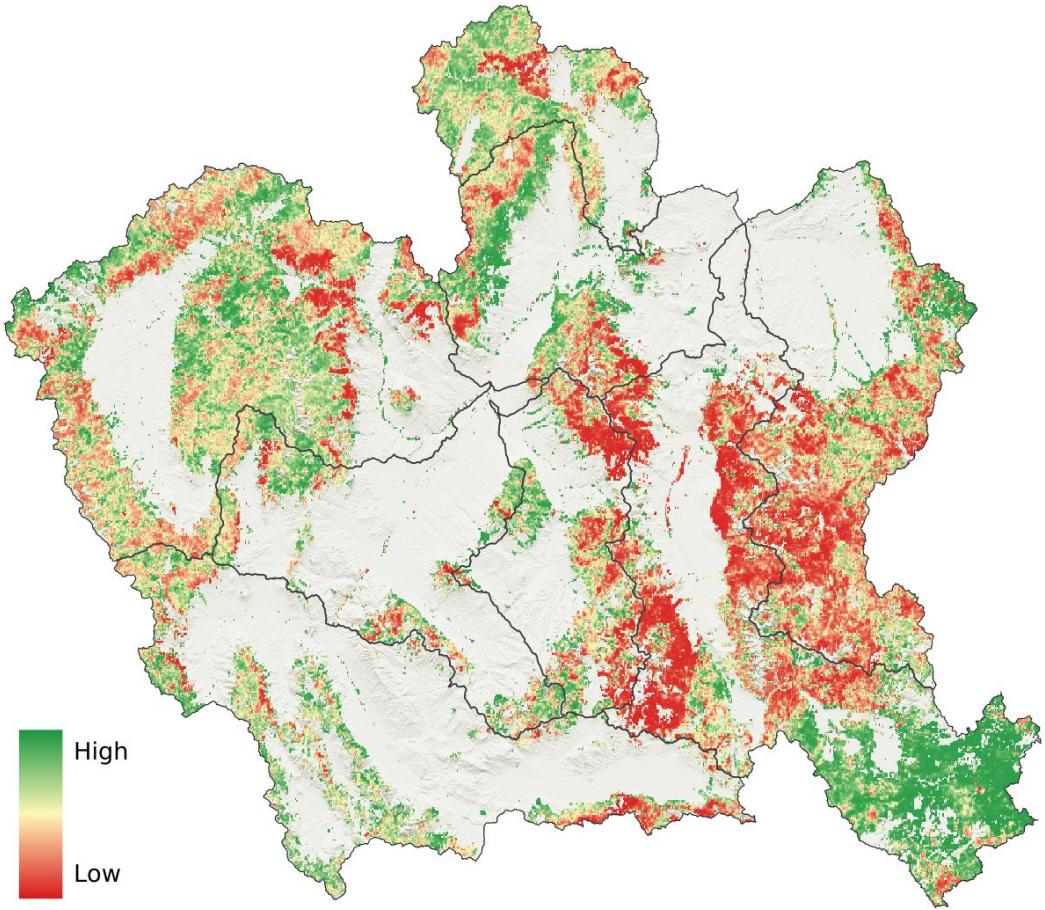
(c)



Ecological drought vulnerability



Trends in forest health over the drought period



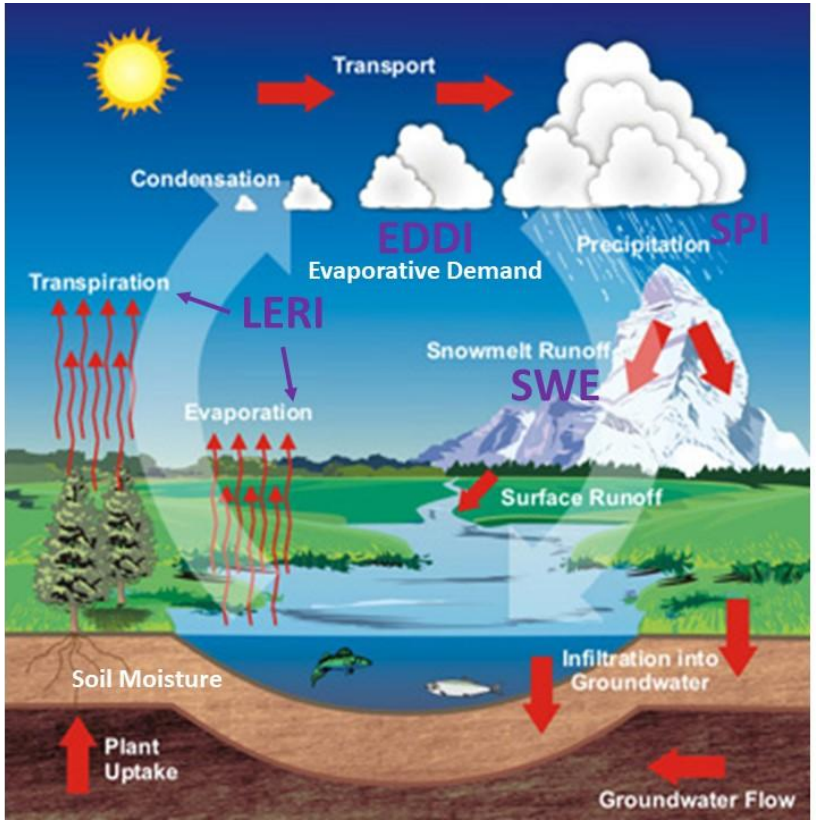
Drought conditions

EDDI (Evaporative Demand Drought Index)

LERI (Landscape Evaporative Response Index)

SPI (Standardized Precipitation Index)

SWE (Snow water equivalent)



Landscape characteristics

Aridity as climatic water deficit (30 yr mean)

