Climate, Habitat, and Genetic Factors Influencing Salmonid Success

A Concurrent Session at the 39th Annual Salmonid Restoration Conference held in Santa Cruz, California from April 19 – 22, 2022.

- **Session Coordinators:**
  - Rachel Shea, PE, *Michael Love & Associates*

Presentations

Minimum flows to support coho smolt outmigration during drought

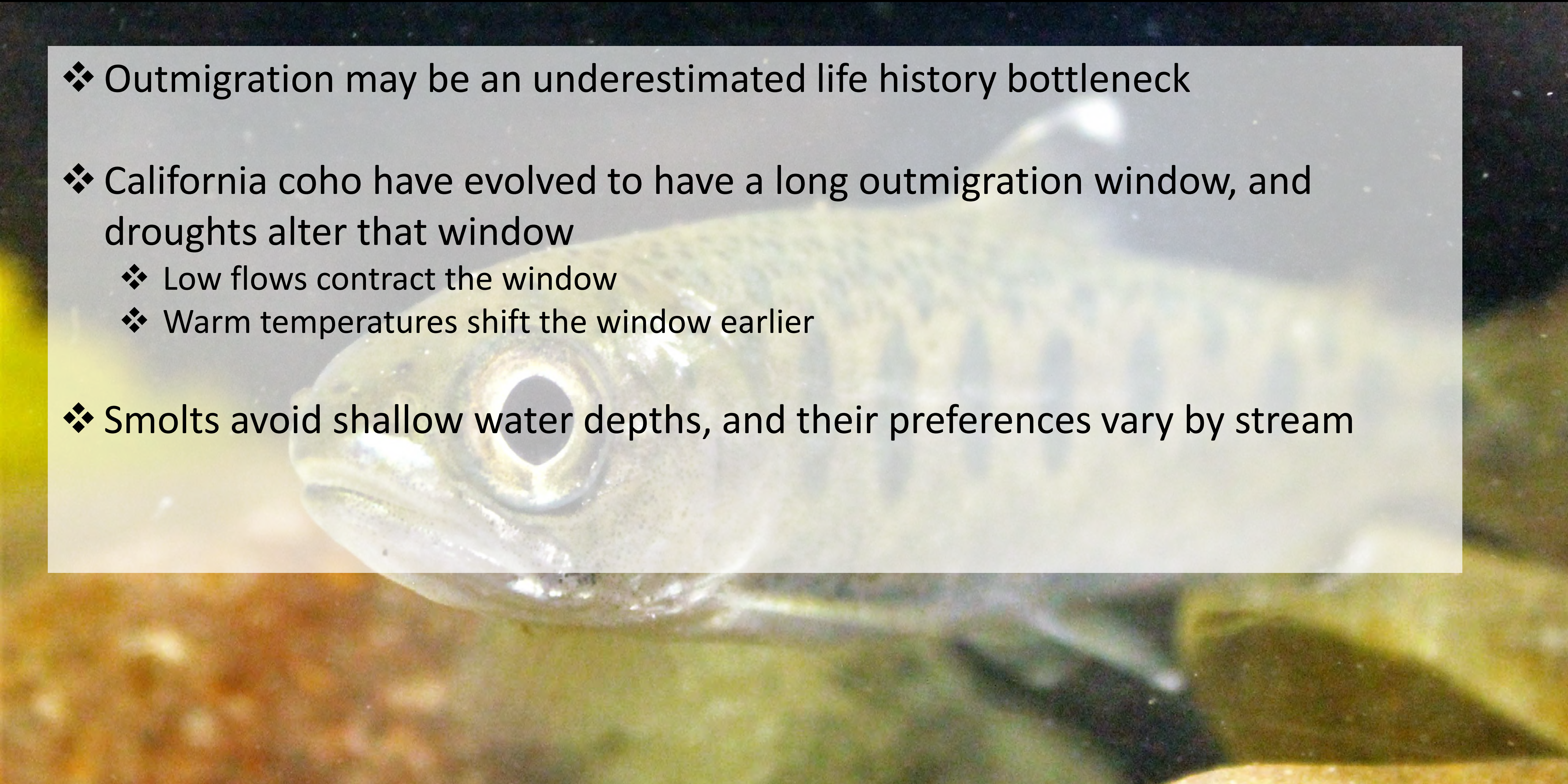
Russian River watershed, California

Brian Kastl, Mariska Obedzinski, Sarah Nossaman Pierce, Elizabeth Ruiz, Krysia Skorko, Mia van Docto, Stephanie Carlson, Will Boucher, Ted Grantham

Salmonid Restoration Federation Conference

April 22, 2022

Key messages



- Outmigration may be an underestimated life history bottleneck
- California coho have evolved to have a long outmigration window, and droughts alter that window
  - Low flows contract the window
  - Warm temperatures shift the window earlier
- Smolts avoid shallow water depths, and their preferences vary by stream

Predictors of outmigration timing

- Endogenous controls
- Environmental drivers:
  - Water temperature[1]
  - Streamflow[1, 2]
  - Lunar phase and photoperiod[1,2]
  - Gradient[3]
  - Productivity[3]

[1] Spence & Dick 2014
[2] Moyle 2002
[3] Johnson 2016

Research questions

- How do *seasonal* streamflow and water temperature affect outmigration timing?
- What are water depth *preferences*, measured at the riffle crest thalweg (RCT)?
- Do shallow water depths *prevent* outmigration?

Methods

- 7 streams located in the lower Russian River basin
  (ancestral and unceded land of the Pomo, Wappo and Miwok tribes)

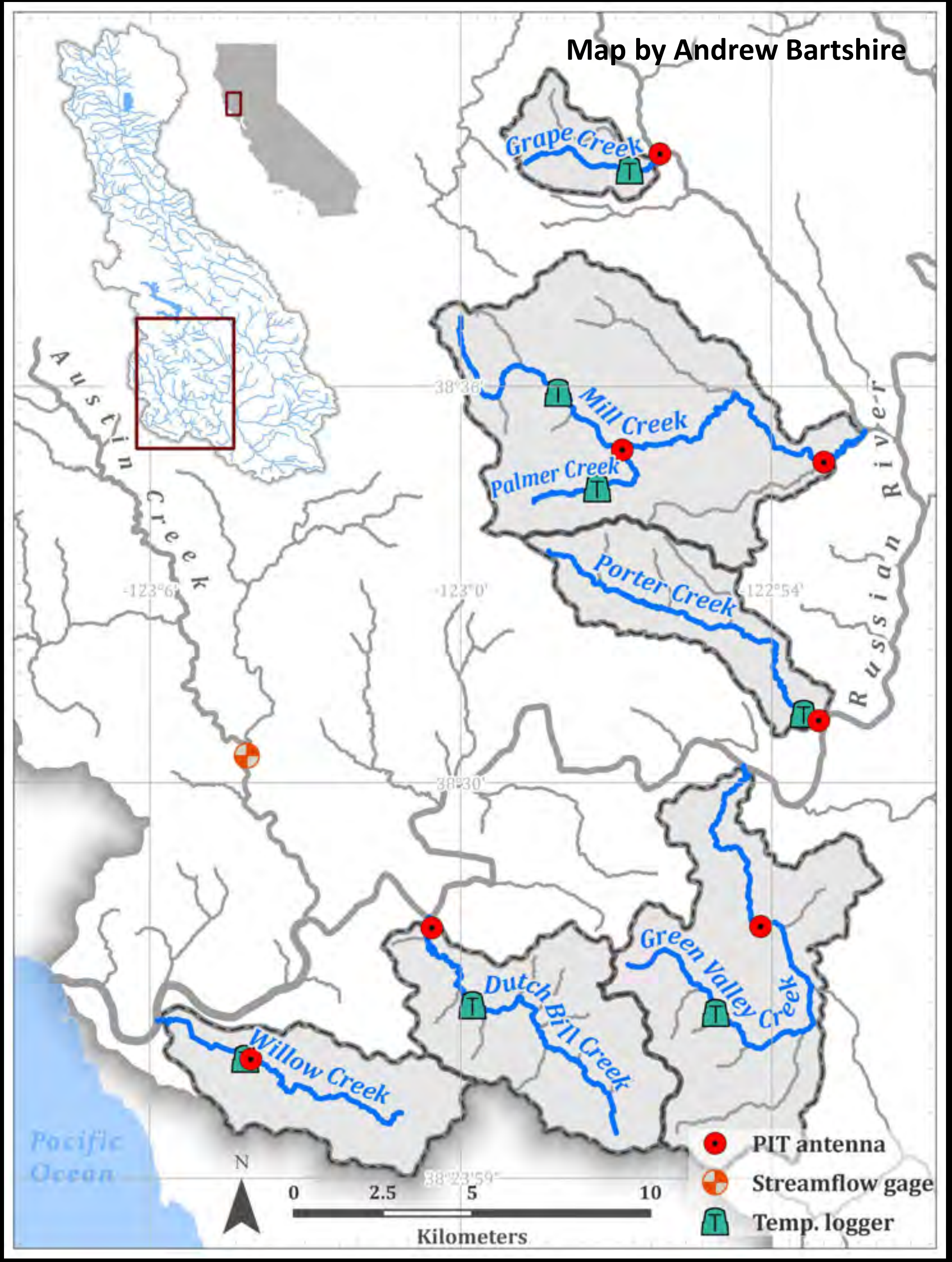
- Passive integrated transponder (PIT) tag antenna arrays, located in lower tributaries

- Outmigration season: March 1 – July 3, 2008-2020

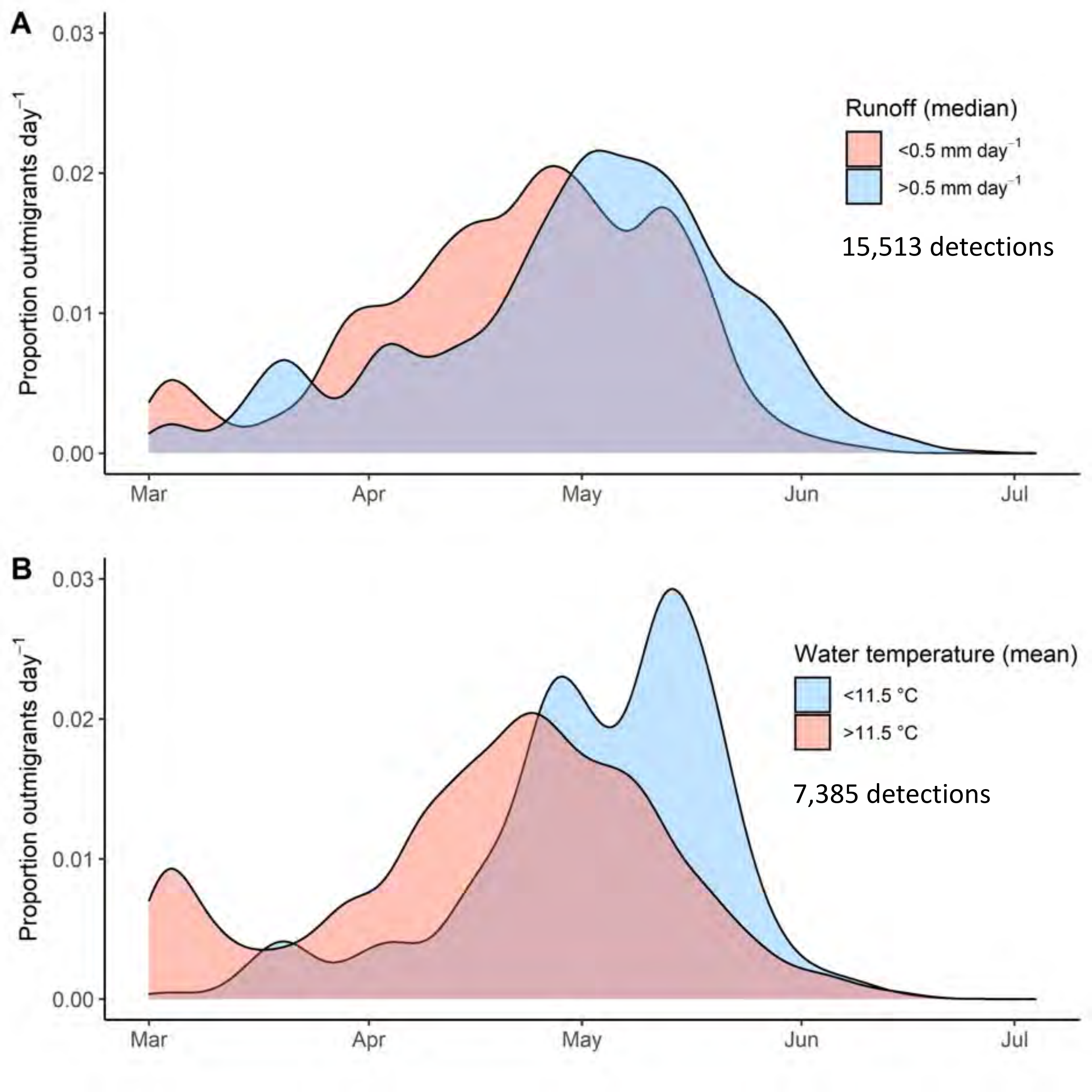
- **Outmigration duration**: 5-95% cumulative outmigration

- **Runoff**: calculated from one representative USGS gage and scaled to precipitation and drainage area

- **Degree-days**: sum of daily mean water temperature



Drought effects

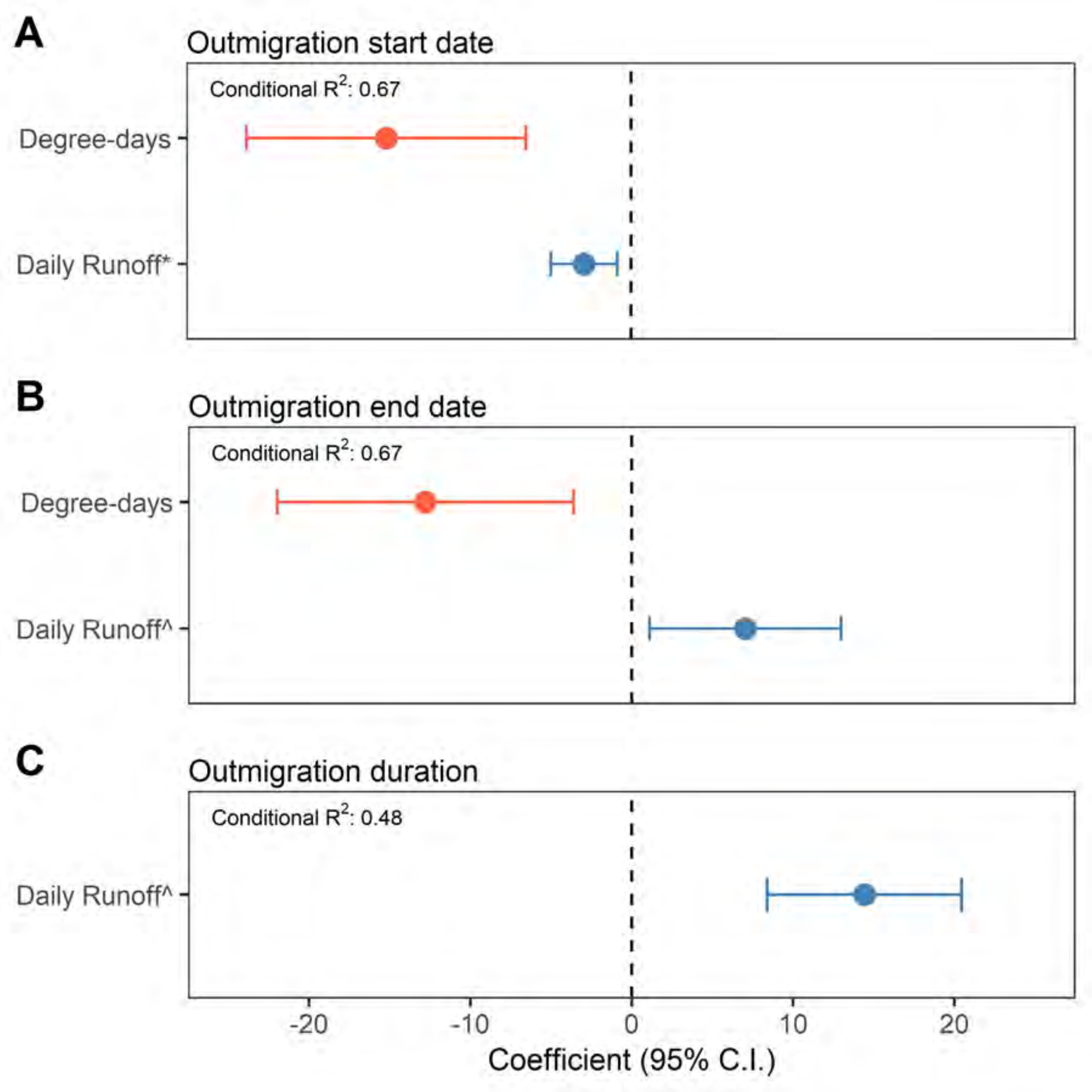


- Dry years:
  - hasten the outmigration end date
  - contract outmigration duration

- Warm years:
  - hasten the outmigration start date
  - shift the outmigration period earlier

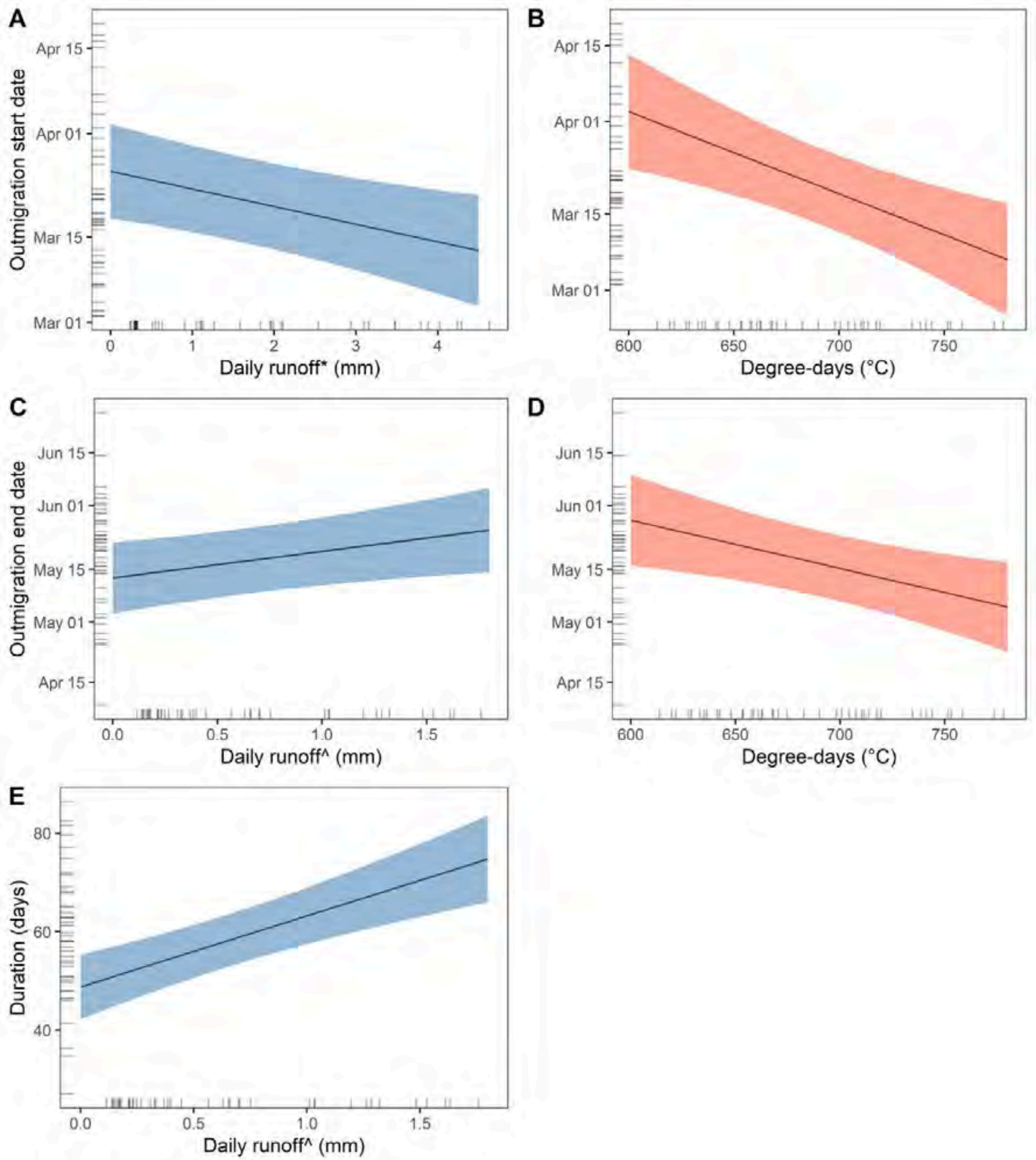
Drought effects

Top performing linear mixed effects models



- ❖ Three models attempted for each response variable
  1. Additive (degree-days & runoff)
  2. Runoff only
  3. Degree-days only
- ❖ Higher degree-days shift outmigration earlier
  - ❖ via earlier start and end dates of outmigration
- ❖ Low runoff contracts outmigration duration
  - ❖ by delaying the outmigration start and advancing the outmigration end

Drought effects



Runoff

- A decrease from **4.5 to 0.5 mm/day** March – April runoff:
  - delays the start by **12 days**

- A decrease from **1.8 to 0.2 mm/day** March – June runoff:
  - hastens the end by **11 days**
  - contracts the duration by **23 days (31% decline)**

Degree-days

- An increase in mean daily water temperatures from **10.2 to 12.8 ℃:**
  - hastens the start by **24 days**
  - hastens the end by **20 days**

Drought implications

- Low-flows may hasten end dates via:
  - barriers or deterring movement, due to increased risk of mortality from predators
  - behavioral adaptations to avoid even lower late season flows and river mouth closure

- Early outmigration end dates could lead to the outmigration of small fish, associated with low survival[1]

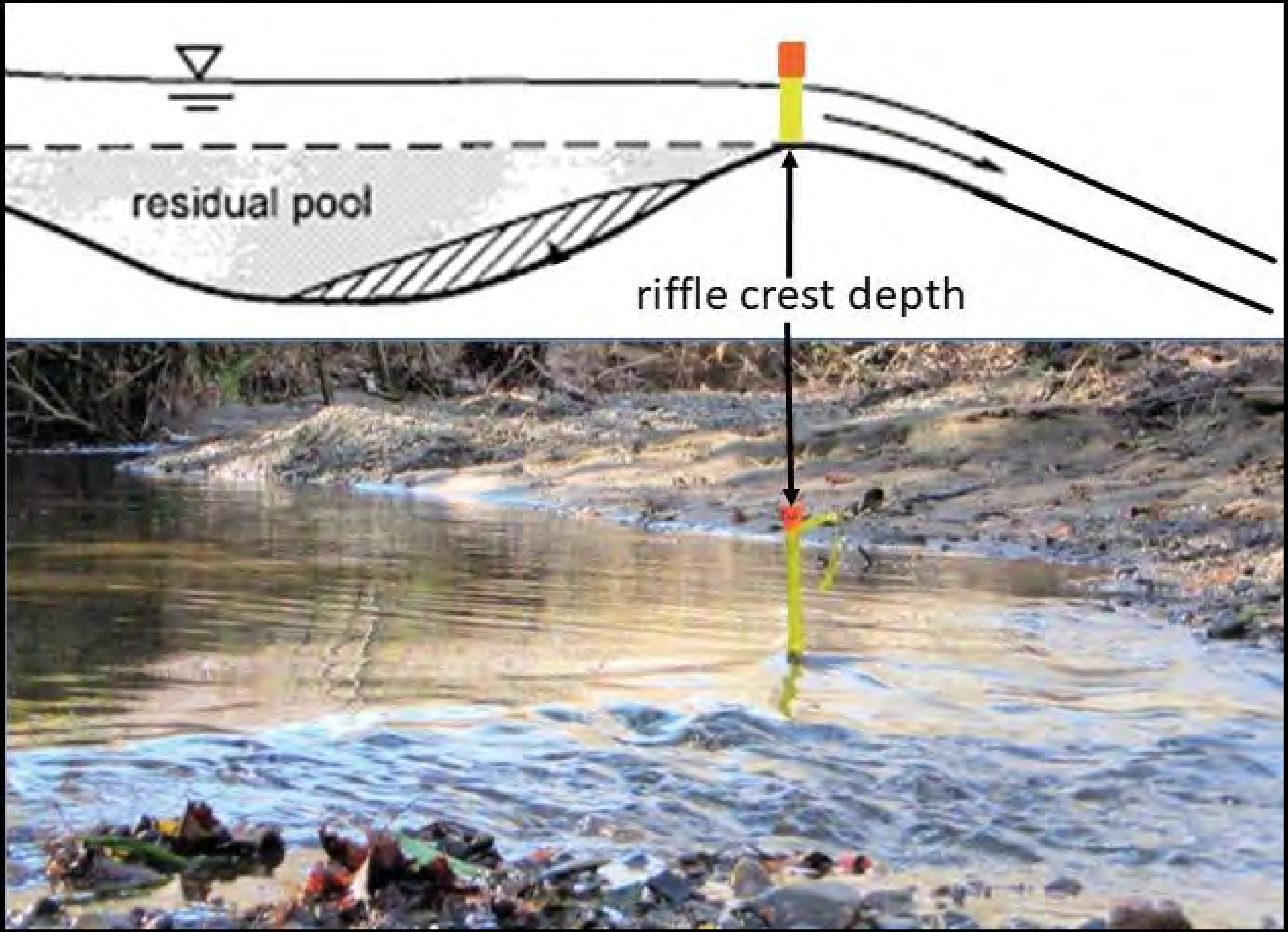
[1] Ward et al. 1989

Phenological mismatch risks

- The timing of upwelling is highly variable among years along the California coast[1]
  - St. dev. 30 days
- A long outmigration period for coho salmon in California reflects an adaptive response to this natural variability in upwelling timing[2]
- A contracted outmigration window *during drought* increases the risk of the entire population entering the ocean outside of periods of abundant food resources

[1] Ainley et al. 1995
[2] Spence and Hall 2010

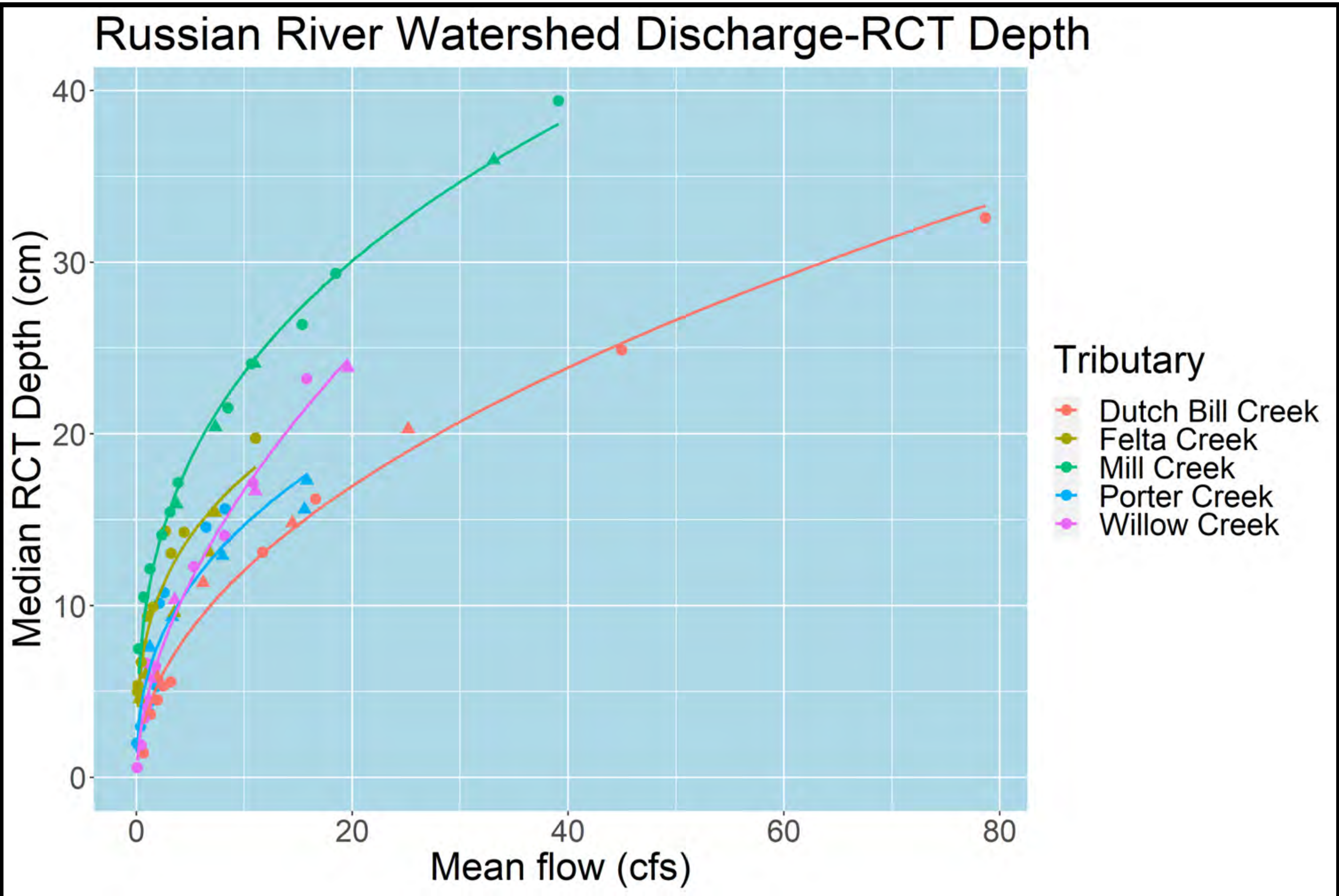
Riffle crest thalweg depth (RCTd)



- Each stream-day:
  - 12 riffle crest thalwegs (RCTs) measured per stream-day
  - 1 discharge measurement
- > 16 stream-days per stream

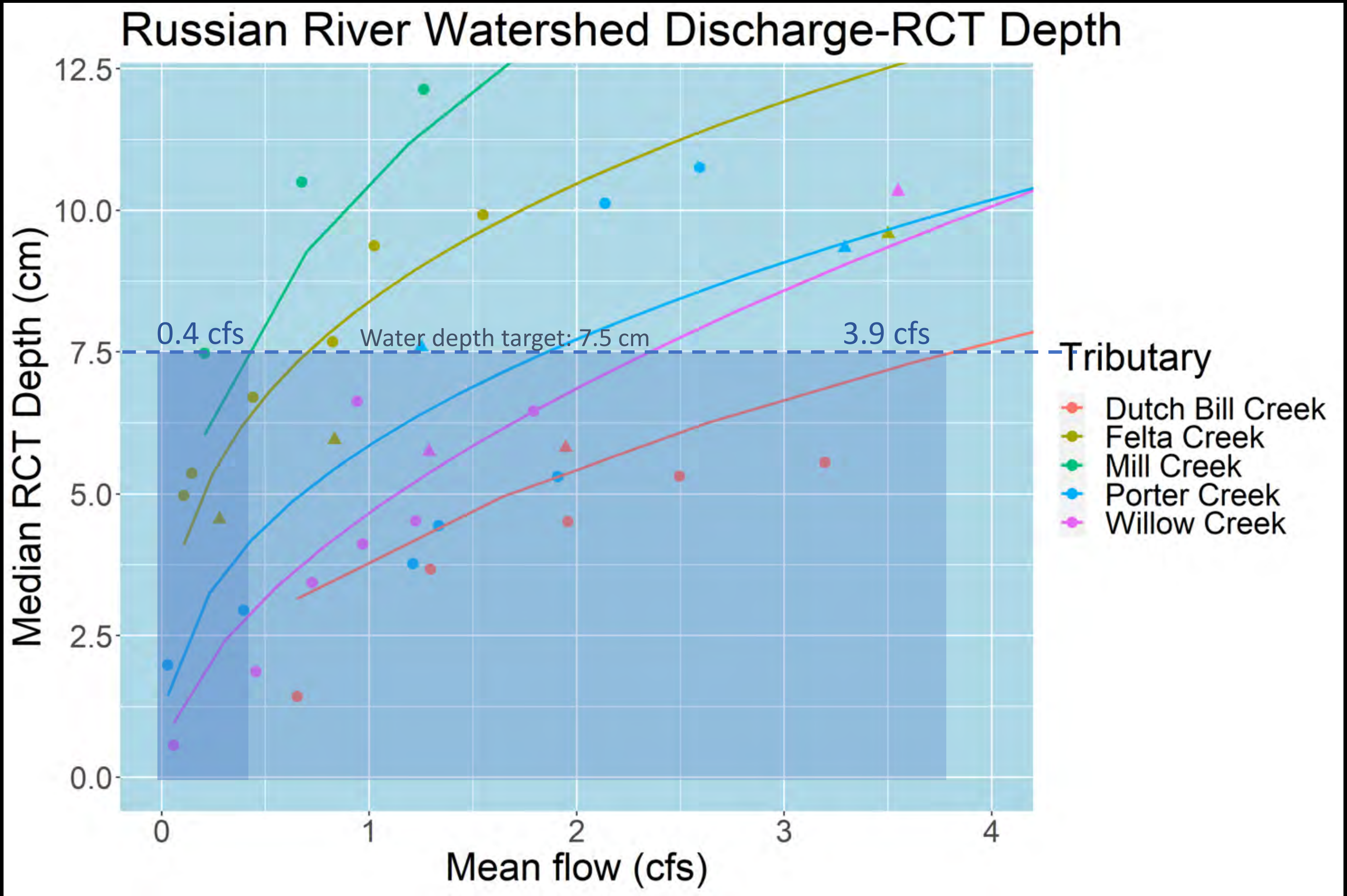
Method adapted from Rossi et al. 2021

RCTd rating curves



Flows required to reach RCT depth targets vary

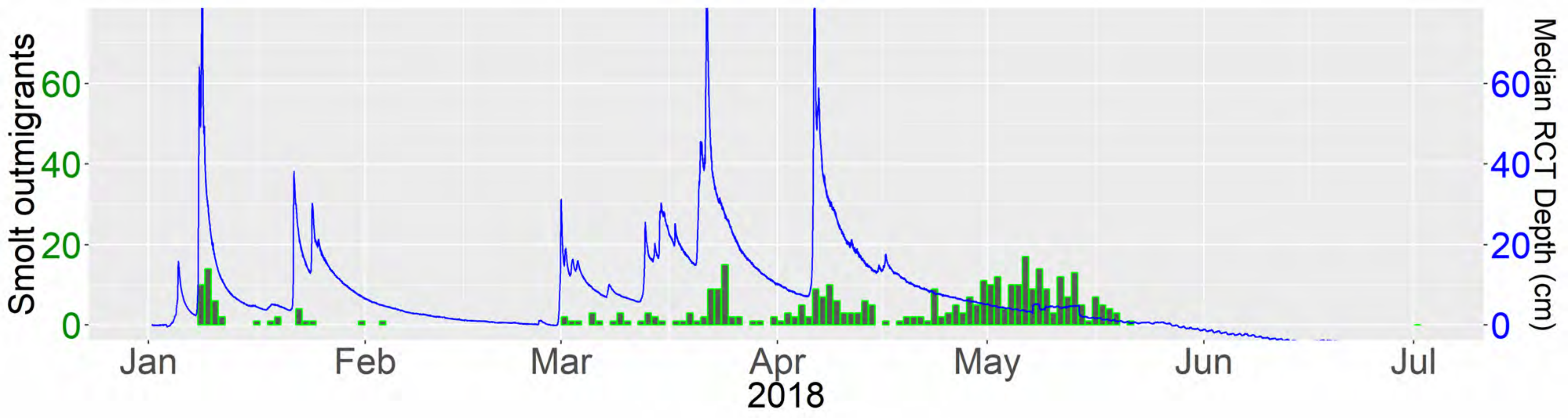
Calculate the diversion reductions/augmentation, needed to reach minimum RCTd



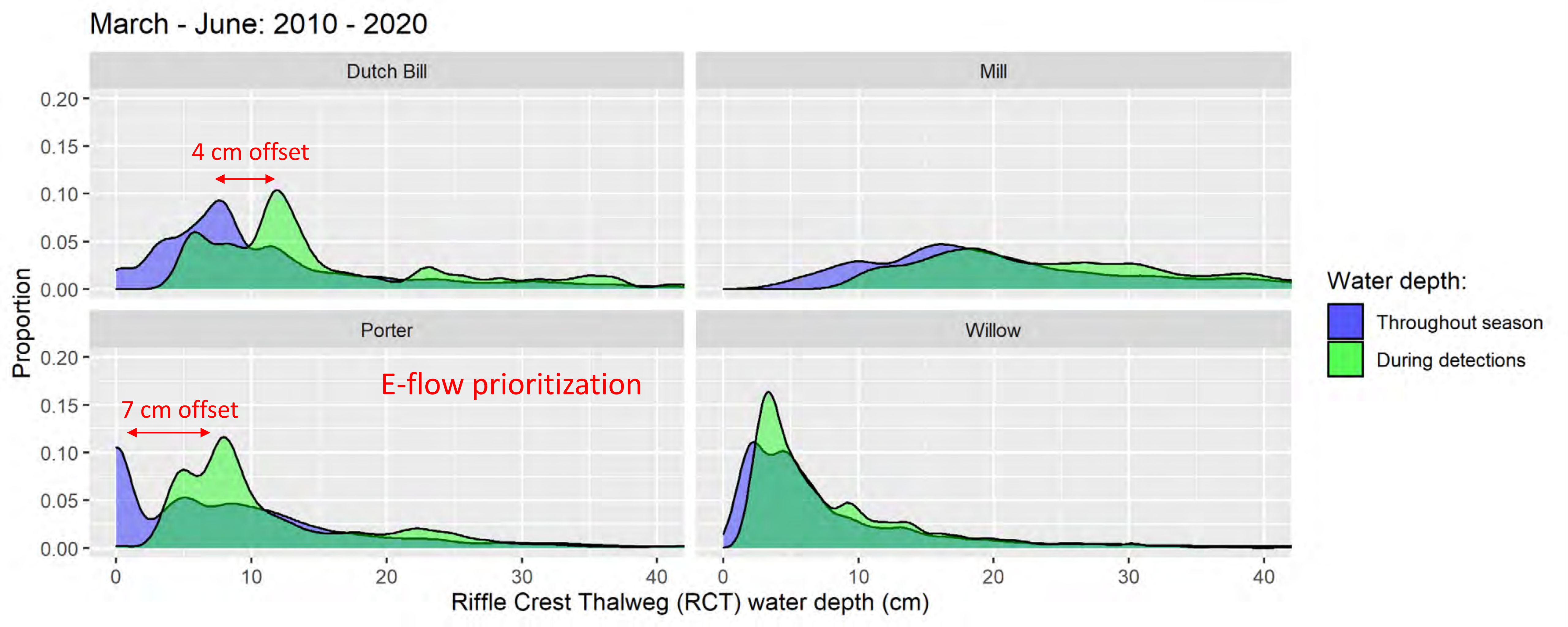
Geomorphic influence on rating curves

RCTd rating curves

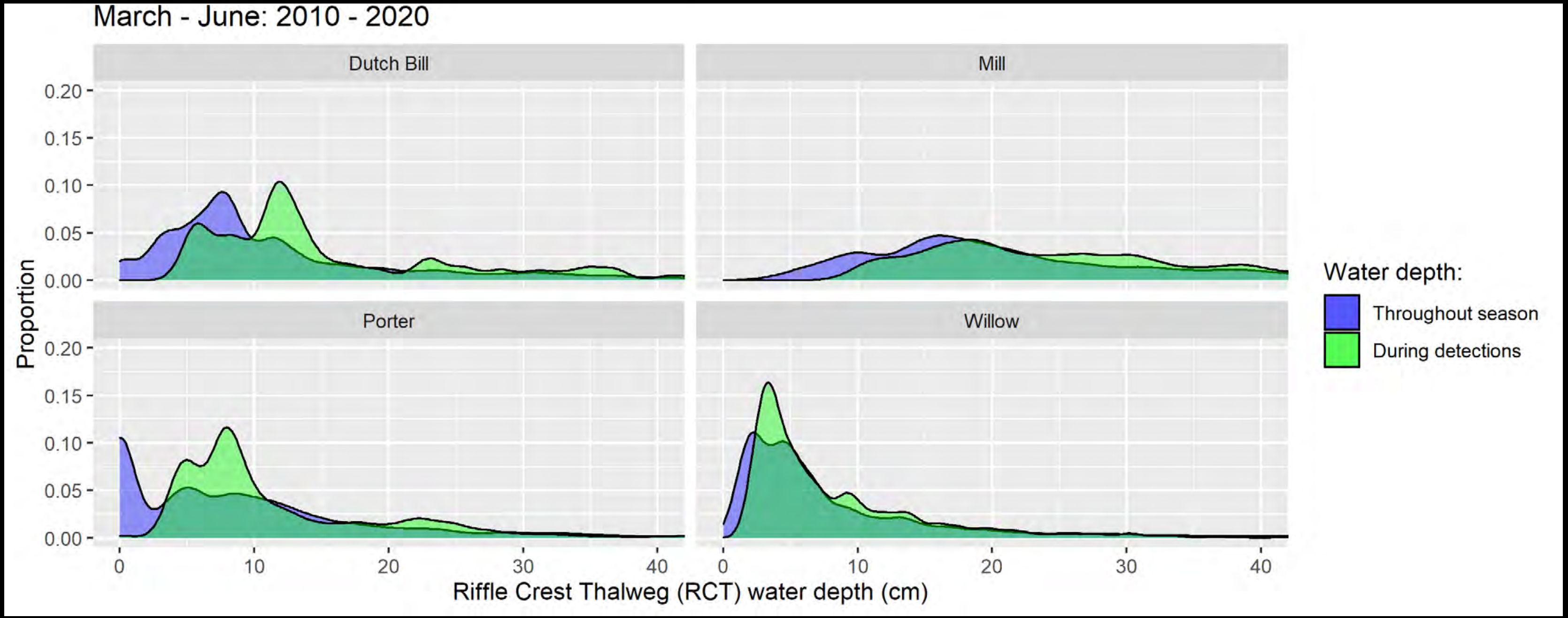
❖ Converted continuous streamflow into continuous RCTd

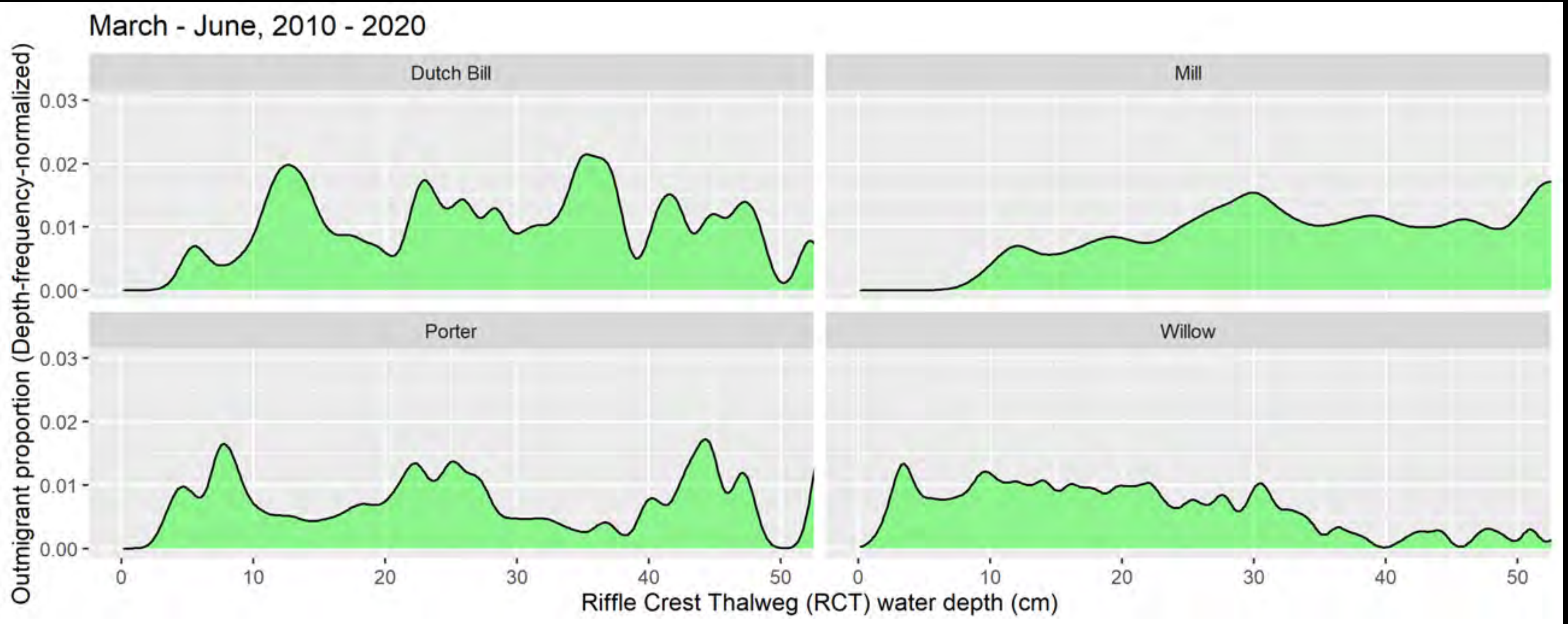


Disparities between available and used water depths



Depth preferences

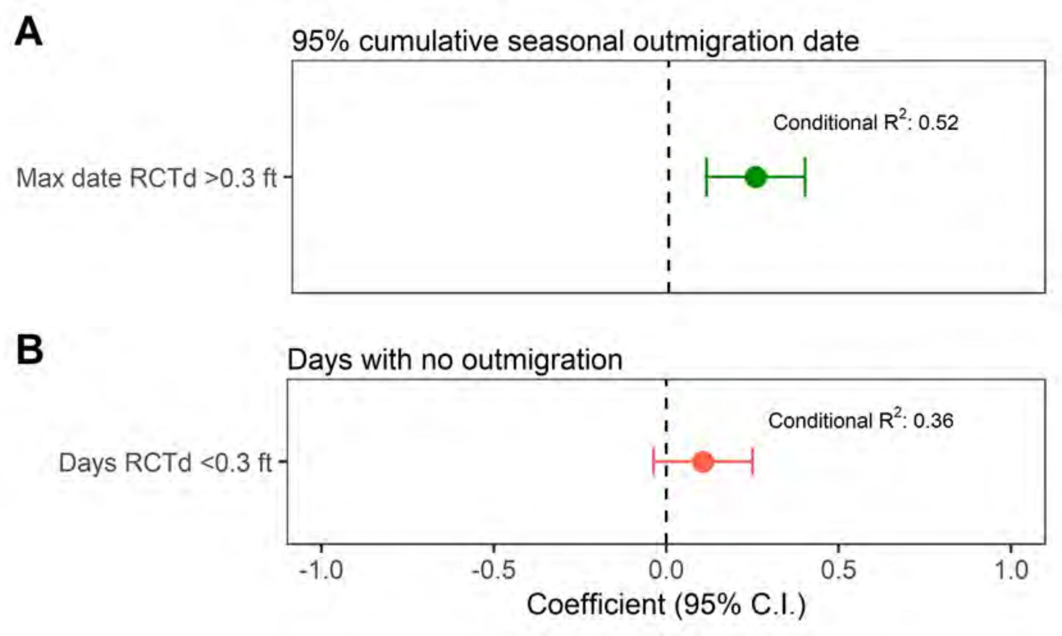


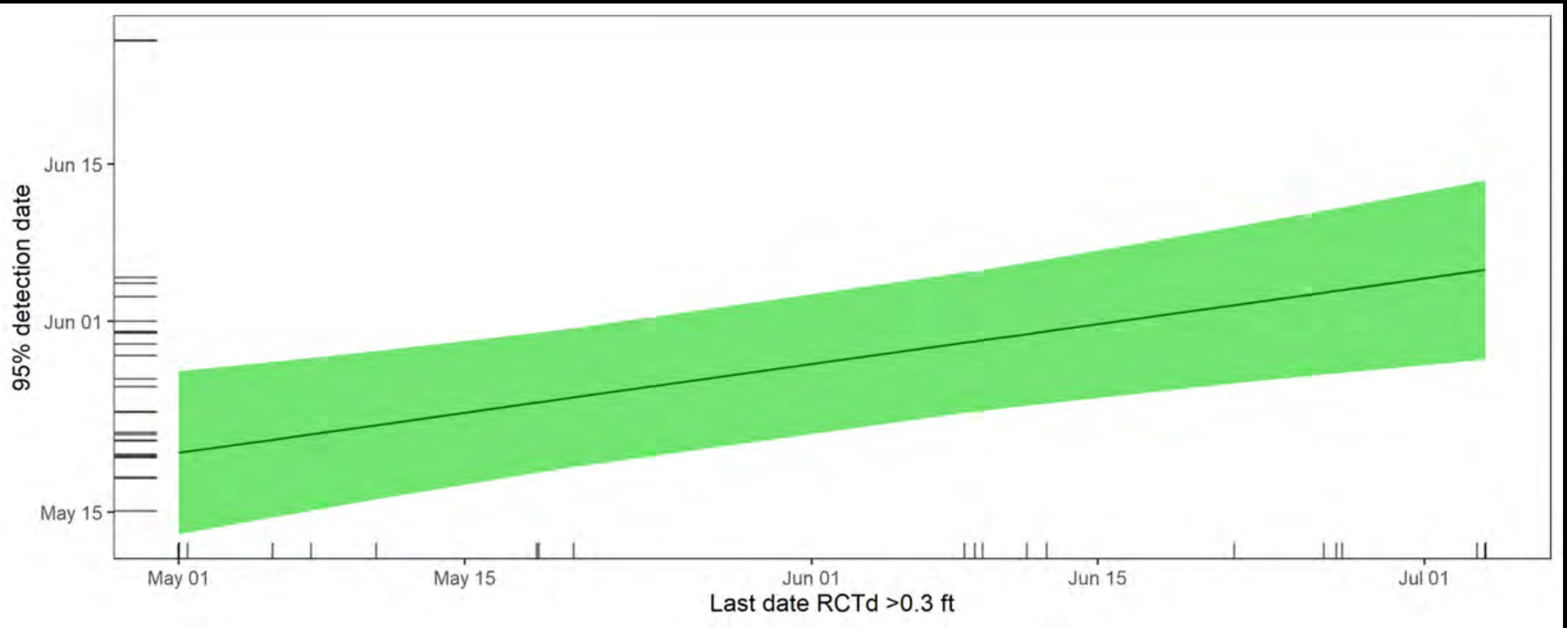


- To account for variability in the frequency of depths *experienced*, divide:
  - water depth *during detections, by*
  - water depth *throughout season*

(Maki-Petays et al. 1997)

Minimum water depth policies support outmigration





- ❖ The end of the outmigration season is prolonged by an extended period of suitable depths
- ❖ A greater number of days below a depth requirement *may* increase the number of days without outmigration

Take-aways

- Low-flows contract outmigration duration, and high cumulative thermal experience hasten the outmigration season
  - each up to 3 weeks
- Drought increases the risk of phenological mismatches
- Water depth preferences of coho can be reached, using environmental flows

Photo by Sean Perez

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Shelby Witherby

California drought influences steelhead productivity through impacts on spring smolt conditions

Haley A. Ohms[1,2], Brian Spence[2], Eric P. Palkovacs[1], David A. Boughton[2]

(1) University of California Santa Cruz, Fisheries Collaborative Program
(2) NOAA, Southwest Fisheries Science Center

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Droughts!

2012-2016

2021/2022

Final blow?

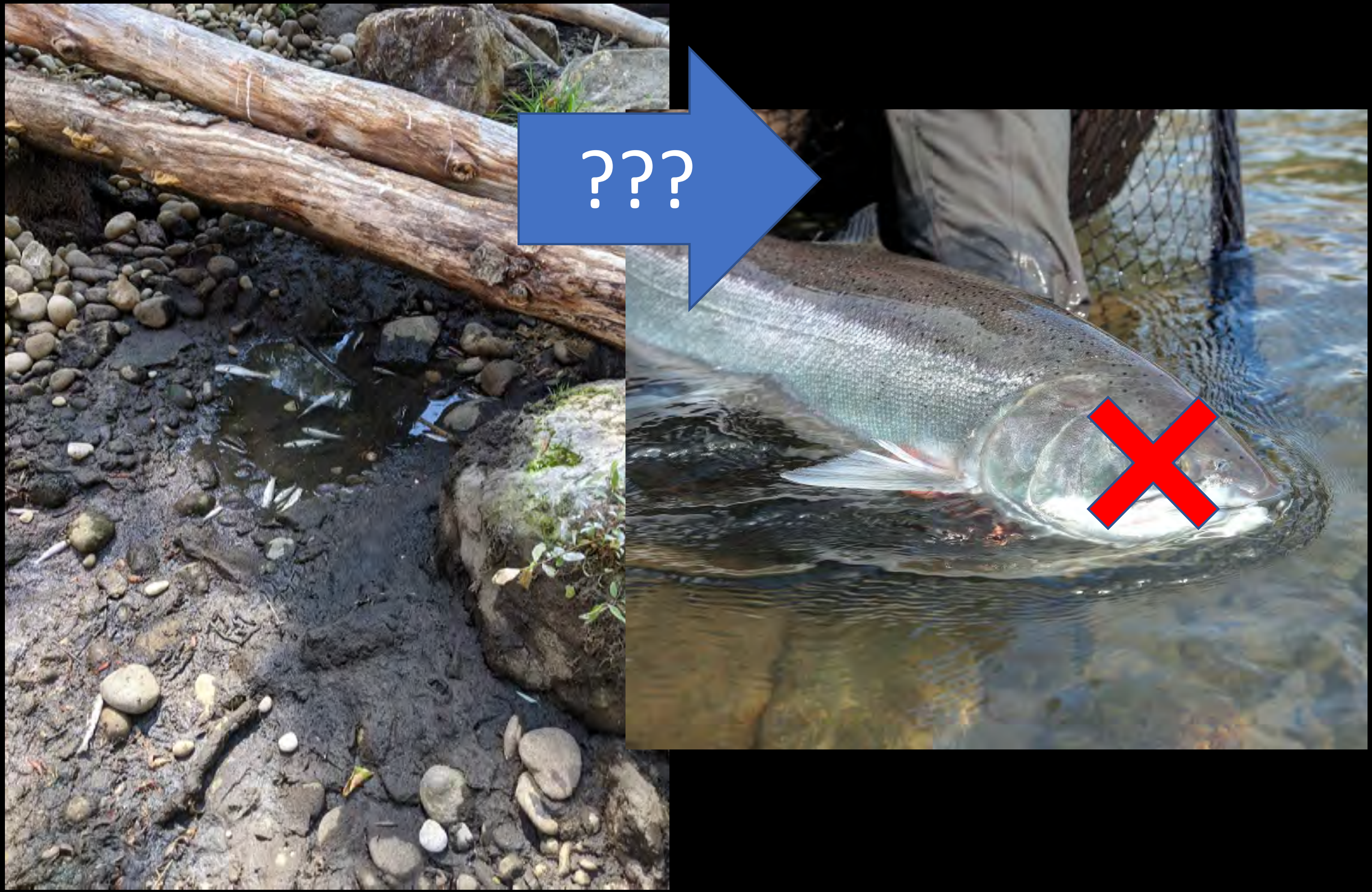
Drought impacts on juveniles

- Lost connectivity
- Higher competition
- Higher metabolic costs
- Lower growth

(Hakala and Hartman 2004, Harvey et al. 2006, Woelfle-Erskine et al. 2017, Grantham et al. 2012, Goertler et al. 2017, Vander Vorste et al. 2020)

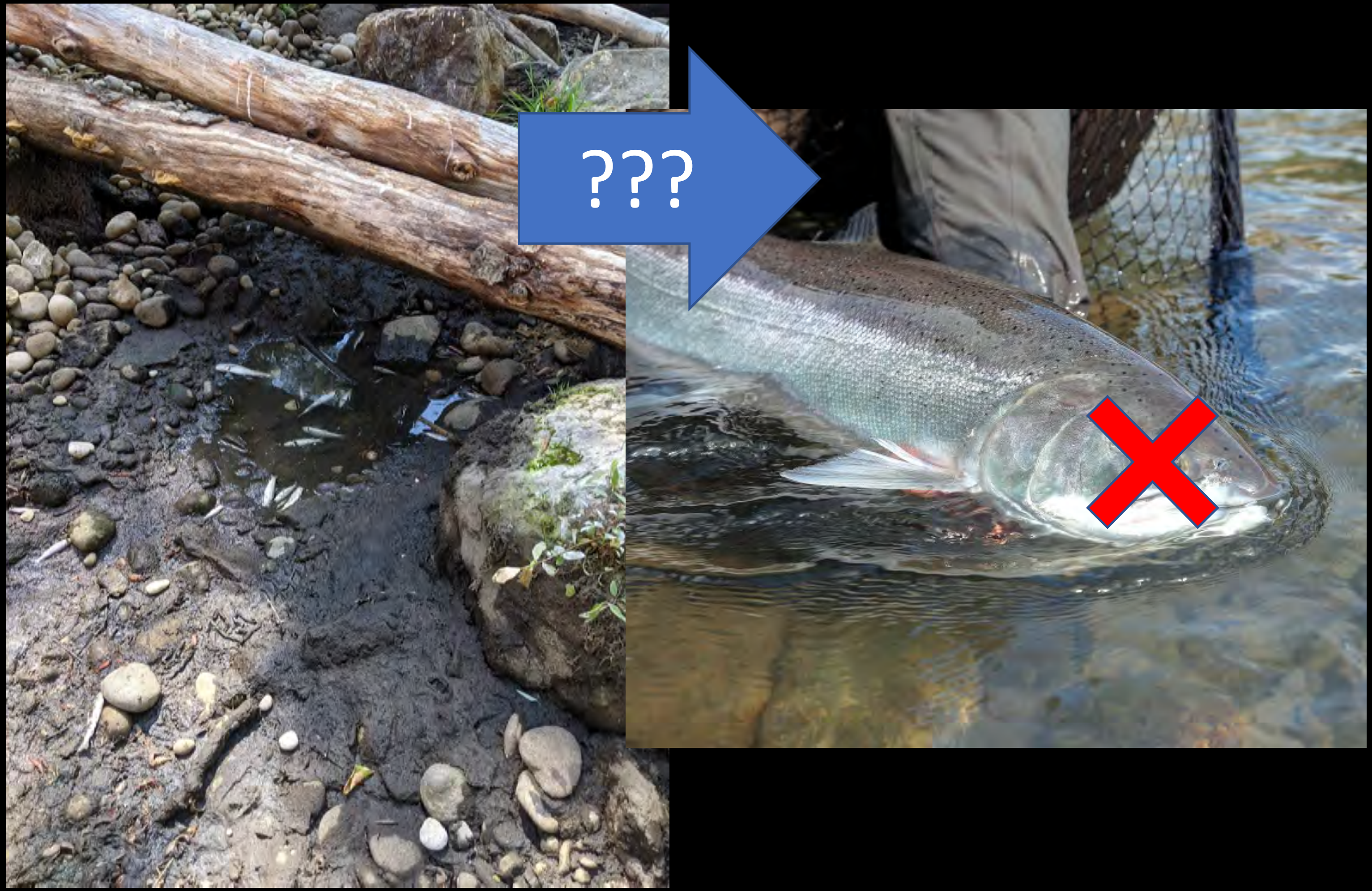
Juvenile impacts -> fewer spawners?

