A River Reborn:Restoration and Monitoring in the Former Footprint of Klamath Dams: Afternoon Session

A Concurrent Session at the 43rd Annual Salmonid Restoration Conference
Redding, California, May 1, 2026

Session Coordinators: Bob Pagliuco, *Marine Habitat Resource Specialist, NOAA Fisheries Restoration Center*; and Mike Belchik *Sr. Water Policy Analyst, Yurok Tribe*

The Klamath River once supported the third-largest salmon runs in the U.S. West Coast. Between 1918 and 1962, PacifiCorp built four hydroelectric dams—J.C. Boyle, Copco Nos. 1 & 2, and Iron Gate—that blocked migratory fish passage and degraded river ecosystems. After decades of advocacy by tribal nations and environmental groups, the Klamath Hydroelectric Settlement Agreement was reached, paving the way for dam removal. Physical removal began in mid-2023 and was completed in September, 2024. The removal of the Klamath River dams marks a historic step toward restoring one of the West Coast's most important salmon runs, but success won't be measured in months—or even just a few years. Restoration and monitoring need to occur to understand the outcomes of this landscape scale project. This session will highlight the current and future restoration efforts in the footprints of the former reservoirs on the Klamath River and highlight what the first year of physical and biological monitoring has revealed thus far after the largest dam removal in history.

Presentations

- **The Klamath River Renewal Project Molecular Library, Describing Landscape-scale Aquatic Biodiversity Change Following Historic Dam-Removal and Restoration** Dylan J. Keel, M.S., *Fisheries Ecologist, Resource Environmental Solutions (RES)*…… Slide 4

- **Occupancy Estimation from Juvenile Salmonid Summer Snorkel Surveys in Newly Accessible Klamath River Tributaries** Ben King, M.S., *Biologist, California Department of Fish and Wildlife*…… Slide 44

- **Immediate responses of Chinook Salmon spawning in the California mainstem Klamath River upstream of Iron Gate** Stephen Gough, M.S., *Biologist, U.S. Fish and Wildlife Service*…… Slide 68

- **Monitoring Klamath Adult Salmon Abundance and Movement in Newly Available Habitat Post Dam Removal** Bob Pagliuco, *Habitat Restoration Specialist, NOAA Restoration Center, Alex Corum -Biologist - Karuk Tribe*……Slide 80

- **Repopulation of Chinook Salmon in Upper Klamath Lake and Its Major Tributaries** Jordan Ortega, Ph.D., *Ecologist, Klamath Tribe*……Slide 114

- **What Does Success Look Like? A Vision for Klamath River Salmon** Thomas Williams, Ph.D., *Ecologist, National Marine Fisheries Service, Southwest Fisheries Science Center, Santa Cruz Laboratory*……Slide 142

Klamath River Renewal Project Molecular Library:

landscape-scale aquatic biodiversity change following historic dam-removal and restoration

Salmonid Restoration Federation - Redding, CA, May 1st, 2026

Presenter: Dylan J. Keel, M.S. – Resource Environmental Solutions LLC.

Authors: Dylan J. Keel[1], Katie Karpenko[2], Scott M. Blankenship[2], Gregg Schumer[2], Oshun O'Rourke[3], Daniel A. Chase[1], Jeffrey J. Duda[4]

Caldera Rapid – Klamath River, OR

USGS[4] science for a changing world

res[1] Restoring a resilient earth for a modern world

Cramer Fish Sciences An Employee Owned Consulting Company

GENIDAQS®[2] aquatic species sampling, simplified

Yurok Tribal Fisheries[3]

Klamath River Renewal Corporation

Outline

- EXTRA-Brief introduction to the Klamath River Renewal Project
- Project Timelines and Responses
    - Some changes happened in weeks
    - Some changes are going to take decades
- Introduce the Molecular Library and Methods
- Visualize Fish Distribution data
- Analysis Results

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Many Project Contributors

KLAMATH RIVER RENEWAL CORPORATION

McMillen
CAMAS
Kiewit
res
SHASTA INDIAN NATION

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RDG River Design Group
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California Department of Fish & Wildlife
Coastal Conservancy
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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
USGS science for a changing world
cbec eco-engineering

Scott River Water Trust
Scott River Watershed Council
RCD Shasta Valley Resource Conservation District
Siskiyou Resource Conservation District
Trinity County California
Trout Unlimited
U.S. Fish & Wildlife Service Department of the Interior
Forest Service U.S. Department of Agriculture
Western Native Trout Initiative
Ross Taylor & Associates

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Project Purpose

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

KLAMATH TRIBES CELEBRATE RETURN OF SALMON IN UPPER BASIN

FOR IMMEDIATE RELEASE

Date: October 10, 2025

Contact: Courtney Neubauer, courtney.neubauer@klamathtribes.com
(541) 576-4458

KLAMATH TRIBES CELEBRATE RETURN OF SALMON IN UPPER BASIN

After a century the Klamath Tribes is calling upon everyone in the basin to allow our c'yaals (salmon) to spawn undisturbed in their natural habitat and refrain from fishing

Chinook salmon found naturally hatching in Upper Klamath River for first time in a century

By Justin Higginbottom (Jefferson Public Radio)
March 25, 2026 11:13 a.m.

The Klamath Tribes are celebrating evidence of Chinook salmon spawning in Klamath River tributary.

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Iron Gate Reservoir, January 2024

Iron Gate Reservoir, February 2024

Iron Gate Reservoir, June 2024

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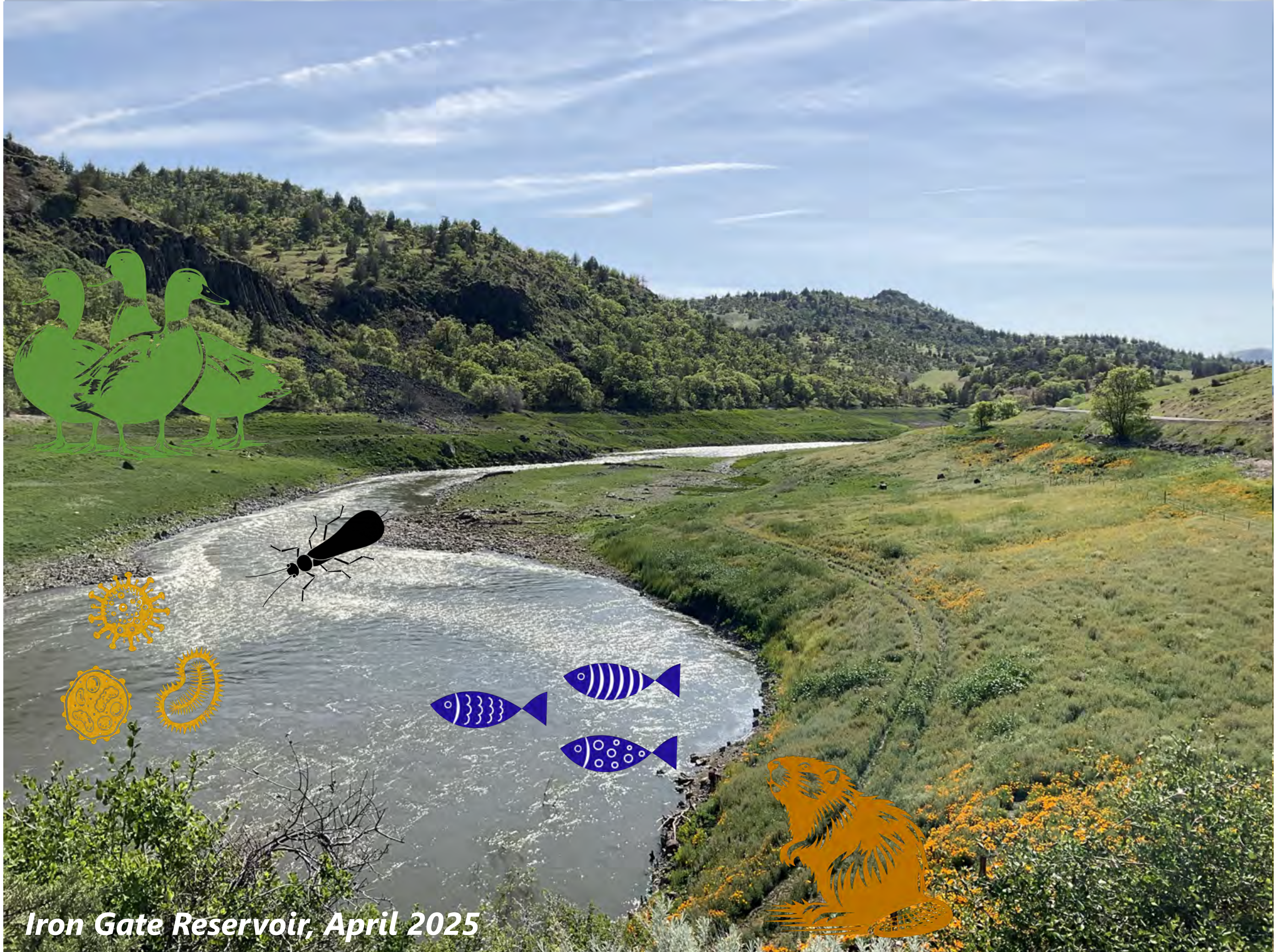

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Project Schedule

Copco No. 2 Dam Re

Reservoir Drawdown

All Dams Removed

Pre-implementation	Construction	Post-implementation

12/1/2022 2/1/2023 4/1/2023 6/1/2023 8/1/2023 10/1/2023 12/1/2023 2/1/2024 4/1/2024 6/1/2024 8/1/2024 10/1/2024 12/1/2024 2/1/2025 4/1/2025 6/1/2025 8/1/2025 10/1/2025 12/1/2025 2/1/2026

Environmental DNA (eDNA) as a Time Capsule

- **eDNA** (genetic material that can be isolated from environmental samples of soil, water, and air) has been shown to be **a cost effective, non-invasive, and sensitive** tool for monitoring the **distribution of species and biotic communities on broad geographic scales.**

- Preserved environmental samples can **retain usable genetic material for decades**, extracted and purified DNA and RNA can retain sufficient quantity and quality for much longer.

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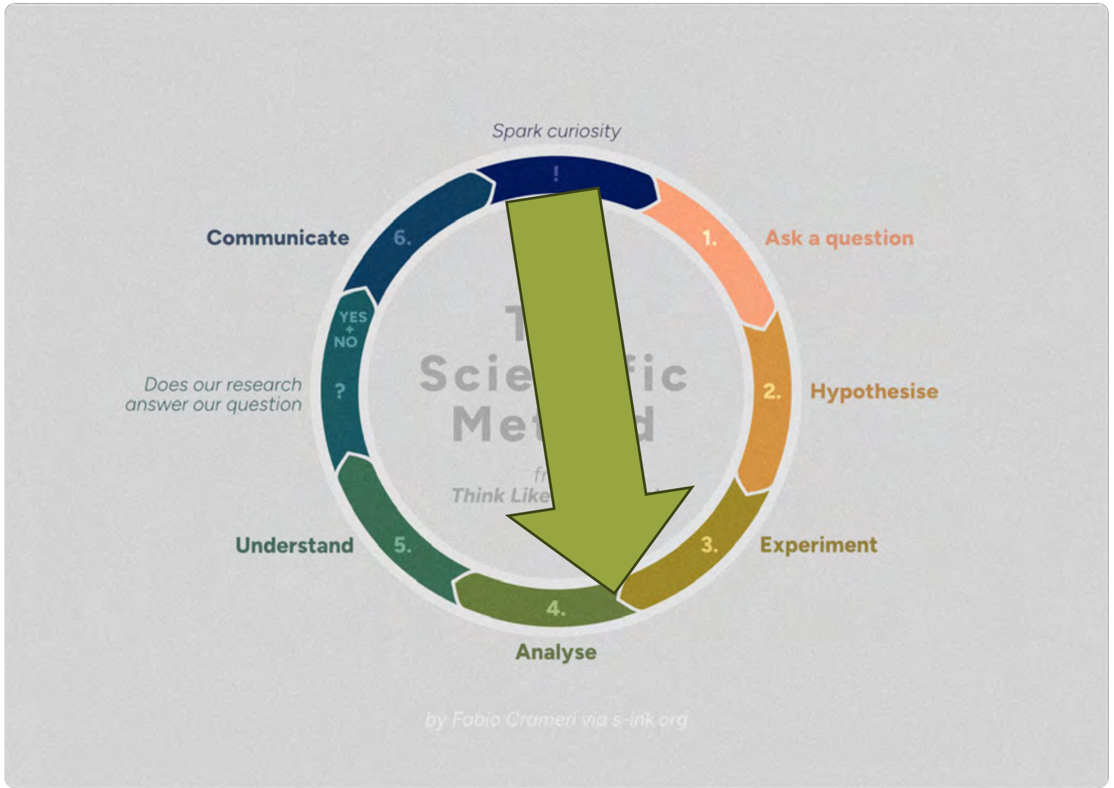
Creating the Klamath River Renewal Project Molecular Library

Independent of the restoration effectiveness monitoring responsibilities defined for the project, RES, YTF, and GIQ staff began collecting baseline environmental DNA and RNA samples throughout the KRRP in July, 2023.

Klamath River Renewal Project Molecular Library, an Environmental Specimen Bank (ESB) with the goals of:

- **Preserving eDNA (and eRNA)** and related data to serve as a **baseline and repeatable survey** for long-term assessment of dam removal outcomes and associated reestablishment of native species along the Klamath River.

- Contributing to the global effort to understand biodiversity response to landscape-scale restoration.



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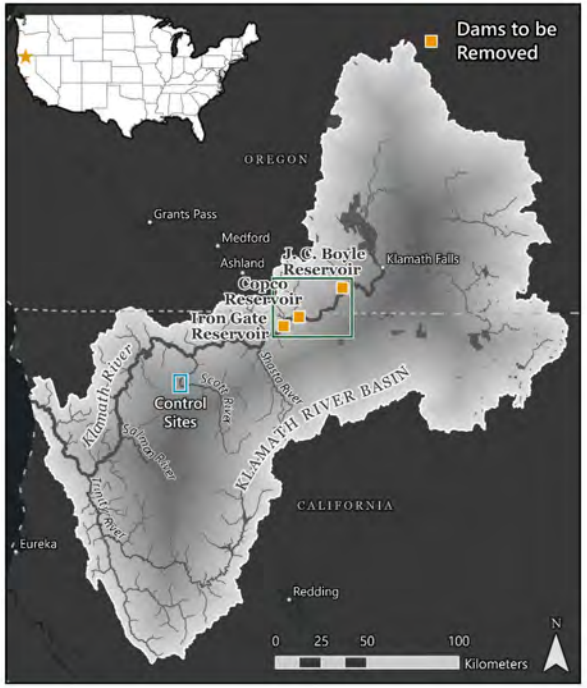
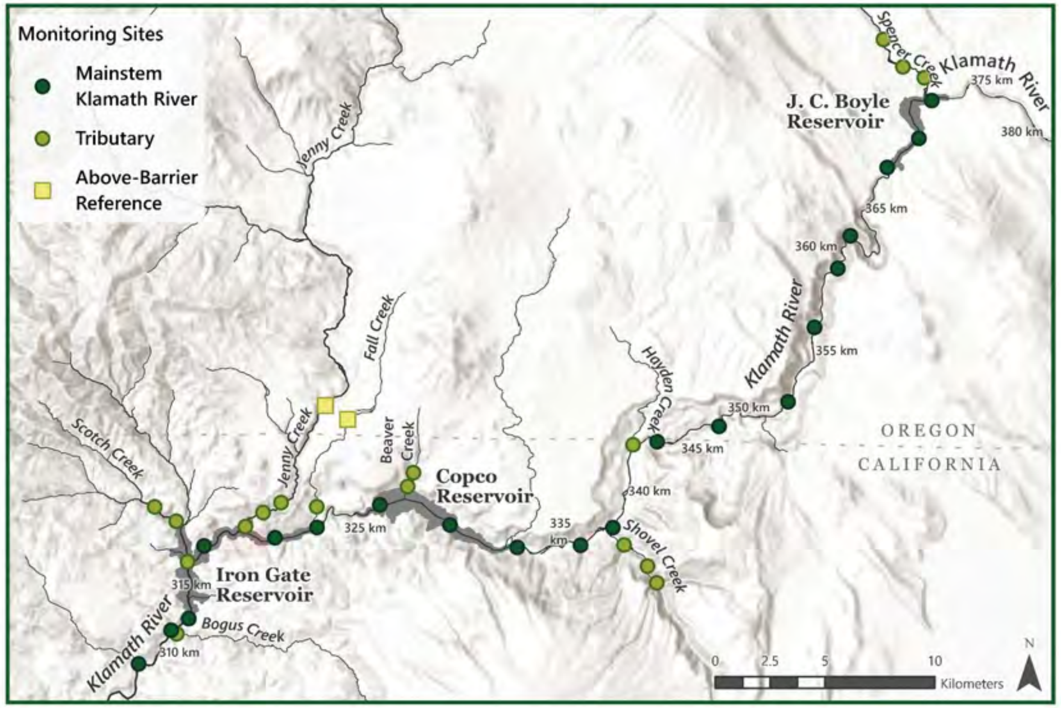
Site Selection

- In 2023 (before dam removal), 2024 (during dam removal), and 2025 (after dam removal was completed) we collected, filtered, and preserved the genetic material
  - **Over 1,100 water samples**
  - Systematically selected **45 mainstem, tributary, and control locations**
  - across more than **70 river miles (114 km)**

- Samples were collected following a **Before-After Reference-Impact (BARI)** monitoring design
  - Control sites within the basin (above waterfalls)
  - Reference sites outside of the impacted watersheds (Scott River & tributaries)





Research Questions

- **Q1 –Did the community composition of fishes change in the dam-removal reach?** Did we see changes outside of the dam-removal reach at the same time?

- **Q2 –Did the count of native fish species increase in the dam-removal reach following dam-removal?**

- **Q3 -Did the count of exotic fish species decrease in the dam-removal reach following dam-removal?**

- **Q4 –Did the native fish community evenness (Shannon diversity) increase in the dam-removal reach following dam removal?**

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Methods Summary

- Filtered 9 replicate water samples in the field with 0.45µm pore-size Sterivex filters per site per year

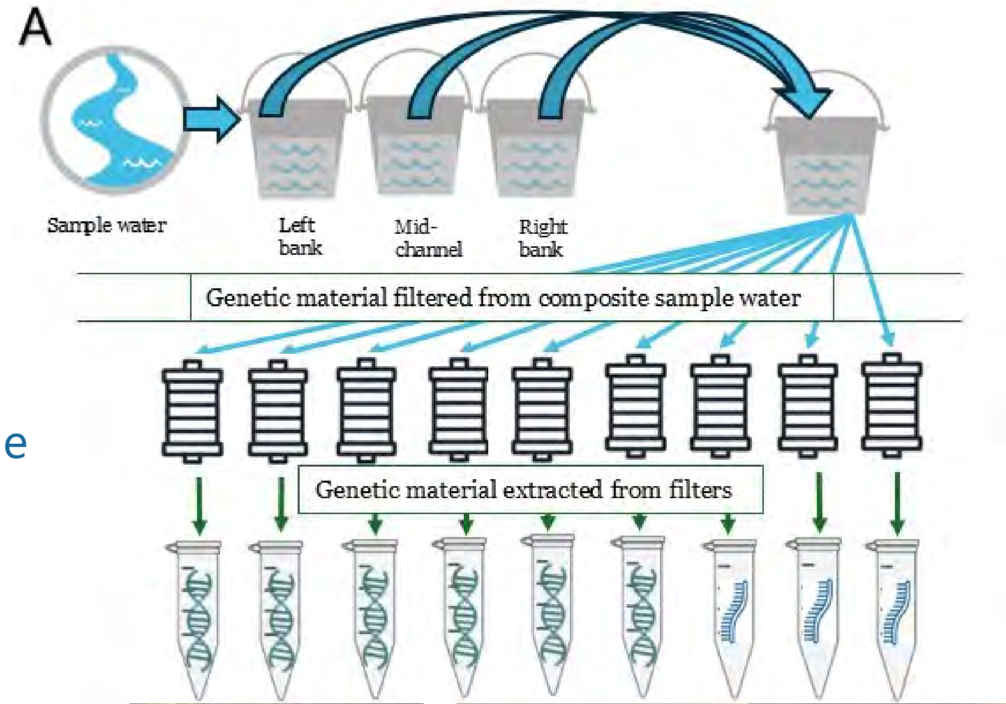
- Preserved genetic material for stable transport with RNA Protect Tissue Reagent

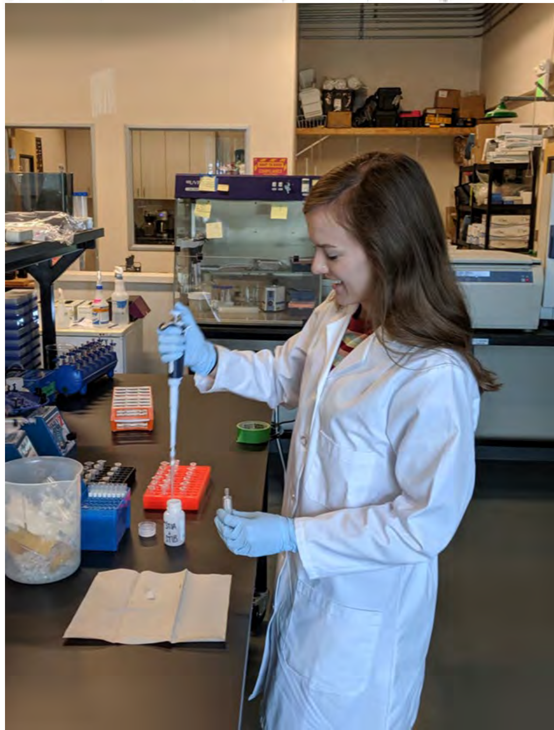
- Extracted eDNA for stable storage and analyzed 3 replicate filters per site
- **Used eDNA metabarcoding to assess the community-level composition of fish taxa at each sampling location**

- We multiplexed **MiFish-U** primer with **GIQHerp-F**

- Quantified & purified libraries sequenced on **Illumina MiSeq** System

- Species ID determined using **MetaWorks pipeline** and verified against NIH NCBI using the BLAST algorithm using a **97% ID match threshold**





Baseline Results

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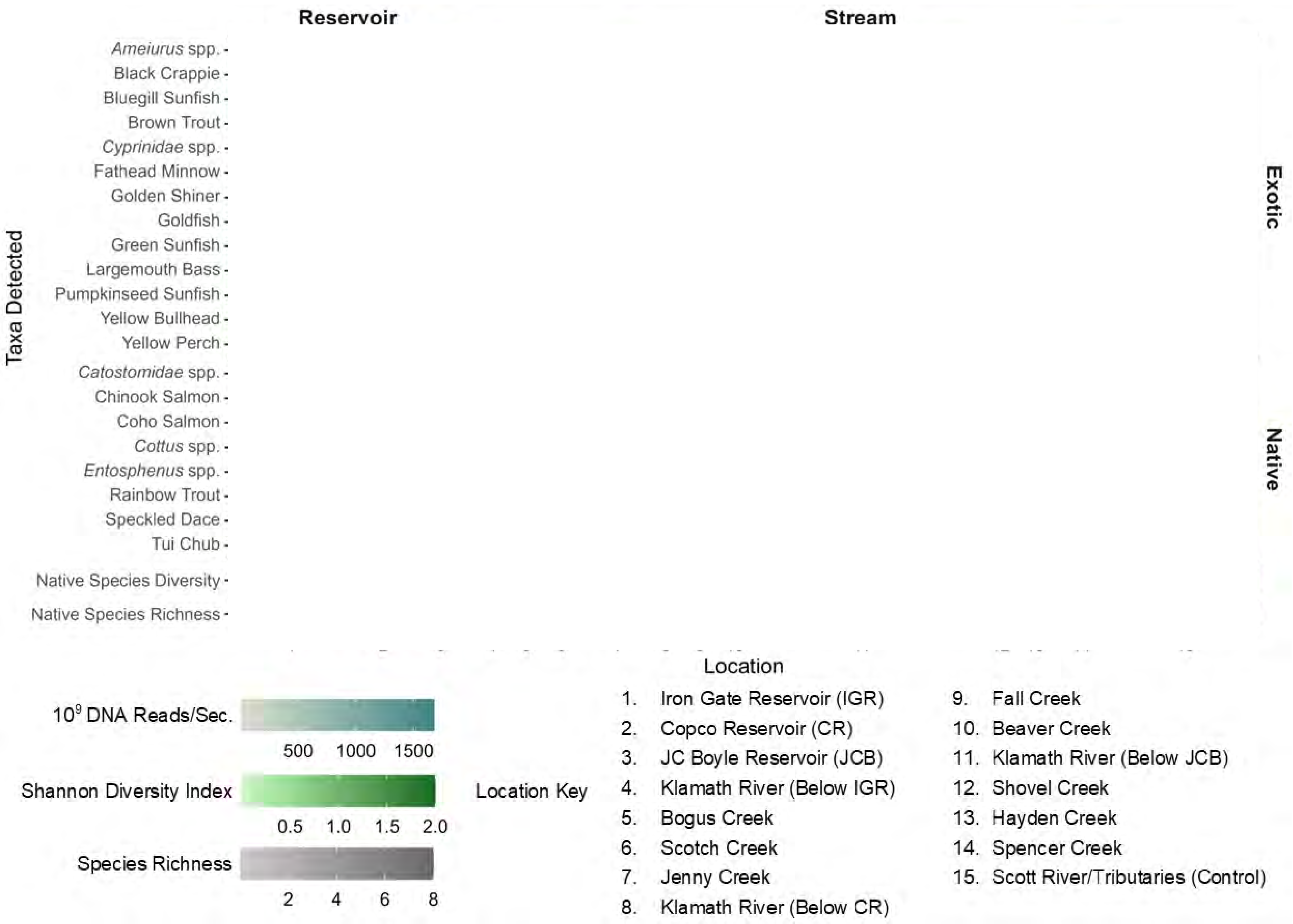
Article | Open access | Published: 01 July 2025

A molecular specimen bank for contemporary and future study captures landscape-scale biodiversity baselines before Klamath River dam removal

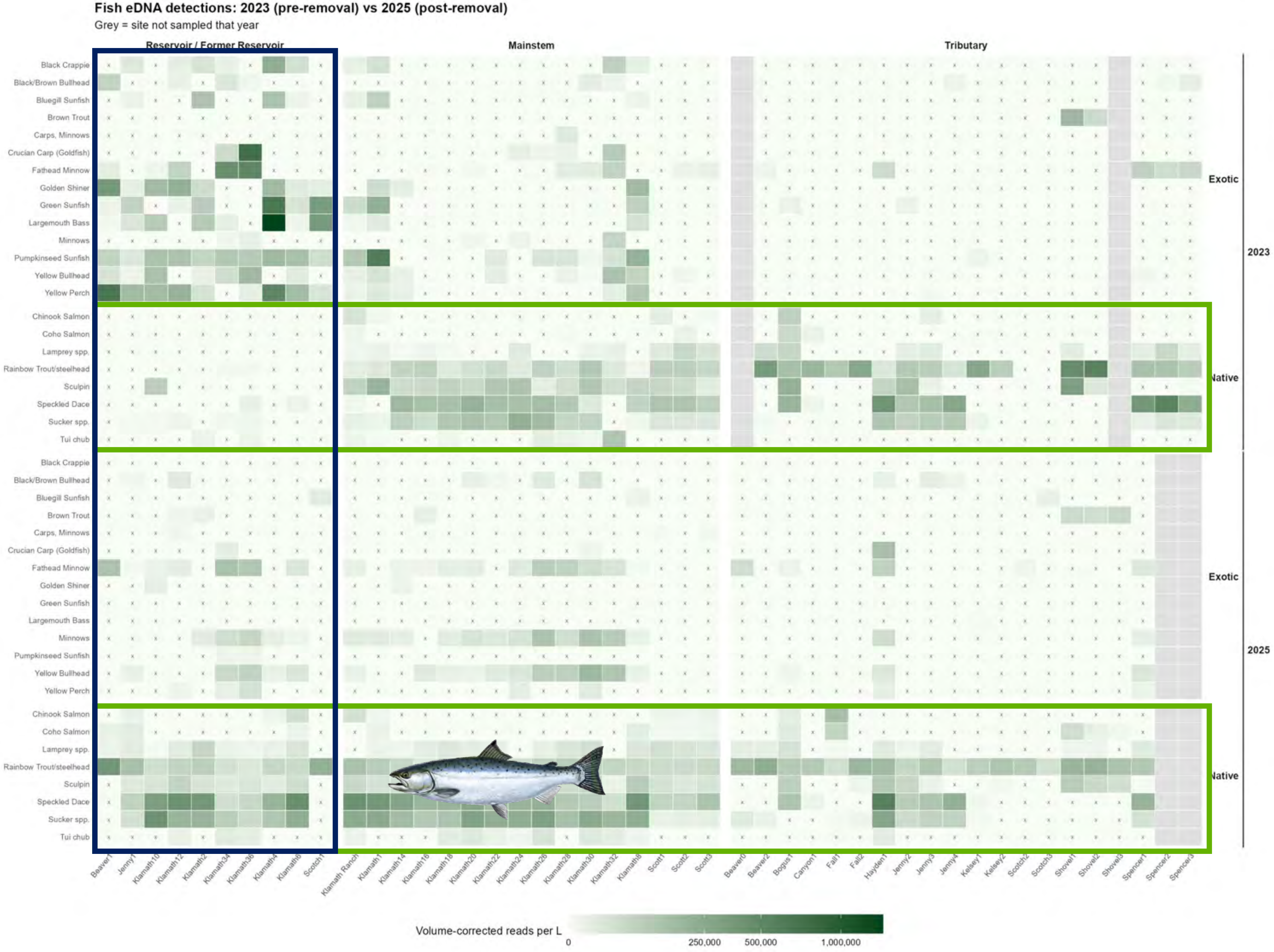
Dylan J. Keel, Katie Karpenko, Scott M. Blankenship, Gregg Schumer, Oshun O'Rourke, Carl O
Daniel A. Chase & Jeffrey J. Duda

Scientific Reports **15**, Article number: 20679 (2025) | Cite this article



Results (2023 to 2025)

- Dramatic reduction in relative abundance of exotic fish species DNA in former reservoirs



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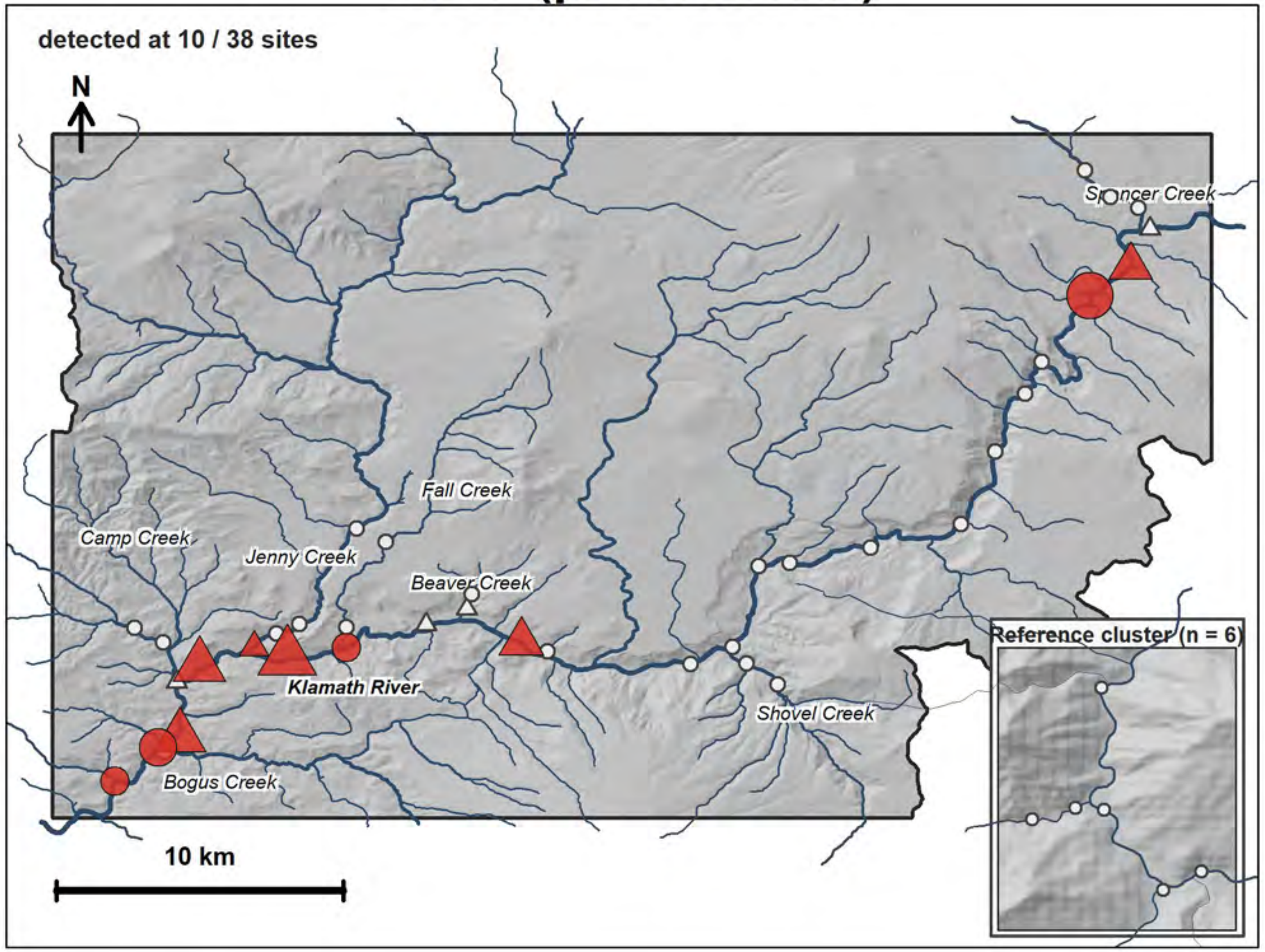
Black Crappie

Exotic | Pre-removal (2023) vs Post-removal (2025)

2023 (pre-removal)



2025 (post-removal)

Site type

○ Stream

△ Reservoir / Former Reservoir

Flow-corrected reads per L (sqrt area)

Detection 11.5B 34.6B 77.0B

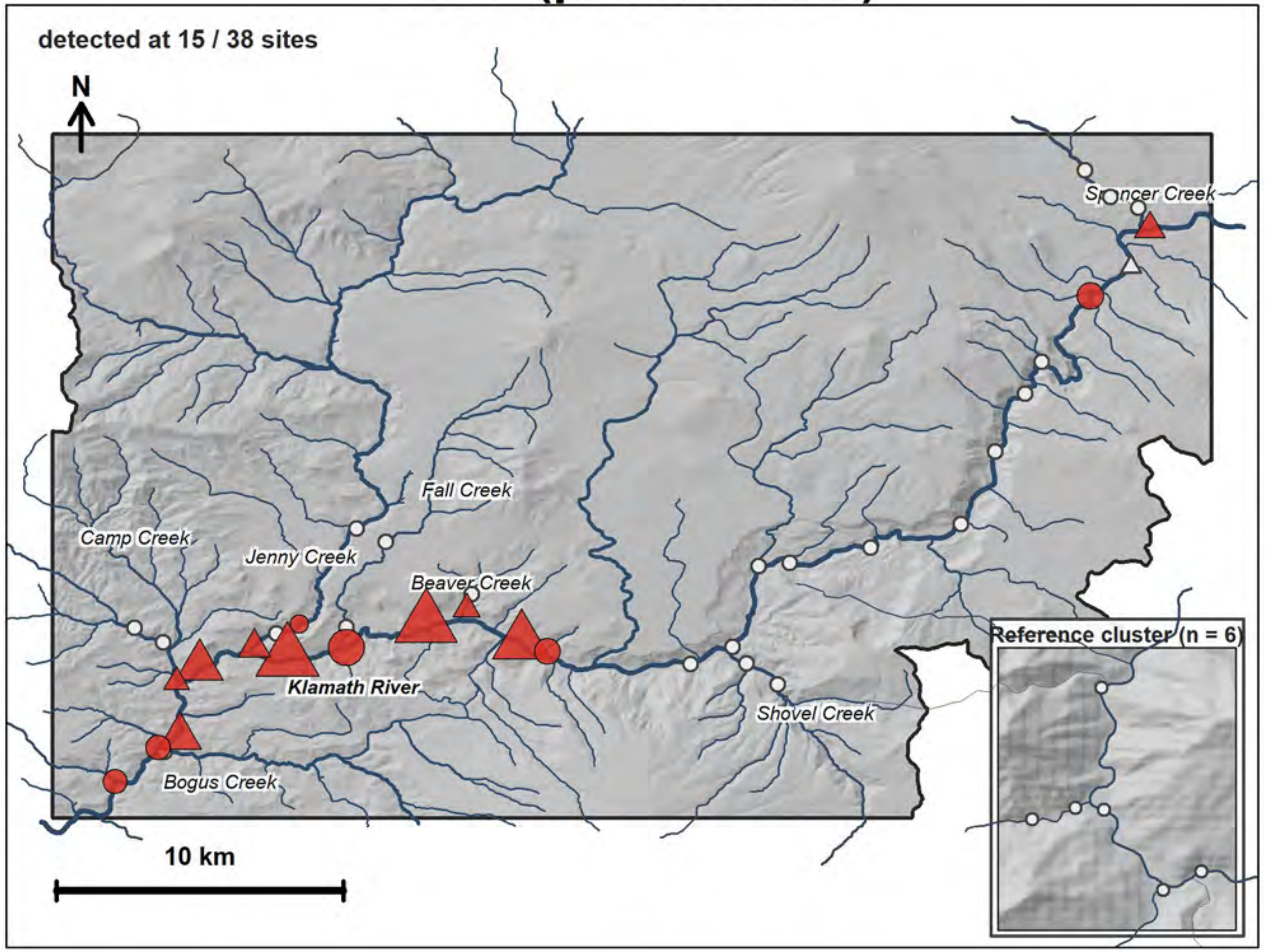
Exotic

Yellow Perch

Exotic | Pre-removal (2023) vs Post-removal (2025)

2023 (pre-removal)

2025 (post-removal)



Site type

○ Stream

△ Reservoir / Former Reservoir

Flow-corrected reads per L (sqrt area)

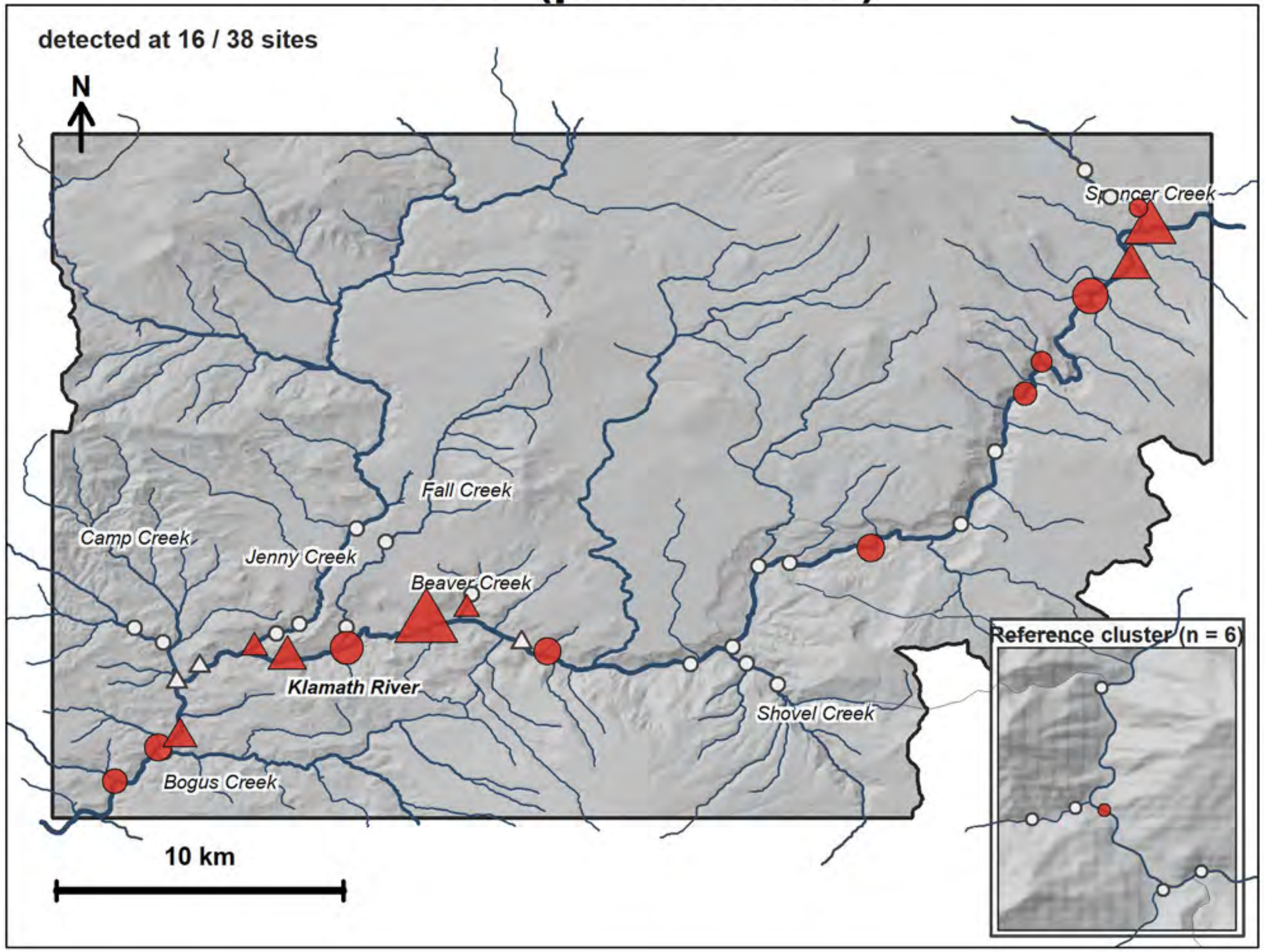
Detection 43.5B 130.6B 290.3B

Exotic

Yellow Bullhead

Exotic | Pre-removal (2023) vs Post-removal (2025)

2023 (pre-removal)



2025 (post-removal)

Site type

○ Stream

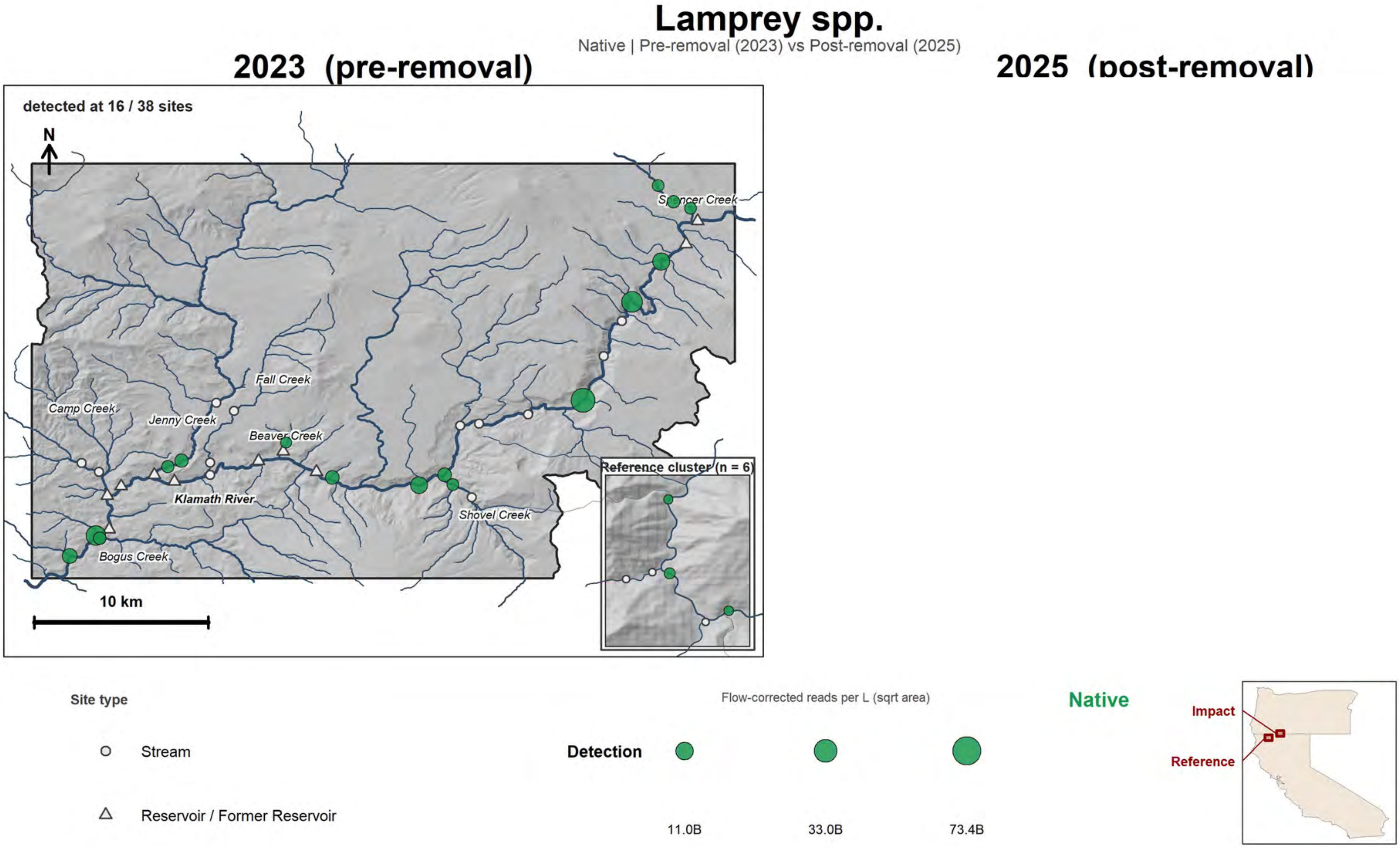
△ Reservoir / Former Reservoir

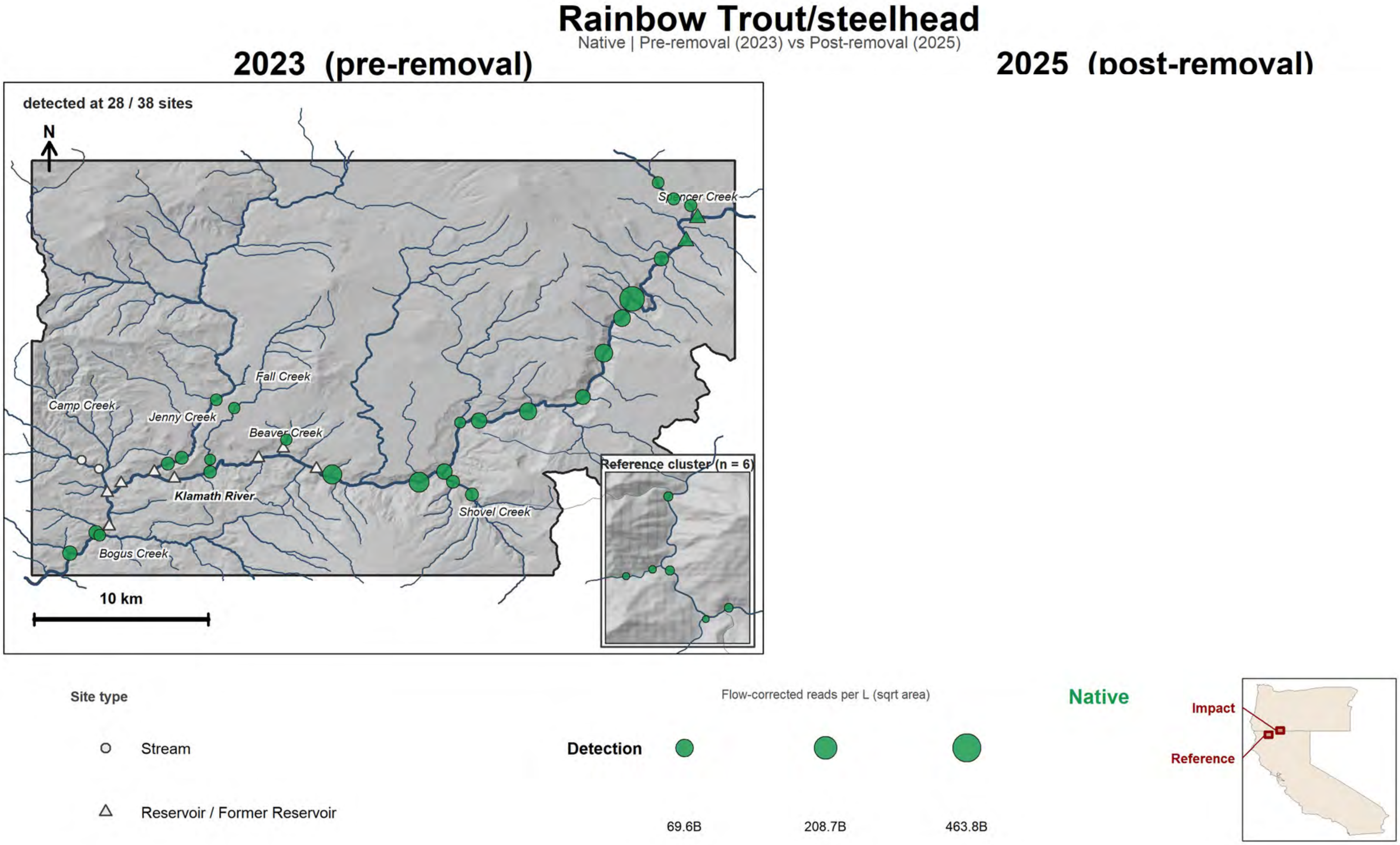
Flow-corrected reads per L (sqrt area)

