DROUGHT PREDICTION FOR NORTHERN GREAT PLAINS STREAMS

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DROUGHTS ARE NATURAL HAZARDS

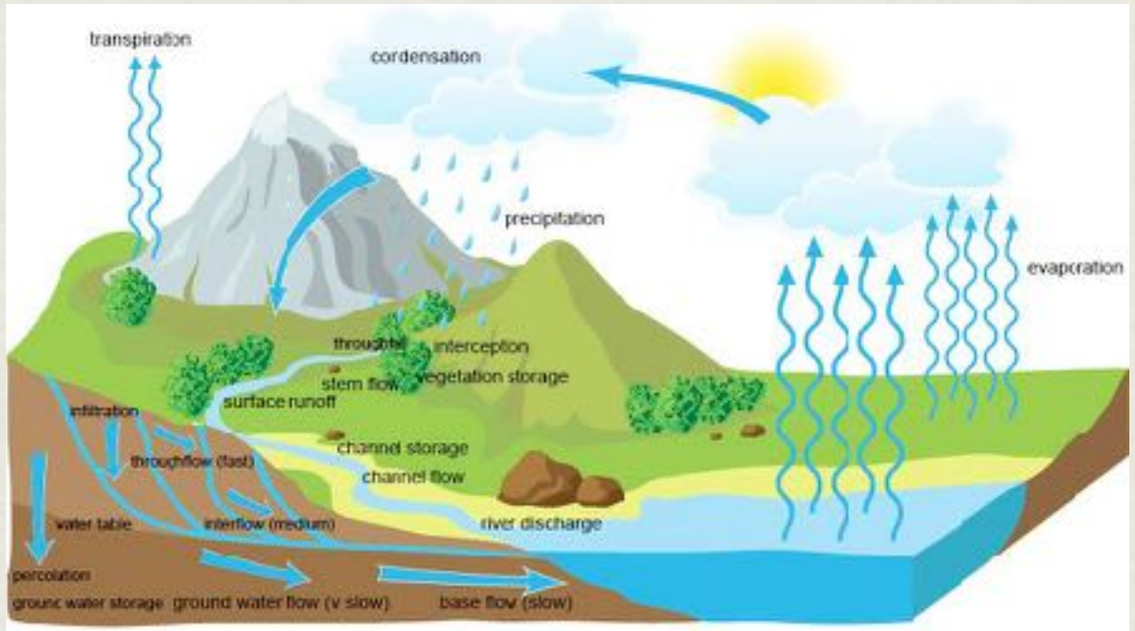
- Droughts are temporary water deficiencies determined relative to prevailing normal local conditions.

- **Meteorological drought:** precipitation deficit that *leads to*:

- **Agricultural drought**: inadequate soil moisture to meet evapotranspiration & vegetation demands that *leads to*:

- **Hydrological drought:** surface & ground water deficit that recovers after precipitation and soil moisture returns to normal conditions

Generalized watershed hydrology



Source: www.alevelgeography.com

AFFECTING HUMAN AND ECOLOGICAL COMMUNITIES

Drought results in stakeholder conflicts

- **Socioeconomic drought:** water demand exceeds water supply—
  - *Caused by* growing human populations, economic development,
  - *Leading to* over-allocation, competing beneficial uses & non-sustainable groundwater use

- **Ecological drought:** ecosystem stress & adversity to plants and animals—
  - *Caused by* flow reduction, higher water temps & salinity;
  - *Resulting from* hydrologic drought, undervaluation of ecosystem services & non-sustainable groundwater use

Extreme drought in South Africa, 2017-18

https://www.timeslive.co.za/news/south-africa/2017-11-16-sa-still-plagued-by-drought/

INDICES CAN HELP TO UNDERSTAND & COMMUNICATE DROUGHT

Drought indices relate dry and wet periods to their frequency and duration

- Standardized Precipitation Index (SPI) for meteorological drought
- Standardized Precipitation Evapotranspiration Index (SPEI) for soil moisture drought —“climate water balance”
- Streamflow drought index (SDI) for hydrological drought