How have recent droughts influenced the number of spawners?



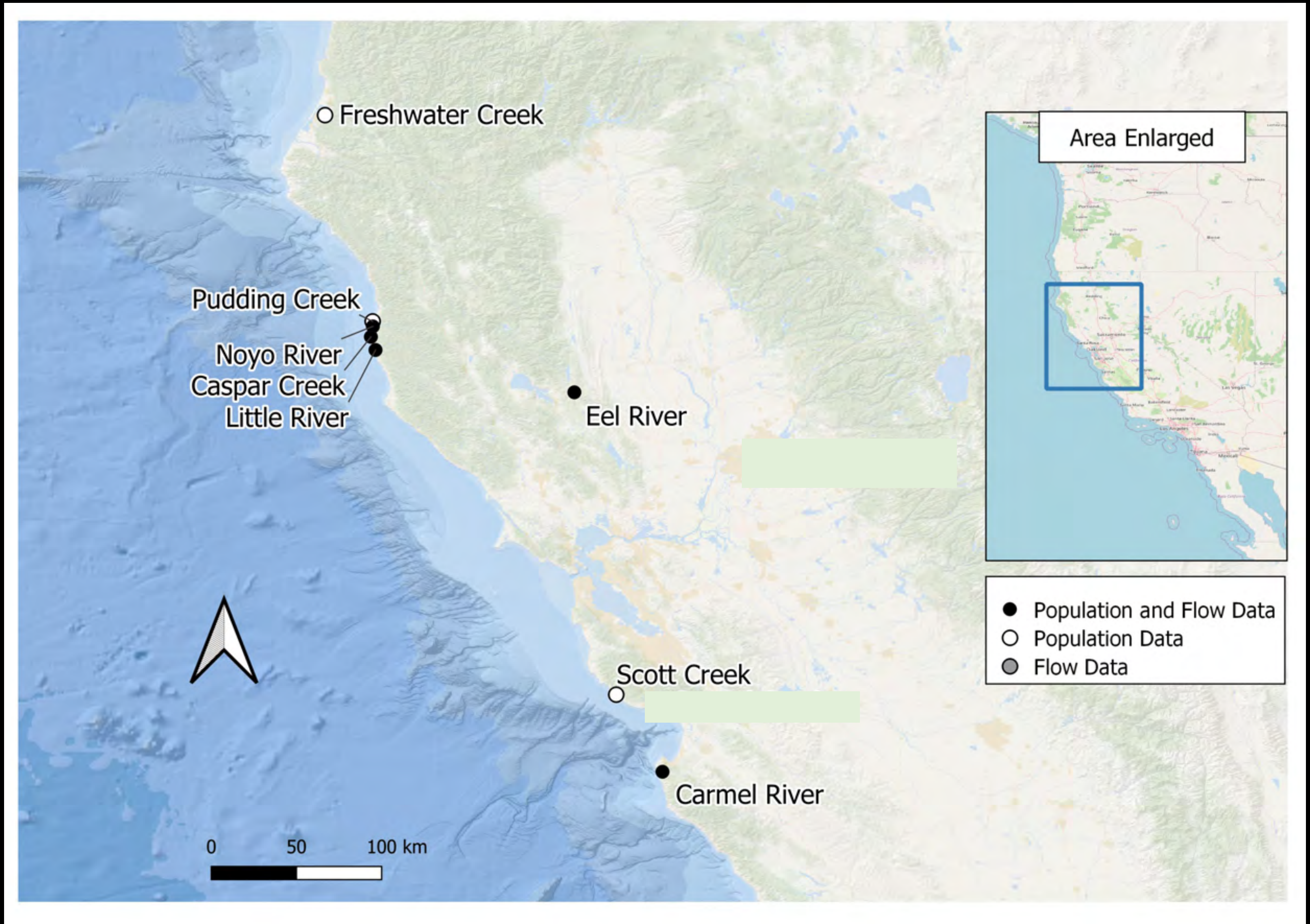
Study question

Did 2012-2016 drought lead to fewer steelhead spawners on the north-central California coast?



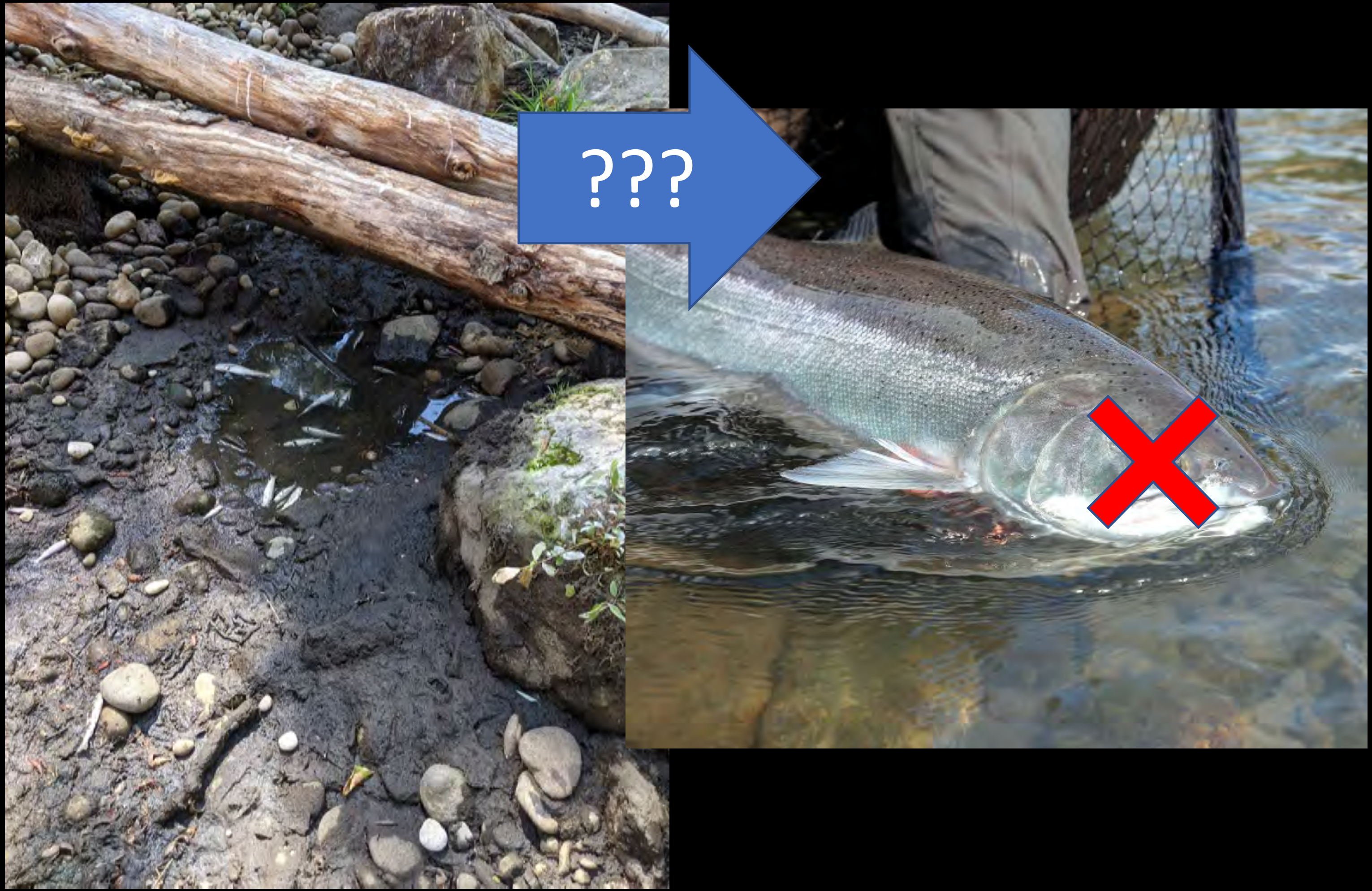
Study populations

- 8 populations
- Winter-run, north-central coast
- Spawner estimates
- 2002-2019



Study approach

1. Identify life stages affected and time lags
2. Fewer spawners in those years?
3. Attribute patterns to drought?



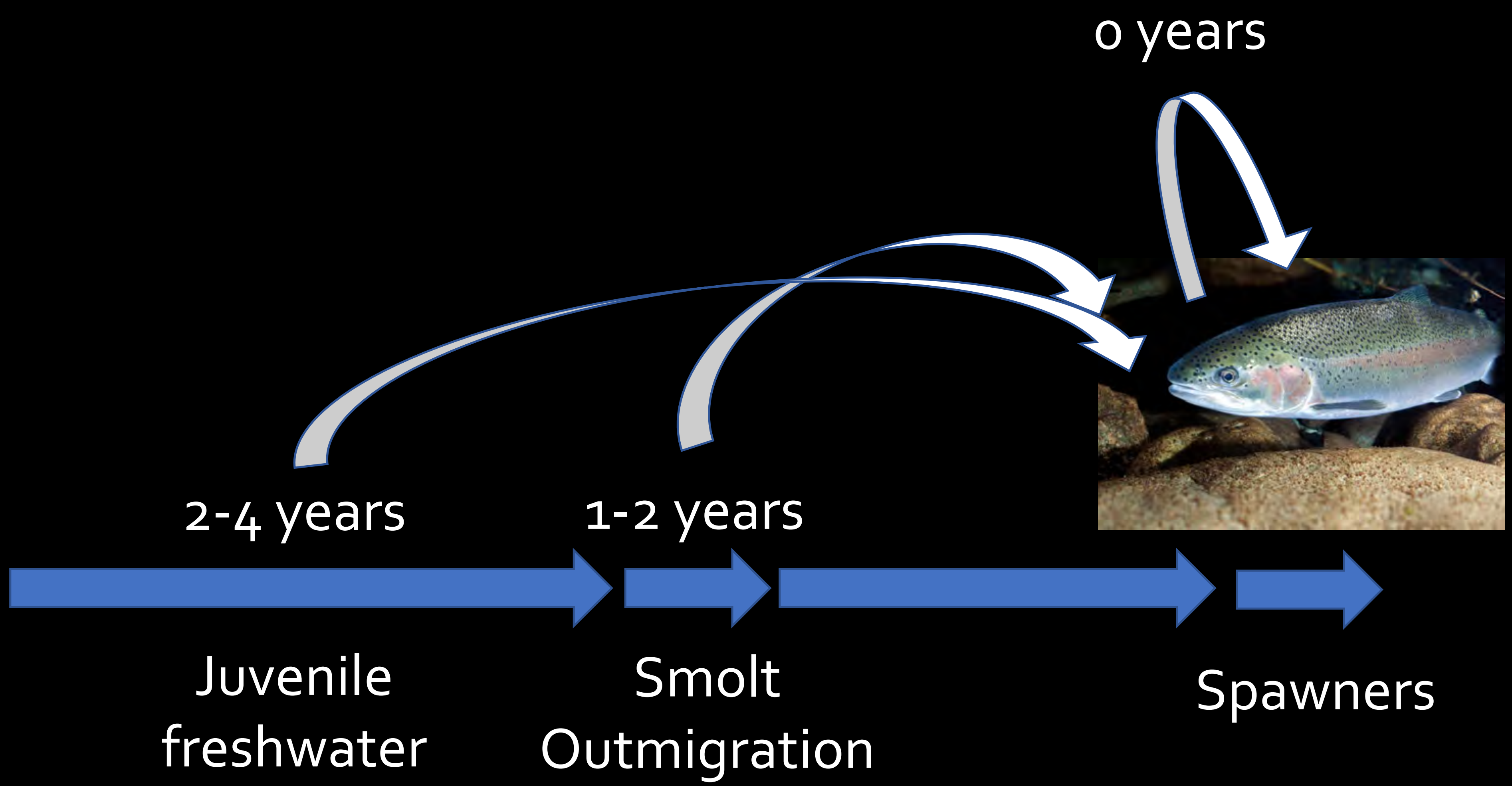
Drought affects different life stages

Juvenile freshwater

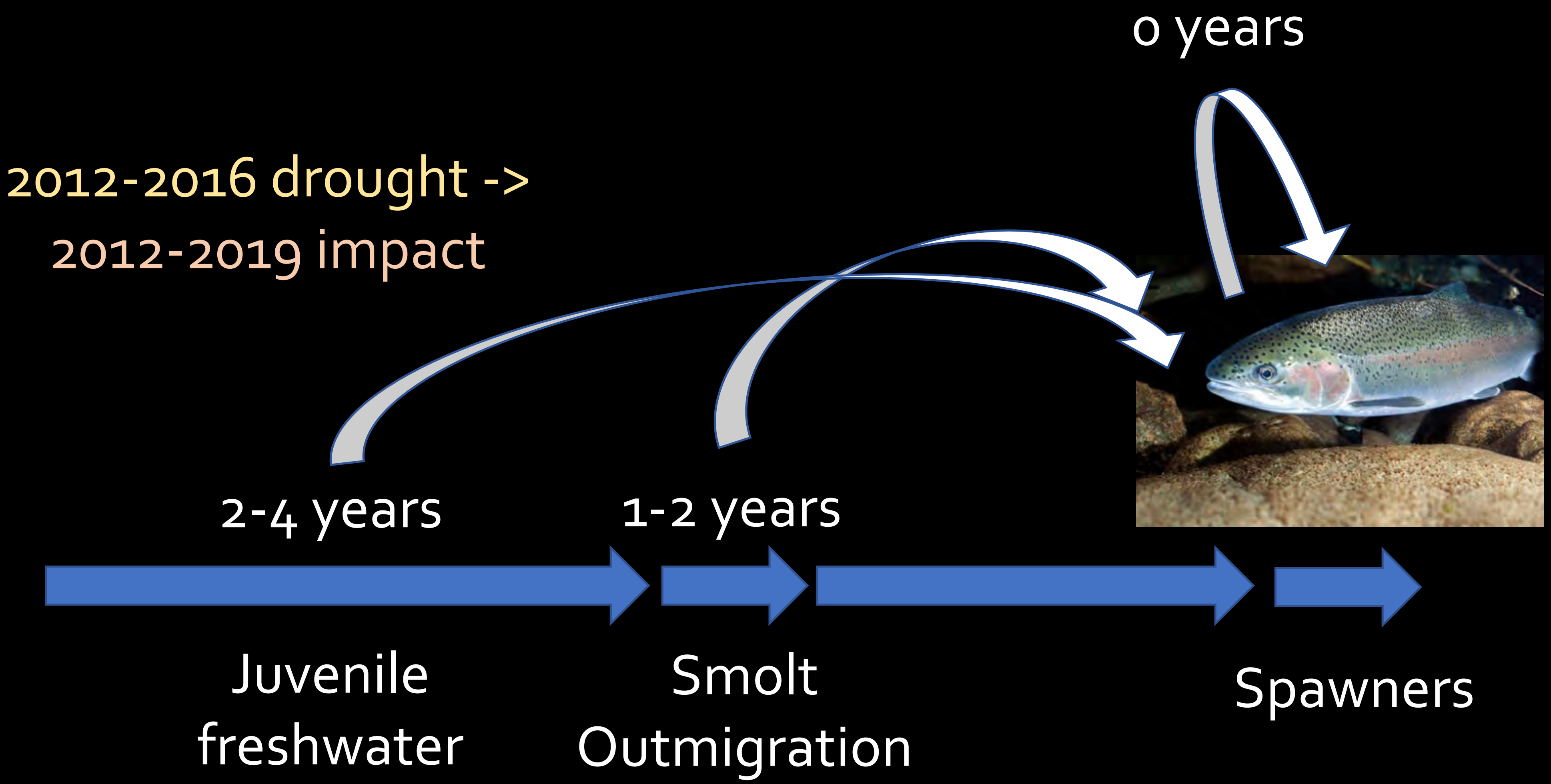
Smolt Outmigration

Spawner Immigration

Drought affects different life stages



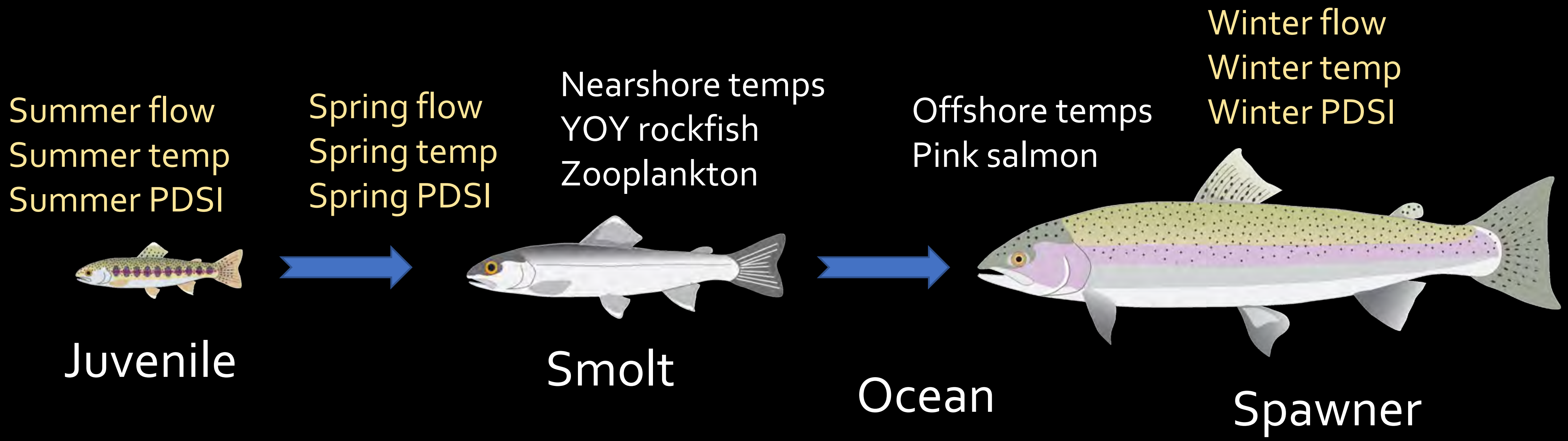
Drought affects different life stages



Below average spawners caused by drought?

- Many below average
- But, *not lower than previous years*

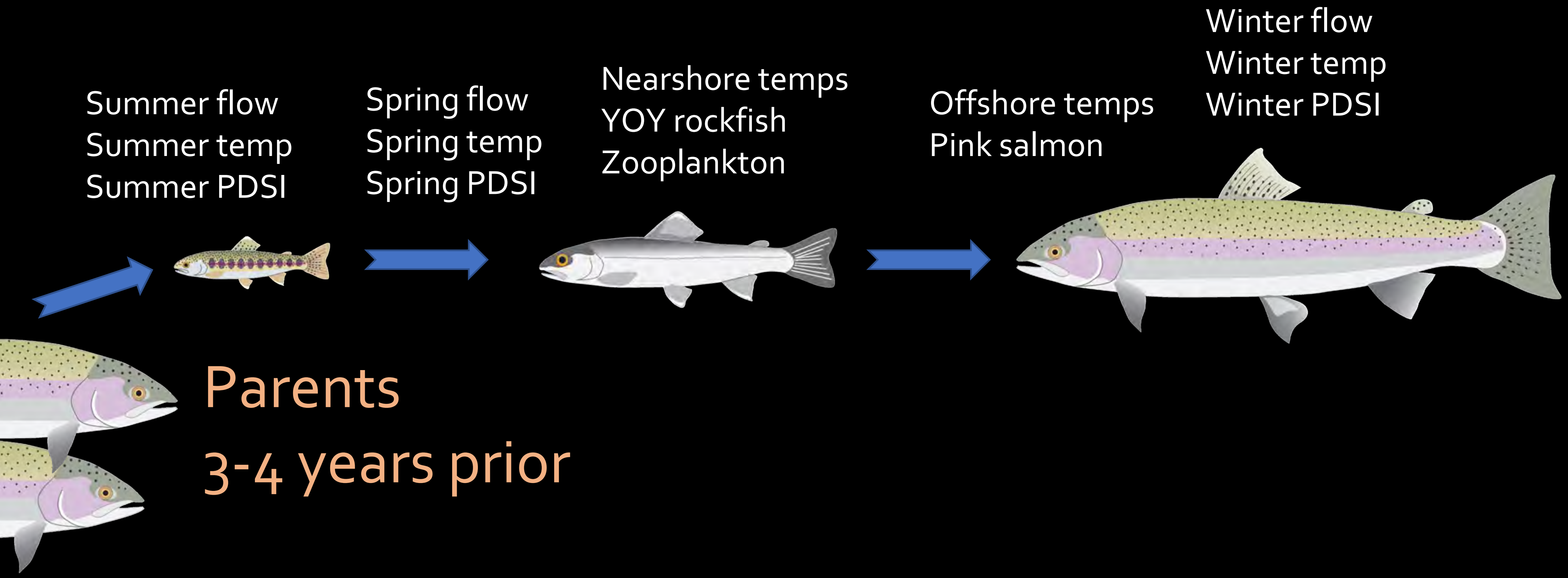
Correlations with environmental conditions?



Dynamic Factor Analysis

- Estimates linear relationship between covariate and each population
- Also, fits a shared trend (or trends) to the population timeseries residuals
    - Indicates trend 'left over' after accounting for the covariate
- Gives: effect size, shared trend(s), loading
- We fit 28 models, 1-2 trends, each with single covariate

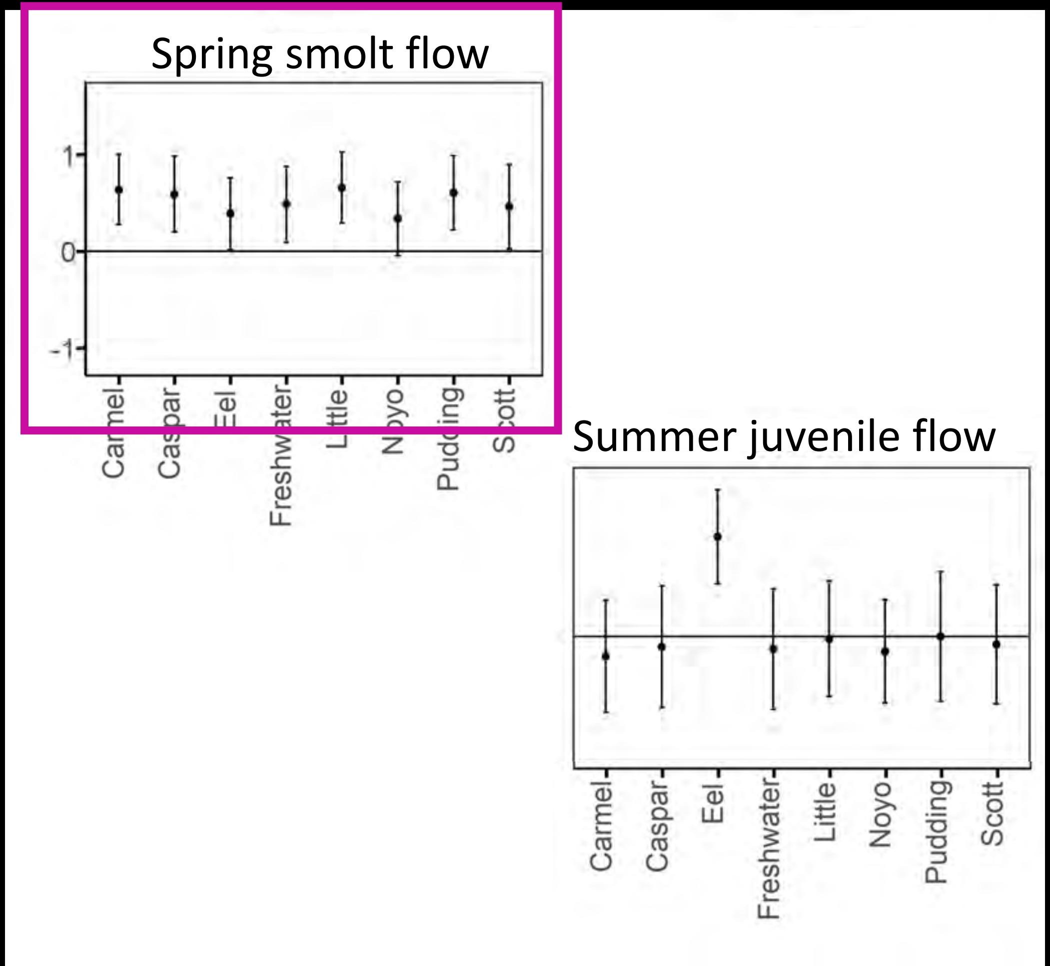
Transform spawners to productivity



$$productivity_t = \log\left(\frac{spawners_t}{0.5(spawners_{t-3} + spawners_{t-4})}\right)$$

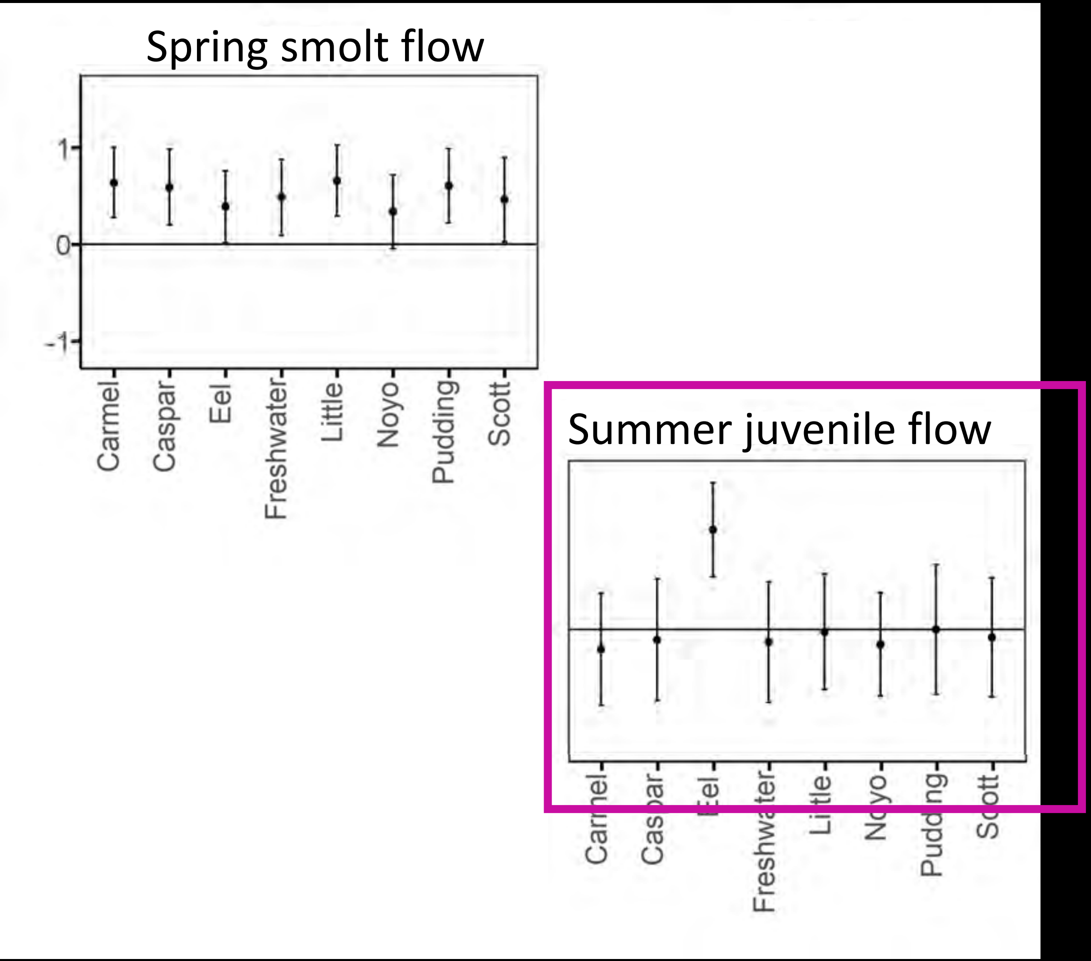
Results

- Spring-smolt flow most consistent correlation

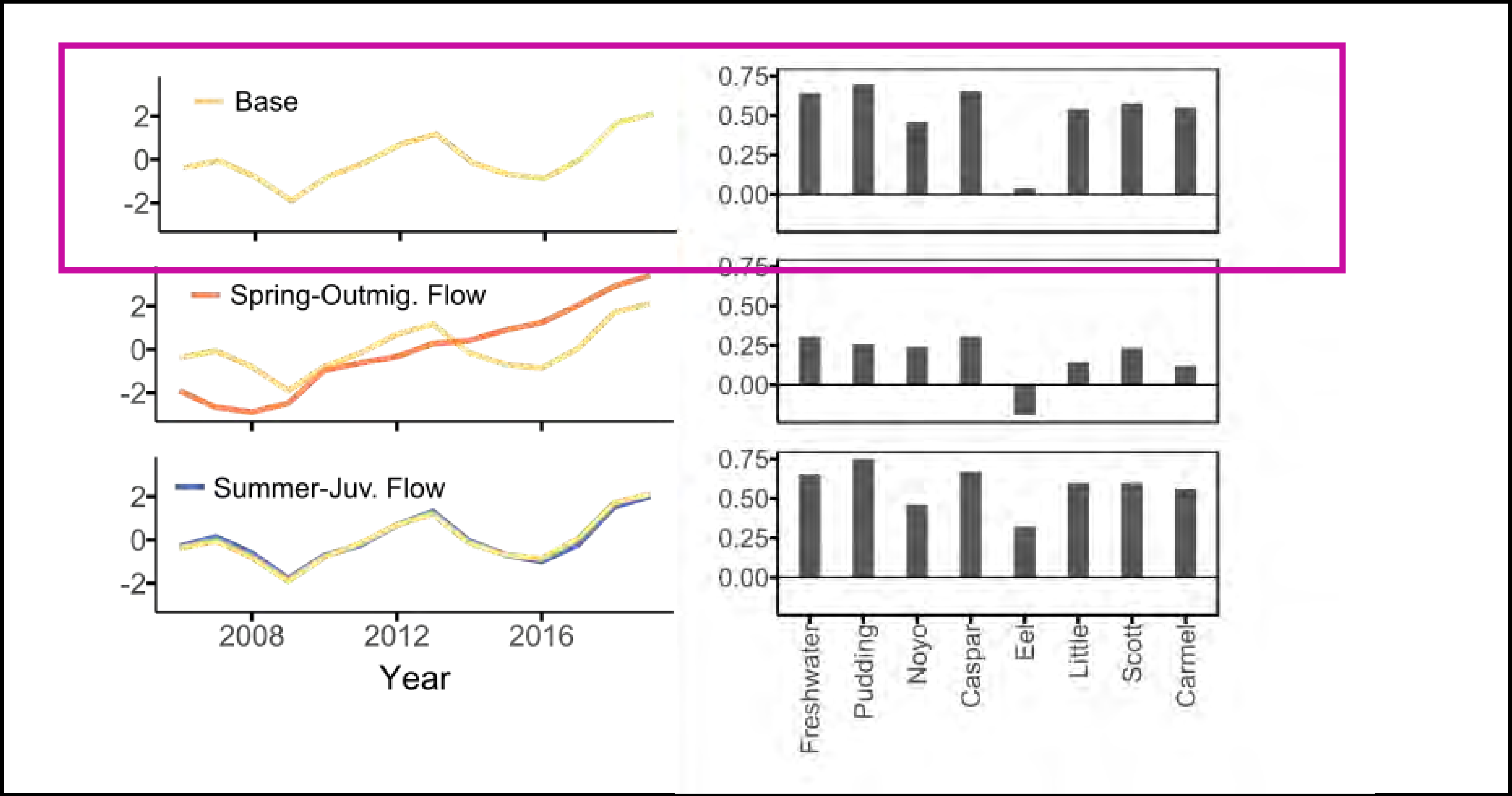


Results

- No effect of summer juvenile flow

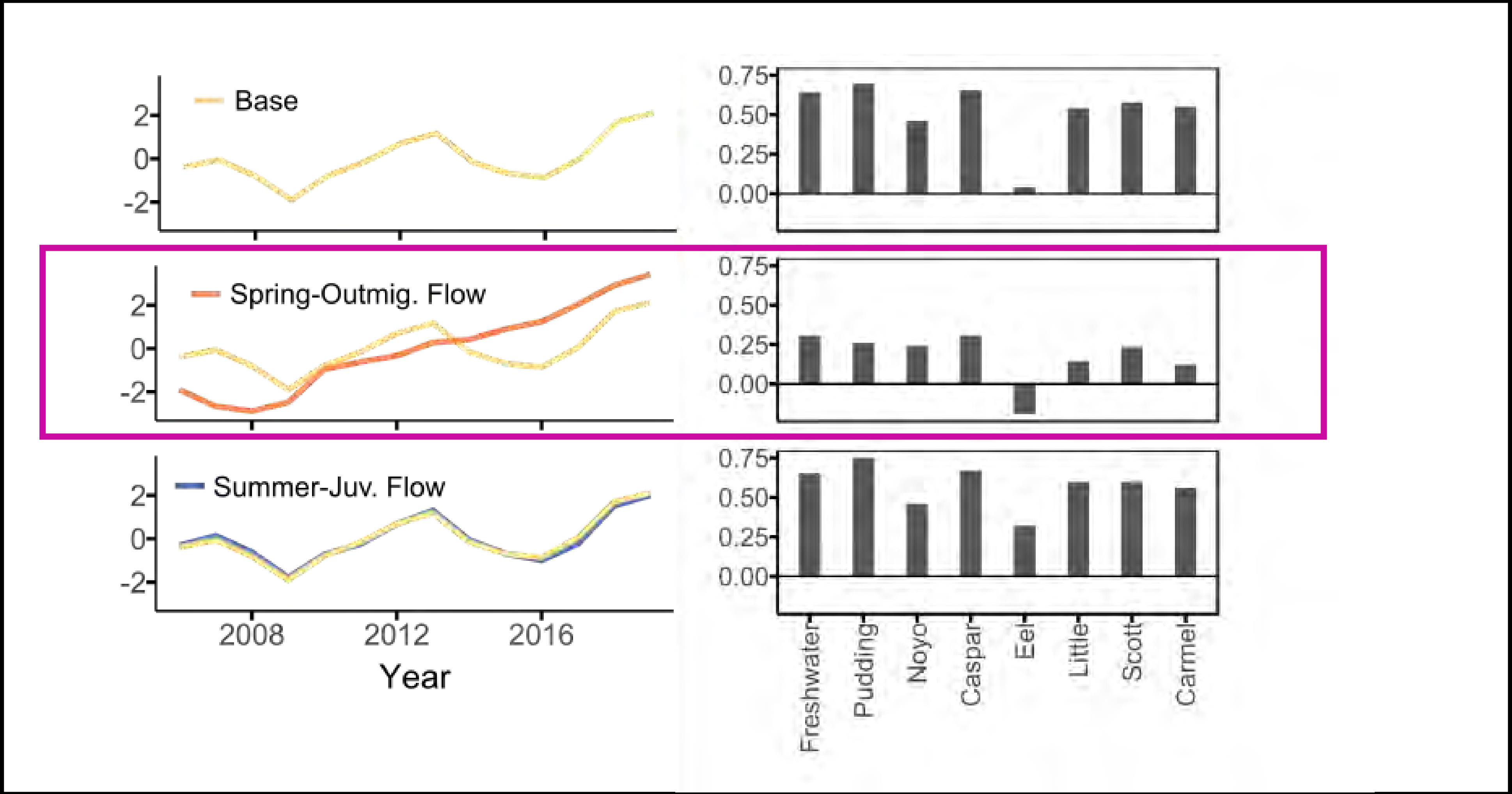


Results



Base
Spring-Outmig. Flow
Summer-Juv. Flow
2
0
-2
2008
2012
2016
Year
0.75
0.50
0.25
0.00
Freshwater
Pudding
Noyo
Caspar
Eel
Little
Scott
Carmel

Results



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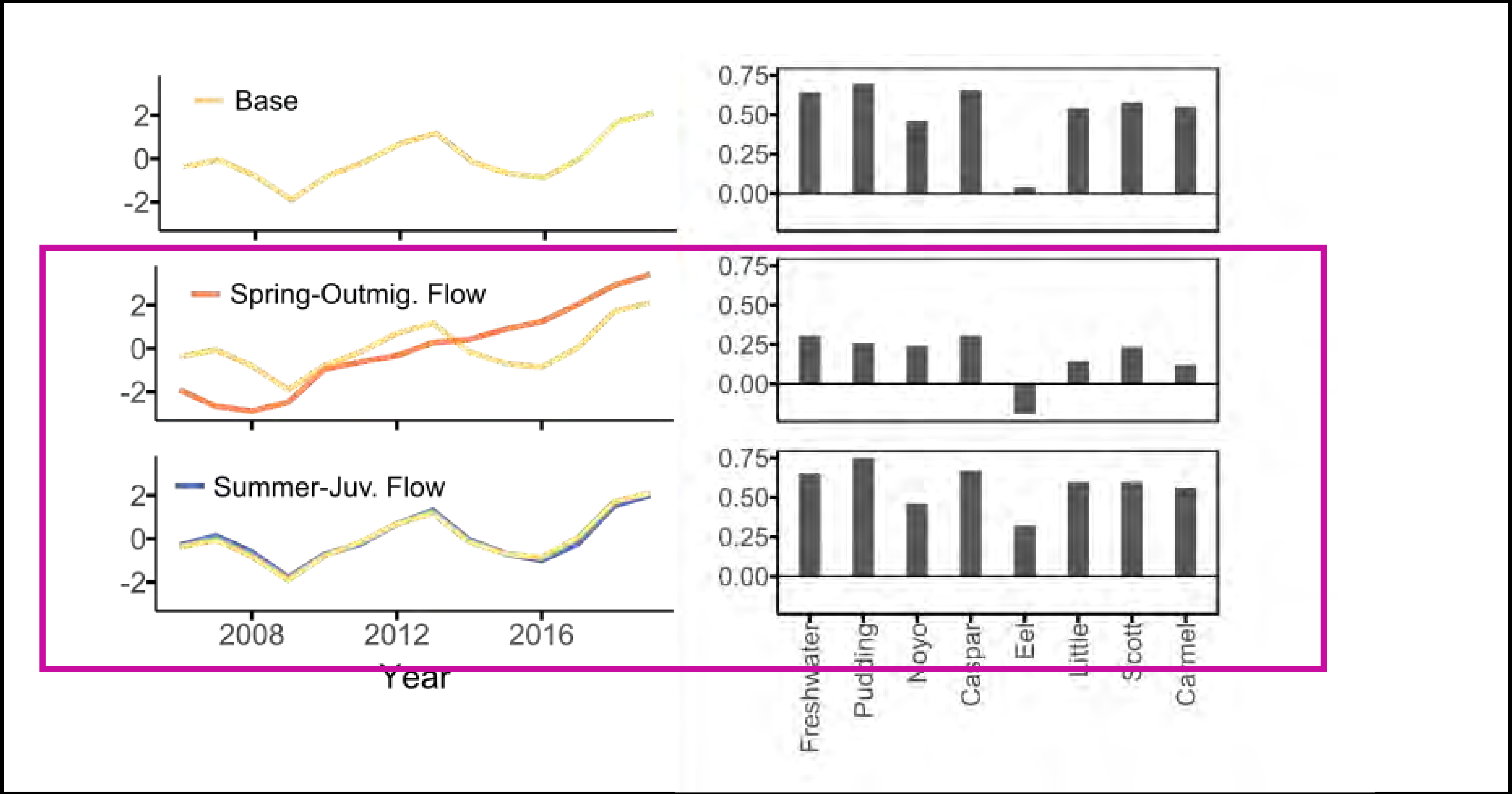

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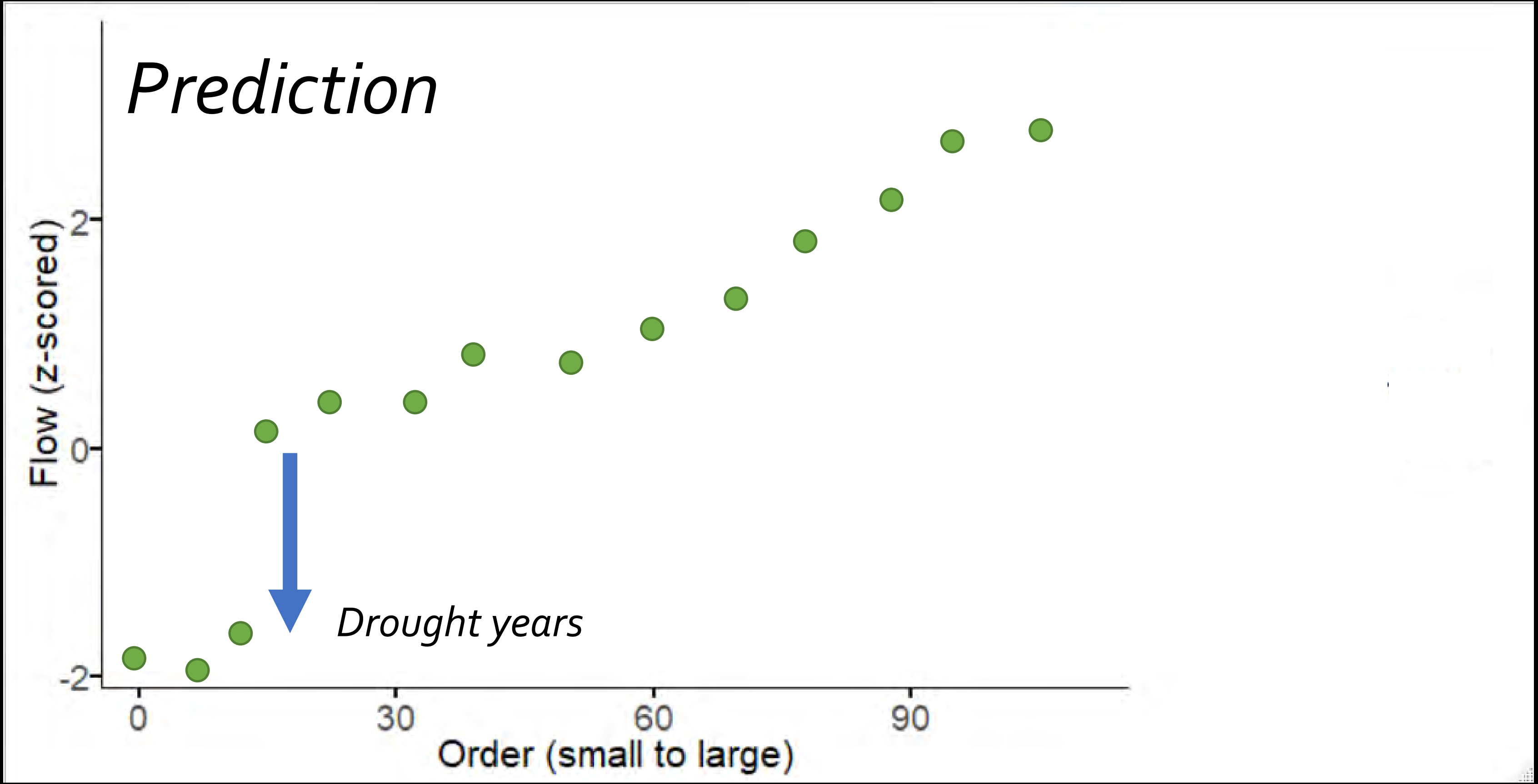
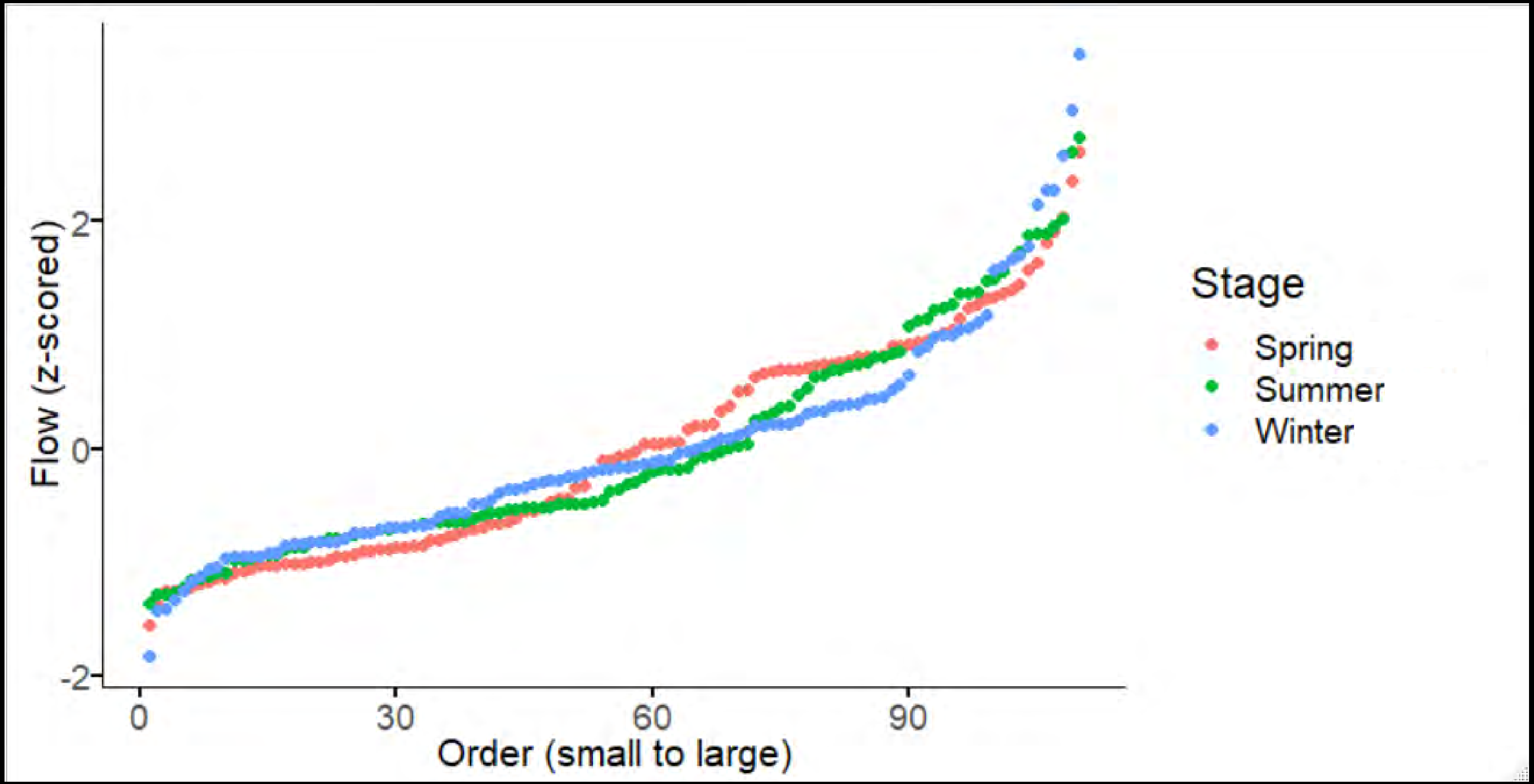
Results

- Spring-smolt flows appear to control most of the shared population dynamics
- Lower spring-smolt flows during drought led to lower productivity
- BUT, productivity wasn’t as low as we thought given the extremity of the drought
- ??? Hmmmm…

Flow context



Flow context



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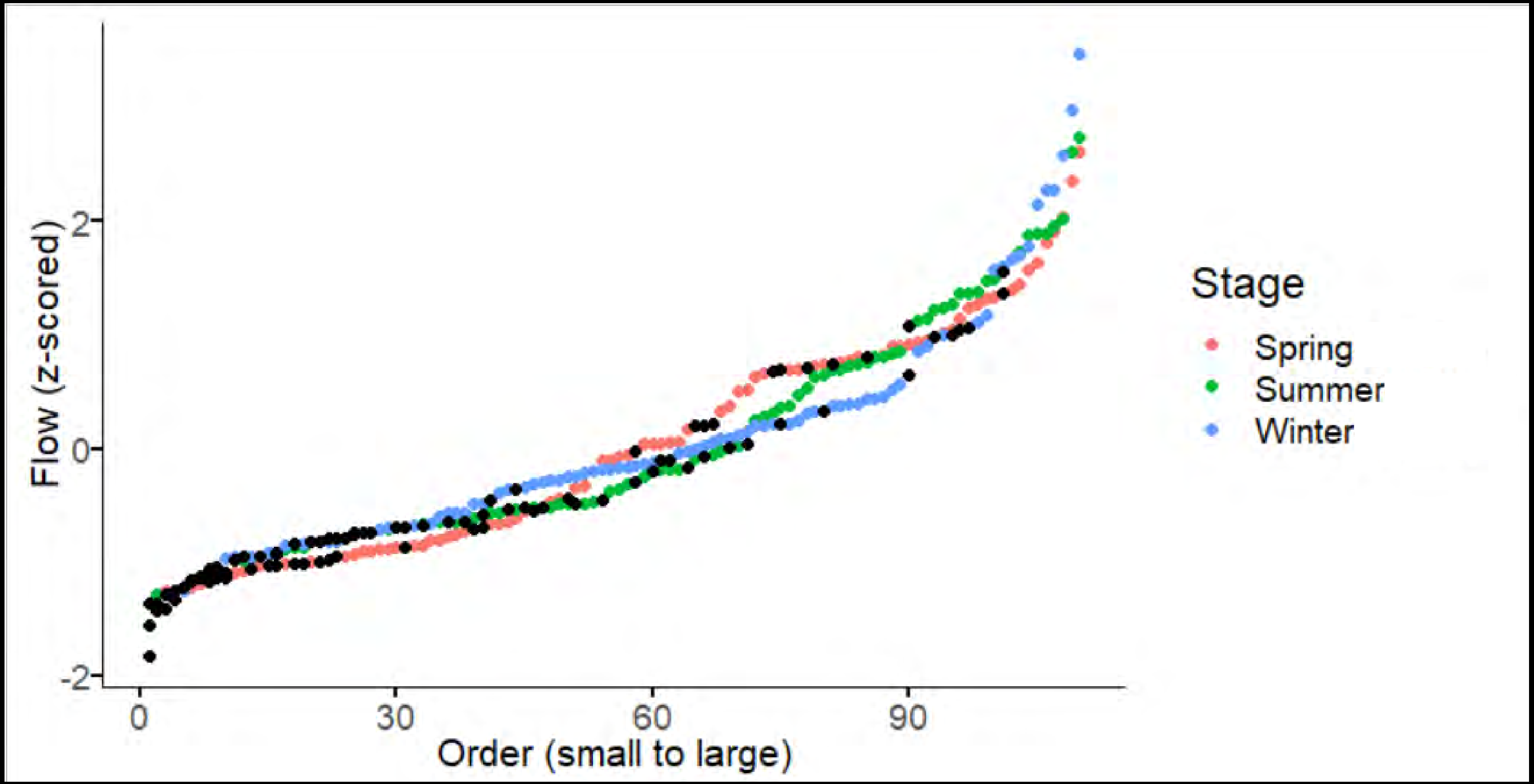
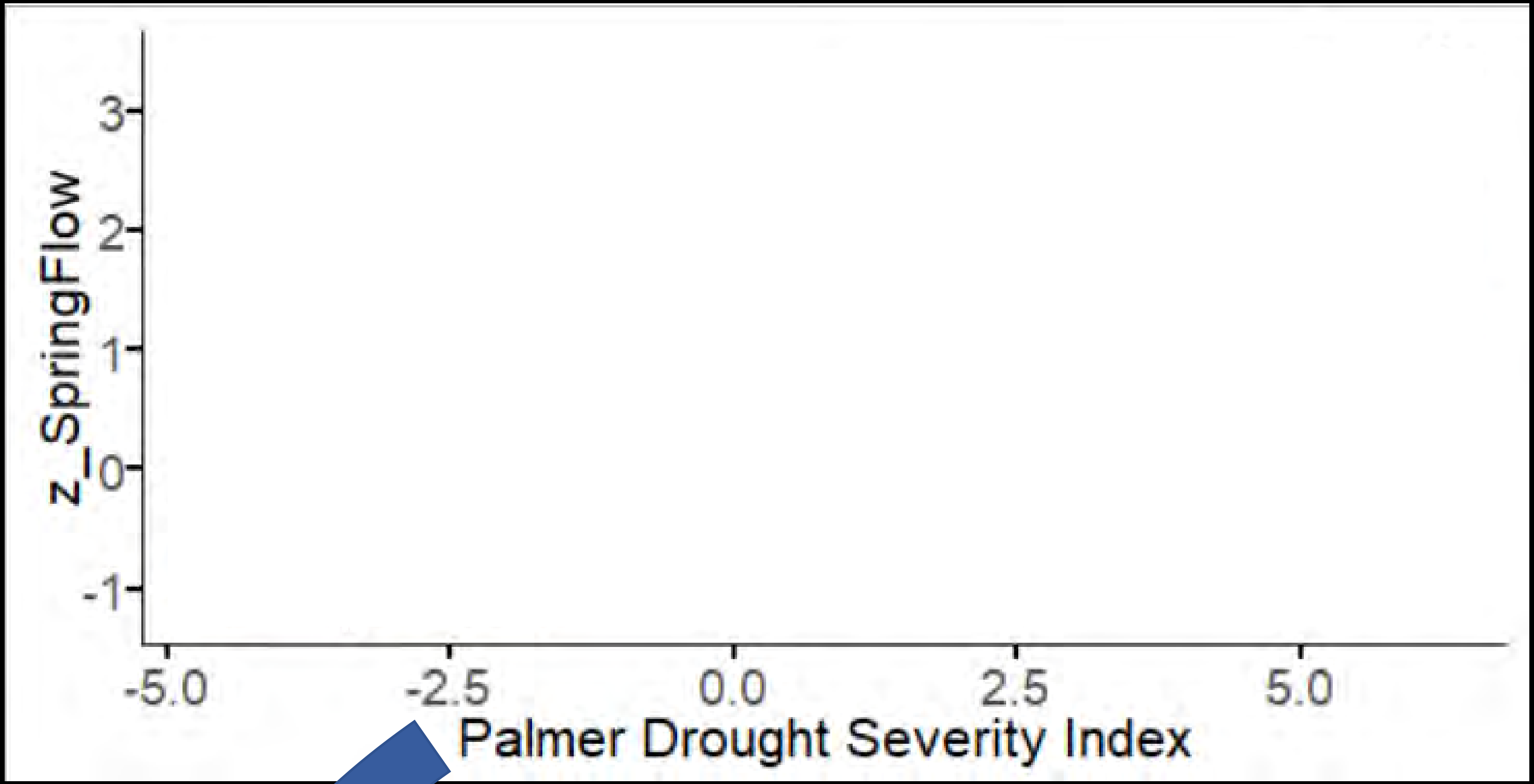
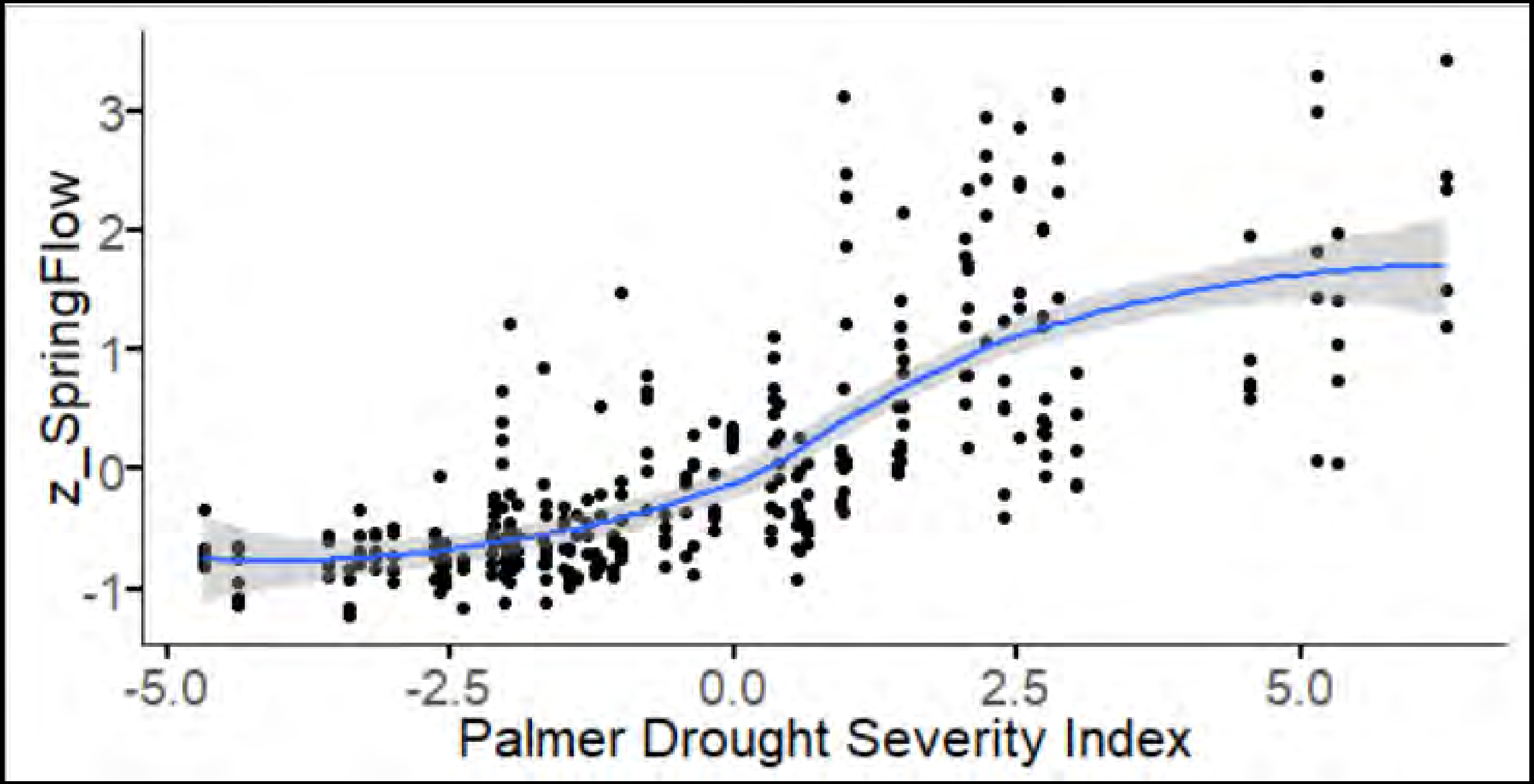