Detection

35.6B	106.9B	237.5B

Exotic

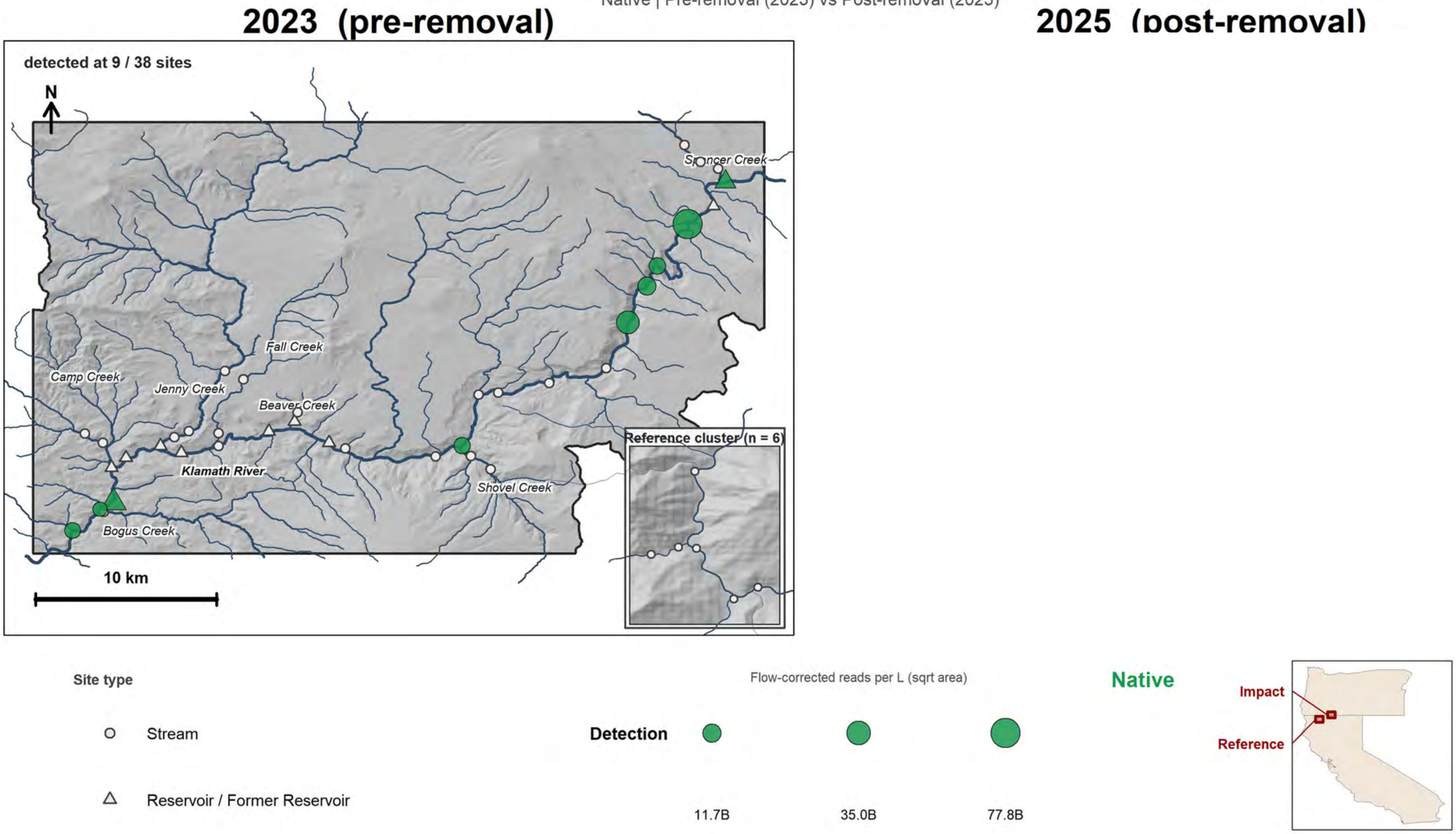

Lamprey spp.
Native | Pre-removal (2023) vs Post-removal (2025)
2023 (pre-removal)
2025 (post-removal)
detected at 16 / 38 sites
N
Spencer Creek
Fall Creek
Camp Creek
Jenny Creek
Beaver Creek
Klamath River
Shovel Creek
Bogus Creek
Reference cluster (n = 6)
10 km
Site type
Stream
Reservoir / Former Reservoir
Flow-corrected reads per L (sqrt area)
Detection
11.0B
33.0B
73.4B
Native
Impact
Reference



Rainbow Trout/steelhead
Native | Pre-removal (2023) vs Post-removal (2025)
2023 (pre-removal)
2025 (post-removal)
detected at 28 / 38 sites
N
Spencer Creek
Fall Creek
Camp Creek
Jenny Creek
Beaver Creek
Klamath River
Shovel Creek
Bogus Creek
Reference cluster (n = 6)
10 km
Site type
Stream
Reservoir / Former Reservoir
Flow-corrected reads per L (sqrt area)
Detection
69.6B
208.7B
463.8B
Native
Impact
Reference

Tui chub

Native | Pre-removal (2023) vs Post-removal (2025)



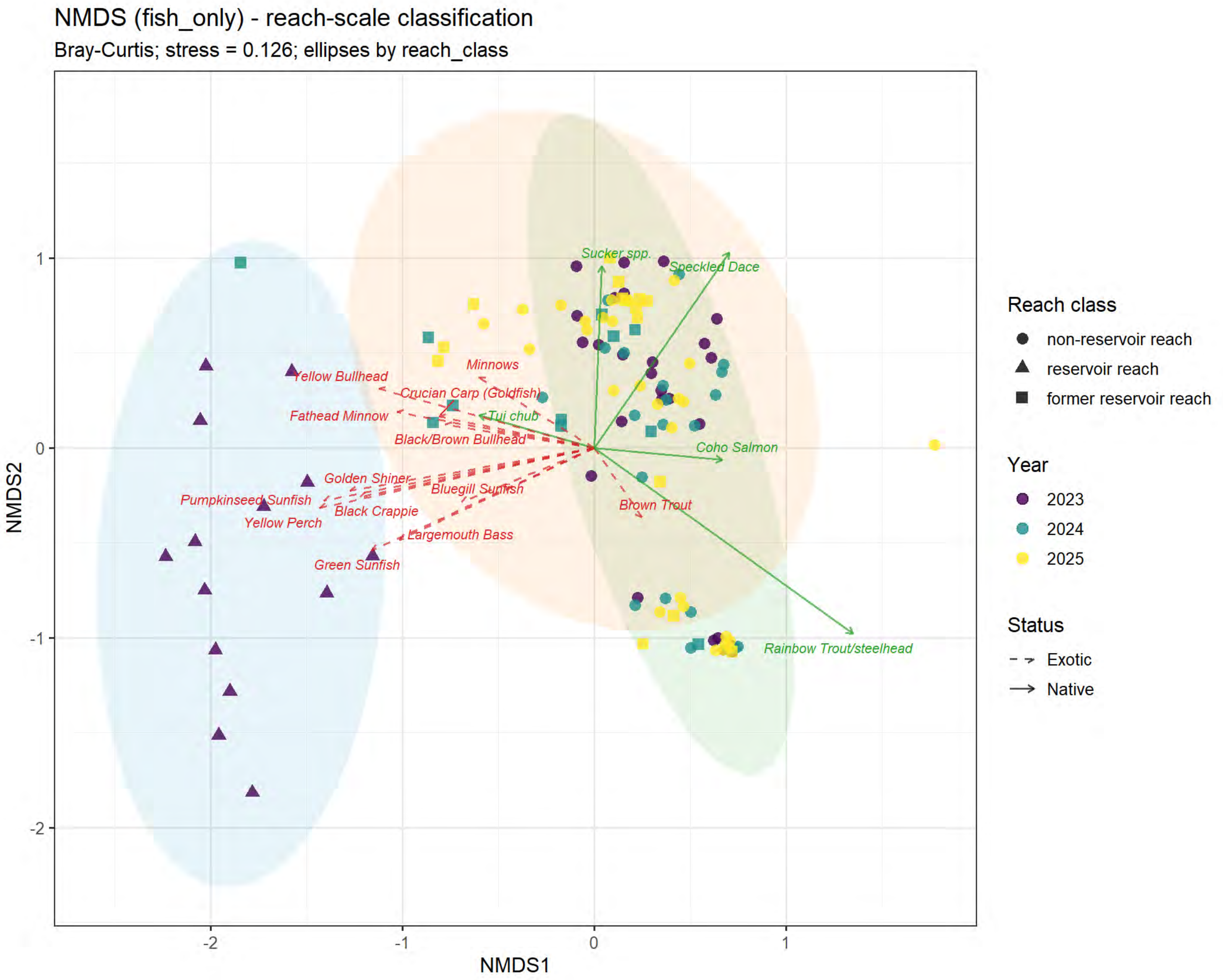
Question 1

Q1 –Did the community composition of fishes change in the dam-removal reach? Did we see the changes outside of the dam-removal reach at the same time?

PERMANOVA Results

- A BARI PERMANOVA; Bray-Curtis dissimilarity, showed that fish community composition at the 14 sites within the dam-removal reach footprint **changed significantly from 2023 to 2024–2025 (era × reach_2023 R^2 = 9.6%,** pseudo-$F_{1,113}$ = 21.3, $p < 0.0001$; total model R^2 = 49.1%).

- No temporal change was detected at the 32 non-reach sites or the 8 a-priori Reference sites in within-subset PERMANOVAs (era $p \geq 0.24$ in both).



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We used GLMMs to answer Questions 2, 3, & 4

Q2 –Did the count of native fish species increase in the dam-removal reach following dam-removal?

Q3 -Did the count of exotic fish species decrease in the dam-removal reach following dam-removal?

Q4 –Did the native fish community evenness (Shannon diversity) increase in the dam-removal reach following dam removal?

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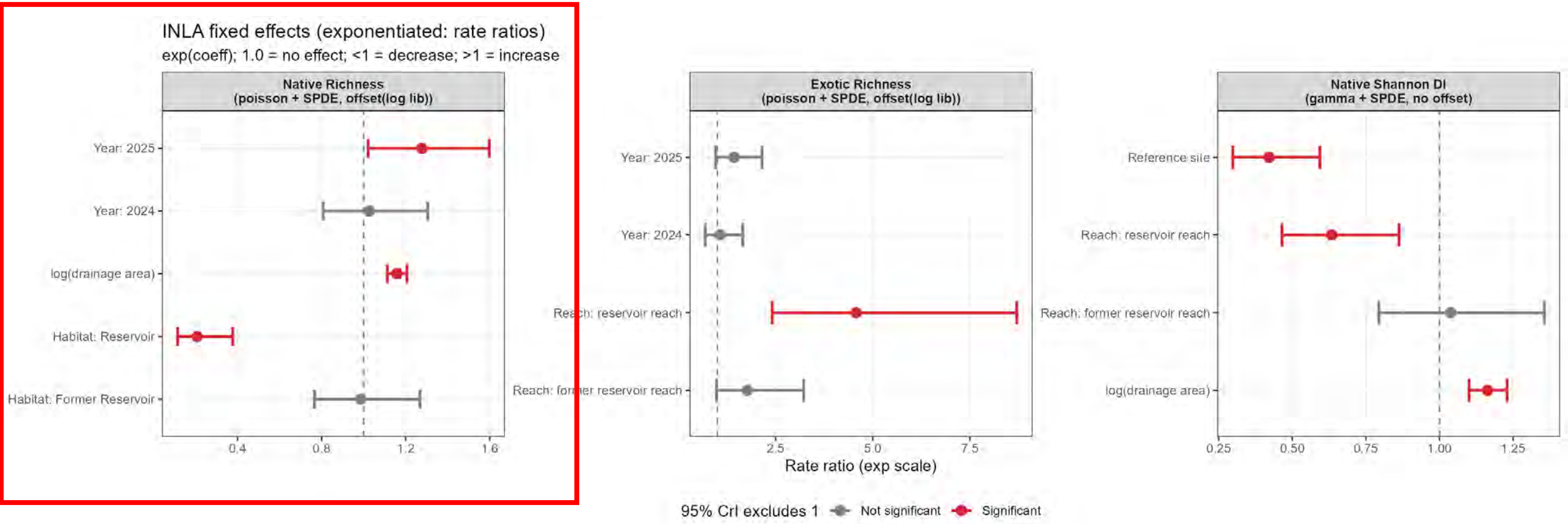
Results



- **Native fish richness in 2025 was 28% (2.1 to 59.8%) above the 2023 baseline** across the project area (2024 not credible)
- Native fish richness increased in larger streams
- **Reservoirs supported only 21% (11.4-37.7%) of the native fish species that free-flowing streams**
- **Former reservoir sites had the same native species richness as stream sites**

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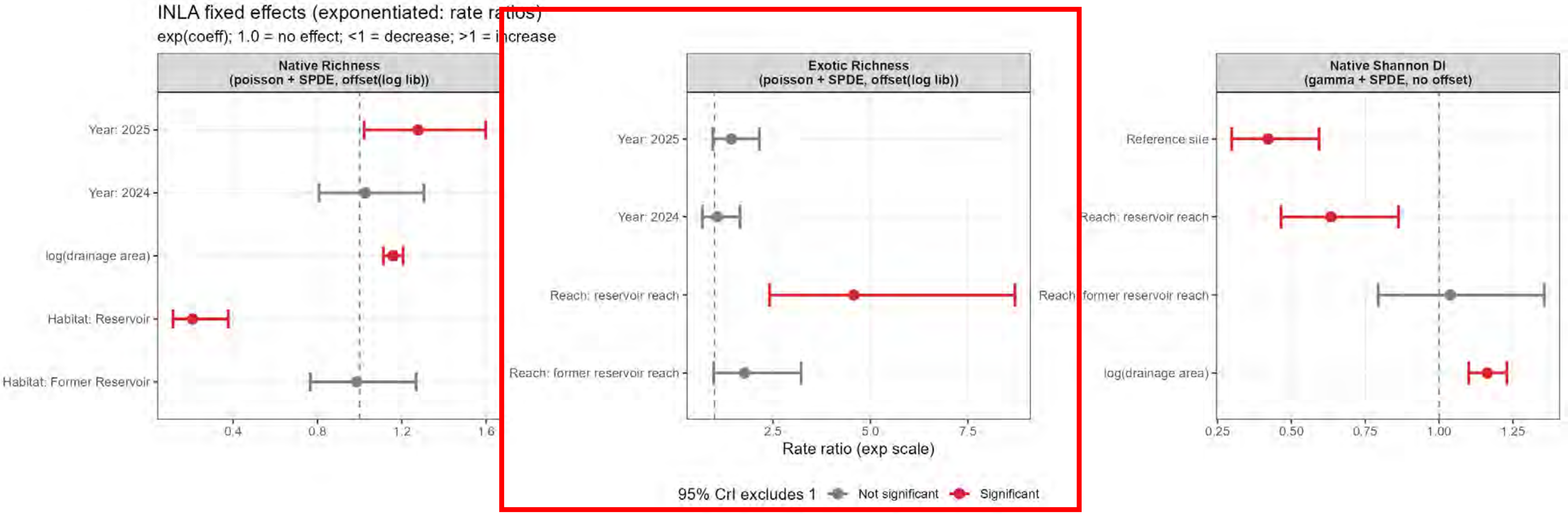
Results



- The whole dam-affected reach supported expected **exotic richness ~4.3–4.6× that of stream sites** in 2023
- Change in exotic fish richness were non-credible in 2024/2025 (**no significant change in exotic richness project wide**)
- Exotic fish richness in **FORMER dam-affected reach was not significantly different than stream sites** (but trending slightly higher)

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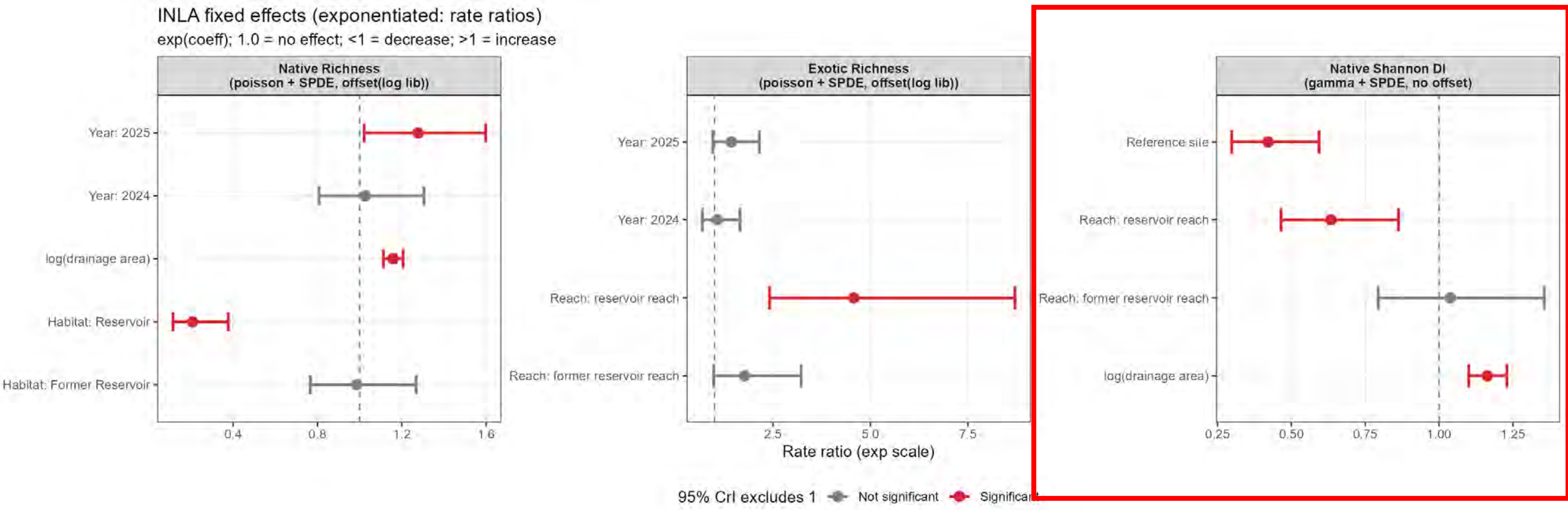
Results



- Reference sites had lower native fish diversity than project-wide impact sites
- The whole dam-affected reach supported lower native fish diversity
- **Native fish diversity in the FORMER dam-affected reach was not significantly different than stream sites**
- Native fish diversity increased with drainage area

Conclusions

- **Fish community composition changed significantly following dam removal** – reference sites experienced no significant change over that time

- Exotic species response to dam removal varied

- **Exotic fish richness in the reservoir reach was >4x as high as streams before dam-removal, but by 2025 was no different than adjacent streams**

- **Native fish richness increased at the site level across the KRRP by ~28% by 2025**

- Native fish diversity was far lower in reservoirs than stream sites, but former reservoir sites were not significantly different than streams

- **The Molecular Library was suitable for detecting landscape-scale changes in aquatic diversity** as well strong natural gradients in community composition

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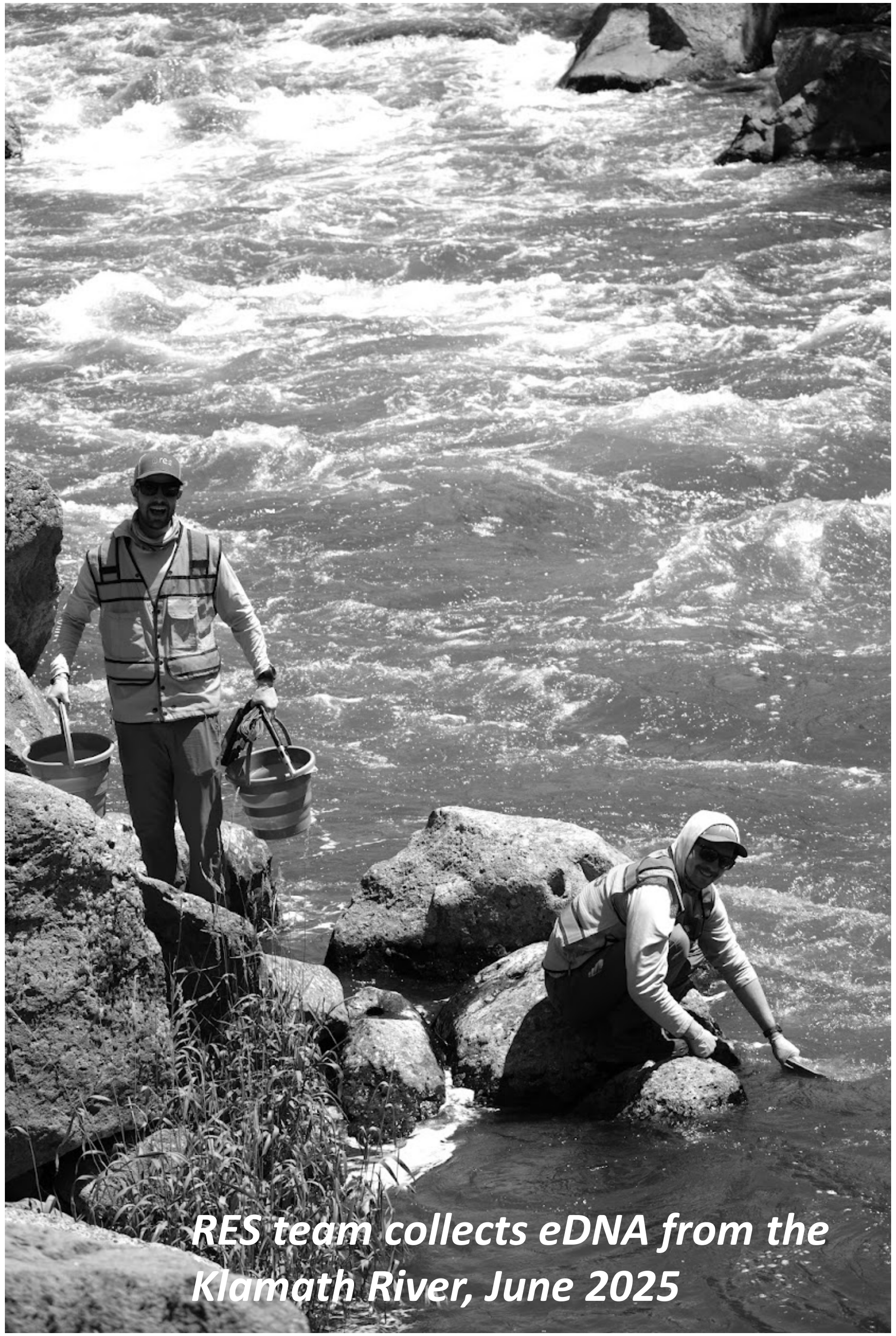
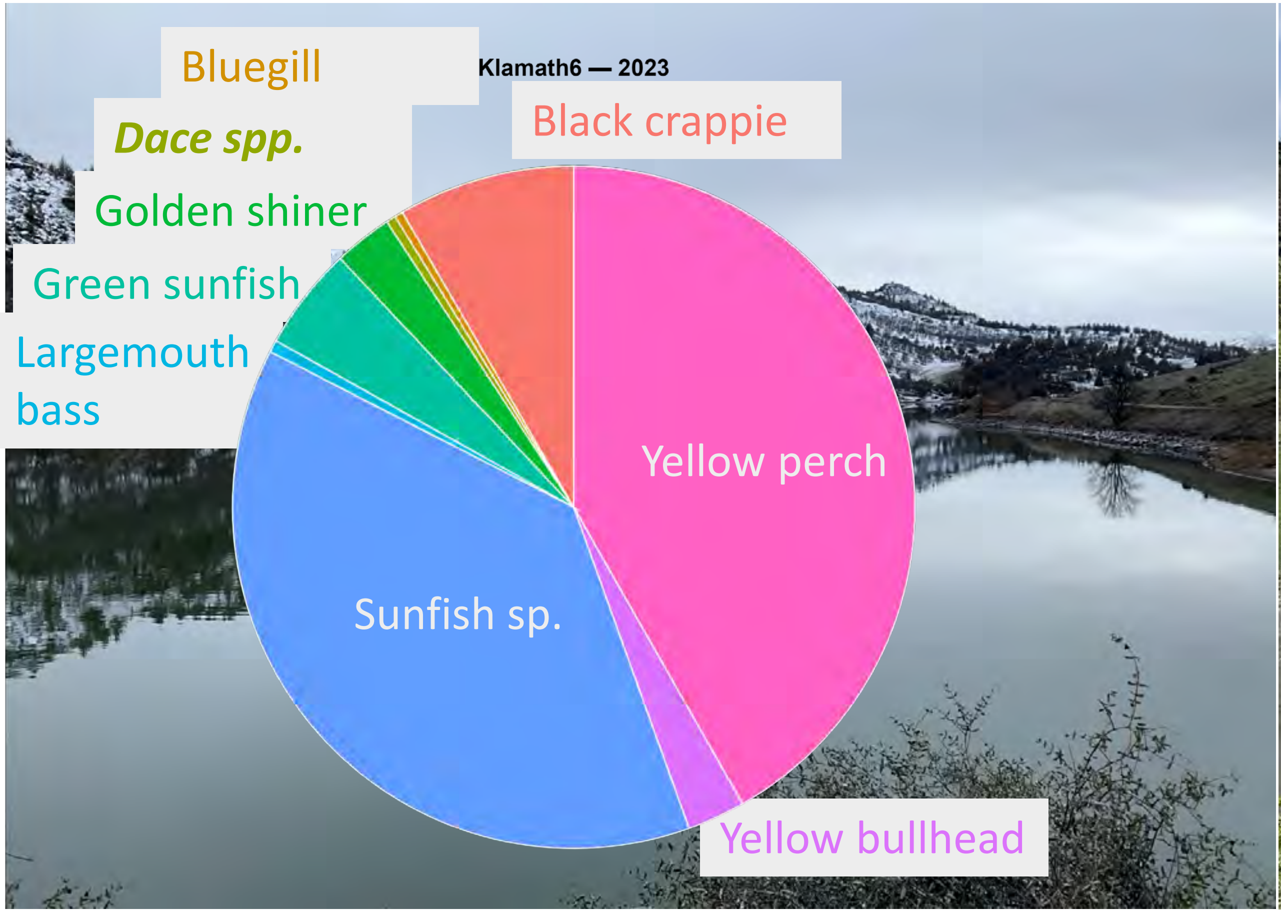
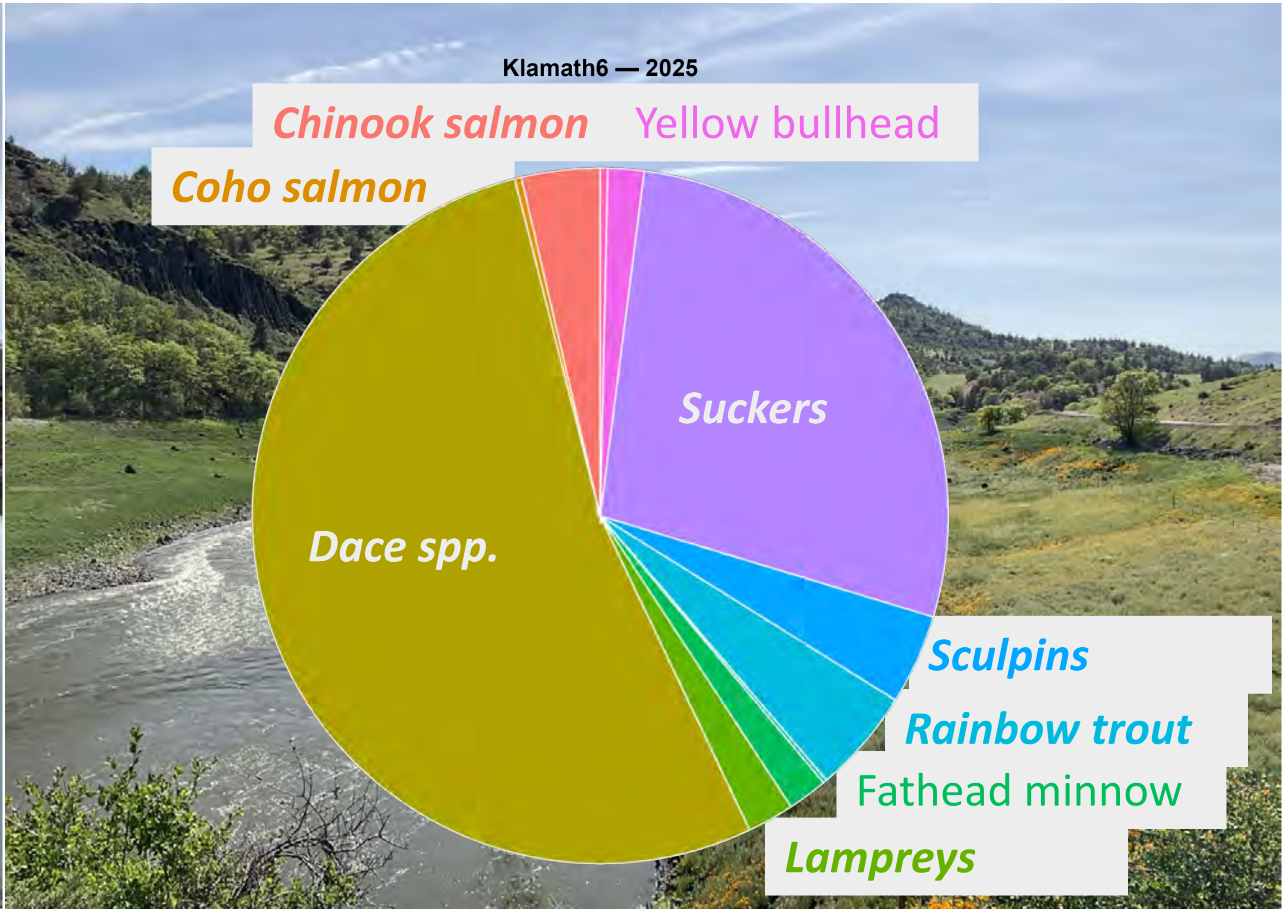


RES team collects eDNA from the Klamath River, June 2025

>95% exotic taxa reads



>95% native taxa reads



Bold and Italic indicate native taxa

Questions?

Dylan J. Keel - dkeel@res.us &
Daniel A. Chase - dchase@res.us

Resource Environmental Solutions, LLC. Sacramento, CA, 95818

Connect with KRRC

Check out the article

View the RES Klamath Story Map

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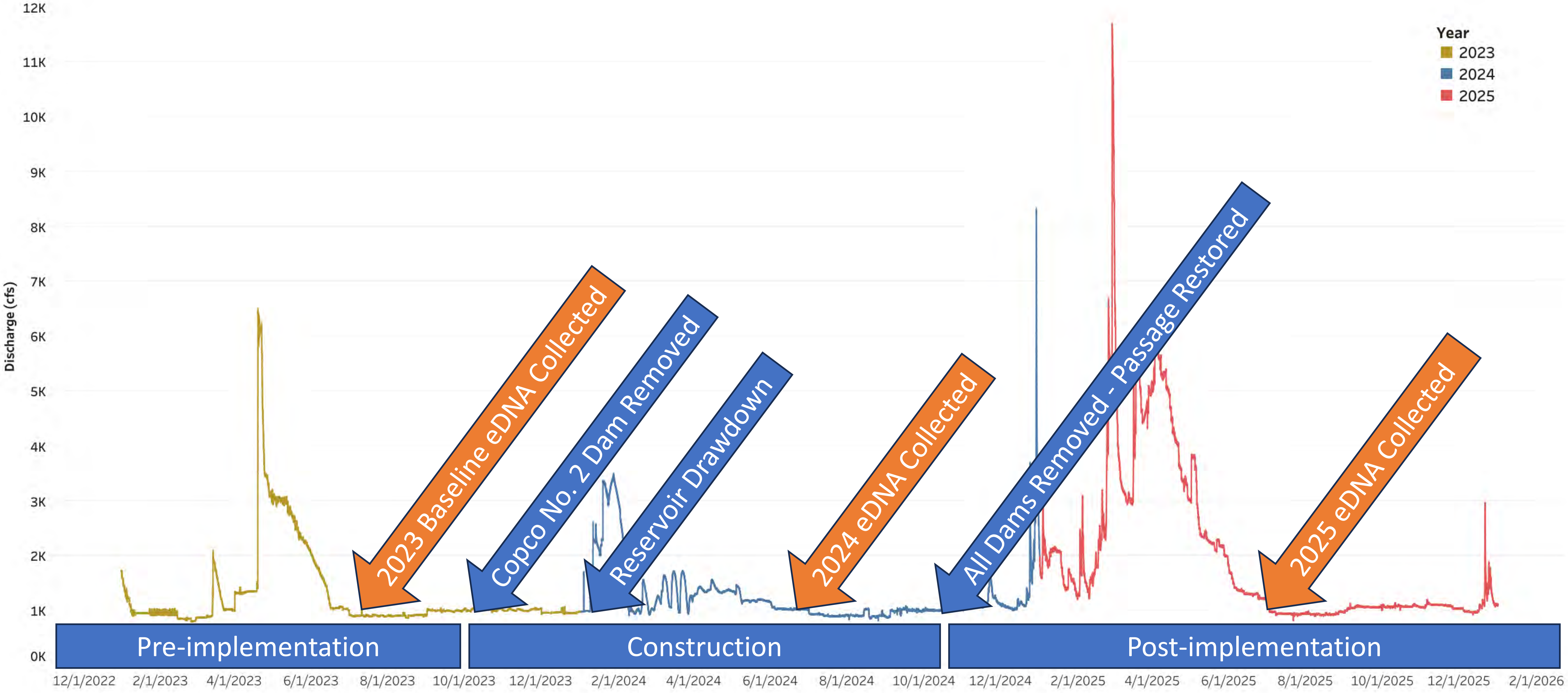
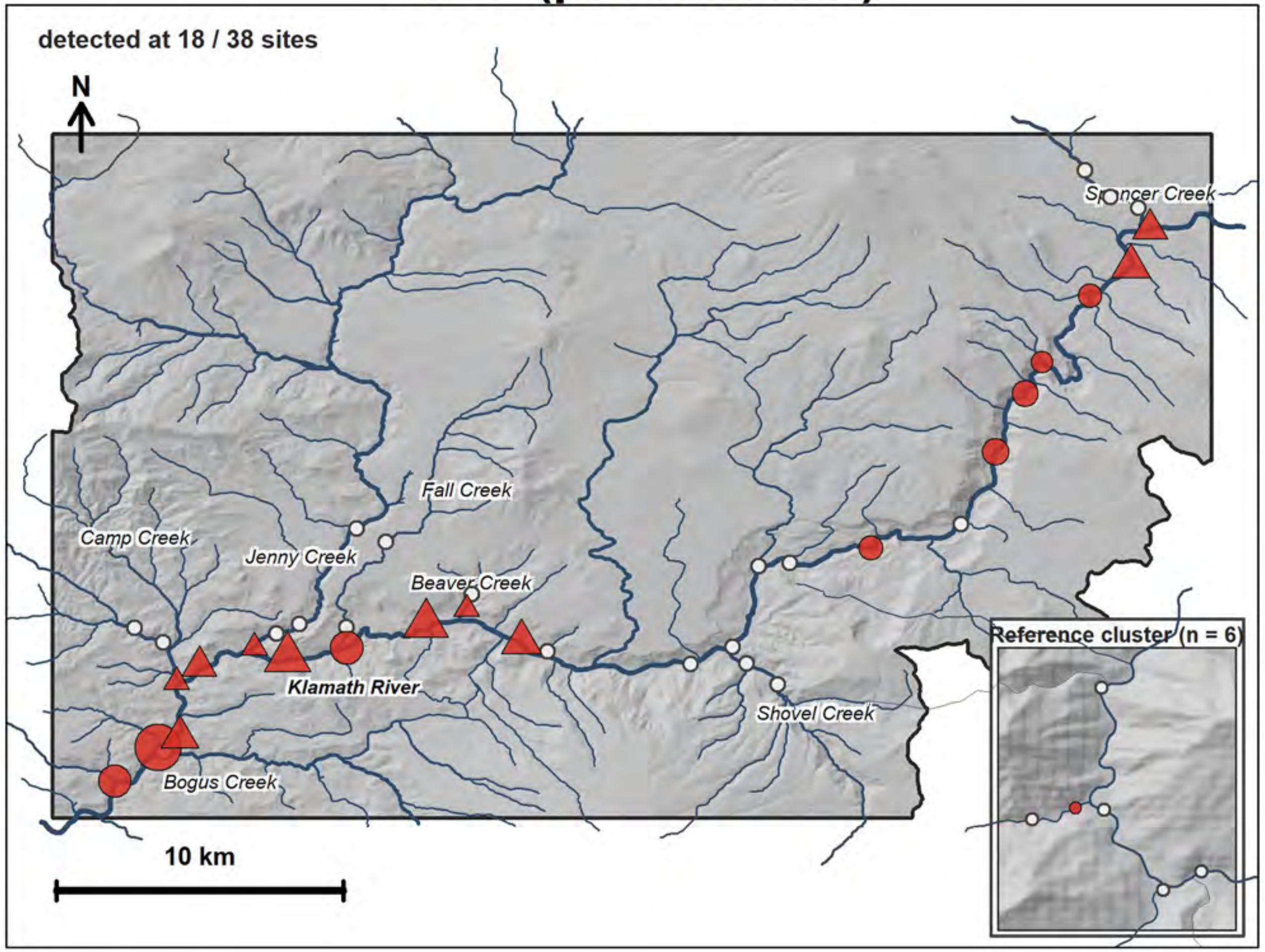
Sampling Schedule and Water Year



Pumpkinseed Sunfish

Exotic | Pre-removal (2023) vs Post-removal (2025)

2023 (pre-removal)



2025 (post-removal)

Site type

○ Stream

△ Reservoir / Former Reservoir

Flow-corrected reads per L (sqrt area)

Detection

126.9B

380.8B

846.3B

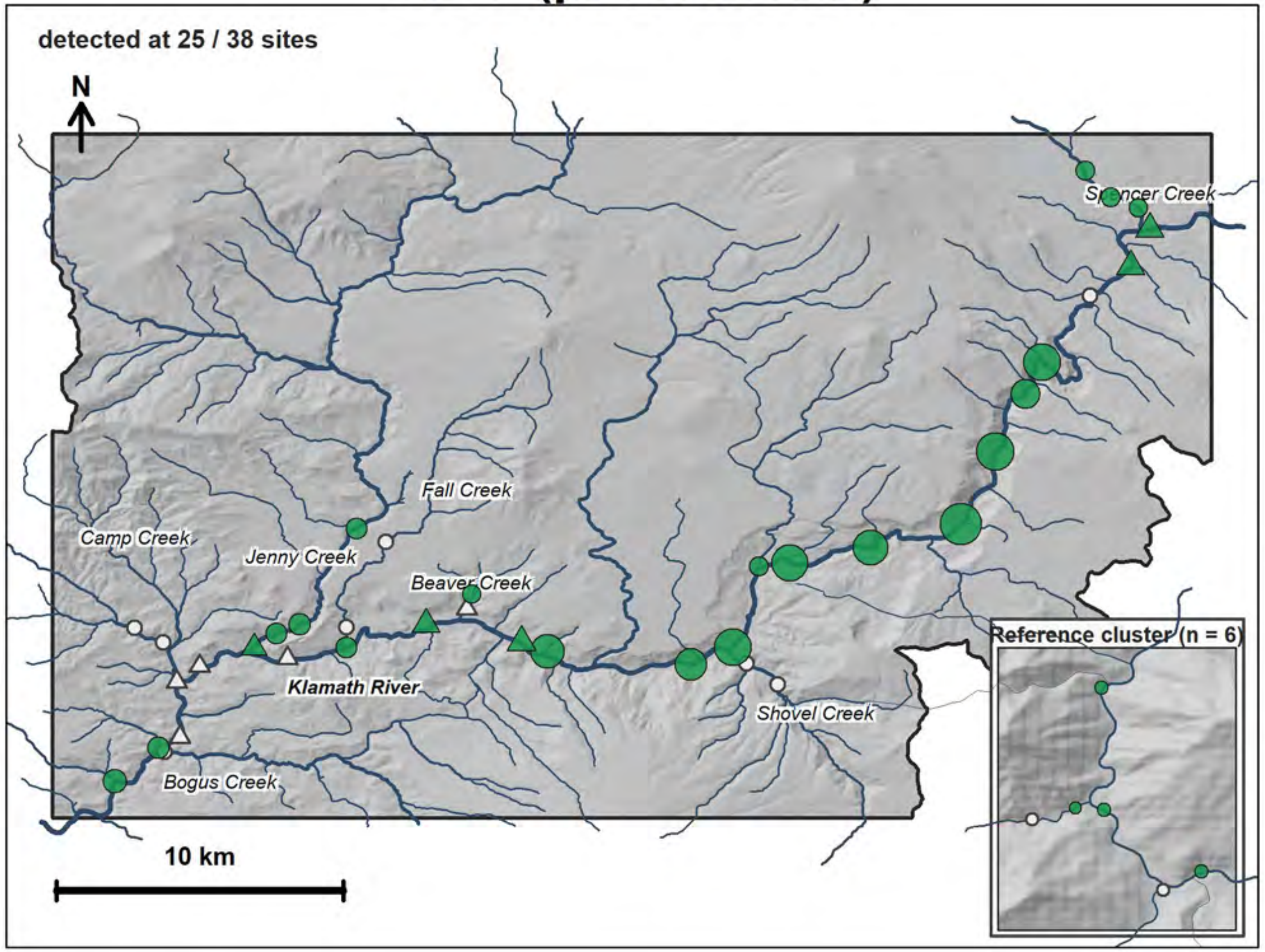
Exotic

Sucker spp.

