

# Science and Research to Inform Management



A Concurrent Session at the 43<sup>rd</sup> Annual Salmonid Restoration Conference  
Santa Cruz, California, April 29 - May 2, 2025

**Session Coordinator:** Eli Asarian, Riverbend Sciences



This session will explore science across a range of topics relevant to river restoration and conservation, including: sampling design, genetics, water management, hydrologic effects of habitat restoration, and climate change effects on salmonids and food webs. Habitats discussed will span from mountain meadows to coastal streams and regulated mainstem rivers, and from the Pacific Northwest to California's North Coast and Sierra Nevada.

# Presentations



- **Assessing Freshwater Biodiversity With eDNA**  
Brooke Penaluna, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station..... Slide 4
- **Hybridization of Coastal Cutthroat Trout and Steelhead at the Southern Tip of Their Range**  
Sam Rizza, TRIB Research .....Slide 29
- **Pacific Salmon Data Discovery Tool**  
Katie Barnas, NOAA Fisheries..... Slide 68
- **The Importance of Flow Variation For Regulated Rivers**  
Seth Naman, NOAA Fisheries..... Slide 90
- **Van Norden Meadow Restoration Project: Hydrologic Benefits of Meadow Restoration**  
Alecia Weisman, M.S., South Yuba River Citizens League, Sam Diaz, Verdantas..... Slide 132
- **Simulating Telemetry Studies That Estimate Component Mortality Rates of Imperiled Juvenile Salmonids**  
Elizabeth M. Greenheck, George Mason University..... Slide 167



# Silent Signals: Assessing Freshwater Biodiversity with eDNA

Brooke Penaluna

Research Fish Biologist

H.J. Andrews Experimental Forest

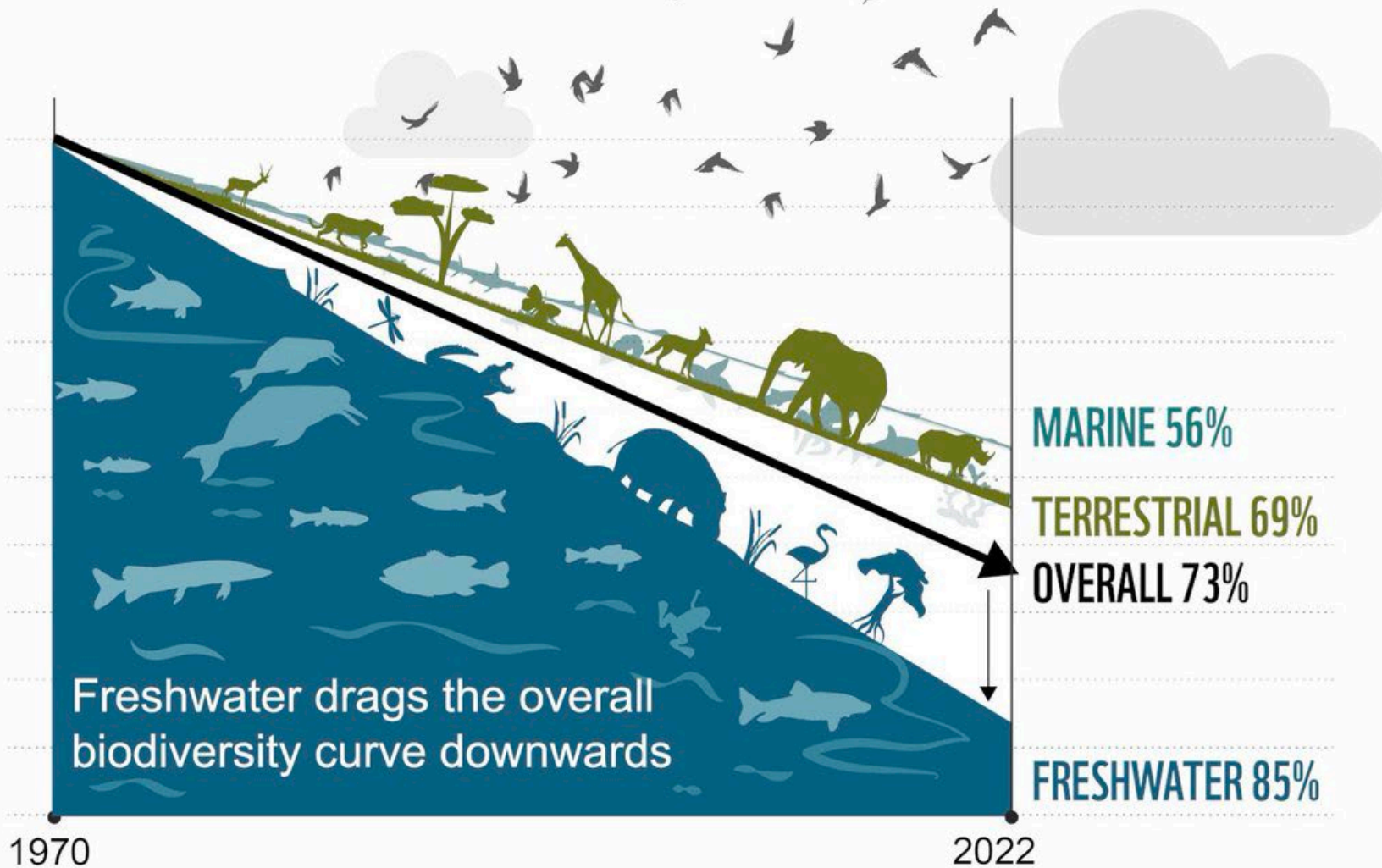
Lead Scientist

PNW Research Station

USDA Forest Service



# Global decline in biodiversity since 1970



Modified from Reid et al. 2018; Statistics from the WWF Living Planet Report (2024)



- Traditional methods are based on visual detections and counting, which is not always standardized and is dependent on practical and taxonomic expertise
- Often limited to assessments of adults, regularly of listed species
- Commonly occurs in summer

# What is eDNA?

Short for  
environmental DNA

Refers to DNA that  
can be extracted  
from soil, air, or water

Can find DNA of  
animals, plants, and  
microorganisms

**eDNA**=Deoxyribonucleic Acid

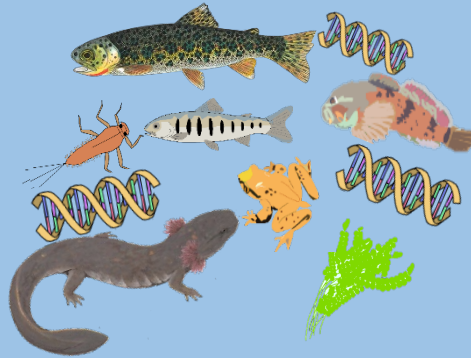


# eDNA Barcoding: Single Species

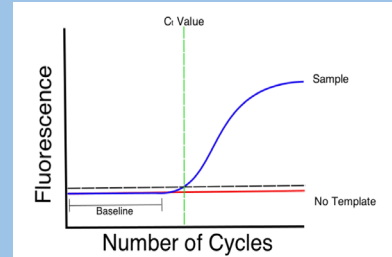
Water  
Filtration



DNA  
Extraction



qPCR  
Using primer for target species



fluorescence of a  
single amplified  
gene that can be  
quantified



A **primer** is a short stretch of DNA that targets unique sequences of a gene

**qPCR**=quantitative PCR, real-time PCR, or quantitative polymerase reaction=amplifies target DNA

electrofishing ⚡

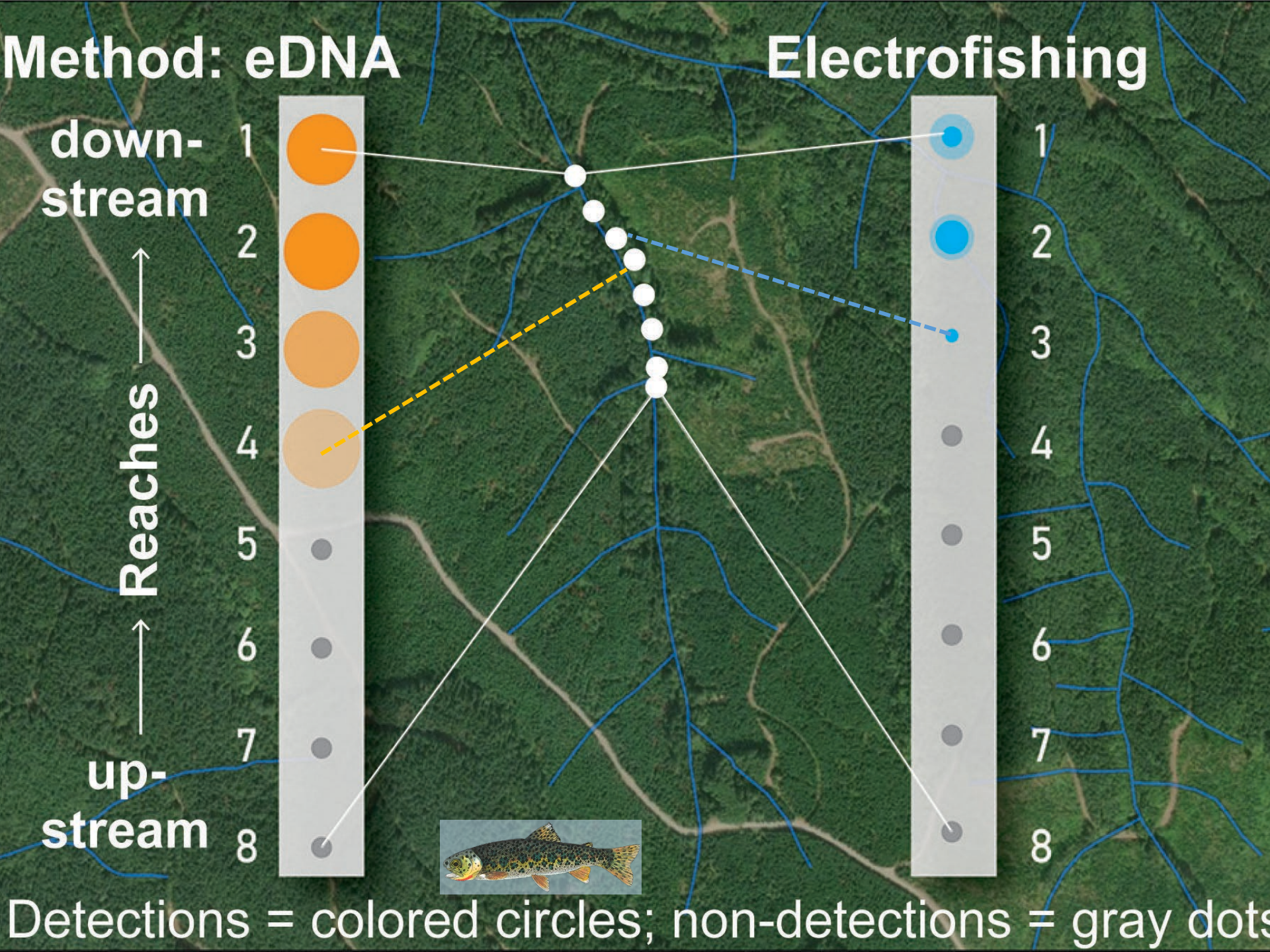


eDNA 🧬

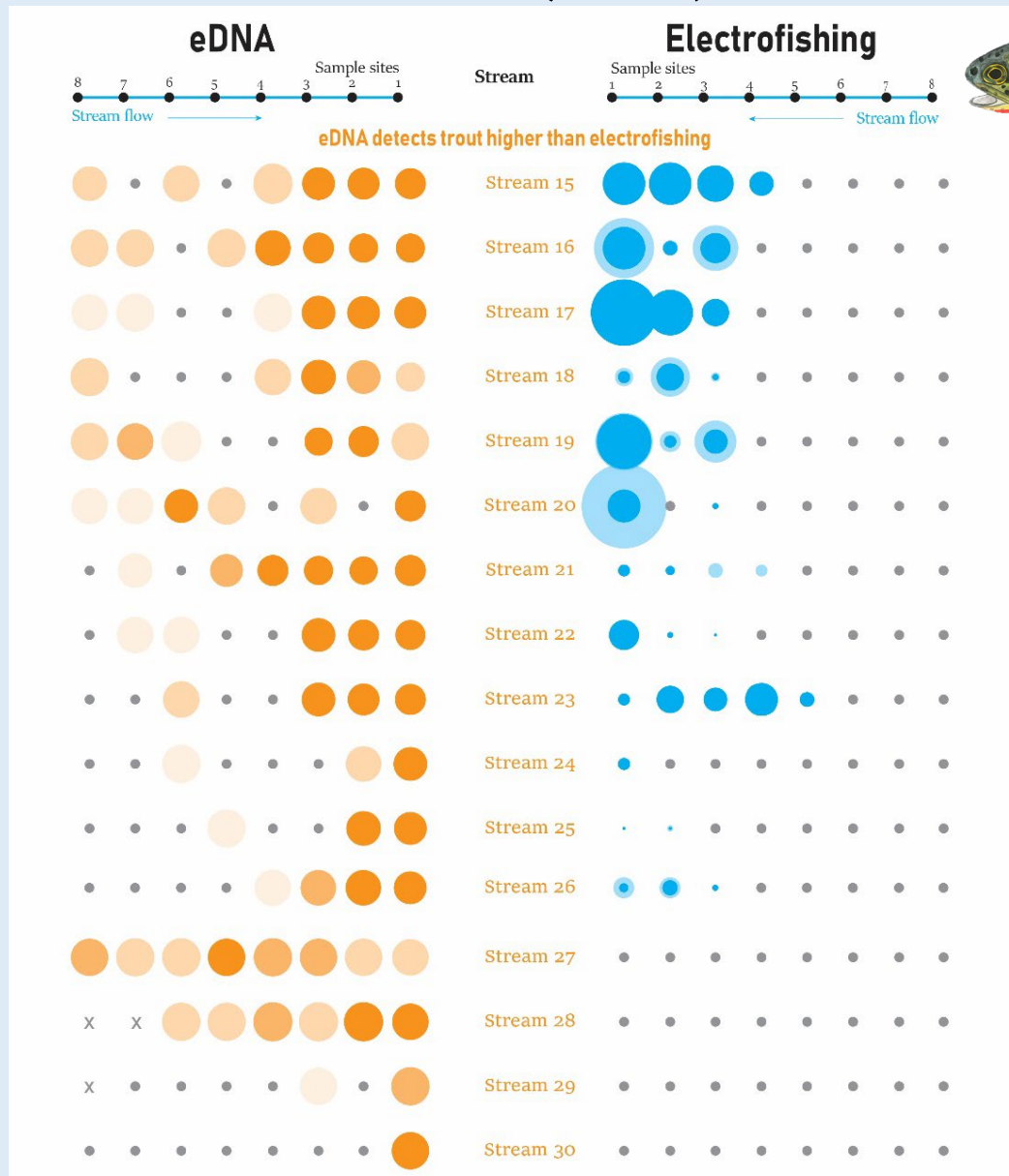


# Method: eDNA

# Electrofishing



# Trout eDNA was detected above efishing uppermost fish in 31 streams (52%) by 50-250m

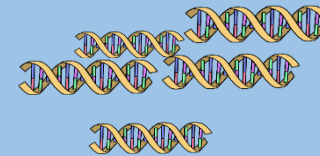
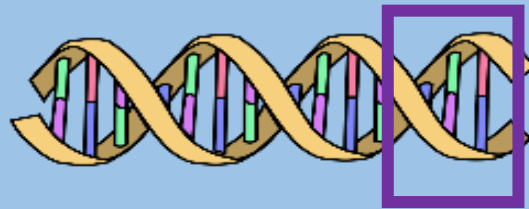


- Last trout detected
- Below last fish
- No trout found

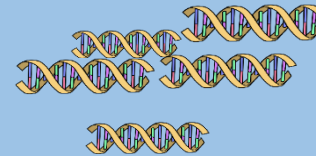
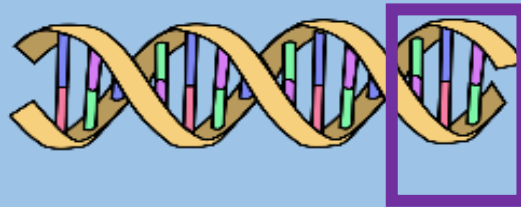
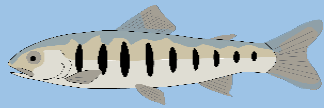
Detection strength

1 2-3 4-6 7-9  
Positive detections

# eDNA Metabarcoding



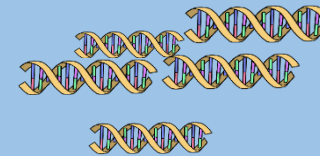
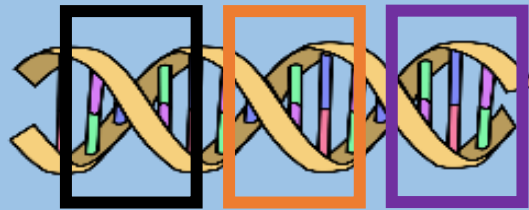
ATGACGGATCAC  
TACTGCCTAGTC



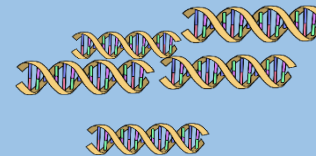
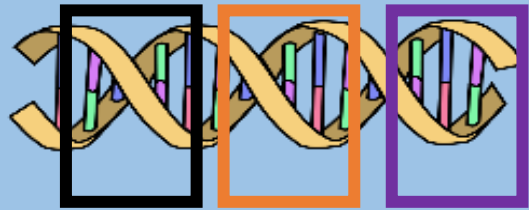
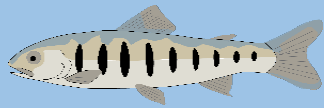
ATGACGGATCAC  
TACTGCCTAGTC

12S

# Multigene eDNA Metabarcoding



ATGACGGATCAC  
TACTGCCTAGTC



ATGACGGATCAC  
TACTGCCTAGTC

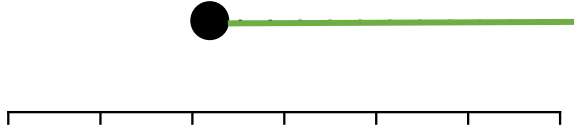
ND2 COI 12S

# Multigene eDNA metabarcoding has built in redundancy because it uses multiple primers

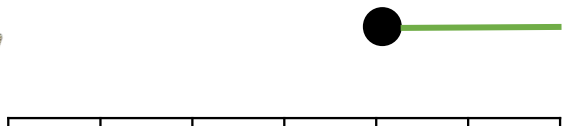
Electrofishing

Multigene eDNA metabarcoding

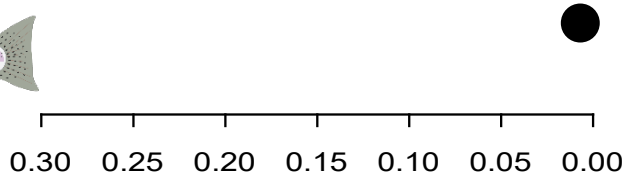
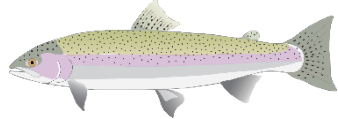
Coho Salmon



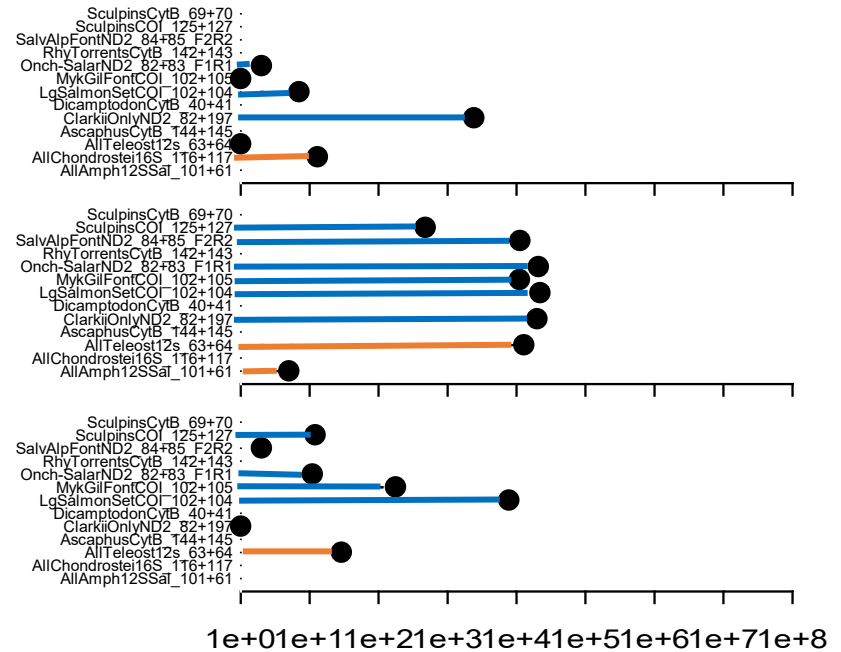
Cutthroat Trout



Rainbow Trout



Density (ind/m<sup>2</sup>)

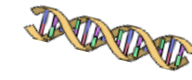


eDNA abundance (# reads)

Taxon-general or universal      Taxon-specific

Pothole Creek

# eDNA distinguishes species across taxon



fish

amphibians

crayfishes

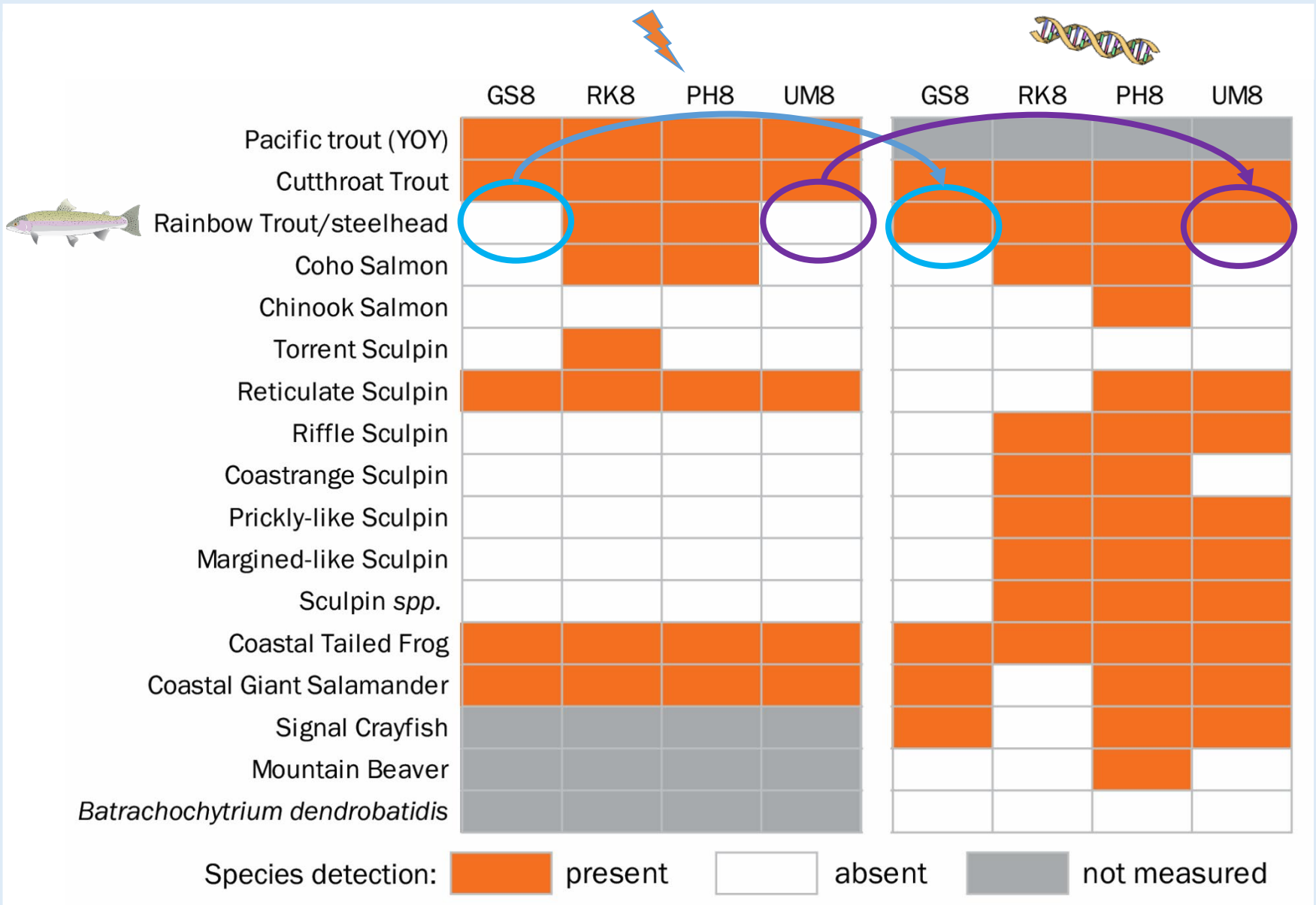
mammals

pathogens

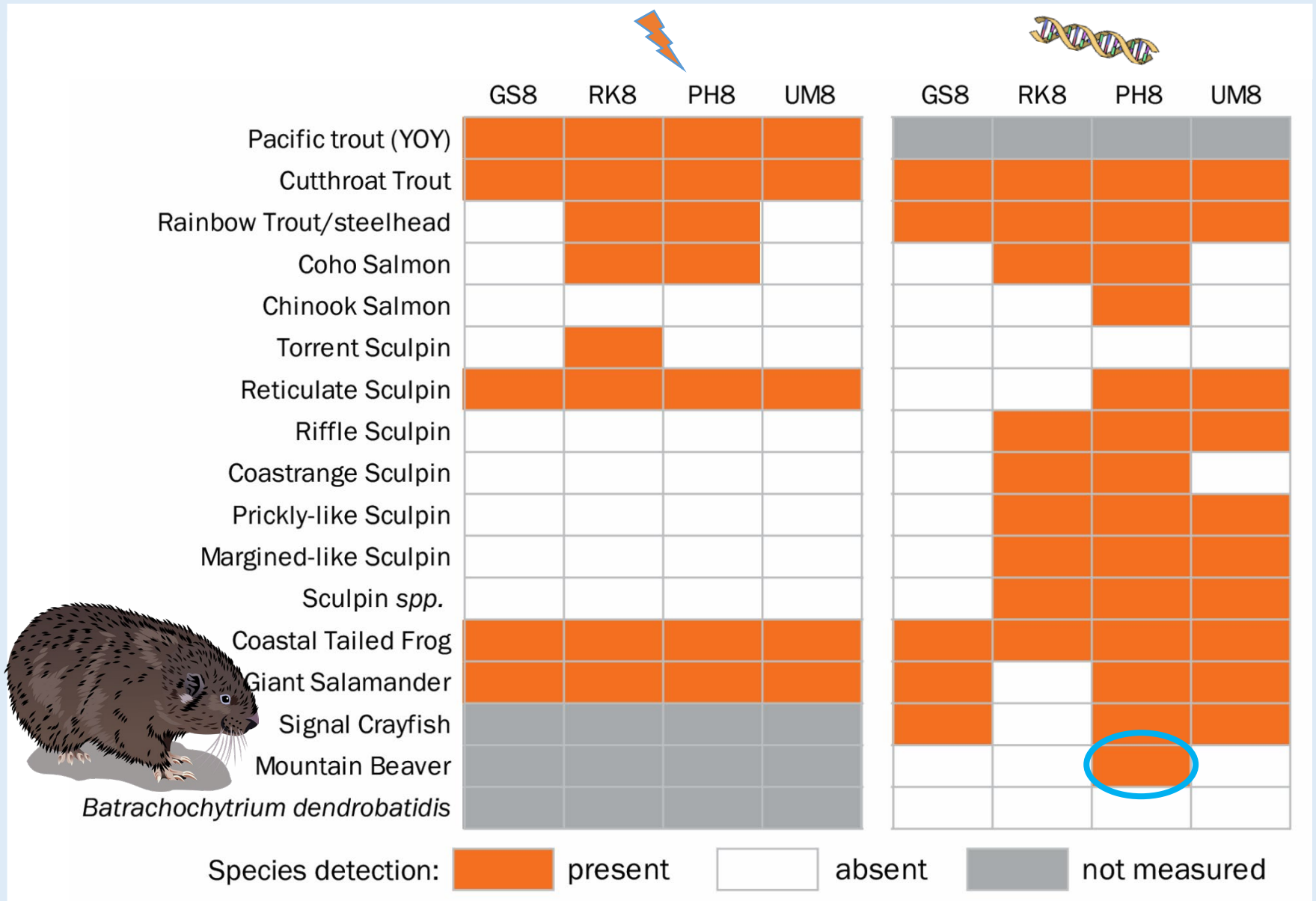
	GS8	RK8	PH8	UM8	GS8	RK8	PH8	UM8
Pacific trout (YOY)	present	present	present	present	not measured	not measured	not measured	not measured
Cutthroat Trout	present	present	present	present	present	present	present	present
Rainbow Trout/steelhead	absent	present	present	absent	present	present	present	present
Coho Salmon	absent	present	present	absent	absent	present	present	absent
Chinook Salmon	absent	absent	absent	absent	absent	absent	present	absent
Torrent Sculpin	absent	present	absent	absent	absent	absent	absent	absent
Reticulate Sculpin	present	present	present	present	absent	absent	present	present
Riffle Sculpin	absent	absent	absent	absent	absent	present	present	present
Coastrange Sculpin	absent	absent	absent	absent	absent	present	present	absent
Prickly-like Sculpin	absent	absent	absent	absent	absent	present	present	present
Margined-like Sculpin	absent	absent	absent	absent	absent	present	present	present
Sculpin spp.	absent	absent	absent	absent	absent	present	present	present
Coastal Tailed Frog	present	present	present	present	present	present	present	present
Coastal Giant Salamander	present	present	present	present	present	absent	present	present
Signal Crayfish	not measured	not measured	not measured	not measured	present	absent	present	present
Mountain Beaver	not measured	not measured	not measured	not measured	absent	absent	present	absent
<i>Batrachochytrium dendrobatidis</i>	not measured	not measured	not measured	not measured	absent	absent	absent	absent

Species detection:  present  absent  not measured

# eDNA increases taxonomic resolution



# eDNA detects of sparsely distributed species

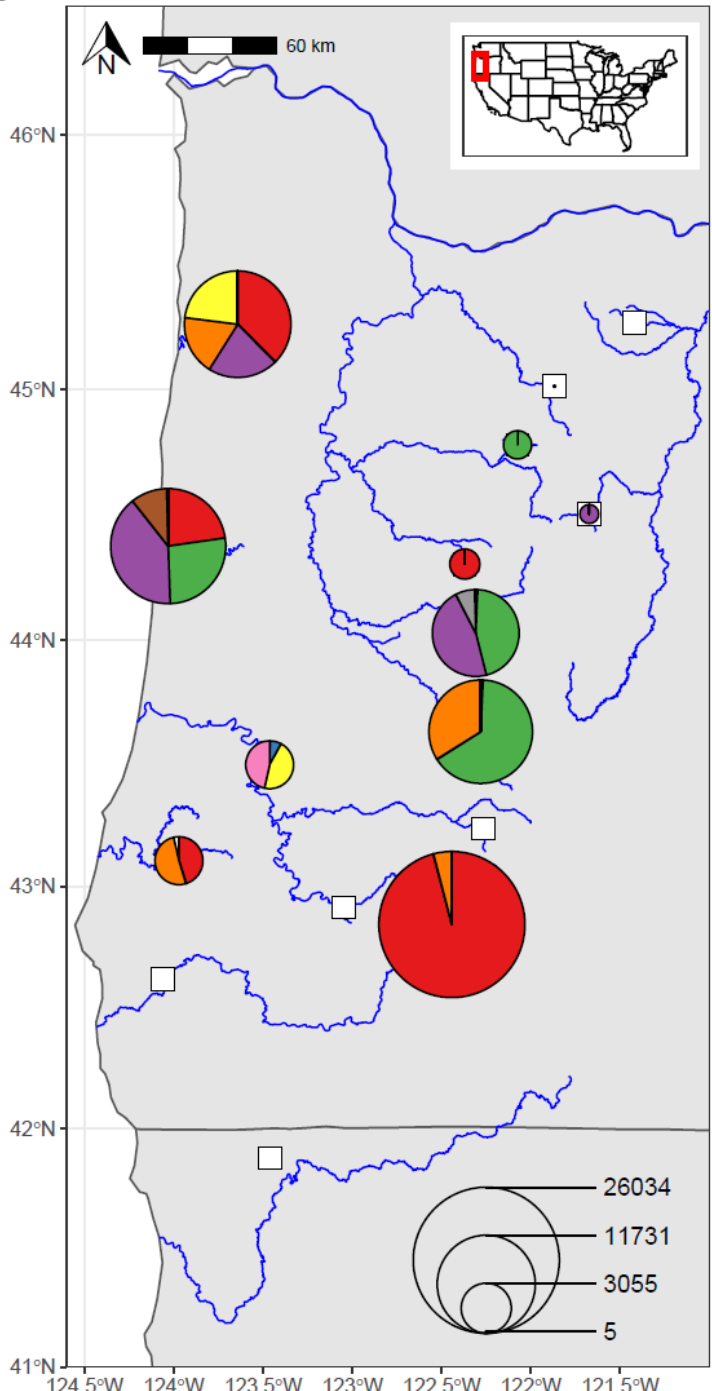


# eDNA identifies cryptic lineages

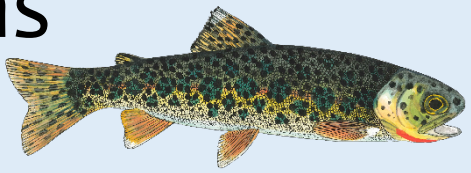


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Riffle Sculpin	absent	absent	absent	absent	absent	present	present	present
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<i>Batrachochytrium dendrobatidis</i>	not measured	not measured	not measured	not measured	absent	absent	absent	absent

Species detection: present absent not measured



# Genetic diversity of Coastal Cutthroat Trout greater in coastal streams



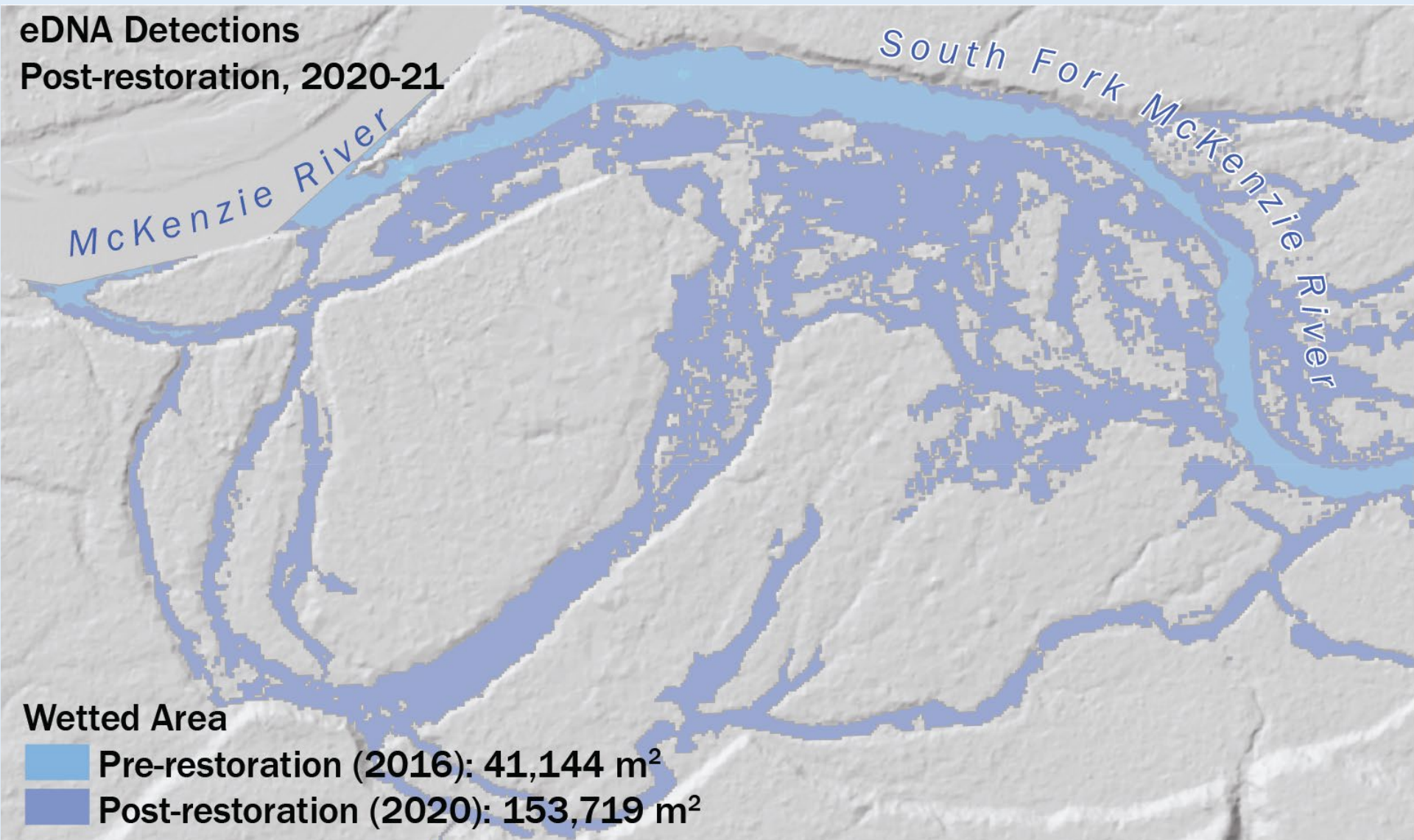
Some rivers have private haplotypes, including one coastal river and the Umpqua River

Moderate diversity in Willamette and Umpqua Rivers, but no shared sequences

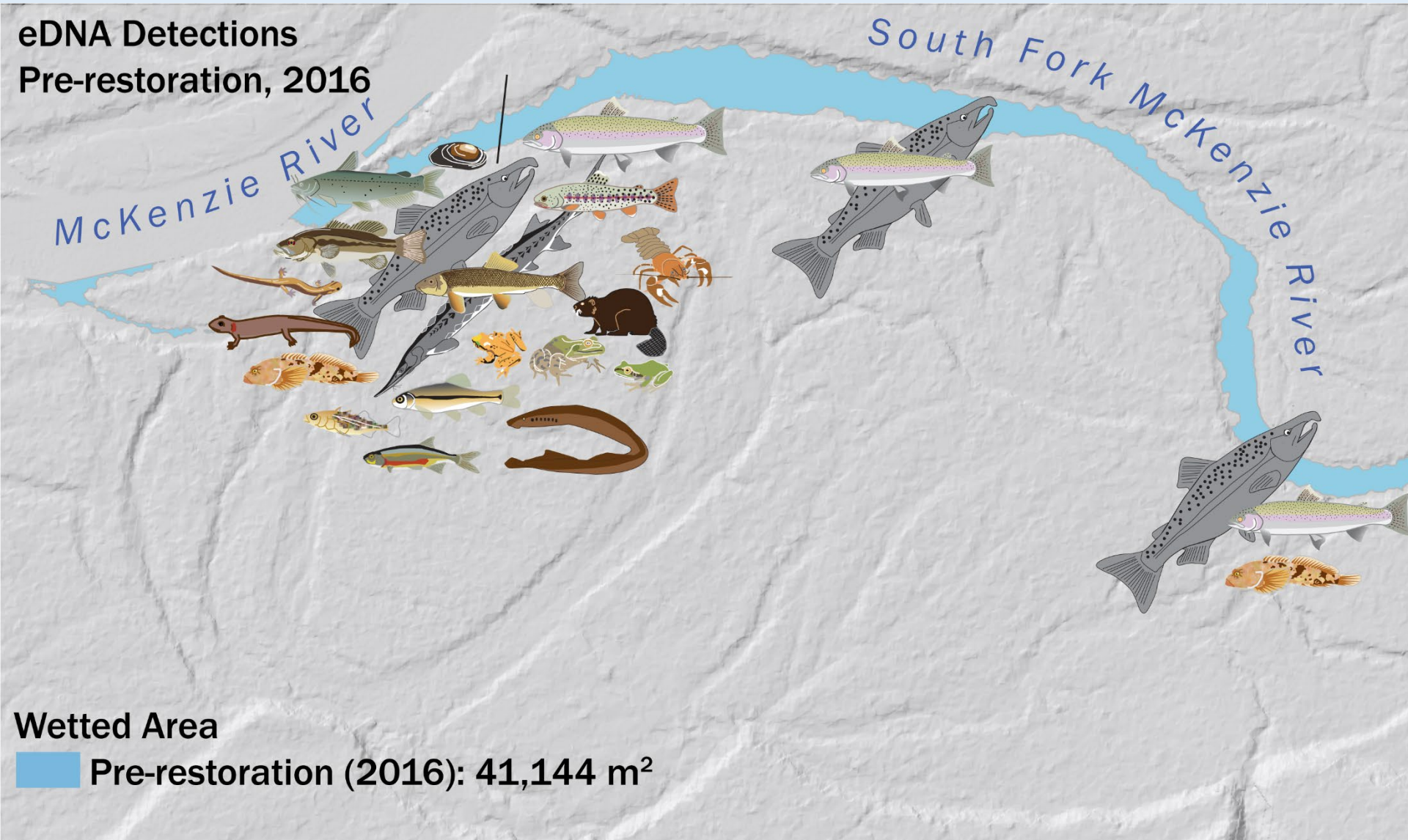
Lowest diversity in the Rogue River, but shared sequences with coastal streams and Willamette watershed

