Modeling Salmonid Habitat: Stream State, Forest Conditions, and Future Climates

A Concurrent Session at the 40th Annual Salmonid Restoration Conference held in Fortuna, California from April 25−28, 2023

Session Coordinators:

- Jonathan Halama, MPH, PhD, US EPA

This session's focus is modeling of salmonid habitats from an aquatic stream reach to full watershed scale. Through the sharing of ideas and techniques we can further endeavors toward strengthening salmonid populations through the improvement of both the fish's direct habitat and the surrounding area (riparian zone to the ridgeline) that all ultimately influence habitat conditions. Modeling efforts that help us further understand summer low flow conditions, mitigate winter flooding, reduce high summer stream temperatures, and improve cold-water refuges will be the focus of this session. A welcomed component will be any modeling techniques that possess the inclusion of climate change scenarios within the watershed evaluations to better understand and help mitigate how future climate conditions may impact the state of salmonid habitats. This session brings together people focused on modeling to share techniques and results to improve our understanding and enhance our watershed planning in hopes to maintain and improve critical salmonid habitat.

Presentations

- Slide 4, **Habitat Mosaics Support Variation in Salmon Foraging and Growth Potential Under Extreme Drought Conditions**, Rachael E. Ryan, Ph.D. Candidate, *University of California Berkeley*
- Slide 56, **Modeling Benefits of Refuge Habitat for Salmonid Populations with InSTREAM**, Steven F. Railsback, Ph.D. and PD, *Lang Railsback & Associates*
- Slide 80, **Modeling the Influences of Diversions and Forest Practices on Streamflow in Streeter Creek near Laytonville, CA**, Julia Petreshen, *Thomas Gast & Associates*
- Slide 104, **Habitat Modeling of Salmonid Movement and Survival in Degraded and Restored Watersheds**, Greg Blair, *ICF*
- Slide 129, **Individual-based Modeling of Stage 0 Treatment on Juvenile Chinook**, Aleah Hahn, MS Student, *Oregon State University*
- Slide 153, **Streams Across Lands (SAL): A New Stream Flow Modeling Method**, Jim Graham, PhD, Associate Professor, *Cal Poly Humboldt*
- Slide 188, **Predicting Fish Movement near Infrastructure in Different River and Reservoir Environments**, R. Andrew Goodwin, Ph.D., PE, *Environmental Laboratory, U.S. Army Engineer Research and Development Center*

Habitat mosaics support juvenile salmon persistence & variation during extreme drought

Rachael Ryan, Ted Grantham, Stephanie Carlson

University of California Berkeley

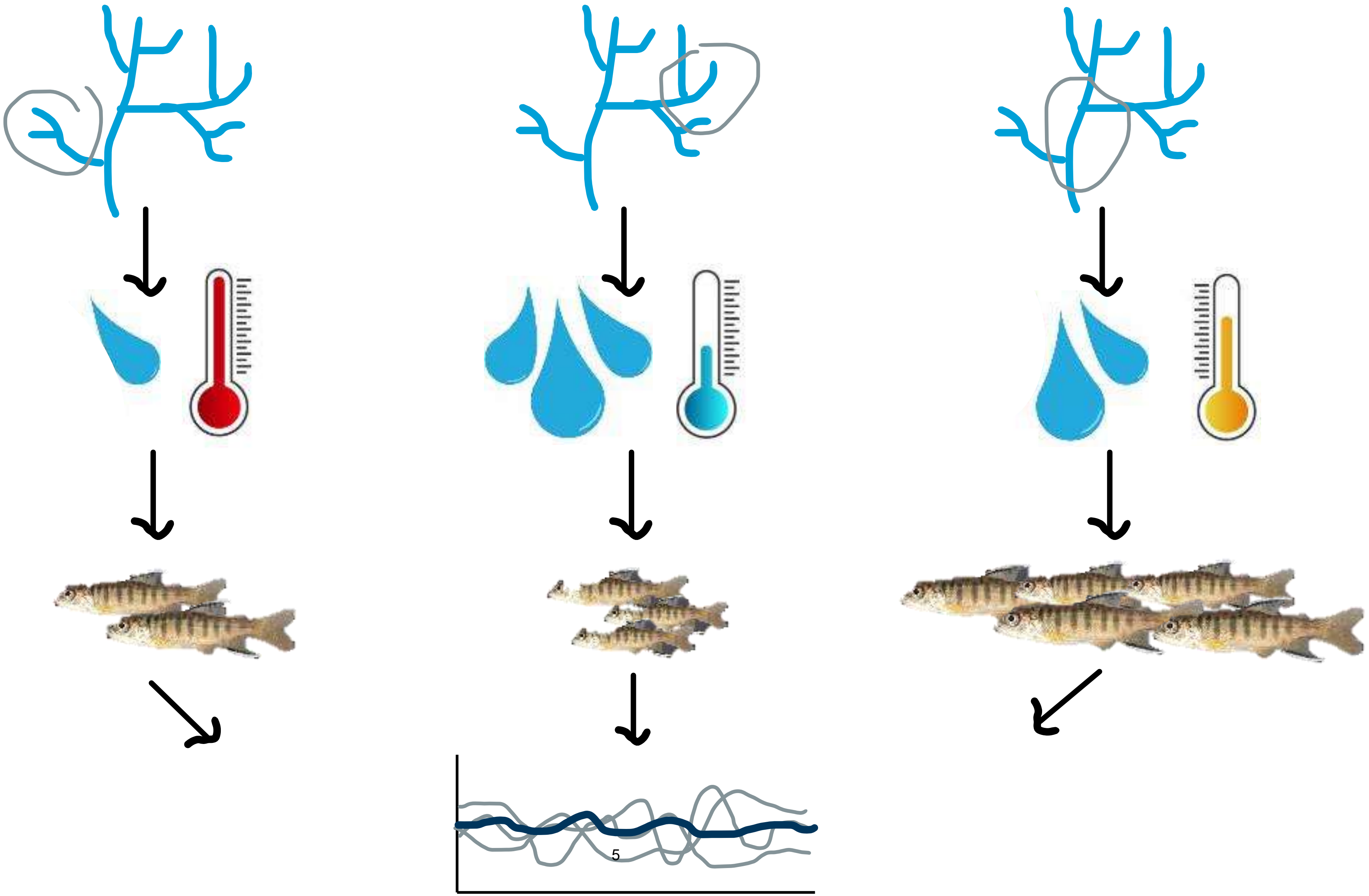
Habitat mosaics lead to population diversity

Diverse watersheds

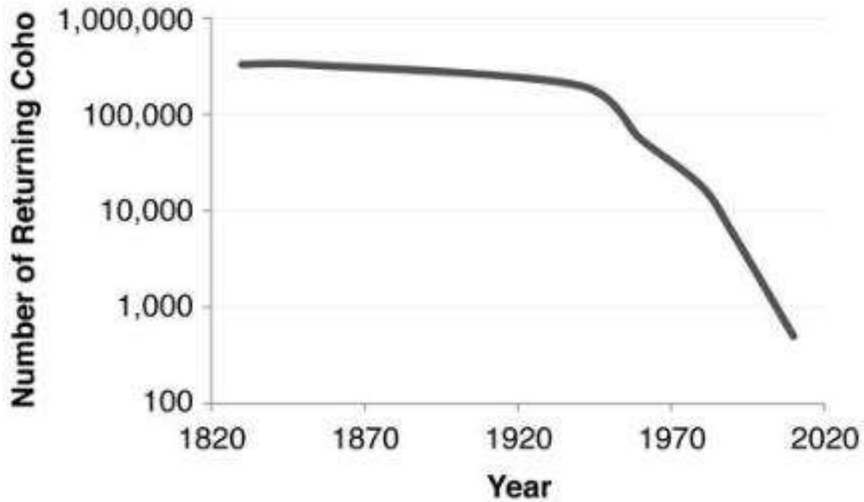
Environmental filtering

Variation in traits & production

Long-term population stability



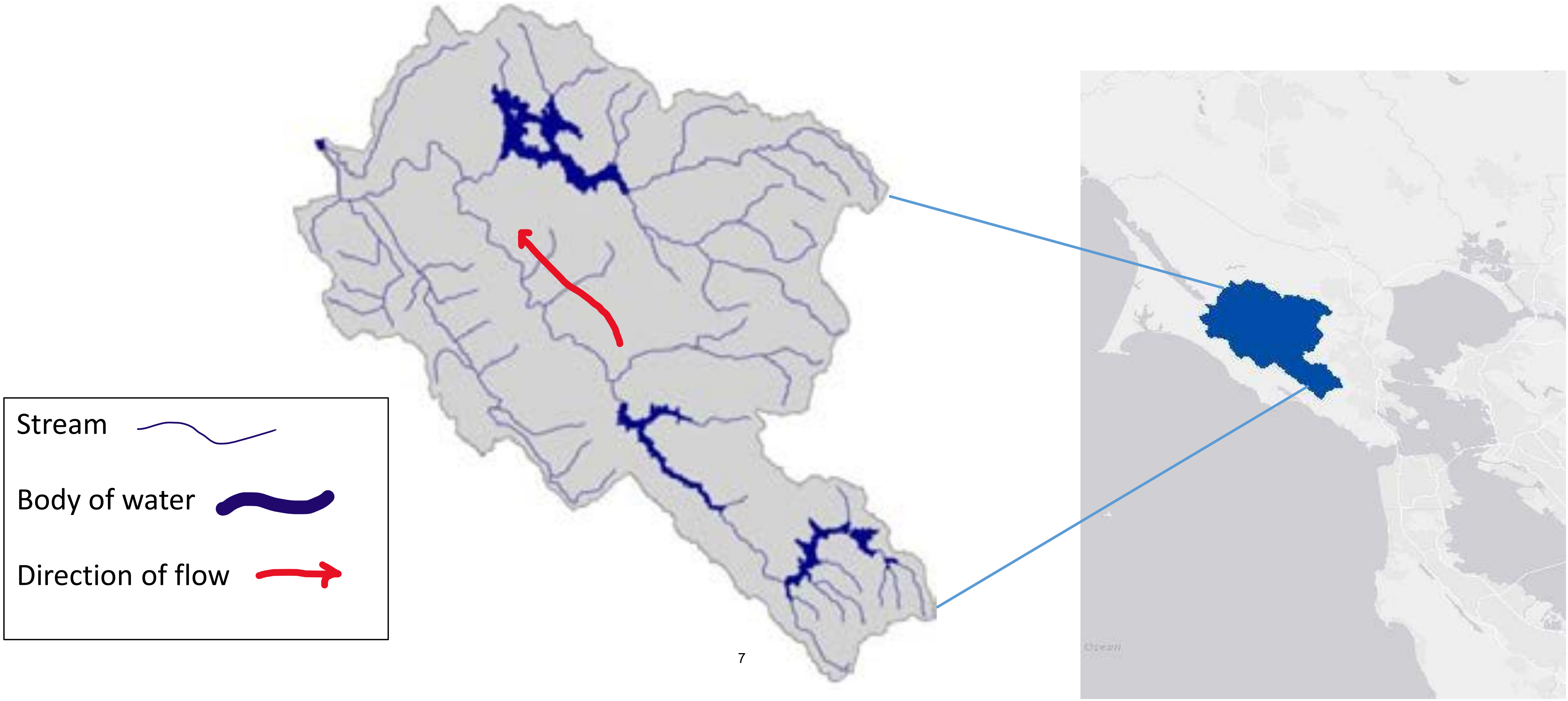
Critically endangered Central California Coast Coho Salmon in the Lagunitas Creek Watershed



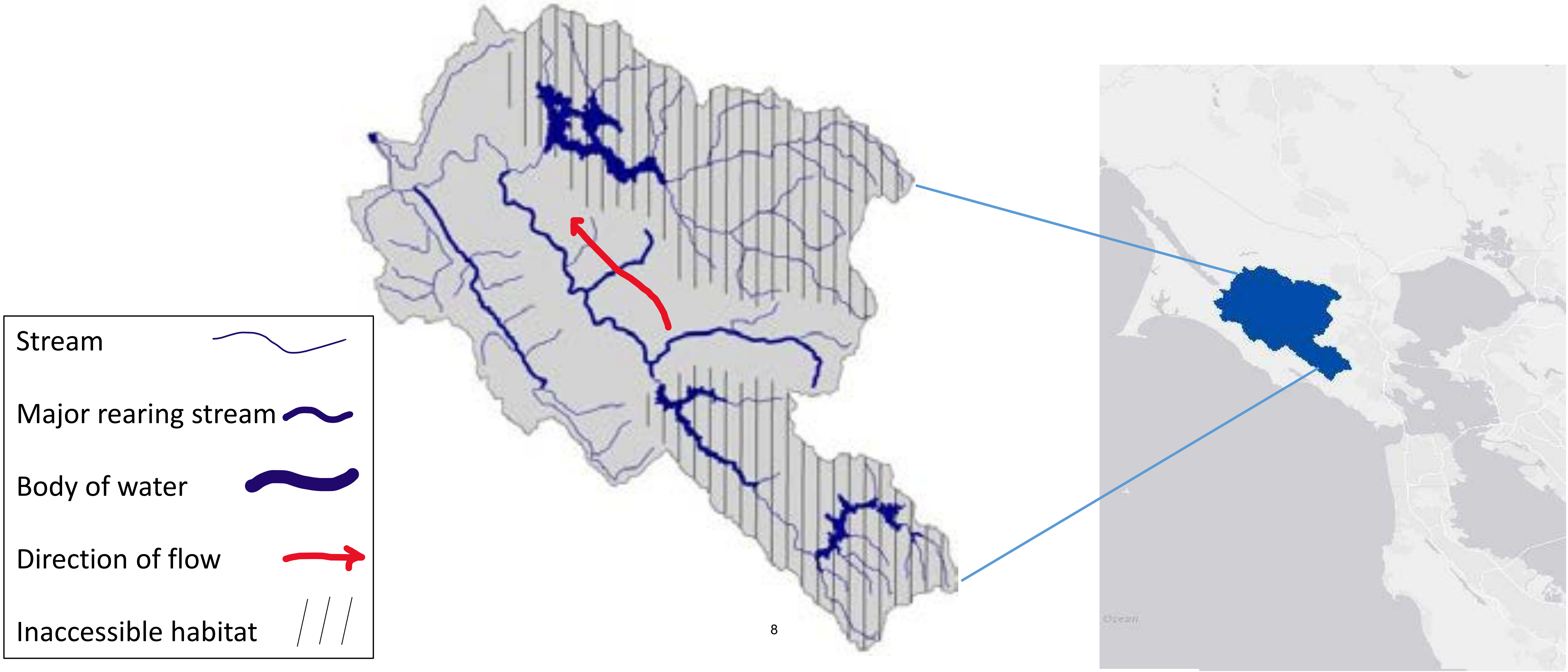
Source: Peter Moyle (2011), based on information from Brown et al. (1994), NMFS 2007 and Katz et al. (2011)

Photo credit: Ramin Rahimian

Stronghold of natural-spawning Coho Salmon population at southern edge of range



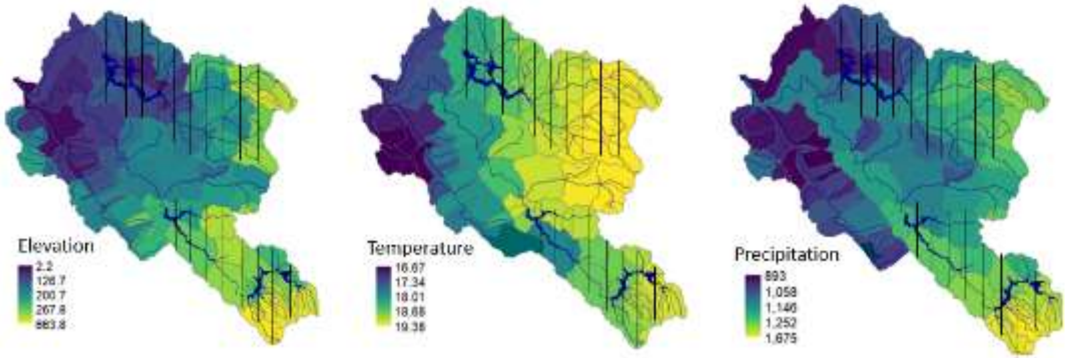
Heavily modified watershed, half of habitat blocked



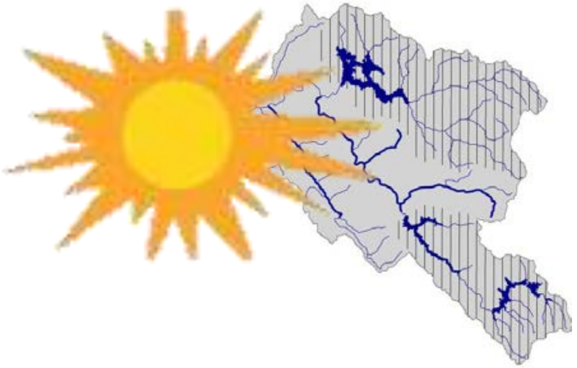
Juvenile salmon vulnerable during summer rearing

↑ **drought intensity**

↓ **landscape diversity**



↑ **fragmentation**



How do habitat mosaics lead to differential impacts of drought and juvenile outcomes?

Streams across the watershed

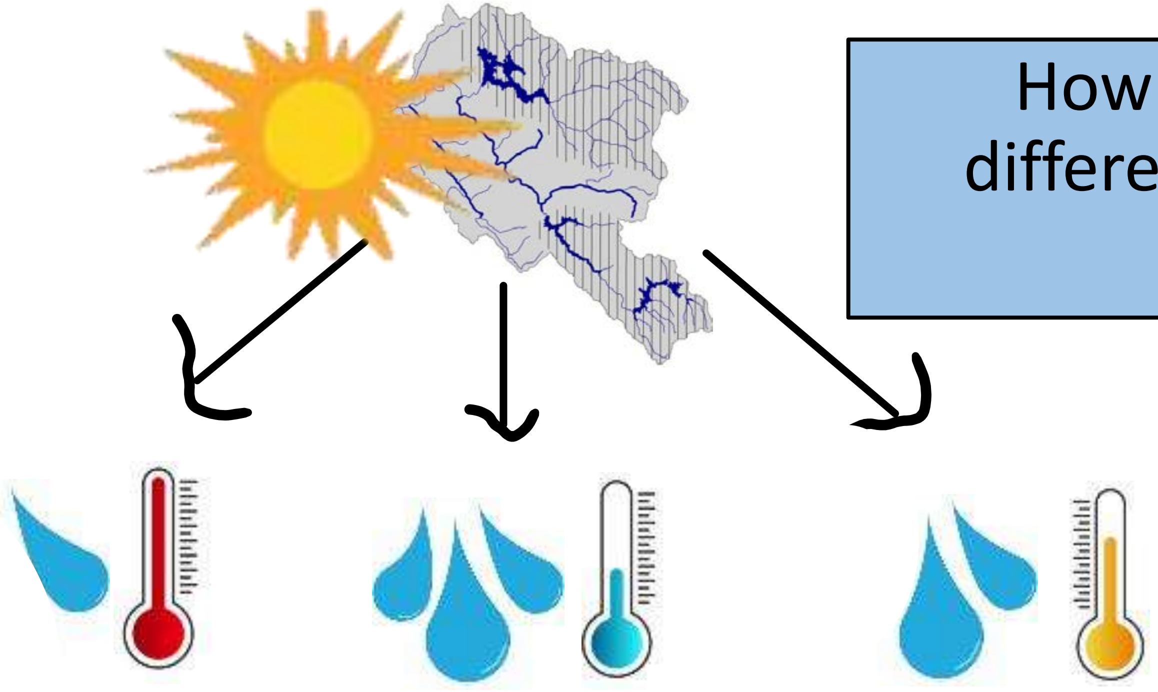
Instream habitat conditions

Invertebrate availability

Foraging behaviour & growth potential

How do habitat mosaics lead to differential impacts of drought and juvenile outcomes?

Streams across the watershed



Instream habitat conditions

1. Characterize instream conditions of the watershed across space and time.

Invertebrate availability

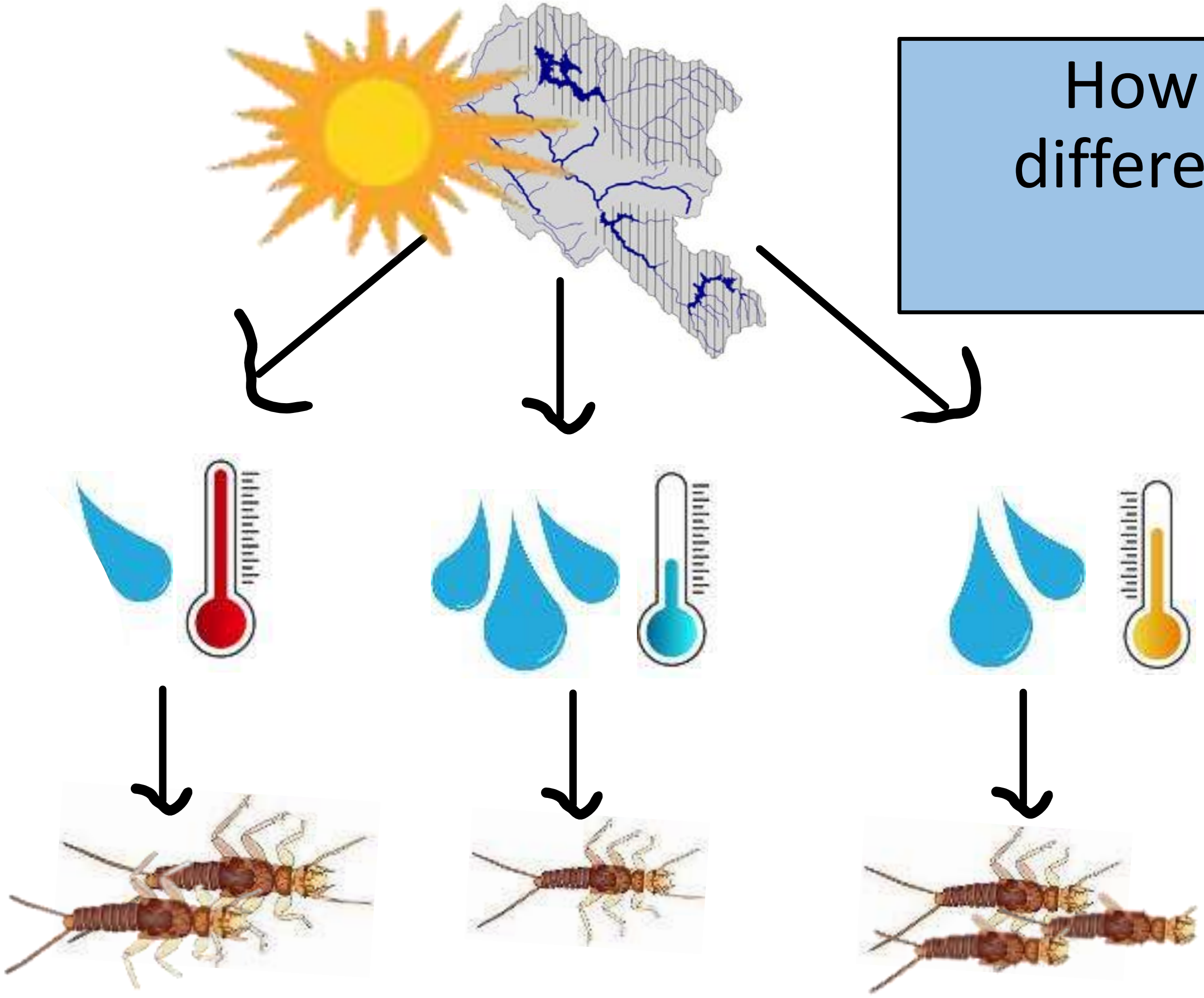
Foraging behaviour & growth potential

Streams across the watershed

Instream habitat conditions

Invertebrate availability

Foraging behaviour & growth potential



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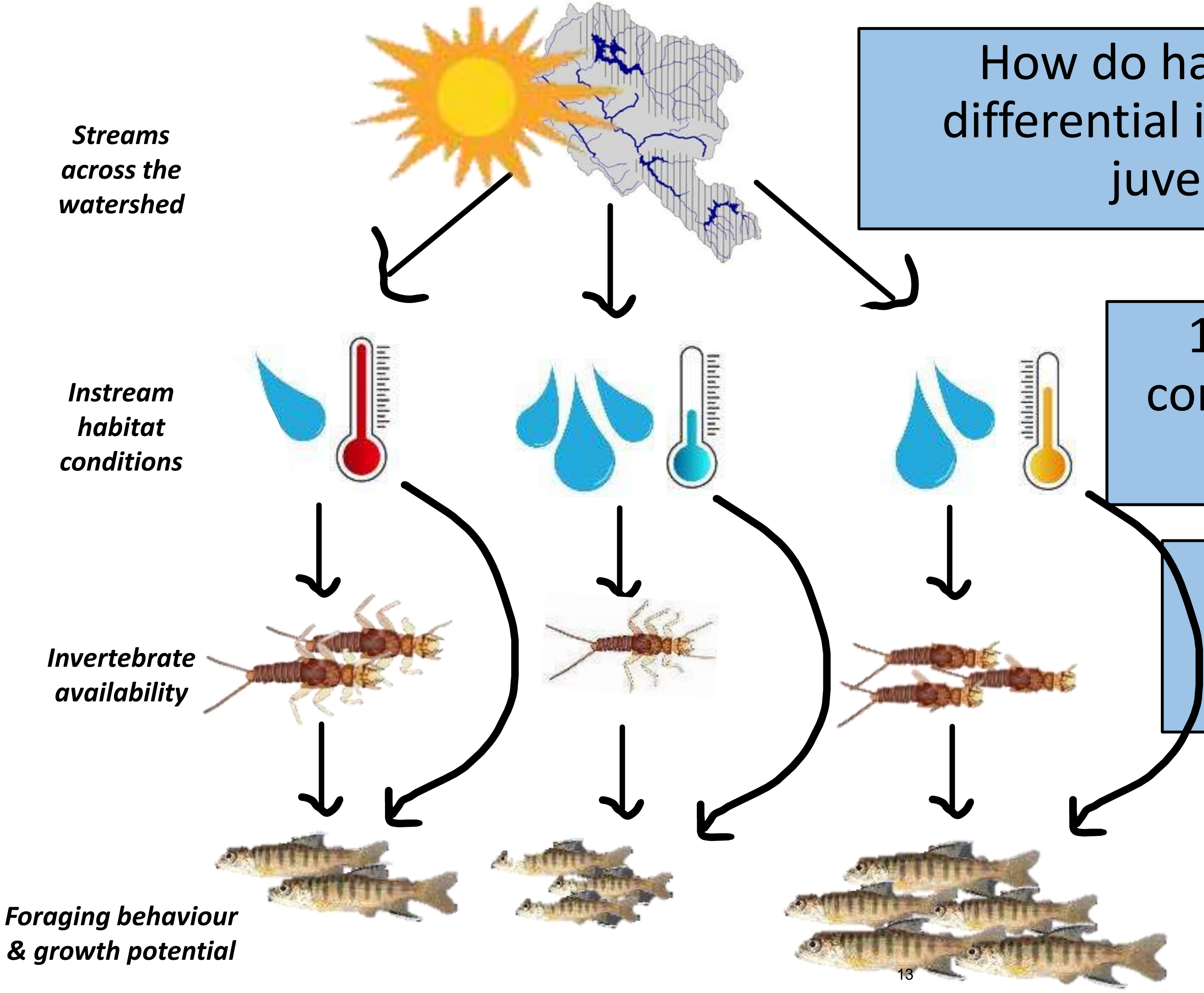
1. Characterize instream conditions of the watershed across space and time.

2. Assess spatiotemporal variation in invertebrate production.



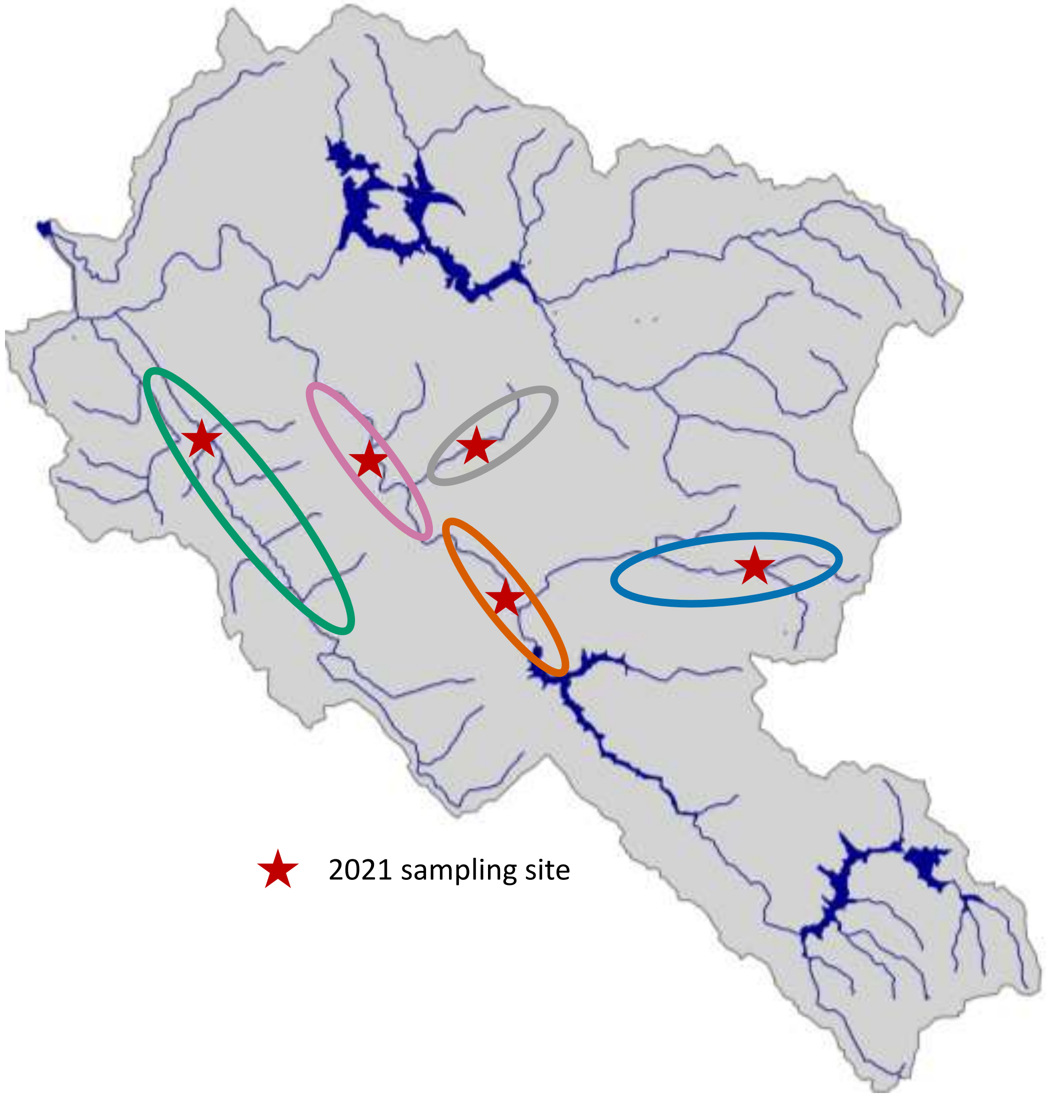
How do habitat mosaics lead to differential impacts of drought and juvenile outcomes?

1. Characterize instream conditions of the watershed across space and time.

2. Assess spatiotemporal variation in invertebrate production.

3. Connect abiotic & biotic variation to juvenile coho traits.

Summer 2021 Sampling Methods



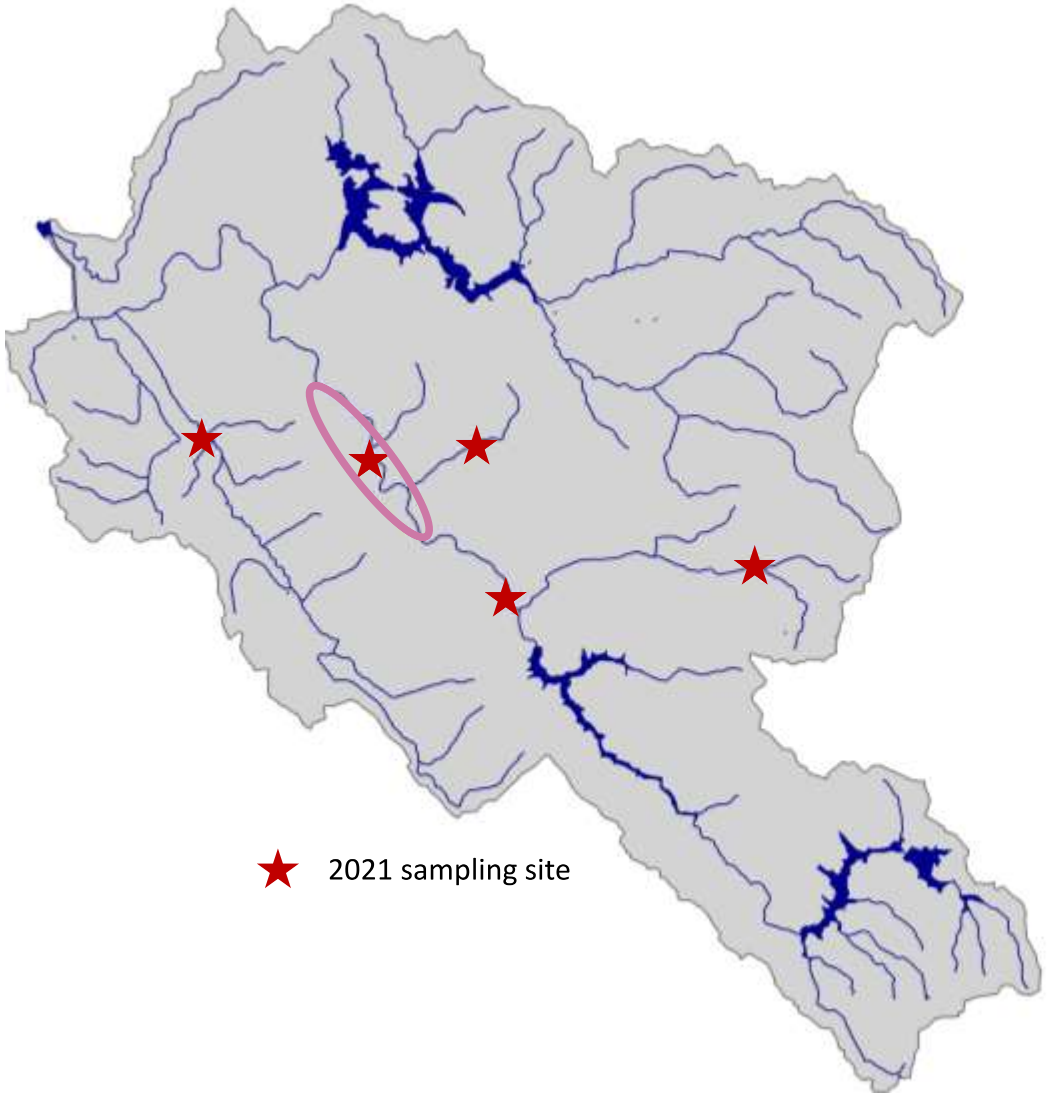
SPATIAL:

5 sites, 3 pools/site across 4 streams

Large --- Small

Perennial --- Intermittent

Summer 2021 Sampling Methods



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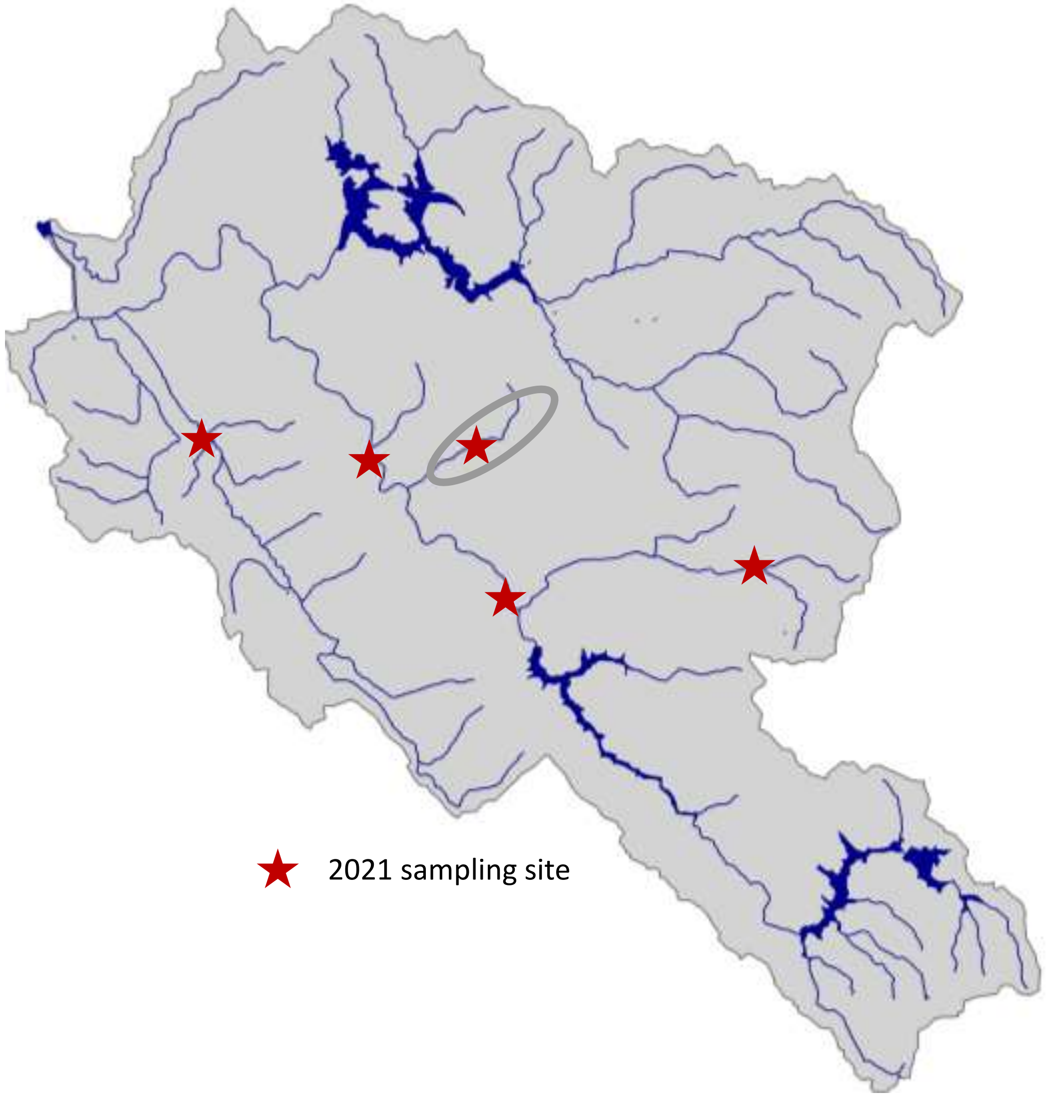


SPATIAL:

5 sites, 3 pools/site across 4 streams

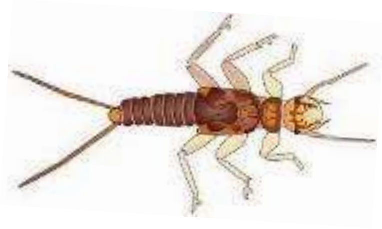
Summer 2021 Sampling Methods

TEMPORAL:

May, June, July

Summer 2021 Sampling Methods

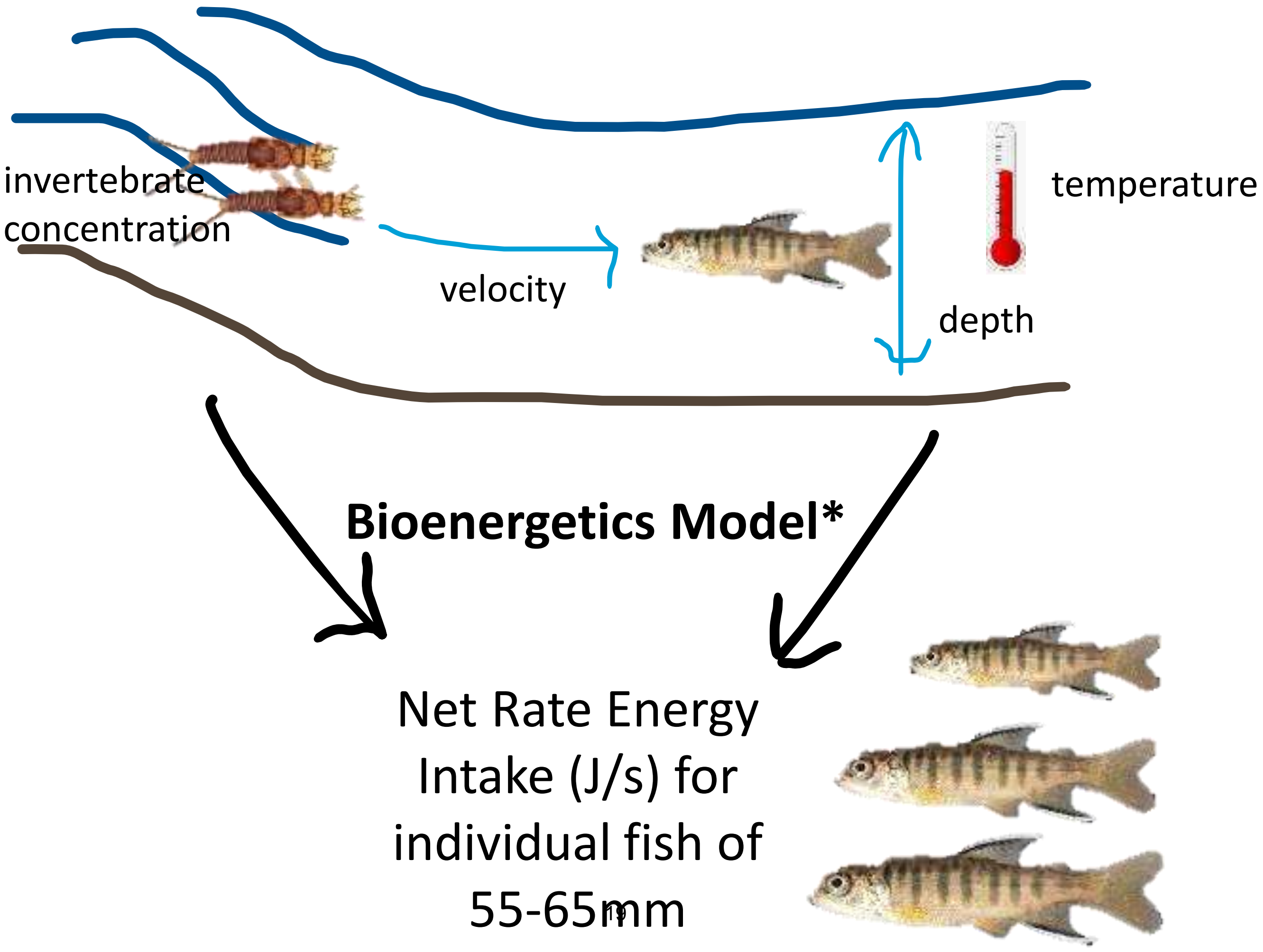
Instream habitat



Aquatic macroinvertebrates

Fish behaviour & growth potential

Growth potential (NREI) of juvenile fish influenced by physical habitat and invertebrate biomass



*Using BioenergeticHSC software, Naman et al. 2020

Instream conditions available to juvenile Coho Salmon at beginning of summer varied across the watershed

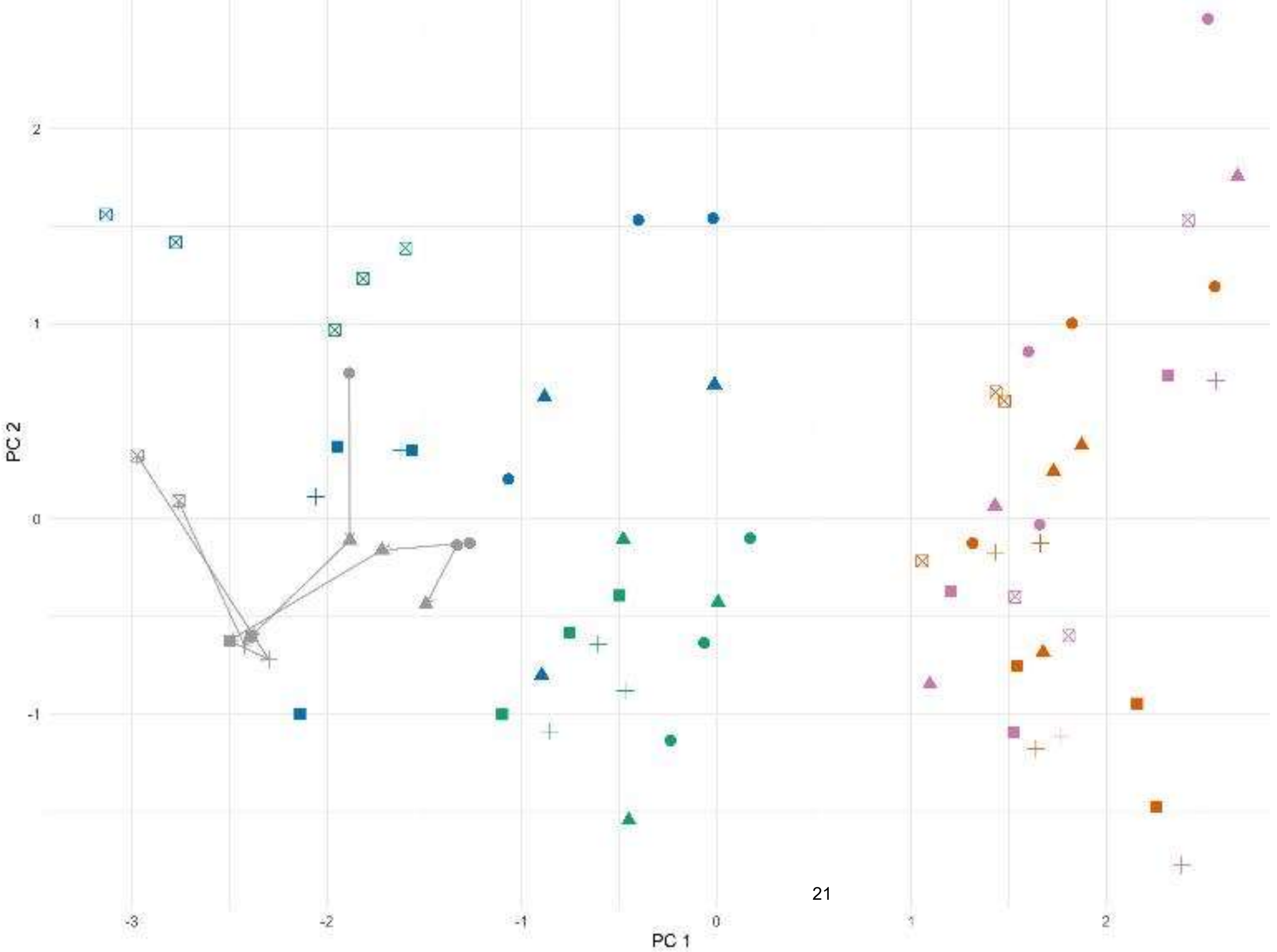


Figure Credit: Jiashu Chen, UC Berkeley Sophomore

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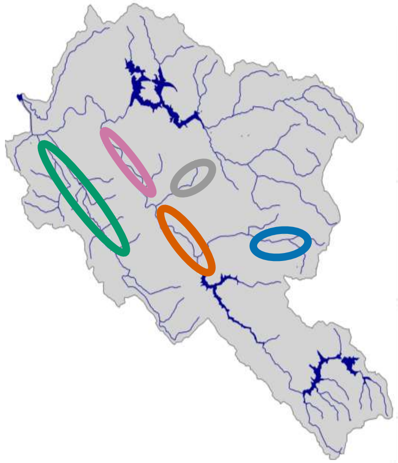

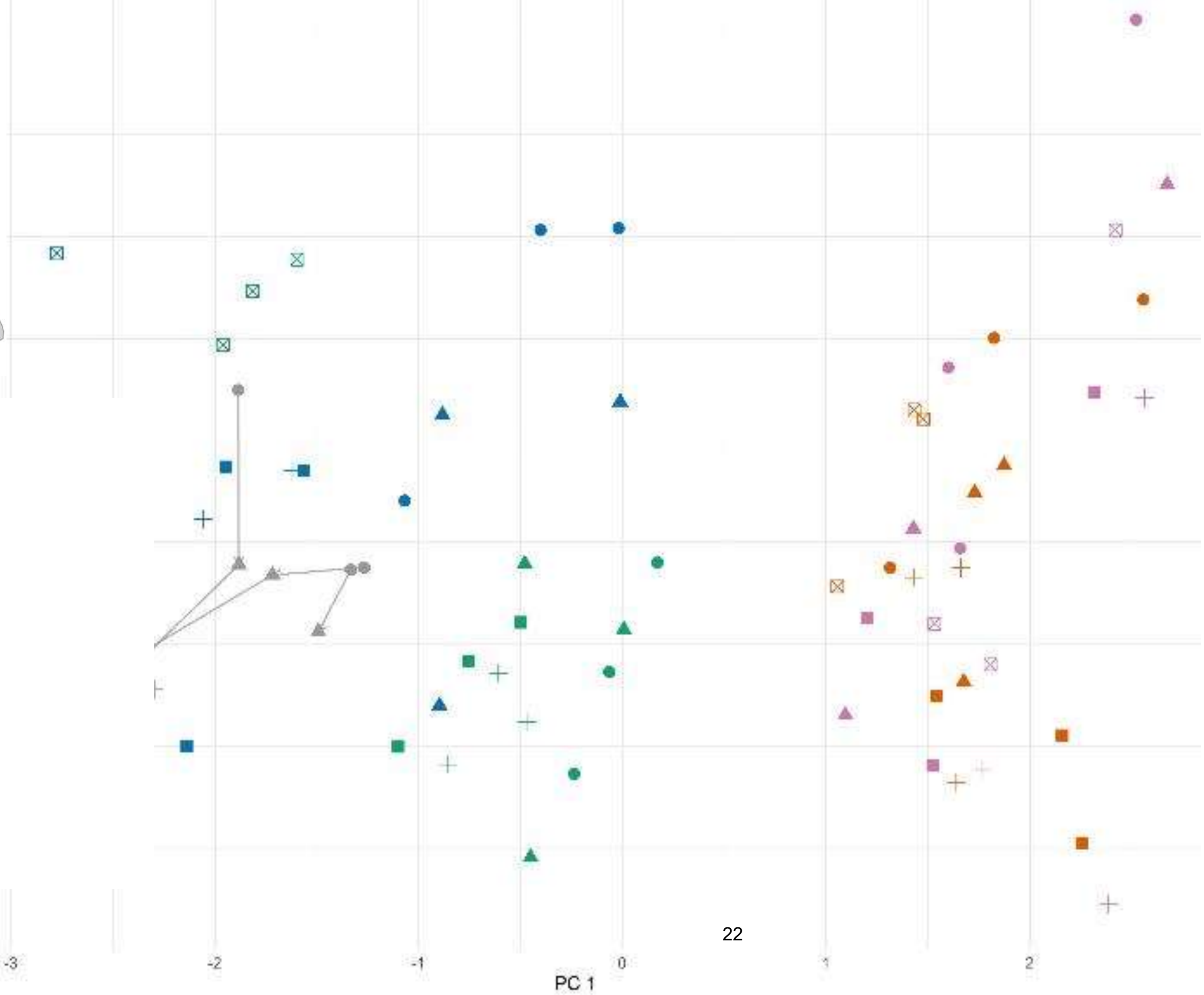

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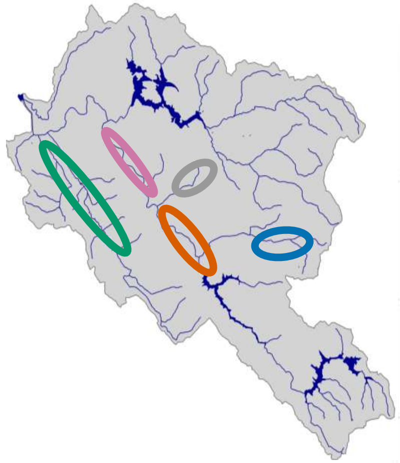