Generalized Calculation Approach

1. Sum daily hydrologic time-series observations by month
2. Calculate probability-weighted moments (PWMs) from the monthly time-series,
3. Fit a distribution using the PWMs
    - SPI - Pearson III distribution
    - SPEI- Log-logistic distribution
    - SDI - Log-Pearson III distribution

DROUGHT IS COMPLEX & POORLY UNDERSTOOD

- Most **small watersheds are ungauged** with no available information [1]

We lack understanding of:

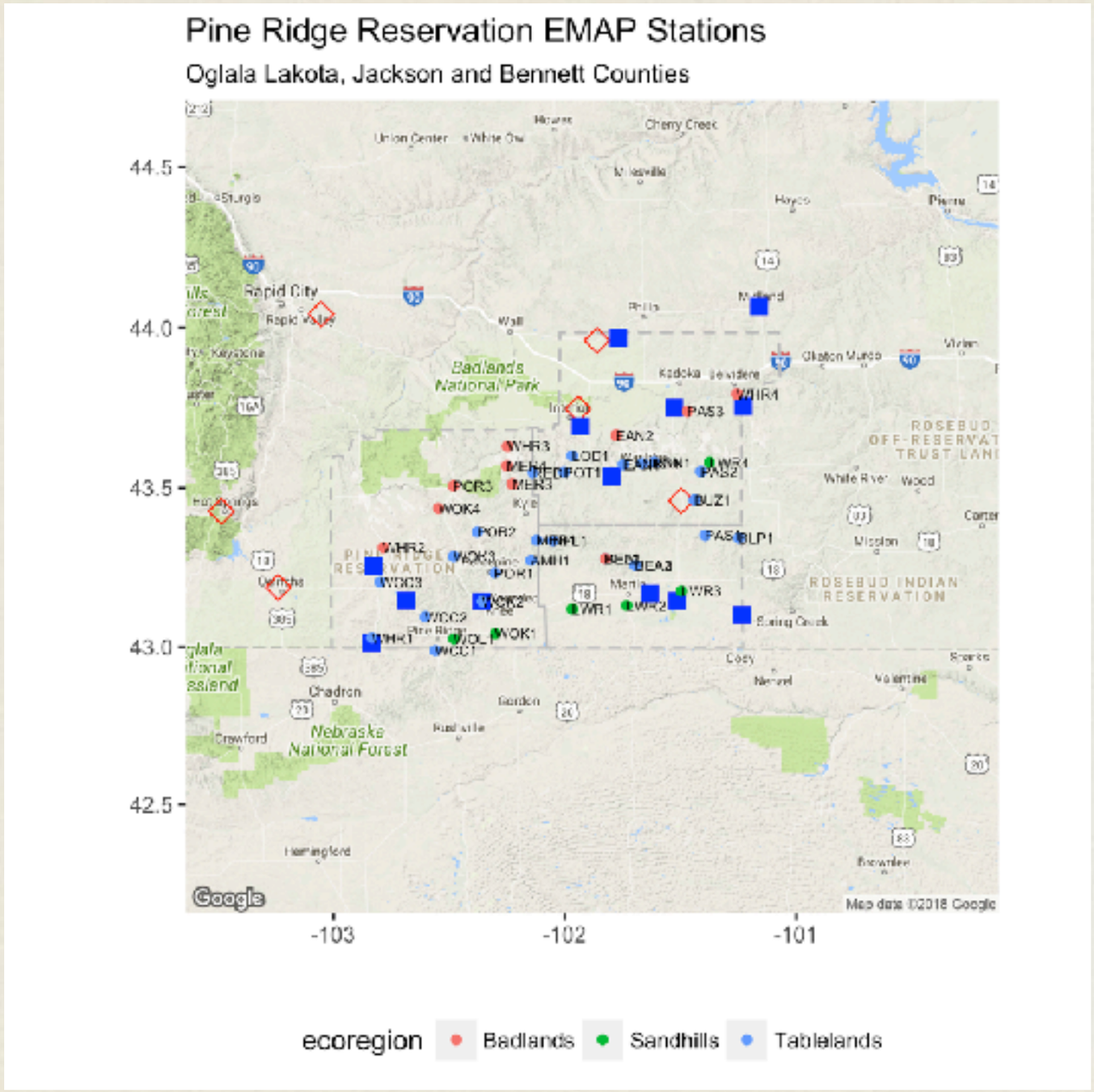
- processes & feedbacks at the watershed-scale,
- how heterogeneity of scale, time and space affects processes [1]