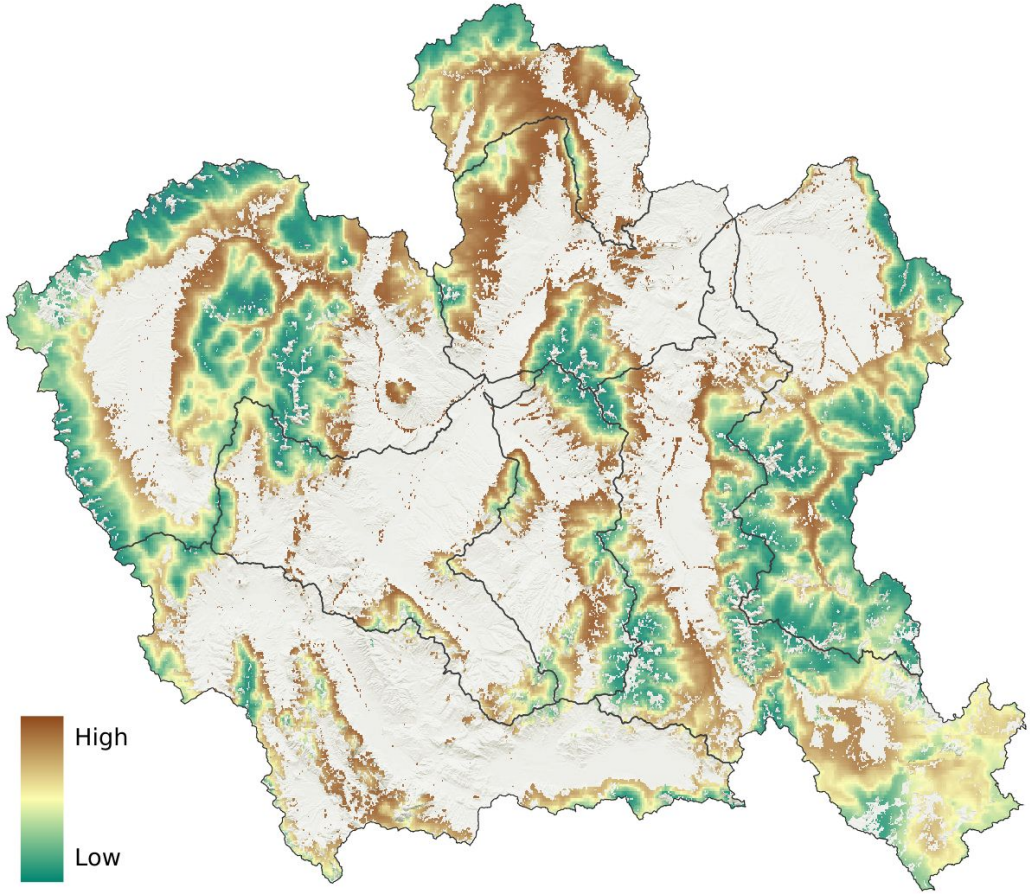
Heat loading index

Slope

TPI

TWI

Aspect



Ecological characteristics

Vegetation type

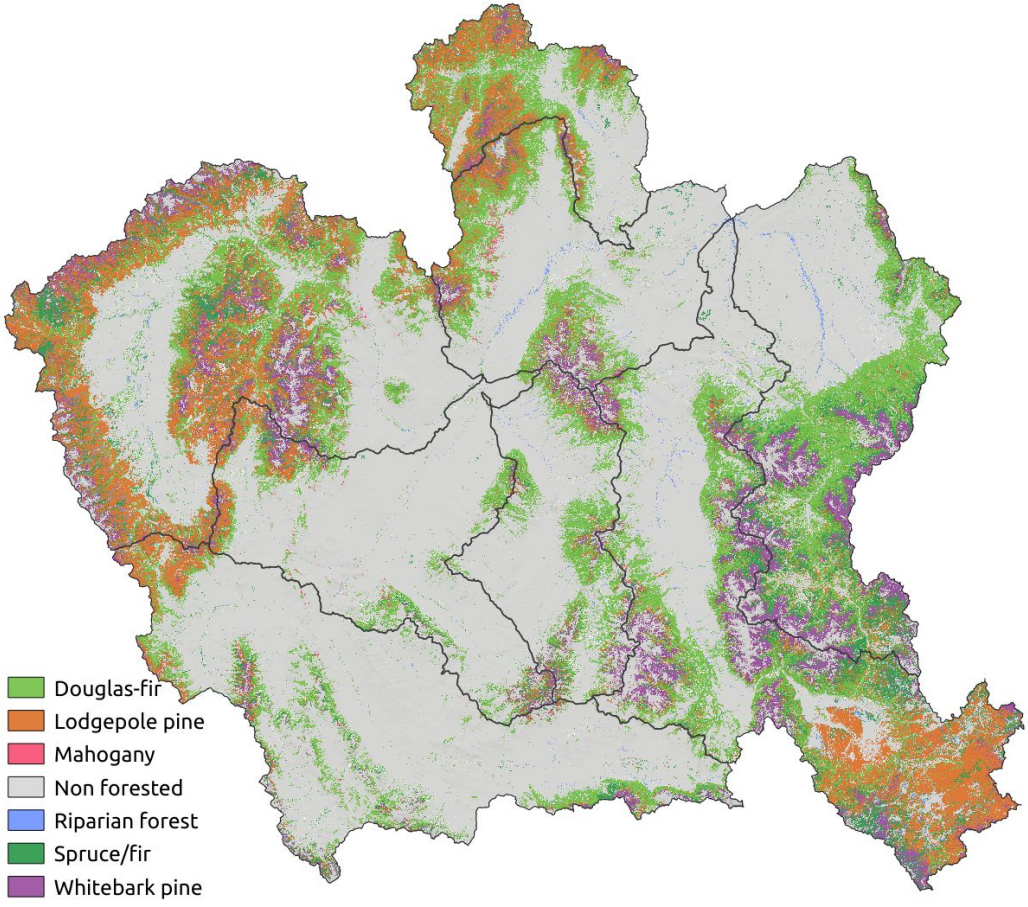
Canopy cover

Time since fire

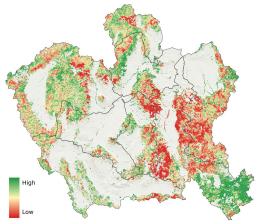
Vegetation height

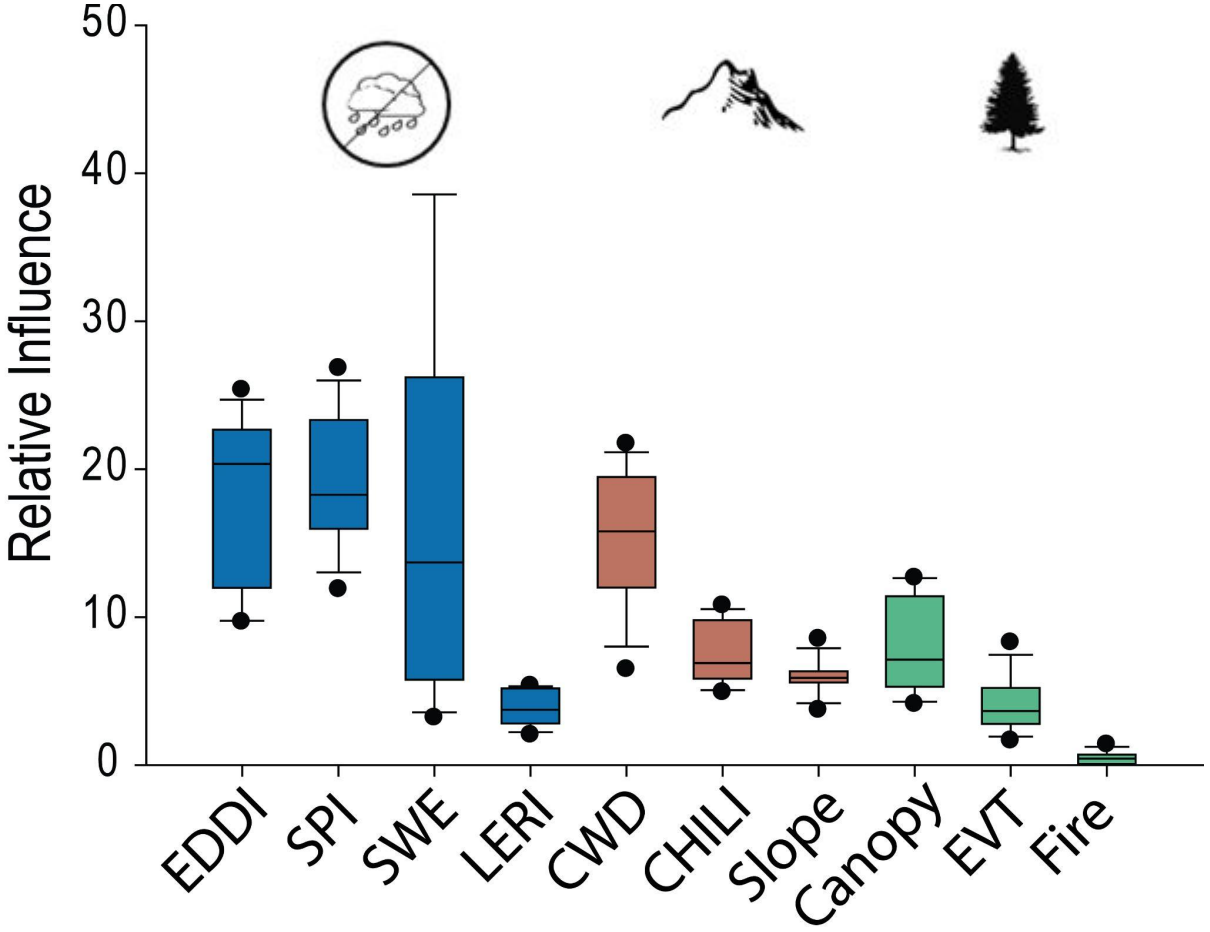
Canopy connectivity

FACTS database (Forest Activity Tracking System)