Flow context

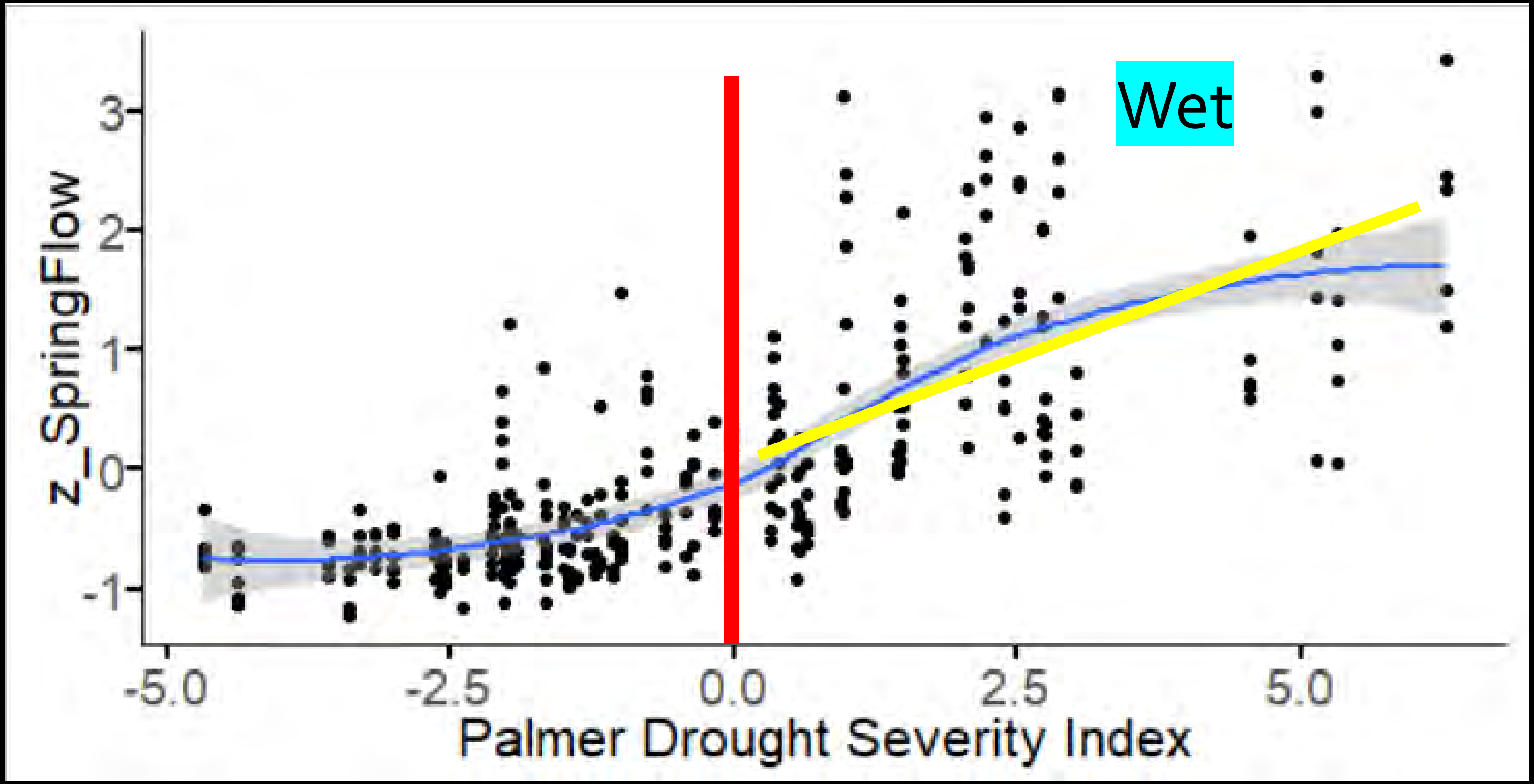


Terrestrial:
Rainfall, temperature, evapotranspiration

Groundwater buffering



Groundwater buffering



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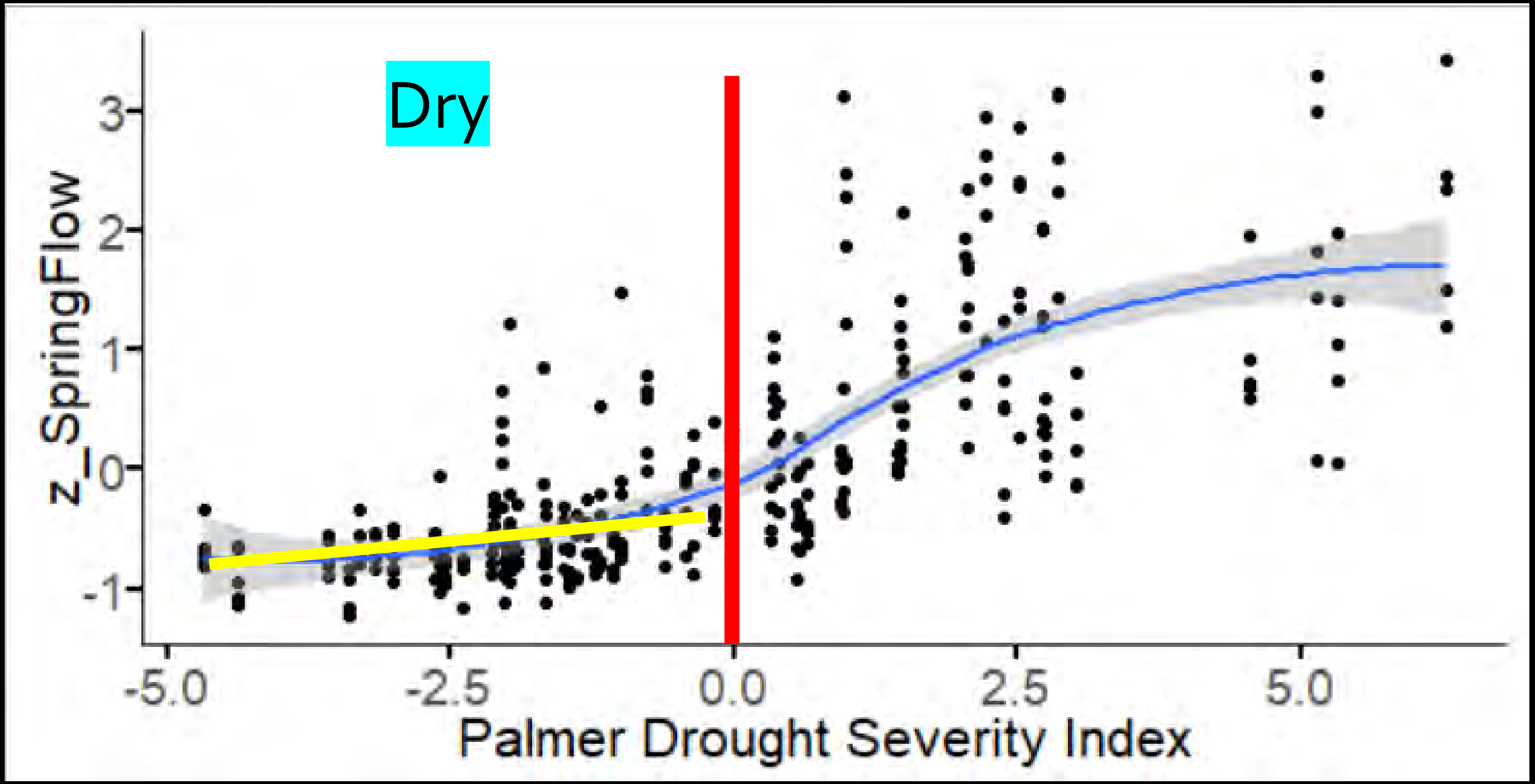
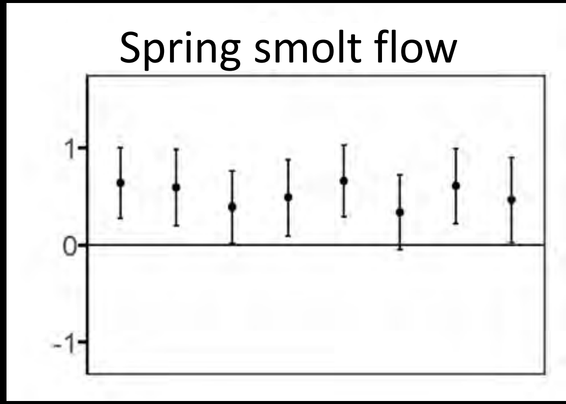
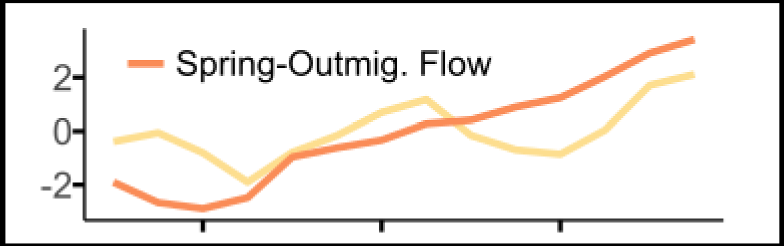


Results round-up

1. Drought appears to have caused lower steelhead productivity by lowering spring-smolt flows
2. Part of a long-term correlation between steelhead productivity and spring-smolt flows
3. Spring-smolt flows an apparent regional driver of productivity





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4. Yet, despite this relationship, productivity *wasn't that low after the drought*

Results round-up

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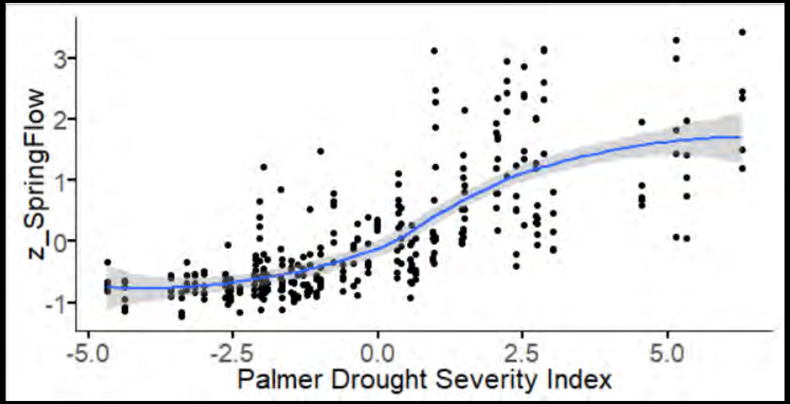
2. Part of a long-term correlation between steelhead productivity and spring-smolt flows
3. Spring-smolt flows an apparent regional driver of productivity
4. Yet, despite this relationship, productivity *wasn't that low after the drought*
5. Drought flows were not as low as we expected
6. Flows appear to be buffered from droughts



Conclusions

1. California steelhead were vulnerable to drought
2. Hydrologic buffering was key to minimizing impacts of drought
3. Without that, productivity would have been lower
4. Identify, preserve watersheds with groundwater capacity

Thank you

- **Many counting crews**
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- Tim Kahles
- Karlee Liddy

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CALIFORNIA AMERICAN WATER

FISHERIES COLLABORATIVE PROGRAM
UC SANTA CRUZ – NOAA FISHERIES

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NOAA
U.S. DEPARTMENT OF COMMERCE

MONTEREY PENINSULA WATER MANAGEMENT DISTRICT

UC SANTA CRUZ

Transform covariates

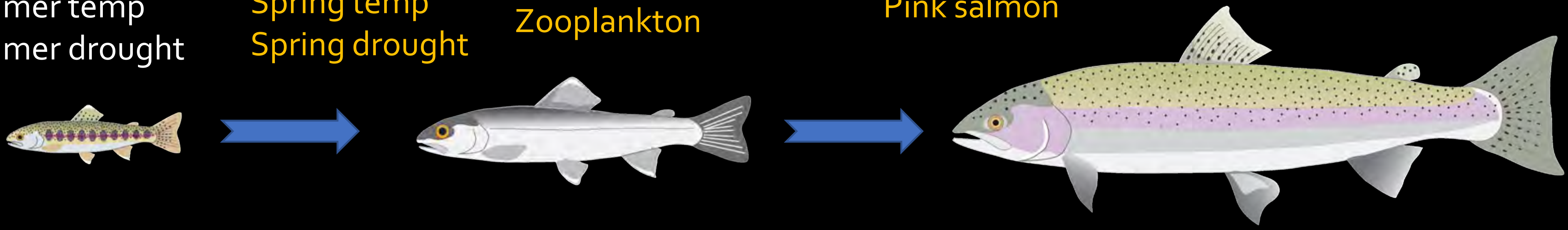
Summer flow
Summer temp
Summer drought

Spring flow
Spring temp
Spring drought

HCI
YOY rockfish
Zooplankton

TMH
Pink salmon

Winter flow
Winter temp
Winter drought



2-4 years later

$$d_t = \frac{d_{t-2} + d_{t-3} + d_{t-4}}{3}$$

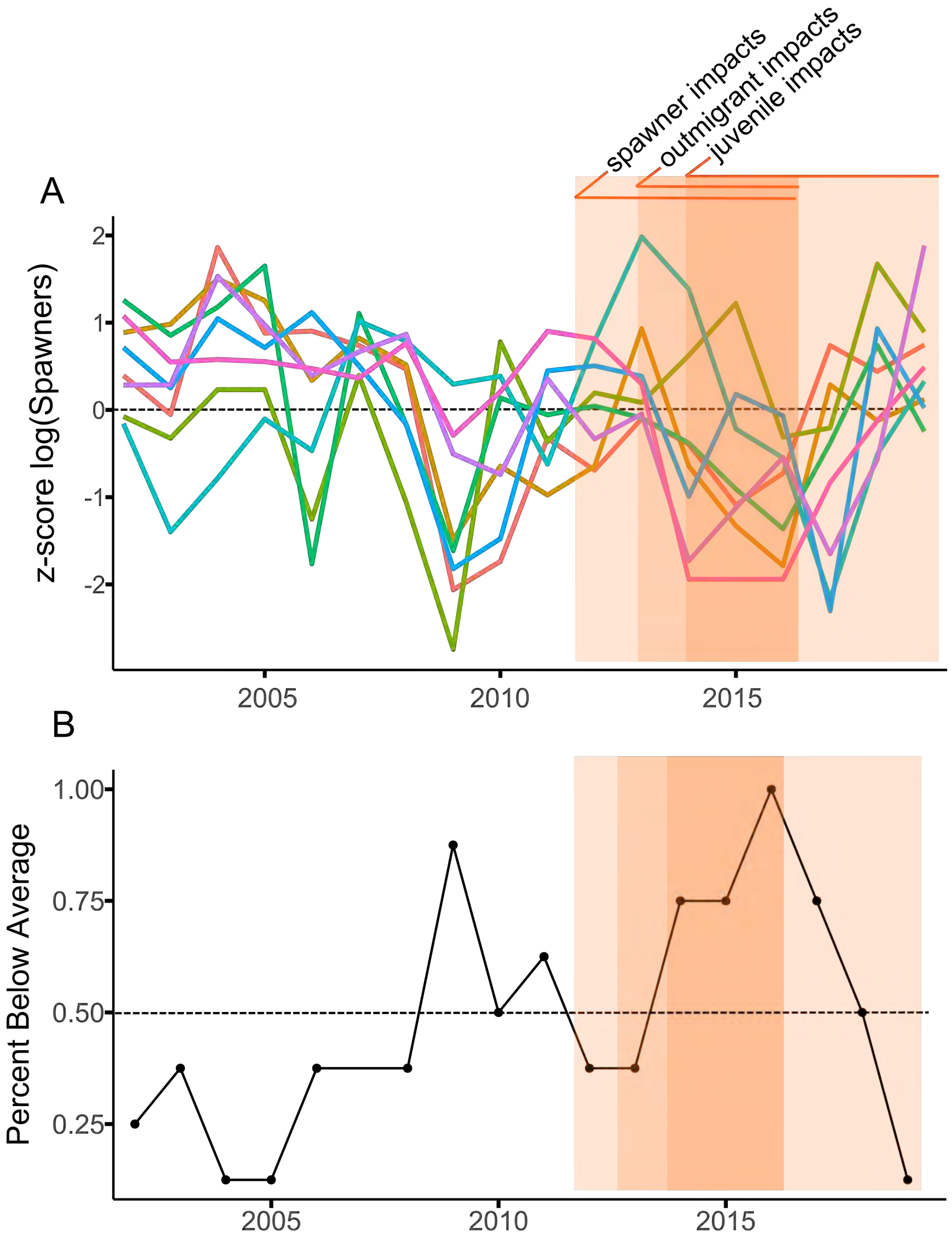
1-2 years later

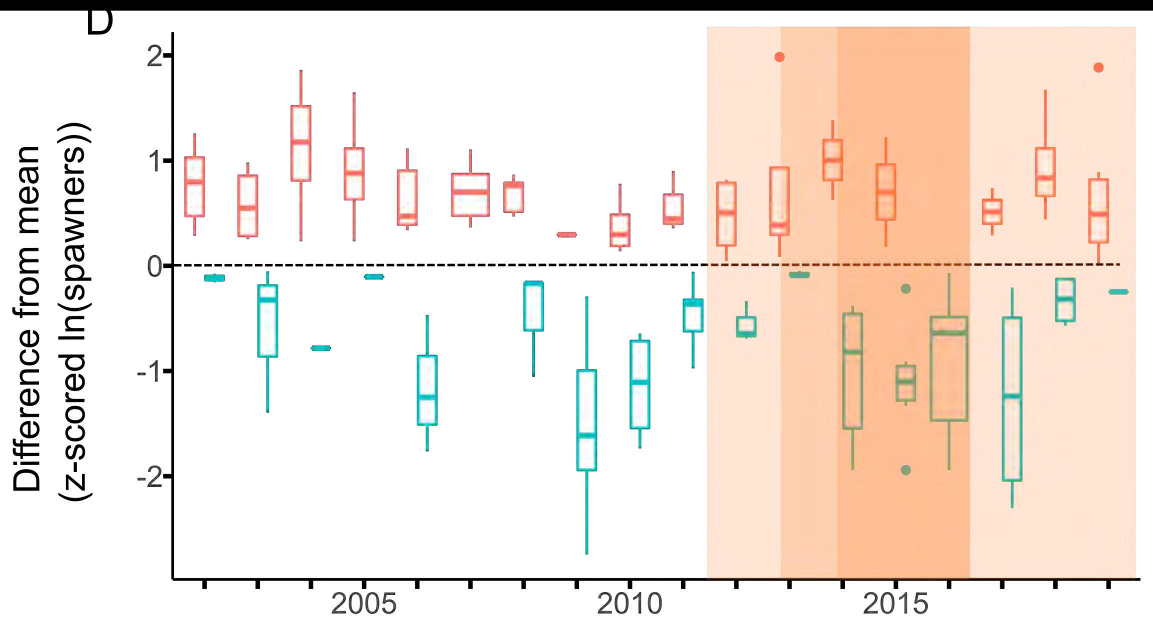
$$d_t = \frac{d_{t-1} + d_{t-2}}{2}$$

Same year

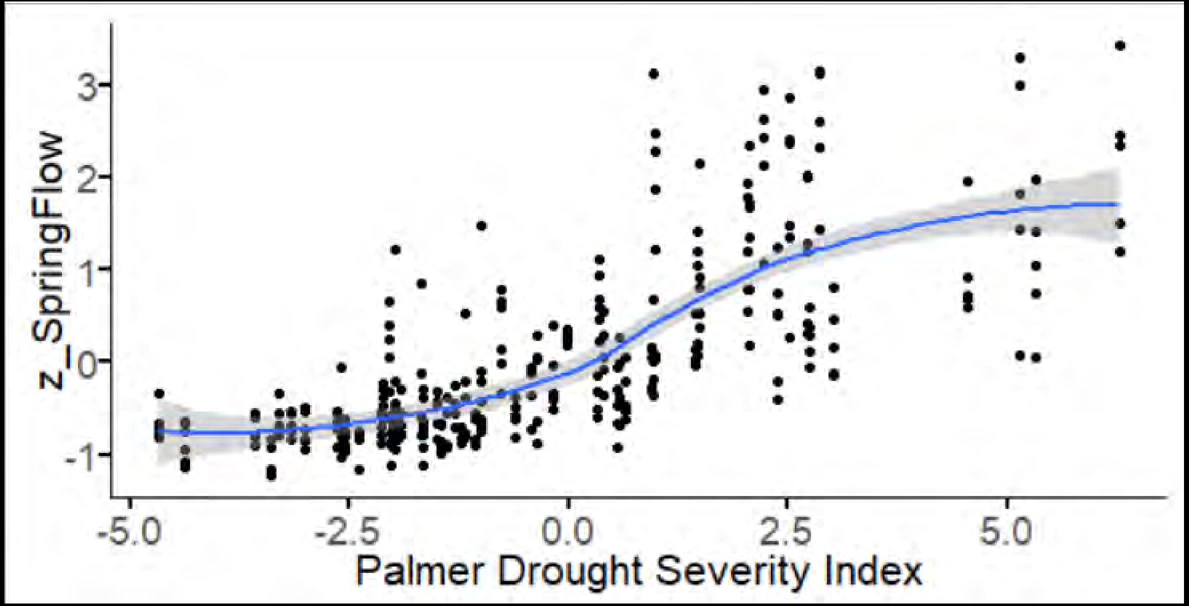
$$d_t = d_t$$

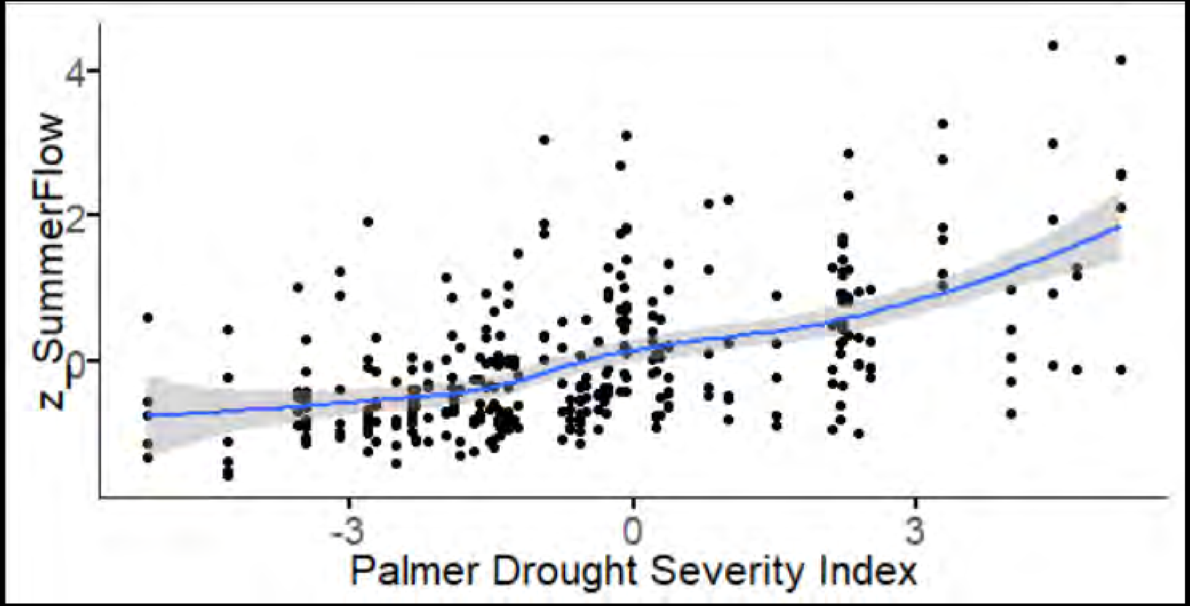
Below average spawners caused by drought?

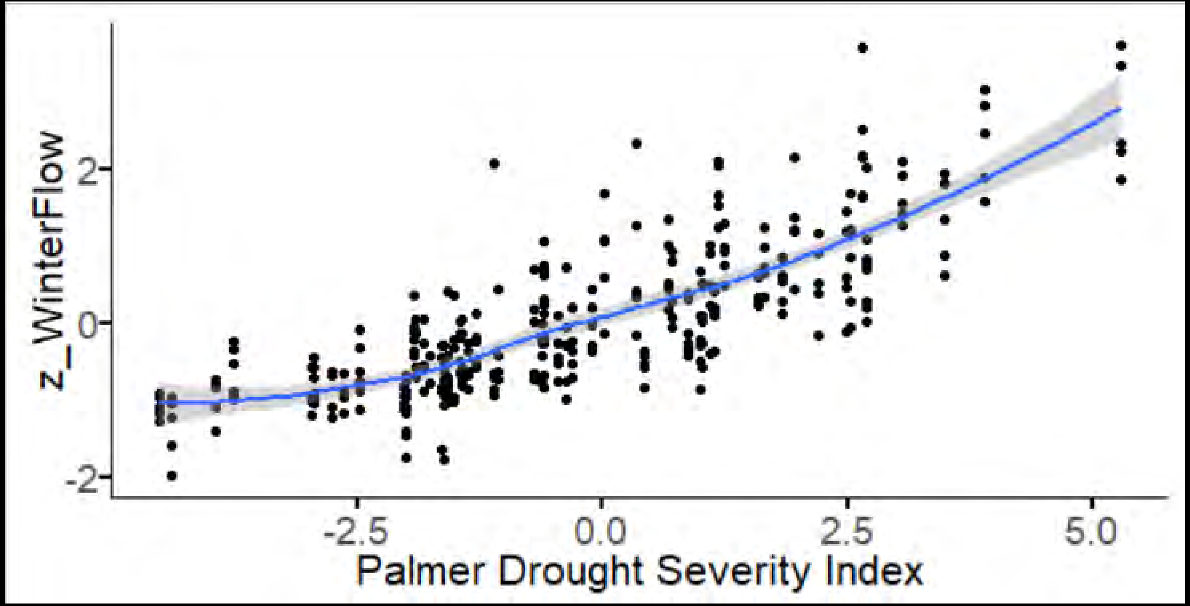


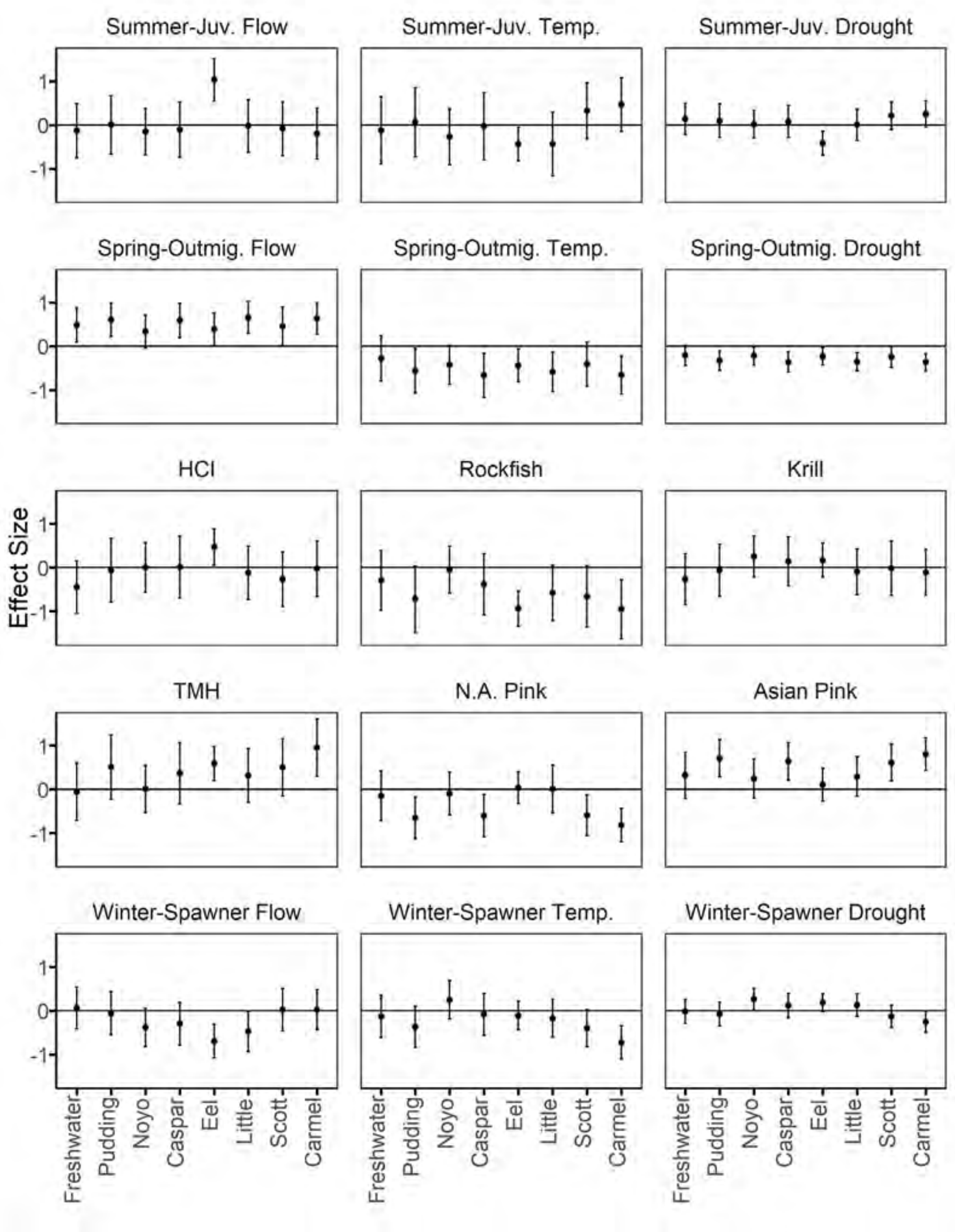


Groundwater buffering?





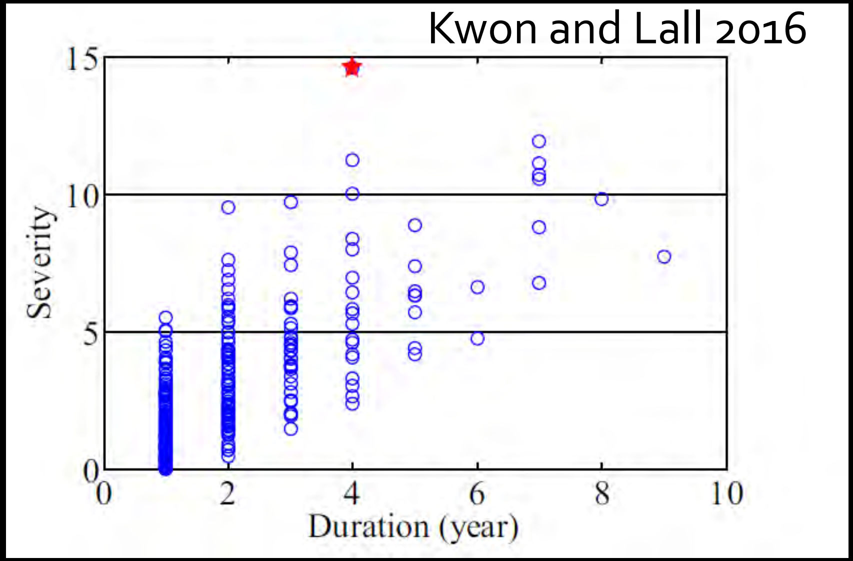


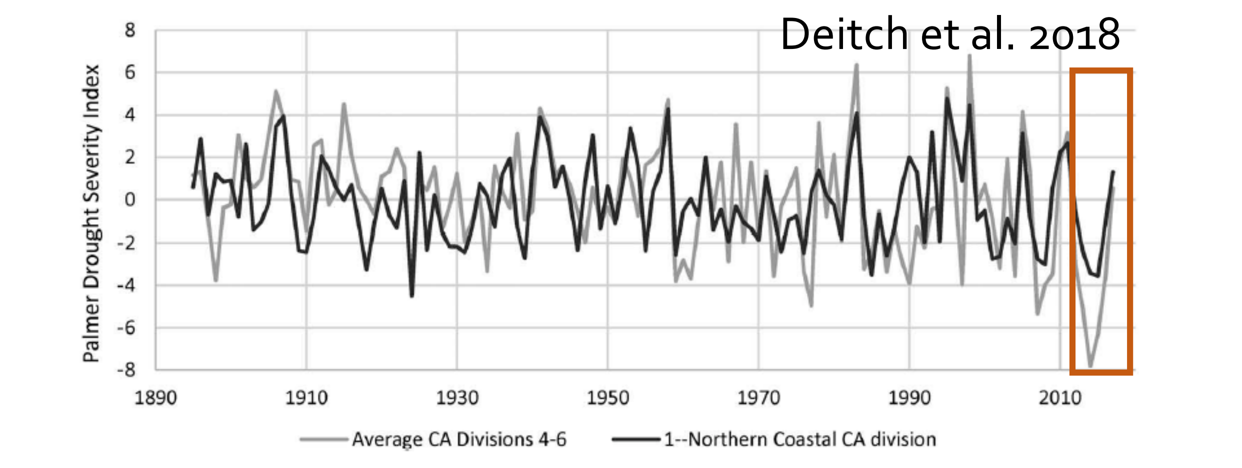


Summer-Juv. Flow
Summer-Juv. Temp.
Summer-Juv. Drought
Spring-Outmig. Flow
Spring-Outmig. Temp.
Spring-Outmig. Drought
HCI
Rockfish
Krill
TMH
N.A. Pink
Asian Pink
Winter-Spawner Flow
Winter-Spawner Temp.
Winter-Spawner Drought
Effect Size
1
0
-1
Freshwater
Pudding
Noyo
Caspar
Eel
Little
Scott
Carmel

2012-2016 California Drought

- Low rainfall, high temperatures, long duration
- Extremity varied state-wide
  - Unprecedented for southern and Central Valley (Kwon and Lall 2016)
  - 3rd most severe for north coast (Deitch et al. 2018)

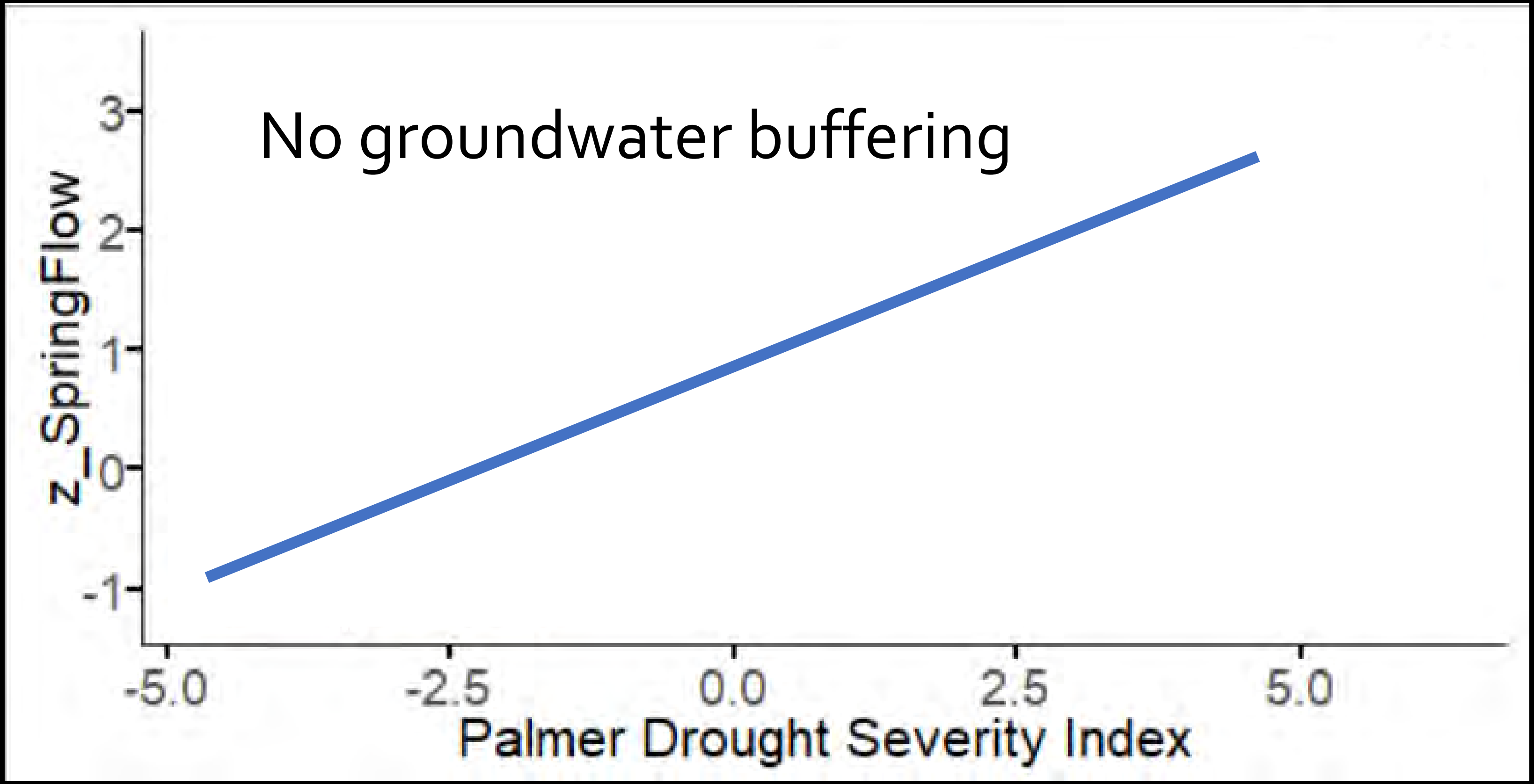




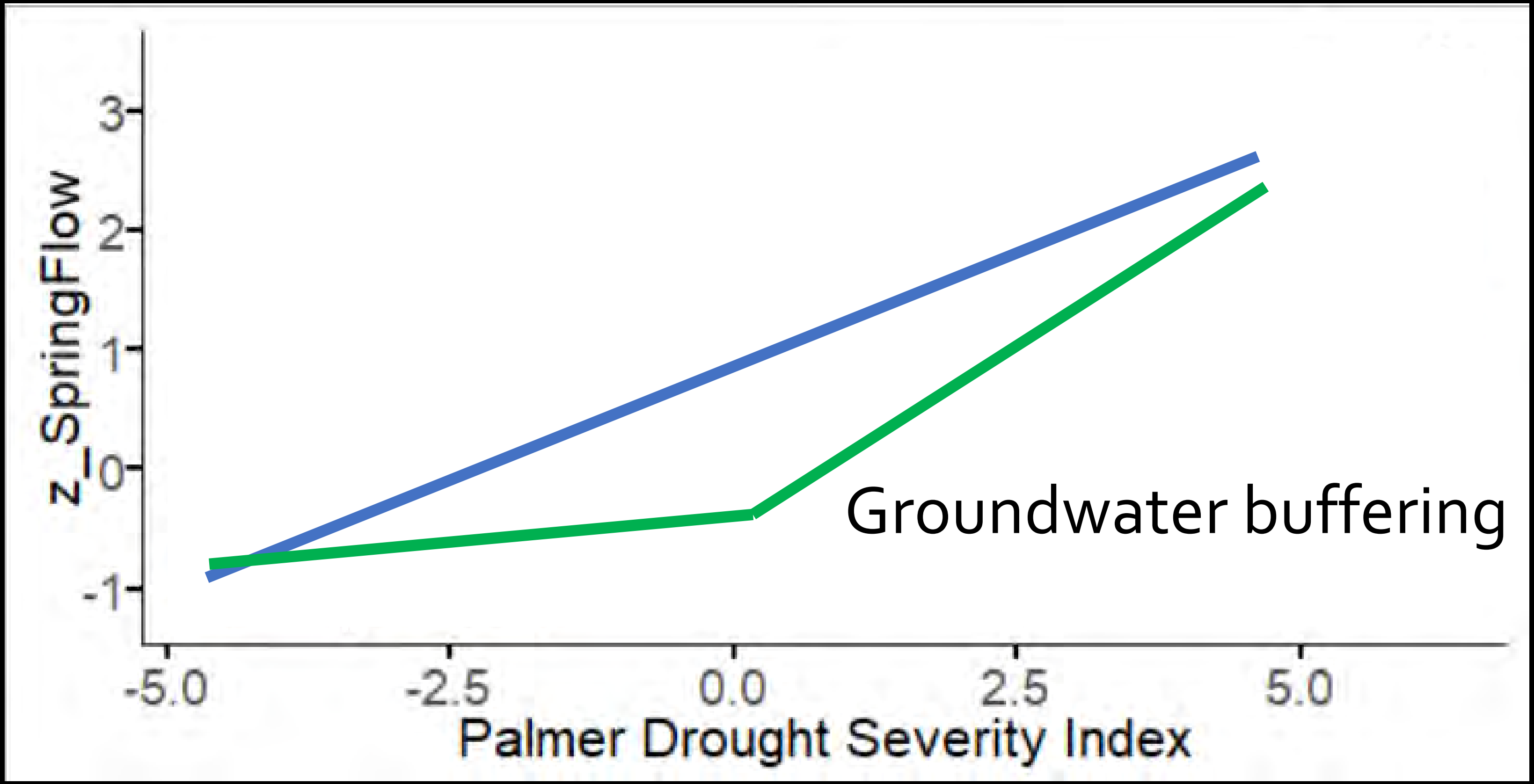
Below average spawners caused by drought?

- Spawner correlation with drought variables?
- Spawner correlation with non-drought variables that could mask drought impacts?

Groundwater buffering?



Groundwater buffering?



Restoration Elements of the Klamath River Renewal Project

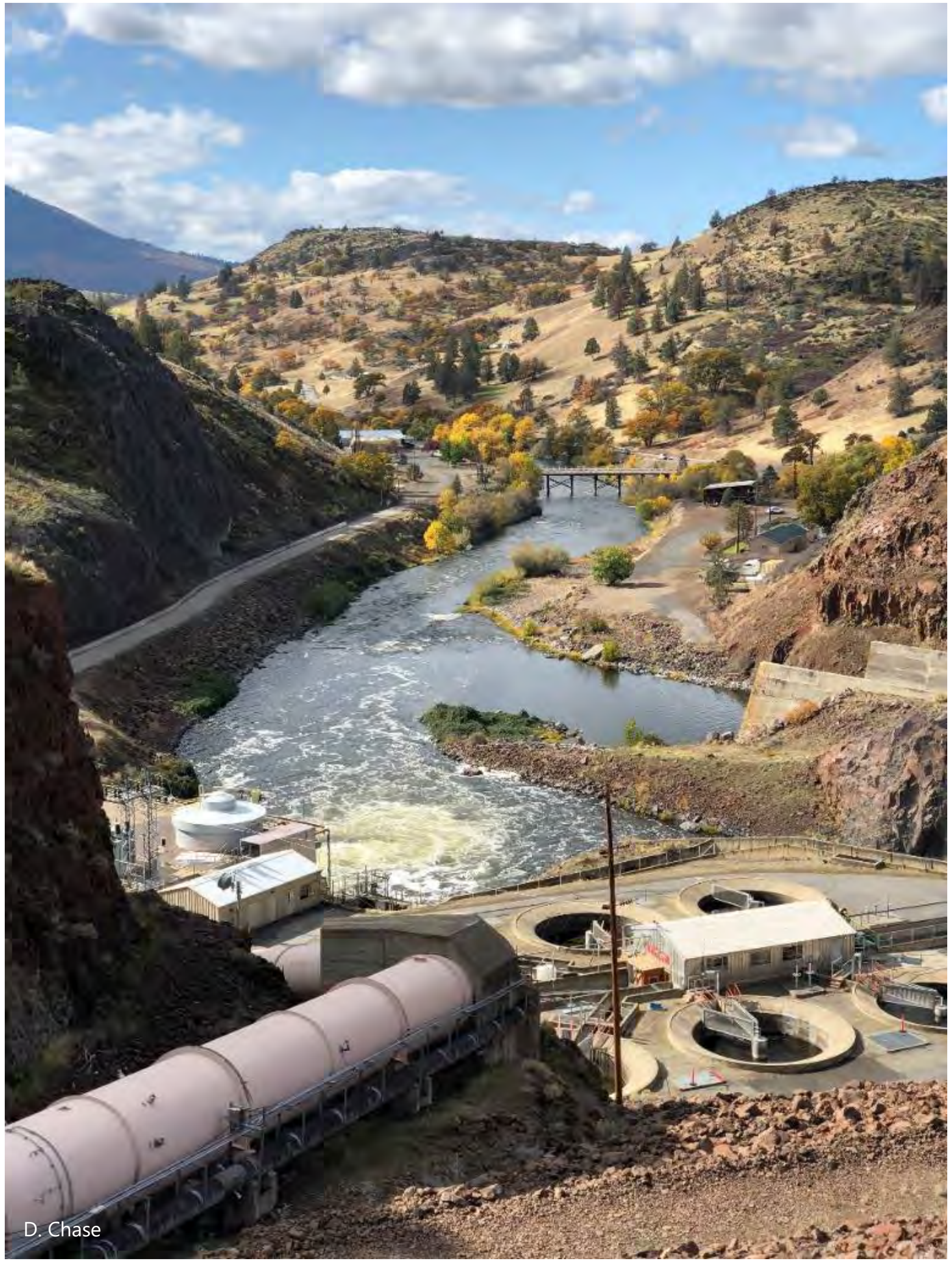
Salmonid Restoration Federation
April 22, 2022

Daniel Chase
Senior Fisheries Biologist

res
Restoring a resilient earth for a modern world

Presentation Overview

- Introduction
  - Who is RES?
  - Role on the KRRP project
  - Background
- Restoration Activities
  - Goals
  - Vegetation
  - Priority Restoration Areas
  - Design Approach and Elements
  - Restoration Activities
- Monitoring Performance



Who is RES?

RES is restoring a resilient earth for a modern world, project by project.

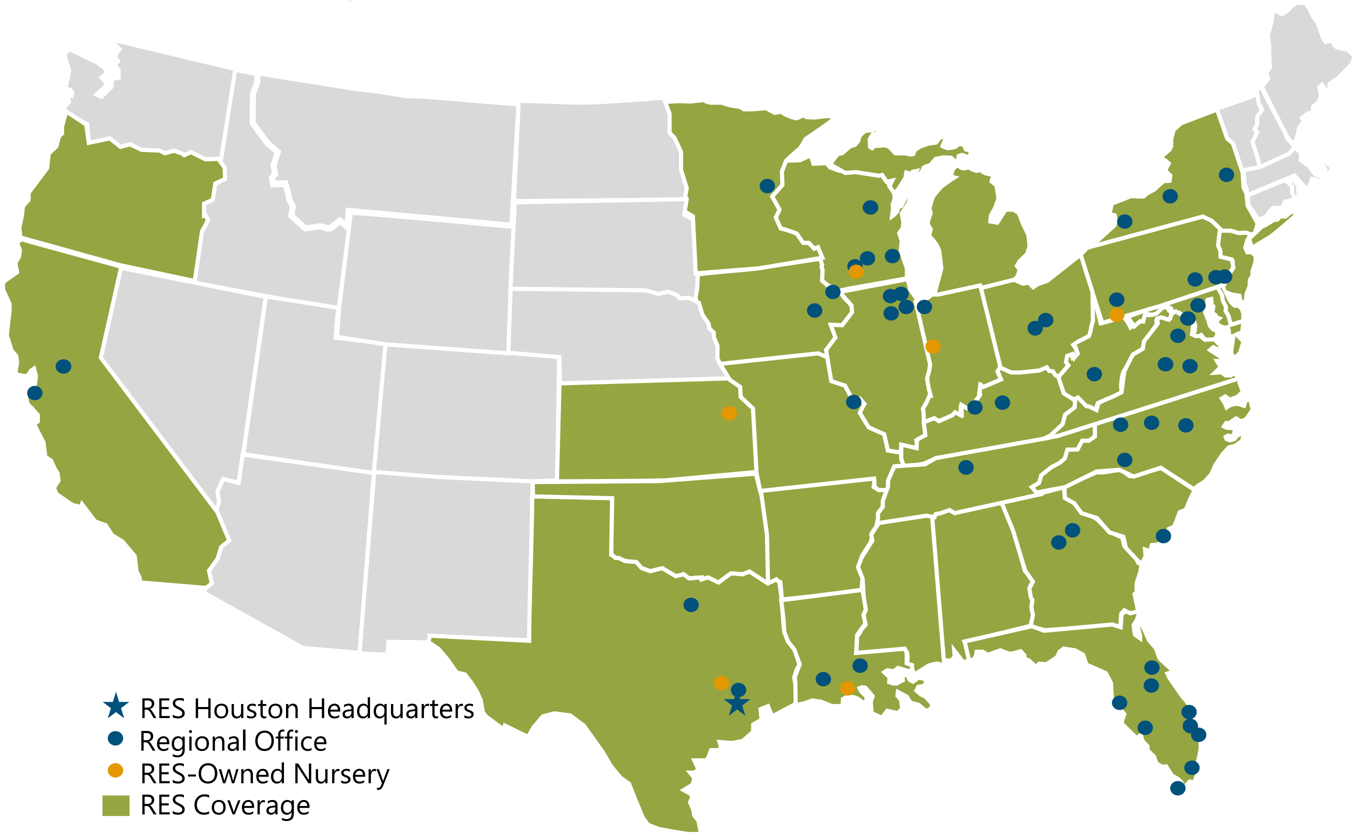
- Founded in 2007, inspired by notion that restoration can be a win/win for both humanity and the environment
- Nation's largest ecological restoration company, creating ecological uplift by doubling down on nature's own processes
- Pioneered how to make environmental mitigation markets work with a turnkey, total-stewardship business model
- Innovative ecological problem solvers dedicated to being long-term stewards of the earth

The ecological uplift of a mitigation project helps offset unavoidable impacts of infrastructure projects like highway expansions.

RES Today

Understanding the needs of the resource, client, regulators, and stakeholders at the nation, regional, and local levels.

- In-state teams with locally experienced, industry-leading talent
- Backed by national experts across the ecological disciplines
- Over 900 dedicated staff in 40 operational hubs



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Recognition

Fastest Growing

Inc. 5000

2010-2020

Project Merit Awards

Environmental Business Journal

Six-time Winner

Milestones

- Founded 2007
- KKR investment, 2016
- Awarded largest PRM mitigation contract in U.S. history, 2018
- Onex/KKR investment, 2022

Acquisitions

- E Sciences, 2022
- Sandra Walters Consultants, 2022
- LECON, 2021
- Applied Ecological Services, 2021
- Blueway, 2020
- Redwing Ecological Services, 2020
- Carolina Environmental Contracting, 2020
- Apache Environmental, 2018
- Angler Environmental, 2016
- EBX, 2014

Restoring our land and waters

406
Mitigation sites

22,900,00
Trees planted

73,932
Acres of restored and protected lands

607
Miles of streams restored and conserved

20,200
Acres of special-status species habitats

292
Tons of water quality nutrient reductions

RES' Role on Project

- Restoration Designer
- Restoration Contractor
- Regulatory approval support
- Implementation of biological conservation measures
- Long term monitoring and maintenance to meet performance criteria
- Performance guarantee

RES' Performance Guarantee

- How is success defined for Klamath (and other RES projects)?
  - Progressive Design-Build with Performance Guarantee
    - Preliminary design to advance permitting
    - Restoration contractor input on design and permitting
    - Success criteria and timeline developed by RES through collaboration with regulatory agency
    - Construction – self-perform or experienced subcontractors
    - RES is responsible for liability/success
    - Monitoring & maintenance – performed by RES
    - RES liable until success criteria are achieved and approved by regulatory agencies

Project Contributors

KLAMATH RIVER RENEWAL CORPORATION

McMILLEN JACOBS ASSOCIATES
CAMAS
Kiewit
res

Stantec
Knight Piésold CONSULTING
WSC Water Systems Consulting, Inc.
Kleinschmidt
AECOM
GMA HYDROLOGY
RDG
CDM Smith

AquaTerra CONSULTING
U.S. DEPARTMENT OF THE INTERIOR BUREAU OF LAND MANAGEMENT
CALIFORNIA CONSERVATION CORPS CCC EST. 1976
Caltrans
CALIFORNIA FISH PASSAGE FORUM
CALIFORNIA DEPARTMENT OF FISH & WILDLIFE
Coastal Conservancy
CALIFORNIA TROUT KEEPER OF THE STREAMS
COUNTY OF DEL NORTE EST 1857

FishPAC
GREAT SEAL OF THE KARUK TRIBE
KLAMATH RIVER RENEWAL CORPORATION
THE KLAMATH TRIBES KLAMATH MODOC YAHOOSKIN
NATIONAL FISH HABITAT PARTNERSHIP
NATIONAL PARK SERVICE
NRCS
The Nature Conservancy

NOAA FISHERIES
Mid Klamath Watershed Council
OREGON Fish & Wildlife
OREGON DEPARTMENT OF FORESTRY
PACIFICORP
PACIFIC STATES MARINE FISHERIES COMMISSION
Salmon River Restoration Council

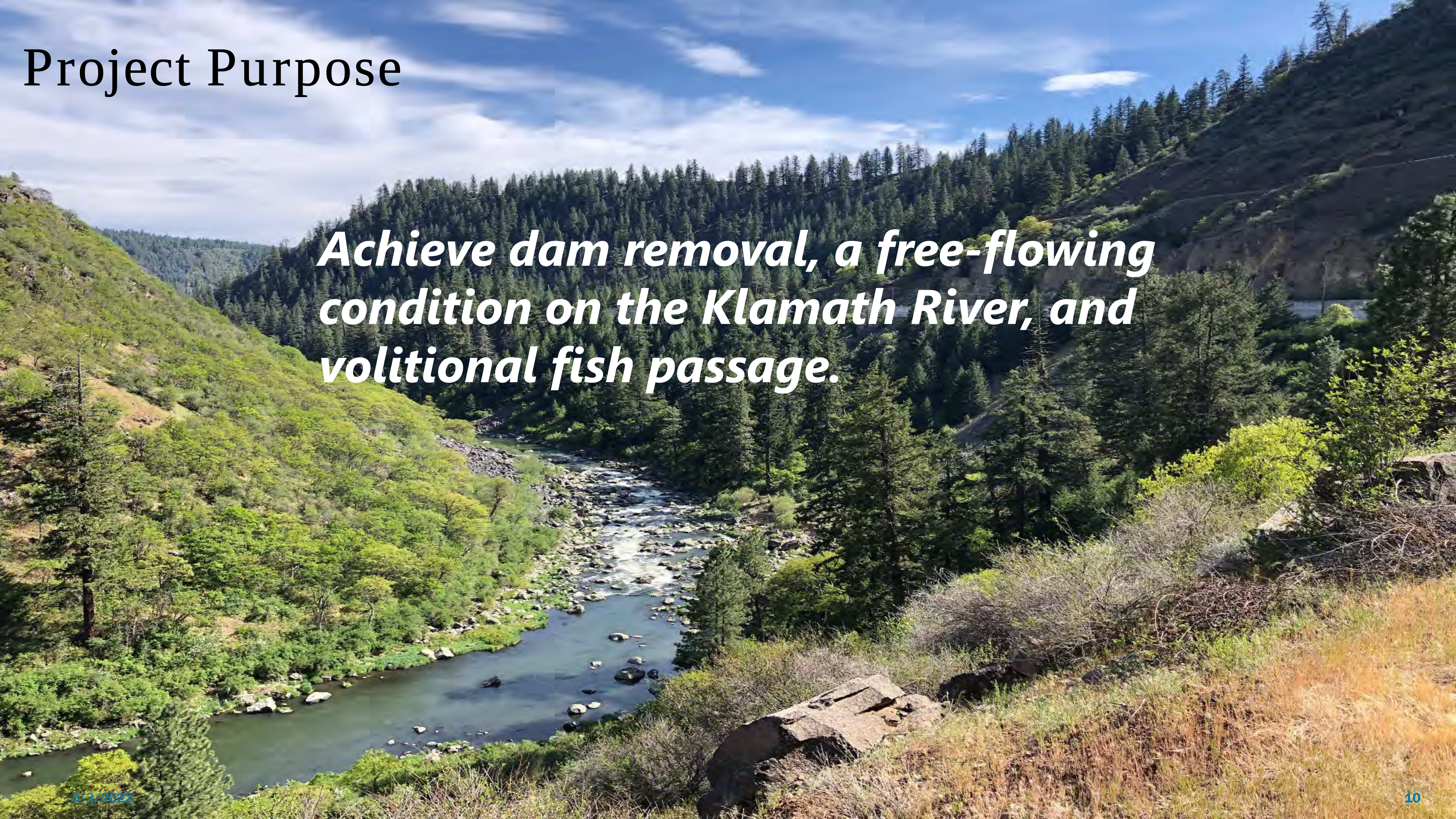
Scott River Water Trust
SCOTT RIVER WATERSHED COUNCIL
RCD SHASTA VALLEY RESOURCE CONSERVATION DISTRICT
SISKIYOU RESOURCE CONSERVATION DISTRICT RCD
TRINITY COUNTY CALIFORNIA
TROUT UNLIMITED
U.S. FISH & WILDLIFE SERVICE
FOREST SERVICE U.S. DEPARTMENT OF AGRICULTURE
WESTERN NATIVE TROUT INITIATIVE

Cultural Significance

Dams continue to impact cultural ceremonies, practices, and culturally-significant resources

Photo: kqed.org/news/11622280/fish-blood-in-their-veins-but-few-salmon-in-their-

Project Purpose



Achieve dam removal, a free-flowing condition on the Klamath River, and volitional fish passage.

Project Purpose

- Deconstruction of four hydroelectric dam facilities on the Klamath River:
  - J.C. Boyle Dam
  - Copco No. 1 Dam
  - Copco No. 2 Dam
  - Iron Gate Dam

These dams do *not* provide flood control, water for agriculture, or drinking water.