- "We understand how freshwater communities persist during normal and high flows better than we understand the ecological effects of droughts" [2]

- **We should improve** information transfer approaches (**downscaling**) from gauged to ungauged watersheds [1]

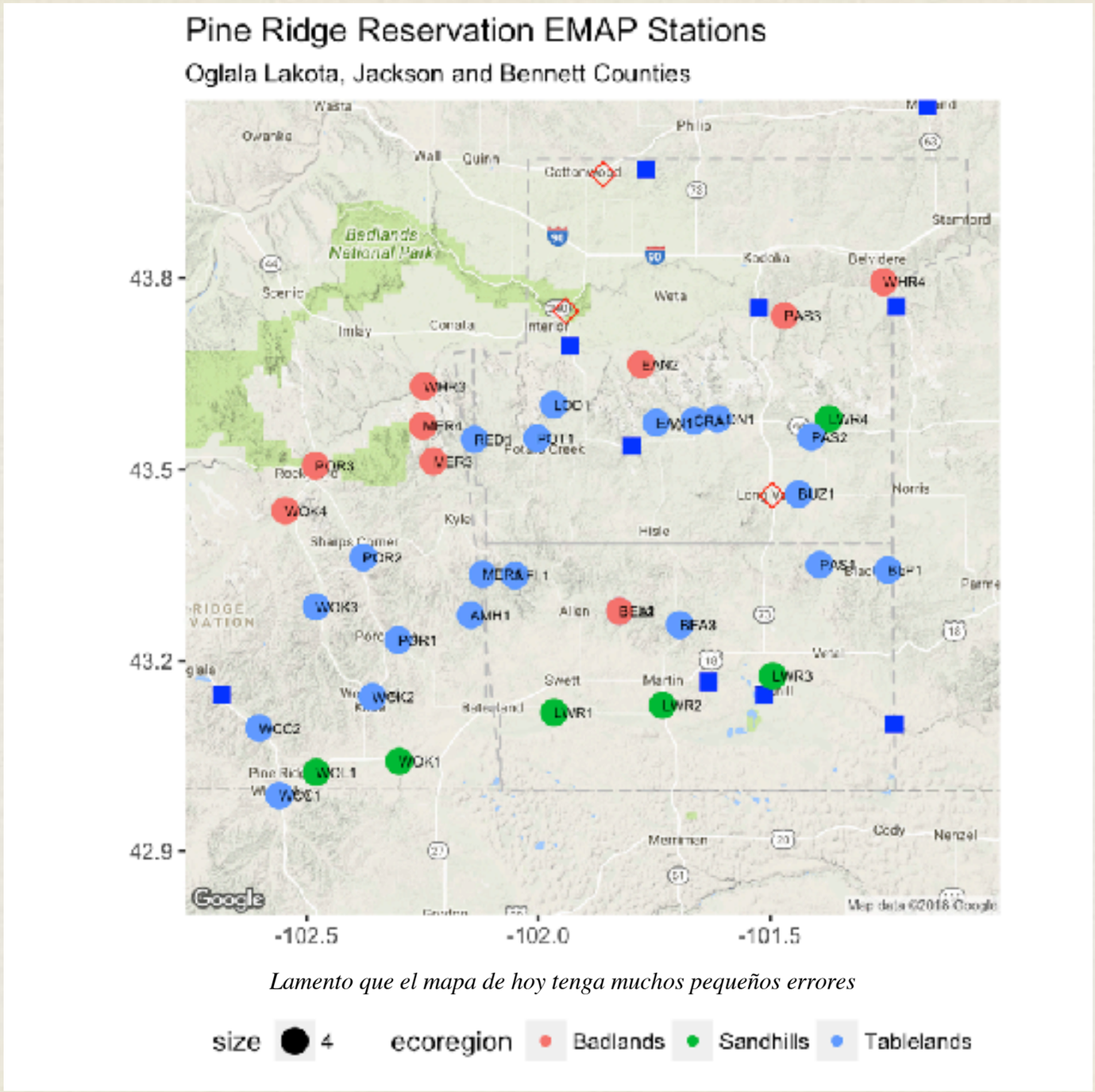
1. A decade of Predictions in Ungauged Basins (PUB)—a review (Hrachowitz et al. 2014)
2. PS Lake - Drought and Aquatic Ecosystems: *Effects and Responses*