Native | Pre-removal (2023) vs Post-removal (2025)

2023 (pre-removal)

2025 (post-removal)



Site type

○ Stream

△ Reservoir / Former Reservoir

Flow-corrected reads per L (sqrt area)

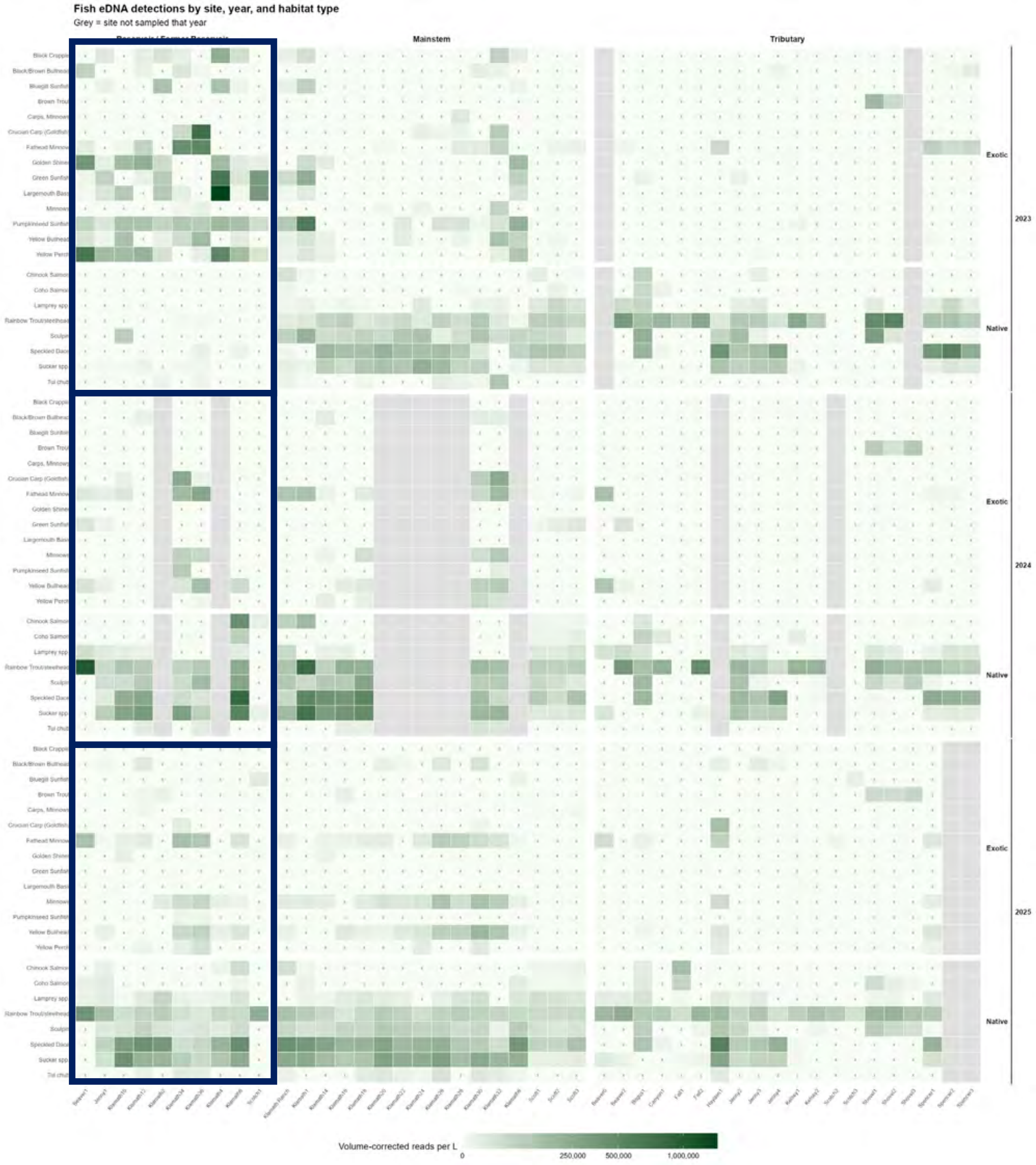
Detection

66.0B | 197.9B | 439.8B

Native

Results (2023, 2024, & 2025)

- Exotic fish relative abundance changes occurred during drawdown



PERMANOVA Results

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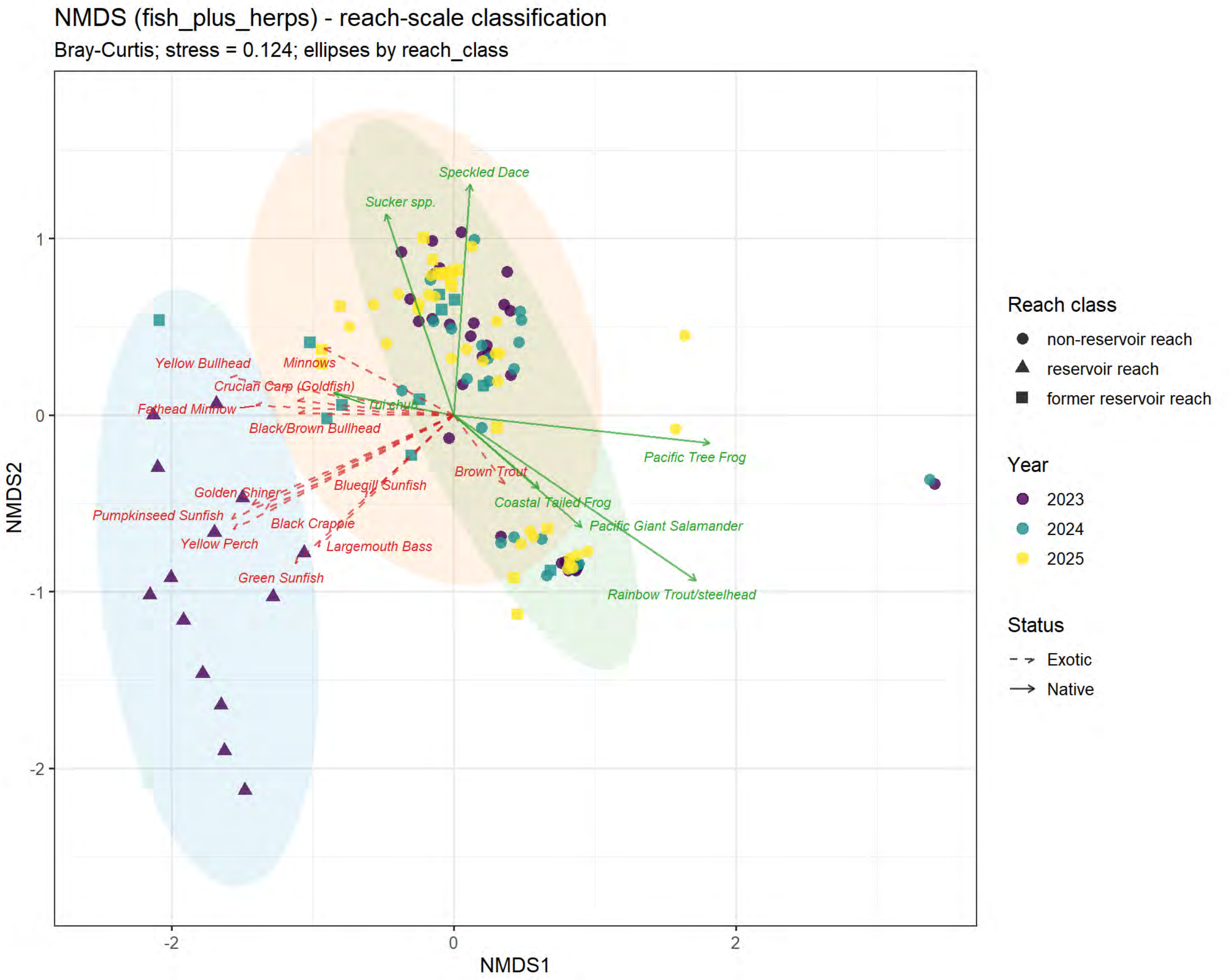

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Responses (per site-year, from volume or flow-corrected reads)
Native richness — count of native fish (or fish+herps)
Exotic richness — count of exotic species
Native Shannon — non-zero subset; single-species sites excluded (qualitatively different state)

Likelihood per response: Poisson if posterior-predictive dispersion P(D_rep>D_obs) ∈ (0.1, 0.9); else negative binomial.
Shannon = Gamma, log link

Random effects: stream-level iid intercept + Matérn SPDE spatial field (PC priors from Cressie variograms, 6 km cutoff); spatial fractions 43–80%

Counts: offset(log library size); Shannon: no offset

Fixed-effect grid — 36 candidate models per response
Habitat-family: none / Habitat (era-varying: Stream/Reservoir/Former) / reach_class (static 3-level)
Size-family: none / Size (Trib vs Mainstem) / log_DA (NHDPlus drainage area)
Year
Reference
Selection: WAIC (Watanabe 2010), strictly within likelihood family
Posterior-predictive: Bayesian p-values (χ^2, 300 draws) confirmed adequacy

Results

Reach-scale GLMM top 5 candidates per response (WAIC selection)
Fish only (22 taxa)

Exotic richness

#	Fixed effects	WAIC	ΔWAIC	Weight	R^2
1★	**reach_class + Year**	**389.8**	**0.0**	**0.427**	**0.708**
2	reach_class + Year + Reference	390.8	1.0	0.265	0.711
3	reach_class + Reference	391.3	1.5	0.200	0.701
4	reach_class	396.0	6.2	0.019	0.695
5	reach_class + log_DA + Year + Reference	396.9	7.1	0.012	0.651

Native richness

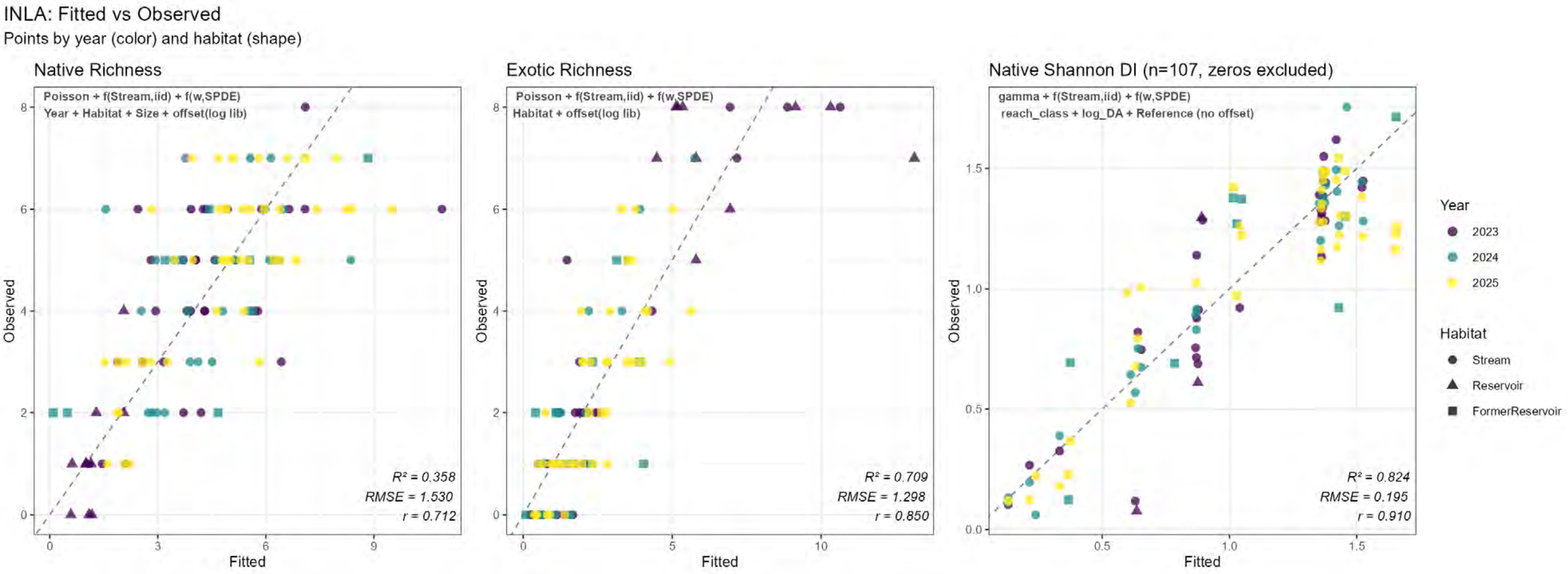
#	Fixed effects	WAIC	ΔWAIC	Weight	R^2
1★	**Habitat + log_DA + Year**	**474.2**	**0.0**	**0.303**	**0.358**
2	Habitat + log_DA + Year + Reference	474.3	0.1	0.287	0.369
3	Habitat + Size + Year	475.4	1.2	0.164	0.369
4	Habitat + Size + Year + Reference	476.7	2.5	0.085	0.372
5	Habitat + log_DA	477.4	3.2	0.061	0.262

Native Shannon

#	Fixed effects	WAIC	ΔWAIC	Weight	R^2
1★	**reach_class + log_DA + Reference**	**60.0**	**0.0**	**0.535**	**0.823**
2	Habitat + log_DA + Reference	62.1	2.1	0.187	0.796
3	reach_class + log_DA + Year + Reference	63.3	3.3	0.105	0.824
4	Habitat + log_DA + Year + Reference	64.9	4.8	0.048	0.800
5	reach_class + Size + Reference	65.5	5.5	0.035	0.794

★ = WAIC-selected best model. Family per response is shown in the headline table. All models include f(Stream, iid) random intercept and SPDE Matern spatial random field; richness models include offset(log lib_size).

Results



- Best models passed GOF
- Best models described a meaningful amount of variance in the response

Estimation of Juvenile Salmonid Summer Occupancy in Shovel and Jenny Creeks

Ben King

Environmental Scientist

Klamath Watershed Program

California Department of Fish and Wildlife

Introduction: Pre-dams

- "The salmon run up the river and go up Shovel creek to spawn in such numbers as to be almost beyond belief. It is a fact that at narrow points in the river the salmon sometimes crowd each other out upon the bank." - San Francisco Call, Volume 106, Number 27, 27 June 1909: Where Shovel Creek Reaches the Klamath

Photo: Jon Kang

Photo: Ben King

Post Dam Removal Monitoring Framework

- Adult Escapement
  - Spawning ground surveys
  - Video Weirs
- Juvenile Outmigration and Rearing
  - Outmigrant traps
  - Summer snorkel surveys
- Water temperature monitoring

Post Dam Removal Monitoring Plan Phases

1

Phase 1: Reintroduction

2

Phase 2: Establishment

3

Phase 3: Abundance and Productivity

4

Phase 4: Spatial Structure and Diversity

Phase 2: Establishment

- "Chinook Salmon, Coho Salmon, steelhead, and Pacific lamprey are generally trending toward or have become established in available habitats (species and life stage specific) in tributary reaches within the monitoring reach"

Phase 3: Abundance and Productivity

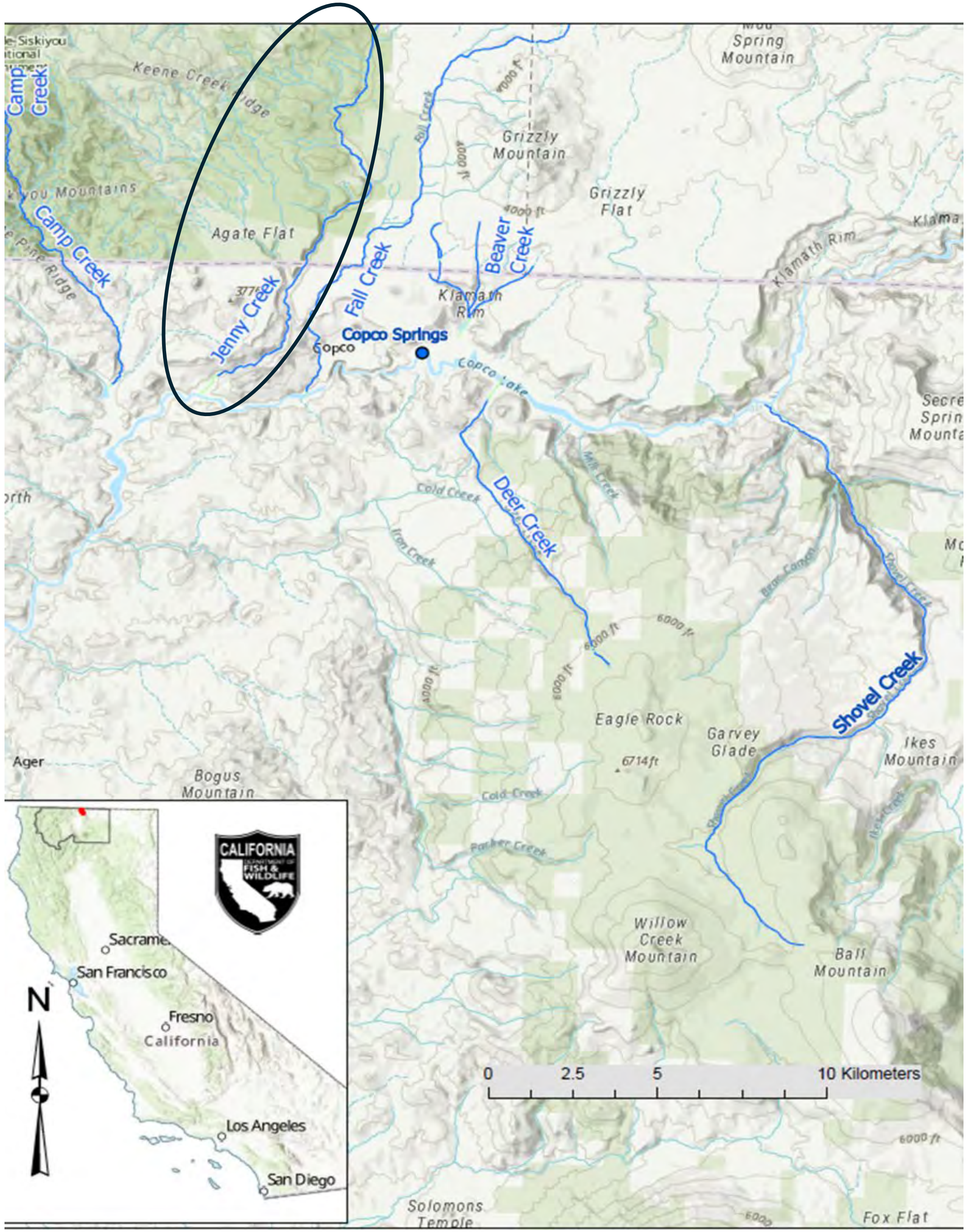
- "Determining annual Chinook Salmon smolt production, spatial and temporal smolt abundance, and movement patterns (timing of downstream movement);"
- "Determining annual Coho Salmon smolt production, spatial and temporal smolt abundance, movement patterns (timing of downstream movement), and age structure. In addition, the relative abundance by reach/tributary and seasonal habitat use of juvenile Coho Salmon"

Phase 4: Spatial Structure and Diversity

- Phase 4 monitoring builds on Phase 3 and has a heavy life history diversity component.

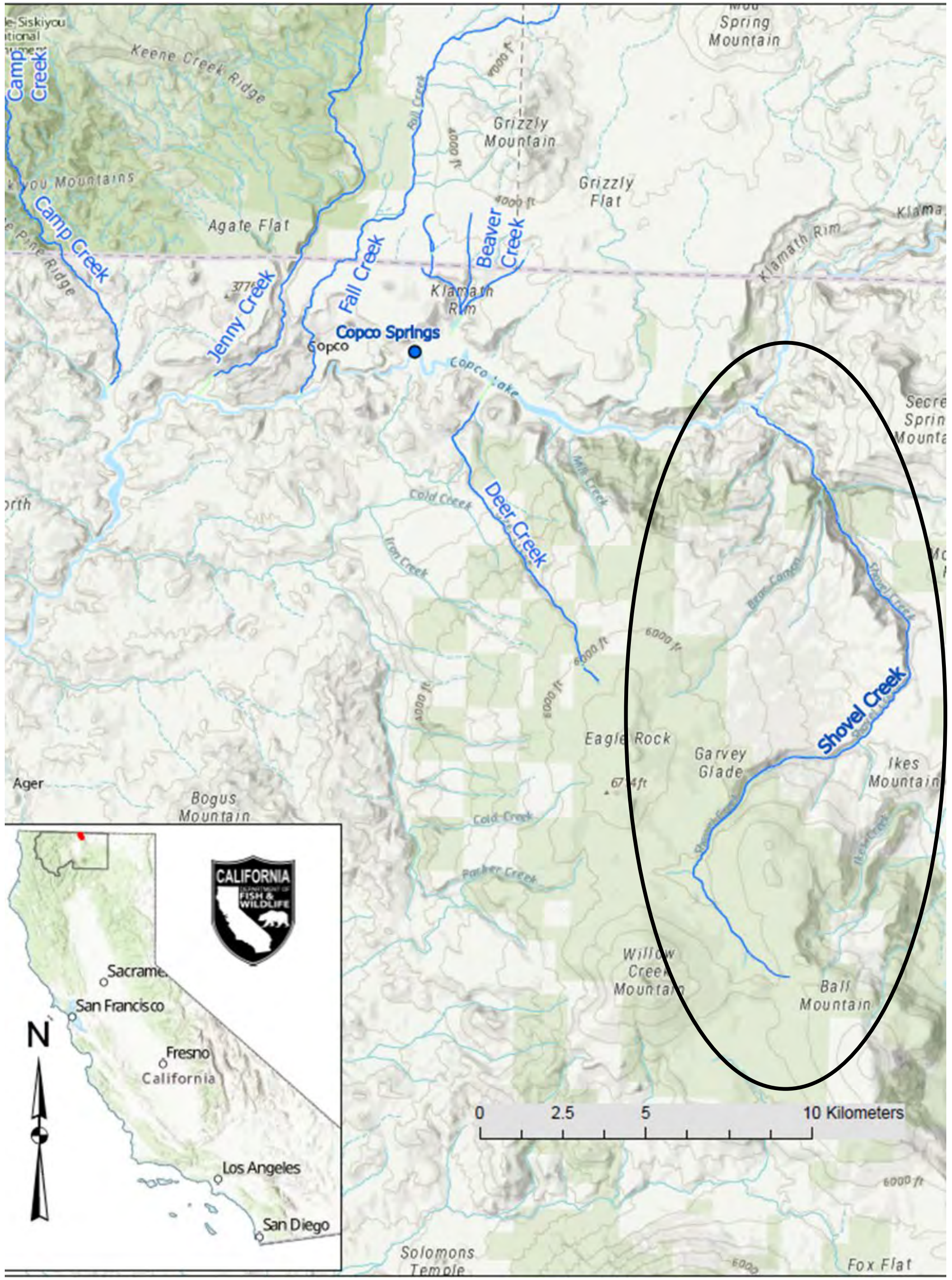
Jenny Creek

- Largest tributary in the newly accessible CA section of the Klamath
  - 544 km^2
- Roughly 3.9 km of anadromous habitat
  - ~ 800m of habitat restored in the reservoir footprint in 2025
- Relatively warm summer water temperatures



Shovel Creek

- Largest tributary in the former hydropower peaking reach
  - 132 km^2
- Roughly 4.5 km of anadromous habitat
- Heavy spring influence



2024 Spawners

- Jenny Creek
  - Chinook estimate: 348
  - Coho estimate : 6
- Shovel Creek
  - Chinook estimate: 287
  - Coho Estimate: 39
- Persistent high flows made Coho monitoring challenging


Photo: Willis Hindle


Photo: Ben King

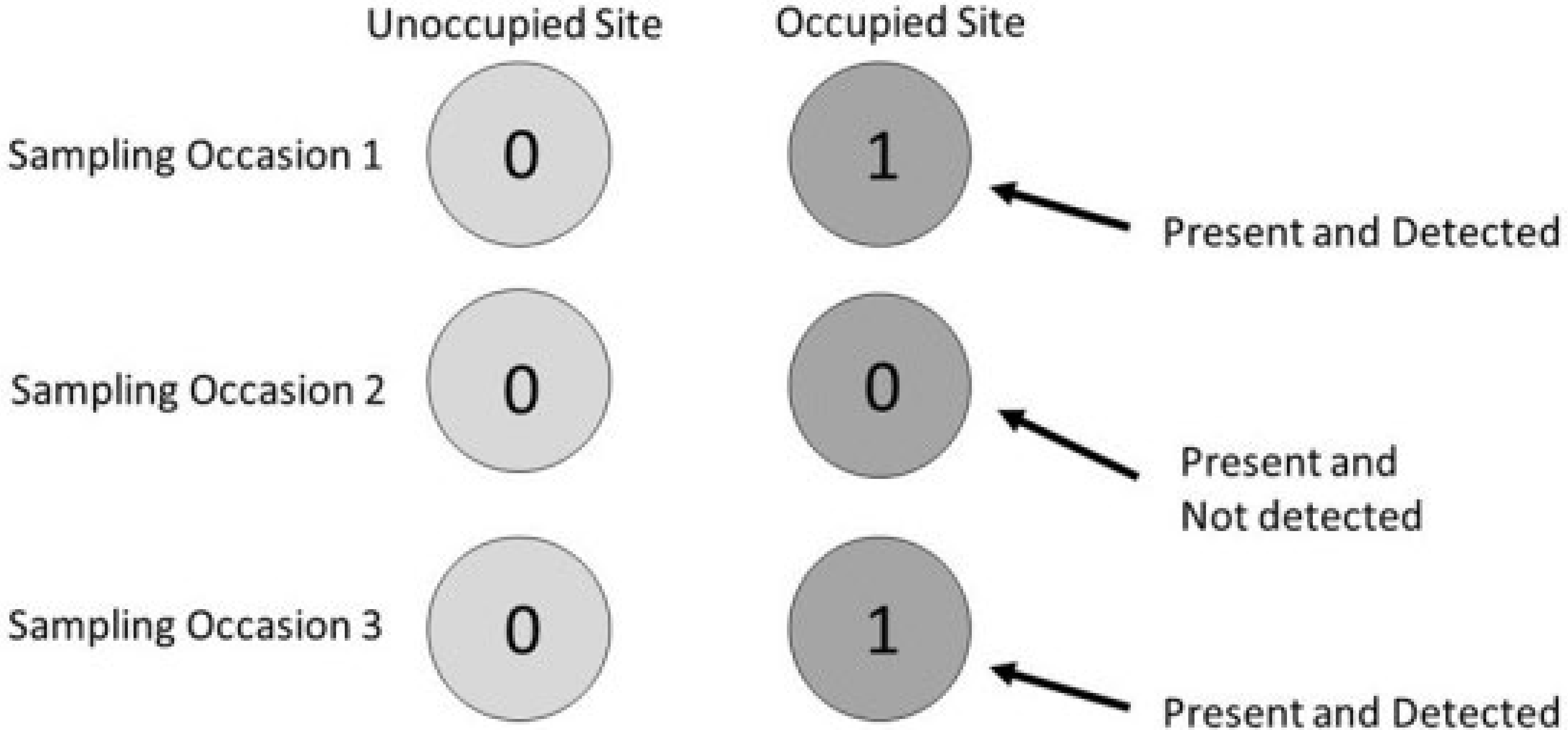
Persistent high flows continued through juvenile trapping season

- Precluded trapping in Jenny entirely.
- Precluded trapping Shovel until late April, 2025.

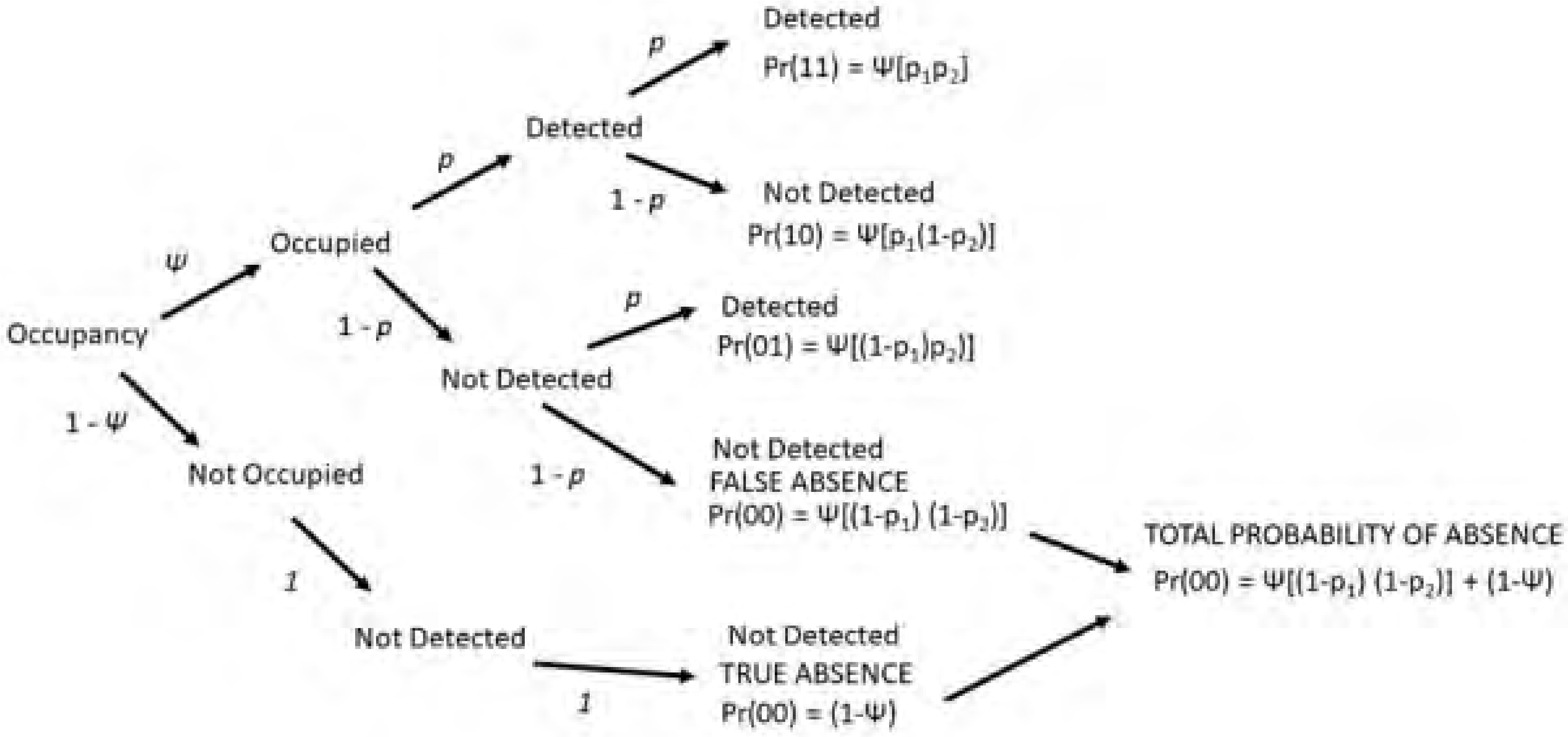
Field Methods

- Random 50% subset of 200m stream reaches
- Coarse level habitat typing
- Snorkel surveys focused on pools + flatwaters
- Upstream snorkels of every unit in selected reaches
  - Every other unit received a second, independent snorkel pass

Occupancy modeling overview



Occupancy modeling overview



Analytical Methods

- Single season multi-scale occupancy models in PRESENCE
    - Allows estimation of occupancy at two scales
        - Reach scale (Ψ) and unit scale (Θ)
        - Product of Ψ * Θ yields percentage of area occupied estimate (PAO)
- Individual habitat units are treated as closed sites
- Assumption that smolt outmigration was complete

Results: Jenny Creek

- 4 of 5 reaches surveyed contained Coho Salmon
- High juvenile Coho Salmon reach level occupancy, moderate unit level = moderate percent area occupied (PAO)
  - Wide CI's

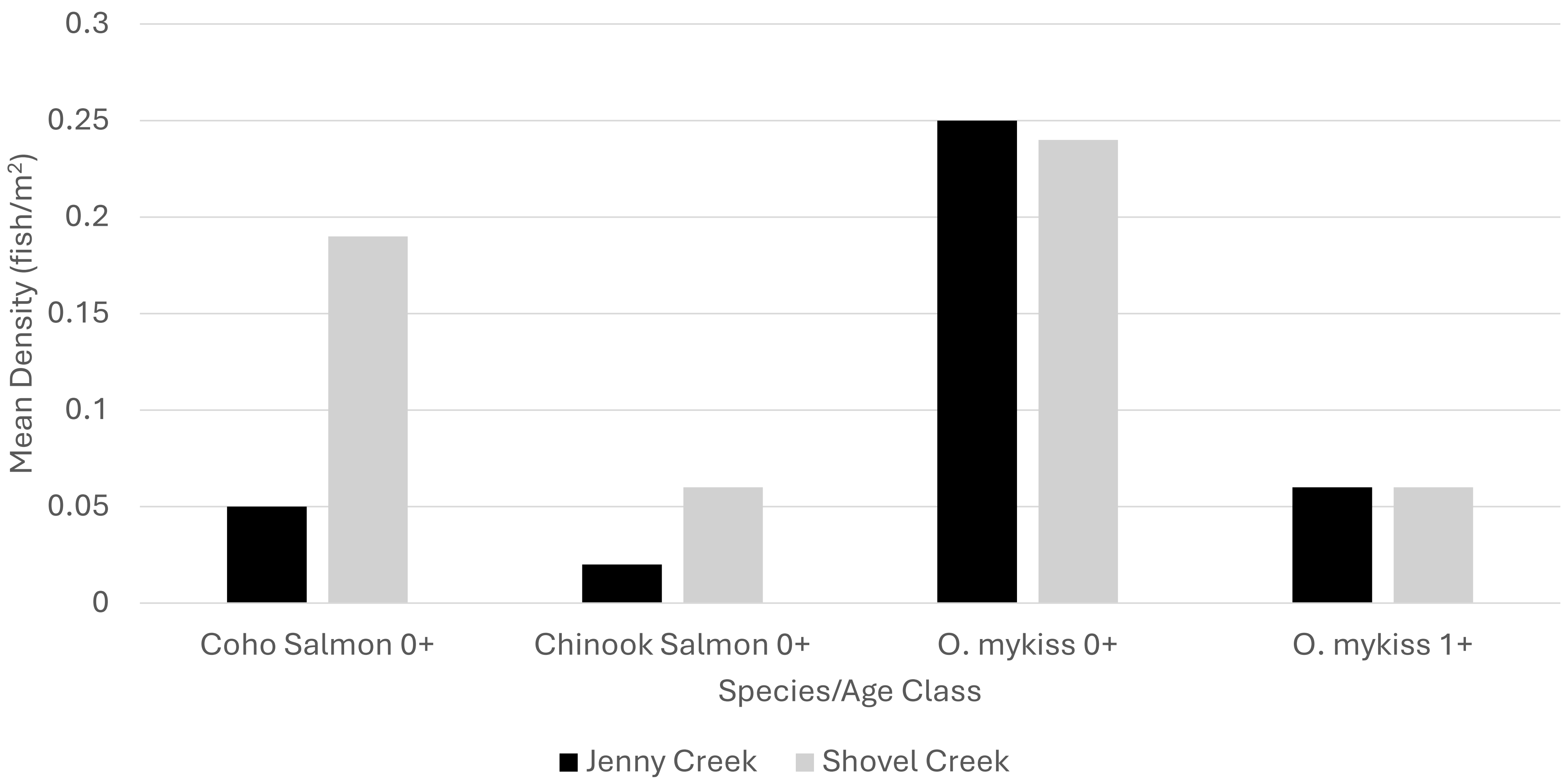
Species	Ψ	95% CI	Θ	95% CI	P	95% CI	% Area Occupied	Total Count
0+ Coho Salmon	83%	27-98%	49%	32-66%	67%	45-84%	41%	64
0+ Chinook Salmon	---	---	---	---	---	---	---	7

Results: Shovel Creek

- 12 of 14 reaches contained juvenile Coho Salmon
- High unit and reach level occupancy for juvenile Coho Salmon
- Moderate occupancy for juvenile Chinook Salmon

Species	Ψ	95% CI	Θ	95% CI	P	95% CI	% Area Occupied	Total Count
0+ Coho Salmon	86%	57-96%	75%	62-85%	88%	76-94%	65%	509
0+ Chinook Salmon	55%	27-80%	33%	19-50%	87%	59-97%	18%	36

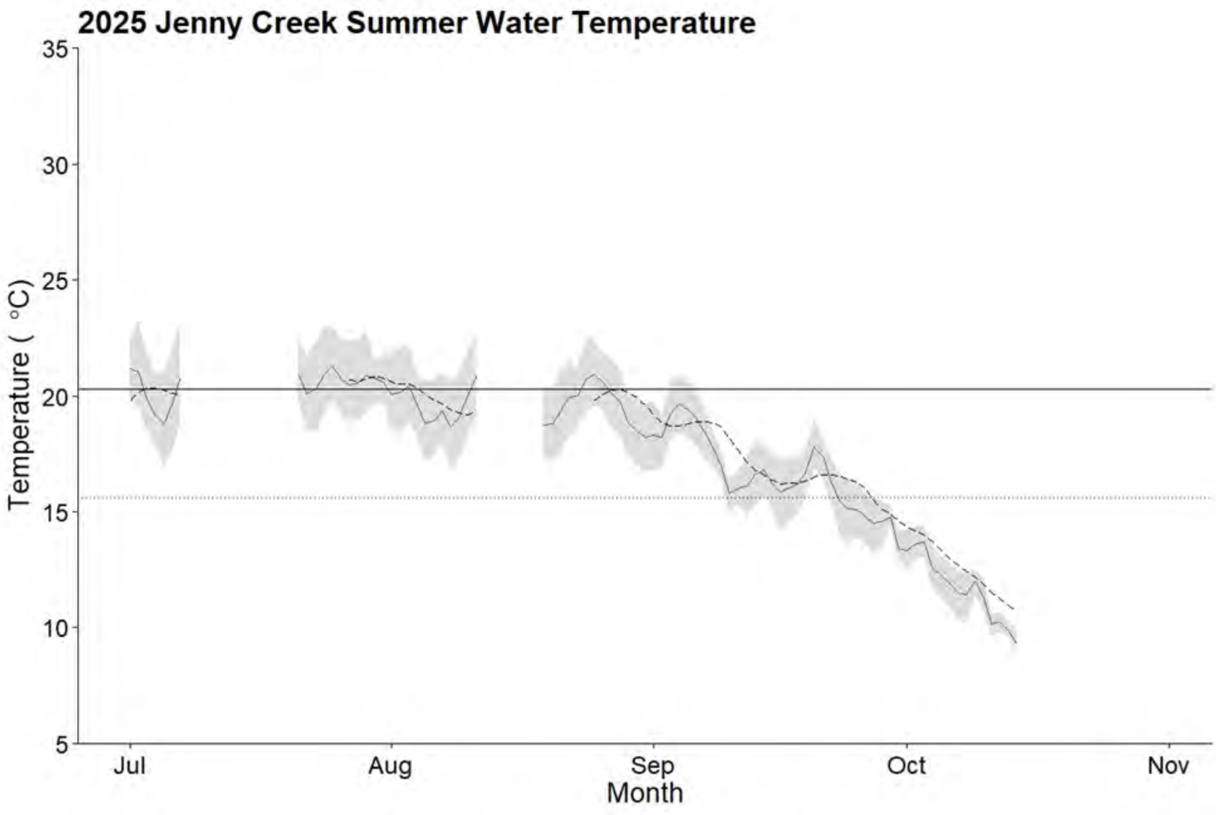
Density Comparison

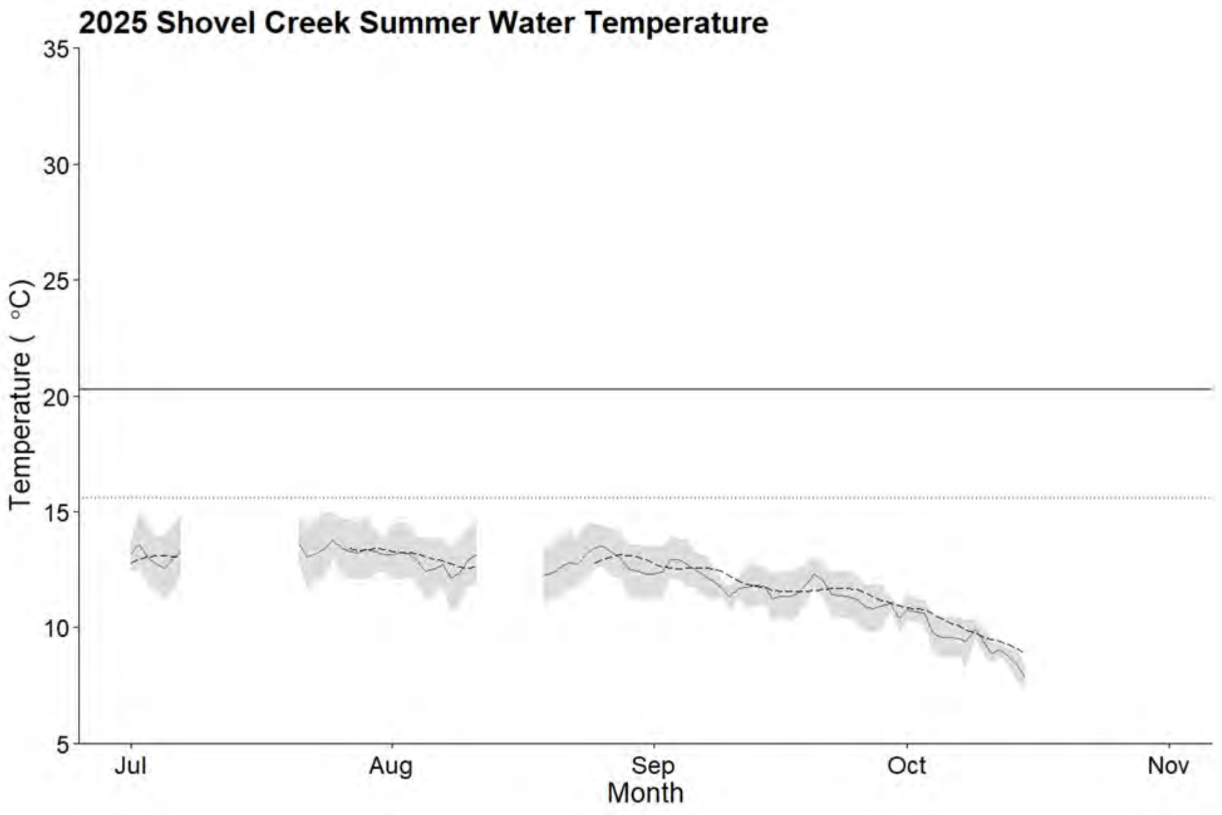


Over-summering Coho Salmon well distributed in year one

- Encouraging to see Coho sprinkled throughout most of the anadromous habitat.
- Low densities, especially in Jenny Creek.
- Prime pools demonstrated the potential for higher densities

Contrasting thermal regimes



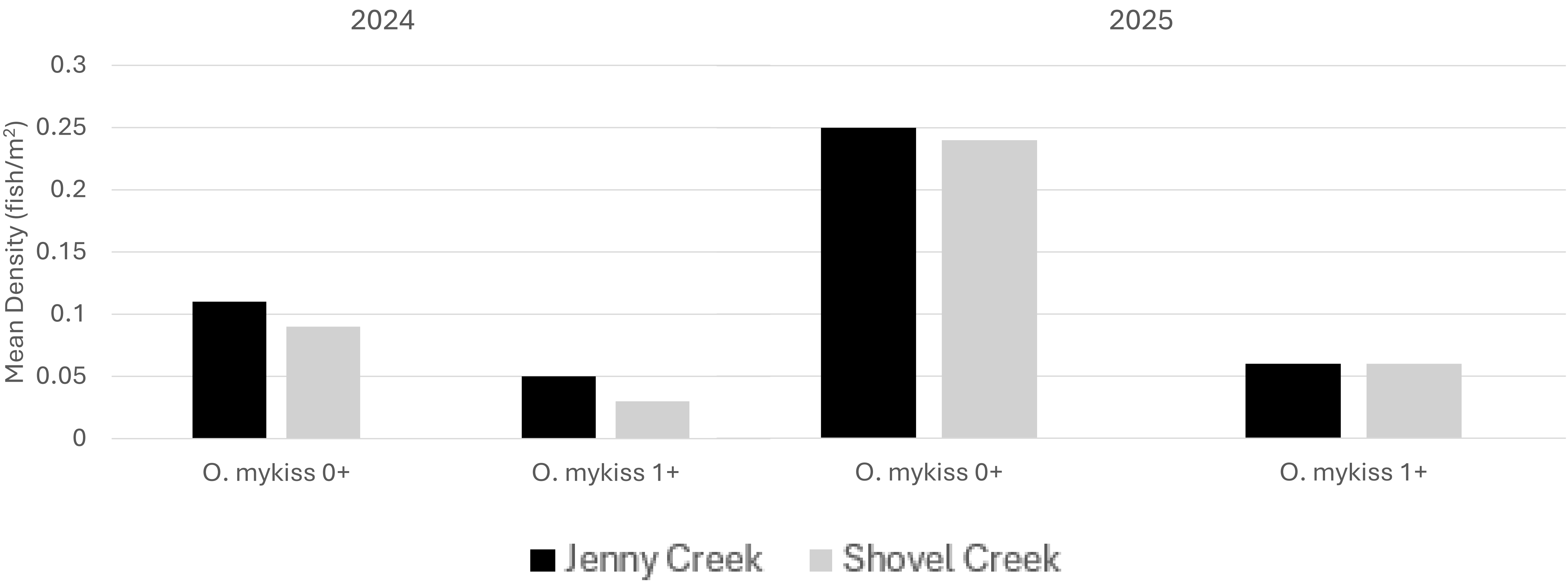


Stream-type Chinook Salmon is exciting!

- Life history diversity in these developing populations is noteworthy
- Size at outmigration and ocean entry linked to survival
- Fall/Winter outmigration could be advantageous with additional distance

Photo: Ben King

Much lower O. mykiss densities than in past studies, 2025 higher than 2024



Next Steps

- Concrete gravity dam removed on Jenny Creek allows access to another mile of habitat
- N-mixture models to estimate over-summering abundance?
- Mainstem reaches

Thanks!

- Alma Nuñez Gutierrez
- Andrew Bachteler
- Christy Wheatley
- Crystal Robinson
- Desiree Hardin
- Gabrielle Camba
- Isobel Moore
- Jason Carnahan
- Justo Tapia-Padron
- Maiya Romero
- McKayla Woodie
- Michael R. Harris
- Rachel Kayen
- Rosemary Romero
- Willis Hindle


Photo: Maiya Romero

Immediate responses of Chinook Salmon spawning in the California mainstem Klamath River upstream of Iron Gate

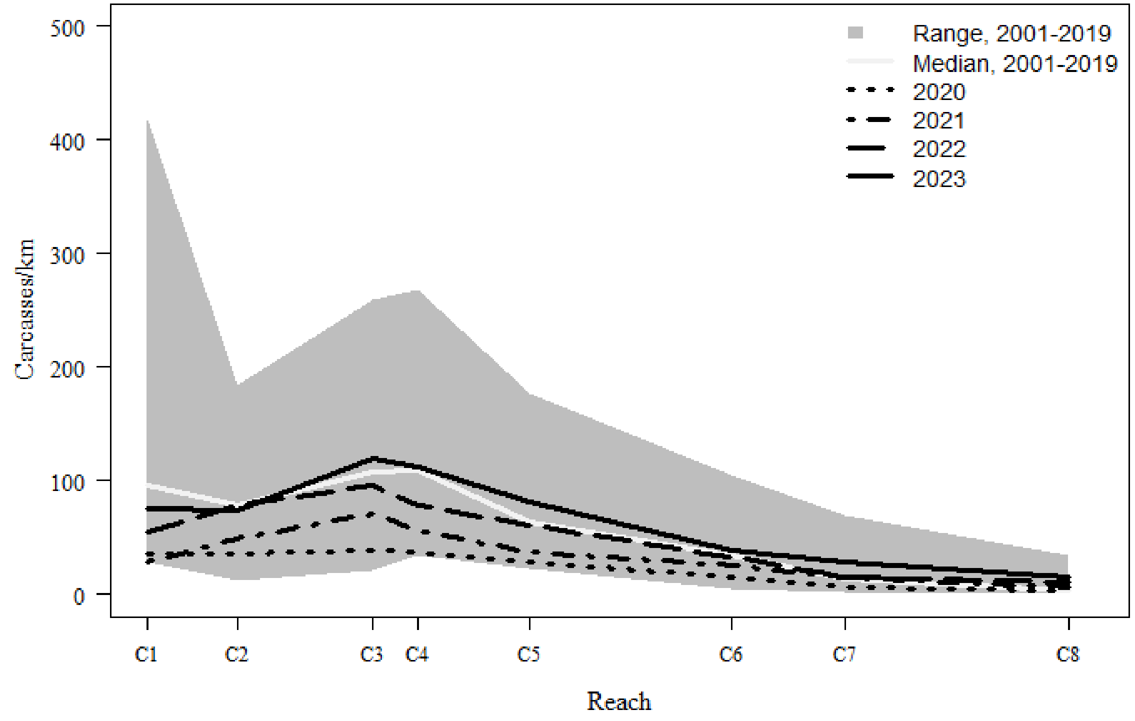
Findings from the first two years of adult salmon population monitoring following dam removal

Steve Gough, U.S. Fish and Wildlife Service
Toz Soto, Karuk Tribe Fisheries Department
Leanne Knutson, Yurok Tribal Fisheries Program

Survey Period of Record

- Pre-dam removal 1993-2023
  - Carcass mark-recapture Iron Gate Dam – Shasta River (21.2 km), since 2001
  - Redd counts Shasta River – Wingate Bar (125.7 km)
- Post-dam removal 2024, 2025
  - Continue surveys downstream of Iron Gate
  - Carcass/redd surveys CA-OR state line – Iron Gate (31 km)

Dam-era distribution



Mainstem Klamath River, Iron Gate Dam to Shasta River, 2001-2023 mean

- 11.2% of natural spawners in the entire Klamath basin (including Trinity)
- 19.4% of natural spawners in the Klamath basin above Weitchpec

Escapement Estimation
What's the best tool for the job?

- Carcass mark-recapture
  - Redd superimposition
  - Abundant carcasses
- Redd count
  - Redds distinguishable
  - Sparse carcasses

Spawning distribution and abundance 2024

168 redds

1-5 redds

6-10 redds

11-15 redds

Spawning distribution and abundance 2025

498 redds

1-10 redds

11-20 redds

21-30 redds

Spawning Area Choice

State Line – Shovel Creek

- large boulders and angular (volcanic) cobble; placed boulders diverting water into long irrigation ditches
- No spawning

Shovel Cr – K’utárawáx·u (Grizzly Hill)

- Best substrate; nice cobble bars
- Highest spawning density

K’íka·c’é·ki Canyon

- High gradient whitewater; not surveyed

Former Iron Gate Reservoir

- Decent substrate; wide and shallow; but it’s better upstream
- Sparse spawning

Photo by Aaron Martin, YTFP

Challenges and Future Surveys

- Carcass scavenging
- Redd superimposition
- Turbidity
- Restoration
- Planning and foresight
- Marking individual redds
- Matching SONAR detections
- Funding gaps
- Dynamic situation
  - Spawn timing, abundance, and distribution
  - Spring-run Chinook Salmon reintroduction/recovery

ACKNOWLEDGEMENTS

Yurok Tribal Fisheries Program
Jamie Holt
Rocky Ericson
Gilbert Myers

Karuk Tribe Fisheries Dept
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Eric Fieberg
Sonny Mitchell
Ben Harrison

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Olivia Black
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Aliah Guerrero
Cameron Lamphere
Ethan Moses
Clara Smith
Adam Wojtczak
Kaitlyn Zedeker

RES
Daniel Chase
John Lang
Joel Ophoff

And all the impassioned and embattled salmon biologists and people of the river

...Thank you!