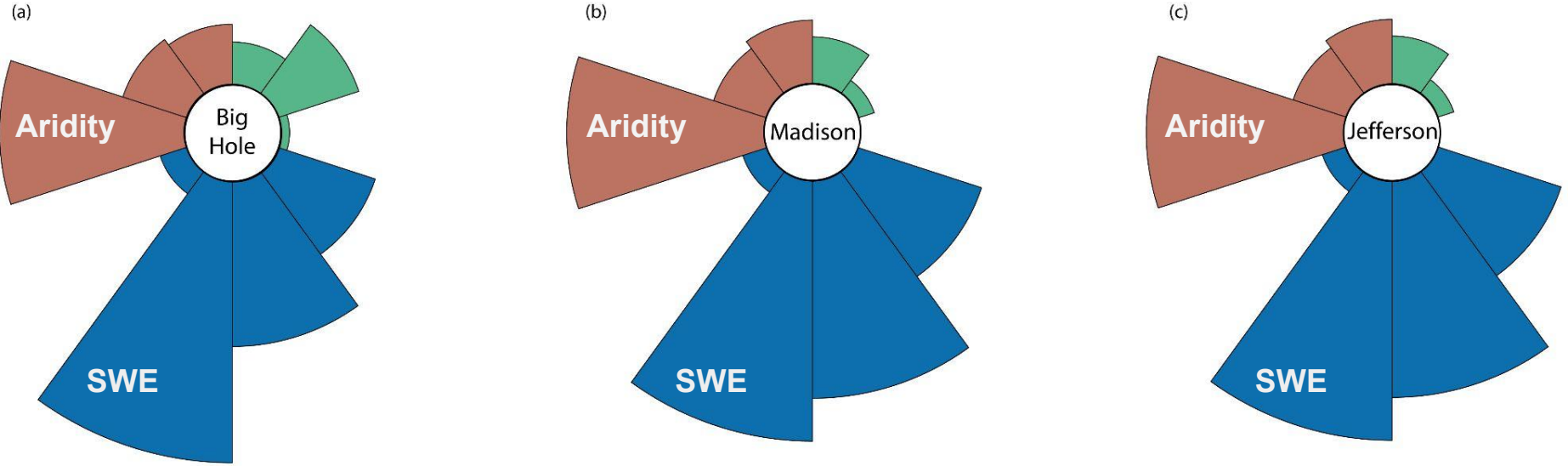


Relative influence on the ecological impact

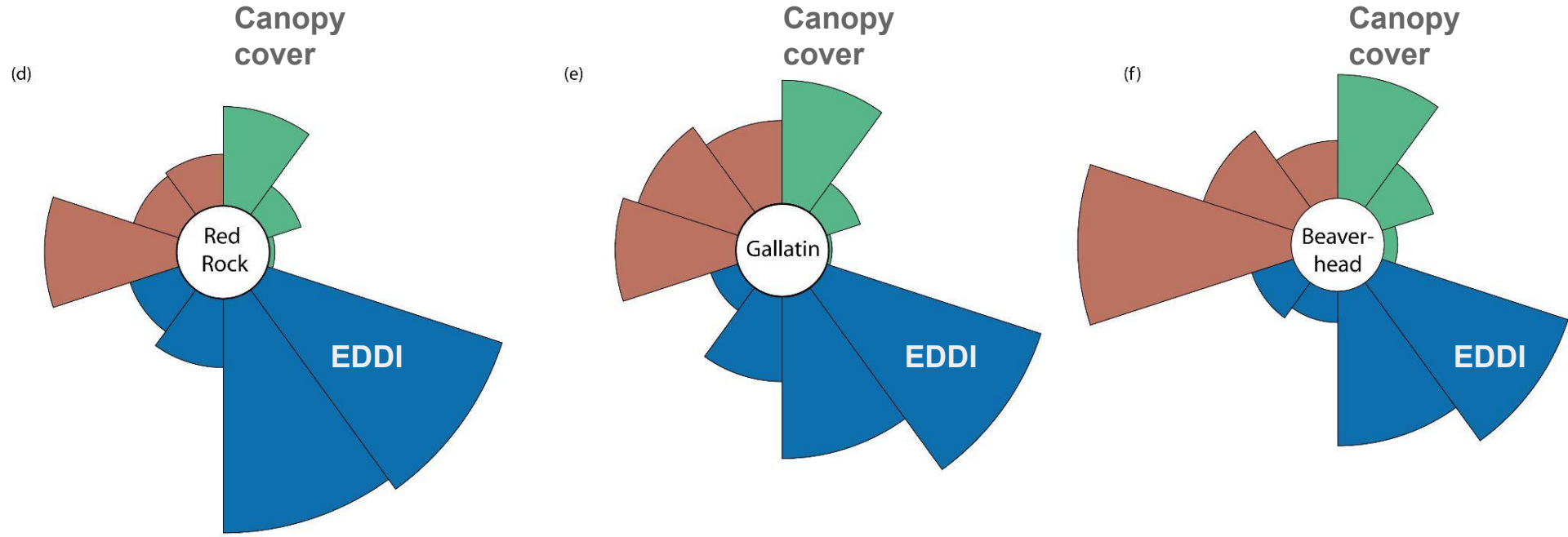




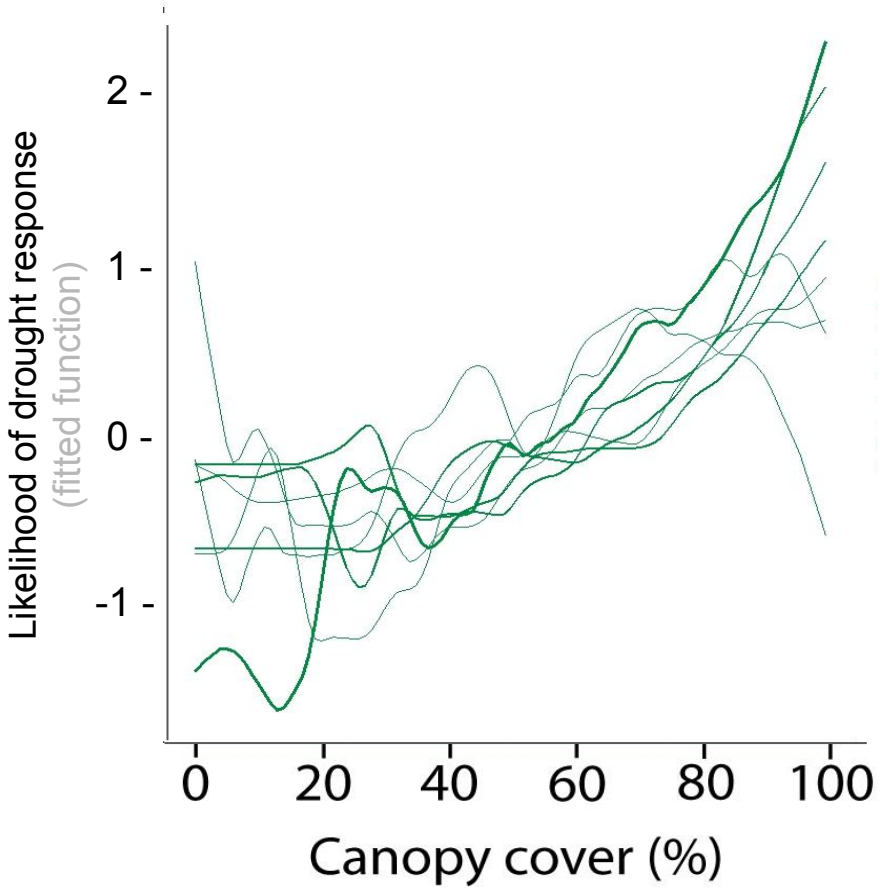
SWE-driven ecodrought

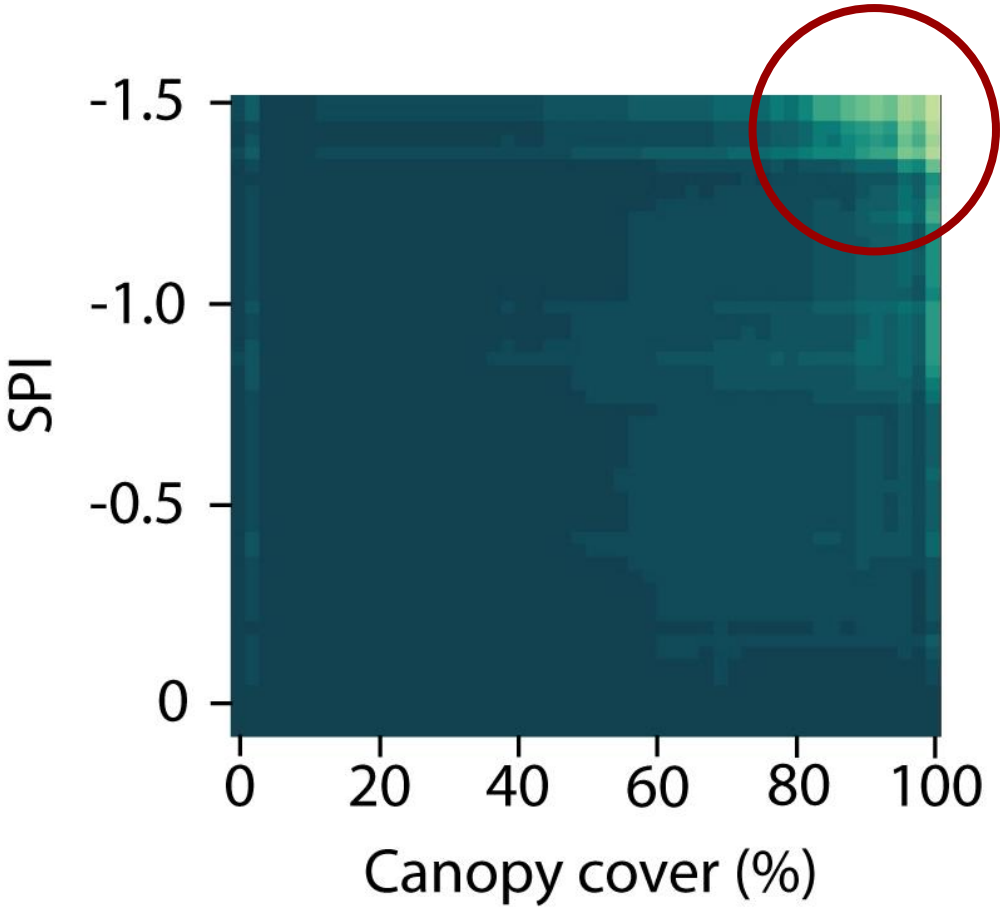


EDDI-driven ecodrought

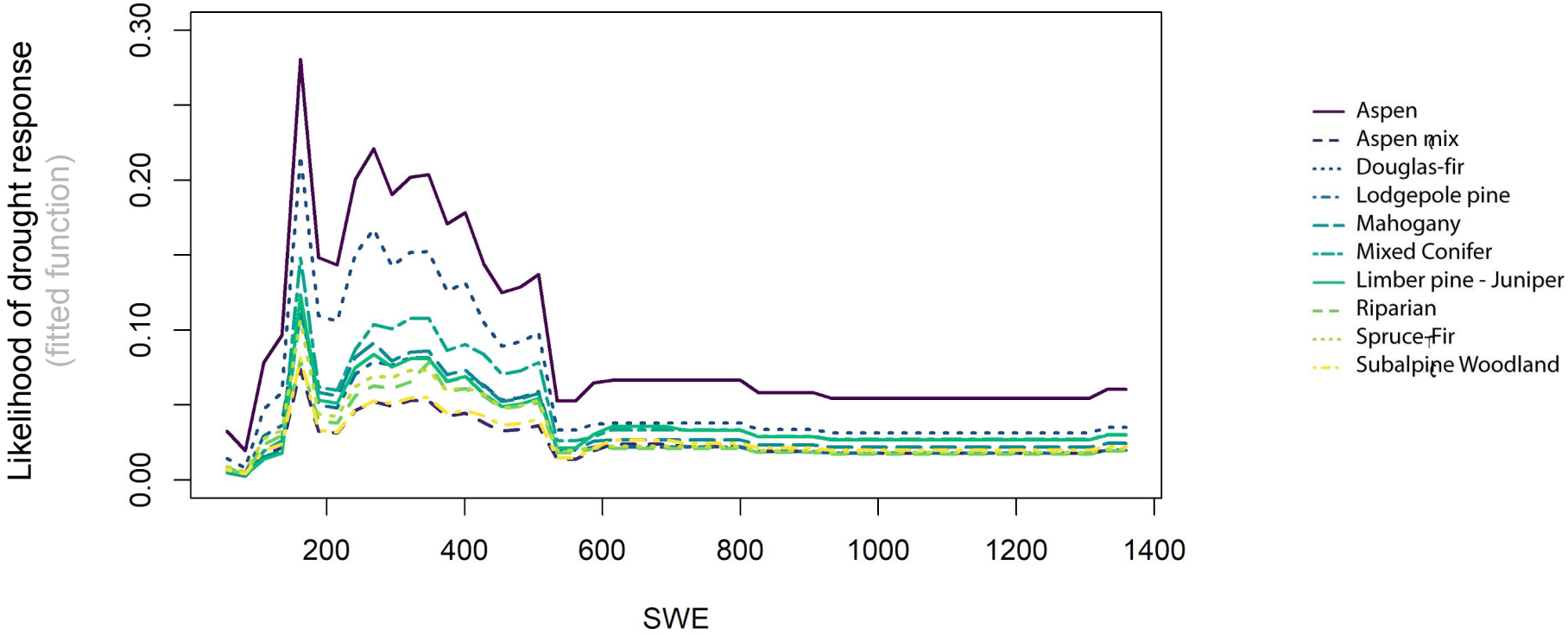


Interactions with drought indices

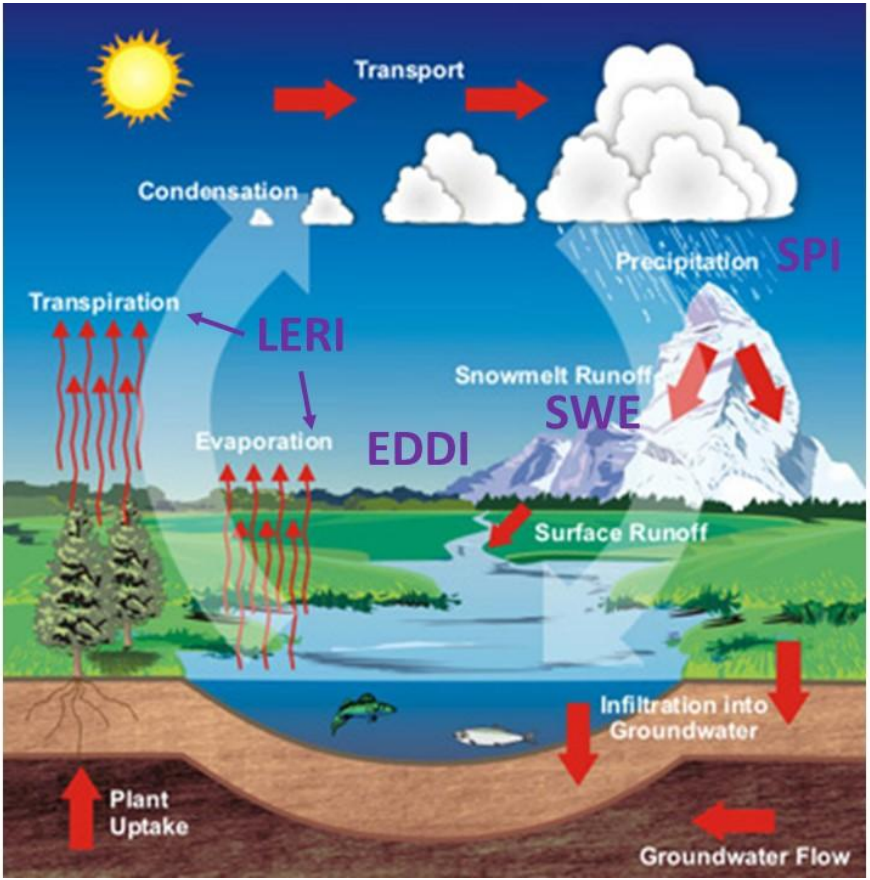


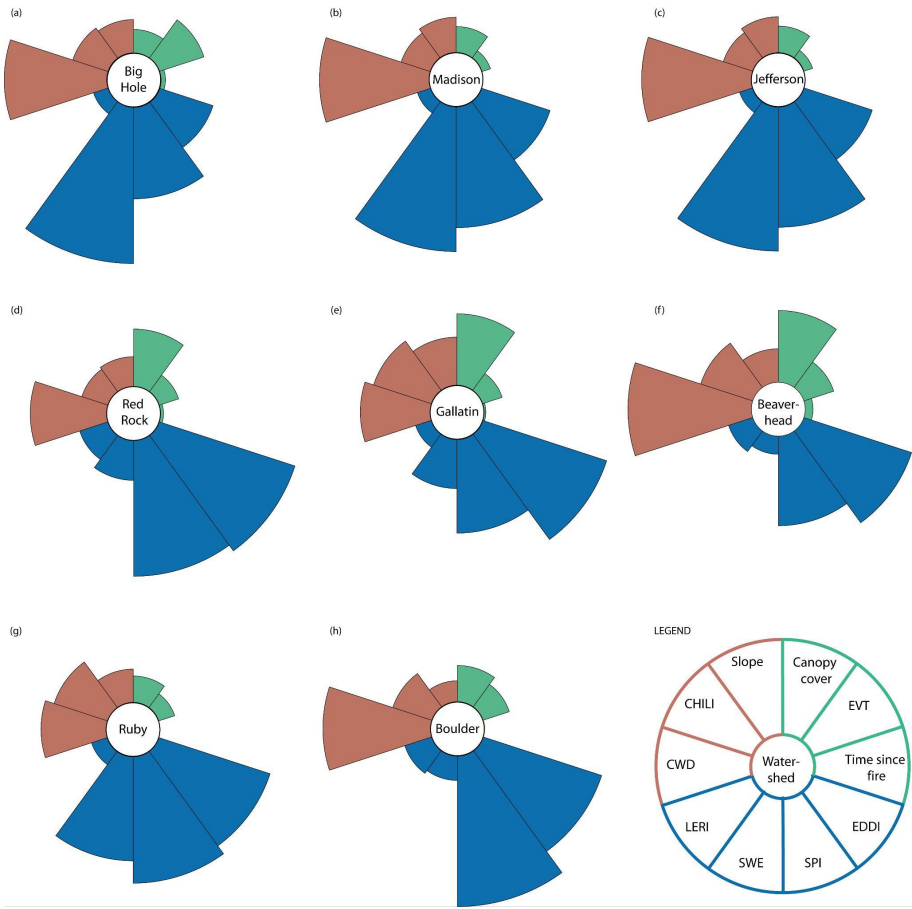


Interactions with drought indices