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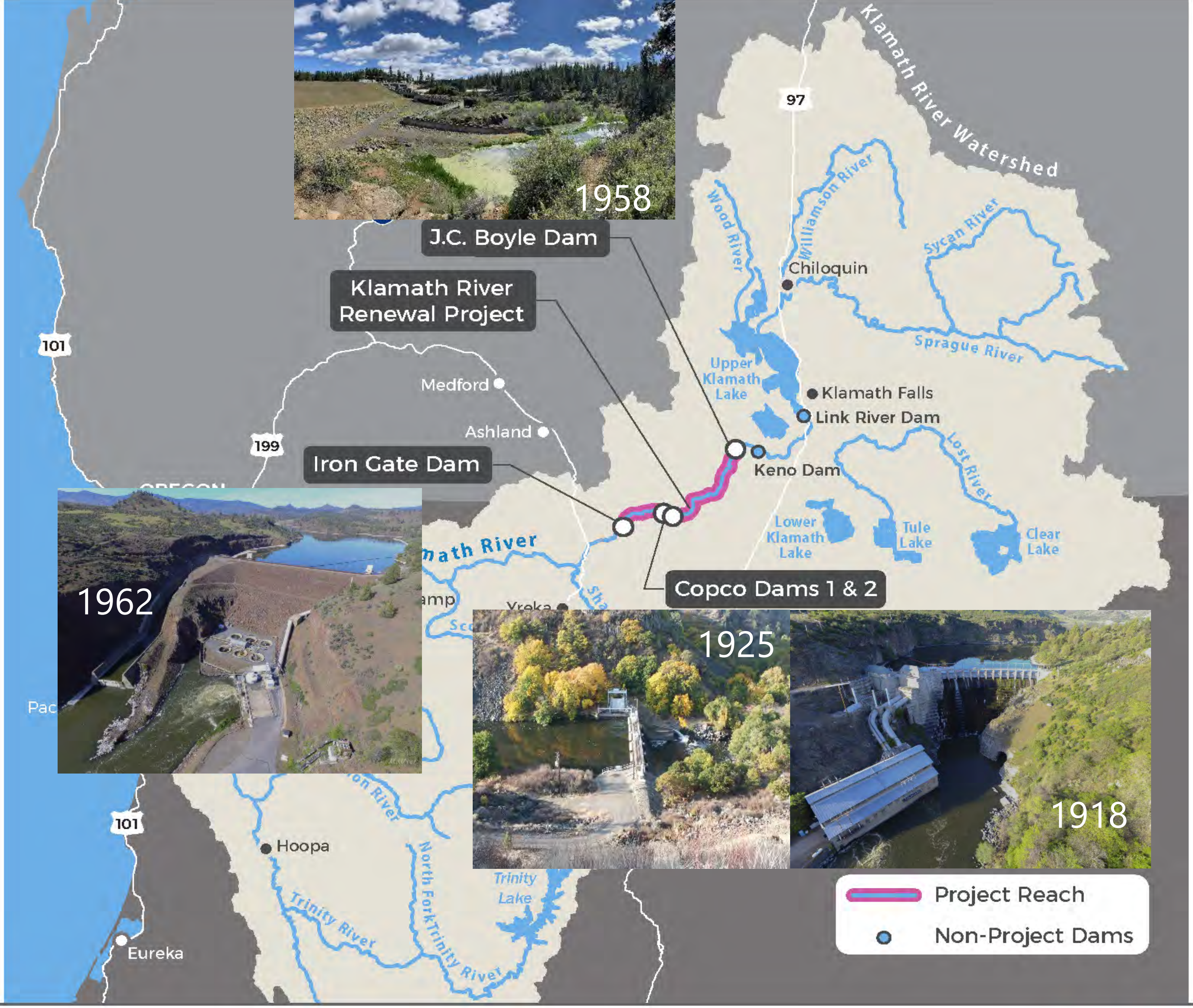


Project Vicinity Map
Klamath River Renewal Project

Ecological Issues

- Reduced water quality
  - Toxic algae blooms in reservoirs
  - Below dams, increased temperature and decreased oxygen
  - Increased prevalence of fish health issues [e.g., *Ceratonova shasta, Ichthyopthirius multifiliis* (ICH), bacterial pathogen columnaris *(Flavobacter columnare)*]
- Imperiled Fish Populations
  - Threatened and endangered species
  - Tribal, commercial, and recreational fishing closures

Photo: Joe Cavaretta/ Associated Press in New York Times Aug 22, 2015

Algal bloom in Iron Gate Reservoir
Photo: EcoFlight; from: klamathrenewal.org

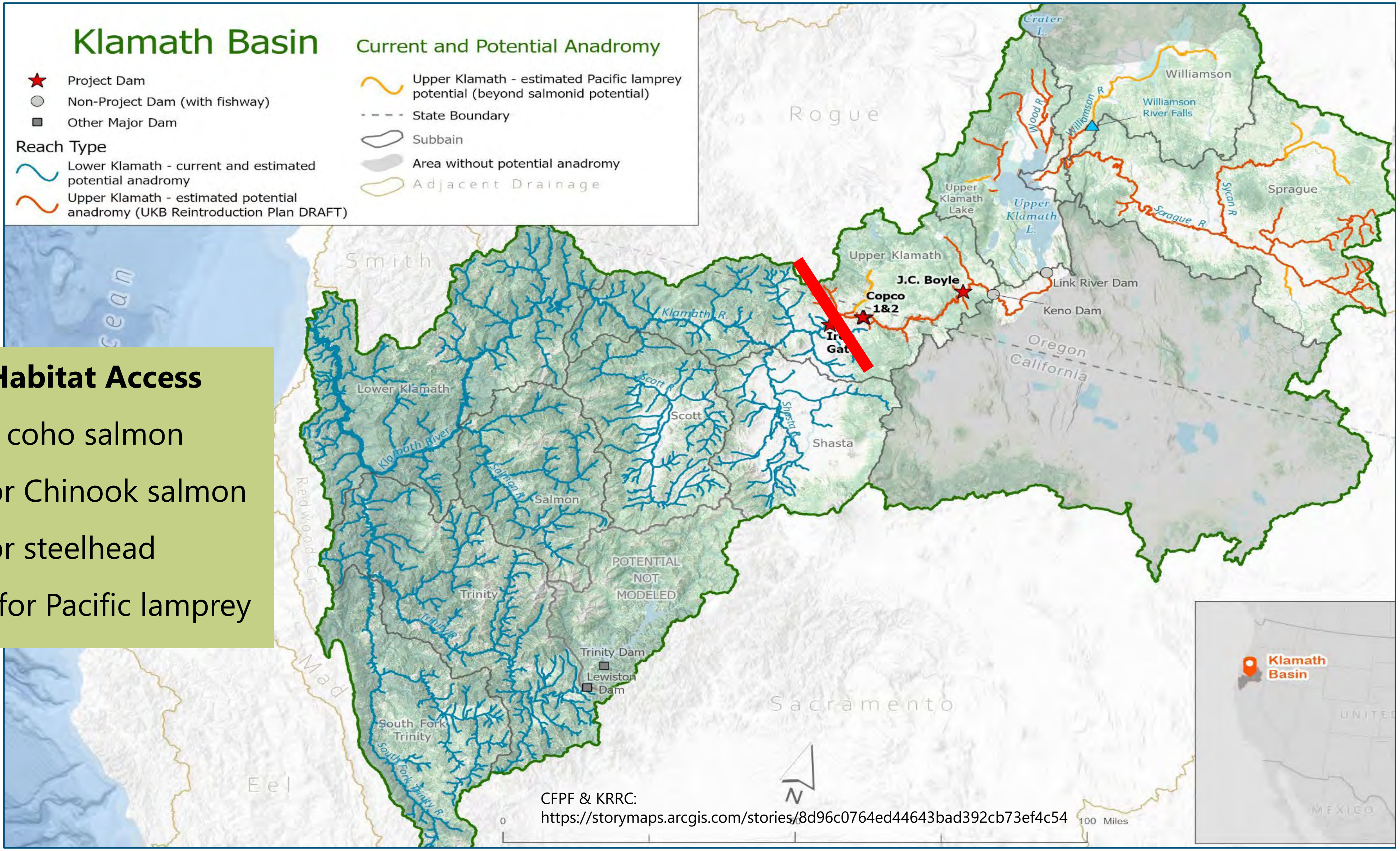
Algae sample.
Photo: Karuk Tribe; from: klamathrenewal.org

Ecological Benefits

- Improve water quality, water temperature, and flow
- Significantly reduce nuisance algae
- Sediment and debris transport
- Significantly reduce disease
- Restore access to historical habitat

Coho salmon
Photo: Karuk Tribe; from: klamathrenewal.org

Ecological Significance



Restored Habitat Access

- 76 mi for coho salmon
- 300 mi for Chinook salmon
- 420 mi for steelhead
- >420 mi for Pacific lamprey

CFPF & KRRC:
https://storymaps.arcgis.com/stories/8d96c0764ed44643bad392cb73ef4c54

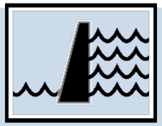
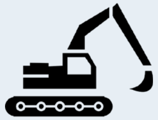
Restoration Activities


G. Troop


G. Troop


J. Chenoweth

Schedule Periods

Period	Actions	Duration
Pre-drawdown 	Preparation Actions and Pre-drawdown Construction	1-year period*
Restoration Construction 	Drawdown, Dam Removal, and Restoration Construction Years 1 and 2	2-year period*
Monitoring and Maintenance 	Maintenance and Monitoring Actions	5-year period**

*=pending timing of FERC/Gov Approvals in place
**= anticipated year performance criteria will be achieved

Pre-Drawdown Fisheries Work

Salvage and relocation of Lost River and Shortnose Suckers

Lost River Sucker – C'waam

Shortnose Sucker - Koptu

Mainstem salvage of overwintering juvenile Coho Salmon

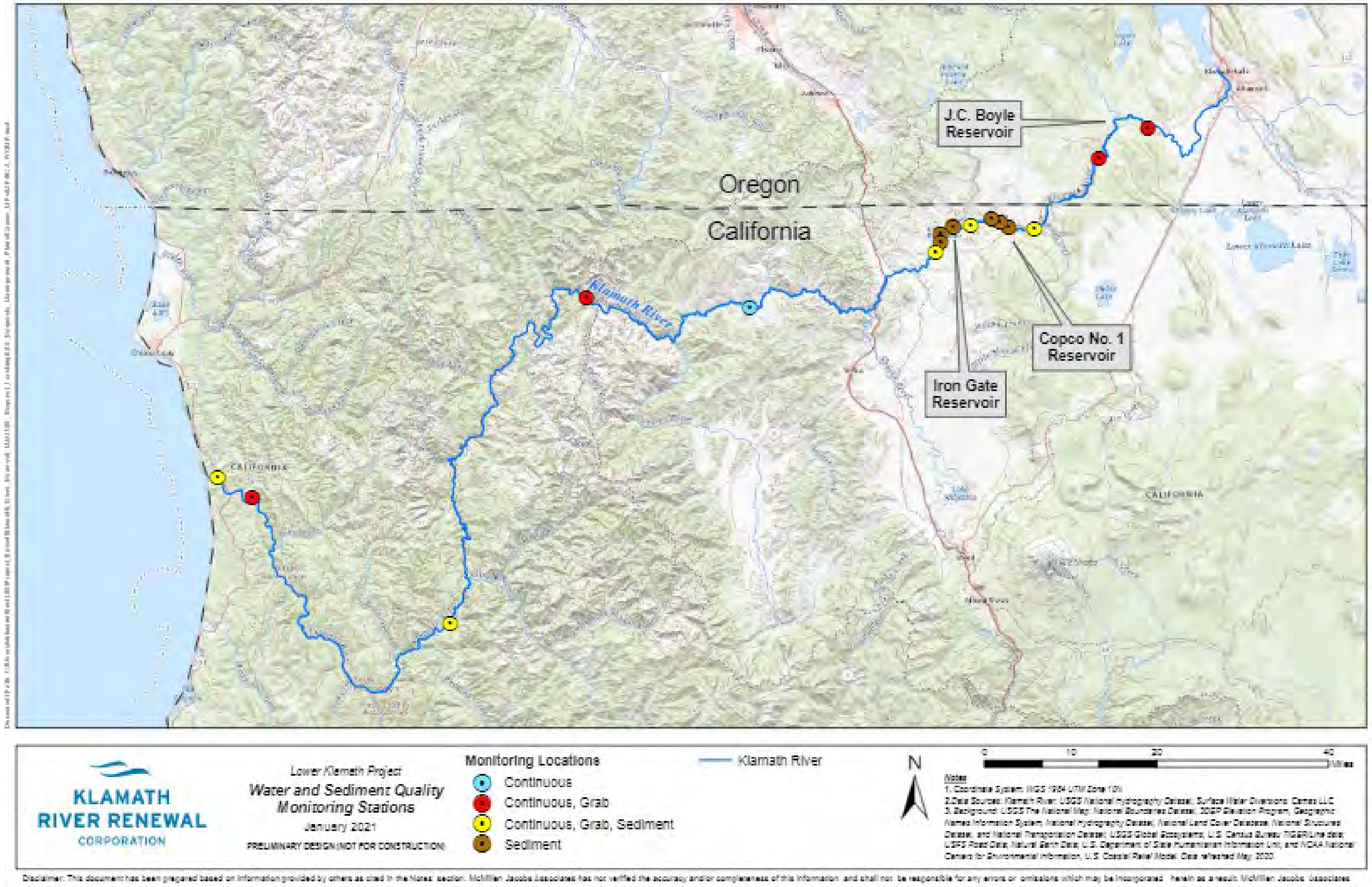
Coho salmon parr

River seining

Drawdown Fisheries Work

Juvenile Salmonid Capture and Relocation

Water Quality Monitoring



Restoration Goals

Free Flowing River

- Fish Passage

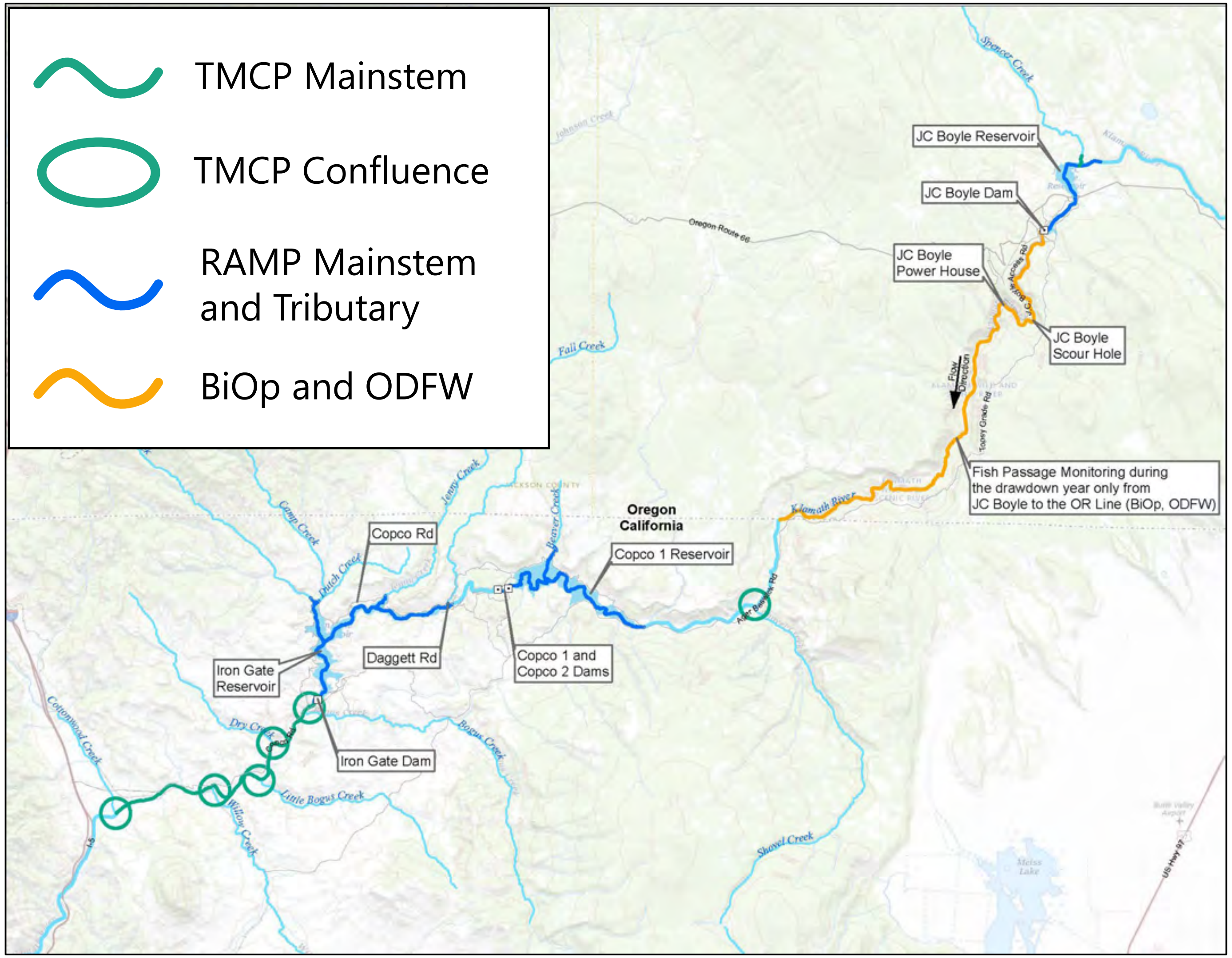
Stabilization of Remaining Sediments

- Supplemental Sediment Evacuation and Sediment Stabilization through Revegetation

Habitat Enhancement

- Large Wood, Habitat Complexity within and along tributary channels

Free Flowing River: Fish Passage Monitoring



Restoration Elements

Sediment Stabilization & Habitat Enhancement

1. Seed Collection and Yield Increase
2. IEV Treatment
3. Reservoir Area & Tributary Restoration
4. Large Wood Placement

Seed Collection & Propagation

- Collect seed directly from the watershed
  - Seed collection began in 2018 and continues
  - Seeds collected from +/- 29 native, species present in the watershed
- Purchase geographically & genetically appropriate seeds to supplement
- Goal is to collect 40-60K seeds/~9 billion seeds!
  - Enough to seed newly exposed reservoir footprints, twice
- Target application rate of 80 seeds/sq.ft.

Seed Collection Team

Seed Cleaning

Klamath plum (*Prunus subcordata*)

Native Plant Palette

- Collect native species from the watershed
- Select species for propagation or direct dispersal

Poppy

Royal Penstemon

Lupine

Ceonothus

Turkey Mullein

Lomatium sp.

Lomatium seed

Yarrow

Smooth Blazing Star

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Invasive Exotic Vegetation (IEV) Management Goals

Minimize IEV abundance at all restoration sites

- Control IEV dispersal into restoration areas after dam removal
- Maintain IEV-free zones around access roads and staging areas
- Ensure early detection and eradication of IEV within restoration sites

IEV Control Methods

- Grubbing (physical removal)
- Mowing or cutting
- Solarization
- Herbicides
- Other Possible Methods (Grazing/Tilling and/or disking)

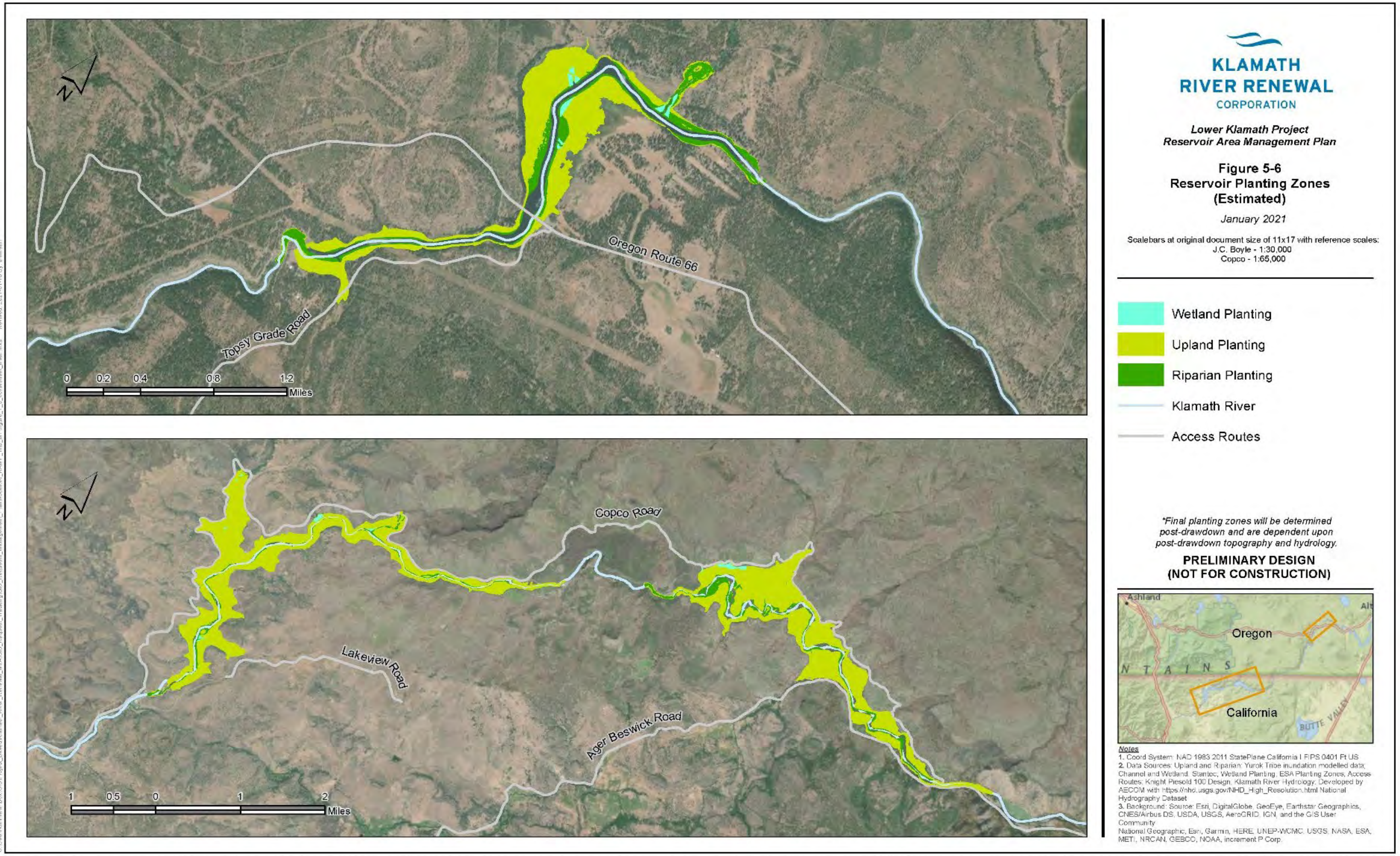
Restoration Approach

G. Troop

- Post-drawdown lakebed surveys
  - LiDAR and Photogrammetric Surveys
  - Supplemental ground surveys
- 60% Design progressed to 90% Design post-drawdown
  - 90% Design progressed to FINAL Design
- Reservoir areas and high priority tributaries
  - *JC Boyle:* Spencer Creek
  - *Copco No. 1*: Beaver Creek
  - *Iron Gate:* Jenny Creek, Scotch Creek, Camp Creek

Restoring the Reservoir Footprint: Copco Example

Pioneer Seeding



Disclaimer: This document has been prepared based on information provided by others as cited in the Notes section. McMillen Jacobs Associates has not verified the accuracy and/or completeness of this information and shall not be responsible for any errors or omissions which may be incorporated herein as a result. McMillen Jacobs Associates assumes no responsibility for data supplied in electronic format, and the recipient accepts full responsibility for verifying the accuracy and completeness of the data.

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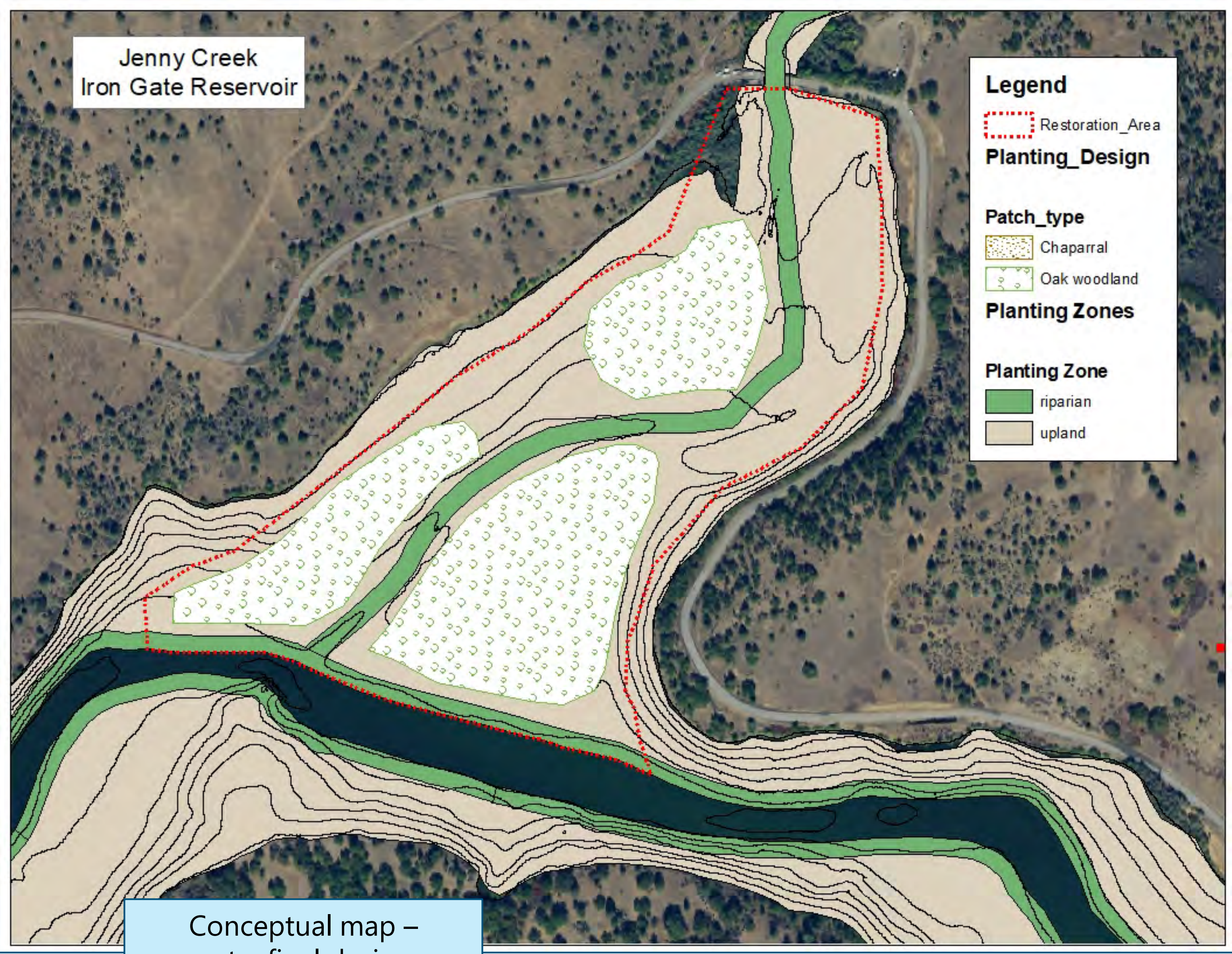
Diversity Seeding

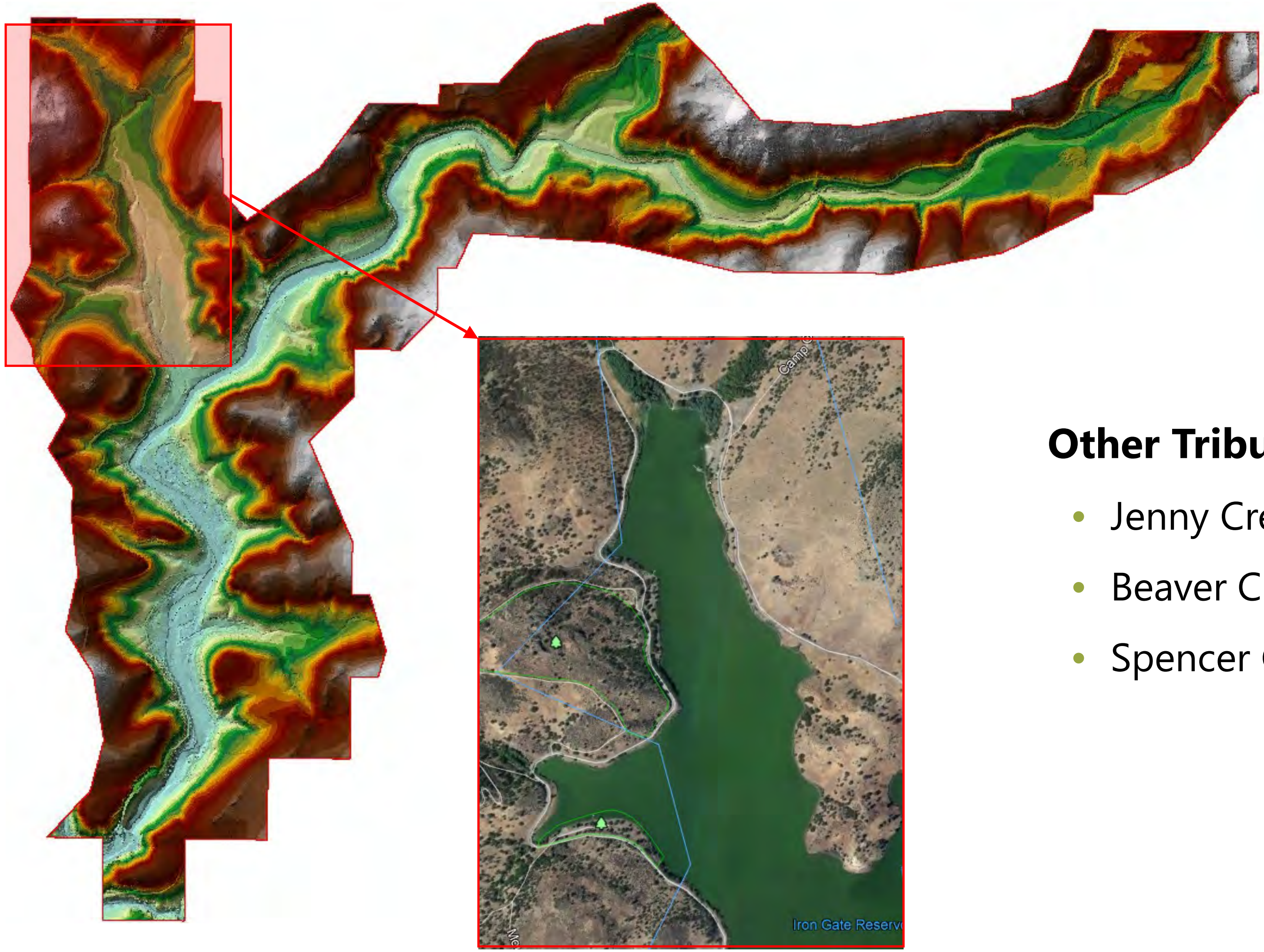


Conceptual map – not a final design

High Priority Tributaries – Camp/Scotch Creek

Restoration Considerations

- Fish passage
- Response at delta deposits
- Compatibility with new culvert designs
- Form (single- or multi-thread)



Other Tributaries

- Jenny Creek
- Beaver Creek
- Spencer Creek

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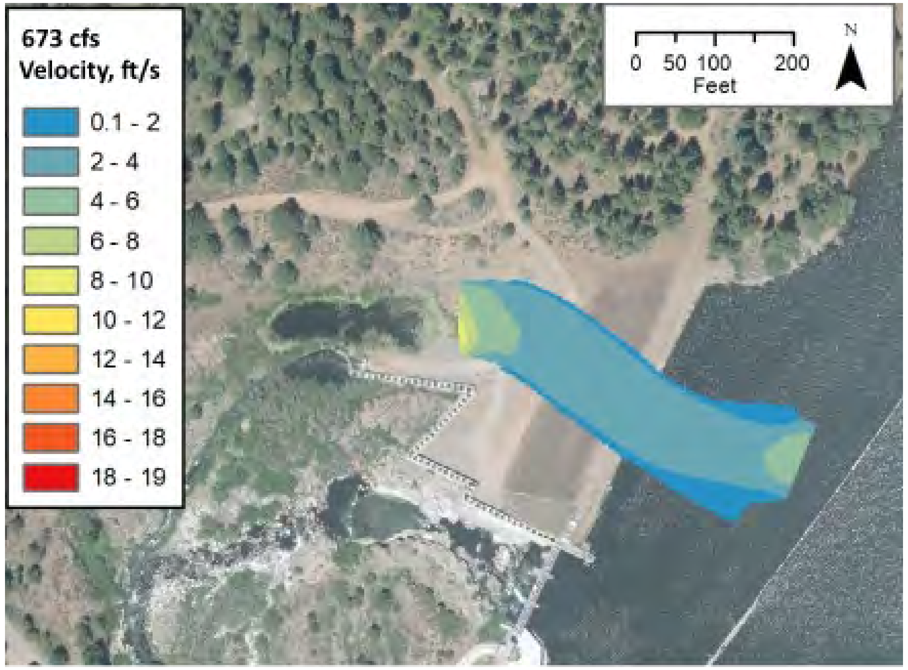
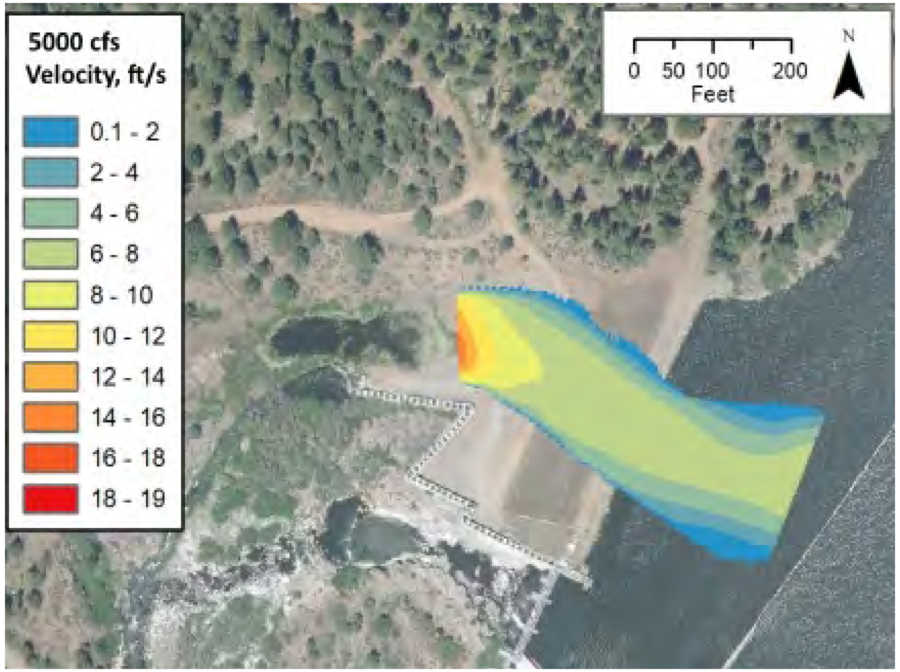
Large Wood Placement

Helicopter Placement

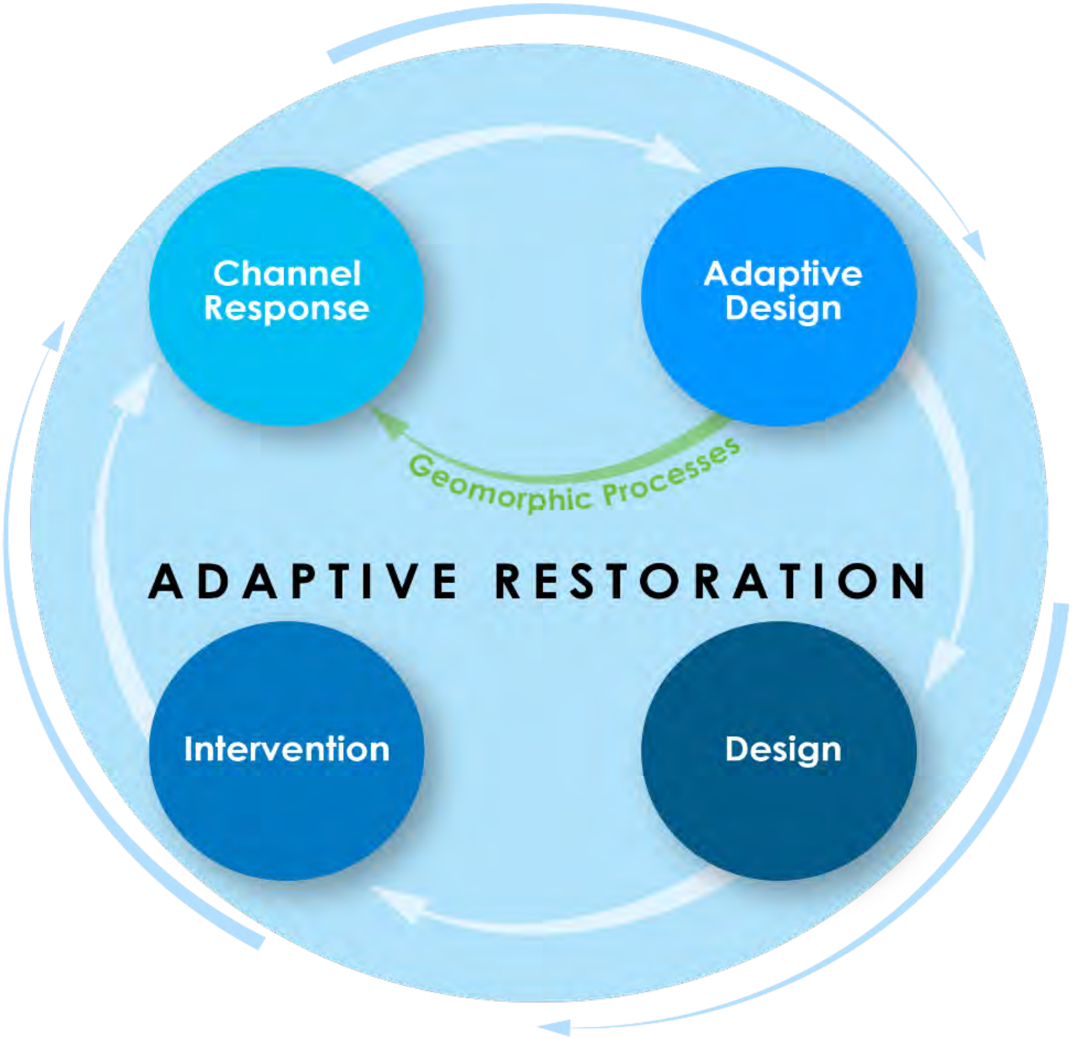
Ground Based Placement

Restoration Activities: Former Dam Footprint





Adaptive Design Feedback Loop



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Monitoring Performance

Restoration Plan Component	Monitoring Element
Riparian and Upland Revegetation	Native Vegetation
IEV Management	% IEV Vegetation
Reservoir Areas	Sediment Stability
Priority Tributaries	Fish Passage
	Bank Stability
	Floodplain Connectivity
	Floodplain Roughness
	Channel Fringe Complexity
Klamath River	Fish Passage
Dam Footprints	Fish Passage

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Additional Monitoring & Resource Measures

Monitoring

- Water quality
- Fish passage
- Fish presence
- Sediment stability
- Landscape photo points

Resource Measures

- Sucker (C'waam & Koptu) rescue and relocation
- Mainstem rescue and relocation of overwintering juvenile coho
- Juvenile salmonid rescue and relocation
- Spawning habitat availability

Management Plans (MP)

- Reservoir Area MP
- Terrestrial and Wildlife MP
- Water Quality MP
- Aquatic Resources MP
  - AR-6 – Suckers (CA & OR)
  - Fish Presence Monitoring Plan
  - Juvenile Salmonid and Pacific Lamprey Rescue and Relocation Plan
  - Spawning Habitat Availability Report and Plan

Restoration Activities: JC Boyle Rendering

Project Contacts

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Gwen Santos
Lead Ecologist
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Dave Meurer
Director of Community Affairs
dmeurer@res.us

res.us/klamath

Websites

Klamath River Renewal Corporation:
https://www.klamathrenewal.org/

RES Klamath Website: res.us/klamath

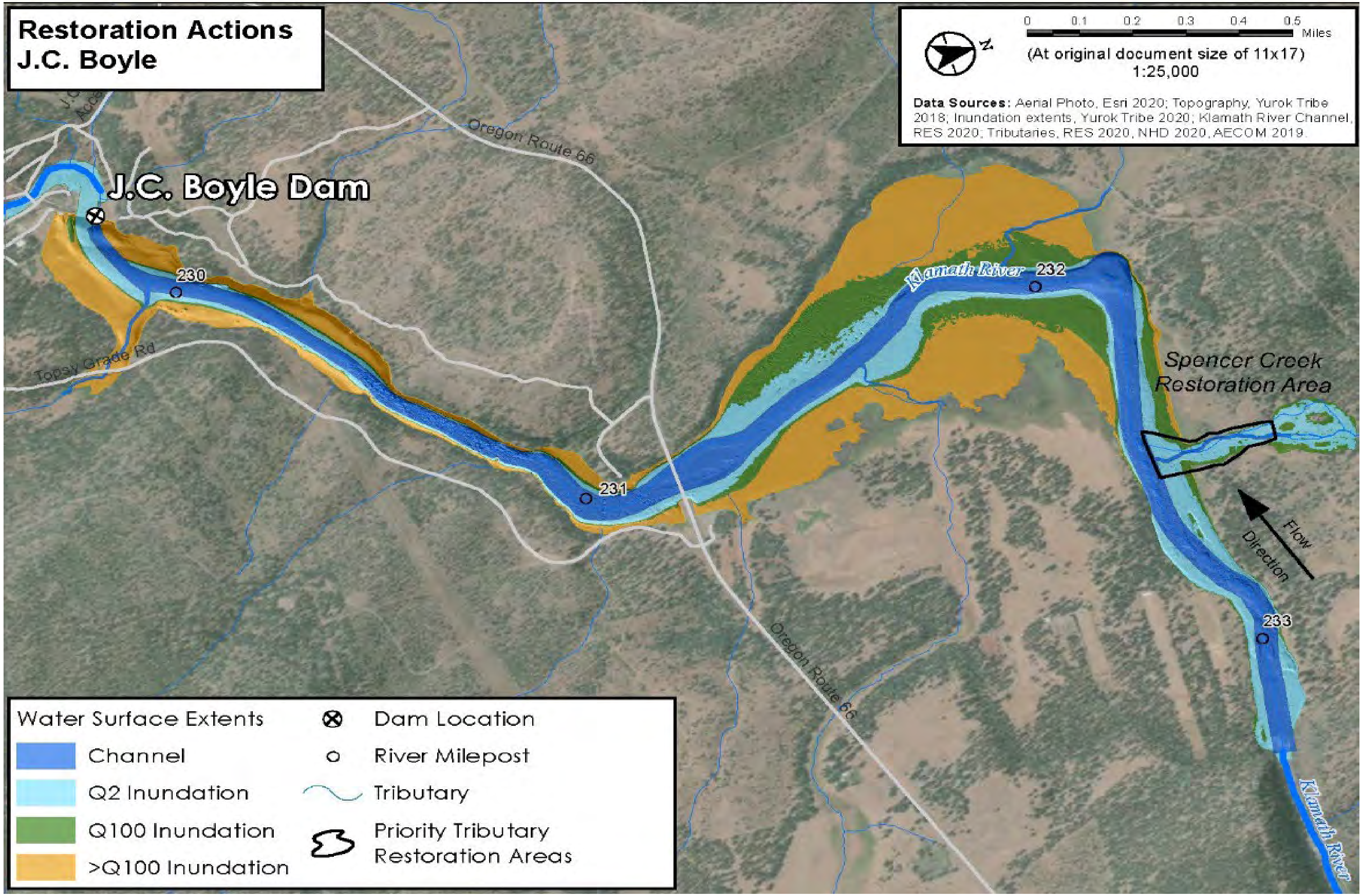
FERC eLibrary Submittal Updated Management Plans:
https://elibrary.ferc.gov/eLibrary/filelist?accession_num=20211214-5058

FERC eLibrary Submittal ALSA:
https://elibrary.ferc.gov/eLibrary/filelist?document_id=14908104&accessionnumber=20201117-5191

Preparing the Klamath Basin for Dam Removal Story Map:
https://storymaps.arcgis.com/stories/8d96c0764ed44643bad392cb73ef4c54

Guardians of the River:
https://www.youtube.com/watch?v=e5lcP_9ateE

J.C. Boyle Restoration Areas



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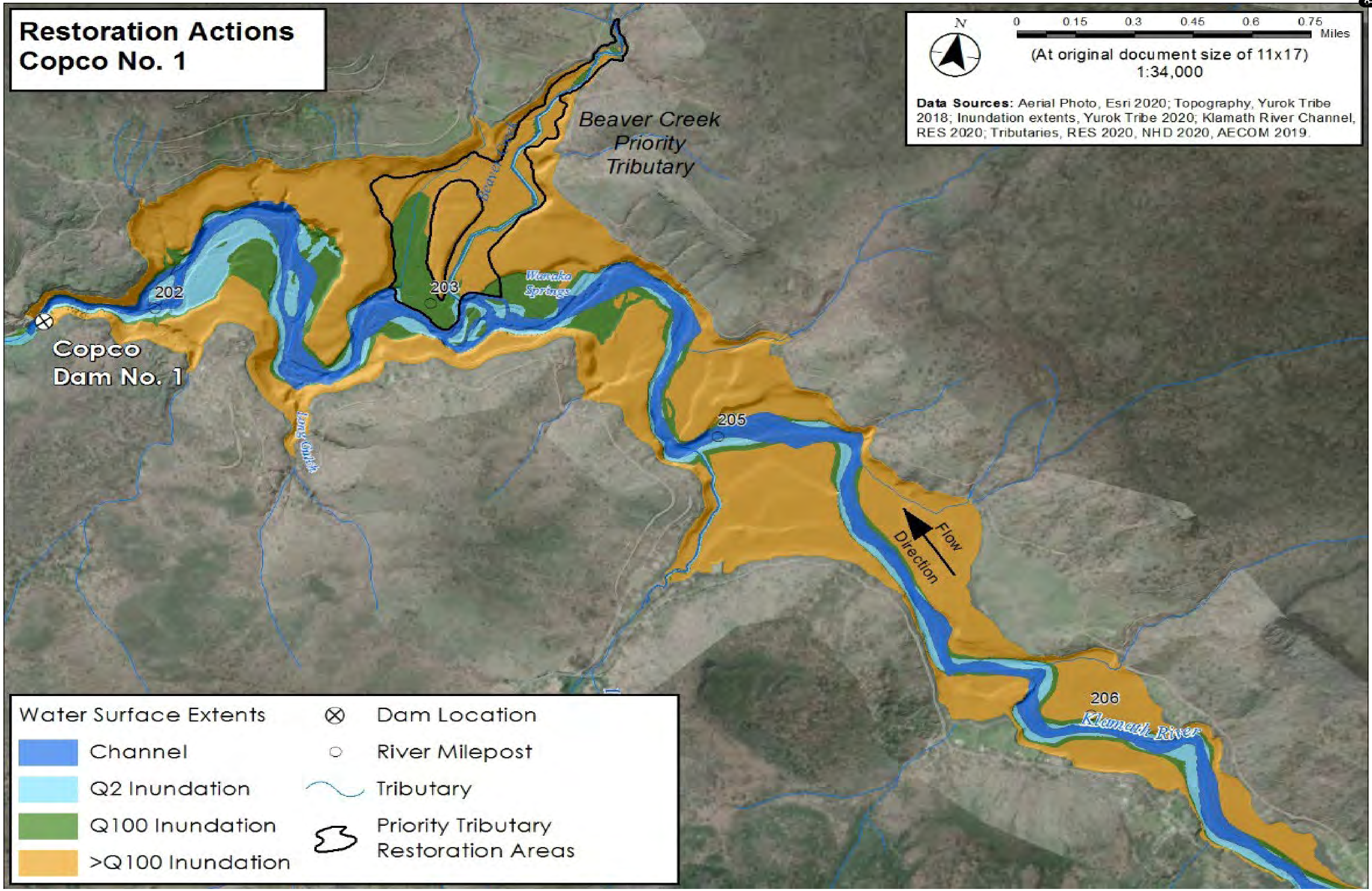
Copco Lake Restoration Areas



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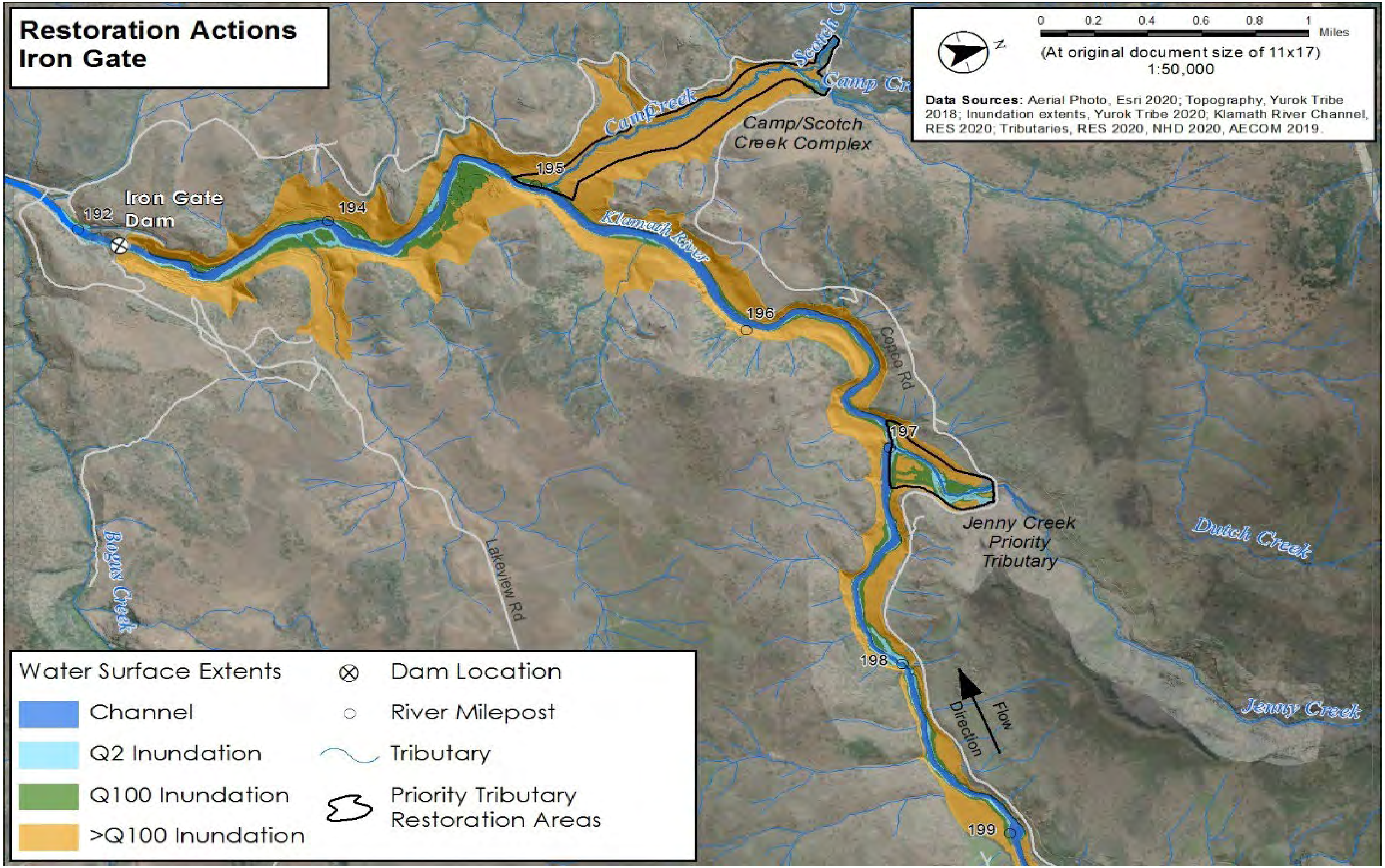
Iron Gate Reservoir Restoration Areas



Project Contacts

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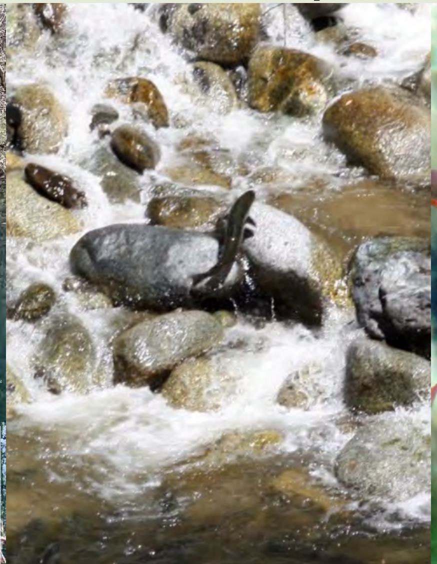
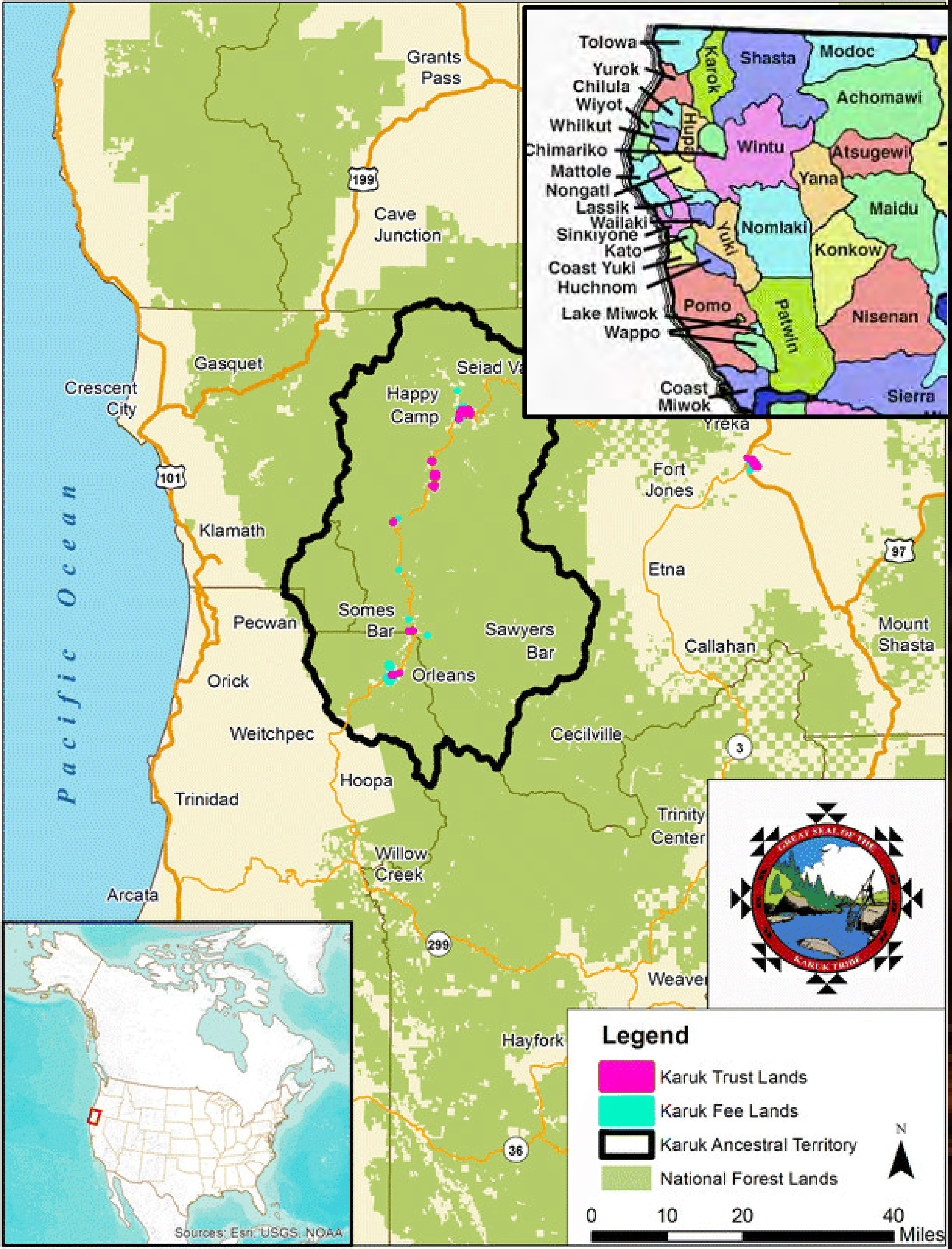
Restoring Key Coho Salmon Habitat in the Klamath River to Increase Population Resilience to Climate/Drought/Wildfire Impacts

Will Harling - Director

Mid Klamath Watershed Council



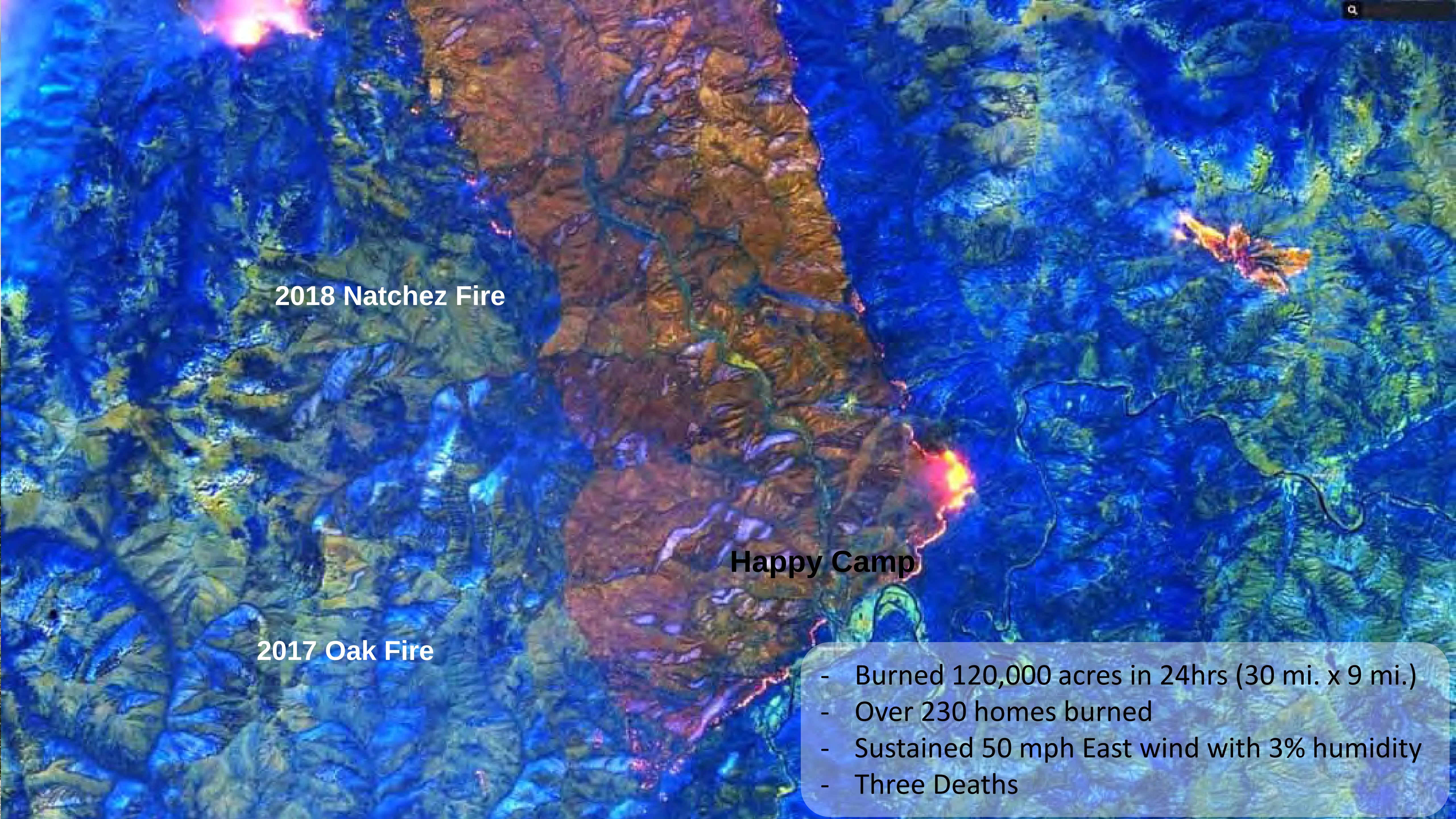

Tolowa
Yurok
Chilula
Wiyot
Whilkut
Chimariko
Mattole
Nongatl
Lassik
Wailaki
Sinkiyone
Kato
Coast Yuki
Huchnom
Lake Miwok
Wappo
Coast Miwok
Karok
Hupa
Shasta
Modoc
Achomawi
Wintu
Atsugewi
Yana
Maidu
Yuki
Nomlaki
Konkow
Pomo
Patwin
Nisenan
Sierra
Grants Pass
Cave Junction
Gasquet
Crescent City
Happy Camp
Seiad Va
Yreka
Fort Jones
Klamath
Etna
Mount Shasta
Somes Bar
Sawyers Bar
Pecwan
Orleans
Callahan
Orick
Weitchpec
Cecilville
Hoopa
Trinidad
Trinity Center
Willow Creek
Arcata
Weaver
Hayfork
Pacific Ocean
199
101
97
3
299
36
GREAT SEAL OF THE KARUK TRIBE
Legend
Karuk Trust Lands
Karuk Fee Lands
Karuk Ancestral Territory
National Forest Lands
N
0
10
20
40
Miles
Sources: Esri, USGS, NOAA