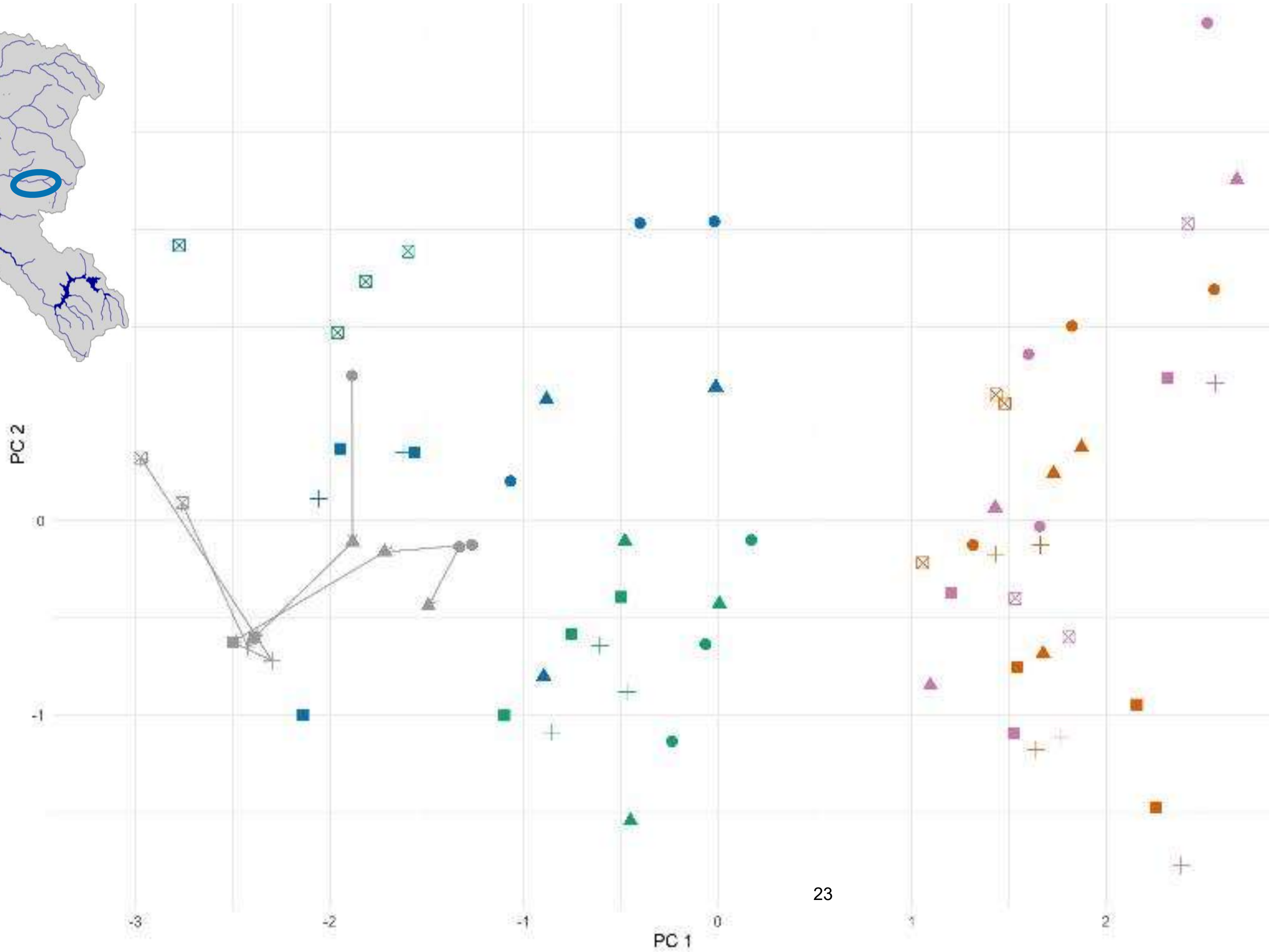

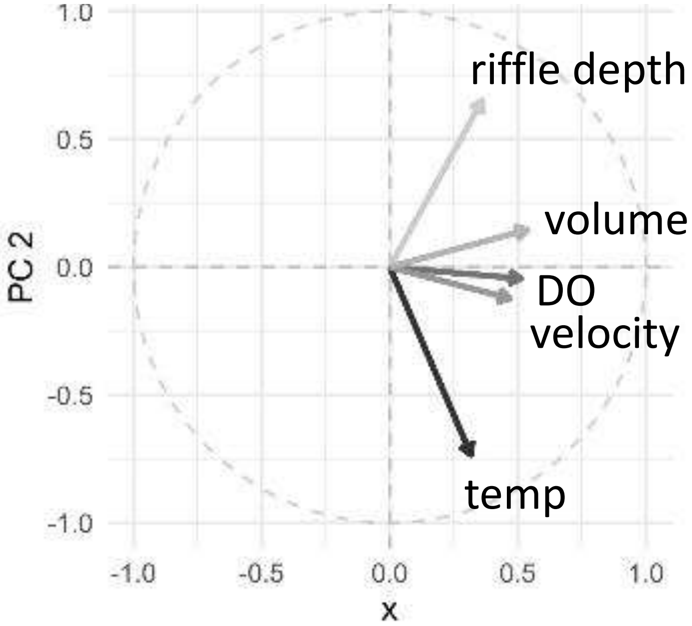

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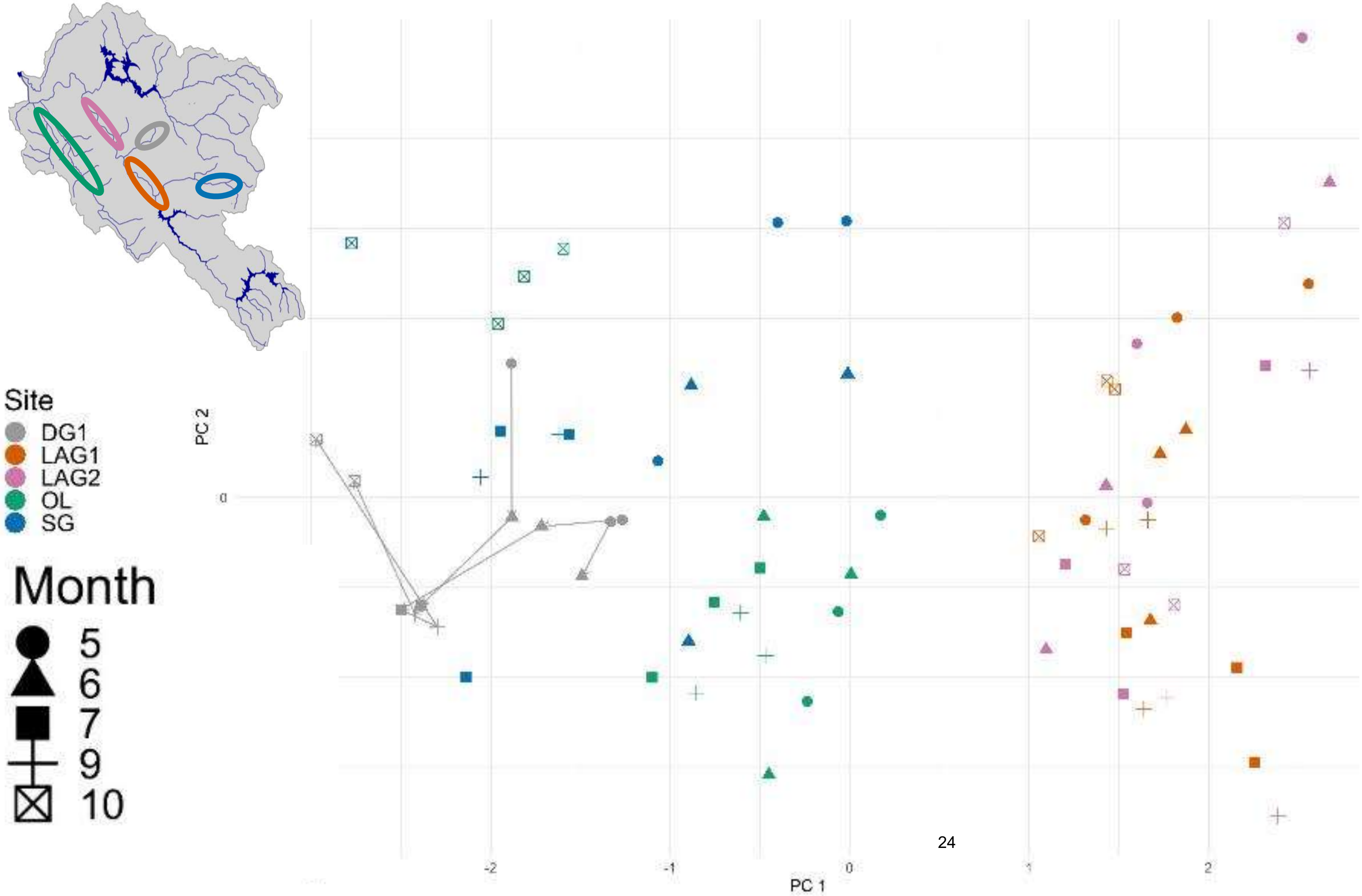


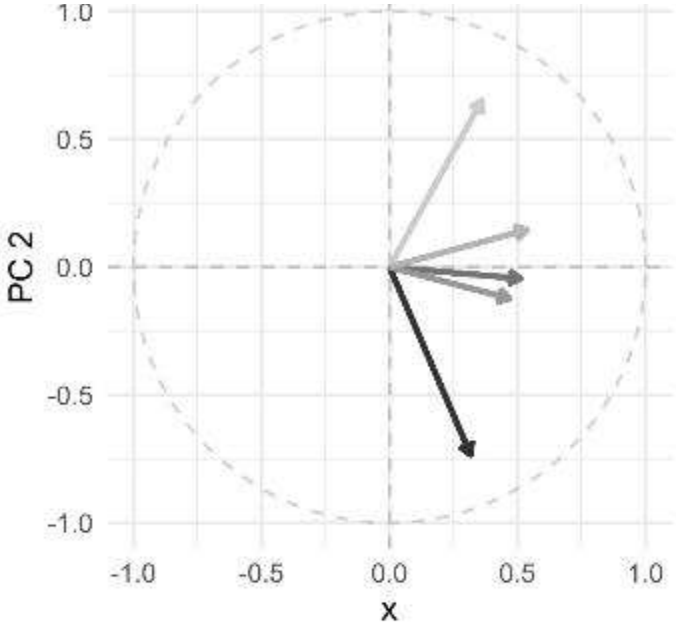
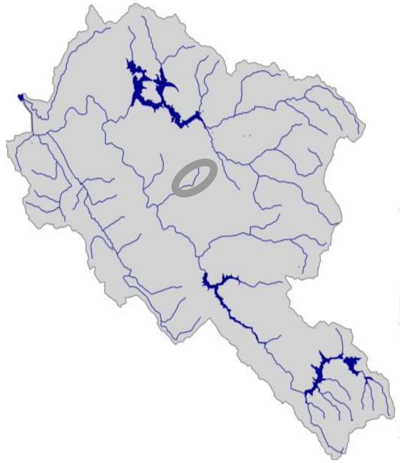
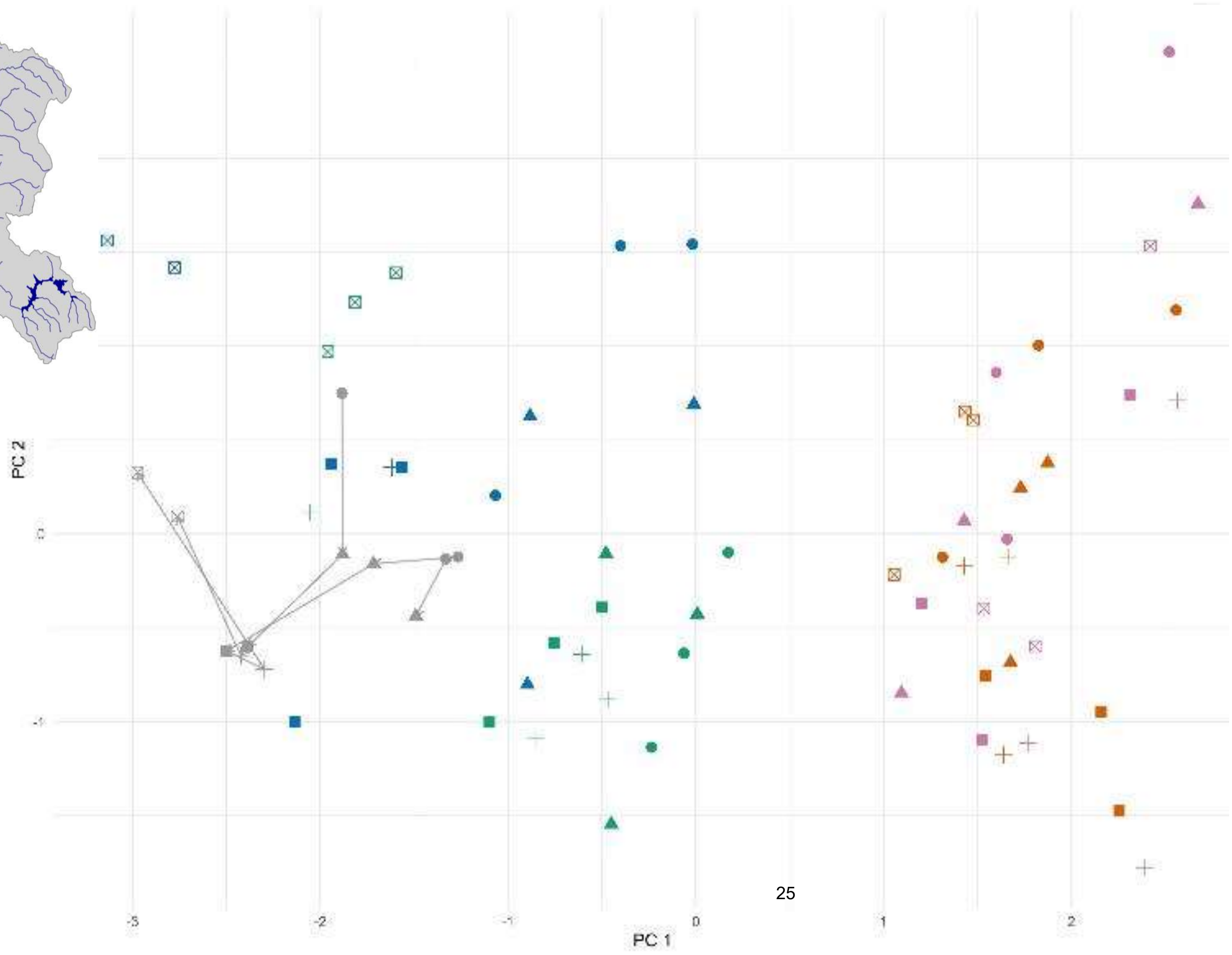
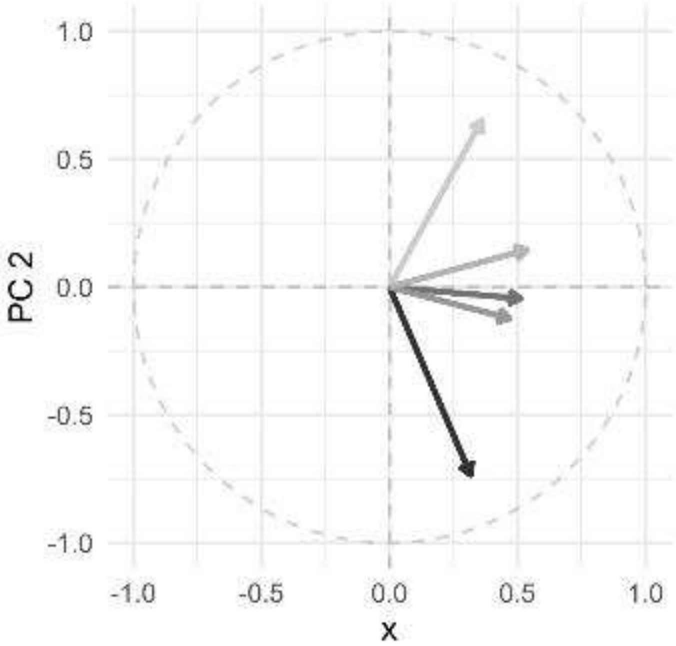


Figure Credit: Jiashu Chen, UC Berkeley Sophomore

As drought intensified, differences in instream conditions more pronounced







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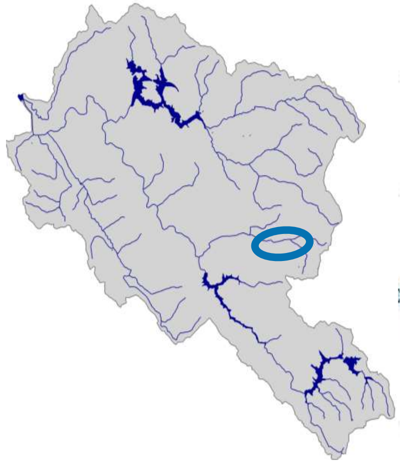

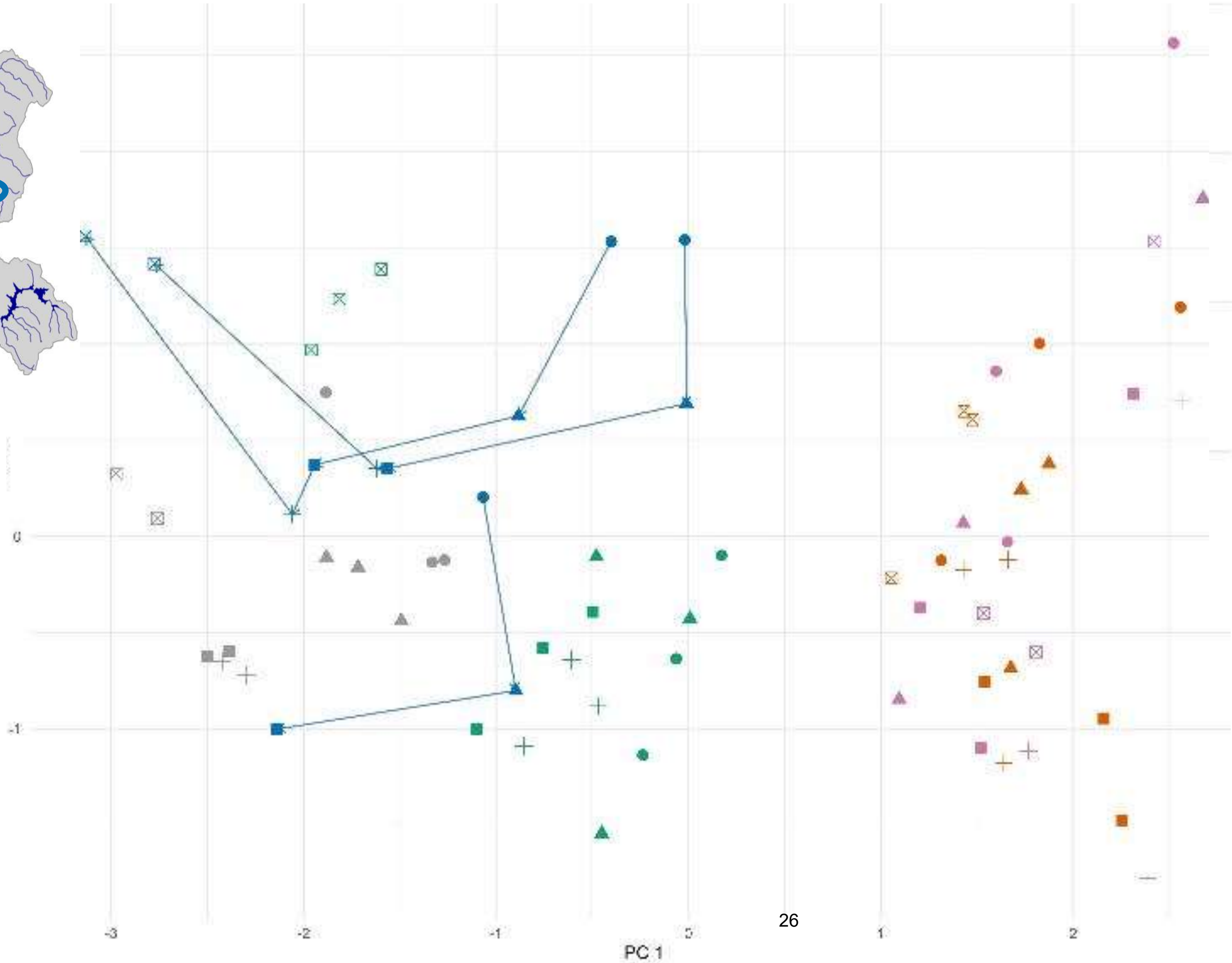

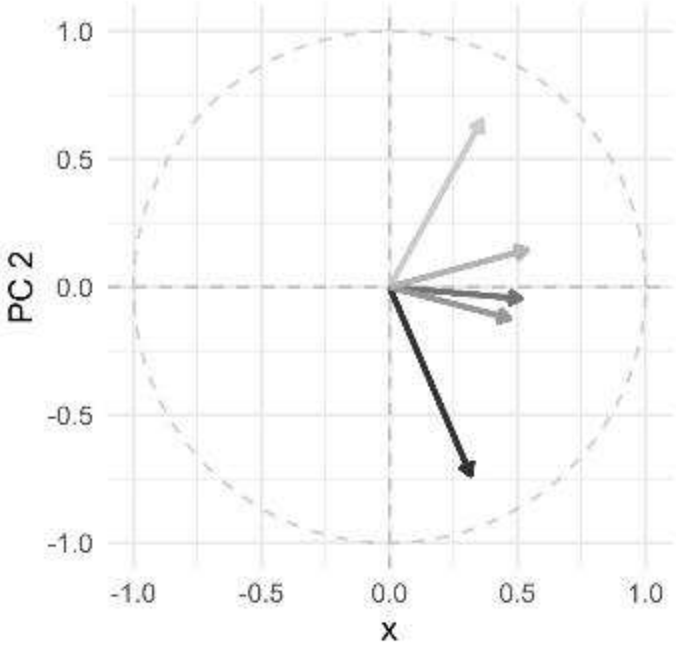

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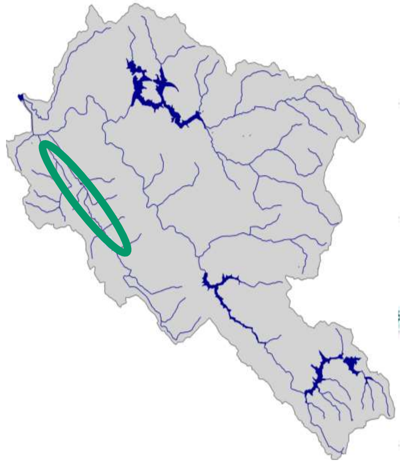

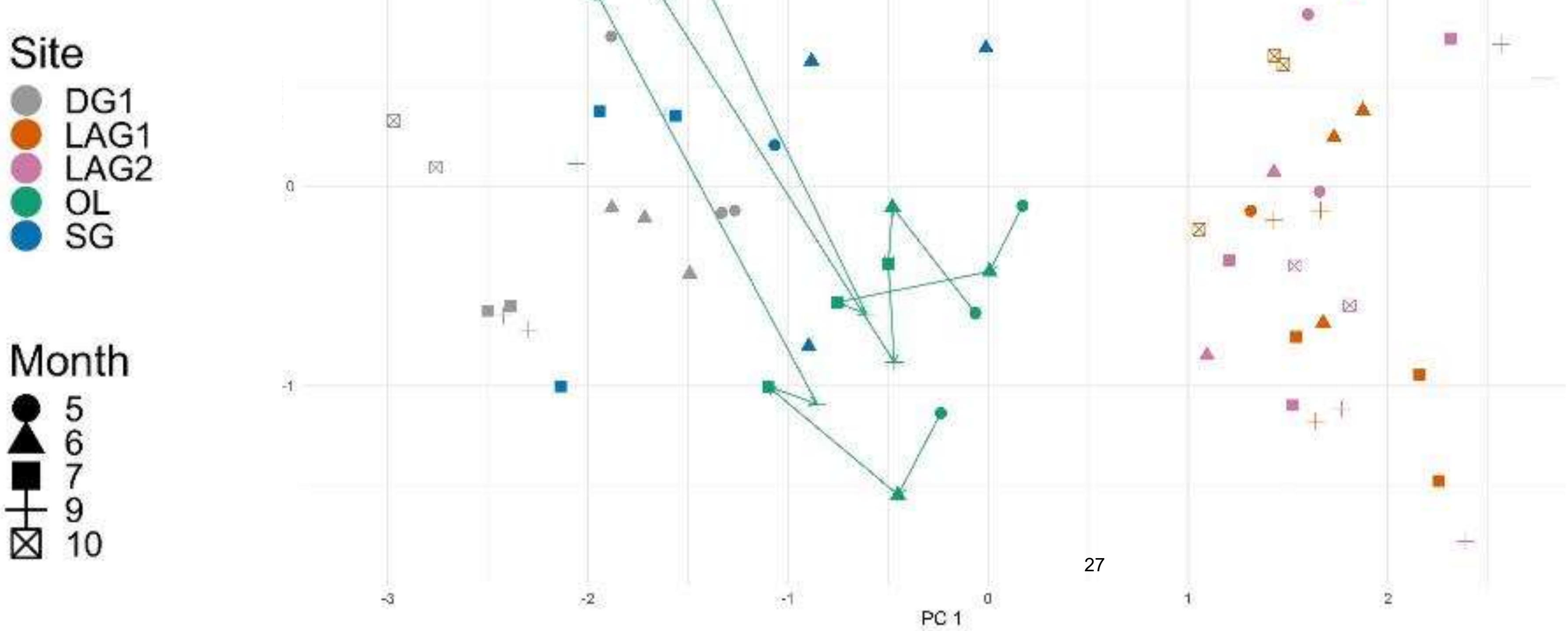

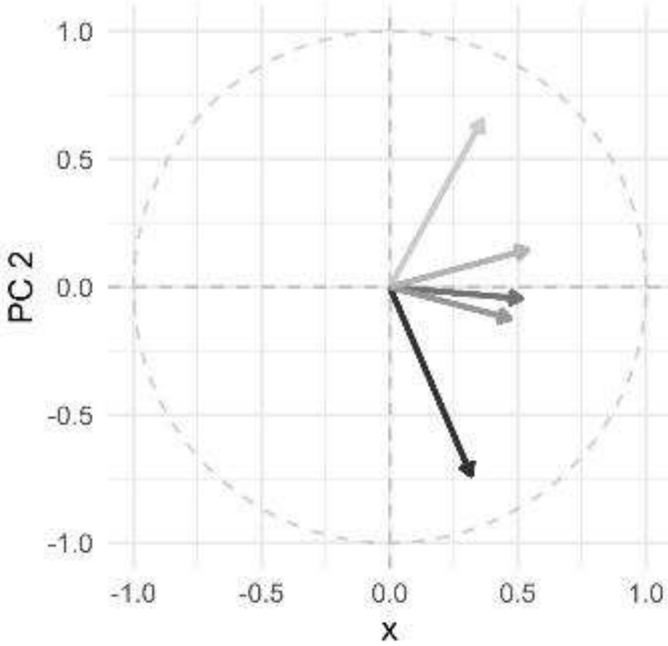

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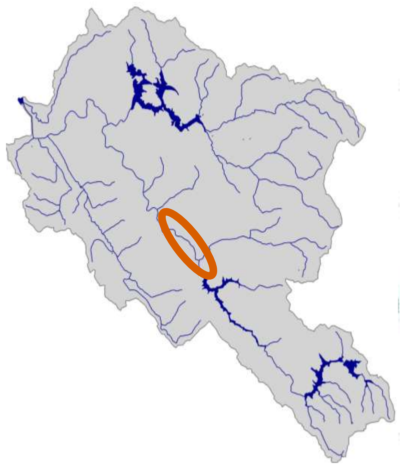

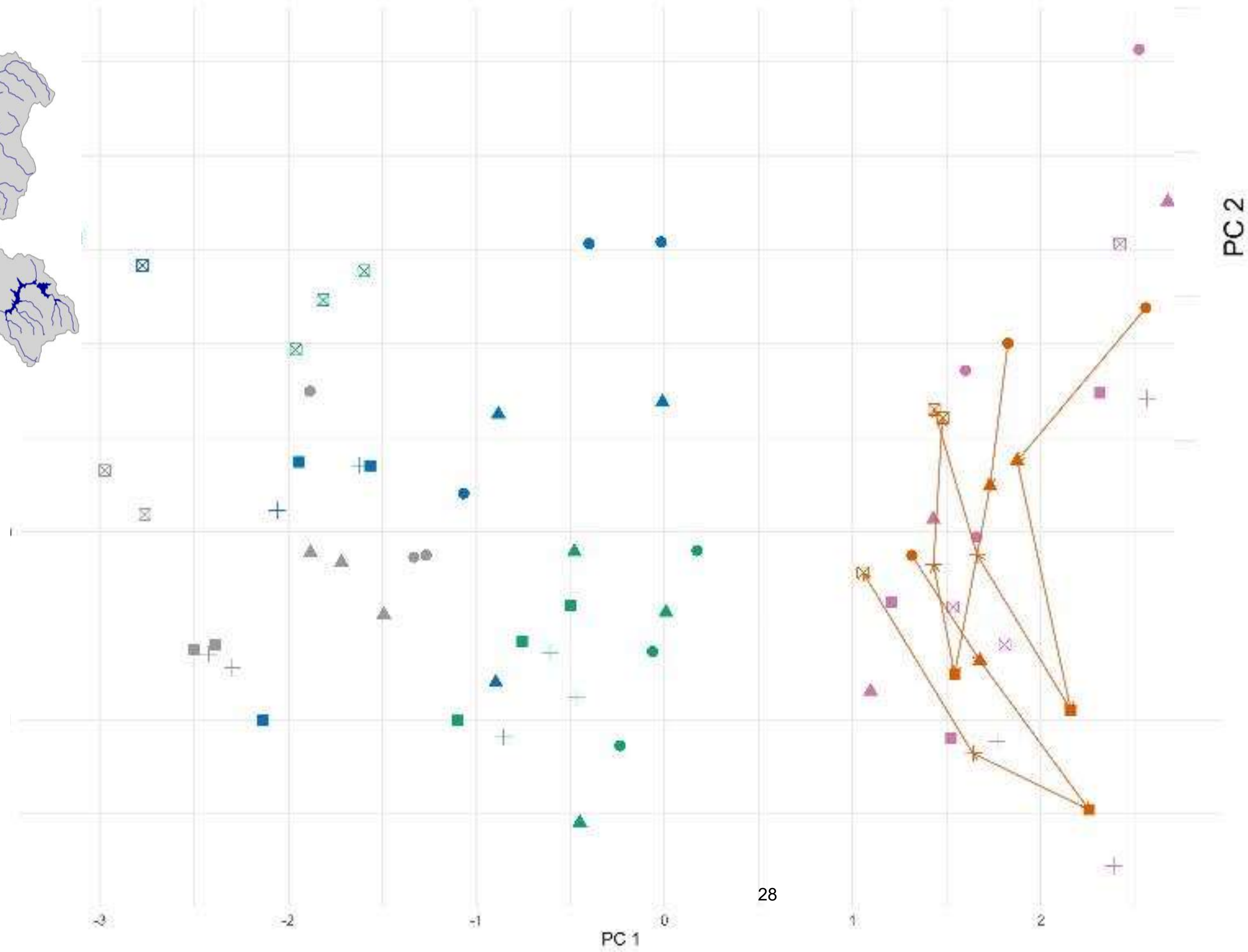

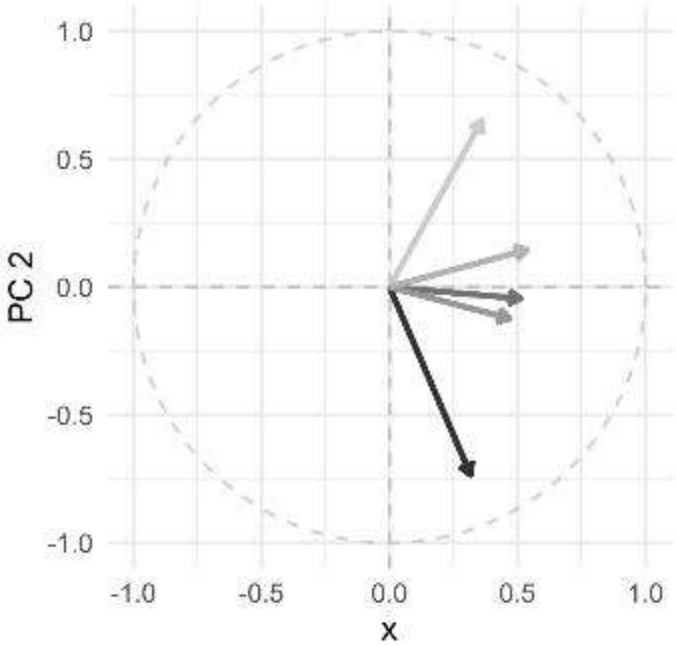

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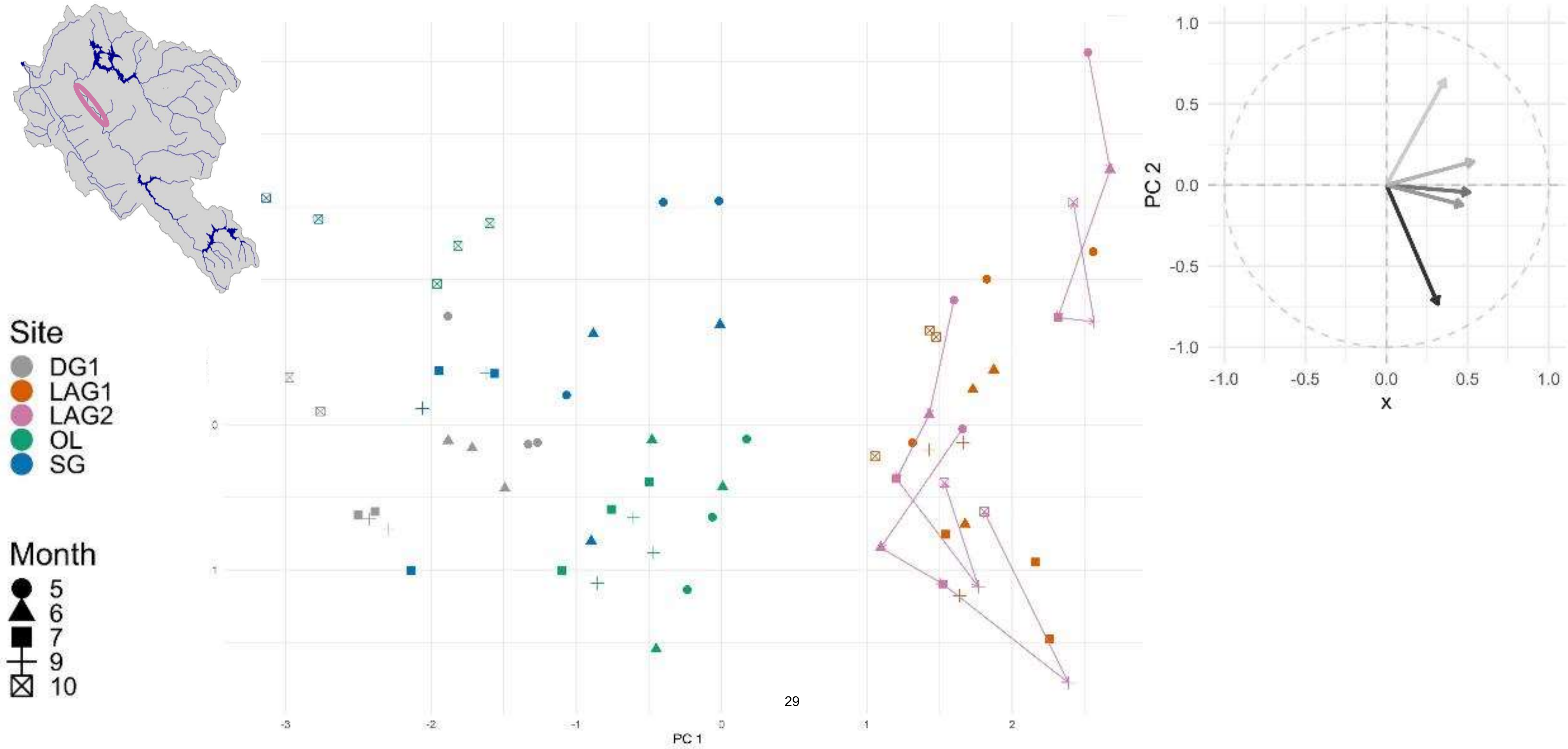


Stream connectivity & dissolved oxygen drive habitat variation

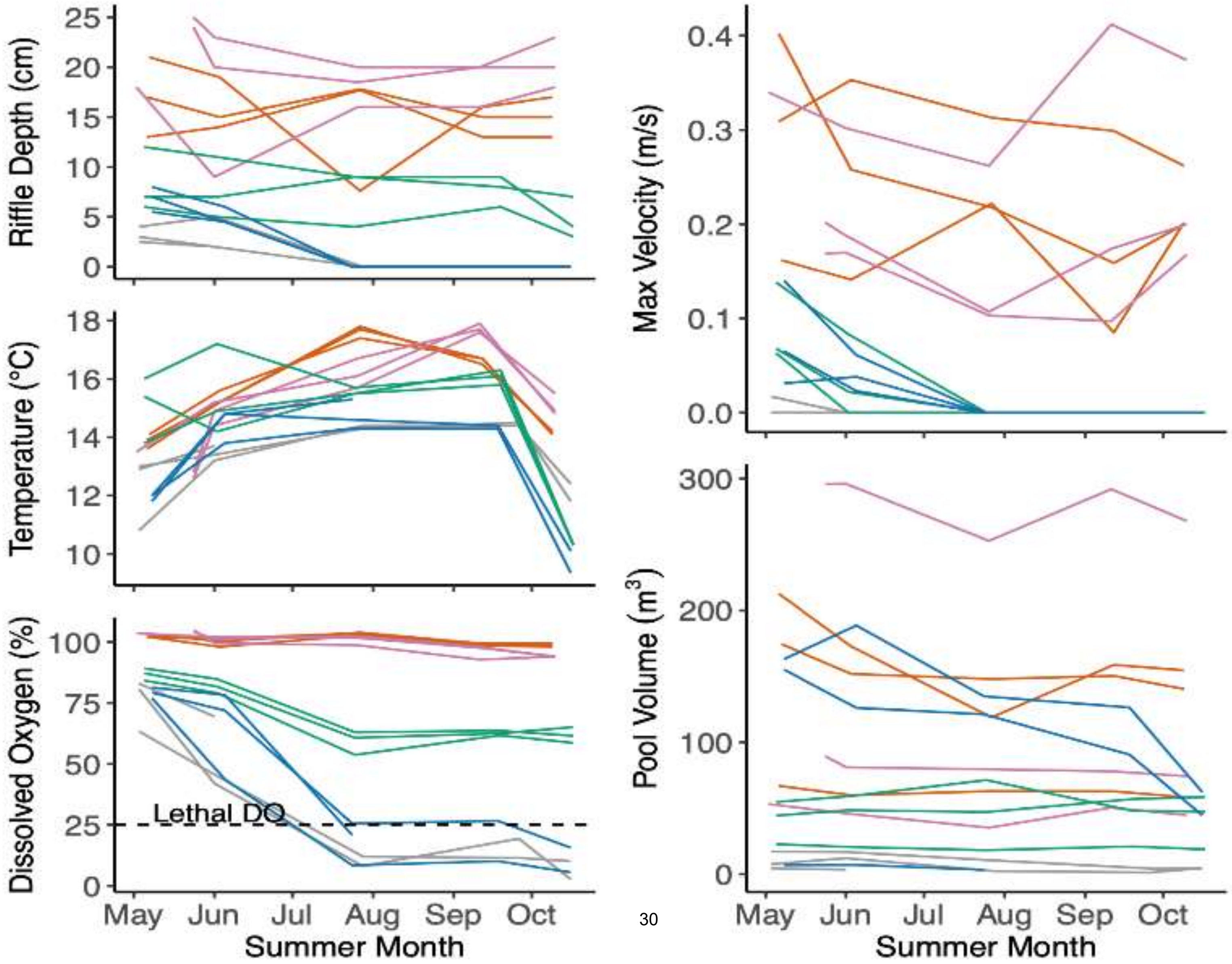
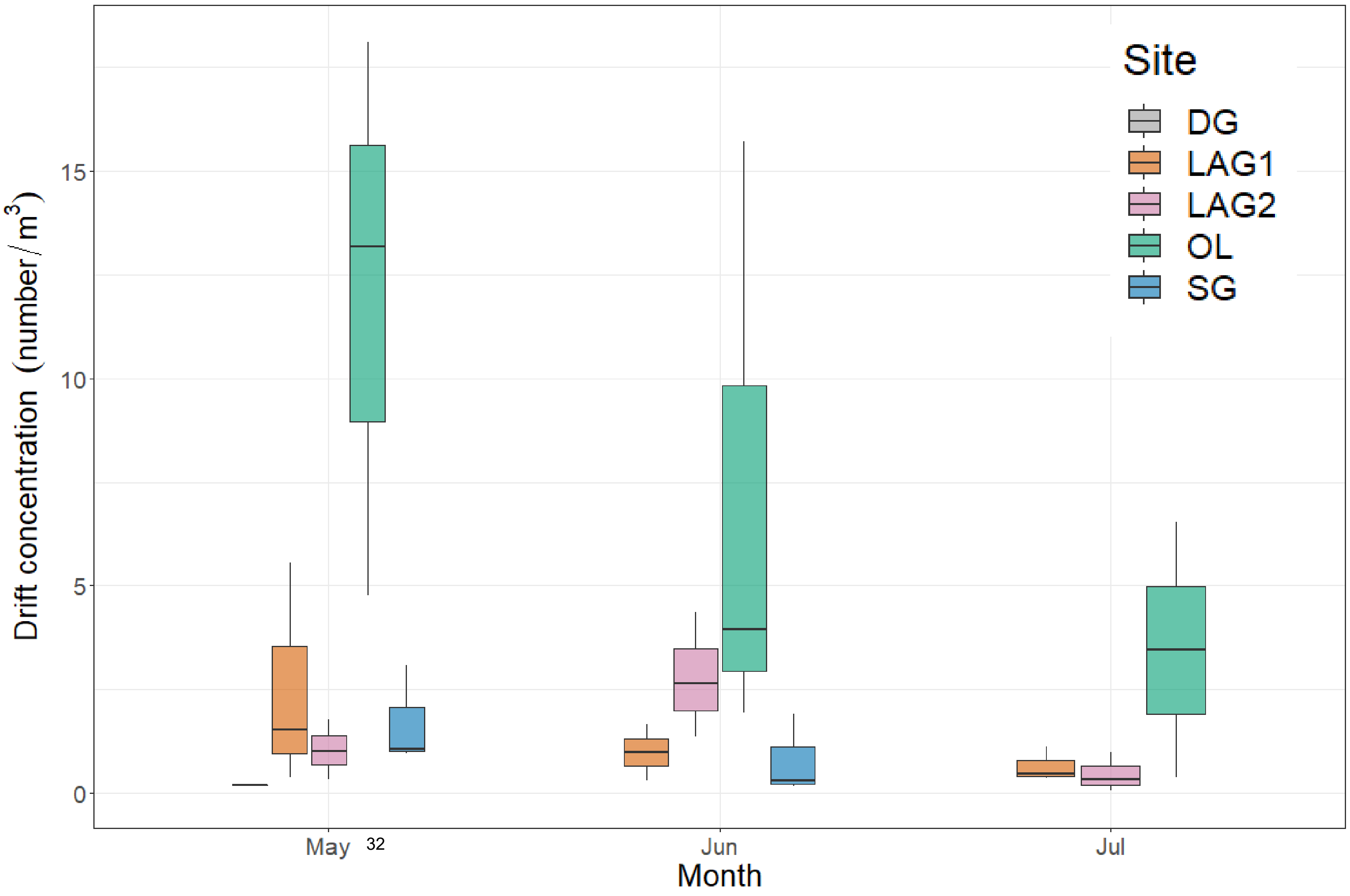


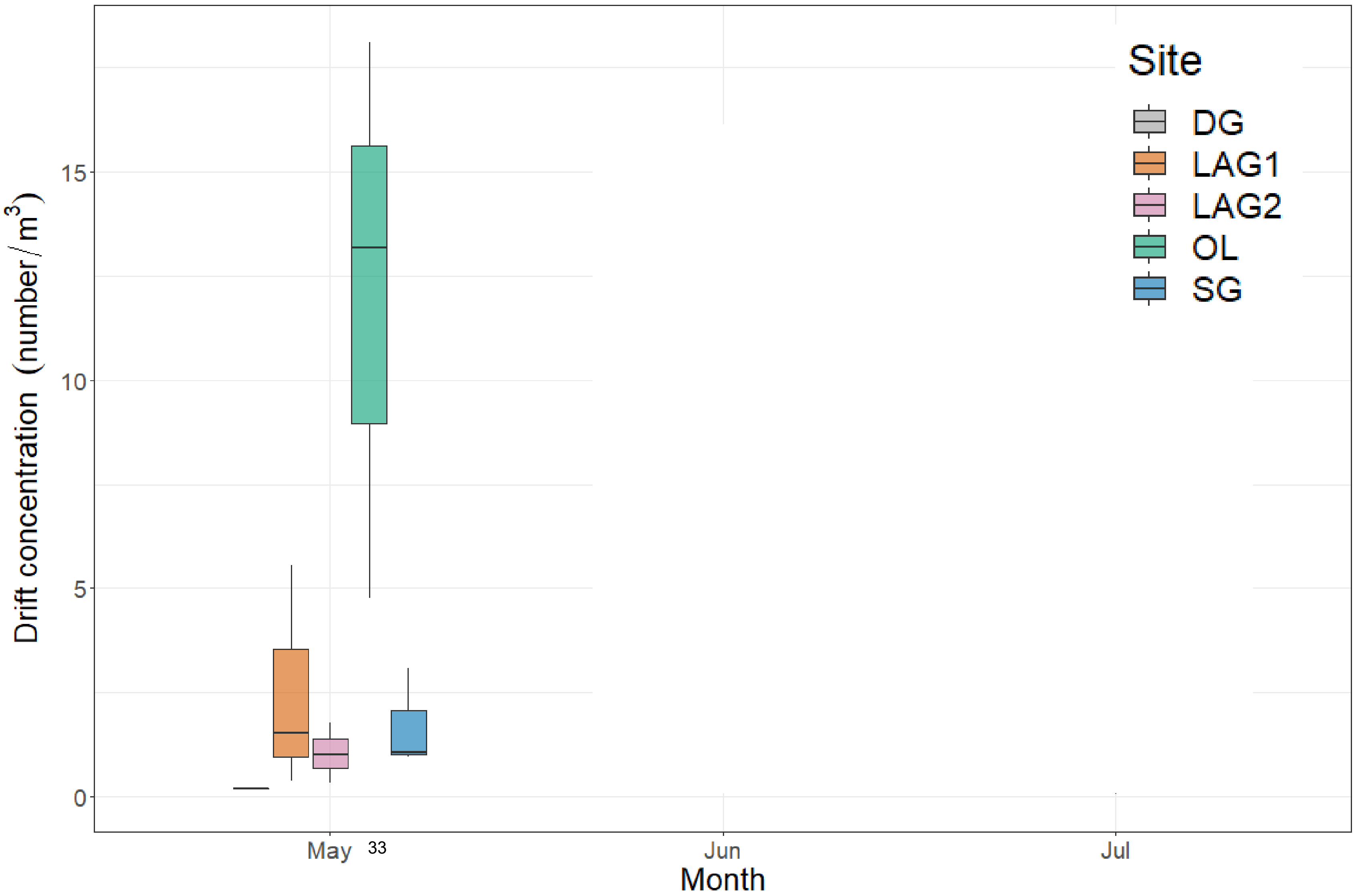
Figure Credit:
Joyce Wang, UC Berkeley Junior

Streams varied in timing & magnitude of peak drift



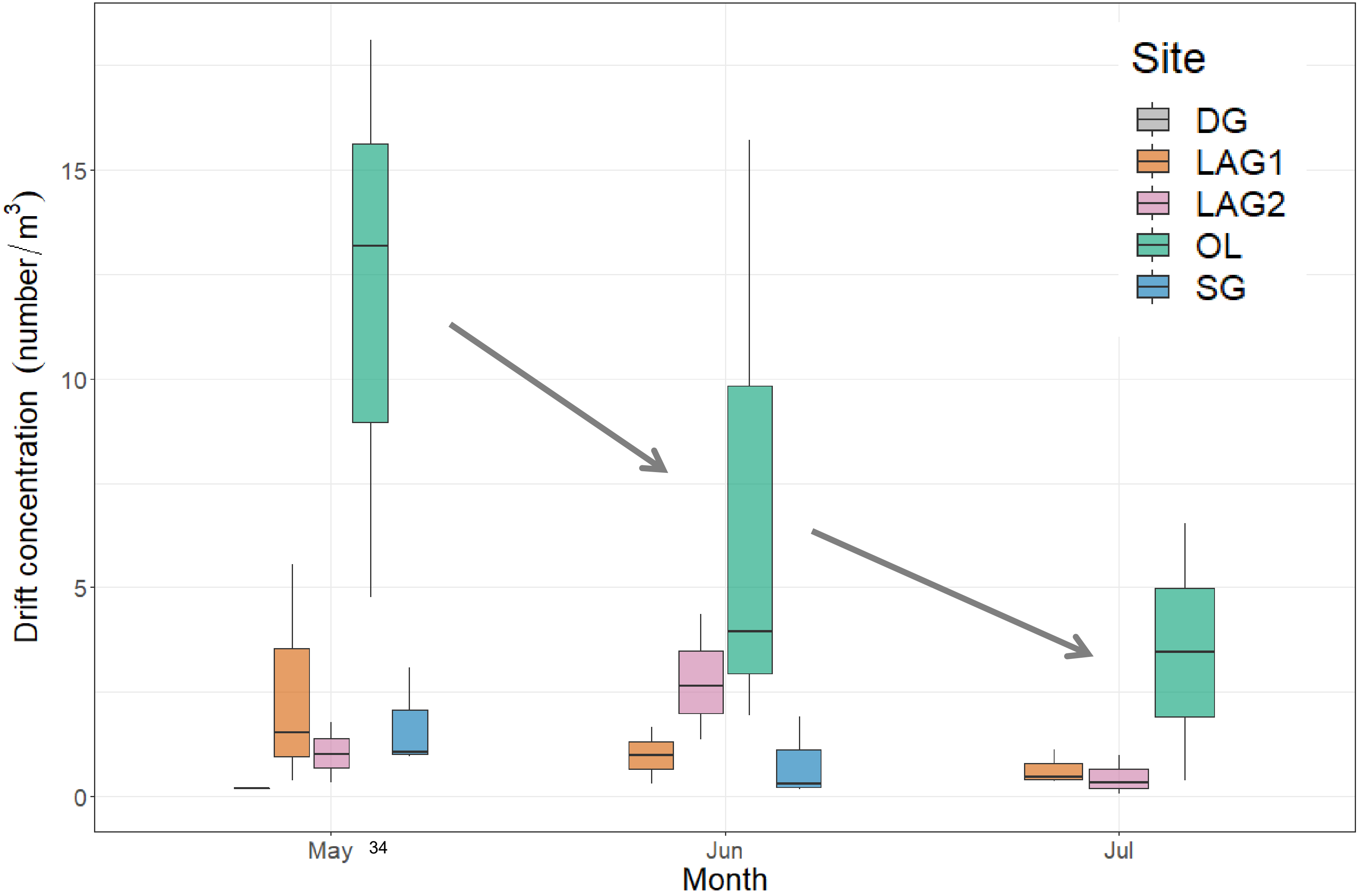
Streams varied in timing & magnitude of peak drift

Spatial differences in drift



Streams varied in timing & magnitude of peak drift

Temporal differences in drift



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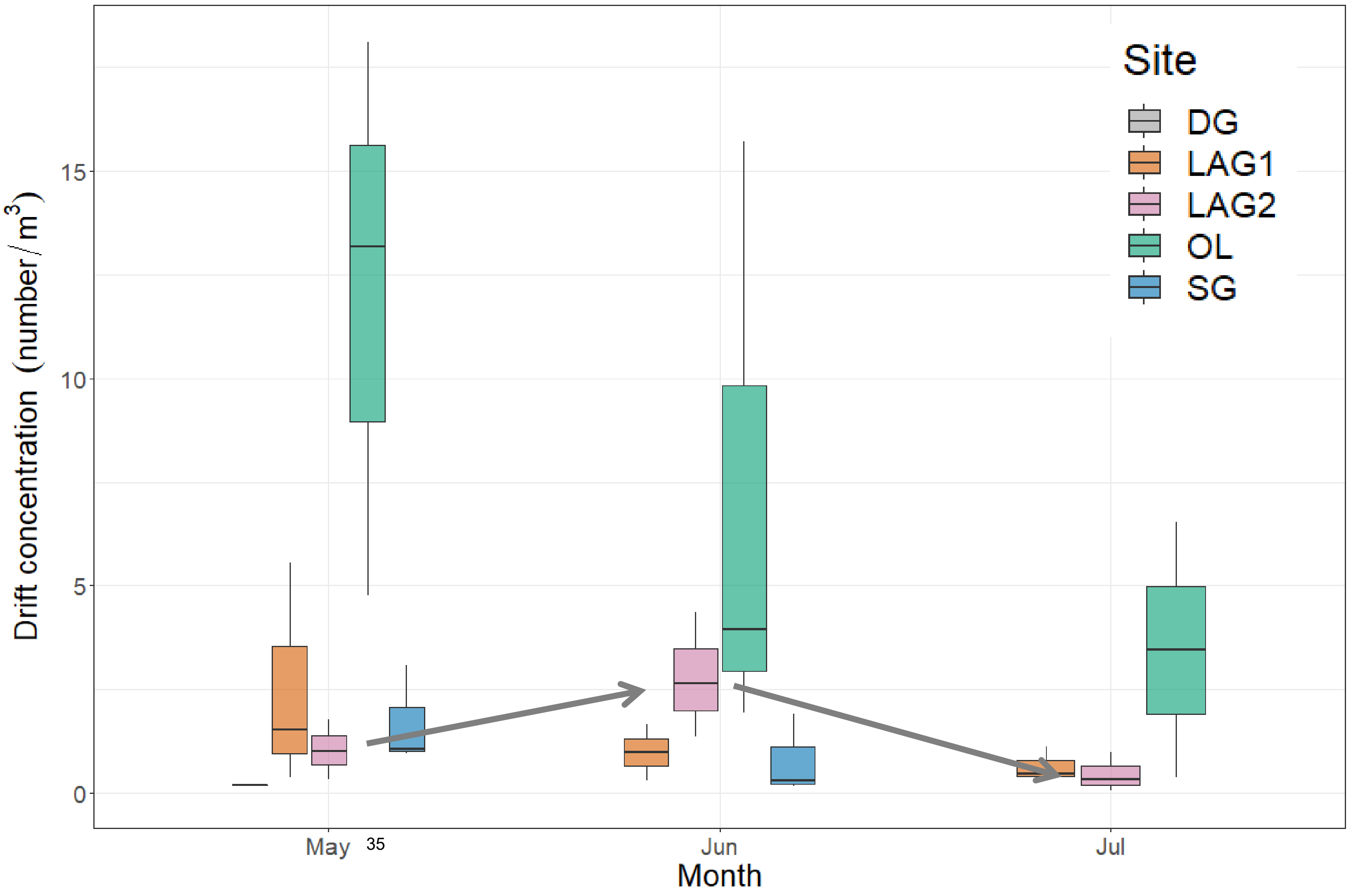
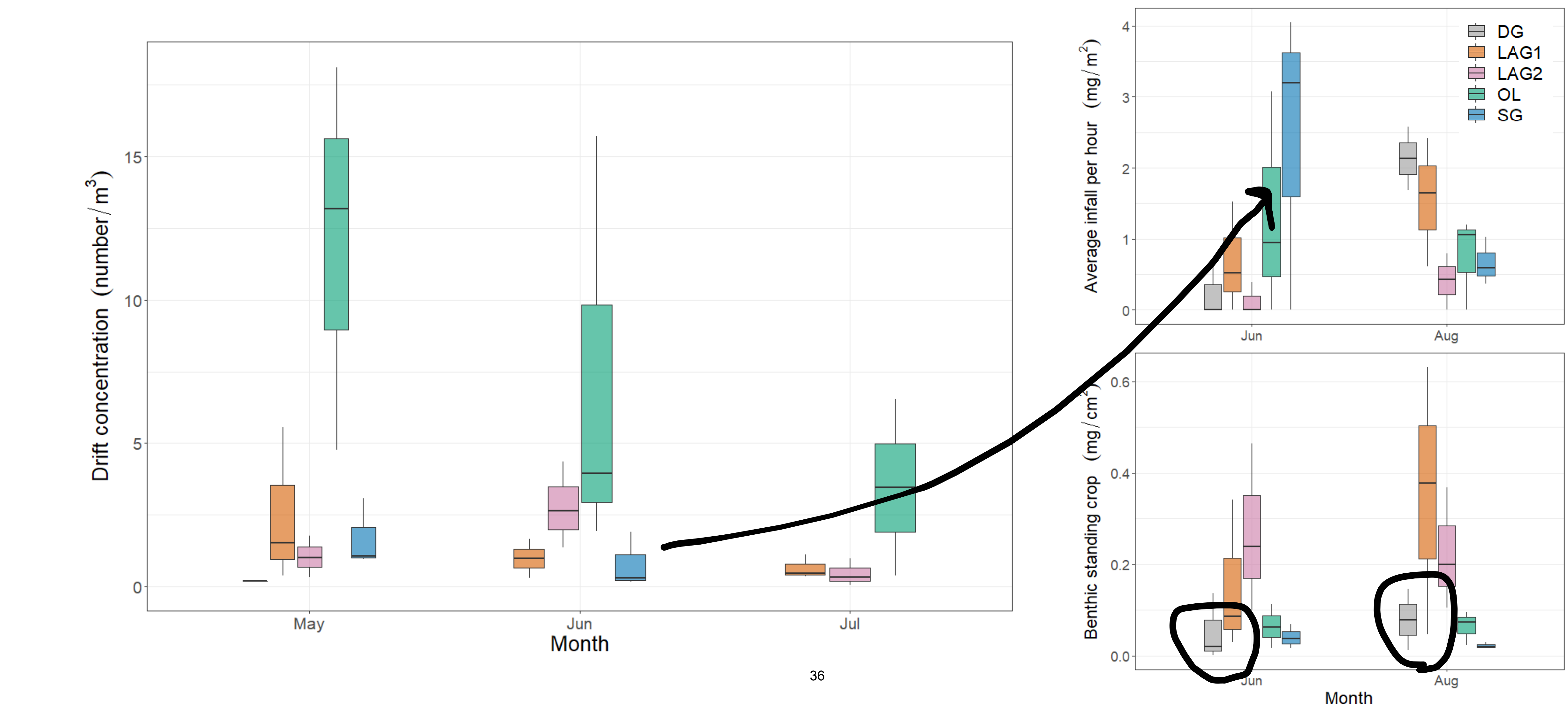
Streams varied in timing & magnitude of peak drift