PINE RIDGE RESERVATION DESCRIPTION



- **Climate:** semi-arid cold mid-latitude steppe (BSk); Precip = 15.8 to 17.2 inches/yr (400 - 450 mm/yr)
- **Elevation:** 2,250 to 3,700 ft (690 - 1,130 m)
- **Land-cover:** Mixed-grass prairie understory with pine savanna on north slopes
- **Stream-type:** Low gradient, dune-ripple morphology streams
- **Land-use:** cattle ranching with minor grass & row crops (N-SE)

ANOTHER LOOK



Lamento que el mapa de hoy tenga muchos pequeños errores

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PINE RIDGE RESERVATION HAS HETEROGENEOUS WATERSHEDS

Ecoregion & Stratigraphy	Topography	Hydrolologic Regime	Stream bed & water clarity	Floodplain & Riparian zone
Nebraska Sand Hills, Q_{SH}	Stabilized sand dunes	Base-flow dominated	Sand, Low turbidity	Well-developed, Little overstay
Keya Paha Tablelands, T_A	Soft silty-sandstone plains	Mixed-flow dominated	Silt, Low turbidity	Moderate to well-developed, Ash-elm forest
Pine Ridge Escarpment, T_A	Sandstone outcrops		Cobbles to silt, Low turbidity	
White River Badlands, T_{WR}	Sod tables overlying highly-dissected expansive-clay soils	Event dominated	Silt to clay, High turbidity	Constantly adjusting, Cottonwood-willow woodlands

PINE RIDGE AQUATIC COMMUNITY SHIFT IS CORRELATED WITH DROUGHT

General Theory

- Streamflow varies in time (floods, droughts) & space (climate, geology, flow abstractions)

- Pollutants, habitat degradation, and streamflow deficits **stress aquatic communities**, which are:
    - Resistant and resilient to pulses (floods)
    - Resilient to presses (seasonal drought & some pollution).
    - Exhibit regime shift to ramps (supra-seasonal drought & land use change)

Pine Ridge Reservation

- **Streamflow** changed from normal to **high flows in 1990s** to dry to **low flows in 2000s**

- **PRR streams -** generally exhibit high fecal loading, locally exhibit habitat degradation & elevated NO3 & generally respond with:
    - High biotic integrity (resistance) to 1990s floods
    - Recover biotic integrity (resilience) following high-intensity grazing pulses
    - Change from EPT-dominated to non-insect & dipteran-dominated (regime shift) following 2000s drought

BUT, DOES DROUGHT CAUSE REGIME SHIFT? ARE LOCAL RESULTS GENERALIZABLE?

- General Hypothesis: **Drought is a key driver of macroinvertebrate community regime shift for Northern Great Plains streams.**

- **Q1:** What are temporal and spatial relationships between meteorological, agricultural, & hydrological drought?

- **Q2:** How does resistance and resilience of taxa common to South Dakota streams compare with taxa resistance and resilience in other published studies?

- **Q3:** Did drought cause the macroinvertebrate community regime shift on the Pine Ridge Reservation?