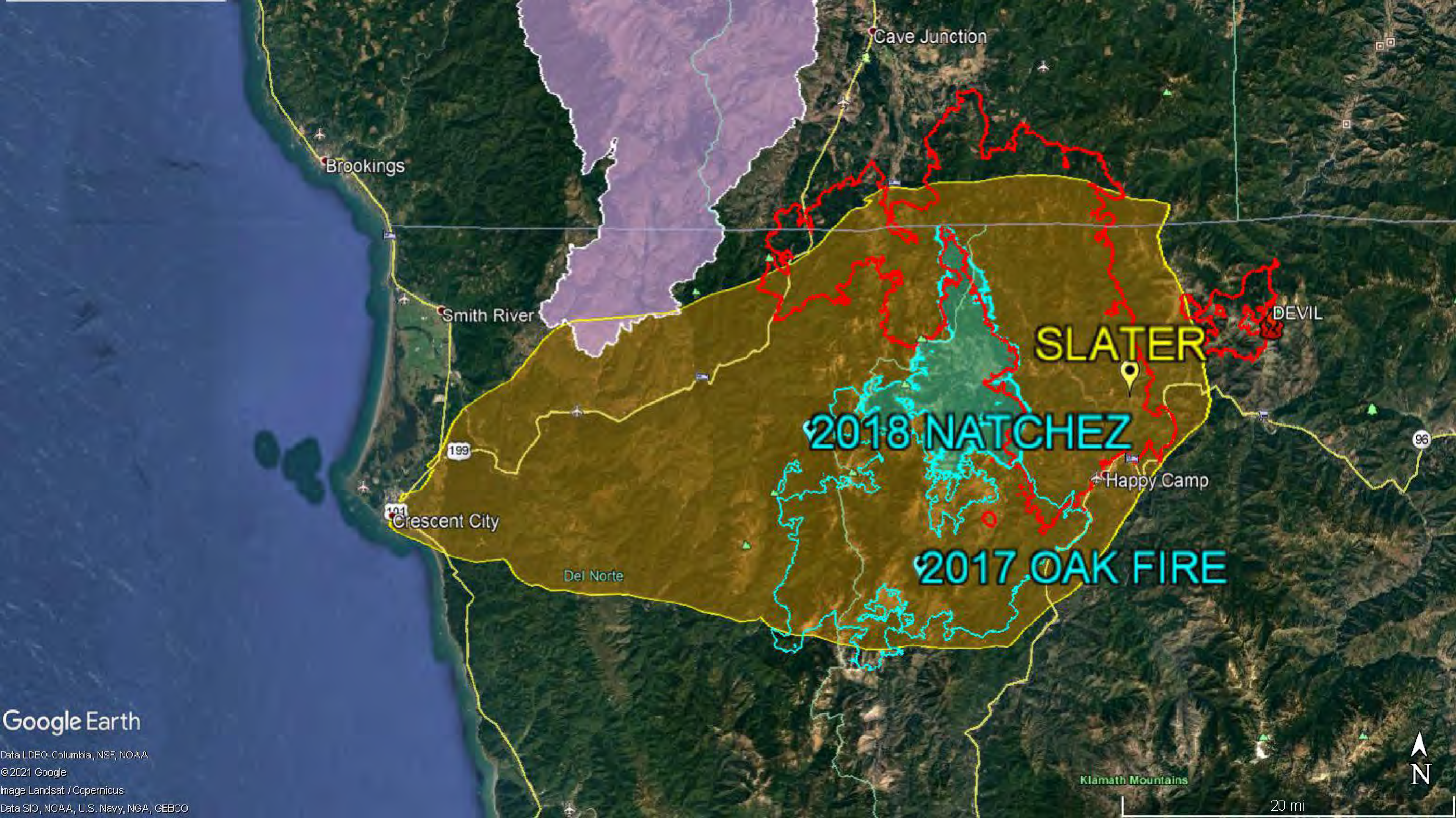



NF Salmon River After 1987 Fires

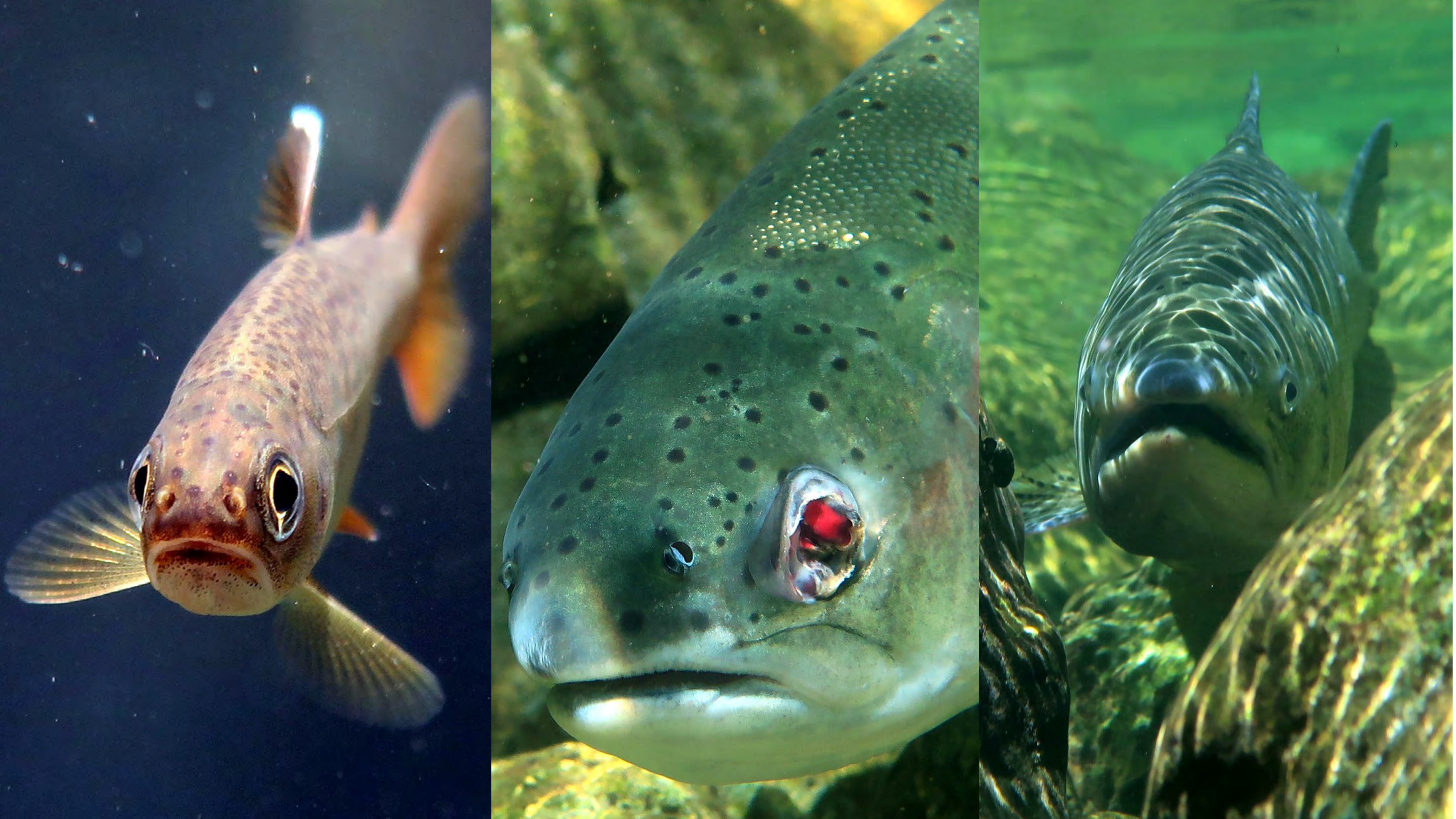
Mid Klamath Watershed Council

MKWC and tribal partners are building a restoration-based economy in the Western Klamath Mountains. We are results oriented and work through developed partnerships to plan and implement projects based on traditional cultural knowledge and the best available western science.


2018 Natchez Fire
Happy Camp
2017 Oak Fire
- Burned 120,000 acres in 24hrs (30 mi. x 9 mi.)
- Over 230 homes burned
- Sustained 50 mph East wind with 3% humidity
- Three Deaths

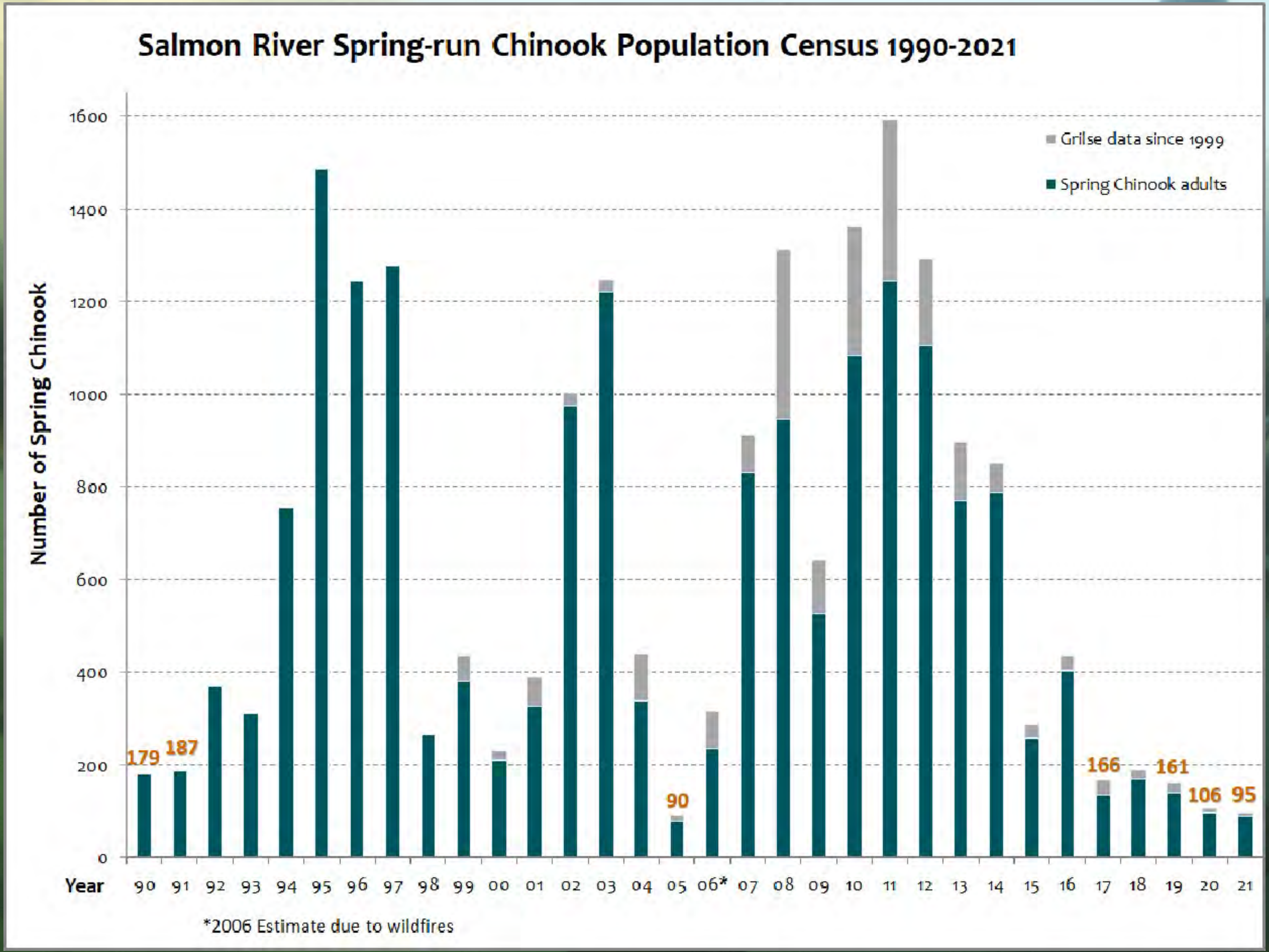

Cave Junction
Brookings
Smith River
SLATER
DEVIL
2018 NATCHEZ
Happy Camp
199
96
101
Crescent City
2017 OAK FIRE
Del Norte
Google Earth
Data LDEO-Columbia, NSF, NOAA
© 2021 Google
Image Landsat / Copernicus
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Klamath Mountains
N
20 mi






Spring Chinook Salmon - Lower Clear Creek

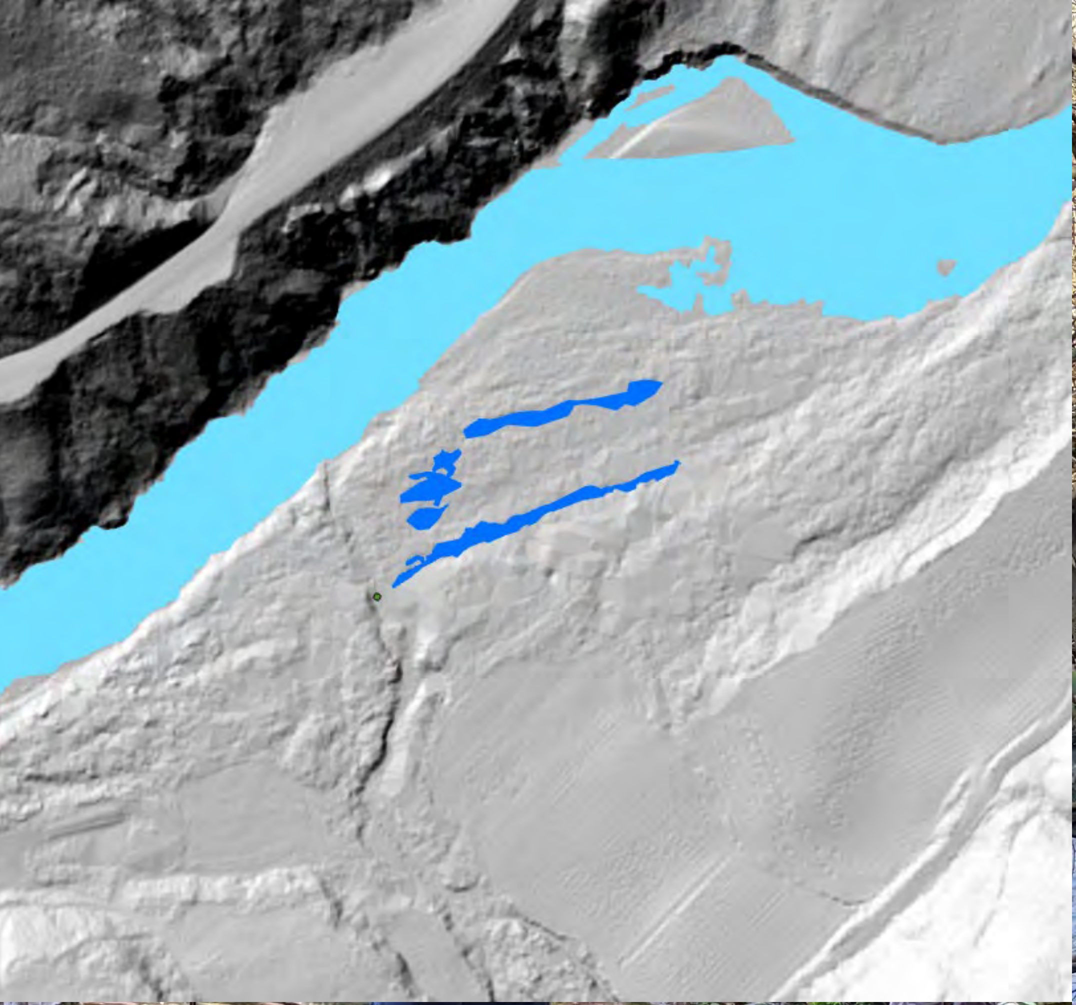

2014: Boulder Gulch – NF Salmon River – Spring Chinook Rotting Under Ledge



Salmon River Spring-run Chinook Population Census 1990-2021
Grilse data since 1999
Spring Chinook adults
Number of Spring Chinook
0
200
400
600
800
1000
1200
1400
1600
179
187
90
166
161
106
95
Year
90 91 92 93 94 95 96 97 98 99 00 01 02 03 04 05 06* 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21
*2006 Estimate due to wildfires

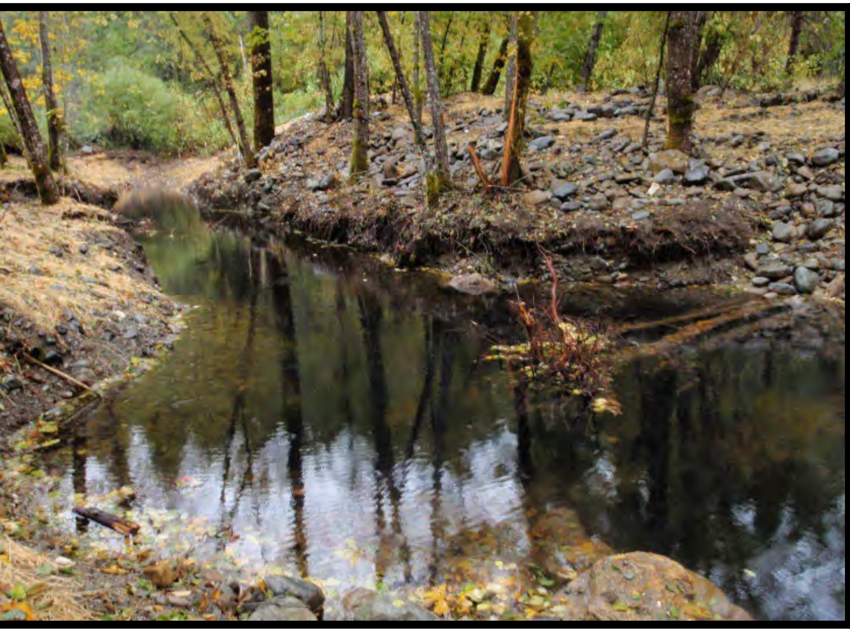
SOLASTALGIA

Solastalgia (/ˌsɒləˈstældʒə/) is a neologism, formed by the combination of the Latin words *sōlācium* (comfort) and the Greek root *-algia* (pain, suffering, grief), that describes a form of emotional or existential distress caused by environmental change. It is best described as the lived experience of negatively perceived environmental change.

Connected over 26,000 square feet of existing beaver ponds using Beaver Dam Analogues (BDAs) in Boise Creek to salmon

Off-Channel Habitat Construction for Juvenile Coho Salmon (2010 – Present)



- 2010: Stender, Buma, Alexander Ponds – All on Seiad Creek
- 2011: Lower Seiad and West Grider Ponds
- 2012: May Pond on Seiad Creek
- 2013: Ponds on Tom Martin, O'Neil, Camp, and Stanshaw Creeks
- 2014: DeCoursey Pond (Middle Creek – trib to Horse Creek) and Durazo Ponds on Seiad Creek.
- 2015: Goodman Pond on Middle Creek
- 2017: Lawrence Ponds on Horse Creek
- 2018: Fish Gulch Ponds on Horse Creek
- 2020: China Creek, Little Horse Creek
- Primary objective is to rapidly increase coho winter rearing habitat, however summer use has been documented in all ponds.
- Extensive Monitoring: water quality (DO, temp), snorkel surveys, mark/recap popn estimates, maintaining habitat connectivity.
- Shari Anderson MS thesis (2014) on coho growth, density, and abundance in constructed habitats, as well as tributary and beaver influenced habitats. HSU grad student Michelle Krall published MS thesis (2016).
- Funding: USFWS Partners Program, NFWF/PacifiCorp, FishAmerica/NMFS, Caltrans/USFS and CDFW.

PACIFICORP
A MIDAMERICAN ENERGY HOLDINGS COMPANY

National Fish and Wildlife Foundation

Caltrans

FISHAMERICA FOUNDATION

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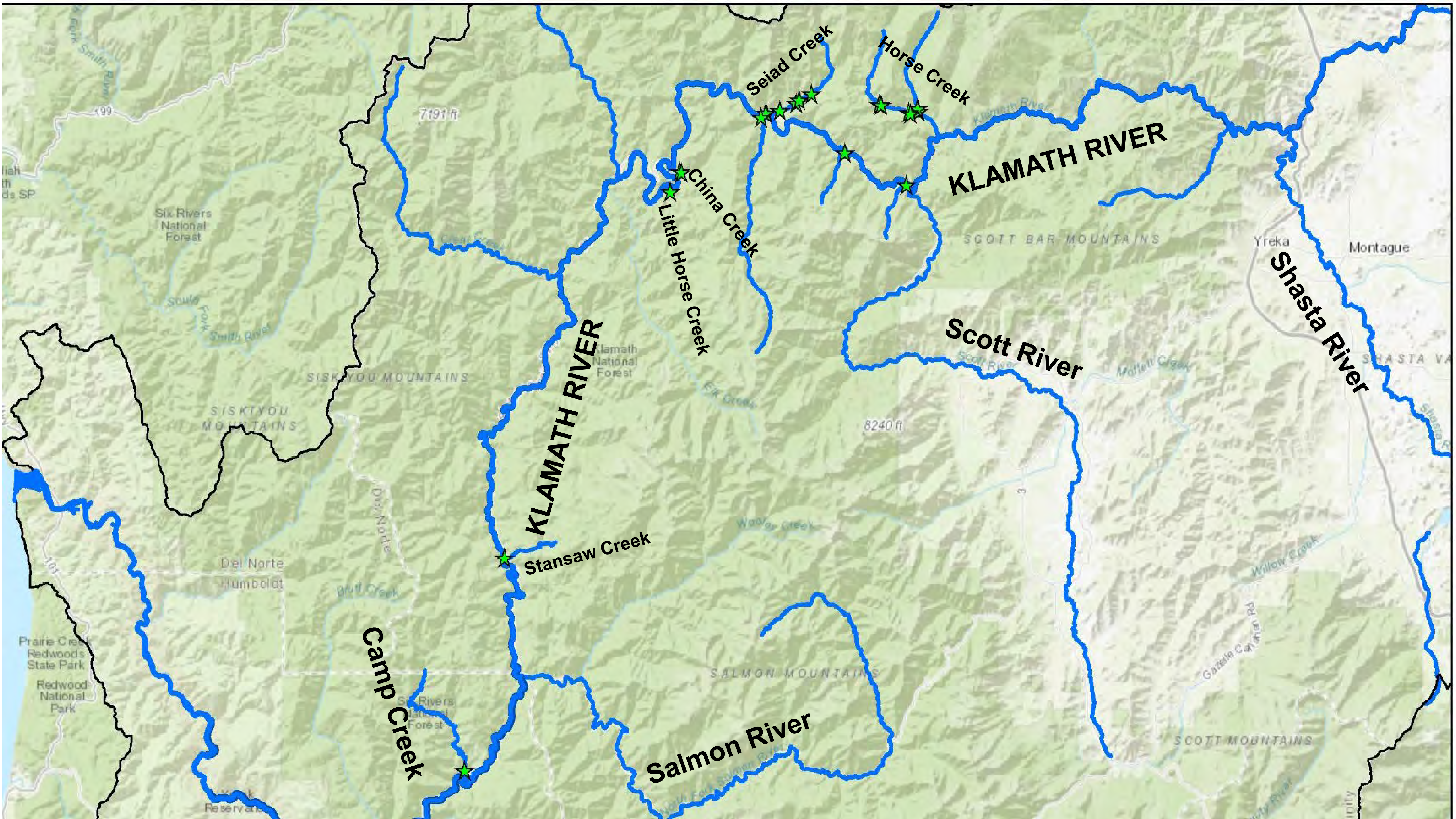
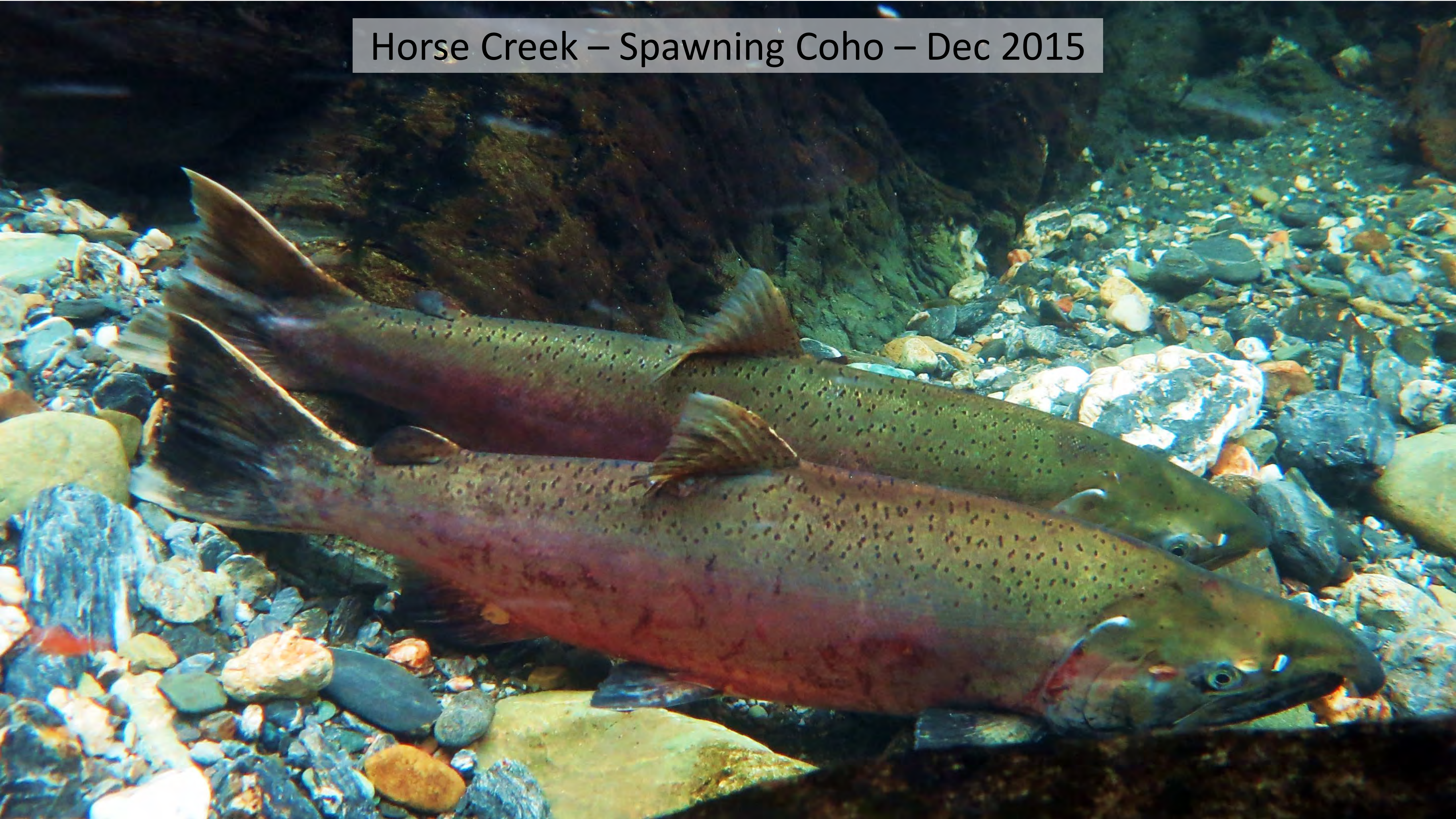
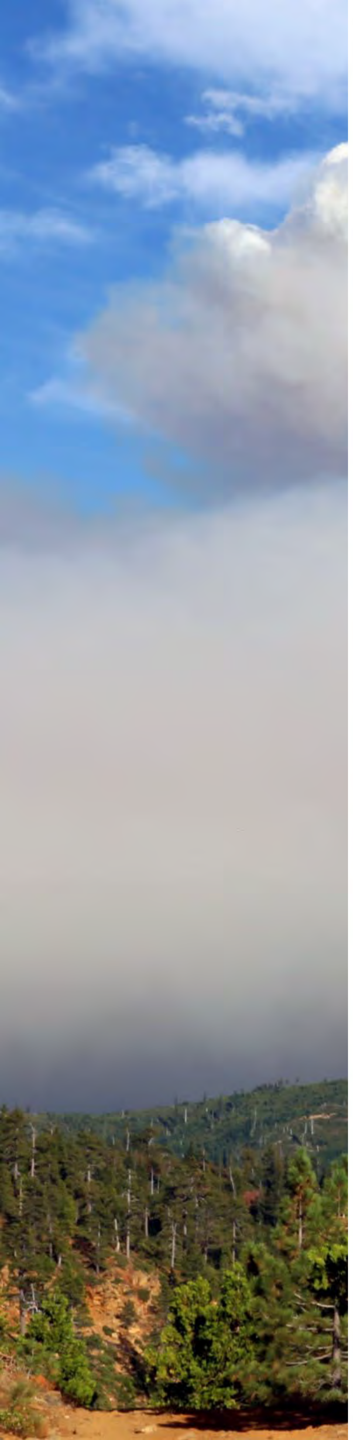
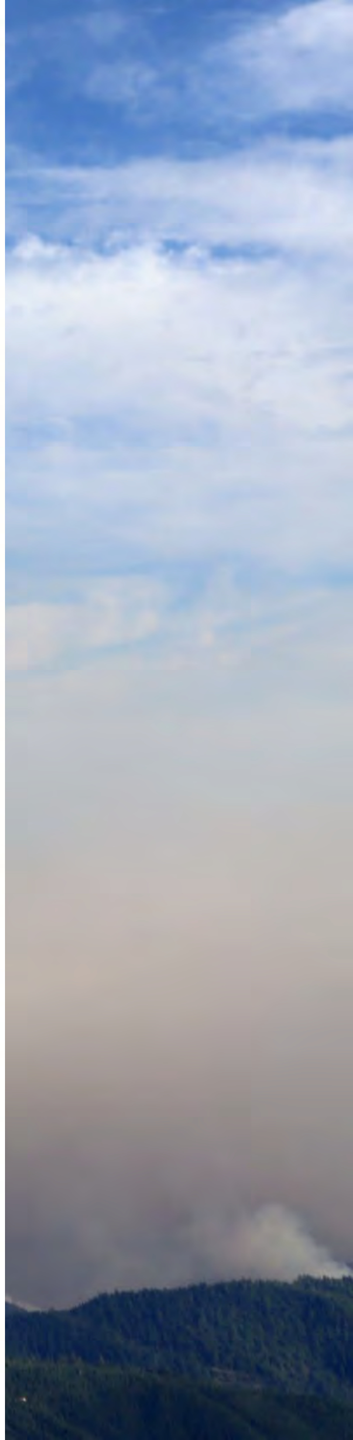


KLAMATH RIVER
KLAMATH RIVER
Seiad Creek
Horse Creek
China Creek
Little Horse Creek
Scott River
Shasta River
Stansaw Creek
Camp Creek
Salmon River
Six Rivers National Forest
Klamath National Forest
SISKIYOU MOUNTAINS
SCOTT BAR MOUNTAINS
SALMON MOUNTAINS
SCOTT MOUNTAINS
Yreka
Montague
Del Norte
Humboldt
Prairie Creek Redwoods State Park
Redwood National Park
7191 ft
8240 ft

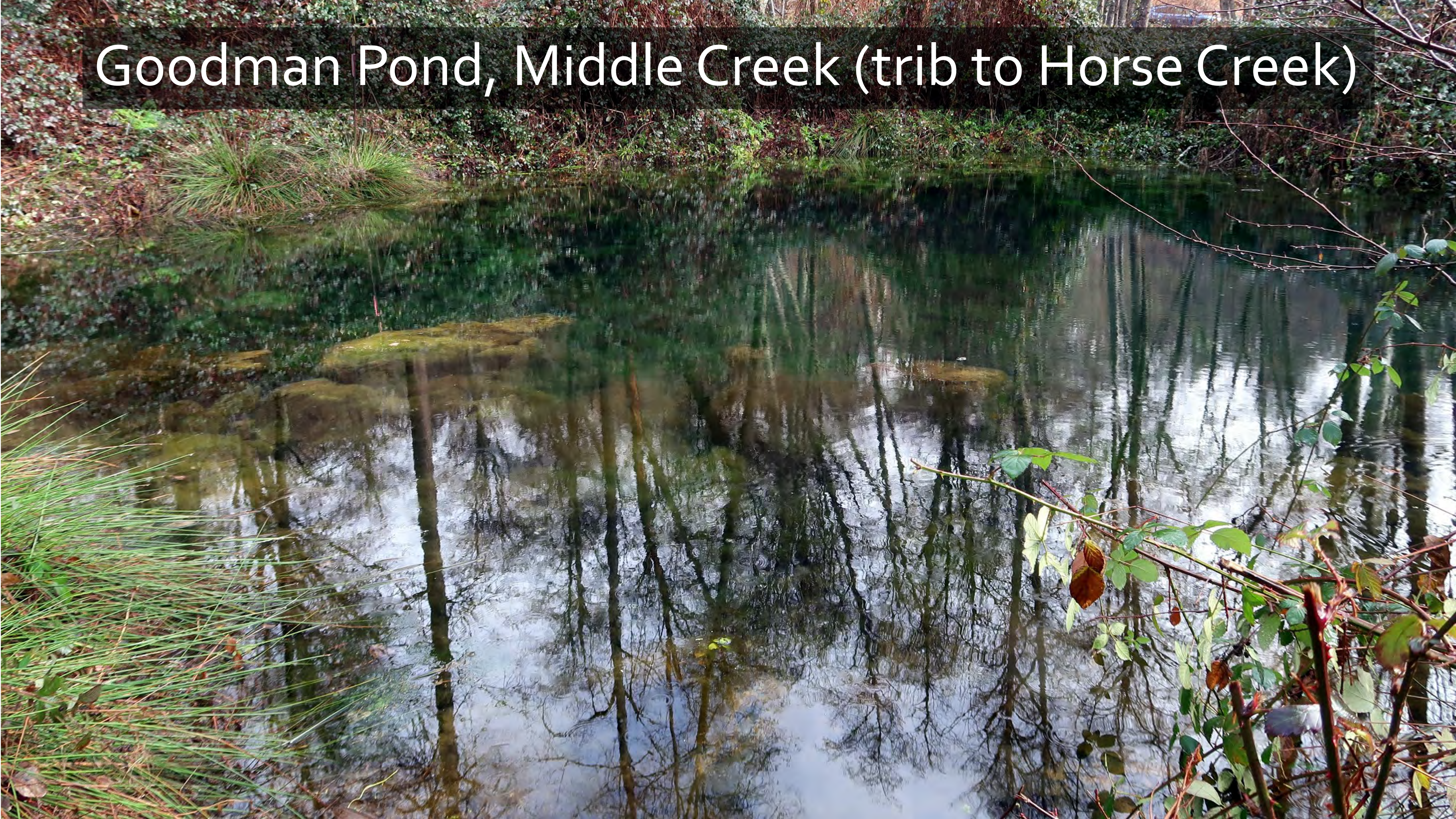

Horse Creek – Spawning Coho – Dec 2015




White Cloud Mtn
Fish Gulch
Chop & Drop
Lawrence Ponds
Goodman Pond
Klamath River Hwy
Google Earth
© 2018 Google
96
N
2000 ft

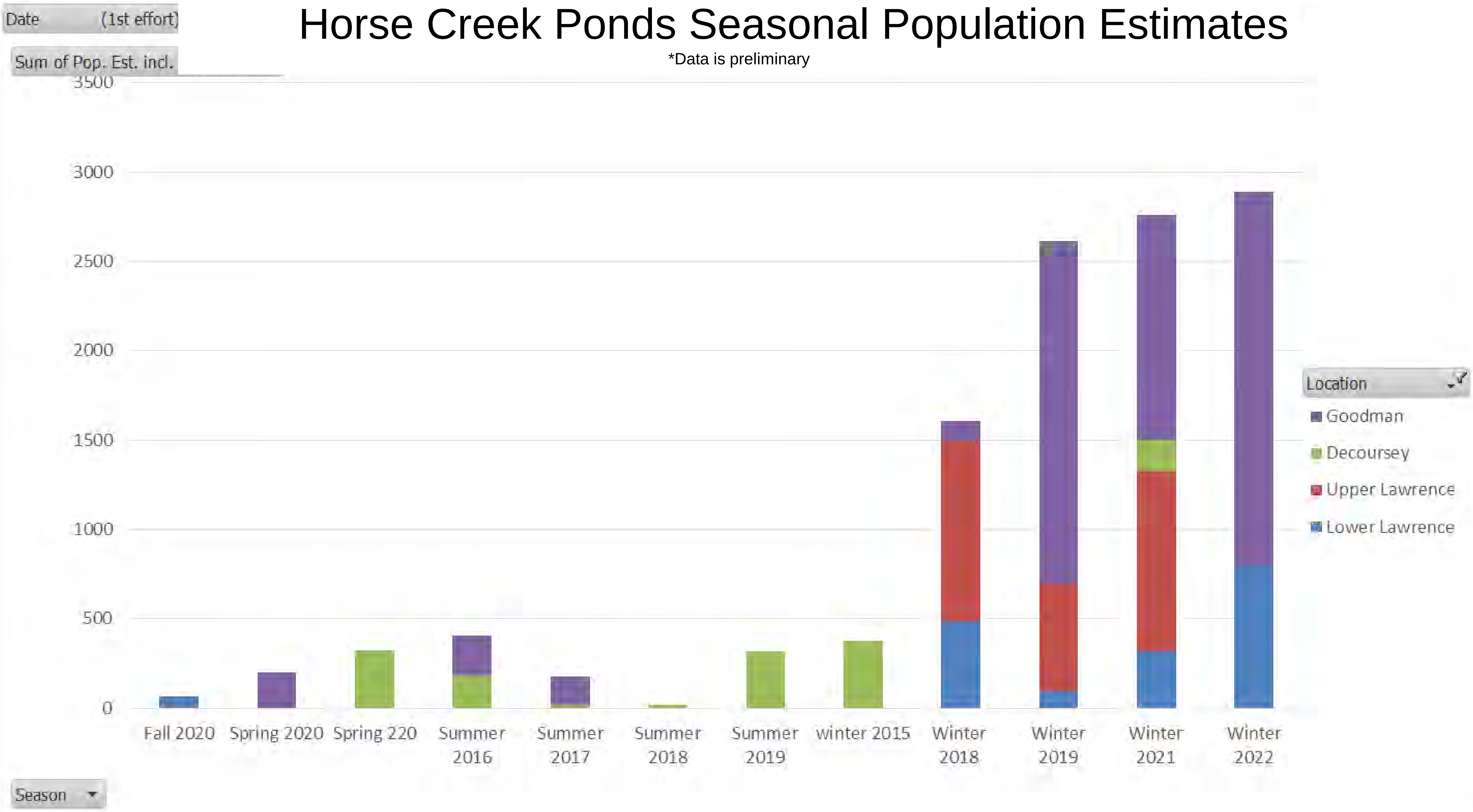


Goodman Pond, Middle Creek (trib to Horse Creek)

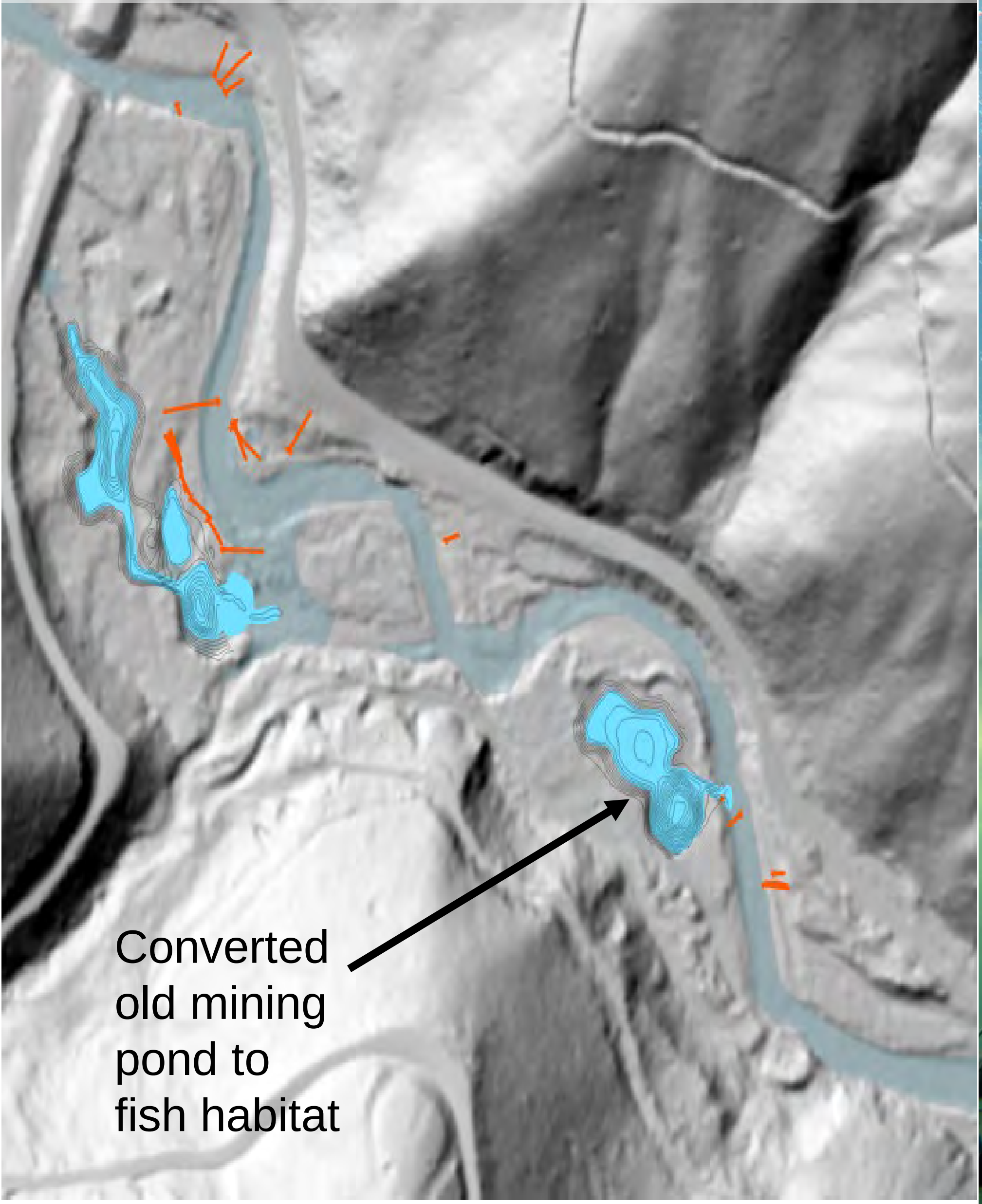


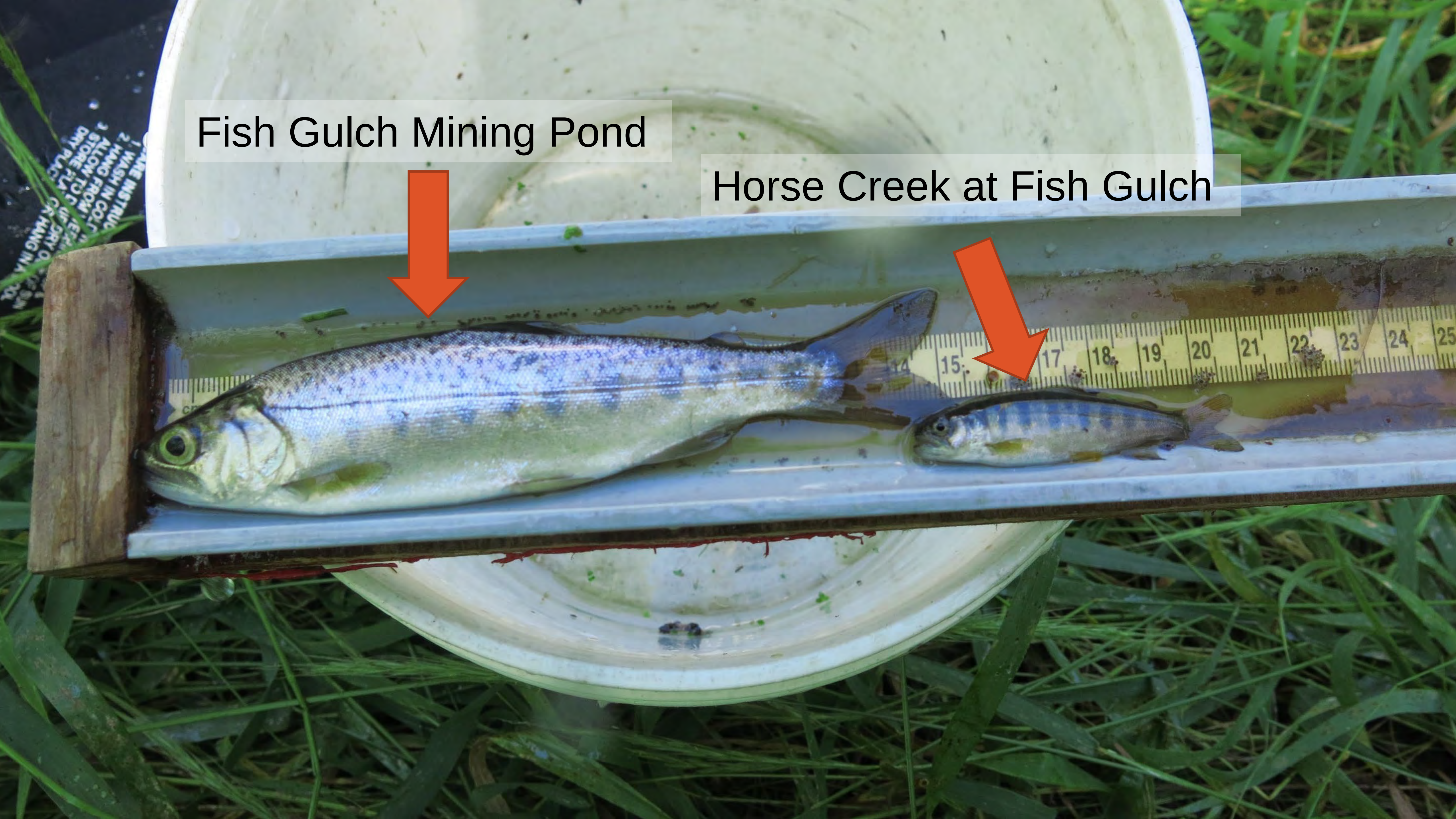
Horse Creek Ponds Seasonal Population Estimates

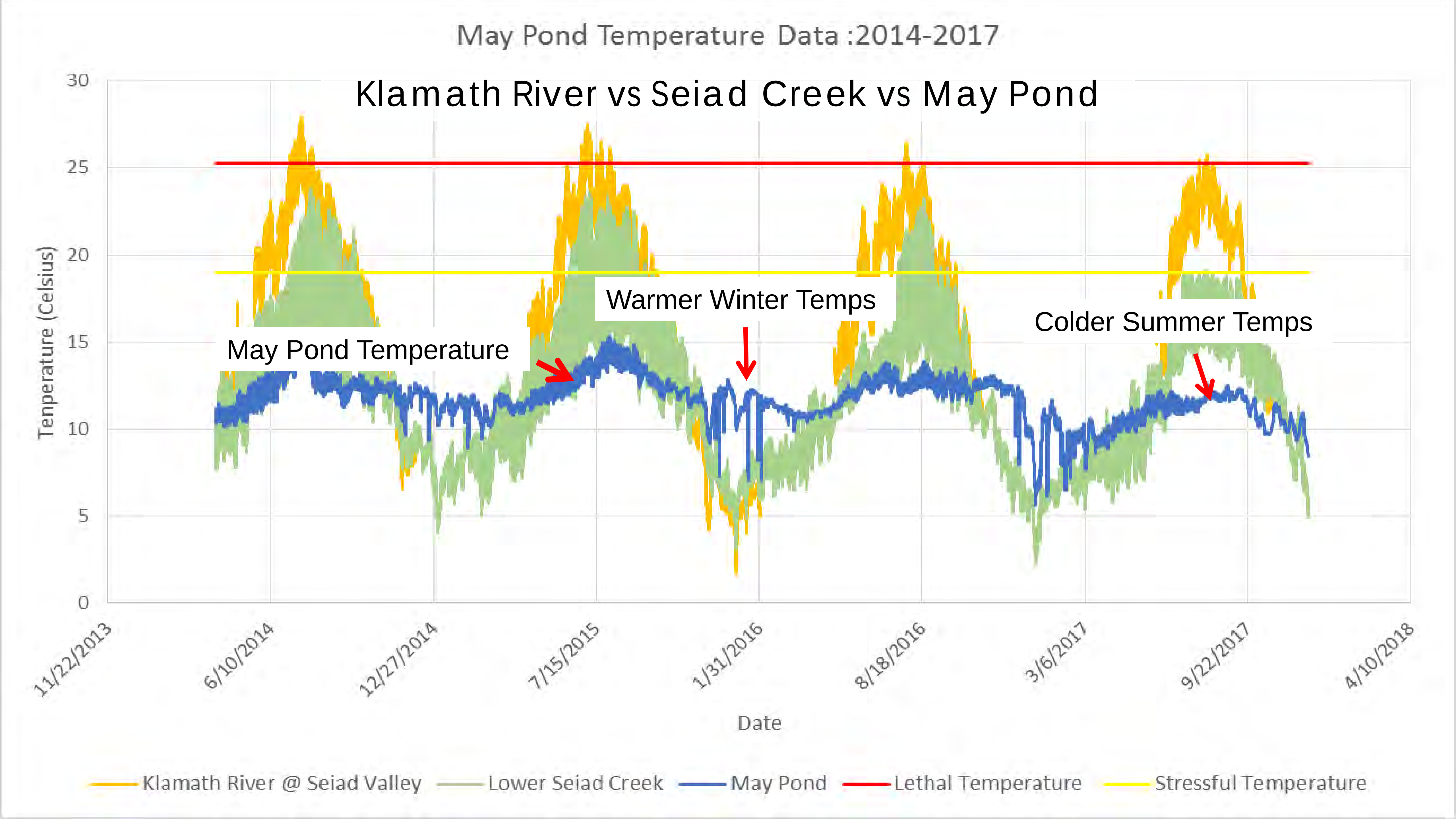
*Data is preliminary



Fish Gulch Off-Channel Ponds & LWD Project




Fish Gulch Mining Pond
Horse Creek at Fish Gulch



May Pond Temperature Data :2014-2017
Klamath River vs Seiad Creek vs May Pond
Warmer Winter Temps
Colder Summer Temps
May Pond Temperature
Tenperature (Celsius)
30
25
20
15
10
5
0
11/22/2013
6/10/2014
12/27/2014
7/15/2015
1/31/2016
8/18/2016
3/6/2017
9/22/2017
4/10/2018
Date
Klamath River @ Seiad Valley
Lower Seiad Creek
May Pond
Lethal Temperature
Stressful Temperature

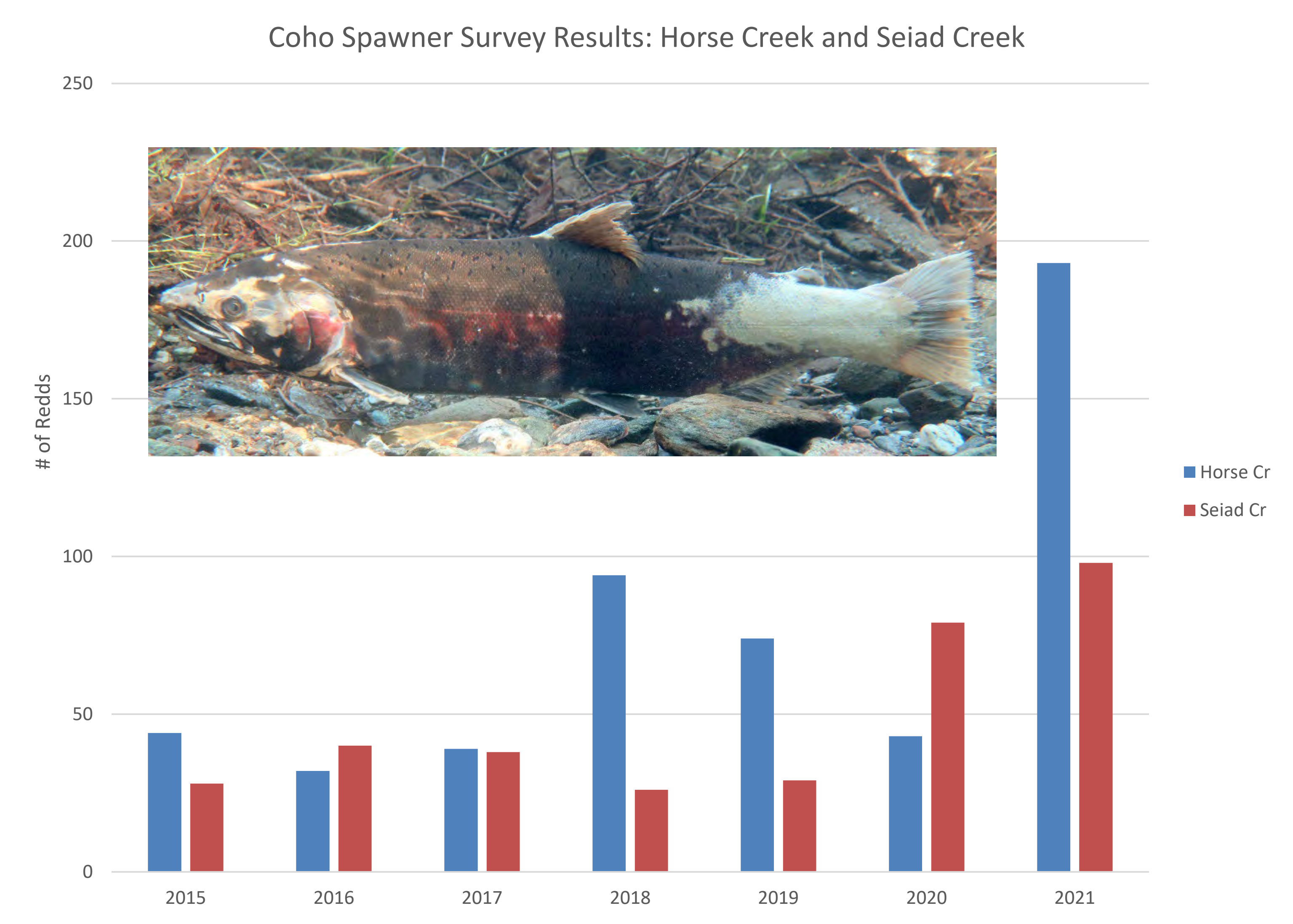
Some Lessons Learned (So Far)

- Deeper is better (2.5m min at summer base flow).
- Groundwater flow improves DO and stabilizes temps.
- Large wood is good but not essential.
- Short access channels that have small apertures at summer base flow and larger apertures at winter base flow ideal.
- These habitats are intended to keep coho genetics around while we work towards restoring larger floodplain processes.
- We have yet to saturate a coho stream with off-channel habitat. The fish are telling us they want more.

