Ecological Drought: Concepts, Drought Metrics & Tools

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Shelley Crausbay, Conservation Science Partners
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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.

Aridity

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

Quantified in various ways:
- $\frac{\text{AET}}{\text{PET}}$
- $\text{PET} - \text{AET}$
- $\text{PET} - \text{Precipitation}$

AET = actual evapotranspiration; PET = potential evapotranspiration

Image: Basche & Edelson 2017
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
- Extent of Aridification
Novel droughts emerging during the 21st century from climate heating

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)
## Standardized Drought Indices

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

*Potential Evapotranspiration, **Vapor Pressure Deficit
2017 Northern Plains Drought
Palmer Drought Severity Index
Sheridan County, MT

Standardized Precipitation-Evapotranspiration Index - 6 month
Sheridan County, MT

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.
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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.

Hydrologic - streamflows, water quality, and reservoir levels decrease.

Agricultural - productivity and crop survival decreases.

Socio-economic - impacts increase to ecosystem services related to recreation, wildlife, and carbon sequestration.

Ecological drought is a water deficiency that creates ecosystem vulnerability, and affects ecological and landscape characteristics, land and water use, and resource management.
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…”

Crausby 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

Ecological impact = Drought conditions + Global warming + Landscape characteristics + Land & water use + Ecological characteristics
Impacts of ecological drought - plant physiological stress

- 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)

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
Climate variability

Meteorological drought

Soil moisture drought

Hydrological drought

Ecological impacts

Anthropogenic climate change

Land use change

Irrigation

Modification of flows

Human water use

Modified from Van Loon et al. 2016, Nature Geoscience
Shifting hydrological drought conditions

Crausbay et al. 2020, *One Earth*
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
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Linking ecodrought impacts to drought indices

Shelley Crausbay, Conservation Science Partners
Ecologically available water
Ecological drought vulnerability

(a) Map showing the location of the area under study.
(b) Detailed map of the area, highlighting different regions such as Boulder, Jefferson, Gallatin, Big Hole, Madison, Ruby, and Red Rock.
(c) Graph representing the percent area of the Missouri Headwaters (100200) under different drought conditions from 2013 to 2019. The graph uses color codes to indicate the severity of drought: Abnormally dry, Moderate drought, Severe drought, Extreme drought, and Exceptional drought.
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

(a) Big Hole
(b) Madison
(c) Jefferson

Aridity

SWE
EDDI-driven ecodrought
Interactions with drought indices

Likelihood of drought response (fitted function)

Canopy cover (%) vs. SPI

Canopy cover (%) vs. Likelihood of drought response
Interactions with drought indices

Likelihood of drought response (fitted function)
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
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Intro to DrIP

Imtiaz Rangwala, CU Boulder
Drought Index Portal (DrIP)
A tool to display, compare, and extract time series for various indicators of drought in the contiguous United States

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

https://droughtindexportal.colorado.edu/
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
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

Future Projections of Selective Drought Indices

Applications to plot and download time-series data for future projections of various drought indices can be accessed through the links provided below. These future projections can be accessed for any point location within the contiguous United States between 1950-2009 available from 40 downscaled projections from MACAv2-METDATA datasets that considers both RCP 4.5 and RCP 8.5 emission scenarios.

These applications also provide observed-historical (1979 onwards) time series based on gridMET, which is the training data used in the development of the MACAv2-METDATA downscaling climate projections. More detailed documentation for each application is provided within its respective link.

- Standardized Precipitation Index (SPI)
- Standardized Precipitation Evapotranspiration Index (SPEI)
- Evaporative Demand Drought Index (EDDI)
- Forest Drought Stress Index (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)

<table>
<thead>
<tr>
<th>Climate Metric</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
<th>Scenario 4</th>
<th>Historical (1971-2000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency of extreme drought years like 2002/2018**</td>
<td>Eight every decade</td>
<td>Nine every decade</td>
<td>Two every decade</td>
<td>Three every decade</td>
<td>None</td>
</tr>
</tbody>
</table>
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:

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 specified 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.*