Weitemier et al. 2021, Molecular Ecology

# Does habitat diversity beget biological diversity?



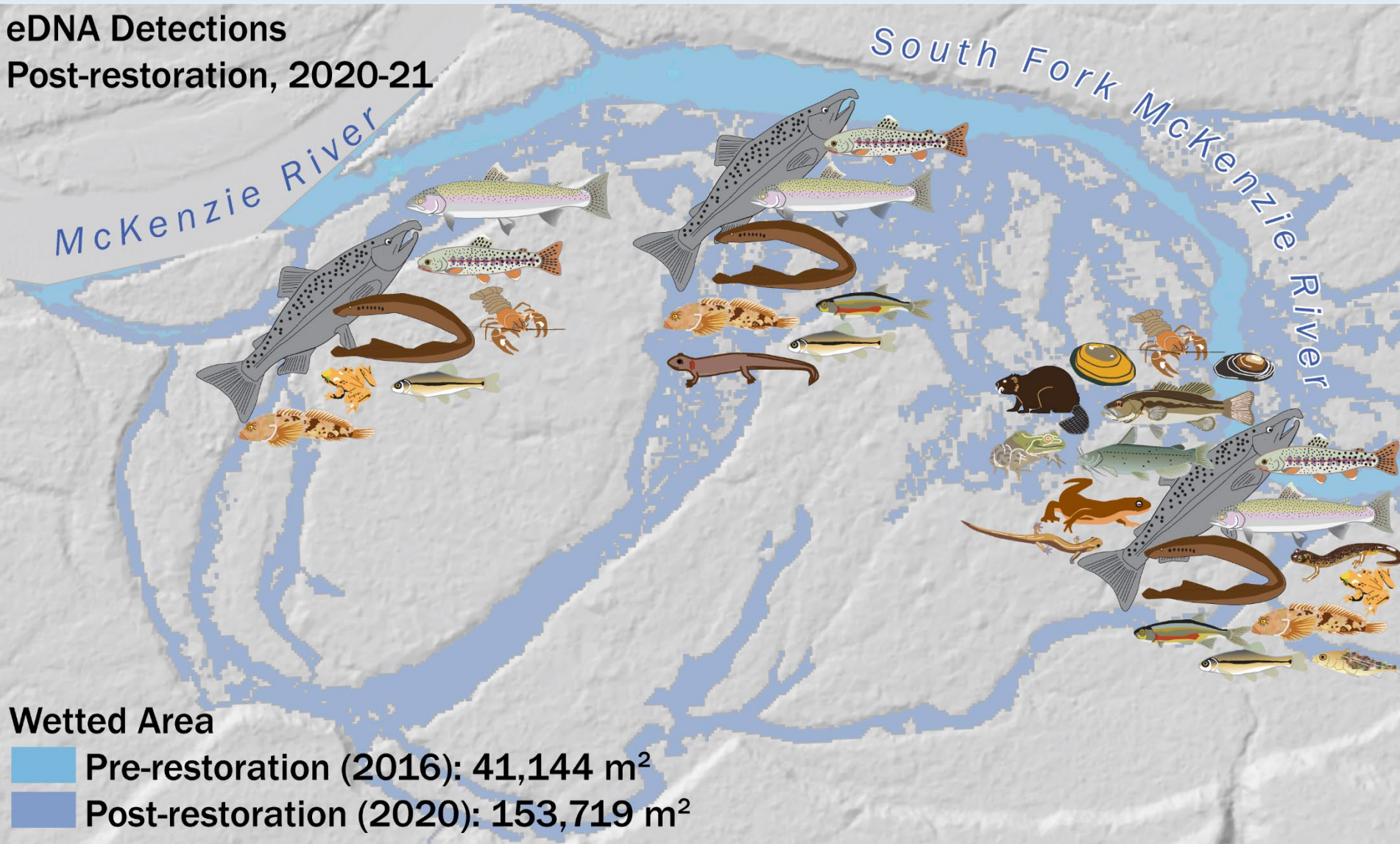
# Prior to floodplain river restoration

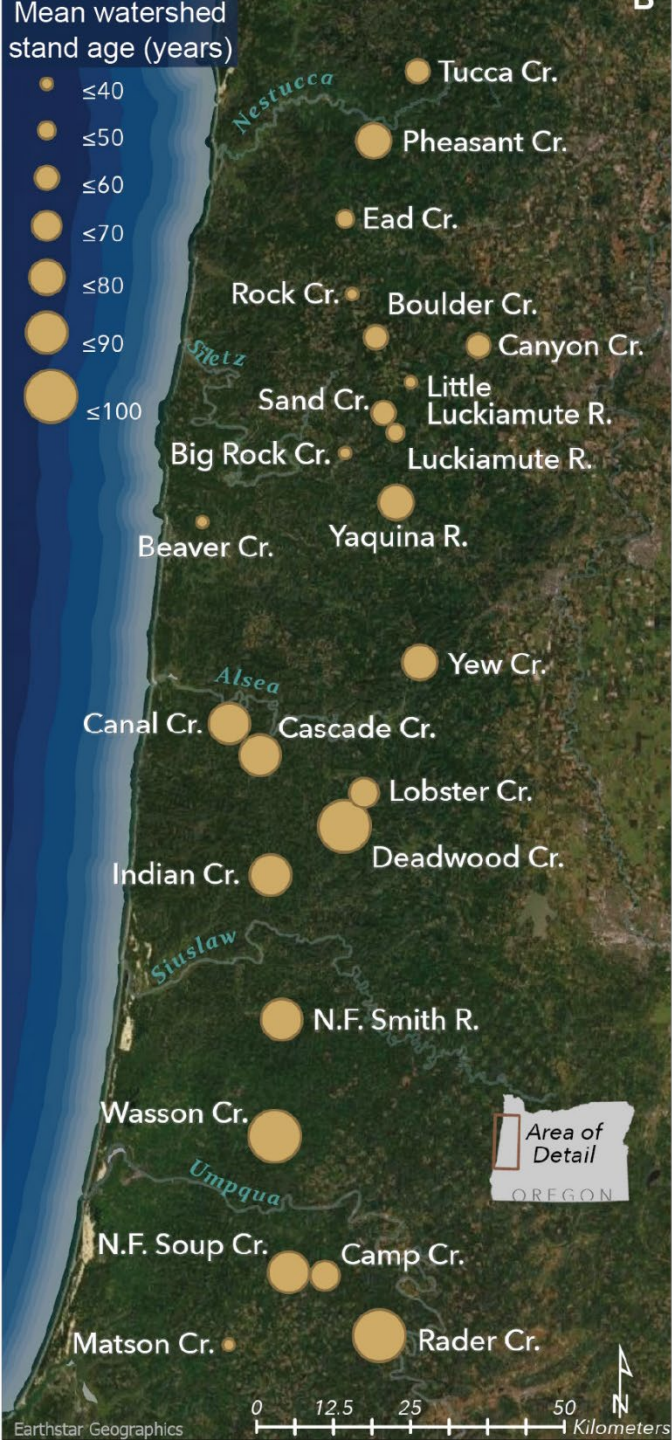


# More species/taxon post-restoration

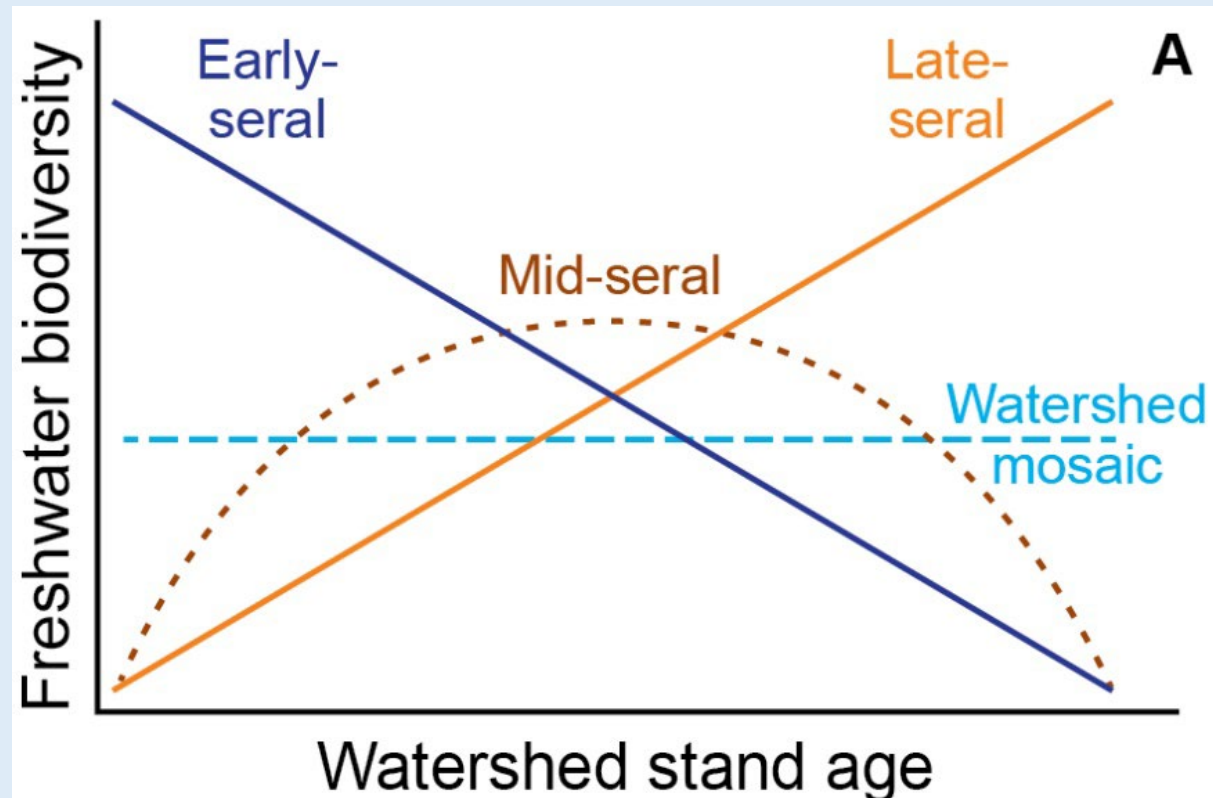
eDNA Detections

Post-restoration, 2020-21

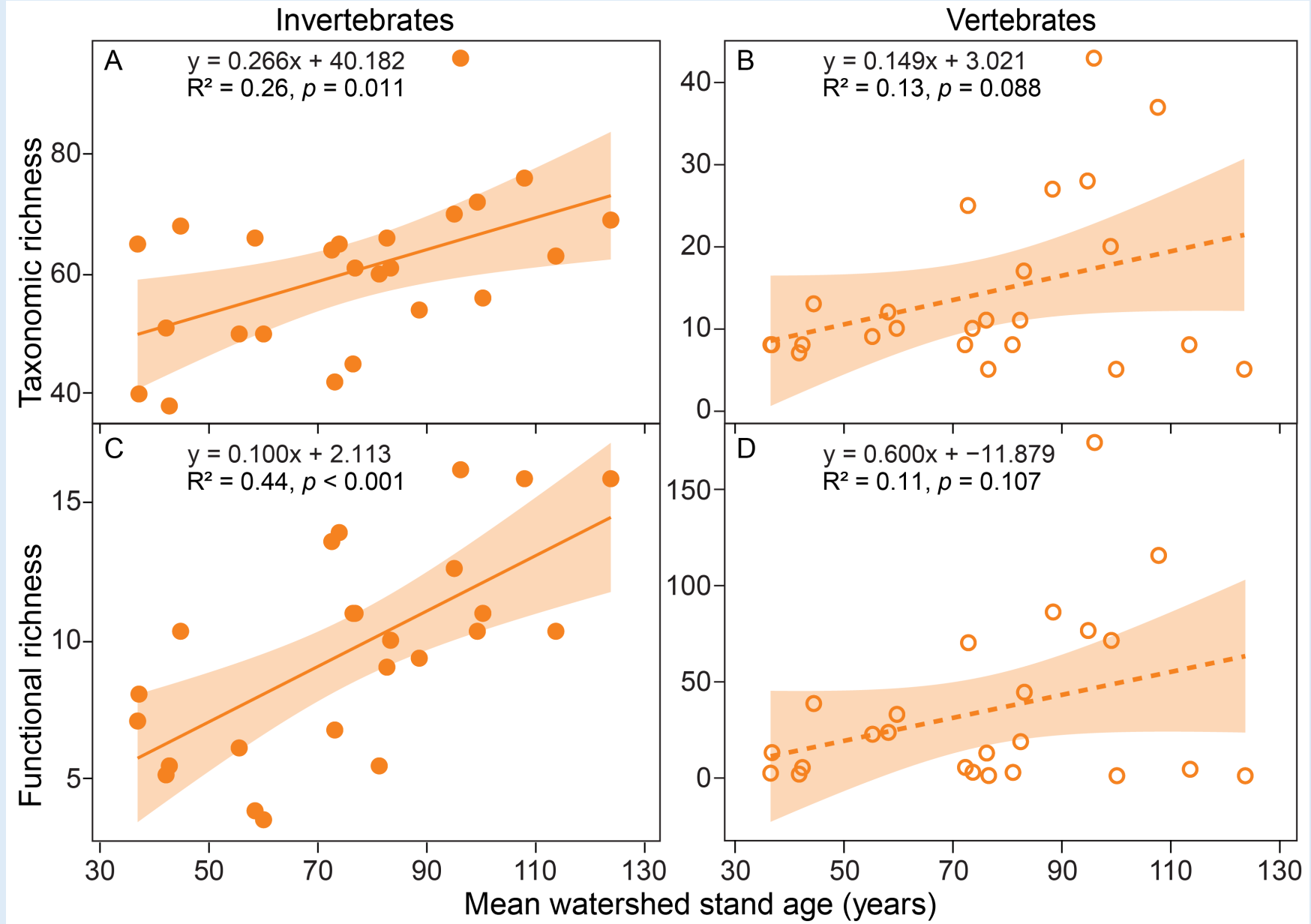


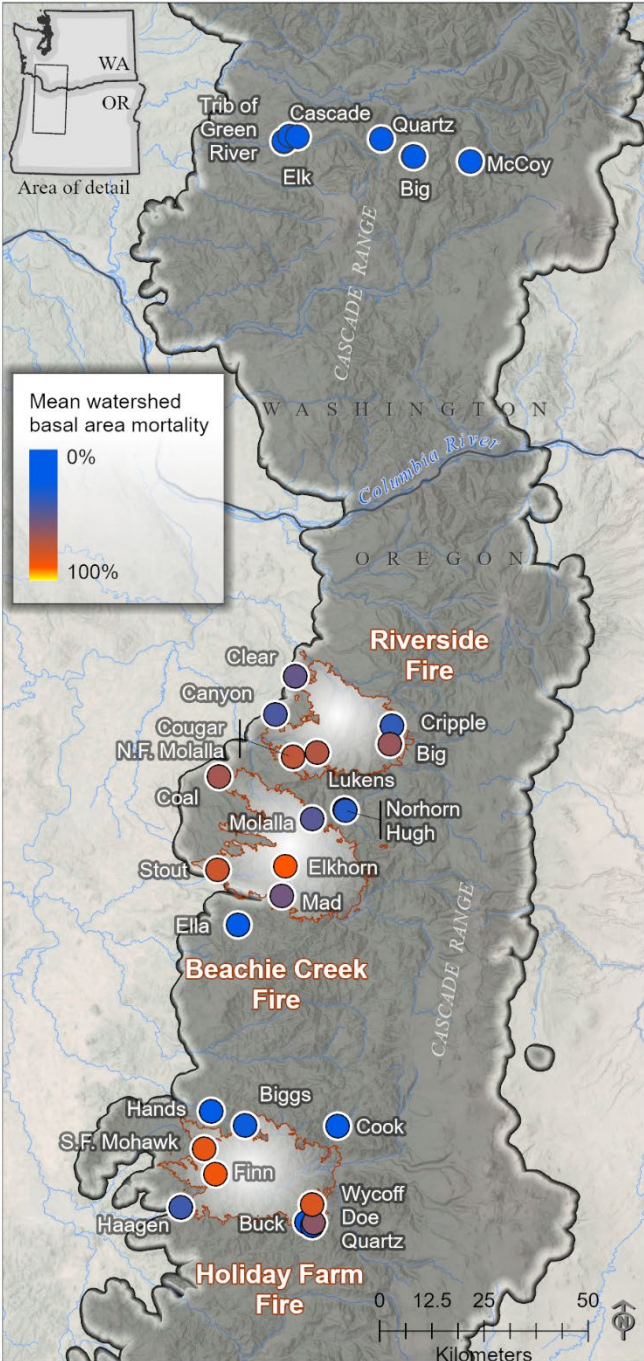


# What is the relationship of freshwater biodiversity to watershed stand age?



# Higher richness in watersheds with older forests

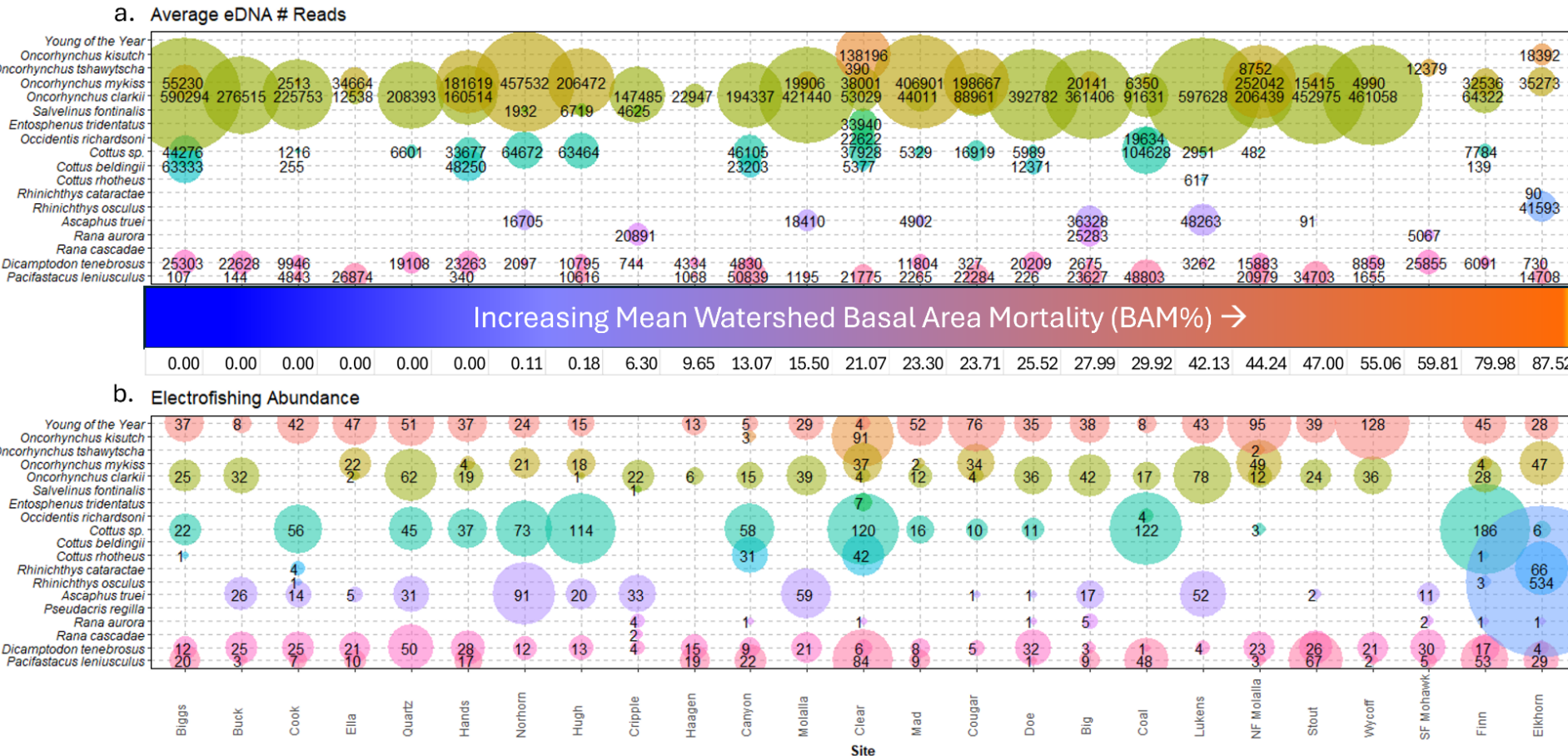




What is the freshwater biodiversity response to fire?

Is there a change in structure or composition?

# Fish and amphibian richness was unaffected by fire, but there were changes in composition following fire



# Take home messages

- Freshwater biodiversity can be comprehensively inventoried using multiple primer sets from a single sample
- There is a world of hidden biodiversity in freshwaters including cryptic species complexes, distribution extensions, and detection of rare, sparsely distributed, and overlooked species
- eDNA information allows for a broad assessment of freshwater biodiversity leading to data-driven prioritization of taxa

# Questions?



Contact information:  
Brooke Penaluna, PhD  
PNW Research Station  
[Brooke.penaluna@usda.gov](mailto:Brooke.penaluna@usda.gov)





## Hybridization of Coastal Cutthroat Trout at the Southern Tip of Their Range

Sam Rizza – TRIB Research



## TRIB Research

- Farming, community events, and fisheries research nonprofit
- Conservation genomics





## TRIB Research

- Farming, community events, and fisheries research nonprofit
- Conservation genomics
- “Shadow organization”



# The Fishes

- Natural hybridization between sympatric species
- Temporal and spatial isolation in spawning
- Physical characteristics

Coastal Cutthroat Trout (*Oncorhynchus clarki*)



Steelhead/Rainbow trout (*Oncorhynchus mykiss*)



## Coastal Cutthroat Trout Character(istics)

- Confidence is high



Photo credit: Vimal Golding



Photo credit: Vimal Golding

## Coastal Cutthroat Trout Character(istics)

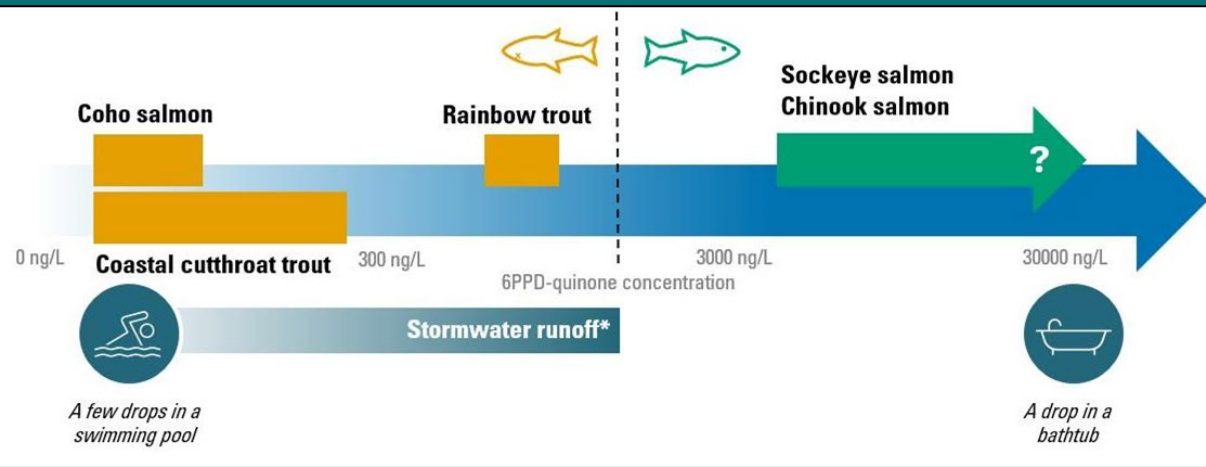
- Confidence is high
- Go it alone attitude

# Coastal Cutthroat Trout Character(istics)

- Confidence is high
- Go it alone attitude
- Sensitive



Photo credit: Vimal Golding

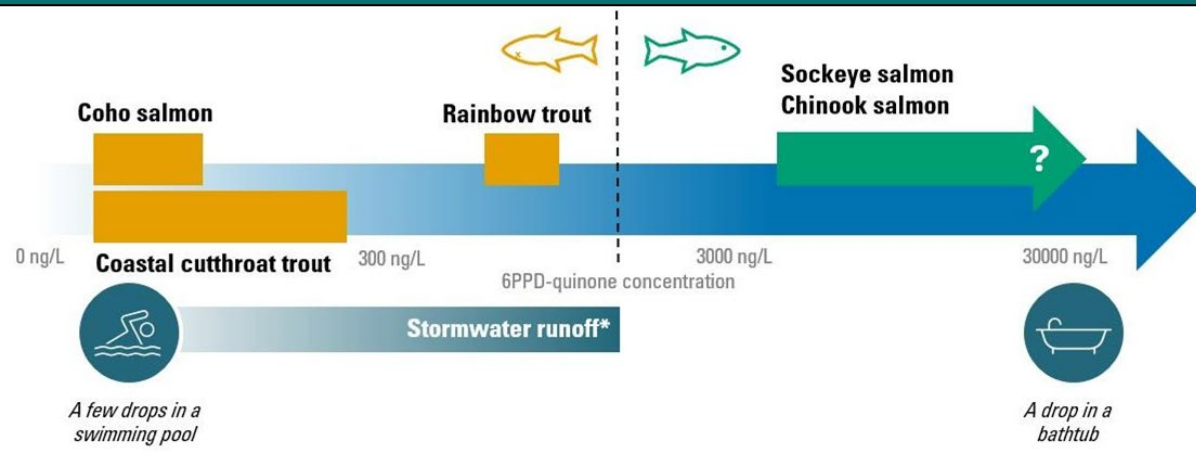


# Coastal Cutthroat Trout Character(istics)

- Confidence is high
- Go it alone attitude
- Sensitive
- Love of science



Photo credit: Vimal Golding



## Research Questions

1. How is hybridization manifested across the landscape?
  - a. Where are F1s (first-generation hybrids) detected?



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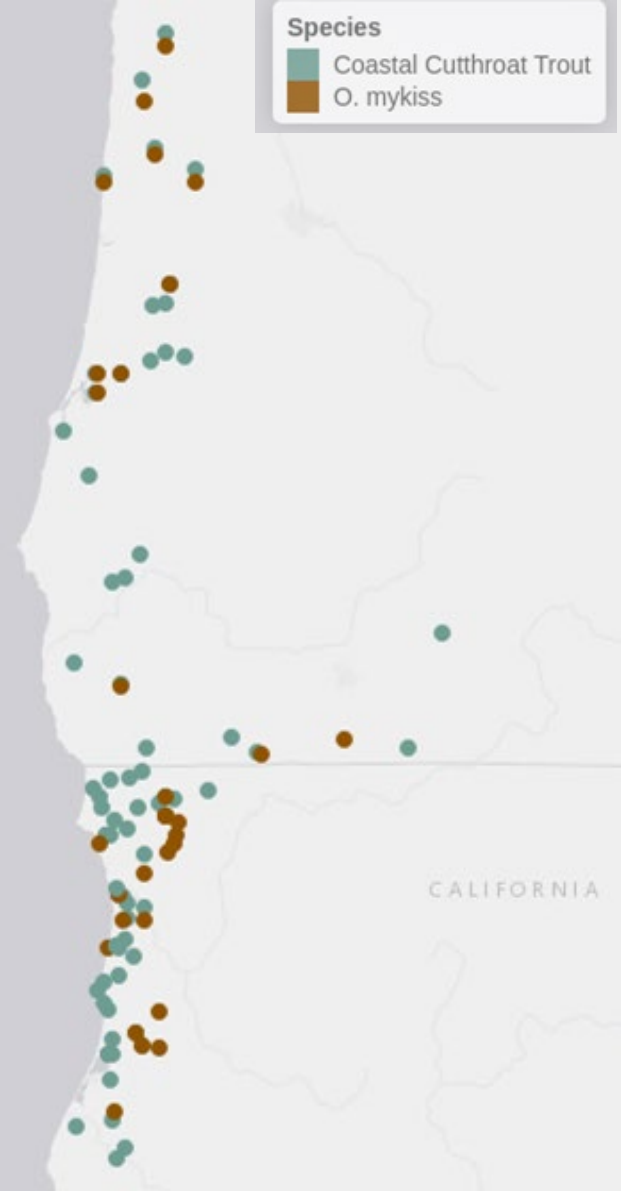
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  - d. Do hybridization rates change over time?



# Methods

- Study area: Eel River, CA to Siletz River, OR
- Night netting, seining, fishing, and outmigrant traps
- ~1,500 samples from 88 locations
- RADseq (sbf1) - 227 diagnostic SNPs



# General Patterns of Hybridization

- Sneak-mating strategy by CCT males



Photo credit: Bob Pagliuco

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- Sneak-mating strategy by CCT males



Photo credit: Bob Pagliuco

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- Sneak-mating strategy by CCT males
- Limited hybridization



Photo credit: Bob Pagliuco

# General Patterns of Hybridization

- Sneak-mating strategy by CCT males
- Limited hybridization
- Hotspots of increased hybridization



Photo credit: Bob Pagliuco

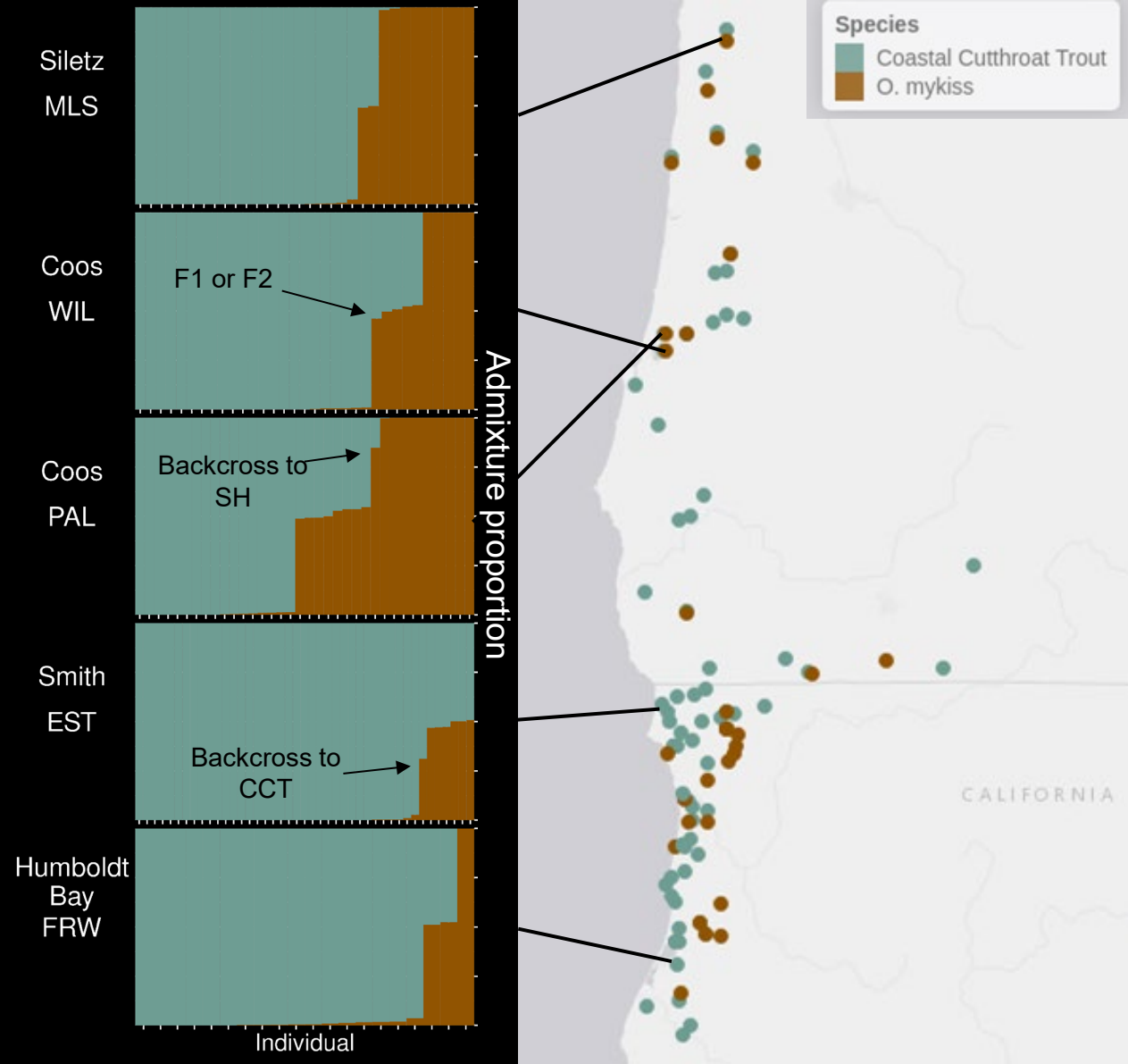
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# F1 Hybrid Detection

- Outmigrant traps and estuary sites
- F1 hybrids tend to outmigrate



# Research Questions

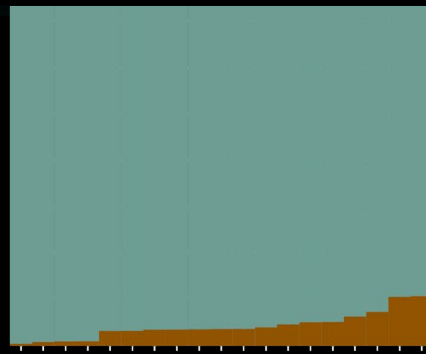
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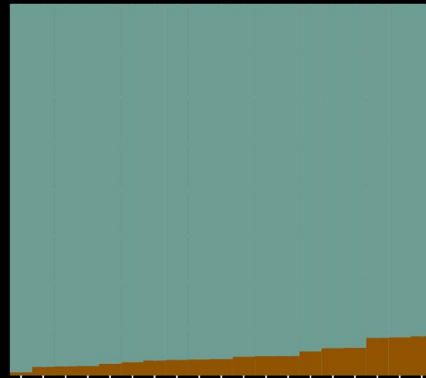
# Hybridization and Barriers

- Manmade barriers

Rogue  
EMI

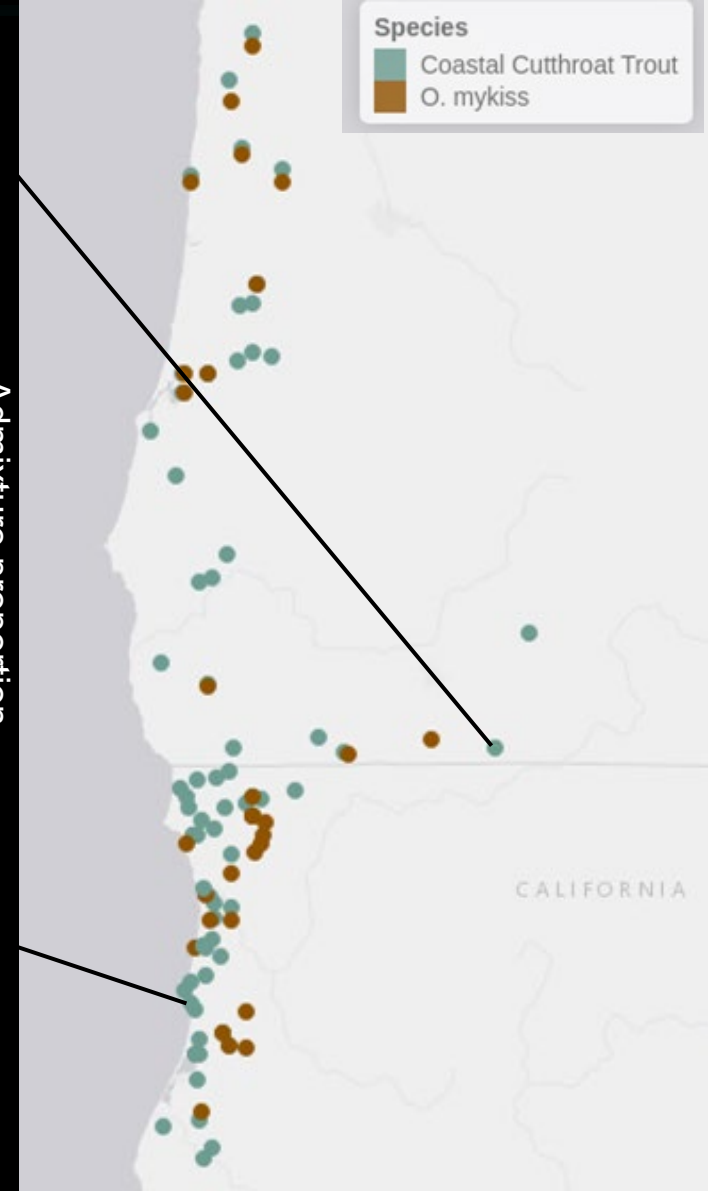


Pacific  
CA-S  
LUF



Individual

Admixture proportion

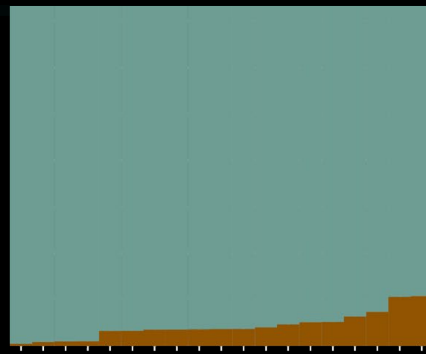


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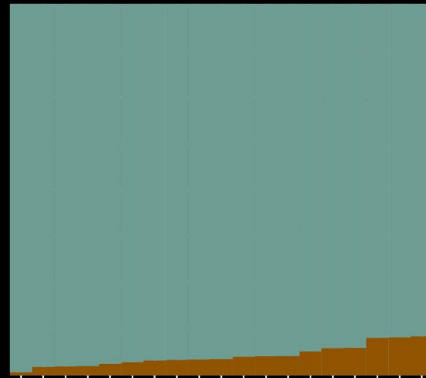
- Manmade barriers
- Historic stocking

“The Humboldt association will receive 150,000 cutthroat trout from the United States Bureau of Fisheries station in Yellowstone Park this summer.” (1924)

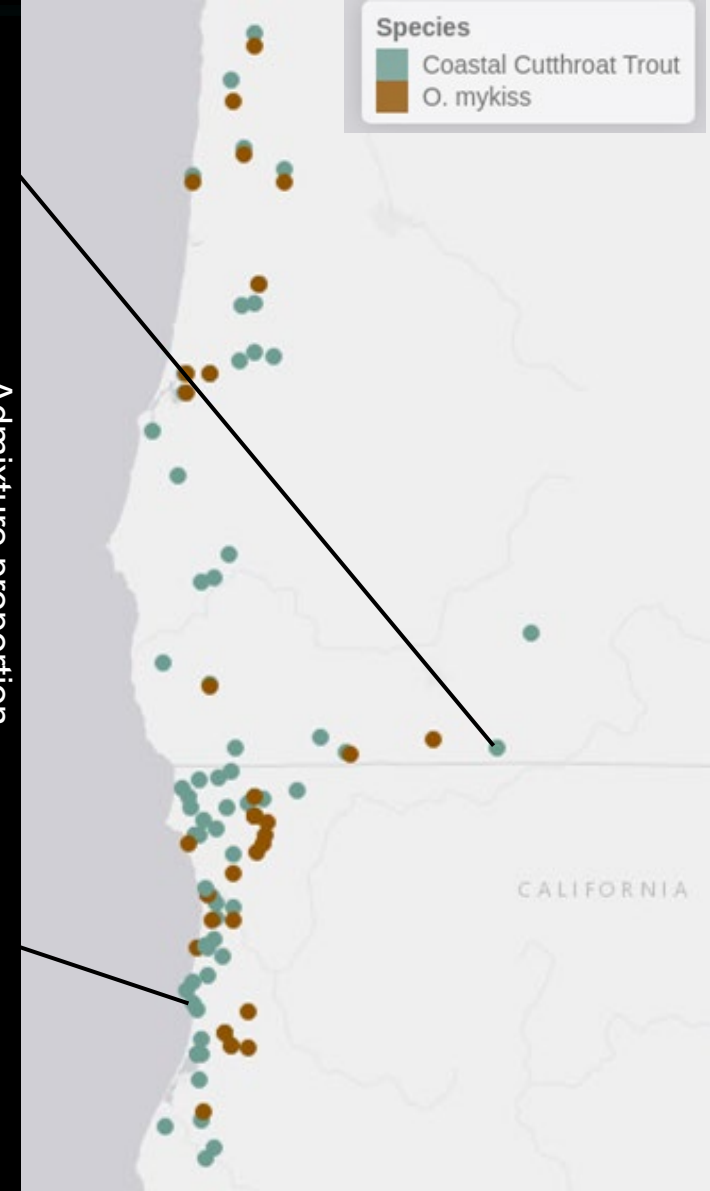
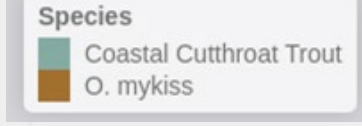
Rogue  
EMI



Pacific  
CA-S  
LUF



Admixture proportion



Individual

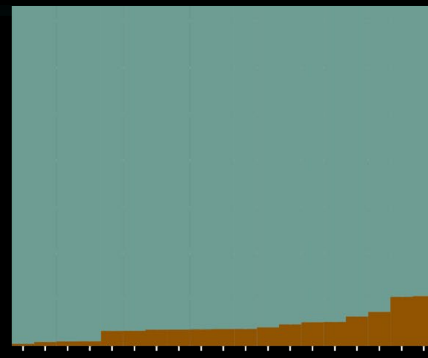
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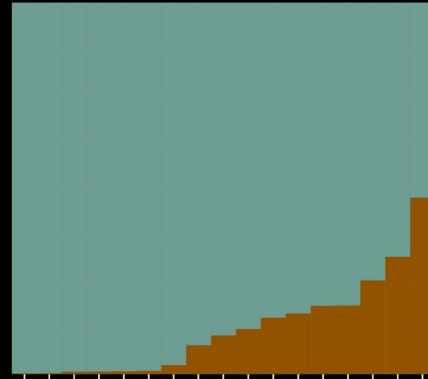
“The Humboldt association will receive 150,000 cutthroat trout from the United States Bureau of Fisheries station in Yellowstone Park this summer.” (1924)

- Partial natural barrier

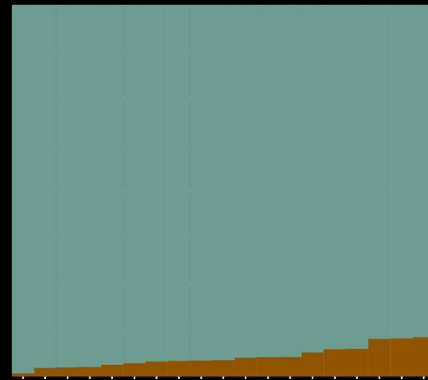
Rogue  
EMI



Klamath  
TEC

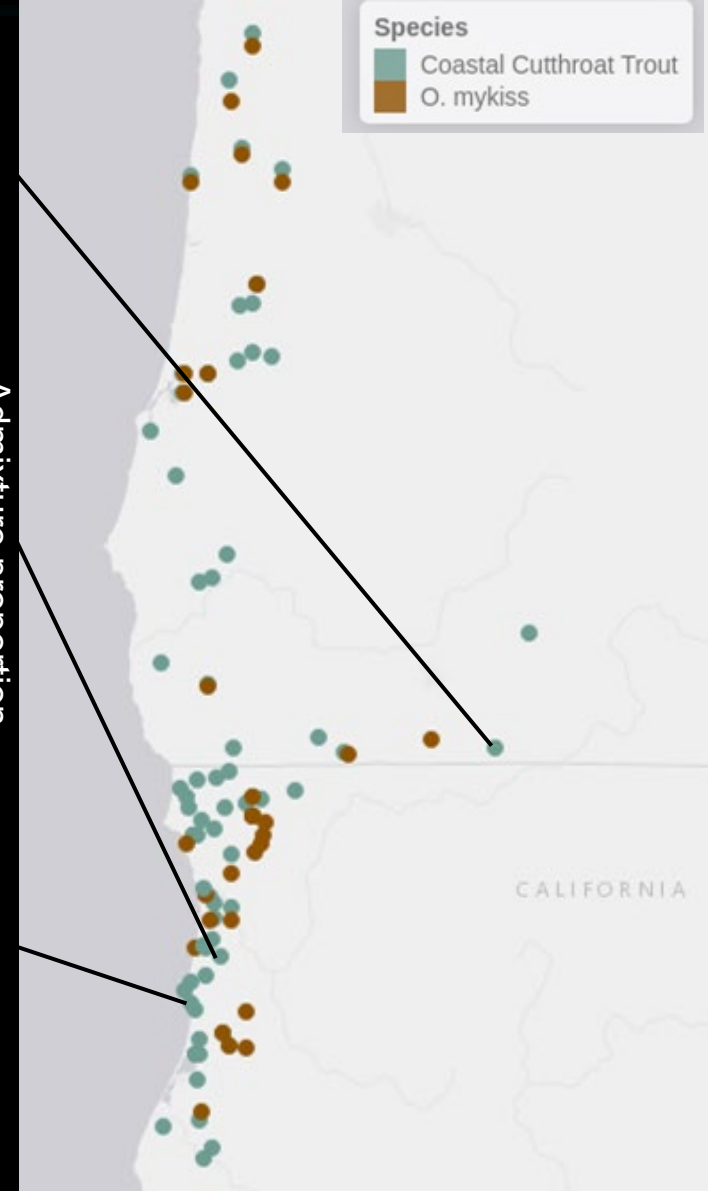


Pacific  
CA-S  
LUF



Admixture proportion

Individual



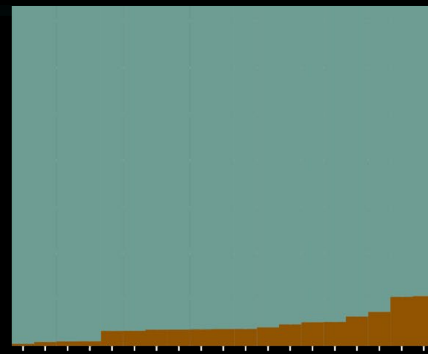
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- Historic stocking

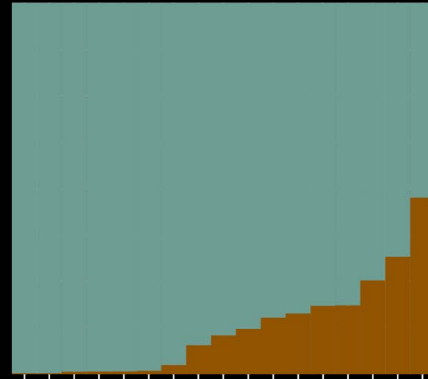
“The Humboldt association will receive 150,000 cutthroat trout from the United States Bureau of Fisheries station in Yellowstone Park this summer.” (1924)

- Partial natural barrier
- Pure populations of CCT

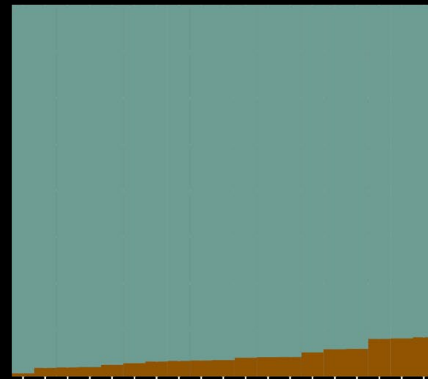
Rogue  
EMI



Klamath  
TEC

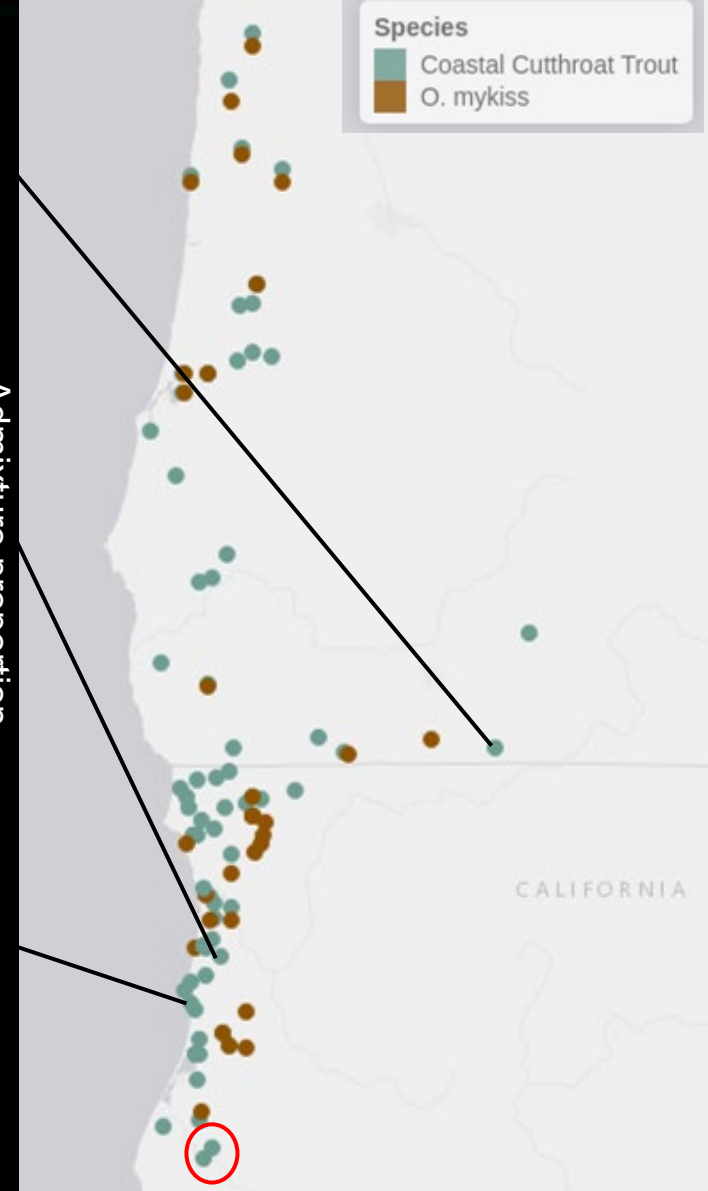


Pacific  
CA-S  
LUF



Individual

Admixture proportion



Species

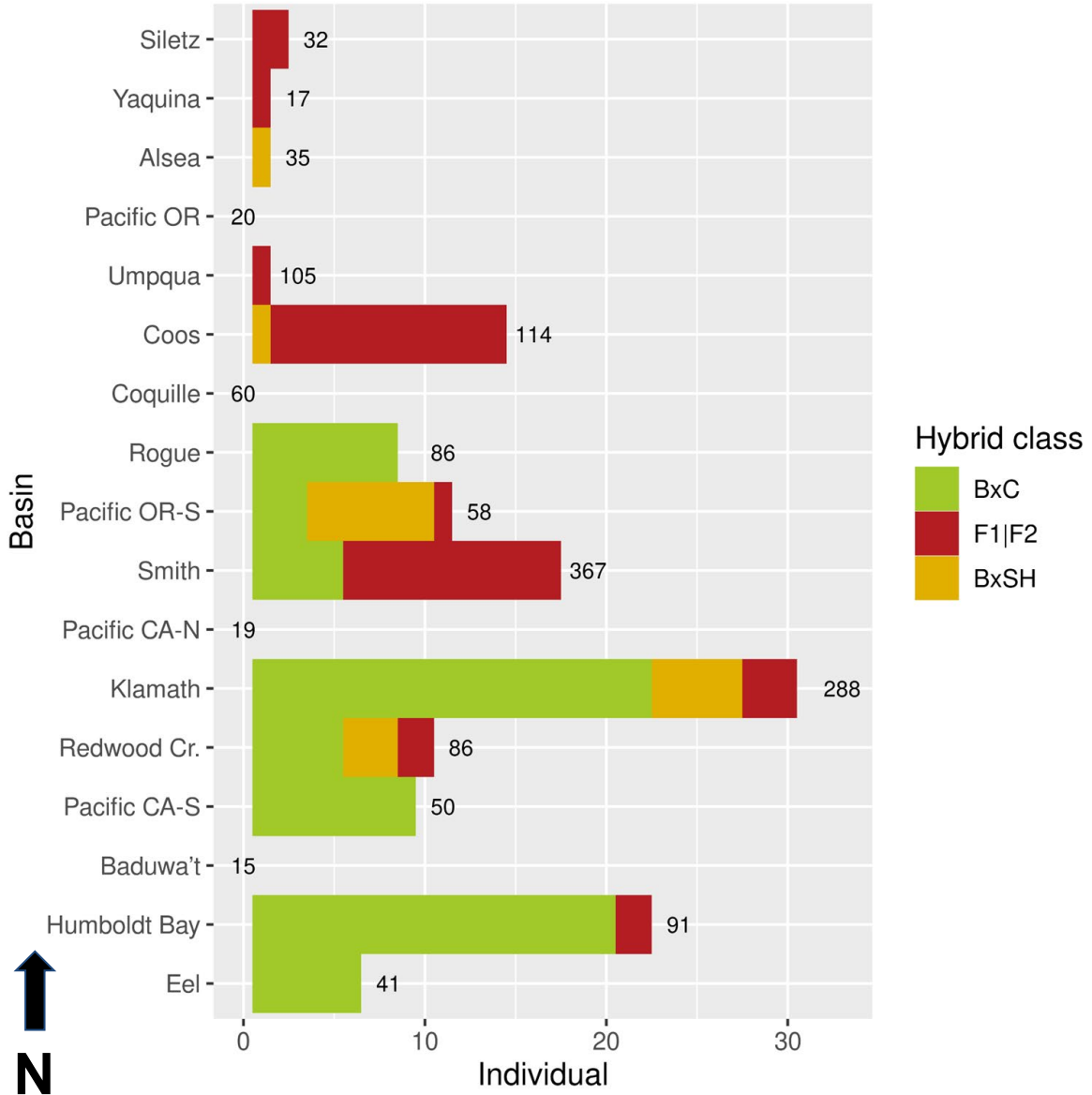
Coastal Cutthroat Trout  
O. mykiss

# Research Questions

1. How is hybridization manifested across the landscape?
  - a. Where are F1s (first-generation hybrids) detected?
  - b. How do barriers affect hybridization rates and hybrid types?
  - c. Do hybridization rates vary geographically?
  - d. Do hybridization rates change over time?