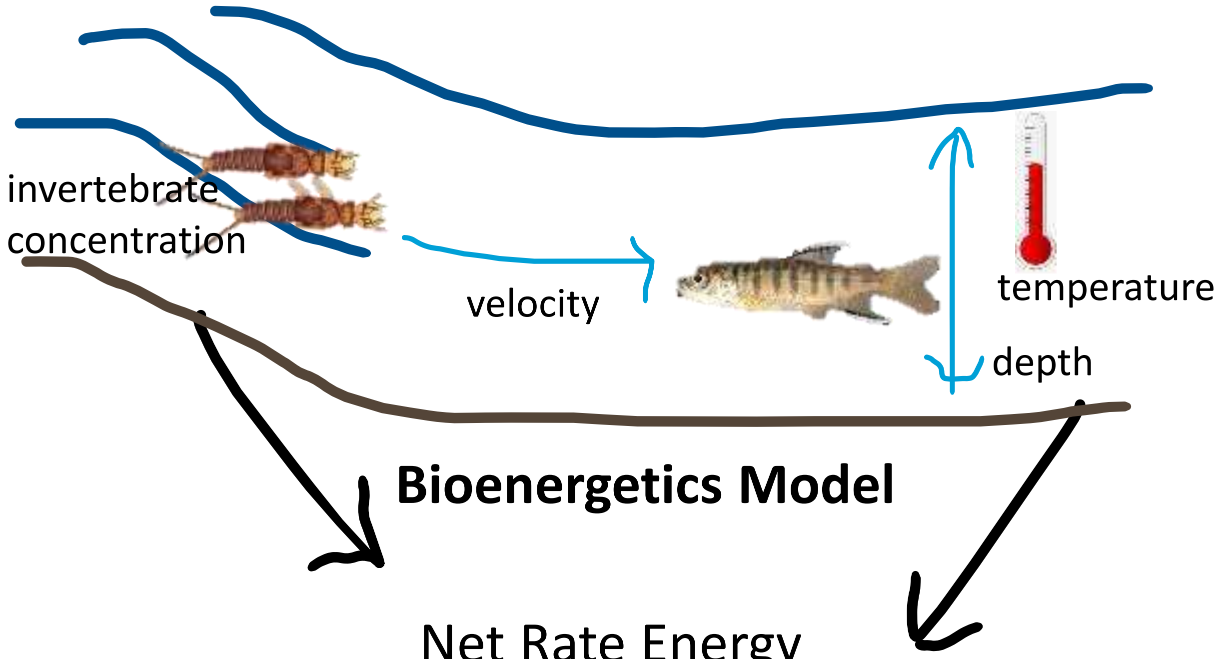
Temporal differences in drift



Streams with lower drift showed relatively higher invertebrate production from other sources

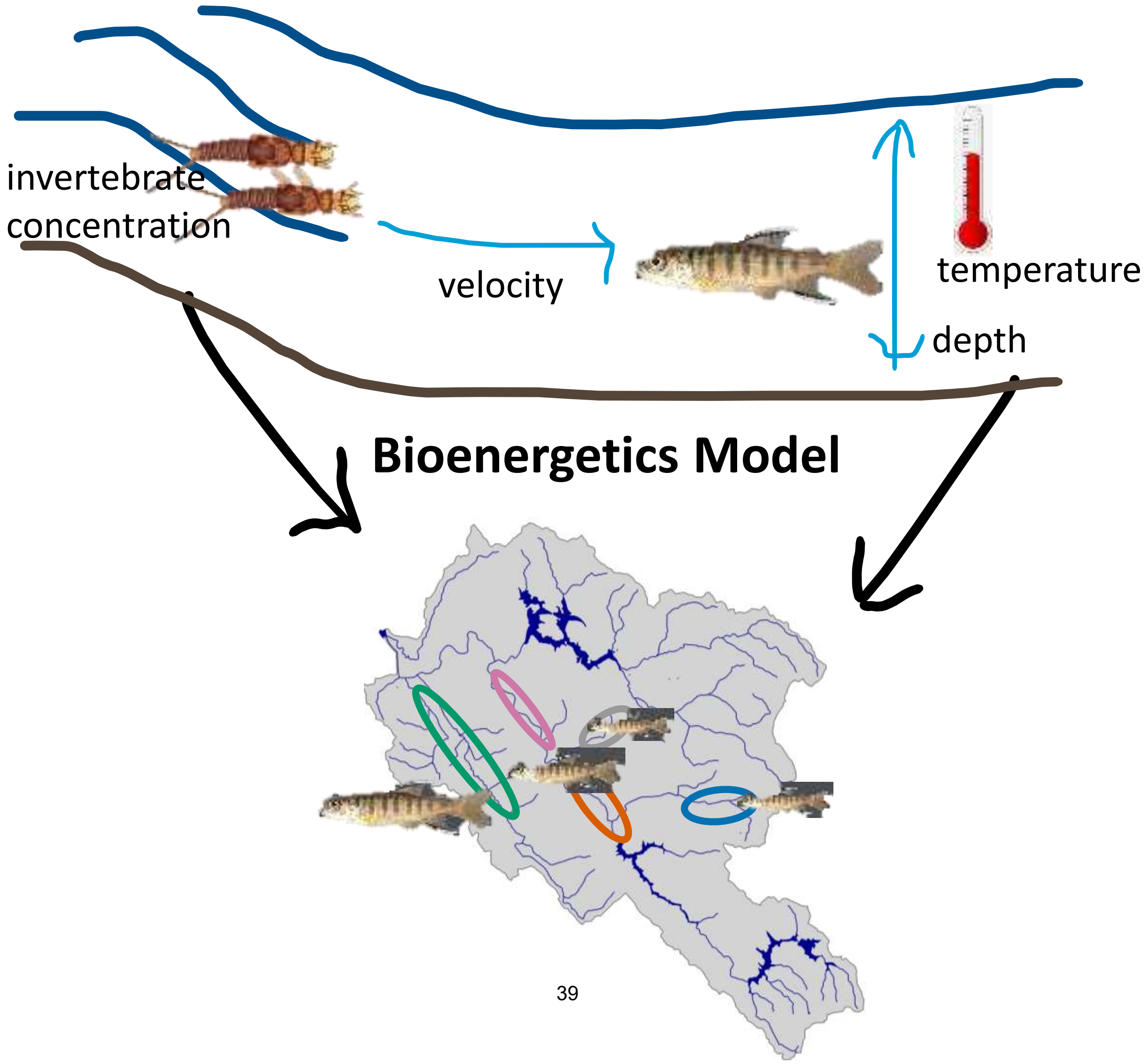


If there is variation in abiotic & biotic habitat factors…

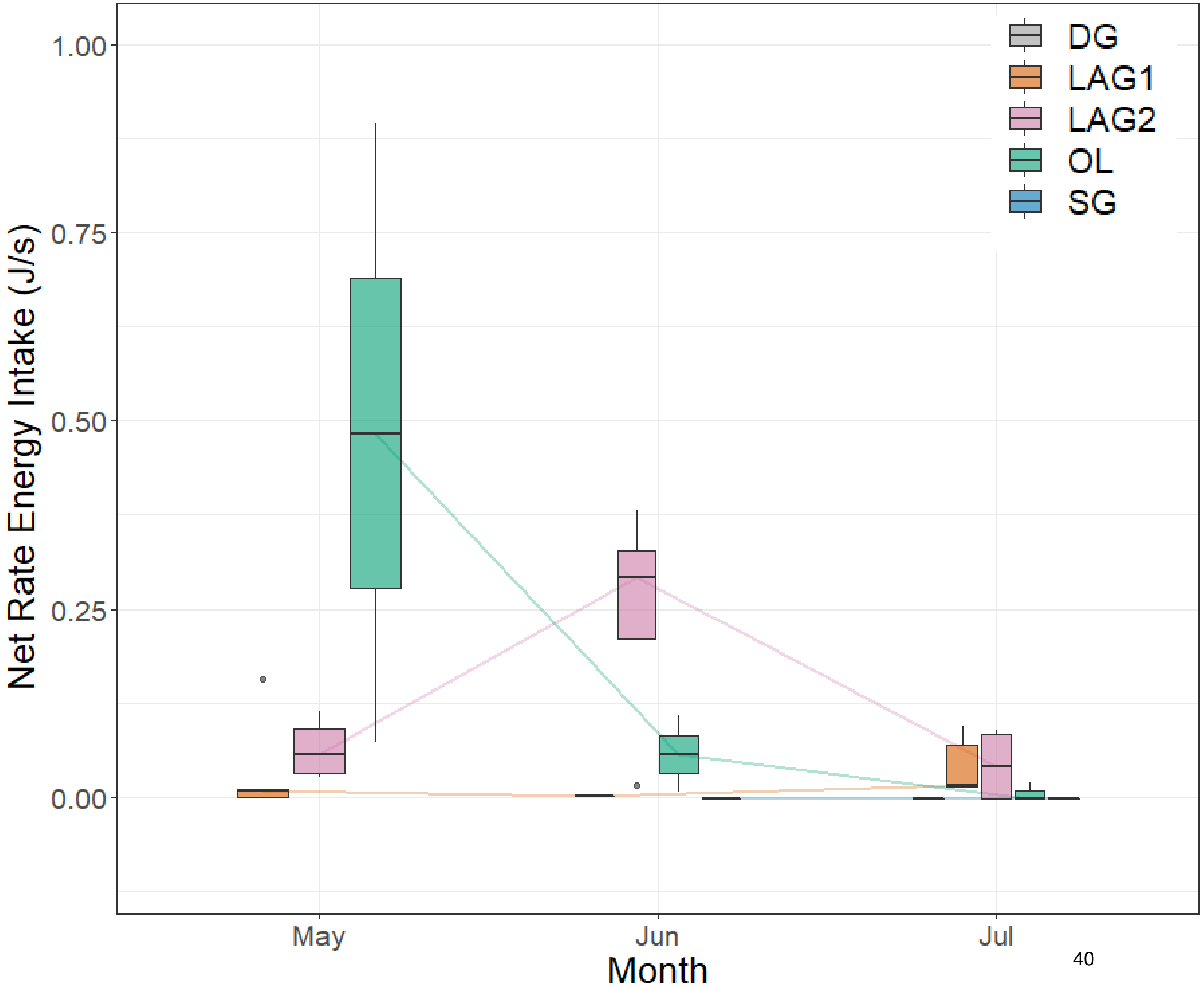


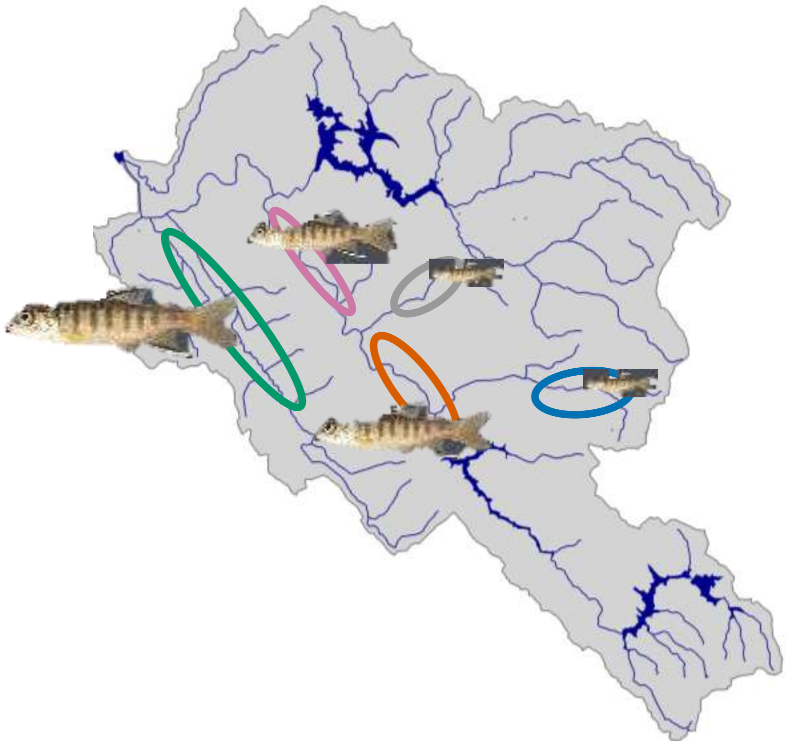
Net Rate Energy Intake (J/s) for individual fish of 55-65mm

Does that translate to variation in juvenile growth potential?

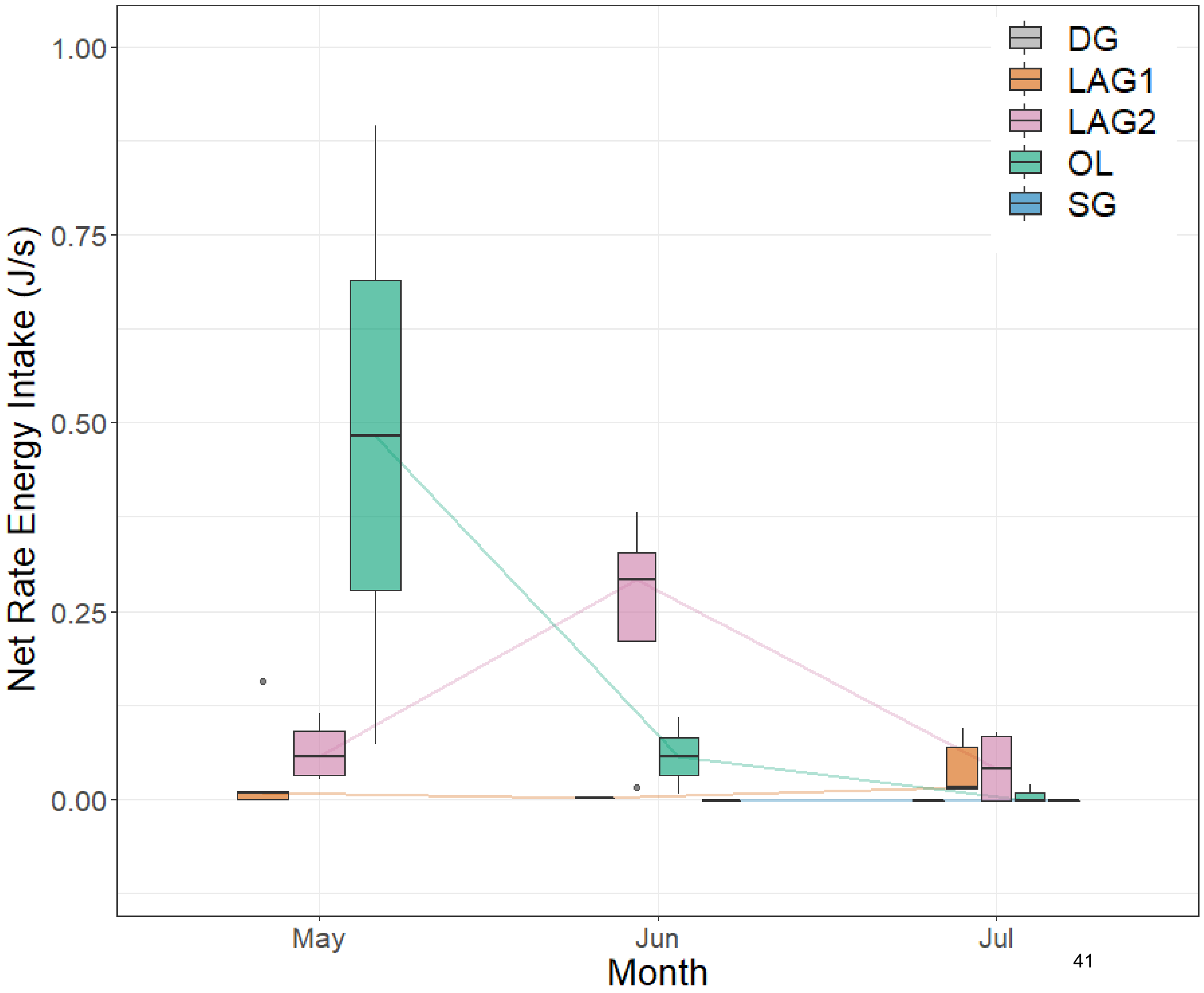


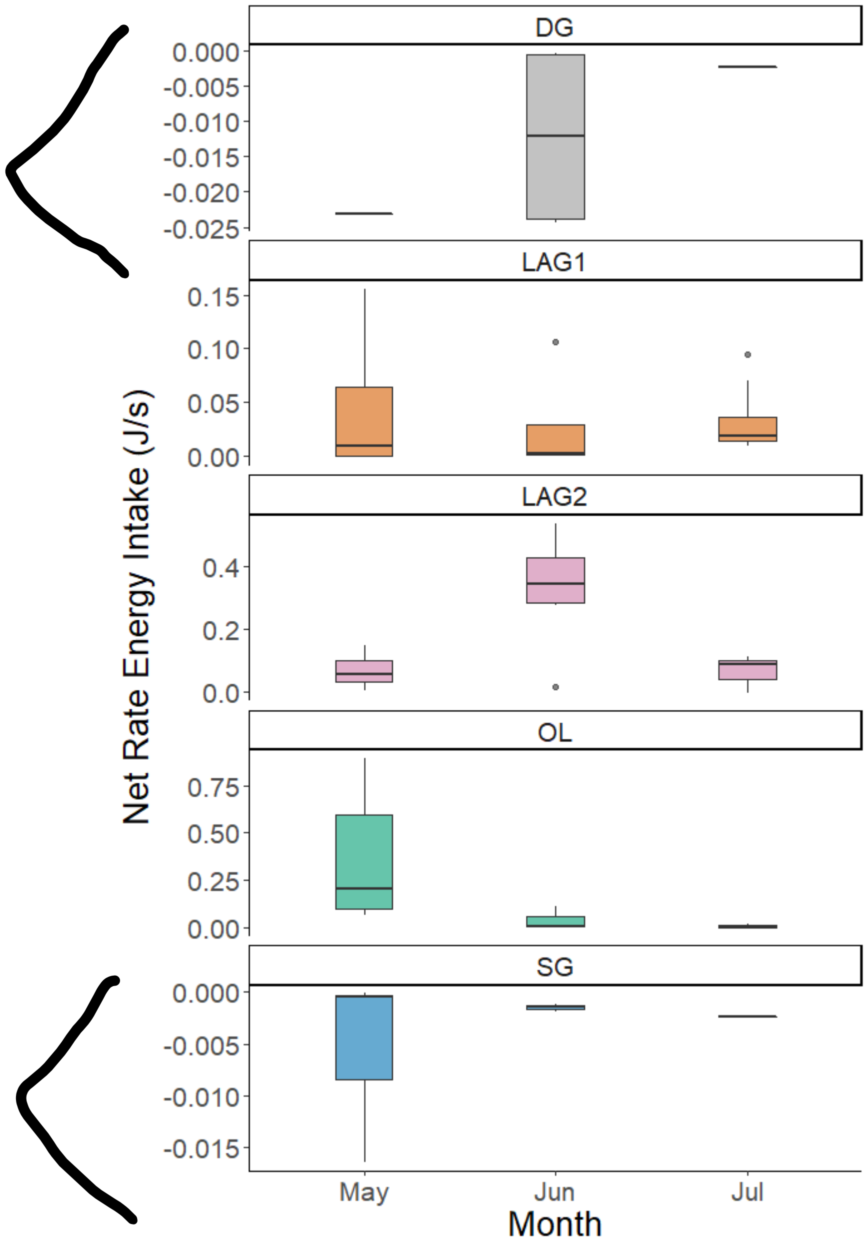
Yes! Variation in abiotic & biotic habitat drives spatiotemporal variation in juvenile growth potential



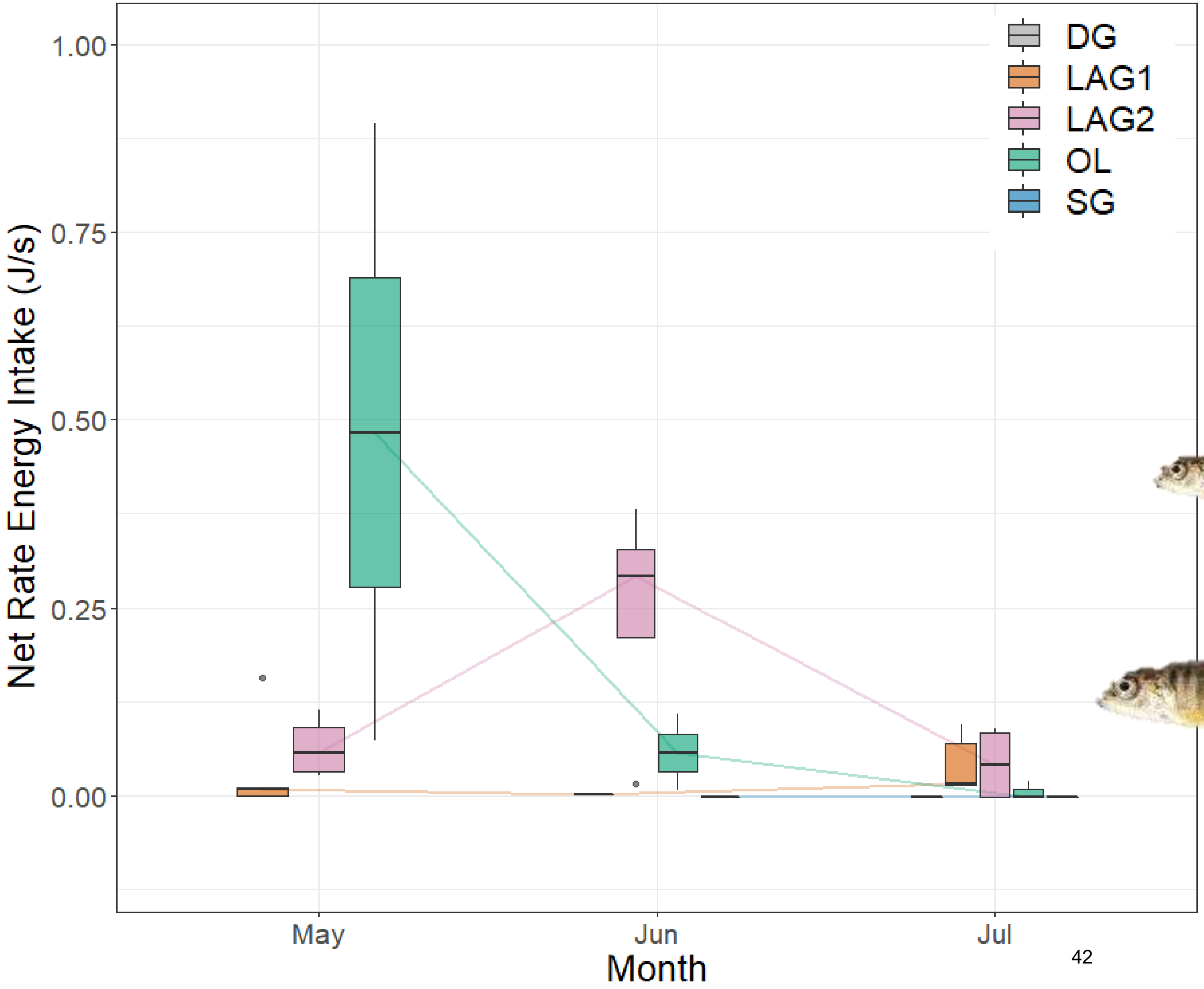


Some streams have negative growth potential

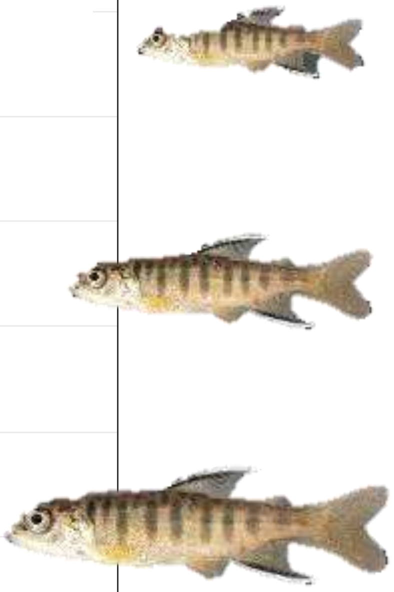


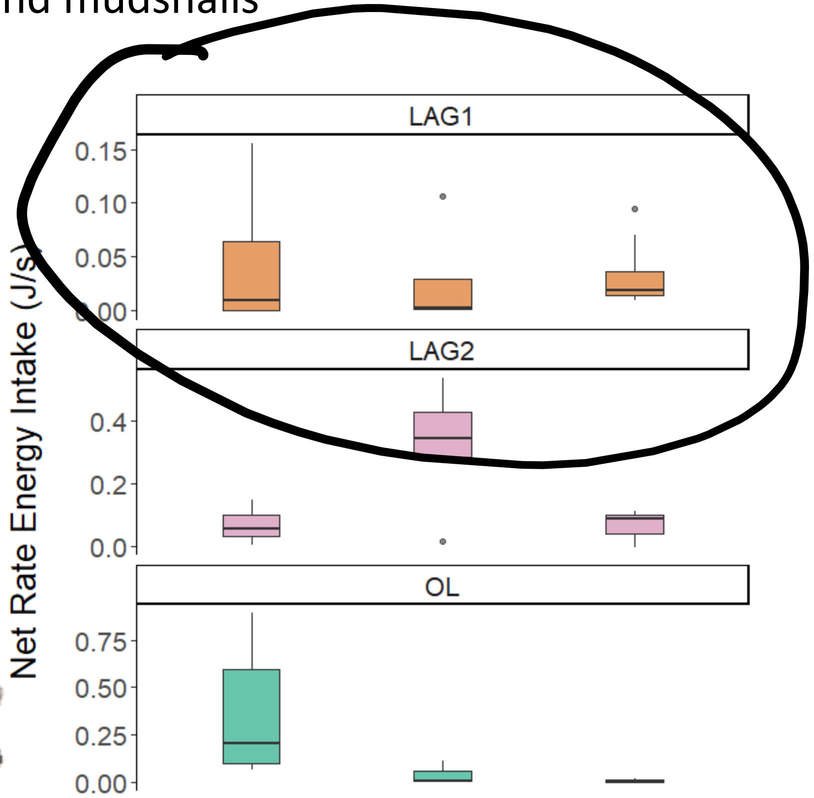


Streams with positive growth potential vary in magnitude

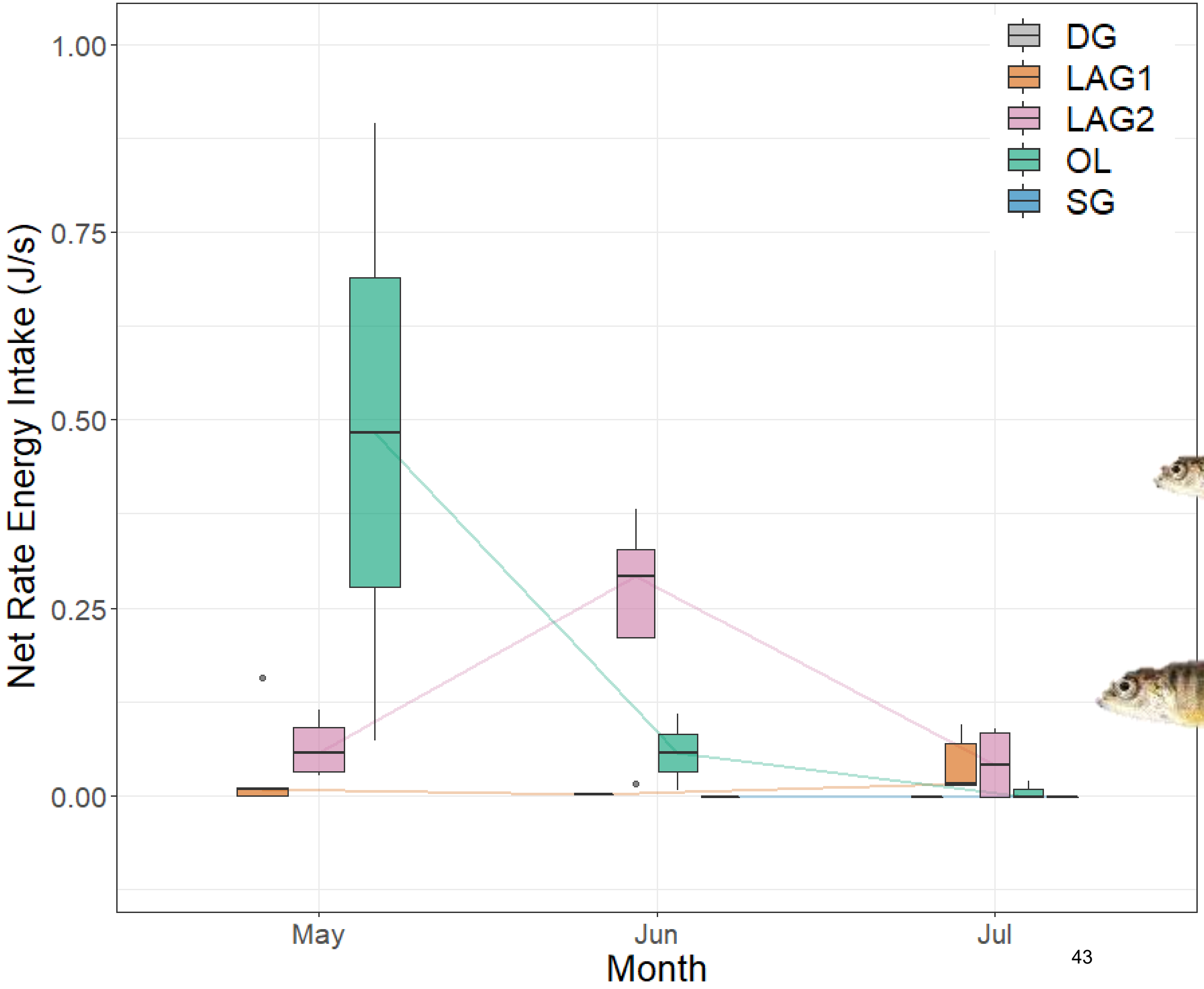


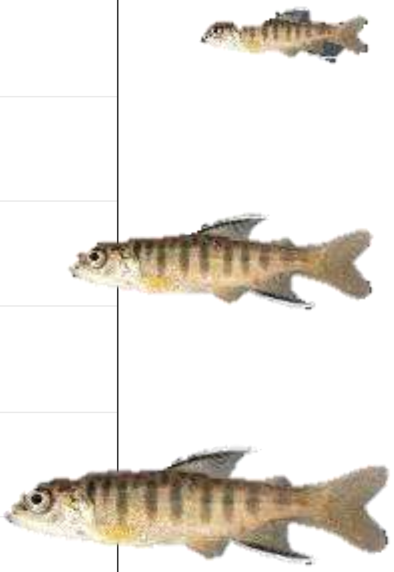
including New Zealand mudsnails



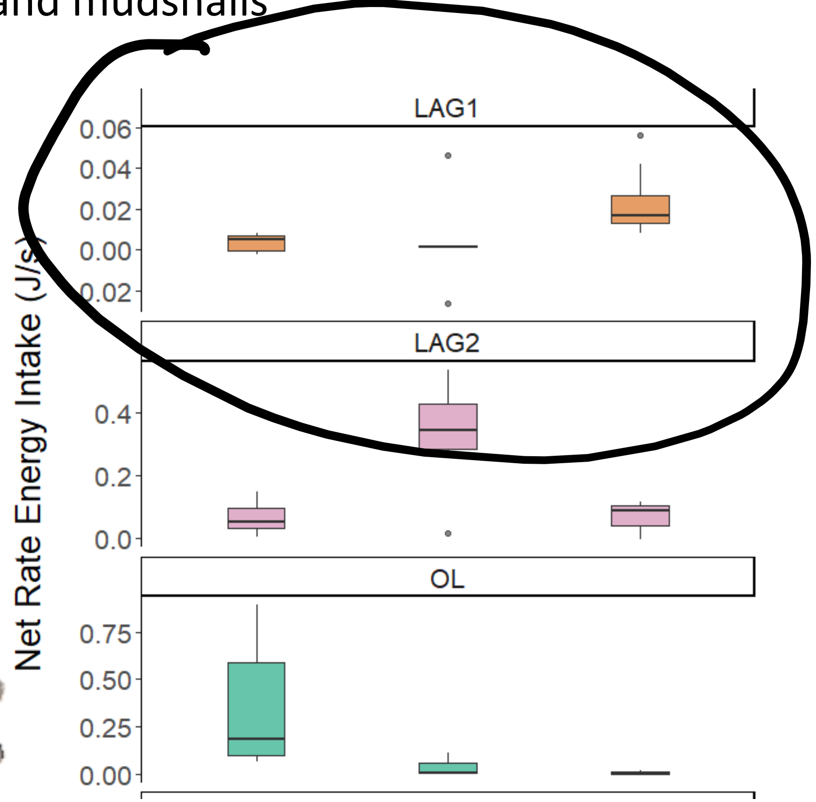


Invasive mudsnails could have impacts on growth of coho



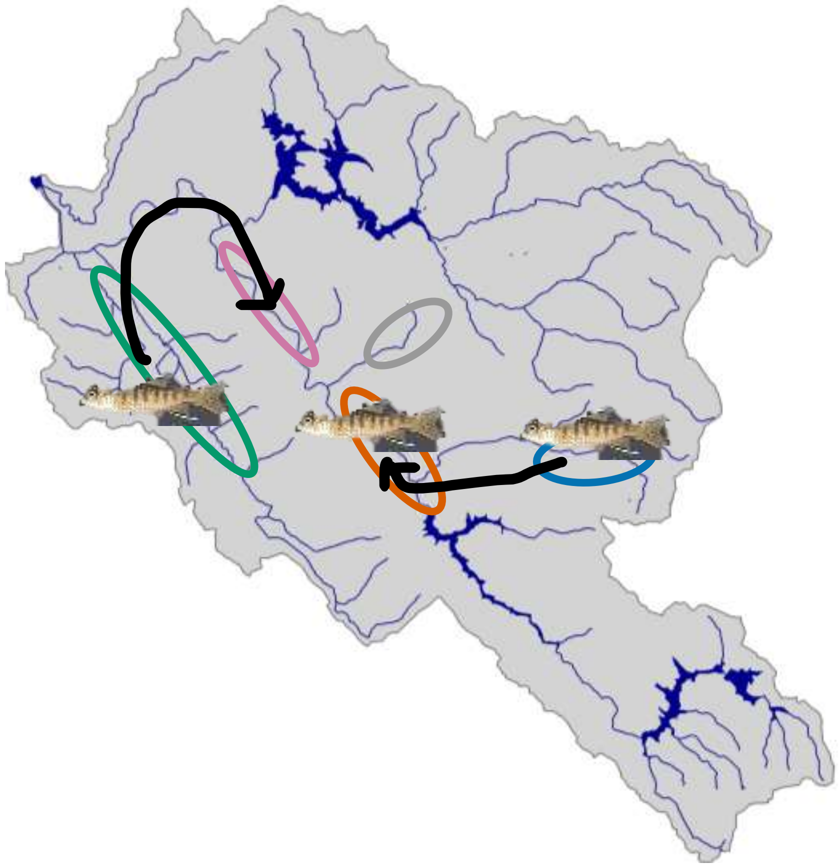


without New Zealand mudsnails



Growth potential in one stream doesn't tell the whole story

Connectivity can support higher growth, trait trajectories – **drought reduces resource tracking opportunities**

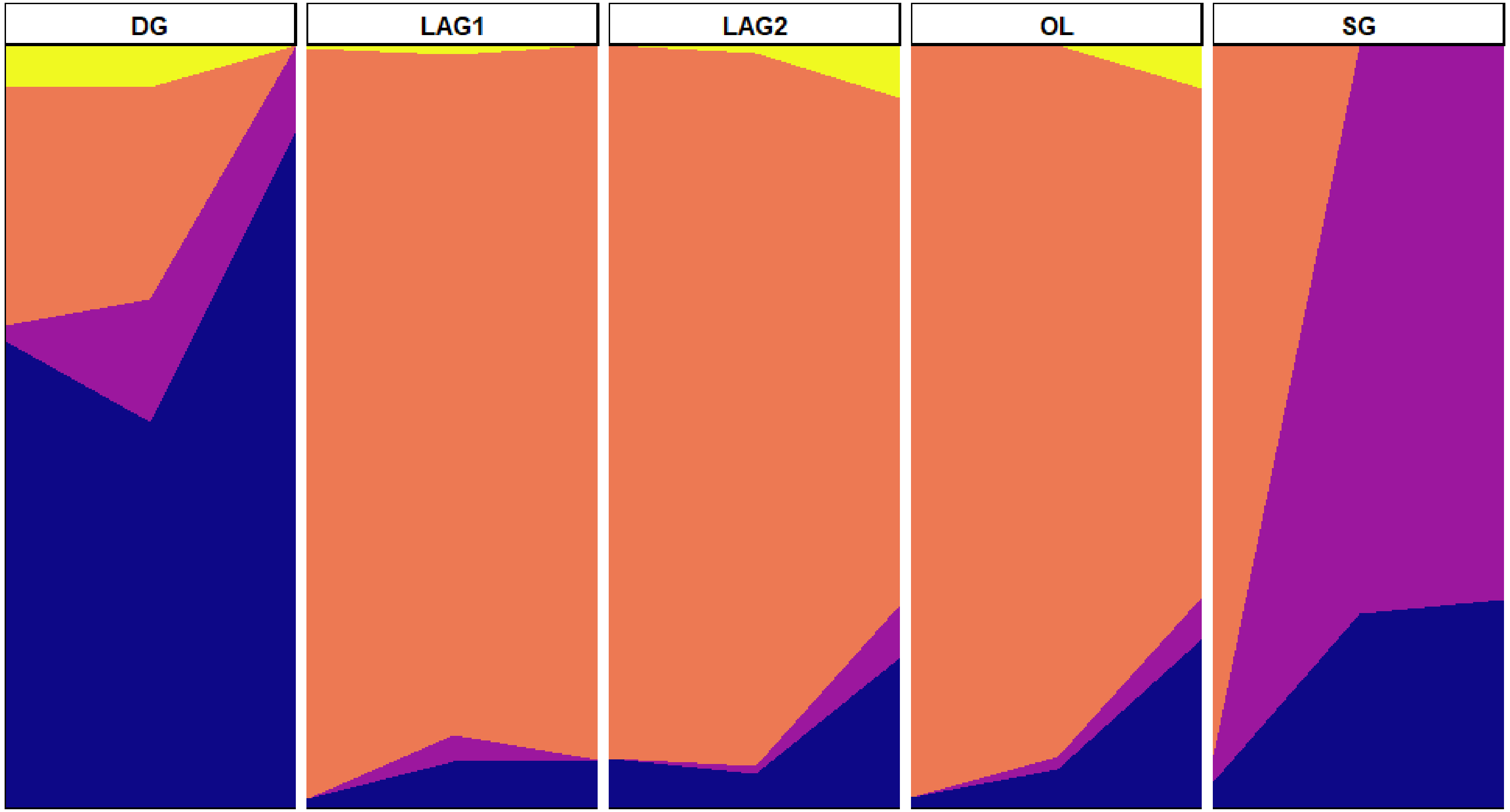


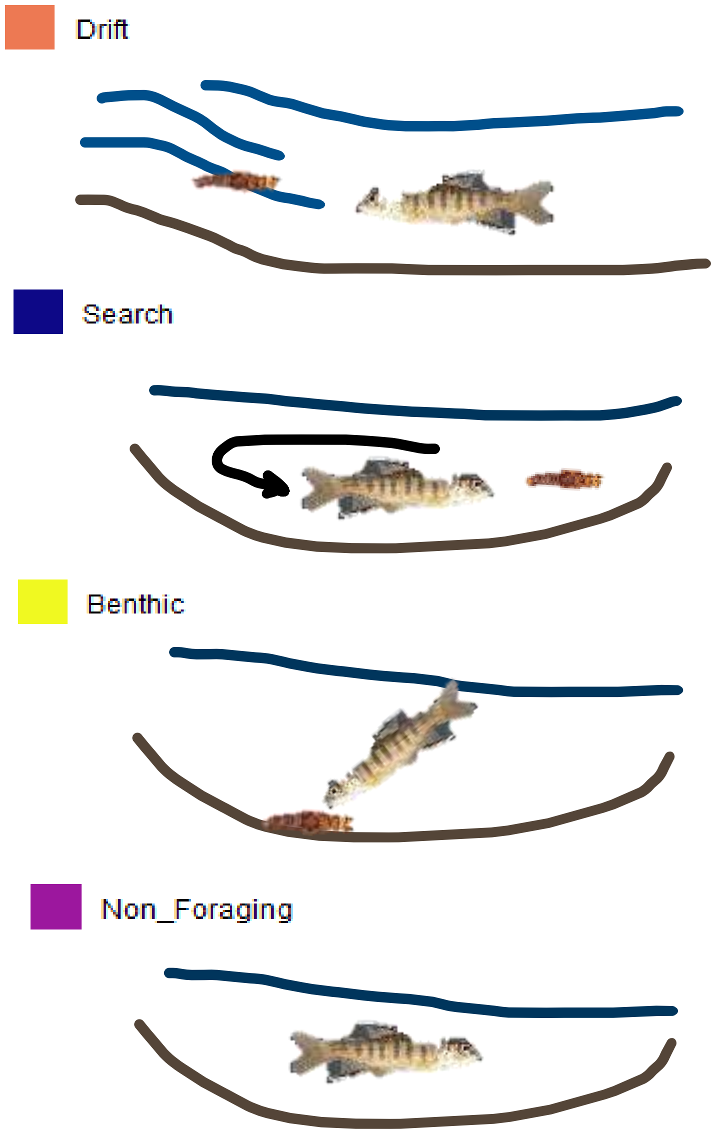
Caveats of modeling:

- density, size of conspecifics
- territoriality*
- drift foraging only

** Check out UC Berkeley undergraduate student Ciara Benson's poster on intraspecific aggression in this system!*

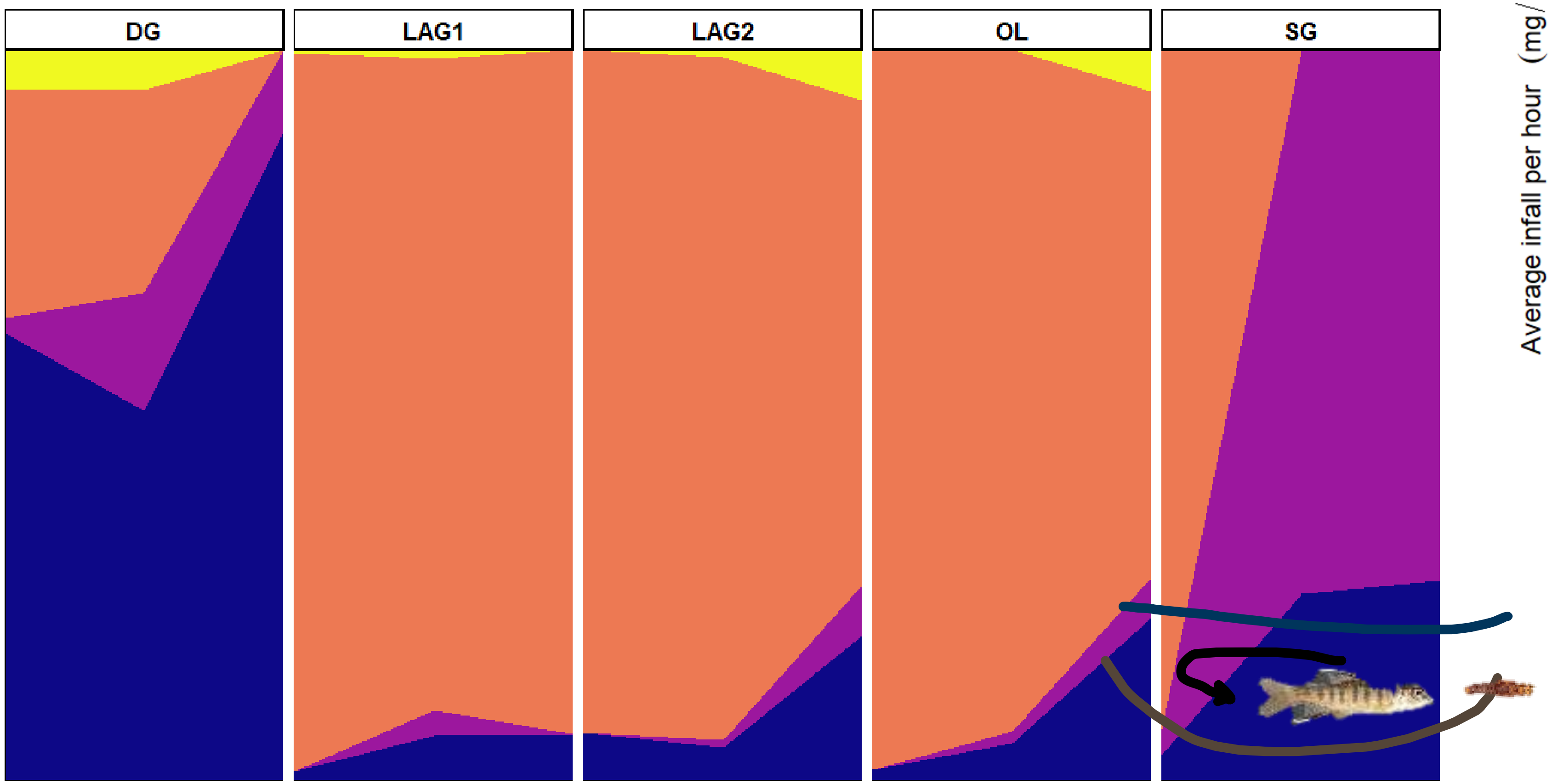
Juvenile foraging behaviour shifts as drought intensifies

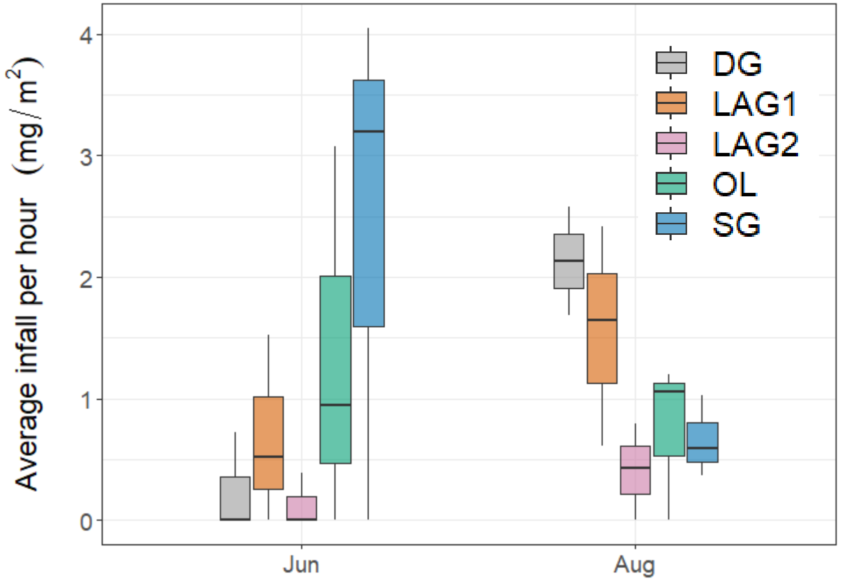




May → *July*

Fish potentially tracking other invertebrate sources





May → ***July***

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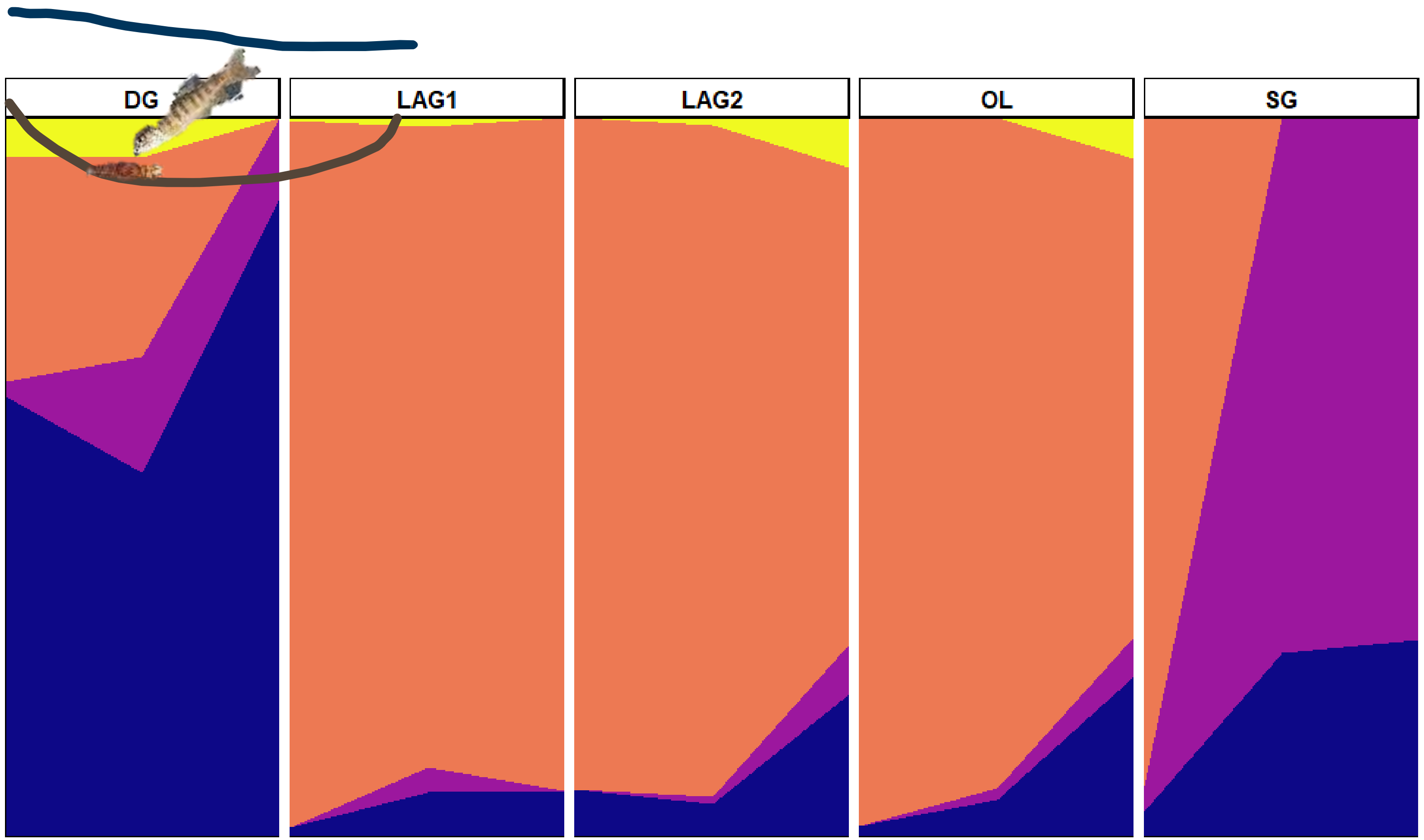
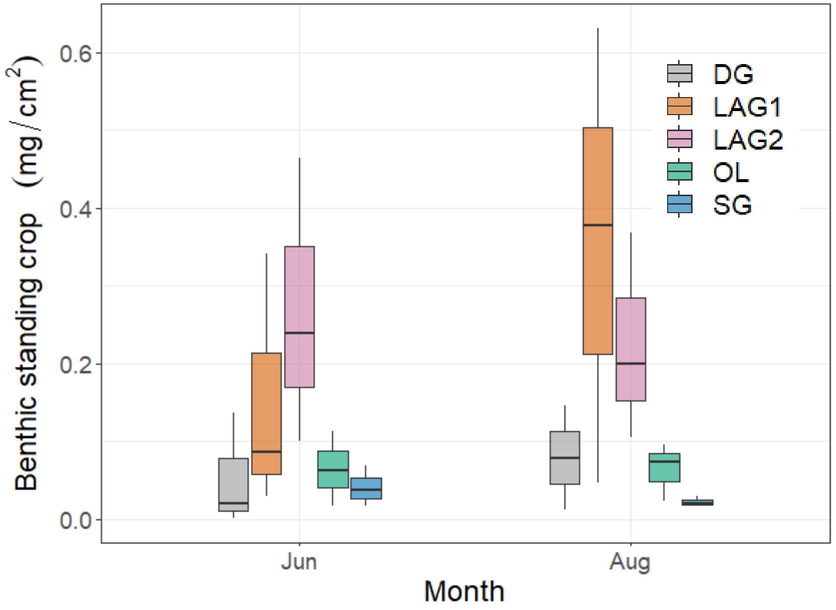
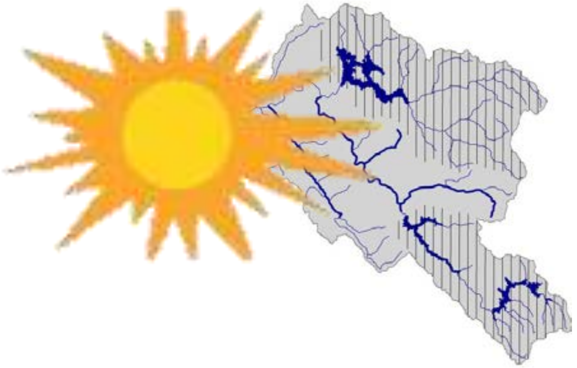




May* → *July

Streams across the watershed

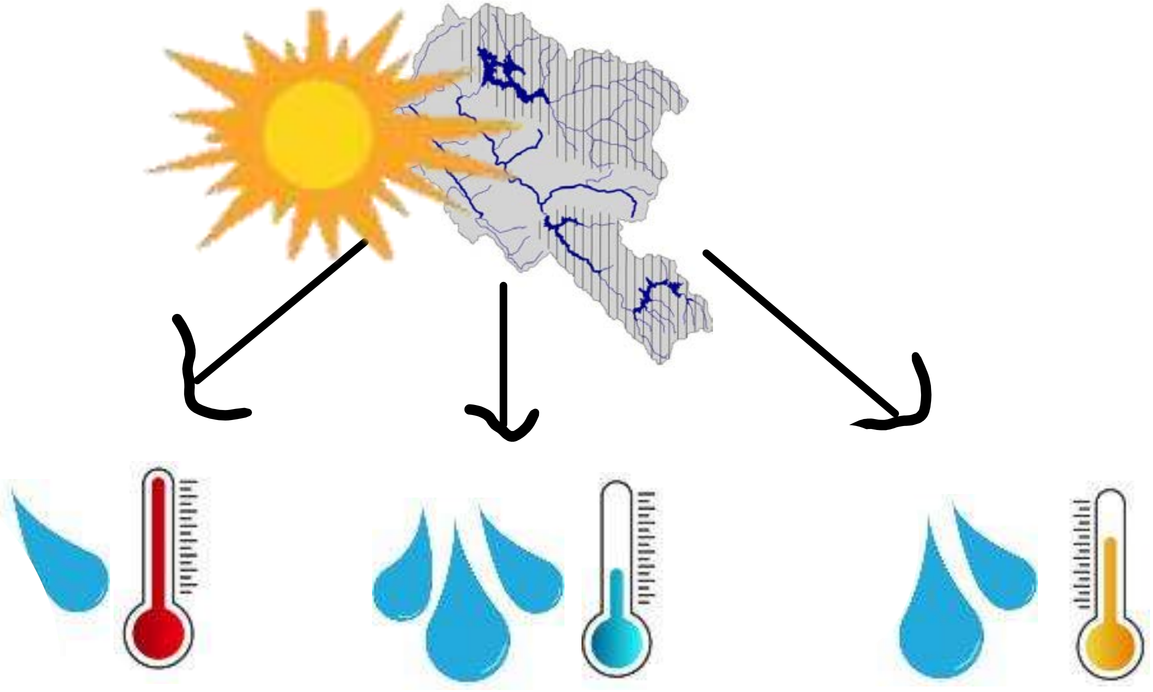


How do habitat mosaics lead to differential impacts of drought and juvenile outcomes?