Monitoring Klamath Adult Salmon Abundance and Movement in Newly Available Habitat Post Dam Removal

Alex Corum, Karuk Tribe
Bob Pagliuco, NOAA Restoration Center
Cyril Michel, University of Santa Cruz, NMFS SWFSC Affiliate
Toz Soto, Karuk Tribe
James Whelan, California Trout
Damon Goodman, California Trout
Mark Hereford, OR Dept. of Fish and Wildlife
Carolyn Malecha, OR Dept. of Fish and Wildlife
Jordan Ortega, Klamath Tribes
Ryan Bart, Klamath Tribes
Ben Grassman, CalPoly Humboldt

A Fishy Working Group

Building a Community around Science and Monitoring

Karuk Tribe	Toz Soto, Alex Corum, Clay, Bo, Eric, Ben
Yurok Tribe	Barry McCovey, Oshun O'Rourke, Leanne Knutson
Klamath Tribes	Ryan Bart, Jordan Ortega
NOAA Fisheries	Bob Pagliuco, Tommy Williams
BOR	Torrey Tyler, Eric Reiland
USFWS	Ryan Fogerty, Steve Gough
CDFW	Crystal Robinson, Rosemary Romero, Morgan Knechtel, Dominic Guidice
ODFW	Mark Hereford, Carolyn Malecha
USGS CRU and CalPoly Humboldt	Nicholas A. Som
CalPoly Humboldt	Andrew Kinzinger, Laura Redfield, Ben Grassman
MIT	Sara Beery, Justin Kay
CalTech	Michael A. Hobley, Madison Van Horn, Pietro Perona
UC Santa Cruz	Cyril Michel
Klamath River Renewal Corp.	Mark Branscomb, Ren Brownell
Ridges to Riffles	Stephanie Quinn-Davidson
Conservation Angler	John McMillan
Skagit Salmon	Erik Young
K. Denton and Associates	Keith Denton, Oleksandr Stefankiv
George Pess Consulting, LLC	George Pess
RES	Daniel Chase, Dave Coffman
CalTrout	Damon H. Goodman, James Whalen, Andrew McLane


Photo - Caltrout

Need for Monitoring Post Dam Removal

A Unique Opportunity to assess *Expansion, Abundance, Timing and Diversity*

- **Restoration** – Information needed to evaluate the effectiveness of dam removal and where to focus future restoration efforts.
- **Regulatory** – Information needed to inform BOR Klamath Project ops/consultations, 5-yr status reviews, and listing petitions.
- **Fisheries Management** – Information needed to manage the tribal, commercial, and sport in-river and ocean fishery.
- **Future Monitoring Efforts**- Information needed to evaluate where to invest future monitoring efforts

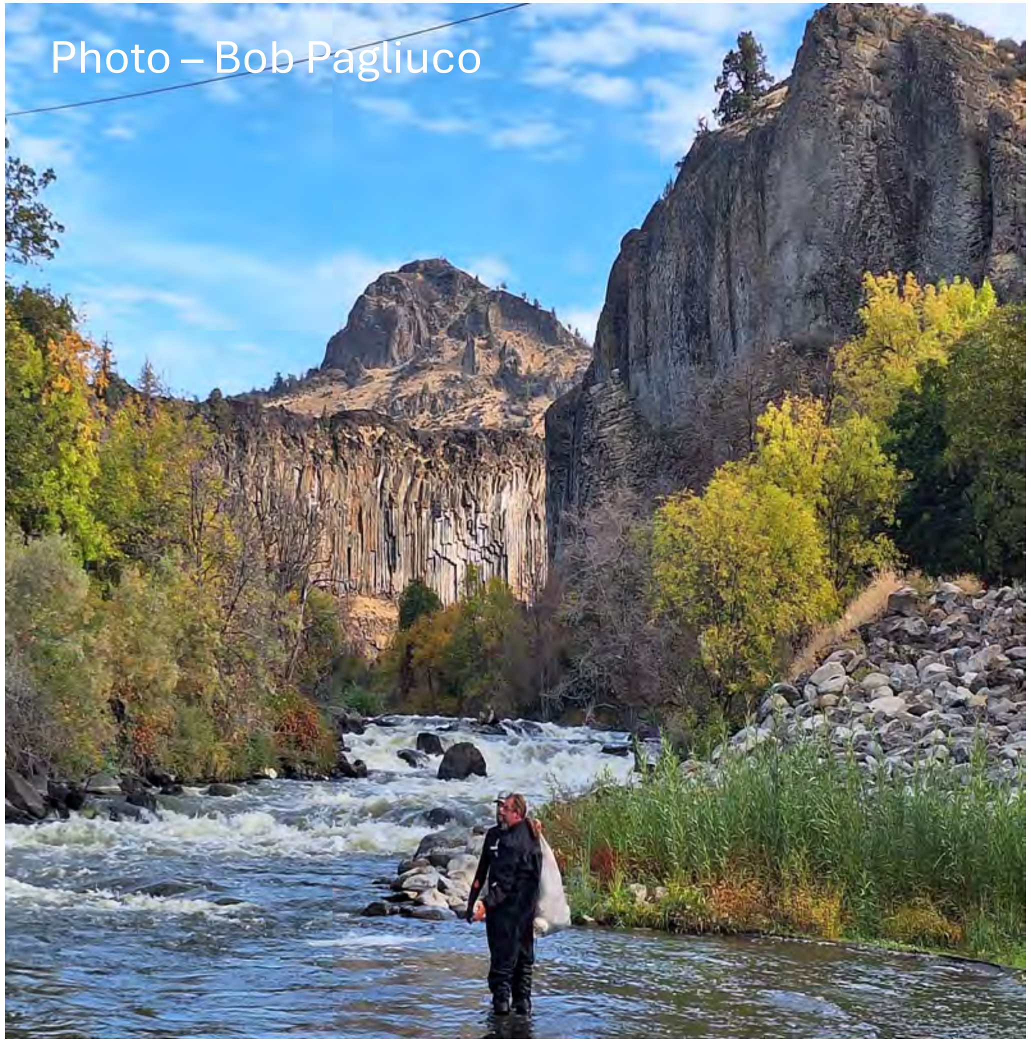


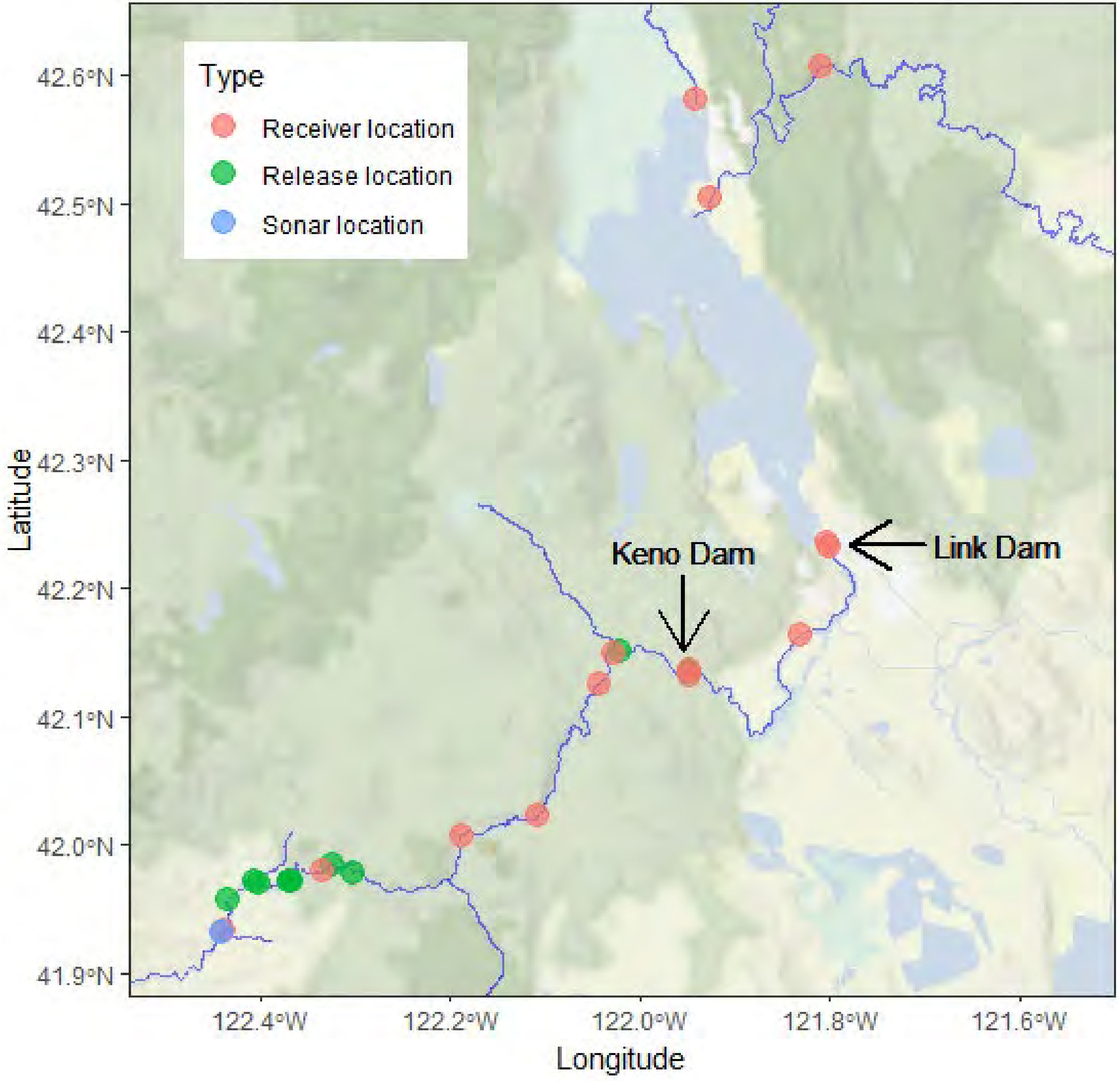
Photo – Bob Pagliuco

Study Design

- **How Many?** – SONAR below Iron Gate
- **What Species?** – Tangle netting and eDNA
- **Where are they going & what conditions are they experiencing?** – Radio telemetry

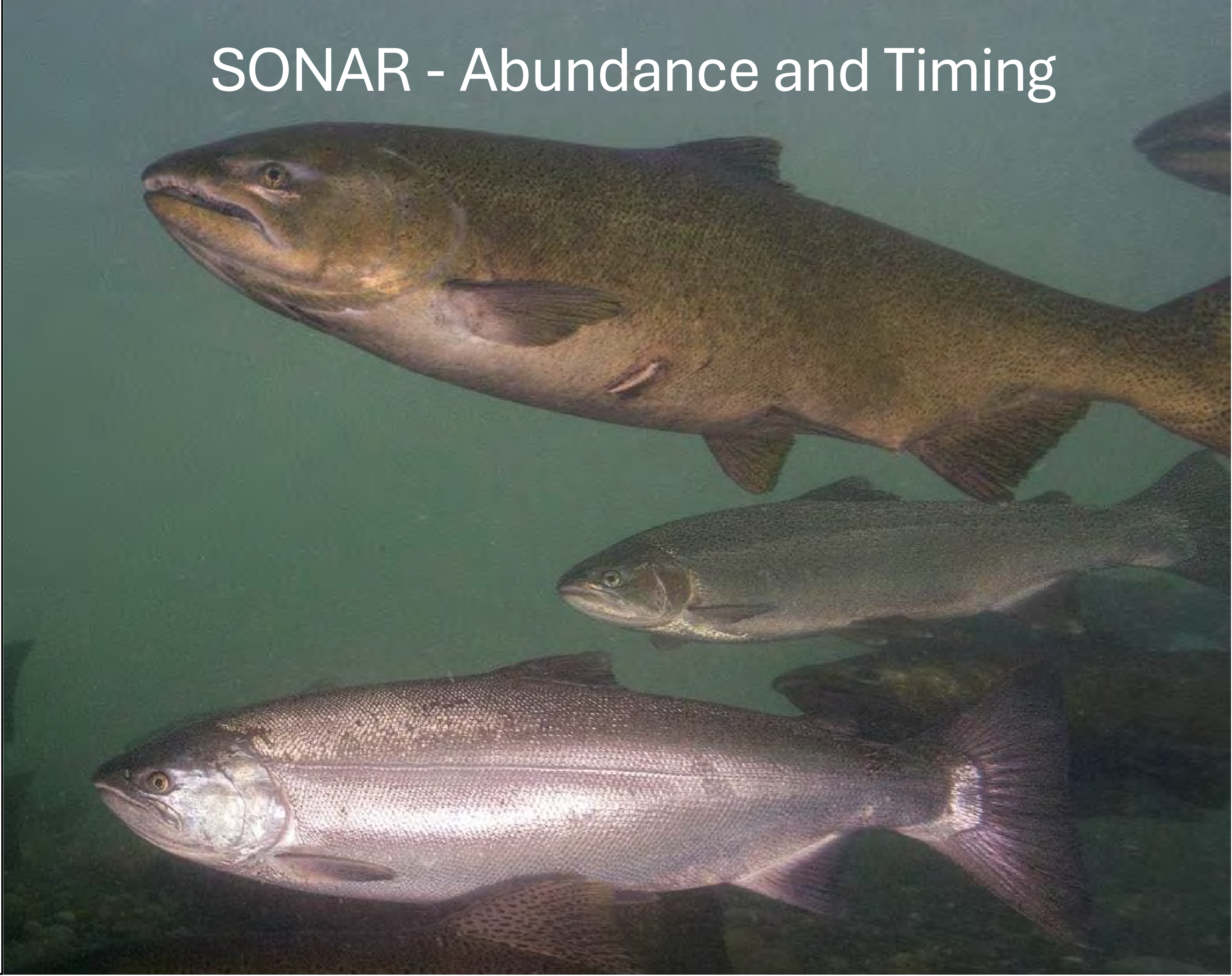
Partners

- ***CalTrout*** (Study design, project management, fundraising)
- ***Karuk Tribe*** (SONAR, tangle netting and CA mobile tracking and telemetry station maintenance)
- ***Klamath Tribes*** *(UKL, Sprague, Williamson, Wood mobile tracking and* telemetry station maintenance)
- ***Yurok Tribe*** (SONAR review)
- ***Ridges to Riffles – (****Technical support)*
- ***ODFW*** (Study design, state line to Link mobile and aerial tracking, tangle netting, and telemetry station maintenance)
- ***CDFW*** (Field support, SONAR camera, and permitting)
- ***NOAA*** (Study design, partner coordination, fundraising)
- **UC Santa Cruz – (**Study design, analysis)
- ***Keith Denton and Cal Poly Humboldt*** (SONAR/apportionment design, analysis, publication)
- ***CalPoly Humboldt –*** *eDNA, mobile tracking, behavioral dynamics*
- ***CalTech & MIT*** – FishEye AI

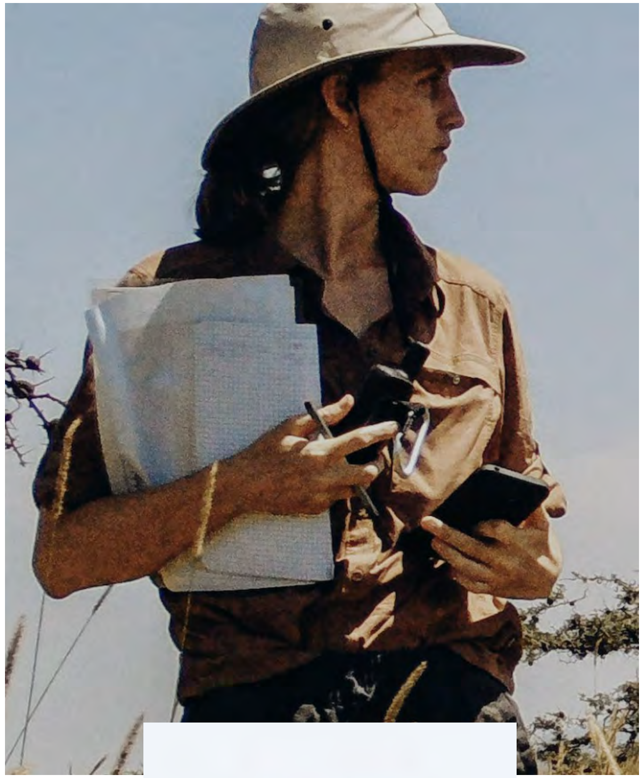


SONAR-Former Iron Gate Dam Footprint

SONAR - Abundance and Timing

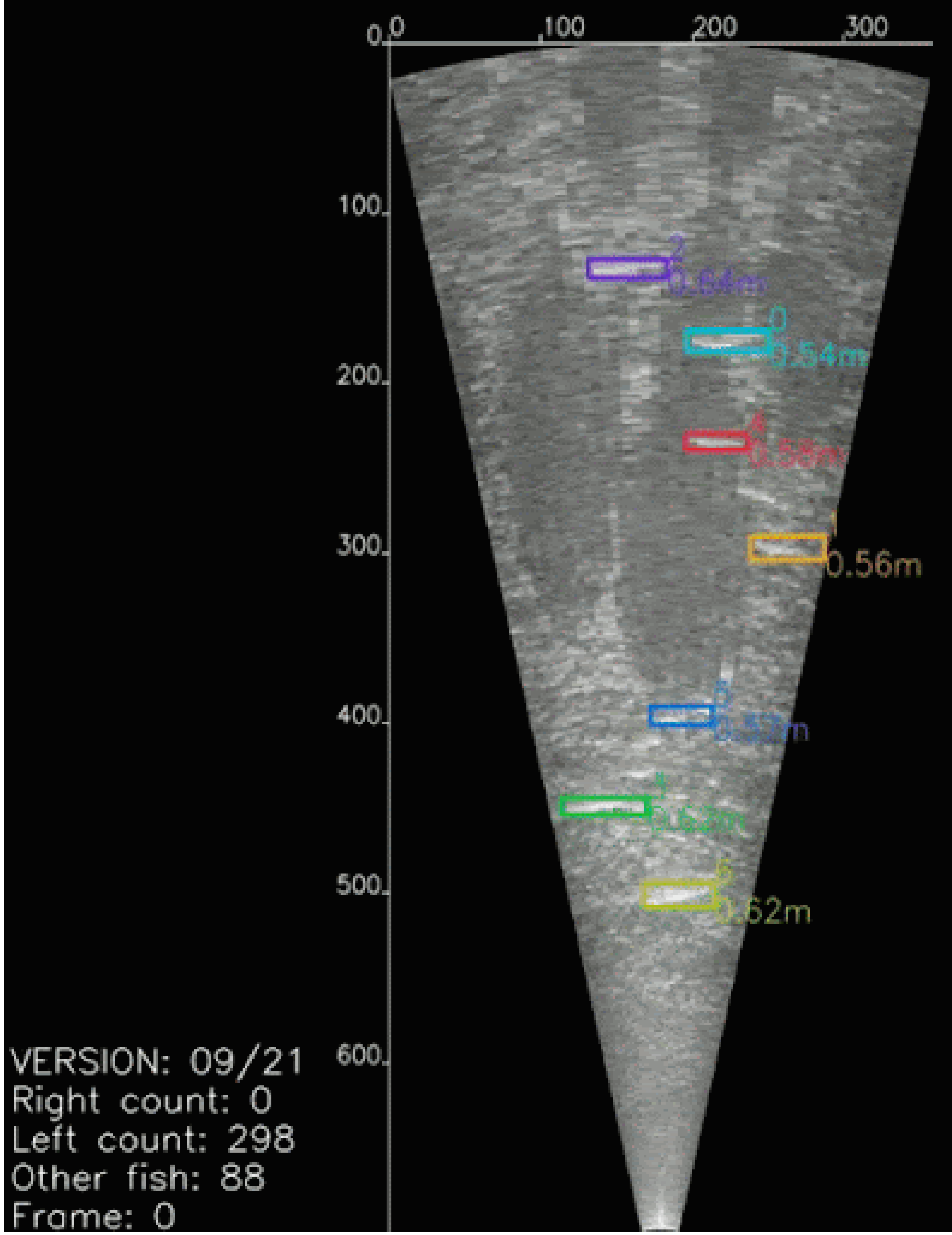


Improving Efficiency through Machine Learning

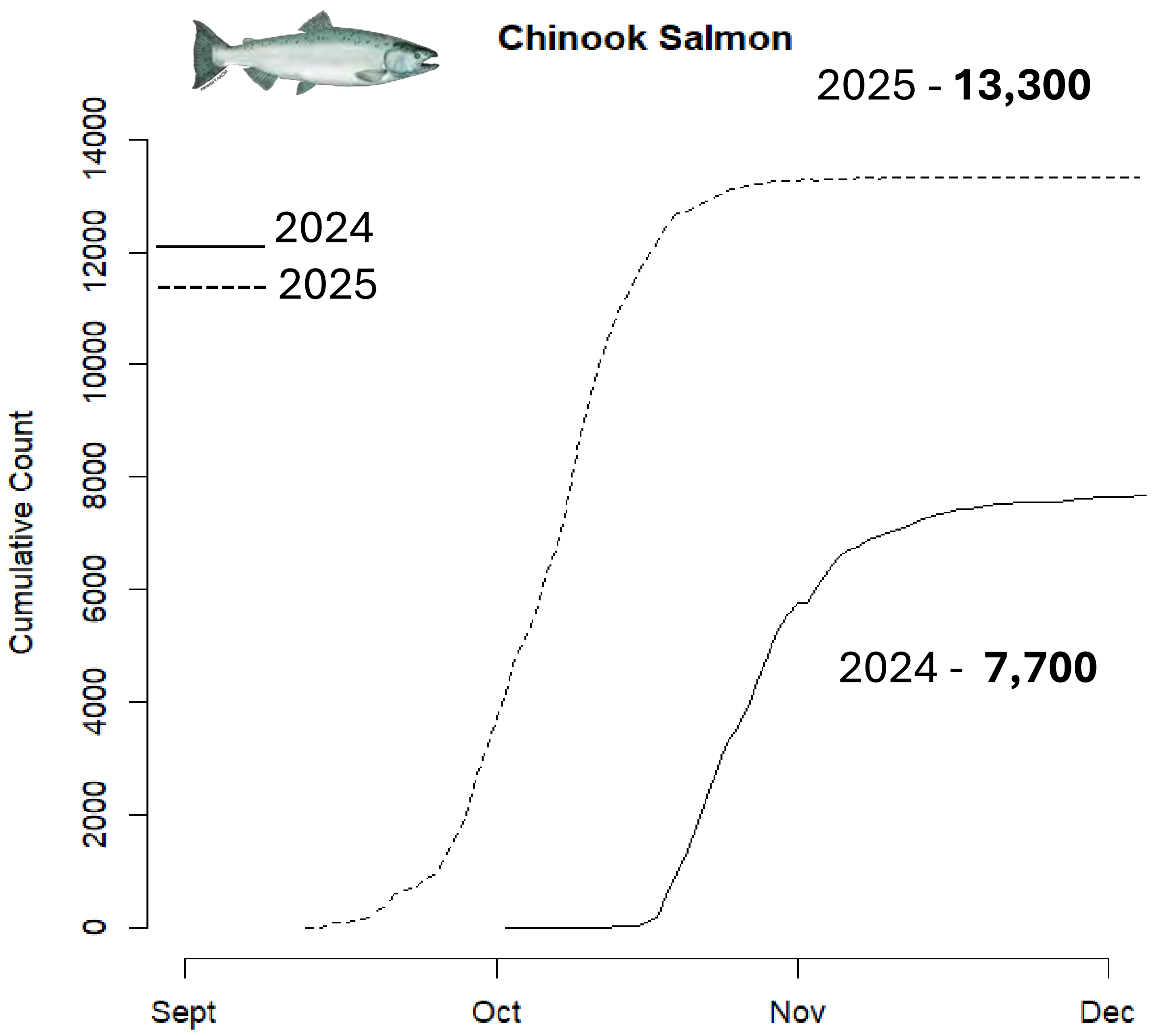


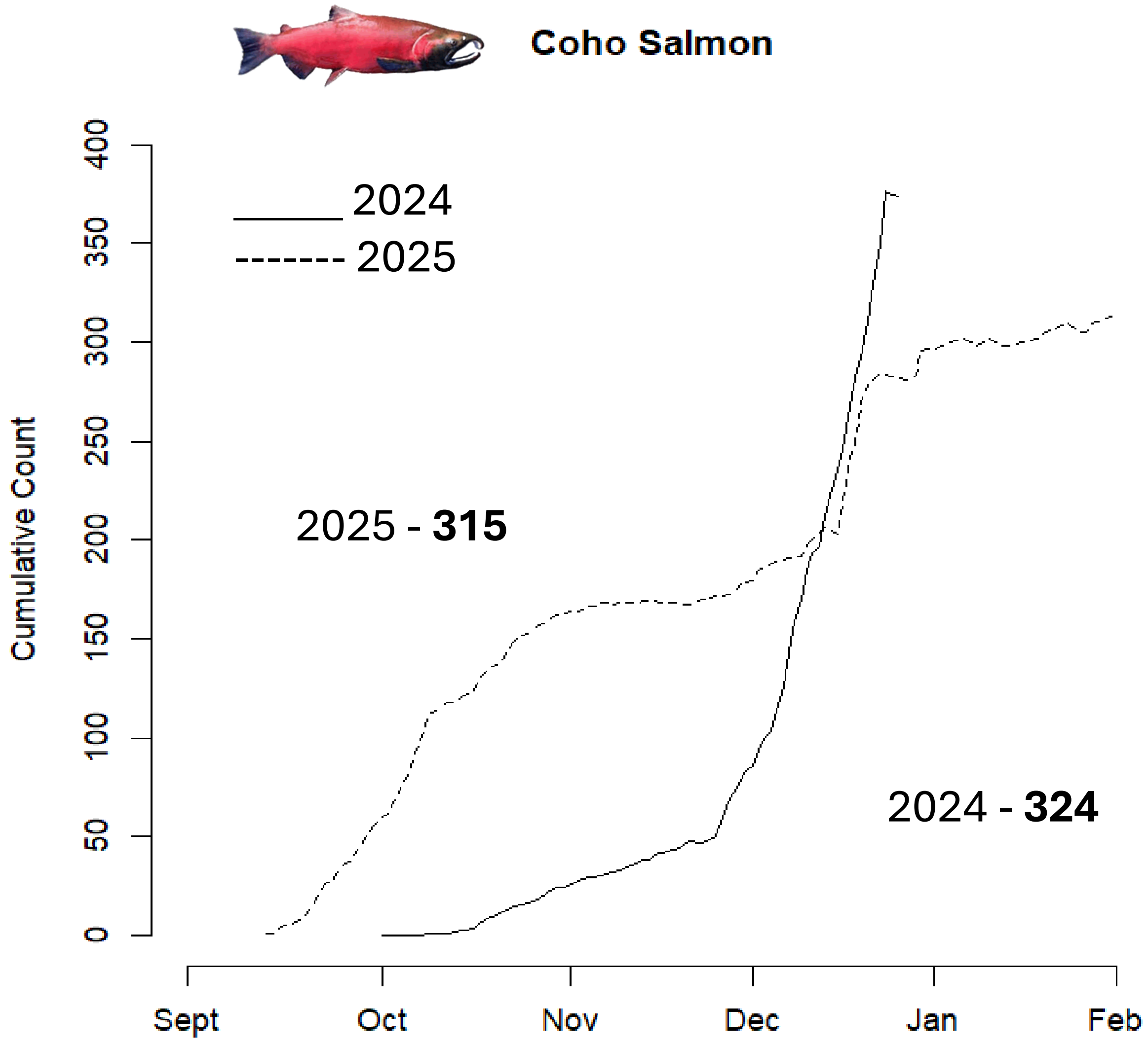
MIT

Caltech



2024/2025 Species Specific Abundance Estimates





Radio Telemetry and Netting for species apportionment and tag deployment

- Tangle netting - weekly
- Fish tagged with PIT and Archival Radio Telemetry Tags
- Scale, lipid and genetic samples
- Fixed radio receivers at 12 locations
- Mobile/Flight tracking
- Tagged Chinook Salmon, Coho Salmon, Steelhead


NRS
SCUBAPRO
SIMMS

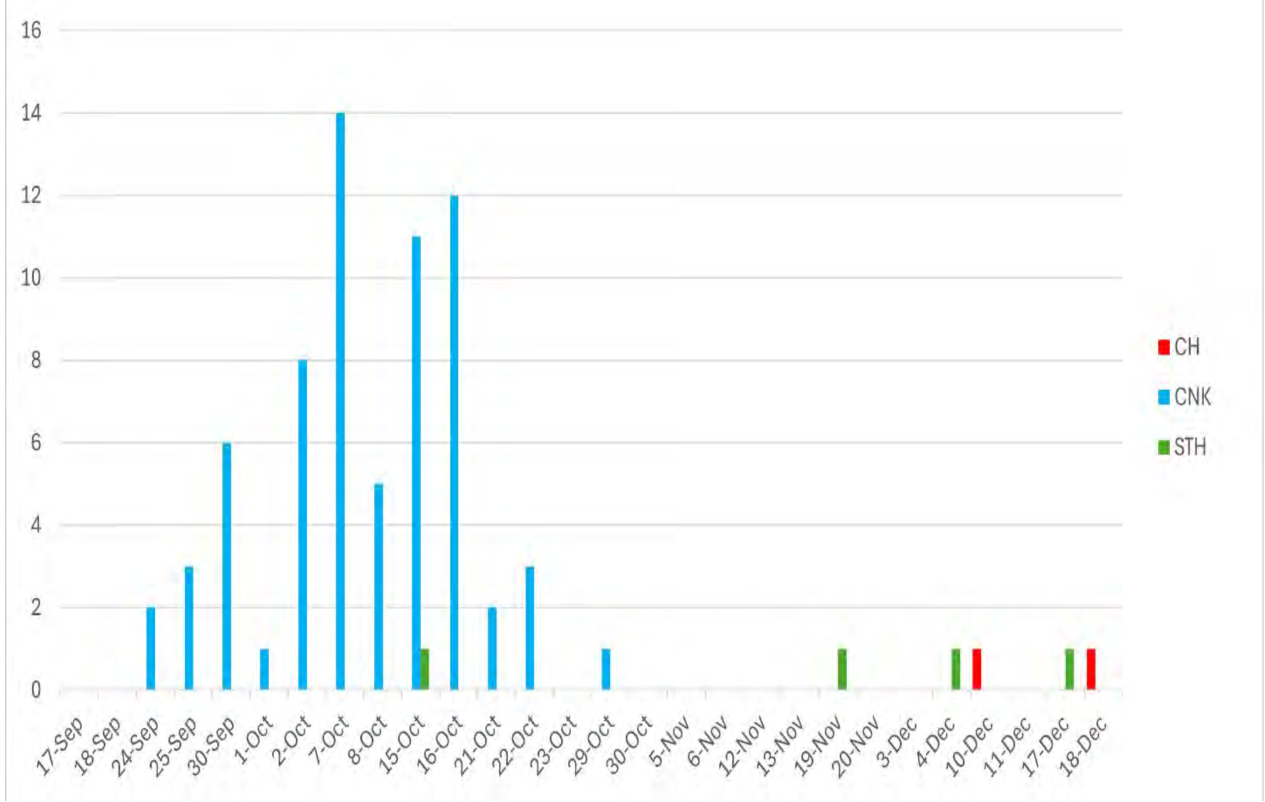
Netting Methods

Big improvement over last year

2025 catch summary

- 3 fishing days/week during October to maximize tag deployments
- 109 fish tagged from Sept 24, 2025 through Feb 4, 2026

- **CA**
  - 68 Chinook captured, 59 tagged (8 ad-clipped)
  - 2 Coho captured and tagged
  - 5 *O. mykiss* captured, 1 tagged
- **OR**
  - 44 Chinook captured and tagged
  - 3 O. mykiss tagged (likely residents)

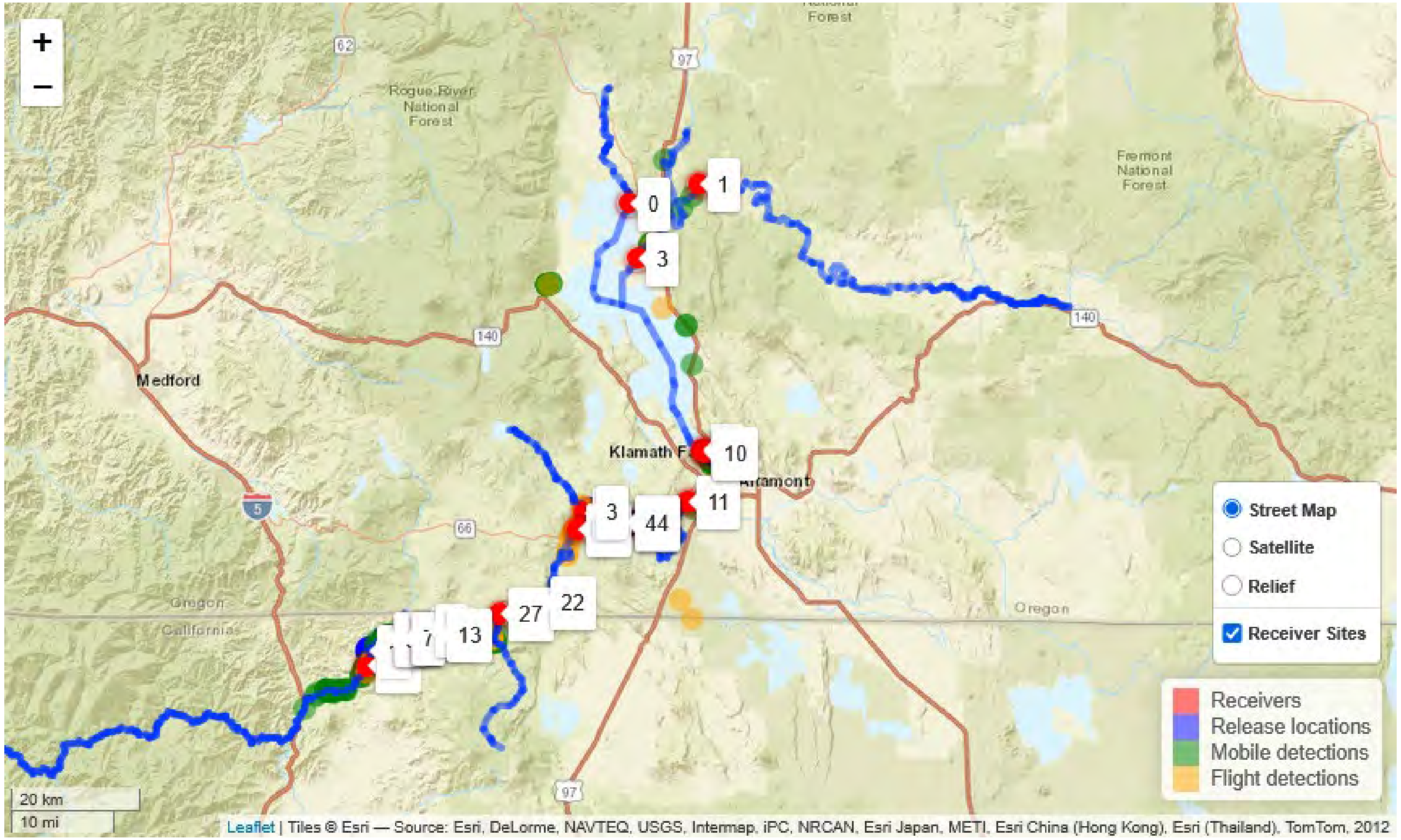


Radio Tagging

Radio Telemetry

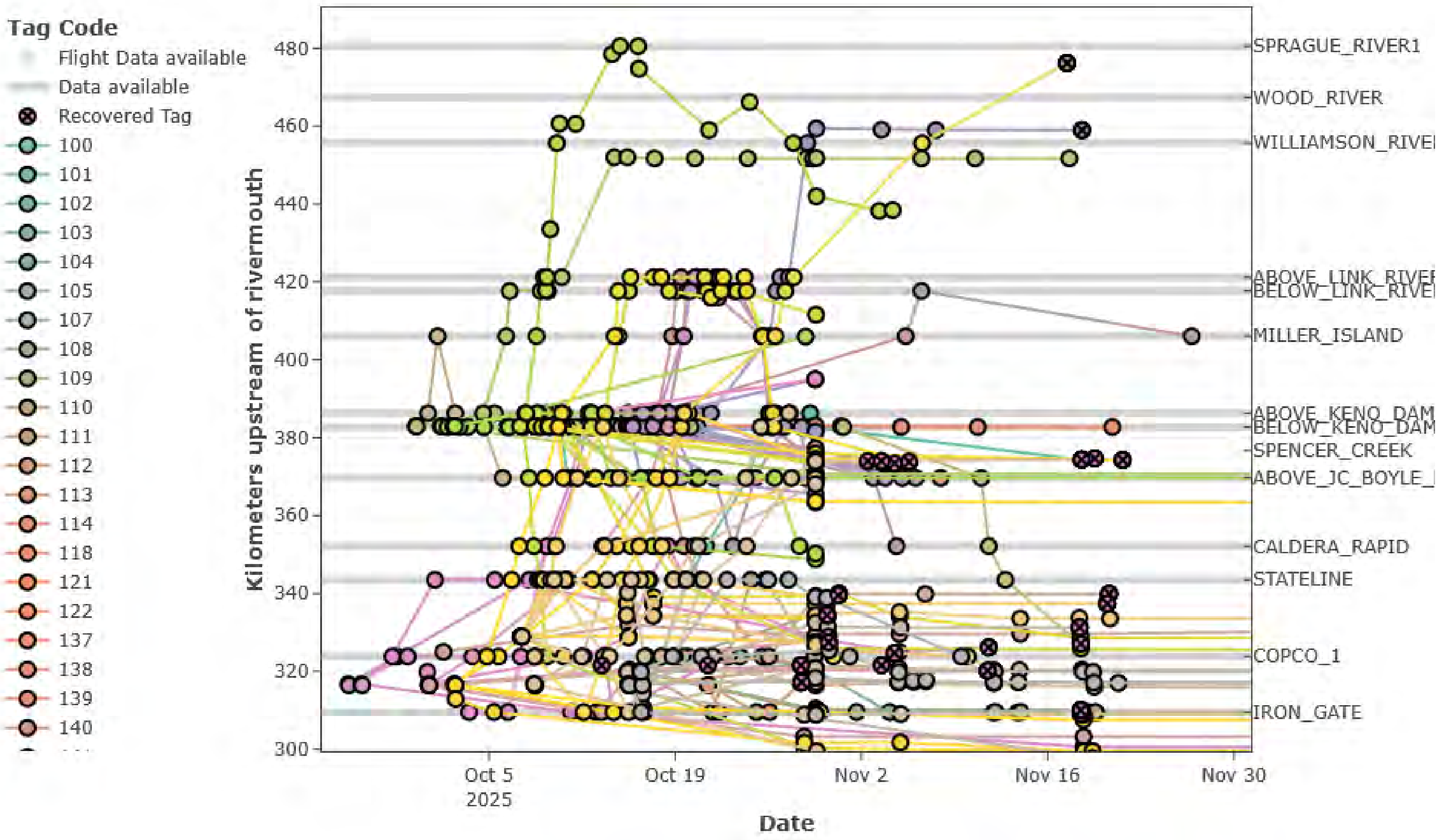
Tracking Fish in Real Time to Inform Monitoring and Management Efforts

Klamath Salmon Track



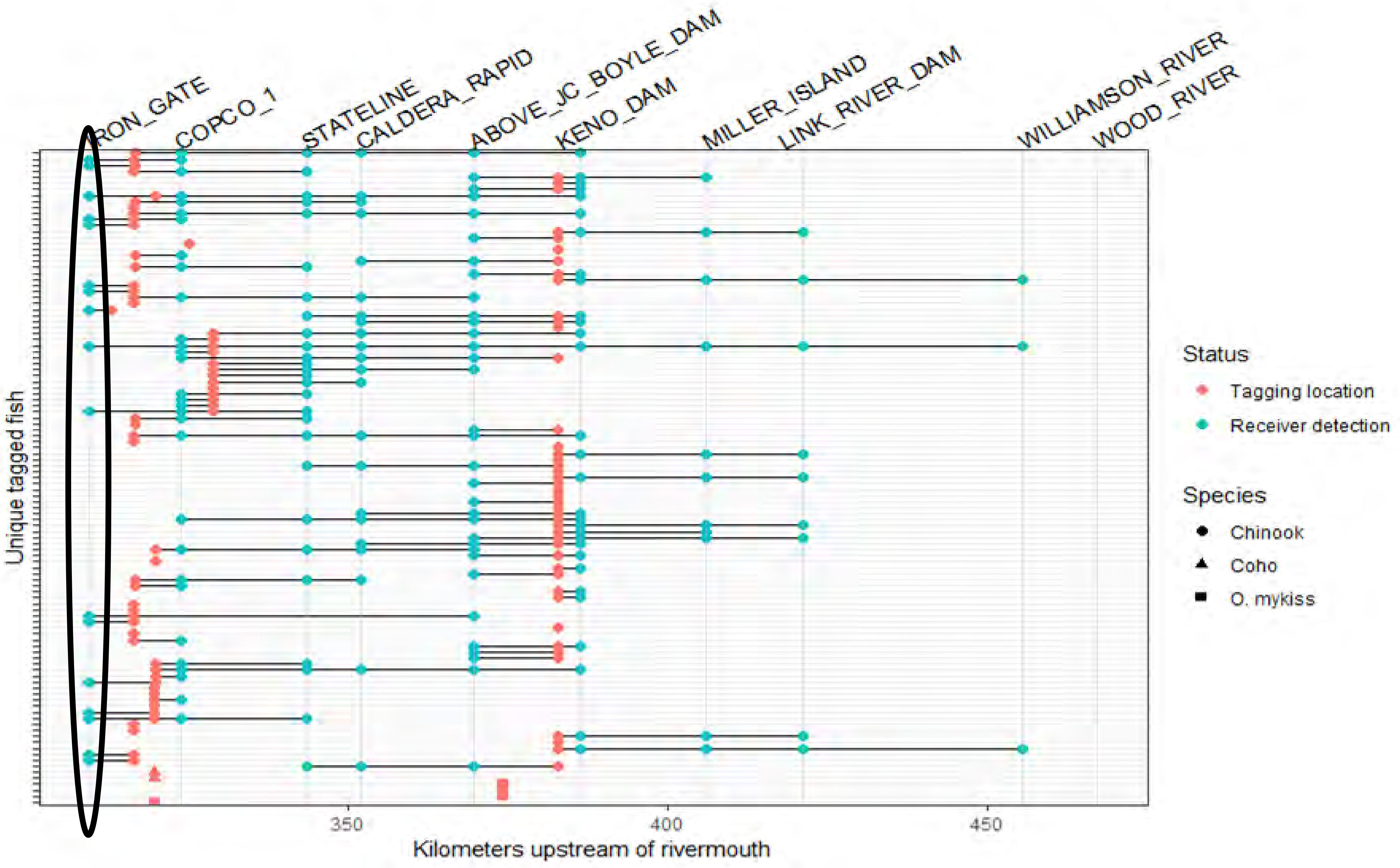
https://oceanview.pfeg.noaa.gov/KlamathSalmonTrack/

Tracking Fish in Real Time to Inform monitoring and Management Efforts



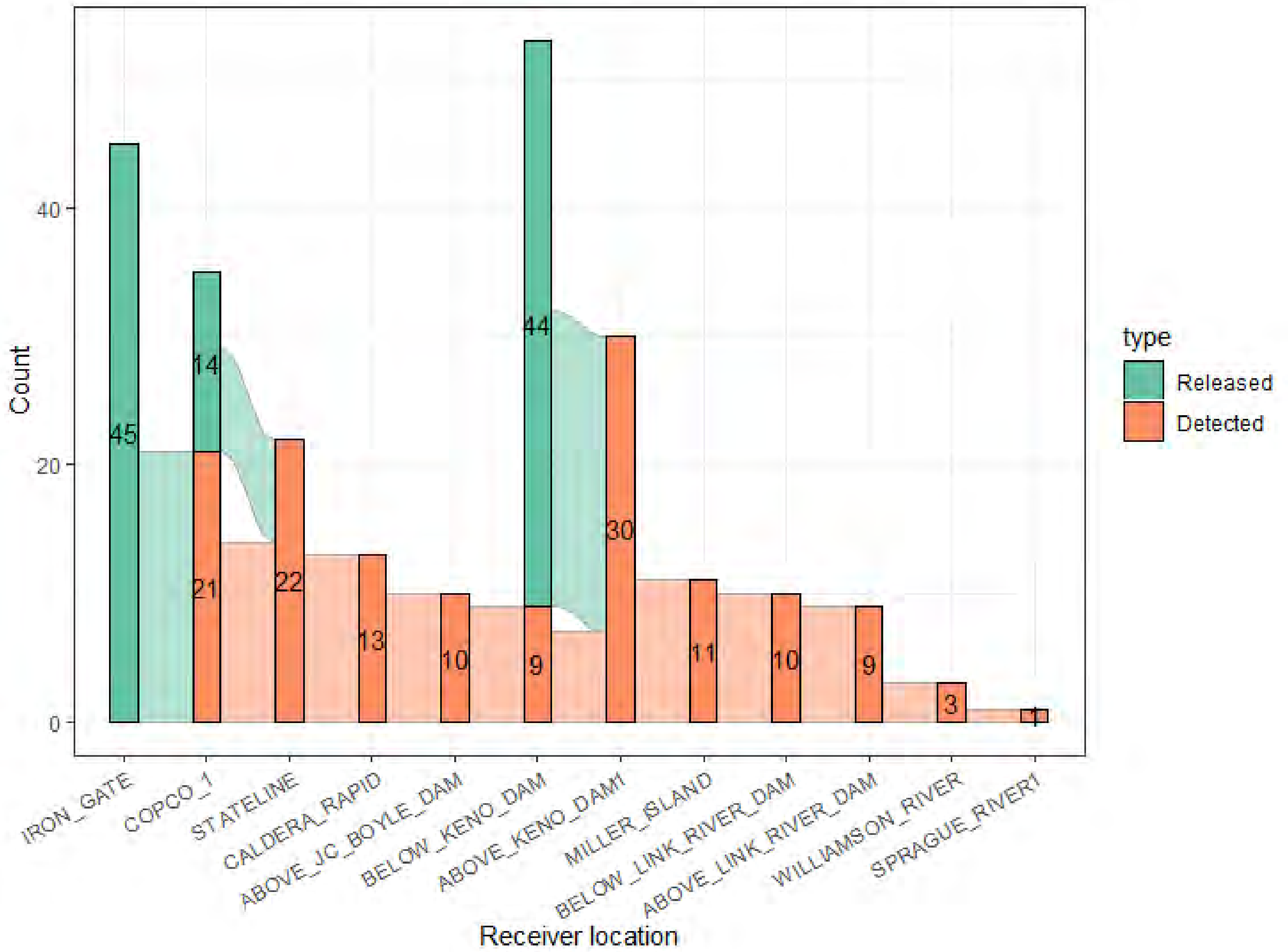
109 fish tagged out of >13,300 seen on the SONAR (0.7%)

Distance traveled



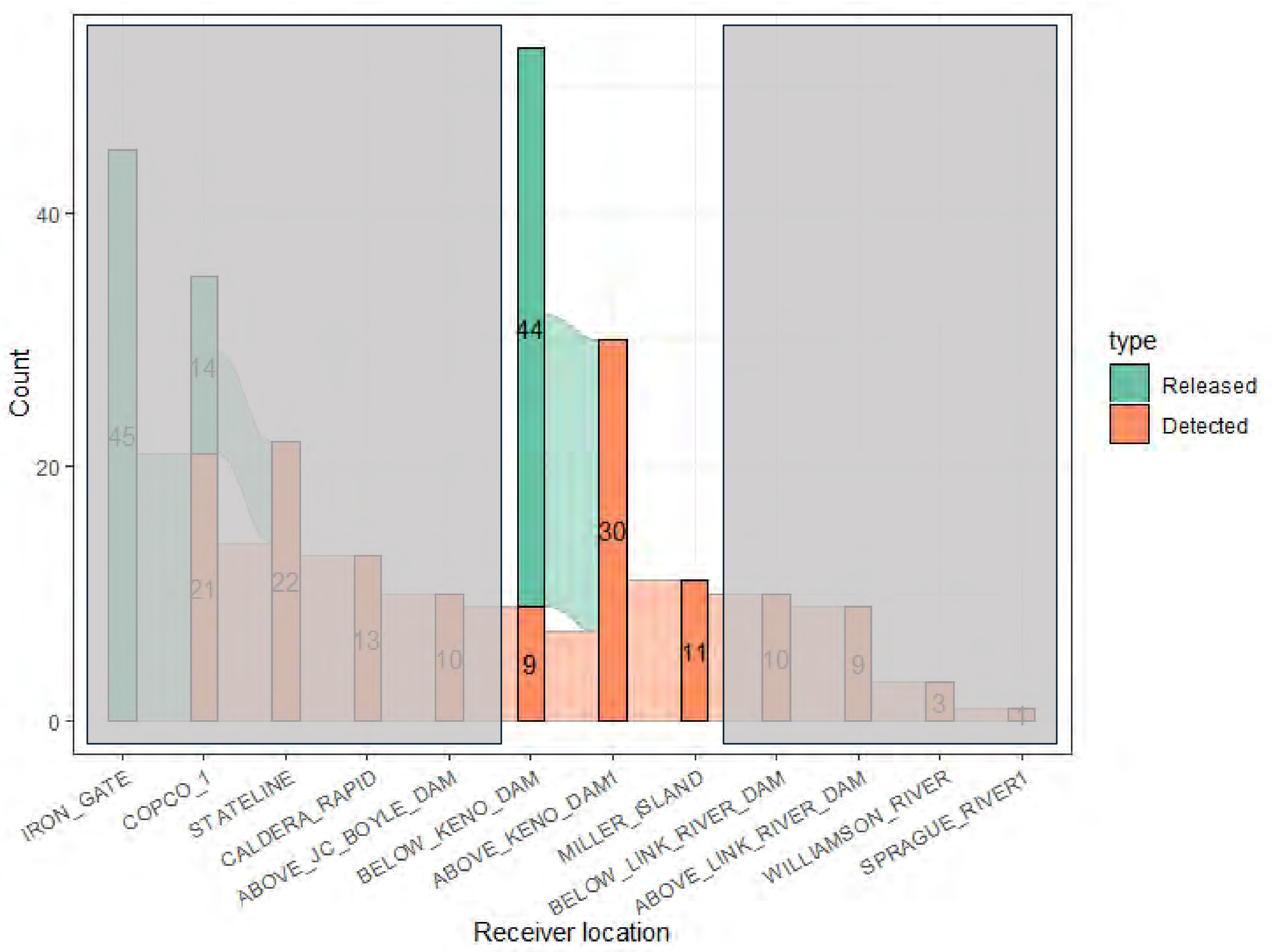
Fish Upstream Passage

- Fish passage through different reaches indicated some chokepoints
- Chokepoints could be due to migratory physical and water quality barriers, but could also be due to fish recruiting to spawning habitat and tributaries
- “Fall-back” leads to ~half of tagged fish not progressing to next receiver site



Fish Passage at Fish Ladders - Keno

- 30 of the 53 fish (56.6%) that were detected or released just downstream of Keno Dam were detected above it
- 11 of the 53 fish (21%) detected downstream of Keno were detected at Miller Island
- Recently tagged and released fish exhibited some “fall-back”, which may bias this rate of passage