Q1: WHAT ARE TEMPORAL AND SPATIAL RELATIONSHIPS BETWEEN METEOROLOGICAL, AGRICULTURAL, & HYDROLOGICAL DROUGHT?

#	Task	Dataset(s)	Method	Approach	Outcome
1	Calculate drought indices for weather stations & gages	Monthly precipitation & temperature, mean streamflow	SPI, SPEI & SDI	'SPEI' package for SPI & SPEI New package for SDI index	Transformed time-series at 1-, 3-, 6-, 9-, 12-month scales
2	Pair weather stations with sites	Geographic coordinates	Theissen polygons	'deldir' package	Precipitation & soil moisture time-series at sites
3	Cluster gaged watersheds	Mean daily streamflow & watershed area	Determine clustering method & optimal number of clusters	'clValid' package	Compact, well-separated & stable clusters of similar watersheds
			Apply clustering method	'vegan' package	

Q1: WHAT ARE TEMPORAL AND SPATIAL RELATIONSHIPS BETWEEN METEOROLOGICAL, AGRICULTURAL, & HYDROLOGICAL DROUGHT?

#	Task	Dataset(s)	Method	Approach	Outcome
4	Estimate streamflow deficit for ungauged watersheds	gSSURGO data for SD and Nebraska	Watershed delineation	Hydrology Toolset' in ArcGIS	Site-level streamflow time-series
			Unsupervised classification	'randomForest' package	
5	Characterize drought relationships	Site-level SPI, SPEI, and SDI time series at 3-, 6- 9- and, 12-month scales, hydrologic group membership	Regression	'lm', 'purrr', and 'broom' packages	Describe associations & model relationships between drought types

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Q2: HOW DOES TAXA RESISTANCE AND RESILIENCE IN SOUTH DAKOTA COMPARE WITH OTHER PUBLISHED STUDIES?

#	Task	Dataset(s)	Method	Approach	Outcome
1	Identify resistance, and resilience of common local taxa in PRR streams	Taxa – site matrix	Enumeration	‘dplyr’, ‘tidyr’, ‘purrr’ packages	Actual likelihoods of taxa being ‘’resistant’, ‘strongly resilient’, ‘weakly resilient’, ’extirpated’
2	Identify resistance and resilience of common local taxa in other streams	Pdfs of published literature	Text mining	‘pdfsearch’ package	Expected likelihoods of taxa being ‘’resistant’, ‘strongly resilient’, ‘weakly resilient’, ‘extirpated’
3	Test for resistance and resilience	Contingency tables of above data	Contingency table analysis	‘vcd’ & ‘vcdExtra’ packages	Likelihood that a given taxon exhibits resistance & resilience traits

Q3:DOES DROUGHT CAUSE MACROINVERTEBRATE COMMUNITY REGIME SHIFT?

#	Task	Dataset(s)	Method	Approach	Outcome
1	Visualize species compositional patterns	Taxa – site matrix, environmental – site matrix	Non-metric dimensional scaling (NMS) ordination	‘vegan’ package	Identify major environmental gradients among sites
2	Compare community structure differences for non-drought, and drought years	Taxa – site matrix, environmental – site matrix	PERMANOVA	‘vegan’ package	Evaluate drought hypothesis

* Environmental matrix includes SDI index values and water quality data.

EXPECTED RESULTS

Hydrology

- Lags in agricultural and hydrologic drought are negatively correlated with geologic age of sediments
- Lags in agricultural and hydrologic drought are positively correlated with geologic age of sediments
- Interesting “outliers” when grouping ungauged watersheds

Ecology

- Strong positive correlation between base-flow volume and community resistance
- Recovery to a pre-drought composition within one-year of a seasonal drought
- Regime shift to smaller-bodied & r-selected taxa & more gastropods following a supra seasonal drought

EXPECTED OUTPUTS

1. Literature review - background to set context for study – published as a state of the science article for competing drought definitions and relationship of these to data sources - may include ecological drought and IBI index approach

2. Methods / application paper on the use of drought indices to characterize hydrology of geologically complex region - how to interpret the different drought indices for a specific geographic region so not a state of the science article but one that focuses on the application of the drought indices and the data that exists for the region.)