Instream habitat conditions

Invertebrate availability

Foraging behaviour & growth potential



Streams across the watershed

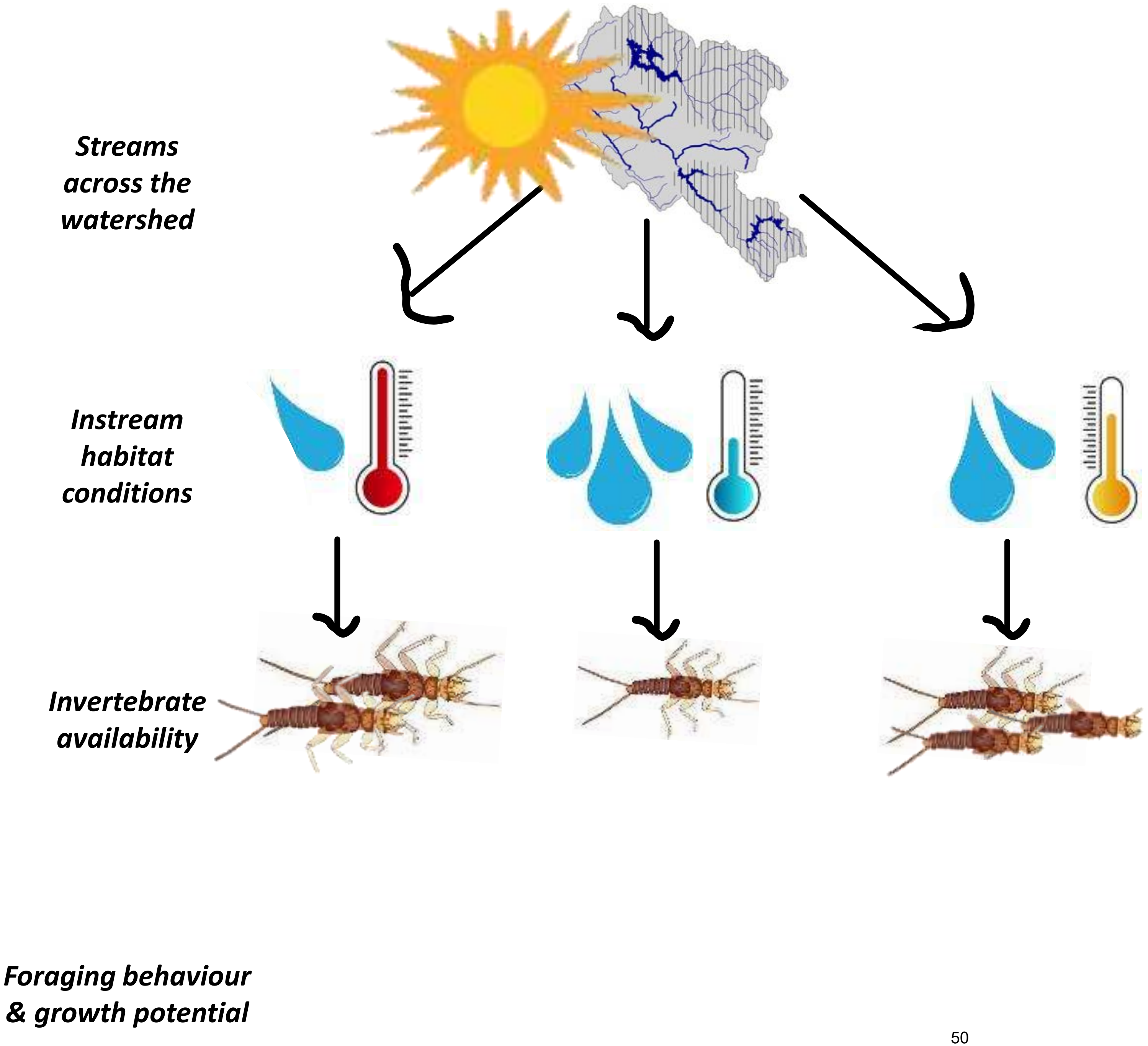
Instream habitat conditions

Invertebrate availability

Foraging behaviour & growth potential

How do habitat mosaics lead to differential impacts of drought and juvenile outcomes?

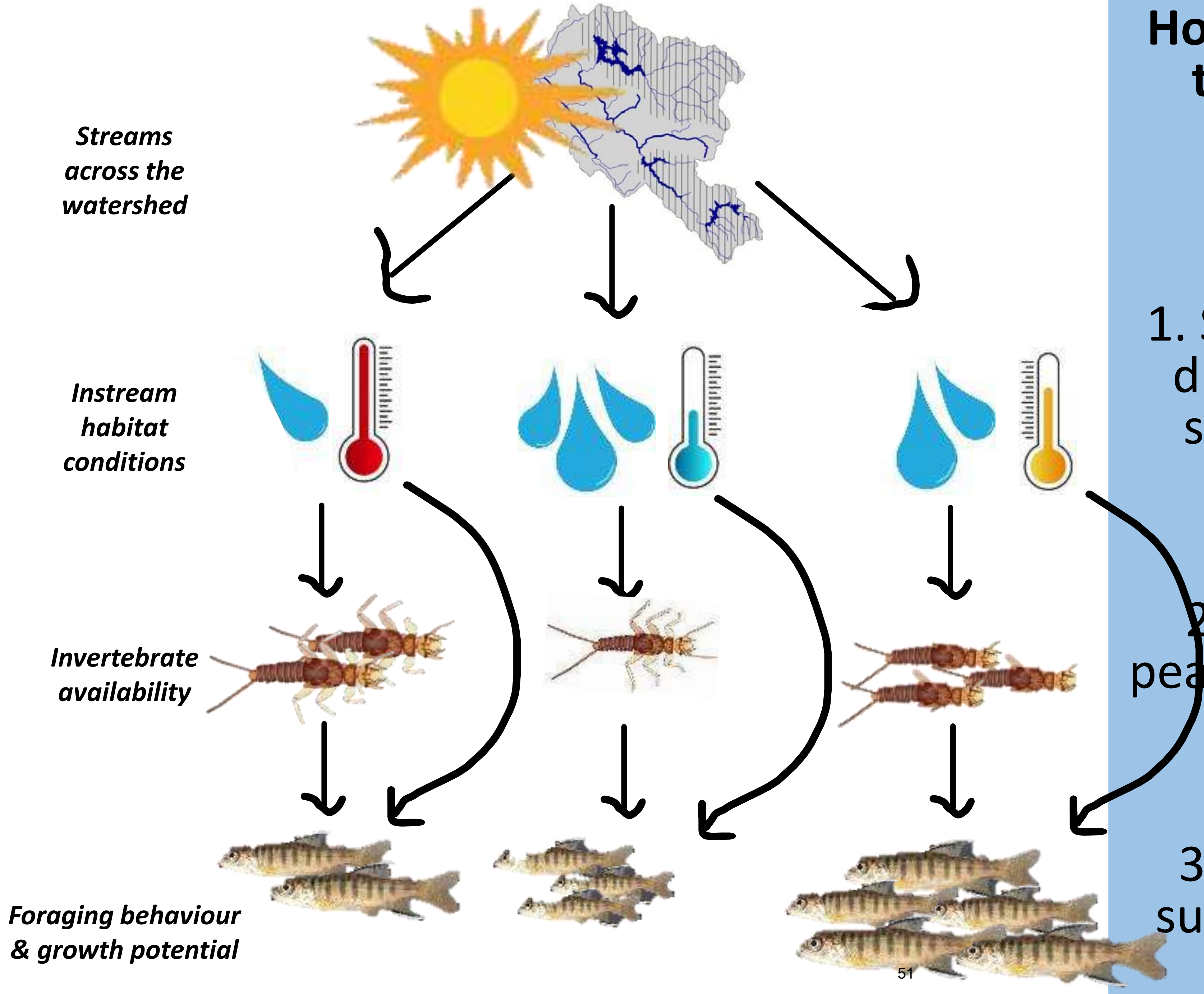
1. Stream habitats responded differently to drought, with some ecological refuges & traps



How do habitat mosaics lead to differential impacts of drought and juvenile outcomes?

1. Stream habitats responded differently to drought, with some ecological refuges & traps

2. Invertebrate availability peaked at different times, from different sources

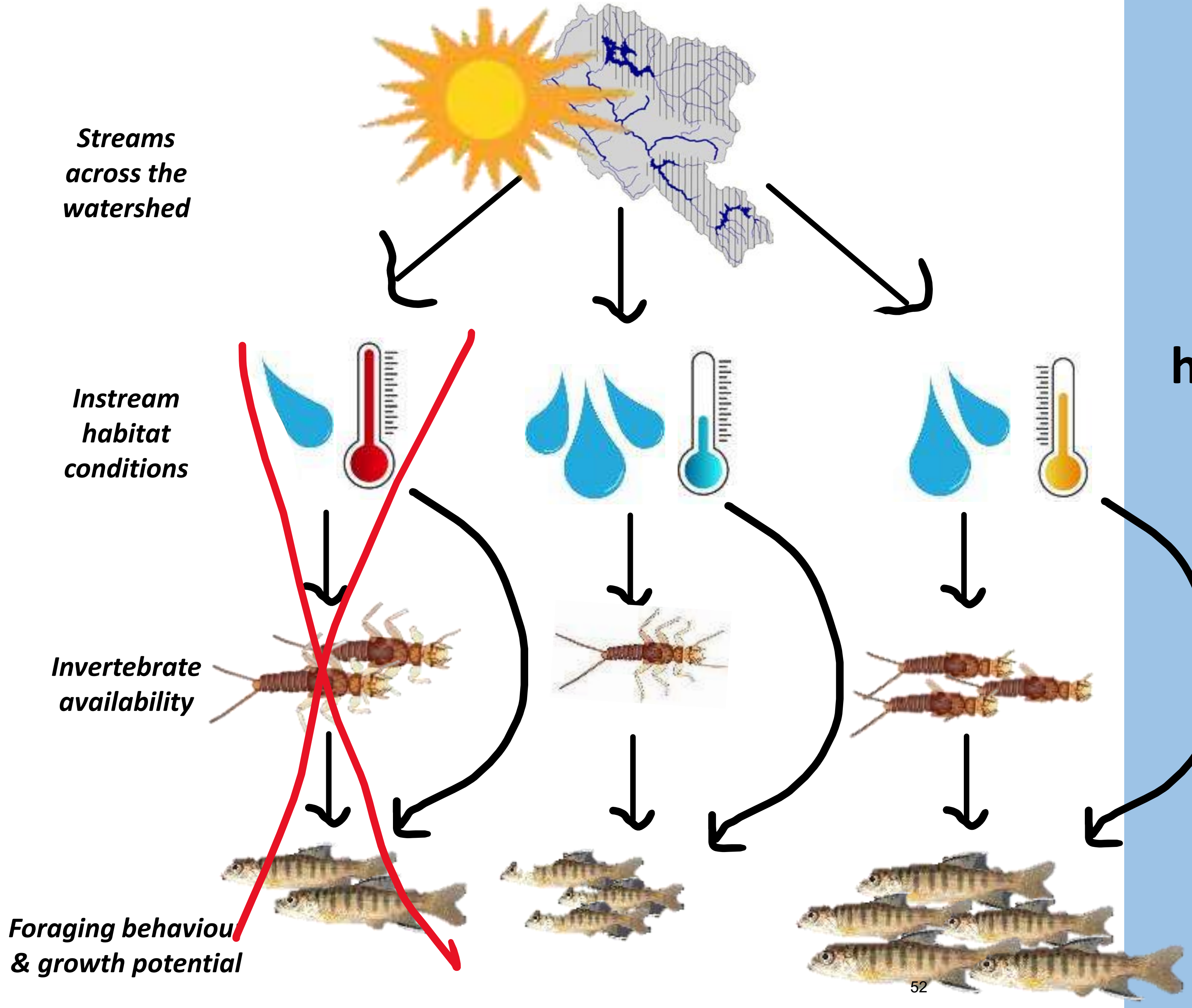


How do habitat mosaics lead to differential impacts of drought and juvenile outcomes?

1. Stream habitats responded differently to drought, with some ecological refuges & traps

2. Invertebrate availability peaked at different times, from different sources

3. Evidence for variation in survival and trait trajectories for fish across sites.



Extreme drought reduces carrying capacity across watershed, but shrunken habitat mosaic still supports potential for life history variation!

Acknowledgements

PEOPLE

ESPM Freshwater Lab
Stephanie Carlson & Ted Grantham
Undergrad Team: Phoebe Gross, Sam Rosenbaum, John Dayron Rivera, Kendall Archie, Maia Griffith, Jae Lee, Sahithi Adiraju, Cho Adolfo, Isabel Kasch, Erica Varon Rodriguez, Jacob Saffarian, Emily Chen, Hana Moidu, Zoe Vavrek, Yuka Takahashi, Joyce Wang, Mikel Malastair, Maxine Mouly, Jiashu Chen, Timonthy Greenberg, Maya Scanlon, Ciara Benson, Cat O'Brien
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Sarah Roy

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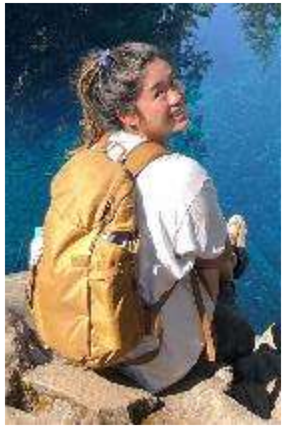
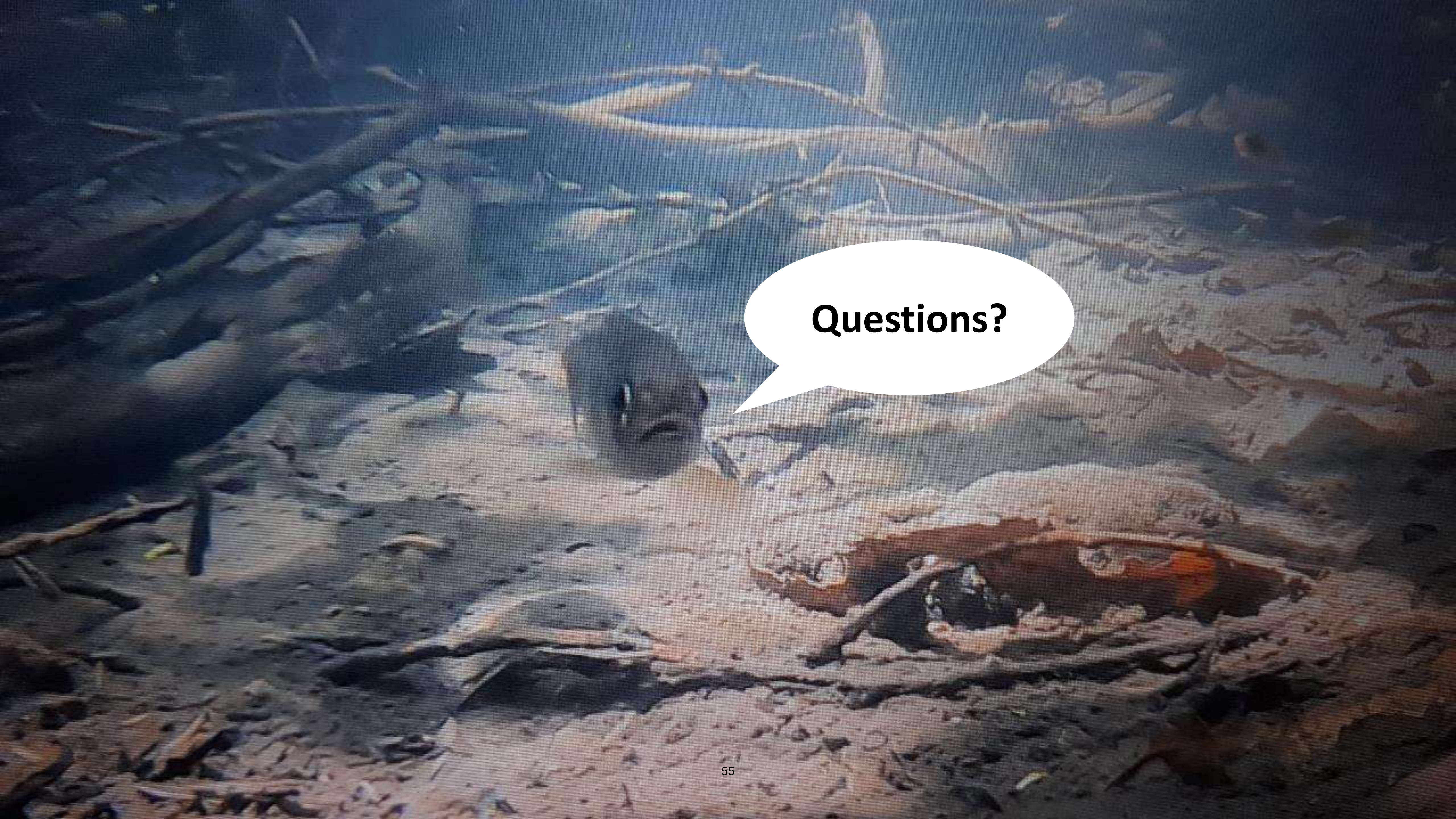
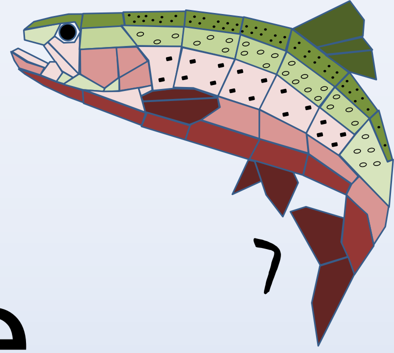
NSERC PGS D Fellowship

Thanks to my amazing field & lab team!




Questions?



Modeling Benefits of Refuge Habitat for Salmonid Populations with InSTREAM

Steven Railsback

Lang Railsback & Assoc.

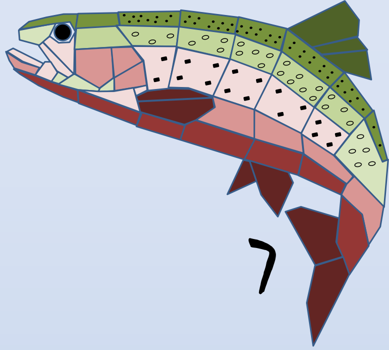
Arcata CA

Bret Harvey

US Forest Service, Pacific Southwest Research Station

Arcata CA

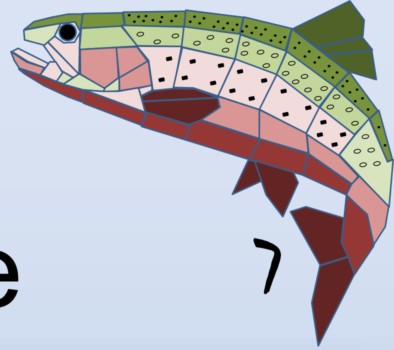
Overview



- The question: population benefits of “cold pool” thermal refuges
- InSTREAM: Individual-based stream trout model for river management
- Simulation results and general conclusions about thermal refuges

Railsback, S. F. and B. C. Harvey. **In press**. Can thermal refuges save salmonids? Simulation of cold pool benefits to trout populations. *Transactions of the American Fisheries Society*.

We *hope* that thermal refuges can buffer salmonid populations from climate change



- Studies of refuge availability

Ecohydrology

Research Article

Preserving, augmenting, and creating cold-water thermal refugia in rivers: concepts derived from research on the Miramichi River, New Brunswick (Canada)

Barret L. Kurylyk, Kerry T. B. MacQuarrie, Tommi Linnansaari, Richard A. Cunjak, R. Allen Curry

First published: 29 September 2014 | https://doi.org/10.1002/eco.1566 | Citations: 100

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Original Articles

Characteristics and Frequency of Cool-water Areas in a Western Washington Stream

Robert E. Bilby

Download citation https://doi.org/10.1080/02705060.1984.9664642

References Citations Metrics Reprints & Permissions Get access

Abstract

Four distinct types of cool-water areas were located during this midsummer survey of Thrash Creek, Washington, a warm, fifth-order stream. These areas were termed lateral seeps, pool bottom seeps, cold tributary mouths and flow through the bed, depending upon the entry point and source of the cool water. These types differed with respect to average size, depth and location in the stream channel. Temperatures in the cool water areas averaged 4.7°C lower than ambient streamwater on warm afternoons. Thirty-nine such

Journal of Environmental Management

Volume 118, 30 March 2013, Pages 170-176

ELSEVIER

Linking landscape variables to cold water refugia in rivers

Wendy A. Monk, Nathan M. Wilbur, R. Allen Curry, Rolland Gagnon, Russell N. Faux

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https://doi.org/10.1016/j.jenvman.2012.12.024 Get rights and content

Abstract

The protection of coldwater refugia within aquatic systems requires the identification of thermal habitats in rivers. These refugia provide critical thermal

Aquatic Sciences (2018) 80:3

https://doi.org/10.1007/s00027-017-0557-9

Aquatic Sciences

RESEARCH ARTICLE

Longitudinal thermal heterogeneity in rivers and refugia for coldwater species: effects of scale and climate change

A. H. Fullerton[1] · C. E. Torgersen[2] · J. J. Lawler[3] · E. A. Steel[4] · J. L. Ebersole[5] · S. Y. Lee[6]

Received: 8 March 2017 / Accepted: 14 November 2017 / Published online: 21 November 2017

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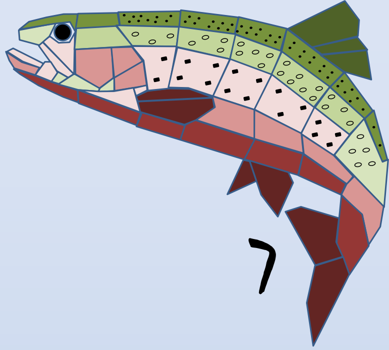
Abstract

Climate-change driven increases in water temperature pose challenges for aquatic organisms. Predictions of impacts typically do not account for fine-grained spatiotemporal thermal patterns in rivers. Patches of cooler water could serve as refuges for anadromous species like salmon that migrate during summer. We used high-resolution remotely sensed water temperature data to characterize summer thermal heterogeneity patterns for 11,308 km of second–seventh-order rivers throughout the Pacific Northwest and northern California (USA). We evaluated (1) water temperature patterns at different spatial resolutions, (2) the frequency, size, and spacing of cool thermal patches suitable for Pacific salmon (i.e., contiguous stretches ≥ 0.25 km, ≤ 15 °C and ≥ 2 °C, cooler than adjacent water), and (3) potential influences of climate change on availability of cool patches. Thermal heterogeneity was nonlinearly related to the spatial resolution of water temperature data, and heterogeneity at fine resolution (< 1 km) would have been difficult to quantify without spatially continuous data. Cool patches were generally > 2.7 and < 13.0 km long, and spacing among patches was generally > 5.7 and < 49.4 km. Thermal heterogeneity varied among rivers, some of which had long uninterrupted stretches of warm water ≥ 20 °C, and others had many smaller cool patches. Our models predicted little change in future thermal heterogeneity among rivers, but within-river patterns sometimes changed markedly compared to contemporary patterns. These results can inform long-term monitoring programs as well as near-term climate-adaptation strategies.

7

- Studies of refuge use by fish

The unanswered question:



- How does the availability of refuges affect *population abundance and persistence*, as temperatures warm??

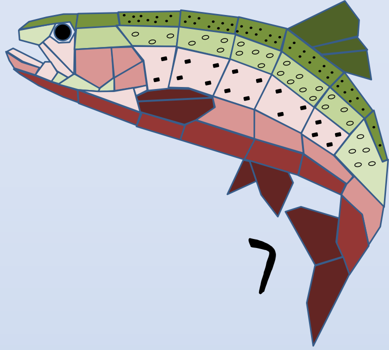
- (Yet another problem *too complex for field experiments alone*)

- (So what can we do??)

InSTREAM and InSALMO*:
Individual-based salmonid models for river management

*L. Hahn, later this session

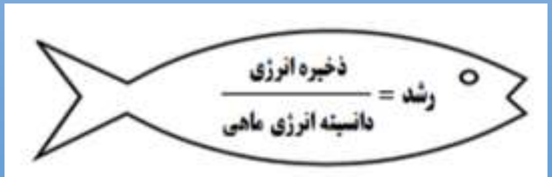
InSTREAM and InSALMO



- Applied at ~50 sites worldwide, since 1999

- For:
  - Instream flow and temperature assessment
  - Restoration project design and evaluation (A. Hahn)
  - Research

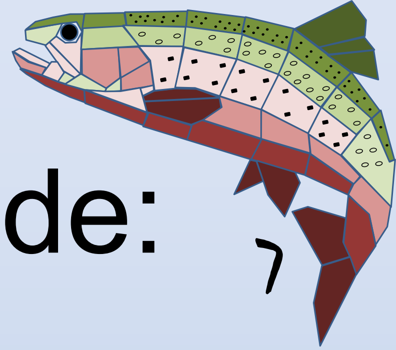
- Documented, tested, free, open-source...



Hajiesmaeili et al. 2022, Journal of Iranian Water Engineering Research

Individual-level mechanisms

- Foraging behavior: deciding when and where to feed
  - ➢Trading off growth vs. predation risk
  - ➢4 times daily: dawn, day, dusk, night
- Growth (bioenergetics)
- Survival (fish and terrestrial predators, high temperature, ...)
- Reproduction
  - ➢Spawning
  - ➢Egg incubation and survival



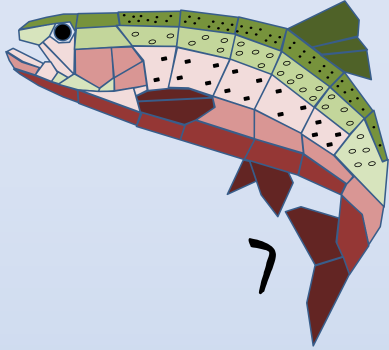
Simulated effects of temperature include:

- Increased metabolic rate →
  - ➢Lower growth →
  - ➢Feeding at riskier times and places →
  - ➢Lower survival

- Acute stress and disease: increases sharply > 24°

- Higher risk of predation by fish

The simulation experiments



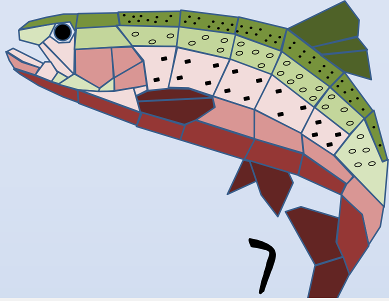
- Scenarios:
  - ➢4 temperature regimes

    ×
  - ➢4 levels of refuge availability

- Population responses:
  - ➢Survival and growth, May–October of 5 separate years
  - ➢Persistence and abundance over 22 years

Study site: Clear Creek near Redding, CA

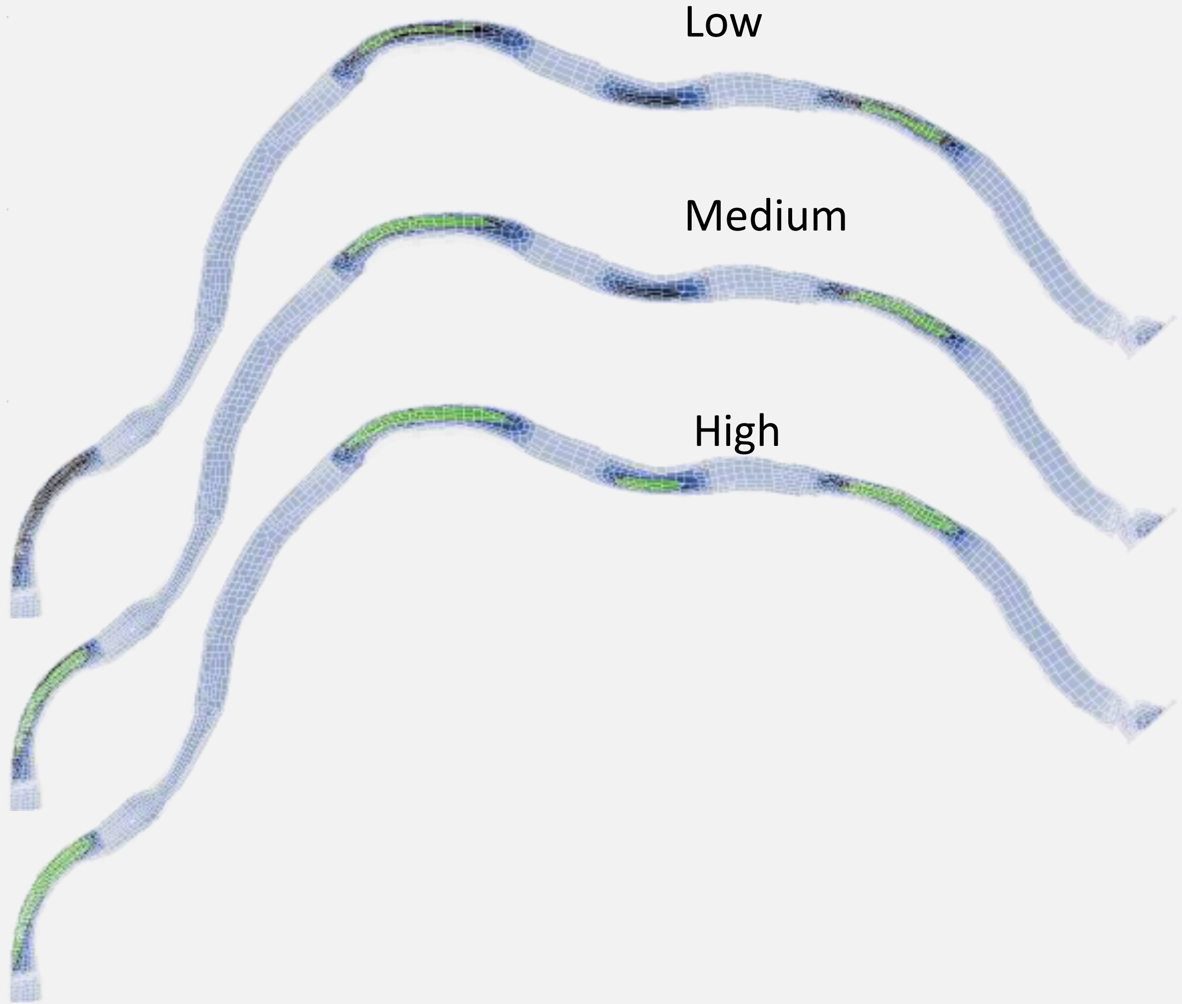
- Channel: A restoration project design, ~1000 m length
- Observed flows and temperatures (strongly controlled by Whiskeytown Reservoir)
- Hypothetical Rainbow Trout population

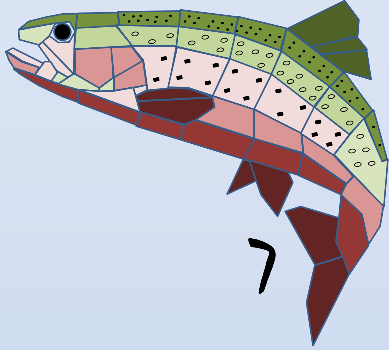


Simulated refuges

- Cool pools: patches with low velocity and high depth

- Availability scenarios:
    - None
    - Low: 2 pools, 2% of area
    - Med: 3 pools, 6% of area
    - High: 4 pools, 10% of area

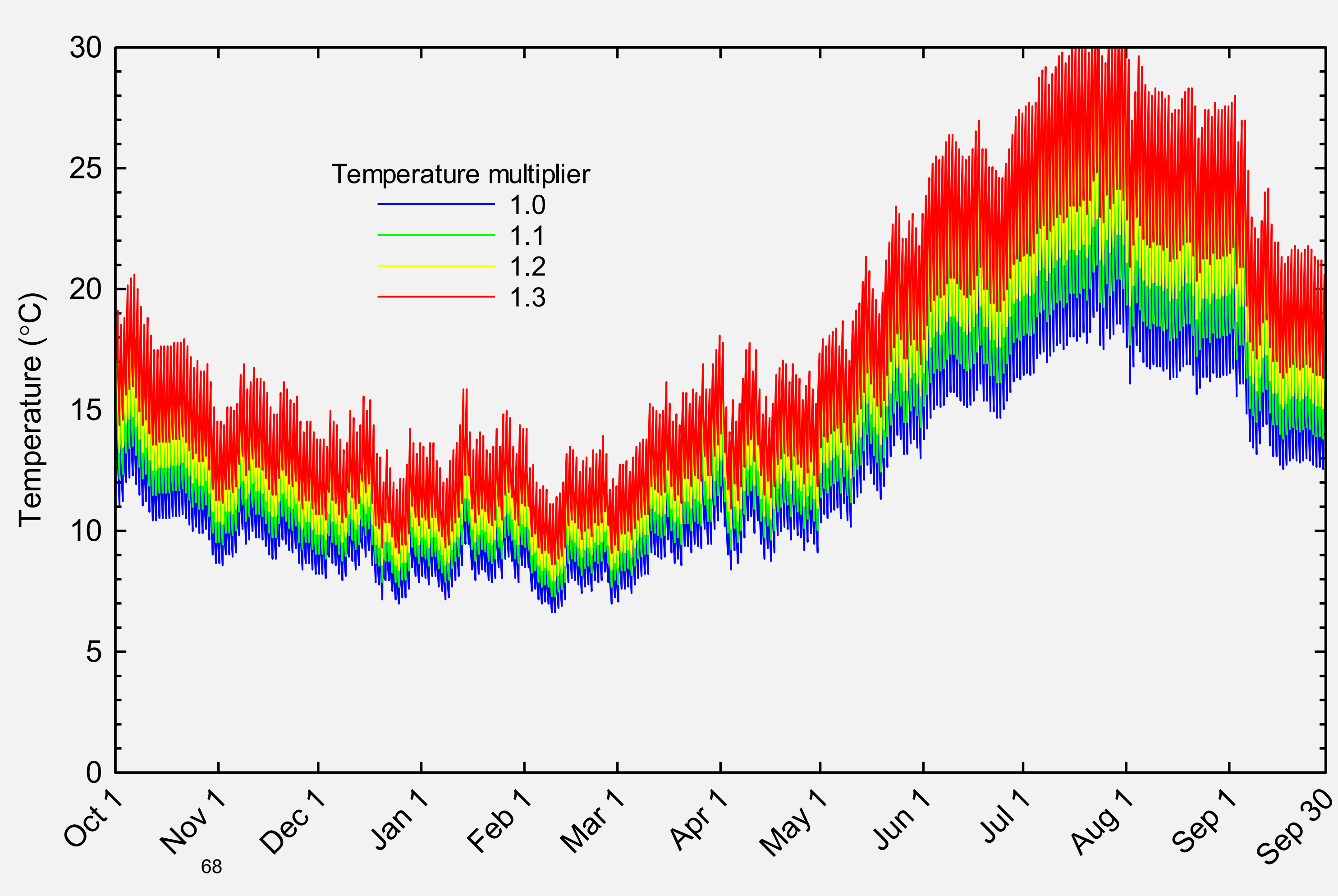




Temperature scenarios

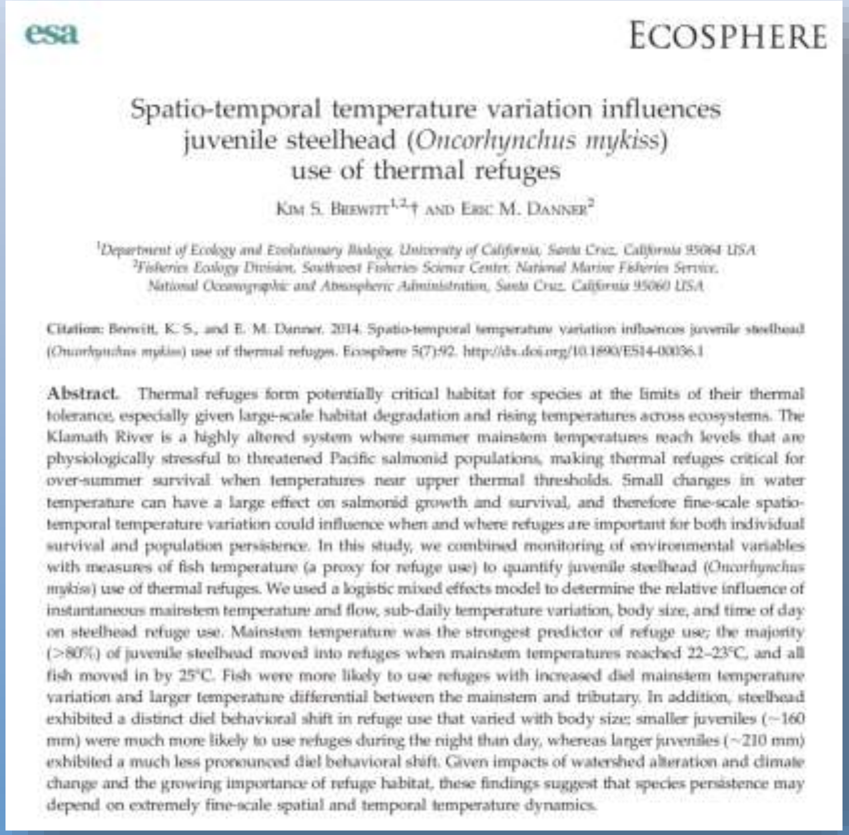
- River:
  - ➢1, 1.1, 1.2, 1.3 × observed
  - ➢Including estimated diurnal variation

- Refuges: Lower of
  - ➢River temperature
  - ➢15°, 16.5°, 18°, 19.5°



Model credibility: Patterns observed in Klamath R. Steelhead (Brewitt & Danner 2014) and reproduced in these simulations

1. Fish used refuges in all summer temperatures*
2. Fish used non-refuge habitat in all summer temperatures, except
3. All* fish were in refuges when the river was above ~25°
4. Refuge use varied widely among individuals
5. Refuge use not related to fish size
6. Below ~22°, higher refuge use at night



esa ECOSPHERE

Spatio-temporal temperature variation influences juvenile steelhead (*Oncorhynchus mykiss*) use of thermal refuges

Kim S. Brewitt[1,2]† and Eric M. Danner[2]

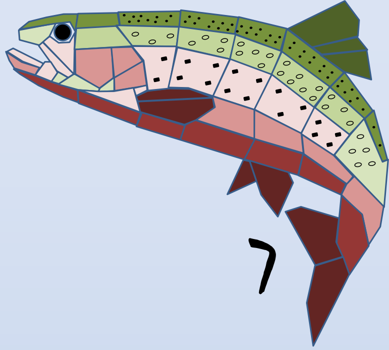
[1]*Department of Ecology and Evolutionary Biology, University of California, Santa Cruz, California 95064 USA*
[2]*Fisheries Ecology Division, Southwest Fisheries Science Center, National Marine Fisheries Service, National Oceanographic and Atmospheric Administration, Santa Cruz, California 95060 USA*

Citation: Brewitt, K. S., and E. M. Danner. 2014. Spatio-temporal temperature variation influences juvenile steelhead (*Oncorhynchus mykiss*) use of thermal refuges. Ecosphere 5(7):92. http://dx.doi.org/10.1890/ES14-00036.1

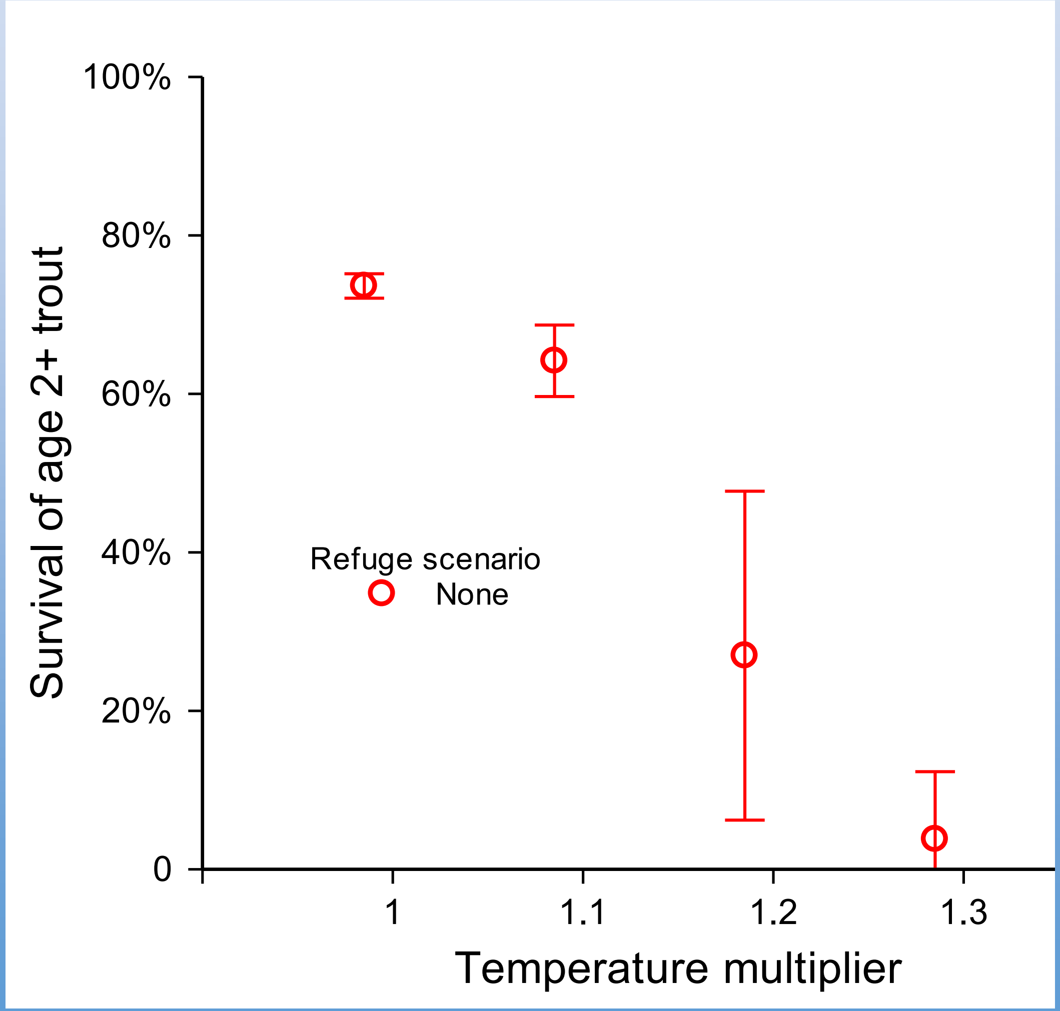
Abstract. Thermal refuges form potentially critical habitat for species at the limits of their thermal tolerance, especially given large-scale habitat degradation and rising temperatures across ecosystems. The Klamath River is a highly altered system where summer mainstem temperatures reach levels that are physiologically stressful to threatened Pacific salmonid populations, making thermal refuges critical for over-summer survival when temperatures near upper thermal thresholds. Small changes in water temperature can have a large effect on salmonid growth and survival, and therefore fine-scale spatio-temporal temperature variation could influence when and where refuges are important for both individual survival and population persistence. In this study, we combined monitoring of environmental variables with measures of fish temperature (a proxy for refuge use) to quantify juvenile steelhead (*Oncorhynchus mykiss*) use of thermal refuges. We used a logistic mixed effects model to determine the relative influence of instantaneous mainstem temperature and flow, sub-daily temperature variation, body size, and time of day on steelhead refuge use. Mainstem temperature was the strongest predictor of refuge use; the majority (>80%) of juvenile steelhead moved into refuges when mainstem temperatures reached 22–23°C, and all fish moved in by 25°C. Fish were more likely to use refuges with increased diel mainstem temperature variation and larger temperature differential between the mainstem and tributary. In addition, steelhead exhibited a distinct diel behavioral shift in refuge use that varied with body size; smaller juveniles (~160 mm) were much more likely to use refuges during the night than day, whereas larger juveniles (~210 mm) exhibited a much less pronounced diel behavioral shift. Given impacts of watershed alteration and climate change and the growing importance of refuge habitat, these findings suggest that species persistence may depend on extremely fine-scale spatial and temporal temperature dynamics.

*Not completely reproduced for reasons discussed later

Results: Summer survival



- Survival decreases as temperature increases
- The rate of survival decrease depends very strongly on refuge availability



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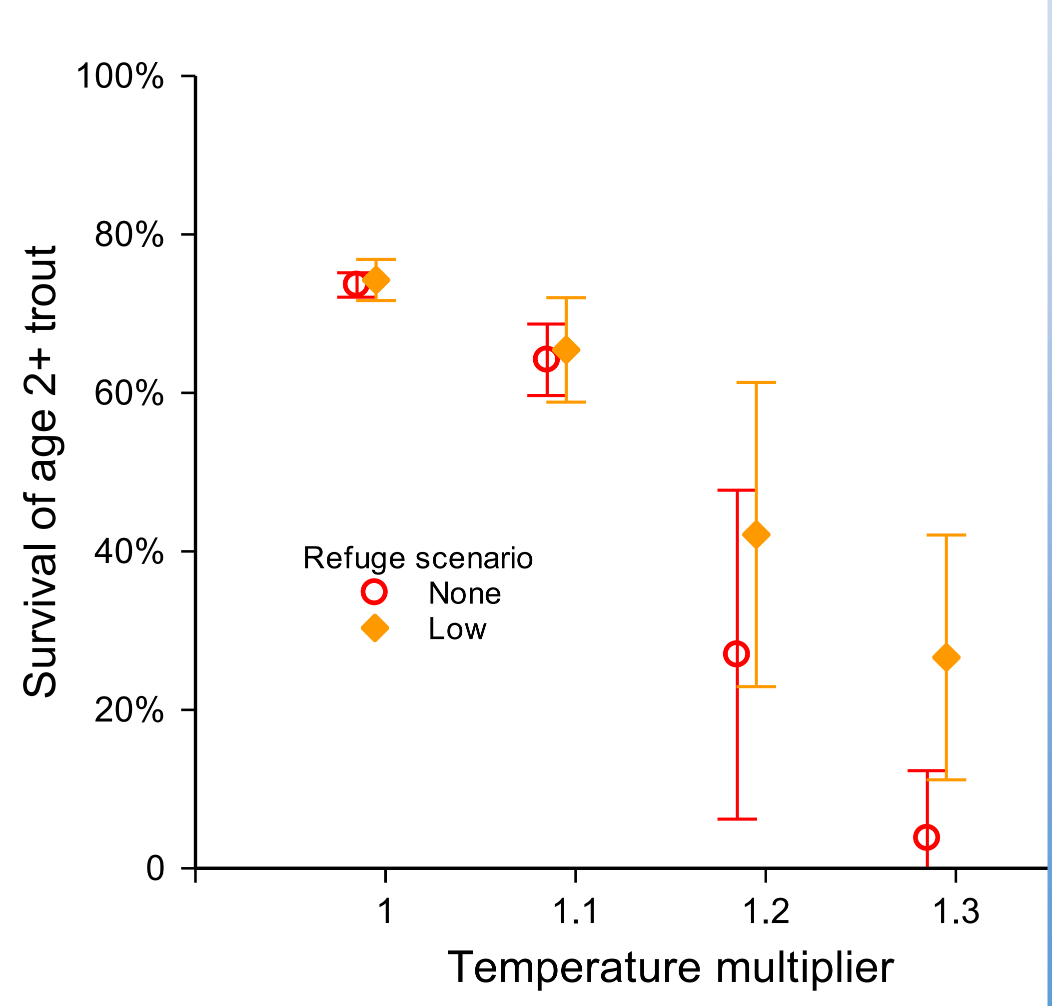

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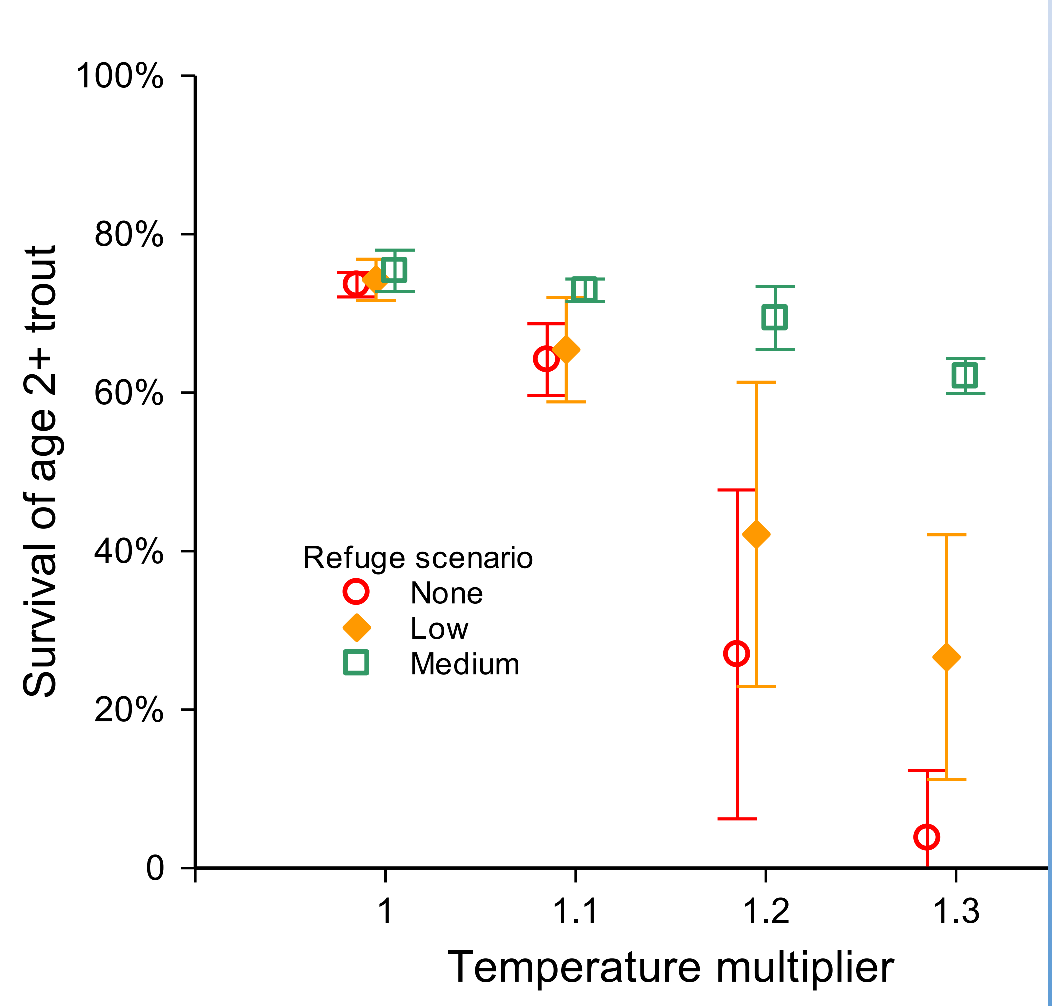

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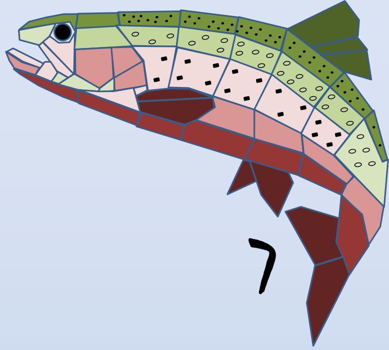