Keno Impoundment Reach

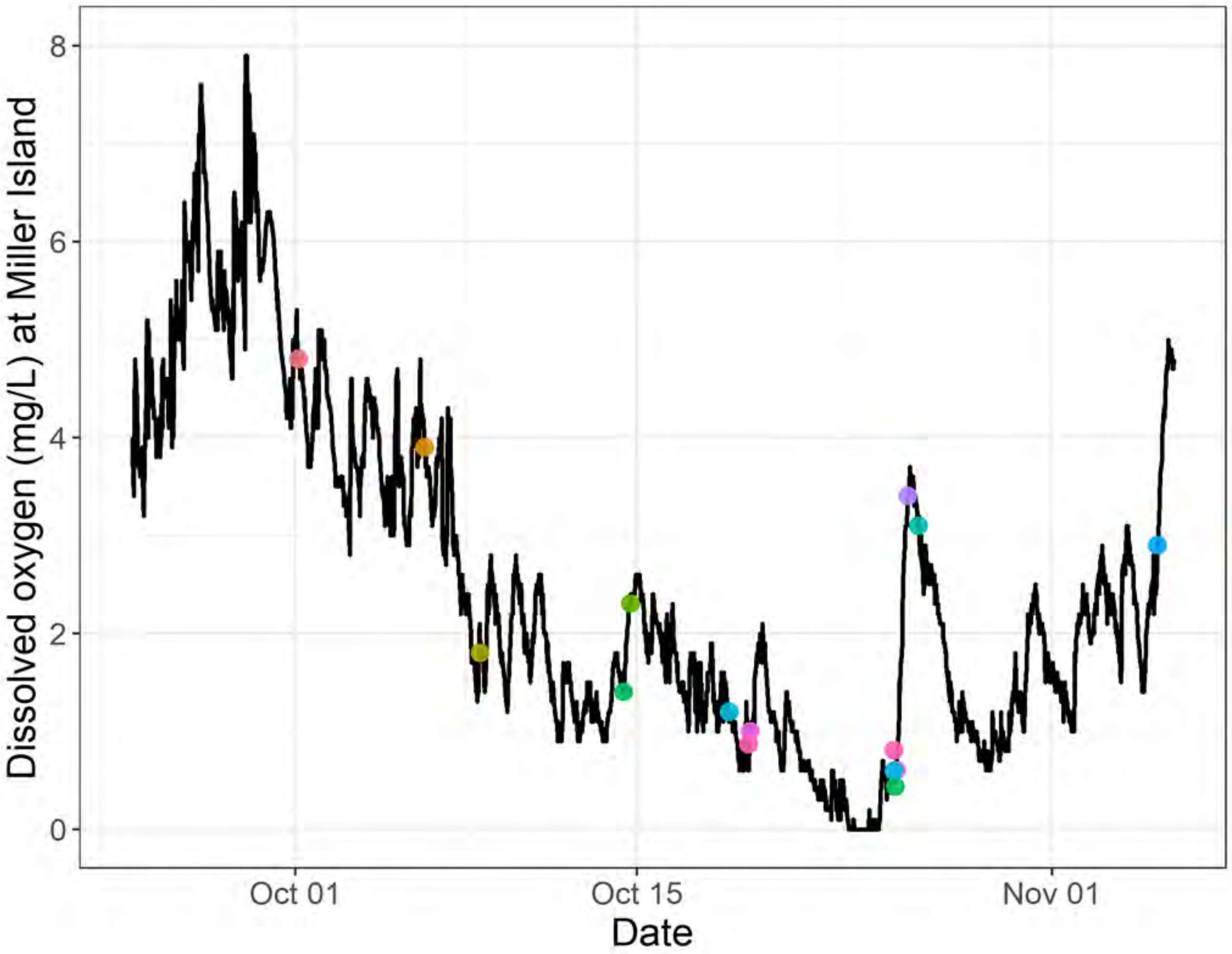
- 11 of the 30 fish detected above Keno were detected at Miller Island (36.7%).
- This section had very low DO values
- 2 fish were detected in agricultural ditches

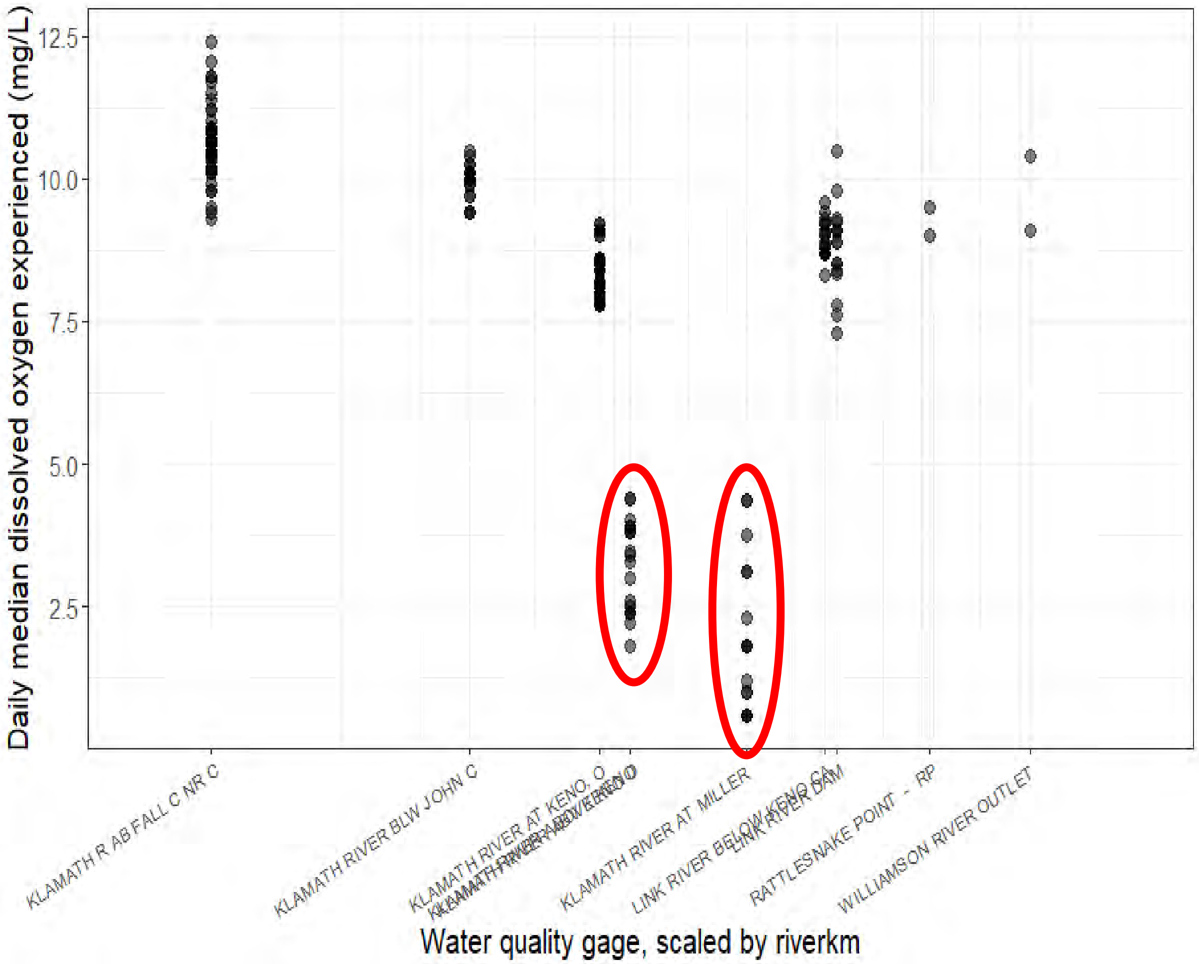
October 21, 2025

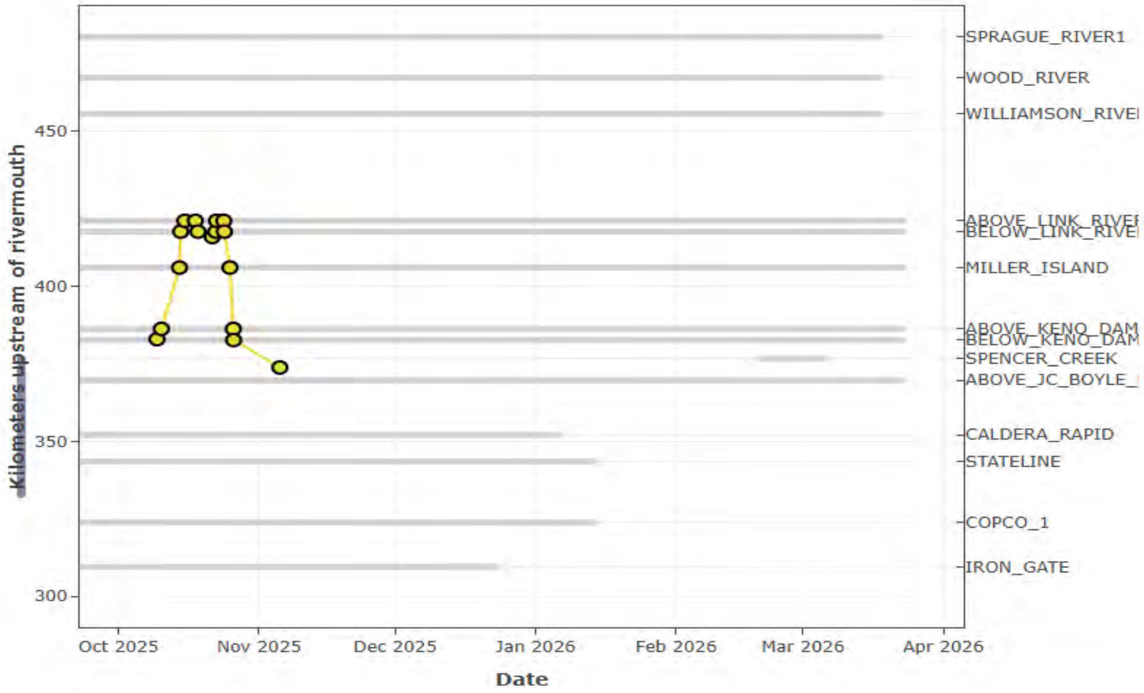
Salmon Sightings in Klamath Drainage District Emphasize Urgency for Fish Screens

Ignored for years, KDD's call for protection for family farms and fish becomes urgent with Chinook spotted in canal.

Water quality conditions experienced - dissolved oxygen






Kilometers upstream of rivermouth
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300
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WILLIAMSON_RIVEI
ABOVE_LINK_RIVEI
BELOW_LINK_RIVEI
MILLER_ISLAND
ABOVE_KENO_DAM
BELOW_KENO_DAM
SPENCER_CREEK
ABOVE_JC_BOYLE_
CALDERA_RAPID
STATELINE
COPCO_1
IRON_GATE
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Nov 2025
Dec 2025
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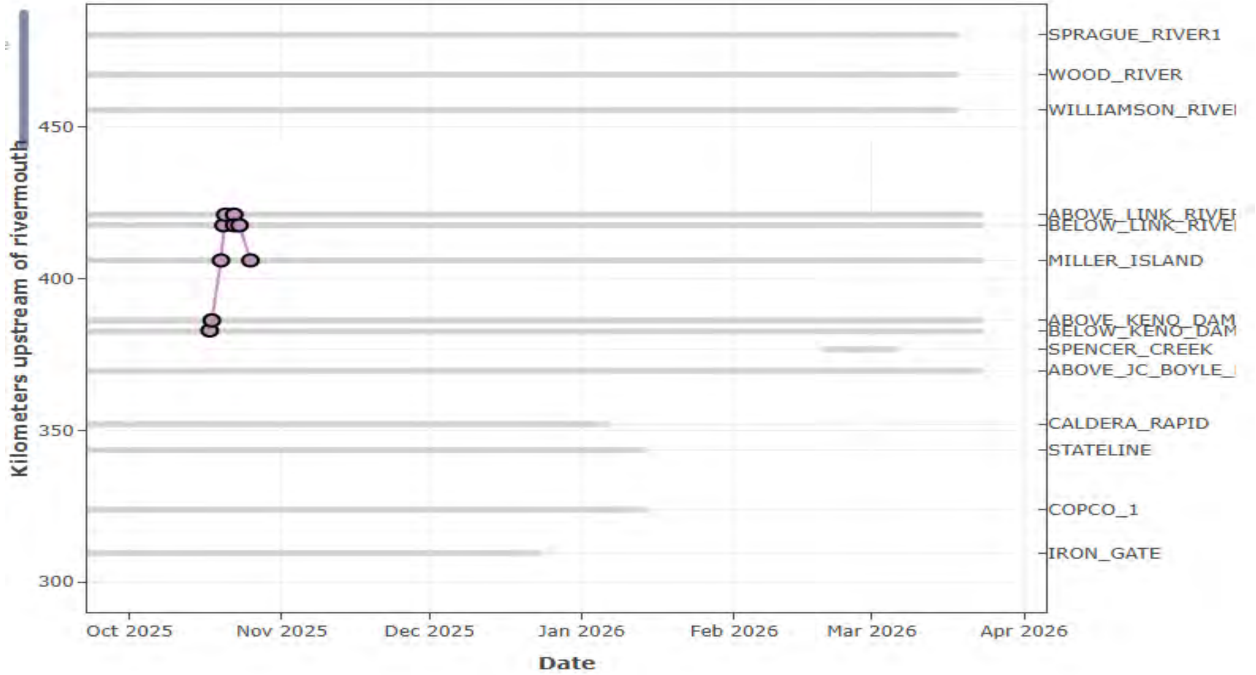
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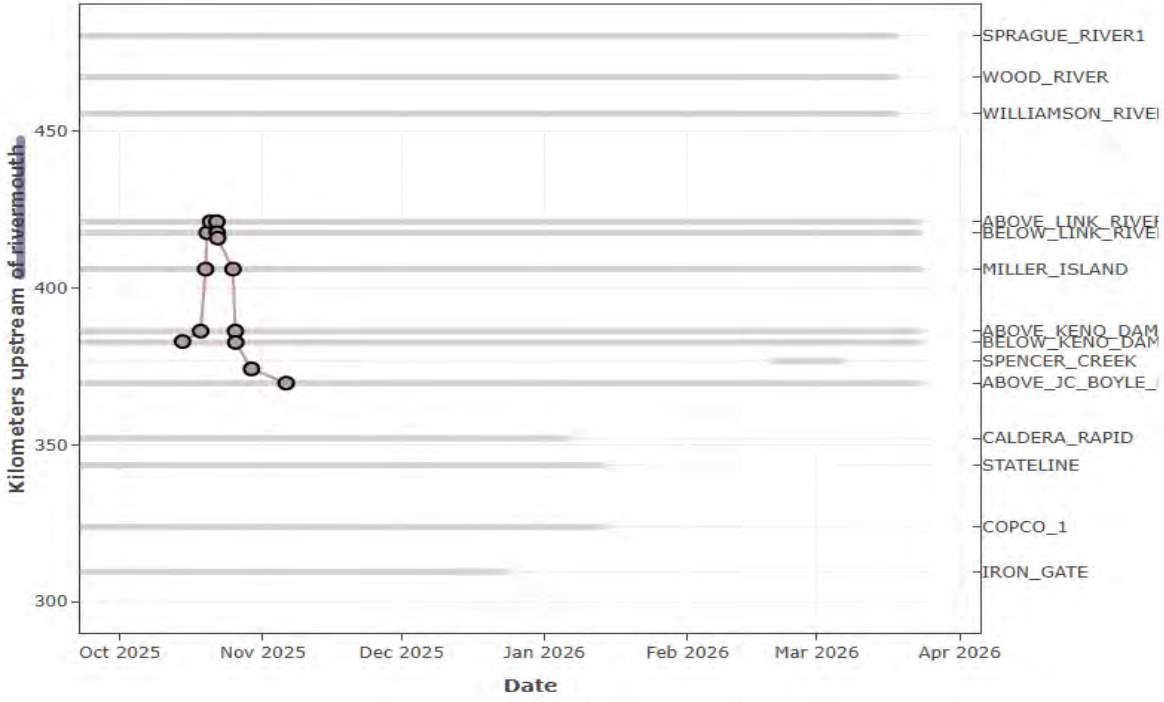
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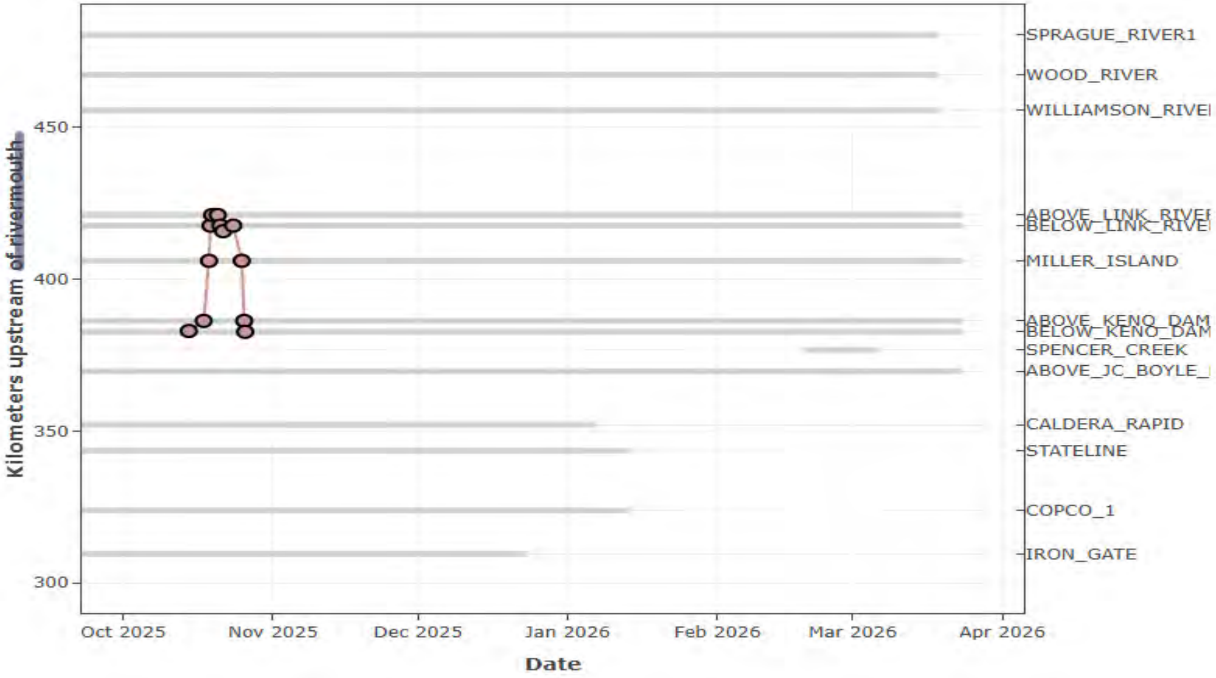
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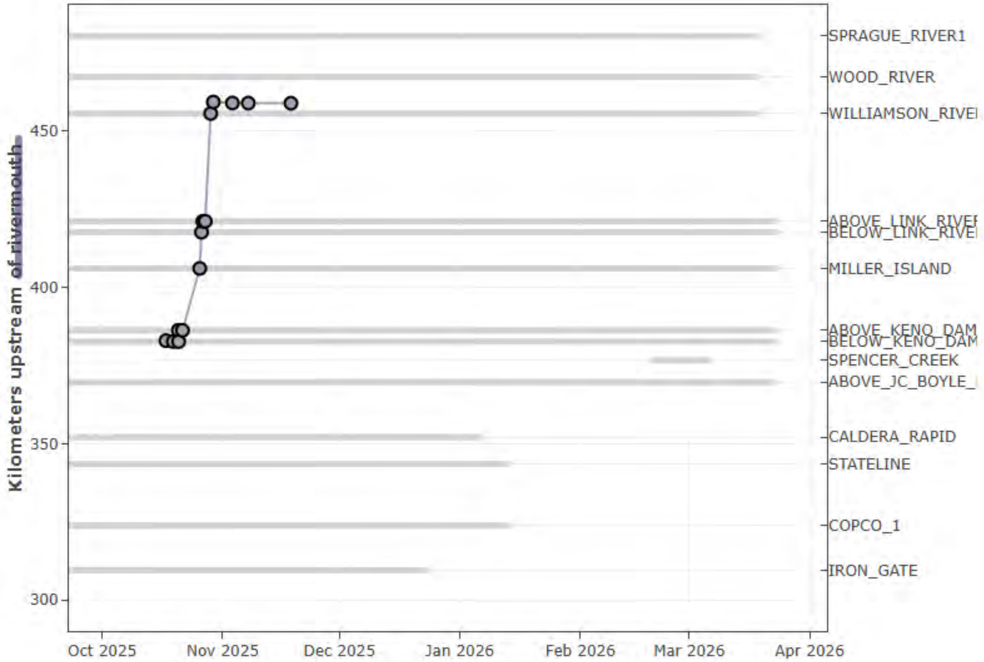
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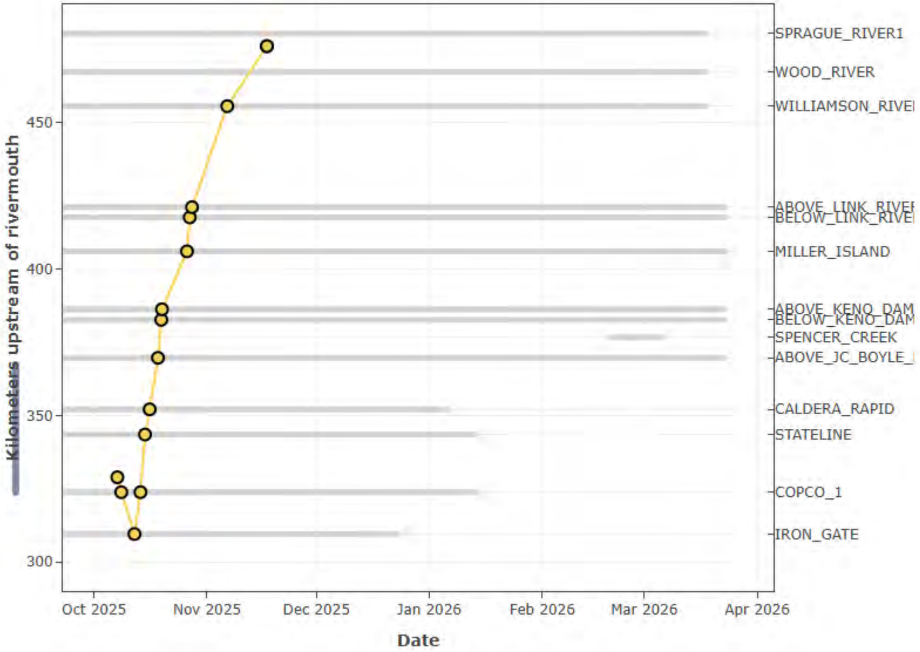
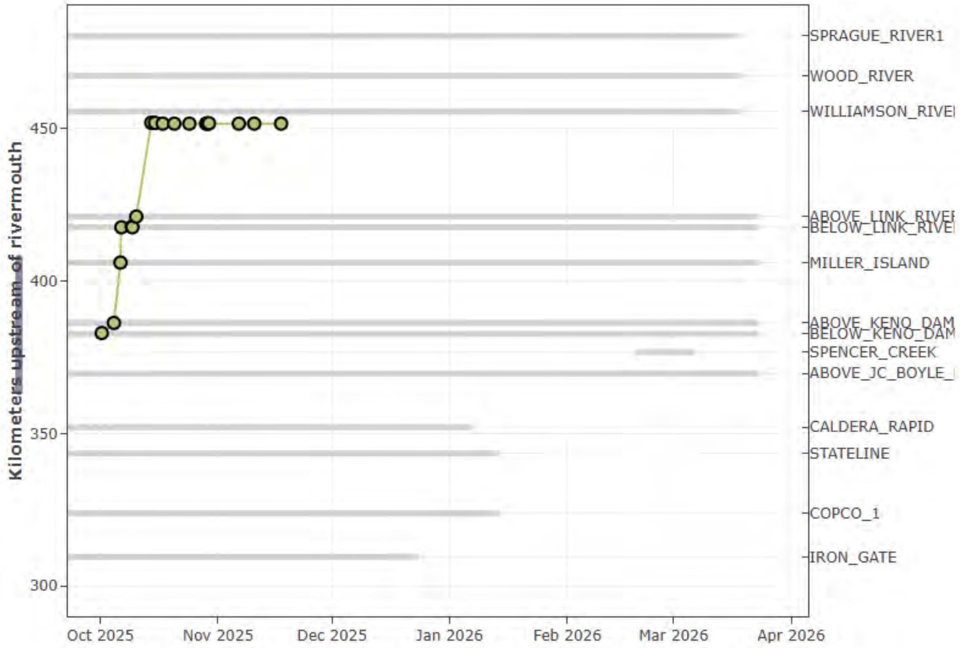
Mar 2026
Apr 2026


Kilometers upstream of rivermouth
450
400
350
300
SPRAGUE_RIVER1
WOOD_RIVER
WILLIAMSON_RIVEI
ABOVE_LINK_RIVEI
BELOW_LINK_RIVEI
MILLER_ISLAND
ABOVE_KENO_DAM
BELOW_KENO_DAM
SPENCER_CREEK
ABOVE_JC_BOYLE_
CALDERA_RAPID
STATELINE
COPCO_1
IRON_GATE
Oct 2025
Nov 2025
Dec 2025
Jan 2026
Feb 2026
Mar 2026
Apr 2026


Kilometers upstream of rivermouth
450
400
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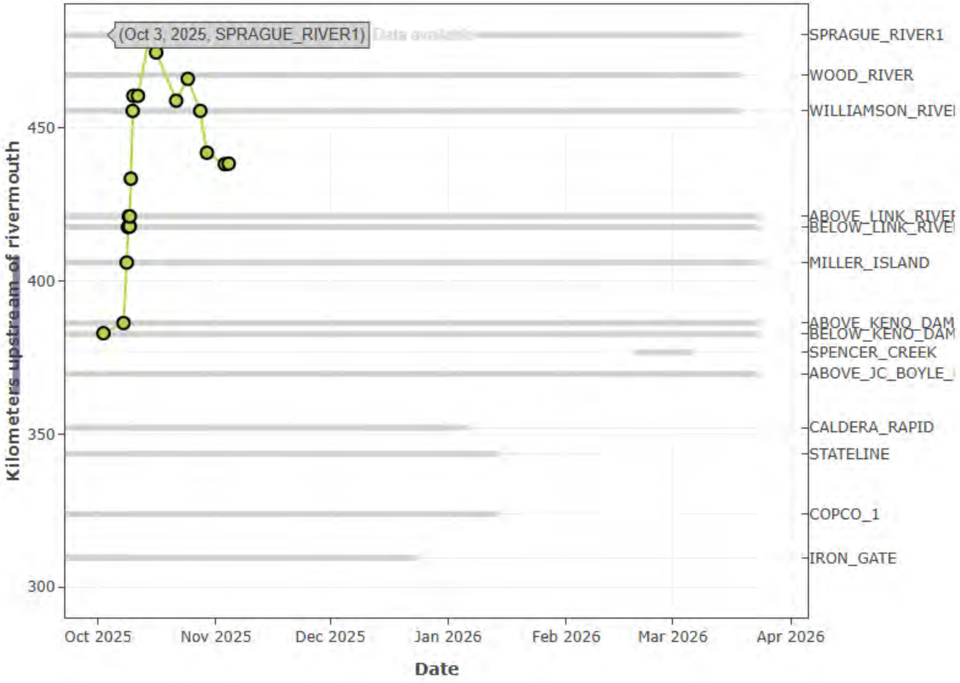
SPRAGUE_RIVER1
WOOD_RIVER
WILLIAMSON_RIVEI
ABOVE_LINK_RIVEI
BELOW_LINK_RIVEI
MILLER_ISLAND
ABOVE_KENO_DAM
BELOW_KENO_DAM
SPENCER_CREEK
ABOVE_JC_BOYLE_
CALDERA_RAPID
STATELINE
COPCO_1
IRON_GATE
Oct 2025
Nov 2025
Dec 2025
Jan 2026
Feb 2026
Mar 2026
Apr 2026
Date


(Oct 3, 2025, SPRAGUE_RIVER1)
Kilometers upstream of rivermouth
450
400
350
300
SPRAGUE_RIVER1
WOOD_RIVER
WILLIAMSON_RIVEI
ABOVE_LINK_RIVEI
BELOW_LINK_RIVEI
MILLER_ISLAND
ABOVE_KENO_DAM
BELOW_KENO_DAM
SPENCER_CREEK
ABOVE_JC_BOYLE_
CALDERA_RAPID
STATELINE
COPCO_1
IRON_GATE
Oct 2025
Nov 2025
Dec 2025
Jan 2026
Feb 2026
Mar 2026
Apr 2026
Date

Summary

- SONAR and radio telemetry is crucial for management, restoration and future monitoring efforts.
- It takes a very large, diverse, intelligent and dedicated team to work across the reconnected Klamath River at this scale.
- Keno and Link River dams pass fish but we also observed migration delays.
- Diversions in the Keno impoundment reach have been shown to entrain fish and future restoration efforts should aim to prevent entrainment.

Questions?

Project Funders

U.S. FISH & WILDLIFE SERVICE
DEPARTMENT OF THE INTERIOR

HUMBOLDT AREA FOUNDATION

Wild Rivers
COMMUNITY FOUNDATION

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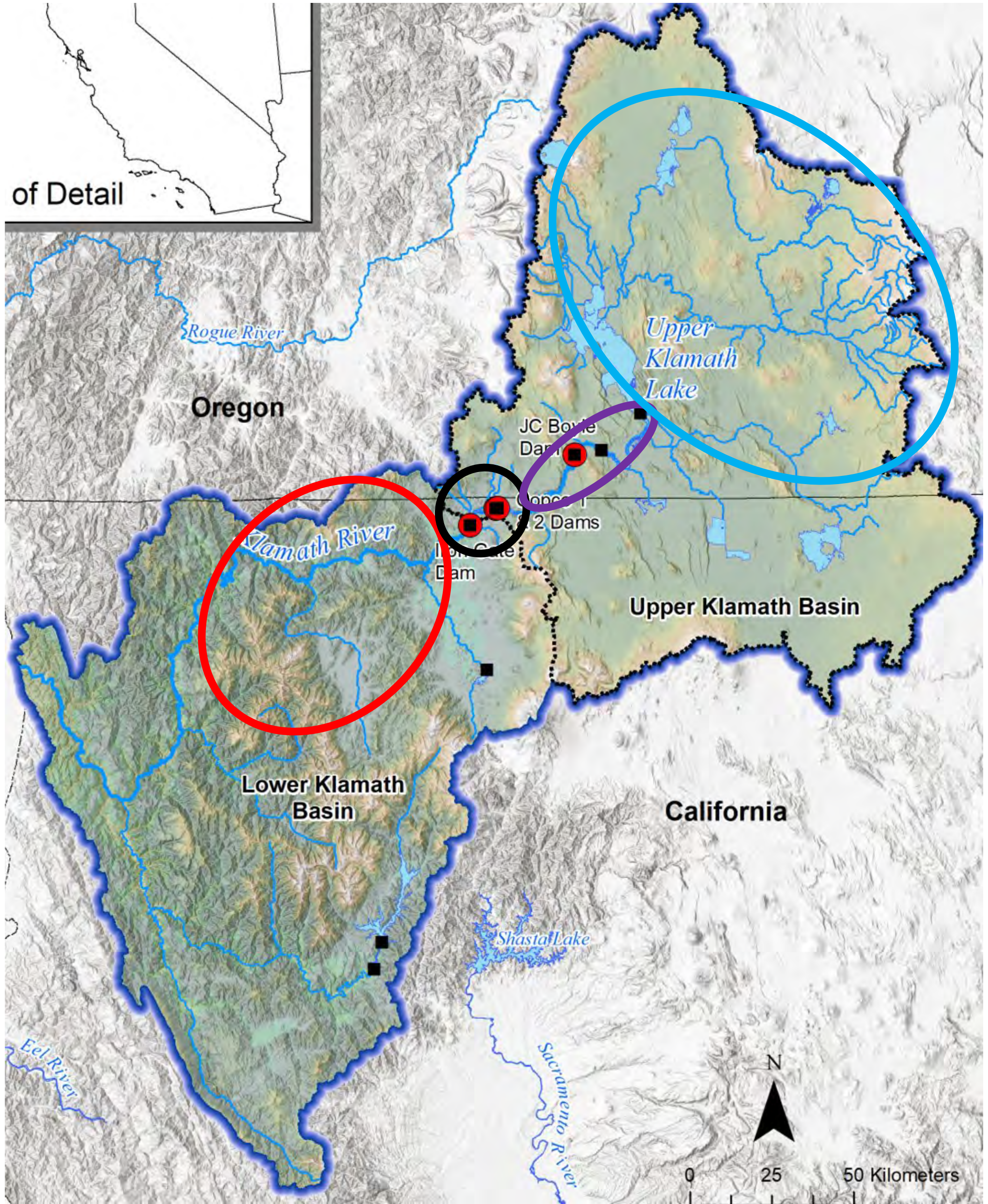
CATENA
FOUNDATION

Complementary Monitoring Designs for Adult Salmon



Current Monitoring efforts - ~350 – 400 additional miles of habitat

Karuk/USFS/MKWC/CDFW – carcass and redd surveys – lower and mid Klamath tributaries

Karuk/Yurok/USFWS – Mainstem carcass and redd surveys - Iron Gate to Wingate Bar

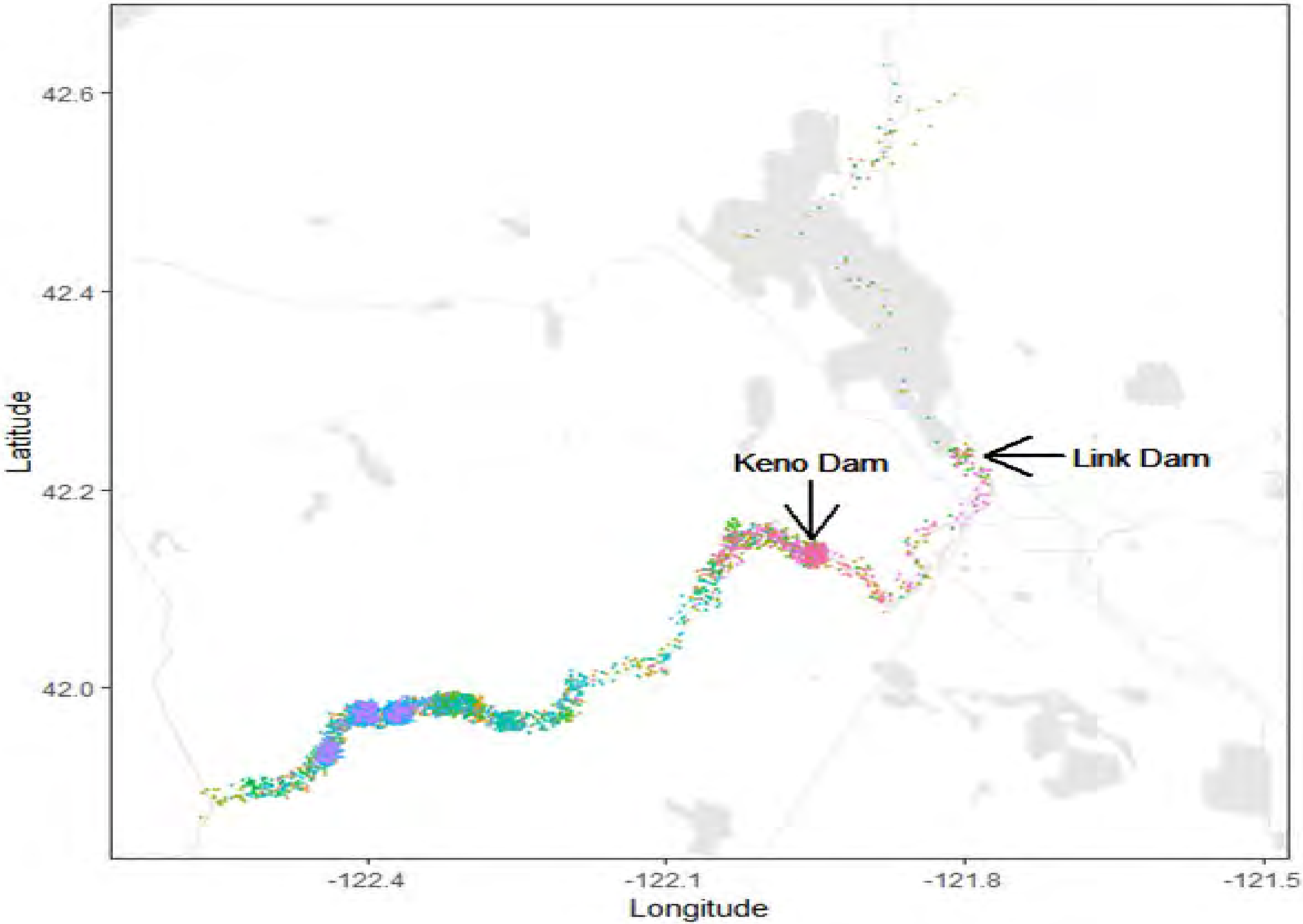
CDFW– Carcass, redd surveys and video weirs – 4 tributaries in the Reservoir Reach

ODFW – Mainstem carcass/redd surveys Keno to Stateline, video weir on Spencer Creek, and cameras on Keno and Link ladders

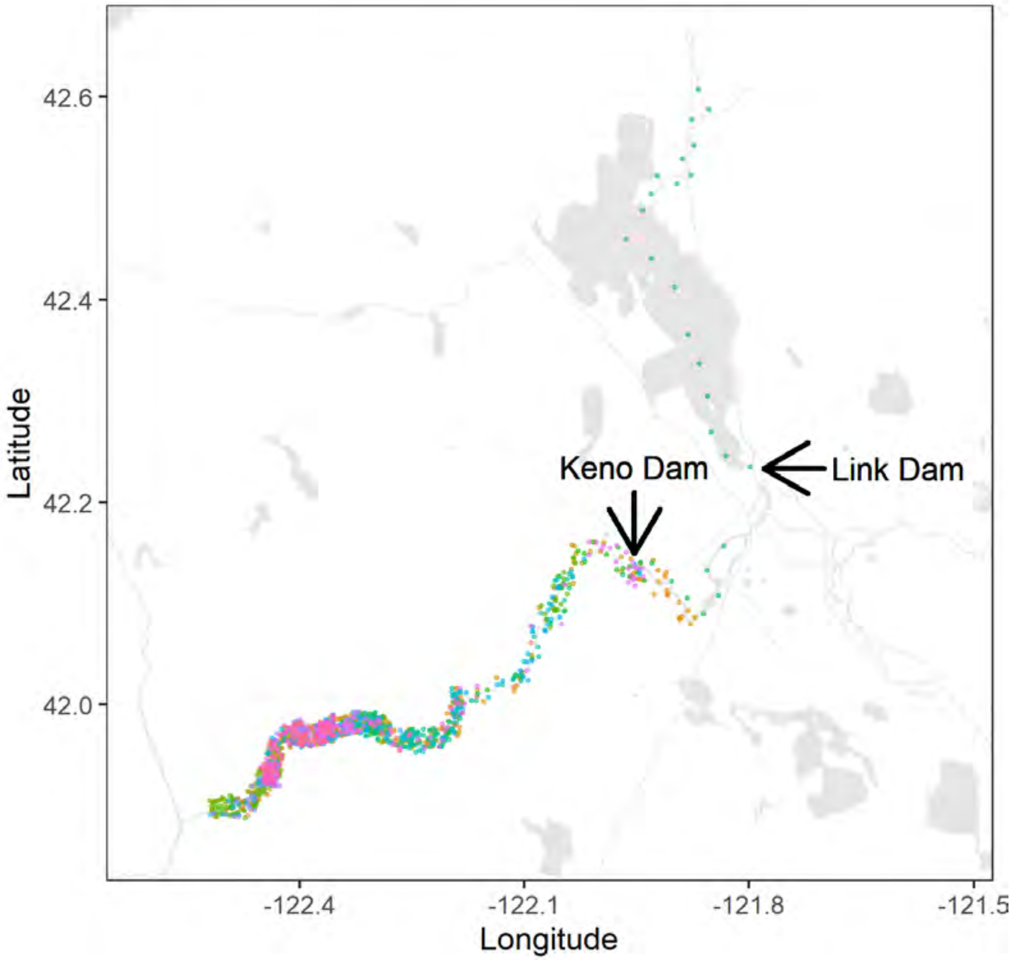
Klamath Tribes – Carcass/redd surveys Williamson, Wood and Sprague Rivers

Where are they spending the most time?

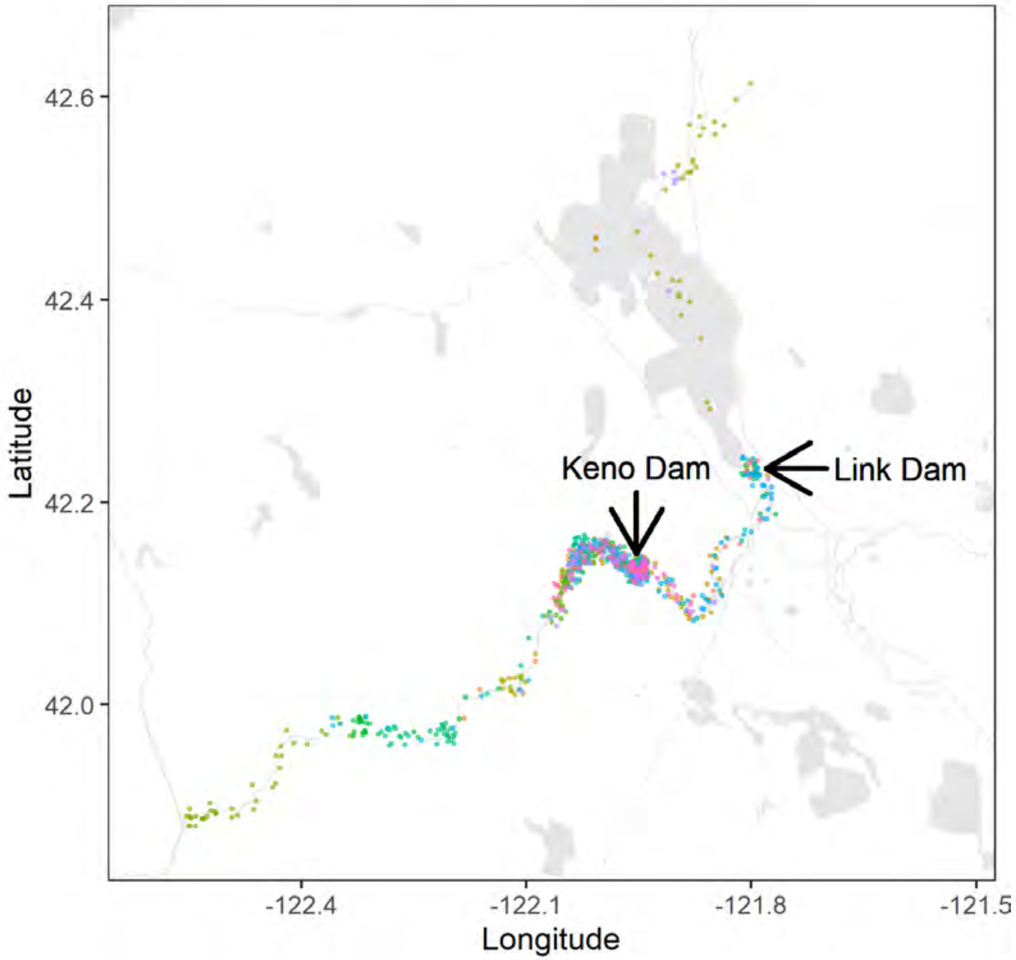
- Each point represents a unique fish on a unique day, colored by individual
- A lot of fish on the spawning grounds of the former Iron Gate and Copco reservoirs
- A lot of fish at Keno Dam