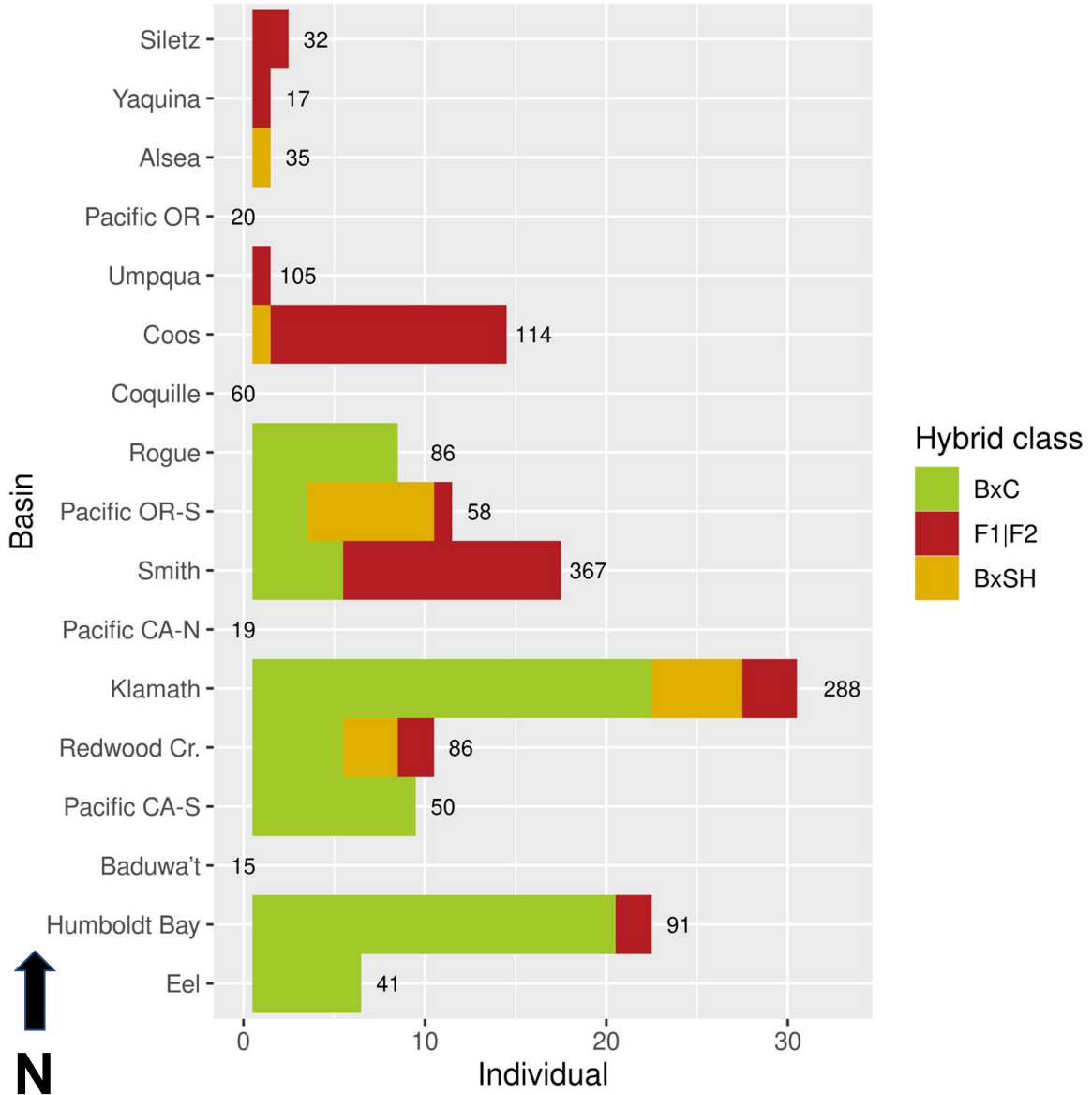


# Geographical Gradient of Hybrids



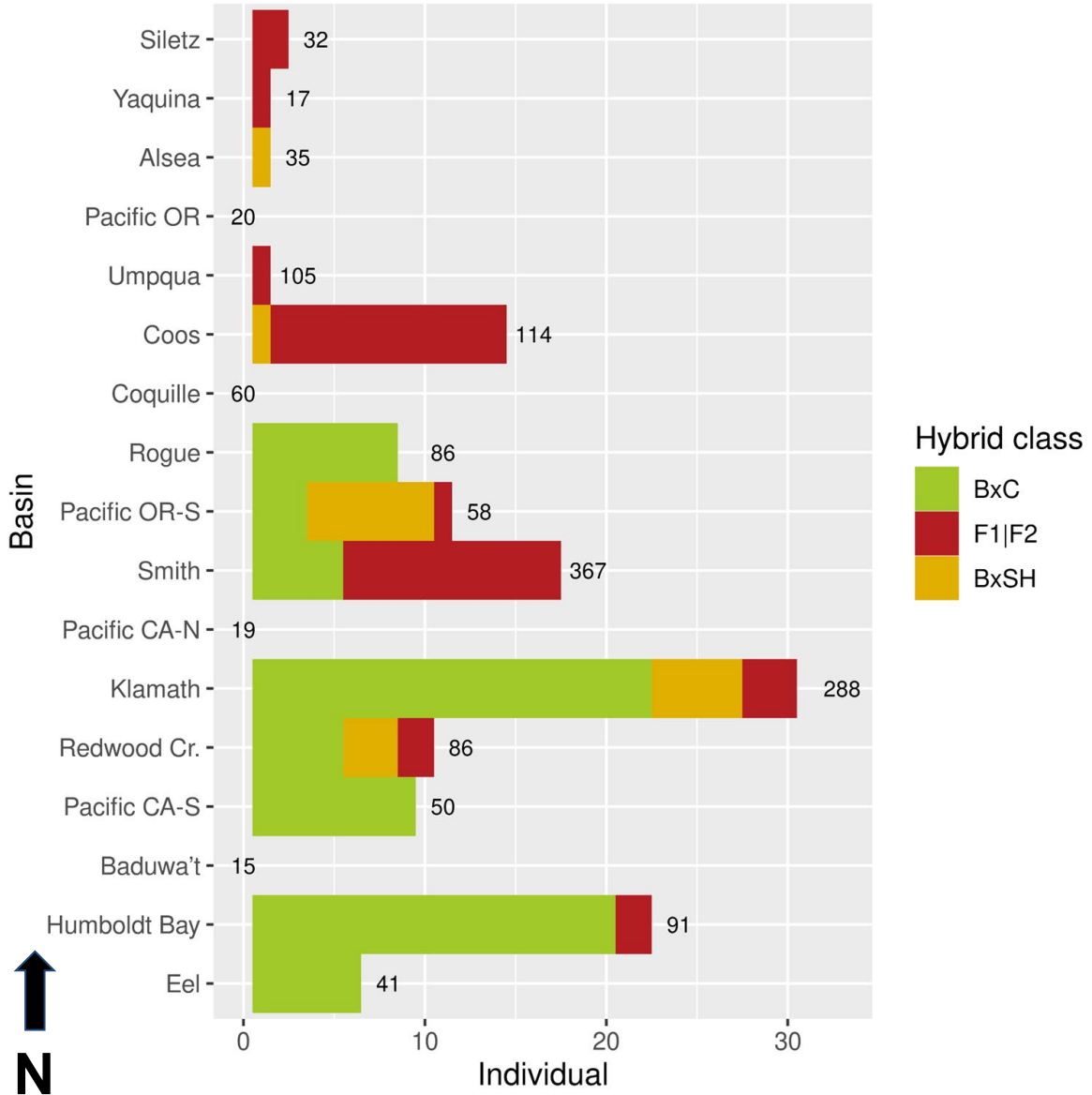
# Geographical Gradient of Hybrids

- Sampling bias



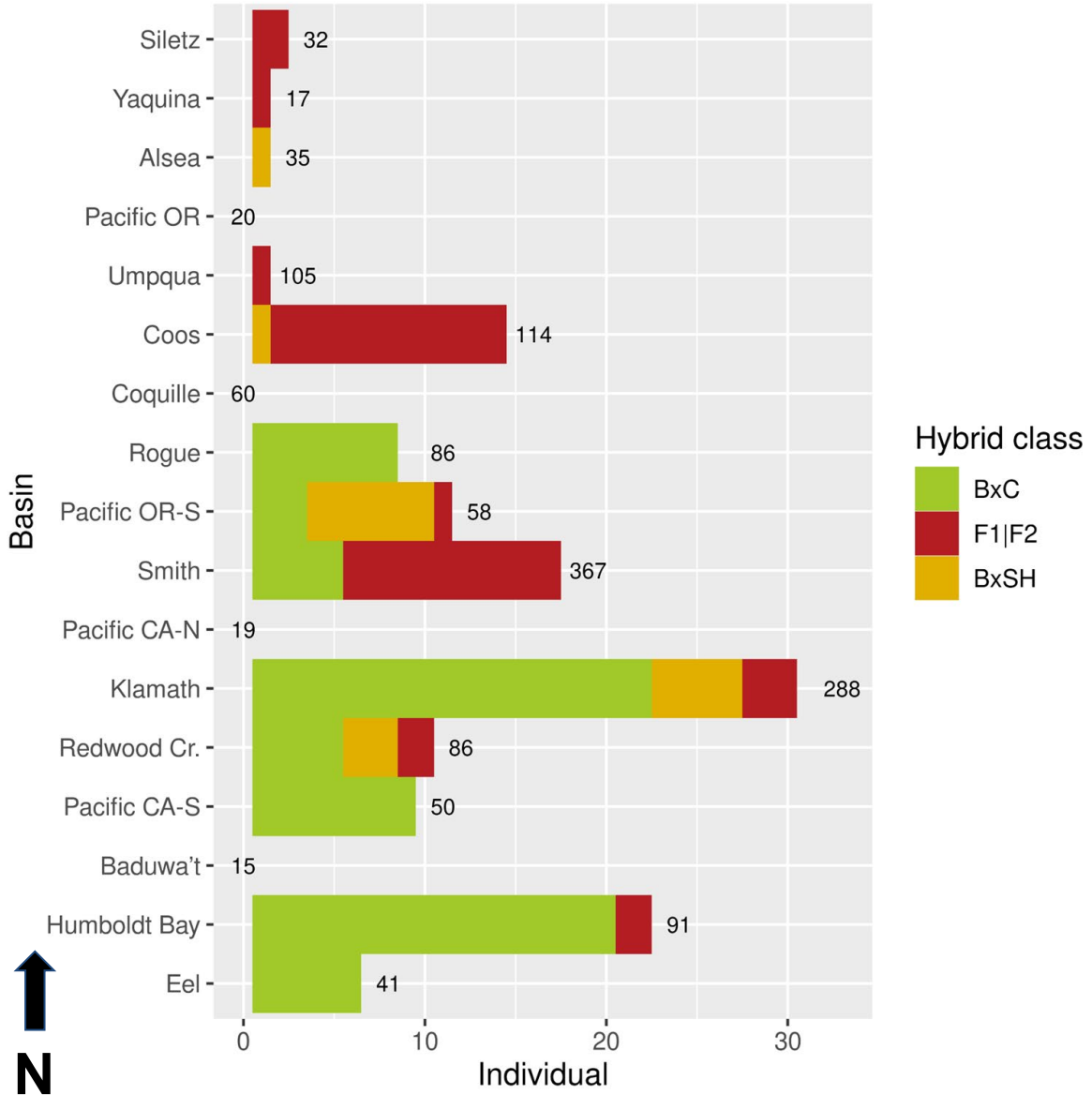
# Geographical Gradient of Hybrids

- Sampling bias
- Genomic incompatibilities



# Geographical Gradient of Hybrids

- Sampling bias
- Genomic incompatibilities
- Differential survival of hybrids



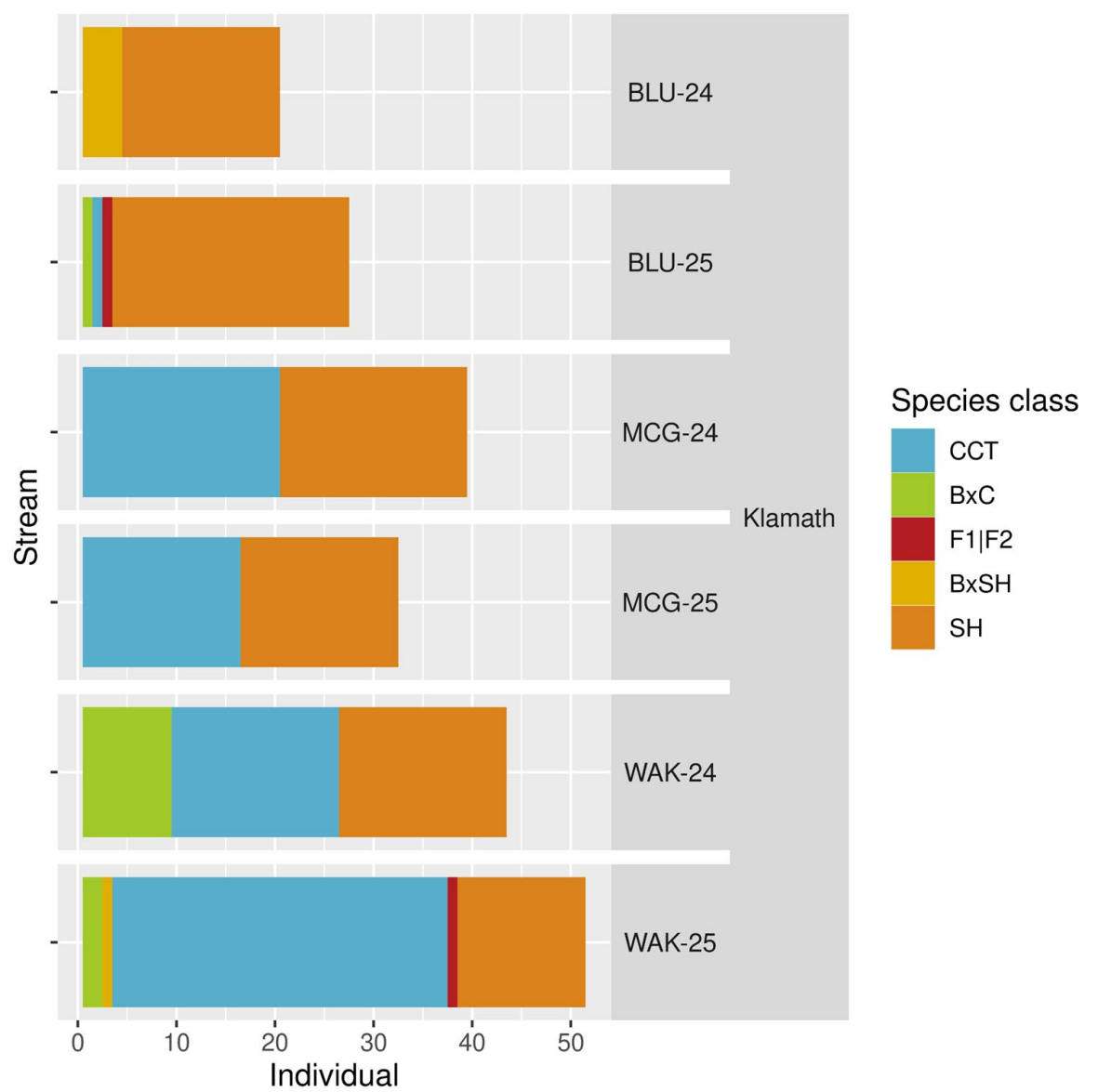
# Research Questions

1. How is hybridization manifested across the landscape?
  - a. Where are F1s (first-generation hybrids) detected?
  - b. How do barriers affect hybridization rates and hybrid types?
  - c. Do hybridization rates vary geographically?
  - d. Do hybridization rates change over time?



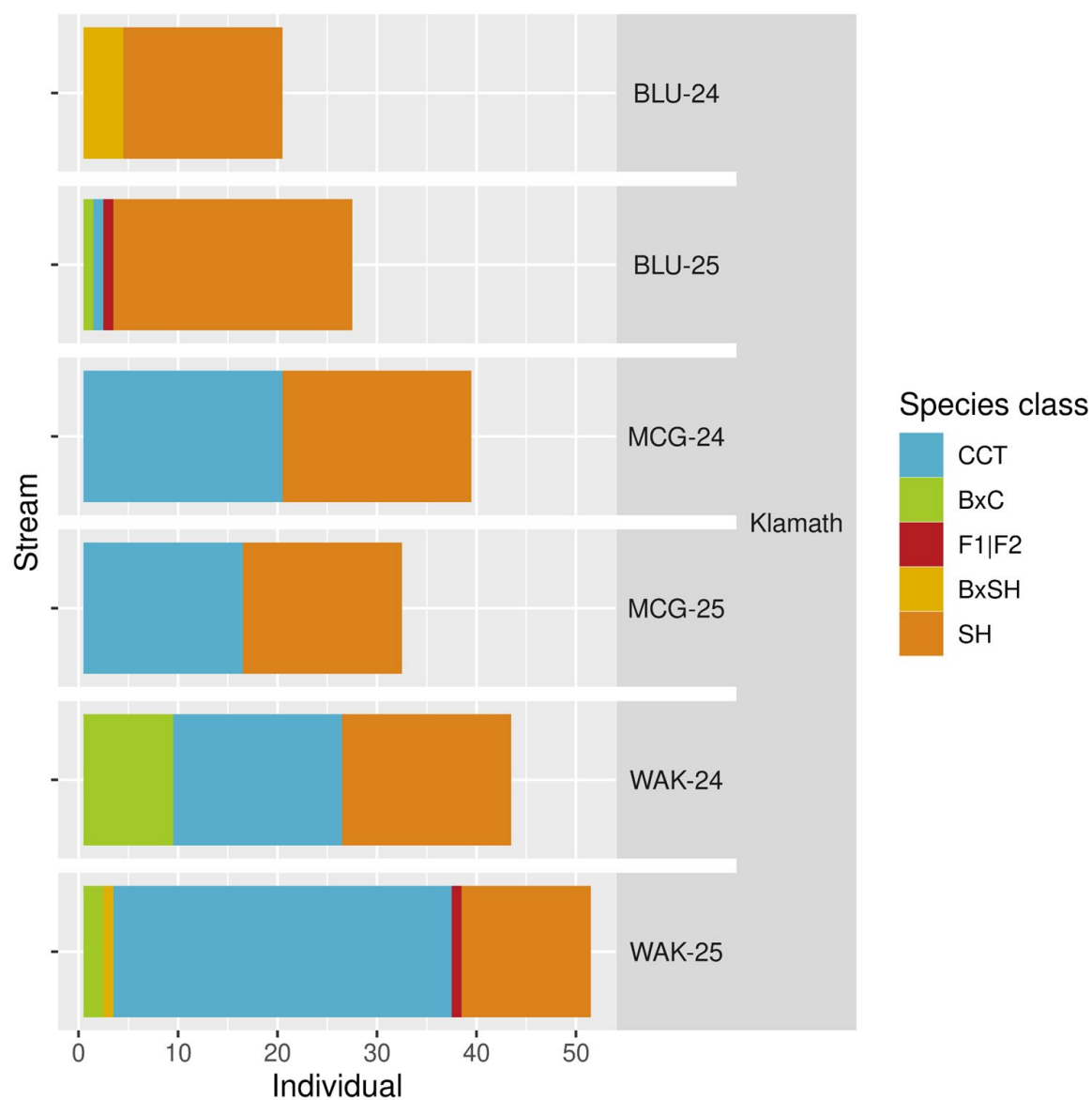
# Hybridization over time

- Three lower Klamath tributaries
- Two years of screw trap data



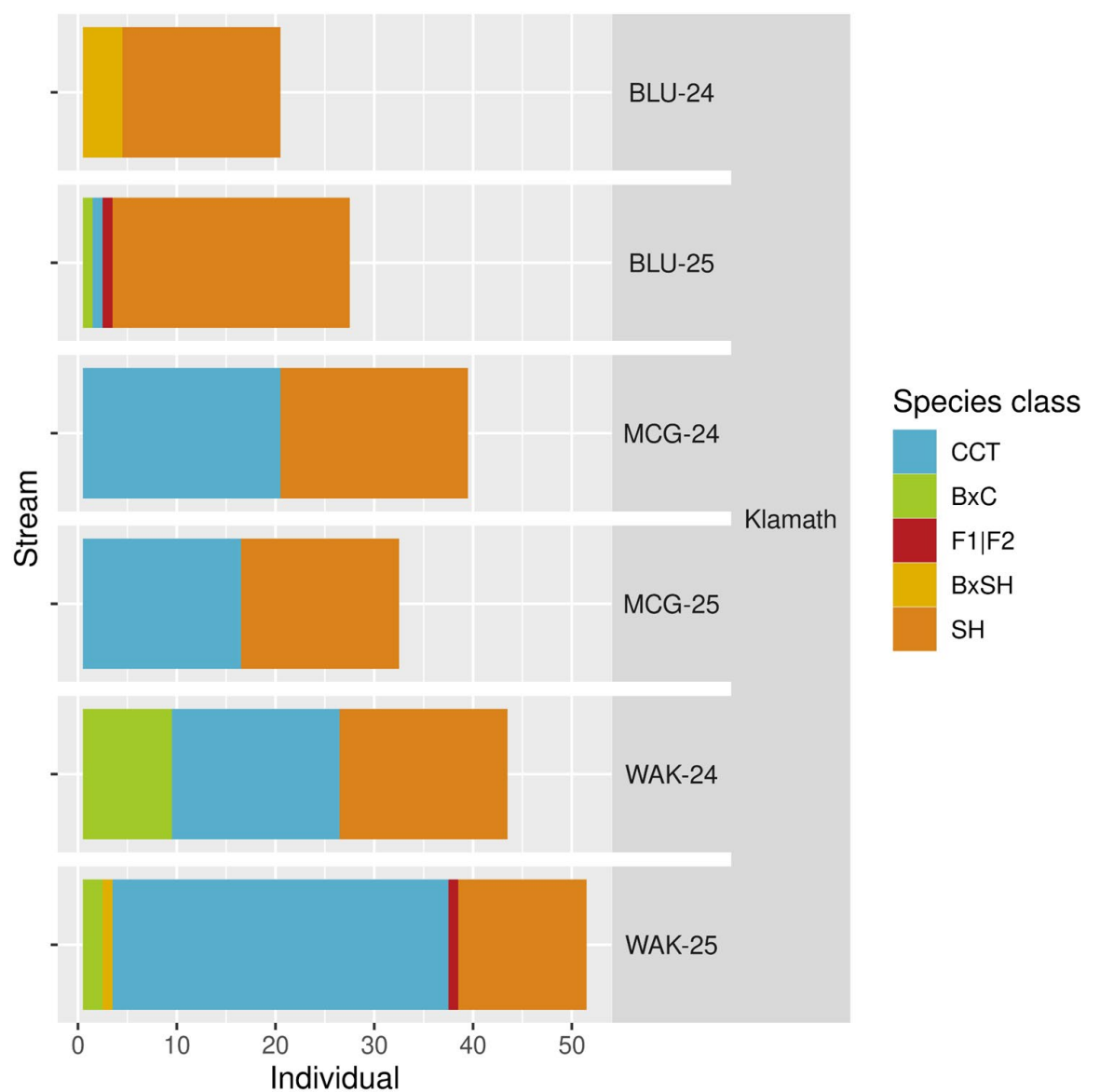
# Hybridization over time

- Three lower Klamath tributaries
- Two years of screw trap data
- Amount of hybridization similar



# Hybridization over time

- Three lower Klamath tributaries
- Two years of screw trap data
- Amount of hybridization similar
- Annual difference in hybrid type



# Conclusions

- Limited hybridization but hot spots are present



# Conclusions

- Limited hybridization but hot spots are present
- F1 hybrids tend to outmigrate



# Conclusions

- Limited hybridization but hot spots are present
- F1 hybrids tend to outmigrate
- Manmade barriers perpetuate hybridization AND isolate pure CCT



# Conclusions

- Limited hybridization but hot spots are present
- F1 hybrids tend to outmigrate
- Manmade barriers perpetuate hybridization AND isolate pure CCT
- Geographical gradient of hybrids



# Conclusions

- Limited hybridization but hot spots are present
- F1 hybrids tend to outmigrate
- Manmade barriers perpetuate hybridization AND isolate pure CCT
- Geographical gradient of hybrids
- Stay tuned for information on annual variation



# Acknowledgements

Samantha Kannry, TRIB Research  
Zane Ruddy, BLM  
Alex Fraik, USFS  
Sean O'Rourke  
Andrea Schreier, UC Davis  
Amanda Finger, UC Davis  
Emily Funk, UC Davis  
Liam Zarri, Cornell  
Andrew Kinziger, Cal Poly Humboldt  
Eric Anderson, NOAA  
Carlos Garza, NOAA  
Margaret Wilzbach, Cal Poly Humboldt  
Bret Harvey, USFS  
Rod Nakamoto, USFS  
Jimmy Faulkner, Yurok Tribe  
Darren Ward, Cal Poly Humboldt  
Colin Anderson, CDFW  
Chris Loomis, CDFW  
Jolyon Walkley, CDFW  
Pat Burns, ODFW  
Ed Hughes, Coos Watershed Association  
Kevin Whittaker, Coos Watershed Association  
Kyle Max, Redwood National Park  
Keith Lackey, Humboldt Redwoods  
Matt Nannizzi, Green Diamond  
Jeff Abrams  
Natalie Okun  
Dylan Keel  
Jon Hollis  
Nick Van Vleet



# The Salmon Data Discovery Tool

## A Salmon Data Partnership

### **NWFSC**

Katie Barnas  
Damon Holzer  
Mary Hunsicker  
Chris Jordan  
Michelle Rub  
Dawn URycki  
Eric Ward

### **PSMFC**

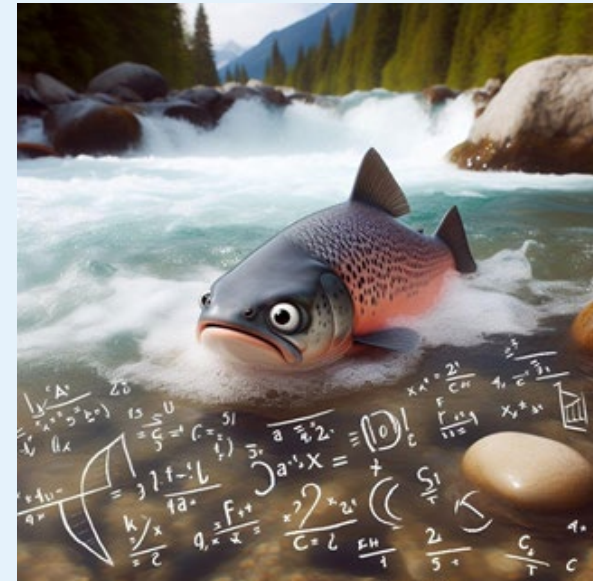
Monica Diaz  
Nancy Leonard  
Gabe Smith  
Greg Wilke  
Mari Williams  
Greg Williams





# The salmon data conundrum..25+ years of Pacific salmon data and products

- Where to find the data
- Where to house the data products
- Different types of products are stored in different places



## Goal: Make salmon related products more findable, accessible, and reusable

Develop a web-based tool to house salmon datasets, derived products, and documents across all ecosystems





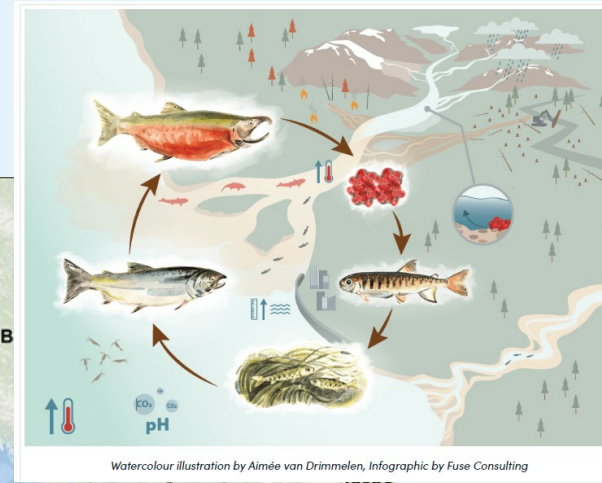
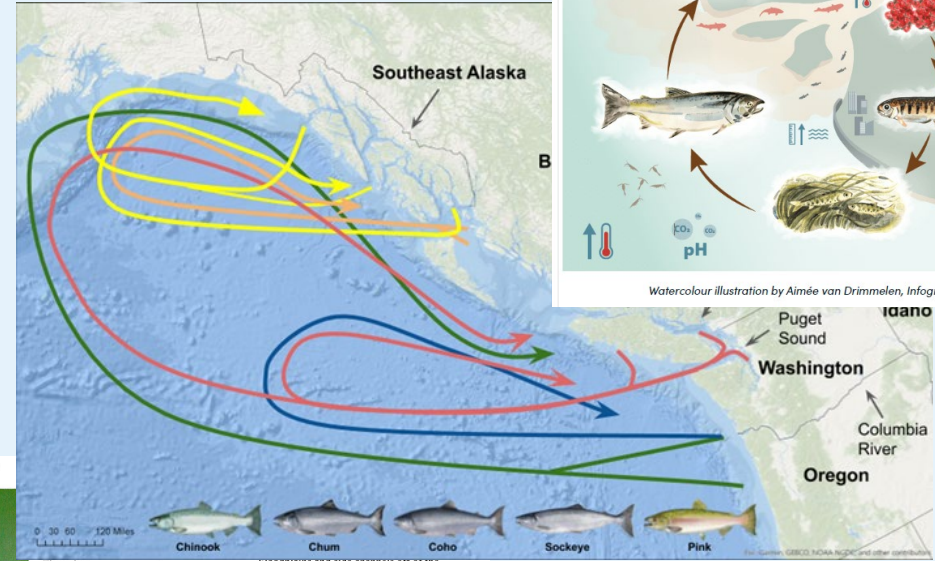
# Geographic and Ecological Scope

## West Coast of North America waters with Pacific salmon

- Freshwater
- Nearshore/ Estuary
- Off-Shore Ocean

## Species/ Environmental indicators

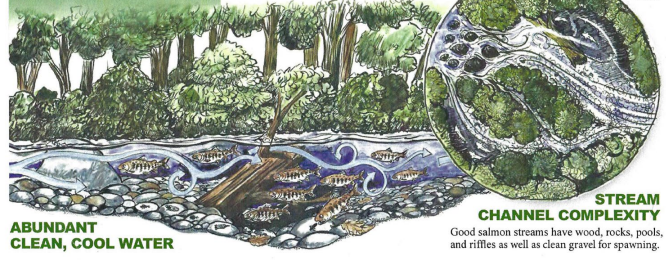
- prey/predator/competitor species
- ecosystem indicators
- habitat metrics



### GOOD SALMON HABITAT

- They also:
- attract insects that salmon eat
  - stabilize the banks against erosion and filter run-off from rain
  - provide woody debris, roots, and fallen trees, to increase the complexity of the stream channel

- Floodplains and side channels off of the main stream provide:
- refuge from high, harmful flows
  - high quality foraging and rearing areas



## Product Types and Users

**Data types:** documents, data files, derived data products, spatial data, GitHub links

**Contributors-** Anyone!

**User -** Anyone!



Documents



Spatial Layers



Data Sets



GitHub Code



### Key Ecosystems



Off-Shore Ocean



Estuary/Nearshore Ocean

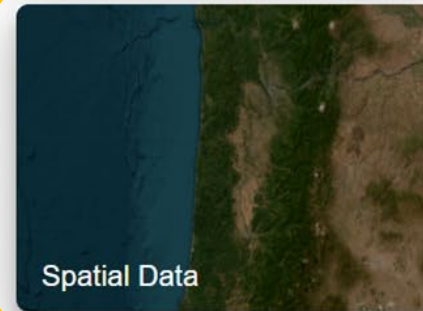
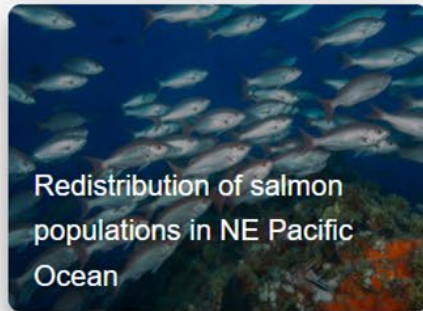
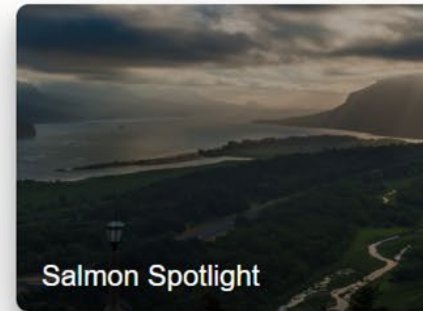


Freshwater Riverscape

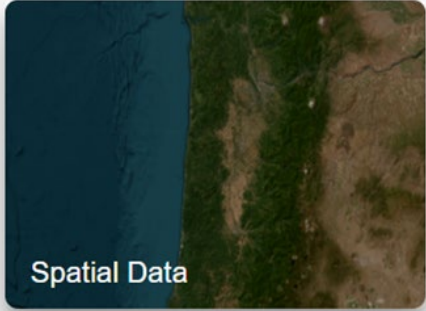


## Data Discovery

*Salmon travel through multiple ecosystems during different stages of their life. Explore the variety of ways data from diverse ecosystems contribute to salmon recovery efforts.*



Browse pre-filtered data, relating to reports, published documents and more



### Intrinsic Potential - Interior Columbia Basin (steelhead, stream-type Chinook)

Built using 1:100k, NHD Hydrography - We developed a reach level intrinsic potential (IP) analysis for application to stream-type Chinook and steelhead spawning reaches to assess habitat quality within currently and historically occupied portions . . .

Tags: ICTRT, steelhead, habitat, snake river, chinook, Interior Columbia Basin, Intrinsic potential, spawn . . .

(140) (10) Type: Spatial Version: 3 Published: 2025

### Intrinsic Potential - Puget Sound (steelhead)

Built using 1:100k, NHD Hydrography We developed a reach level intrinsic potential (IP) analysis for application to steelhead spawning reaches for assessing habitat quality within currently and historically occupied portions of the Puget Sound ste . . .

Tags: steelhead, Salish Sea, Intrinsic potential, summer-run, winter-run, spatial, IP, Puget Sound

(51) (5) Type: Spatial Version: 1 Published: 2025

### Intrinsic Potential - Puget Sound (steelhead)

Last updated 12/1/2025 Views (52) Downloads (5)

[Report this data](#)



#### About Dataset

Built using 1:100k, NHD Hydrography We developed a reach level intrinsic potential (IP) analysis for application to steelhead spawning reaches for assessing habitat quality within currently and historically occupied portions of the Puget Sound steelhead DPS. This approach enabled us to formulate a baseline perspective from which we could assess contemporary changes to productivity. Utilizing established relationships between habitat type, stream structure, landscape processes, and spawning use, we built a locally adapted Geographic Information System (GIS) based model. The GIS was used for the development, presentation, management and modeling of spatially referenced data. Geomorphological characteristics were assigned to unique categories of gradient and width and these classes were given IP scores that reflect relative steelhead spawning preferences based on observed densities within those habitat characteristics. Additionally, we identified natural stream blockages and scored reaches above waterfalls, cascades, and DEM calculated gradients with zero spawning potential.

**Ecosystem:** Freshwater Riverscape

**Project:** PSTRT

**Date Ranges:** 9/28/2025 - 9/28/2025

**Content Type:** Spatial

**Species:** Steelhead

**Data Collection:** Not a Time Series

**ESU/DPS:** Steelhead Salmon (Puget Sound)

**Frequency:**

**Population:** Steelhead (Puget Sound) - Baker River;  
Steelhead (Puget Sound) - Canyon Creek;  
Steelhead (Puget Sound) - Deer Creek;

**Season:** Not Applicable

**Fishery Management**

[View more](#)

**Published Date**

2025

**Version**

1

**Access and Use**

Non-sensitive Data

**Download**

[Download](#)

**Contacts**

Damon Holzer

**Tags**

[steelhead](#) [Salish Sea](#)

[Intrinsic potential](#) [IP](#)

[Puget Sound](#) [summer-run](#)

[winter-run](#) [spatial](#)

#### More Information Expand All

##### Download and Versions

SOURCE TYPE ↓	DESCRIPTION ↓	UPLOAD DATE ↓	DATA FILE/CONNECTION ↓
File	This compressed file contains a shapefile describing intrinsic potential habitat for listed steelhead within the Puget Sound DPS	9/29/2025	<a href="#">Download</a>



## Data Discovery

*Salmon travel through multiple ecosystems during different stages of their life. Explore the variety of ways data from diverse ecosystems contribute to salmon recovery efforts.*



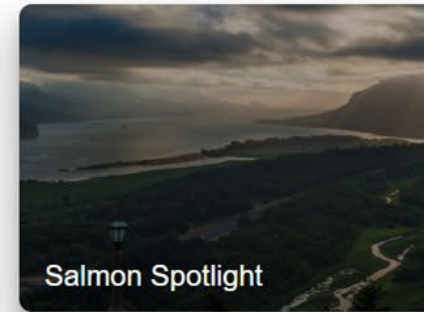
What goes into a Viability Report?



Ecological Concerns



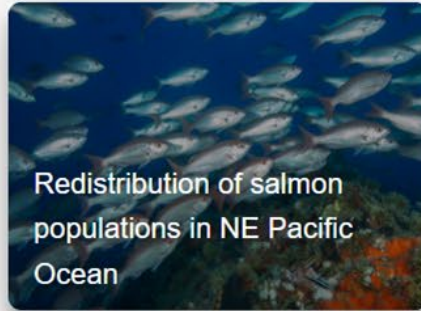
Abundance trends of Pacific Salmon



Salmon Spotlight



Essential Fish Habitat



Redistribution of salmon populations in NE Pacific Ocean



Salmon Technical Recovery Teams (TRT) documents



Spatial Data

# LINKING DATA WITH DOCUMENTS



**Filter Options**

- Freshwater Riverscape (9)
- Off-Shore Ocean (6)
- Estuary/Nearshore Ocean (0)

**Species**

**Filter Options**

- Chinook (8)
- Steelhead (4)
- Coho (3)
- Sockeye (3)
- Chum (2)

Show 2 more

**ESUDPS**

**Filter Options**

- Chinook Salmon (Upper Columbia River ESU) (6)
- Sockeye Salmon (Snake River) (3)
- Chinook Salmon (Lower Columbia River ESU) (5)
- Chinook Salmon (Puget Sound ESU) (6)
- Chinook Salmon (Snake River Fall Run) (5)

Show 49 more

**Population**

**Biological Viability Assessment Update for Pacific Salmon and Steelhead Listed Under the Endangered Species Act: Pacific Northwest (Jan 2022)**  
 Agency Report, required 5 year assessment for ESA listed species  
 Tags: Viability Report, 2022 viability, steelhead, chum, coho, esa, biological viability assessment, chiro ...  
 (23) (0) Type: Document Version: 1 Published: 2022

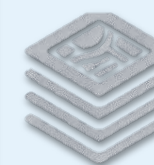
**Chinook Salmon Populations**  
 Distinct watershed based subsets of Chinook salmon sharing spatial, genetic, and/or life history characteristics.  
 Tags: salmon, chinook, 2022 viability, Viability Report  
 (4) (0) Type: Spatial Version: 1 Published: 2021

**Salmon Population Summary 2022 Viability Report dataset**  
 Dataset used for the 2020 Viability Report to support the Status Review.  
 Tags: Viability Report, 2022 viability  
 (5) (1) Type: Tabular Version: 1 Published: 2022

**Salmon Viability Github**  
 These are R code and data packages used for the PNW Salmonid 5-year Viability Report (prepared by NWFSC) which supports with 5-year Status Reviews (prepared by WRO). <https://nwfsc-math-bio.github.io/>  
 Tags: 2022 viability, biological viability report, coho, chum, esa, chinook, salmon, sockeye, sps, steelha ...  
 (2) (1) Type: Document Version: 1 Published: 2022



Report



Spatial Layers



Abundance Data



GitHub Code



## Ways to Search - Filters

### Filters Reset

**Ecosystem** ^

Filter Options

- Off-Shore Ocean (8)
- Estuary/Nearshore Ocean (5)
- Freshwater Riverscape (30)

**Species** ^

Filter Options

- Chinook (30)
- Steelhead (19)
- Coho (14)
- Sockeye (9)
- Chum (11)

[Show 2 more](#)

**ESU/DPS** ^

Filter Options

- Chinook Salmon (Sacramento River winter-run ESU) (2)
- Chinook Salmon (Upper Columbia River ESU) (12)
- Coho Salmon (Central California Coast ESU) (2)
- Sockeye Salmon (Snake River) (8)
- Steelhead (Southern California Coast DPS) (1)

[Show 49 more](#)

**Population** ^

Filter Options

- Chinook (Snake River Fall Run) - Snake River Lower Mainstem (1)
- Not Applicable (2)
- Chinook (Deschutes River Summer/Fall run) - Deschutes Fall (0)
- Chinook (Mid-Columbia River Spring-Run) - Upper Deschutes Spring (0)
- Chinook (Mid-Columbia River Spring-Run) - American Spring (0)

[Show 1085 more](#)

**Time Period** ^

To:

From:

Update
Reset

**Fishery Management Areas** ^

Filter Options

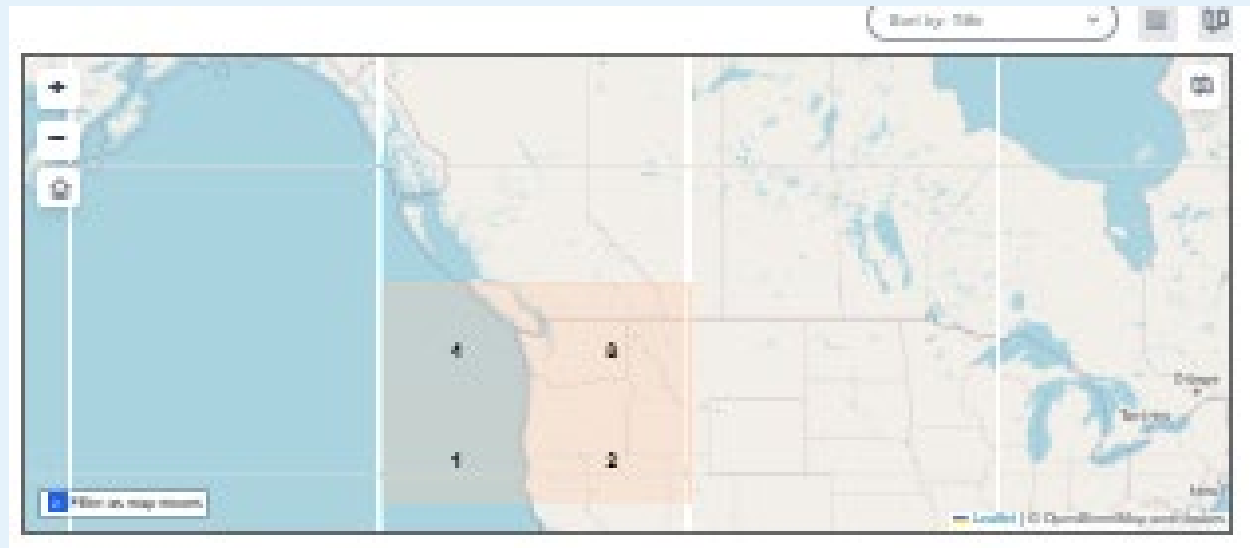
- Columbia River Basin (8)
- Puget Sound (2)
- Pacific Coast (5)
- Snake River (2)
- Willamette River (3)

[Show 4 more](#)


## More Ways to Search

**Advanced Search** [Home](#) > [Advanced Search](#)


## Location




# Search: California




**Oregon Coast and Southern Oregon & Northern California Chinook ESUs; Population, Run-Type, Use, and Catchment Attributes Used for ESU Listing Assessment**  
 This dataset is a key spatial tool developed to support the Oregon Coast and Southern Oregon & Northern California Chinook Biological Review Team (BRT) in evaluating population structure, listing potential, and associated ecological conditions for th ...  
 Tags: Chinook salmon, biological review team, spring, population, esu, use, spatial, OC, SONC, fall, ...  
 (2) (0) Type: Spatial Version: 1 Published: 2025



**STEELHEAD OF THE SOUTH-CENTRAL/SOUTHERN CALIFORNIA COAST: POPULATION CHARACTERIZATION FOR RECOVERY PLANNING**  
 South Central/ Southern California Steelhead Population Identification Document NOAA-TM-NMFS-SWFSC-394  
 Tags: Technical Recovery Team, Pop ID, California, South Central/Southern CA Coast, steelhead  
 (1) (0) Type: Document Version: 1 Published: 2005



**VIABILITY CRITERIA FOR STEELHEAD OF THE SOUTH-CENTRAL AND SOUTHERN CALIFORNIA COAST**  
 Technical Recovery Team Tech Memo NOAA-TM-NMFS-SWFSC-407  
 Tags: TRT, steelhead, California, South Central/Southern CA Coast, Technical Recovery Team  
 (0) (0) Type: Document Version: 1 Published: 2007



**West Coast of North America Shoreline**  
 This shapefile contains the merged features of the best available shorelines circa 2005. The scales vary, but generally range between 1:24k to 100k (most of the WC of the US and Canada are closer to 24k). Some island names have been attributed, but t ...  
 Tags: Alaska, Baja, British Columbia, California, Canada, coastline, Mexico, Oregon, shoreline, USA, West, ...  
 (64) (8) Type: Spatial Version: 1 Published: 2025



**A FRAMEWORK FOR ASSESSING THE VIABILITY OF THREATENED AND ENDANGERED SALMON AND STEELHEAD IN THE NORTH-CENTRAL CALIFORNIA COAST RECOVERY DOMAIN**  
 TRT Viability Document for the North Central California Coast  
 Tags: TRT, California, North-Central California Coast, Technical Recovery Team  
 (5) (0) Type: Document Version: 1 Published: 2008



**AN ANALYSIS OF HISTORICAL POPULATION STRUCTURE FOR EVOLUTIONARILY SIGNIFICANT UNITS OF CHINOOK SALMON, COHO SALMON, AND STEELHEAD IN THE NORTH-CENTRAL CALIFORNIA COAST RECOVERY DOMAIN**  
 TRT Document, Historical population structure for the North Central CA Coast recovery domain  
 Tags: Technical Recovery Team, North Central CA Coast, population structure, TRT  
 (0) (0) Type: Document Version: 1 Published: 2005



**Data for northern California Current salmon stoplight table**  
 Raw data for northern California Current salmon stoplight table.  
 Tags: trends, stoplight table, coho, indicators, conditions, Salmon Stoplight  
 (45) (2) Type: Tabular Version: 2 Published: 2024



**FRAMEWORK FOR ASSESSING VIABILITY OF THREATENED COHO SALMON IN THE SOUTHERN OREGON / NORTHERN CALIFORNIA COAST EVOLUTIONARILY SIGNIFICANT UNIT**  
 TRT Viability Document for SONC Coho  
 Tags: TRT, viability, California, Oregon, Technical Recovery Team, SONC Coho  
 (0) (0) Type: Document Version: 1 Published: 2008



**HISTORICAL POPULATION STRUCTURE OF COHO SALMON IN THE SOUTHERN OREGON/NORTHERN CALIFORNIA COASTS EVOLUTIONARILY SIGNIFICANT UNIT**  
 TRT Document SONC Coho Population Structure  
 Tags: SONC Coho, Technical Recovery Team, population structure, TRT  
 (0) (0) Type: Document Version: 1 Published: 2005

Ecosystem ⌵

Filter Options

- Off-Shore Ocean (3)
- Estuary/Nearshore Ocean (1)
- Freshwater Riverscape (8)

Species ⌵

Filter Options

- Chinook (5)
- Steelhead (4)
- Coho (6)
- Sockeye (1)
- Chum (1)
- Pink (0)
- Coastal Cutthroat Trout (0)

[Show fewer](#)

ESU/DPS ⌵

Filter Options

- Coho Salmon (Central California Coast ESU) (1)
- Steelhead (Southern California Coast DPS) (2)
- Chinook Salmon (Central California ...

[Show 49 more](#)

## Data Upload - Create Login

**Sign up**

First Name

Last Name

Agency

Email

Password

Confirm Password

[Sign Up](#)

Already have an account? [Login](#)

This site is protected by reCAPTCHA and the Google Privacy Policy and Terms of Service apply.

Hi Katie! ^

My Datasets

Home > My Datasets

---

[Add New Dataset](#)

# Data Upload - Content Description

### Content Description

\* Ecosystem:

\* Title:

Description:

Project:

\* Content Type:

\* Keywords:

Dates Range:  to

Species:

Range of Years:  to

ESU/DPS:

Data Collection Frequency:

Population:

Season:

Fishery Management Area:

Dataset used in Reports:

TITLE ↓	ECOSYSTEM ↓	LAST UPDATED ↓	VERSION ↓	CONTACT NAMES ↓
No data found!				

Thumbnail:   Acknowledgement:

Notes:



## Roles

### Contacts

Add

CONTACT NAME ↓	TITLE ↓	AGENCY ↓	ACTIONS ↓
No data found!			

### Collaborators

Add Collaborator

Transfer Ownership

Katie Barnas (you)  
katie.barnas@noaa.gov • NMFS - NOAA **Owner**



# Data Upload - Citation

## Citations

We are committed to ensuring proper attribution for all dataset contributors. When uploading data, please include comprehensive acknowledgment of all organizations, institutions, and tribal entities whose data informed or contributed to these records.

\* Dataset Name:

\* Data Type:

\* Min Date:

\* Max Date:

\* Contact Organization:

Dataset DOI:

Location of dataset (URL):

Document DOI:

Reference or application DOI:

Version:

Data Collectors:

Access Date:

Data User(s):

\* Year Published:

Citation Notes:



- Files
- Location

**Upload / Connect Data** Add

SOURCETYPE ↓	DESCRIPTION ↓	DATA FILE CONNECTION ↓	METADATA ↓	CITATION ↓	UPLOAD DATE ↓	EDIT/DELETE ↓
No data found!						

**Dataset Coverage Areas** + Add Coverage Area

Click 'Add Coverage Area' to start drawing a new coverage area on the map.  
Use the map controls to draw rectangles, clear drawings, or change the basemap.

Coverage Areas (0)

**Upload / Connect Data** ×

\* Source Type:  
File

\* File/Link Description:

If submitting more than one file, please bundle them into a ZIP archive for uploading. Total file size for uploads should not exceed 2GB.

\* File  Browse

Download the template for metadata ([click here](#))

Metadata  Browse


Citation File  Browse

Cancel Save



### Data Sensitivity

*Provide the category the best describes the level of sensitivity of your data*

Non-sensitive data 

None of the data includes private or sensitive information.

Some Sensitivity 

Sensitive or private data has been aggregated or summarized to remove sensitivities to enable safe distribution.

Sensitive Data 

The data contains private or sensitive data or private land owner information that can cause harm to individuals, violate property rights and personal property.

\* I have obtained permission from all parties who contributed to compiling this data and am authorized to share it publicly. I have reviewed the data and verify it contains no unauthorized personal information, confidential material, or sensitive content requiring protection. I understand this data will be publicly accessible, may be downloaded and used by others, and cannot be guaranteed complete removal once published. I take responsibility for the data's accuracy, compliance with applicable regulations, and confirmation that its sharing does not violate any agreements or rights.

Save



## Benefits of contributing to SDDT

Public Access to Research Results: All federal data and data products funded by taxpayer dollars must be freely available

Data Principles:



# SALMON DATA DISCOVERY TOOL

Making Salmon Science Accessible—One Repository, Infinite Insights



## PSMFC & NOAA TEAM

Monica Diaz, Nancy Leonard, Gabe Smit, Greg Wilke, Greg Williams, Mari Williams, Katie Barnas, Damon Holzer, Mary Hunsicker, Chris Jordan, Michelle Rub, Dawn URYcky, Eric Ward



## PROBLEM

Data are scattered among many sites and platforms

- Disconnected from the reports and publications they support
- Difficult to find, stored in numerous locations, and often inaccessible
- Not documented in a way that allows for easy reuse

## SOLUTION

Develop a web-based tool for datasets, derived products and documents across all ecosystems

- Accepts all Pacific salmon related data, including environmental and biological indicators
- Accommodates most file types including reports, spatial and tabular data, and GitHub links
- Allows full downloadable access with complete citation information

## SCOPE

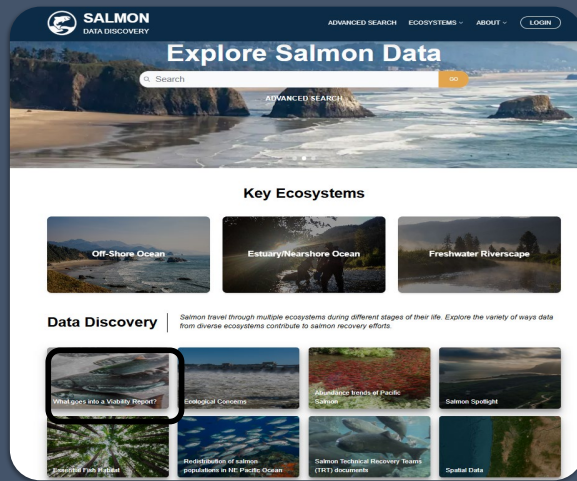
**Geographic:** West Coast of North America waters with Pacific salmon

**Environmental indicators:** prey/predator/competitor species, ecosystem, habitat

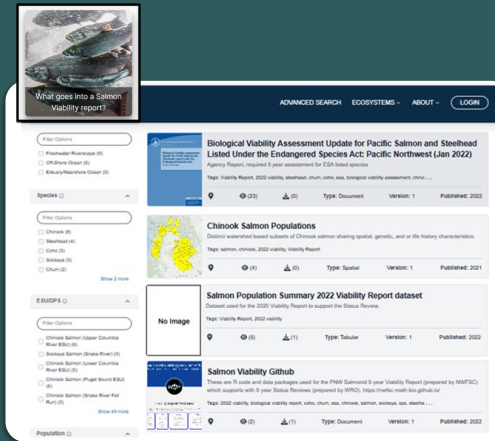
**Data types:** documents, data files, derived data products, spatial data, GitHub links

**Contributor:** any data collectors and interested collaborators

**User:** Anyone!



## LINKING DATA WITH DOCUMENTS



Report



Spatial Layers

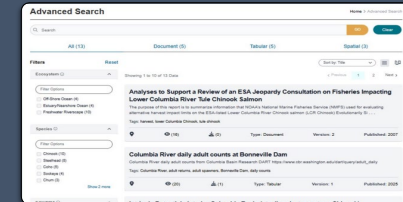


Abundance Data



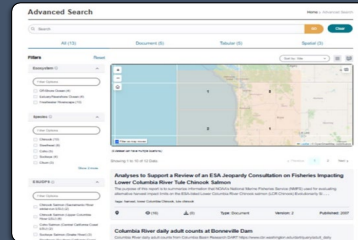
GitHub Code

## DATA SEARCH OPTIONS



**Advanced Search**  
Search options include keyword search bar, sidebar filters for refining results, and file type selection to help users efficiently find relevant data

**Location Explorer**  
The Location Explorer enables geographic data exploration by assigning spatial areas to data and documents. Datasets can appear at multiple map locations, facilitating comprehensive spatial searches.