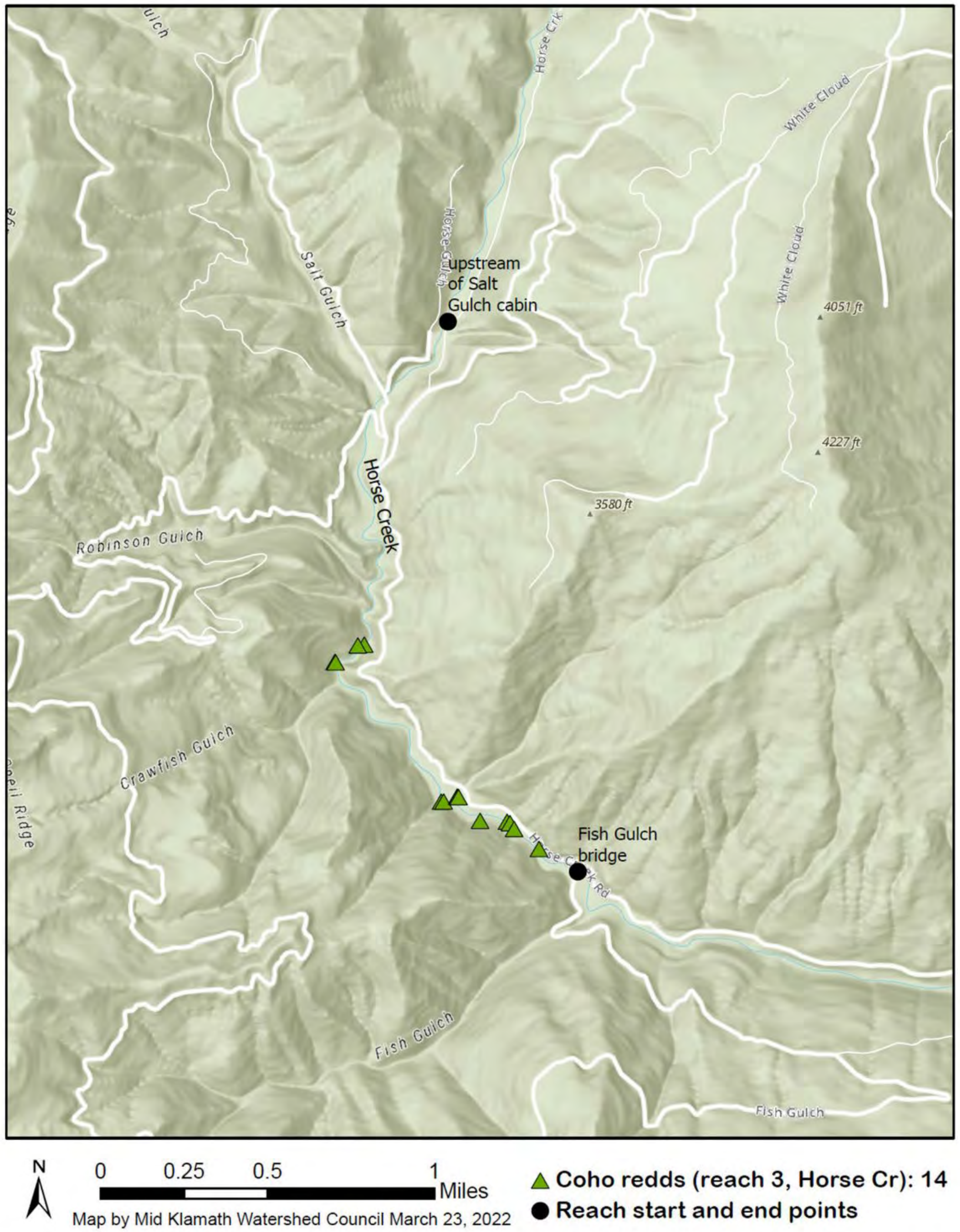
Upper Horse Valley (February 4, 2022)

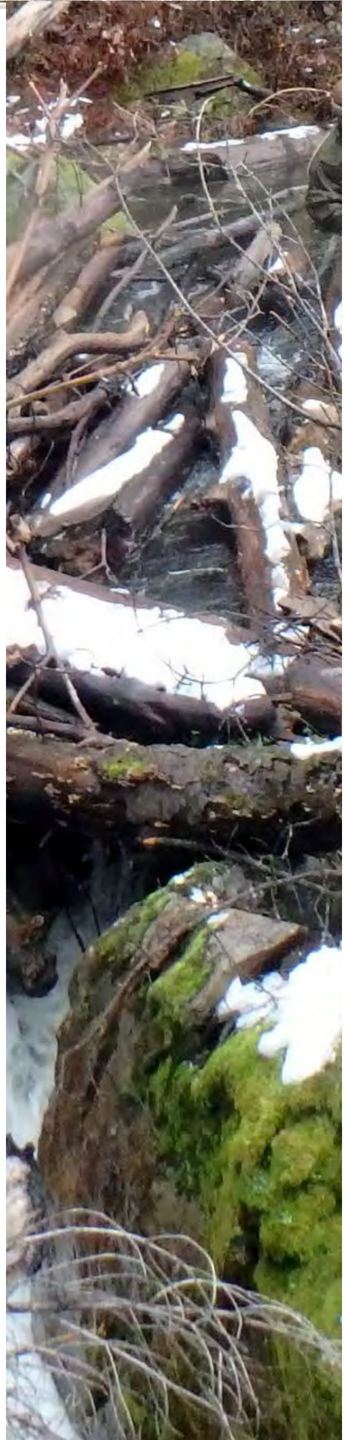
60 coho redds in the 2021-2022 season utilizing 12 installed wood structures

Horse Creek Valley

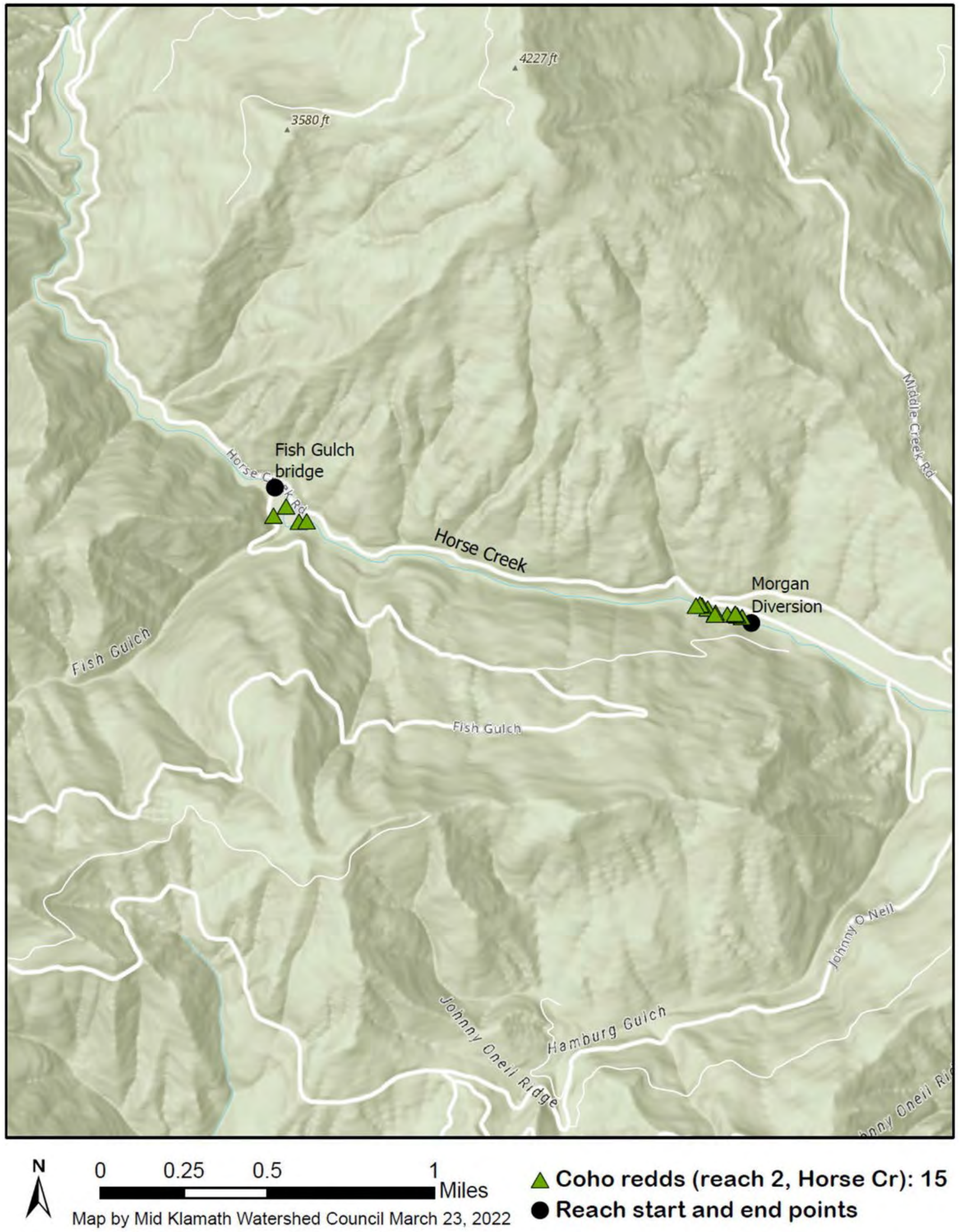


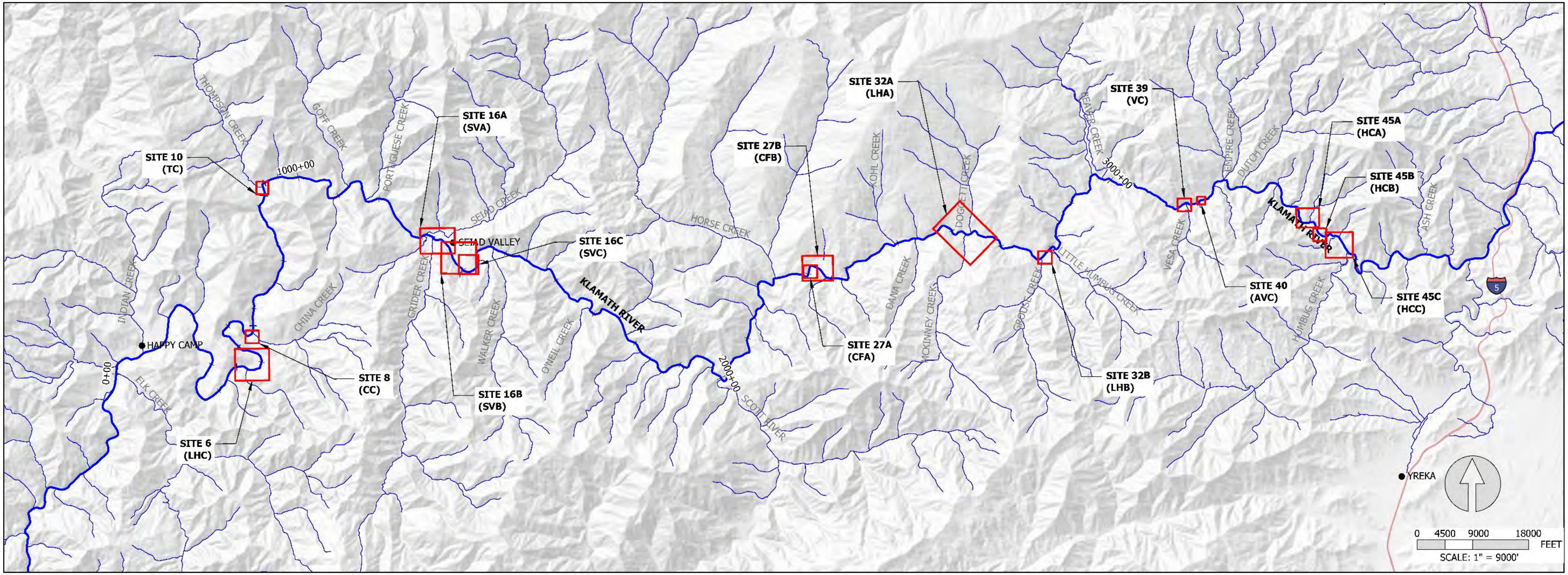
Horse Creek 2021/2022 Coho Survey
Reach 3: Fish Gulch to Salt Gulch





Horse Creek 2021/2022 Coho Survey
Reach 2: Morgan Diversion to Fish Gulch





MID-KLAMATH FLOODPLAIN HABITAT ENHANCEMENT PROJECT

SISKIYOU COUNTY, CA

Stillwater Sciences
850 G ST, SUITE K
ARCATA, CA 95521
P: (707) 822-9607

DOES NOT MEASURE 1" DRAWING IS NOT TO SCALE – ADJUST ACCORDINGLY

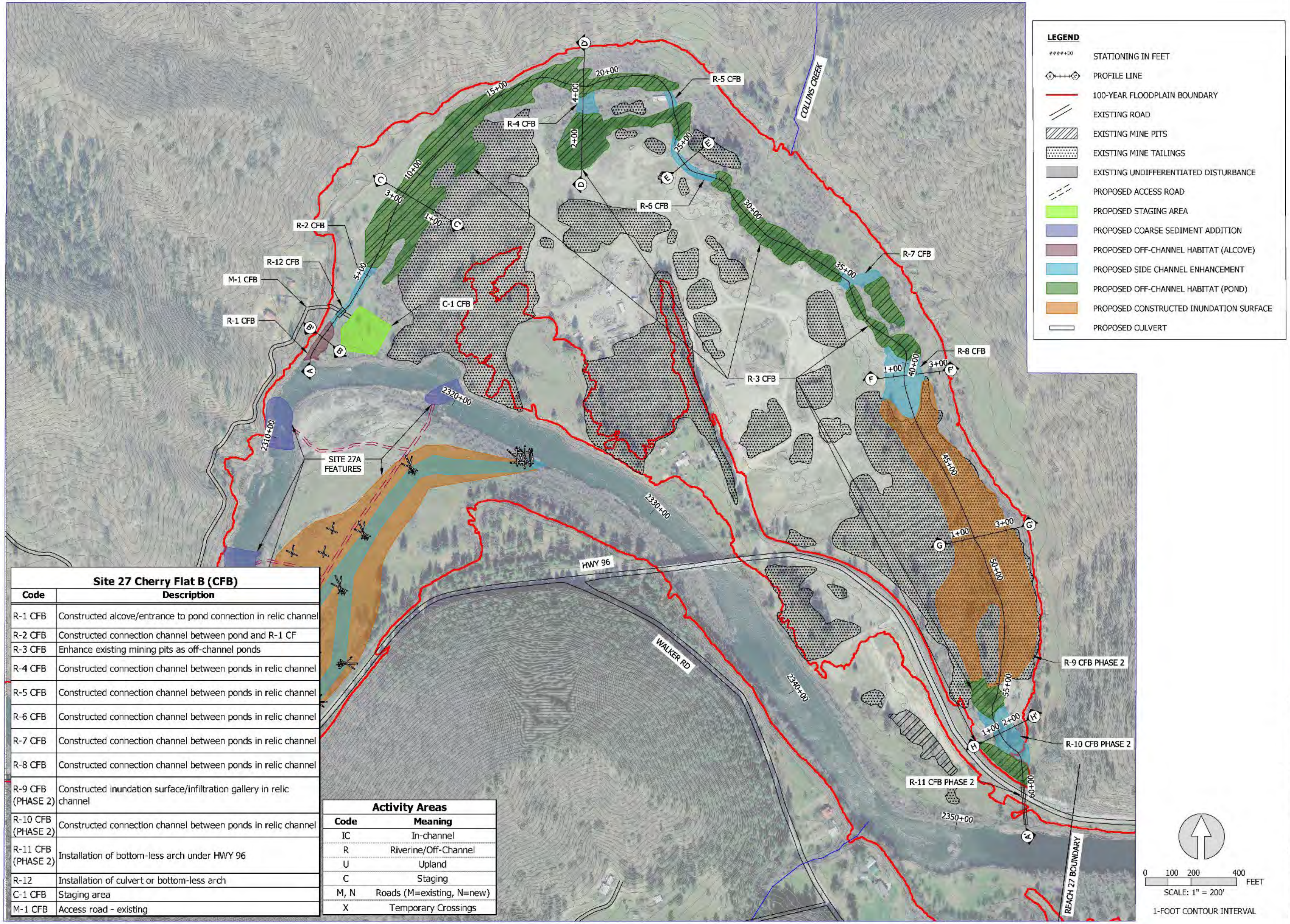
LEGEND

- KLAMATH RIVER
- ####+00 STATIONING IN FEET
- TRIBUTARIES
- CITY
- SITE VIEW FRAME

Site List

Code	Design Site	Site No.	Reach No.
LHC	Little Horse Creek	6	6
CC	China Creek	8	8
TC	Thompson Creek	10	10
SVA	Lower Seiad Valley	16A	16
SVB	Mid-Seiad Valley	16B	16
SVC	Upper Seiad Valley	16C	16
CFA	Cherry Flat A	27A	27
CFB	Cherry Flat B	27B	27
LHA	Little Humbug Creek A	32A	32
LHB	Little Humbug Creek B	32B	32
VC	Vesa Creek	39	39
AVC	Above Vesa Creek	40	40
HCA	Lower Humbug Creek	45A	45
HCB	Humbug Creek	45B	45
HCC	Upper Humbug Creek	45C	45

C



Site 27 Cherry Flat B (CFB)	
Code	**Description**
R-1 CFB	Constructed alcove/entrance to pond connection in relic channel
R-2 CFB	Constructed connection channel between pond and R-1 CF
R-3 CFB	Enhance existing mining pits as off-channel ponds
R-4 CFB	Constructed connection channel between ponds in relic channel
R-5 CFB	Constructed connection channel between ponds in relic channel
R-6 CFB	Constructed connection channel between ponds in relic channel
R-7 CFB	Constructed connection channel between ponds in relic channel
R-8 CFB	Constructed connection channel between ponds in relic channel
R-9 CFB (PHASE 2)	Constructed inundation surface/infiltration gallery in relic channel
R-10 CFB (PHASE 2)	Constructed connection channel between ponds in relic channel
R-11 CFB (PHASE 2)	Installation of bottom-less arch under HWY 96
R-12	Installation of culvert or bottom-less arch
C-1 CFB	Staging area
M-1 CFB	Access road - existing

Activity Areas	
Code	**Meaning**
IC	In-channel
R	Riverine/Off-Channel
U	Upland
C	Staging
M, N	Roads (M=existing, N=new)
X	Temporary Crossings

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SCALE: AS NOTED
DATE: 1/29/19

DESIGN: JS
DRAWN: RT
CHECKED: JM
APPROVED: ----

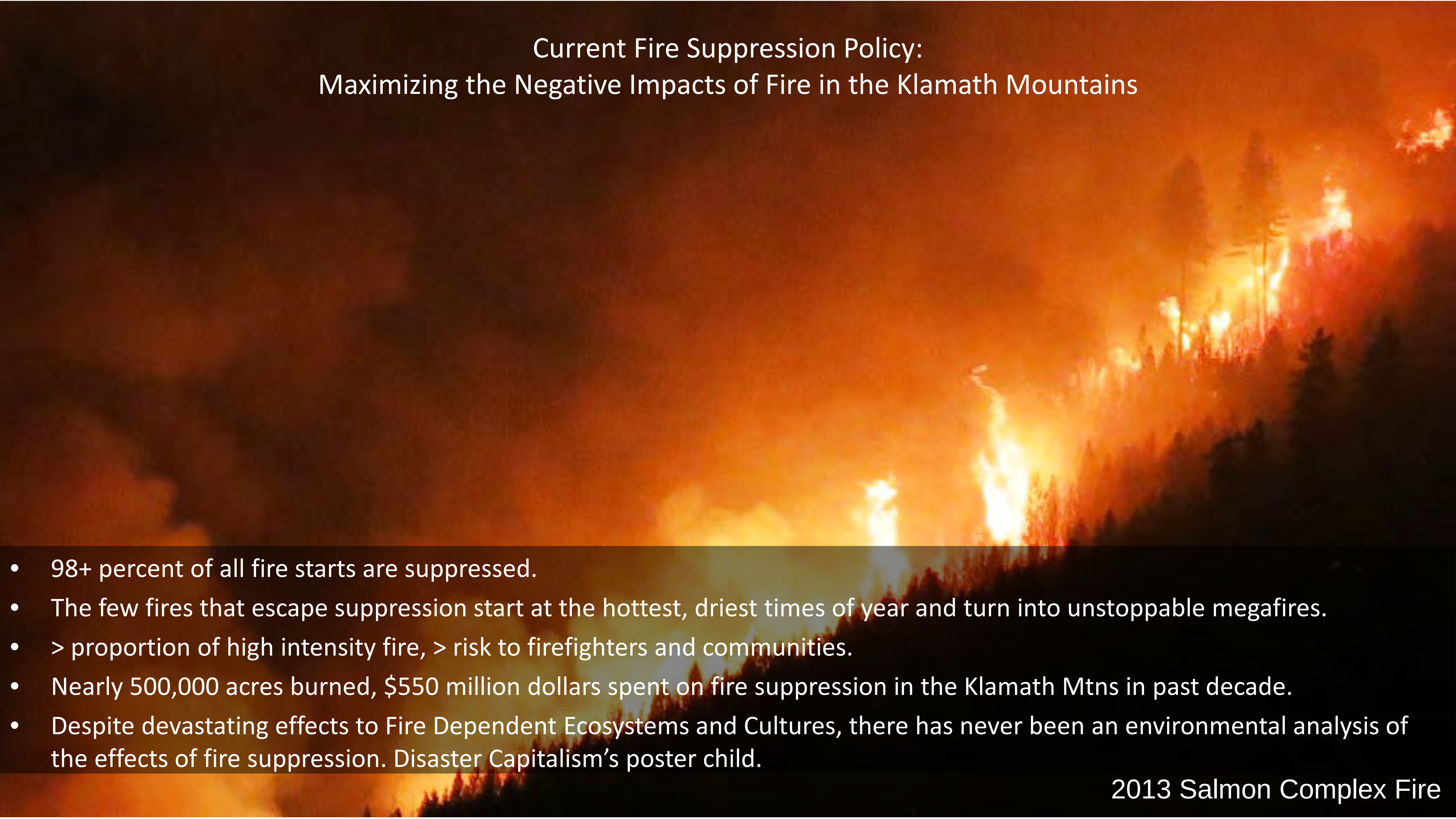
SITE 27B - UPPER CHERRY FLAT (CFB)

PLAN VIEW

SHEET 1 OF 2

Creating a Social and Cultural Movement to Change How We Manage Fire

Current Fire Suppression Policy:
Maximizing the Negative Impacts of Fire in the Klamath Mountains



- 98+ percent of all fire starts are suppressed.
- The few fires that escape suppression start at the hottest, driest times of year and turn into unstoppable megafires.
- > proportion of high intensity fire, > risk to firefighters and communities.
- Nearly 500,000 acres burned, $550 million dollars spent on fire suppression in the Klamath Mtns in past decade.
- Despite devastating effects to Fire Dependent Ecosystems and Cultures, there has never been an environmental analysis of the effects of fire suppression. Disaster Capitalism’s poster child.

2013 Salmon Complex Fire

2017 Klamath TREX Prescribed Burn


PBR nerds arguing about fossil fuel use
Will Harling's carbon footprint for restoring 10,000 acres
Mobil


Offield Mountain

2022 Klamath River Prescribed Fire Training Exchange (TREX)

Three two week-long trainings this Fall: Oct 3 – 14, Klamath Women's TREX Oct 17-28, Oct 31-Nov 10

Acknowledgements

- MKWC Fisheries: Charles and Mitzi Wickman, Jimmy Peterson, Rachel Krasner, Florance Condos.
- Karuk Fisheries: Toz Soto
- Salmon River Restoration Council: Karuna Greenberg, Sophie Price
- Researchers: Shari Whitmore, Michelle Krall, Jessie Moravek
- Stillwater Sciences: Jay Stallman and Co.
- Karuk Ceremonial Leaders: Bill Tripp, Kathy McCovey, Leaf Hillman, Ron Reed
- Restoration Warriors: Petey Brucker, Jim Villeponteaux, Rocco Fiori
- My Kids: Owen and Rory

"I will tell you something about stories . . . They aren't just entertainment. Don't be fooled. They are all we have, you see, all we have to fight off illness and death. You don't have anything if you don't have the stories. Their evil is mighty but it can't stand up to our stories. So they try to destroy the stories, let the stories be confused or forgotten. They would like that. They would be happy. Because we would be defenseless then. He rubbed his belly. "I keep them here.""

— **Leslie Marmon Silko, [Ceremony]**

Running the gauntlet: the burdens of aquatic pathogens and river conditions on California's Central Valley Chinook salmon

Camilo Sanchez, Ben Atencio, Florian Mauduit, Amelie Segarra, Felix Biefel, Sascha L. Hallett, Stephen D. Atkinson, Richard Connon, Miles E. Daniels

Mark Conlin
SuperStock/Corbis

Why study salmonid pathogens?

Worldwide decline in salmonid abundance

- Southern salmon at a particularly high risk
- California’s salmonids are the most at risk

Anthropogenic changes

- Change in hydrodynamics, water chemistry
- Habitat loss, degradation
- Climate change

Anthropogenic factors and pathogens

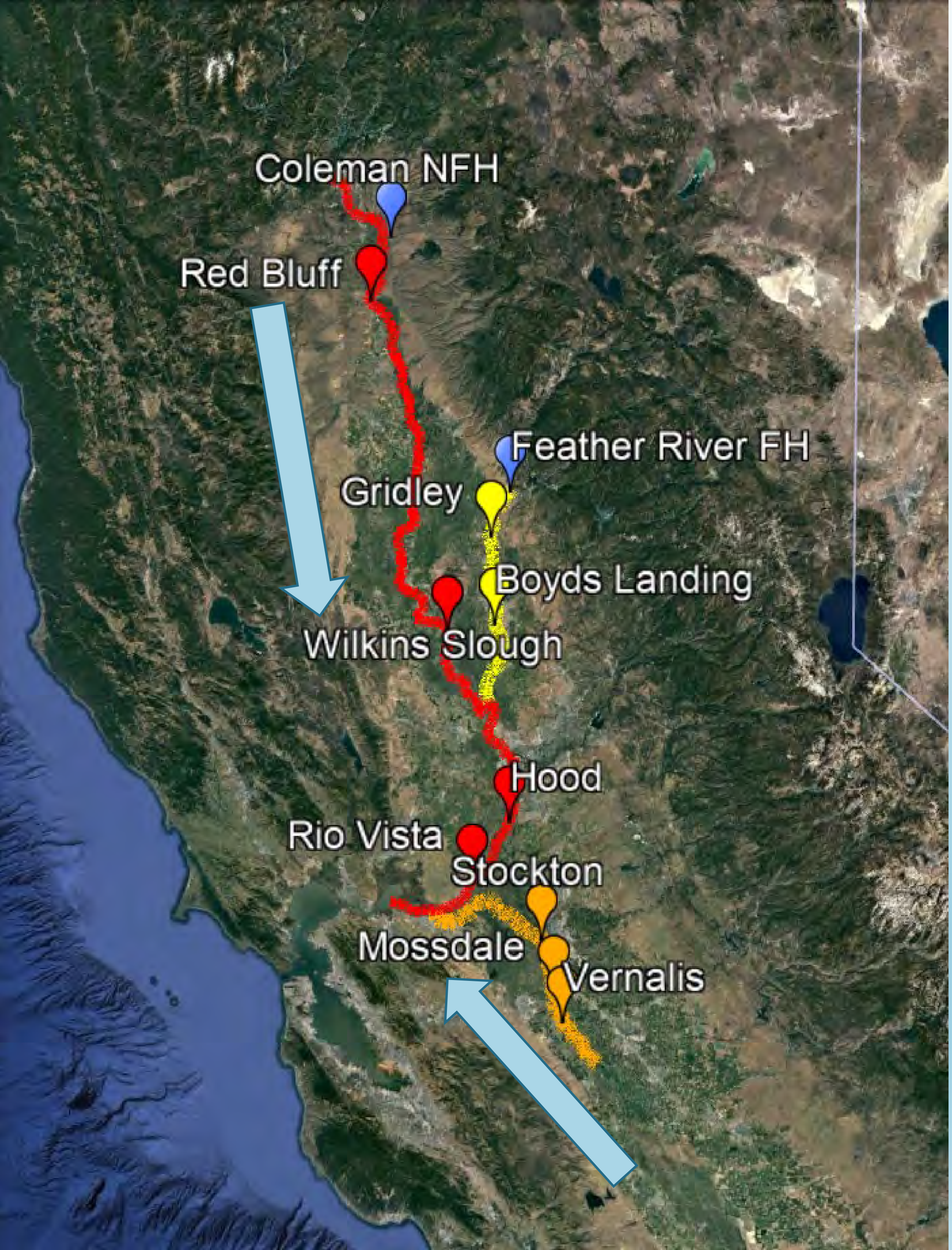
- Produces increased pathogen abundance and decreased salmonid fitness
- Pathogens increasingly identified as stressors on North American west coast
- Changes in life-cycle dynamics

Questions and hypotheses

- **<u>Question 1</u>**: What salmonid pathogens are found in these rivers? How does prevalence vary in space?
  - **<u>Hypothesis</u>**: Distribution and diversity of pathogens will not be uniform in space. These factors can be tied to locations and environmental conditions.
- **<u>Question 2</u>**: What is the expected abundance of, and mortality from, these pathogens and how does that vary in space?
  - **<u>Hypothesis</u>**: Hotspots for infection and mortality risk will be correlated to locations and will change with environmental conditions

Study outlook and goals

- Sentinel fish caging study
- Assess pathogen prevalence
- Tie to infection risk
- Validation of monitoring methods

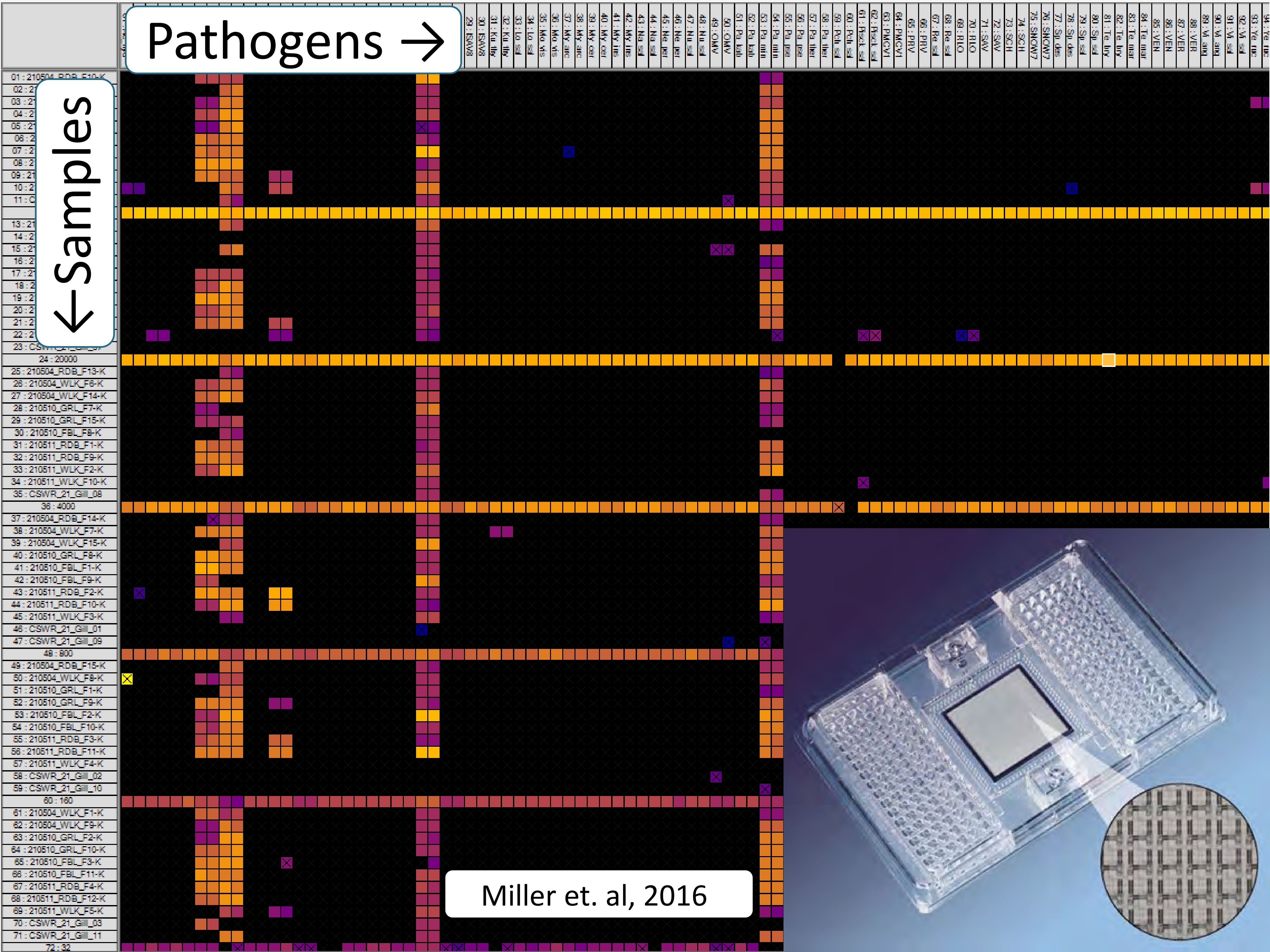


- 9 total sites
  - 2 Feather sites
  - 4 Sacramento sites
  - 3 San Joaquin sites
  - Control

- Sentinel sites near DWR monitoring stations

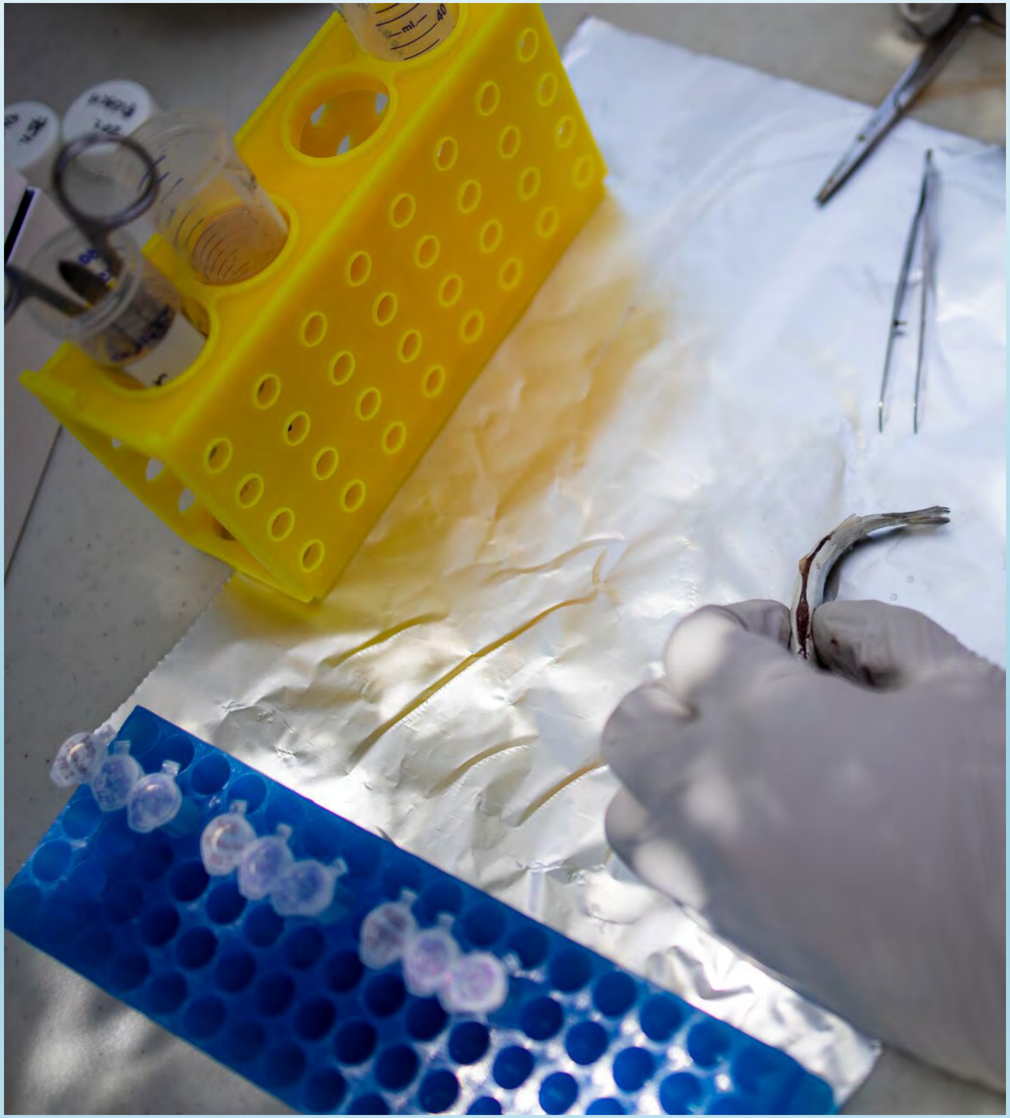
Methods

- Hatchery-reared fish in surface floating cages
  - Deployed for 14 days
  - Subsampled on days 7 & 14 for gill, kidney, and intestinal tissues
- Water samples taken concurrently with deployments



Miller et. al, 2016

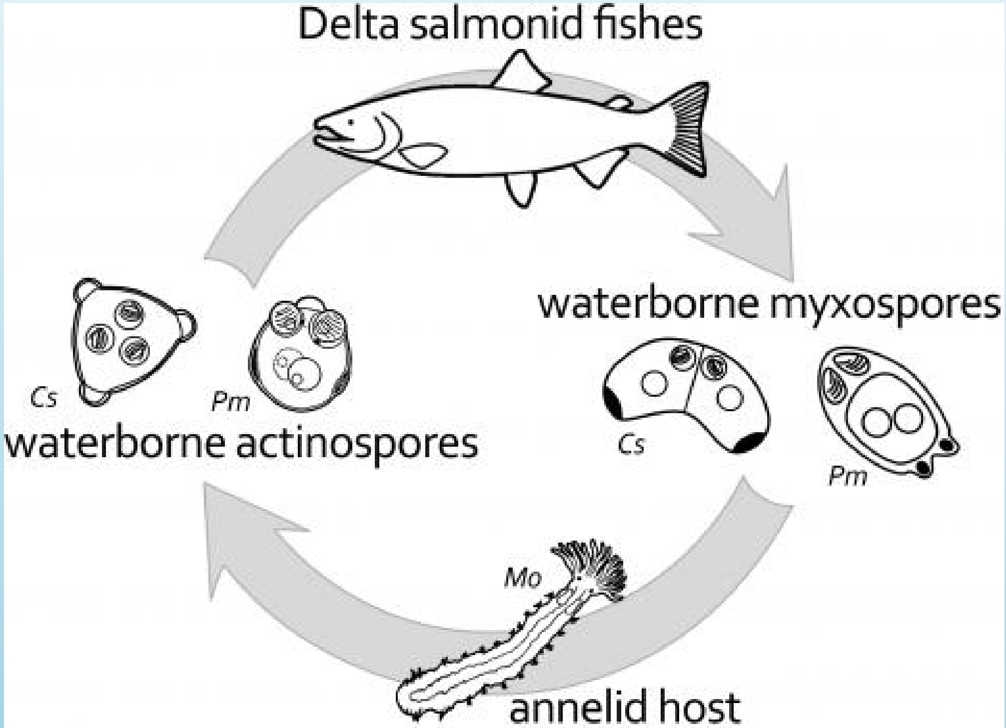
Most Commonly Detected Pathogens



- Myxozoan parasites
  - *Ceratonova shasta*
  - *Parvicapsula minibicornis*
- Epithelial pathogens
  - *Candidatus Branchiomonas cysticola*
  - *Dermocystidium salmonis*
  - *Ichthyoptherius multifiliis*, “Ich”

Myxozoan parasites

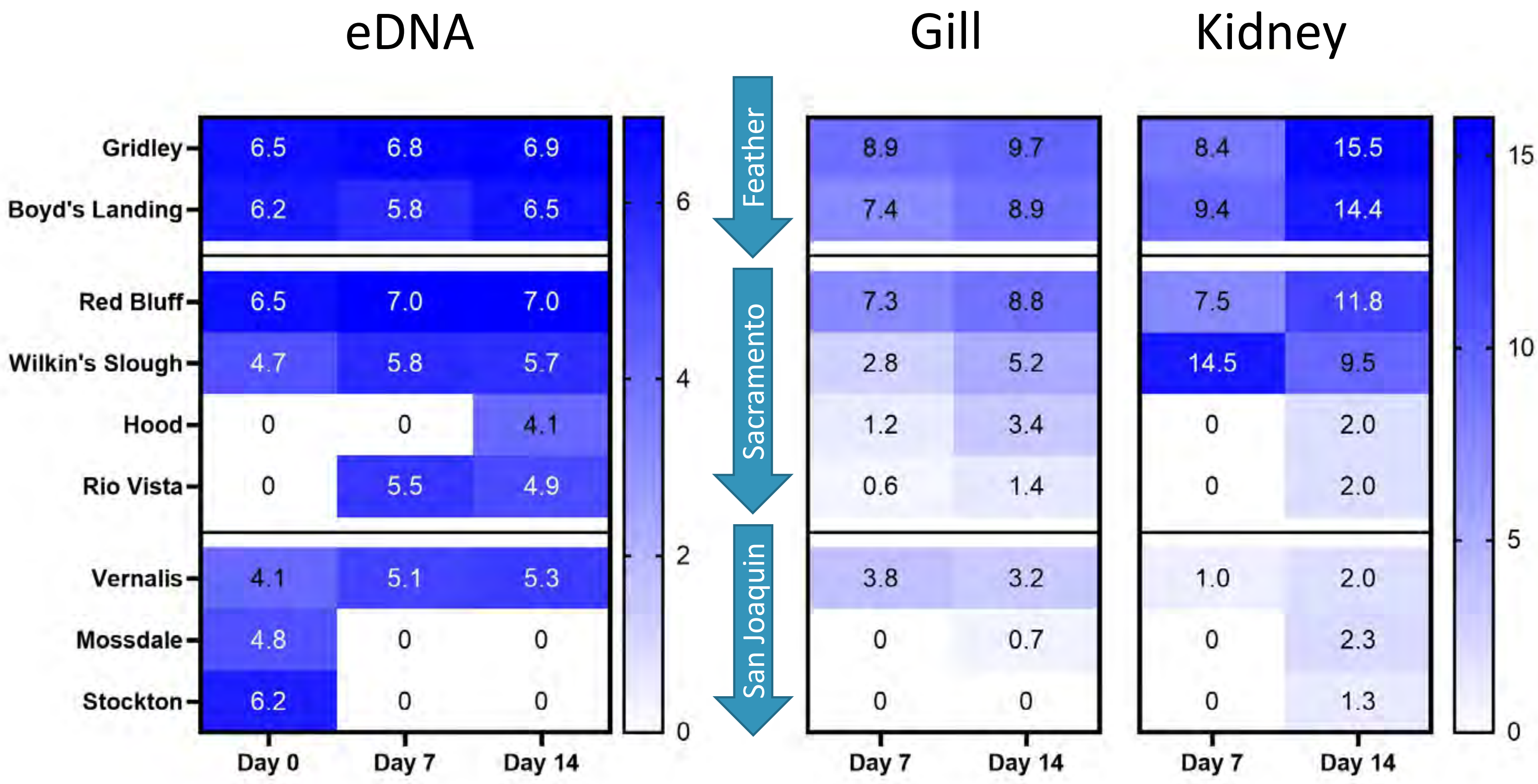
- *Ceratonova shasta*
  - Enters the gills
  - Affects digestive tract, other organs, and muscle
  - “Gut rot”
  - Infection progression is temperature dependent
  - Utilizes an annelid intermediate host
- *Parvicapsula minibicornis*
  - Affects gill, kidney
  - Utilizes an annelid intermediate host



Bartholomew Lab

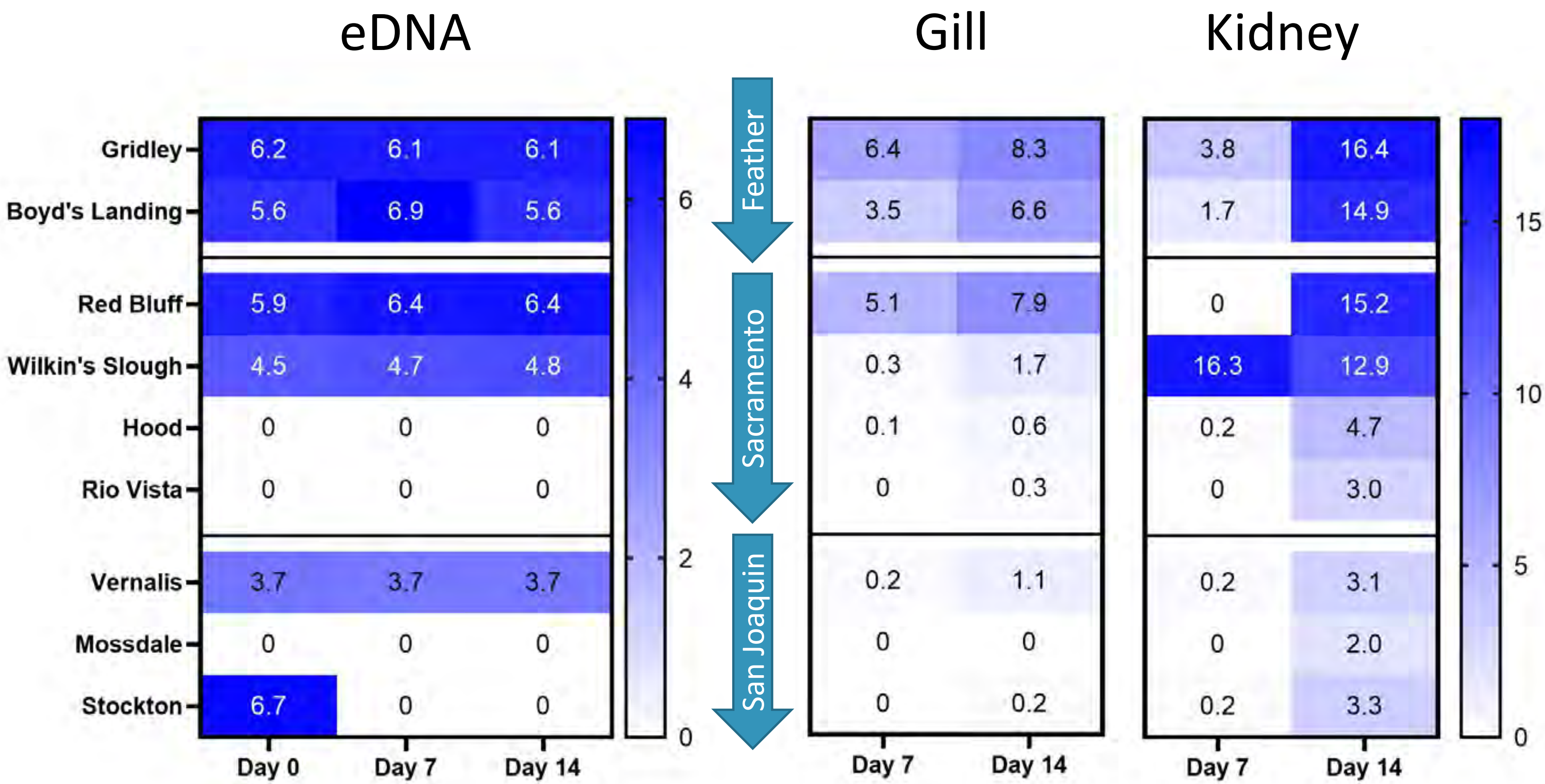
Myxozoan Parasite: *C. shasta*

- eDNA in $\log_2$ (copy#/L H_2O)
- Tissue in $\log_2$ (copy#/100ng DNA)



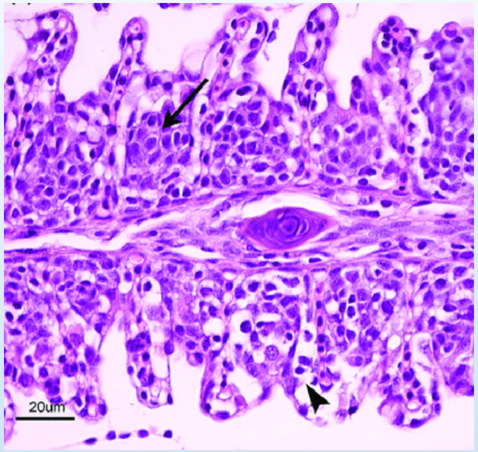
Myxozoan Parasite: *P. minibicornis*

- eDNA in $\log_2$ (copy#/L H_2O)
- Tissue in $\log_2$ (copy#/100ng DNA)



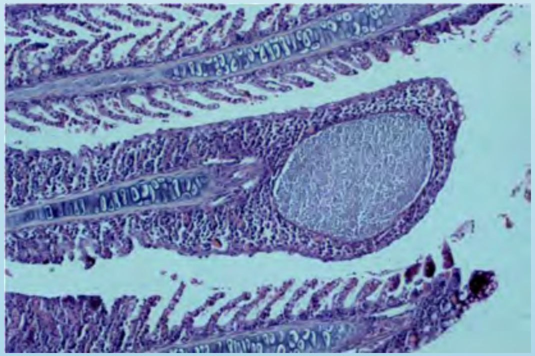
Epithelial pathogens

- *Candidatus Branchiomonas cisticola*



Wiik-Nielsen et. al, 2017

- *Dermocystidium salmonis*



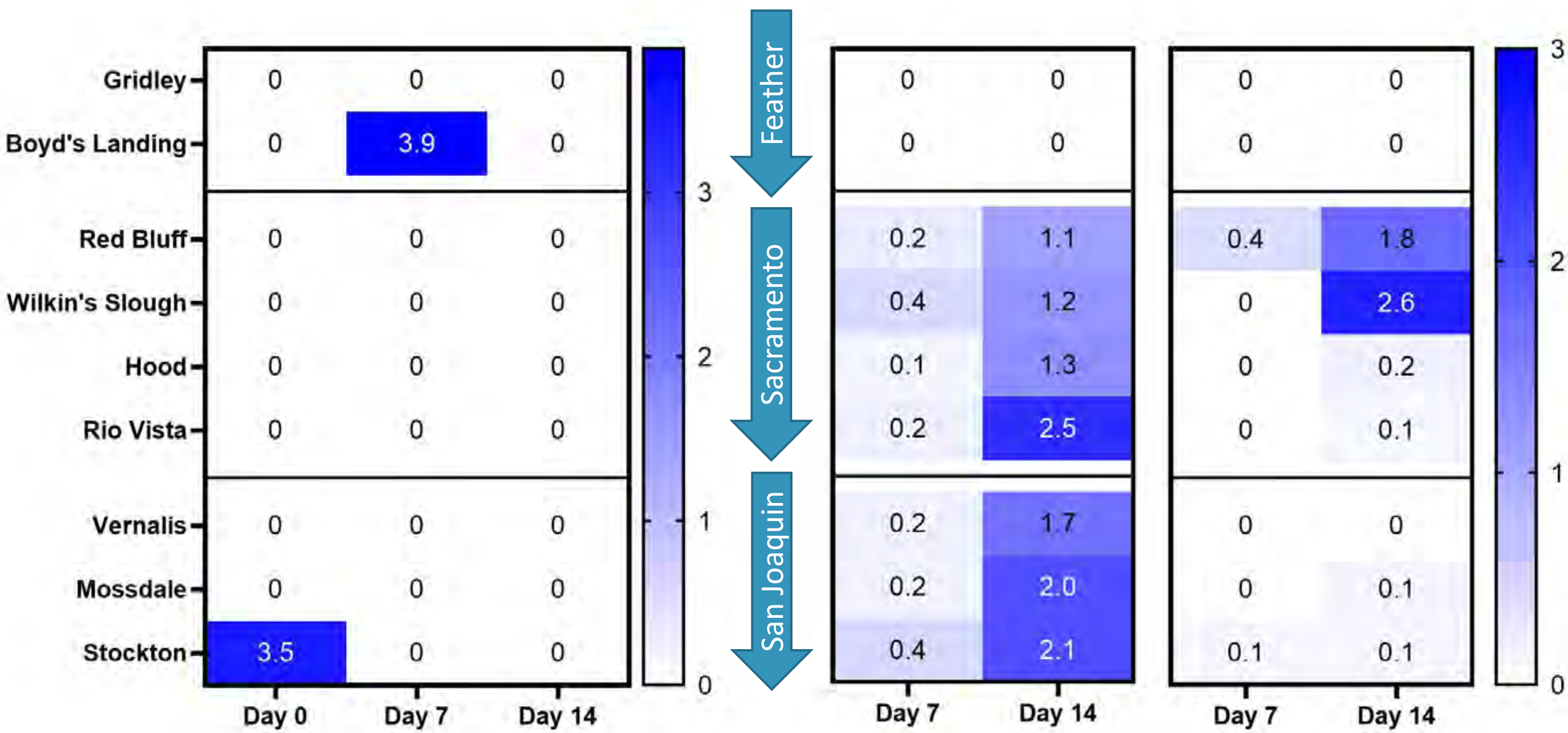
USGS / Bob Olsen

- *Ichthyoptherious multifiliis*, “ich”

Leah Mellinger

Epithelial Pathogen: *C. B. cysticola*

- eDNA in $\log_2$ (copy#/L H_2O)
- Tissue in $\log_2$ (copy#/100ng DNA)



eDNA:

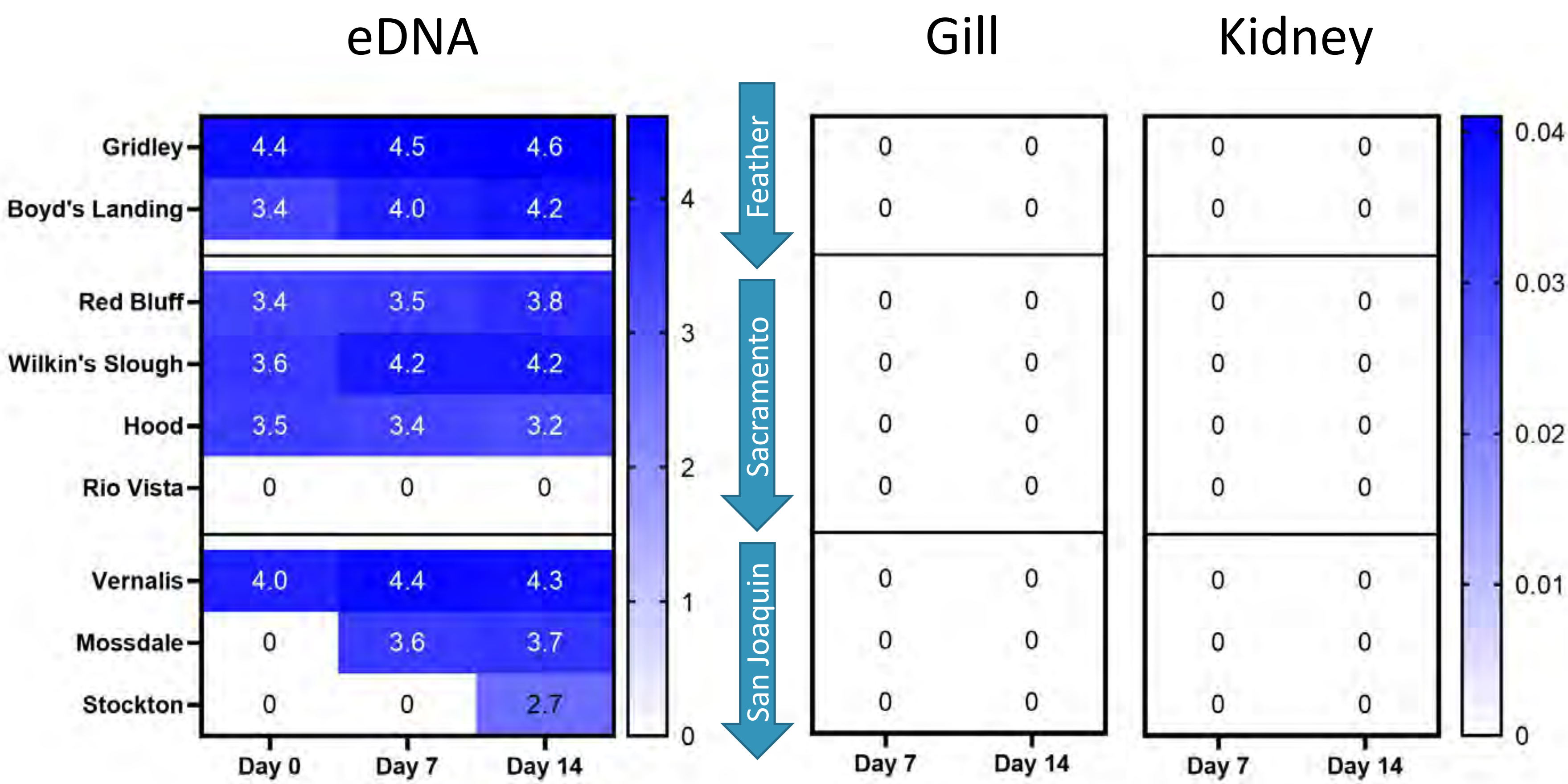
	Day 0	Day 7	Day 14
Gridley	0	0	0
Boyd's Landing	0	3.9	0
Red Bluff	0	0	0
Wilkin's Slough	0	0	0
Hood	0	0	0
Rio Vista	0	0	0
Vernalis	0	0	0
Mossdale	0	0	0
Stockton	3.5	0	0

Gill and Kidney:

	Gill Day 7	Gill Day 14	Kidney Day 7	Kidney Day 14
Gridley	0	0	0	0
Boyd's Landing	0	0	0	0
Red Bluff	0.2	1.1	0.4	1.8
Wilkin's Slough	0.4	1.2	0	2.6
Hood	0.1	1.3	0	0.2
Rio Vista	0.2	2.5	0	0.1
Vernalis	0.2	1.7	0	0
Mossdale	0.2	2.0	0	0.1
Stockton	0.4	2.1	0.1	0.1

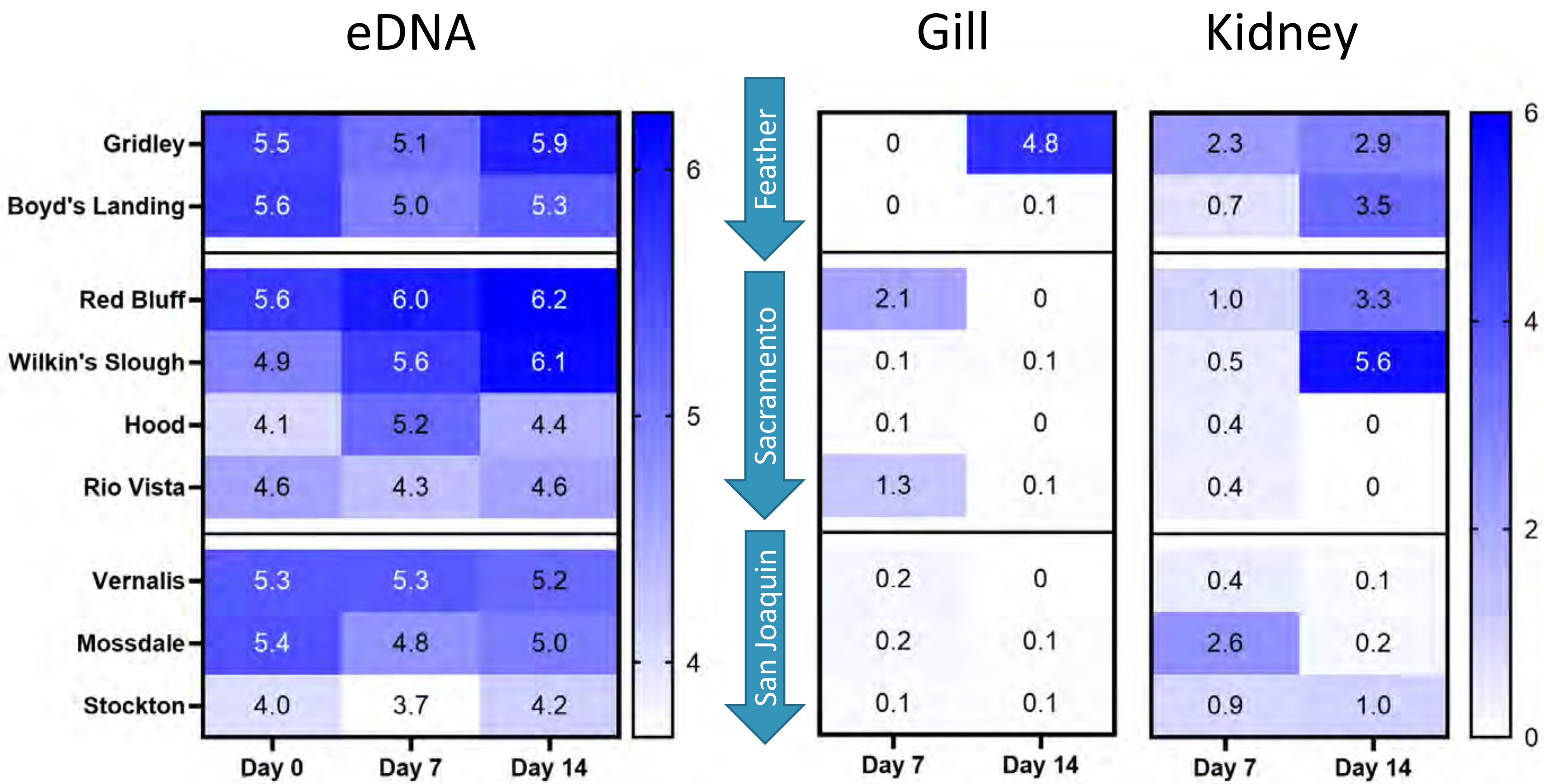
Epithelial Parasite: *D. salmonis*

- eDNA in $\log_2$ (copy#/L H_2O)
- Tissue in $\log_2$ (copy#/100ng DNA)

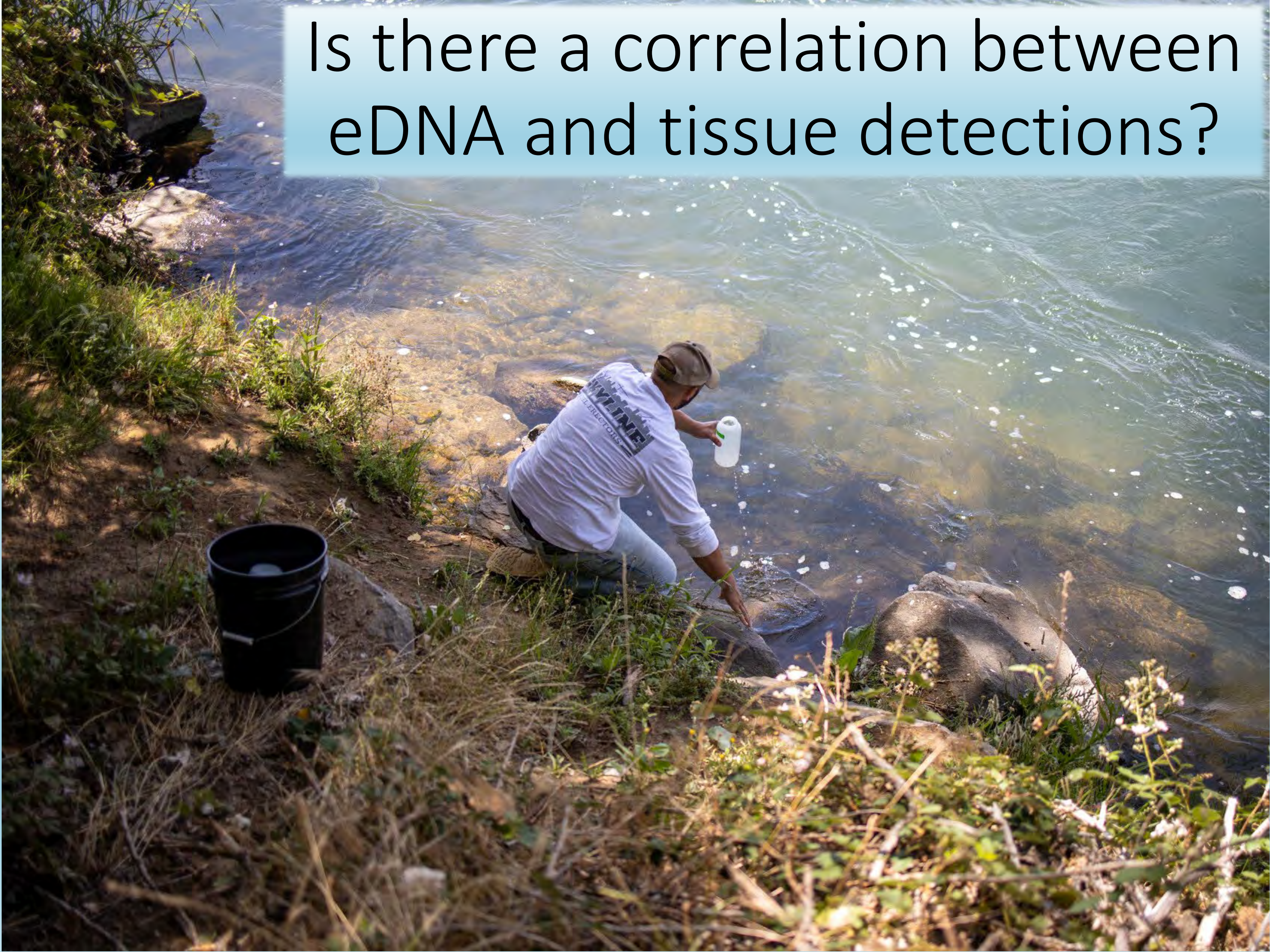


Epithelial Parasite: *I. multifiliis*

- eDNA in $\log_2$ (copy#/L H_2O)
- Tissue in $\log_2$ (copy#/100ng DNA)



Is there a correlation between eDNA and tissue detections?