Movement of tagged fall Chinook

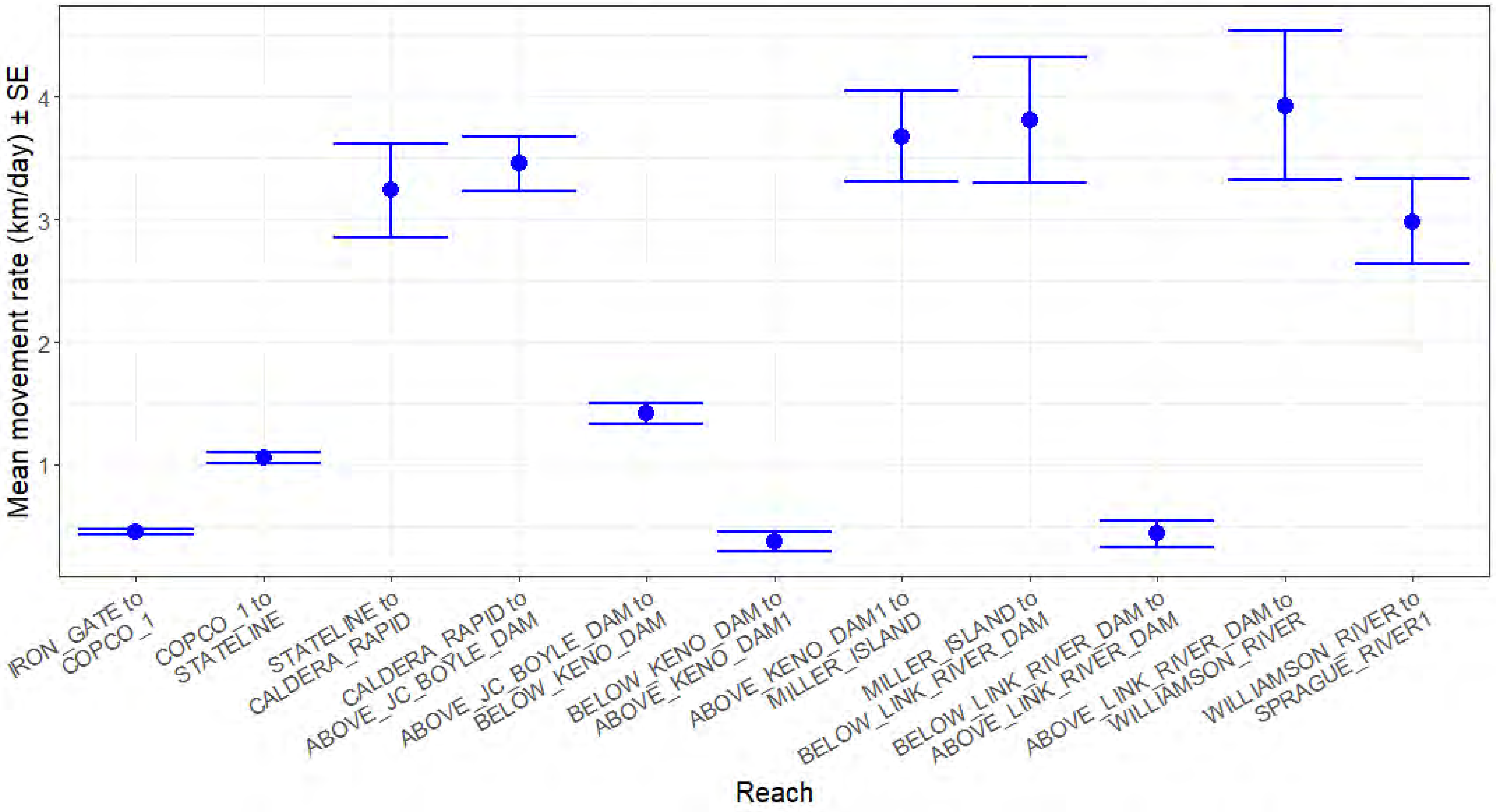


California-tagged fish

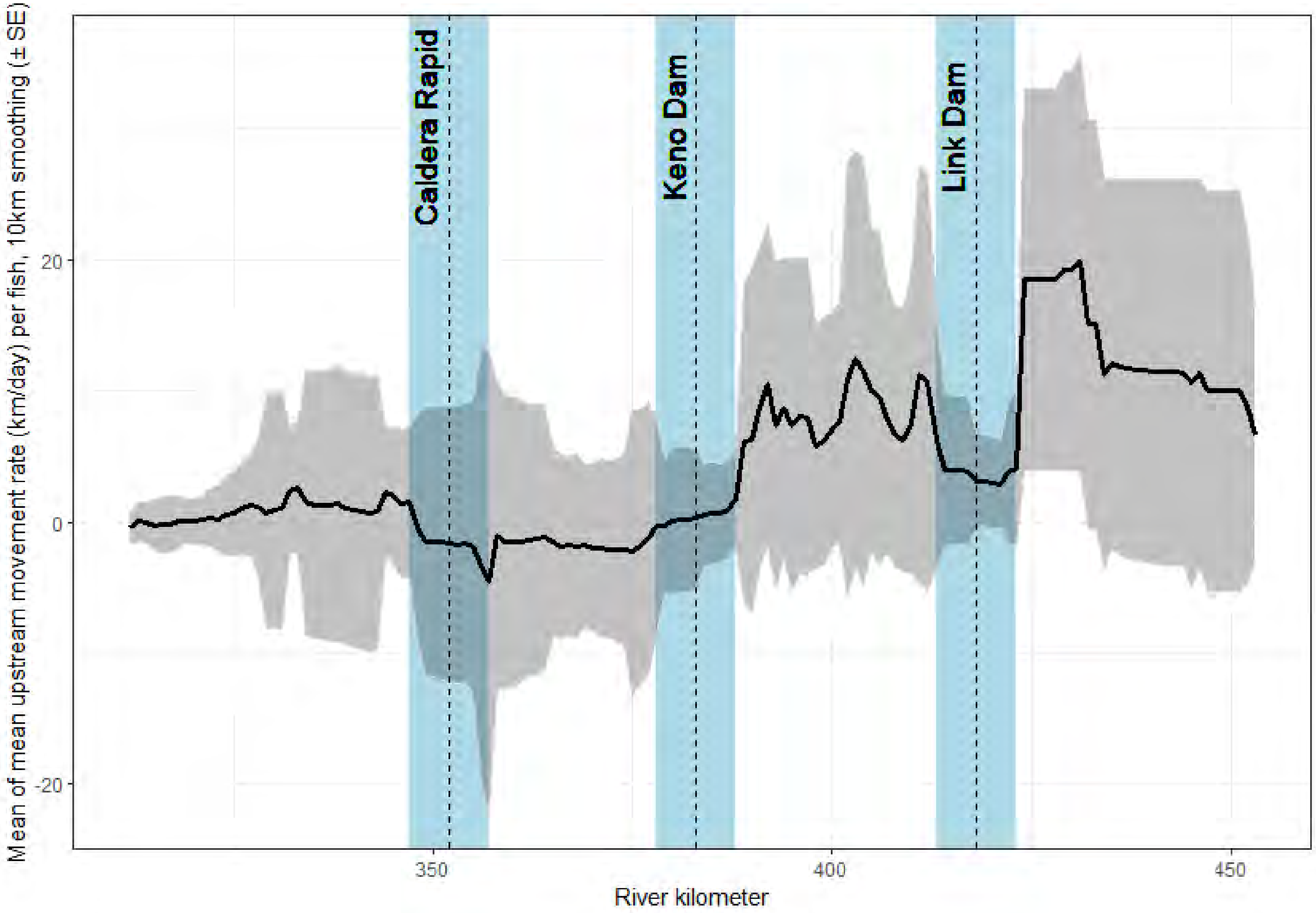


Oregon-tagged fish

Unique Movement Patterns

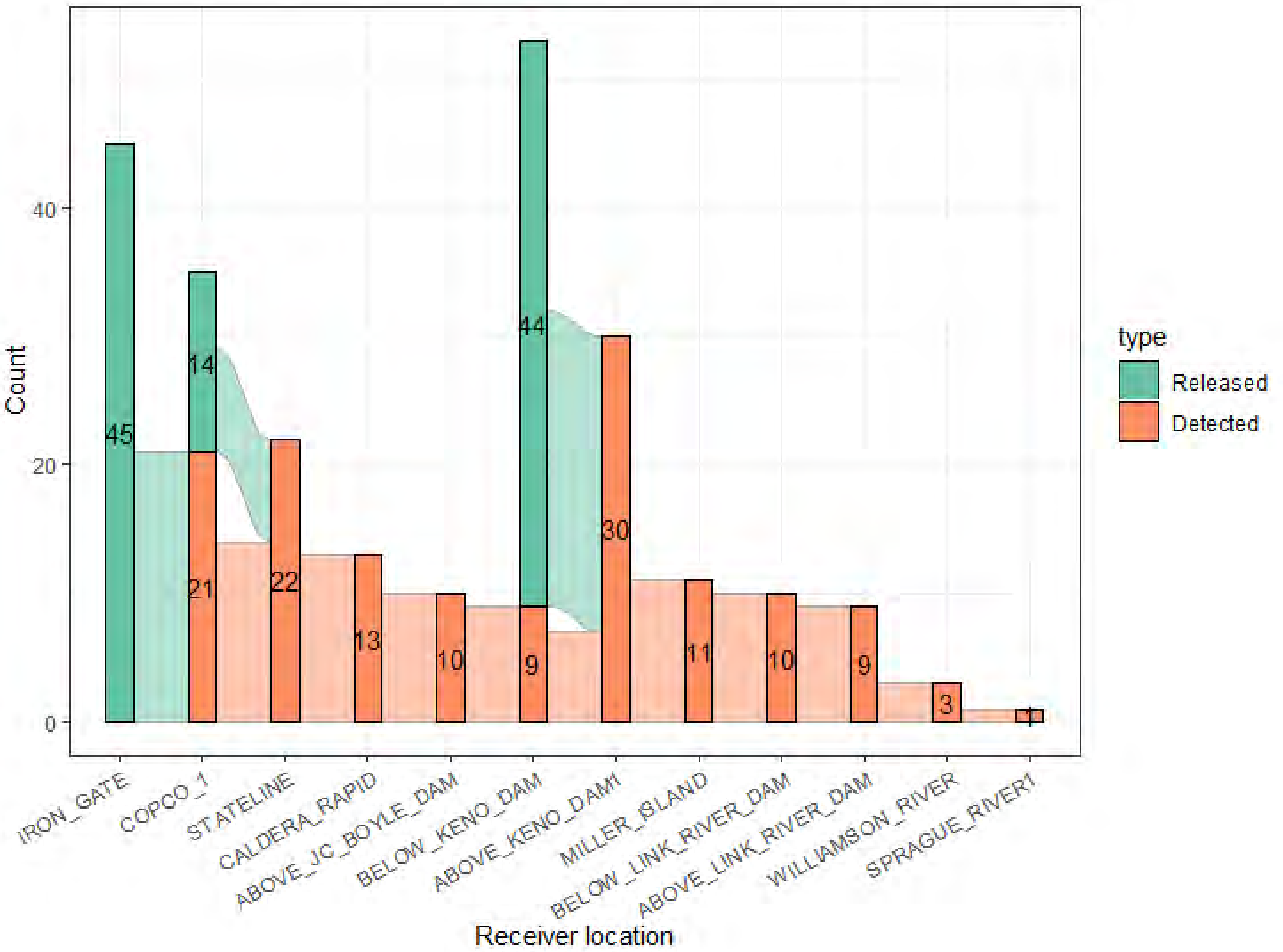


Unique Movement Patterns



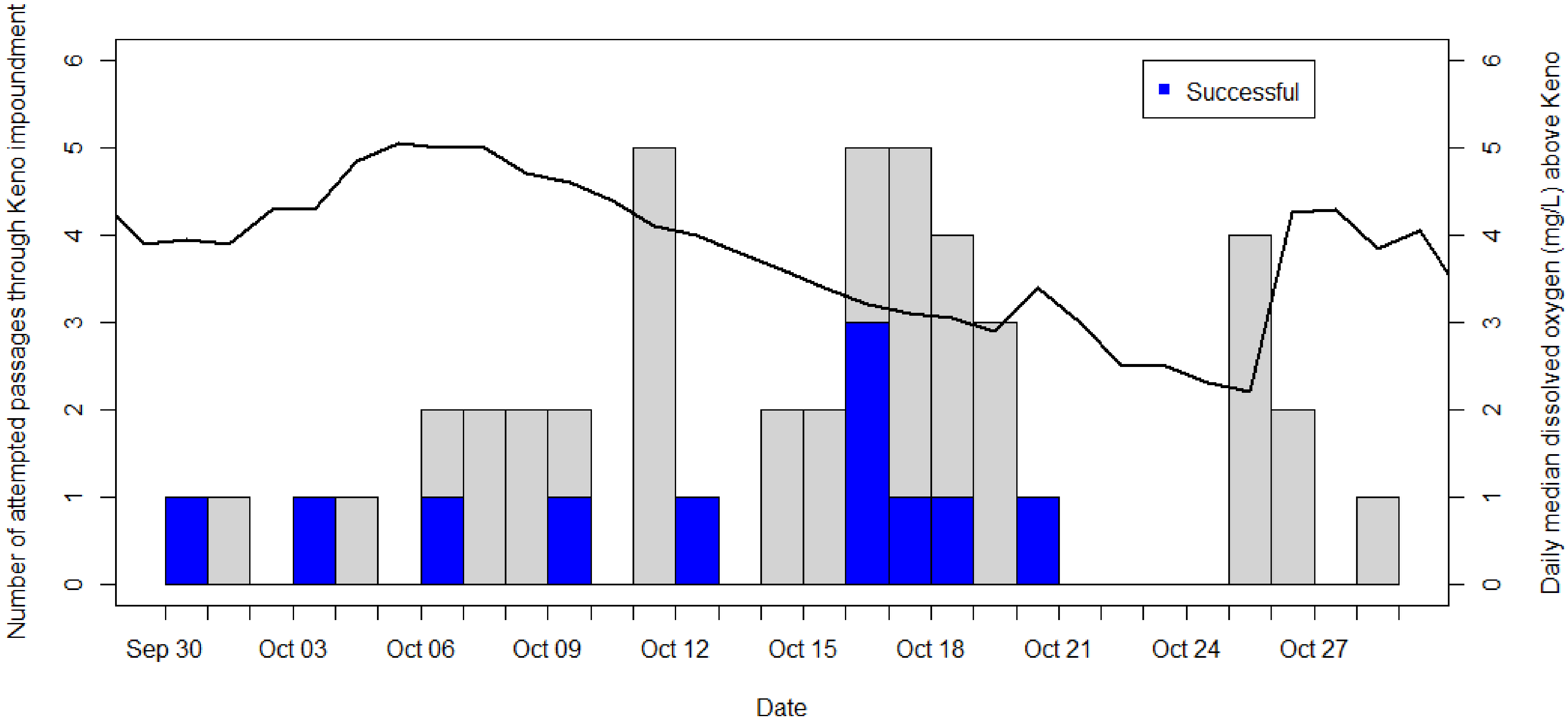
Fish Upstream Passage

- Fish passage through different reaches indicated some chokepoints
- Chokepoints could be due to migratory physical and water quality barriers (BAD!), but could also be due to fish recruiting to spawning habitat and tributaries (GOOD!)
- “Fall-back” leads to ~half of tagged fish not progressing to next receiver site



Fish Passage at Fish Ladders - Keno

- This section had very low DO values



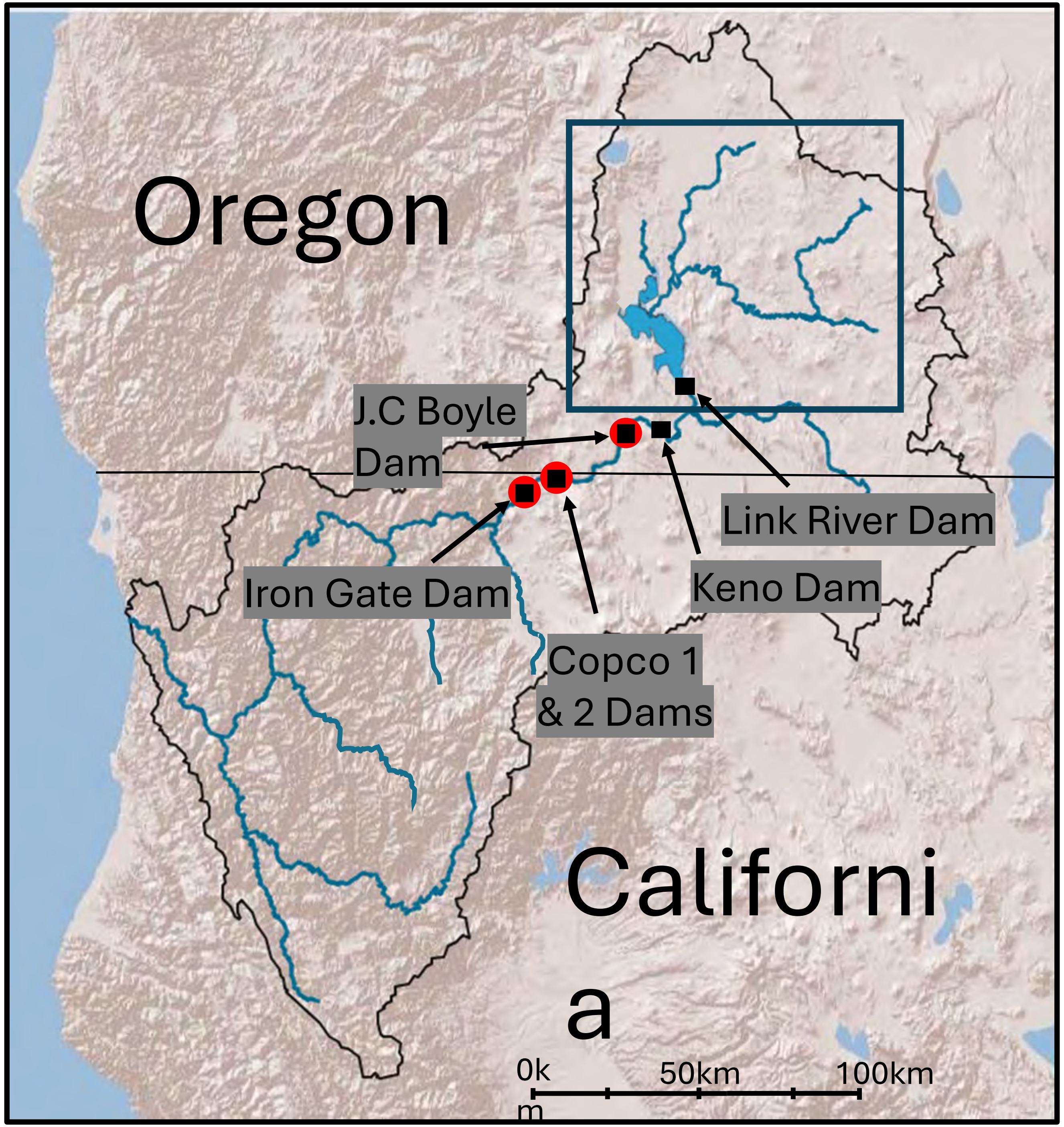
Repopulation of Chinook Salmon in Upper Klamath Lake and It’s Major Tributaries

By Jordan Ortega
Anadromous Fish Specialist
The Klamath Tribes Ambodat Department

Photo: Paul Wilson

Klamath Dam Removal

- 4 dams removed August 2024
  - 3rd largest producer of Chinook on west coast
  - 2-4% of historical abundance
  - 751 km of stream habitat upstream of dams



An Inland Basin with Ocean Connections

- Klamath Basin covers 3 physiographic regions
    - Basin and Range (UKB)
    - Cascades Range (LKB)
    - Klamath Mountains (LKB)
- Distinct "Great Basin" fish not found downriver

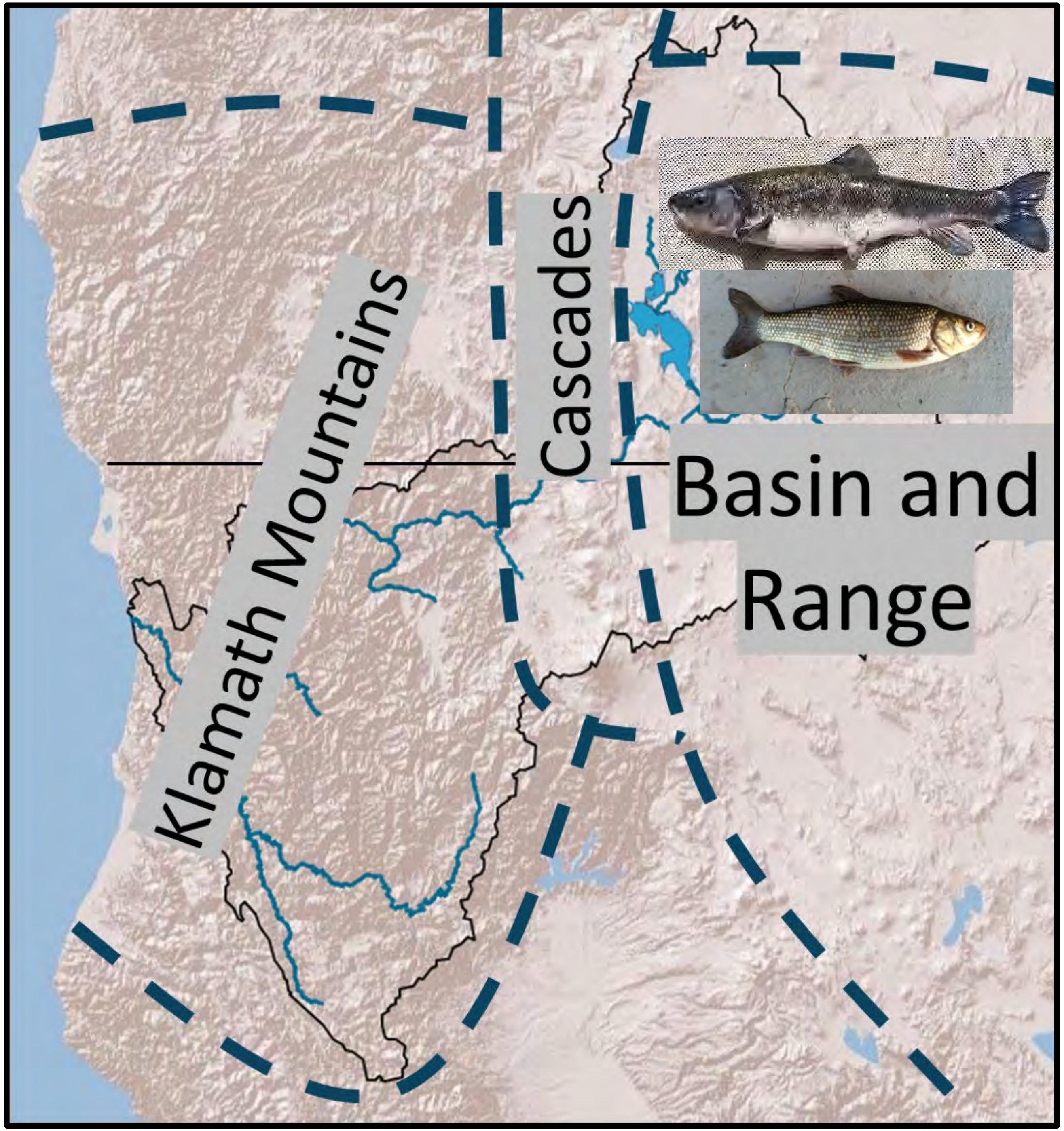


Photo Paul Wilson

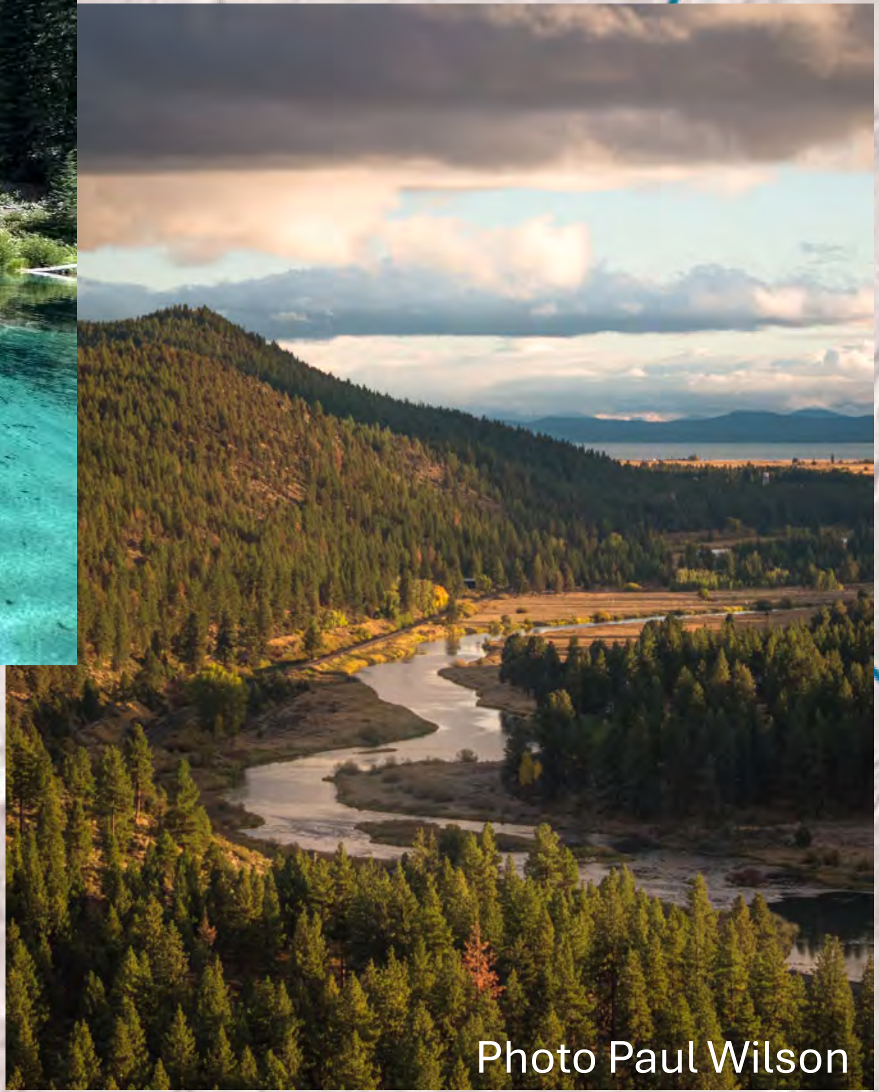
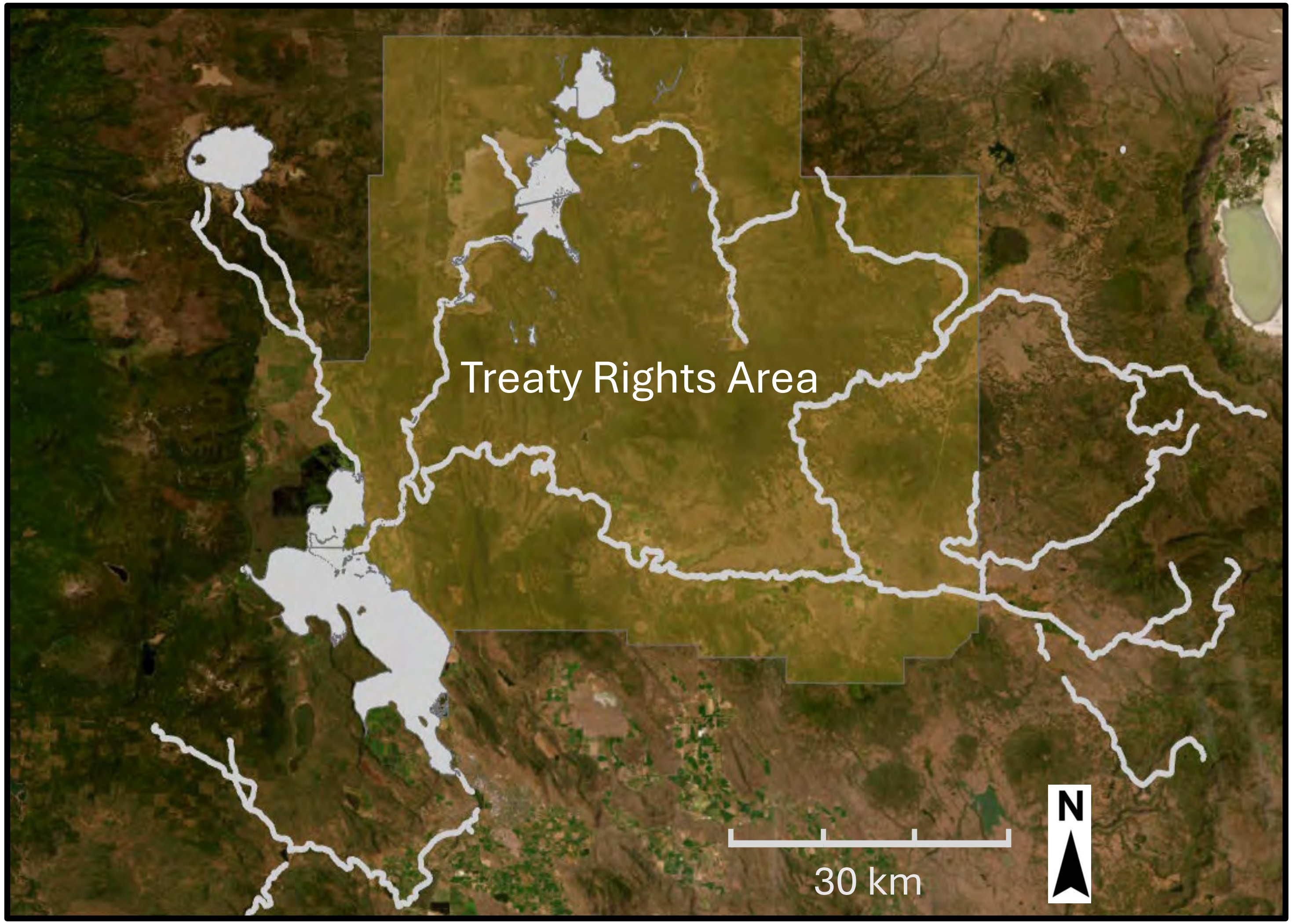


Photo Paul Wilson

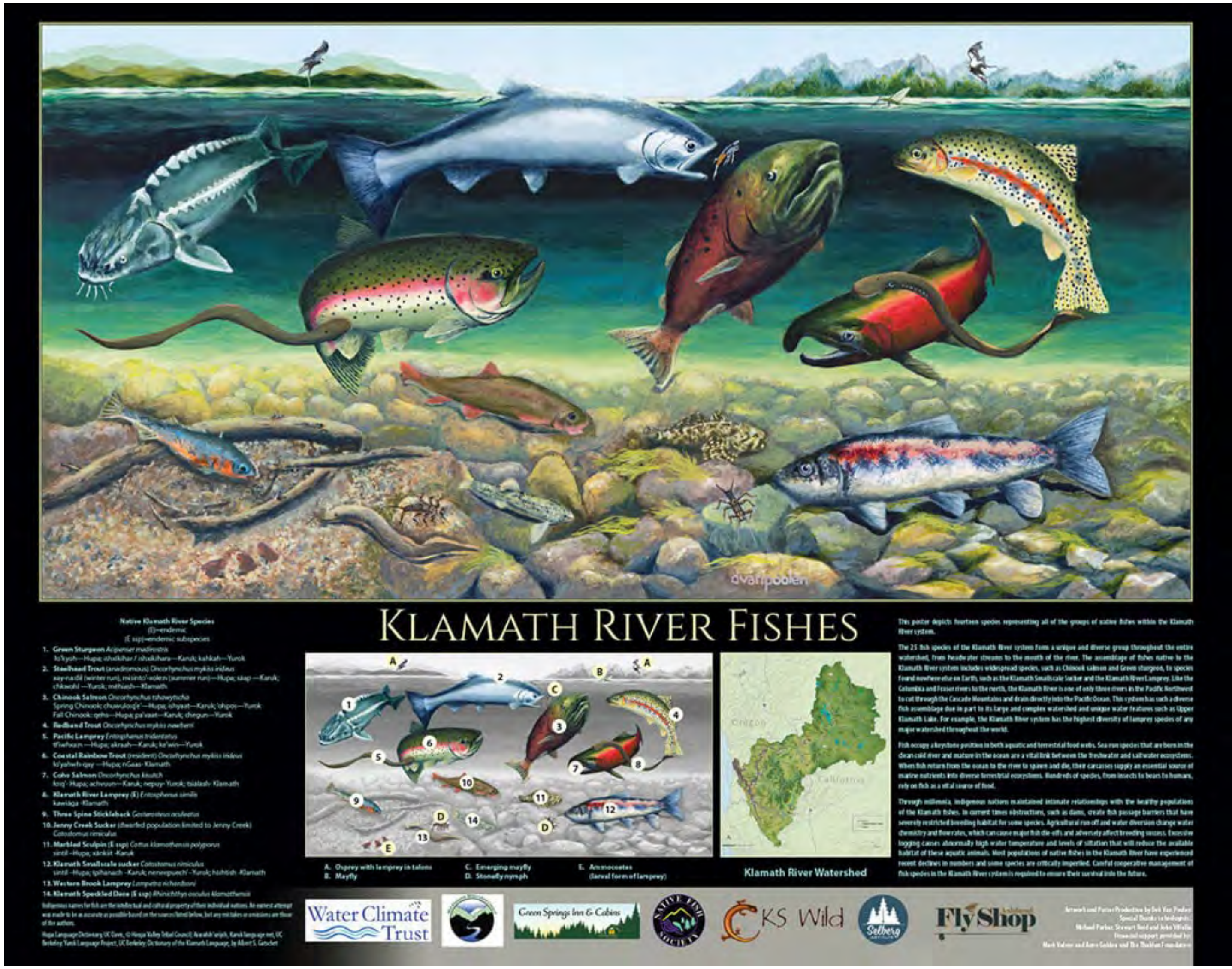
The Klamath Tribes

- Federally recognized tribe.
- Reserved Treaty Rights Area
- Restoring salmon essential given the loss of traditional subsistence fisheries



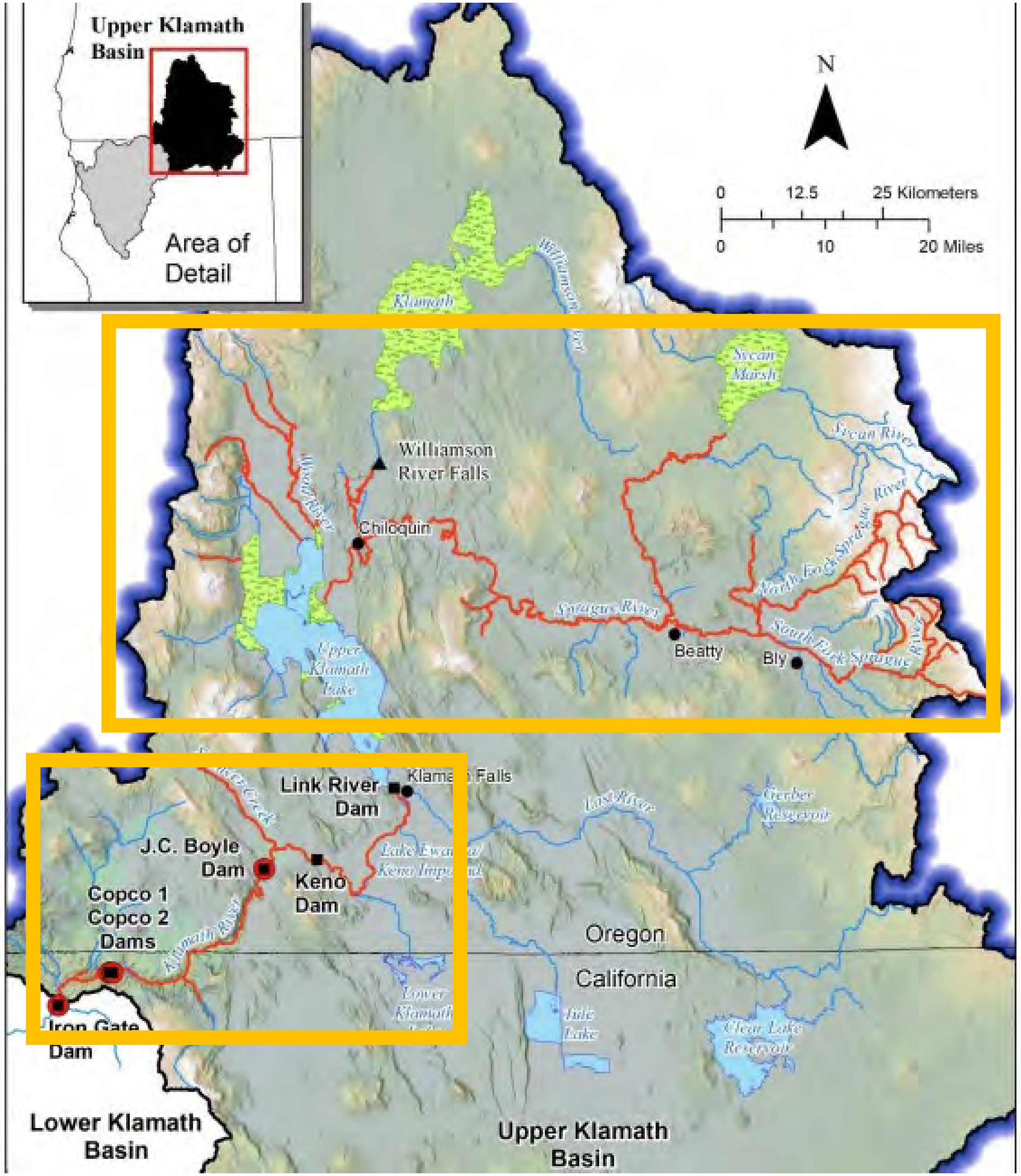
The Monitoring Challenge

- Spatial Challenge
  - So much space!
- Temporal Challenge
  - Fish moving throughout time!

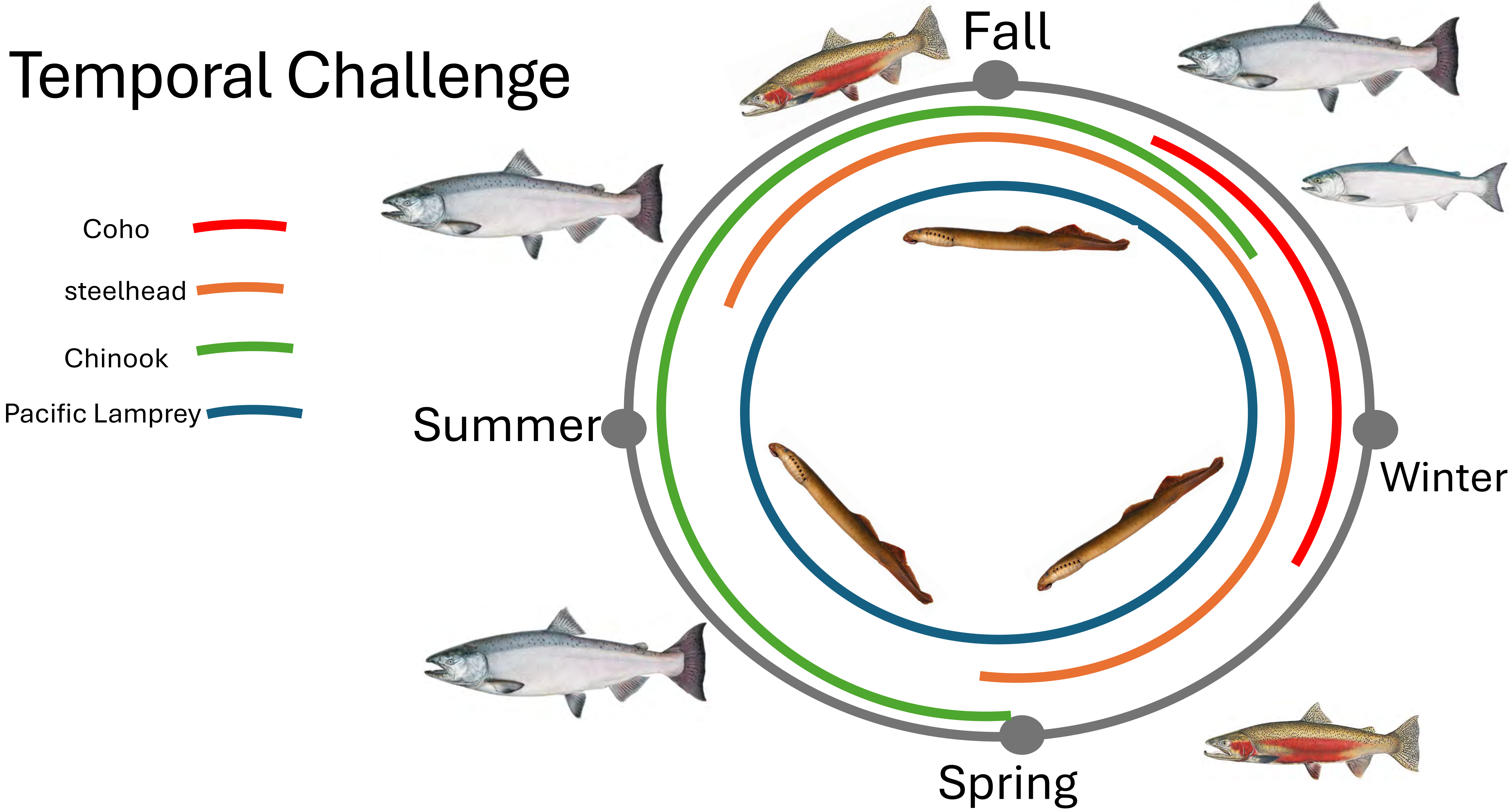


Spatial Challenge

- 152.5 km between Iron Gate dam and UKL (including tributaries)
- 598.5 km upstream of UKL



Temporal Challenge



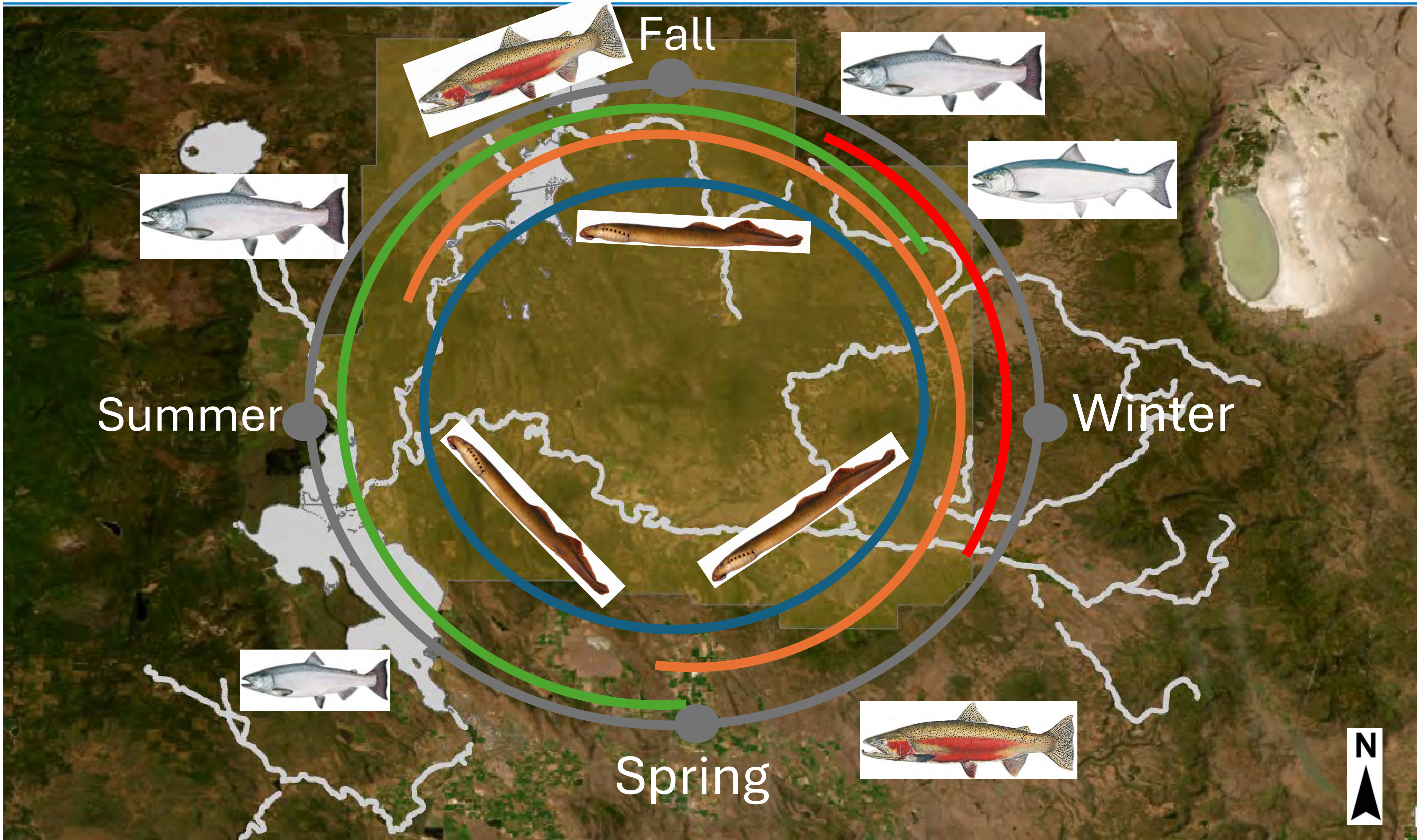

Fall
Summer
Winter
Spring
N

Photo: Paul Wilson

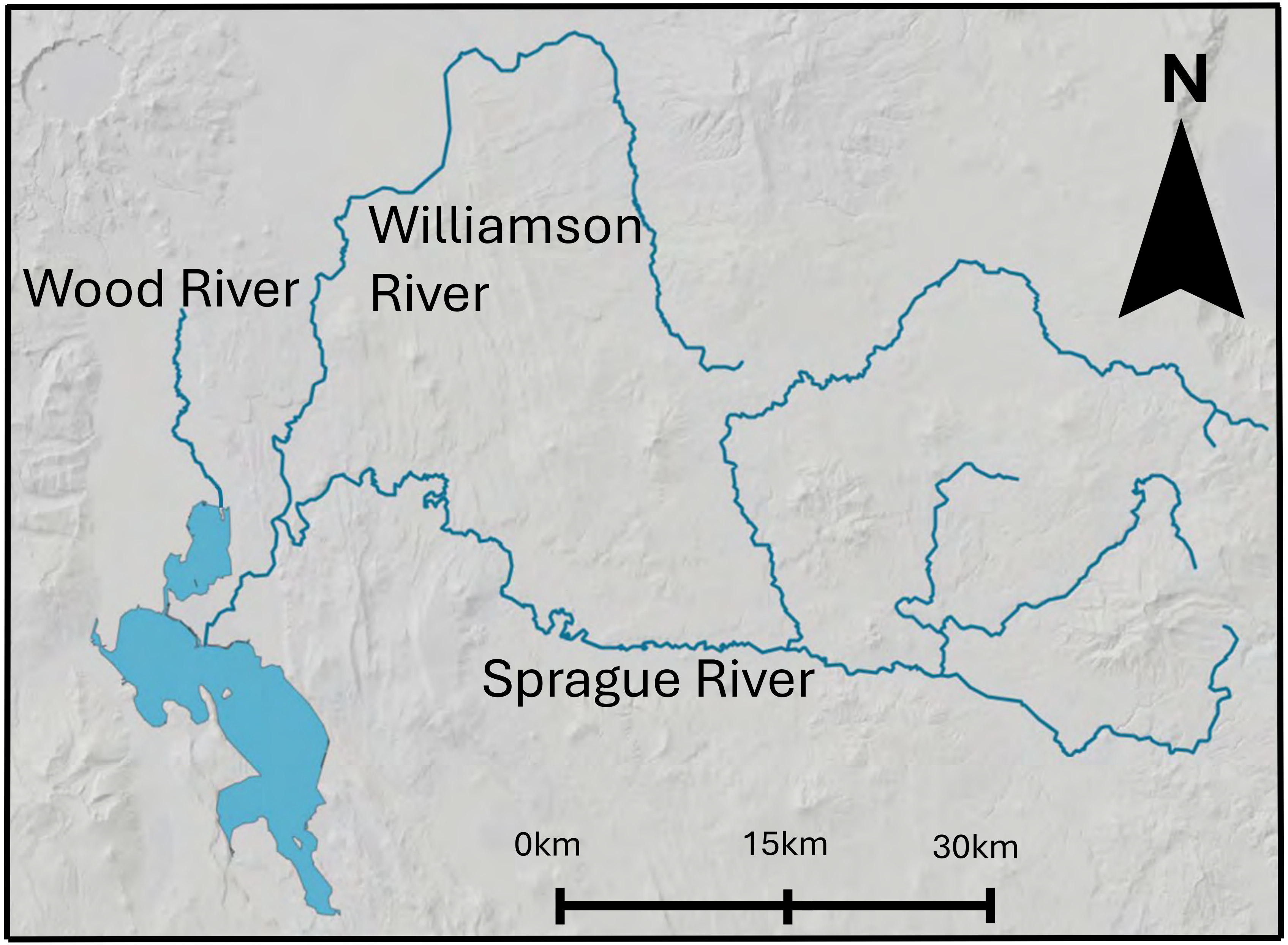
Monitoring Strategy

- Radio Telemetry
- Motion Sensing Camera
- Visual Surveys

Focal Area

- Klamath Tribes monitoring focus is major tributaries of UKL

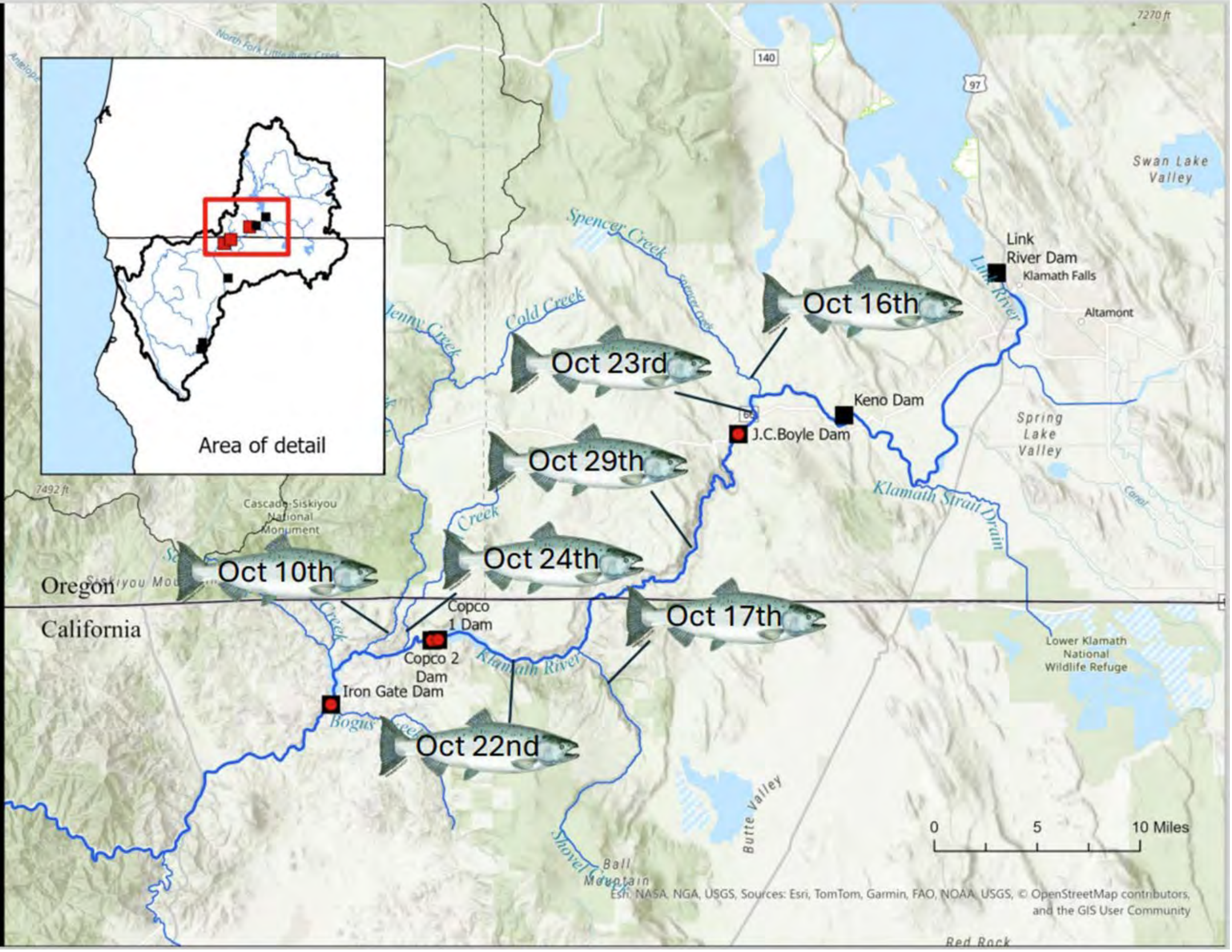
- ODFW, Karuk Tribe USFWS, CalTrout etc. monitor Downstream



2024 Chinook Salmon Run: First Year Post-Removal

First observations of fall-run Chinook Salmon

- Oct 10th - Jenny Creek, CA
- Oct 16th - Spencer Creek, OR
- Oct 17th - Shovel Creek, CA
- Oct 22nd – Klamath River, CA above former Copco 1 Dam
- Oct 23rd – Klamath River, OR above former JC Boyle Dam
- Oct 24th – Fall Creek Hatchery, CA
- Oct 29th – Klamath River, OR below former JC Boyle Dam