3. Taxa drought resilience - focus on the identified taxa for the geographic region identified as being drought resistant or resilient and how the identified types compare to those identified in the literature as being drought resistant or resilient

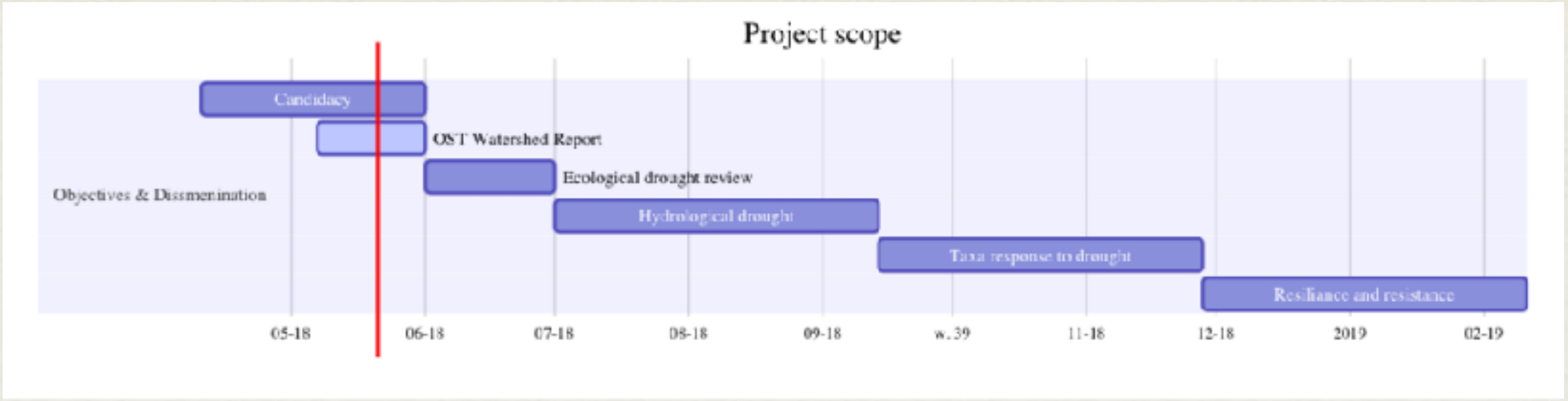
4. Abiotic drivers of taxa regime changes - expand on the previous article by linking the changes seen in Taxa to the identified drivers that precede the changes