Data Management

- Data contributors can edit their content at any time, and those edits are tracked and publicly visible
- Multiple versions of data can be uploaded under the same title (e.g., time series or yearly water quality)
- Multiple collaborators can be invited to edit a dataset
- File uploads are limited to 2GB to ensure reasonable download times

Quality Control

- Only non-sensitive data can be submitted
- Contributors must have permissions from all partners, and are responsible for data accuracy and ethical data standards
- Submissions require complete data documentation and proper citation to promote transparency and reusability
- Users can report errors or issues with any published dataset



email: [SDDT@psmfc.org](mailto:SDDT@psmfc.org)

website: <https://sddt.psmfc.org/>



**SALMON**  
DATA DISCOVERY



**NOAA**  
FISHERIES

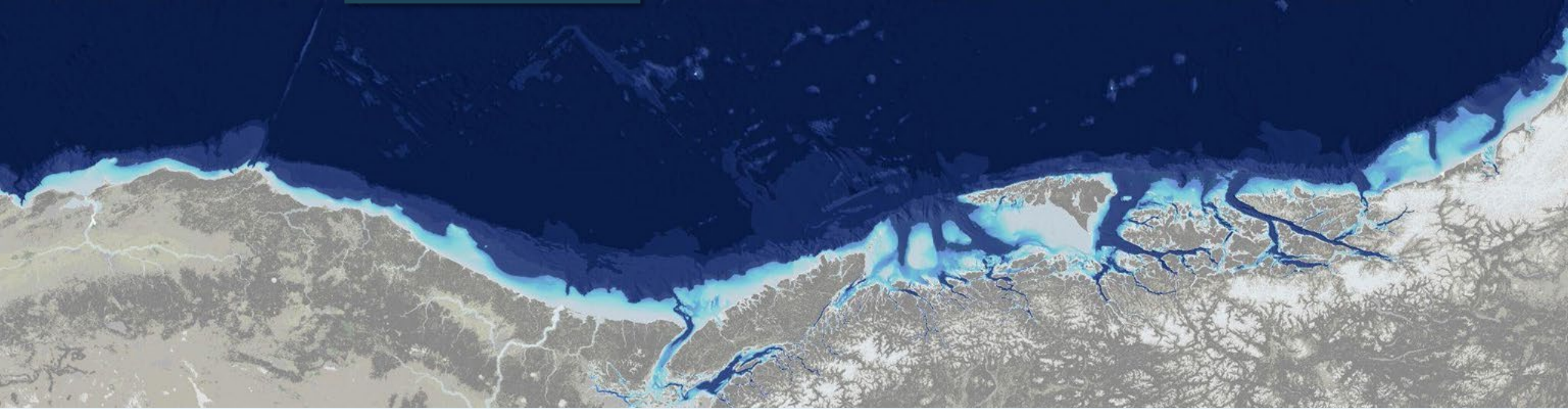


A Salmon Data Partnership



# Questions?

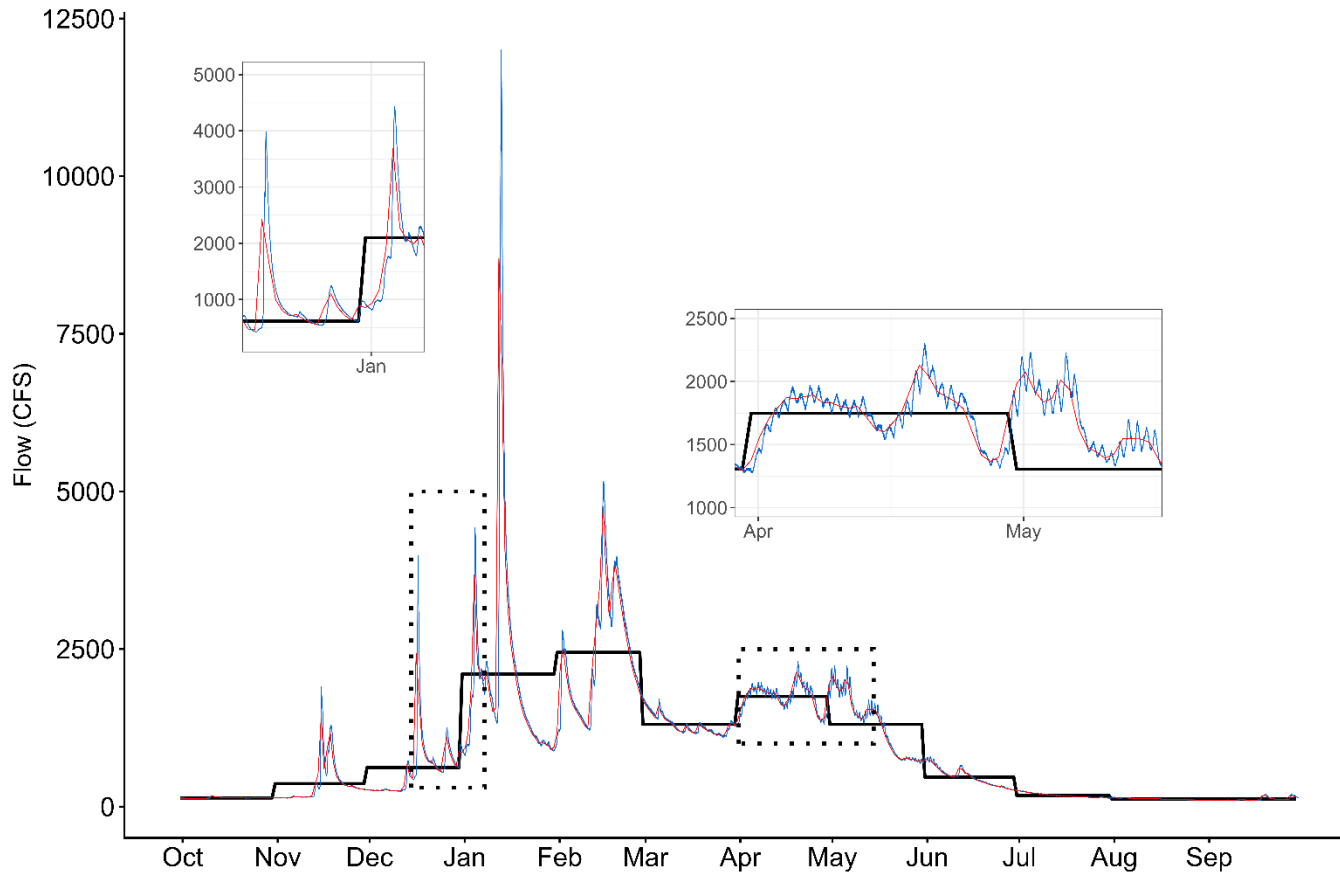
<https://sddt.psmfc.org/>



# The Importance of Flow Variation for Regulated Rivers

Seth W. Naman

— 15 min — Daily mean — Monthly mean



43<sup>RD</sup> Annual  
**Salmonid Restoration Conference**  
*Bridging the Gaps in Restoration*  
APRIL 28 - MAY 1, 2026 REDDING, CA



# Bridging Gaps

## The Natural Flow Regime

*A paradigm for river conservation and restoration*

N. LeRoy Poff, J. David Allan, Mark B. Bain, James R. Karr, Karen L. Prestegard, Brian D. Richter, Richard E. Sparks, and Julie C. Stromberg

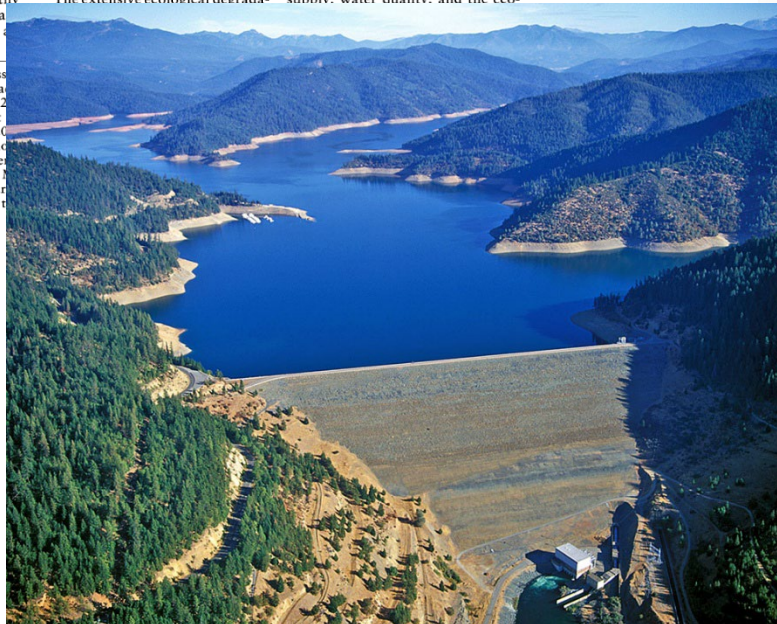
Humans have long been fascinated by the dynamism of free-flowing waters. Yet we have expended great effort to tame rivers for transportation, water supply, flood control, agriculture, and power generation. It is now recognized that harnessing of streams and rivers comes at great cost: Many rivers no longer support socially valued native species or sustain healthy ecosystems that provide important goods and services (Naiman et al. 1995, NRC 1992).

N. LeRoy Poff is an assistant professor in the Department of Biology, Colorado State University, Fort Collins, CO 80523-1878 and formerly senior scientist, Trout Unlimited, Arlington, VA 22204. J. David Allan is a professor at the School of Natural Resources & Environment, University of Michigan, Ann Arbor, MI 48109-1115. Mark B. Bain is a research scientist and associate professor at the

The ecological integrity of river ecosystems depends on their natural dynamic character

The extensive ecological degrada-

ing. However, current management approaches often fail to recognize the fundamental scientific principle that the integrity of flowing water systems depends largely on their natural dynamic character; as a result, these methods frequently prevent successful river conservation or restoration. Streamflow quantity and timing are critical components of water supply, water quality, and the eco-



43<sup>RD</sup> Annual

Salmonid Restoration Conference  
*Bridging the Gaps in Restoration*

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Between science  
and implementation

# Is 15 minutes Instantaneous?



Water Services Web

Services Test Tool

Documentation

Blog

Documentation and Help

▼ Instantaneous Values Service

FAQs

Service Details

▶ Daily Values Service

▶ Site Service

▶ Statistics Service

▶ Groundwater Levels Service

General Questions

[Documentation and Help](#) > Instantaneous Values Service

## Instantaneous Values

This service lets you acquire near real-time water data from thousands of sites managed or monitored by the USGS across the country. Readings are usually made every 15 minutes and transmitted hourly.

[Instantaneous Values Frequently Asked Questions](#)

Questions that are most often asked that do not fall in any specific service topic.

[Instantaneous Values Service Details](#)

You can use this service to retrieve recent and historical values for streamflow as well as data for other regular time-series parameters served by the USGS.

# Inspiration



Lewis Fry  
Richardson

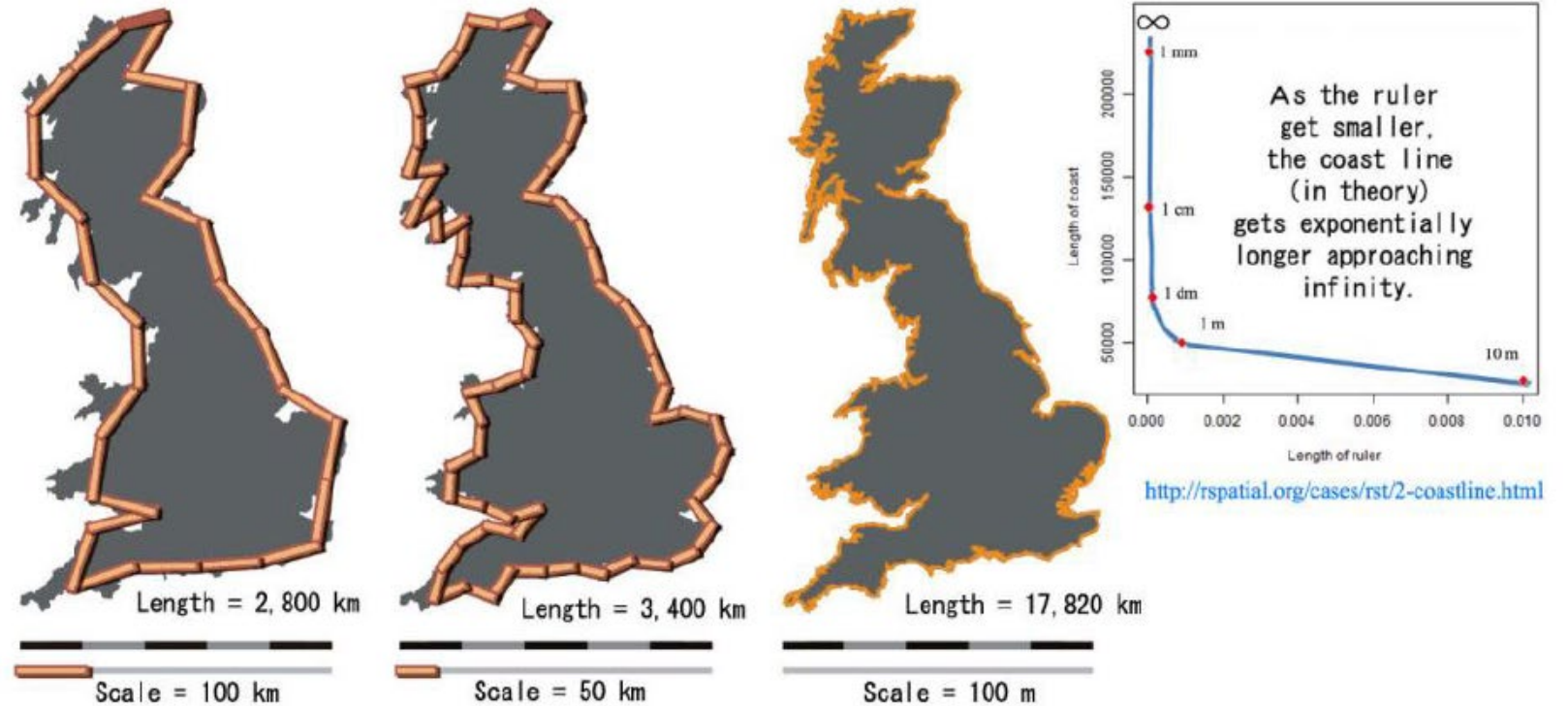


Benoit Mandelbrot



# Coastline Paradox

- First described by Lewis Fry Richardson and then by Benoit Mandelbrot
- As measurement length decreases, measured distance increases
- Coastlines have fractal-like properties, especially rocky coastlines
- Fractal dimensions (between 1 and 2) can be used to categorize coastal geomorphic processes



Blakemore 2018 and Wikipedia

# Coastline Paradox

- Has not been disproven
- But authors have shown there are practical limits
- E.g. water molecule size and minimum measurement increment

Journal of Coastal Research	00	0	000-000	Coconut Creek, Florida	Month 0000
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## The Coastline Paradox: A New Perspective

Gerard McNamara\* and Guilherme Vieira da Silva

Coastal and Marine Research Center  
Griffith University  
Gold Coast, QLD 4215, Australia



www.cerf-jcr.org



www.JCRonline.org

### ABSTRACT

McNamara, G. and Vieira da Silva, G., 0000. The coastline paradox: A new perspective. *Journal of Coastal Research*, 00(0), 000-000. Coconut Creek (Florida), ISSN 0749-0208.

The coastline paradox, which suggests that coastlines have indefinite lengths, is a widespread and misleading concept that has endured in scientific literature for over 50 years. This paper argues that the length of a coastline is real and finite. The measurement of coastlines allows for the quantification of coastline dynamics and engineering responses to these changes. The real difficulties in measuring sometimes complex coastal shapes have taken the appearance of an unreal impossibility. The paradox is resolved using three methods. The first examines definitions used to establish the features to which "coastline" refers. The second applies these definitions to the measurement of real coastlines. Finally, a geometrical analysis is carried out to resolve the paradox mathematically. The purpose of this paper is to help resolve the paradox and reduce confusion surrounding the topic, which will be of direct use for coastal communities and planners to assess and respond to coastline changes and sea-level rise.

**ADDITIONAL INDEX WORDS:** *Coastal, geomorphology, fractals.*

### INTRODUCTION

The formulation of the concept now referred to as the "coastline paradox" was outlined in Mandelbrot's (1967) paper "How long is the coast of Britain." In this paper, Mandelbrot referred to and built on observations made by Richardson (1961) concerning differing Spanish and Portuguese estimates of the length of their shared border and their coastlines. Using the coastline of Great Britain as a case study, Mandelbrot (1967, p. 636) claimed more generally that, "Geographical curves are so involved in their detail that their lengths are often infinite or, rather, undefinable."

Although Mandelbrot sometimes questioned whether this abstract mathematical concept applied to real coastlines (Mandelbrot, 1967), much of the citing literature highlights only the idea of immeasurability and not the potential misalignment with measuring real coastlines. Concepts such as scaling, fractals, and self-similarity are commonly referenced in mapping and geosciences, where they have found

A typical example of distortion in the analysis of geographical data by the paradox concept is found in Galloway and Bahr's (1979) paper titled "What is the length of the Australian coast." This work correctly notes that an increase in the measuring resolution results in a longer coastline length measurement. The paper then concludes, in reference to Mandelbrot's work, that "the study has demonstrated once again that coast length is indeterminate" (Galloway and Bahr, 1979, p. 3).

Using Quine's terminology, the coastline paradox can be seen as a "falsidical paradox," that is, one that appears false and is false (Quine, 1966). It appears counterintuitive that an object, once it becomes part of a coastline, should lose its capacity to be measured. General concepts of immeasurability from the realms of physics, due to the uncertainty principle or relativity, can be factored into measurements when relevant, such as the time-dilation corrections used in satellite positioning (Lucchesi *et al.*, 2019). As such, the challenges involved in the measurement of all objects as revealed by fundamental

# How Can the Coastline Paradox and Fractals Help Us Understand Hydrologic Alteration by Dams?

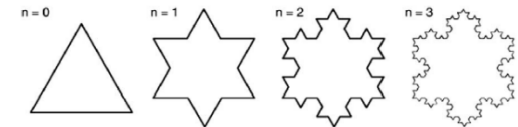
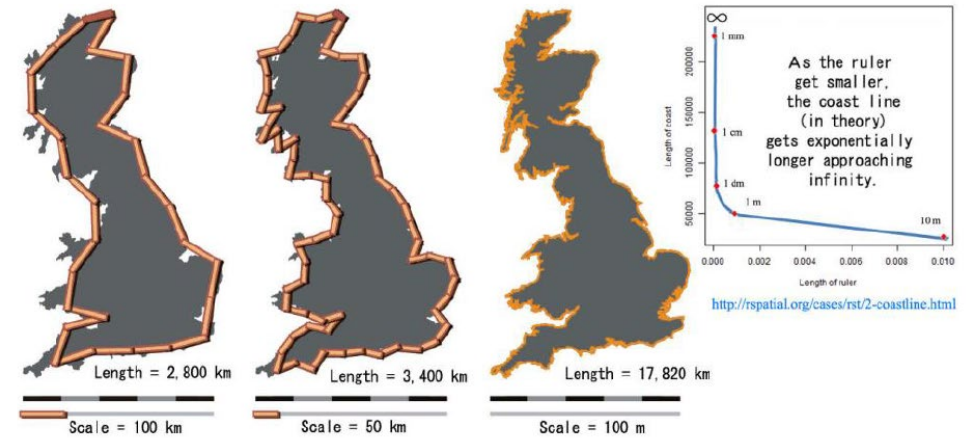
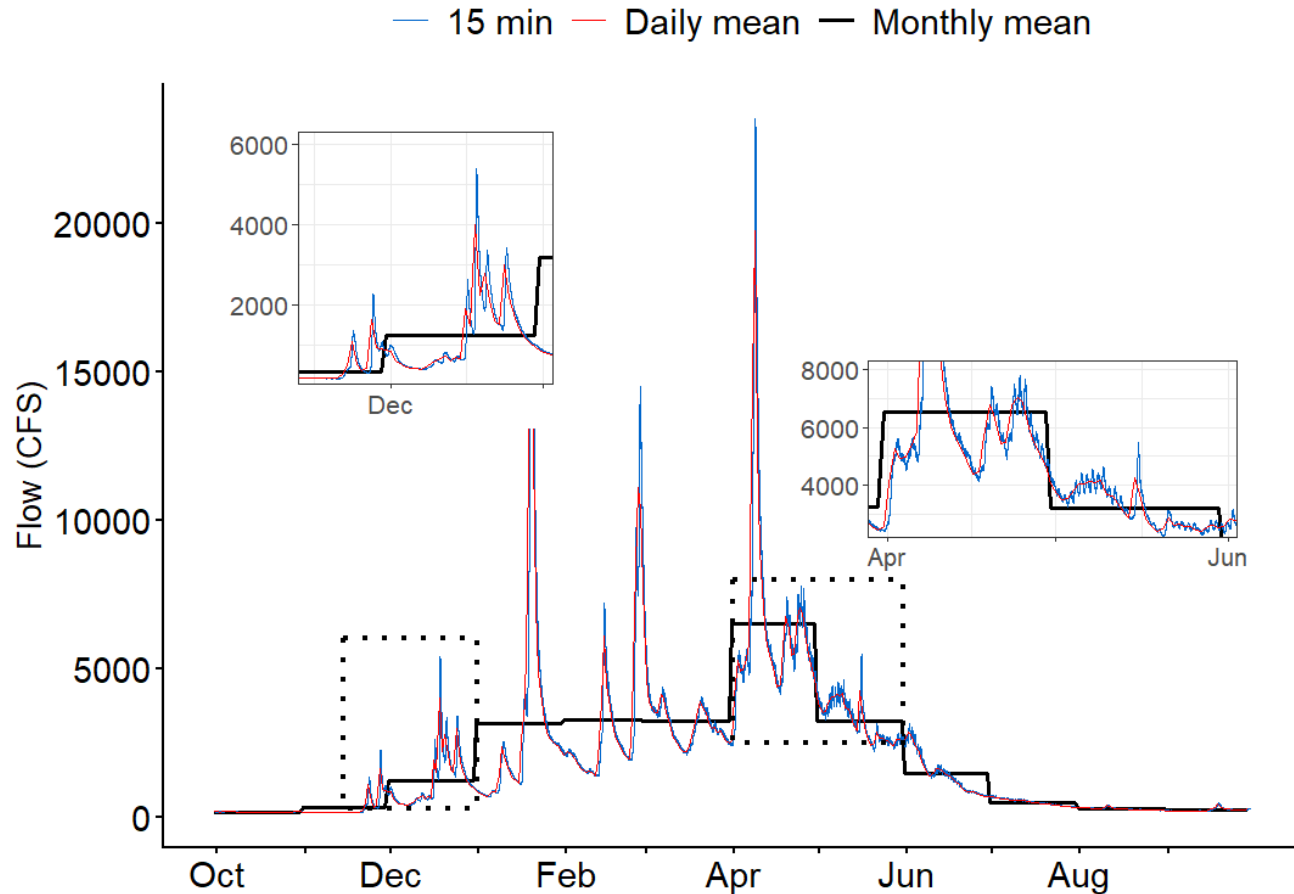


Figure 7. The Koch snowflake pattern.

# Some Terms

1. Richardson-Baker Flashiness Index (RBI)

$$R - B \text{ Index} = \frac{\sum_{i=1}^n |q_i - q_{i-1}|}{\sum_{i=1}^n q_i}$$

2. Baseflow Index (BFI; low flow ratio)

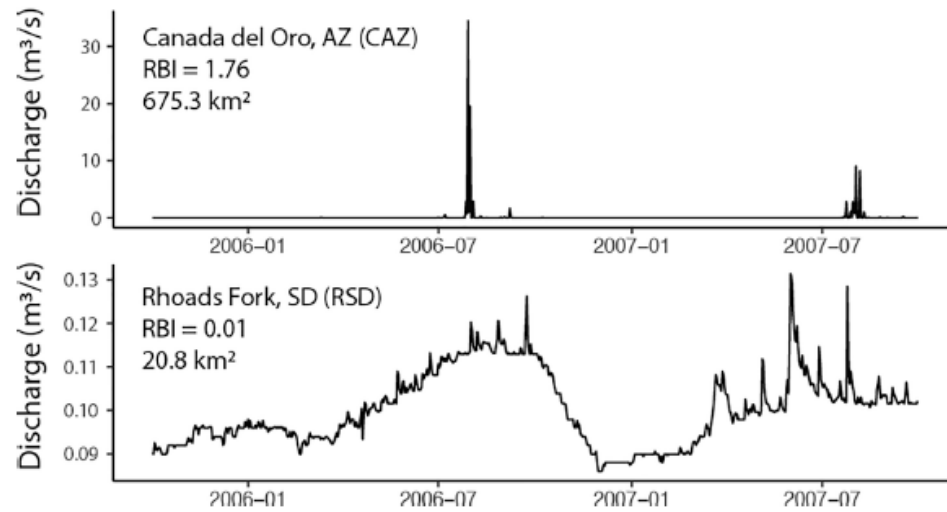
$$\frac{q_{min}}{\bar{q}_a}$$

3. Synchronicity (COR)

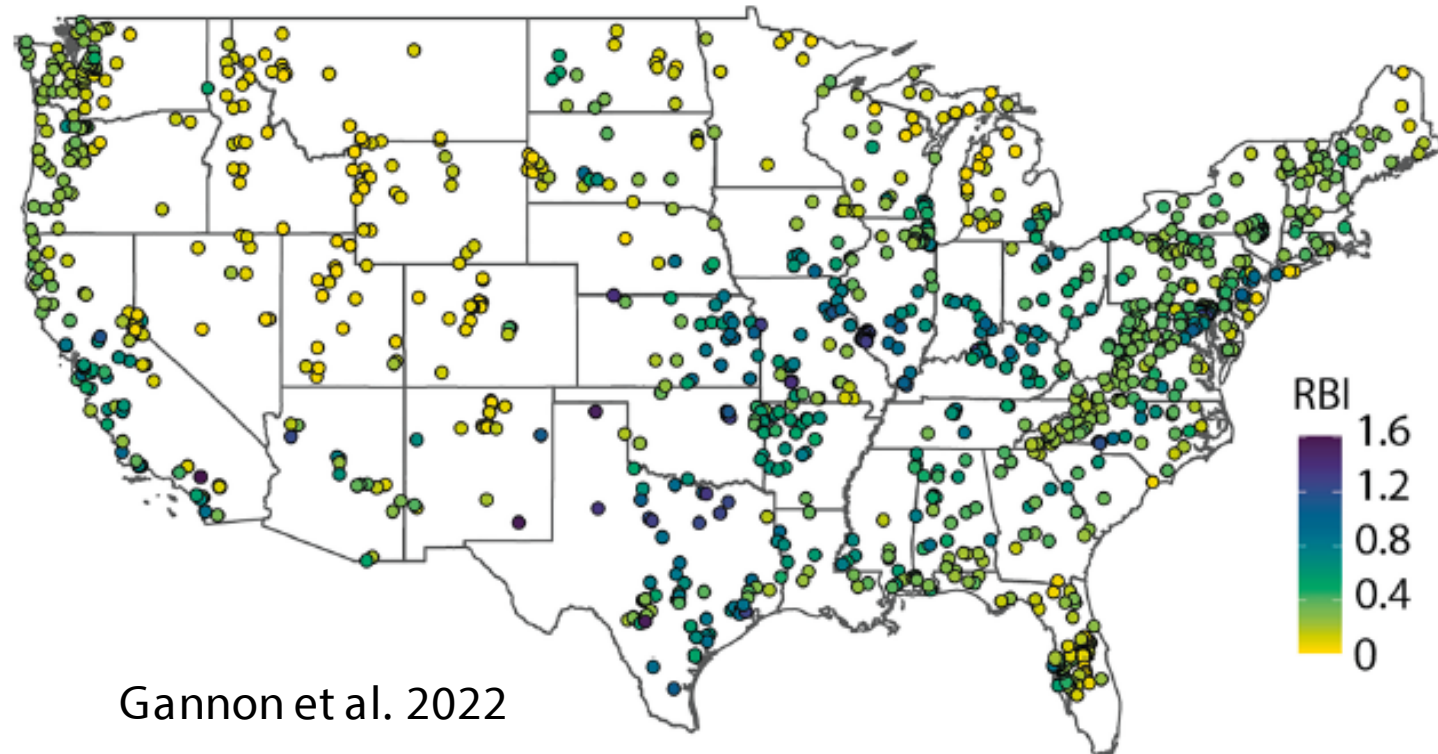
$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n \sum x^2 - (\sum x)^2][n \sum y^2 - (\sum y)^2]}}$$

RBI and BFI are dimensionless

- High flashiness-desert southwest RBI  $\sim$  1.5

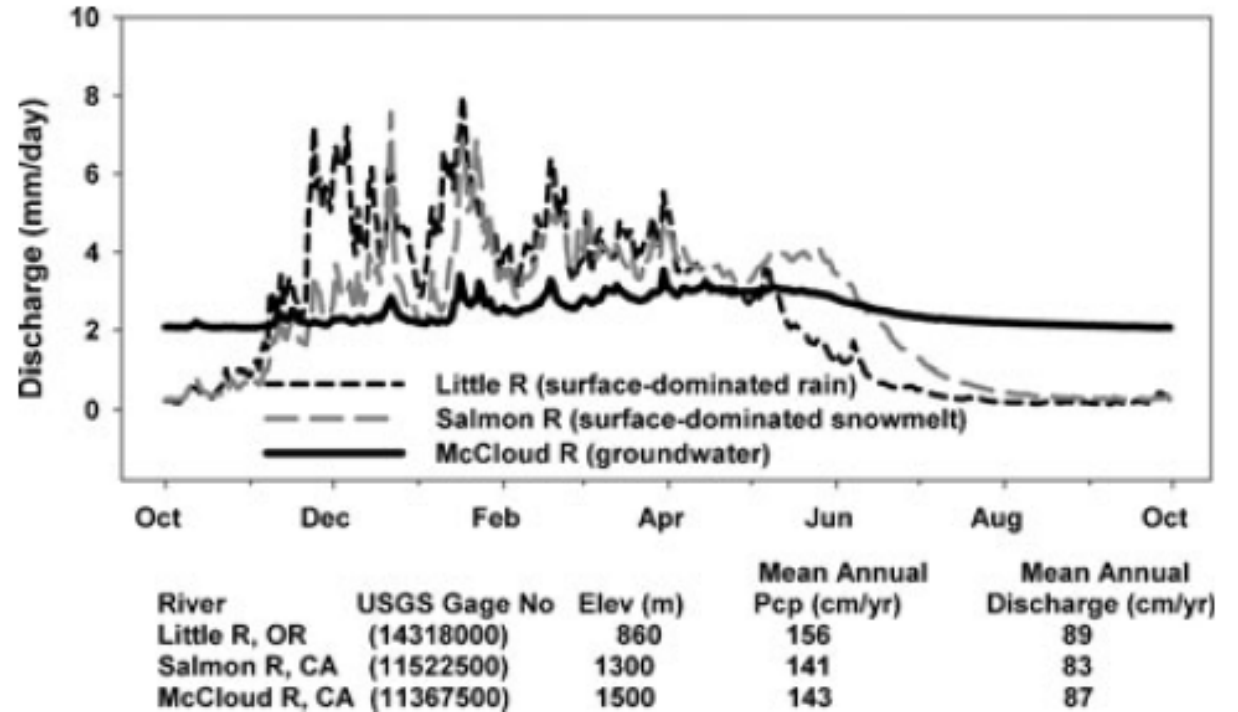


- Moderately flashy-N. CA RBI  $\sim$  0.15
- Low flashiness-intermountain west, Midwest RBI  $\sim$  0.01



# Relationship Between RBI and BFI

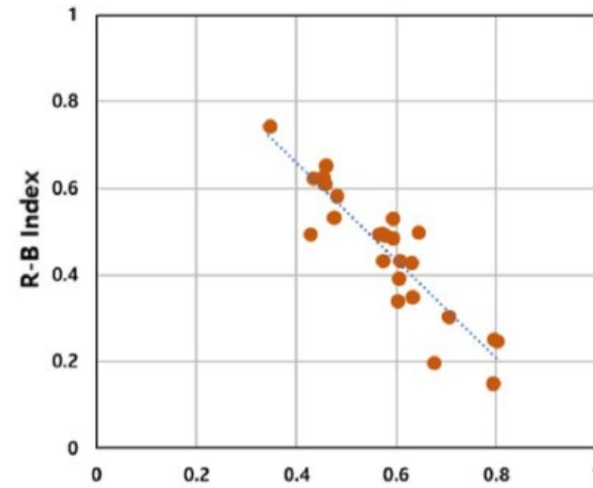
- Groundwater dominated streams are less flashy than rain or rain-snow mix dominated streams



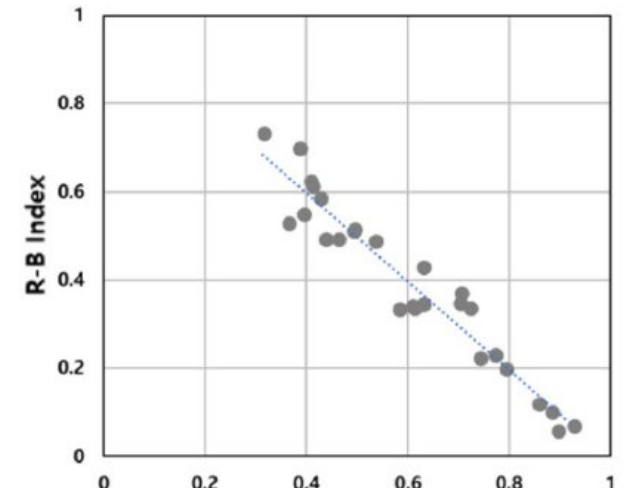
Mayer and Naman 2011

# Relationship Between RBI and BFI

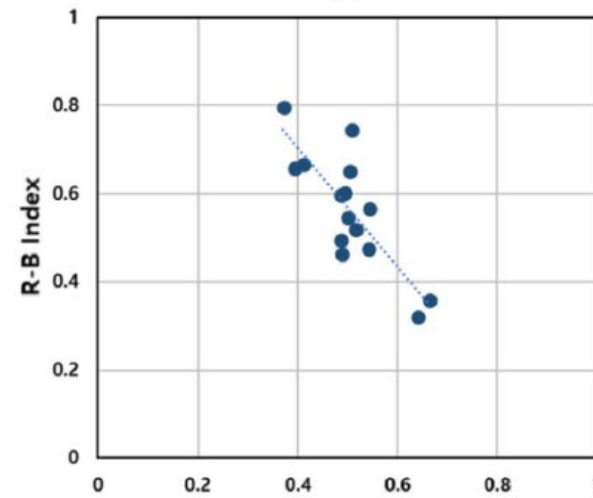
- Strong negative relationship
- As BFI increases, RBI decreases



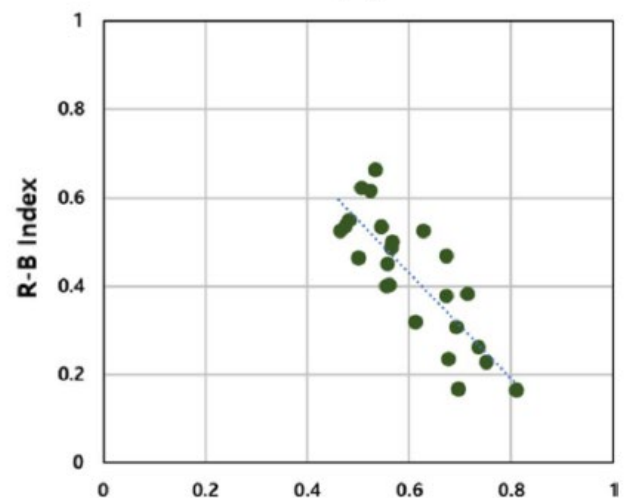
(a)



(b)



(c)



(d)

# RBI at multiple timescales

## Pathlength Ratio

TABLE 3. Effects of Using Hourly Rather Than Daily Flows on Magnitude of Annual Path Lengths for Stations of Varying Drainage Areas in Northwestern Ohio. Stations are arranged in order of increasing drainage area.

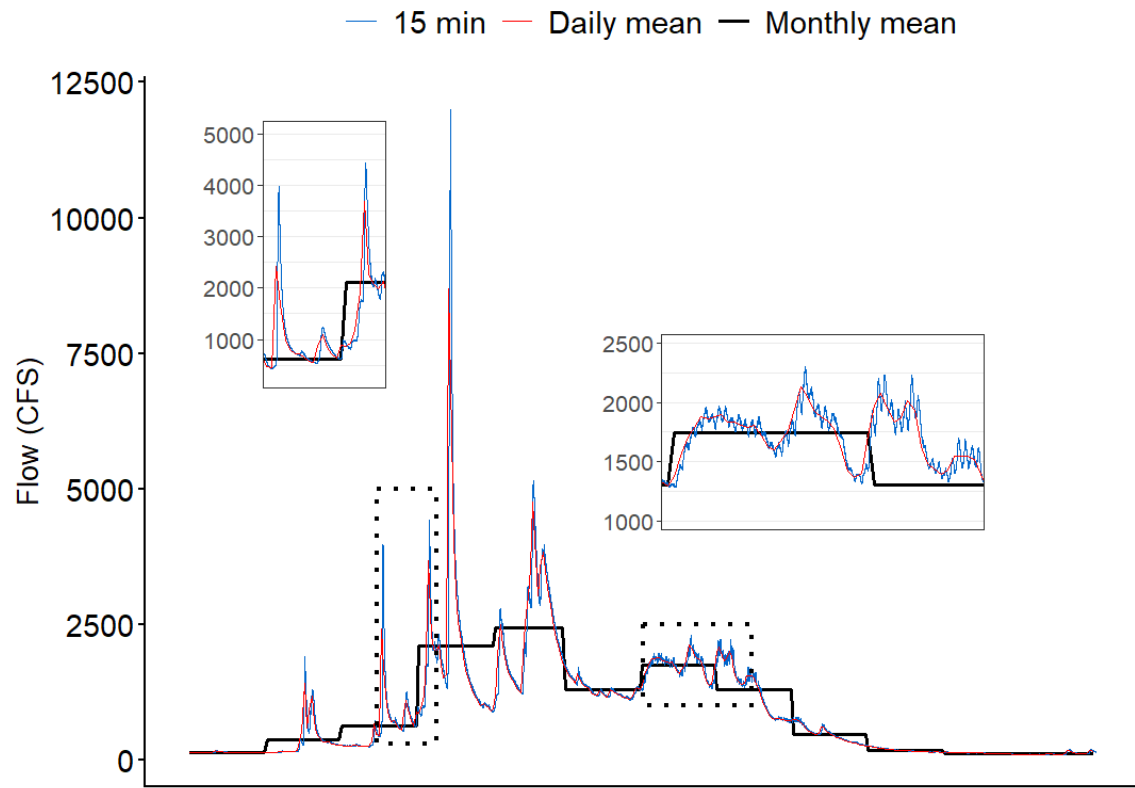
Stream	Drainage Area (km <sup>2</sup> )	Pathlength Based on Daily Average Flows (10 <sup>6</sup> m <sup>3</sup> )	Pathlength Based on Hourly Flows (10 <sup>6</sup> m <sup>3</sup> )	Pathlength Ratio (hourly/daily)
Unnamed Tributary to Lost Creek	10.96	3.3	11.4	3.44
Rock Creek	89.6	19.4	34.6	1.78
Honey Creek	386	48.8	68.4	1.40
Sandusky River	3,240	298.2	337.8	1.14
Maumee River	16,480	980.7	1,660.9	1.69

- Streams with smaller basins are more flashy than larger ones, so time measurement interval matters more

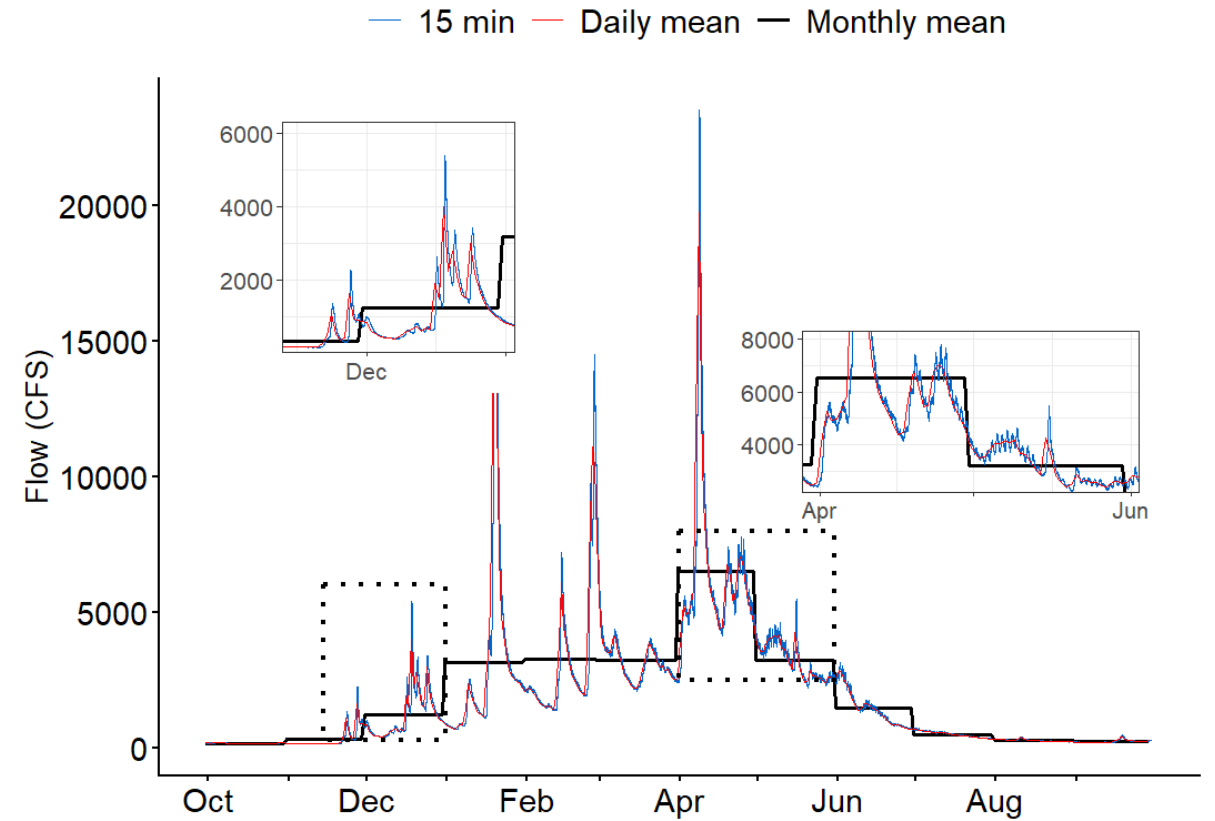
Baker et al 2004

# RBI at multiple timescales

## Salmon River at Somes Bar Example



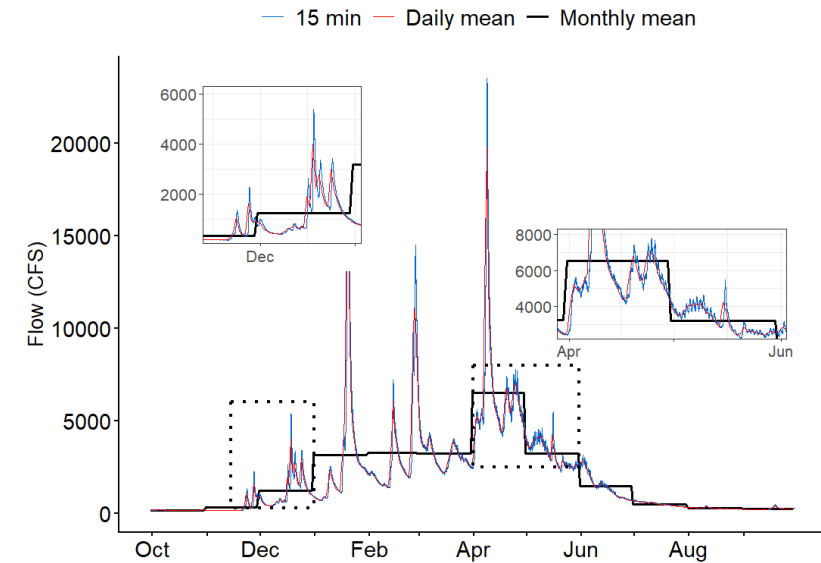
2021, critically dry



2019, wet

# RBI at multiple timescales

## Salmon River at Somes Bar Example



Year	Water Year Type	RBI 15 min	RBI daily	Ratio (15 min RBI/daily RBI)
2017	Extremely Wet	0.961	0.189	5.08
2018	Critically Dry	0.758	0.153	4.95
2019	Wet	0.997	0.181	5.51
2020	Critically Dry	0.629	0.148	4.25
2021	Critically Dry	0.564	0.150	3.76

# Storage Reservoirs Increase BFI, decrease RBI

**Table 1**  
*Basin Characteristics of Potential Source Gages and Target Gage (TRAL)*

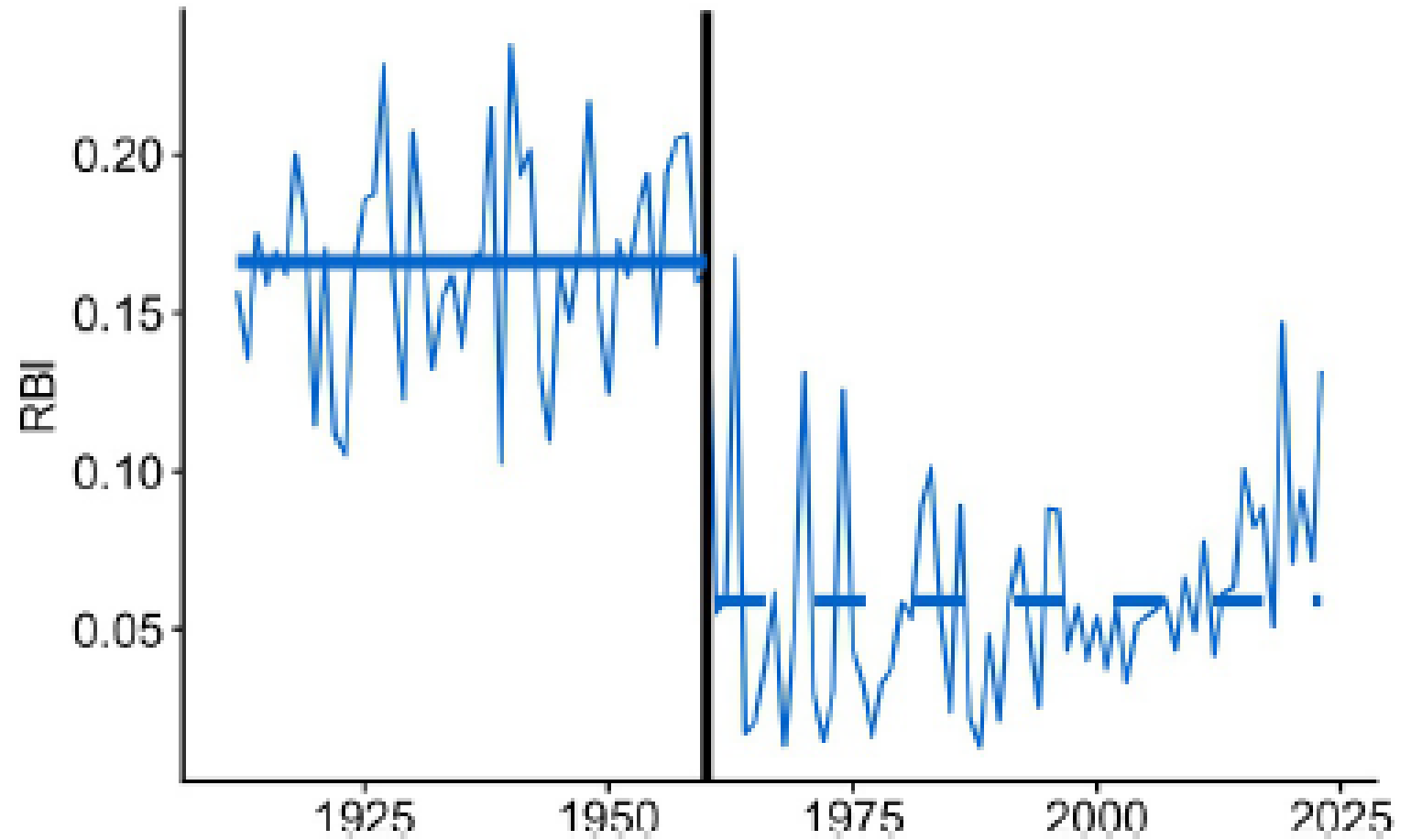
Characteristic	TRABCC	TRAL <sub>pre</sub>	TRAL <sub>post</sub>	SRASB	SFTRBLH	ICNRDC	RCNRL
Gage No.	11523200	11525500	11525500	11522500	11528700	11525670	11525530
Drainage Area (km <sup>2</sup> )	386	1862	1862	1945	1979	87	58
Elevation (m)	773	558	558	147	233	518	559
POR	1958–present	1912–1960	1961–present	1912–present	1966–present	2005–present	2003–present
Distance from TRAL (km)	44	0	0	76.42	27.27	12.02	2.74
RBI	0.188	0.166	0.059 ↓	0.166	0.591	0.006	0.009
BFI	0.081	0.069	0.462 ↑	0.089	0.040	0.056	0.026
Mean Q (m <sup>3</sup> s <sup>-1</sup> )	11.4	46.5	17.9	50.2	36.7	0.9	1.0
CV	1.35	1.18	0.98	1.14	1.64	1.35	1.36
Adv Pred	Yes	NA	Yes	Yes	Yes	No	No

*Note.* Gage acronyms include Trinity River at Lewiston, CA (TRAL), before dam construction (TRAL<sub>pre</sub>), after dam construction (TRAL<sub>post</sub>), Trinity River above Coffee Creek (TRABCC), Salmon River at Somes Bar (SRASB), South Fork Trinity River Below Hyampom (SFTRBLH), Indian Creek near Douglas City (ICNRDC), and Rush Creek near Lewiston (RCNRL). Other acronyms include period of record (POR), Richardson-Baker flashiness index (RBI), and baseflow index (BFI).