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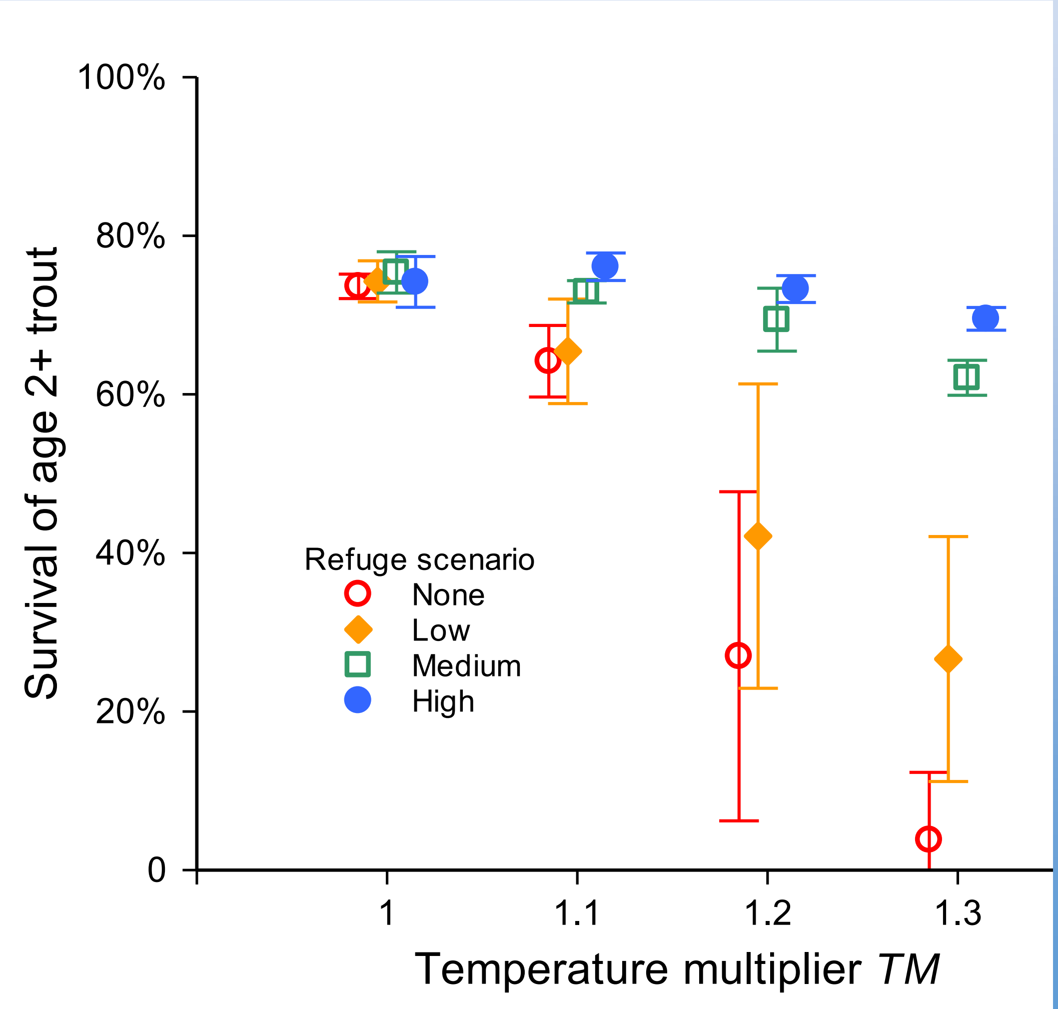
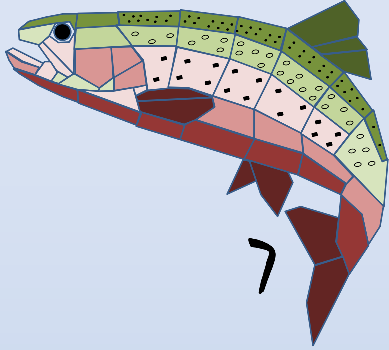
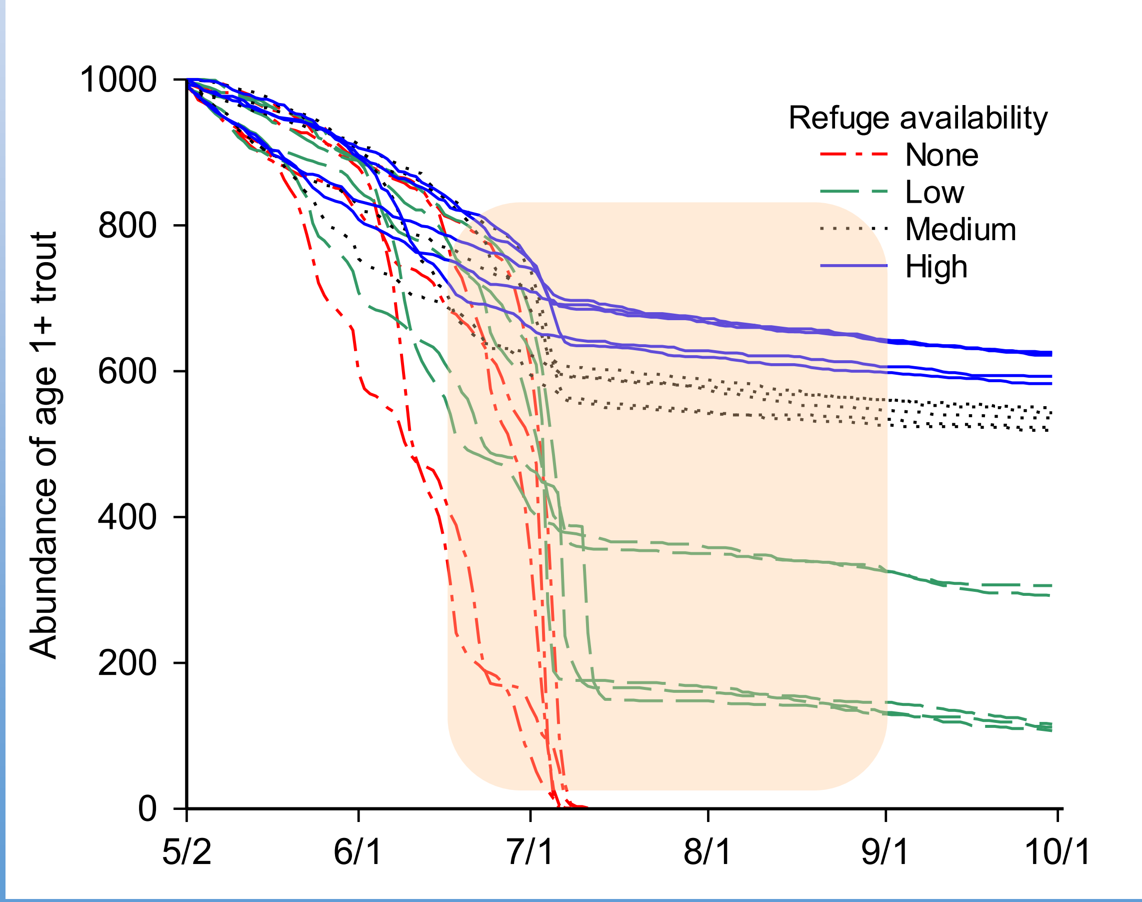


Time series of summer abundance, Warmest temperature regime

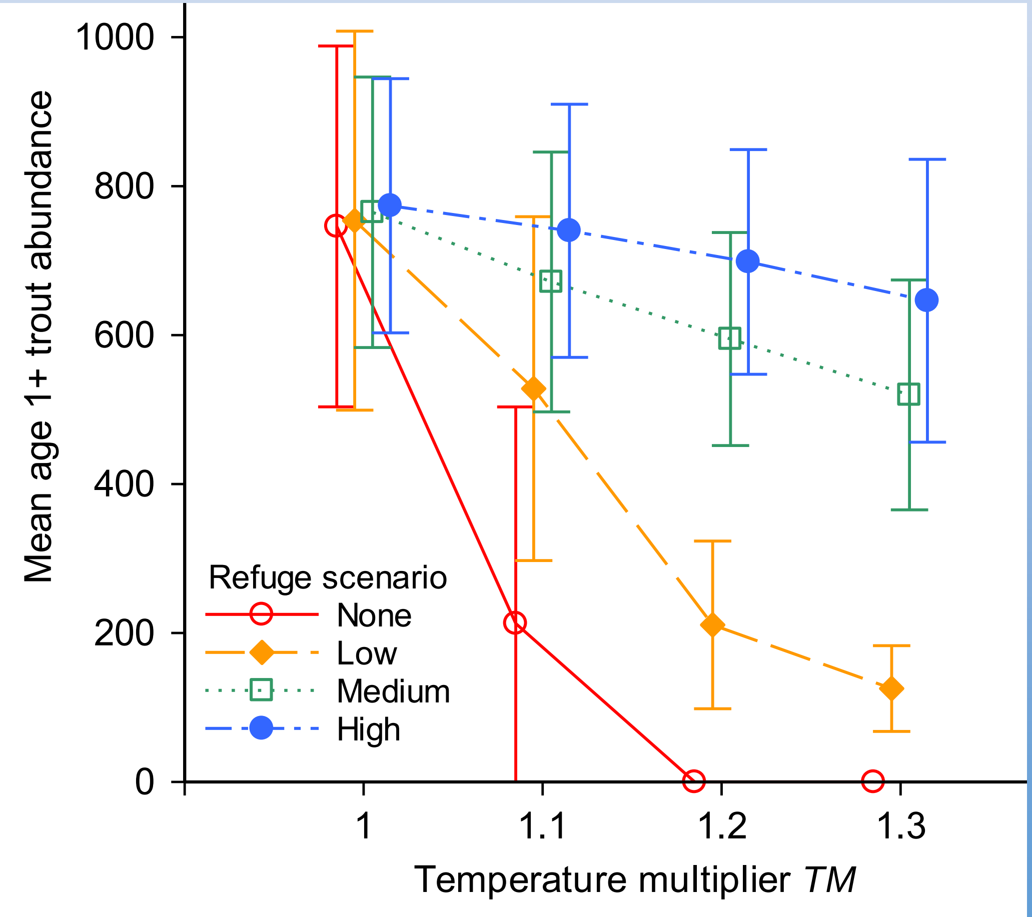


- Abundance drops rapidly at onset of summer low flows and high temperatures
- Survival of this “bottleneck” depends on refuge availability
- (NOT: hanging on in refuge through stressful period)

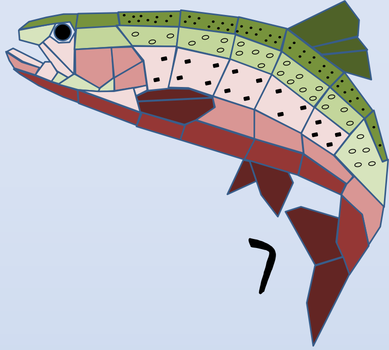


Results: Long-term abundance (22-year simulations)

- Even low refuge availability allows population to persist at highest temperatures
- Higher refuge availability → less effect of temperature on abundance



Conclusions (1)



- “Hanging on” conceptual model is not supported:
  - At extreme temperatures, abundance may be limited by how many fish can maintain body weight while using refuges much of the time
  - Real fish may be more willing to lose weight than our digital fish, but they must survive for months

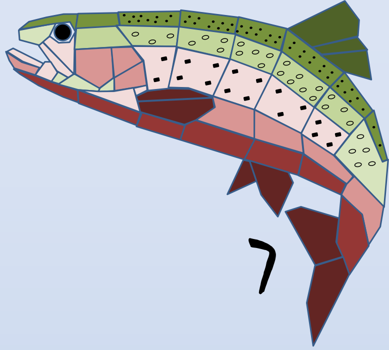
Conclusions (2)

- Refuge characteristics other than temperature are important!
  - ➢Food and feeding habitat, for all ages
  - ➢Cover for concealment, escape
  - ➢Water quality, etc.

- These characteristics vary among refuge types
  - ➢Pools are not great feeding habitat and risky for juveniles
  - ➢Tributary mouths can be very productive

Mouth of Horse Linto Creek

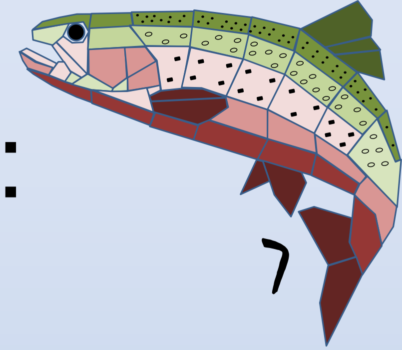
Conclusions (3)

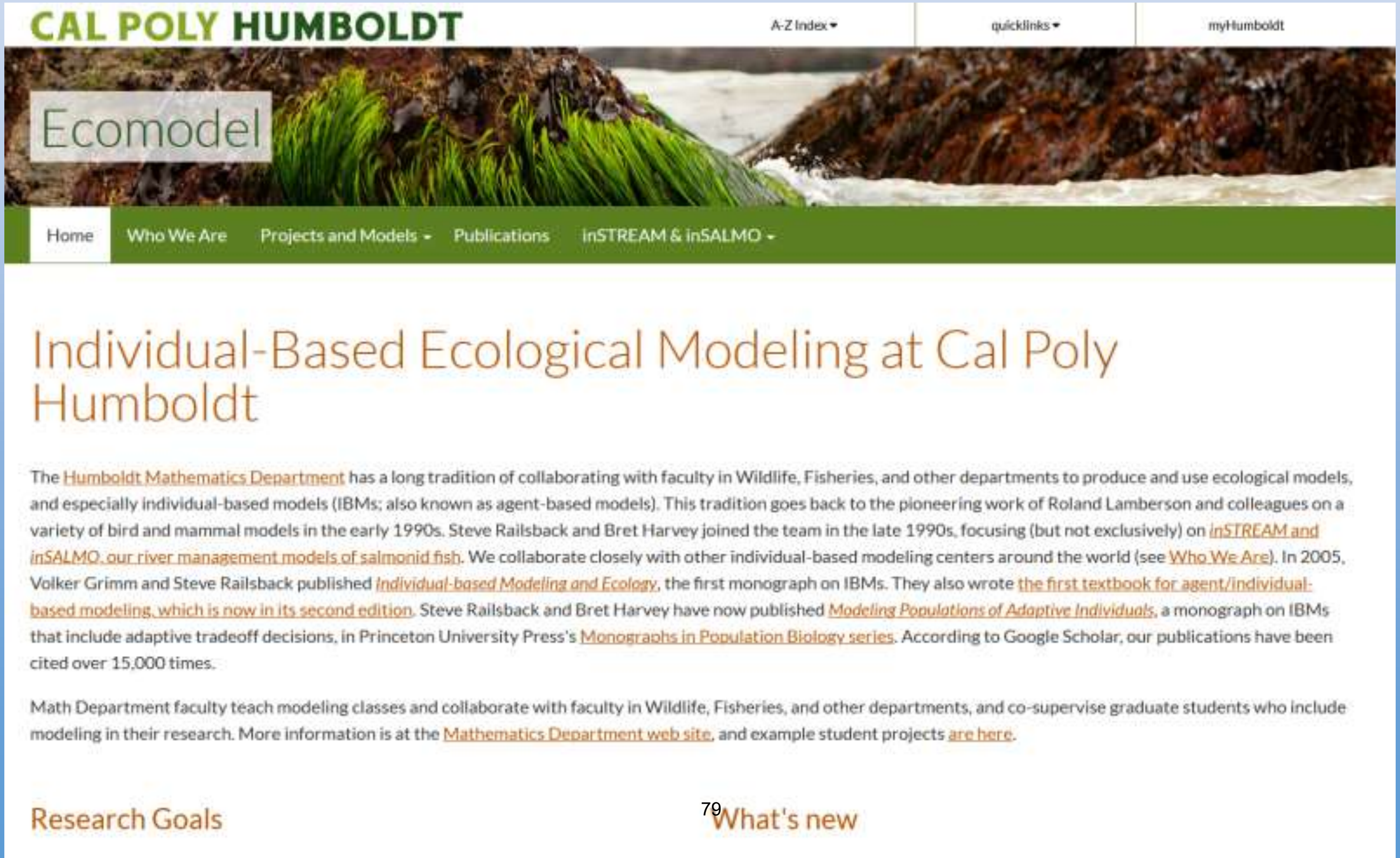


- Refuges may be as or more important at night (so look!)

  - If fish must leave a refuge to feed, it could be safer to feed rapidly in daylight

Models, documentation, publications, etc.: https://ecomodel.humboldt.edu

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Ecomodel

Home | Who We Are | Projects and Models | Publications | inSTREAM & inSALMO

Individual-Based Ecological Modeling at Cal Poly Humboldt

The Humboldt Mathematics Department has a long tradition of collaborating with faculty in Wildlife, Fisheries, and other departments to produce and use ecological models, and especially individual-based models (IBMs; also known as agent-based models). This tradition goes back to the pioneering work of Roland Lamberson and colleagues on a variety of bird and mammal models in the early 1990s. Steve Railsback and Bret Harvey joined the team in the late 1990s, focusing (but not exclusively) on *inSTREAM and inSALMO, our river management models of salmonid fish*. We collaborate closely with other individual-based modeling centers around the world (see Who We Are). In 2005, Volker Grimm and Steve Railsback published *Individual-based Modeling and Ecology*, the first monograph on IBMs. They also wrote the first textbook for agent/individual-based modeling, which is now in its second edition. Steve Railsback and Bret Harvey have now published *Modeling Populations of Adaptive Individuals*, a monograph on IBMs that include adaptive tradeoff decisions, in Princeton University Press's Monographs in Population Biology series. According to Google Scholar, our publications have been cited over 15,000 times.

Math Department faculty teach modeling classes and collaborate with faculty in Wildlife, Fisheries, and other departments, and co-supervise graduate students who include modeling in their research. More information is at the Mathematics Department web site, and example student projects are here.

Research Goals

What's new

Modeling influences of diversions on streamflow using SAL model

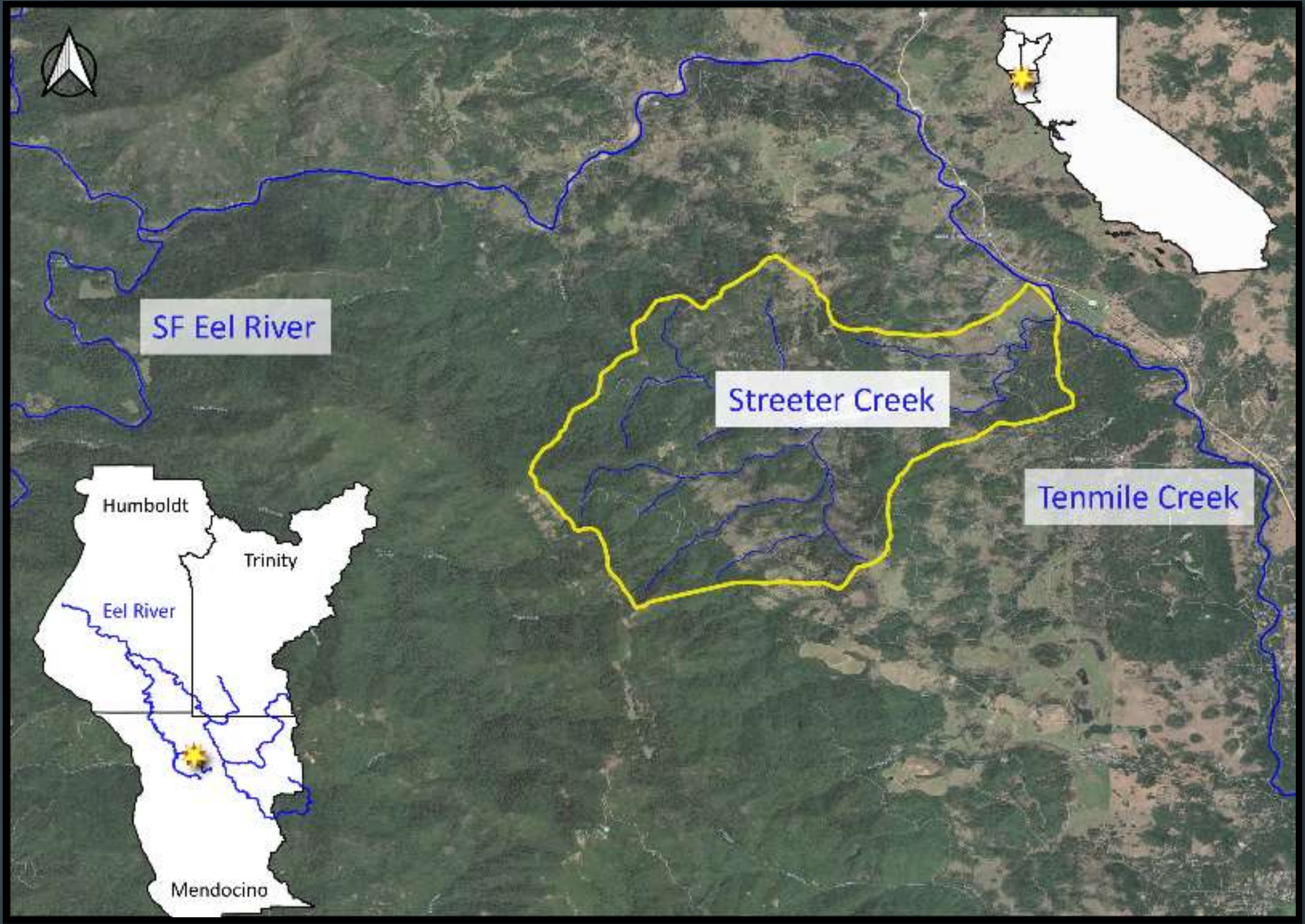
Streeter Creek, Laytonville, CA

•••

Julia Petreshen, Thomas Gast & Associates
Jim Graham, PhD, California Polytechnical University - Humboldt

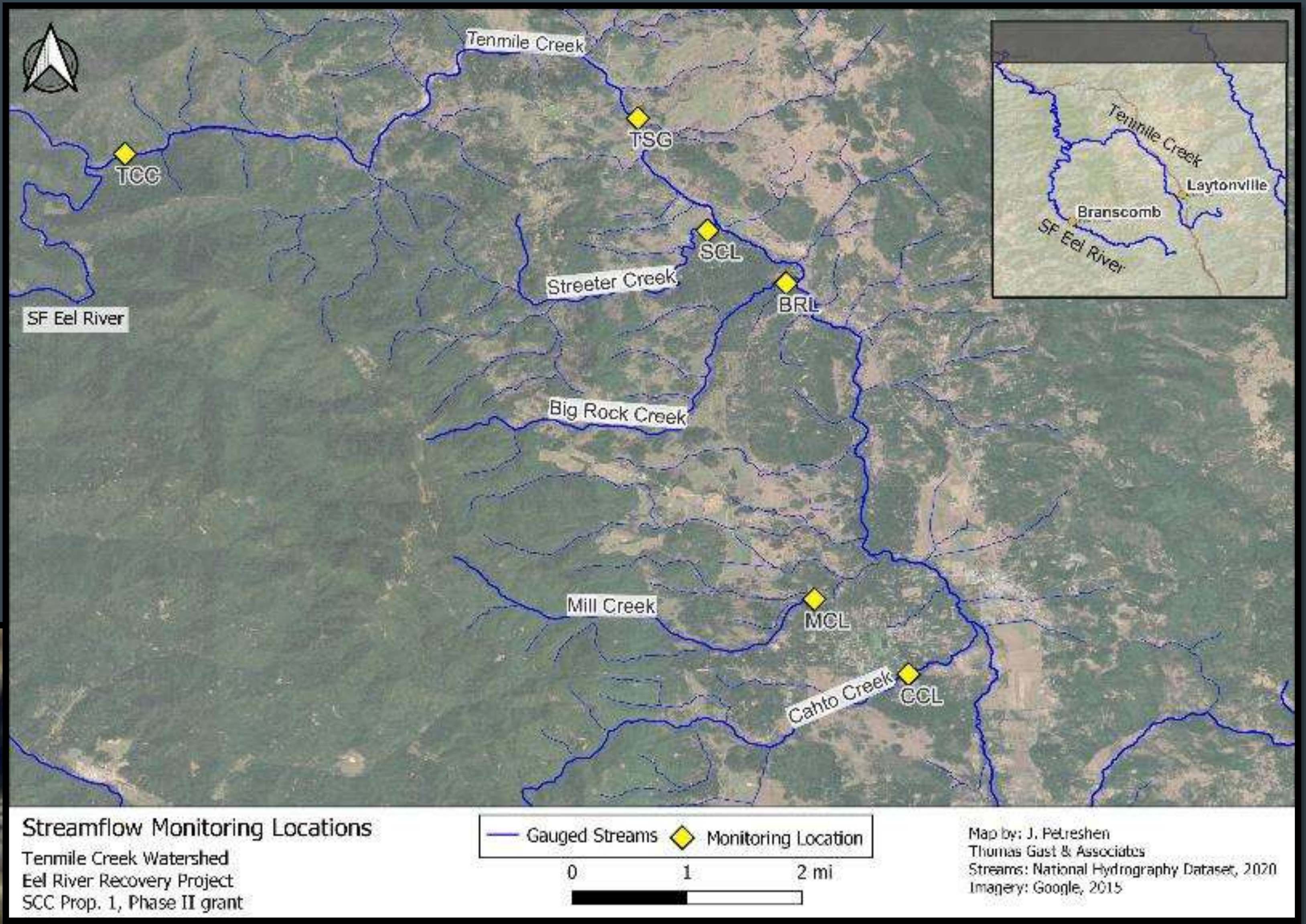
Streeter Creek

- 5 mi² watershed
- Trib. to Tenmile Creek, SF Eel River
- Eel River Recovery Project (ERRP)
    - Tenmile Creek Water Conservation & Erosion Control Project



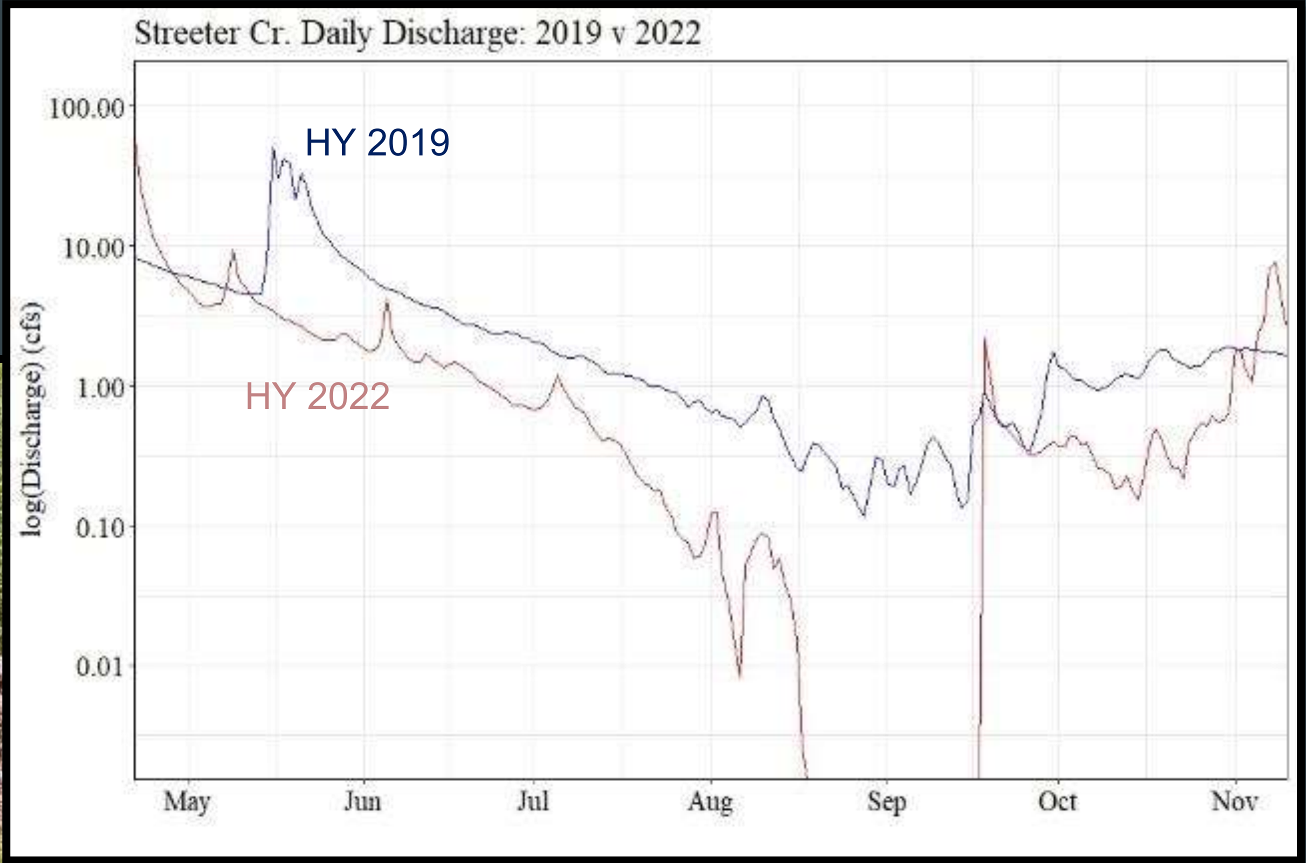
Streeter Creek Fisheries

- ERRP: monitor temp., streamflow, fisheries surveys
- Streeter:
  - Steelhead and Chinook juveniles
  - Historically supported Coho salmon as well



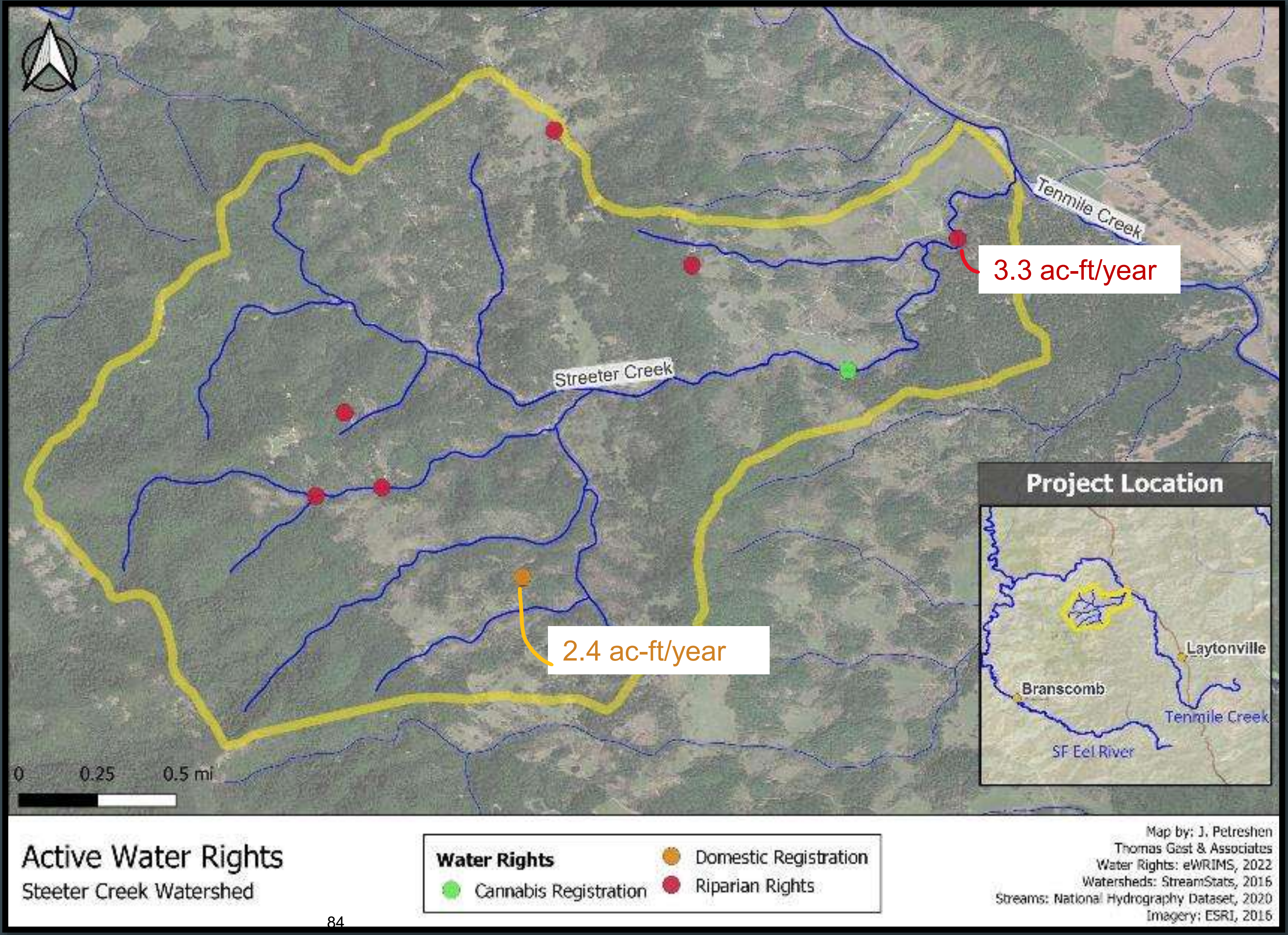
Chinook salmon juvenile at left feeding next to a young of the year steelhead or rainbow trout in lower Streeter May 26, 2022. (Higgins, 2022)

Streeter Creek Flow



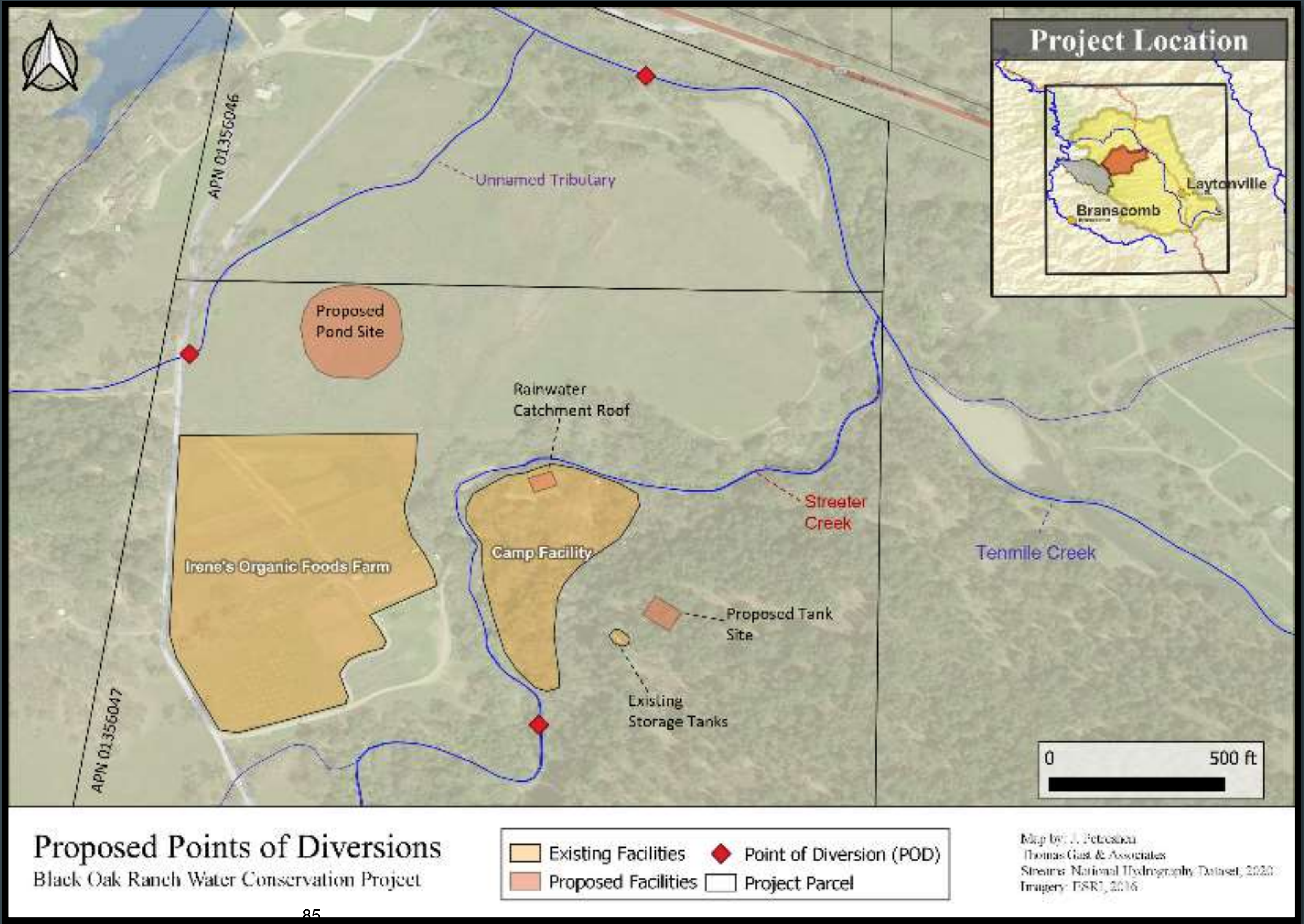
Streeter Creek: Diversions

- Riparian right near confluence
  - Black Oak Ranch
    - Irene's Garden Produce
    - Campground
- Riparian Rights
  - Can't store water more than 30 days
  - Diversions during low-flow season



Tenmile Creek Water Conservation Project

- SCC Prop. 1 grant to Eel River Recovery Project:
  - Plan, design, permit water storage infrastructure
  - Storage and forbearance
    - Rainwater, diversion during winter season
    - No summer diversion



Tenmile Creek Water Conservation Project

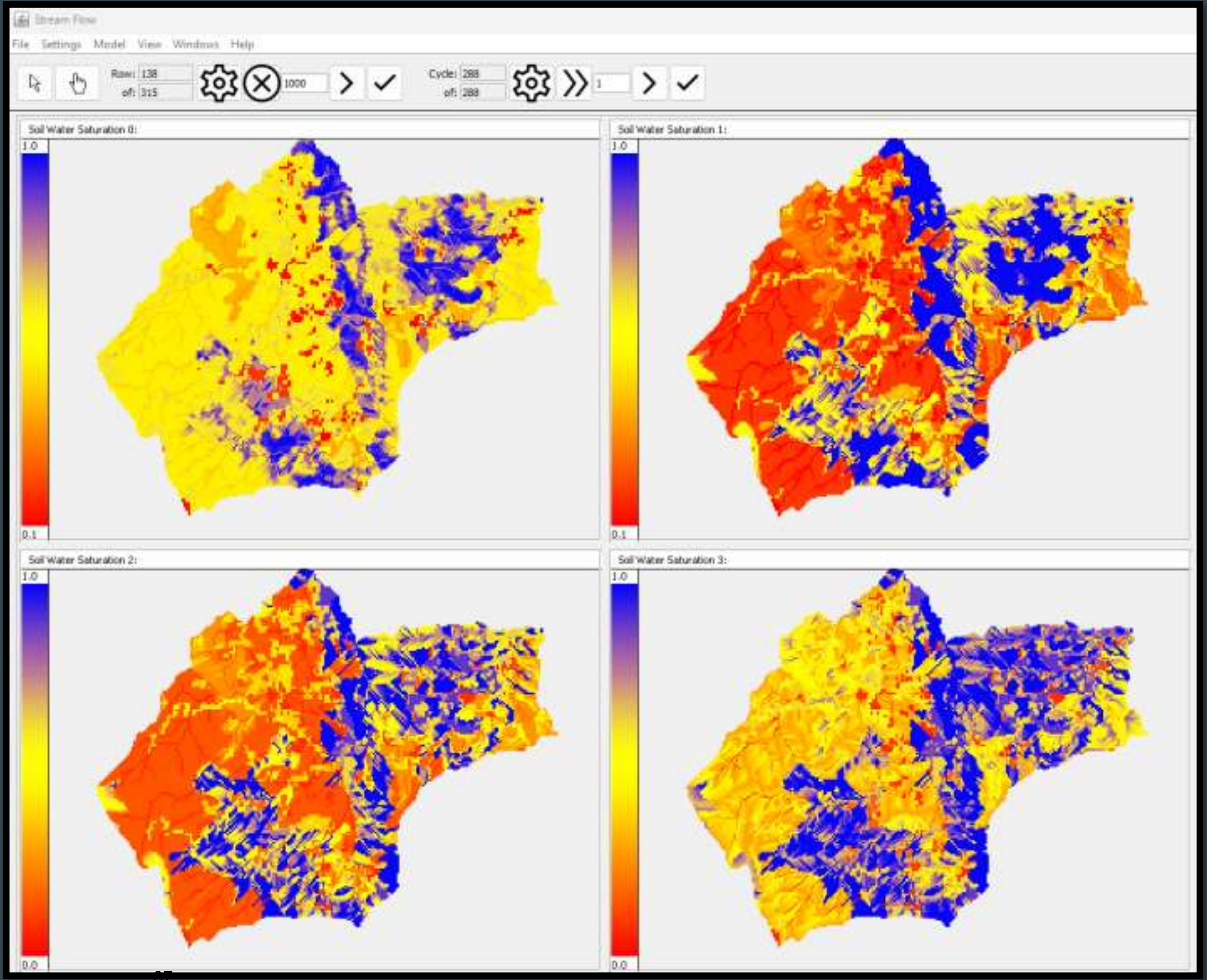
- Water conservation through forest management
- Cahto Tribe
  - burned, maintain oak woodlands
  - Low water demand
- Fire suppression = Douglas fir encroachment
  - High water demand

Photo of Douglas fir encroachment into oak woodland, by Yana Valachovic, UCCE Forest Advisor

SAL: Modelling Streamflow in Streeter

- SAL: model impacts of diversions, forest management

- Model Streeter streamflow:
  - 2022 – unimpaired flow
  - Implement diversions, match observed streamflow?



SAL: soil water saturation at different soil depths;

SAL Inputs : Weather

- Laytonville RAWS station
- Hourly > Daily

Laytonville RAWS site. Source: *Western Regional Climate Center*

prev day **Station Summary** next day

Laytonville California

Daily Summary for

August 2, 2022

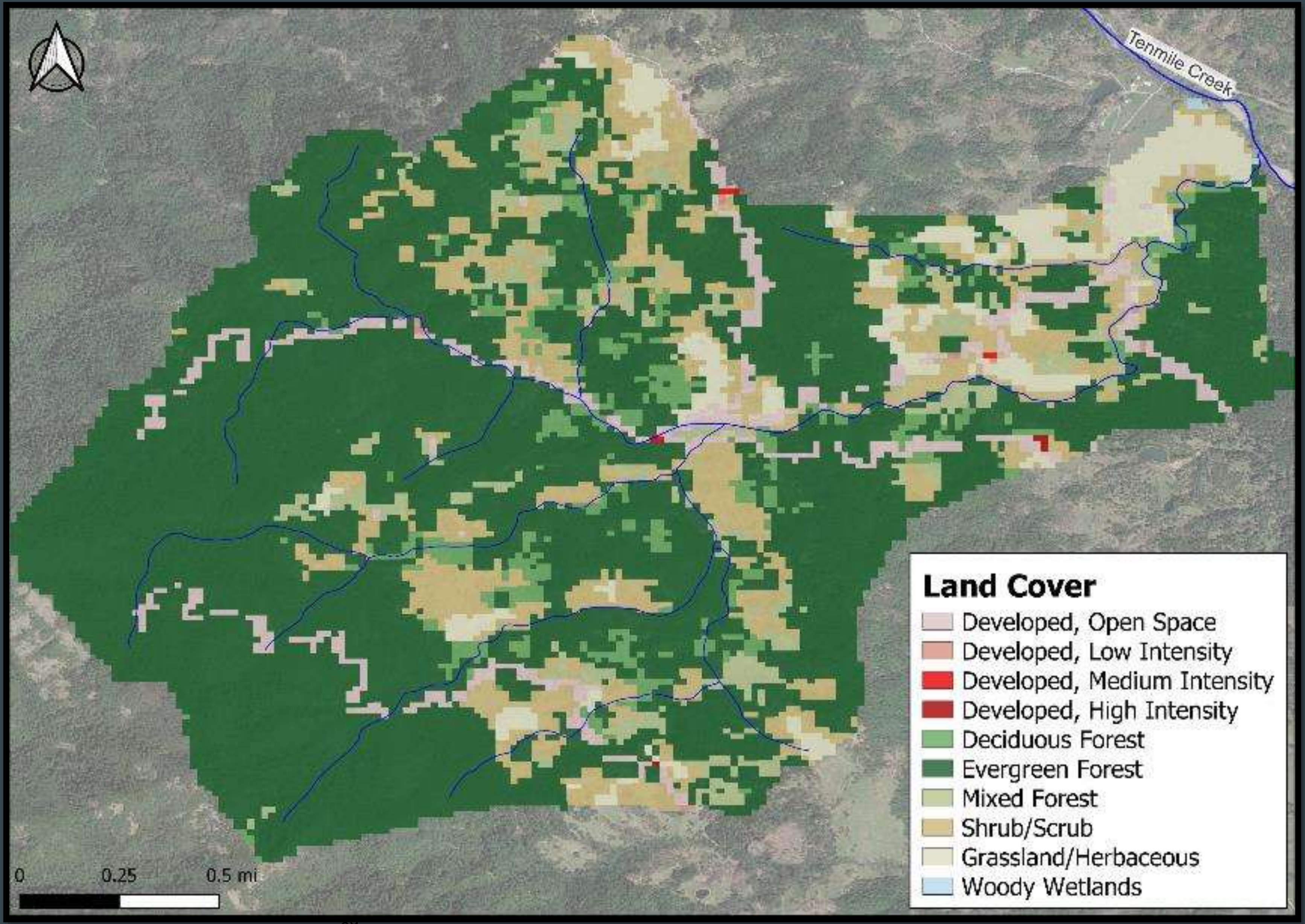
Hour of Day Ending at L.S.T.	Total Solar Rad. ° ly.	Wind Ave. mph	Wind V. Dir. Deg	Wind Max. mph	Air Temperature Mean Deg. F.	Fuel Temperature Mean Deg. F.	Fuel Moisture Mean Percent	Relative Humidity Mean Percent	Dew Point Deg. F.	Wet Bulb Deg. F.	Total Precip. inches
1 am	0.0	0.0	11	0.0	62.0	61.0	17.5	94	60	61	0.00
2 am	0.0	0.0	11	0.0	61.0	60.0	19.2	96	60	60	0.00
3 am	0.0	0.0	12	0.0	61.0	59.0	20.0	97	60	60	0.00
4 am	0.0	0.0	11	0.0	60.0	59.0	20.8	95	59	59	0.00
5 am	0.2	0.0	346	2.0	60.0	59.0	21.9	98	59	60	0.00
6 am	3.5	0.0	343	2.0	61.0	61.0	22.1	94	59	60	0.00
7 am	11.4	0.0	309	0.0	68.0	68.0	21.1	83	63	64	0.00
8 am	30.2	0.0	16	2.0	77.0	79.0	18.7	67	65	69	0.00
9 am	33.2	1.0	346	3.0	81.0	87.0	13.8	58	65	69	0.00
10 am	63.2	2.0	214	6.0	90.0	101.0	9.6	39	62	70	0.00
11 am	65.6	2.0	213	9.0	92.0	104.0	6.7	34	60	69	0.00
12 pm	63.2	2.0	214	6.0	93.0	111.0	6.0	30	57	68	0.00
1 pm	72.0	4.0	205	8.0	93.0	111.0	4.8	28	55	67	0.00
2 pm	66.5	1.0	215	10.0	94.0	110.0	4.2	26	54	67	0.00
3 pm	56.4	4.0	191	8.0	90.0	91.0	4.6	29	53	66	0.00
4 pm	29.5	4.0	208	10.0	86.0	87.0	5.1	32	53	64	0.00
5 pm	5.8	3.0	184	7.0	82.0	82.0	5.7	36	52	63	0.00
6 pm	5.2	2.0	118	8.0	80.0	79.0	6.1	40	54	63	0.00
7 pm	1.2	3.0	345	6.0	77.0	75.0	6.7	42	52	61	0.00
8 pm	0.2	1.0	339	7.0	74.0	72.0	7.2	47	53	60	0.00
9 pm	0.0	0.0	226	2.0	71.0	69.0	7.8	53	53	59	0.00
10 pm	0.0	0.0	22	2.0	69.0	66.0	8.4	60	55	60	0.00
11 pm	0.0	0.0	33	2.0	67.0	65.0	8.9	63	54	59	0.00
12 am	0.0	0.0	73	2.0	66.0	64.0	9.8	69	56	59	0.00

DAILY STATISTICS

	Total Solar Rad. ° ly.	Wind Ave. mph	Wind V. Dir. Deg	Wind Max. mph	Air Temperature Mean Deg. F.	Fuel Temperature Mean Deg. F.	Fuel Moisture Mean Percent	Relative Humidity Mean Percent	Dew Point Deg. F.	Wet Bulb Deg. F.	Total Precip. inches
Total	507.4										0.00
Ave.		1.2	329		75.6	78.3	11.5	59	57	63	
Max.				10.0	94.0	111.0	22.1	98			
Min.					60.0	59.0	4.2	26			

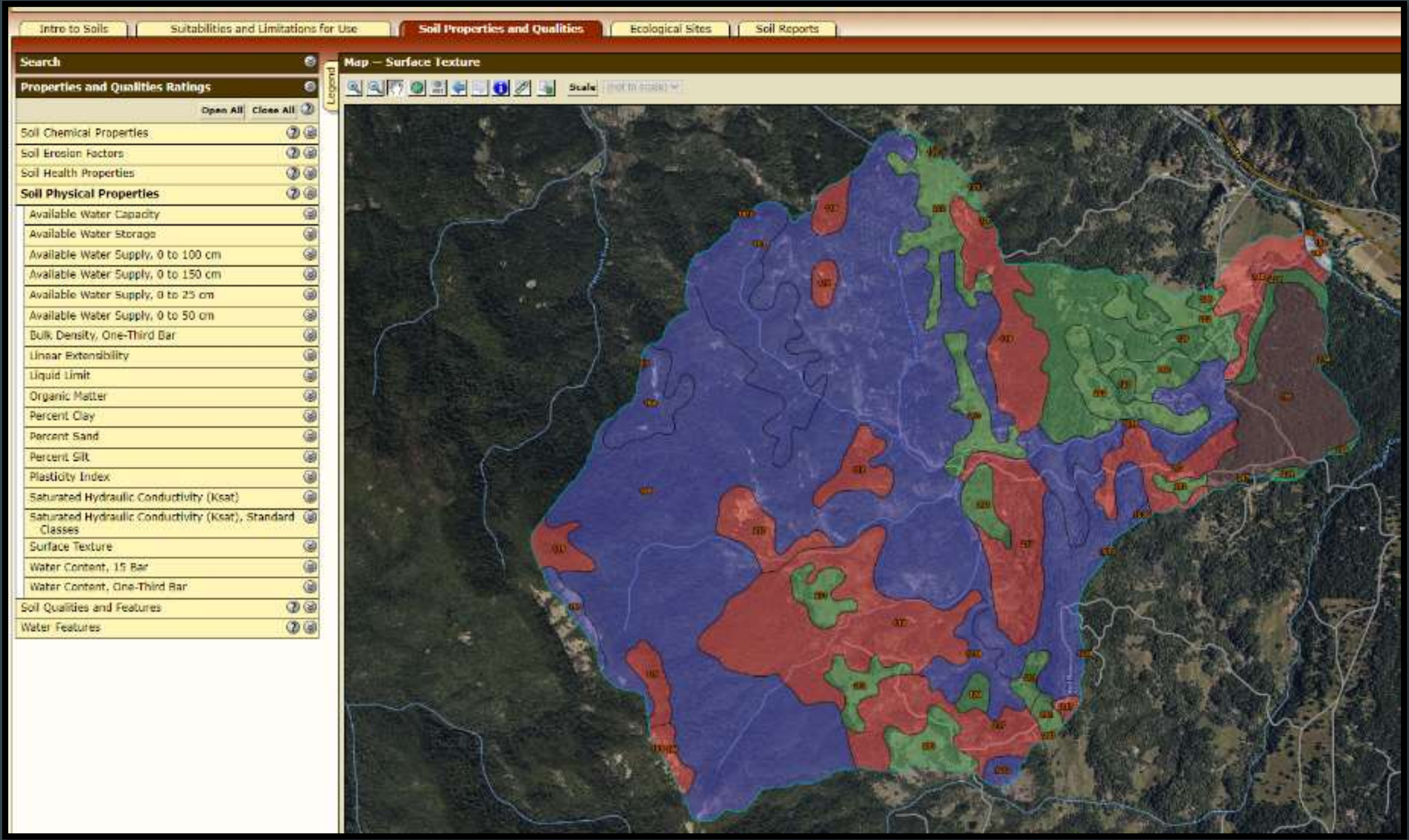
SAL Inputs: Land Cover

- Used for:
  - Surface runoff
  - Evapotranspiration (ET)
- 2019 NLCD



SAL Inputs: Soils!

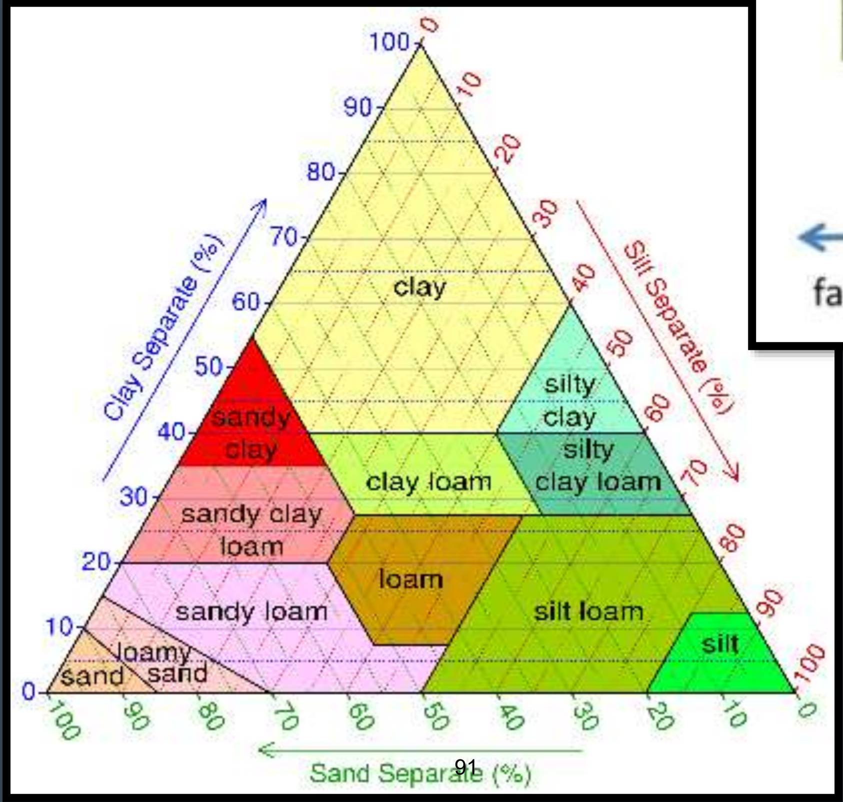
- Subsurface flow – timing and pathways of water reaching the stream channel
- NRCS Web Soil Survey (SSURGO) database



Web Soil Survey (SSURGO) for Streeter Creek watershed; NRCS

SAL Inputs: Soils!