No one-size-fits-all drought index for ecodrought



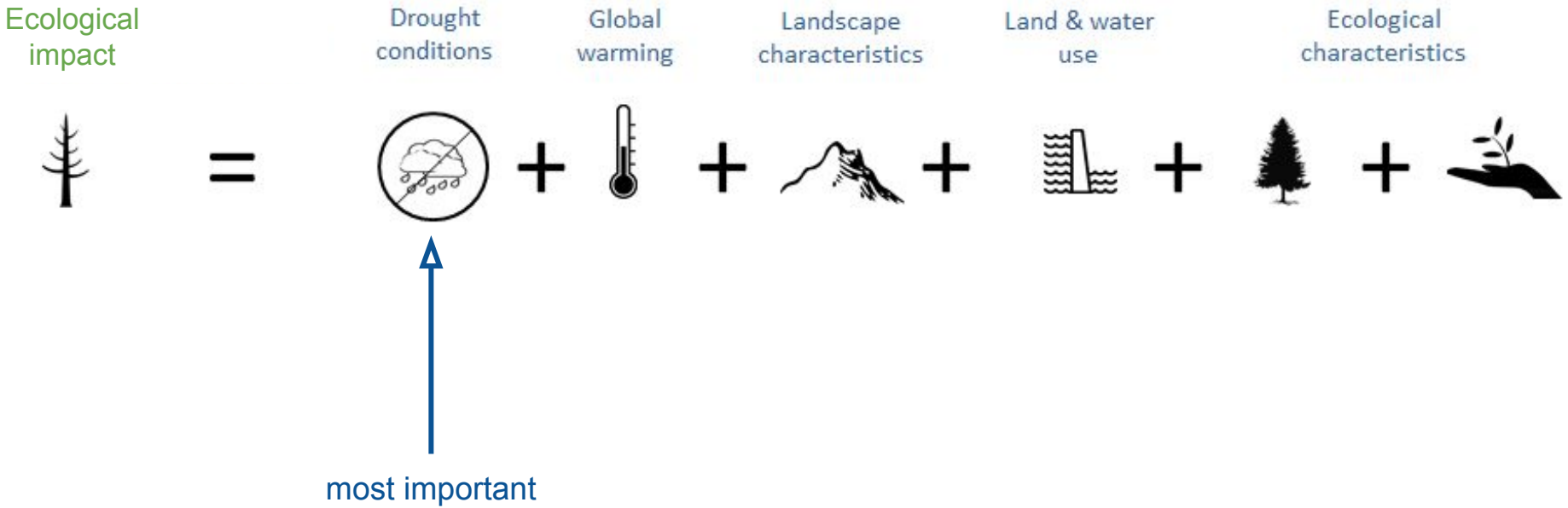


Ecological impact

Drought conditions

=

not this simple

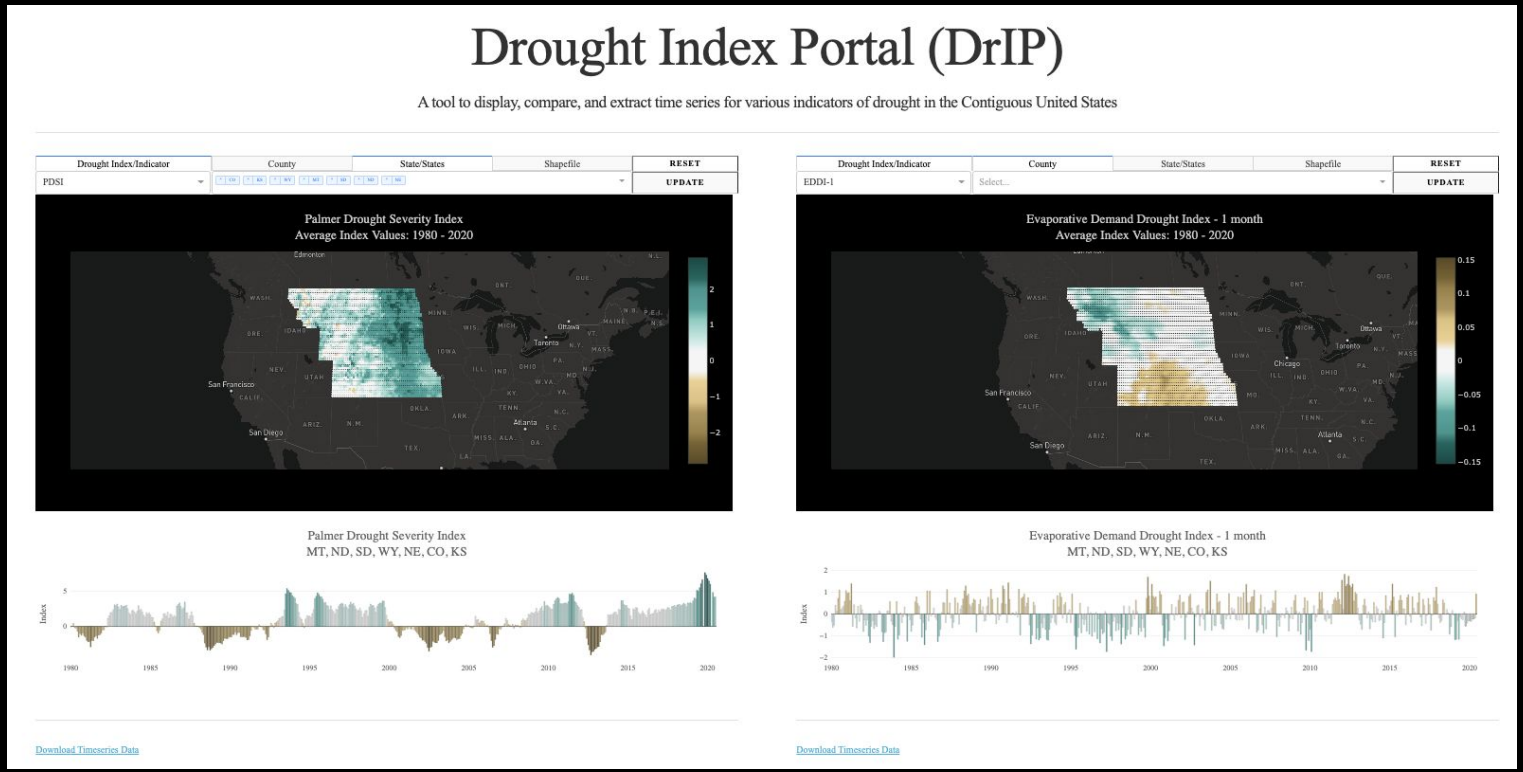

Ecological impact
=
Drought conditions
+
Global warming
+
Landscape characteristics
+
Land & water use
+
Ecological characteristics
+
most important

Shelley Crausbay
shelley@csp-inc.org

Intro to DrIP

Imtiaz Rangwala, *CU Boulder*

https://droughtindexportal.colorado.edu/



Leads: Travis Williams, Imtiaz Rangwala, Bill Travis, Brian Johnson
Other Advisors: Mike Hobbins, Gabriel Senay

Some Vital Functionalities

- Several drought indices
  - PDSI
  - Palmer Z
  - PDSI-sc
  - SPI (1-12 months)
  - SPEI (1-12 months)
  - EDDI (1-12 months)
- Climate variables
  - Tmin
  - Tmax
  - Tmean
  - Precipitation
  - VPD

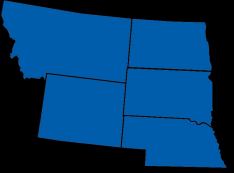
- Plot each drought index using USDM categories