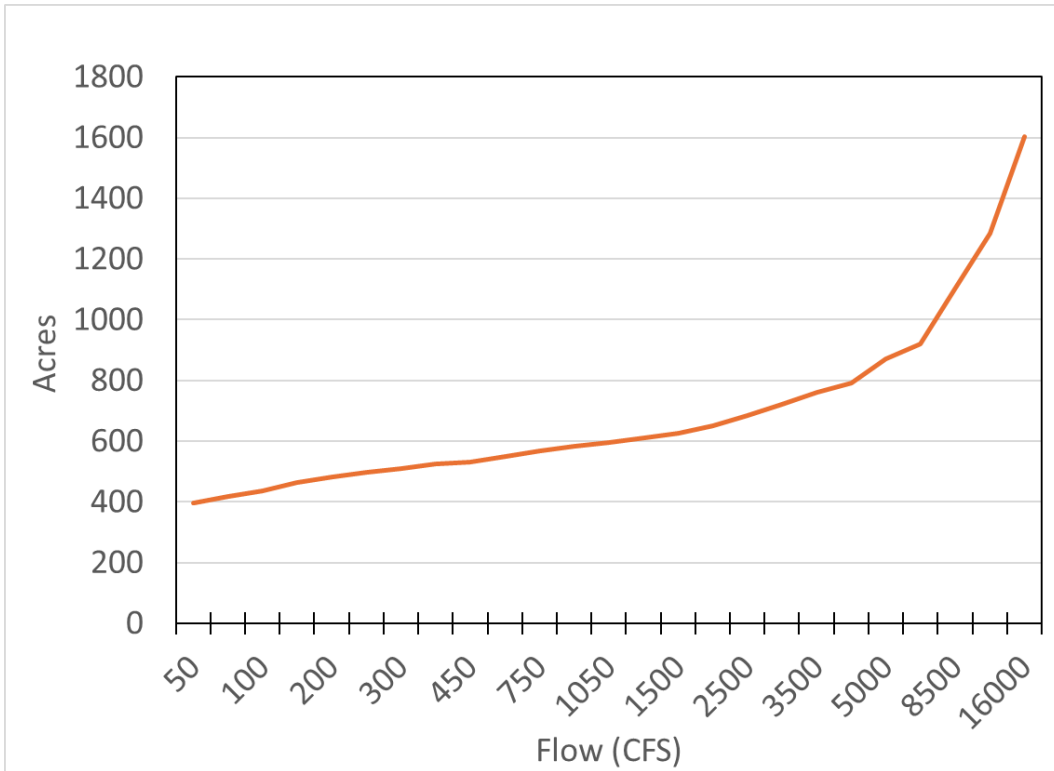
# TRAL 1912-2003

Black line is Trinity Dam

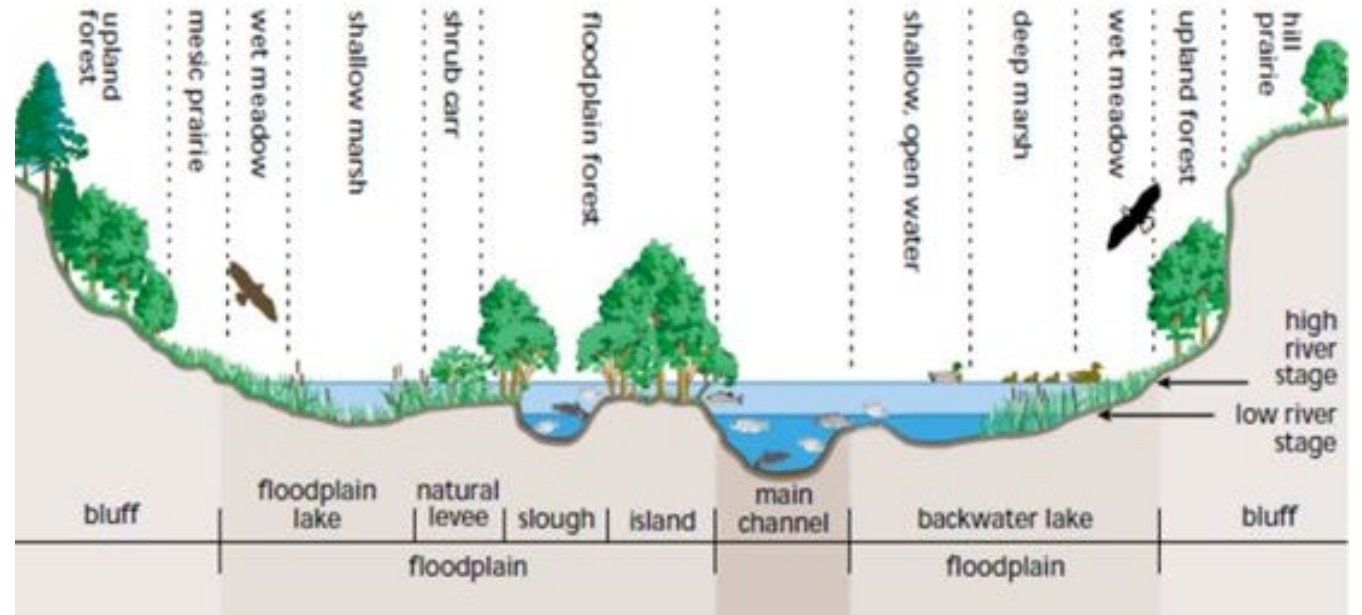
- 65% decrease in RBI using daily flows.
- More like 90% with 15 minute data



# Why Does RBI matter as a metric for regulated rivers?



Petersen,  
2026

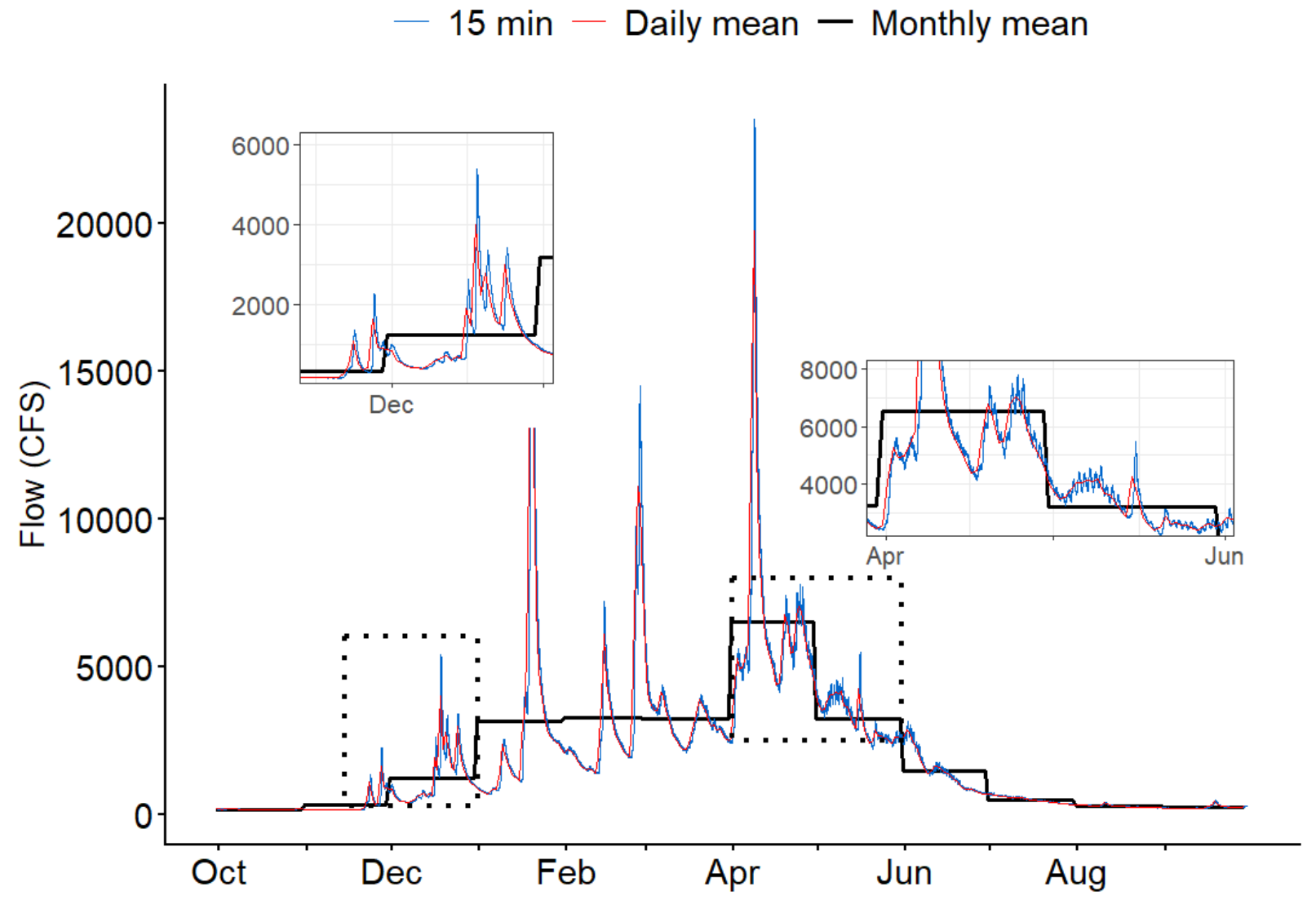


[https://tpcovino.github.io/Git\\_home/hydrology/6\\_geomorph/6\\_geomorph.html](https://tpcovino.github.io/Git_home/hydrology/6_geomorph/6_geomorph.html)

Floodplain inundation, entrainment of organic material, sediment transport, nutrient uptake, and ecosystem metabolism, to name a few

# Are we underestimating alteration caused by dams?

- We begin many calculations of "Alteration" at daily or more frequently monthly timescales
- How much has that alone altered our assessment of alteration by dams?

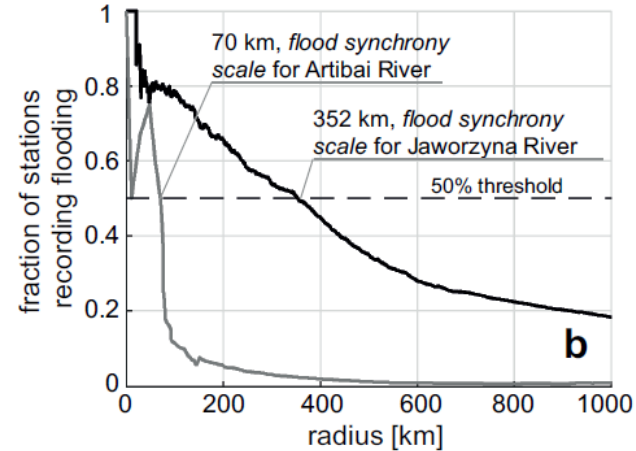
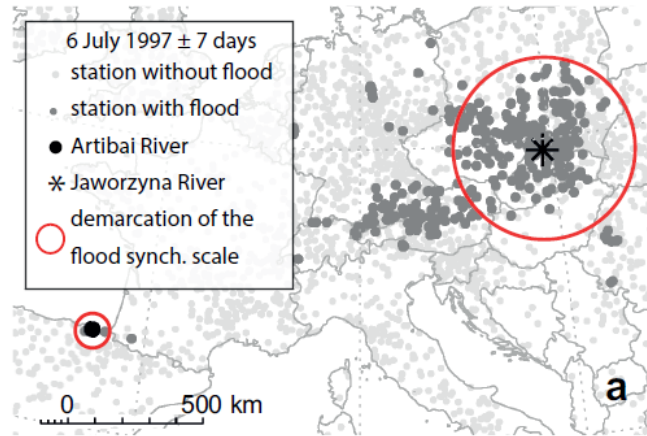


# Synchronicity

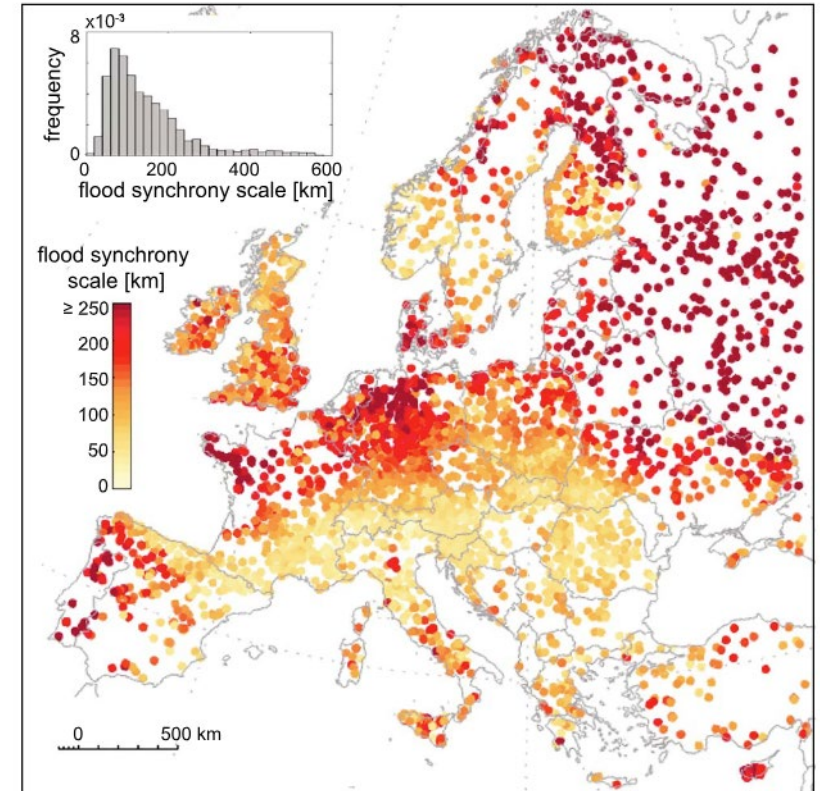
(as measured by correlation)

# Synchronicity

**When rivers flood, surrounding rivers often flood at the same time**



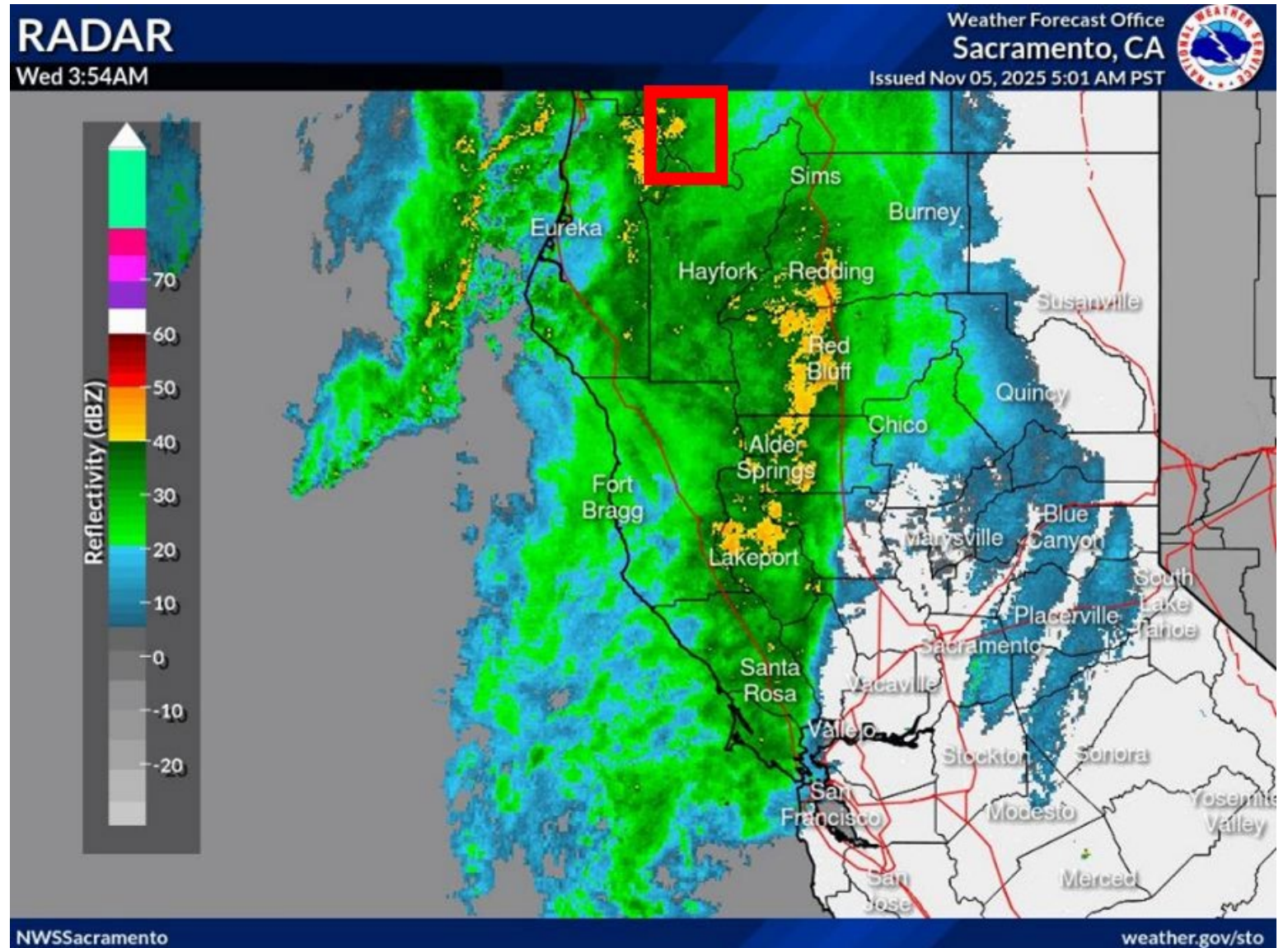
*Flood synchrony scale* is maximum radius around an individual river gauge within which at least half of the other river gauges also record flooding almost simultaneously



Berghuijs et al 2019

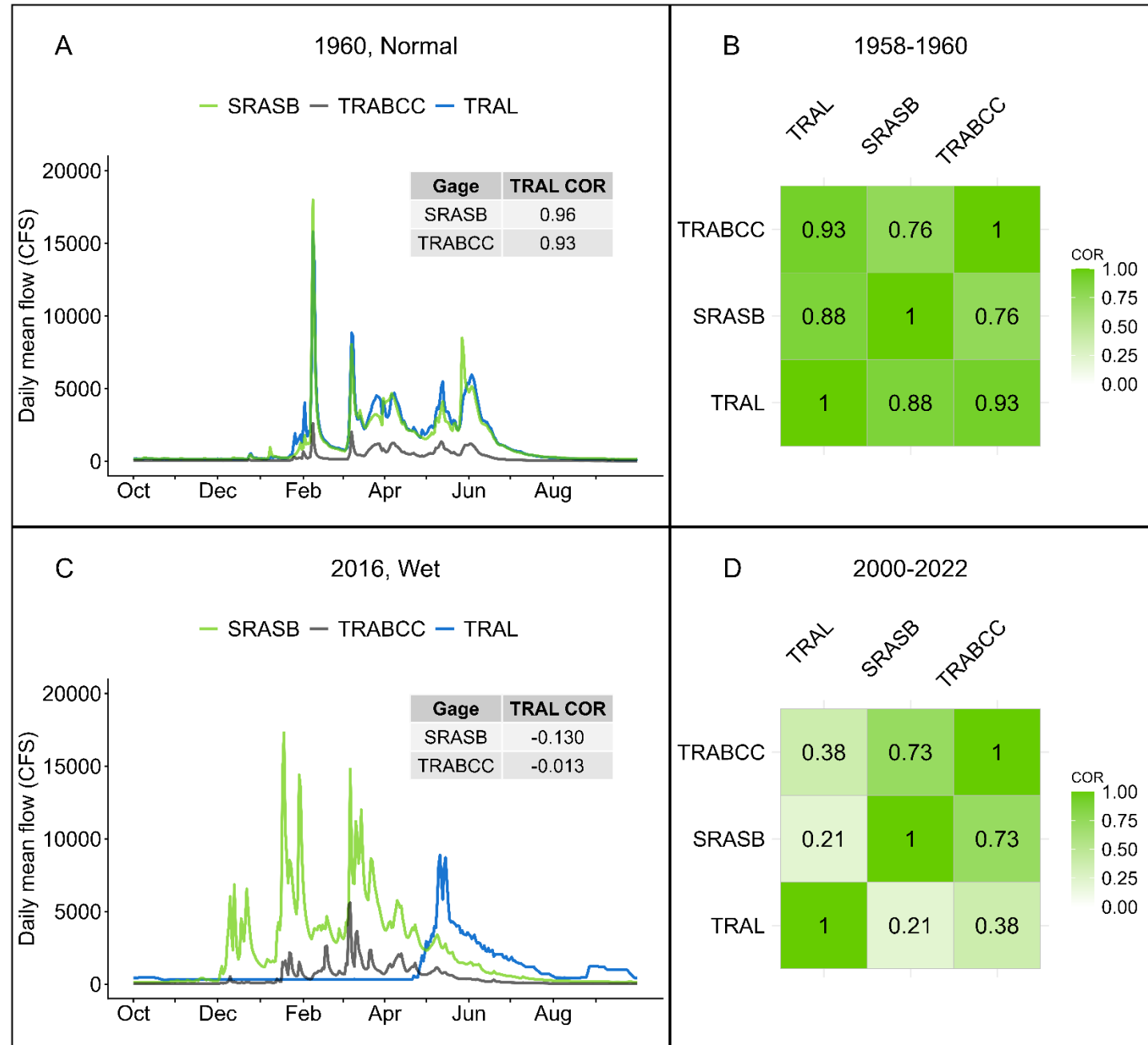
# Synchronicity

- The same is true in California



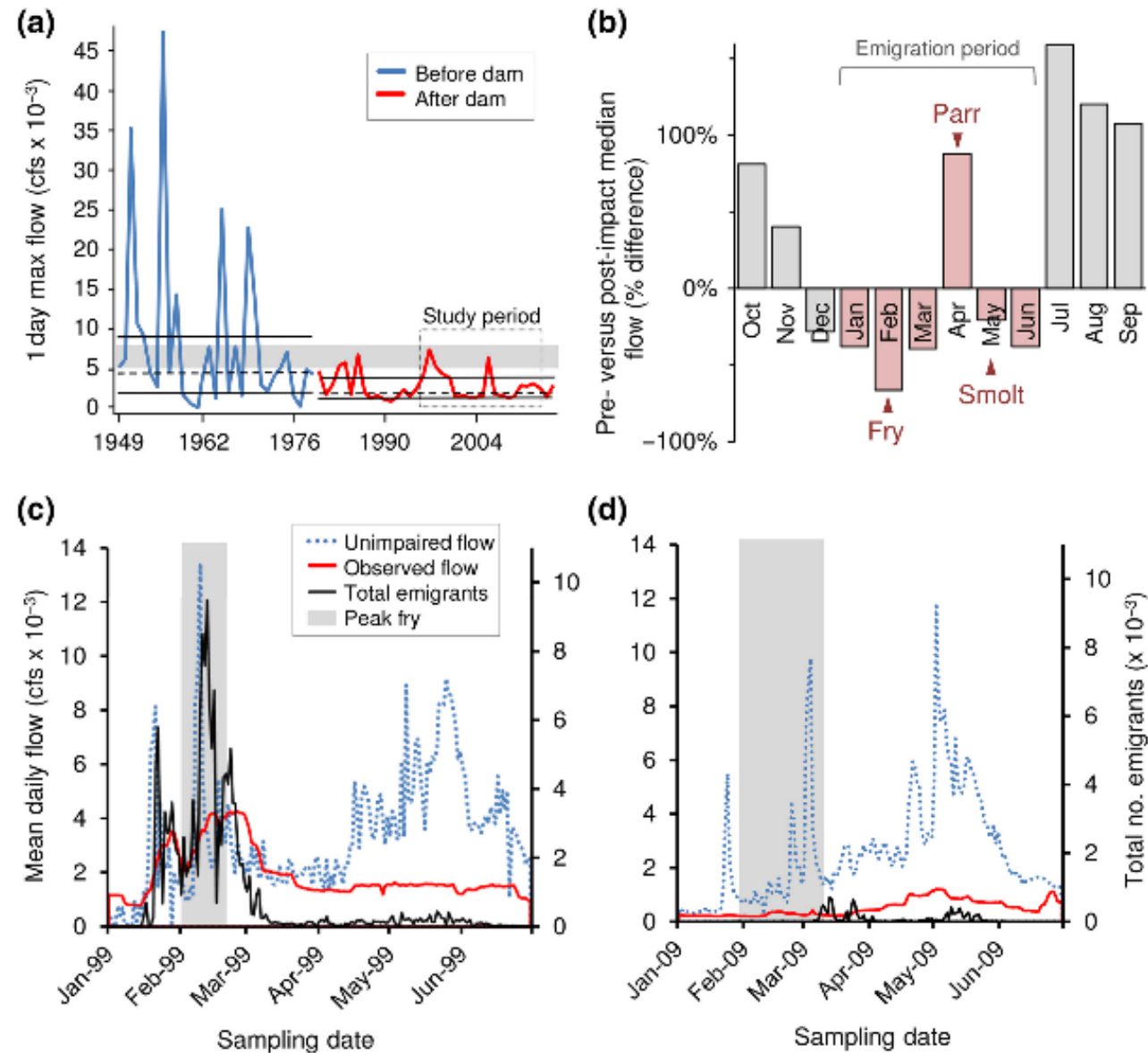
# Synchronicity

- Unimpaired river basins in close geographic proximity are often highly synchronous
- Dams disrupt this



# Why Does Synchronicity matter?

- “Even marginal increases in [fry] survival would have significantly boosted recruitment.”
- “On the Stanislaus River, these cues are now largely artificial and often **decoupled** from the unimpaired hydrograph”
- Lack of synchronicity can contribute to a weakened portfolio effect



# Why Does Synchronicity matter?



Indicators of Hydrologic Alteration (IHA)

Range of Variability Approach (RVA)

Degree of Alteration (DOA)

TABLE 7. Coefficients of Variation and Occurrence of Trends in IHA Indices, Coefficient of Variation in Daily flows (CVD) and R-B Index in 100 Randomly Selected Streams.

IHA Parameter Group, CVD, and R-B Index	IHA Individual Parameters	Average Coefficient of Variation for 27 Annual Values	Number of Stations From Set of 100 With Trends Significant at Indicated p Values		
			p < 0.05	0.05 < p < 0.1	Percent With p < 0.1
IHA-Magnitude of Monthly Water Conditions	October, Mean	1.0809	6	4	10
	November, Mean	0.9492	3	2	5
	December, Mean	0.7884	2	2	4
	January, Mean	0.6898	9	7	16
	February, Mean	0.6557	8	5	13
	March, Mean	0.6123	13	26	39
	April, Mean	0.5733	10	4	14
	May, Mean	0.7358	3	6	9
	June, Mean	0.8355	22	10	32
	July, Mean	0.9970	4	4	8
	August, Mean	1.1256	3	8	11
	September, Mean	1.2815	7	5	12
IHA-Magnitude and Duration of Annual Extreme Water Conditions	1-Day Minimum	0.7265	16	6	22
	3-Day Minimum	0.7034	16	9	25
	7-Day Minimum	0.6684	18	12	30
	30-Day Minimum	0.6531	15	11	26
	90-Day Minimum	0.7697	6	9	15
	1-Day Maximum	0.4859	5	5	10
	3-Day Maximum	0.4607	6	2	8
	7-Day Maximum	0.4353	6	5	11
	30-Day Maximum	0.3982	12	3	15
	90-Day Maximum	0.3546	7	8	15
	Number of Zero Days	0.5604	1	4	5
	Baseflow	0.5923	17	16	33
IHA-Timing of Annual Extreme Conditions	Date of Minimum	0.1654	8	13	21
	Date of Maximum	0.2062	1	2	3
IHA-Frequency and Duration of High and Low Pulses	Low Pulse Count	0.5373	14	4	18
	Low Pulse Duration	0.7237	9	6	15
	High Pulse Count	0.7946	0	2	2
	High Pulse Duration	0.7946	0	2	2
IHA-Rate and Frequency of Water Condition Changes	Rise Rate	0.4371	8	4	12
	Fall Rate	-0.3998	8	4	12
	Number of Reversals	0.1099	21	4	25
CVD		0.2499	12	6	18
R-B Index		0.1982	33	9	42

## What are the Indicators of Hydrologic Alteration (IHA)?

- 32 metrics commonly used to assess flow alteration by dams
- Significant trends were present more often in RBI than in any of the IHA parameters for 100 selected streams

# Indicators of Hydrologic Alteration (IHA)

110

J. D. OLDEN AND N. L. POFF

- Problem: Intercorrelation of IHA metrics

RIVER RESEARCH AND APPLICATIONS  
*River Res. Applic.* 19: 101–121 (2003)  
 Published online 13 January 2003 in Wiley InterScience  
 (www.interscience.wiley.com). DOI: 10.1002/rra.700

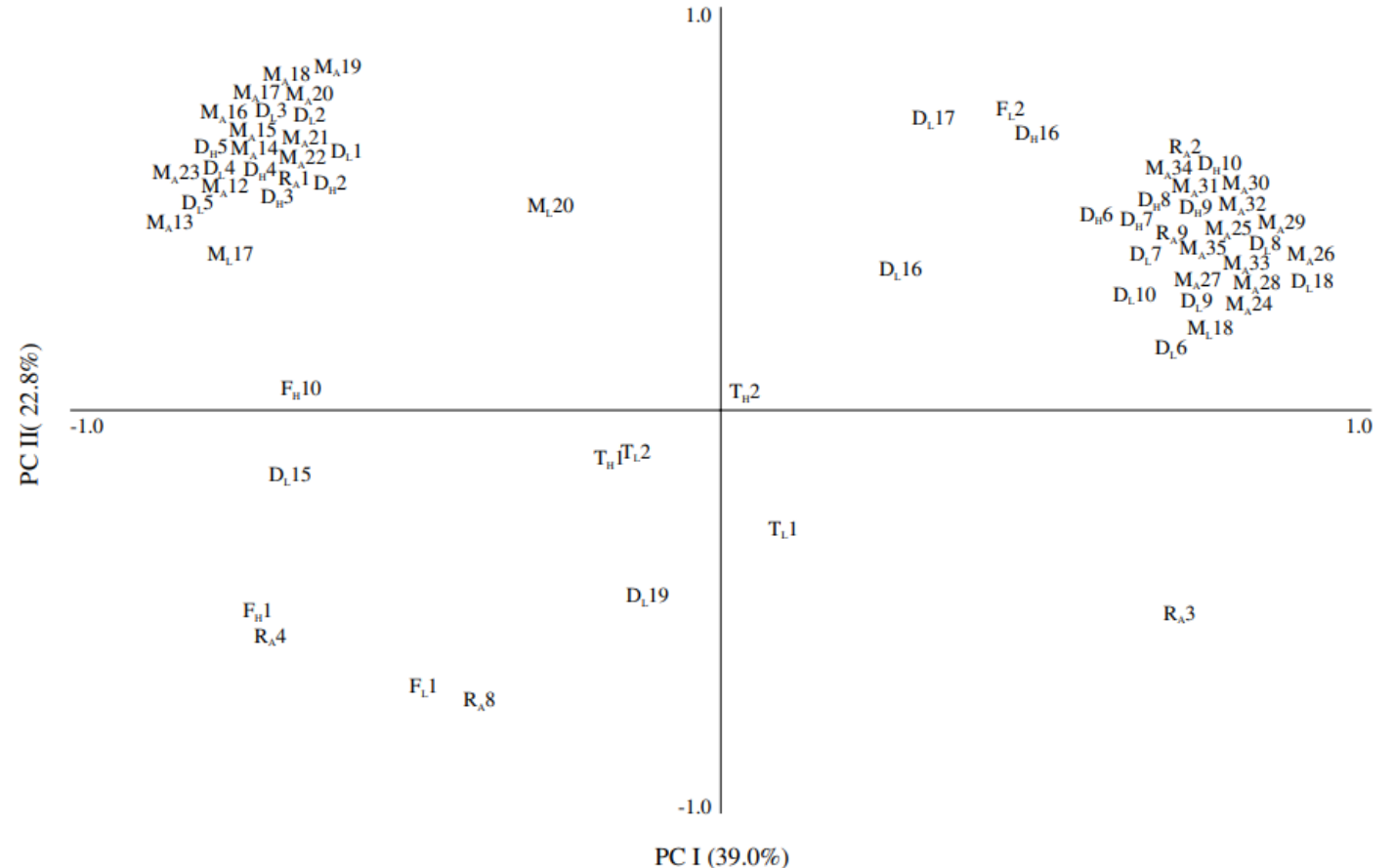
## REDUNDANCY AND THE CHOICE OF HYDROLOGIC INDICES FOR CHARACTERIZING STREAMFLOW REGIMES

JULIAN D. OLDEN\* and N. L. POFF  
 Department of Biology, Colorado State University, Fort Collins, CO 80523-1878, USA

### ABSTRACT

The utility of hydrologic indices for describing various aspects of streamflow regimes has resulted in their increased application in riverine research. Consequently, researchers are now confronted with the task of having to choose among a large number of competing hydrologic indices to reduce computational effort and variable redundancy prior to statistical analyses, while still adequately representing the major facets of the flow regime. The present study addresses this concern by providing a comprehensive review of 171 currently available hydrologic indices (including the commonly used Indicators of Hydrologic Alteration) using long-term flow records from 420 sites from across the continental USA. We highlight patterns of redundancy among these hydrologic indices and provide a number of statistically and ecologically based recommendations for the selection of a reduced set of indices that can simultaneously (1) explain a dominant proportion of statistical variation in the complete set of hydrologic indices and (2) minimize multicollinearity while still adequately representing recognized, critical attributes of the flow regime. In addition, we examine the transferability of hydrologic indices across 'stream types' by identifying indices that consistently explain dominant patterns of variation across streams in varying climatic and geologic environments. Together, our results provide a framework from which researchers can identify hydrologic indices that adequately characterize flow regimes in a non-redundant manner. In combination with ecological knowledge, this framework can guide researchers in the parsimonious selection of hydrologic indices for future hydroecological studies. Copyright © 2003 John Wiley & Sons, Ltd.

KEY WORDS: hydrology; dams; alteration; variability; indicators



# Indicators of Hydrologic Alteration (IHA)

Hydrol. Earth Syst. Sci., 24, 4091–4107, 2020  
<https://doi.org/10.5194/hess-24-4091-2020>  
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Hydrology and  
Earth System  
Sciences  Open Access

- Problem: equal weighting of metrics
- Authors have recommended weighting of IHA metrics

## Development of a revised method for indicators of hydrologic alteration for analyzing the cumulative impacts of cascading reservoirs on flow regime

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<sup>2</sup>College of Water Resource & Hydropower, Sichuan University, Chengdu 610065, China

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Revised: 8 June 2020 – Accepted: 16 July 2020 – Published: 21 August 2020

**Abstract.** The impacts of reservoirs, especially multiple reservoirs, on the flow regimes and ecosystems of rivers have received increasing attention. The most widely used metrics to quantify the characteristics of flow regime alterations are the indicators of hydrologic alteration (IHAs) which include 33 parameters. Due to the difference in the degree of alteration and the intercorrelation among IHA parameters, the conventional method of evaluating IHA parameters that assigns the same weight to each indicator is obviously inadequate. A revised IHA method is proposed by utilizing the

have a positive response to the flood peak process caused by manual regulation.

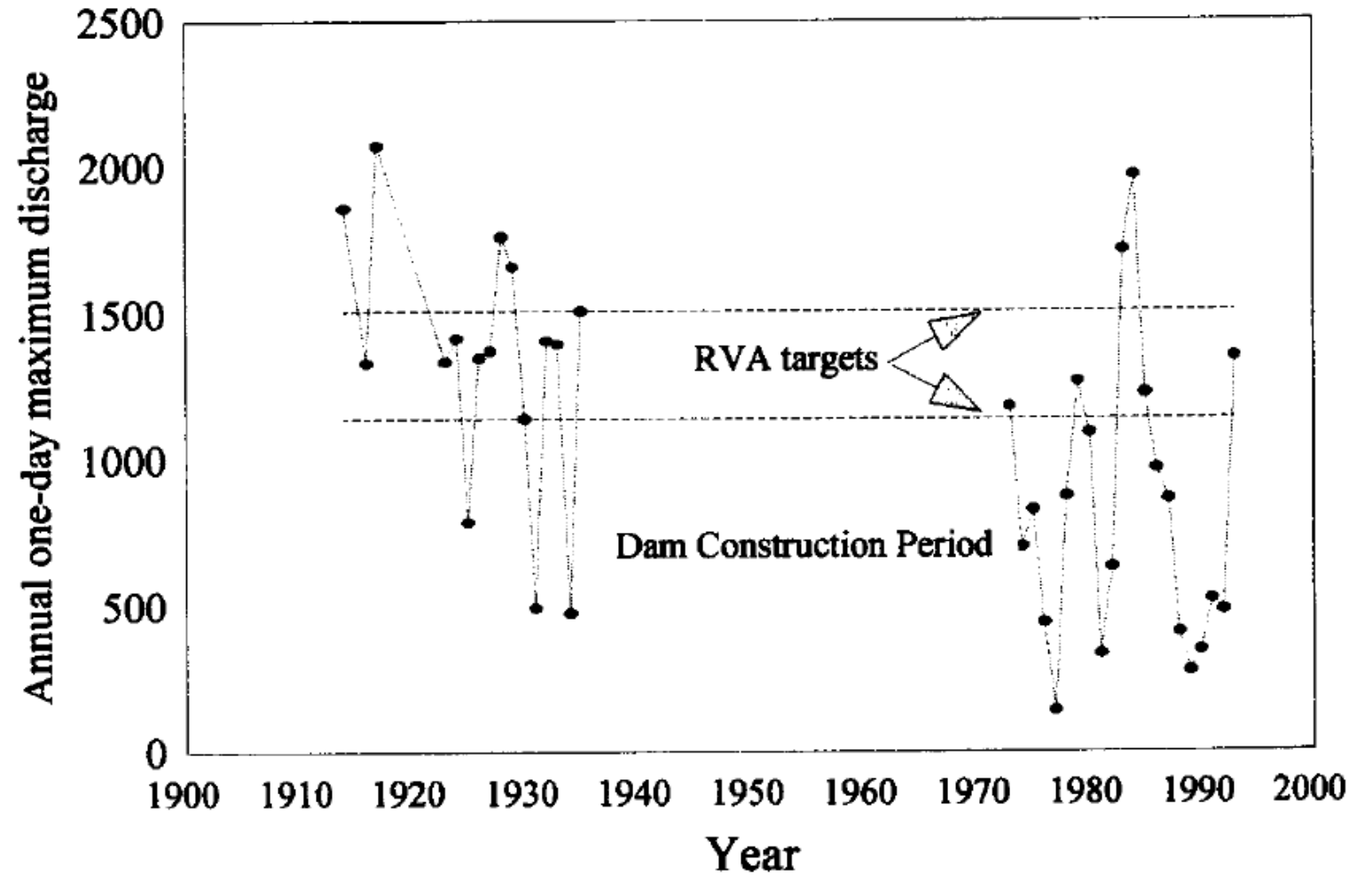
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### 1 Introduction

Free-flowing rivers (FFRs) support diverse, complex and dynamic ecosystems globally, providing important societal and economic services (Grill et al., 2019). Humans have ex-

# Range of Variability Approach (RVA)

- RVA targets at 25<sup>th</sup> and 75<sup>th</sup> percentiles: management goal is to maintain max 1-day flood within range 50% of years
- Does RVA imply that river flow outside of the 25<sup>th</sup> and 75<sup>th</sup> percentiles are bad?
- RVA is not written this way, but does it contribute to us managing to the median?



# Degree of Alteration (DOA)

$N_o$  is the observed number of post-impacted years for which the value of the indicator falls within the RVA target range, from 25th percentile to 75th percentile

$$D_i = \left| \frac{N_o - N_e}{N_e} \right| \times 100\%$$

$N_e$  is the expected number of post impacted years for which the value of indicator falls within the targeted range

An overall degree of hydrological alteration for all 32 indicators is calculated by

$$D = \sqrt{\frac{\sum_{i=1}^{32} D_i^2}{32}}$$

Does Using 32 indicators, most based on monthly or annual values, many of them intercorrelated, calculating the number of years they are within the RVA, squaring that result, summing them, and dividing by 32 tell how dams alter rivers?

$$D = \sqrt{\frac{\sum_{i=1}^{32} D_i^2}{32}}$$

# Hundreds of metrics have been developed

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Journal of Hydrology

journal homepage: [www.elsevier.com/locate/jhydrol](http://www.elsevier.com/locate/jhydrol)



## Development of representative indicators of hydrologic alteration

Yongxuan Gao<sup>a</sup>, Richard M. Vogel<sup>a,\*</sup>, Charles N. Kroll<sup>b</sup>, N. LeRoy Poff<sup>c</sup>, Julian D. Olden<sup>d</sup>

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### SUMMARY

In an ideal world, a few overall indicators of hydrologic alteration would adequately describe the degree of hydrologic alteration caused by various forms of river regulation. Currently over 170 hydrologic indicators have been developed to describe different components of flow regimes, including the widely used Indicators of Hydrologic Alteration (IHA) that characterize the impact of river regulation on flow regimes in environmental flow studies. Many of these IHA indicators are intercorrelated, resulting in considerable information redundancy, which could lead to ineffective environmental flow management decisions. The objective of this research is to develop a small set of independent and representative hydrologic indicators that can best characterize hydrologic alteration caused by reservoirs and other forms of river regulation. Two sets of pre- and post-dam streamflow records are used: (1) based on artificial simulations of a wide range of reservoir release rules and (2) streamflow records for 189 gaging stations throughout the United States. Principal component analysis was used to address the intercorrelation among the IHA parameters. Results revealed that the recently introduced metrics termed ecodeficit and ecosurplus can provide a good overall representation of the degree of alteration of a streamflow time series. Across both datasets, 32 individual IHA statistics and several potential generalized indices, three indices based on the ecodeficit and ecosurplus explained the most variability associated with the ensemble of 32 IHA statistics.

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## The ecological limits of hydrologic alteration (ELOHA): a new framework for developing regional environmental flow standards

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<sup>¶¶¶</sup>School of Aquatic & Fishery Sciences, University of Washington, Seattle, WA, U.S.A.

<sup>\*\*\*\*</sup>University of the Witwatersrand, Johannesburg, South Africa

<sup>††††</sup>International Water Management Institute, Colombo, Sri Lanka

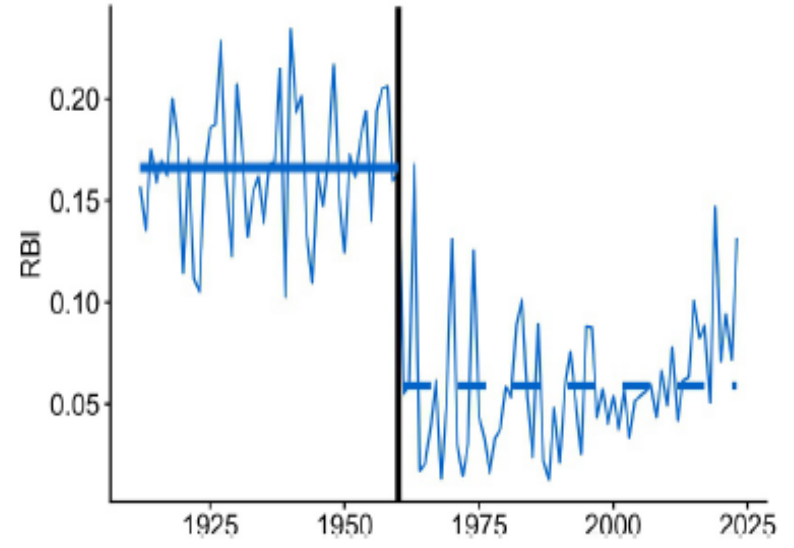
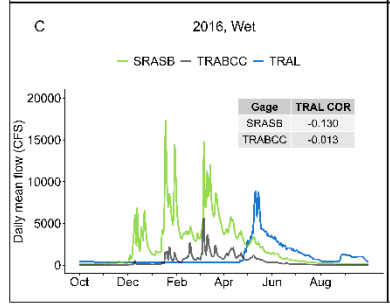
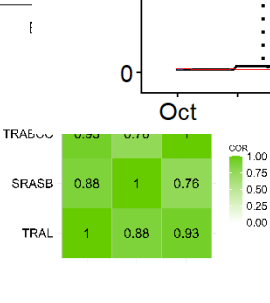
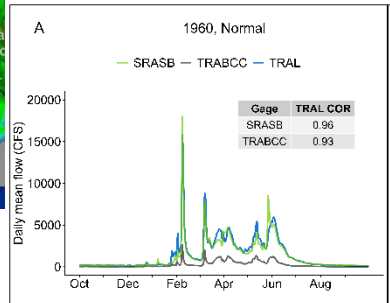
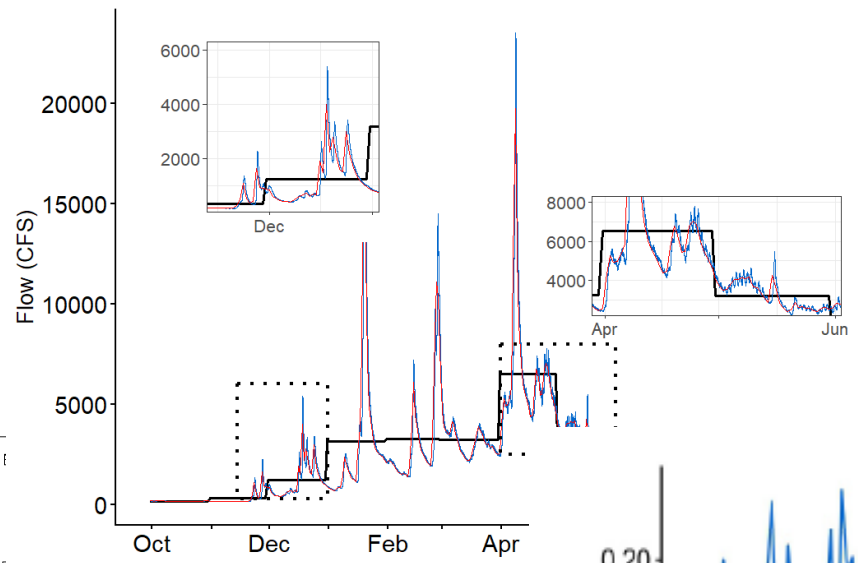
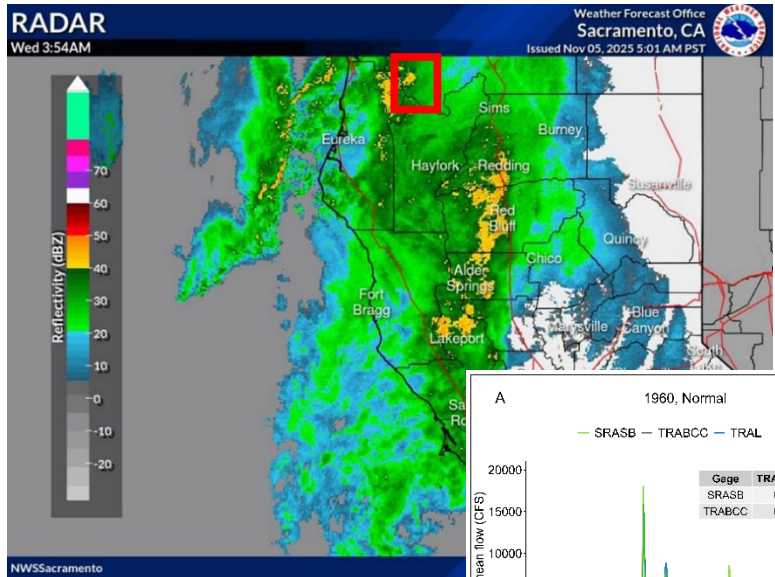
<sup>††††</sup>The Nature Conservancy, University Park, Pennsylvania, PA, U.S.A.