- Subsurface flow – timing and pathways of water reaching the stream channel
- NRCS Web Soil Survey (SSURGO) database
- Characterized by texture class
  - Porosity
  - Hydraulic conductivity
  - Wilting point
  - Field capacity



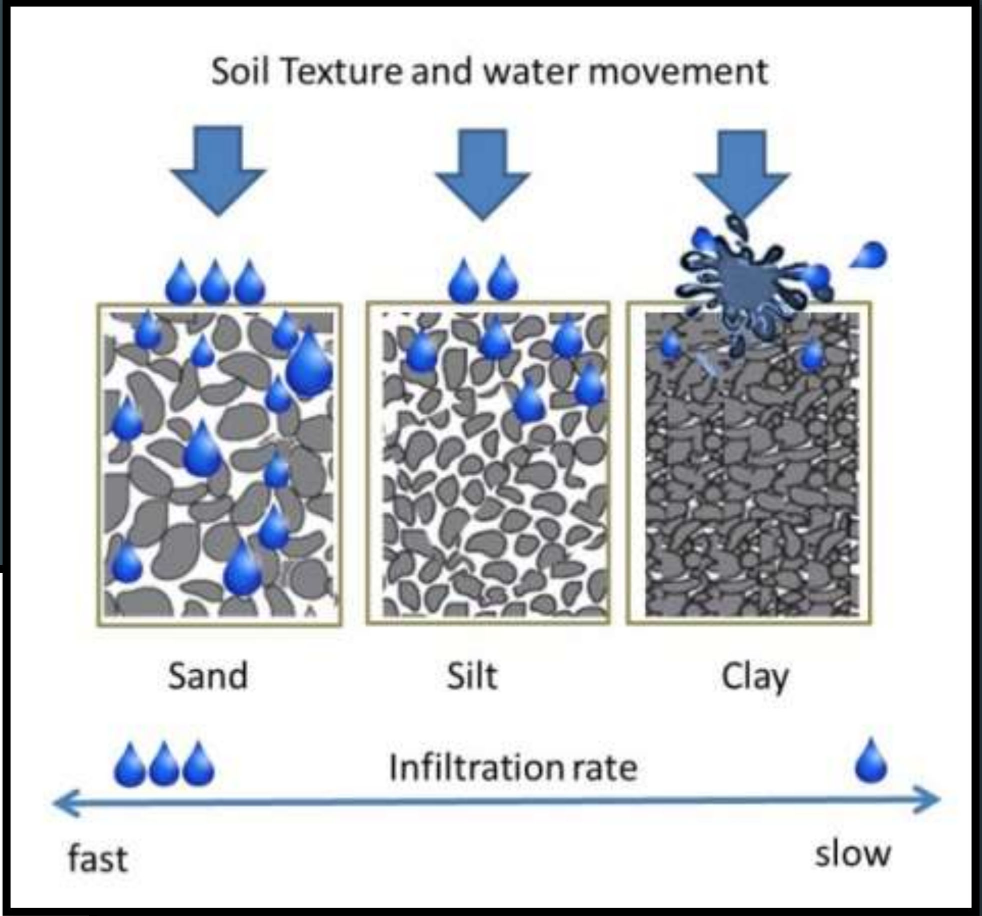
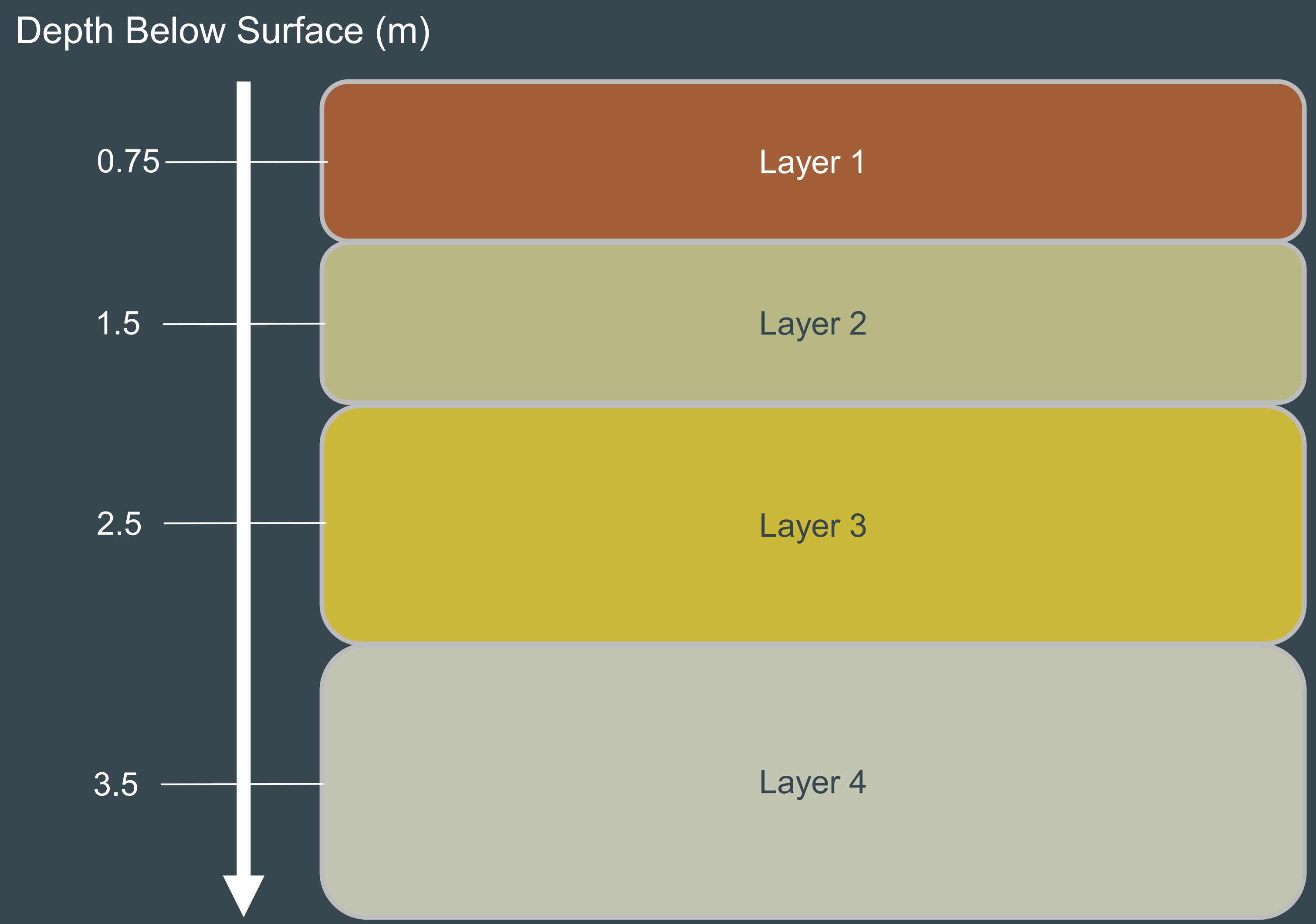


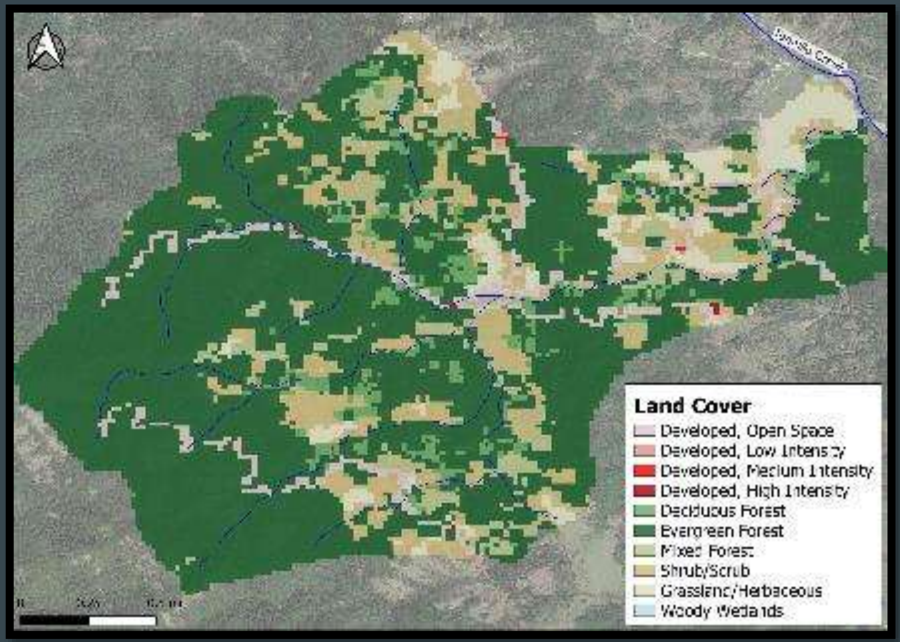
Figure source: Agriculture and Food Development Authority

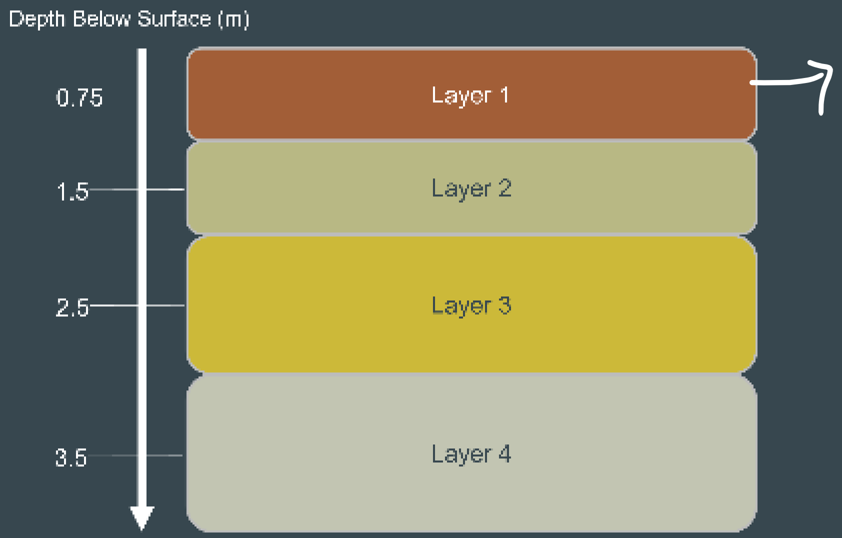
SAL Inputs: Soil Layers

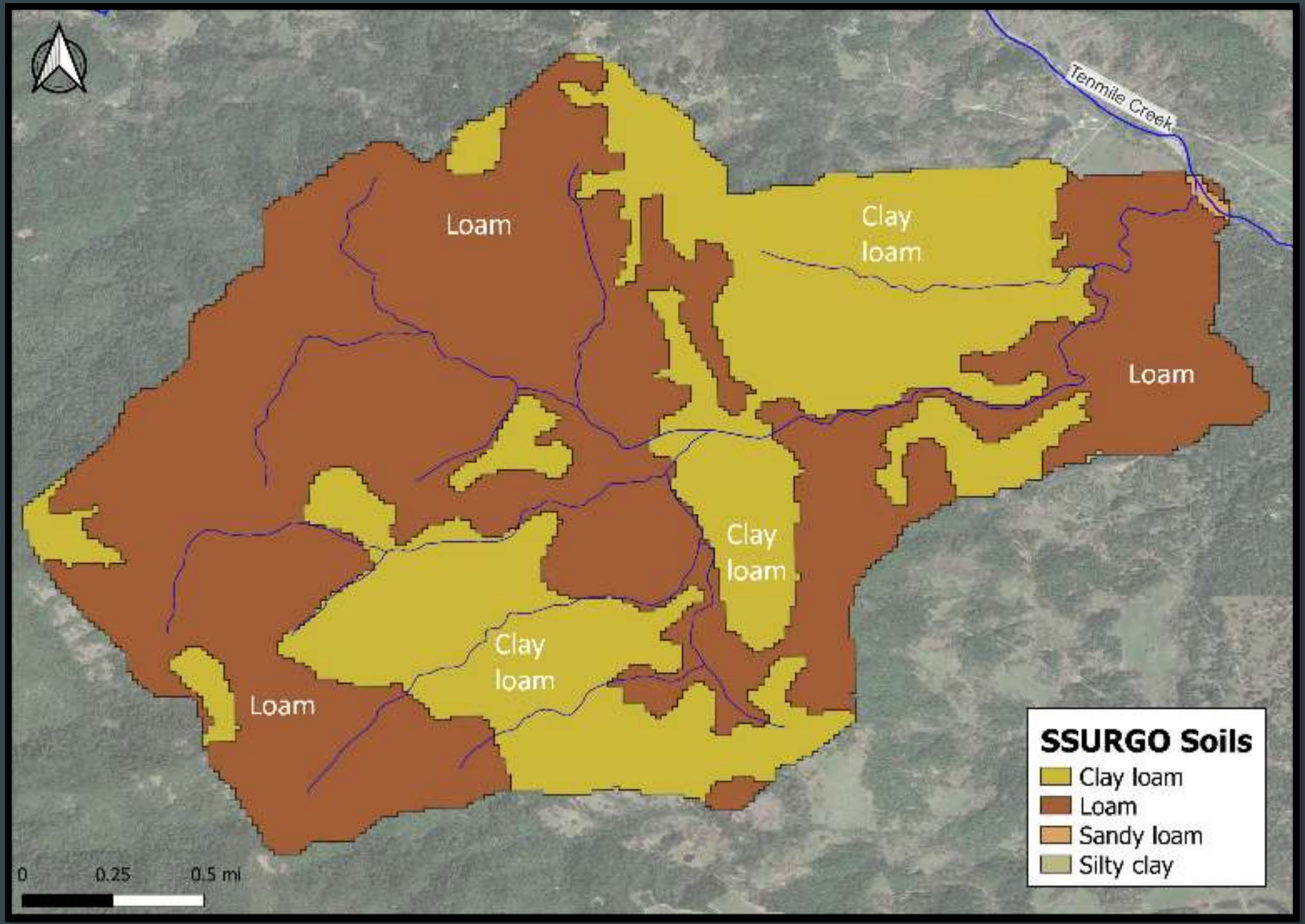
- 30-m DEM
- Four soil profiles
  - characterized based on dominant texture



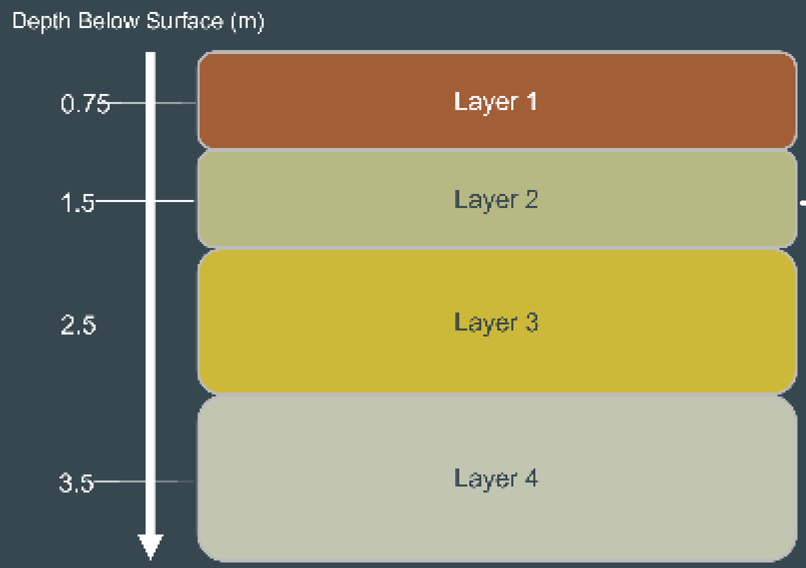
SAL Inputs: Soil Layers

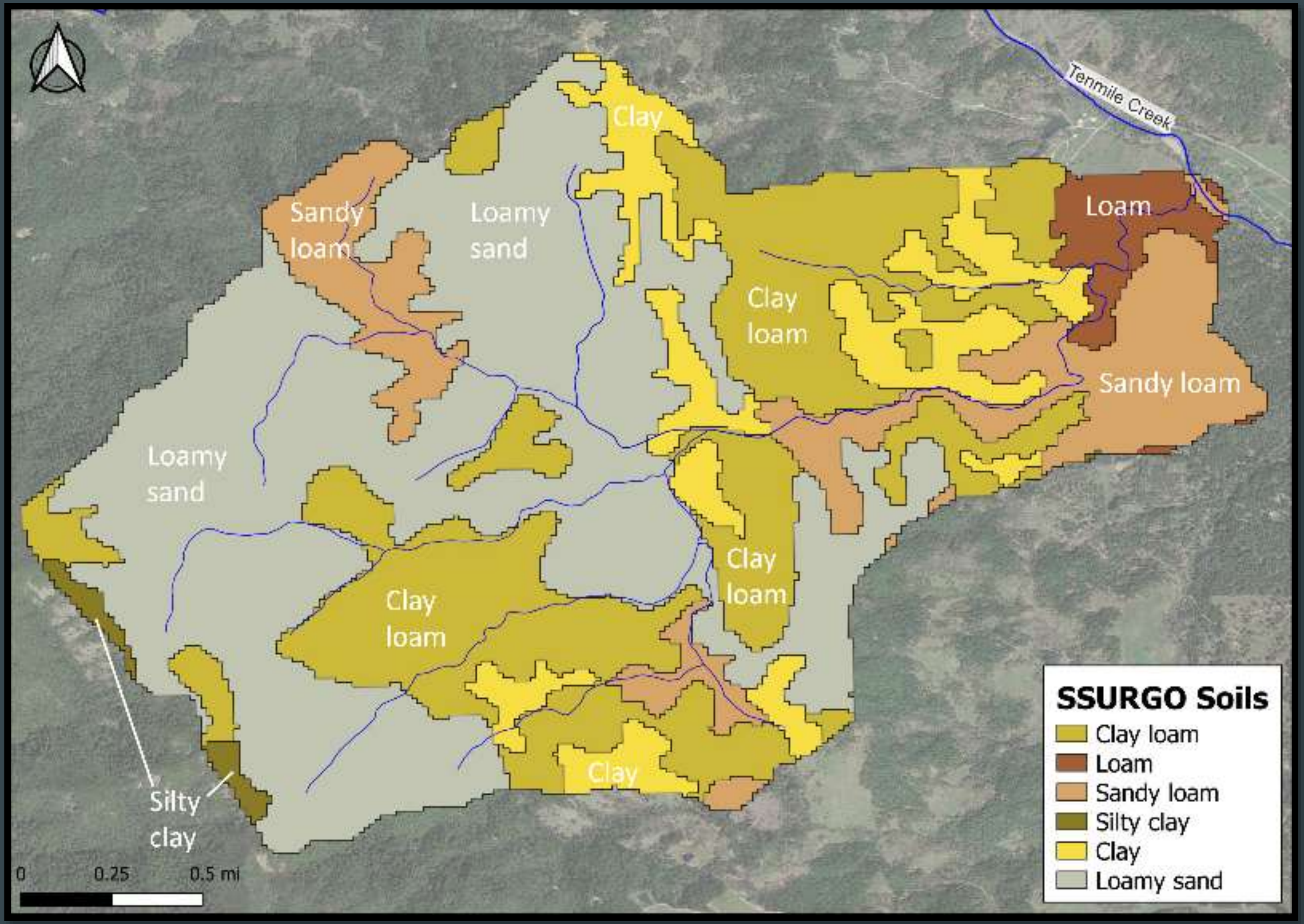




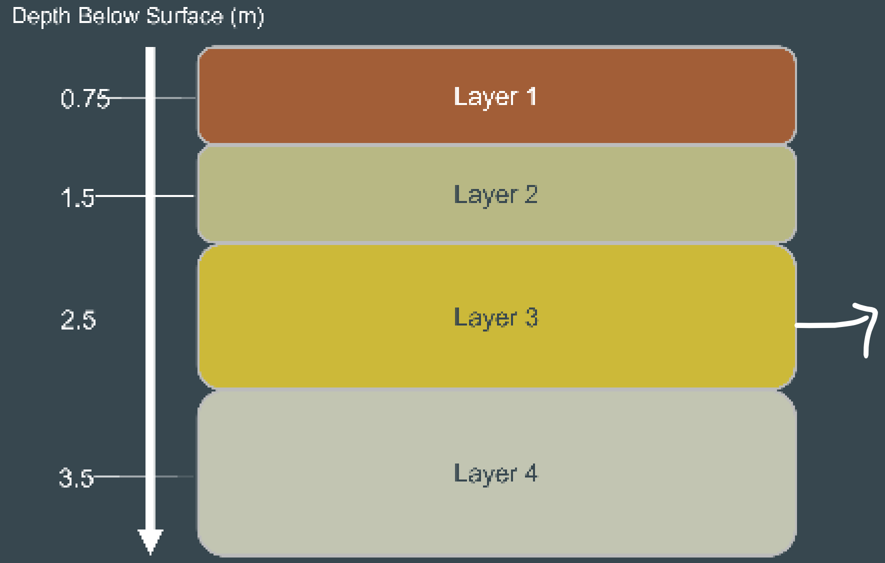


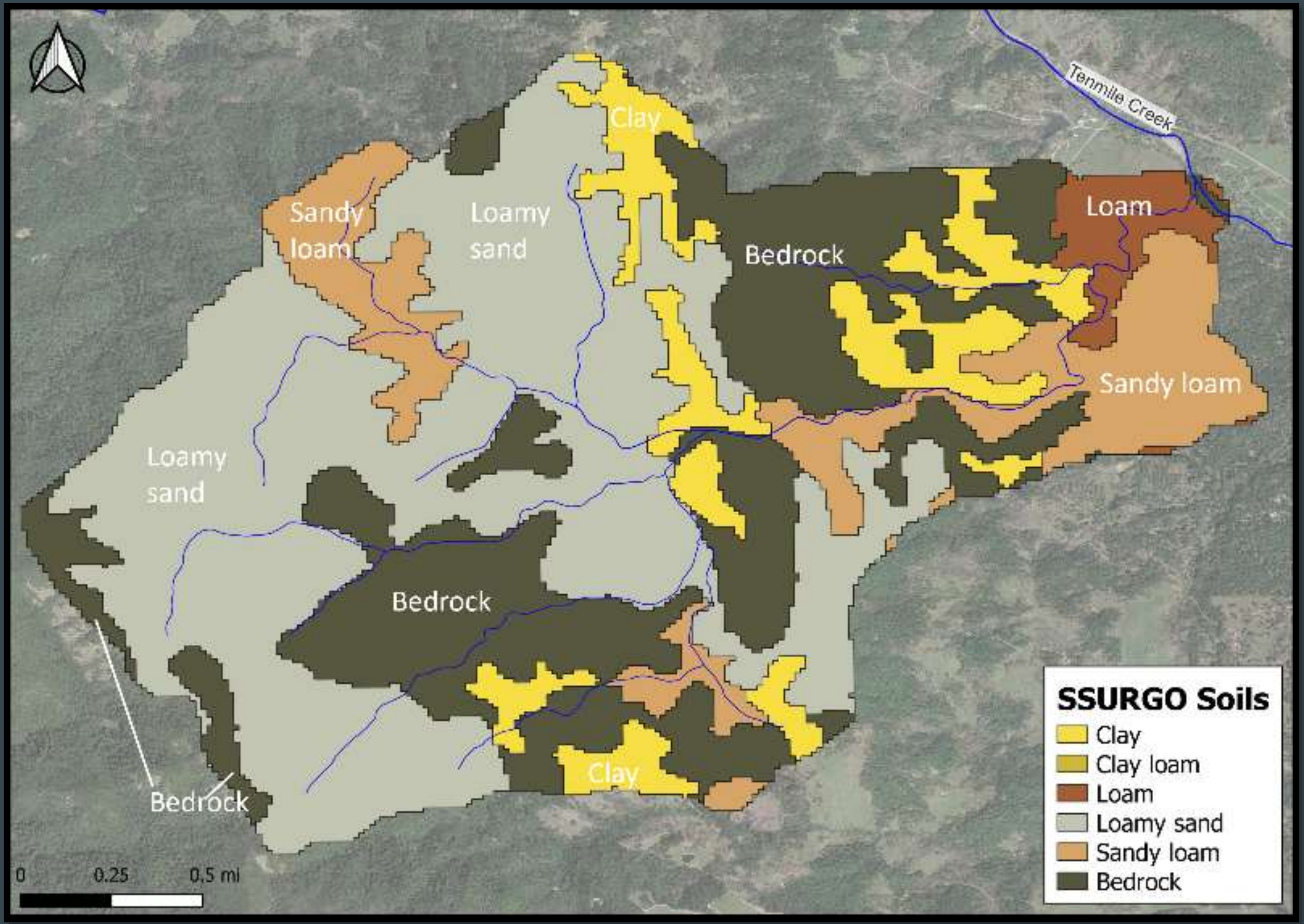
SAL Inputs: Soil Layers





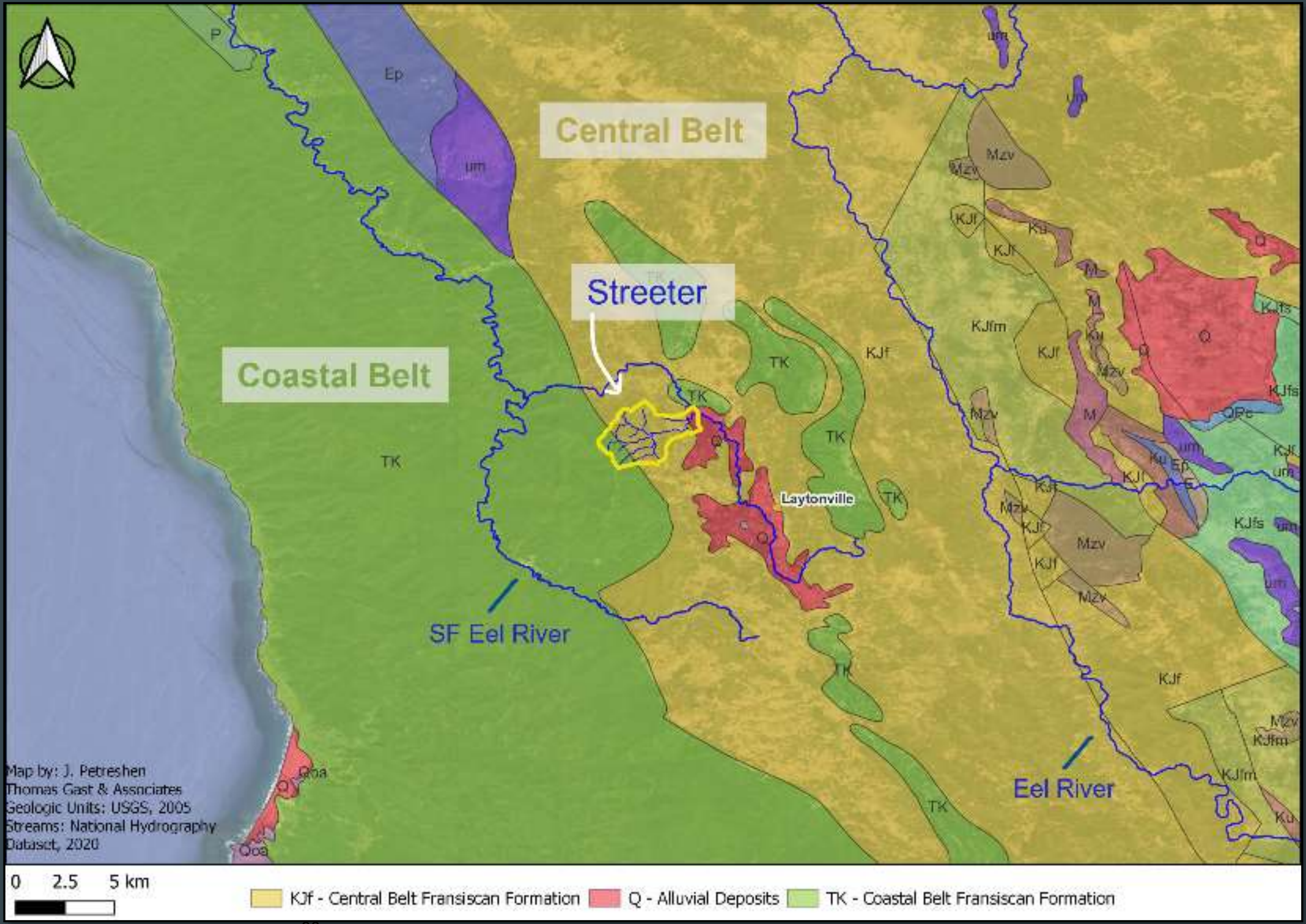
SAL Inputs: Soil Layers



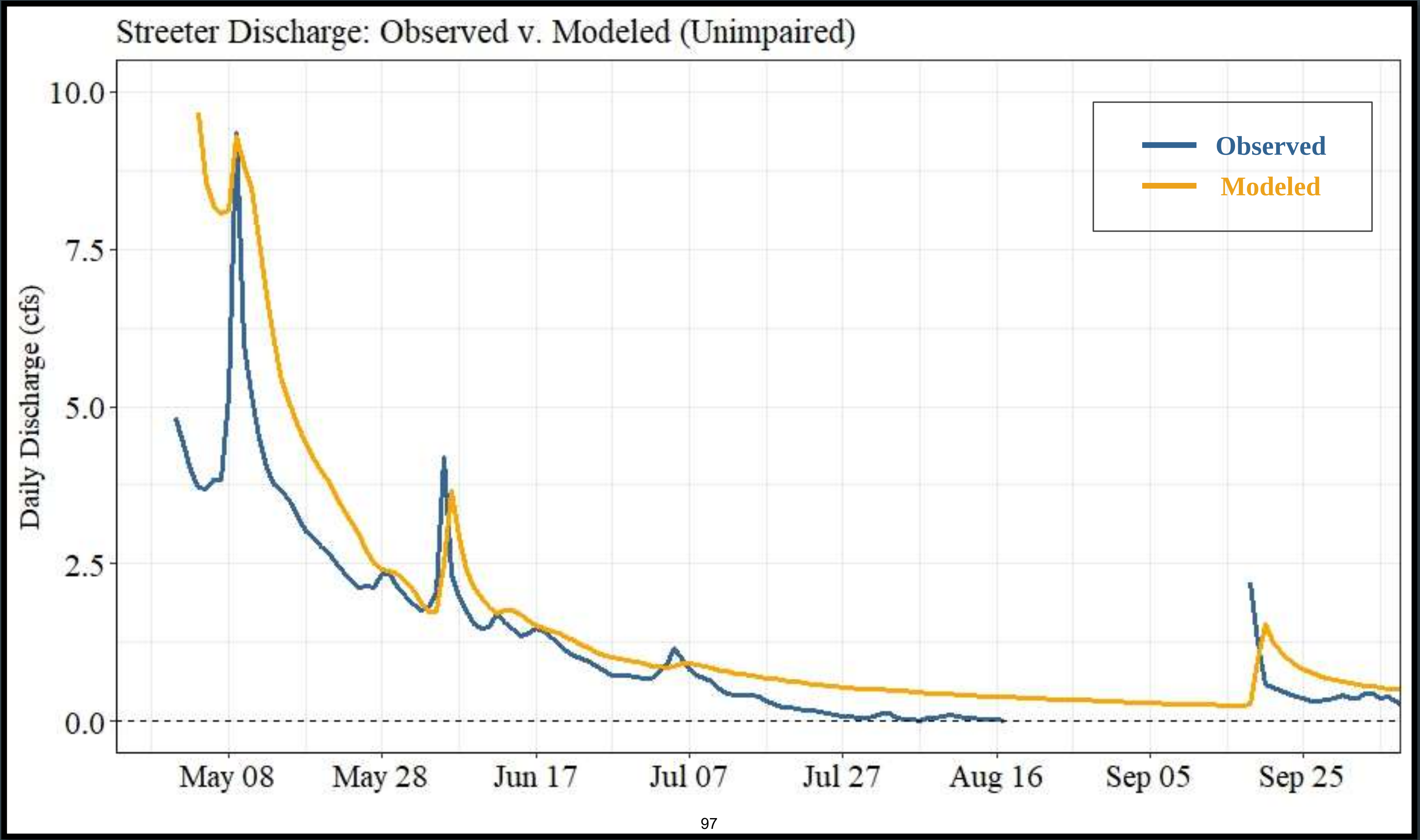


SAL Inputs: Soils... and Bedrock!

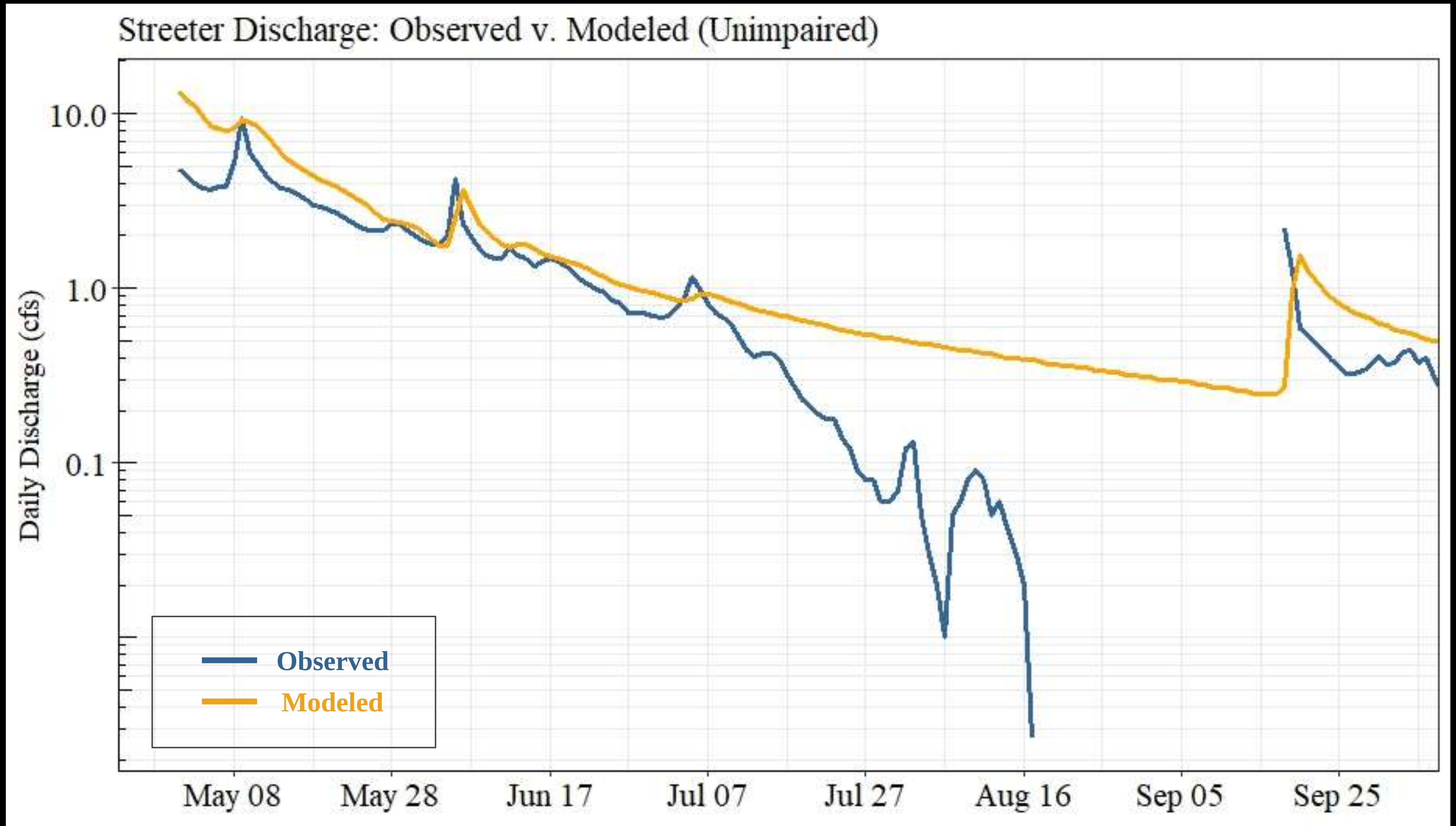
- Lithology determines stream “flashiness”, water storage, land cover (Hahm et al., 2019)
- Understanding storage = critical in modeling baseflow
- Coastal and Central Belt: Franciscan Complex
- Streeter – primarily in Central
  - Slow water conductivity, shallow soils, smaller storage = lower baseflows



Results: “Unimpaired Flow” using SAL model

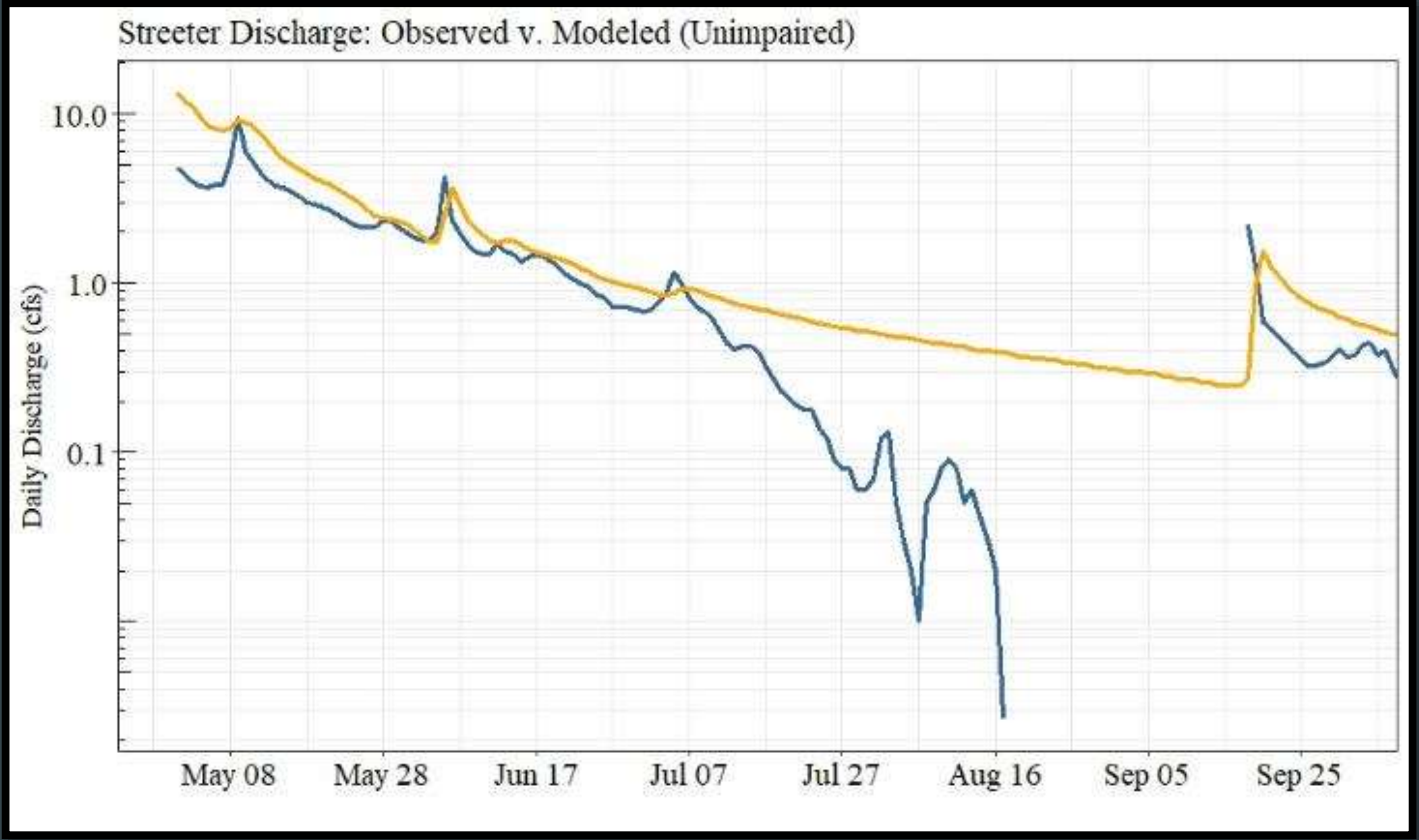


Results: “Unimpaired Flow” – Log scale



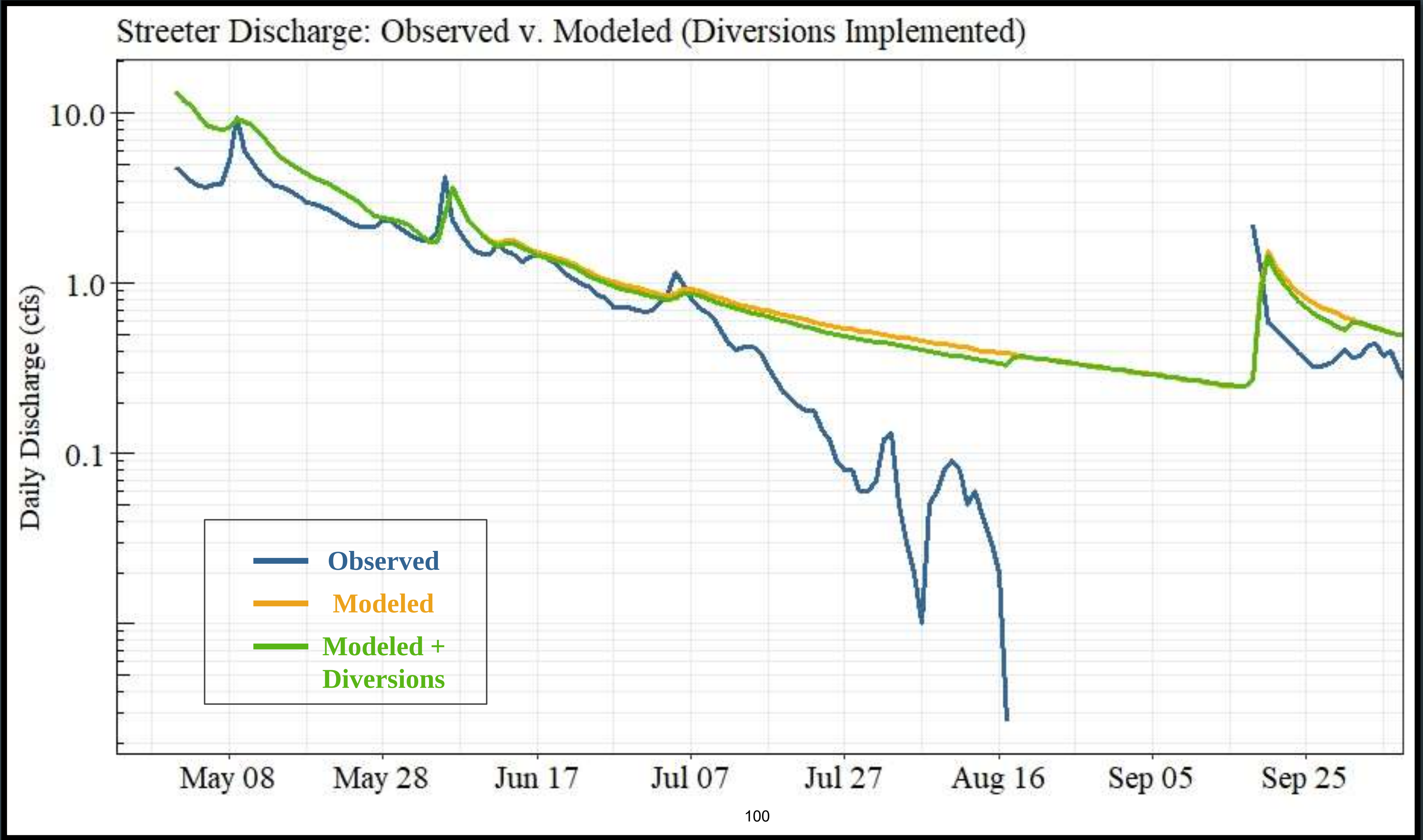
SAL: Implement Diversions

- Diversion:
  - 2022: Approximately 1.8 MG diverted (May – Sept.) by Black Oak Ranch
- SAL:
  - Point of Diversion (lat/long)
  - Point of Use (lat/long)
  - Total diversion volume
  - Start/end dates of diversion

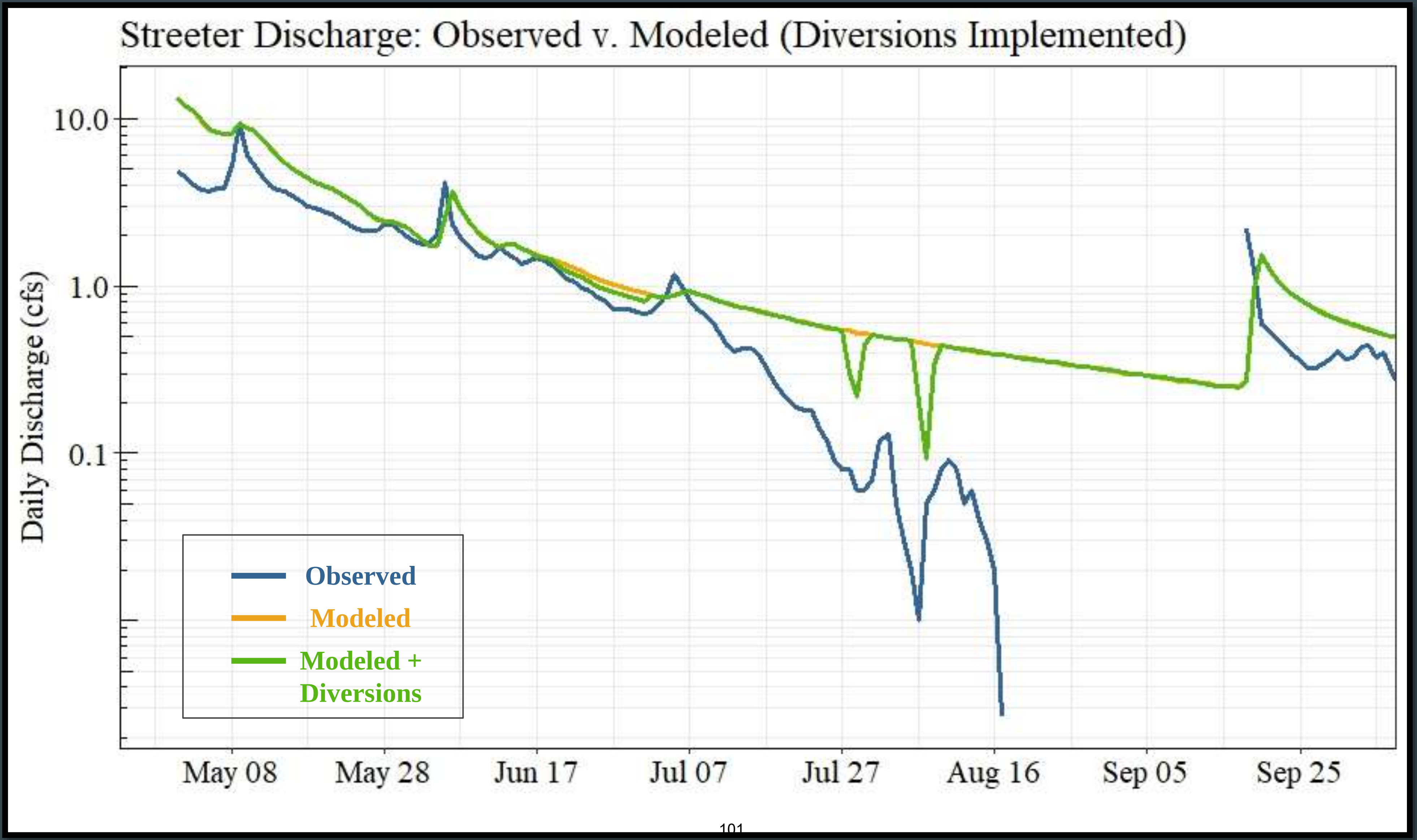


	Point of Diversion		Point of Use		Total Volume	Diversion Season	
Water Right ID#	lat	long	lat	long	Million gal (MG)	start	end
S015602	39.7417398	-123.53223			1.32	6/10/2022	8/17/2022
S015602	39.7417398	-123.53223			0.53	9/19/2022	9/30/2022

Results: Streeter Flow plus Diversions

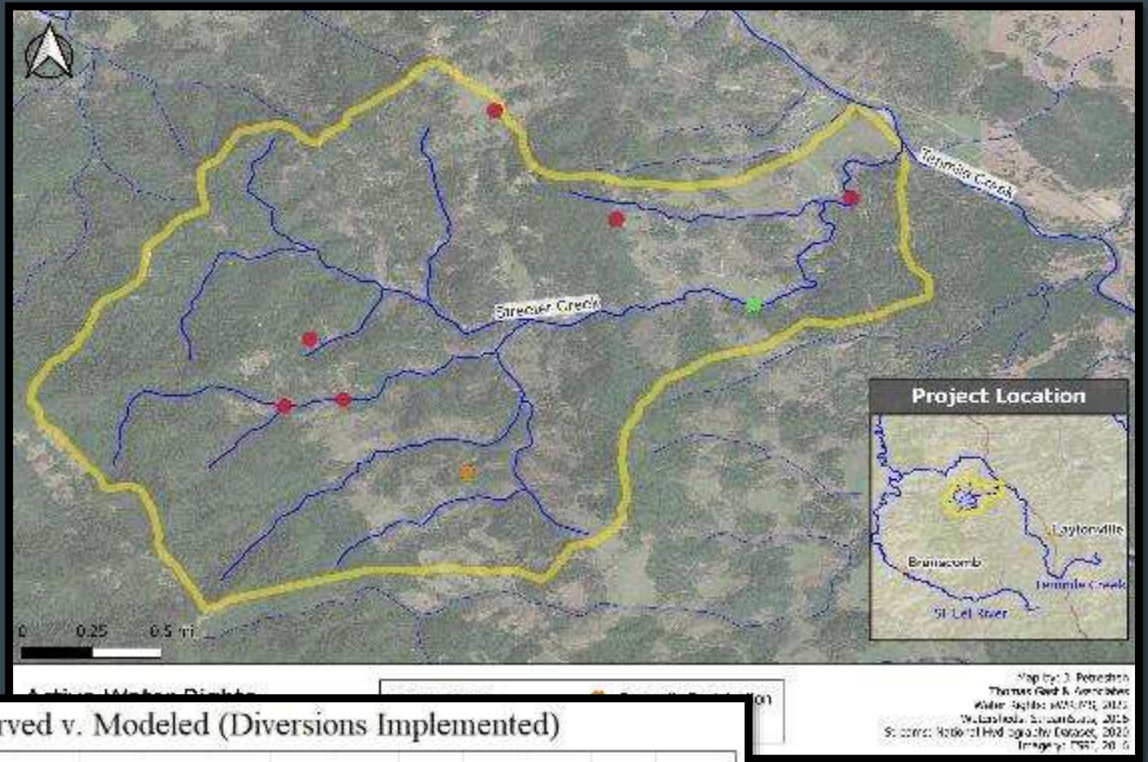


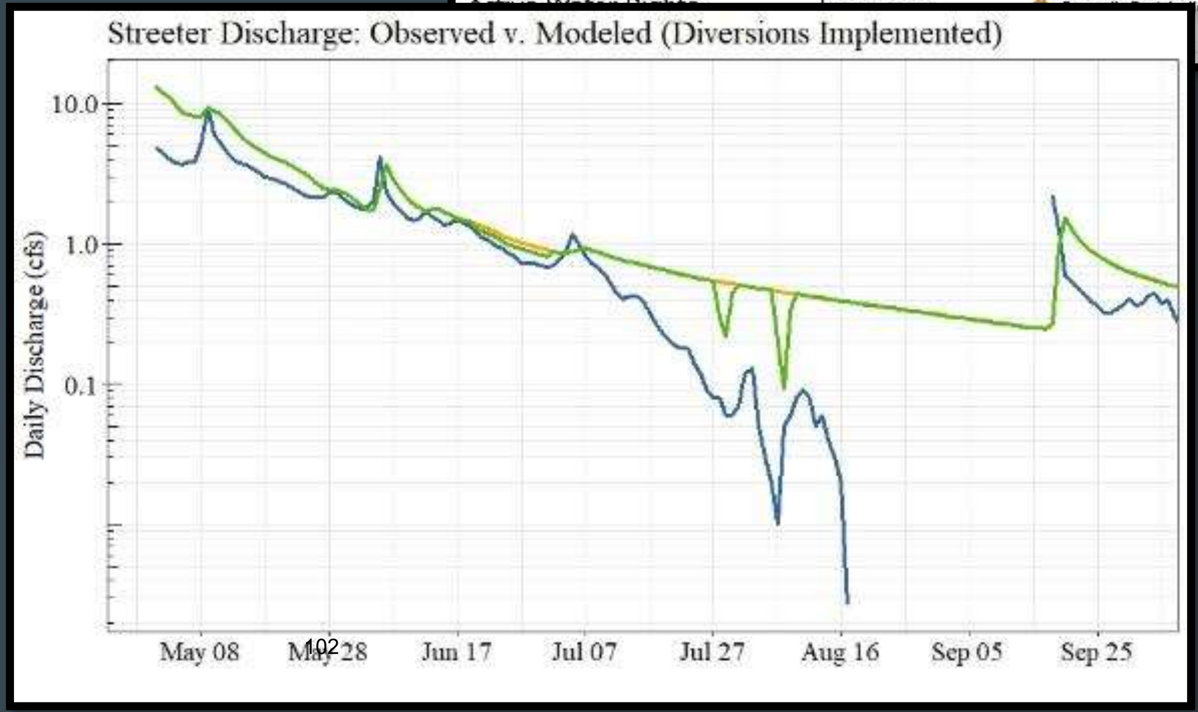
Results: Streeter Flow plus Diversions



Cause for Discrepancies?

- Cumulative impact of water diversions?
- Not modelling enough ET?
  - Need more accurate land use, canopy age
  - LiDAR!
- Dips caused by flow becoming disconnected?
  - Daily diversion records?

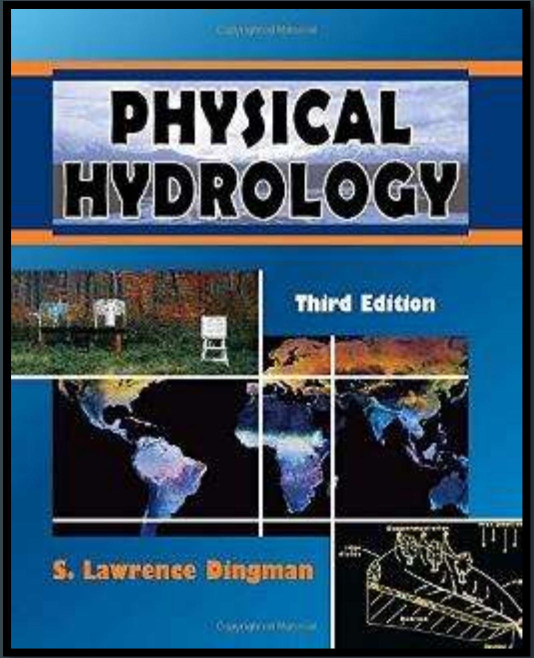




To be continued...

- SAL – useful in modeling streamflow under different climate and management scenarios
  - Testing, application to other watersheds necessary to make it widely applicable

- Thank you!
  - Eel River Recovery Project
  - State Coastal Commission, Prop. 1 Grant program
  - S. Lawrence Dingman – Physical Hydrology



HABITAT MODELING OF SALMONID MOVEMENT AND SURVIVAL IN DEGRADED AND RESTORED WATERSHEDS – 40th Annual Salmonid Restoration Federation Conference

04/27/2023

Greg Blair ICF

Introduction

- Using the Ecosystem Diagnosis and Treatment (EDT) model to evaluate "Habitat Performance", I explore the relative importance of natal and non-natal habitats for coho salmon within a diverse watershed and the impact of degraded non-natal habitats. Coho salmon are a good species to explore how habitat may influence life history expression as coho express many different life history pathways from emergence to ocean entry that include unique non-natal habitats.

- "Habitat Performance" defined as the average performance expected when a species makes optimal use of the available habitat. It is the theoretical performance achieved when the population utilizes habitat segments over time in a manner that maximizes survival over the life cycle of a cohort. In other words, the population is optimally distributed over space and time.

- Optimal usage of two habitat segments implies that at any given spawning escapement level, the progeny of spawners are distributed between the two habitat production functions in such a way that total recruitment is maximized. I recognize this concept is an over-simplification of a complex process of biotic and abiotic factors driving life history expression during freshwater rearing.

- But what if there is an underlying genetic (evolutionary) component to the observed complex freshwater life histories observed over the range of the species? How might we use that in species reintroduction and population recovery plans?