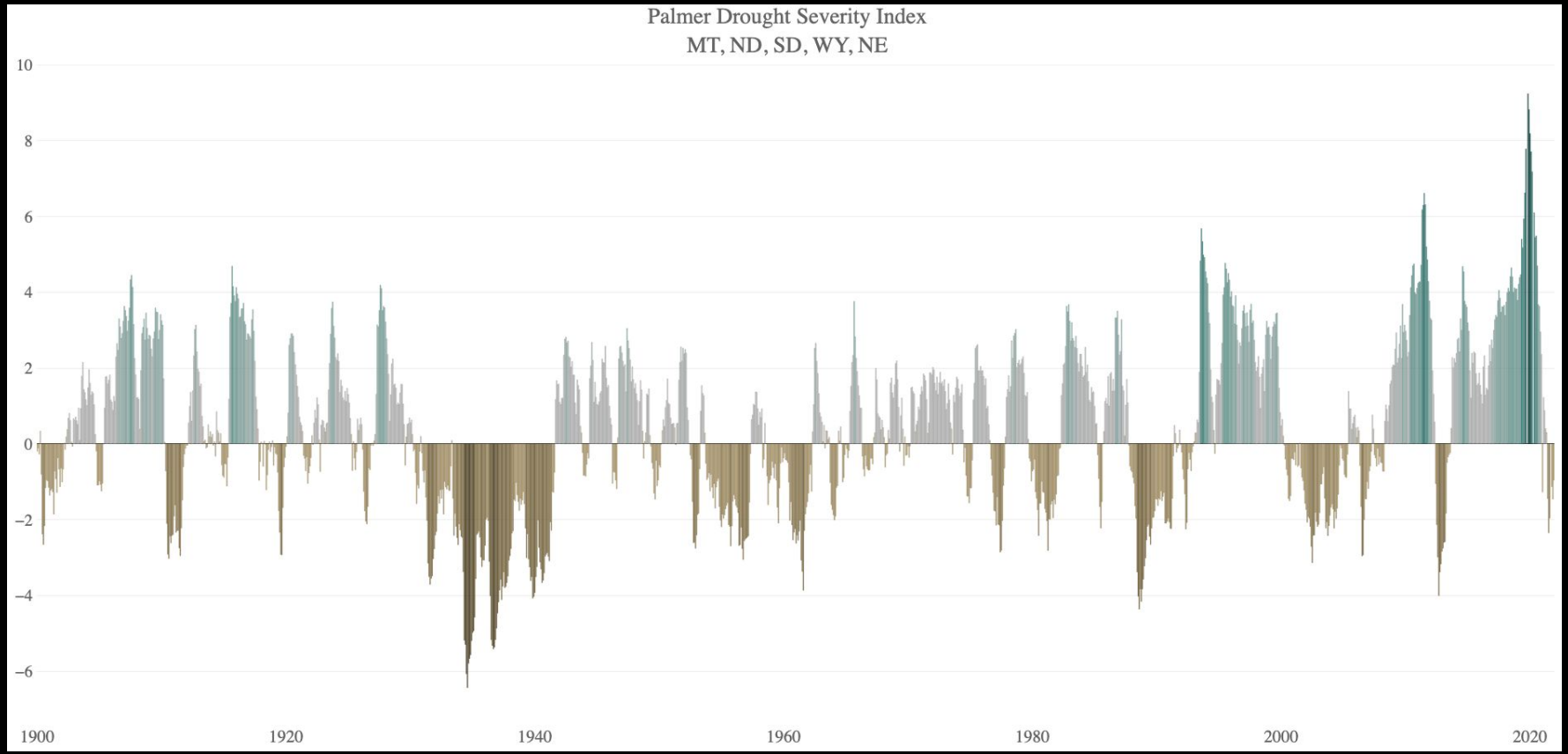
- Estimate Drought Severity Coverage Index (DSCI) for each index

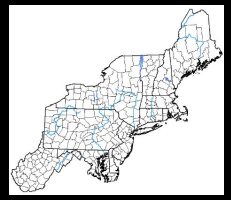
- Region Selection
  - CONUS
  - State
  - County
  - Shapefile
  - Polygon

- Time selection
  - Long historical period (1900-present; updated monthly)
  - Flexibility with month selection

- Download
  - Picture file
  - Time series data

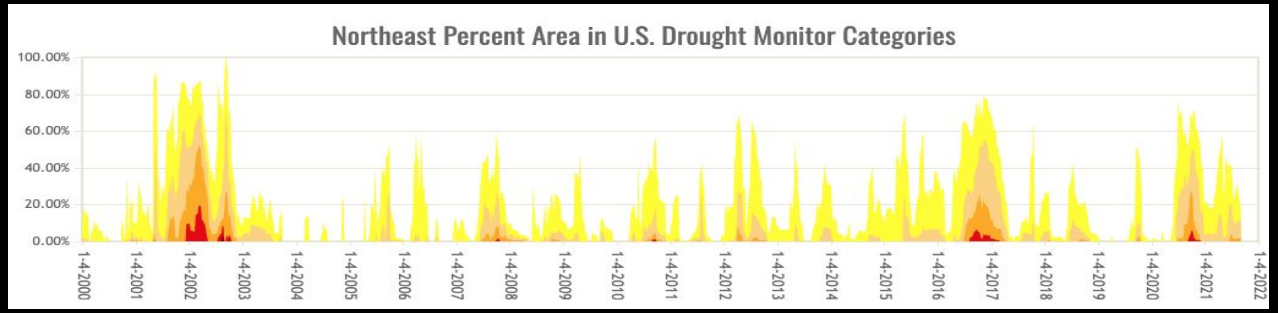



Palmer Drought Severity Index
MT, ND, SD, WY, NE
10
8
6
4
2
0
−2
−4
−6
1900
1920
1940
1960
1980
2000
2020

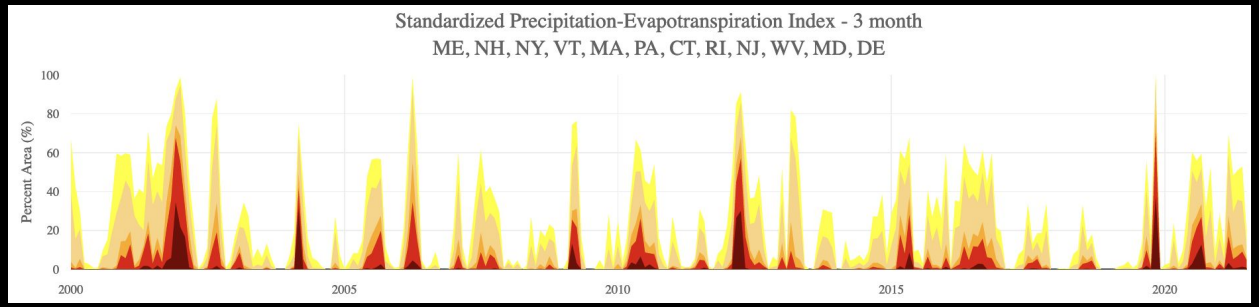


Plotting Drought Indices in UDSM Categories

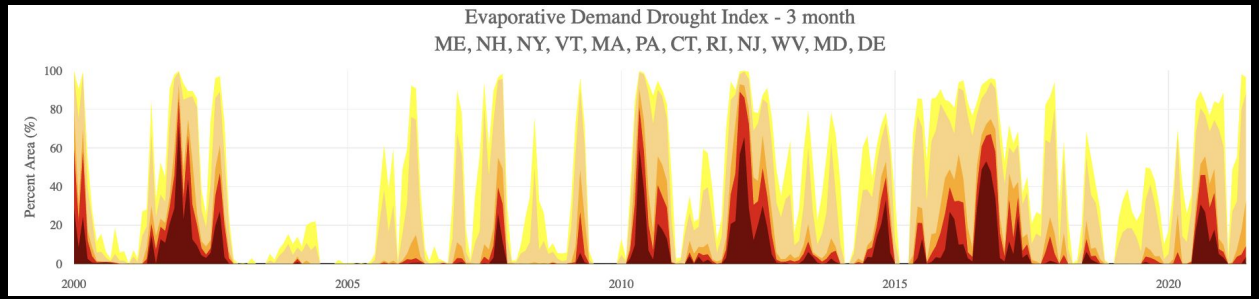
USDM



3 month SPEI



3 month EDDI



https://droughtindexportal.colorado.edu/

DrIP Demo

Exploring the DrIP tool: breakout groups

First, think of a drought that you have personally experienced - you will now explore that drought in more detail using DrIP

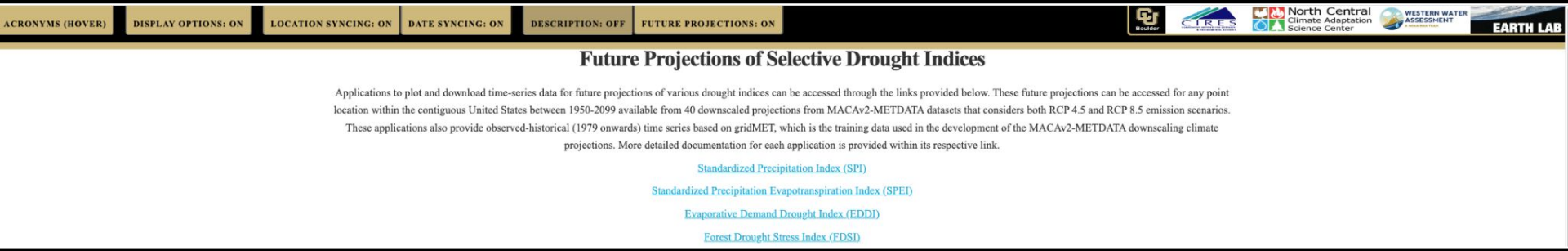
In your breakout rooms:

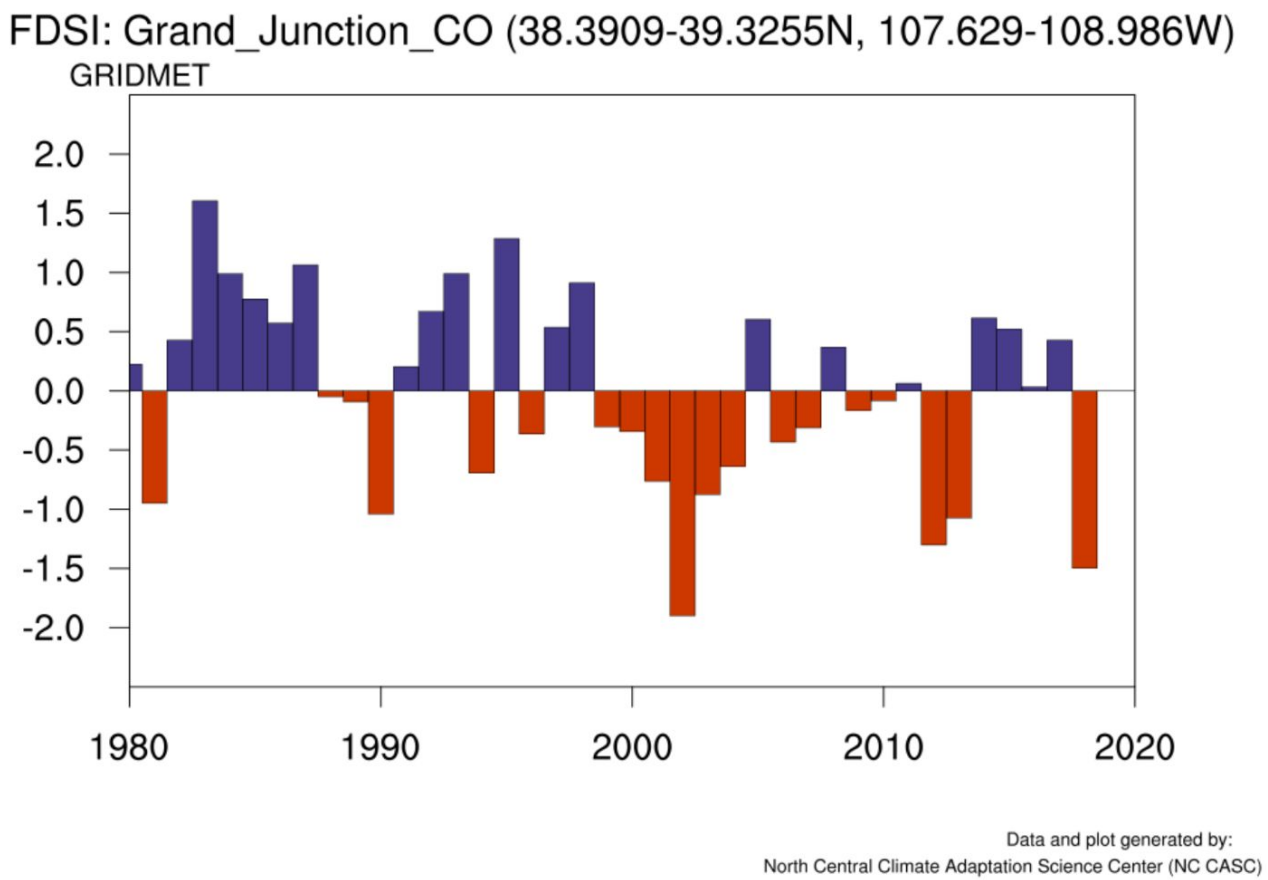
- 10 -15 minutes: explore drought metrics in an area of interest
  - Use our tutorial document to guide you (link in chat)
  - Questions? Ask your fellow breakout participants for help - or use the “ask for help” function in Zoom to call a moderator in.
- 5 - 8 minutes: share your insights in breakout groups
  - What did you learn?
  - Which indices captured your perception of how drought manifested?
  - What did you have trouble with?

Future Projections of Drought Indices

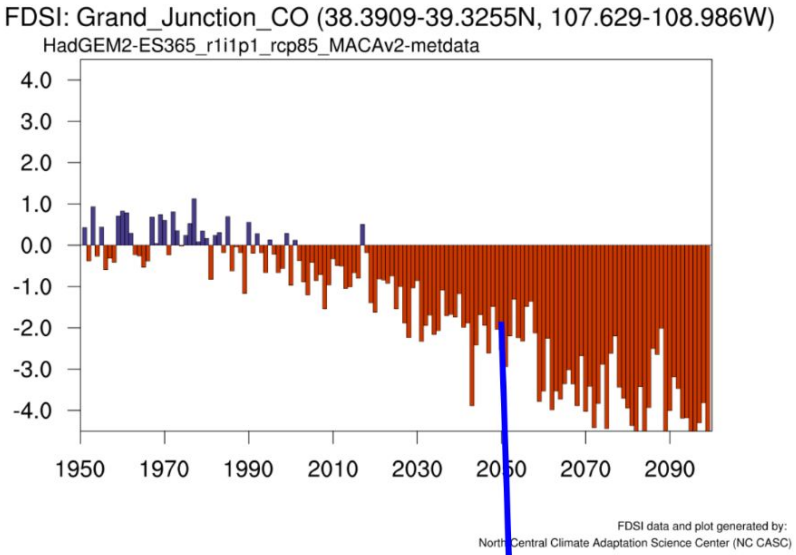
(Point Location only)

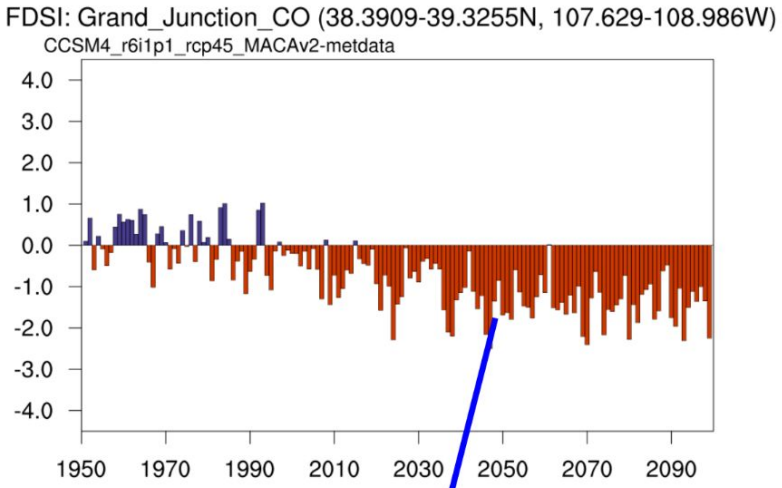
- ❑ SPI
- ❑ SPEI
- ❑ EDDI
- ❑ FDSI





How frequently will we see extreme drought years like 2002, 2018 under different future climate scenarios?