### SUMMARY

1. The flow regime is a primary determinant of the structure and function of aquatic and riparian ecosystems for streams and rivers. Hydrologic alteration has impaired riverine ecosystems on a global scale, and the pace and intensity of human development greatly

# Why aren't synchronicity (COR) or RBI among them?

— 15 min — Daily mean — Monthly mean



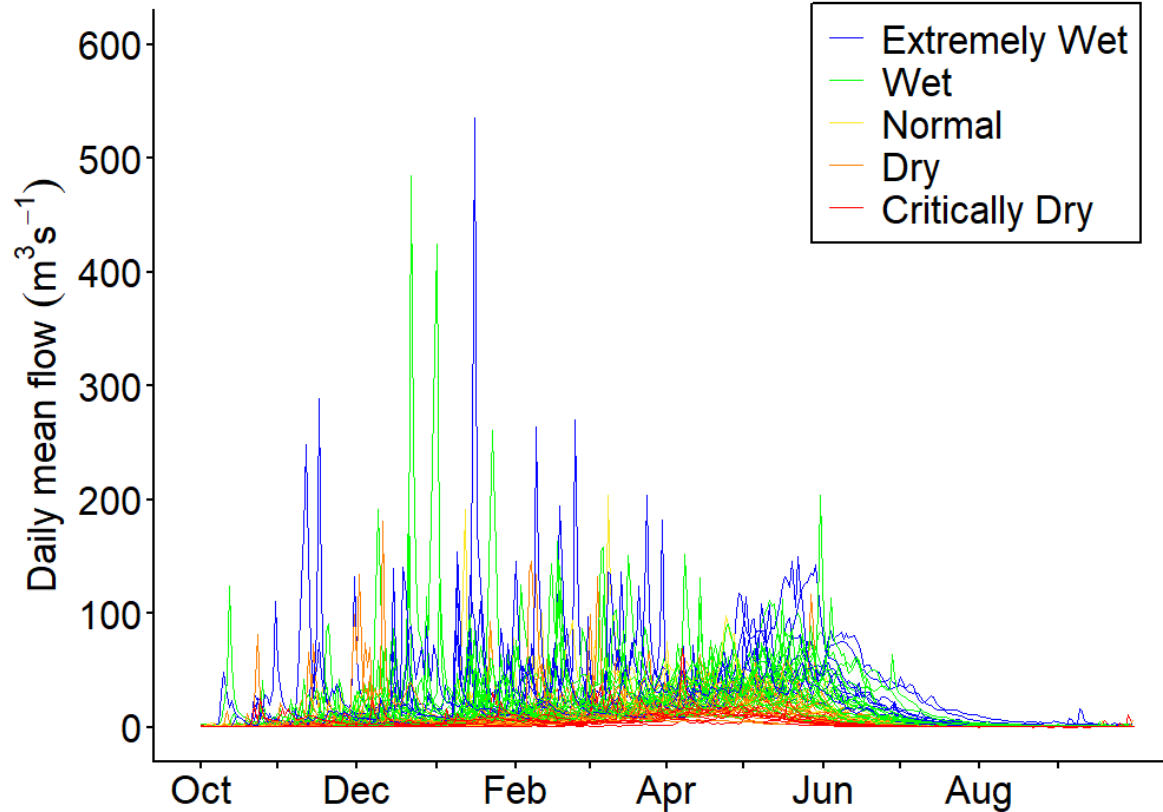
# Conclusion

- Most current methods to quantify alterations underestimate river alteration
- Reliance on daily and monthly data contribute to this
- Aggregating indicators into secondary and tertiary indicators conceals important results
- Using percentiles and/or RVA assumes linearity in processes and/or ignores the importance of the years or flows that lie outside the percentiles

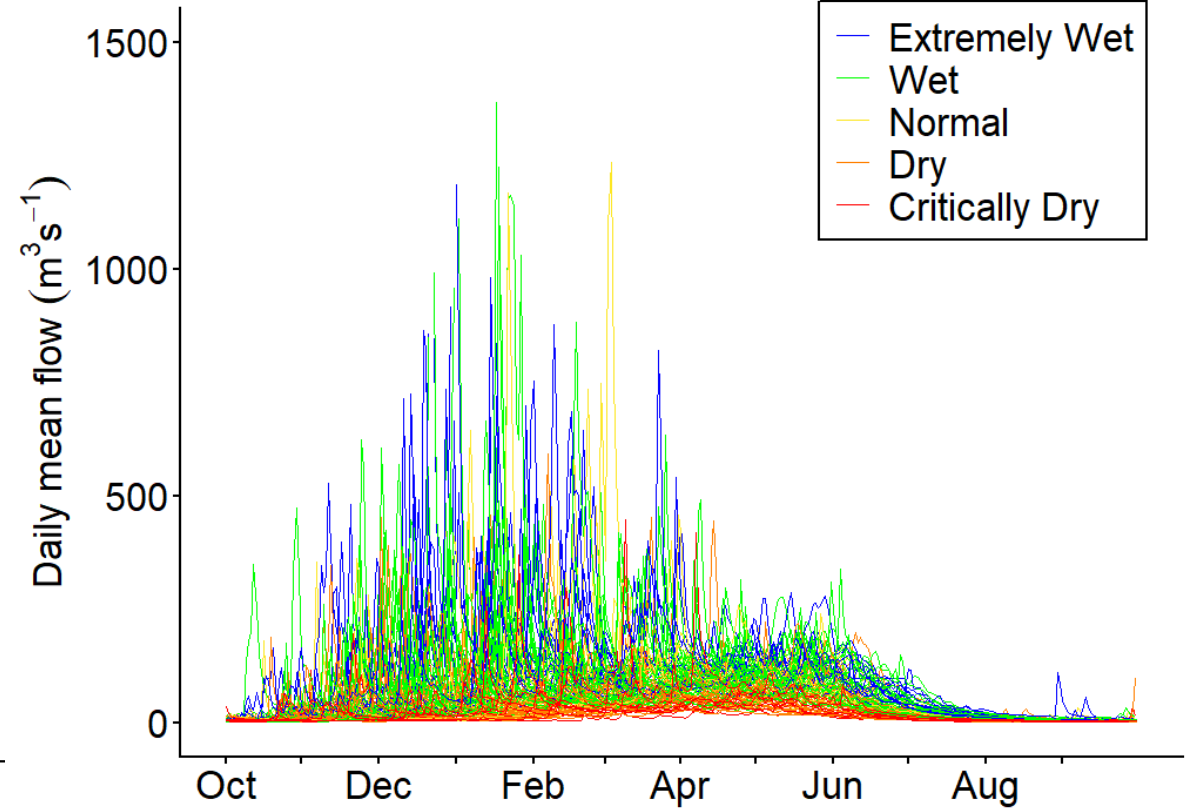


# Rain and rain-snowmelt mix rivers have an infinite number of annual flow patterns

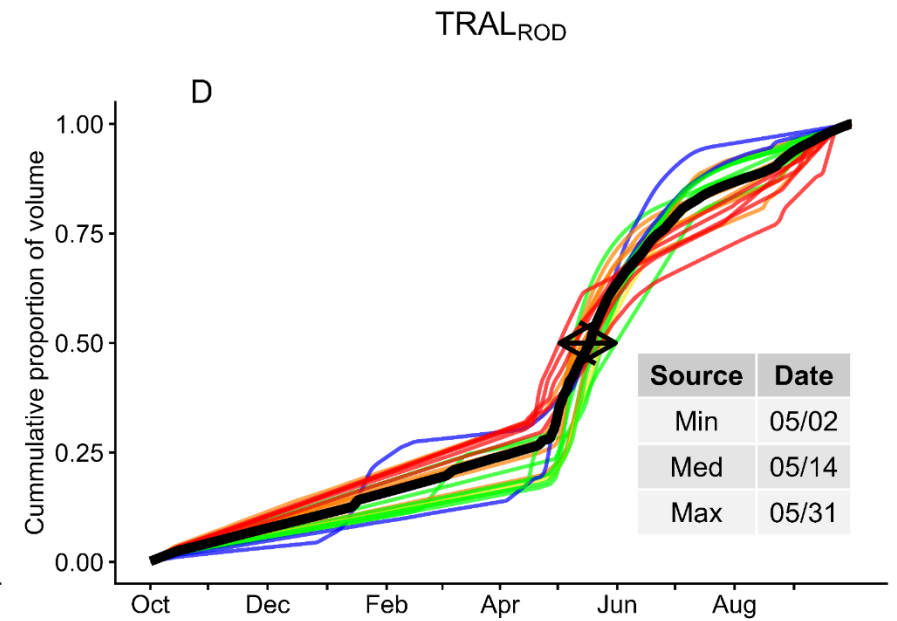
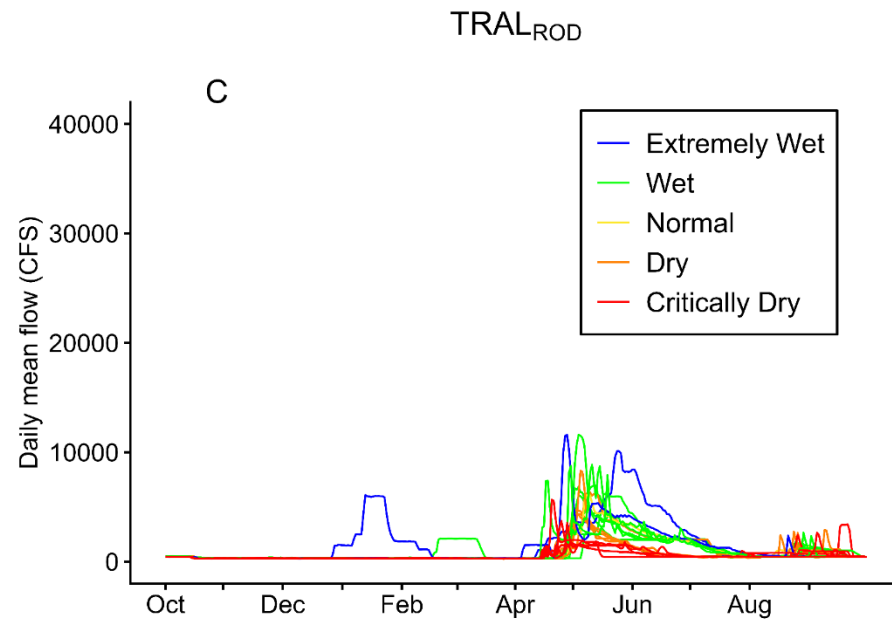
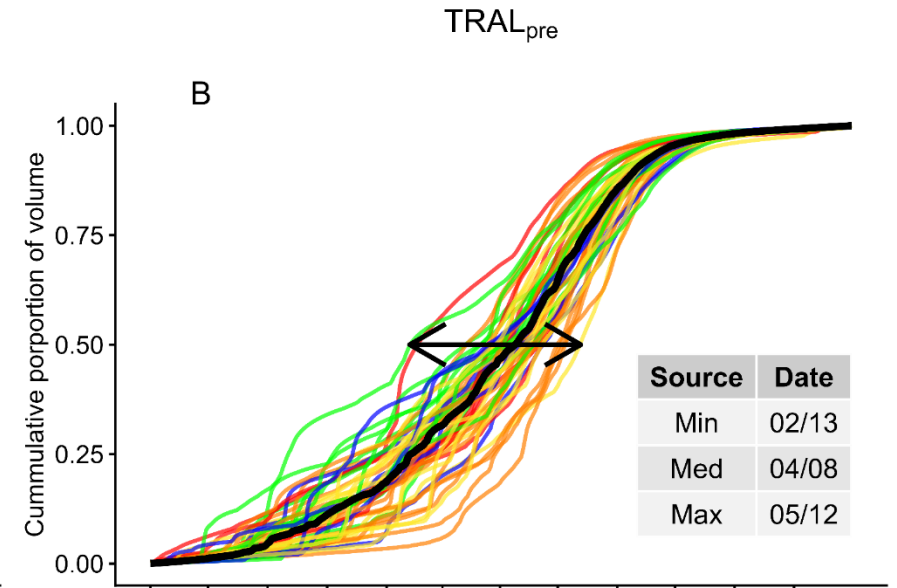
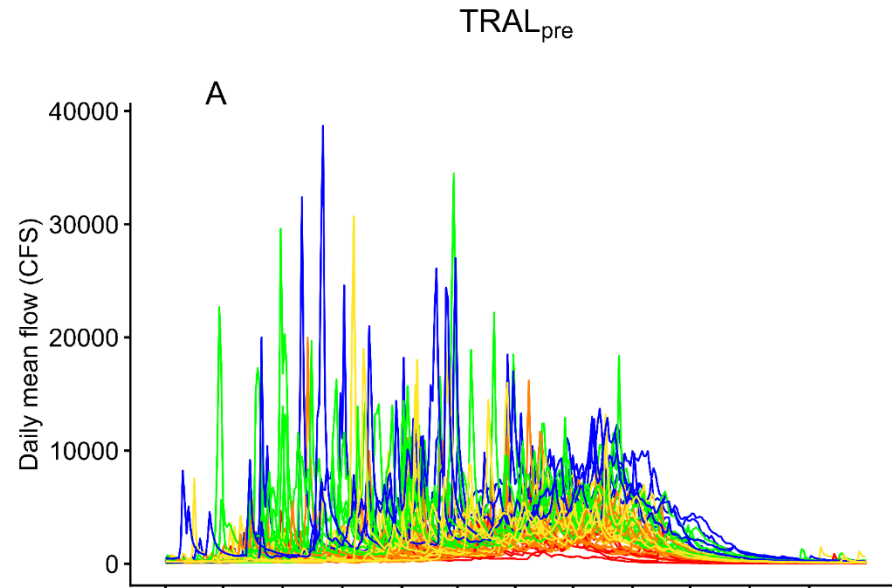
TRABCC



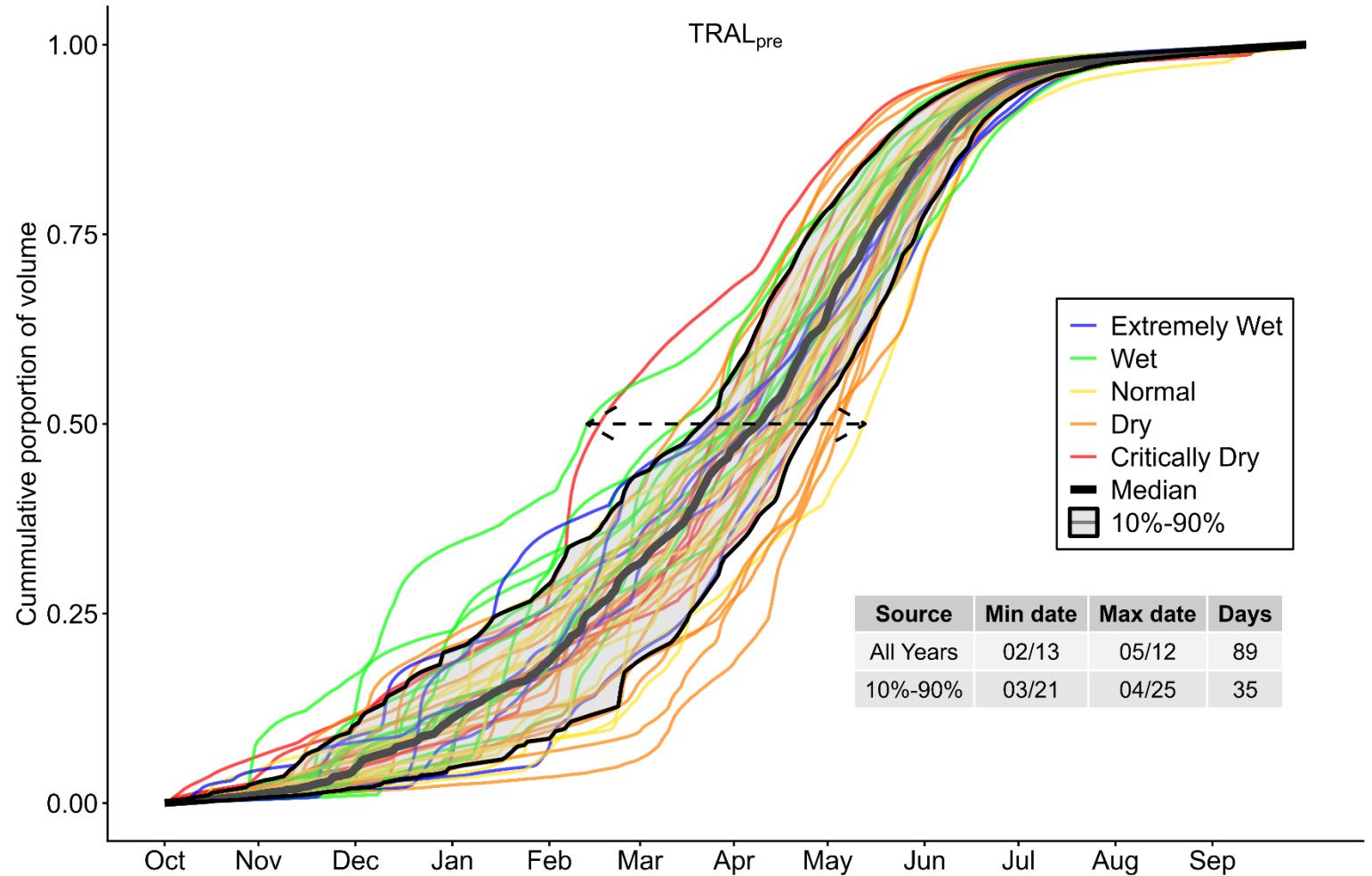
SRASB



- If flow restoration does not restore all flow patterns, important ecological processes will suffer



- Our flow recommendations for dam releases restoration of the natural flow regime itself (to the extent possible), not the statistical properties underlying unimpaired flows or the components we like to group them into



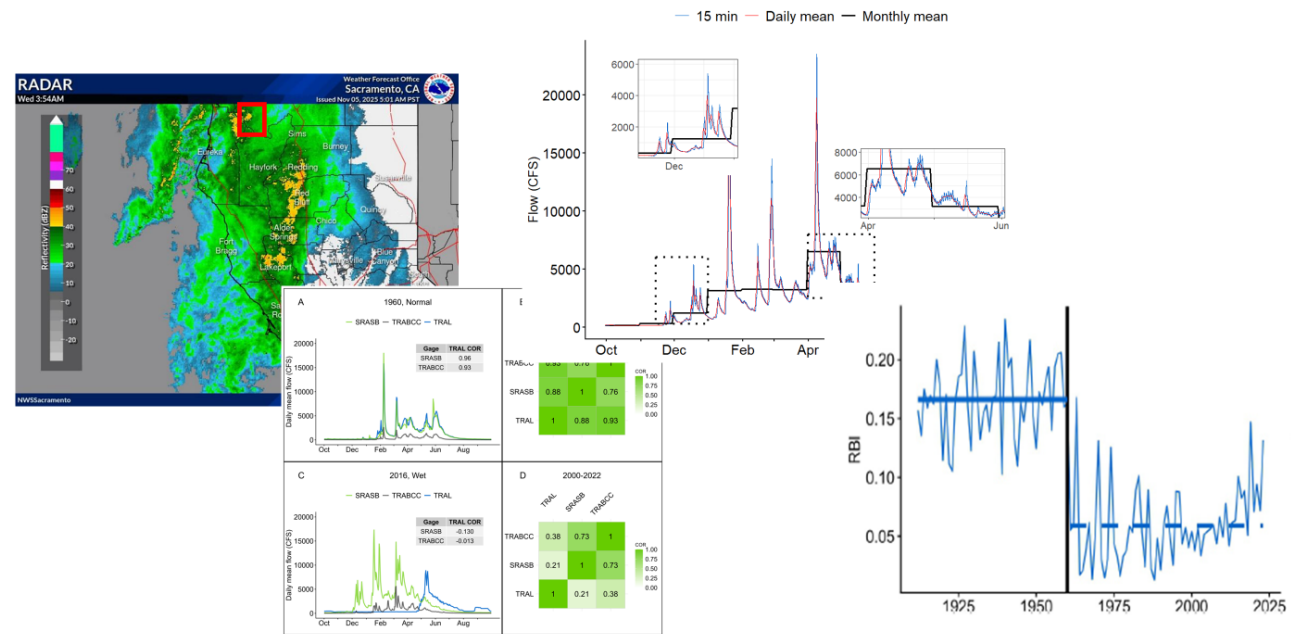
# So What?



# So what can we do differently?

Why aren't synchronicity (COR) or RBI among them?

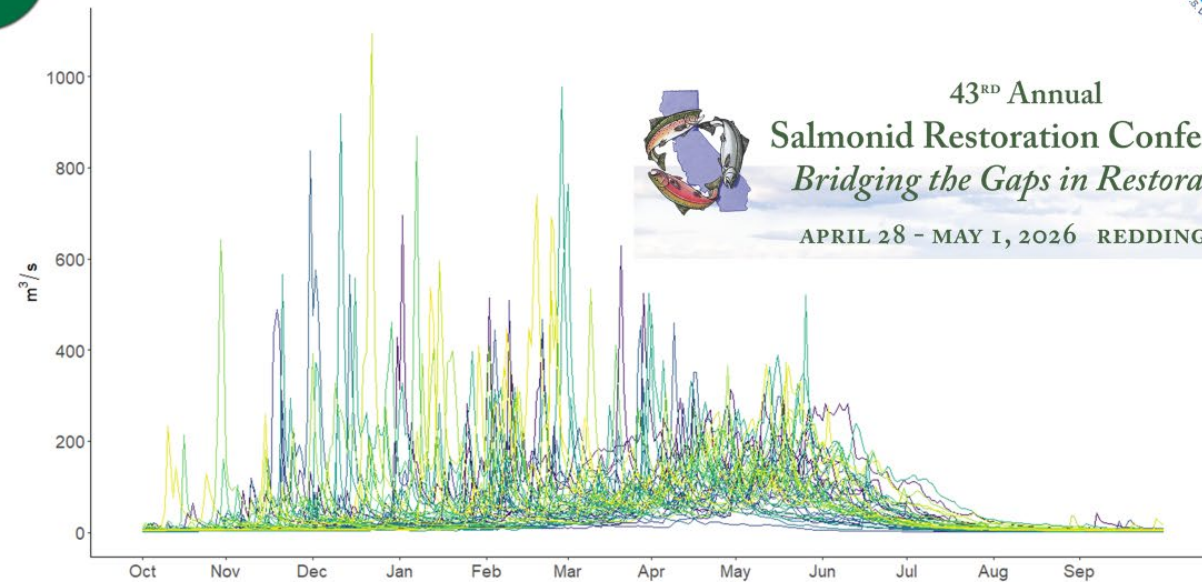
Use synchronicity and RBI to analyze alteration and guide future flow restoration recommendations



# So what can we do differently?

## A Method to Implement Natural Flow Regimes for Regulated Rivers

Nicholas A. Som and Seth W. Naman



# Thank You!

- Kyle De Juilio (Yurok Tribe)
- Nick Som (USGS)
- Eric Petersen (BOR/TRRP)



# Questions?

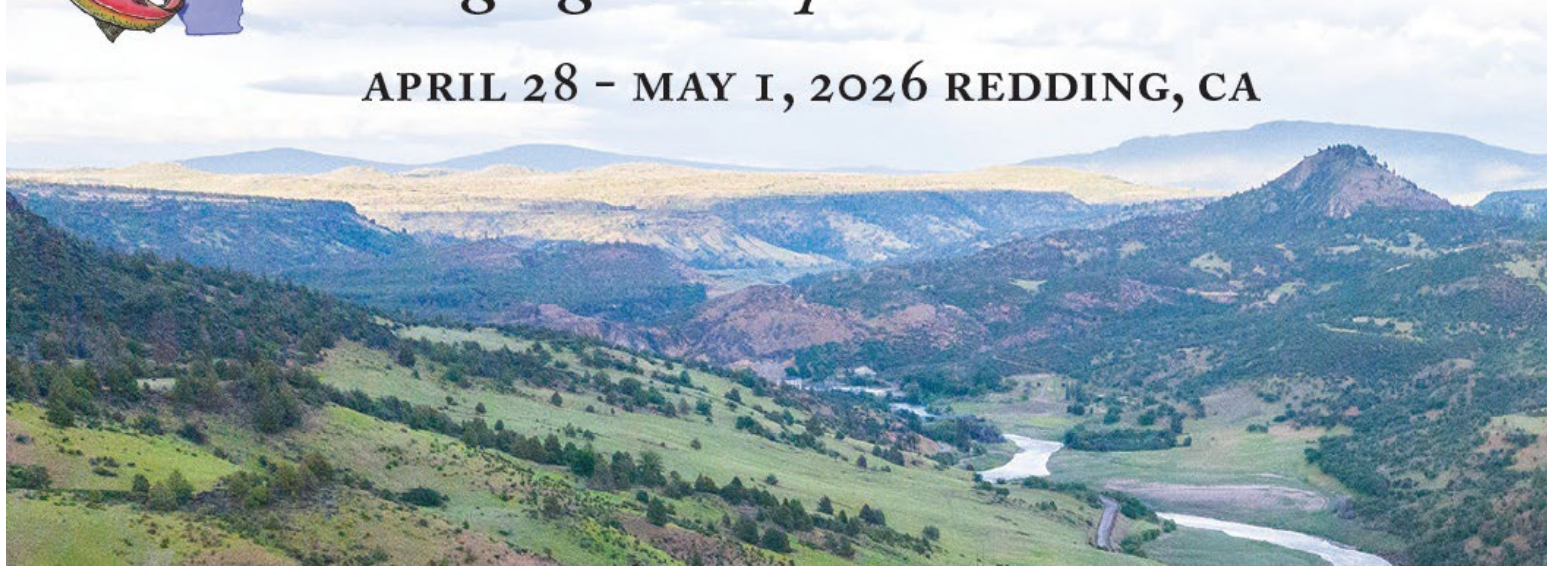
## Bridging Gaps



43<sup>RD</sup> Annual

### Salmonid Restoration Conference *Bridging the Gaps in Restoration*

APRIL 28 - MAY 1, 2026 REDDING, CA



# Between theory and implementation



# Van Norden Meadow Restoration Project

## Hydrologic Benefits of Meadow Restoration

Alecia Weisman<sup>1</sup>, Sam Diaz<sup>2</sup>, Kyle McNeil<sup>1</sup>  
Sarah Yarnell<sup>3</sup>

South Yuba River Citizens League<sup>1</sup>, Verdantas<sup>2</sup>, UC  
Davis Center for Watershed Sciences<sup>3</sup>

[alecia@yubariver.org](mailto:alecia@yubariver.org)

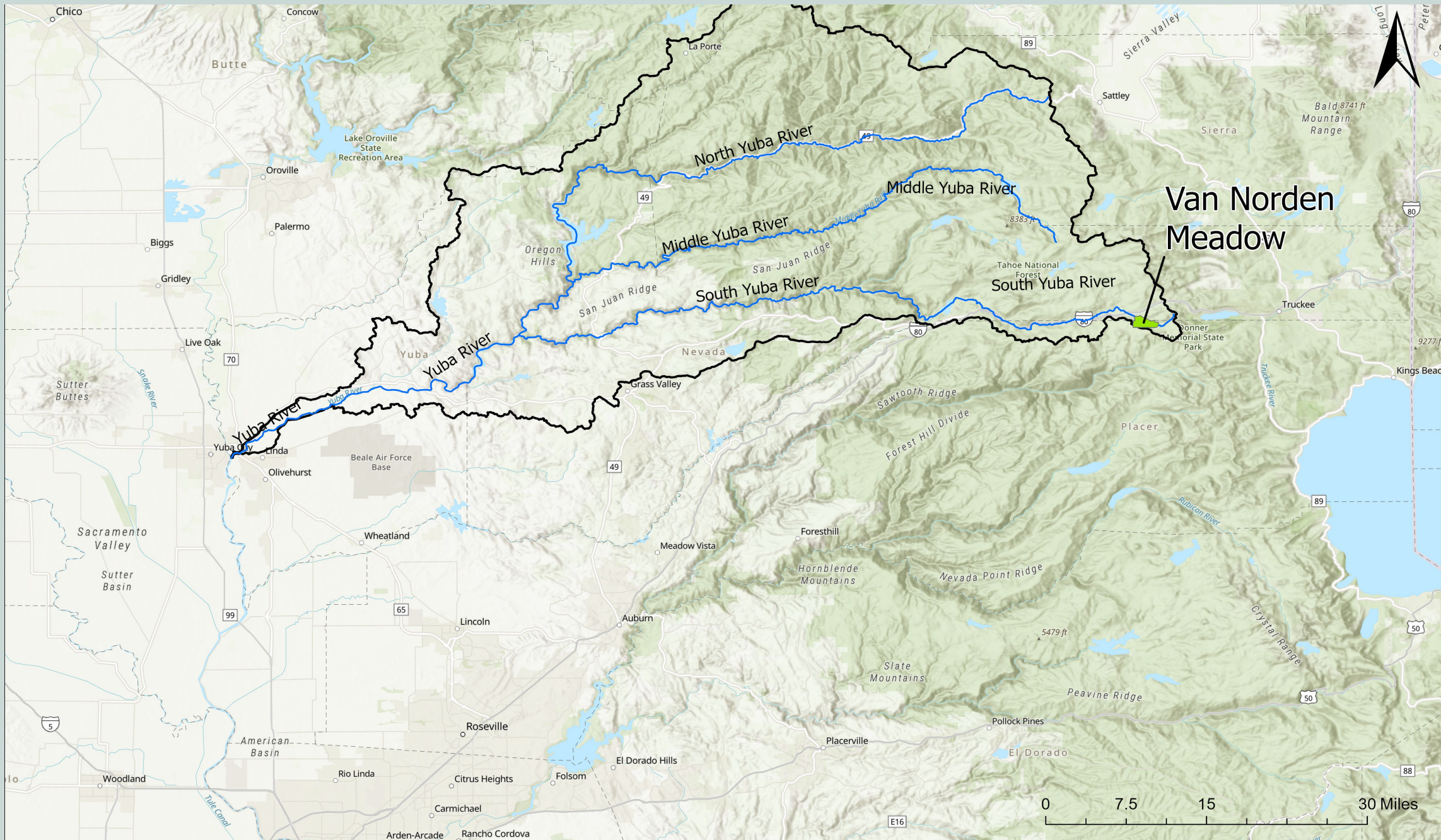


# Outline

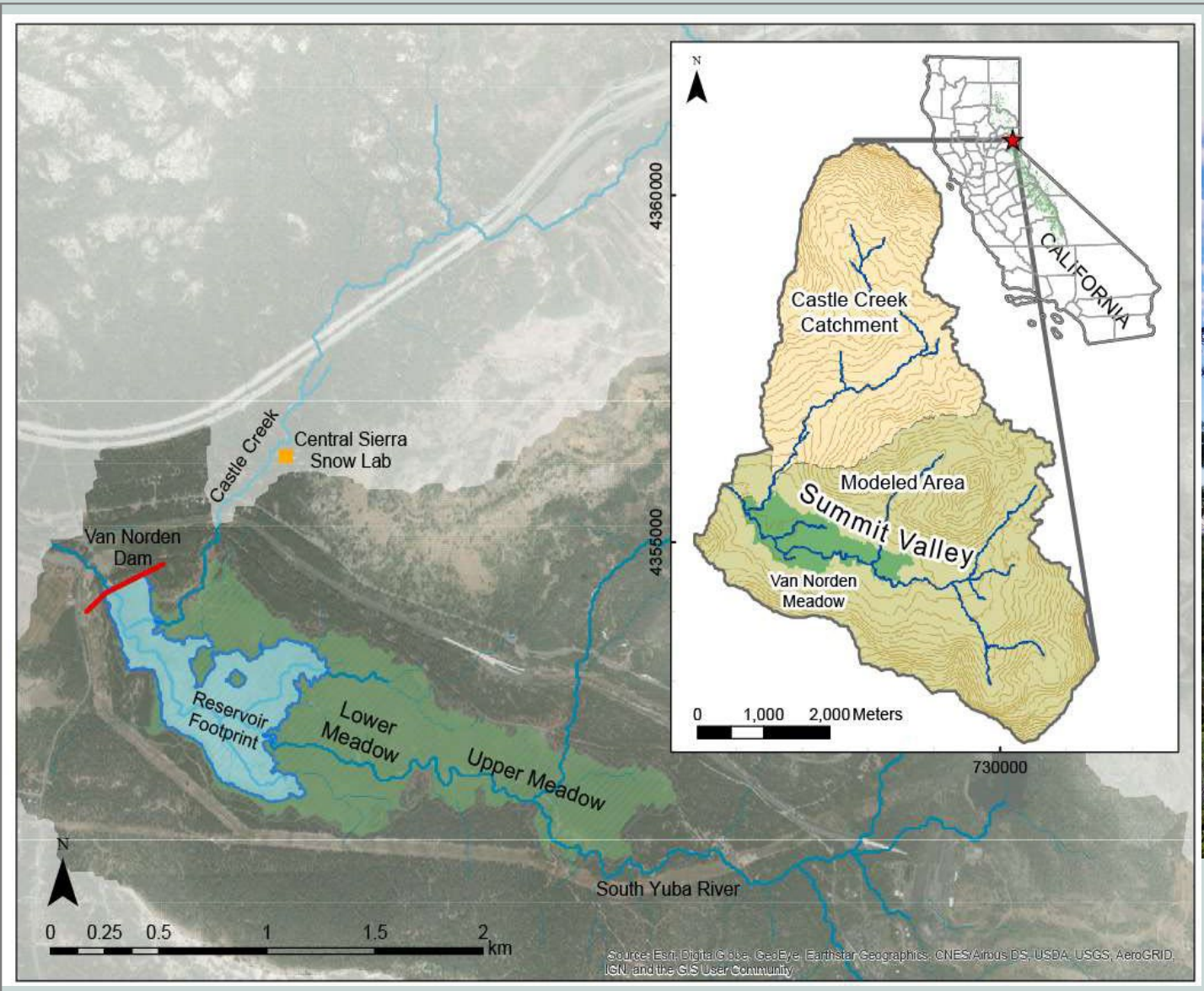


- **Historic and Landscape Context**
- Assessment and Monitoring
- Design Approach
- Implementation Actions
- Outcomes and Results





# Van Norden Meadow



# Human use as early as the late 1800's has impacted Van Norden Meadow



Aerial Photo from 1952 showing reservoir extent, railroad and road systems.



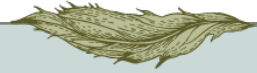
Extensive grazing from 1800's through 1970

# Current Use



Meadow on USFS land, recreational use in both summer and winter with easement held by Royal Gorge for Cross Country ski trails.

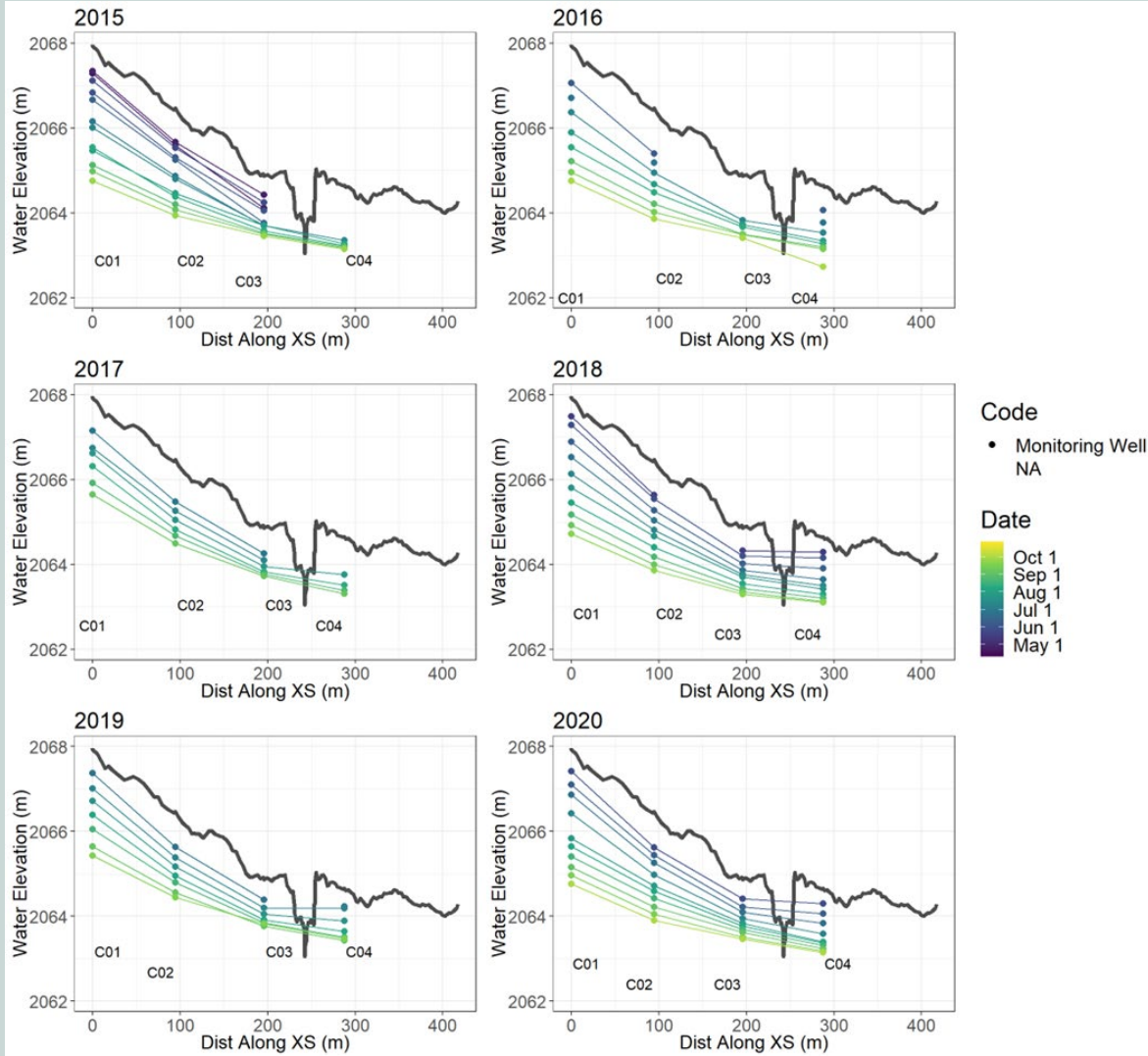
# Outline



- Historic and Landscape Context
- **Assessment and Monitoring**
- Design Approach
- Implementation Actions
- Outcomes and Results



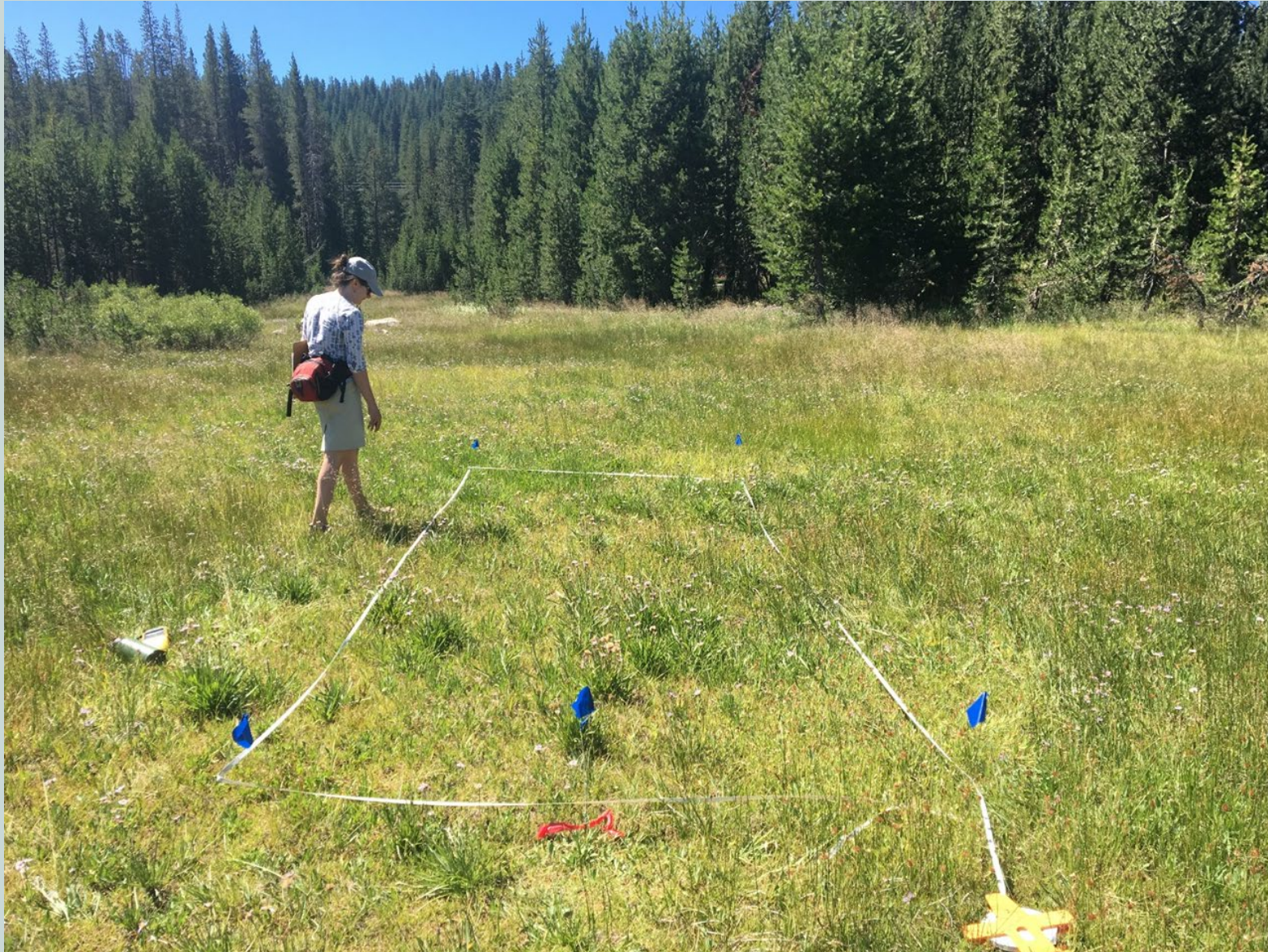
# Severe Incision in the South Yuba, Lytton and Castle Creeks



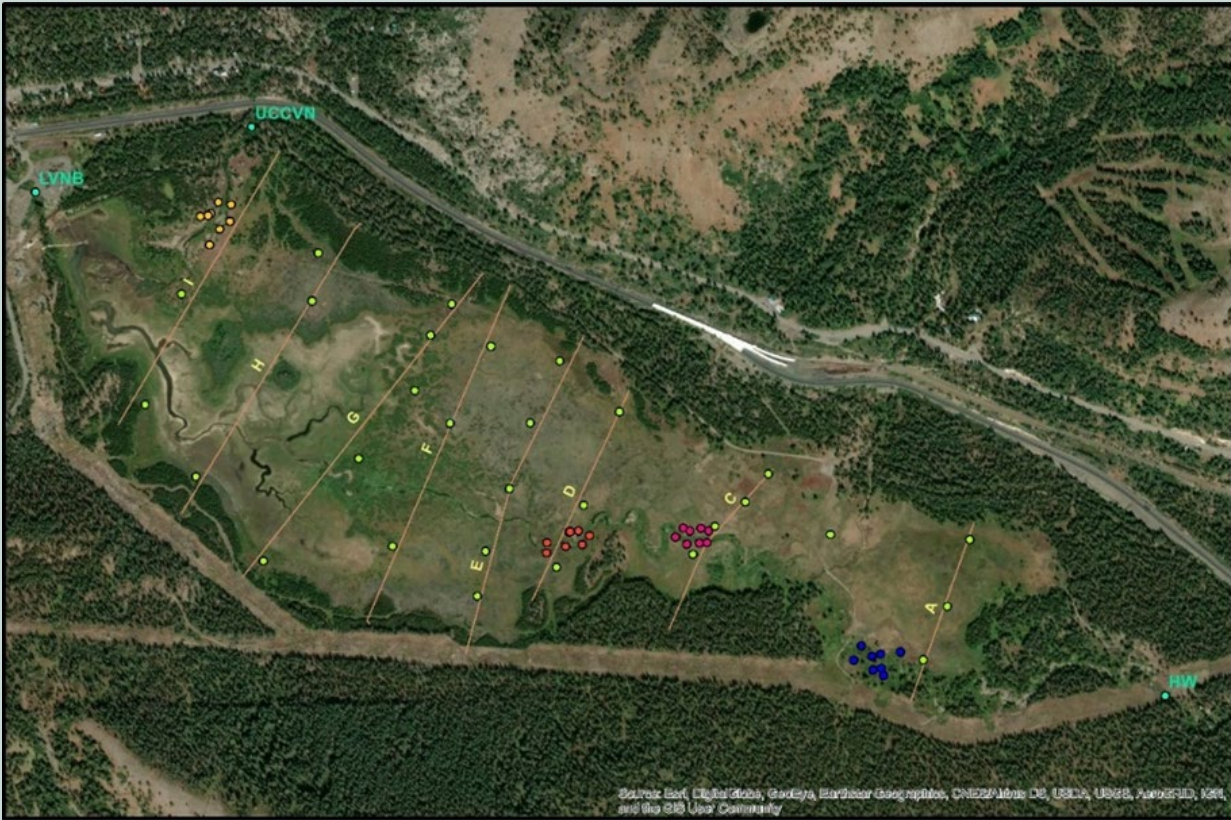
# Road and Culvert impacts: concentrated flow



# Conifer Encroachment & Invasive Species



# Extensive Pre and Post Project Monitoring



**Van Norden Meadow Monitoring Locations**

- XS1
- XS2
- XS3
- XS4
- Groundwater Wells
- Water Quality
- Vegetation Transects

0 0.125 0.25 0.5 Miles




**Van Norden Meadow Monitoring Locations**

- Carbon Data Collection Points
- Conifer Transects

0 0.125 0.25 0.5 Miles



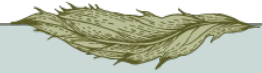
# Expected Benefits of Restoration

- Increase spring and summer inundation
- Increase groundwater recharge
- Attenuate peak flows
- Delay Spring recession period
- Improve water quality
- Increase wet meadow vegetation
- Increase Carbon storage
- Improve habitat for avian species
- Decrease conifer encroachment
- Reduce invasive Reed Canary Grass



Photo Credit – Kyle McNeil - SYRCL

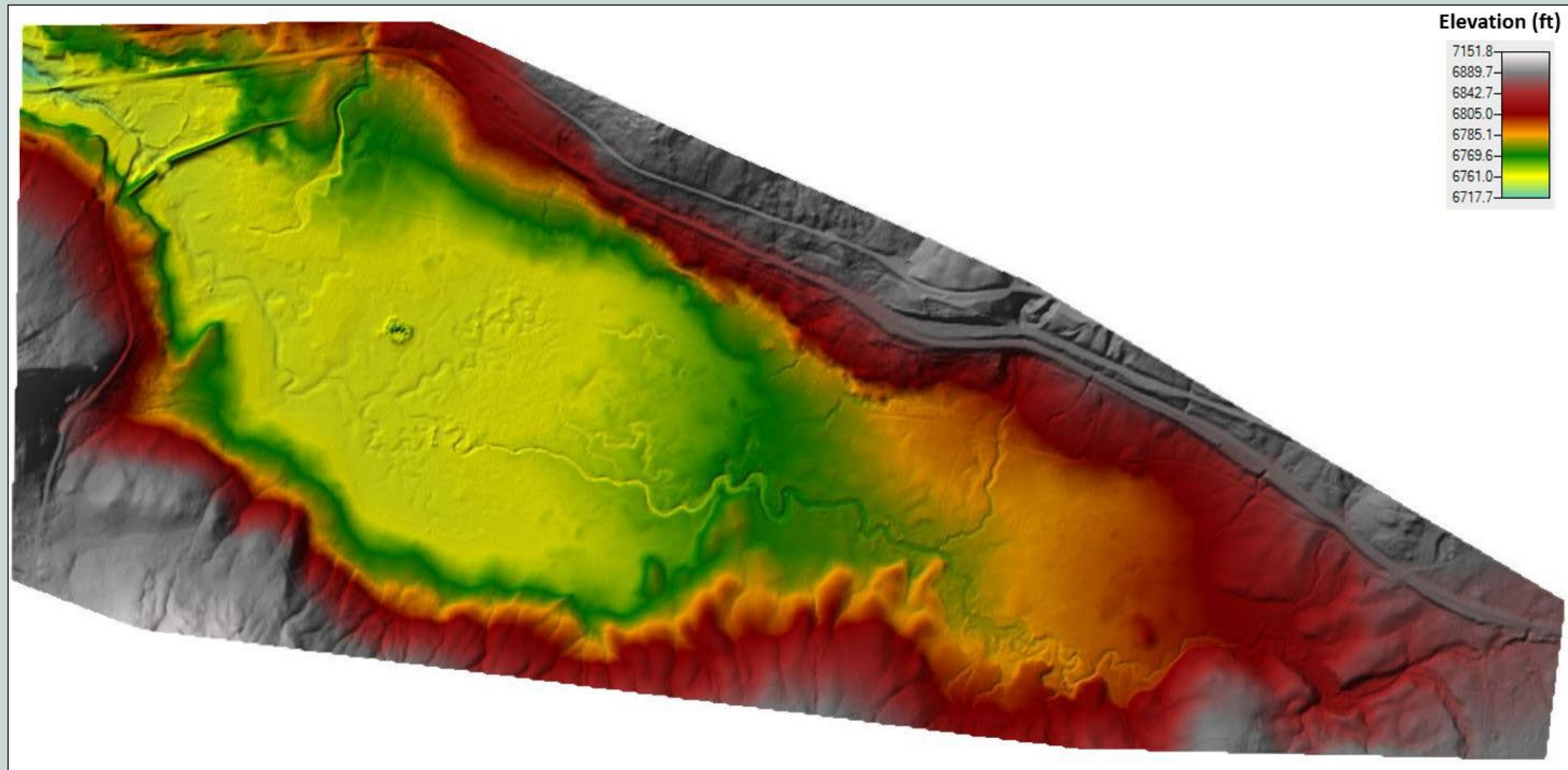
# Outline



- Historic and Landscape Context
- Assessment and Monitoring
- **Design Approach**
- Implementation Actions
- Outcomes and Results



# Design Process



# Collaborative Stakeholder Team and Public Input Informed Restoration Designs




- Washoe Tribe
- Tahoe National Forest
- Truckee Donner Land Trust
- Sugar Bowl and Royal Gorge
- Soda Springs
- UC Davis
- University of Nevada-Reno
- Point Blue Conservation Science
- Verdantas (cbec ecoengineering)
- South Yuba River Citizens League



# Floodplain Connection at low flows

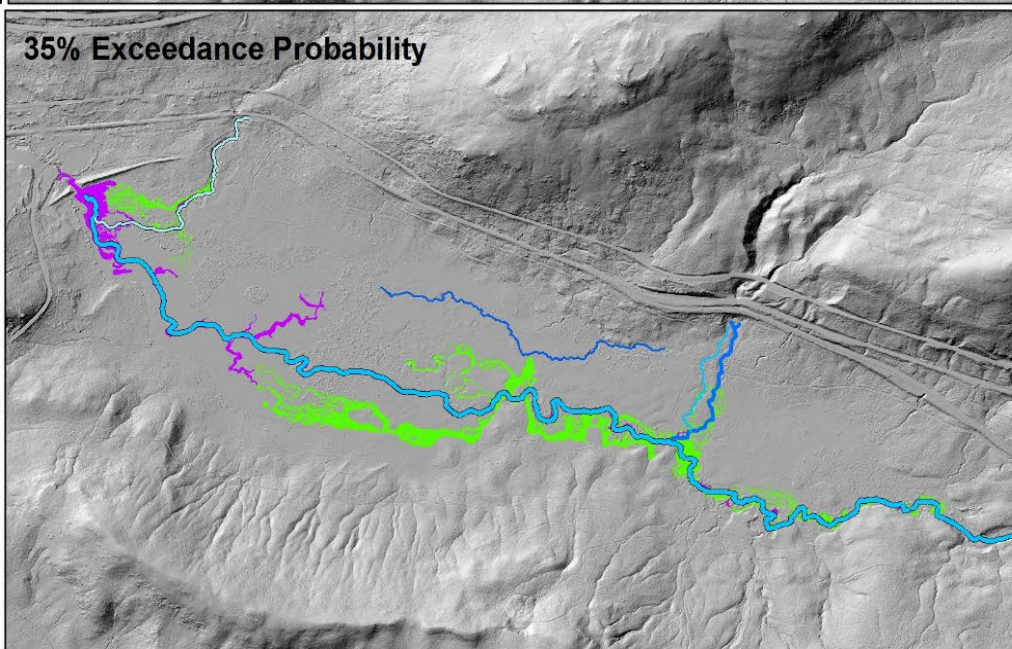
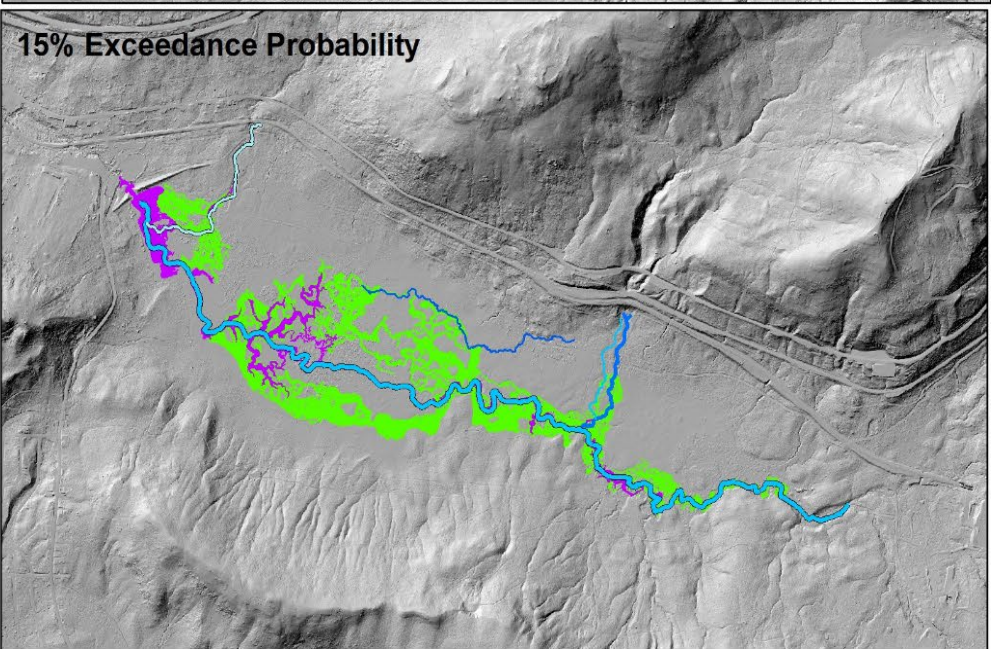
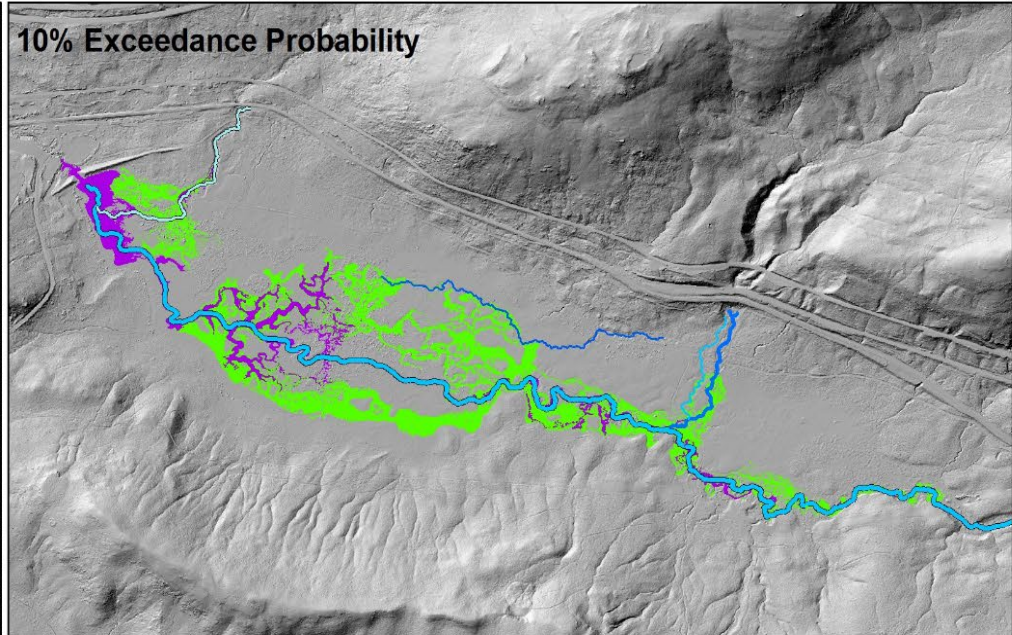
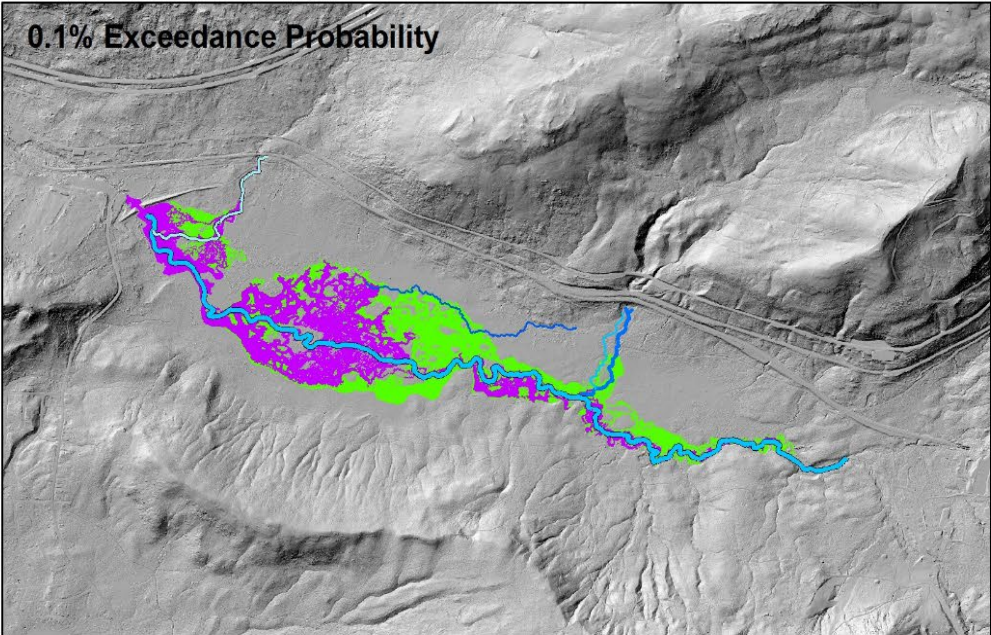