Slide by Mark Hereford

2025 Monitoring Objectives

- Spatial Distribution
- Run Phenology
- Size, Sex, and Age Structure
- Hatchery Contribution
- Run Size

Photo Paul Wilson

Methods

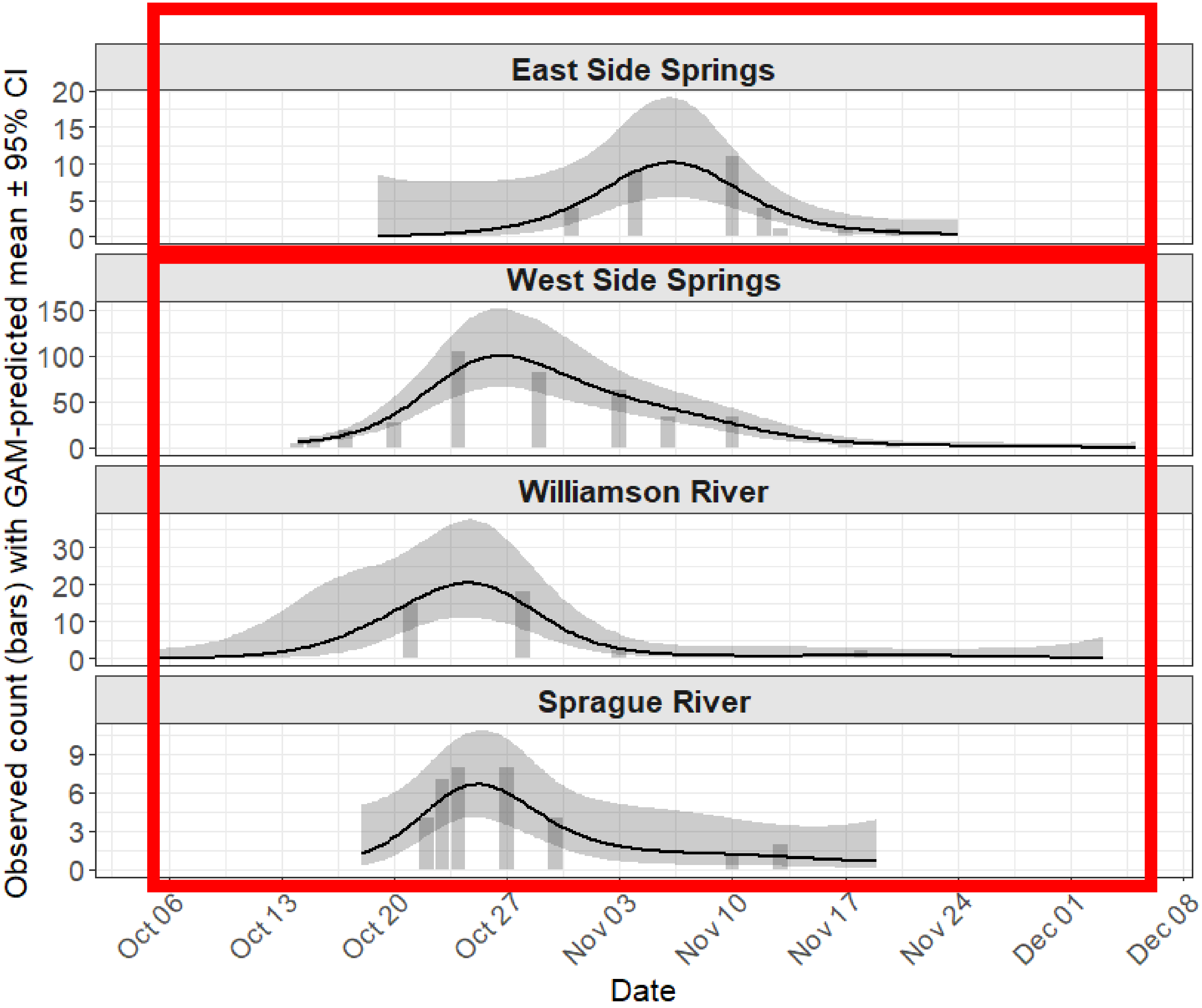
- Spatial Distribution
  - Visual surveys
- Run Size & Timing
    - Redd counts
    - Live fish counts
- Population Characteristics
  - Carcass collection
    - Size distribution
    - Age Distribution
    - Hatchery Contribution

Spatial Distribution

- Widespread spawning distribution
- Farthest upstream observation
  - 150 km to UKL
  - 580 km to ocean

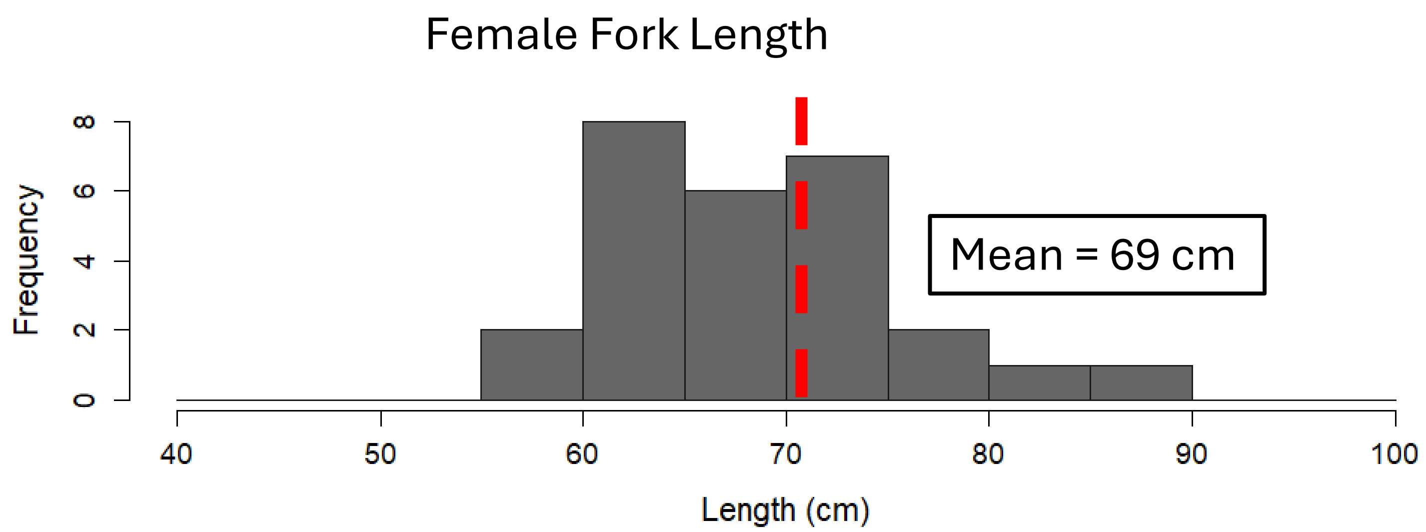
Run Phenology

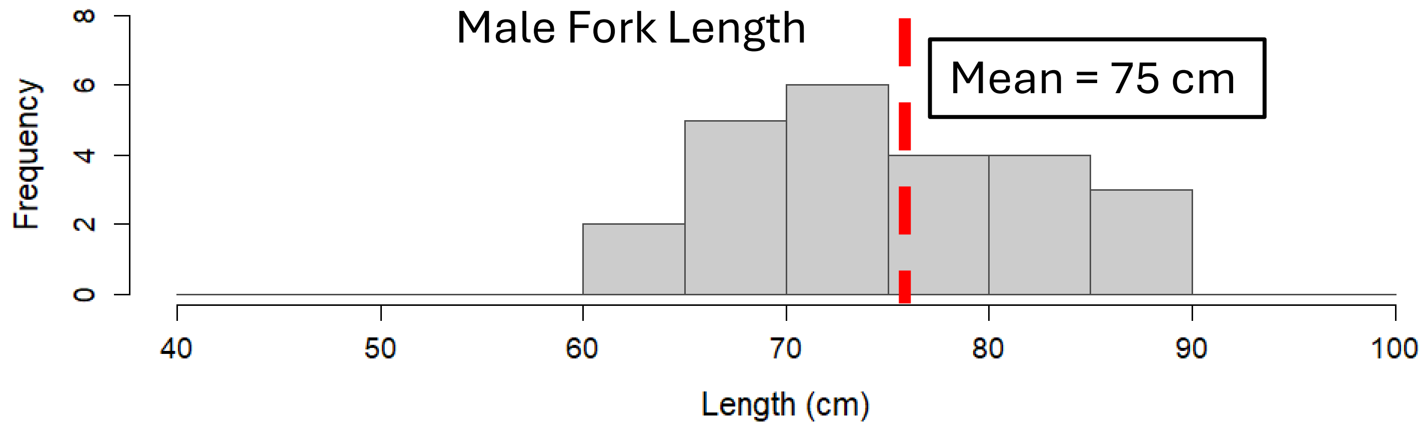
- Spawning activity spanned 1.5 months
- Peak spawning late October at West Side Springs, Williamson, Sprague
- Peak spawning 2-weeks later at East Side Springs



Sex, Size, and Age

- Approximately even sex ratio
- Males > Females
- Consisted of age 3 & 4 adults
    - No jacks observed





Hatchery Contribution

63/219=29 %

★ Majority of run was *wild fish!*

2025 UKL Miscellaneous Tribs Survey CWT and Hatchery Contribution								
CWT	Location	Release type a/	Brood year	Sample number	Production multiplier b/	Production estimate c/	Sample expansion d/	Expanded estimate e/
60032	IGH	AF	2022	3	4.0363	12.1090	3.9000	47.2251
60478	IGH	AF	2021	1	1.0101	1.0101	3.9000	3.9394
60788	IGH	AF	2021	1	1.0157	1.0157	3.9000	3.9614
61546	IGH	F	2021	1	1.0146	1.0146	3.9000	3.9570
62269	IGH	F	2021	1	1.0056	1.0056	3.9000	3.9218
CWT sample subtotal =				**7**				
Hatchery contribution of carcasses sampled subtotal =						**16**		
Total of estimated hatchery contributions =								**63**
a/	Release type; F=fingerling, Y=yearling, AF=advanced fingerling							
b/	Production multiplier is the ratio of # of fish released/fish marked							
c/	Production estimate is the sample number multiplied by the production multiplier							
d/	Sample expansion is the ratio of the estimated total run size and the number of carcasses sampled							
e/	Expanded estimate is the production estimate multiplied by the sample expansion							

Run Size

- Groundwater Portions of UKL
  - *Trapezoidal approximation method* to calculate area under the curve (AUC)

$$\textbf{Run Size} = \textbf{AUC/Residence Time} = \sum \left[\frac{(C_i + C_{(i+1)})}{2} \times \Delta t \right]$$

- Williamson, Wood, Sprague
  - *Redd count* based run size estimate
    - Number of Redds **x** 2 = Run Size

Run Size

- Upper Klamath Lake: 219
- Williamson: 82
- Sprague: 22
- Wood: 12

TOTAL RUN SIZE (minimum) =
335 Fall Chinook

Photo: Paul Wilson

Next Monitoring Steps…

- Returning adults encouraging but does not reveal if they will be able to establish self sustaining populations

- To evaluate reproductive success we implemented a monitoring strategy that includes the use of rotary screw traps

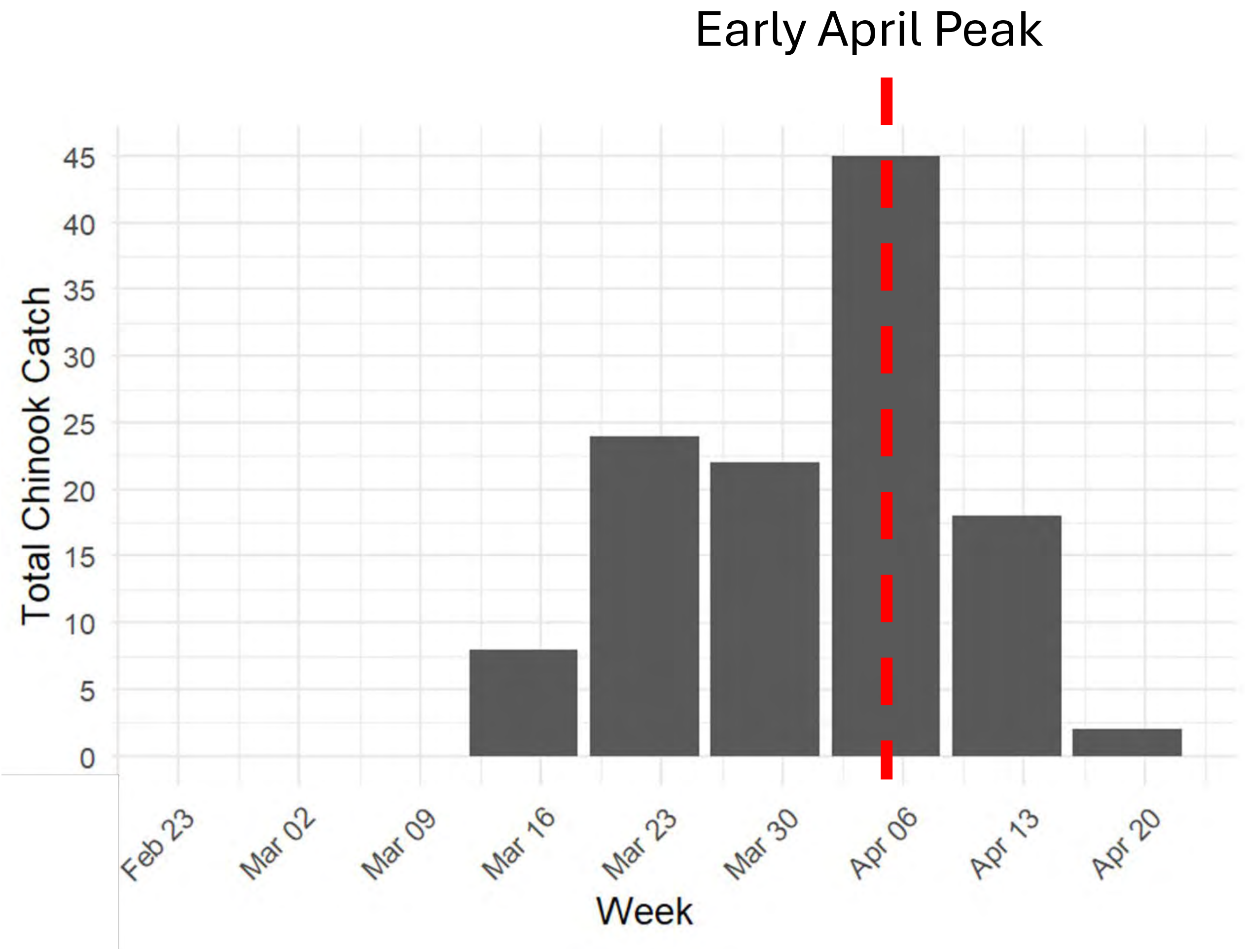
Photo Mark Martin

Juvenile Chinook Salmon Monitoring

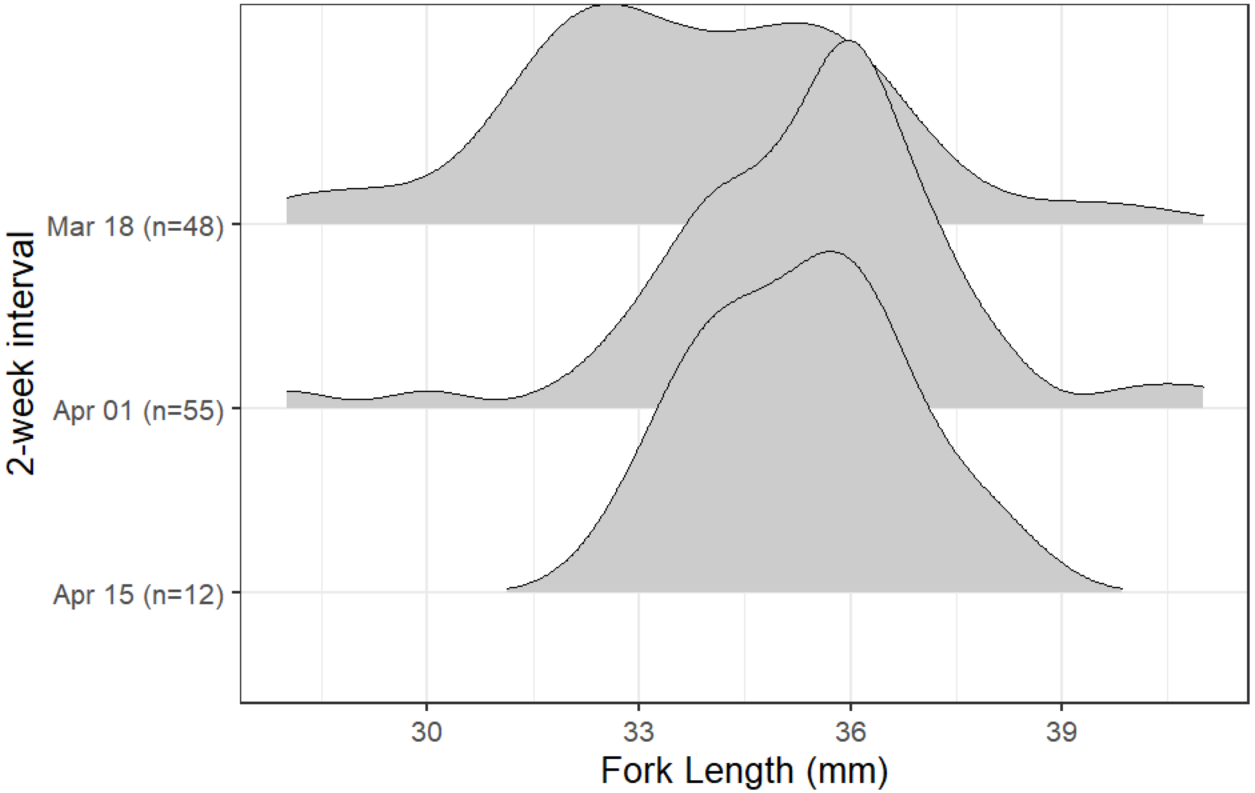
- Operating two 5-ft rotary screw traps
  - Sprague River
  - Williamson River

Catch Through Time

Photo: Paul Wilson



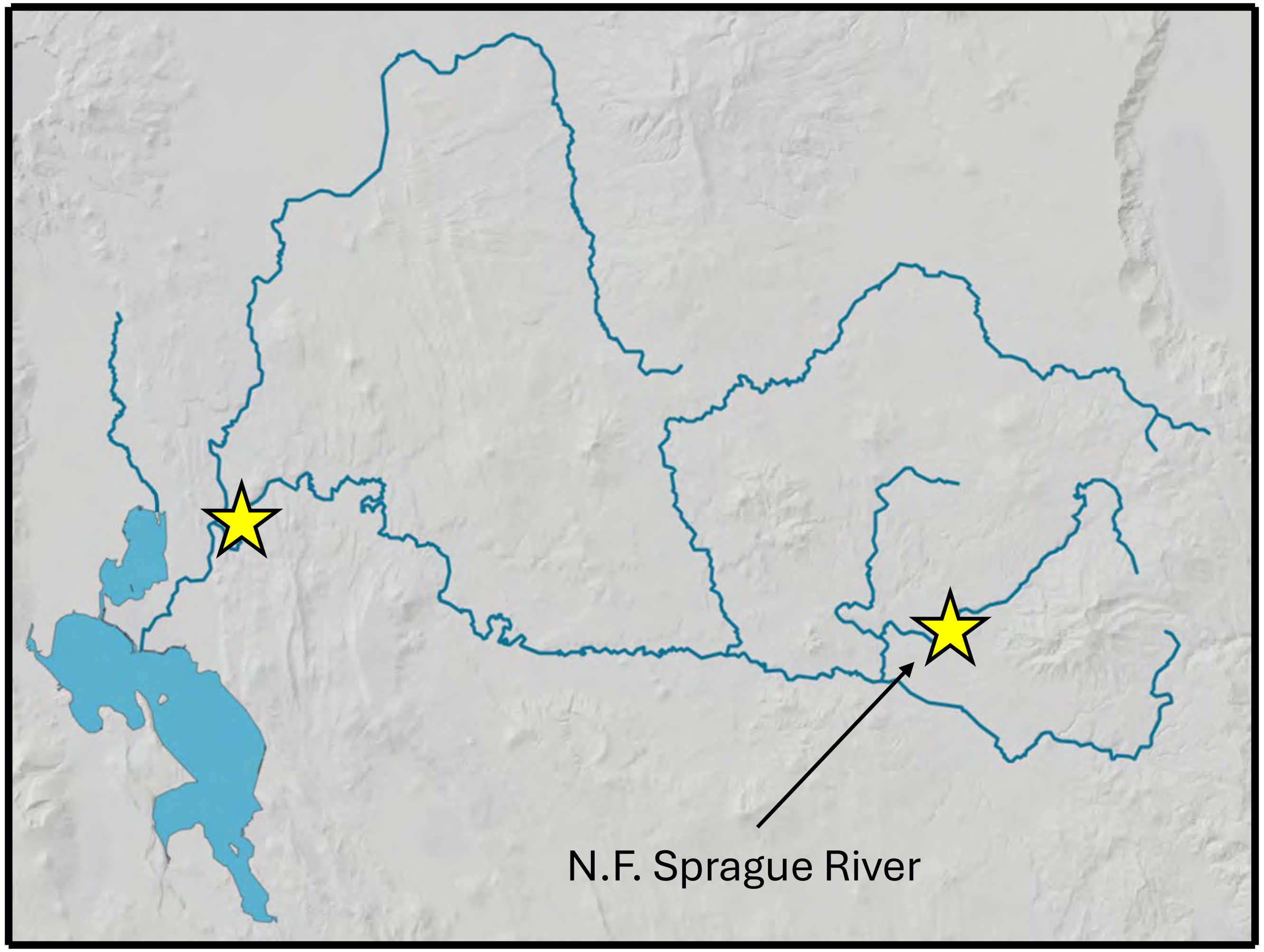
Size Through Time



Chinook size indicates growth and downstream movement of the 2026 cohort

Screw Trap Highlight

- Released Fall 2025 on North Fork Sprague
- 3 captured April 2026
    - Over-wintered in Sprague
- Distance of > 130km



2025 Chinook Monitoring Take Home…

- Adults distributed upstream rapidly across a broad spatial extent
- Evidence of successful spawning as indicated by the presence of recently emerged chinook fry
- Early response underscores the importance of restoring connectivity in large watersheds
- Continued monitoring by The Klamath Tribes Ambodat Department

Photo Paul Wilson

Our Partners

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NOAA National Marine Fisheries Service

What does success look like?
A vision for Klamath River salmon

Thomas Williams

Research Fisheries Biologist
Southwest Fisheries Science Center
Fisheries Ecology Division – Santa Cruz, California

Santa Cruz, California
1 May 2026

Knowing what we want – a conceptual framework for restoring Klamath River salmon populations

Thomas Williams
Research Fisheries Biologist
Southwest Fisheries Science Center
Fisheries Ecology Division – Santa Cruz, California

Salmonid Restoration Conference   1 May 2025

To be viable (i.e., persist) – fish need to be able to track changes in environment.

- **Individuals (within and between life stages)**
- **Populations**
- **Groups of populations**
- **Larger regional groups (e.g., ESUs)**
- **Species**

Natural disturbance events that influence salmonid populations throughout their range include:

- fires
- landslides
- glaciers
- earthquakes
- volcanic eruptions
- floods

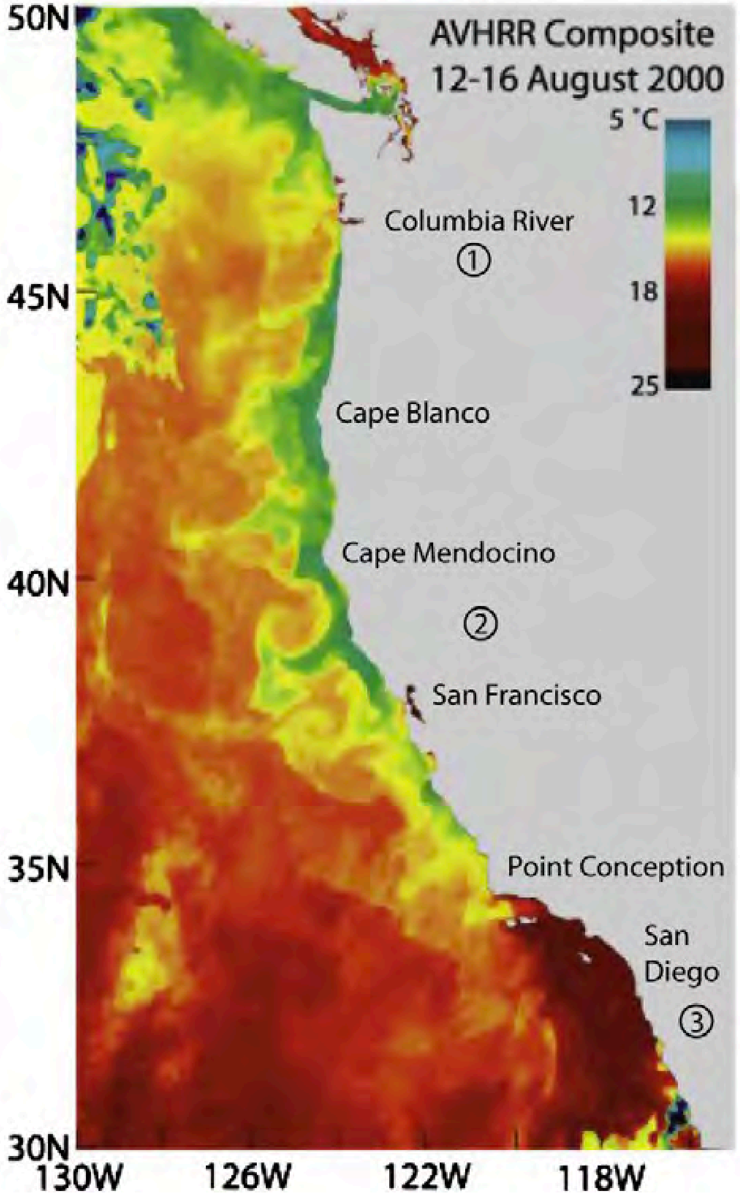
Anthropogenic constraints that can influence the ability of salmonid populations to track changes in environmental conditions include:

- migration barriers
- land management activities (e.g., timber, agriculture)
- fire (magnitude, frequency)
- Water withdrawal

Fresno Bee (9/27/2009)

The California Current System is dynamic

This mid-summer surface temperature snapshot shows how complex and diverse “ocean conditions” are at any given time in response to variable weather, winds, ocean currents, etc.



VSP Viable Salmonid Populations

Viability of populations are evaluated based on four parameters (VSP parameters):

- **abundance**
- **population growth rate**
- **spatial structure**
- **diversity**

ESU viability

- **catastrophic events**
- **long-term demographic processes**
- **long-term evolutionary potential**

McElhany et al. 2000. Viable salmonid populations and the recovery of Evolutionarily Significant Units. NOAA Technical Memorandum NMFS-NWFSC-42.

http://www.nwr.noaa.gov/1salmon/salmesa/pubs.htm

To be viable (i.e., persist) – fish need to be able to track changes in environment.

- **Individuals (within and between life stages)**
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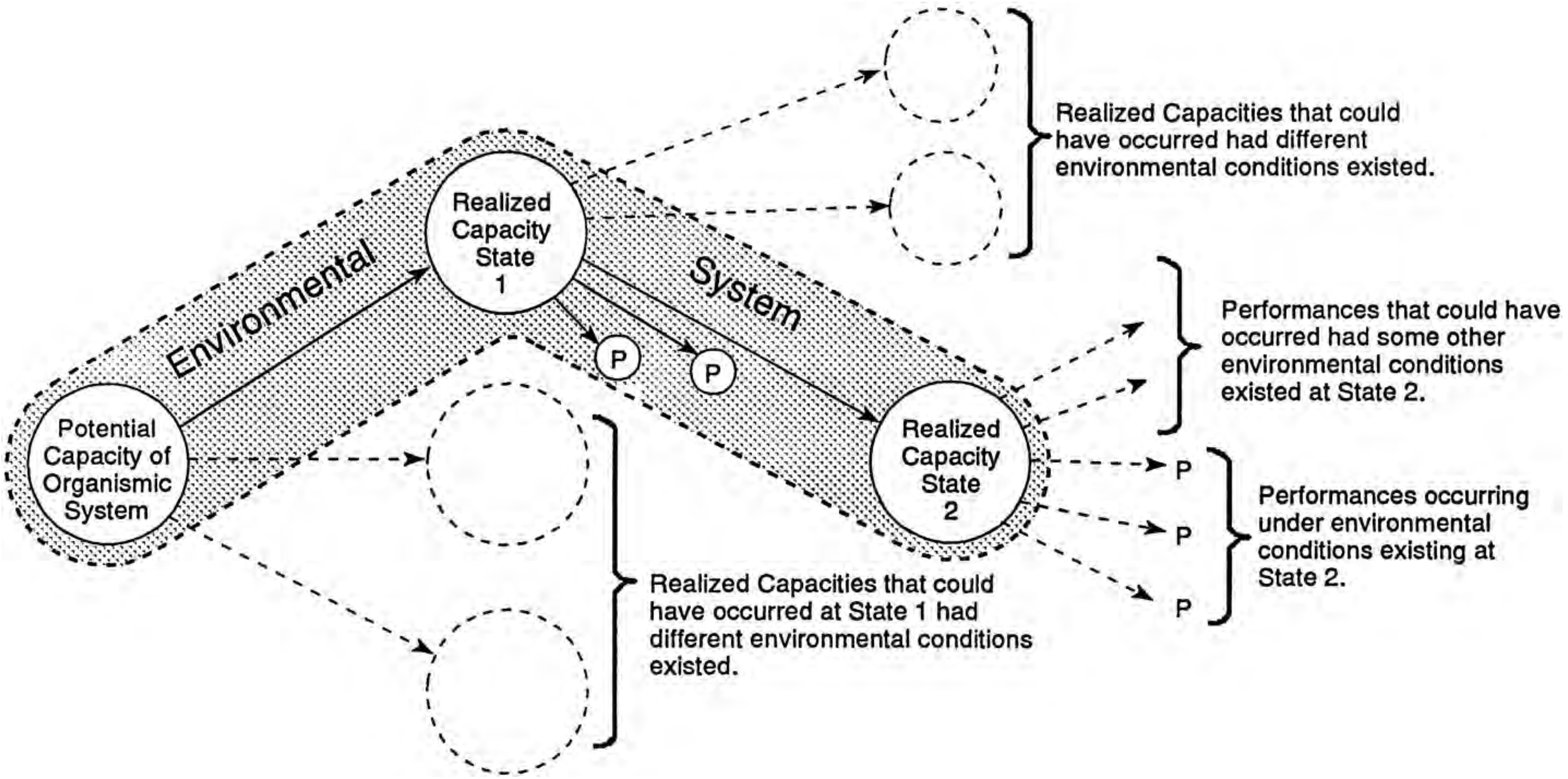
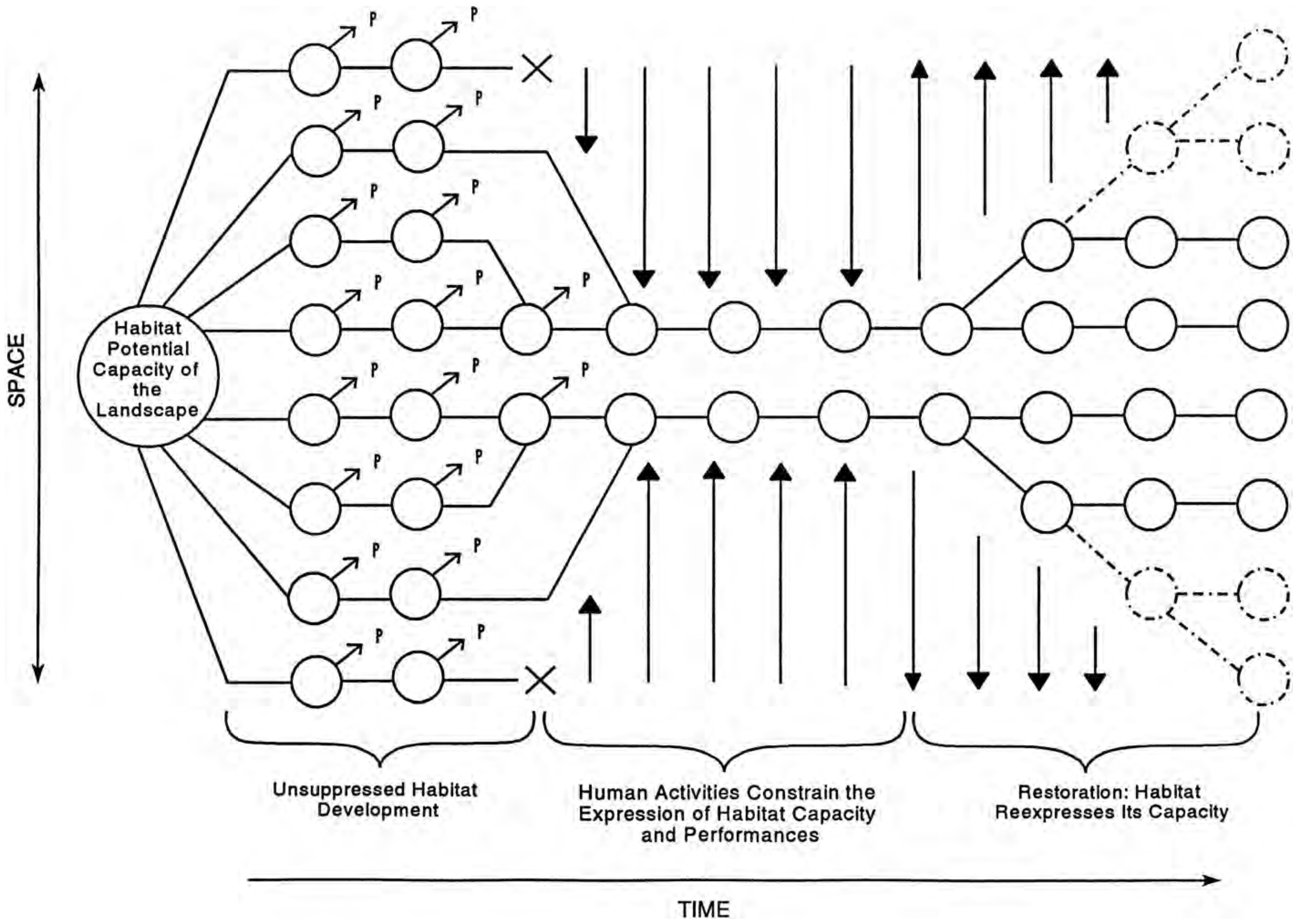
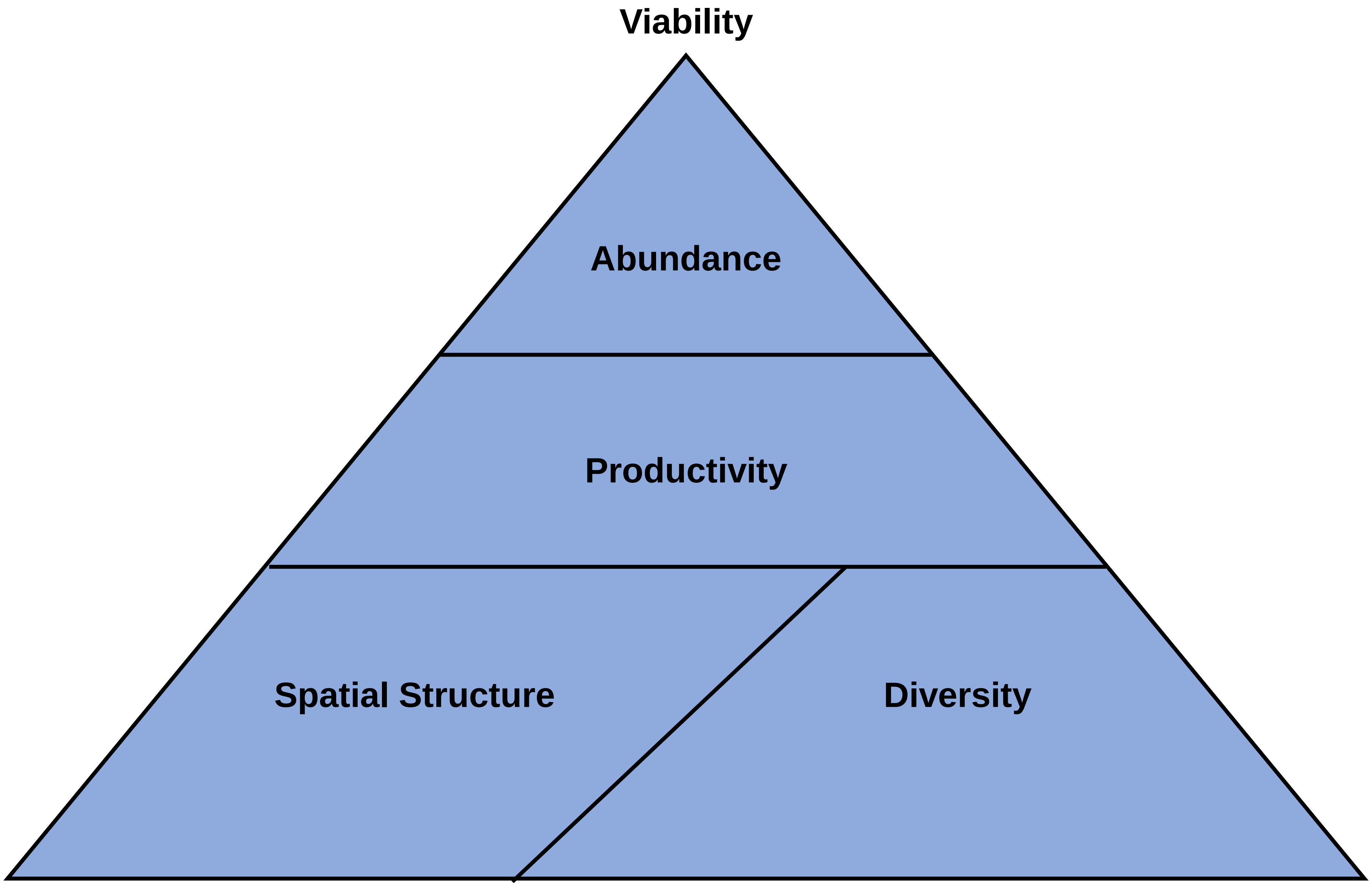
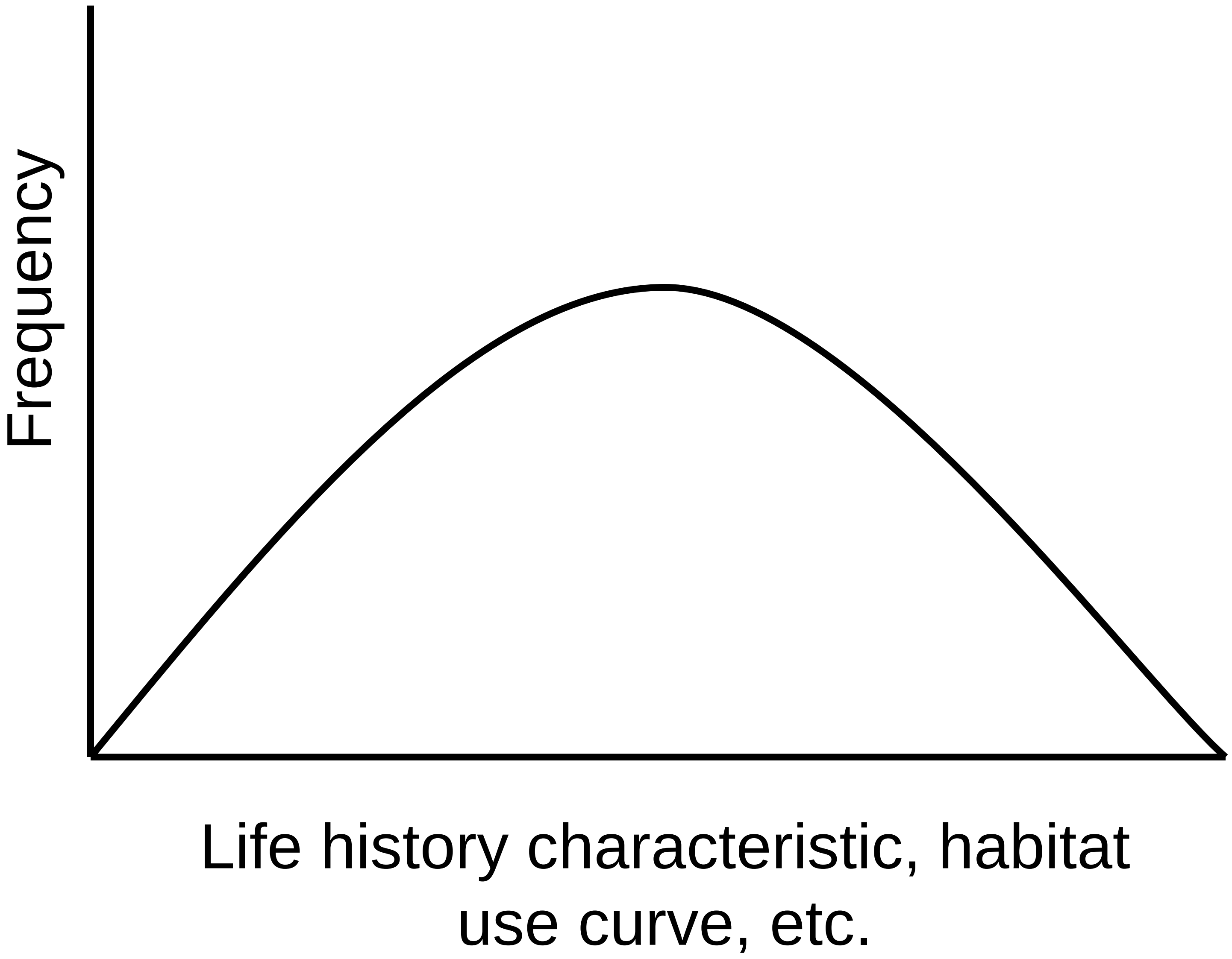


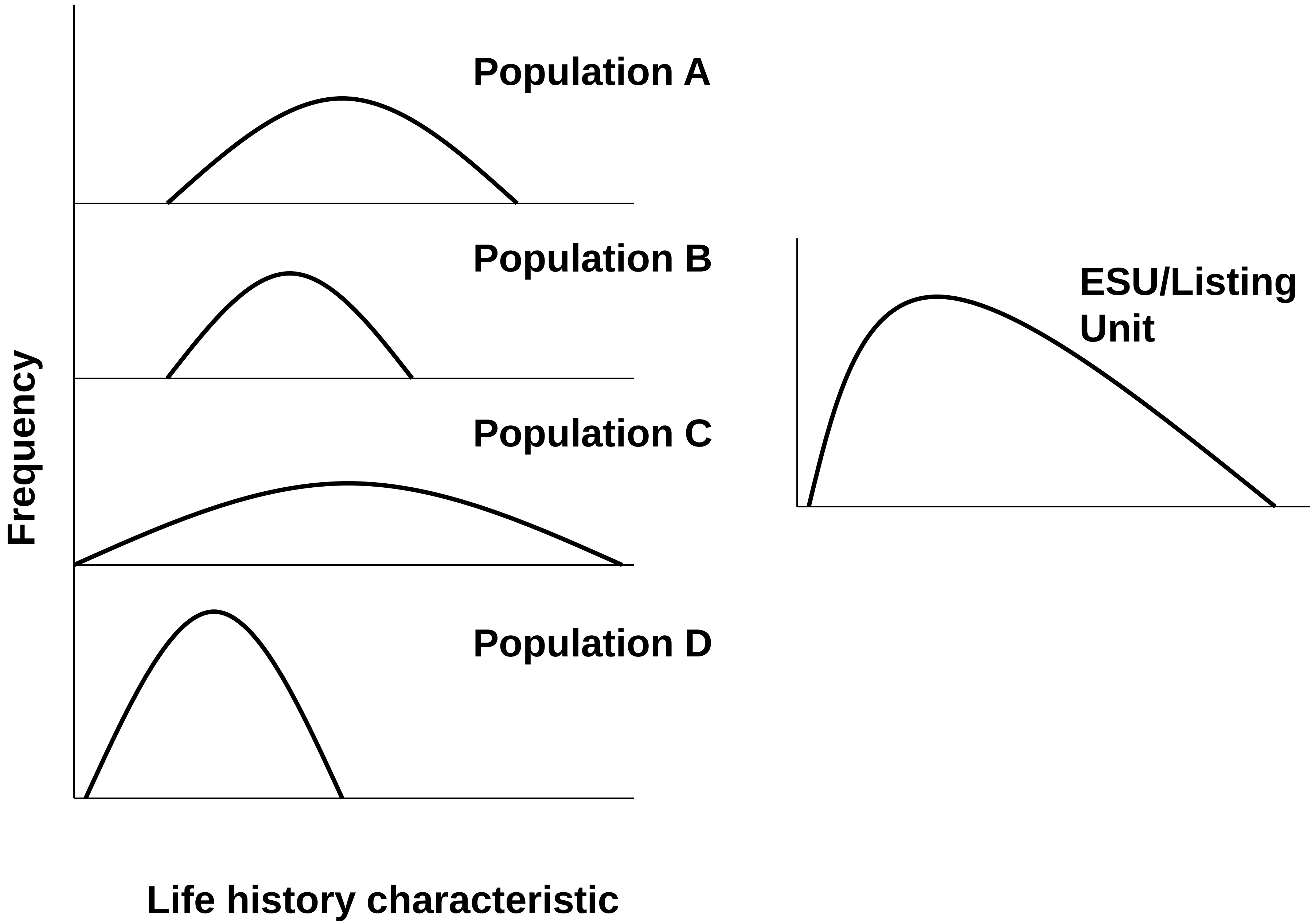
From Ebersole et al. 1997. Envir. Mgt. 21:1-14.

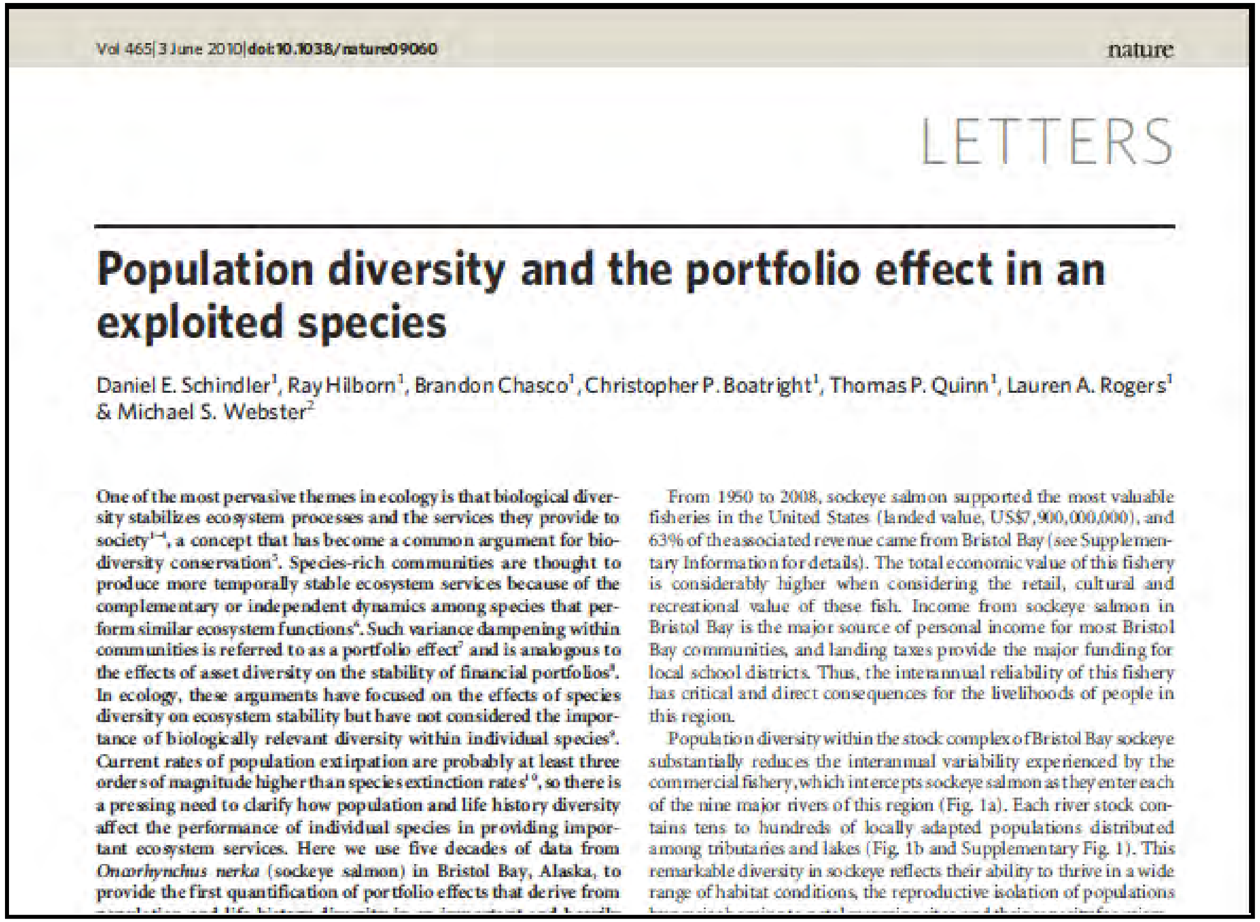


From Ebersole et al. 1997. Envir. Mgt. 21:1-14.