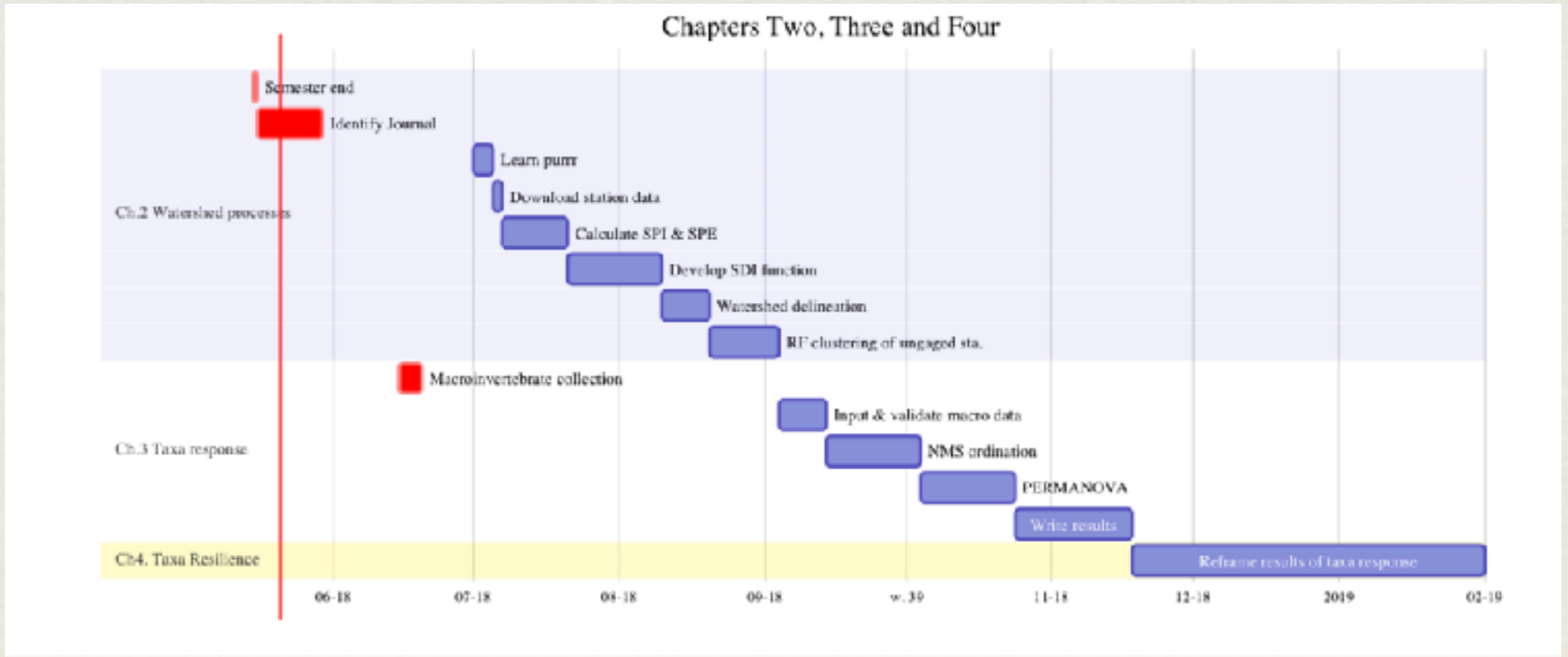
- Use ‘thesisdown’ to create dissertation template in R Studio https://github.com/ismayc/thesisdown (mostly complete)

- All analysis / data is repeatable using GitHub pull requests https://github.com/cjtinant

- Three to four co-authored papers following the test of a committee member "providing substantial feedback on the development of a paper”

TIMELINE


Project scope
Candidacy
OST Watershed Report
Ecological drought review
Objectives & Dissmenination
Hydrological drought
Taxa response to drought
Resiliance and resistance
05-18
06-18
07-18
08-18
09-18
w. 39
11-18
12-18
2019
02-19


Chapters Two, Three and Four
Semester end
Identify Journal
Learn purrr
Download station data
Ch.2 Watershed processes
Calculate SPI & SPE
Develop SDI function
Watershed delineation
RF clustering of ungaged sta.
Macroinvertebrate collection
Input & validate macro data
Ch.3 Taxa response
NMS ordination
PERMANOVA
Write results
Ch4. Taxa Resilience
Refine results of taxa response
06-18
07-18
08-18
09-18
w. 39
11-18
12-18
2019
02-19

NEXT STEPS: HOW DO PINE RIDGE RESERVATION RESULTS COMPARE WITH OTHER DRYLAND STUDIES?

#	Task	Dataset(s)	Method	Approach	Outcome
1	Define seasonal vs. supra seasonal drought	Literature	Expert opinion	NA	Quantify drought types
2	Prepare meta-analysis	Monthly precip. & temp., geographic coordinates, taxa data	Email, telephone	NA	Data for meta-analysis
3	Visualize species compositional patterns	Taxa – site matrix, environmental – site matrix	Non-metric dimensional scaling (NMS) ordination	'vegan' package	Identify major environmental gradients among sites
4	Compare community structure differences for non-drought, and drought years	Taxa – site matrix, environmental – site matrix	PERMANOVA	'vegan' package	Evaluate drought hypothesis

* Environmental site index includes SPEI values, elevation, & geographic coordinates