Simulated Inundation Extents at 87 cfs (15% exceedance probability)

-  Royal Gorge Ski Trails
-  Existing Conditions Inundation Extents - 28MAY2020
-  Proposed Design Inundation Extents - 28MAY2020

0 0.125 0.25 0.5 Miles





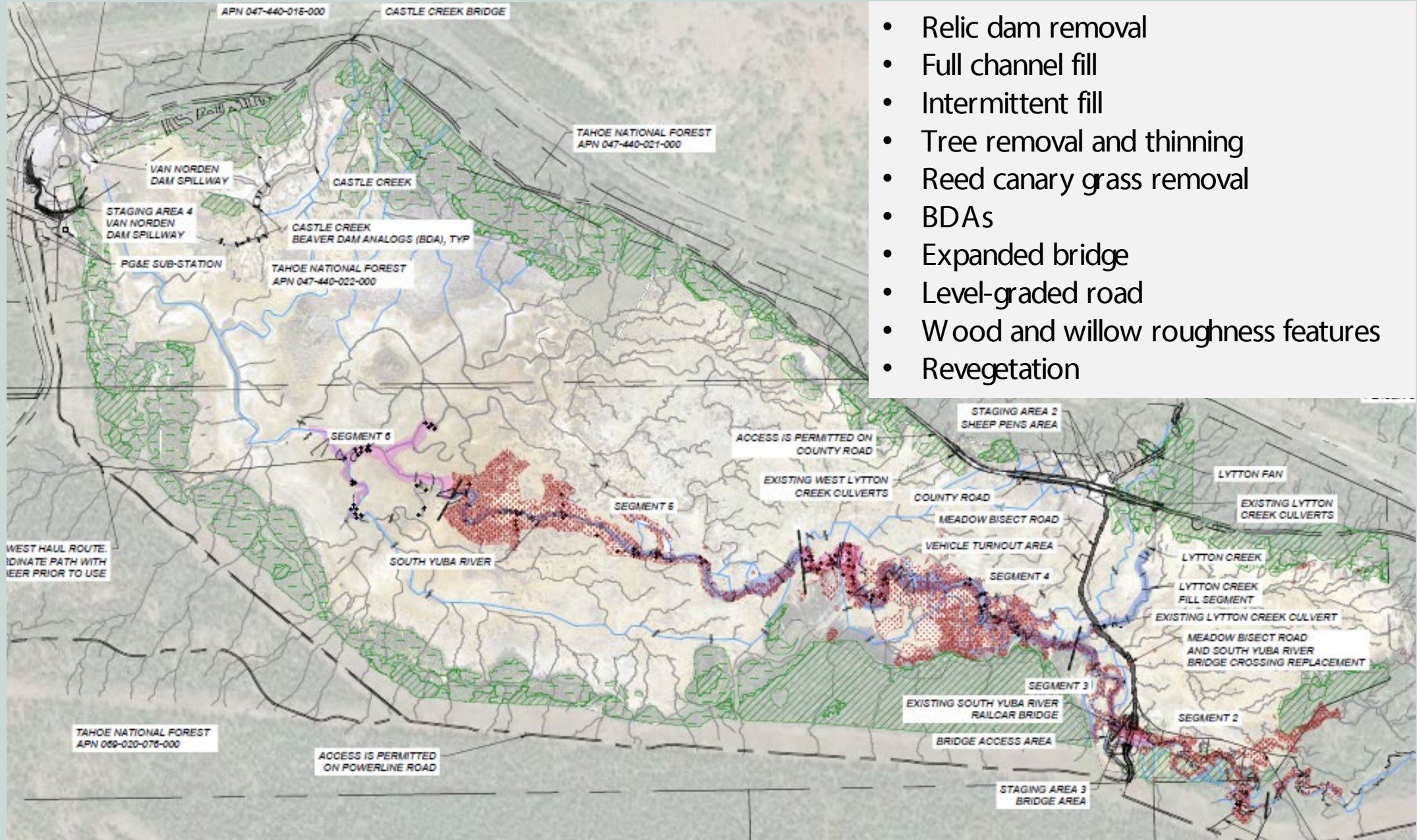
Existing Condition
  Future Condition

Lytton Creek
  Lytton West
  South Yuba River

Lytton Overflow

Upper Castle Creek
 0
0.5
1 Miles

# Restoration Features



- Relic dam removal
- Full channel fill
- Intermittent fill
- Tree removal and thinning
- Reed canary grass removal
- BDAs
- Expanded bridge
- Level-graded road
- Wood and willow roughness features
- Revegetation

# Outline



- Historic and Landscape Context
- Assessment and Monitoring
- Design Approach
- **Implementation Actions**
- Outcomes and Results



# 2022 - Phase 1 - Restoration Actions

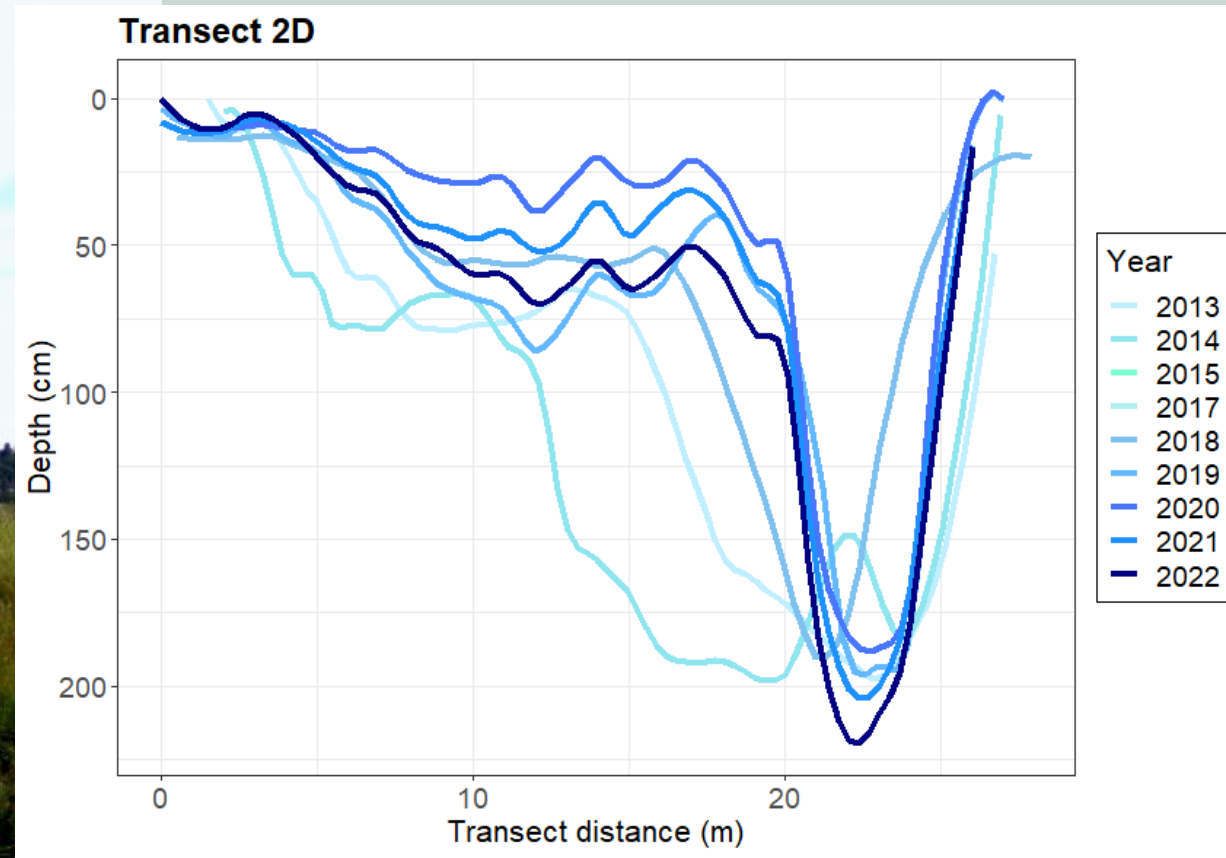


- Remove/degrade Relic Dam Berm
- Fill 2.75 miles of South Yuba and Lytton Creek Channels
- Install BDAs and PALS in Castle Creek, Lytton Creek and Swales
- Complete road improvements on Cross Meadow Road
  - Remove existing bridge
  - Replace with longer, higher bridge
- Remove encroaching conifers and invasive reed canary grass
- Revegetate areas disturbed in implementation process

# Degrading Relic Dam Berm



# Filling Incised Stream Channels



# Beaver Dam Analogs and Post Assisted Log Structures



# Road Improvements



# Revegetation



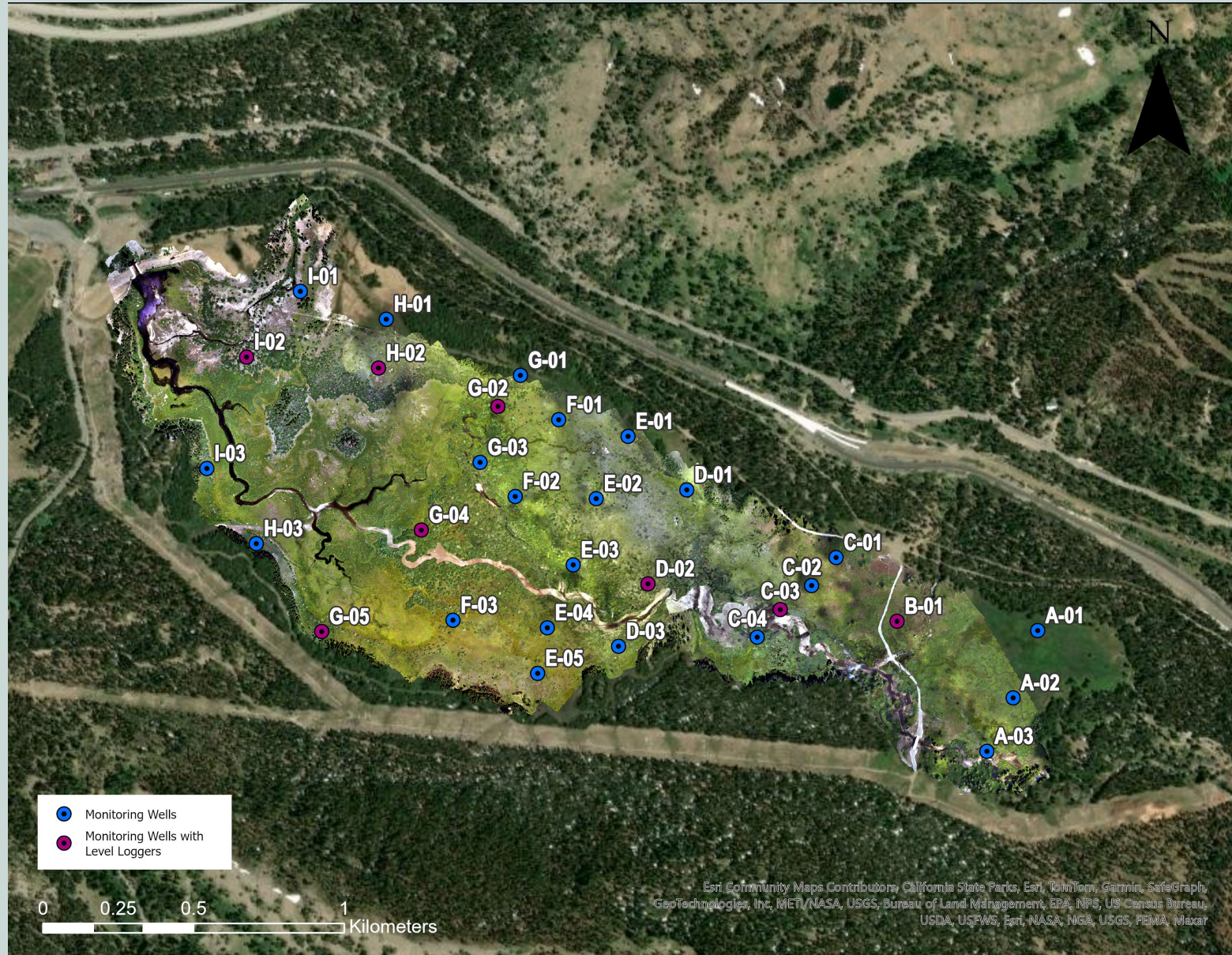
# Outline



- Historic and Landscape Context
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- Design Approach
- Implementation Actions
- **Outcomes and Results**

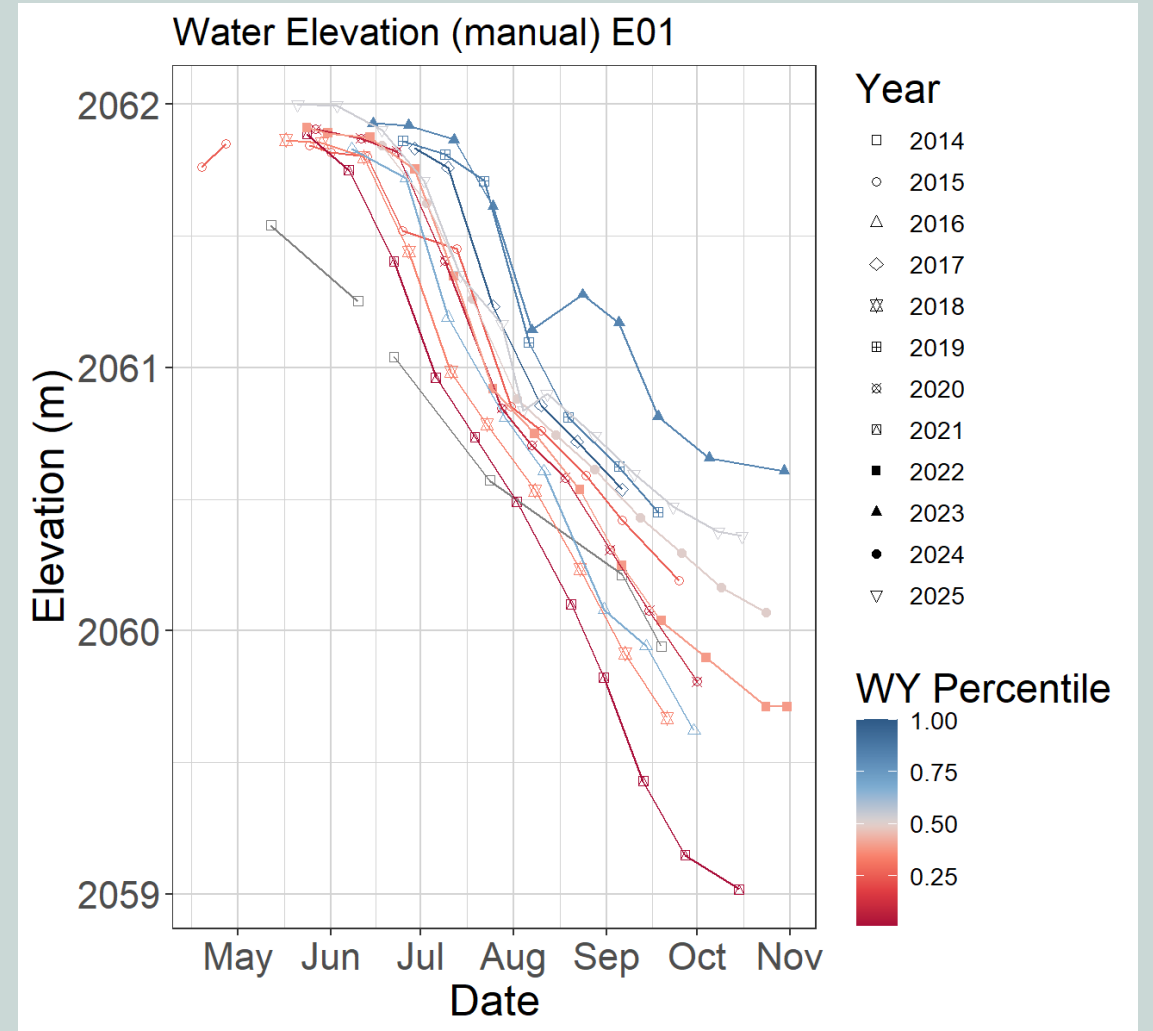
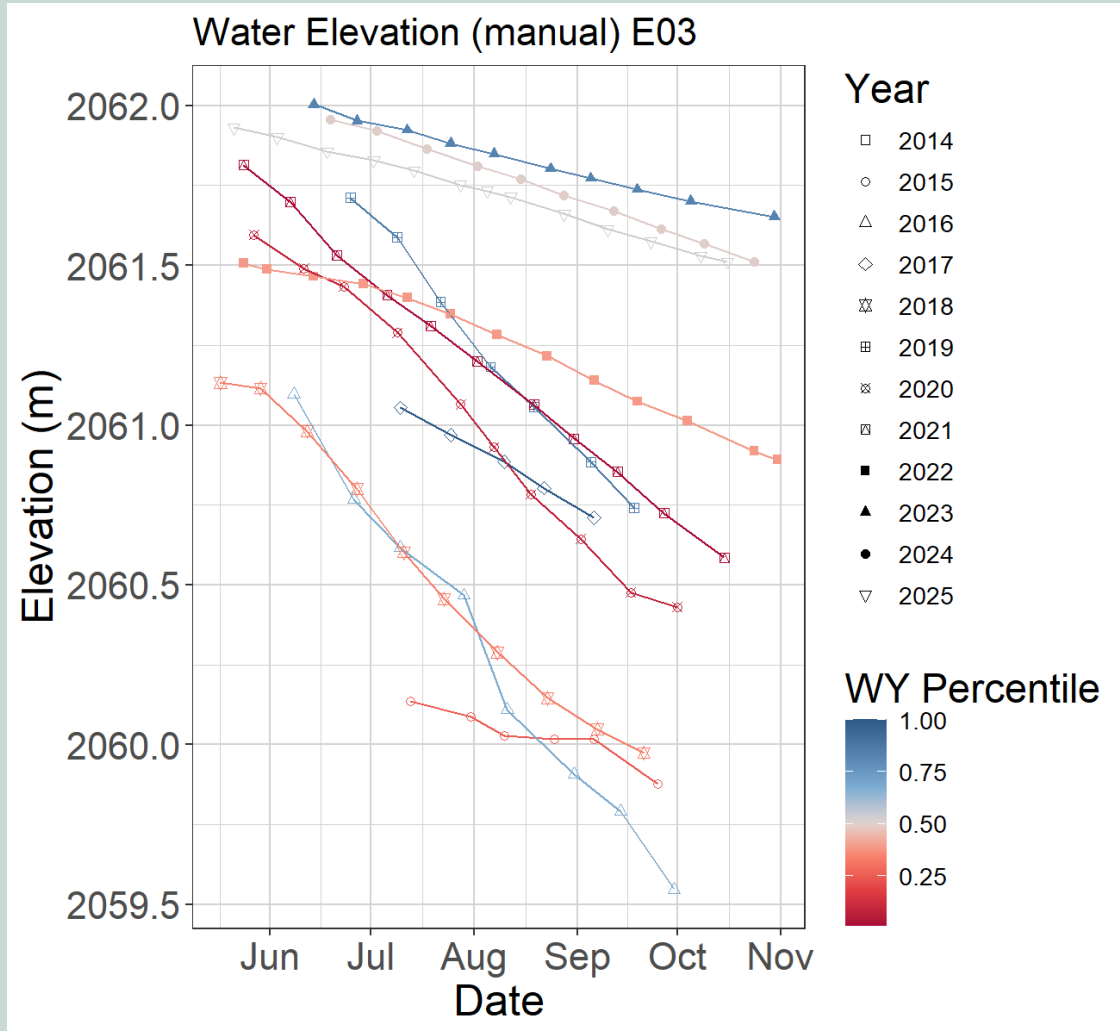


# Groundwater



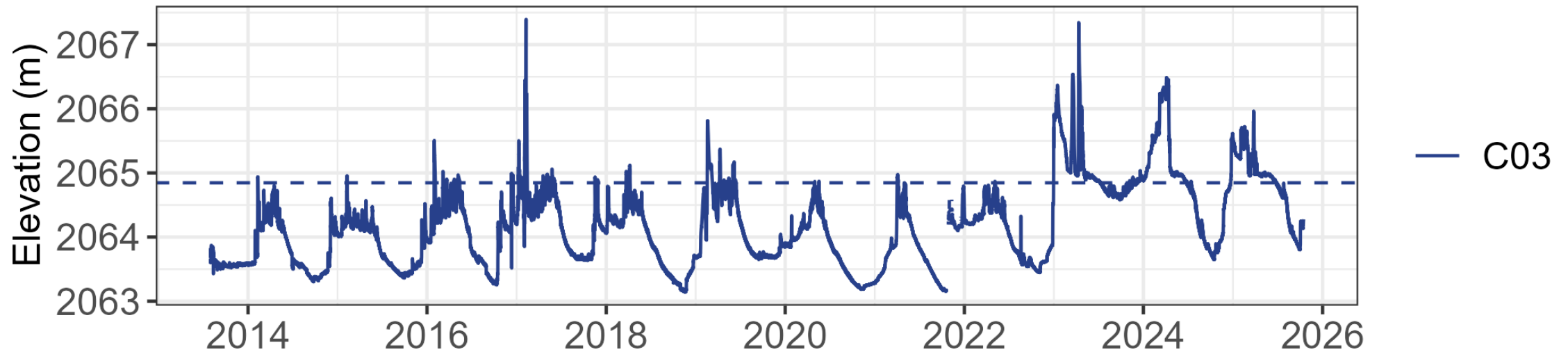
# Groundwater recharge

Is groundwater staying closer to the surface later into the year?



# Groundwater recharge: Levelogger data

Van Norden Meadow: 07/31/2013 - 10/15/2025

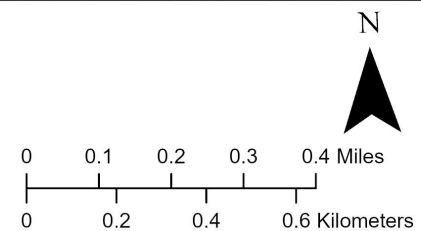


# Streamflow



## Van Norden Meadow Stream Gages

- Stream Gage
- Primary Streamlines
- Project Boundary



# Streamflow

## Is flow attenuation enhanced as a result of restoration?

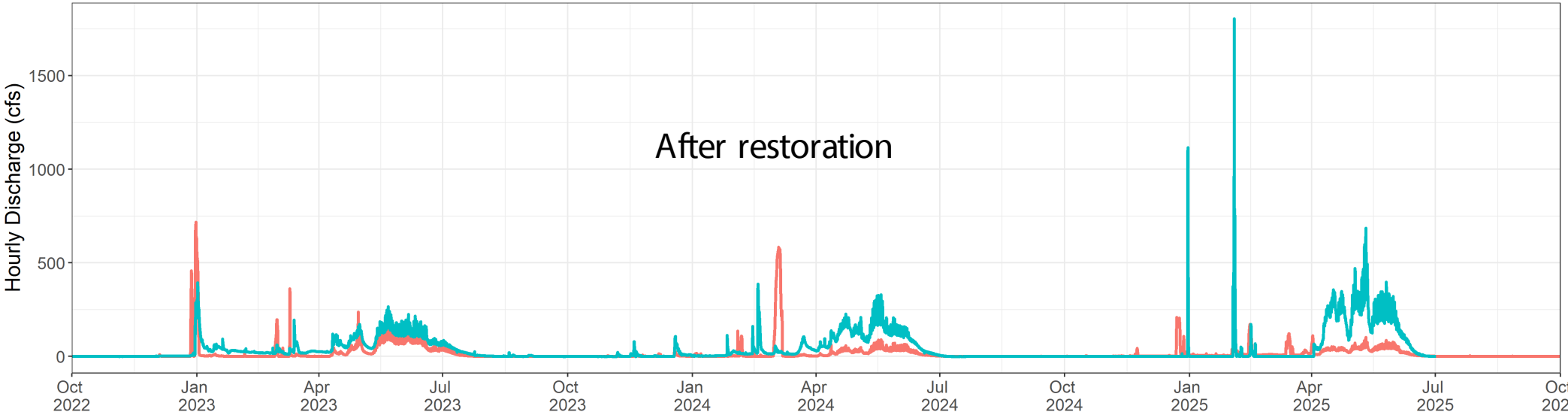
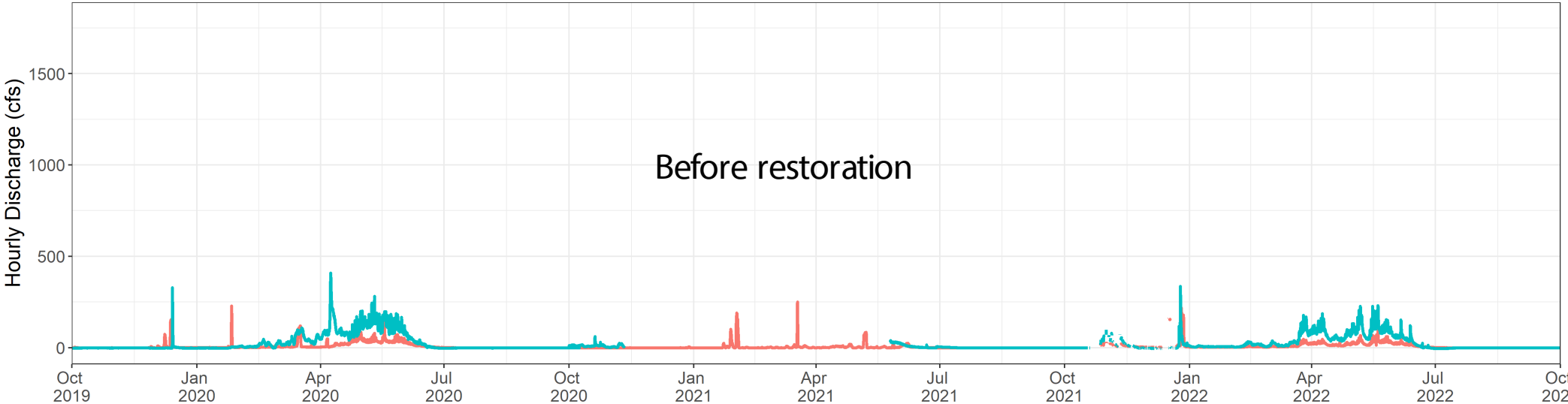
Van Norden WYs 20–25 Hydrographs | YRAM (Inlet) & YRBD (Outlet)

Resto\_Status — Pre-Restoration — Post-Restoration    Precipitation > 0.75 in    ○ 1 ○ 3 ○ 5 ○ 7



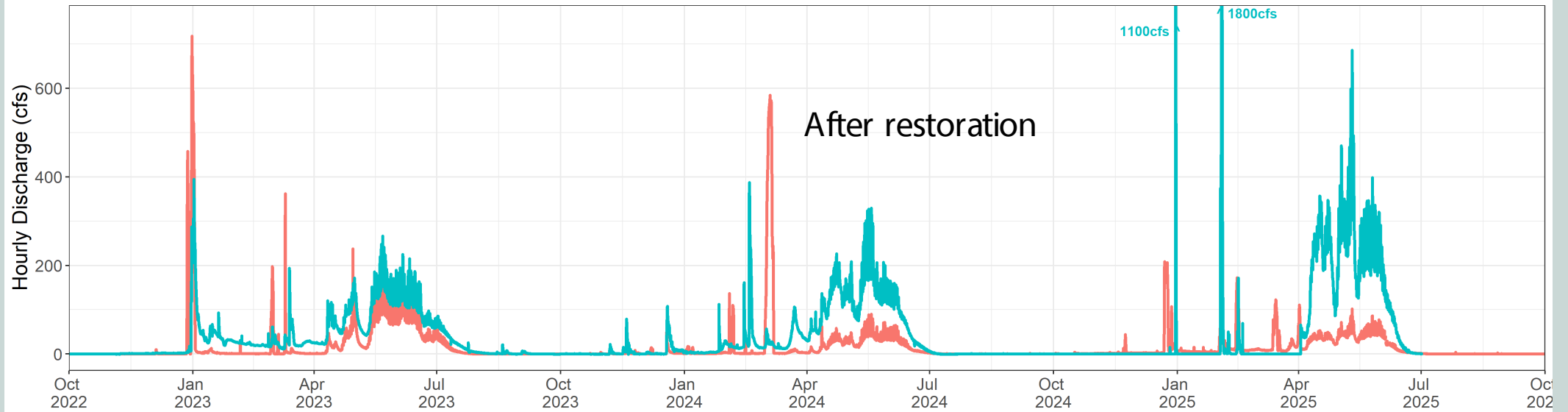
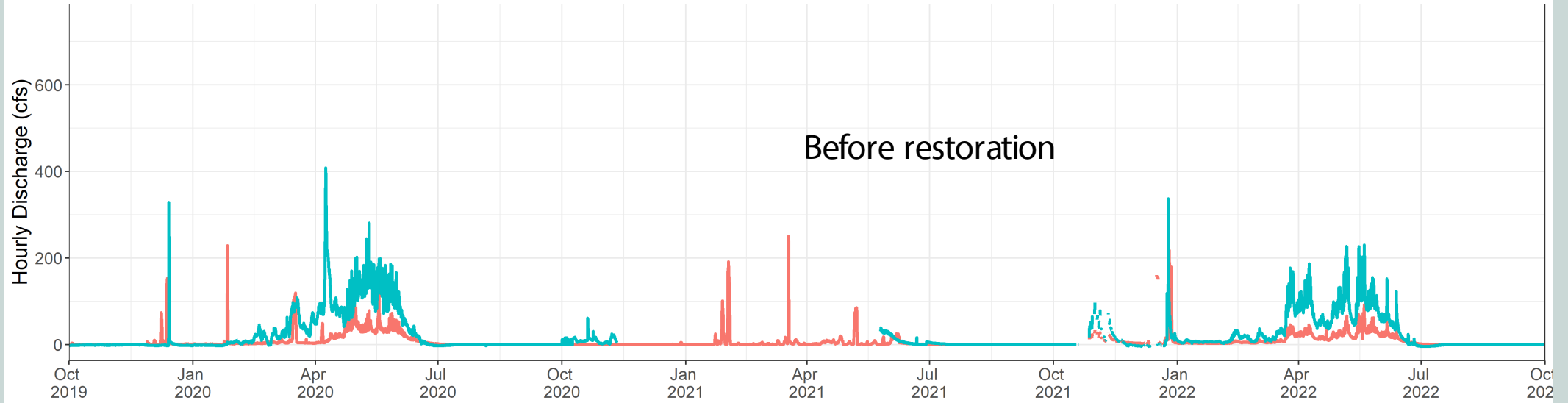
# Van Norden WYs 2020–2025 Hydrographs | YRAM (Inlet) & YRBD (Outlet)

— YRAM — YRBD



# Van Norden WYs 2020–2025 Hydrographs | YRAM (Inlet) & YRBD (Outlet)

— YRAM — YRBD



# Streamflow

Is the spring recession period delayed as a result of restoration?

Van Norden Meadow | Spring Recession 2020–2025



# Take Aways

- **Is groundwater staying closer to the surface later into the year?**

Yes – especially in center of floodplain. The effect of restoration on the meadow edge is less pronounced and influenced more by water year and forest ET.

- **Is flow attenuation enhanced as a result of restoration?**

Yes – but the floodplain has a max capacity. Whether the meadow can attenuate flows depends on previous years saturation and rate and type of precipitation.

- **Is the spring recession period delayed as a result of restoration?**

Unclear – Seems to be driven by rate of snowmelt and restoration. More data and more in-depth analysis needed



# Thank You to our Funders



# Simulating telemetry studies that estimate component mortality rates of imperiled juvenile salmonids

Elizabeth M. Greenheck<sup>1</sup>,

Matt L. Peterson<sup>2</sup>, Tyler J. Pilger<sup>2</sup>, Matea A. Djokic<sup>2</sup>, T. Reid Nelson<sup>1</sup>

<sup>1</sup>George Mason University, Department of Environmental Science and Policy, Fairfax, VA

<sup>2</sup>FISHBIO, Chico, CA

# Juvenile Mortality

- Survival of fishes during early life stages is critical for adult recruitment
  - mortality is highest during this time
  - intrinsic and extrinsic factors affect juvenile survival
- Important to quantify for sustainable fisheries
  - imperiled species (e.g., salmonids)
  - improve management actions (e.g., restocking, restoration actions)

# How do we study juvenile mortality?

- Previous studies have estimated survival and single-source mortality
- Novel telemetry tags can detect predation events (PDATs)
- Multistate mark-recapture models (MSMRs) + PDATs can aid in quantifying component mortality
- Component estimates can aid in more targeted management
  - e.g., assessing restoration actions

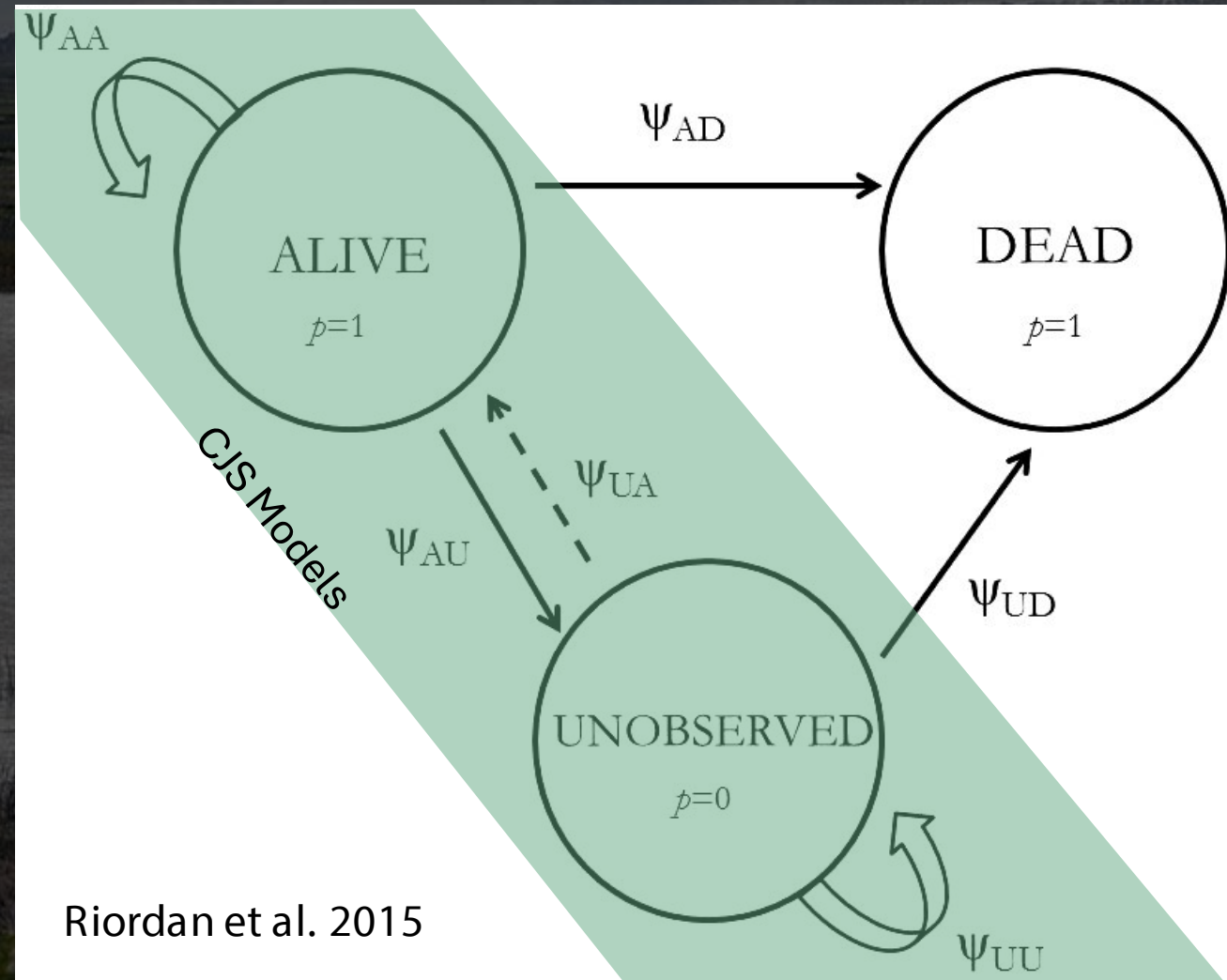
# Multistate mark-recapture models (MSMRs)

## Utility of MSMRs

- expansion of CJS models
- more than two states
- flexible
- informative
  - however, increased data requirements?

## Utility of simulations

- allow for development of clear analysis plan
- useful in understanding requirements for desired model precision



# Objectives

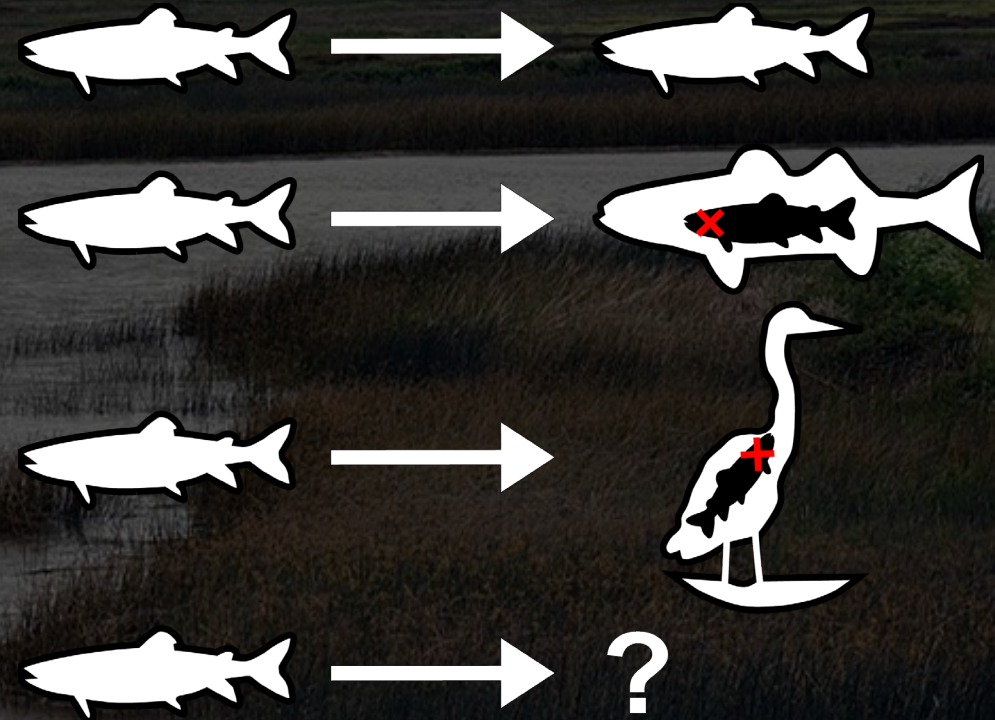
1. Demonstrate the utility of multistate mark-recapture models (MSMRs) using simulations
  - states are fates (survival, predation mortality, unknown mortality)
  - calibrated spatially (fate per reach)
2. Simulating multistate models that assess habitat use and survival of emigrating salmonids
  - states are state-fate (survival in restored area, etc.)
  - calibrated temporally (fate per day)

	Reach 1	Reach 2	Reach 3	Reach 3
Fish1	1	3	1	1
Fish2	1	2	2	2
Fish3	1	3	3	3

# Objective 1

## 1. Demonstrate the utility of multistate mark-recapture models (MSMRs) using simulations

- low vs high detection probabilities
  - passive-only vs active tracking
- three- and four-states
- addition of model covariates
  - biological (length)
  - environmental (temperature)
- varying sample size (all models)



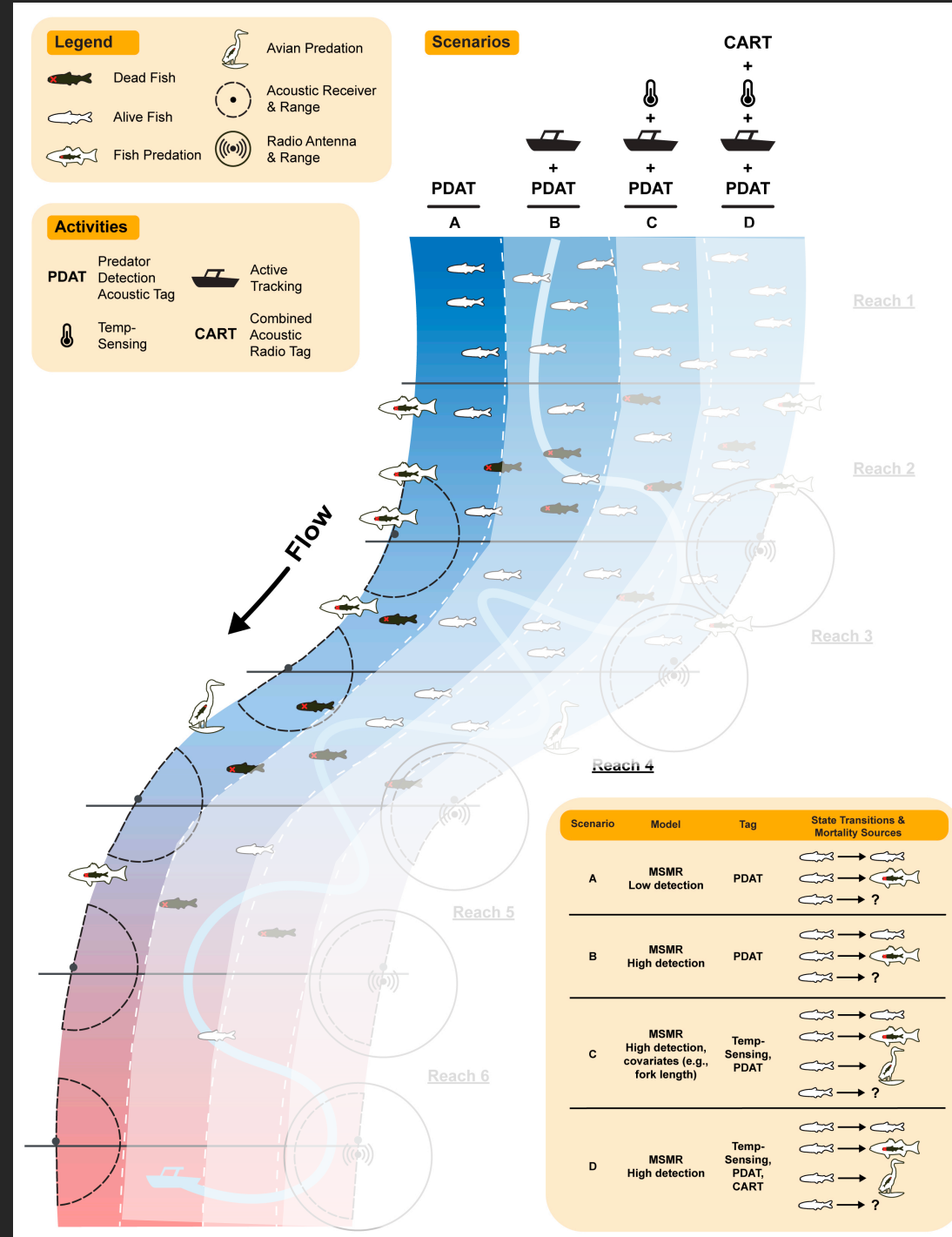
## Focus on CCV salmonid populations

- can be applied to other salmonid populations and species

# Obj 1: Simulating MSMRs

## Telemetry-based study designs

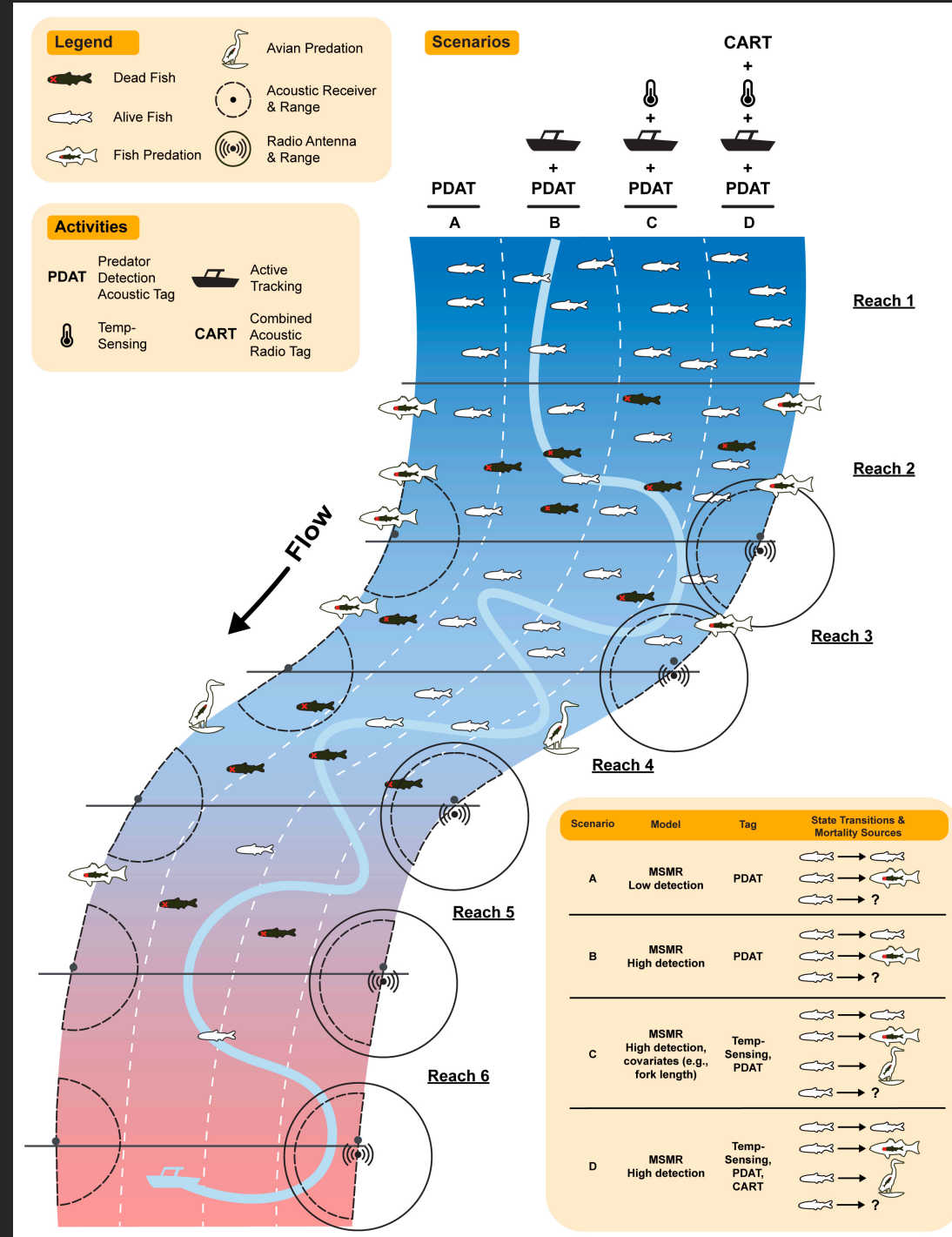
- Scenario A: low detection probability ( $p$ ) (passive-only;  $p = 0.65$ )
  - survival ( $S$ ), predation mortality ( $P$ ), unknown mortality ( $M$ )
- Scenario B: high detection probability (active & passive,  $p = 0.90$ )
  - $S$ ,  $M$ ,  $P$
- Scenario C: Scenario B + covariates with high  $p$  ( $p=0.90$ )
  - $M$ ,  $P$
- Scenario D: high detection probability ( $p = 0.90$ ), added model state
  - $S$ ,  $M$ ,  $P_f$ ,  $P_a$