ICF

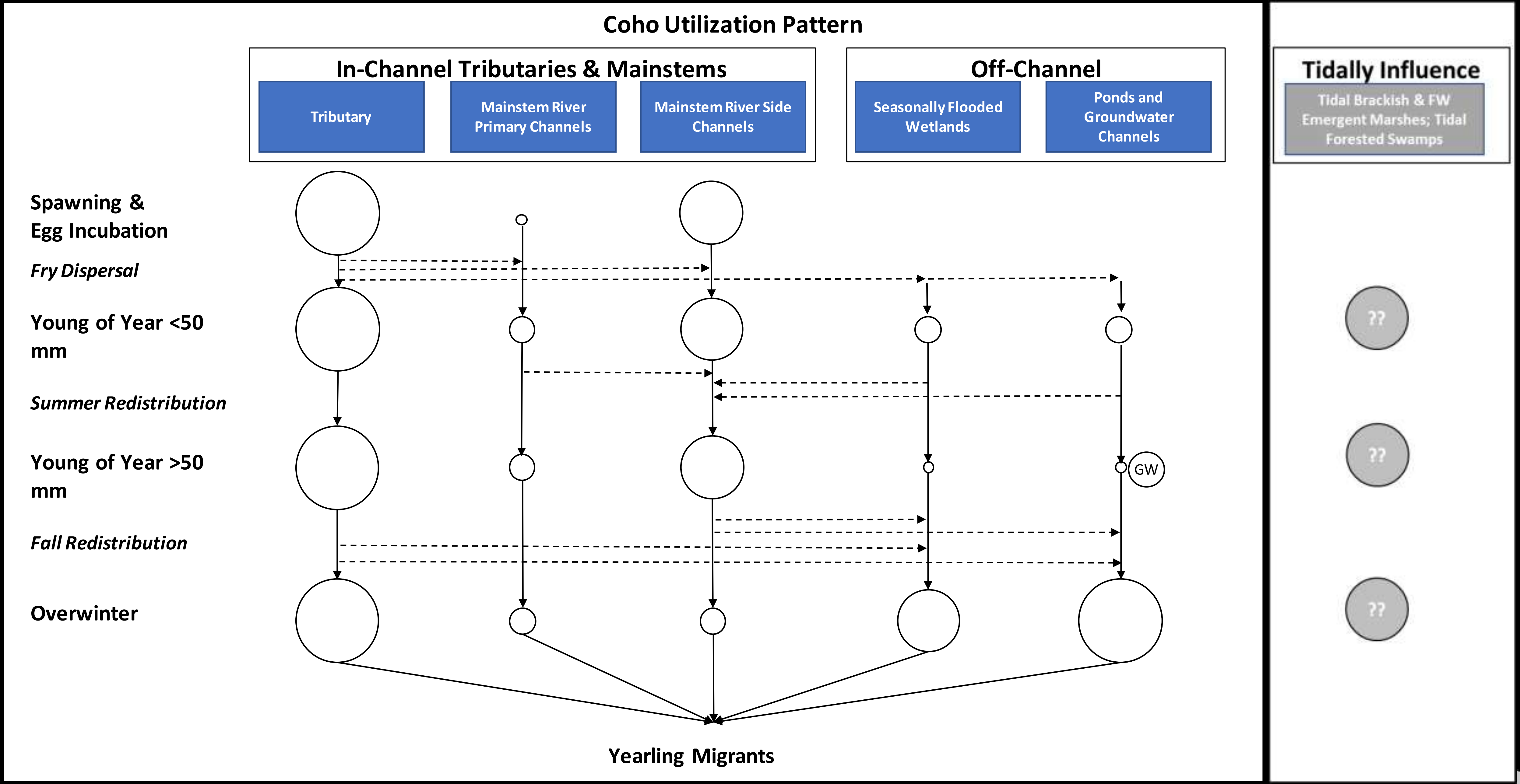
Contents

- Patterns of Habitat Utilization
  - Coho Salmon life histories to optimize foraging and shelter in a diverse environment

- Modeling Habitat Potential in Case Study Watersheds:
  - Historical and current potential associated with a subset of life history patterns

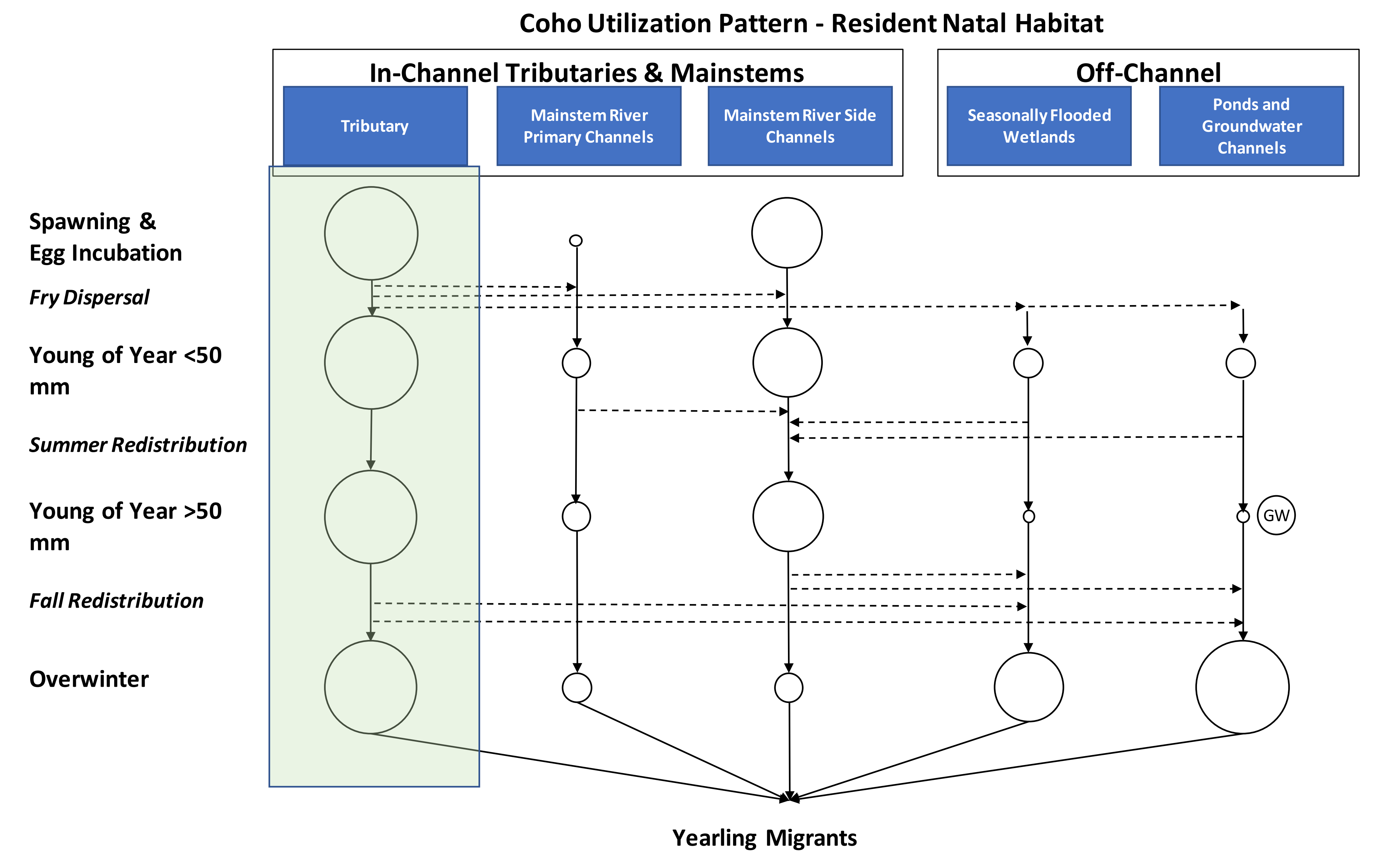
- Implications for Recovery – Habitat and Life Histories Lost and the Challenges for Recovery
  - How might the loss of non-natal habitats influence the potential future expression of life histories within a population?
  - Is there a genetic (evolutionary) component and if so, how might that shape recovery and recovery strategies?

Step 1: Coho Salmon Utilization Patterns



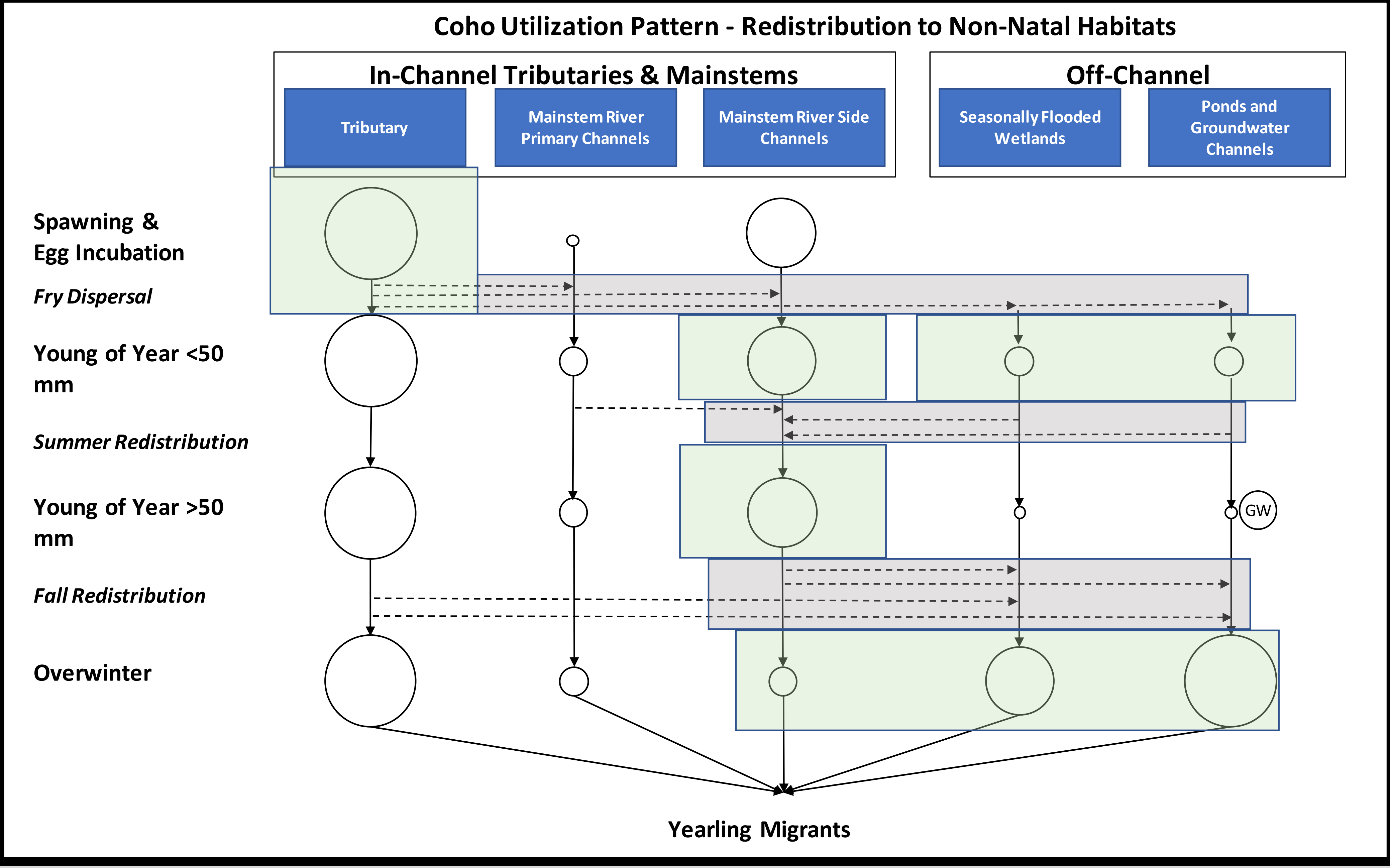
Modified from:
Lestelle, L.C., G.R. Blair, S.A. Chitwood. 1993. Approaches to supplementing coho salmon in the Queets River, Washington. Pages 104-119 in L. Berg and P.W. Delaney (eds.) Proceedings of the coho workshop. British Columbia Department of Fisheries and Oceans, Vancouver, BC.

Step 1a: Coho Salmon Natal Tributary Pattern



Modified from:
Lestelle, L.C., G.R. Blair, S.A. Chitwood. 1993. Approaches to supplementing coho salmon in the Queets River, Washington. Pages 104-119 in L. Berg and P.W. Delaney (eds.) Proceedings of the coho workshop. British Columbia Department of Fisheries and Oceans, Vancouver, BC.

Step 1b: Coho Salmon Redistribution Pattern



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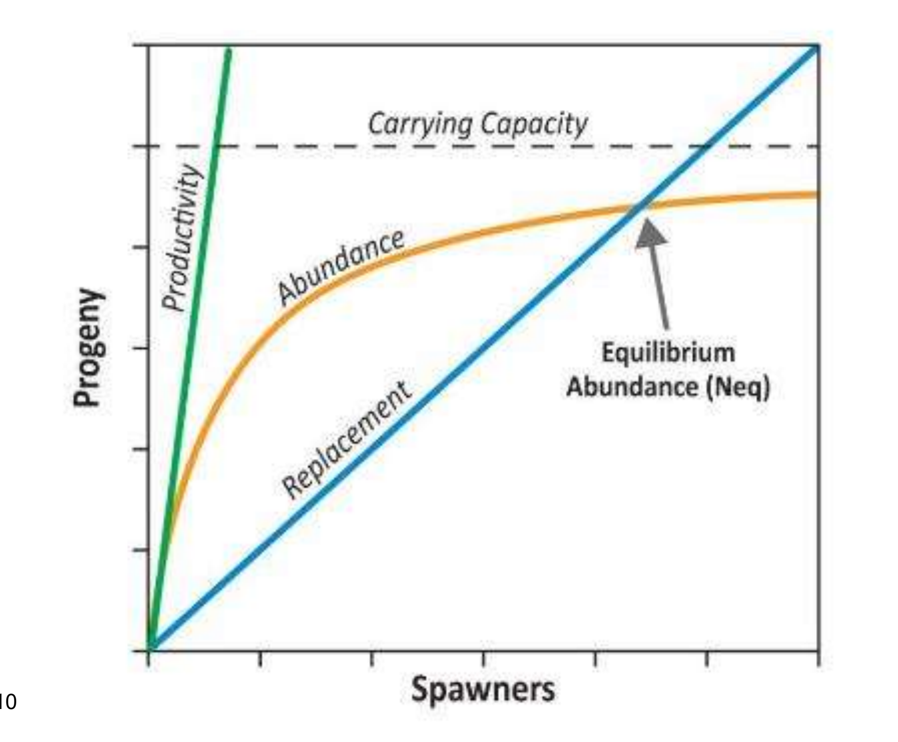
Lestelle, L.C., G.R. Blair, S.A. Chitwood. 1993. Approaches to supplementing coho salmon in the Queets River, Washington. Pages 104-119 in L. Berg and P.W. Delaney (eds.) Proceedings of the coho workshop. British Columbia Department of Fisheries and Oceans, Vancouver, BC.

EDT Model Overview

Evaluates habitat along life history pathways (trajectories)

- Pathways shaped by fish life history
- Exposure to conditions along pathways set by life history tactics (speed, spatial movement, residence time).
- Species-habitat rules evaluate conditions by life stage
- Evaluates thousands of pathways varying conditions in time and space within a range of life history characteristics.

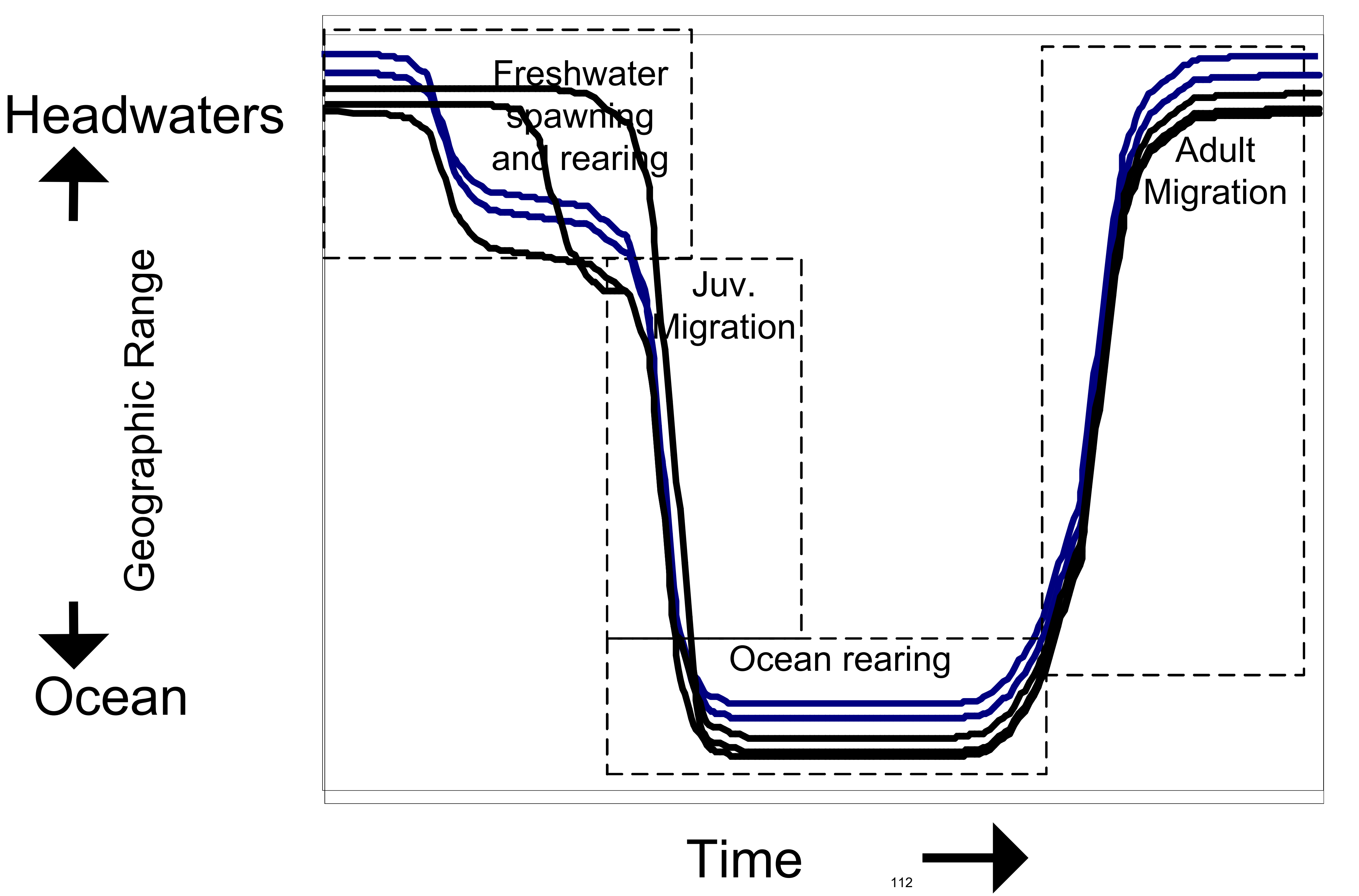
Pathways evaluated using Beverton-Holt S-R function



Off-Channel Habitat Types in EDT

Photos from
Lestelle, L. C. 2007. Coho salmon (Oncorhynchus kisutch) life history patterns in the Pacific Northwest and California. Biostream Environmental, Poulsbo, WA.

Modeled Patterns of Habitat Utilization



Optimization of Habitat Performance

- The simplest case of an optimal distribution question arises when we consider two life histories with production functions R_1 and R_2 for a population. Suppose R_1 and R_2 are both Beverton-Holt functions:

$$R_1(S) = \frac{p_1 S}{1 + {p_1 S}/{c_1}}$$

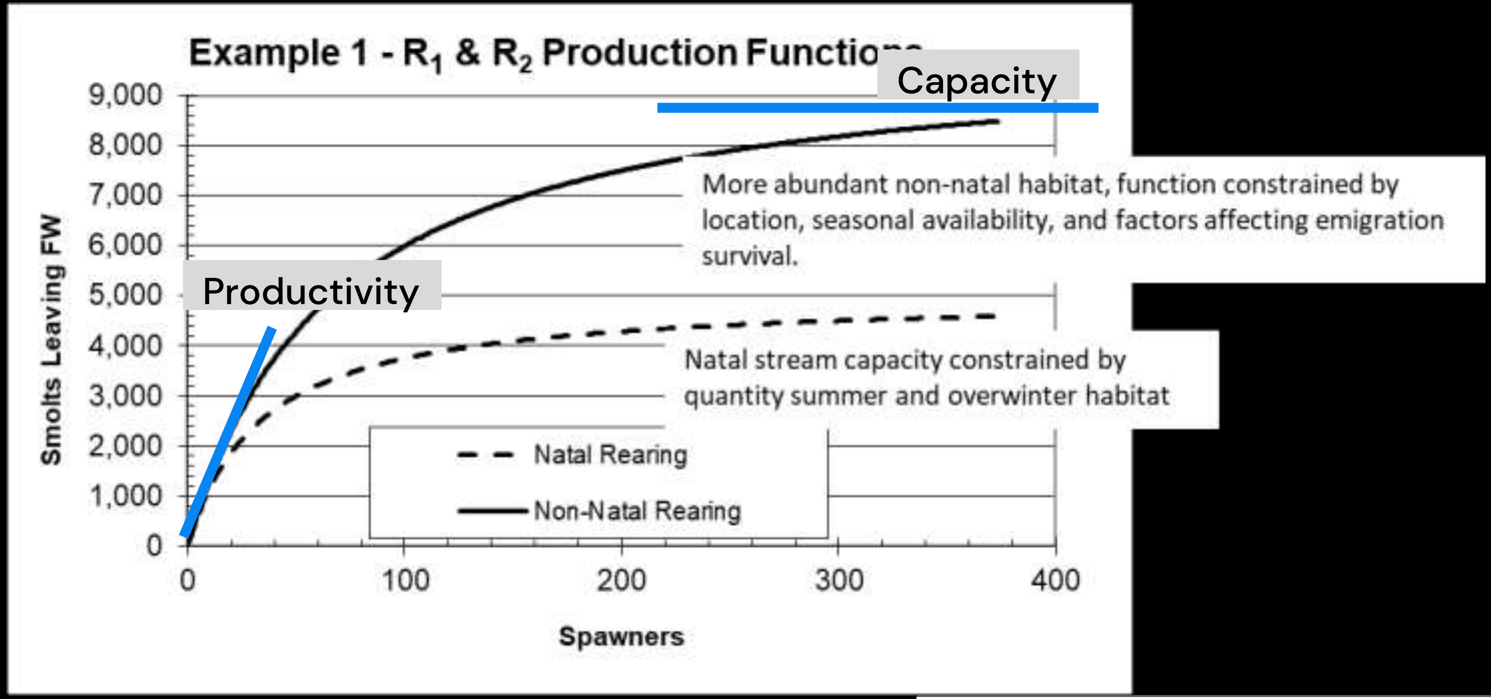
$$R_2(S) = \frac{p_2 S}{1 + {p_2 S}/{c_2}}$$

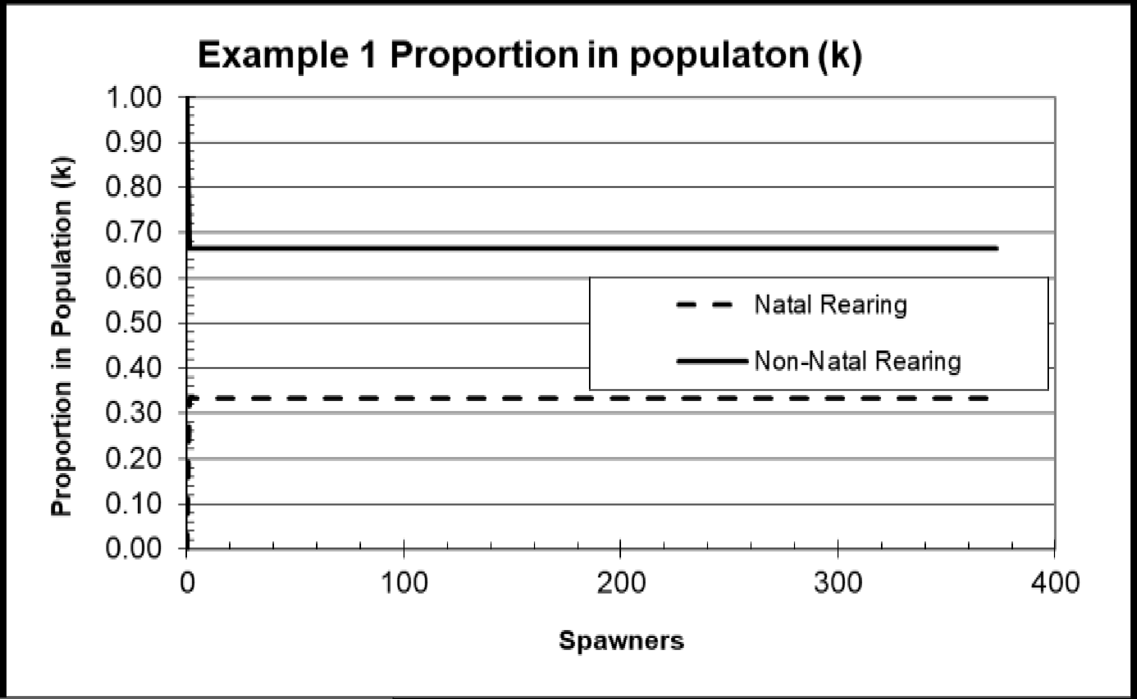
- Optimal usage of these two life histories implies that at any given spawning escapement level, the progeny are distributed between the two production functions in such a way that total recruitment is maximized.
- Total recruitment is given by:

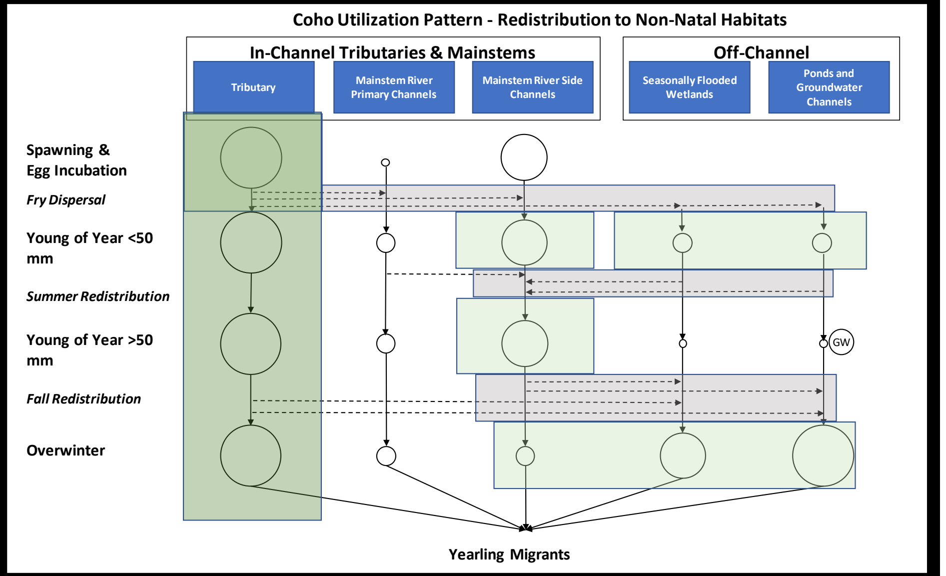
$$R(S) = R_1(kS) + R_2((1-k)S) = \frac{p_1 kS}{1 + {p_1 kS}/{c_1}} + \frac{p_2 (1-k) S}{1 + {p_2 (1-k) S}/{c_2}}$$

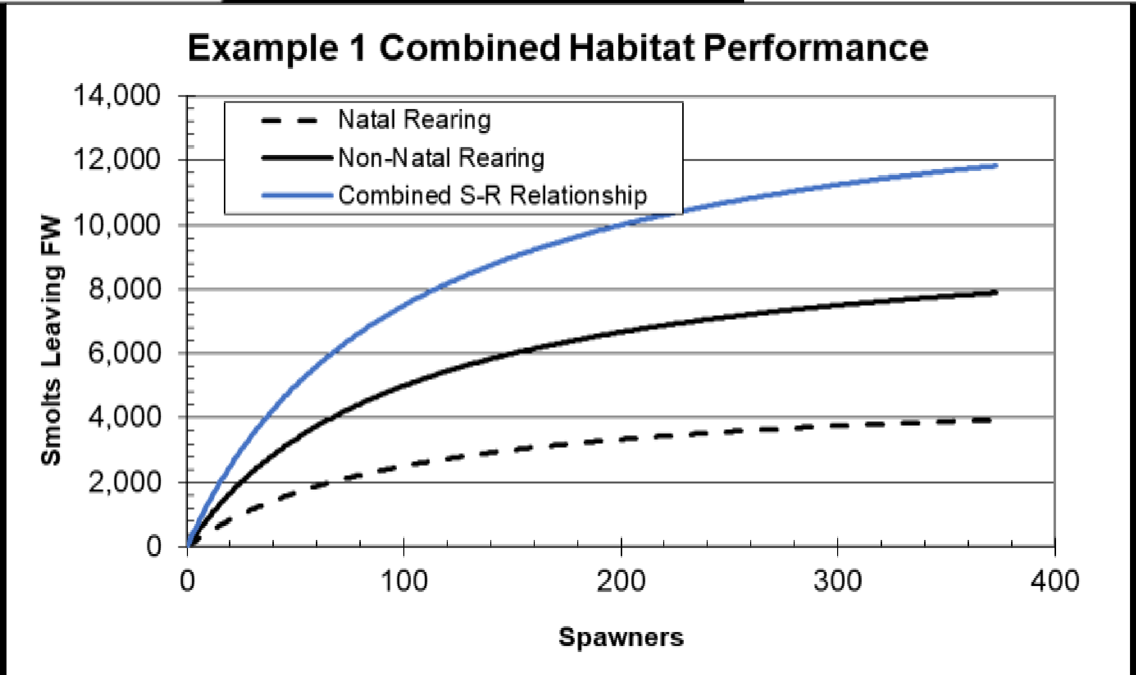
where k maximizes R(S) for every S.

Optimization of Habitat Performance





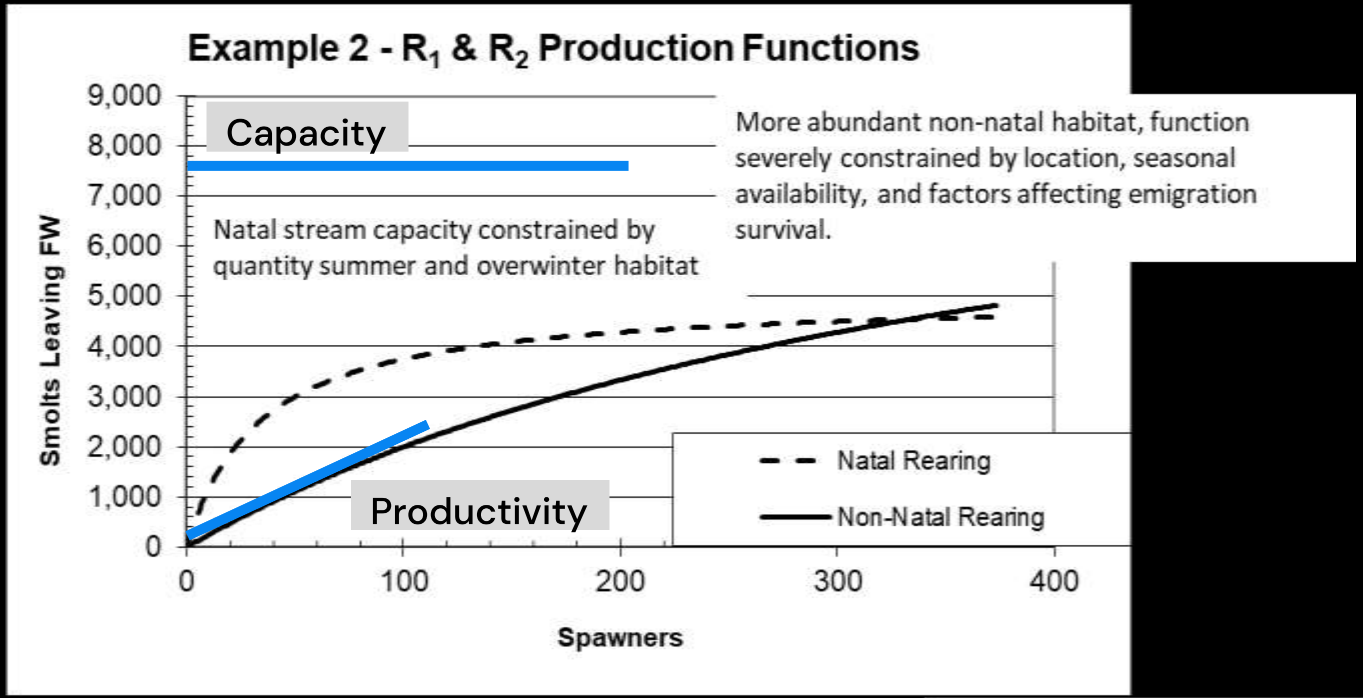


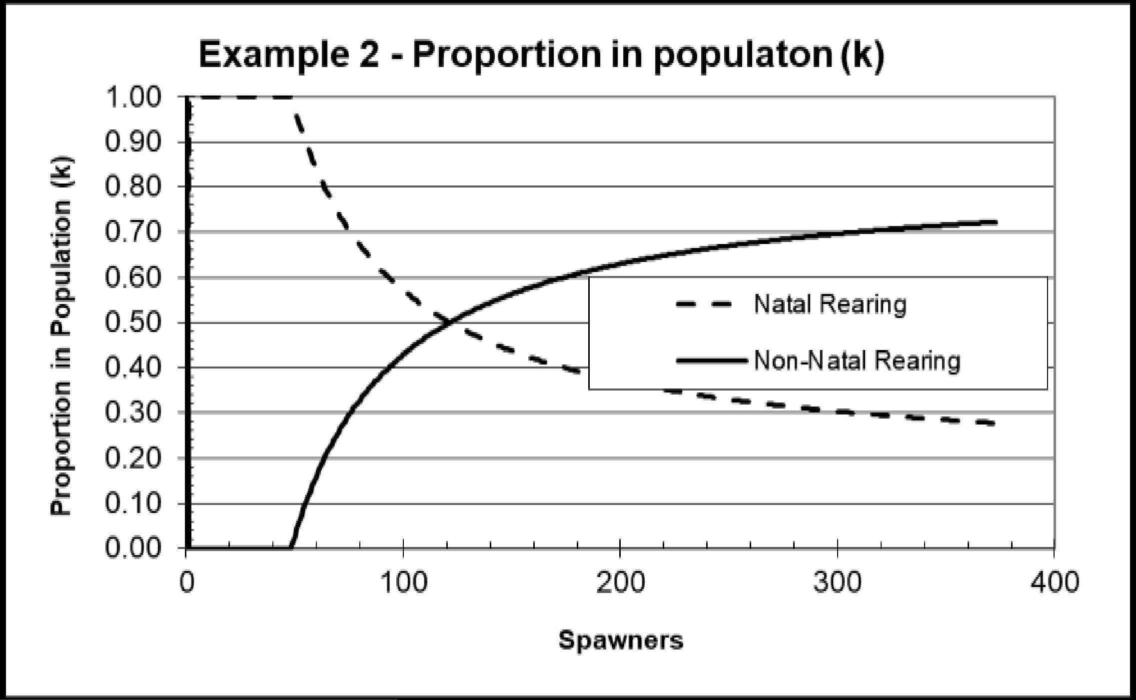


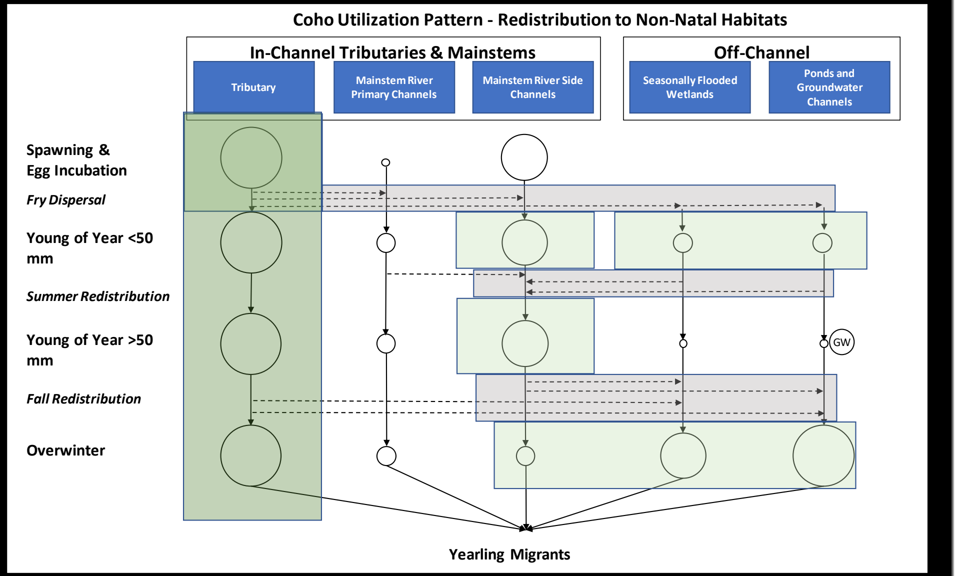
Example 1

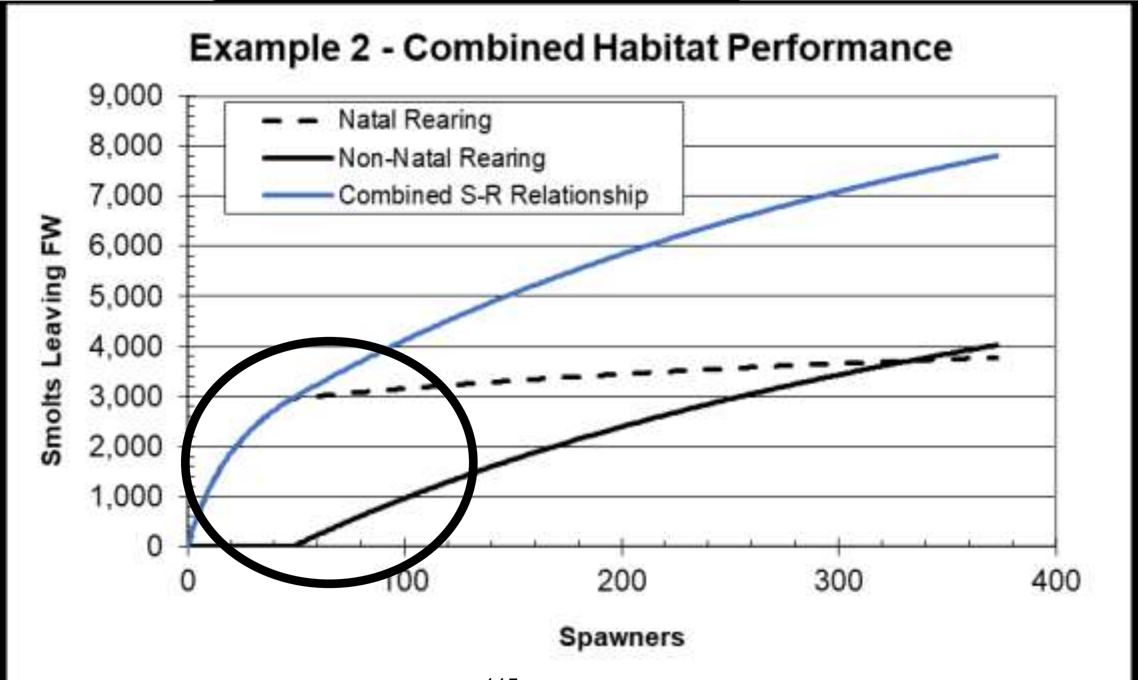
- Similar productivities
- Natal capacity constrained by quantity of summer and overwinter habitat in tributary

Optimization of Habitat Performance







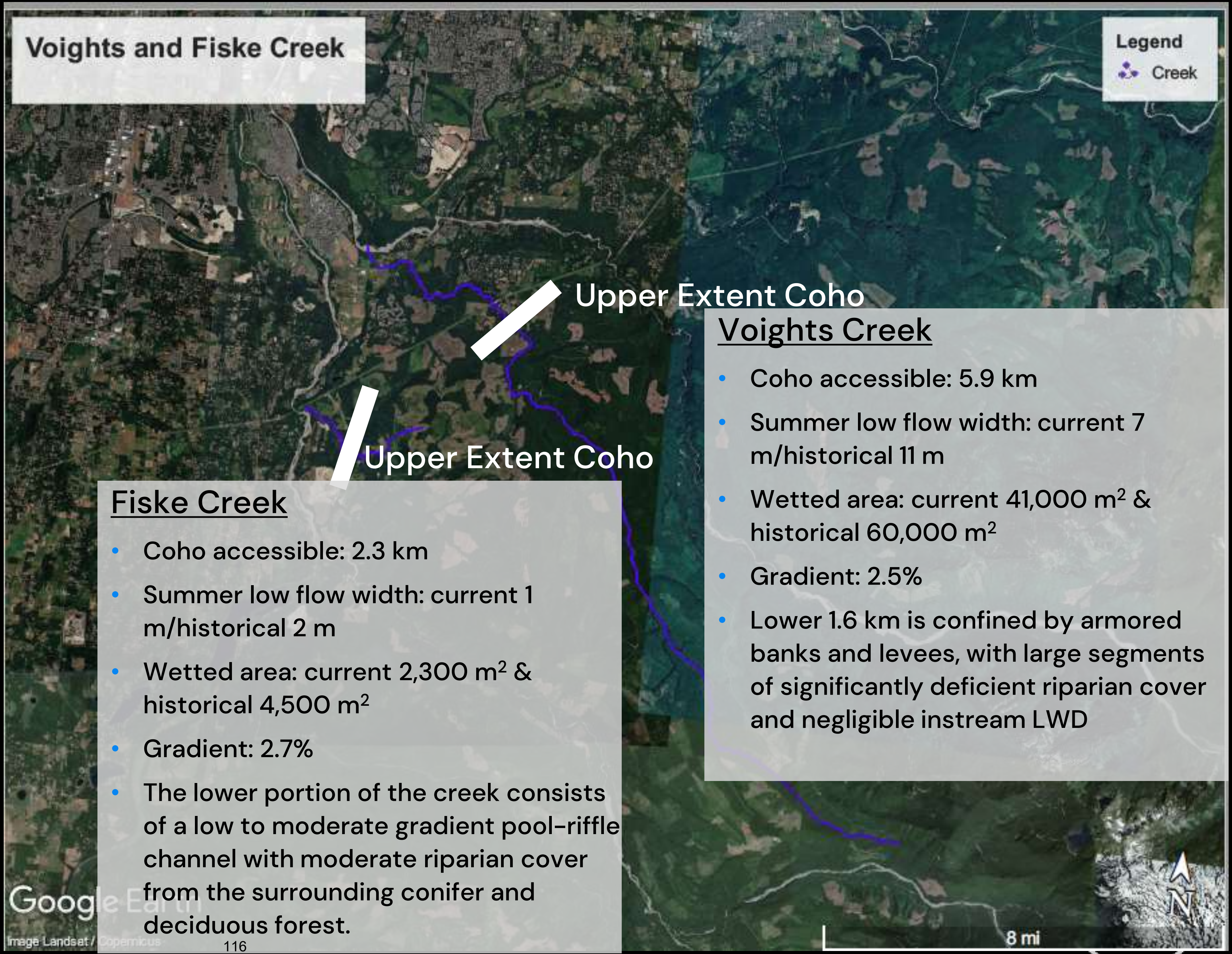


Example 2

- Non-natal productivity low from factors affecting survival during migration to mainstem habitats
- Natal capacity constrained by quantity of summer and overwinter habitat in tributary

Puget Sound – Puyallup Coho Case Studies

- <u>Puyallup Watershed</u>
  - Primary mainstems are Puyallup, Carbon, and White, originate from Mt Rainier glaciers
  - Tributaries a combination of lowland, low gradient and mid elevation moderated gradient
  - Lower and mid watershed tributaries historically included extensive portions within the mainstem floodplains
  - <u>Hydrology:</u>
    - Mainstems glacial with episodic winter peak flows from rainfall and rain-on-snow
    - Tributaries rainfall driven
  - <u>Current Habitat:</u>
    - Mid to lower mainstem leveed on both banks for most of length, off-channel habitats scatter middle portions decades of restoration investments
    - Tributaries combination of past forest practices and urban encroachment
  - <u>Coho Salmon</u>
    - Unlisted, two populations, Puyallup population managed for hatchery production



<u>Voights Creek</u>

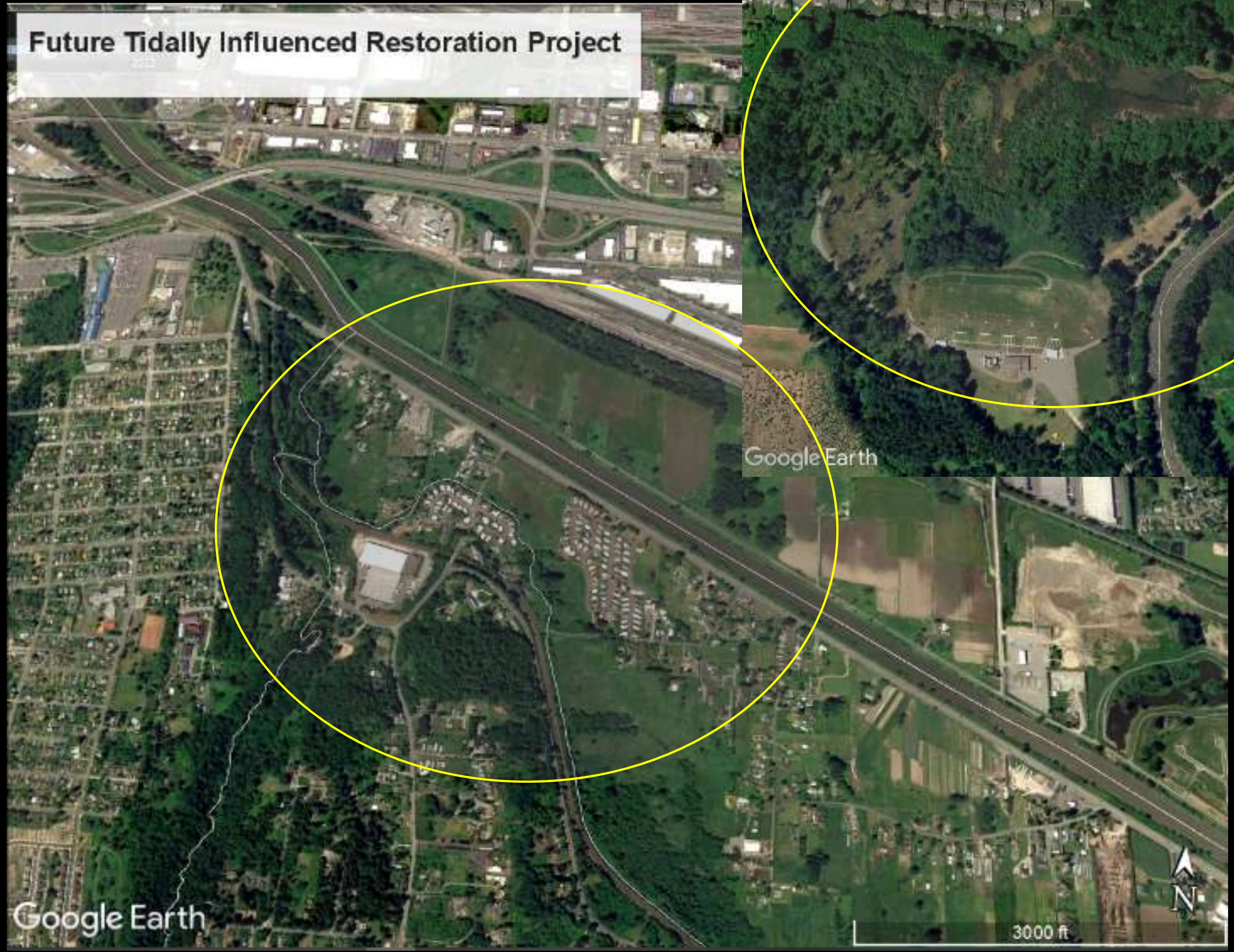
- Coho accessible: 5.9 km
- Summer low flow width: current 7 m/historical 11 m
- Wetted area: current 41,000 m^2 & historical 60,000 m^2
- Gradient: 2.5%
- Lower 1.6 km is confined by armored banks and levees, with large segments of significantly deficient riparian cover and negligible instream LWD

<u>Fiske Creek</u>

- Coho accessible: 2.3 km
- Summer low flow width: current 1 m/historical 2 m
- Wetted area: current 2,300 m^2 & historical 4,500 m^2
- Gradient: 2.7%
- The lower portion of the creek consists of a low to moderate gradient pool-riffle channel with moderate riparian cover from the surrounding conifer and deciduous forest.

ICF

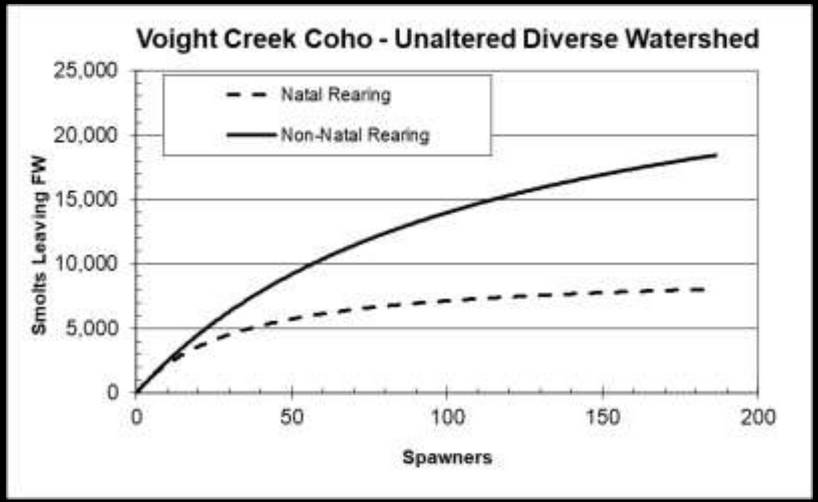
Puget Sound – Puyallup Coho Case Studies

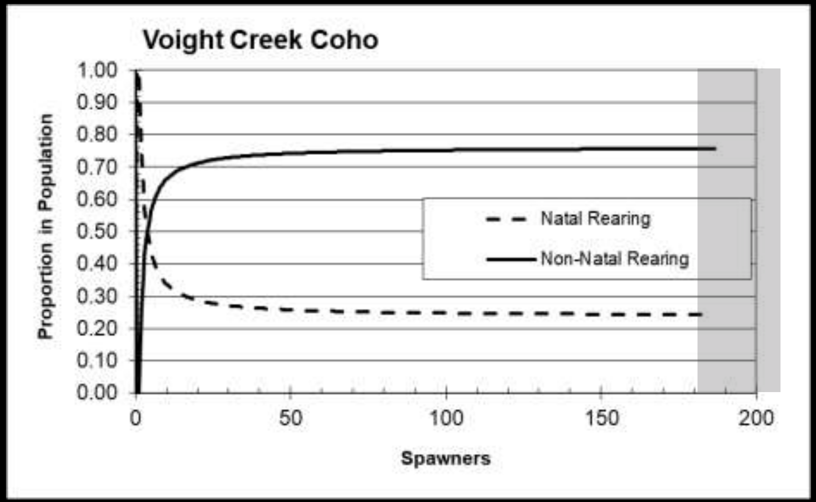


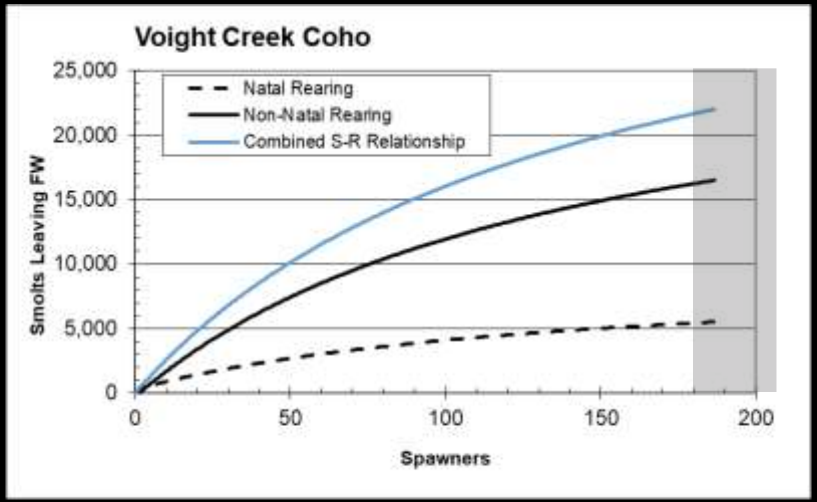
Puget Sound – Puyallup Coho Case Studies

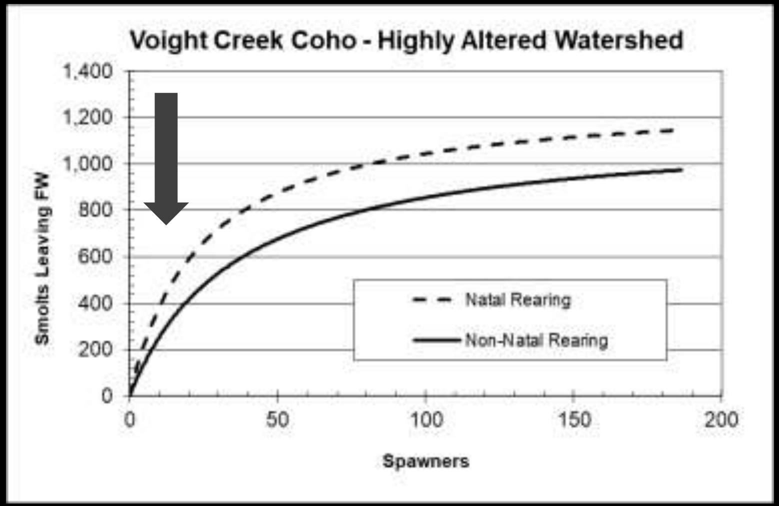
- <u>Nisqually Watershed</u>
  - Used as historical reference for Puget Sound rivers (e.g., Collins and Montegomery)
  - Originates from Mt Rainier Nisqually Glacier
  - However hydroelectric Dam in upper watershed has greatly impacted sediment supply to anadromous portion of watershed.