Research is ongoing!

- Incorporate data from intestinal tissue
- 3 months of 2021 sentinel studies
- Correlating to environmental parameters
- Year-round eDNA monitoring

Acknowlegments

Collaborators

- Oregon State Univeristy
  - Sascha L. Hallett
  - Stephen D. Atkinson
- UC Davis
  - Dennis Cocherell
  - Leah Mellinger
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- CA Dept. of Water Resources
- U.S. Fish and Wildlife Service
- CA Dept. Fish and Wildlife

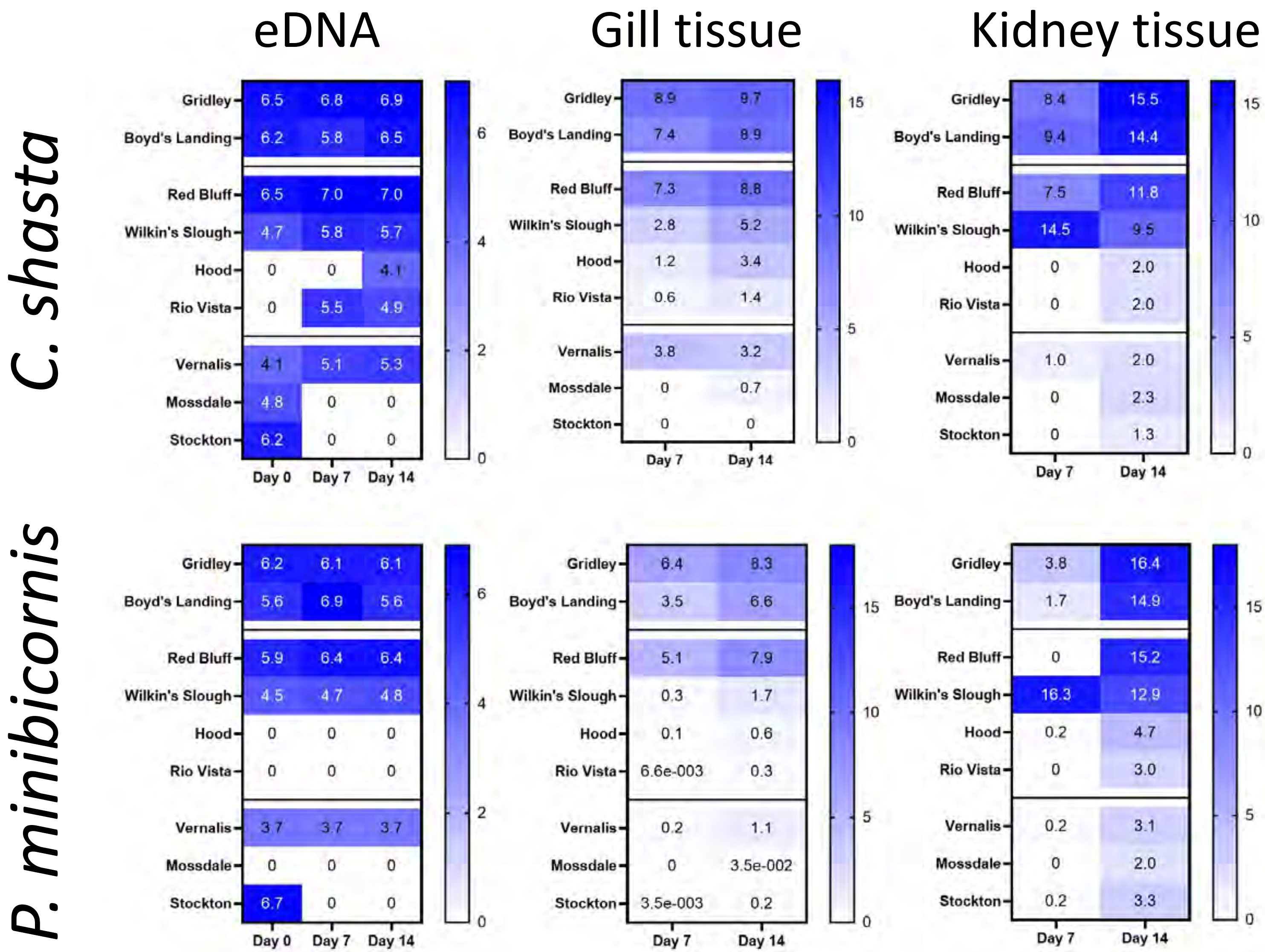
Connon Lab

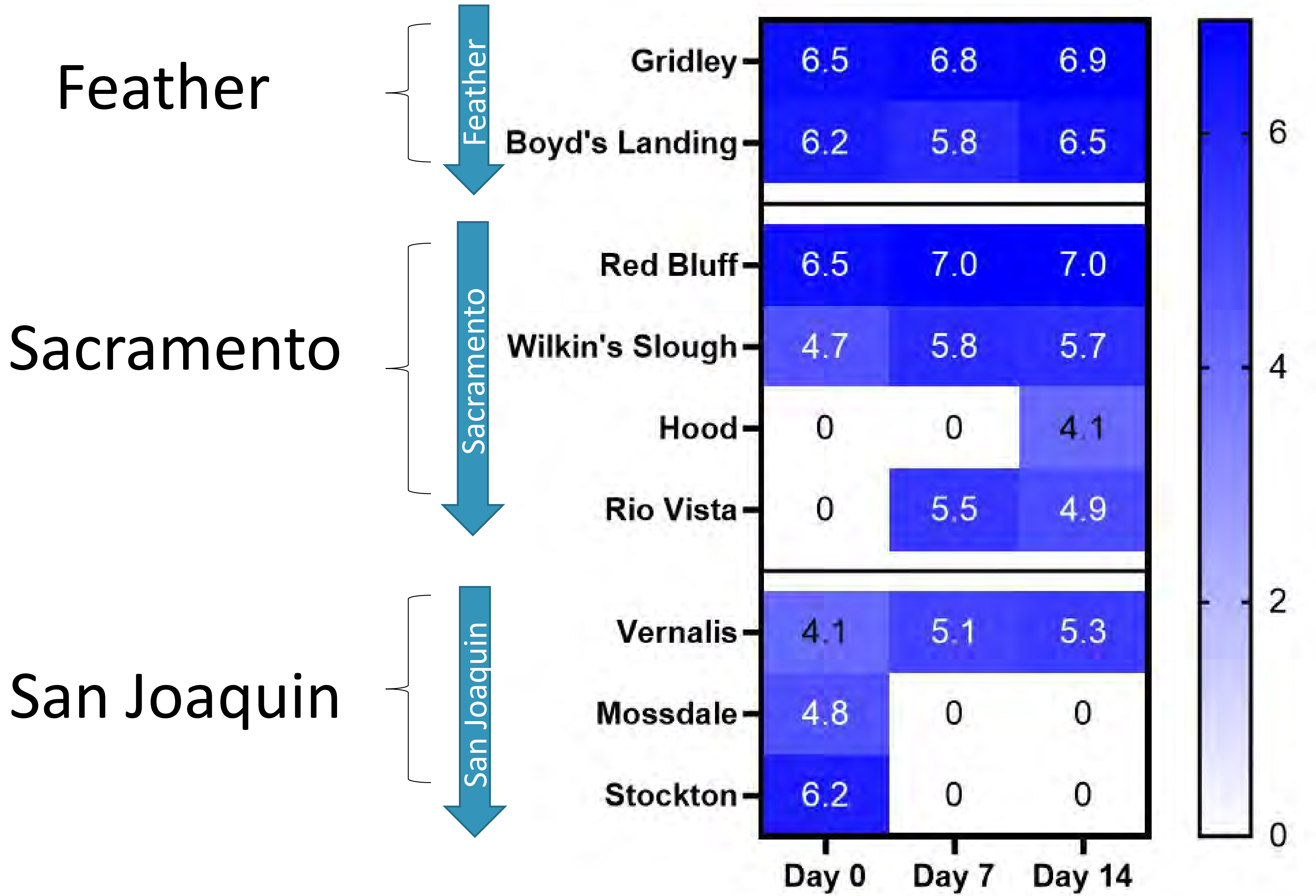
- Post-docs
  - Amelie Segarra
  - Florian Mauduit
- Graduate students
  - Samah Abdelrazek
  - Sarah Stinson
  - Felix Biefel
- Jr. Specialists
  - Nicole Egan
  - Celeste Valdivia
  - Paola Perez
- Volunteers
  - Rose Sherman
  - Cheuk Ling
  - Esperanza Cortez

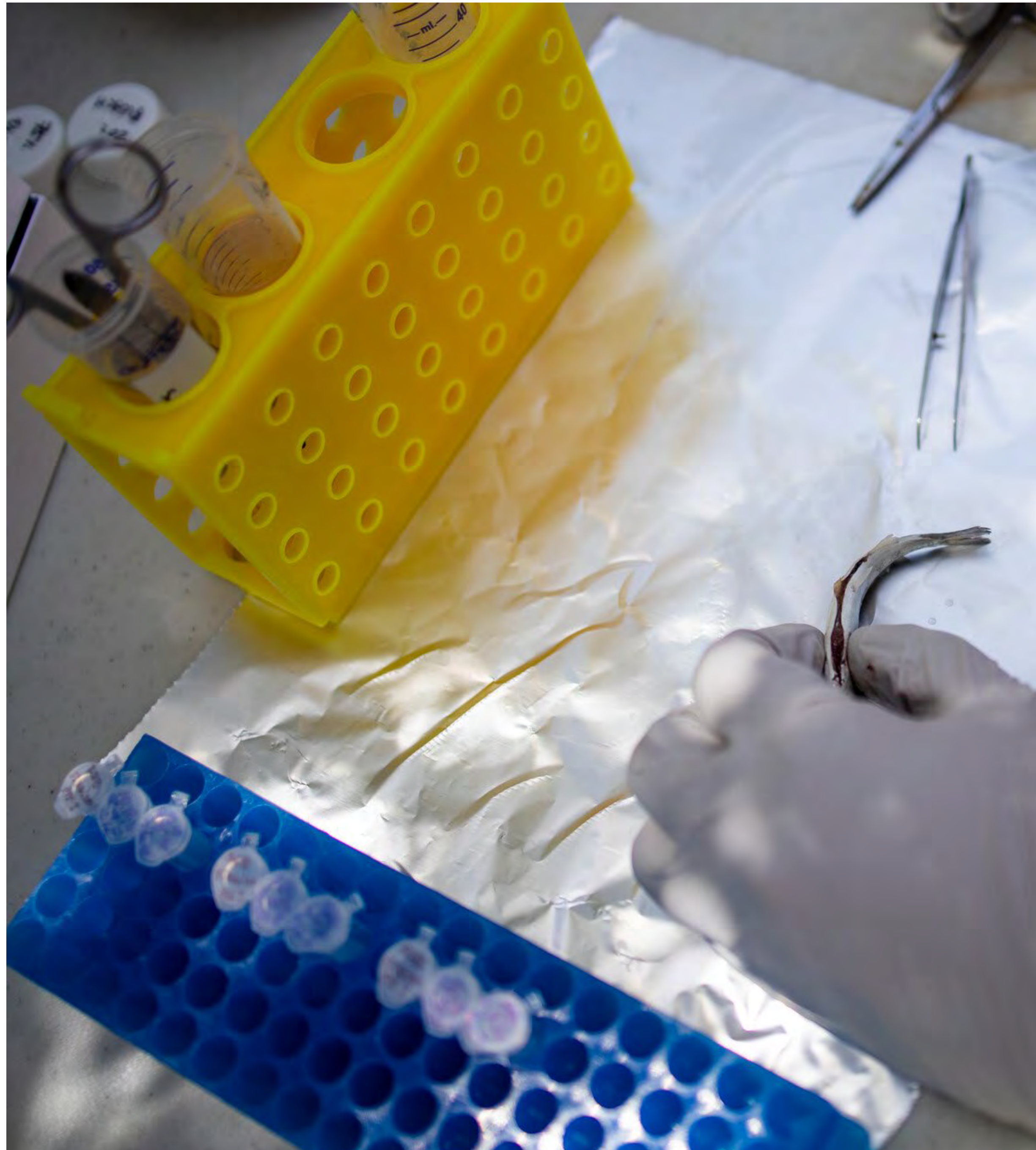
Grant Numbers:
P1896051
Q1996036

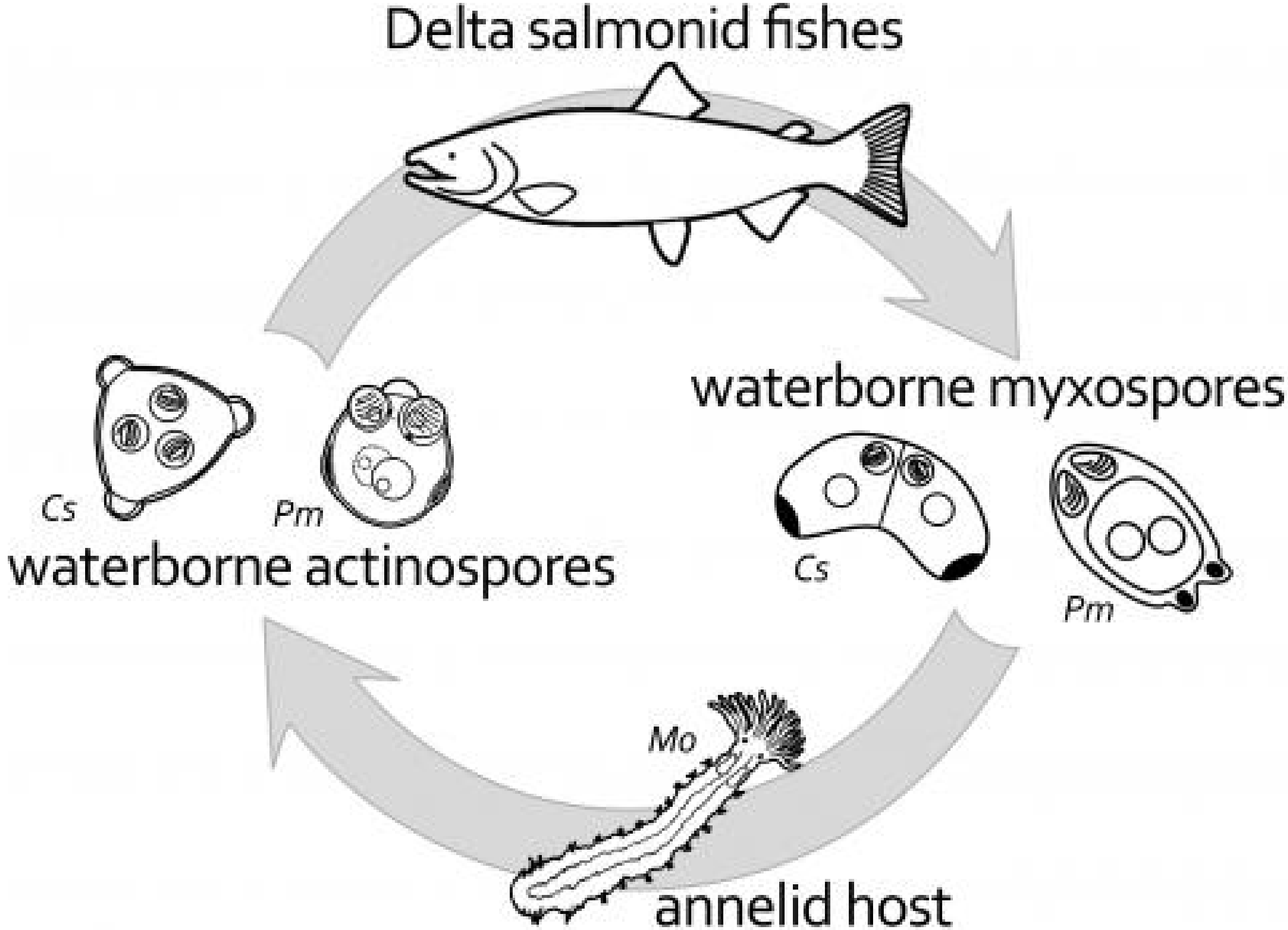
END

Myxozoan parasites




Feather
Sacramento
San Joaquin
Feather
Sacramento
San Joaquin
Gridley
Boyd's Landing
Red Bluff
Wilkin's Slough
Hood
Rio Vista
Vernalis
Mossdale
Stockton
6.5
6.8
6.9
6.2
5.8
6.5
6.5
7.0
7.0
4.7
5.8
5.7
0
0
4.1
0
5.5
4.9
4.1
5.1
5.3
4.8
0
0
6.2
0
0
Day 0
Day 7
Day 14
6
4
2
0

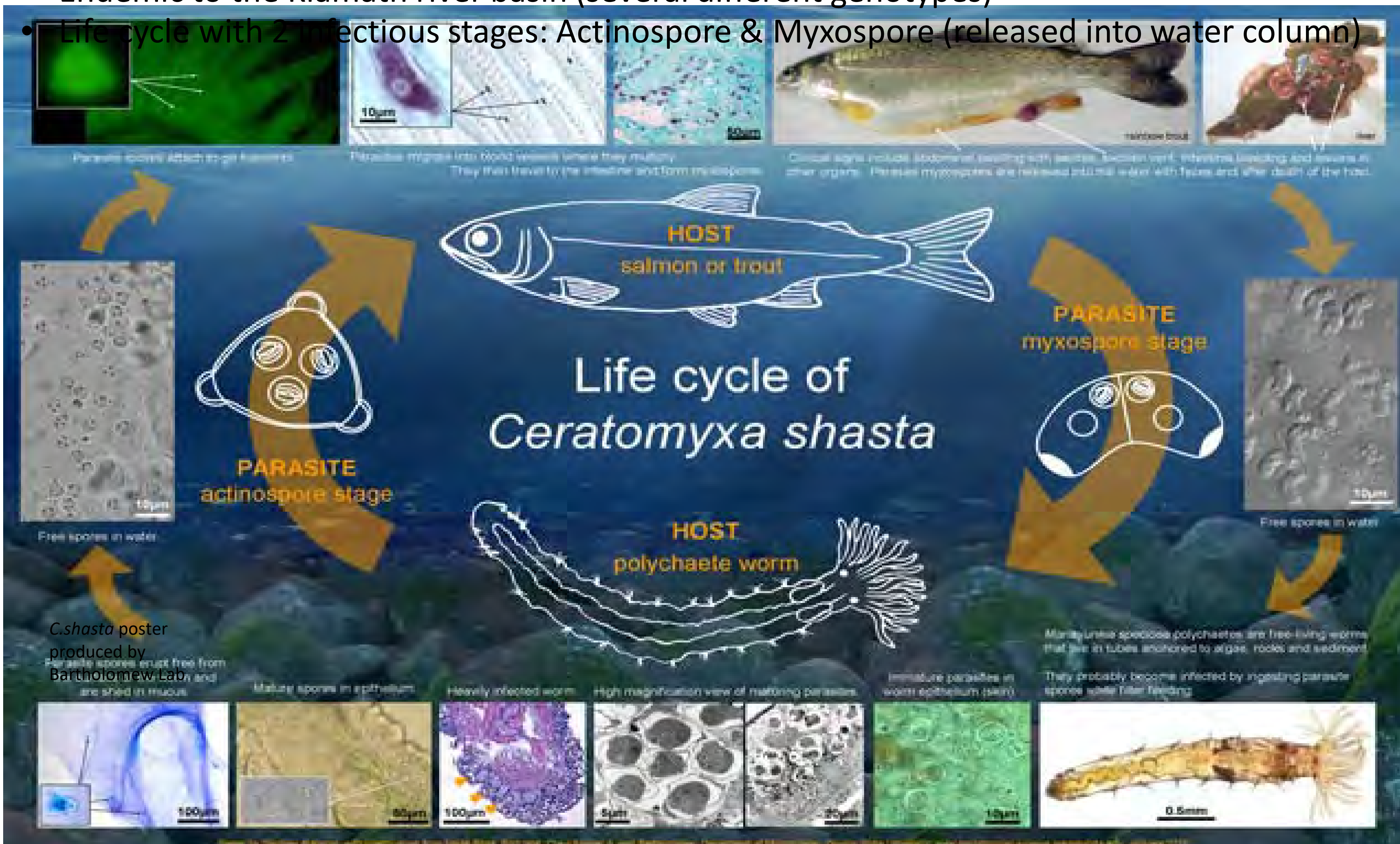




Delta salmonid fishes
waterborne myxospores
Cs
Pm
Cs
Pm
waterborne actinospores
Mo
annelid host

Ceratonova shasta

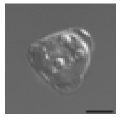
- *C.shasta:*
  - Endemic to the Klamath river basin (several different genotypes)
  - Life cycle with 2 infectious stages: Actinospore & Myxospore (released into water column)

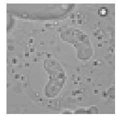


C.shasta poster produced by Bartholomew Lab.

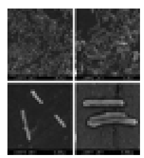
Pathogens

- *Ceratonova shasta:*



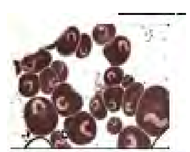


    - "Gut rot"
    - **Myxosporean parasite**
    - Affects digestive tract, other organs, gills, and muscle
    - Infection progression is temperature dependent
    - Utilizes a polychaete and salmonid host



- *Flavobacterium psychrophilum:*
    - "Cold water disease"
    - **Bacterial**
    - Gill disease common in hatchery fish

- *Ichthyophthirius multifiliis:*

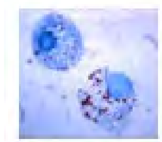


    - "White spot disease; Ich"
    - **Protozoan, Parasitic cilia**
    - Causes ulceration and loss of skin
    - Most common and persistent fish disease

- *Parvicaposula minibicornis:*

    - **Myxosporean parasite**
    - Affects gill, kidney
    - Utilizes a polychaete and salmonid host

- *Rickettsia-like organism*



    - "Cat scratch disease"
    - **Bacterial**
    - Causes abnormal swimming behavior

- *Tetracapsuloides brysalmonae:*

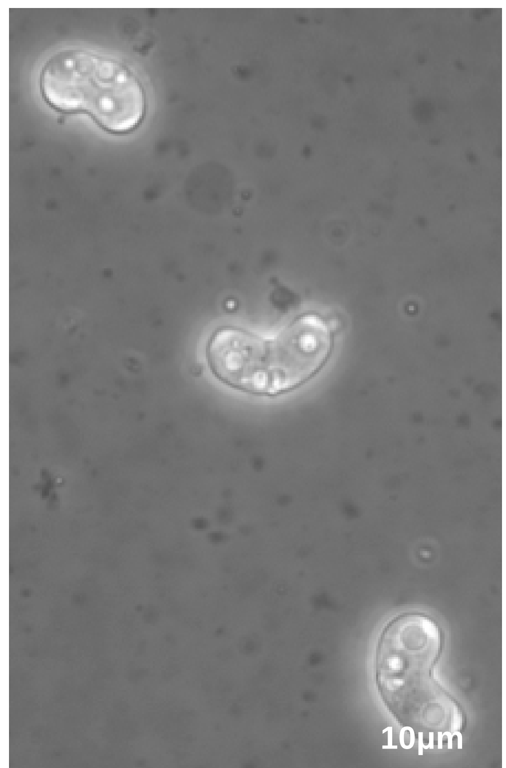
    - "Proliferative kidney disease"
    - **Myxosporean parasite**
    - Affects kidney, spleen, gills
    - Utilizes a bryozoan and salmonid host

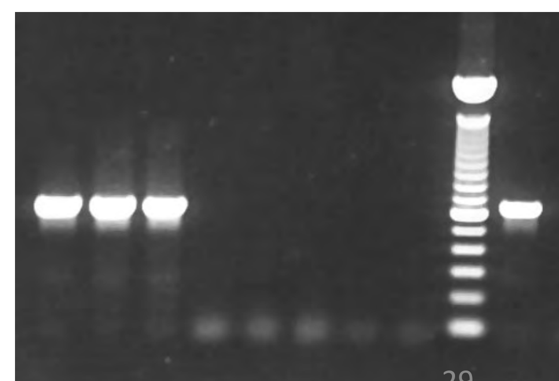
Sampling fish

Capture two different datasets to inform population level impacts

Free ranging fish 	**Sentinel fish** 
USFWS Arcata & Ca-Nv Fish Health Center	OSU, Bartholomew Lab
Outmigrating juveniles	Caged juveniles
Natural and hatchery origin	Hatchery origin
Chinook	Chinook, coho, rainbow trout
Moving through the system, history unknown	Set location and time, known history
Killed upon capture, qPCR & histology	Observed 60 days, microscopy & PCR

Sentinel Fish Exposures





Sampling fish - metrics

<u>Free Ranging Fish</u>

Prevalence of infection

Severity of infection (disease?)

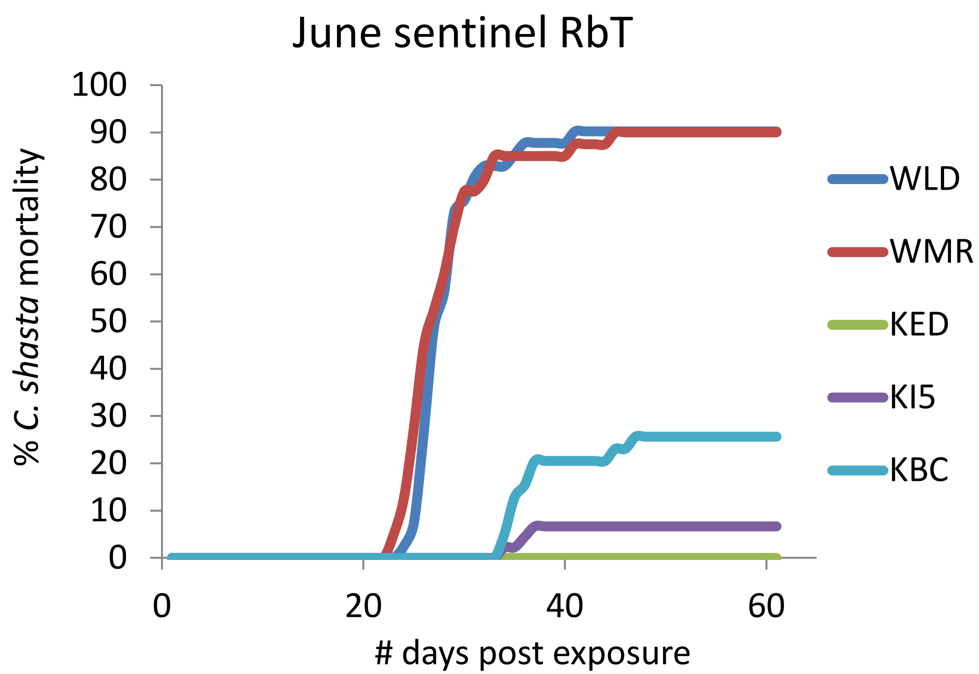
- amount of parasite DNA
- histopathology score

<u>Sentinel Fish</u>

Prevalence of infection

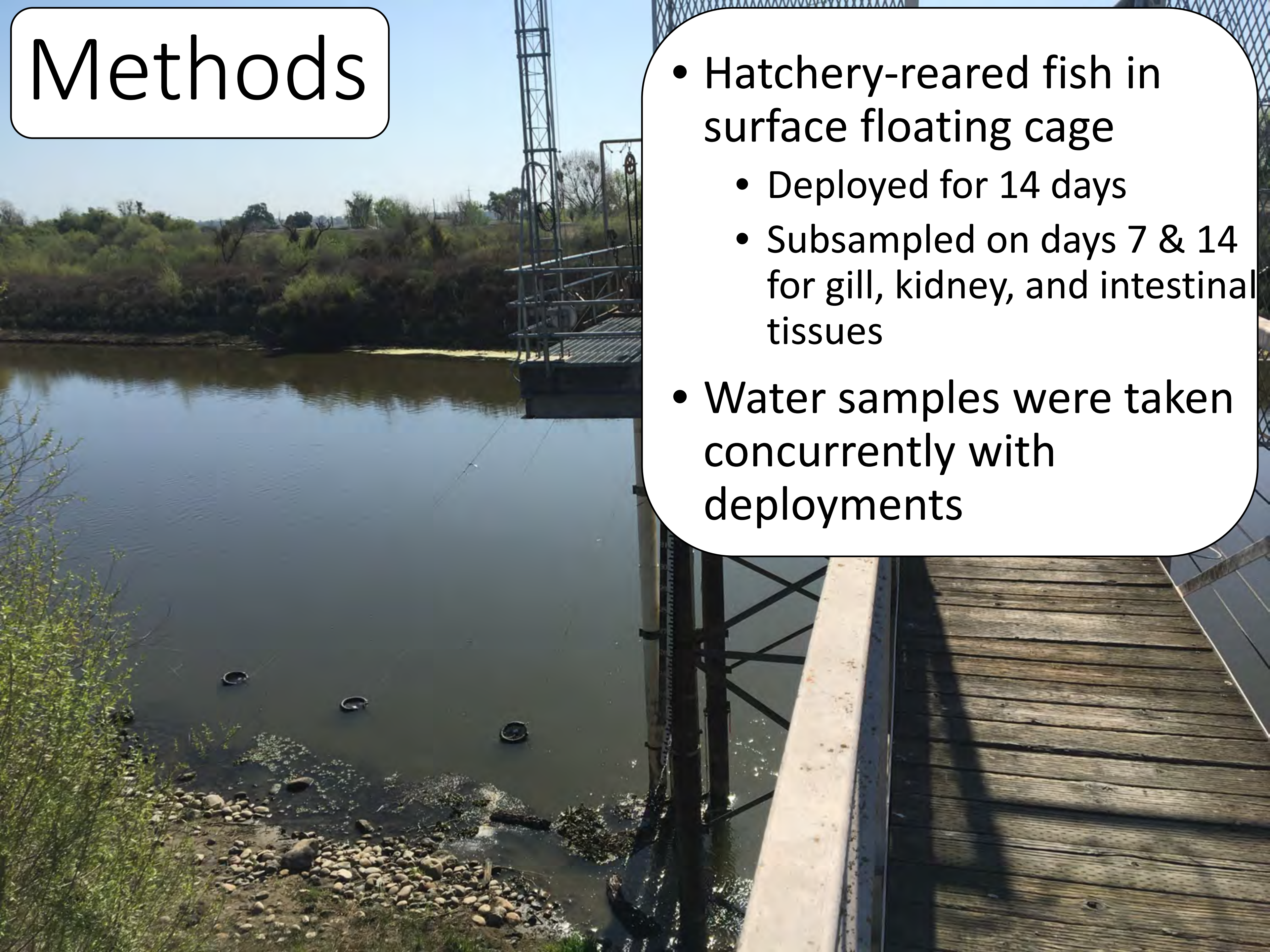
Severity of infection (disease?)

- percent mortality (moribund)
- rate of progression

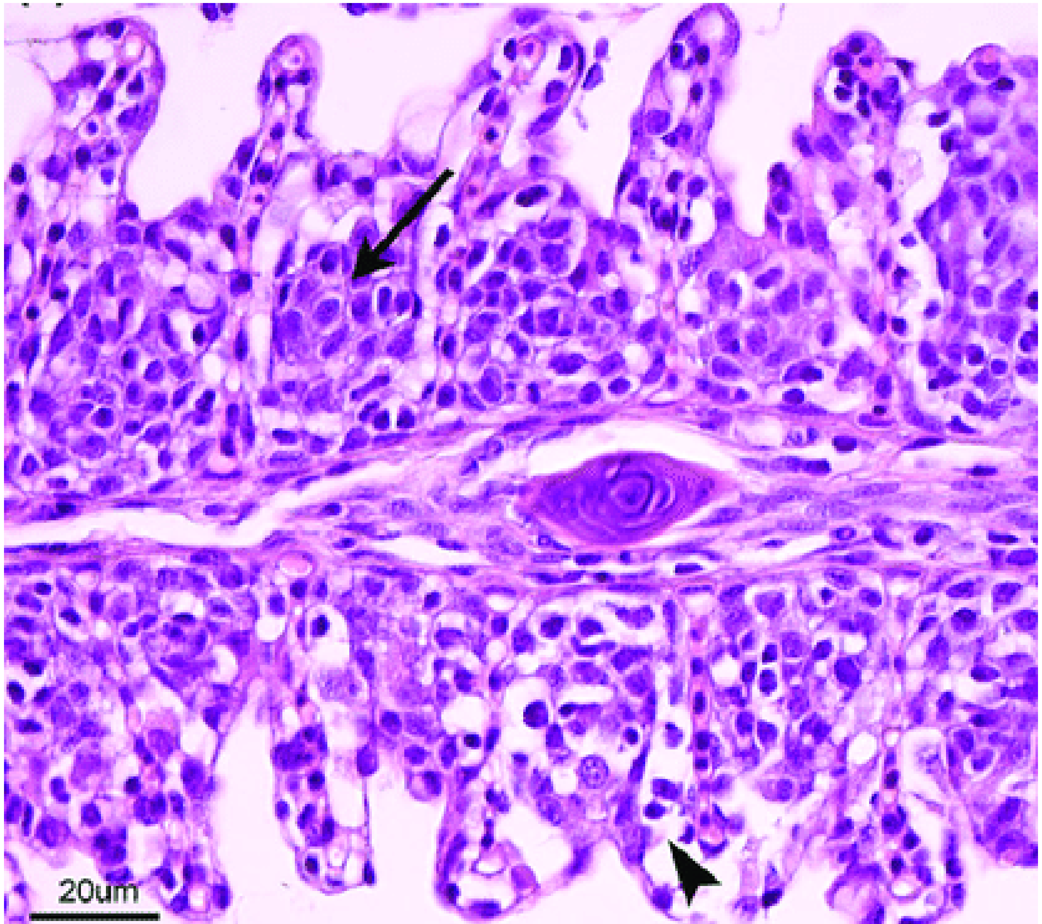


Methods

- Hatchery-reared fish in surface floating cage
  - Deployed for 14 days
  - Subsampled on days 7 & 14 for gill, kidney, and intestinal tissues
- Water samples were taken concurrently with deployments



- C.B. cysticola Wiik-Nielsen et. al, 2017



Conservation and Restoration of Adaptive Genomic Variation

Devon Pearse

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Fisheries Ecology Division/Southwest Fisheries Science Center
and
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Dept. of Ecology & Evolutionary Biology
University of California, Santa Cruz

SRF, Santa Cruz, CA
April 22, 2022

>Genetics 101:

A LOCUS is a single piece of the genome.

Region, Gene, or Single Nucleotide (base) Polymorphism (SNP)

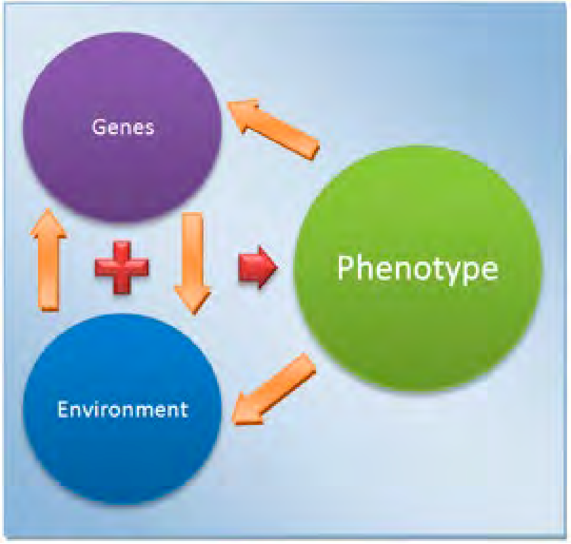
A single locus can have multiple ALLELES, e.g. A and a.
multiple haplotypes-- SARS-CoV-2 variants!

Unlike SARS-CoV-2, in most animals these ALLELES combine within individuals into GENOTYPES: AA, Aa, aa

How is genetic variation—*biodiversity*– distributed among the fundamental biological units—individuals, populations, species?

How can we best conserve it given that knowledge?

Adaptive Genomic Variants are variable, and their connection with specific phenotypes varies



Genetics → Genomics: data is now almost limitless.

1996 2006 2016→→???

Fraction of genome

Sanger sequencing

Whole genome re-sequencing

1 locus mtDNA 10-100s of Allozymes/Microsats/SNPs Millions of SNPs

"Neutral"
Population Genetic Data
ANCESTRY

"Adaptive" or "Functional"
Adaptive Genomic Variation
ADAPTATION
(AGV)

Neutral vs Adaptive is not binary--really a continuum!

mod. from Peterson et al. 2012, Plos One

AGV associated with Salmonid Life-History traits:

>**Age-of-Return**: How many years at sea?
Vgll3: **Early = 1 or 2 years** **Late = 2 or 3 years**

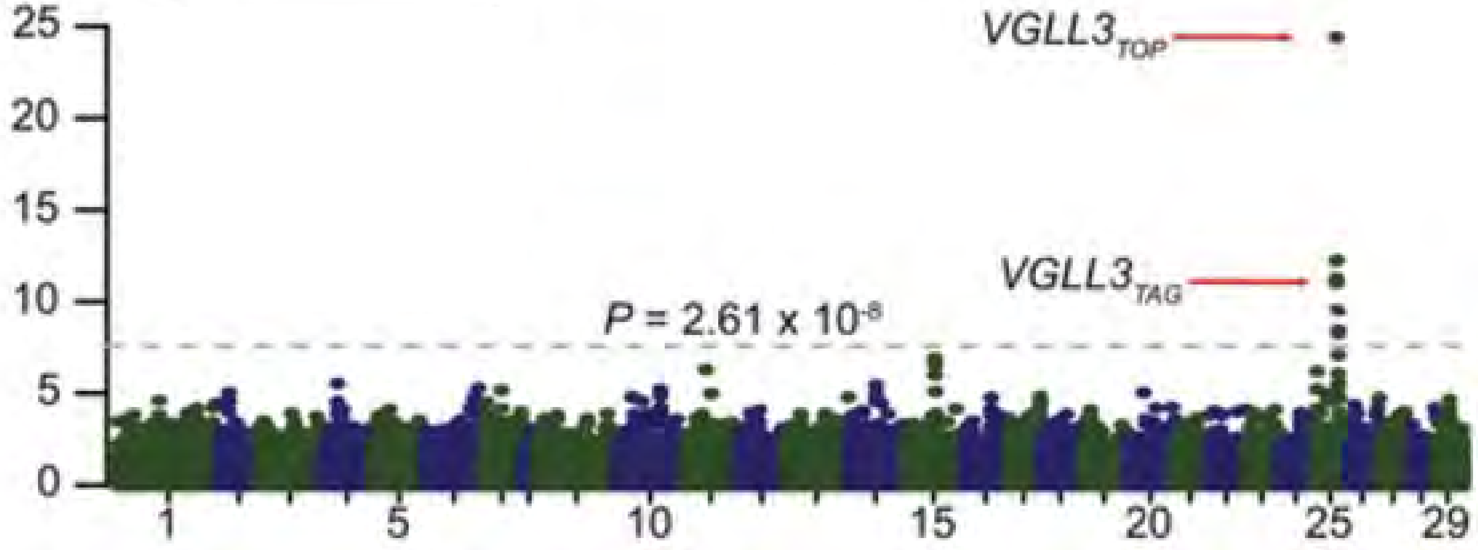
>**Run-Timing**: When do adults migrate into freshwater?
Greb1L/Rock1: **Early=Spring/Summer**, **Late=Fall/Winter**

>**Anadromy/Residency**: Migrate to the ocean or not?
Omy05: *O. mykiss*: **steelhead** or **Rainbow trout**

>**Many others,** e.g. Larson et al. 2017 Beach/stream sockeye

>AGV is ubiquitous! What does this mean for conservation?

Vgll3; Early vs. Late **Age-of-Return** in Atlantic Salmon



Barson et al. 2015

Early = 1 or 2 years
Late = 2 or 3 years

EE, EL, LL

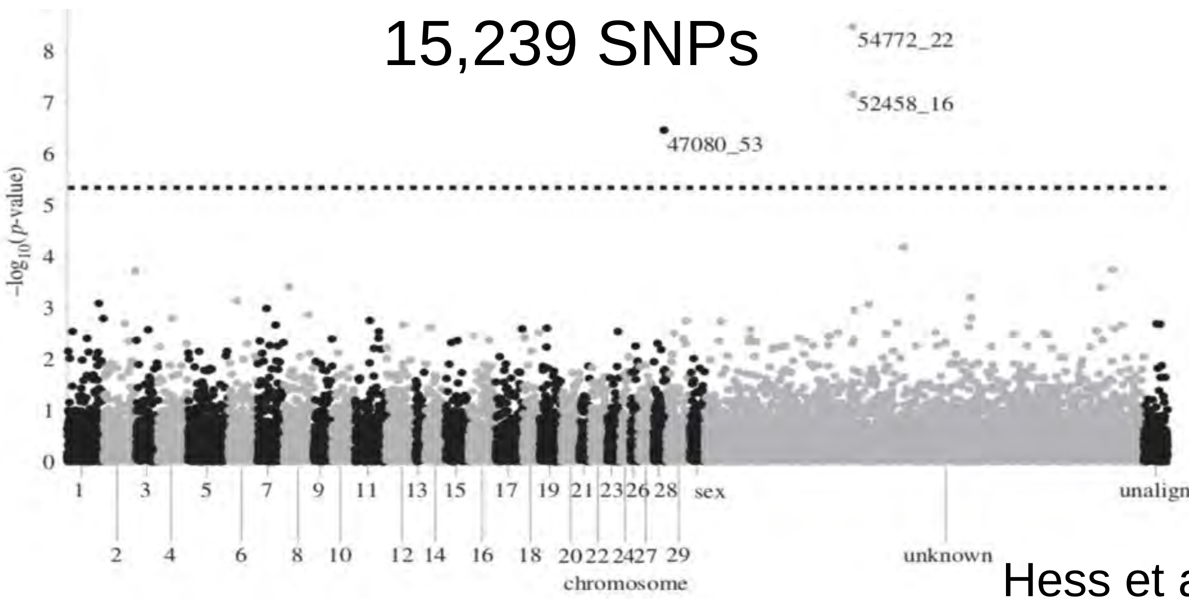
>Sex-dependent **dominance**
EL male = EE
EL female = LL

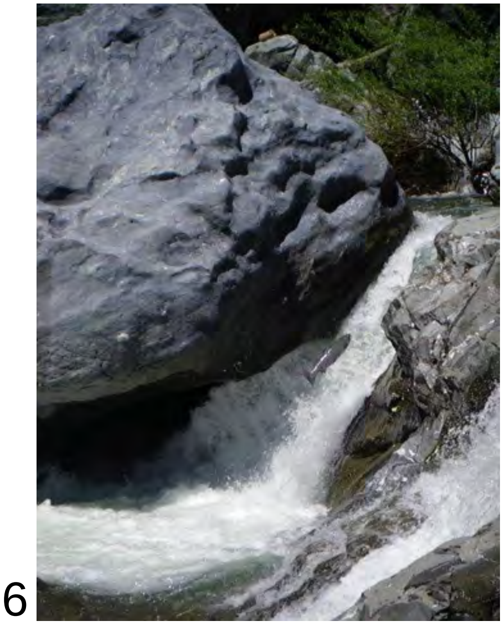
>**Single locus of major effect**.

>Explains 39% of variance.

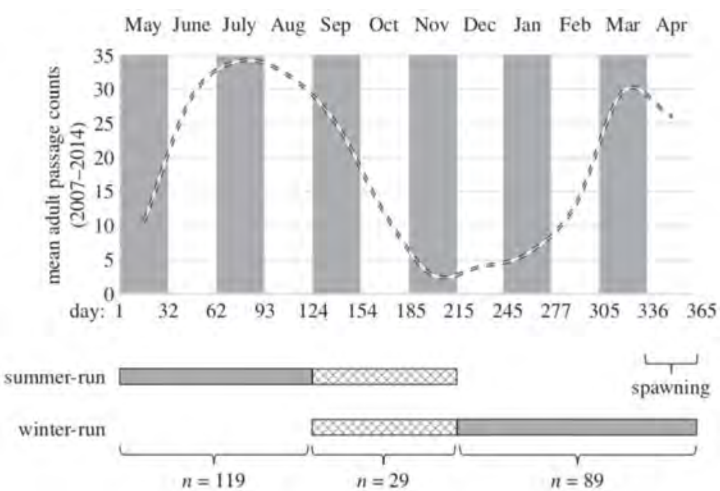
>Not associated with age-of-return in Pacific Salmon. (Waters et al. 2021)

***Greb1L*: Early vs. Late Run-Timing in steelhead**





Hess et al. 2016

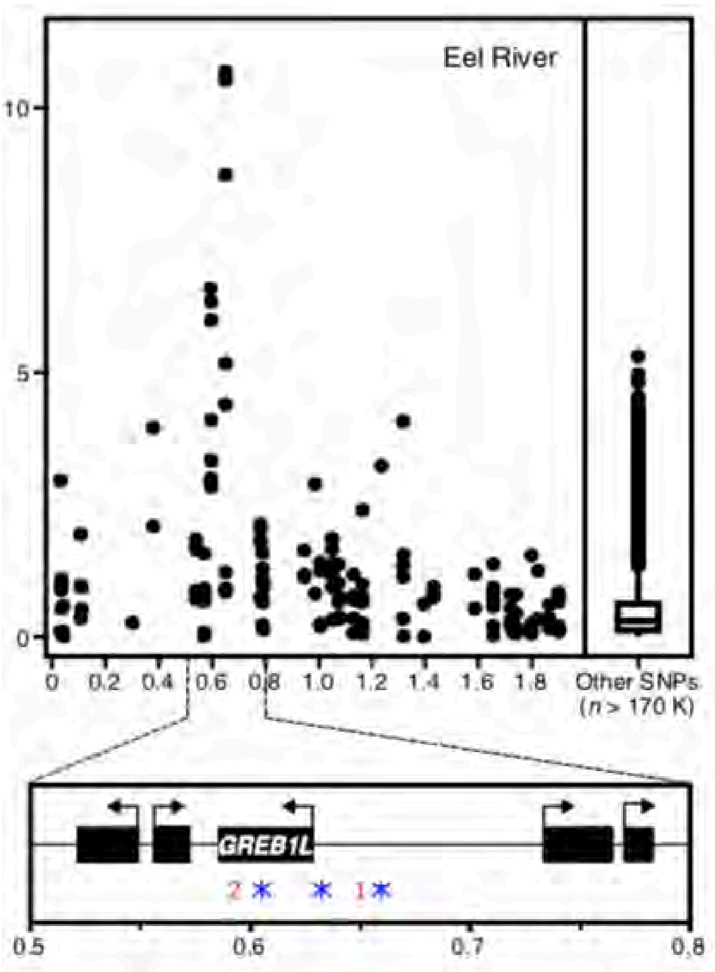


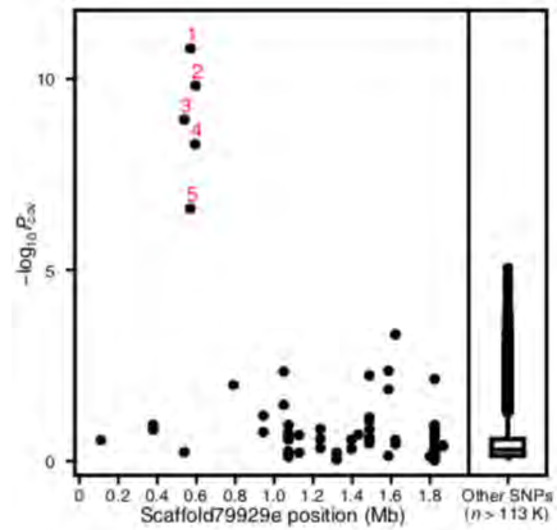
>**Single locus of major effect?**

>Explained 46% of trait variation.

>*Greb1L* conserved physiological functions across vertebrates.

Early vs. Late Run-Timing in Steelhead & Chinook!!





Prince et al. 2017

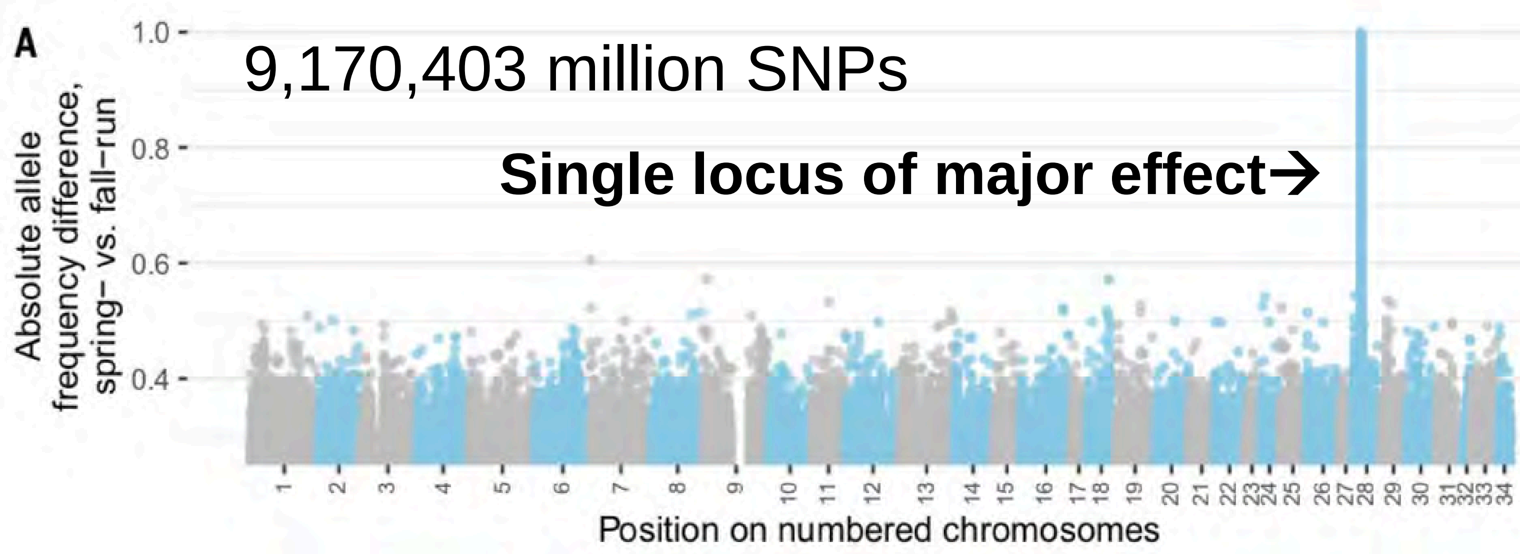
>**Single locus of major effect.**

>**Parallel molecular evolution** in the *Greb1L* region in both species

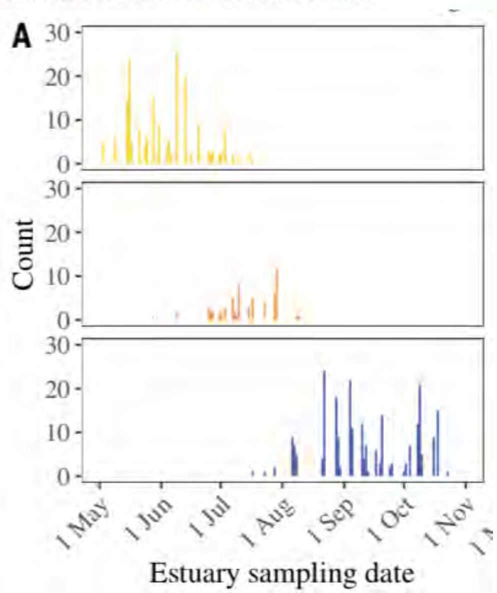
Early vs. Late Run-Timing in Chinook Salmon:

9,170,403 million SNPs

Single locus of major effect→



Thompson et al. 2020



EE=Early, Spring

EL=Heterozygotes

LL=Late, Fall

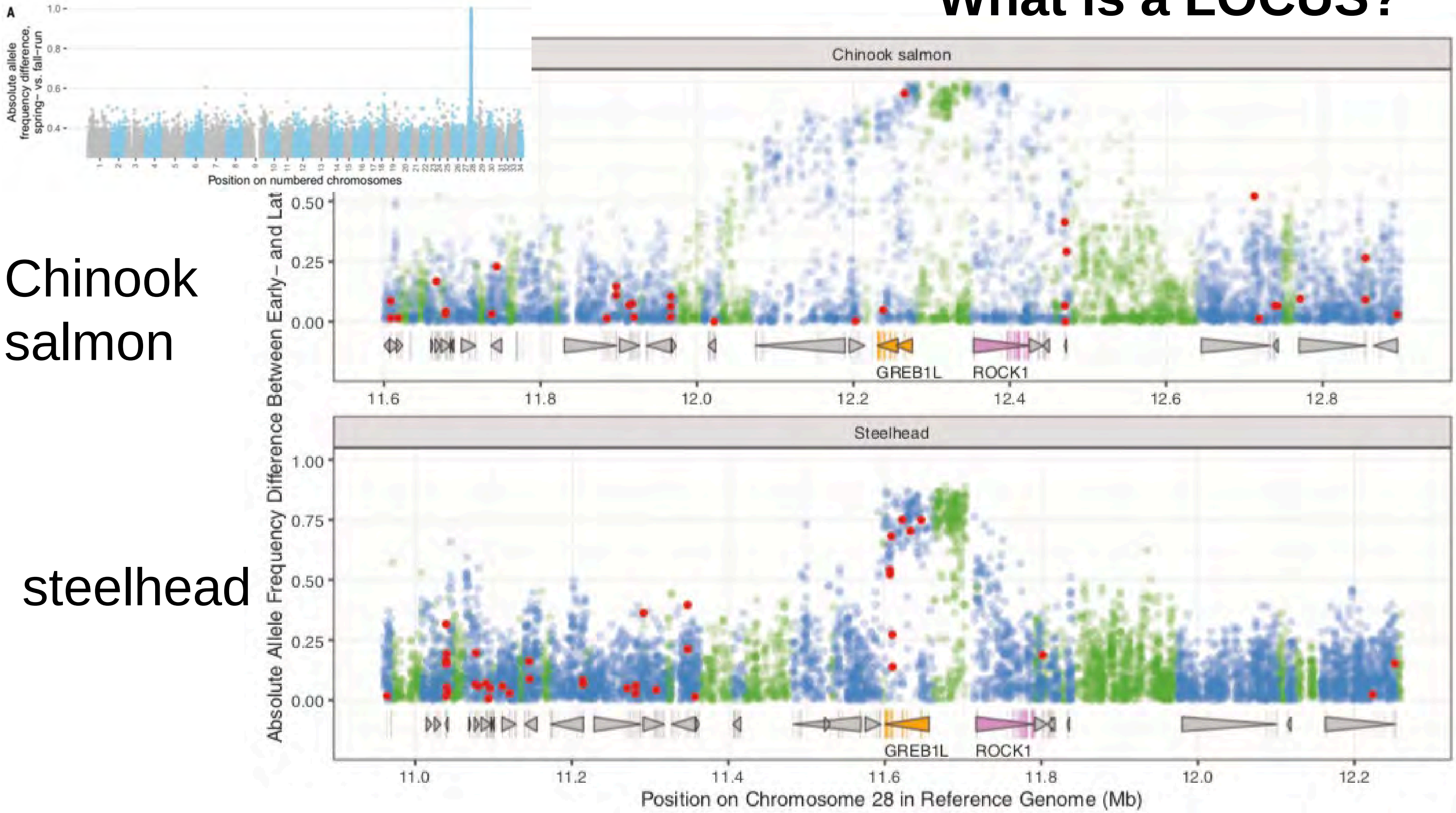
>Klamath River entry
>Heterozygotes

Sequence variation in the Greb1L/Rock1 region

What is a LOCUS?