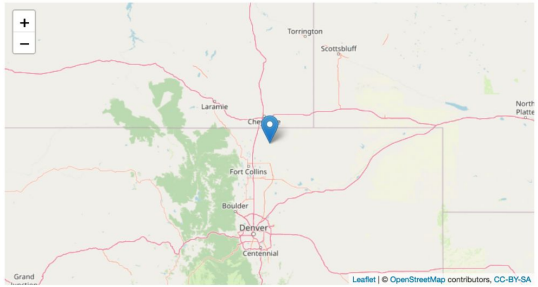


Climate Scenarios by 2050 for DeBeque Phacelia and CO Hookless Cactus

The summary table below describes changes in the future climate by 2050 (2040-2069) relative to the 1971-2000 period under four climate scenarios: **Scenario 1** (HadGEM2-ES365.rcp85), **Scenario 2** (MIROC-ESM-CHEM.rcp85), **Scenario 3** (MIROC5.rcp45) and **Scenario 4** (CCSM4.rcp45)

Climate Metric	Scenario 1	Scenario 2	Scenario 3	Scenario 4	*Historical (1971-2000)*
Frequency of extreme drought years like 2002/2018**	Eight every decade	Nine every decade	Two every decade	Three every decade	***None***

EDDI Projections | Observed - GRIDMET | Future Projections - MACAv2-METDATA | Documentation



Enter Latitude: 40.81

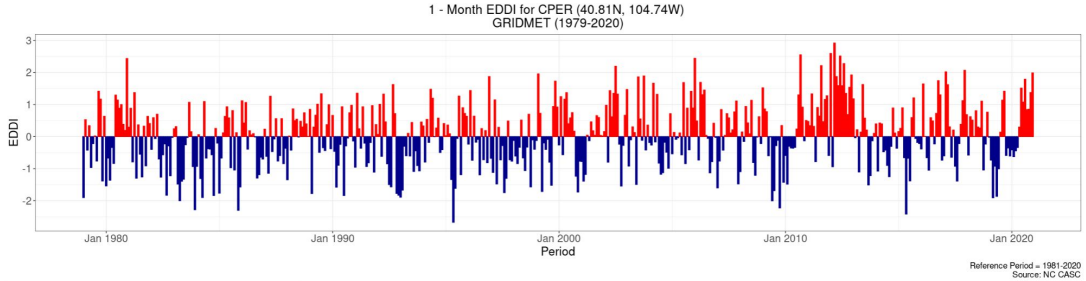
Enter Longitude: -104.74

Enter Name of Location: CPER

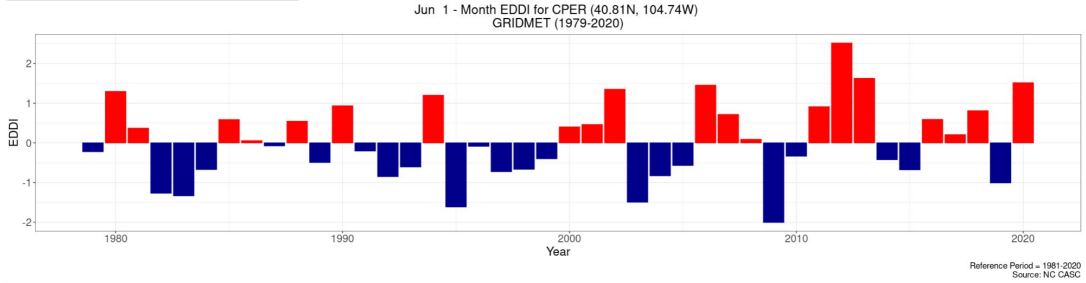
Choose Month: Jun

Choose Scale: 1 - Month EDDI

Please allow few seconds for the app to do the calculations and draw the plots for a given input



Click here to Download the EDDI Data for all months as .csv



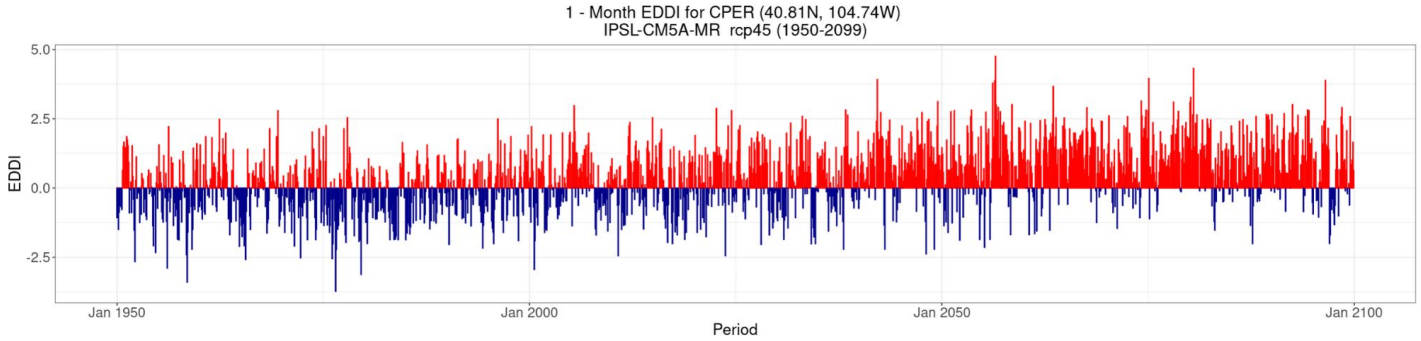
Click here to Download the EDDI Data for the selected month as .csv

EDDI Projections | Observed - GRIDMET | Future Projections - MACAv2-METDATA | Documentation

Choose Model: IPSL-CM5A-MR

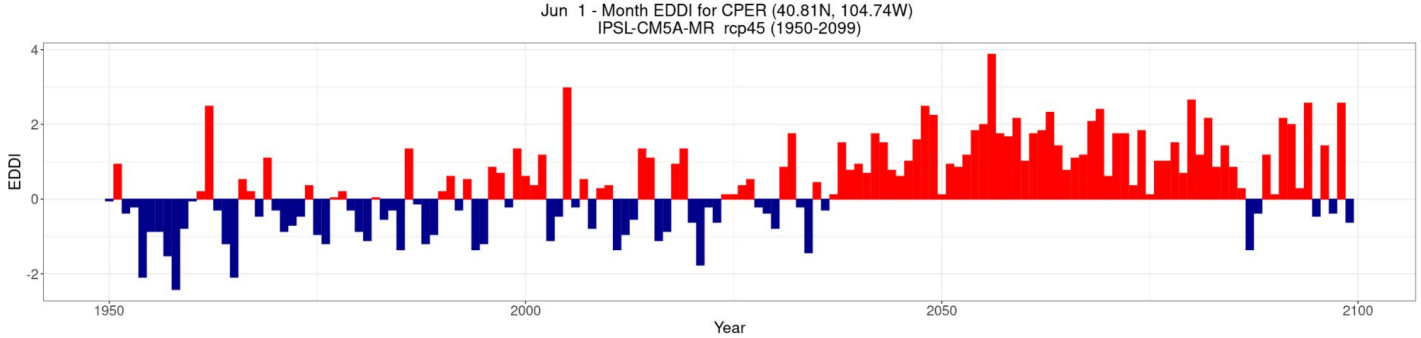
Choose Scenario: rcp45

Please allow few seconds for the app to do the calculations and draw the plots for a given input



Reference Period = 1981-2020
Source: NC CASC

Click here to Download the EDDI Data for all months as .csv



Reference Period = 1981-2020
Source: NC CASC

Click here to Download the EDDI Data for the selected month as .csv

Evaporative Demand Drought Index (EDDI) quantifies standardized departures in Potential Evapotranspiration (PET) at different timescales. For more information on EDDI go to https://psl.noaa.gov/eddi/.

The primary objective of this app is to quantify and visualize the time series of EDDI at different timescales (1-month to 12-month) projected into the future under different climate scenarios for a point location within the Contiguous United States (CONUS). This app also provides observed historical time series of EDDI based on the training data, gridMET, which is used in the development of the MACAv2-METDATA downscaling climate projections data that is considered in this application.

This application allows a user to quantify, visualize and download EDDI for a user-selected month and timescale (1 month - 12 month) for the (i) observed period (1979-2020) and (ii) future climate scenario (1950-2099) available from 40 downscaled projections from MACAv2-METDATA datasets that considers both RCP 4.5 and RCP 8.5 emission scenarios.

Datasets

Monthly potential evapotranspiration data is obtained from the following sources:

Observations (1979-2020): gridMET (http://www.climatologylab.org/gridmet.html)

Future Projections (1950-2099): MACAv2-METDATA (http://www.climatologylab.org/maca.html)

Methodology

Estimation of EDDI (as z-scores) uses the normal (gaussian) distribution of potential evapotranspiration. **Both observed and projected EDDI time series are calculated relative to the 1981-2020 reference period.**

How to use the app

Enter the latitude and longitude of your point location of interest. Select the month and timescale for which EDDI has to be computed. For future projections, select the desired climate scenario, i.e. model name and RCP, to calculate and visualize the time series.

Output

This application generates and provides the following output:

- Monthly EDDI time series for a specified timescale (i.e. anywhere between 1-month and 12-month EDDI) for both observed and projected period
- EDDI time series only for the selected month and aspecified timescale for both observed and projected period

Contact

If you have any questions please contact Imtiaz Rangwala (Imtiaz.Rangwala@colorado.edu) or Prasad Thota (Samba.Thota@colorado.edu)

How to cite this app

If you use plots or data from this app in publications, we ask that you acknowledge the North Central Climate Adaptation Science Center. Example template:

"*Image/data provided by the North Central Climate Adaptation Science Center (NC CASC), University of Colorado-Boulder accessed at https://nccasc.shinyapps.io/EDDI_Projections/ on yyyy-mm-dd.*"