Viability
Abundance
Productivity
Spatial Structure
Diversity


Frequency
Life history characteristic, habitat use curve, etc.


Population A
Population B
Population C
Population D
Frequency
Life history characteristic
ESU/Listing Unit



Vol 465 | 3 June 2010 | doi:10.1038/nature09060 nature

LETTERS

Population diversity and the portfolio effect in an exploited species

Daniel E. Schindler[1], Ray Hilborn[1], Brandon Chasco[1], Christopher P. Boatright[1], Thomas P. Quinn[1], Lauren A. Rogers[1] & Michael S. Webster[2]

One of the most pervasive themes in ecology is that biological diversity stabilizes ecosystem processes and the services they provide to society[1–4], a concept that has become a common argument for biodiversity conservation[5]. Species-rich communities are thought to produce more temporally stable ecosystem services because of the complementary or independent dynamics among species that perform similar ecosystem functions[6]. Such variance dampening within communities is referred to as a portfolio effect[7] and is analogous to the effects of asset diversity on the stability of financial portfolios[8]. In ecology, these arguments have focused on the effects of species diversity on ecosystem stability but have not considered the importance of biologically relevant diversity within individual species[9]. Current rates of population extirpation are probably at least three orders of magnitude higher than species extinction rates[10], so there is a pressing need to clarify how population and life history diversity affect the performance of individual species in providing important ecosystem services. Here we use five decades of data from *Oncorhynchus nerka* (sockeye salmon) in Bristol Bay, Alaska, to provide the first quantification of portfolio effects that derive from

From 1950 to 2008, sockeye salmon supported the most valuable fisheries in the United States (landed value, US$7,900,000,000), and 63% of the associated revenue came from Bristol Bay (see Supplementary Information for details). The total economic value of this fishery is considerably higher when considering the retail, cultural and recreational value of these fish. Income from sockeye salmon in Bristol Bay is the major source of personal income for most Bristol Bay communities, and landing taxes provide the major funding for local school districts. Thus, the interannual reliability of this fishery has critical and direct consequences for the livelihoods of people in this region.

Population diversity within the stock complex of Bristol Bay sockeye substantially reduces the interannual variability experienced by the commercial fishery, which intercepts sockeye salmon as they enter each of the nine major rivers of this region (Fig. 1a). Each river stock contains tens to hundreds of locally adapted populations distributed among tributaries and lakes (Fig. 1b and Supplementary Fig. 1). This remarkable diversity in sockeye reflects their ability to thrive in a wide range of habitat conditions, the reproductive isolation of populations

Schindler et al. 2010. Nature 465 (June 2010)

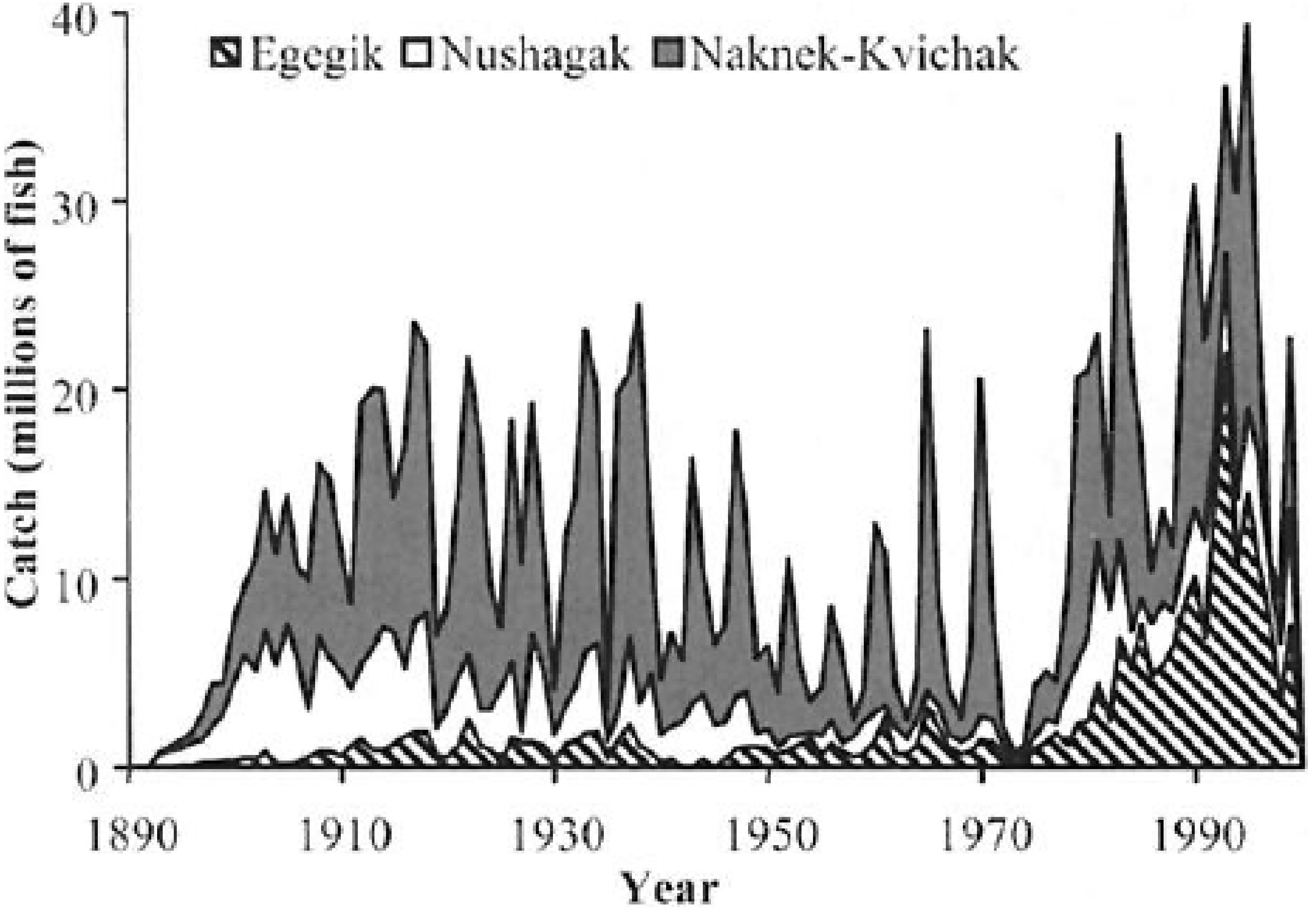


Fig. 3. Catch history of the three major fishing areas within Bristol Bay, Alaska. Contributions of the minor districts, Ugashik and Togiak, have averaged 4.6% since 1955.

Hilborn et al. 2003 Proceedings of the National Academy of Sciences 100:6564-6568

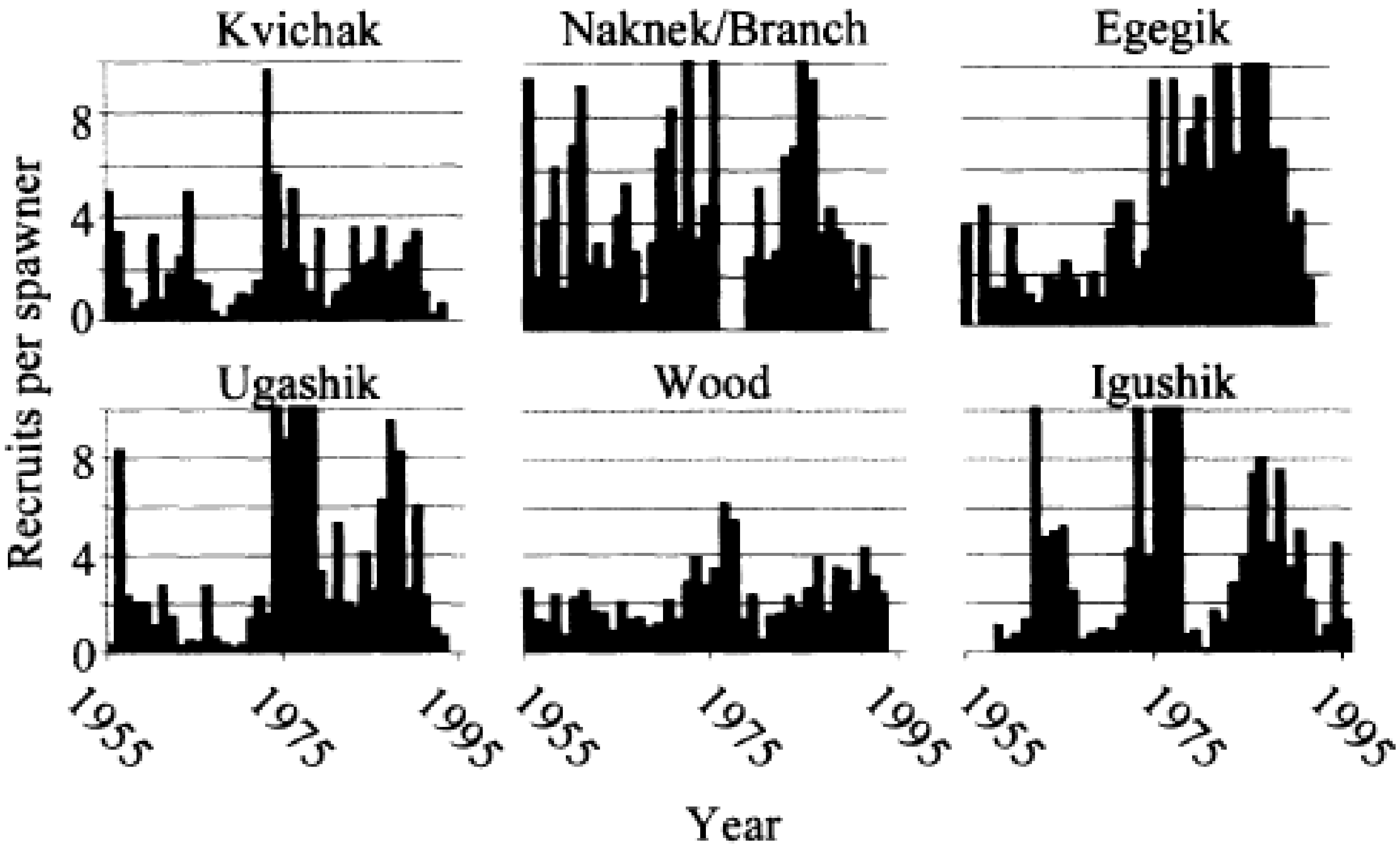


Fig. 4. Number of recruits per spawner for different Bristol Bay sockeye salmon stocks. Values >10 were truncated; the maximum was 27.4 for the Ugashik River in 1978.

Hilborn et al. 2003 Proceedings of the National Academy of Sciences 100:6564-6568

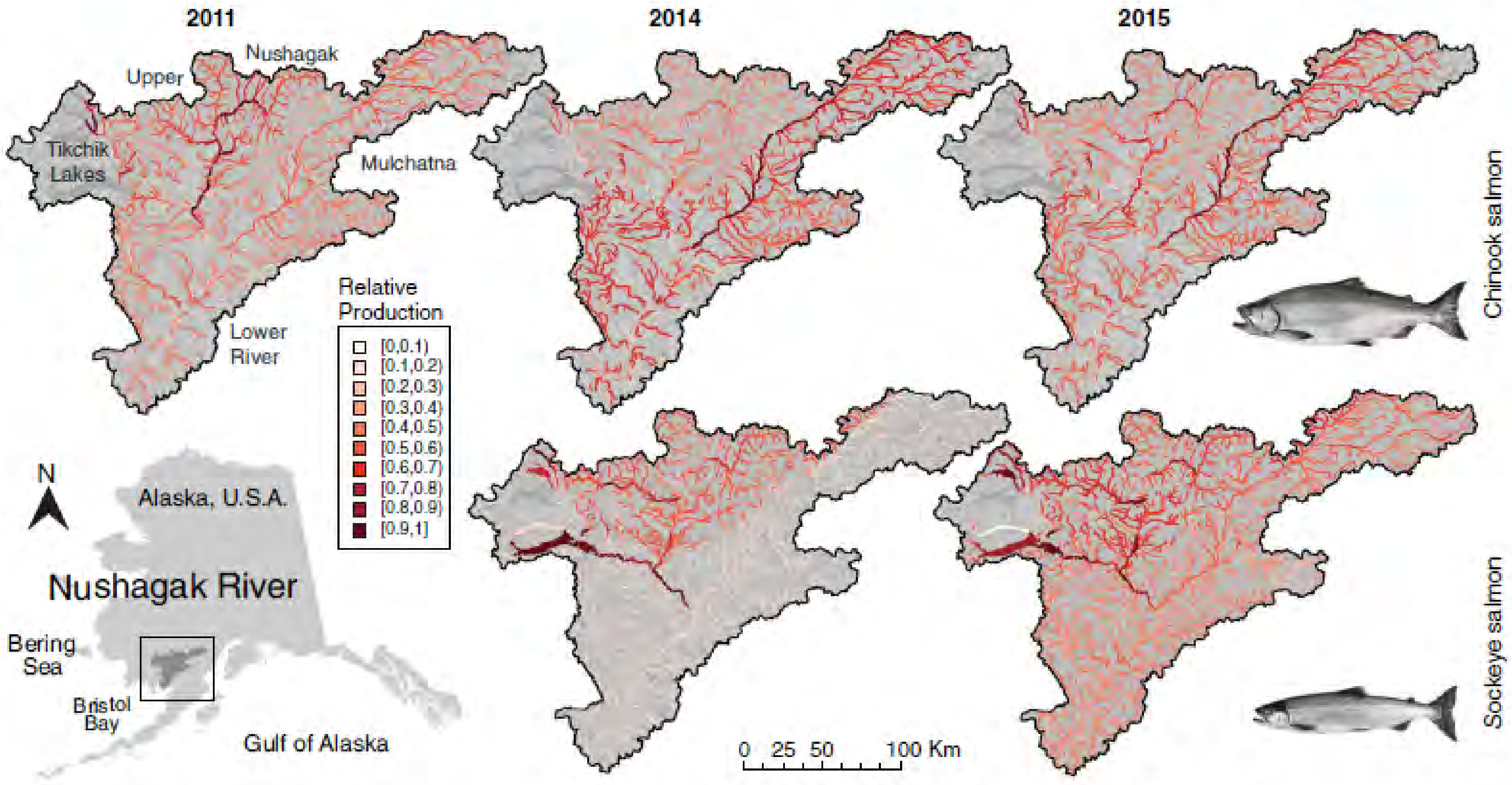


Fig. 1. Productive habitats for salmon shift across river basins. Areas of high Chinook salmon production in 2011 shifted from the upper Nushagak River to the Mulchatna River in 2014 and 2015. Sockeye salmon production was concentrated in Tikchik lakes in 2014 but was more evenly distributed in 2015 including across riverine habitats.

Brennan et al. 2019. Shifting habitats mosaics and fish production across river basins. Science 364:783–786.

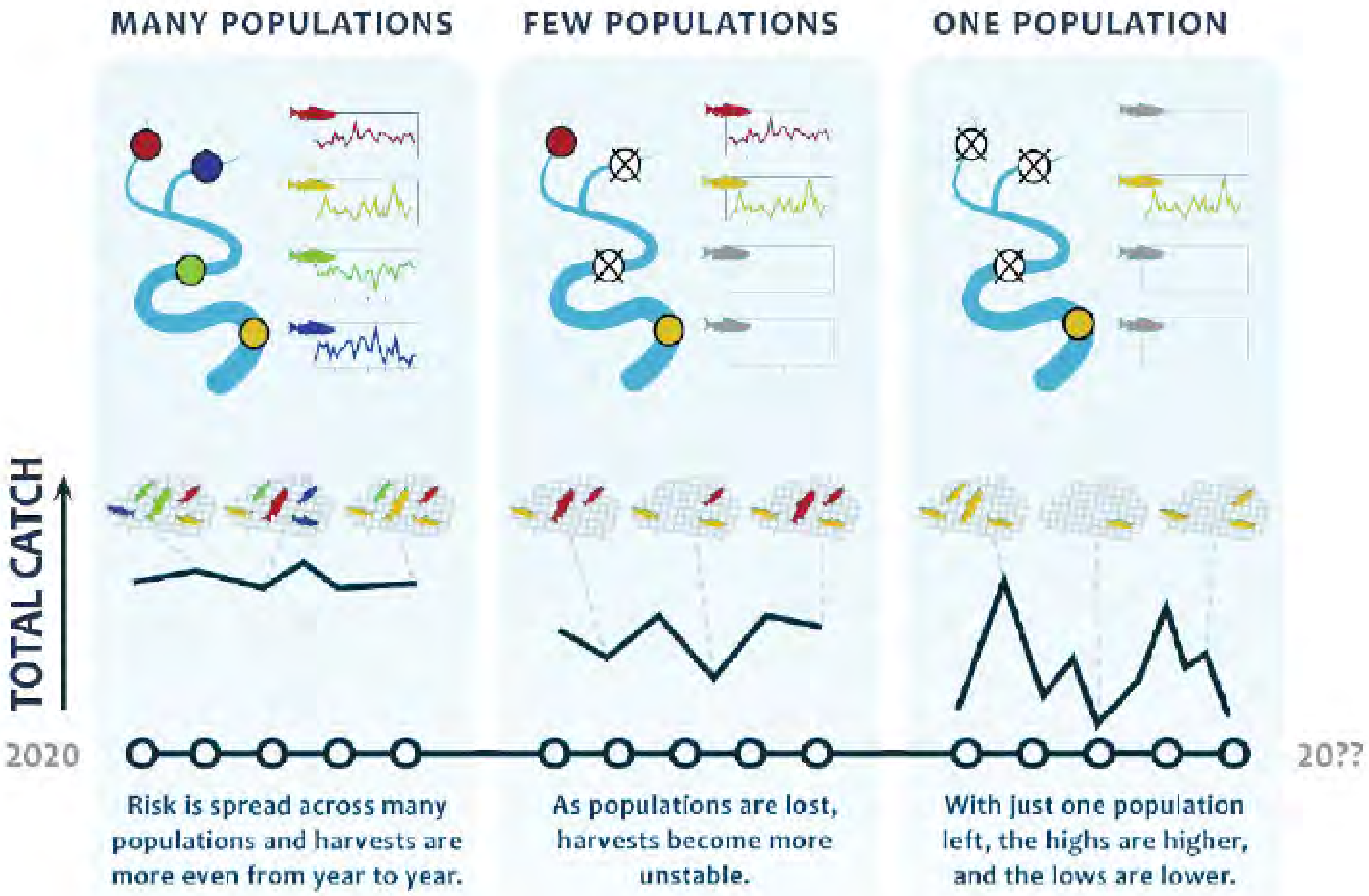


Figure 2: Illustration of how population diversity contributes to harvest stability. When diversity is high, individual populations doing very well can compensate for those that are doing badly, leading to a more stable average harvest over time. When diversity is low, all your eggs are in one basket and so harvest is more unpredictable from year to year

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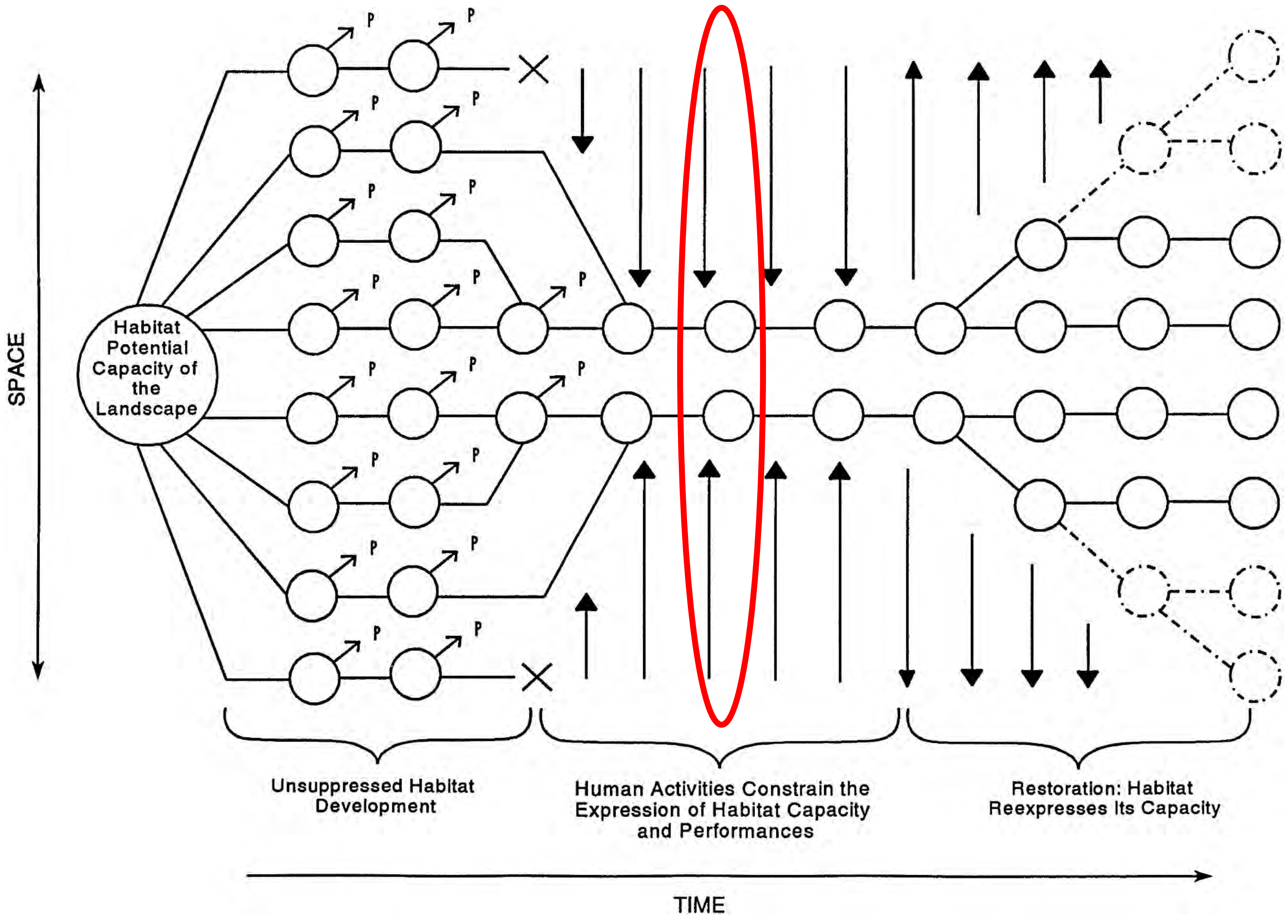

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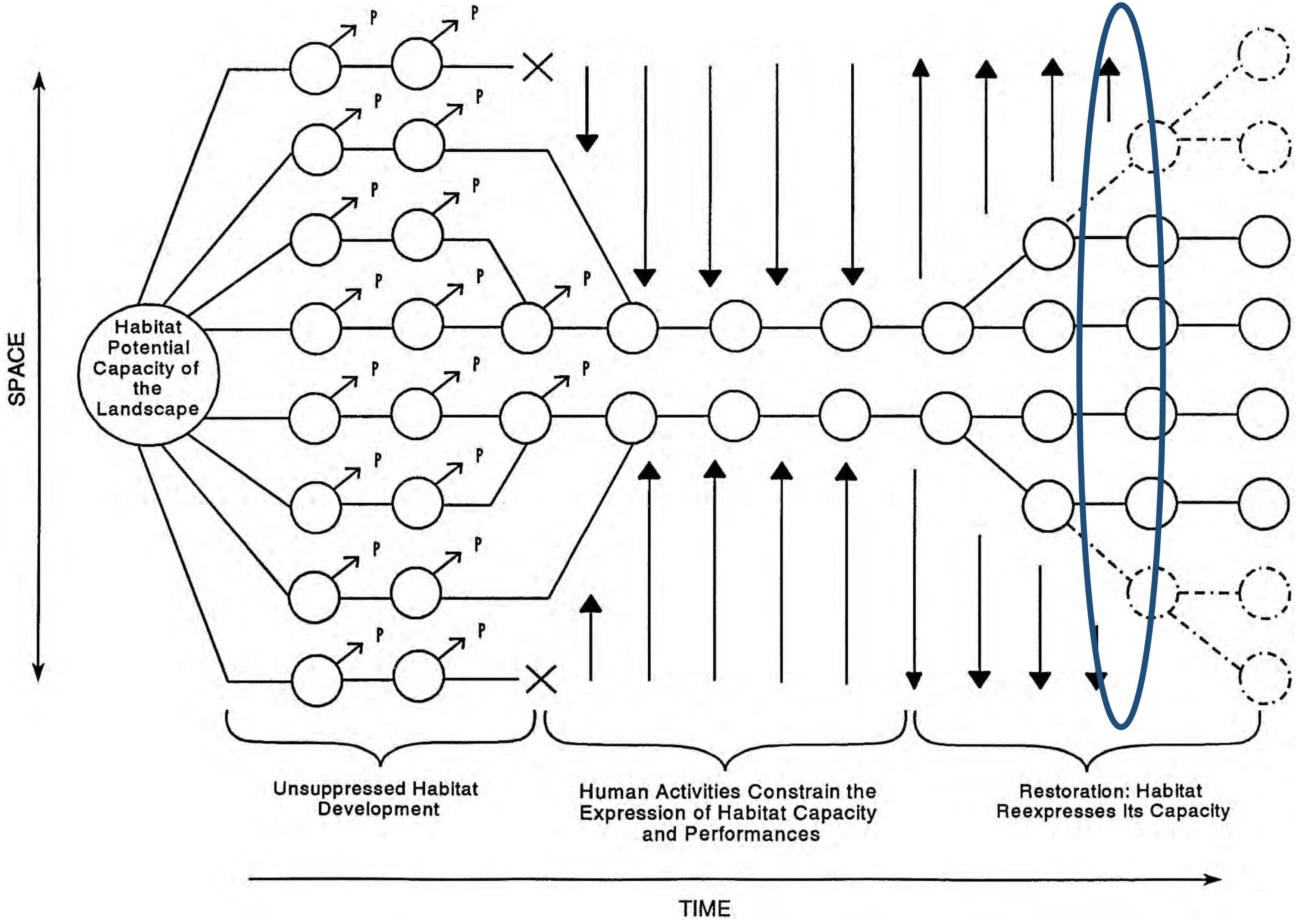

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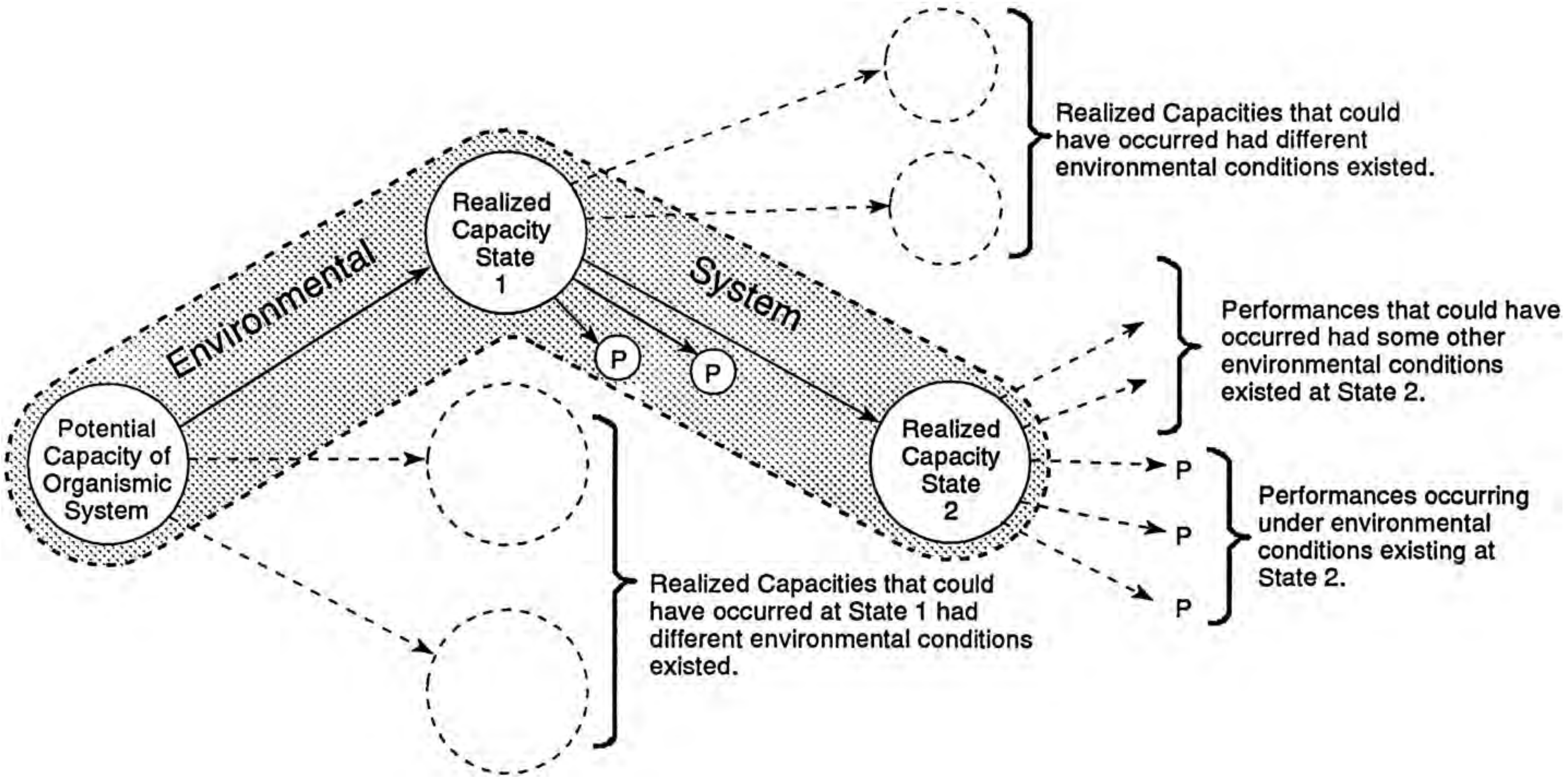

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Bottom, D. L., K. K. Jones, C. A. Simenstad, and C. L. Smith. 2009. Reconnecting social and ecological resilience in salmon ecosystems. *Ecology and Society* 14(1): 5. [online] URL: http://www.ecologyandsociety.org/vol14/iss1/art5/

Guest Editorial, part of a Special Feature on Pathways to Resilient Salmon Ecosystems

Reconnecting Social and Ecological Resilience in Salmon Ecosystems

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ABSTRACT. Fishery management programs designed to control Pacific salmon (*Oncorhynchus* spp.) for optimum production have failed to prevent widespread fish population decline and have caused greater uncertainty for salmon, their ecosystems, and the people who depend upon them. In this special feature introduction, we explore several key attributes of ecosystem resilience that have been overlooked by traditional salmon management approaches. The dynamics of salmon ecosystems involve social–ecological interactions across multiple scales that create difficult mismatches with the many jurisdictions that manage fisheries and other natural resources. Of particular importance to ecosystem resilience are large-scale shifts in oceanic and climatic regimes or in global economic conditions that unpredictably alter social and ecological systems. Past management actions that did not account for such changes have undermined salmon population resilience and increased the risk of irreversible regime shifts in salmon ecosystems. Because salmon convey important provisioning, cultural, and supporting services to their local watersheds, widespread population decline has undermined both human well-being and ecosystem resilience. Strengthening resilience will require expanding habitat opportunities for salmon populations to express their maximum life-history variation. Such actions also may benefit the "response diversity" of local communities by expanding the opportunities for people to express diverse social and economic values. Reestablishing social–ecological connections in salmon ecosystems will provide important ecosystem services, including those that depend on clean water, ample stream flows, functional wetlands and floodplains, intact riparian systems, and abundant fish populations.

Key Words: *fishery management; Pacific Northwest; Pacific salmon; resilience; salmon ecosystem*

INTRODUCTION

In an open letter to the Oregon State legislature in 1875, U.S. Commissioner of Fish and Fisheries Spencer Baird painted a grim future for Pacific salmon (*Oncorhynchus* spp.) in the Columbia River (Baird 1875). Based on the collapse of Atlantic salmon (*Salmo salar*) in Northeast American rivers decades earlier, Baird predicted that Columbia River salmon would suffer a similar fate for the same reasons: habitat loss, excessive harvest, and dams and other impediments to fish migration. The Commissioner enthusiastically endorsed hatchery technology as the means to maintain a stable salmon supply and to avoid the highly unpopular regulatory alternatives. Numerous state and federal fishery management agencies were established thereafter, and Baird's simple formula—artificial fish propagation to compensate for habitat loss and intensive harvest—was institutionalized, setting the priorities for U.S. fishery management for the next century (Bottom 1997).

Despite such early knowledge of the principal threats, Baird's predicted collapse of Columbia River salmon proved quite accurate. The total annual run of all anadromous salmon in the basin, estimated at 10 to 16 million fish before European settlement (Northwest Power Planning Council 1986), has declined to around one million fish, of which approximately 80% or more are now produced artificially in hatcheries (Northwest Power Planning Council 1992, National Research Council 1996, Genovese and Emmett 1997). Of the estimated 385 historical Columbia River populations of five salmon species—chum (*O. keta*), coho (*O. kisutch*), sockeye (*O. nerka*), Chinook (*O. tshawytscha*), and steelhead (*O. mykiss*)—212

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"Of particular importance to ecosystem resilience are large-scale shifts in oceanic and climatic regimes or in global economic conditions that unpredictably alter social and ecological systems"

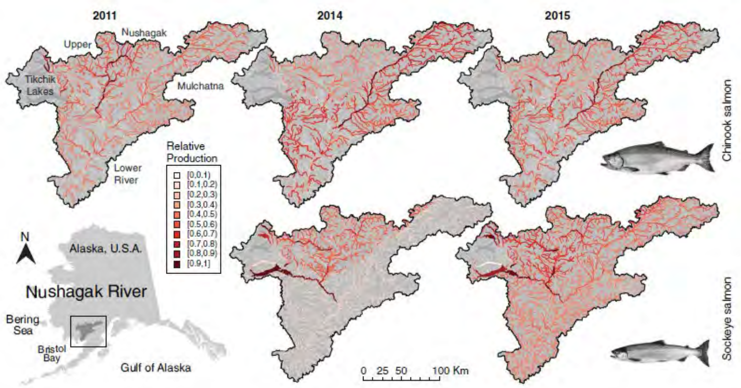
"Strengthening resilience will require expanding habitat opportunities for salmon populations to express their maximum life-history variation"

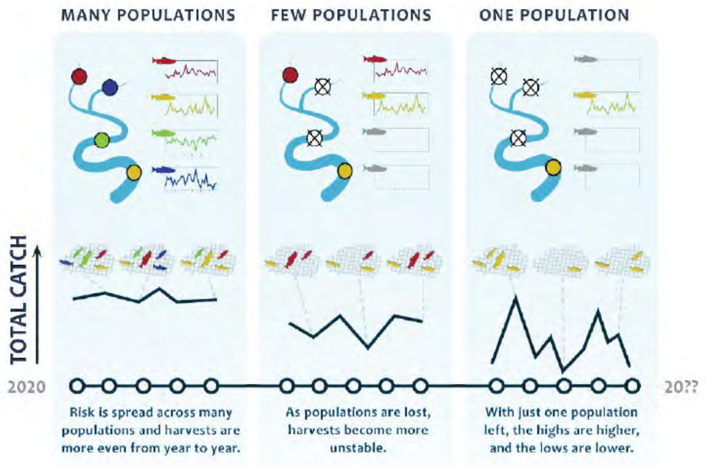
Bottom et al. 2009. Reconnecting social and ecological resilience in salmon ecosystems. Ecology and Society 14(1):5

"First, biologists, managers, and planners need to think in longer time frames than they are generally accustomed to using. They need to acknowledge that ecosystems are dynamic in space and time over these longer periods.

Reeves et al. 1995. A disturbance-based ecosystem approach to maintaining and restoring freshwater habitats of evolutionarily significant units of anadromous salmonids in the Pacific Northwest. American Fisheries Society Symposium 17:334–349.

“Shifting habitat mosaics are a central feature of what makes ecosystems resilient. Because patterns of high and low production, or conditions most suitable for growth, shift among locations through time, the biological performance of a landscape tends to be more reliable at aggregate spatial scales. This means that conservation of the processes that generate and maintain heterogeneity and connectivity across landscapes (e.g., fires, floods, and migration) is as important as the biological communities that they support”





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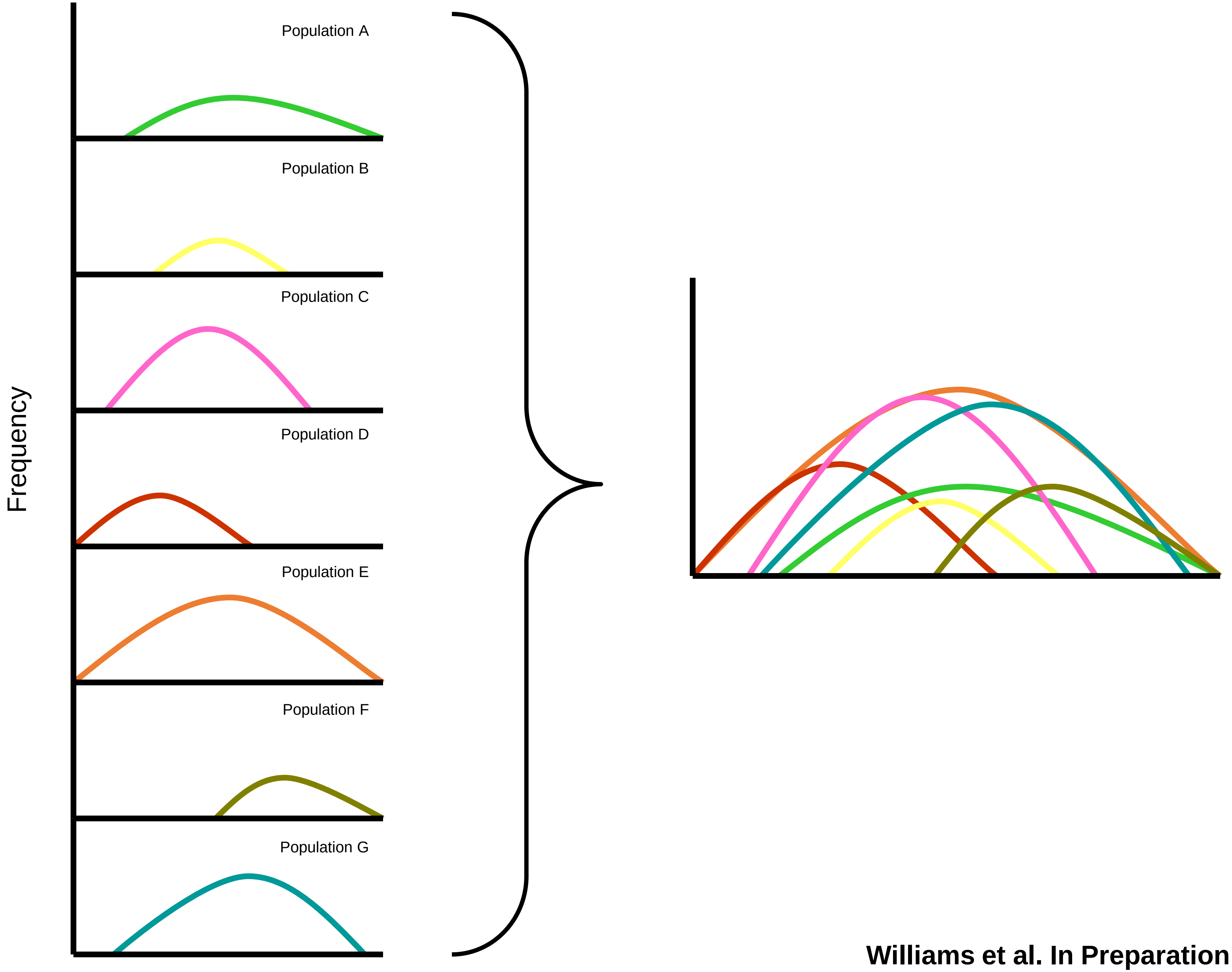

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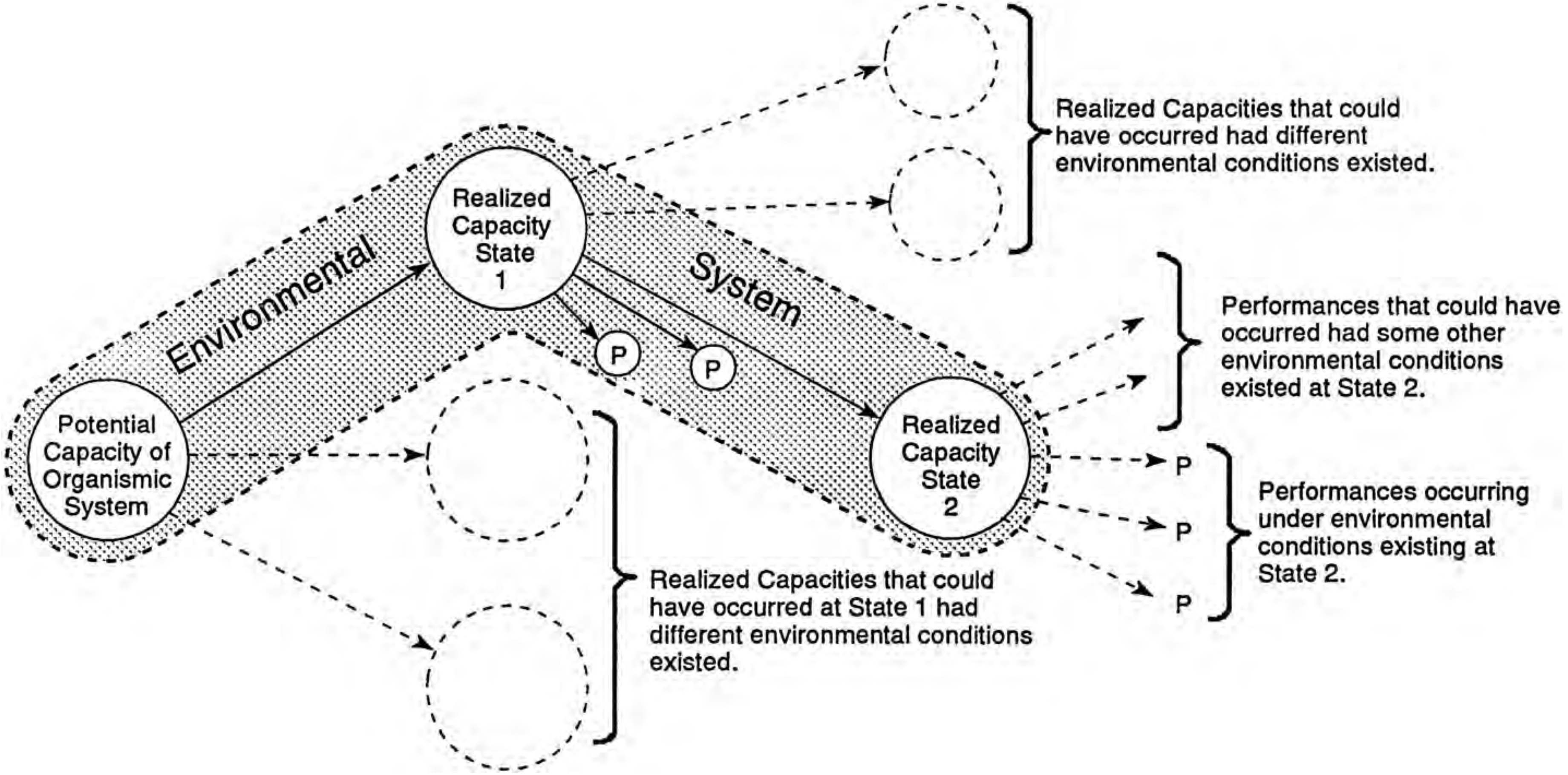

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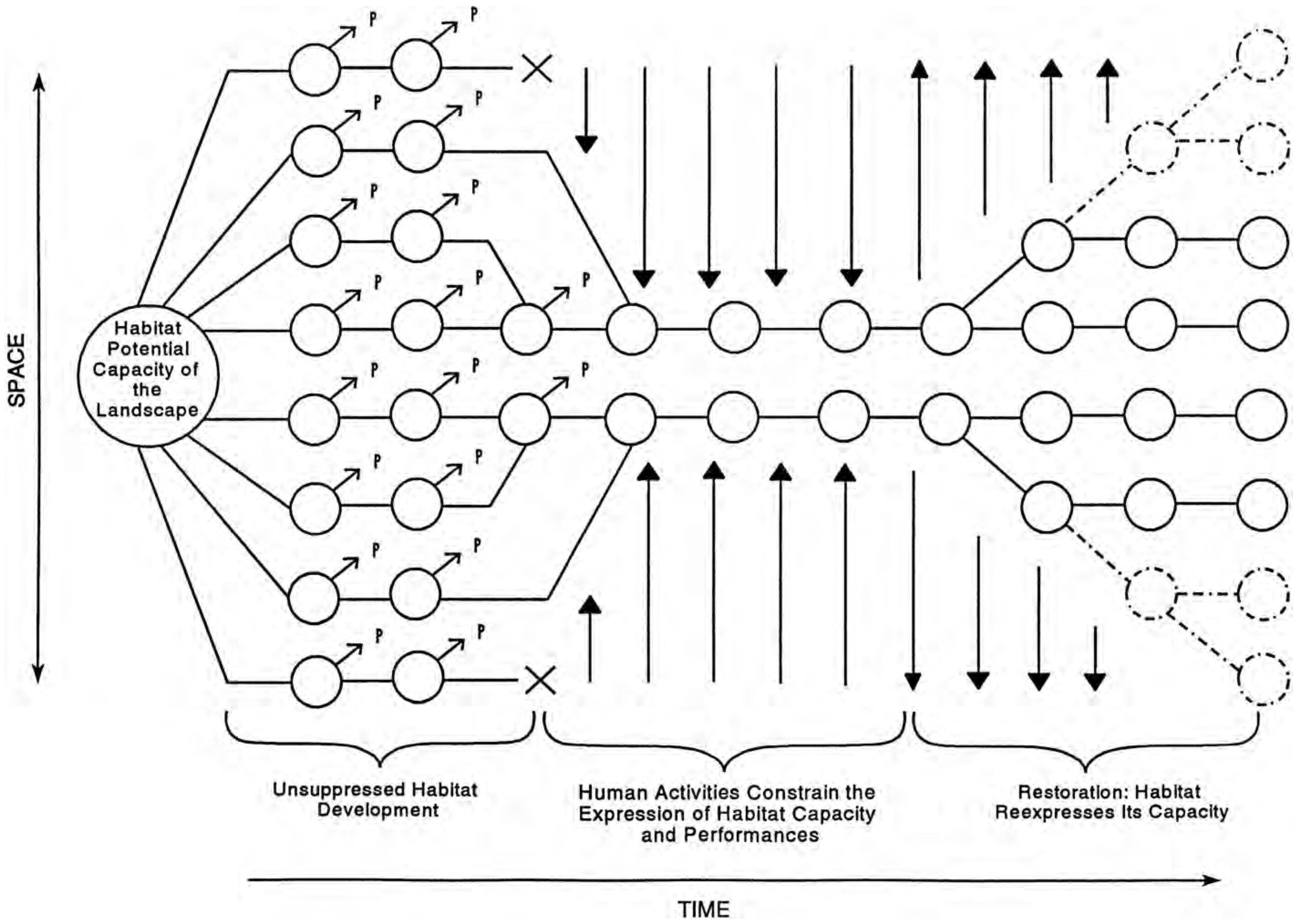

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What does success look like? A future landscape connected hydraulically, geomorphically, ecologically, etc. at a spatial and temporal scale that allows fish to move across the landscape to track changing environmental conditions and disturbances. The greater the connectivity for each level of biological organization (individuals, families, populations, etc.) the more likely we will have resilient fish populations supporting a range of interests and expectations.

D. Chase