# Obj 1: Simulating MSMRs

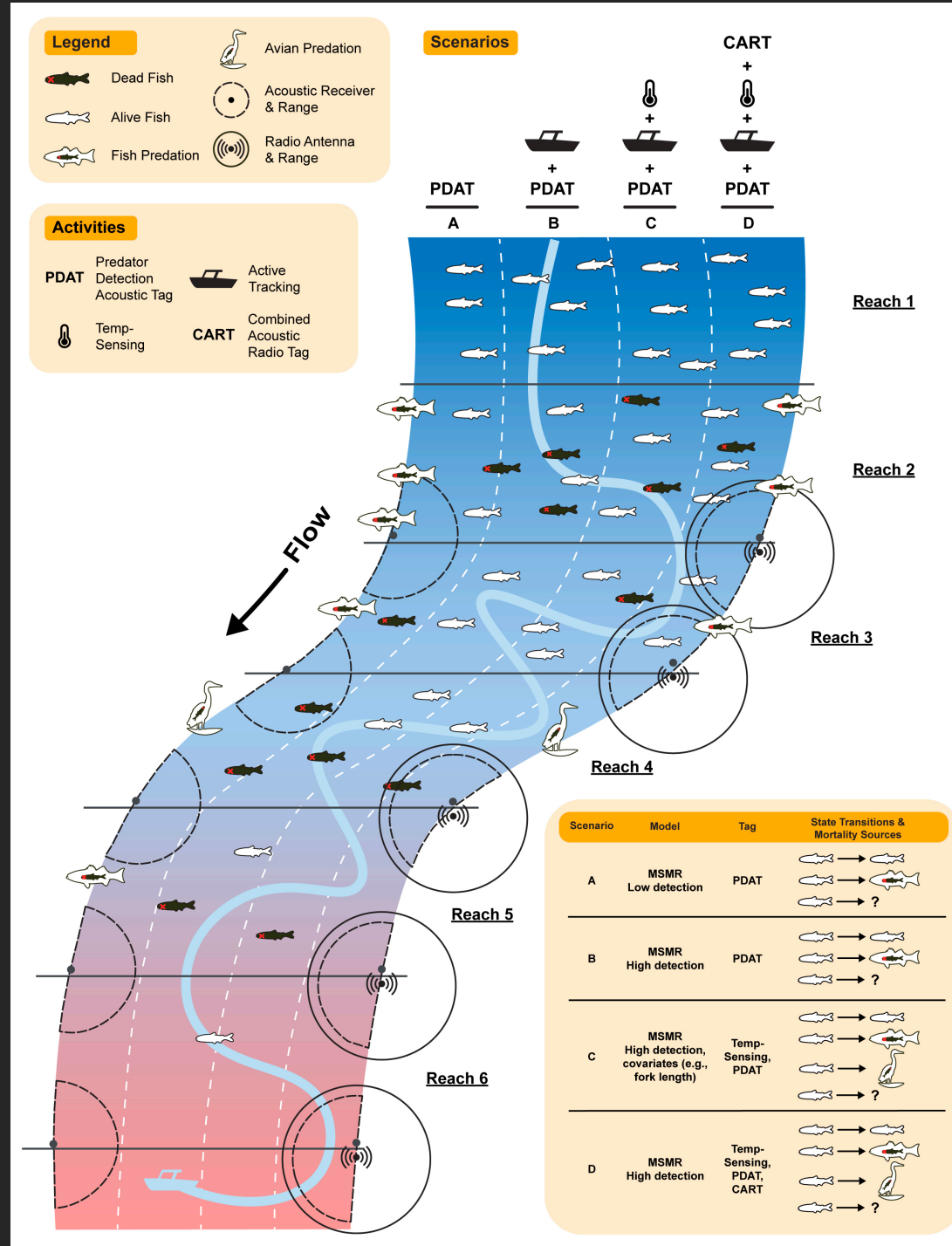
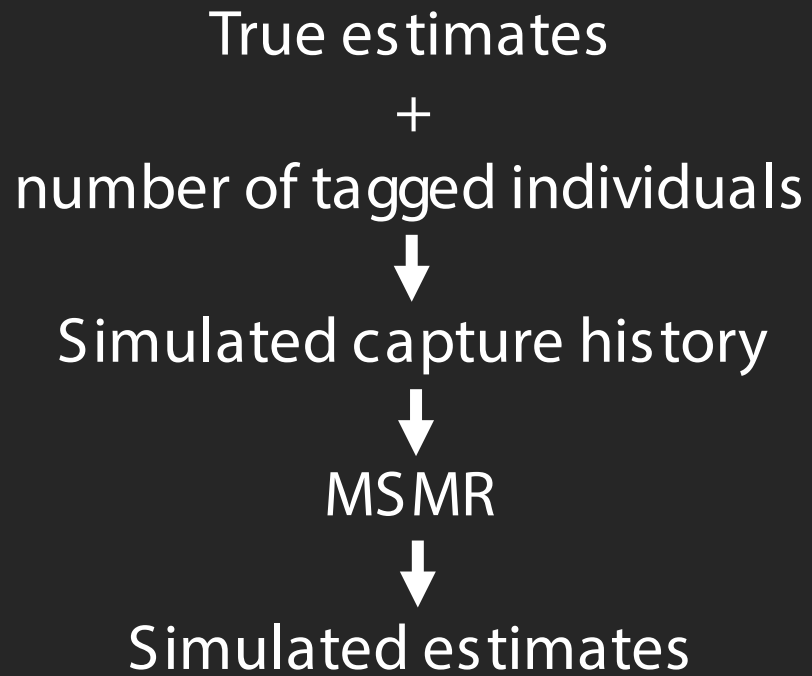
## Telemetry-based study designs

- Scenario A: low detection probability ( $p$ ) (passive-only;  $p = 0.65$ )
  - survival ( $S$ ), predation mortality ( $P$ ), unknown mortality ( $M$ )
- Scenario B: high detection probability (active & passive,  $p = 0.90$ )
  - adding high  $P$  scenario
- Scenario C: Scenario B + covariates with high  $p$  ( $p=0.90$ )
  - adding low  $p$  scenario
- Scenario D: high detection probability ( $p = 0.90$ ), added model state
  - $S, M, P_f, P_a$



# Obj 1: CH structure + flow

- columns = "reaches"
- rows = number of tagged individuals
  - n = 50, 100, 150, 500, 1000

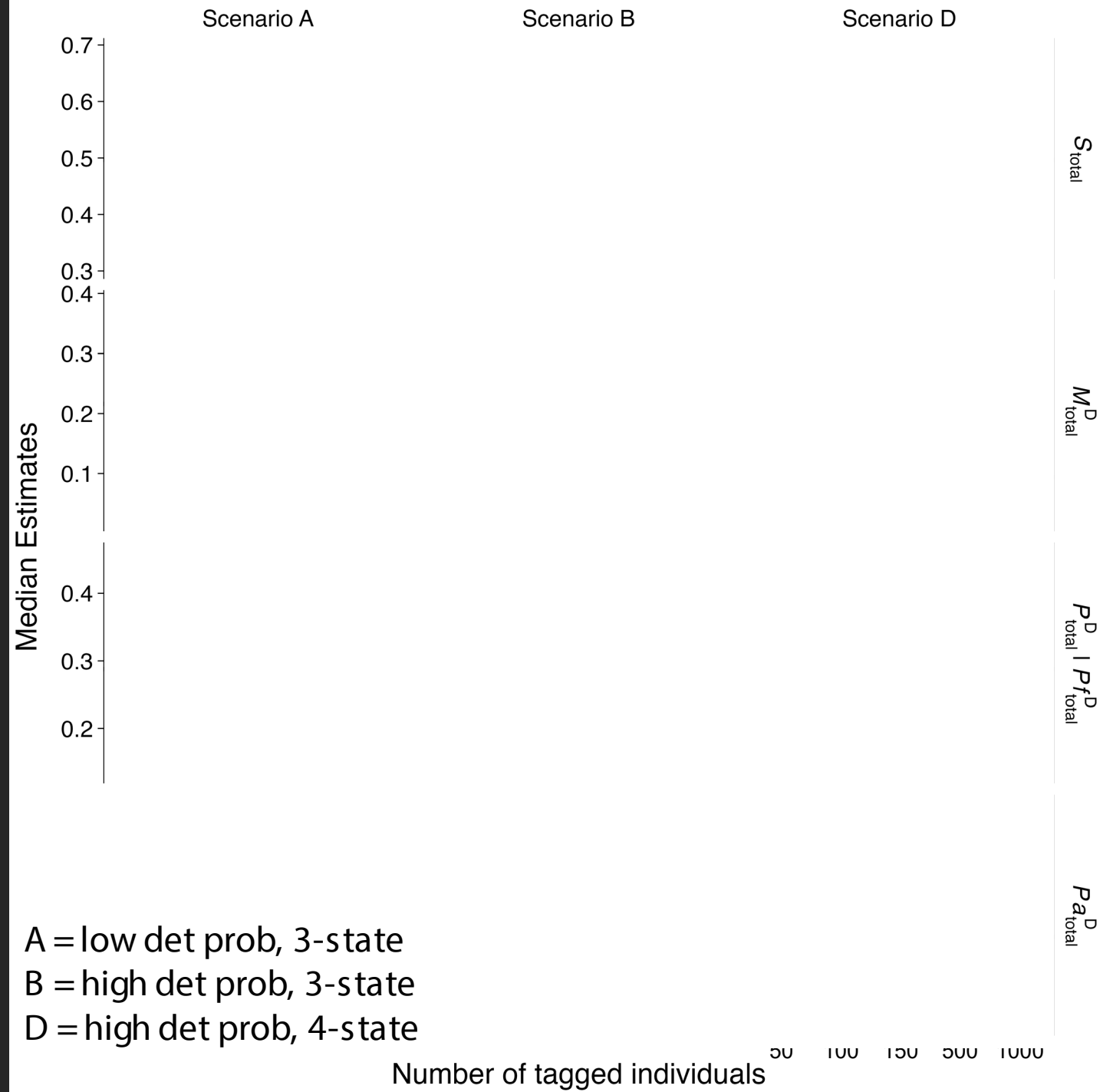


# Obj 1: Overall ests

- increasing tagging effort may be more effective than increasing detection probability
- M estimate improved with added state

Cost-benefit of increased fish tagging vs increased receiver effort

Plot: Median estimate distribution for all reaches; black line = true estimate

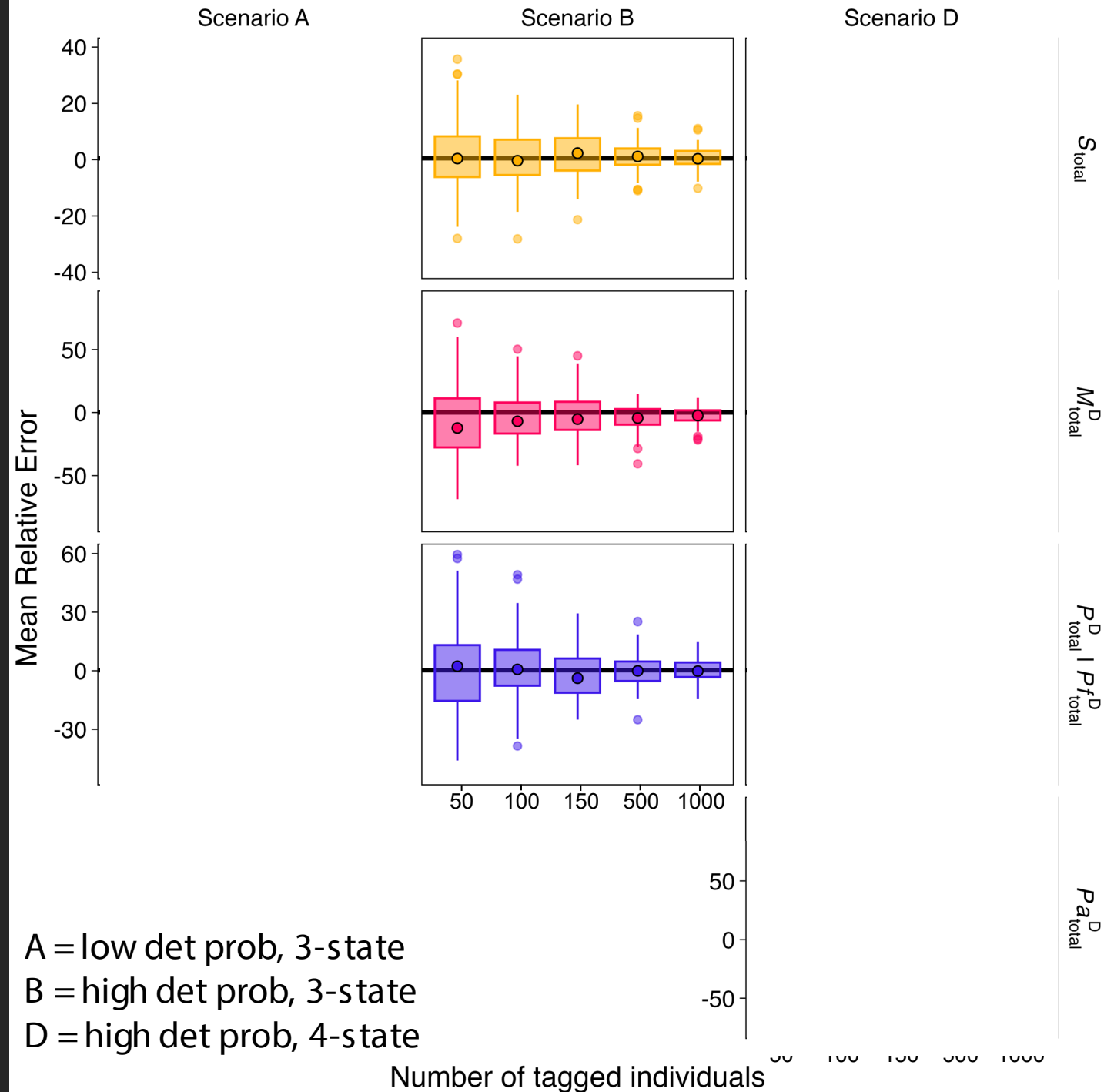


# Obj 1: Overall MRE

$$\text{MRE} = \frac{(\text{Simulated Estimate} - \text{True Estimate})}{\text{True Estimate}}$$

- MRE decreases as tagging effort increases
- MRE for  $M$  with added state wider spread under low tagging effort
  - despite smaller spread for median estimates

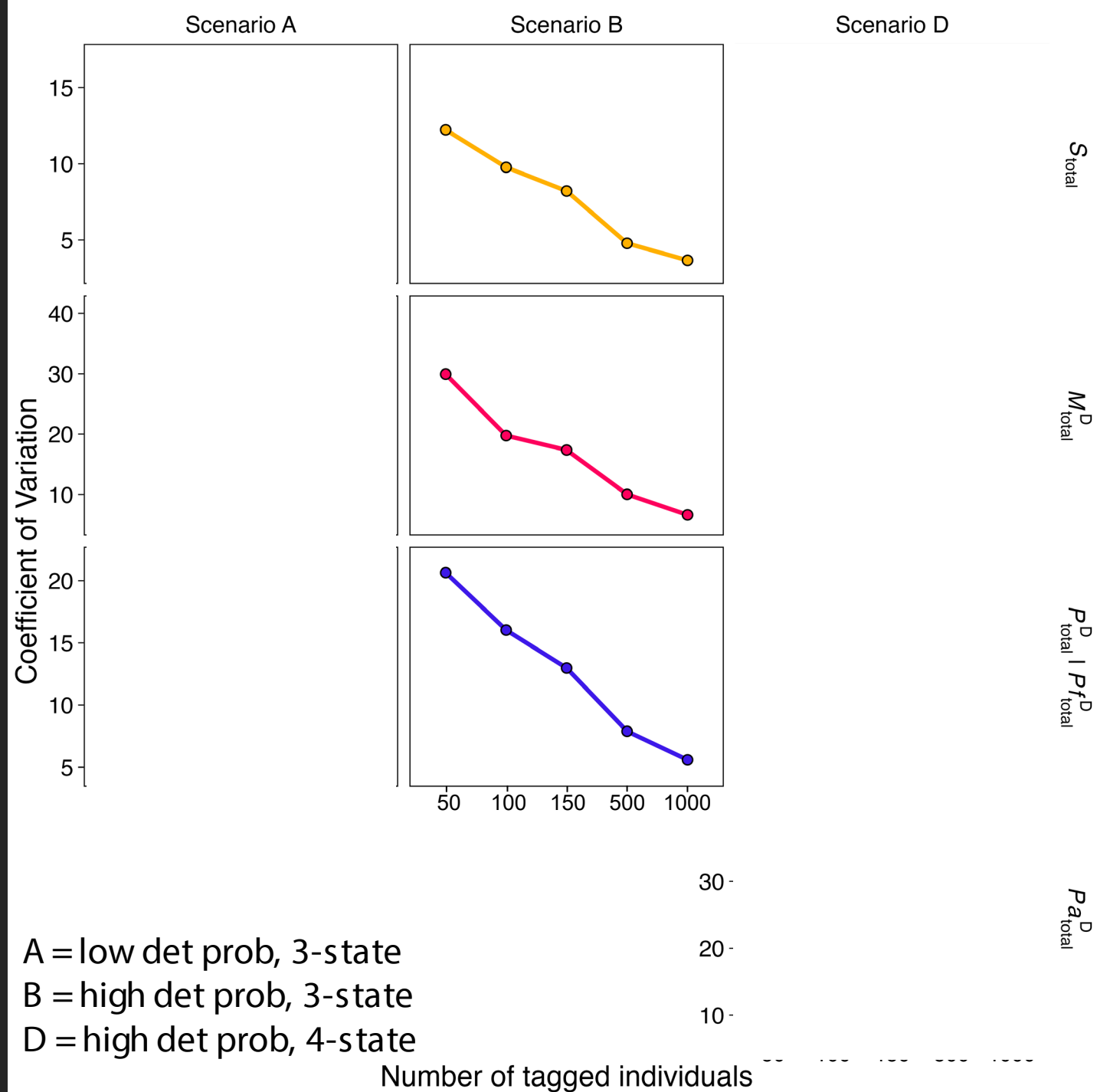
Plot: Mean relative error across all scenarios for all reaches; MRE = 0 is no error



# Obj 1: Overall CV

$$CV = \frac{sd_{estimate}}{mean_{estimate}}$$

- CV decreases as tagging effort increases
- S has lower CV (<20)
- unobserved state (M) has highest CV, especially with added state



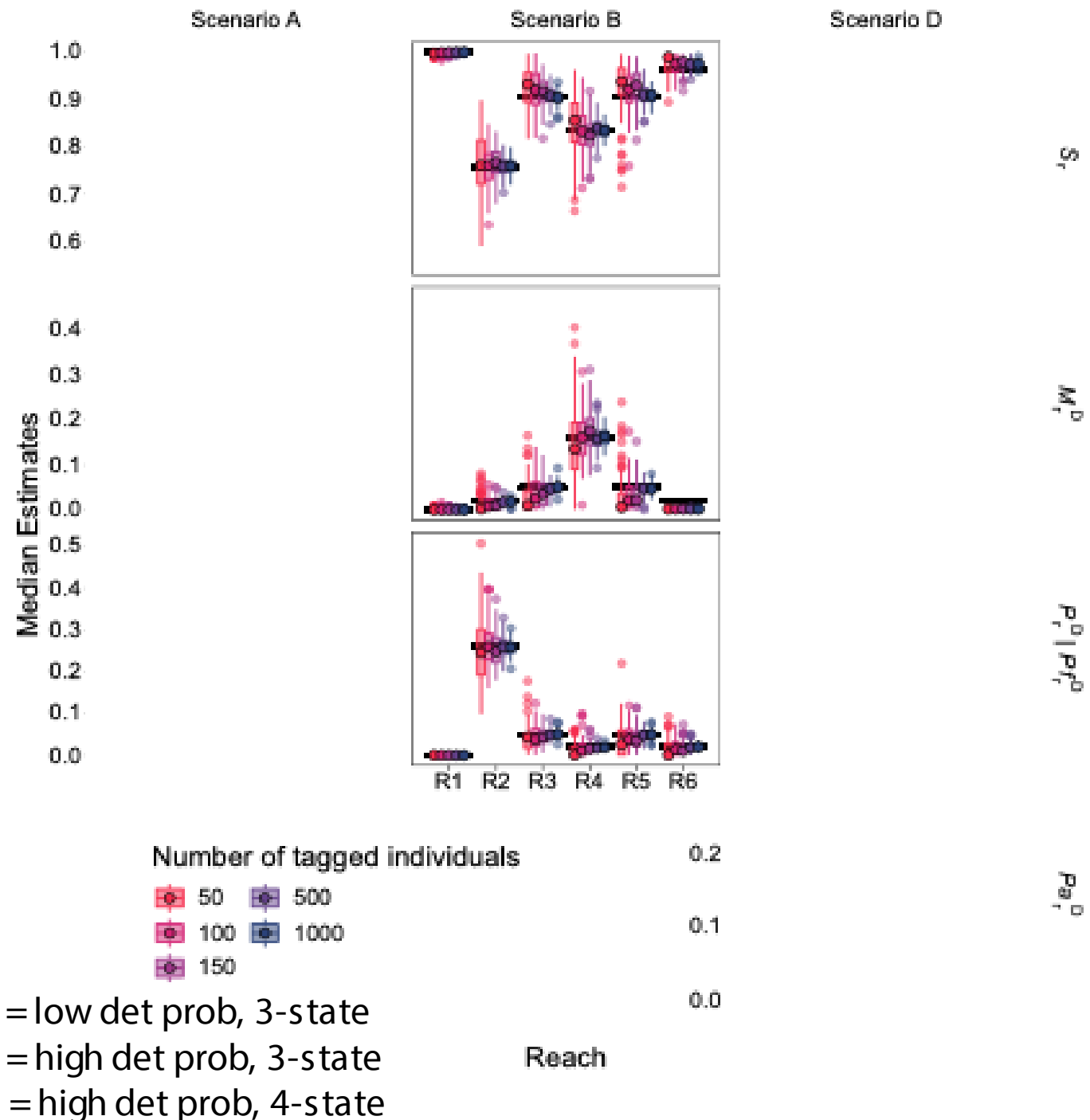
Plot: Coefficient of variation across all scenarios for all reaches

# Obj 1: R-specific ests

- reach-specific median estimates wider error under low tagging effort
  - R2 – high P
  - R4 – high M
- especially when the estimates are low
  - apparent with added state

Increasing tagging effort is important if reach-specific estimates are needed

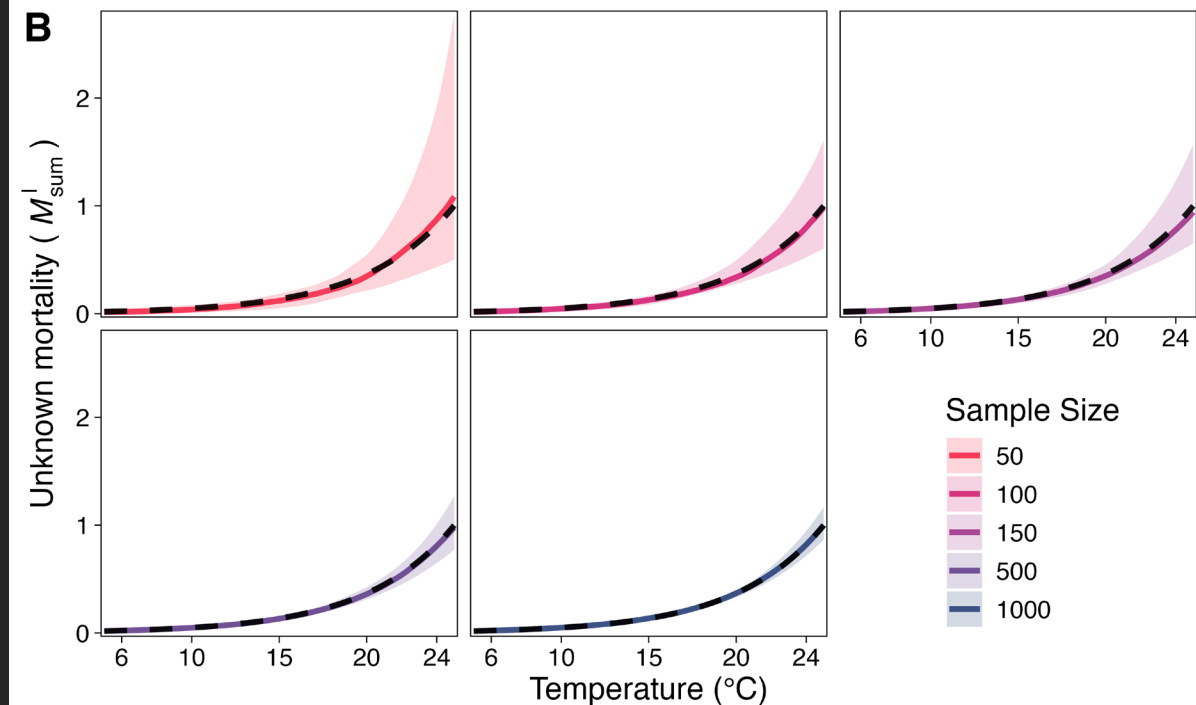
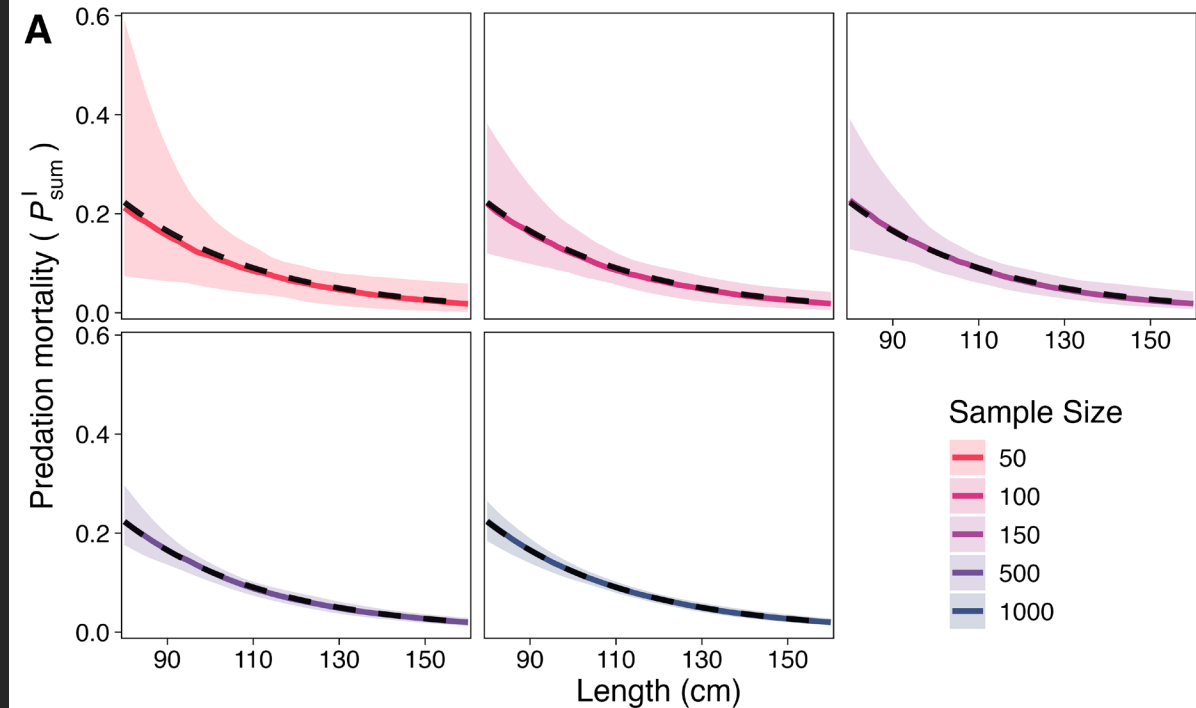
Plot: Reach-specific median estimate distributions



# Obj 1: Covariates

- median estimates matched true relationship
- error decreased as tagging effort increased
  - higher tagging effort required ( $n \geq 500$ )

Plot: True covariate relationship (black, dashed line) and predicted median relationship (line = q50, area = q2.5 and q97.5) across all tagging efforts.



# Objectives

2. Simulating multistate models that assess habitat use and survival of emigrating salmonids that use restoration areas

- main-stem versus restored
- survival benefits of using restored area
  - survival in main-stem for non-restoration versus restoration fish
- component mortality of main-stem versus restoration
  - fish predation

# Obj 2: Simulating MSMRs

## Telemetry-based study designs






### Scenario A: main-stem versus restored

- State transitions monitored:
  - 1 → 1 main stem survival
  - 1 → 2 transition to restoration area
  - 1 → 3 main stem emigration (survival)
  - 1 → 4 main stem mortality
  - 2 → 2 restoration survival
  - 2 → 3 restoration emigration (survival)
  - 2 → 4 restoration mortality

### Parameters

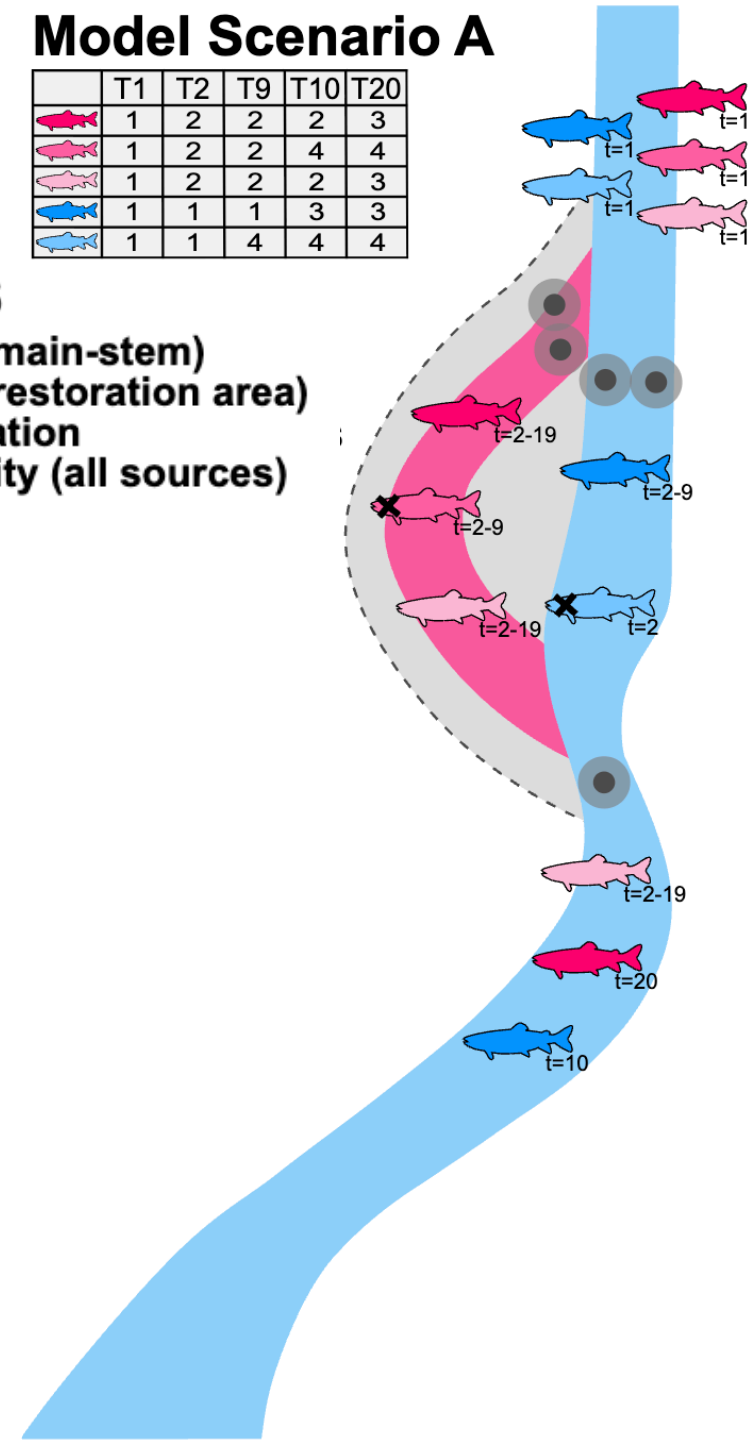
- 20 days monitored
  - 5-10 days in main-stem
  - 10-20 days in restoration area
- 10, 30, and 50% of fish transition to restored area
- 10, 30, and 50% of fish die in main-stem
- 10, 20, and 40% of fish die in restored area

## Model Scenario A

	T1	T2	T9	T10	T20
	1	2	2	2	3
	1	2	2	4	4
	1	2	2	2	3
	1	1	1	3	3
	1	1	4	4	4

## STATES

- 1 = Alive (main-stem)
- 2 = Alive (restoration area)
- 3 = Emigration
- 4 = Mortality (all sources)








# Obj 2: Simulating MSMRs

## Telemetry-based study designs

- Scenario A: main-stem versus restored
- Scenario B: survival benefits of using restored area
  - A + 40 days monitored (10-40 days in restoration area)

## Model Scenario B

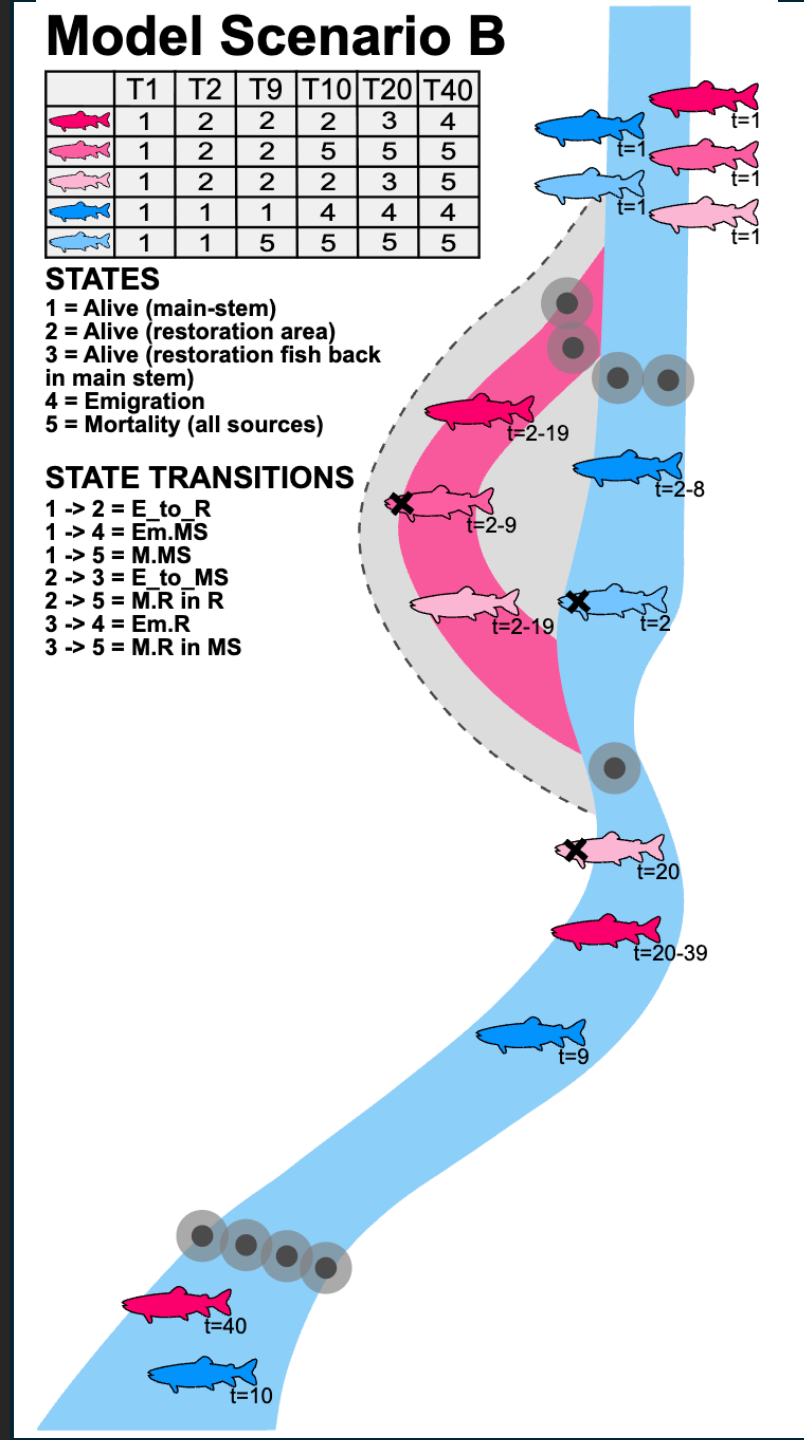
	T1	T2	T9	T10	T20	T40
	1	2	2	2	3	4
	1	2	2	5	5	5
	1	2	2	2	3	5
	1	1	1	4	4	4
	1	1	5	5	5	5

### STATES

- 1 = Alive (main-stem)
- 2 = Alive (restoration area)
- 3 = Alive (restoration fish back in main stem)
- 4 = Emigration
- 5 = Mortality (all sources)

### STATE TRANSITIONS

- 1 → 2 = E\_to\_R
- 1 → 4 = Em\_MS
- 1 → 5 = M\_MS
- 2 → 3 = E\_to\_MS
- 2 → 5 = M\_R in R
- 3 → 4 = Em\_R
- 3 → 5 = M\_R in MS




# Obj 2: Simulating MSMRs

## Telemetry-based study designs

- Scenario A: main-stem versus restored
- Scenario B: survival benefits of using restored area
  - A + 40 days monitored (10-40 days in restoration area)
- Scenario C: component mortality of main-stem versus restoration
  - B + fish predation versus other mortality

## Model Scenario C

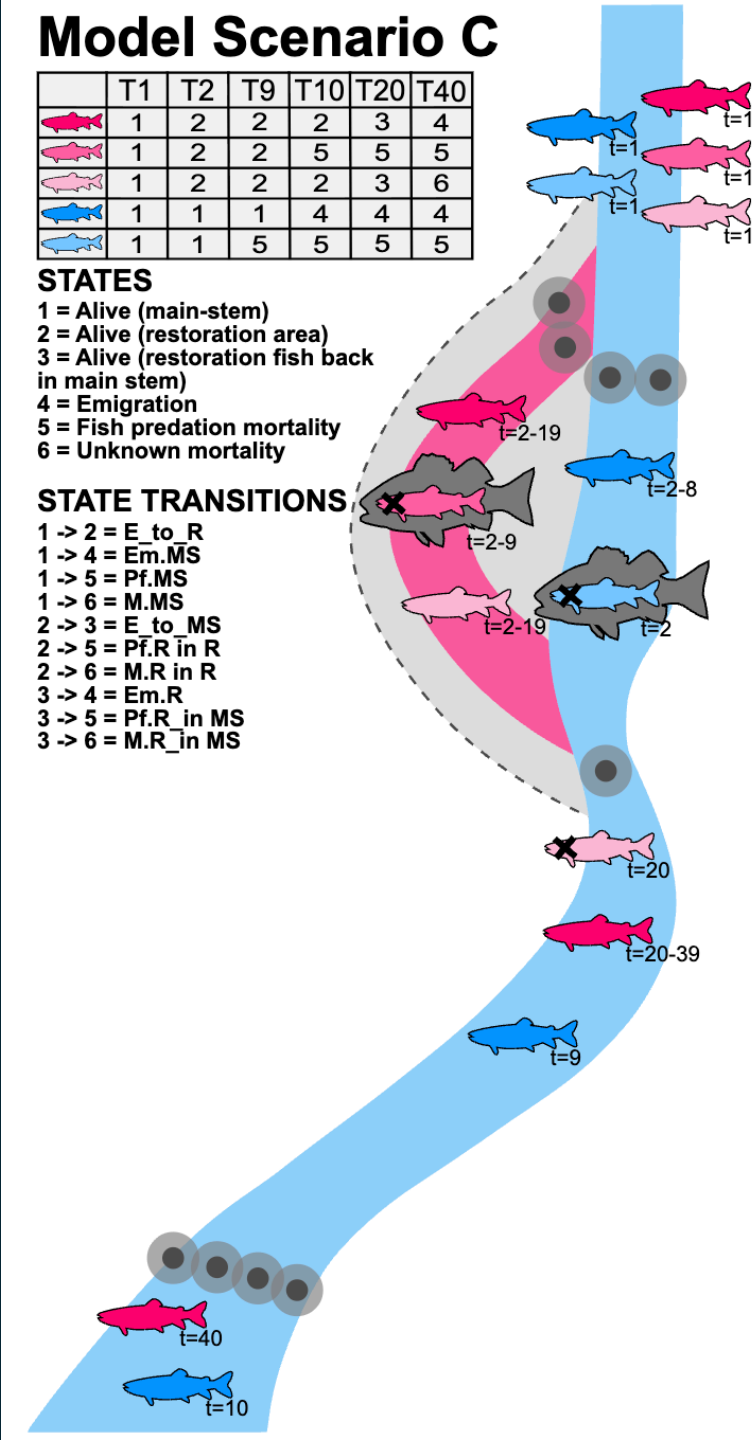
	T1	T2	T9	T10	T20	T40
	1	2	2	2	3	4
	1	2	2	5	5	5
	1	2	2	2	3	6
	1	1	1	4	4	4
	1	1	5	5	5	5

### STATES

- 1 = Alive (main-stem)
- 2 = Alive (restoration area)
- 3 = Alive (restoration fish back in main stem)
- 4 = Emigration
- 5 = Fish predation mortality
- 6 = Unknown mortality

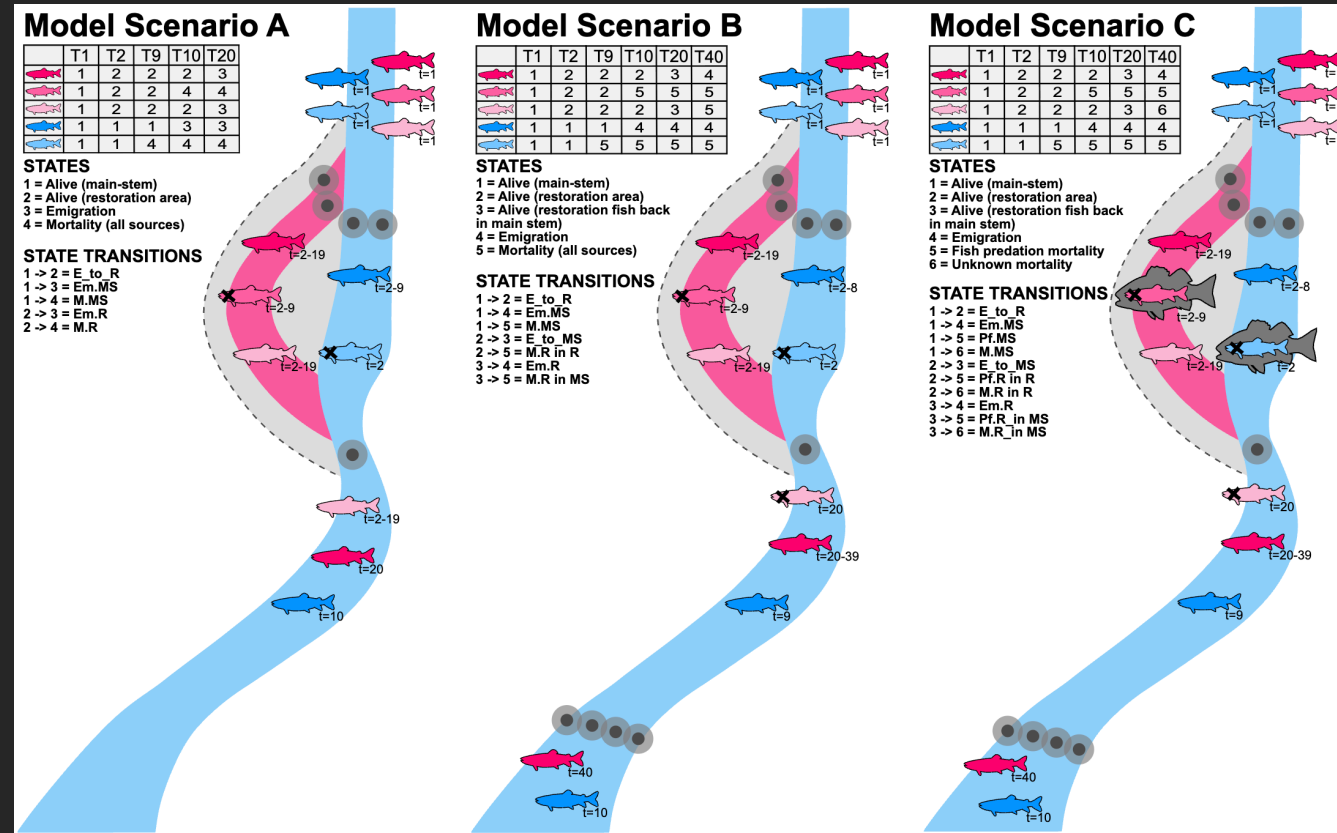
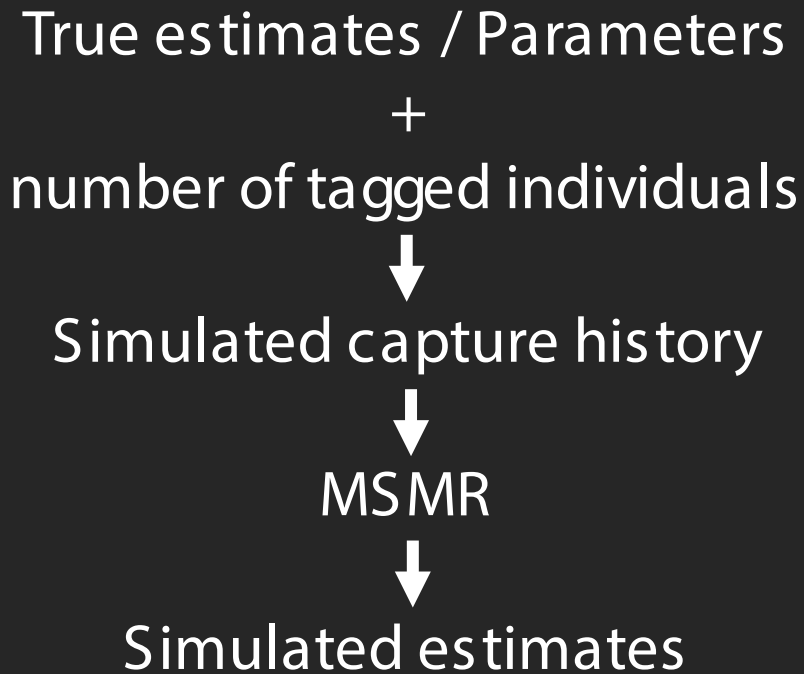
### STATE TRANSITIONS

- 1 → 2 = E\_to\_R
- 1 → 4 = Em\_MS
- 1 → 5 = Pf\_MS
- 1 → 6 = M\_MS
- 2 → 3 = E\_to\_MS
- 2 → 5 = Pf\_R\_in\_R
- 2 → 6 = M\_R\_in\_R
- 3 → 4 = Em\_R
- 3 → 5 = Pf\_R\_in\_MS
- 3 → 6 = M\_R\_in\_MS



# Obj 2: CH structure + flow

- columns = "days"
- rows = number of individuals
- $n = 50, 100, 150, 500$



# Implications/Future directions

- Realistic study design scenarios and model code
- Can be used by resource managers when designing projects
- Increase the likelihood of achieving desired precision while considering costs
  - tag versus receiver effort trade-off
  - manual tracking effort considerations
- Informed data collection

## Future directions:

- finish Objective 2 – focus on restored areas

## Appendix S1

**Model Scenario 1: Low detection probability (only passive acoustic telemetry array); three-state and three-observation multistate mark-recapture model (MSMR)**

### Section 1: Creating the simulation data

This code constructs the simulated capture histories and provides model code for a three-observation, three-state multistate mark-recapture model. Researchers interested in simulating data should modify the below code to fit their research needs starting at Section 1: Creating the simulation data. Researchers that have already collected empirical data and are looking to analyze it should load their capture histories and modify the model code from Section 2: Three-observation three-state capture-recapture model.

The capture history (CH) consists of reaches (columns) and individuals (rows), with each column indicating the fate (state) of a fish by the end of a reach (see Figure 1). The CH consists of 7 columns, including the release site where all fish are assumed alive (column 1) and reaches R1-R6 (columns 2 – 7) that represent river stretches separated by receiver gates (see Figure 1).

These simulations vary the number of individuals (rows) within the study to illustrate the effects of increasing sample size on model estimates, relative error, and the coefficient of variation. In this example code, we will run models across five sample sizes: 50, 100, 150, 500, and 1000 individuals.

```
16 # Defining our number of reaches (columns; mortality estimate
17 # periods)
18 n.reach <- 6
19 n.reach.obs <- n.reach + 1 # Defining our number of observations
20
21 # Defining our number of individuals to be modeled
22 ind_sims <- c(50, 100, 150, 500, 1000) # our individual scenarios
23 nind_sims <- as.numeric(length(ind_sims)) # the number of individual scenarios
```

### Setting up our state process

For this model, we set total (sum across all reaches) discrete survival (S\_D) at roughly 0.5 (50%), with 0.288 total discrete predation mortality (P\_D) and 0.216 total discrete unknown mortality (M\_D). We provide known reach-specific values of instantaneous predation (P) and unknown mortality (M), which are used to estimate the state transition probabilities from each reach to the next. These transition probabilities produce the true reach-specific state of each fish, with all fish known alive at release (R1). The total number of elements in reach-specific estimates (P, M, etc.) need to equal n.reach in length; the data setup check code will identify any mismatches.

```
24 # Defining our number of model states
25 n.states <- 3
26
27 # Defining our estimates for predation mortality (P)
28
29 # Here, P is 0 in the first reach (it cannot actually be zero in
30 # the model code), reach 2 has high P, P is moderate in reaches 3
31 # and 5, and low in reaches 4 and 6.
32 P <- c(1e-05, 0.26, 0.05, 0.02, 0.05, 0.02) # instantaneous P, sum = 0.4
33
34 # Defining our estimates for unknown mortality (M)
35
```

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Questions?

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