Chinook salmon

steelhead



From Waples et al. 2022: Chinook data from Thompson et al. 2020, steelhead data from Micheletti et al. 2018

Genomic Basis of Anadromy/Residency

>Numerous studies on genetic basis of anadromy in *O. mykiss*:
Robison et al. 2001; O'Malley et al. 2003; Thrower et al. 2004; Leder et al. 2006; Phillips et al. 2006;
Nichols et al. 2007, 2008; Haidle et al. 2008; Colihueque et al. 2010; Paibomesai et al. 2010; Easton et al. 2011;
Le Bras et al. 2011; Martínez et al. 2011; Miller et al. 2012; Narum et al. 2011; Limborg et al. 2012; Hecht et al. 2012a,b;
Hale et al. 2014; Pearse et al. 2014; McKinney et al. 2015; Baerwald et al. 2015; Leitwein et al. 2016; Apgar et al. 2017;
Abadia-Cardoso et al. 2019; Arostegui et al. 2019; Pearse et al. 2019; Kelson et al. 2019a,b, 2020a,b,c; Fraik et al. 2021

>**Polygenic** — multiple loci with environmentally-dependent effects.

>Chromosome Omy05 contains single locus of major affect for this trait.

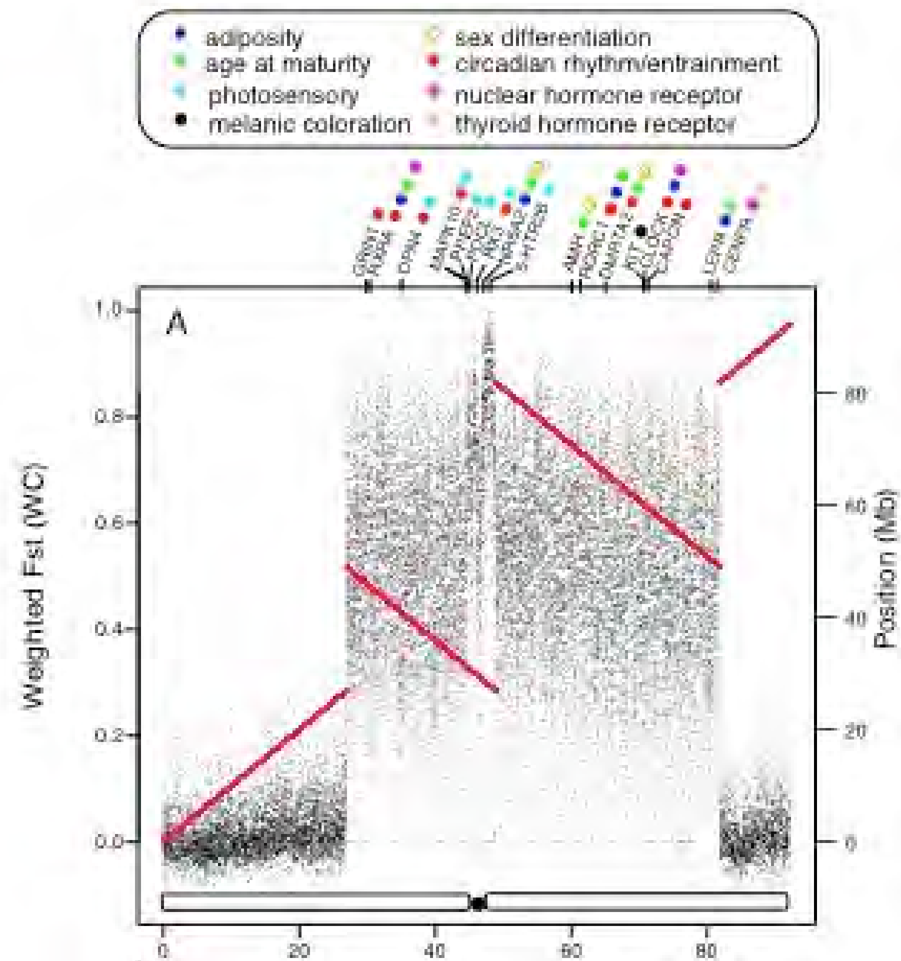
Genomic Basis of Anadromy/Residency: Omy05

Massive double inversion complex on chromosome Omy05

>50 million DNA base pairs
>1,000 genes
Acts as a single locus **‘supergene’**.

A = ancestral, anadromy
R = rearranged, resident
Individuals have genotypes:
AA, AR, RR

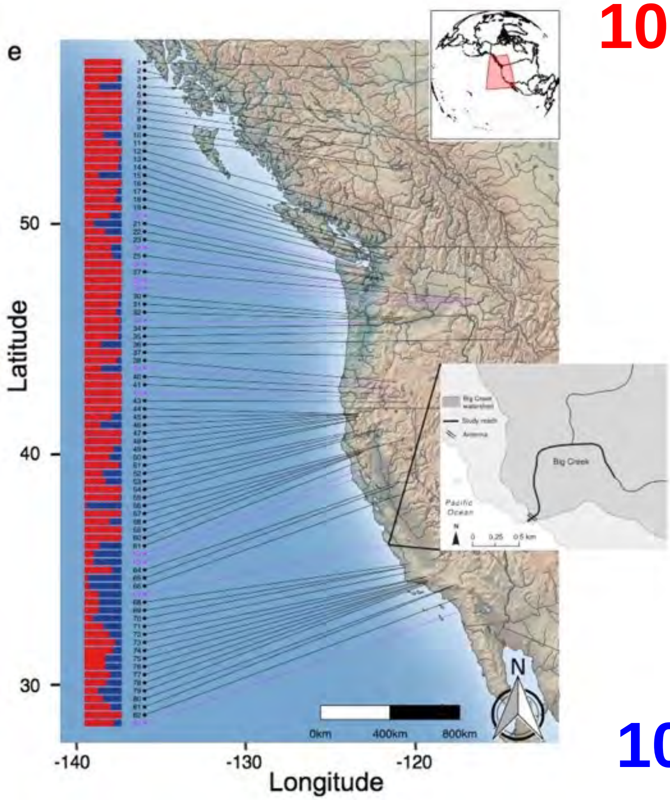
Sex-specific phenotypic effects

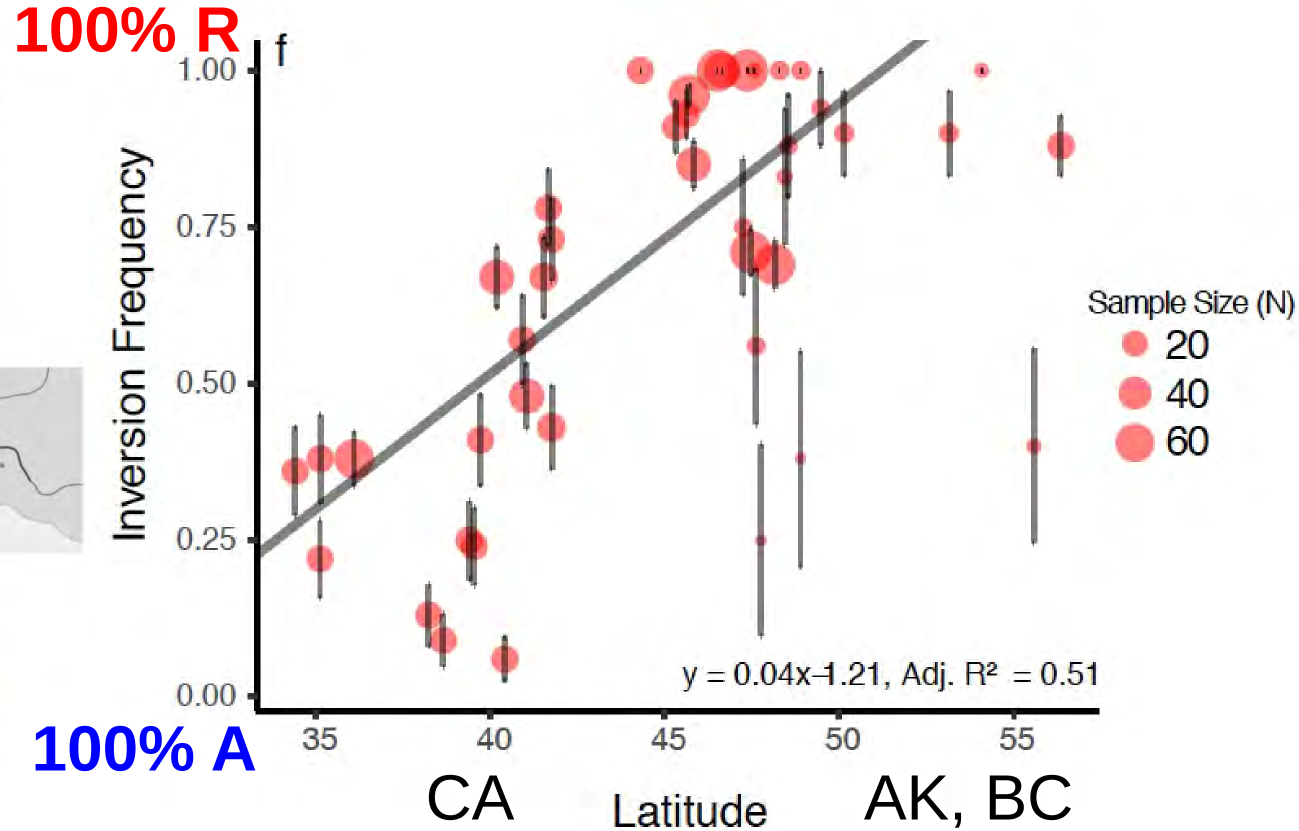


Pearse et al. 2019, *Nature ecology & evolution*

Genomic Basis of Anadromy/Residency: Omy05

Strong cline in **steelhead** (below barrier) populations:





Pearse et al. 2019,
Nature ecology & evolution

So what does all this mean for conservation and restoration?

American Genetic Association

Journal of Heredity, 2022, 1–24
https://doi.org/10.1093/jhered/esab069
Invited Review
Advance Access publication March 19, 2022

Invited Review

Implications of Large-Effect Loci for Conservation: A Review and Case Study with Pacific Salmon

Robin S. Waples, Michael J. Ford, Krista Nichols, Marty Kardos, Jim Myers, Tasha Q. Thompson, Eric C. Anderson, Ilana J. Koch, Garrett McKinney, Michael R. Miller, Kerry Naish, Shawn R. Narum, Kathleen G. O'Malley, Devon E. Pearse, George R. Pess, Thomas P. Quinn, Todd R. Seamons, Adrian Spidle, Kenneth I. Warheit, and Stuart C. Willis

So what does all this mean for conservation and restoration?

>**Adaptive variants reflect ecological conditions** that favor the phenotypes they are associated with.

>**Relative reproductive success** of individuals with different genotypes/phenotypes.

Vgll3

Science REPORTS

Cite as: Y. Czorlich *et al.*, *Science* 10.1126/science.abg5980 (2022).

Rapid evolution in salmon life history induced by direct and indirect effects of fishing

Y. Czorlich[1,2,3,4], T. Aykanat[3], J. Erkinaro[2], P. Orell[2], C. R. Primmer[3,5]*

[1]University of Turku, Department of Biology, FI-20014, Turku, Finland. [2]Natural Resources Institute Finland (Luke), POB 413, FI-90014 Oulu, Finland. [3]University of Helsinki, Organismal & Evolutionary Biology Research Programme, POB 56, FI-00014 Helsinki, Finland. [4]Norwegian Institute for Nature Research (NINA), NO-7485 Trondheim, Norway. [5]University of Helsinki, Institute of Biotechnology, Helsinki Institute of Life Science (HiLIFE), POB 56, FI-00014 Helsinki, Finland.

So what does all this mean for conservation and restoration?

>Adaptive variants reflect ecological conditions: *Omy05*.

modified from
Lindley et al. 2006

>Dams separate populations into trapped *O. mykiss* **above** and mixed resident and anadromous steelhead **below**.

>Create reservoirs above them.

>Can retain adaptive variation.

Photo: Alex McHuron

<u>Omy05 A variant present in reservoirs in</u>:

Coastal CA	Pearse et al. 2014, 2019
San Francisco Bay area	Leitwein et al. 2017
Tuolumne and Merced	Pearse & Campbell 2018
American River	Abadía-Cardoso et al. 2019

So what does all this mean for conservation and restoration?

>Adaptive variants reflect ecological conditions: *Greb1L*.

Butte Creek Spring Run Chinook. Photo by D. Pearse

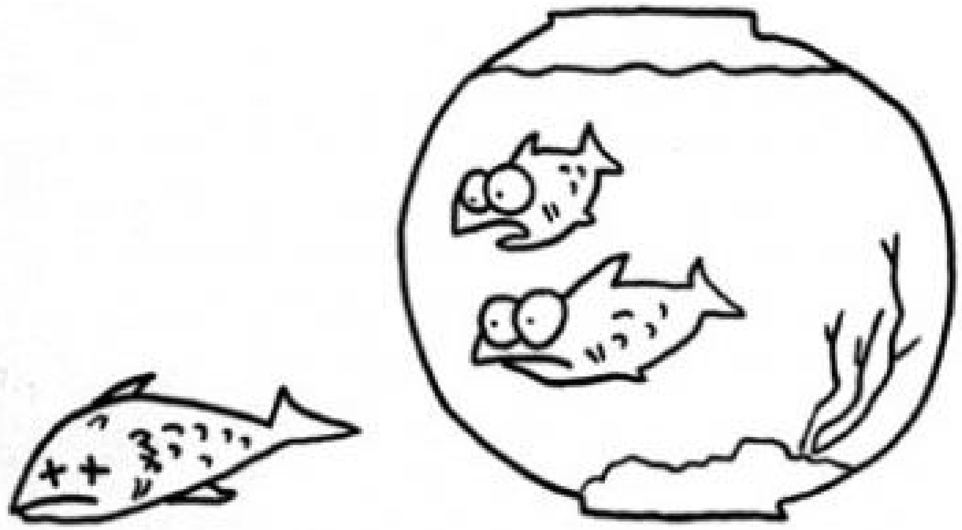
Conclusions

- **Advances in genomics provide tools for understanding, but**
  Lack of scientific knowledge is often not the limiting factor for conservation

- **Complex variation and interactions among adaptive variants.**
  steelhead have both Greb1L/Rock1 and Omy05

- **Diverse, dynamic, connected habitats and the portfolio effect.**
  Focus on conservation 'units' creates challenges in the face of the biological diversity of nature

Thank you!



... then he yelled "evolution!"
and simply jumped out ...

NOAA FISHERIES

Factors affecting spatiotemporal variation in survival of endangered winter-run Chinook salmon outmigrating from the Sacramento River

Jason L. Hassrick | Arnold J. Ammann | Russell W. Perry | Sara N. John | Miles E. Daniels

First published: 21 January 2022

North American Journal of Fisheries Management

Article | Open Access

Salmonid Restoration Federation

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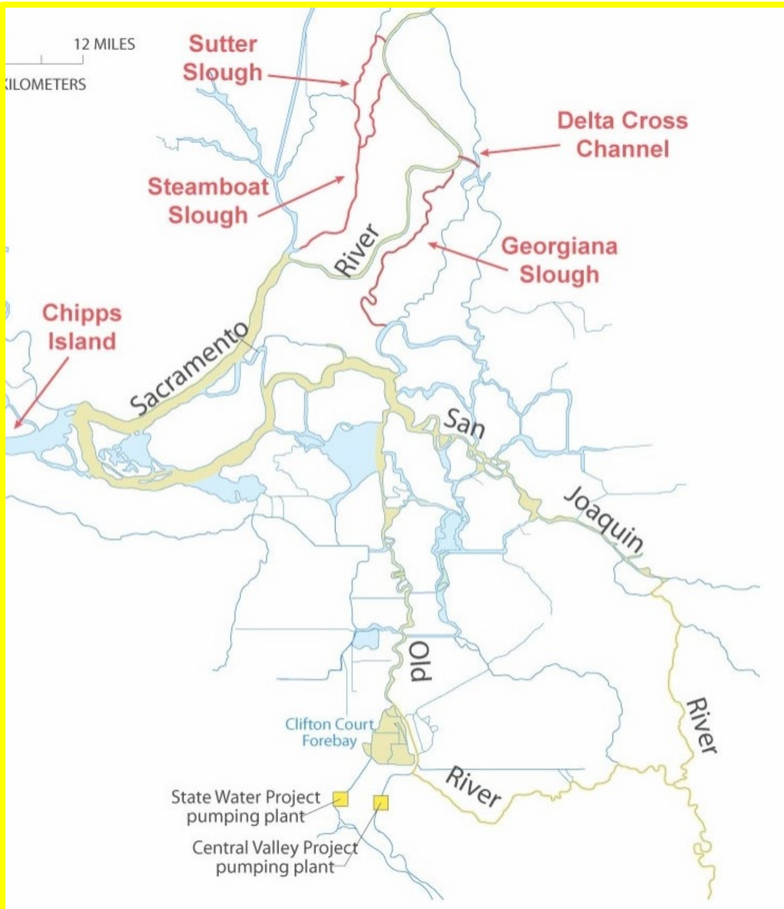
US Bureau of Reclamation
The Sites Reservoir Authority

Timing is everything

Illustration: Robin Ade, 1997

Why bother?



Diversions

Takeaways

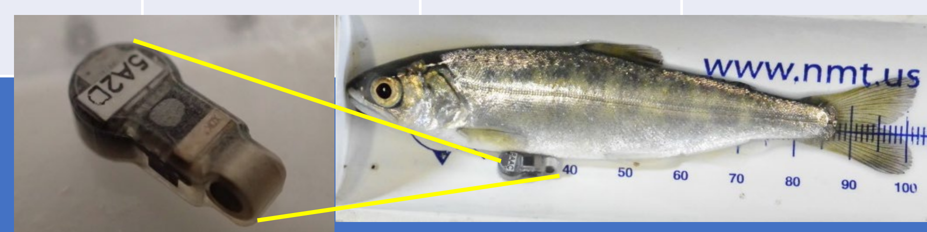
1. Life history traits for stopover behavior persist
2. Stopover behavior occurs in a key stretch of river with evidence for density dependent habitat availability
3. The effect of habitat covariates on survival changes
4. Flow matters in different ways, depending on scale
5. Implications for increased temps on survival of natural-origin fish

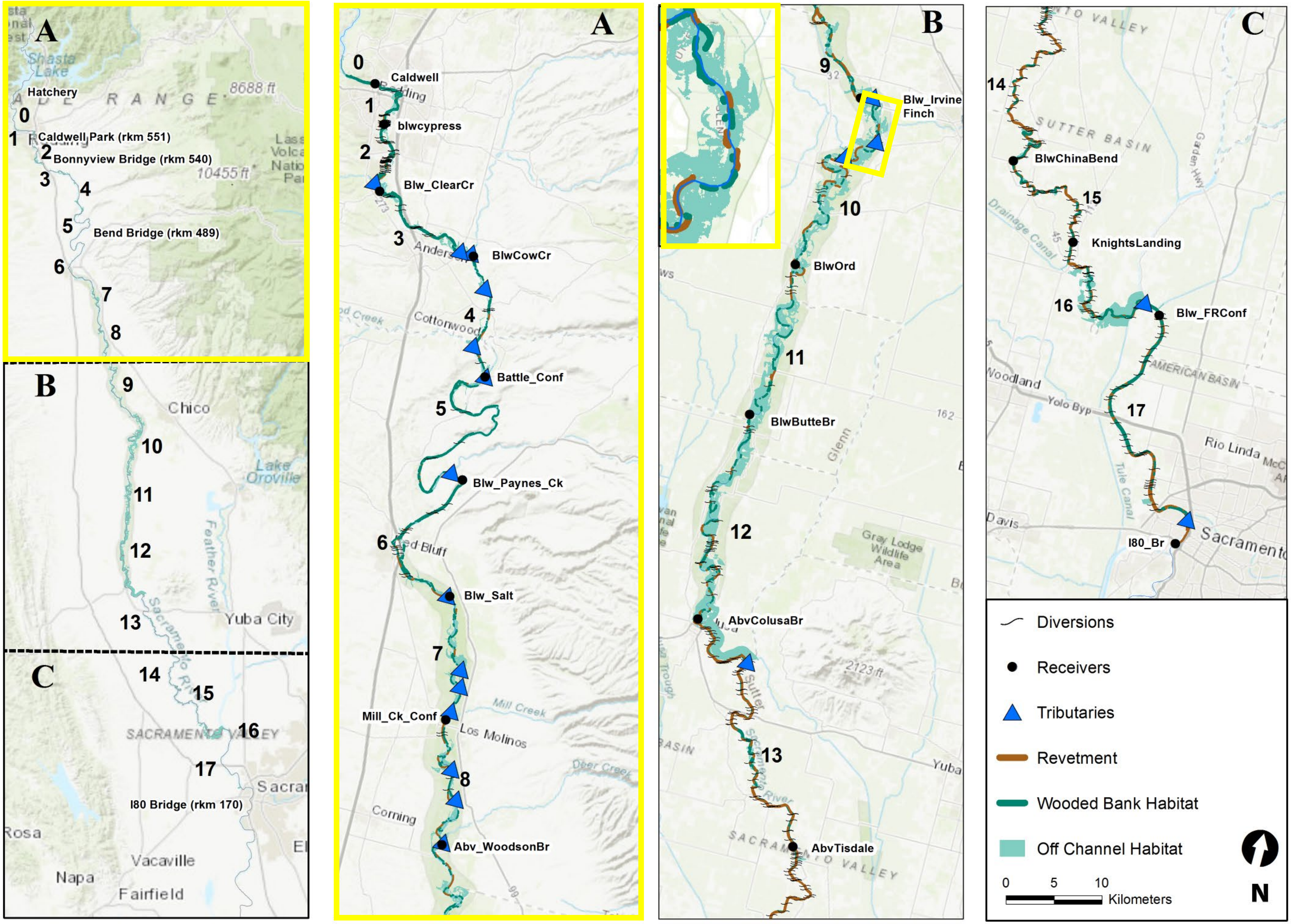

SANTA CRUZ

Summary of Tagged Winter-Run

Release date	Number fish acoustic tagged	Weight in grams (mean ± SD)	Fork length in mm (mean ± SD)	Tag burden in % (mean, range)	Hatchery winter-run released	Flow at Bend Bridge in m^3 sec^{-1} (mean, range)
7 Feb 2013	148	10.3 ± 1.7	98 ± 5.0	4.3 (2.5-5.4)	166,967	168 (127-289)
14 Feb 2014	358	9.4 ± 2.4	95 ± 7.7	3.9 (2.0-5.8)	190,905	187 (108-790)
4, 6 Feb 2015	249, 318	10.5 ± 2.0	100 ± 6.1	3.2 (2.0-5.9)	590,623	197 (105-1,453)
17-18 Feb 2016	285, 285	9.3 ± 1.6	96 ± 5.1	3.6 (2.3-5.3)	415,865	432 (151-1,603)
2 Feb 2017	569	9.1 ± 2.4	93 ± 7.5	3.7 (1.7-5.7)	141,388	1,315 (385-2,832)

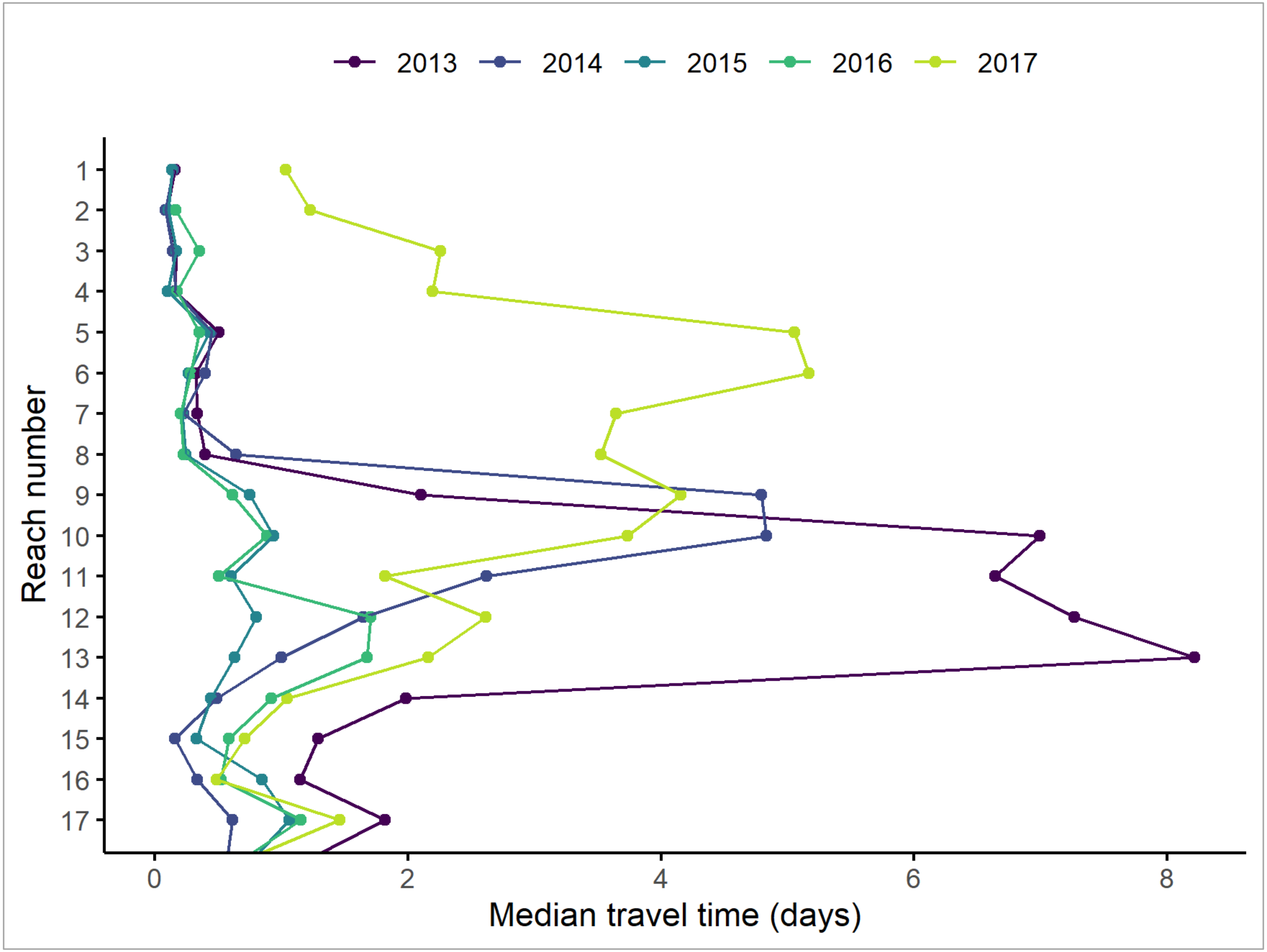
*** Bend Bridge (USGS 2021)**



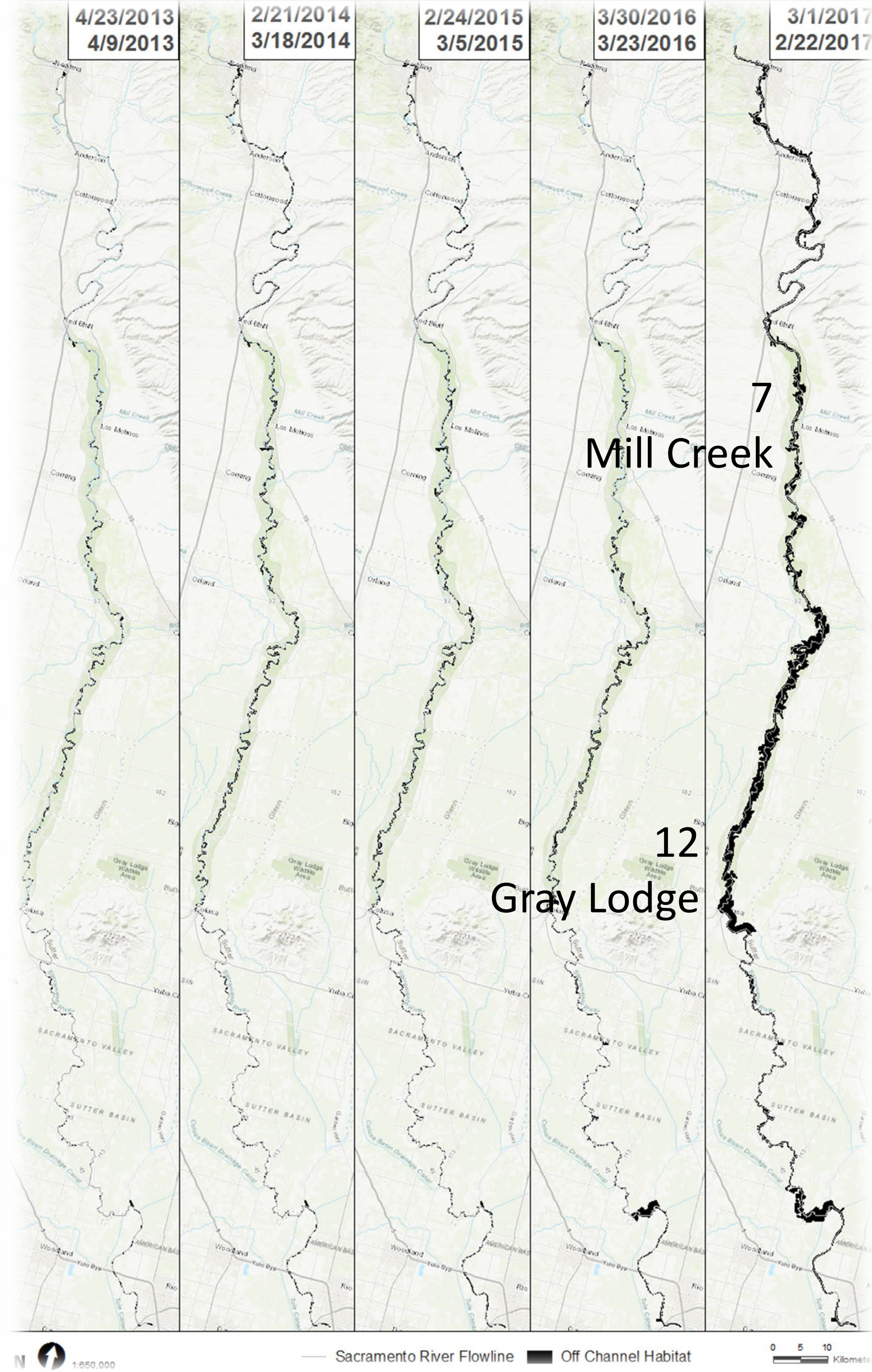


A
Hatchery
0
1
Caldwell Park (rkm 551)
2
Bonnyview Bridge (rkm 540)
3
4
5
Bend Bridge (rkm 489)
6
7
8
B
9
Chico
10
11
12
13
Yuba City
C
14
15
16
17
I80 Bridge (rkm 170)
Vacaville
Napa
Fairfield
A
0
Caldwell
1
blwcypress
2
Blw_ClearCr
3
BlwCowCr
4
Battle_Conf
5
Blw_Paynes_Ck
6
Blw_Salt
7
Mill_Ck_Conf
8
Abv_WoodsonBr
B
9
Blw_Irvine Finch
10
BlwOrd
11
BlwButteBr
12
AbvColusaBr
13
AbvTisdale
C
14
BlwChinaBend
15
KnightsLanding
16
Blw_FRConf
17
I80_Br
Diversions
Receivers
Tributaries
Revetment
Wooded Bank Habitat
Off Channel Habitat
0 5 10
Kilometers
N

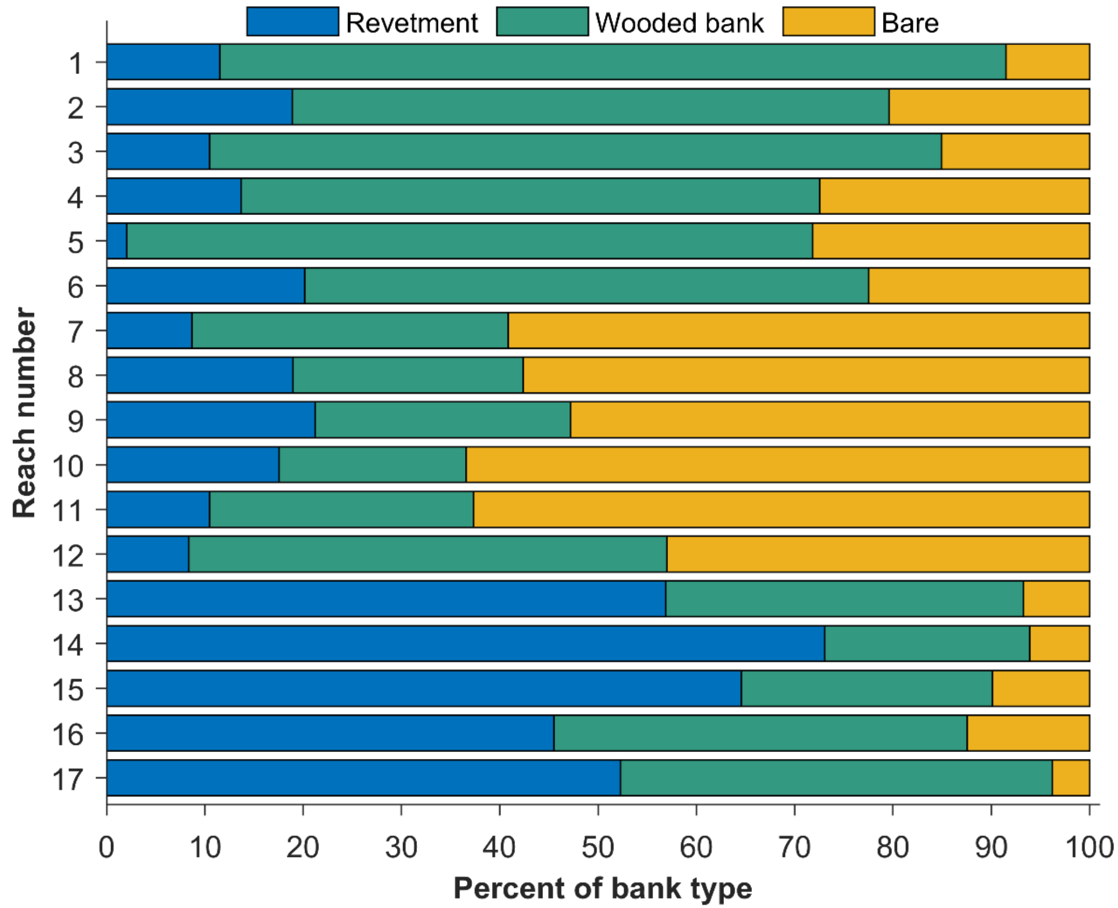
Median travel time per reach



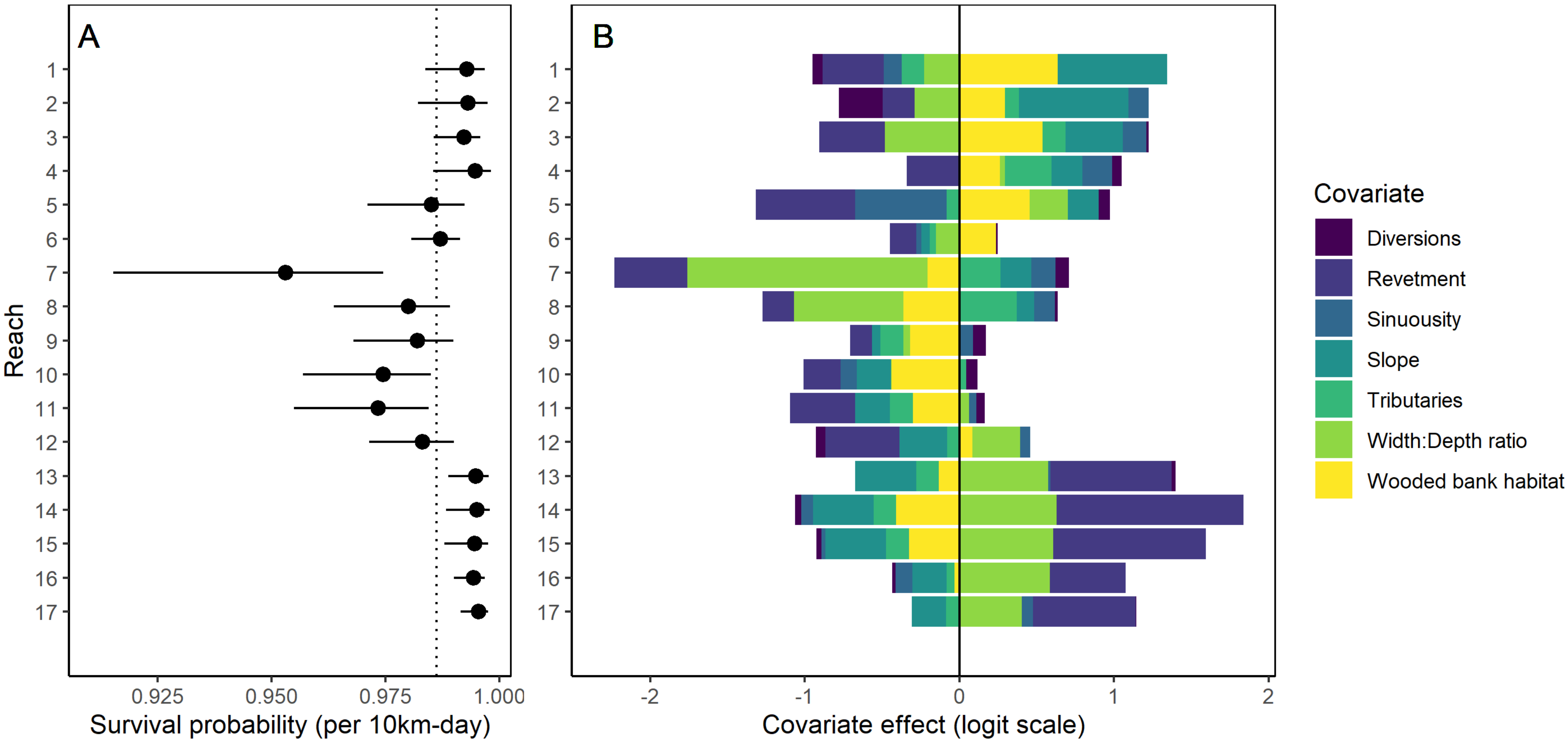
Off-channel habitat



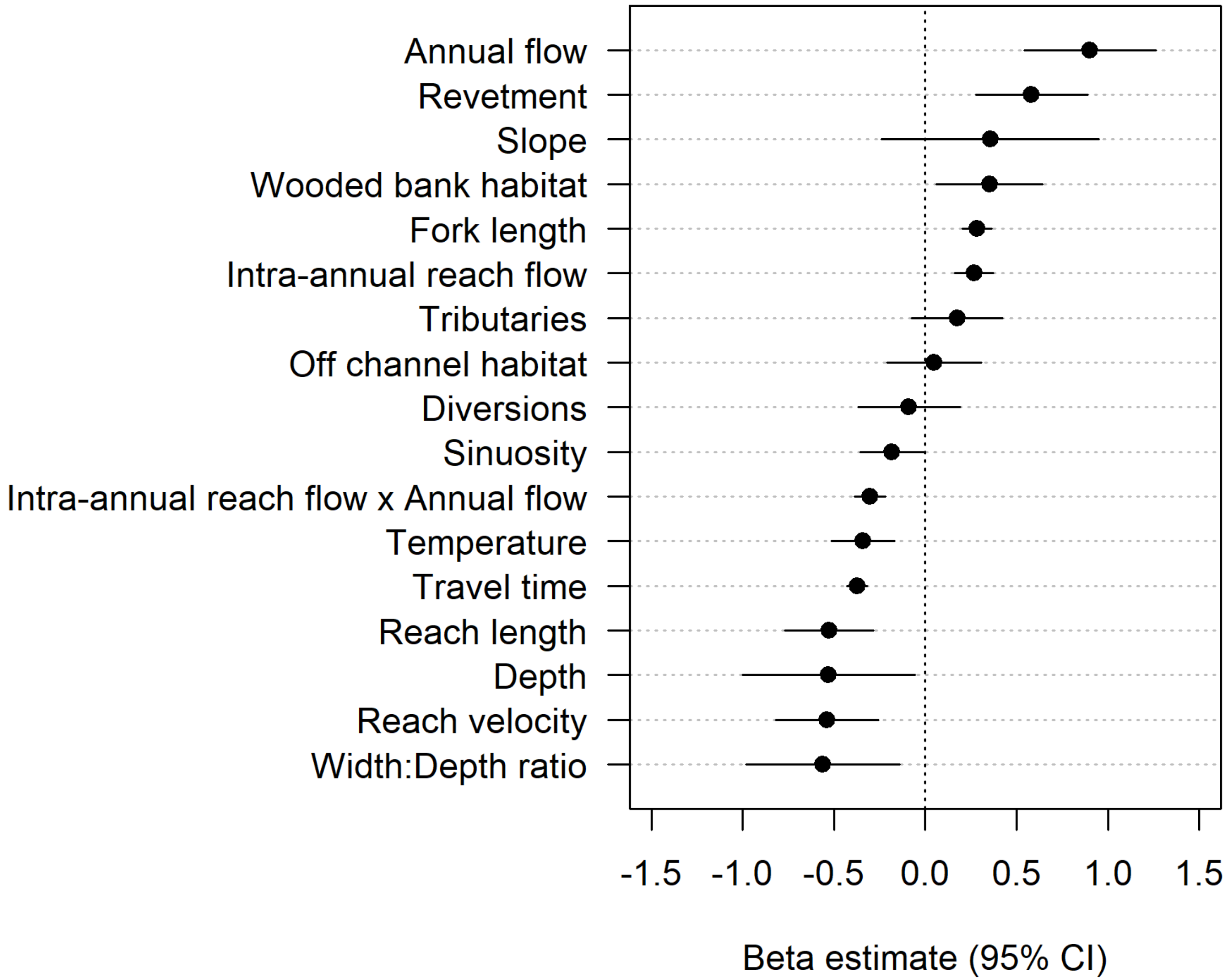
Habitat-Survival depends on fish behavior and where they are



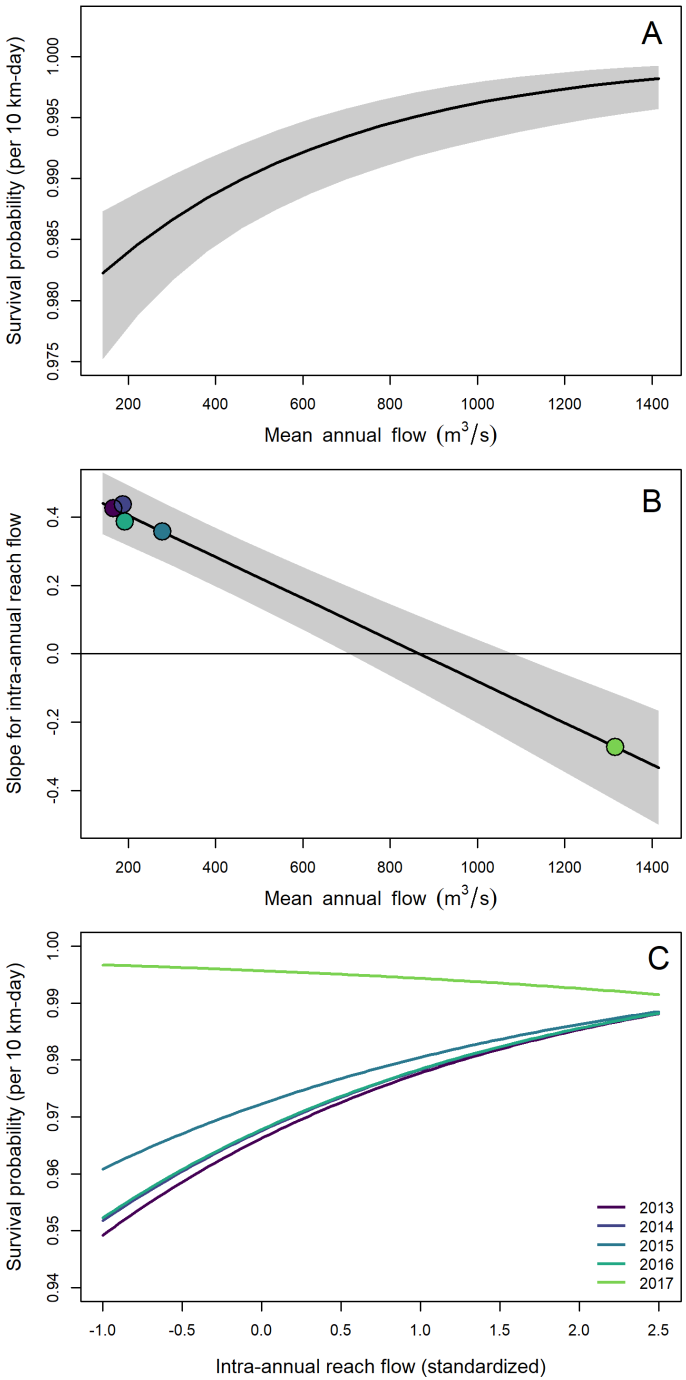
Habitat-Survival depends on fish behavior and where they are



Association of covariates with survival



Flow-survival relationships

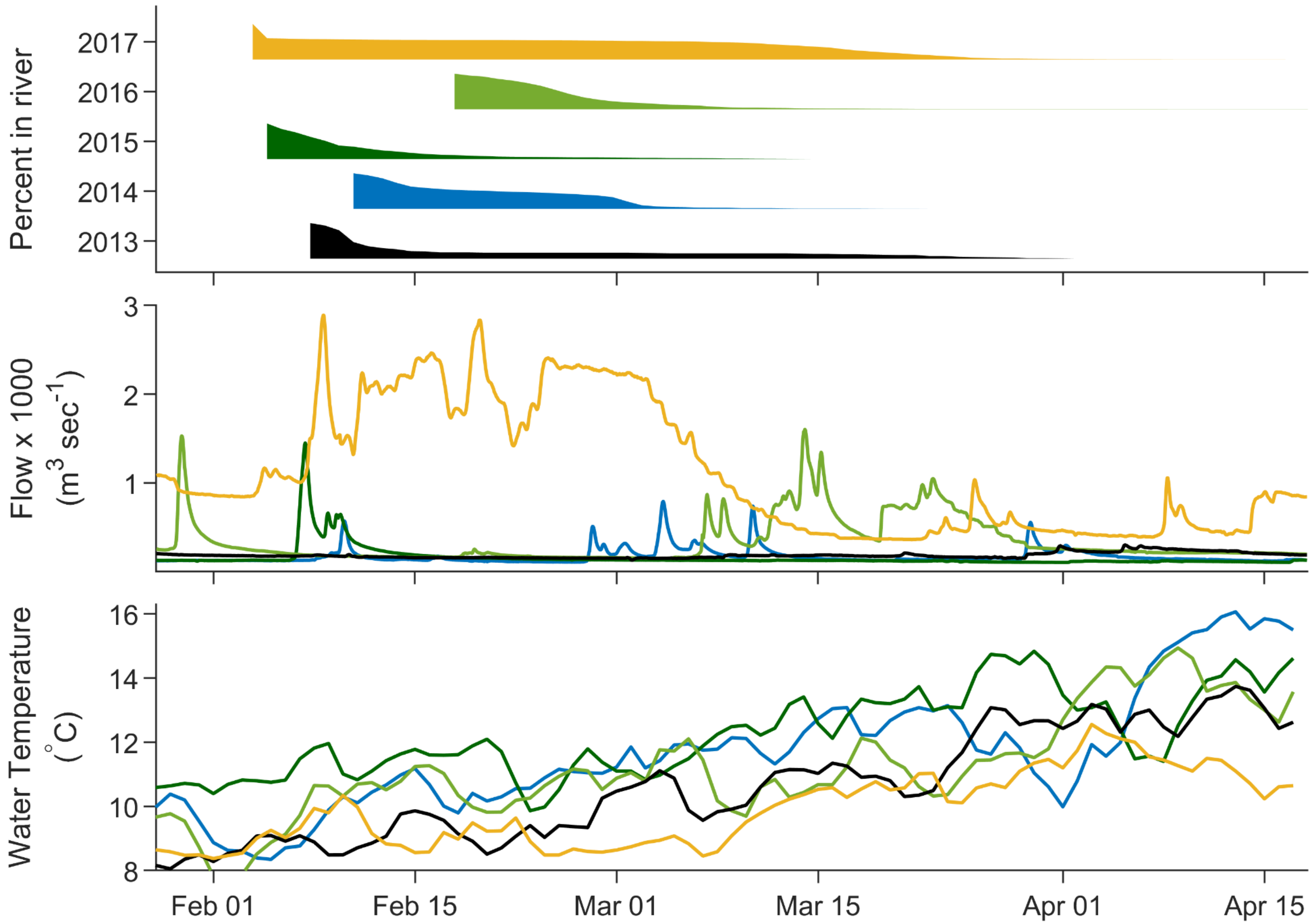


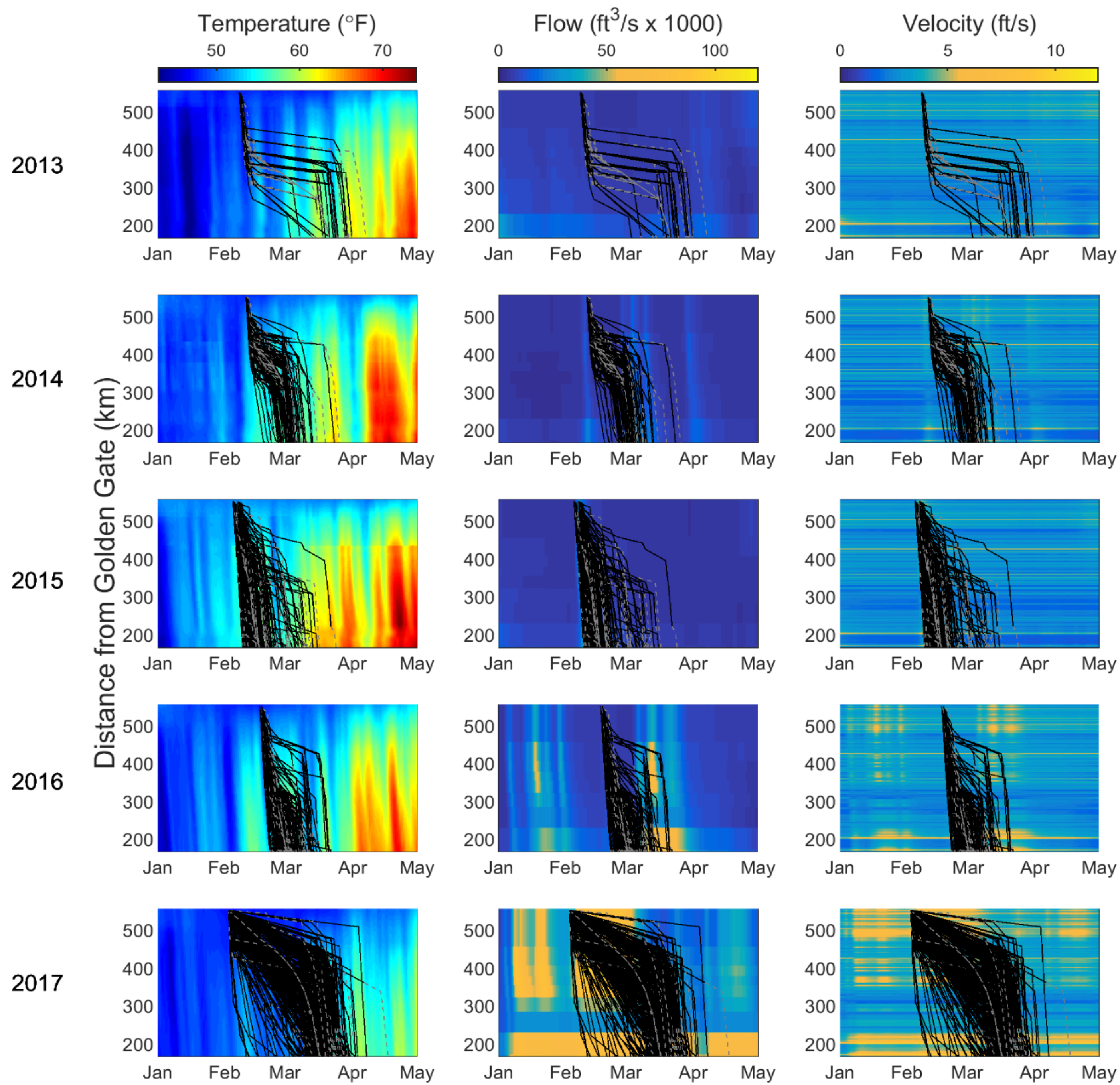
A. Survival as a function of mean annual flow

B. Effect of the reach x annual flow interaction

C. Survival as a function of reach flow

Winter-run don’t go with the flow





Temperature (°F)
50
60
70
Flow (ft^3/s x 1000)
0
50
100
Velocity (ft/s)
0
5
10
2013
2014
2015
2016
2017
Distance from Golden Gate (km)
500
400
300
200
Jan
Feb
Mar
Apr
May

Summary

1. Fixed habitat variables unevenly distributed and the effect of habitat variables on survival changed as fish moved from holding to outmigrating.

2. Fish exhibited higher mortality in the middle section of the Sacramento, even when survival was scaled by travel time.

3. The top-ranked model included indirect associations with predator exposure, particularly with revetment and reach velocity.

4. Pulse flows are more important for improving reach survival in low flow years.

5. Temperature impacts on natural-origin fish outmigrating in the fall are likely to me more severe.

Questions?

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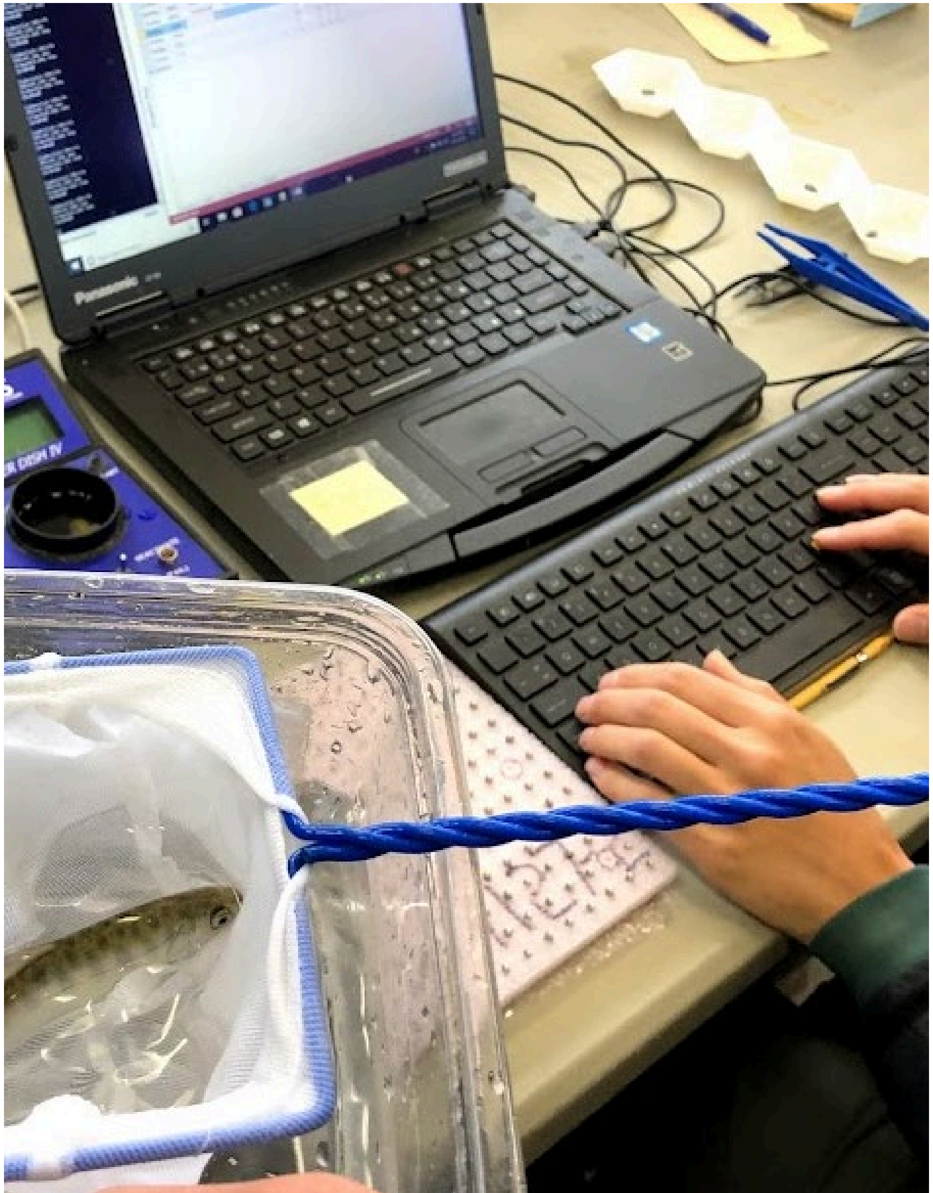
ICF | Fish and Aquatic Science Team

Questions?



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