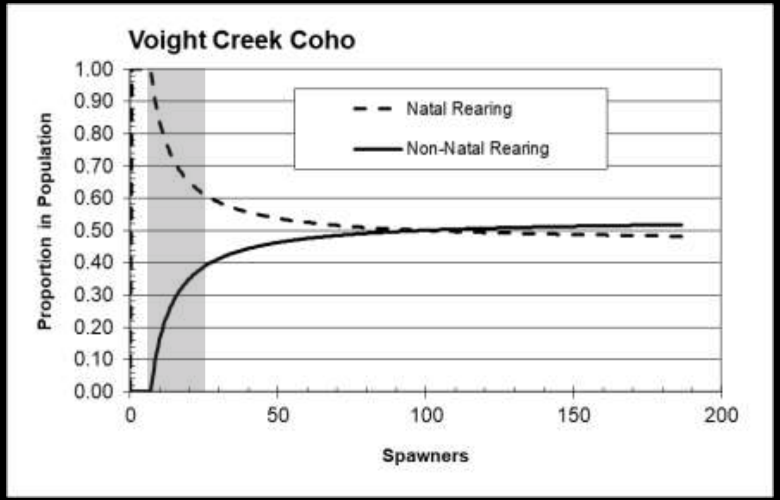
Puget Sound Coho – Historical & Current Habitat Performance

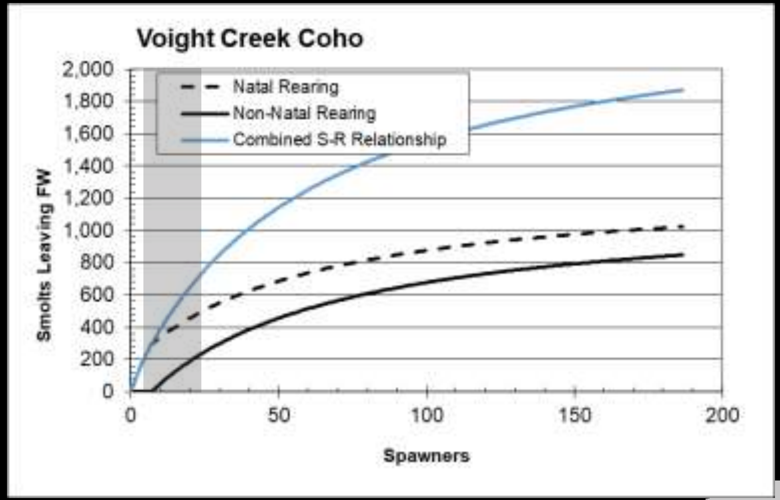




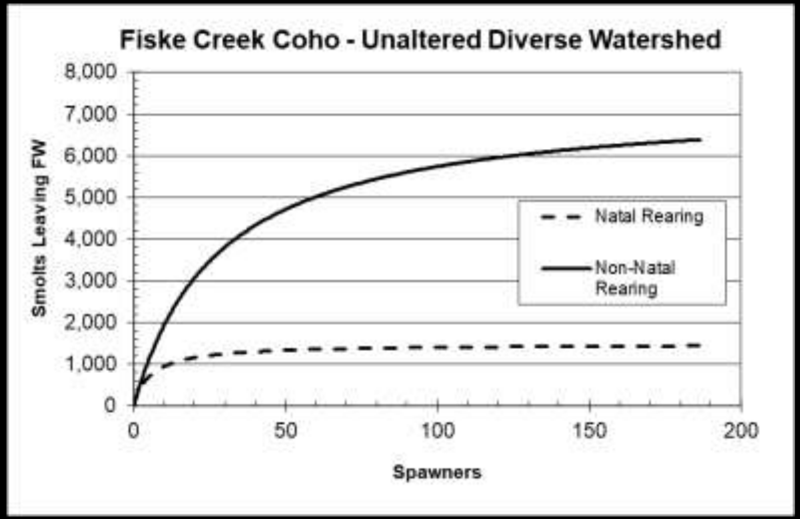


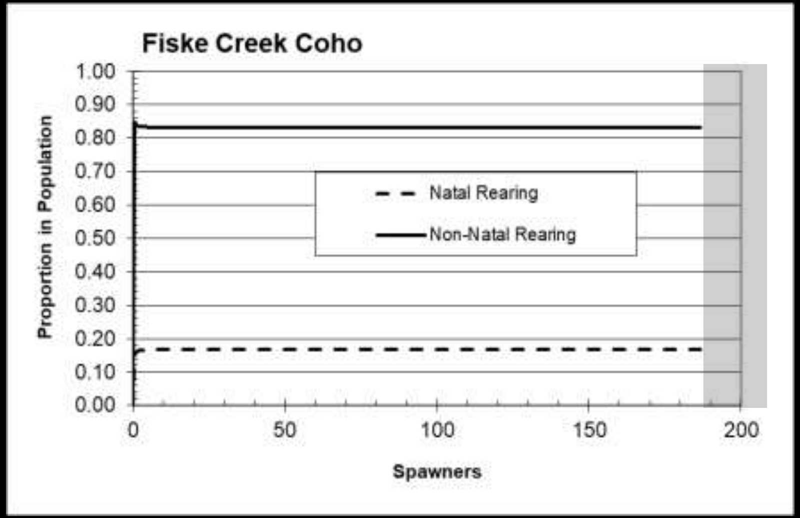


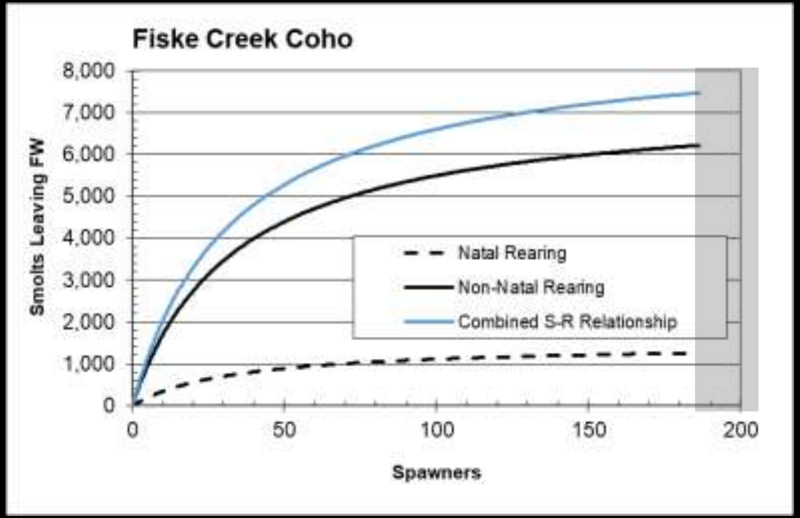


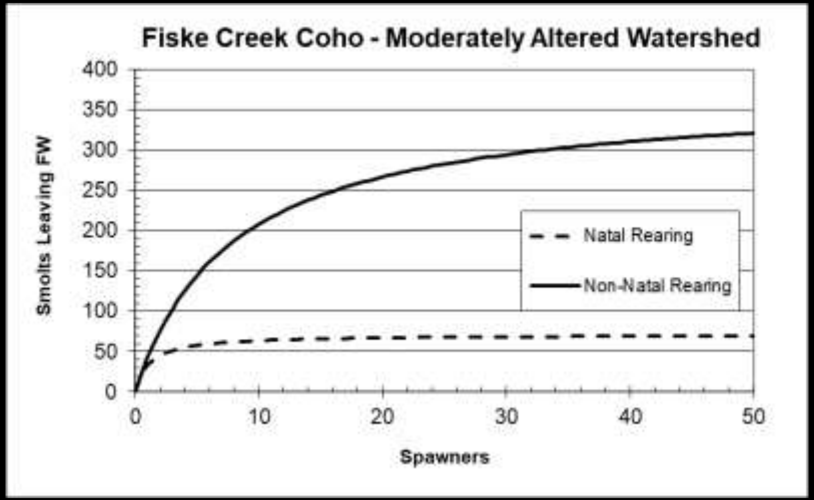


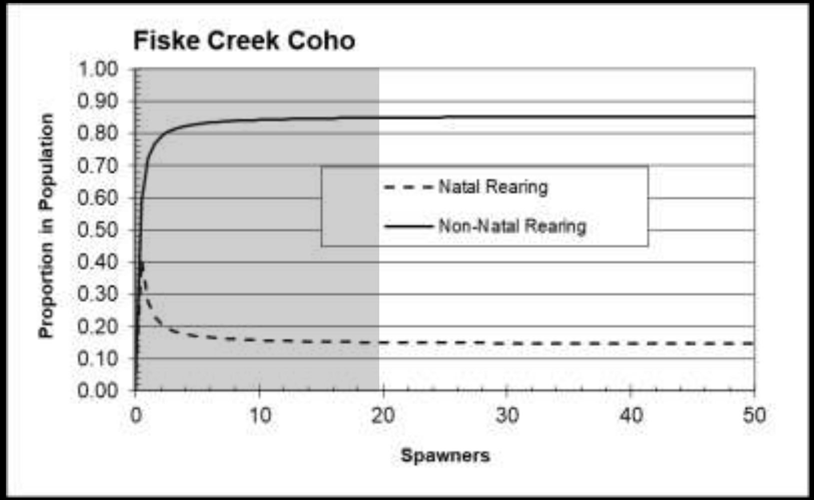
Puget Sound Coho – Historical & Current Habitat Performance

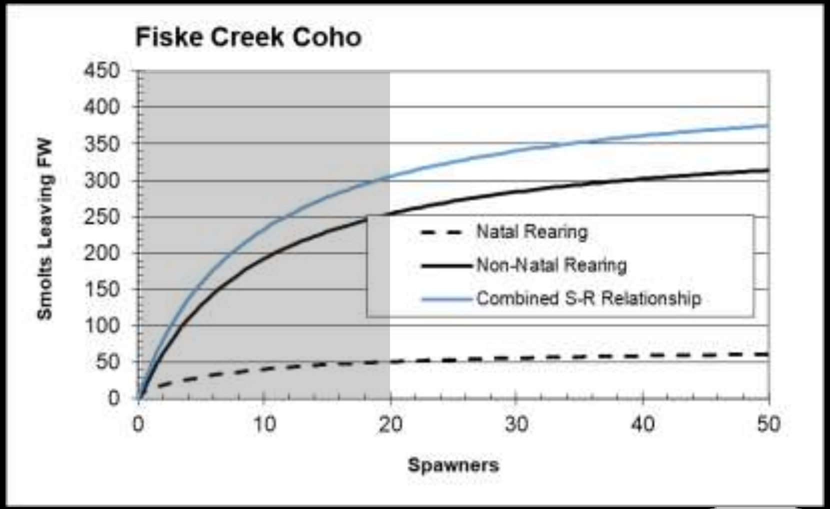




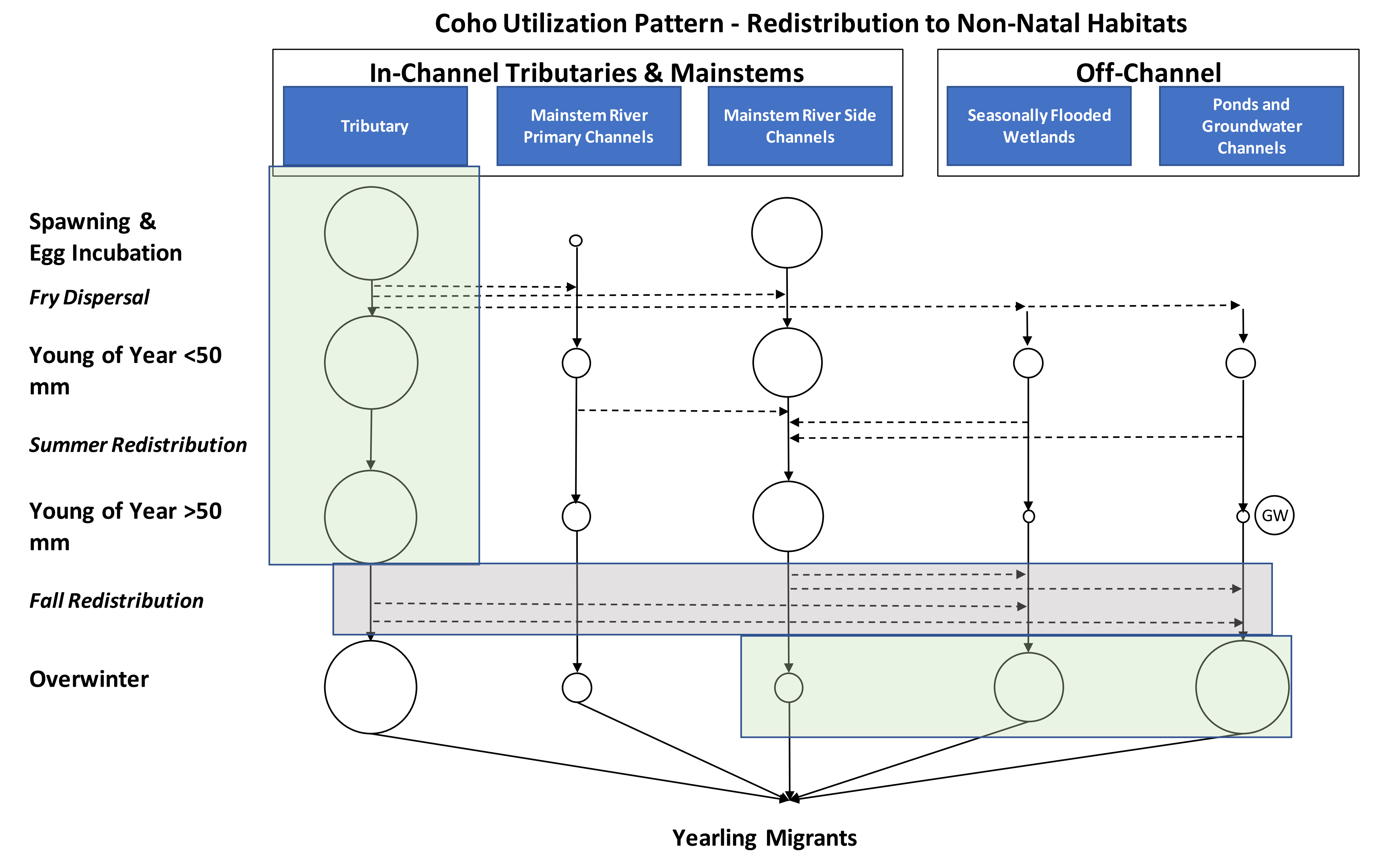






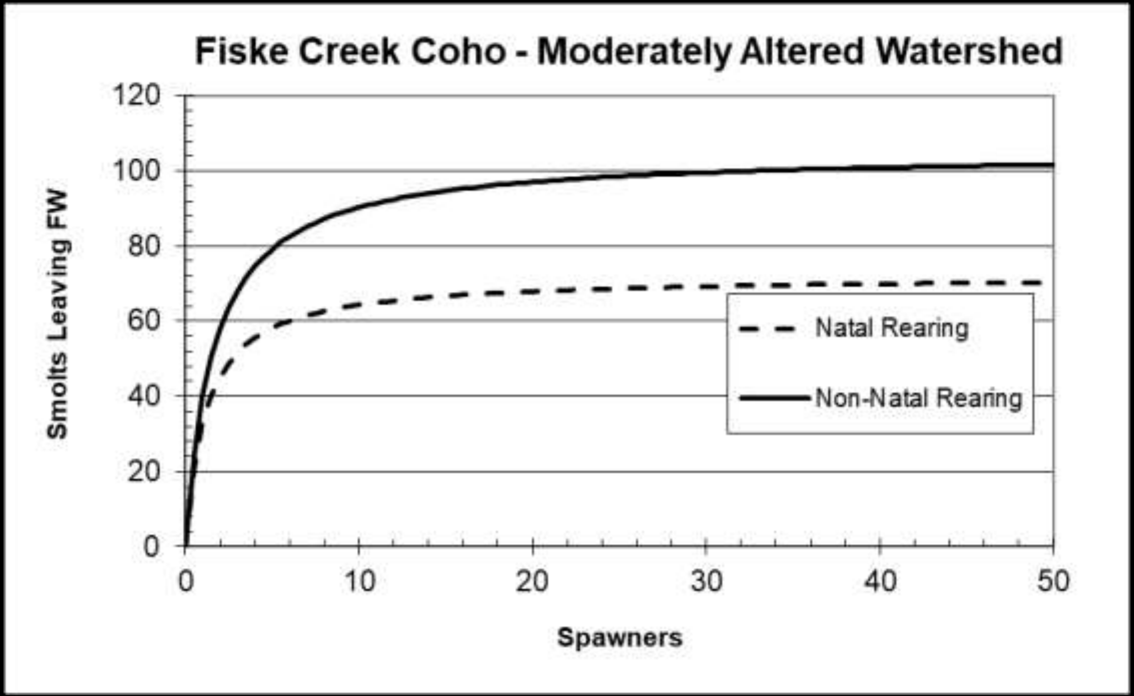


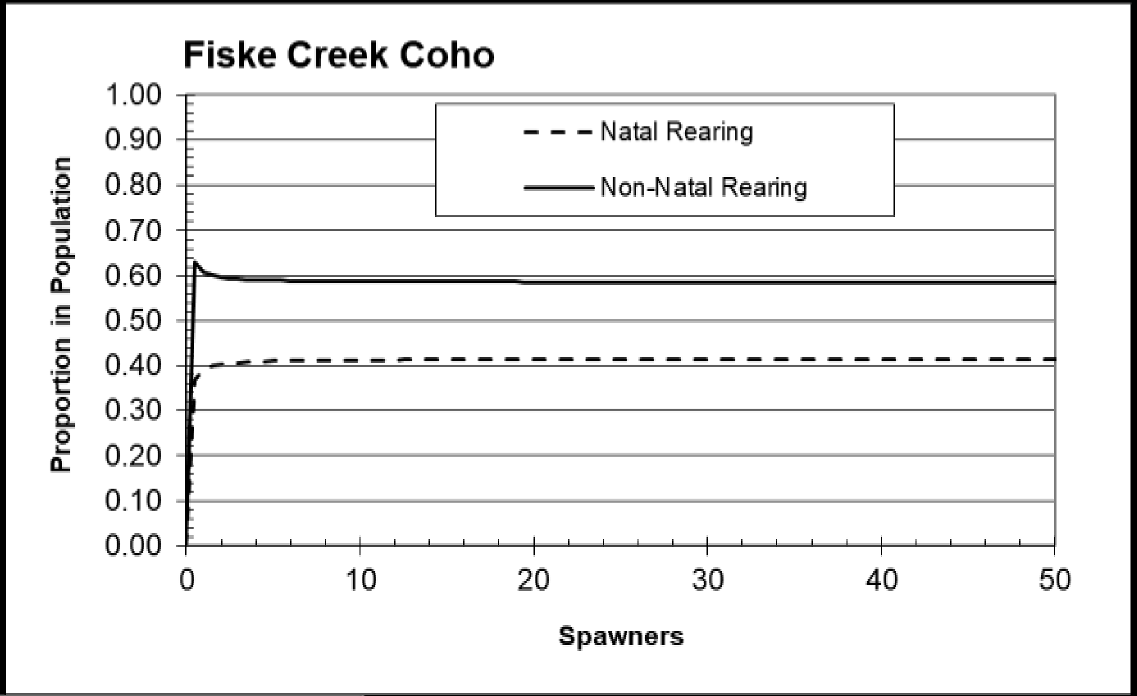
Step 1c: Coho Salmon Redistribution Pattern

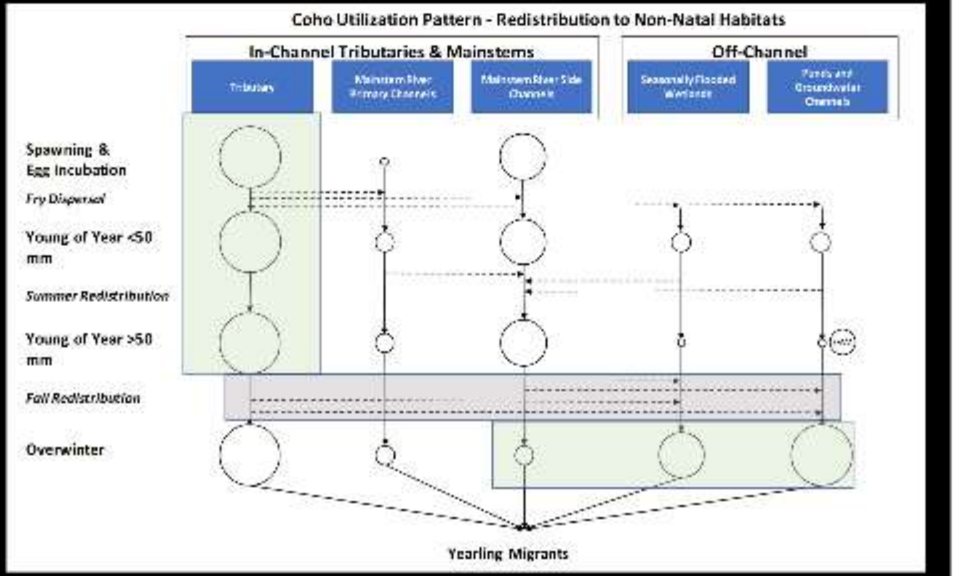


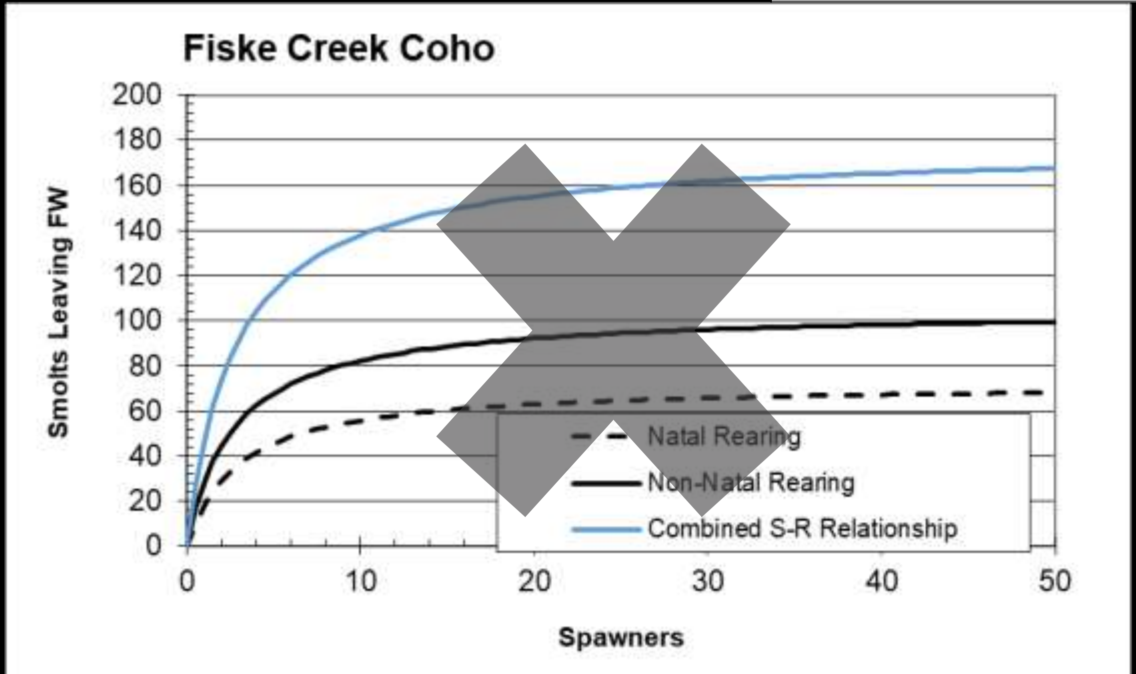
Modified from:
Lestelle, L.C., G.R. Blair, S.A. Chitwood. 1993. Approaches to supplementing coho salmon in the Queets River, Washington. Pages 104-119 in L. Berg and P.W. Delaney (eds.) Proceedings of the coho workshop. British Columbia Department of Fisheries and Oceans, Vancouver, BC.

Optimization of Habitat Performance





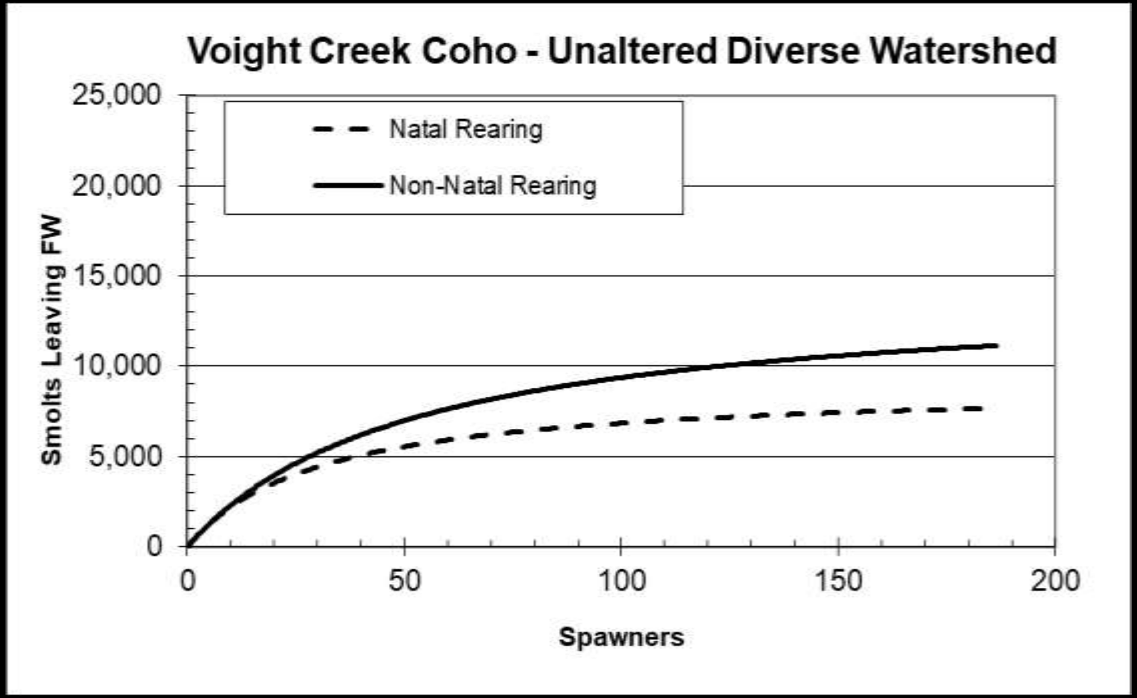


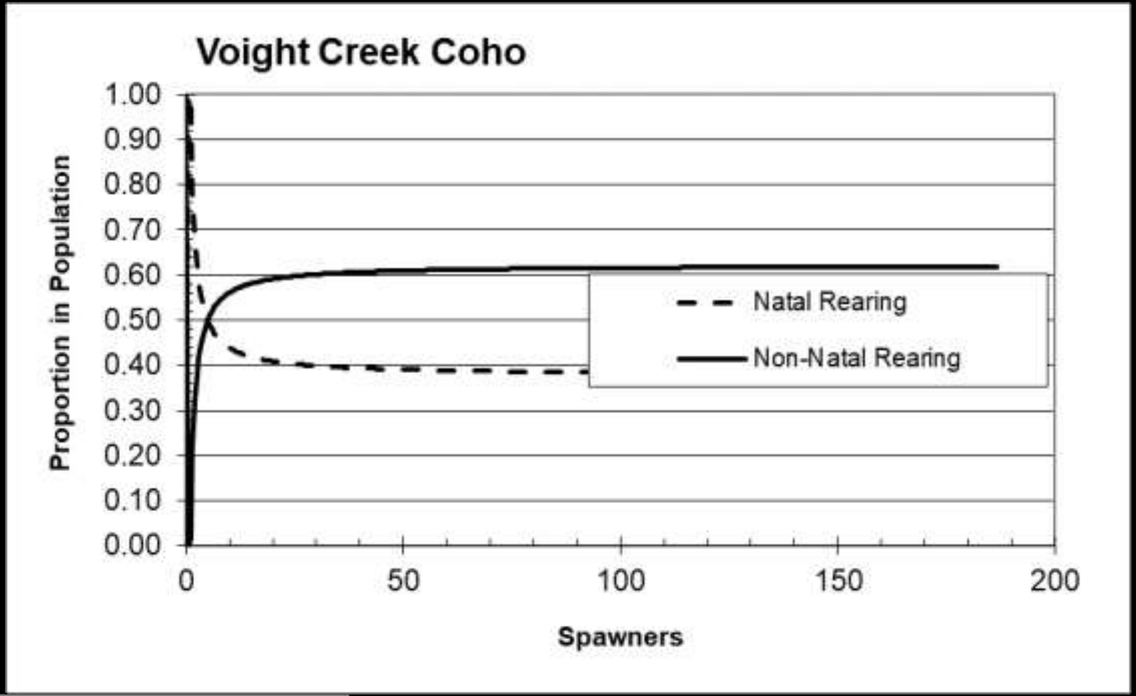


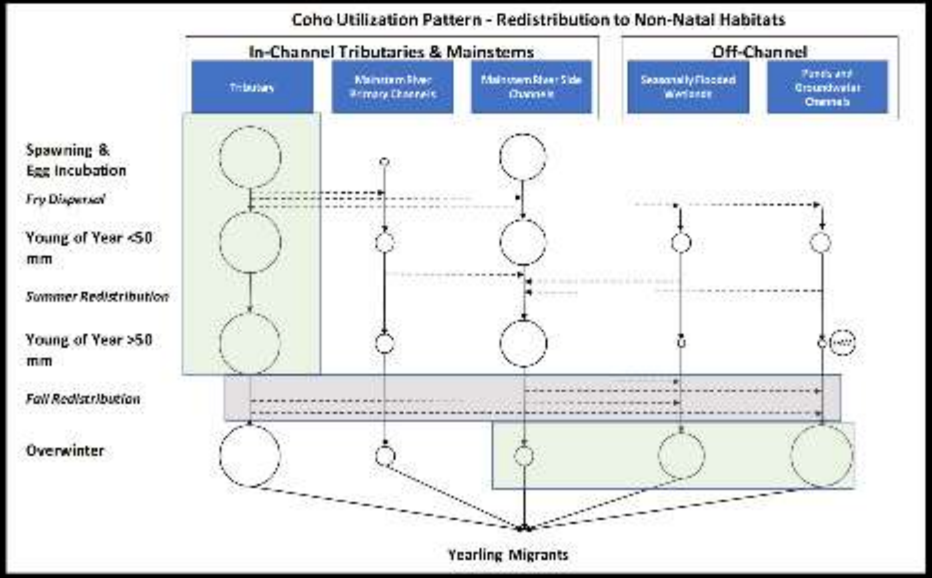
Fall emigration from natal stream

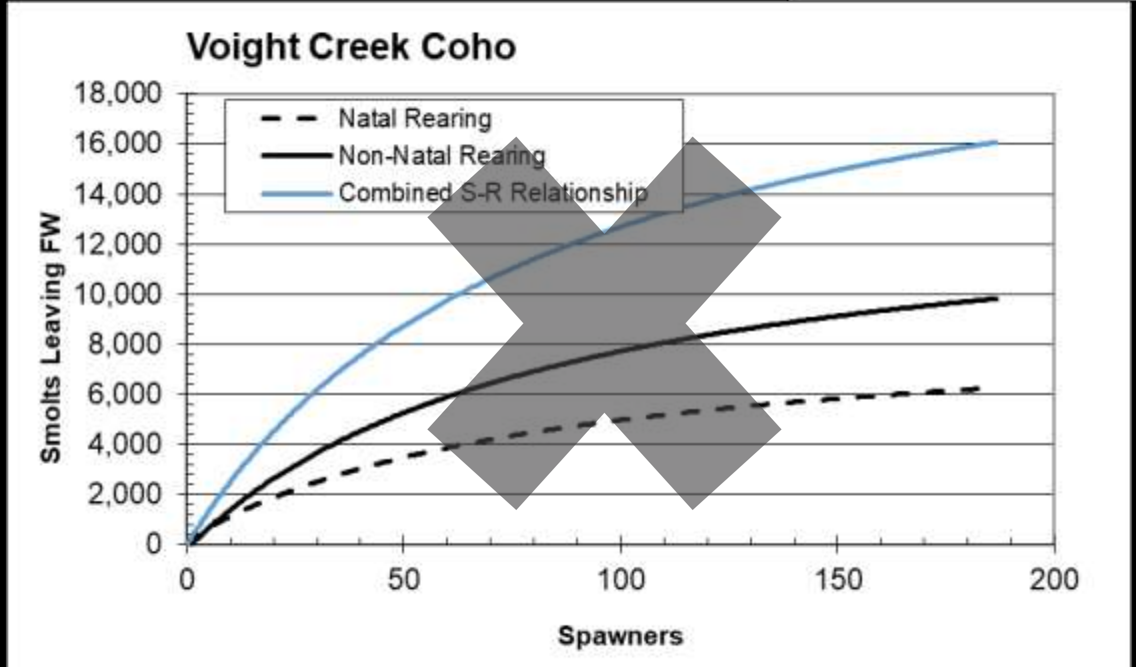
- Occurs after summer low flow period, a significant period constraining in freshwater production in Puget Sound rivers.
- Combined S–R invalid, need to reconsider B–H survival functions by life stages – spawning/egg incubation, summer rearing, and overwinter.

Optimization of Habitat Performance









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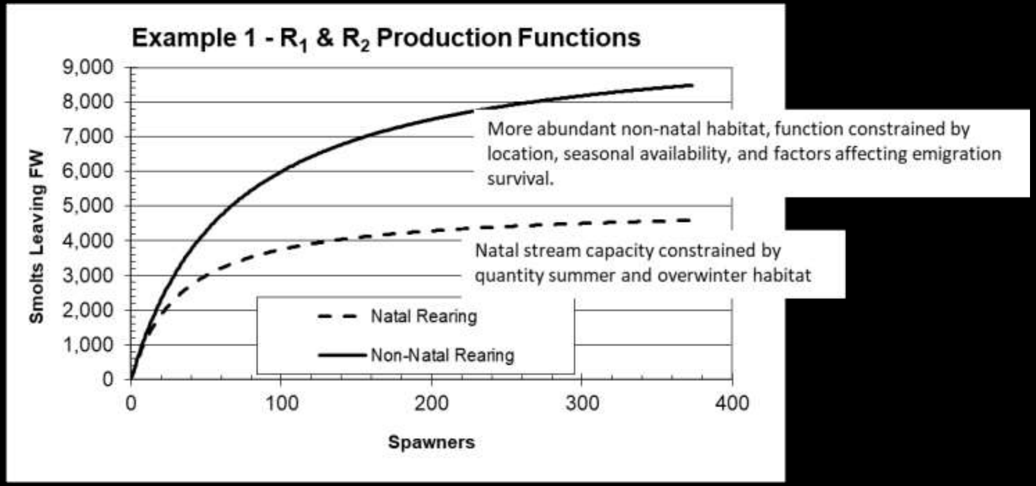
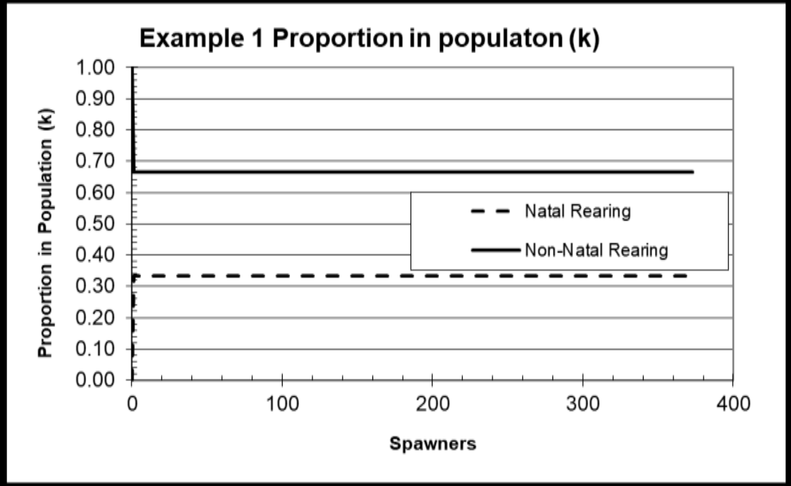
- Combined S-R invalid, need to reconsider B-H survival functions by life stages – spawning/egg incubation, summer rearing, and overwinter.

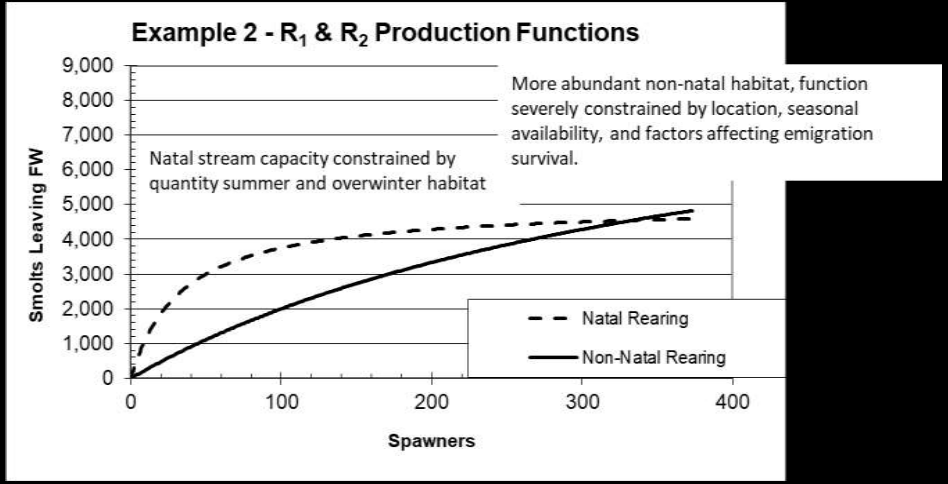
Conclusions

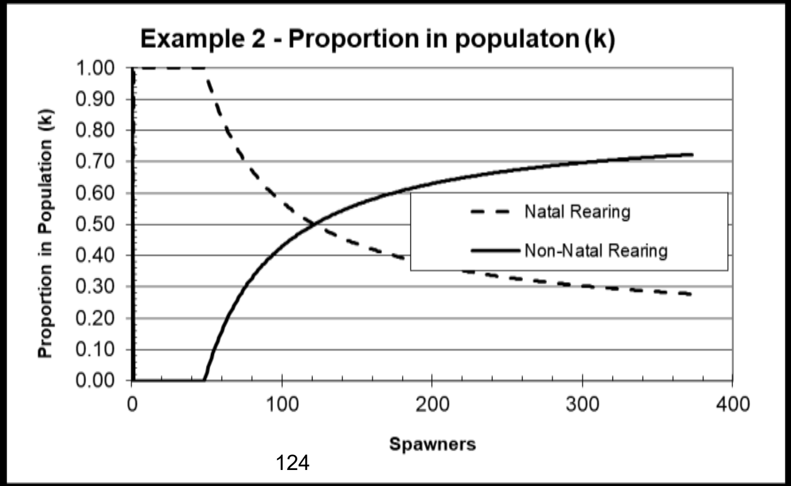
- <u>Example Model Simulations</u>
  - Example 1 – similar density independent productivities, fitness advantage for a portion of spawner progeny to emigrate to non-natal habitats to avoid competition for food and space in natal habitats





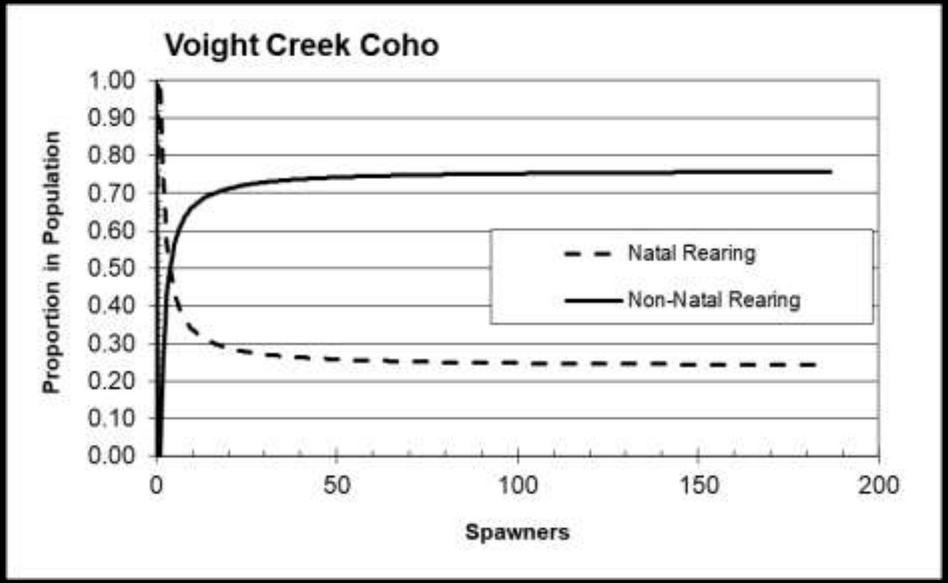
  - Example 2 – dissimilar density independent productivities, a substantial cost to emigration from natal stream to larger non-natal habitats. The fitness advantage for a portion of spawner progeny to emigrate from natal stream occurs at higher escapements in natal stream with higher competition for food and space.

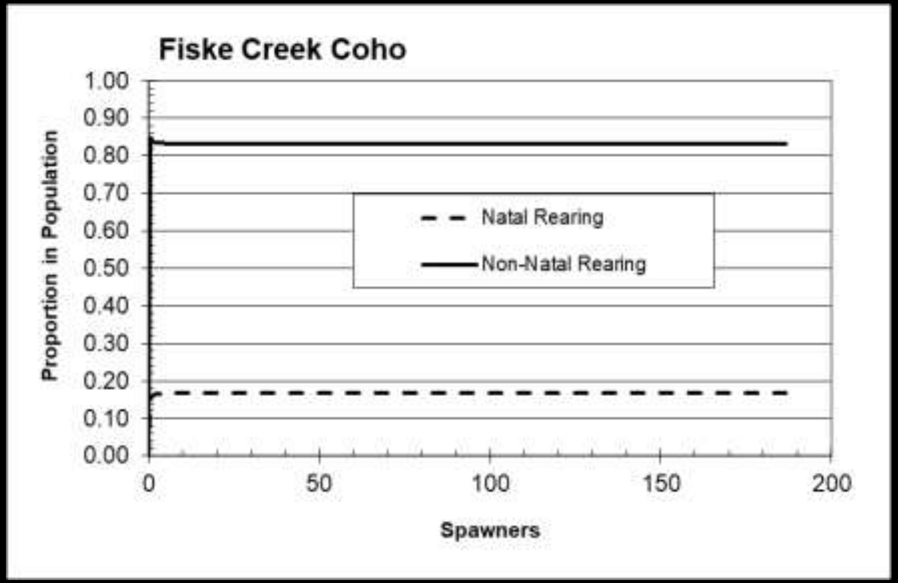




Conclusions

- <u>Puyallup Case Studies – Historical Condition</u>
  - Voight Creek more abundant natal habitat combined with abundant non-natal mainstem habitats would suggest a fitness advantage of emigrants at intermediate escapements and above.
  - Fiske Creek would have largely functioned as a spawning channel with escapements exceeding natal stream juvenile carrying capacity (there is a reasonable assumption of surplus spawning habitat)

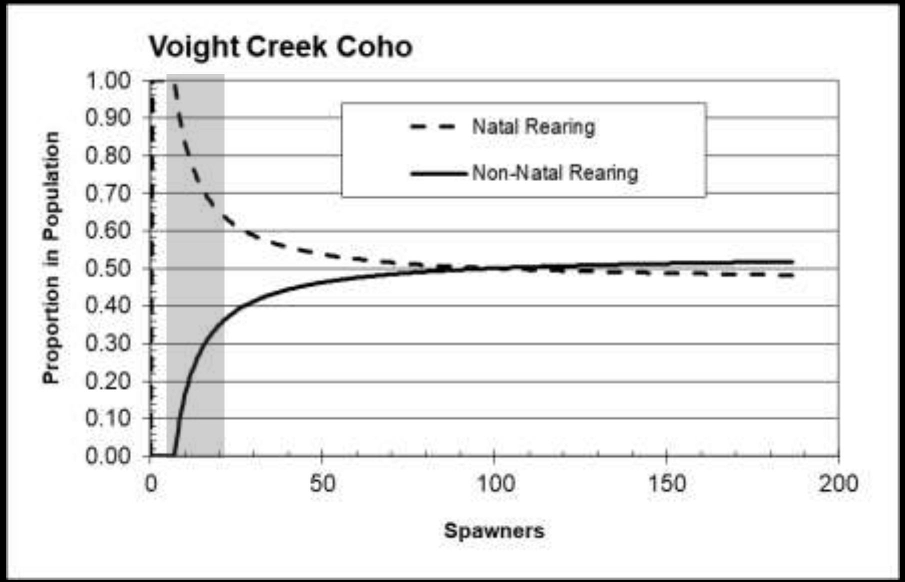


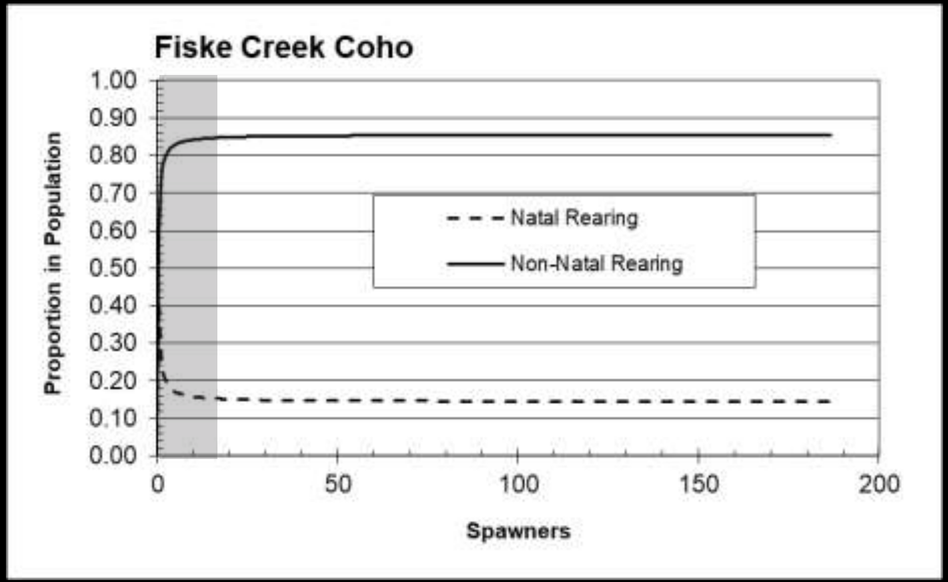


ICF

Conclusions

- <u>Puyallup Case Studies – Altered Condition</u>
  - Voight Creek - the highly degraded mainstem would suggest a fitness advantage to remain in natal stream when combined with depressed escapements.
  - Fiske Creek the higher functioning mainstem adjacent to the creek and low tributary capacity suggest a continued fitness advantage for a portion of the progeny from spawning to emigrate to non-natal mainstem habitats.





Conclusions

- Patterns of movement and habitat utilization in an unaltered watershed suggest a large fitness advantage at historical escapement levels suggesting a possible evolutionary adaptation to a diverse freshwater environment.
- Our altered watersheds may threaten intraspecific diversity by reducing local adaptation and genetic variation within populations
- Recovery of lost diversity (i.e, habitat utilization patterns) may be slow, reintroduction and recovery of severely depleted populations may benefit from infusion of new genetic material to promote diverse life histories

Thank you,

Questions?

Stage 0 restoration impacts on spring Chinook juveniles within South Fork McKenzie River in Oregon

Aleah Hahn[1]

MS Student - Marine Resource Management

Desiree Tullos[1], Steve Railsback[2], Guillermo Giannico[1]

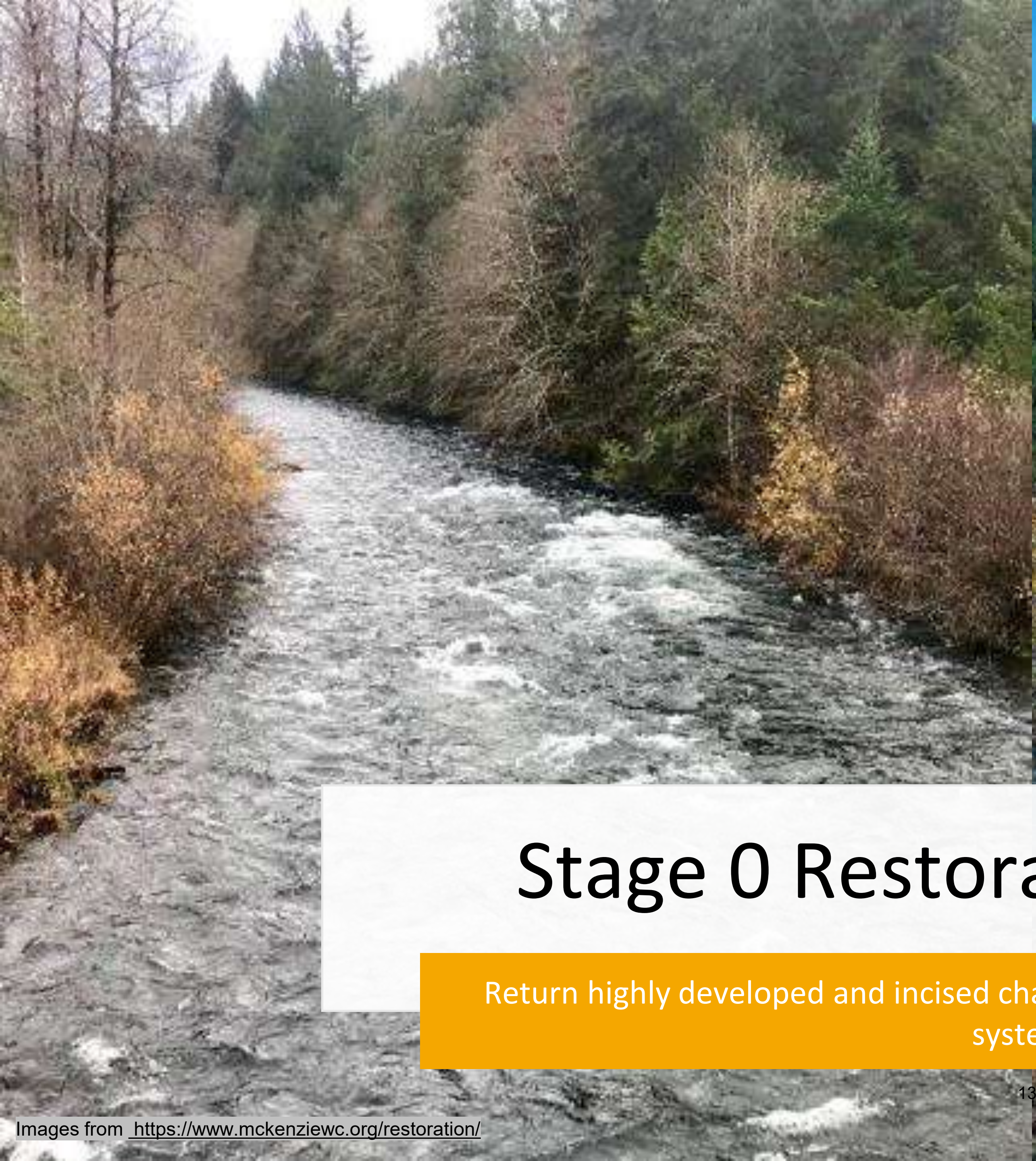
1. Oregon State University
2. Humboldt State University

https://www.mckenziewc.org/restoration/

Why do we need to restore rivers?

Loss of habitat for spawning and rearing salmon.

- Floodplain conversion to farmland
- Loss of large wood
- Dam building for flood protection and hydroelectric power



Stage 0 Restoration Overview

Return highly developed and incised channels into highly connected floodplain systems.

Images from https://www.mckenziewc.org/restoration/

Geomorphic Gradeline Approach

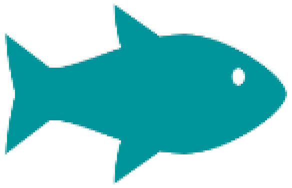
1. Divert Channel

2. Re-Grade Channel

3. Large Wood Placement

4. Rewater channel

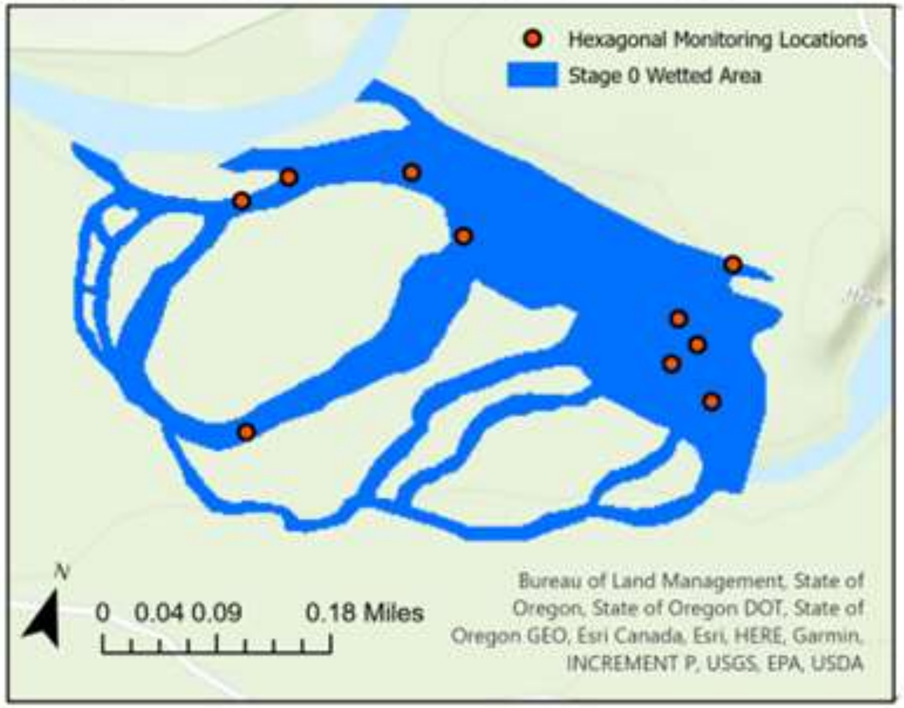
Study Questions

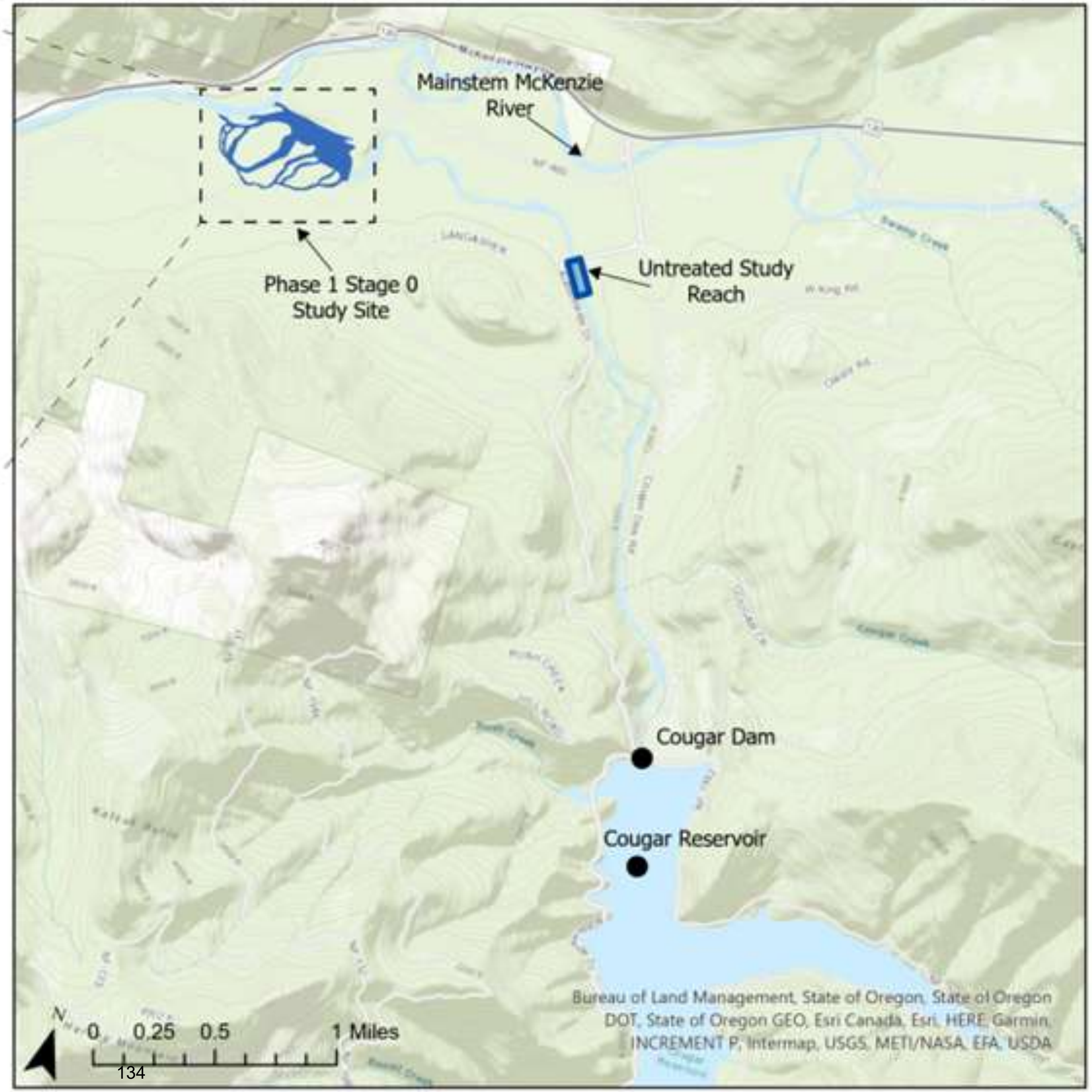


How do habitat conditions within a Stage 0 rehabilitation site impact size and abundance of juvenile spring Chinook relative to the site prior to treatment?

How do restoration impacts vary among hydrological conditions: wet years vs dry years vs typical years?

How do future stream temperatures impact juvenile size and abundance?

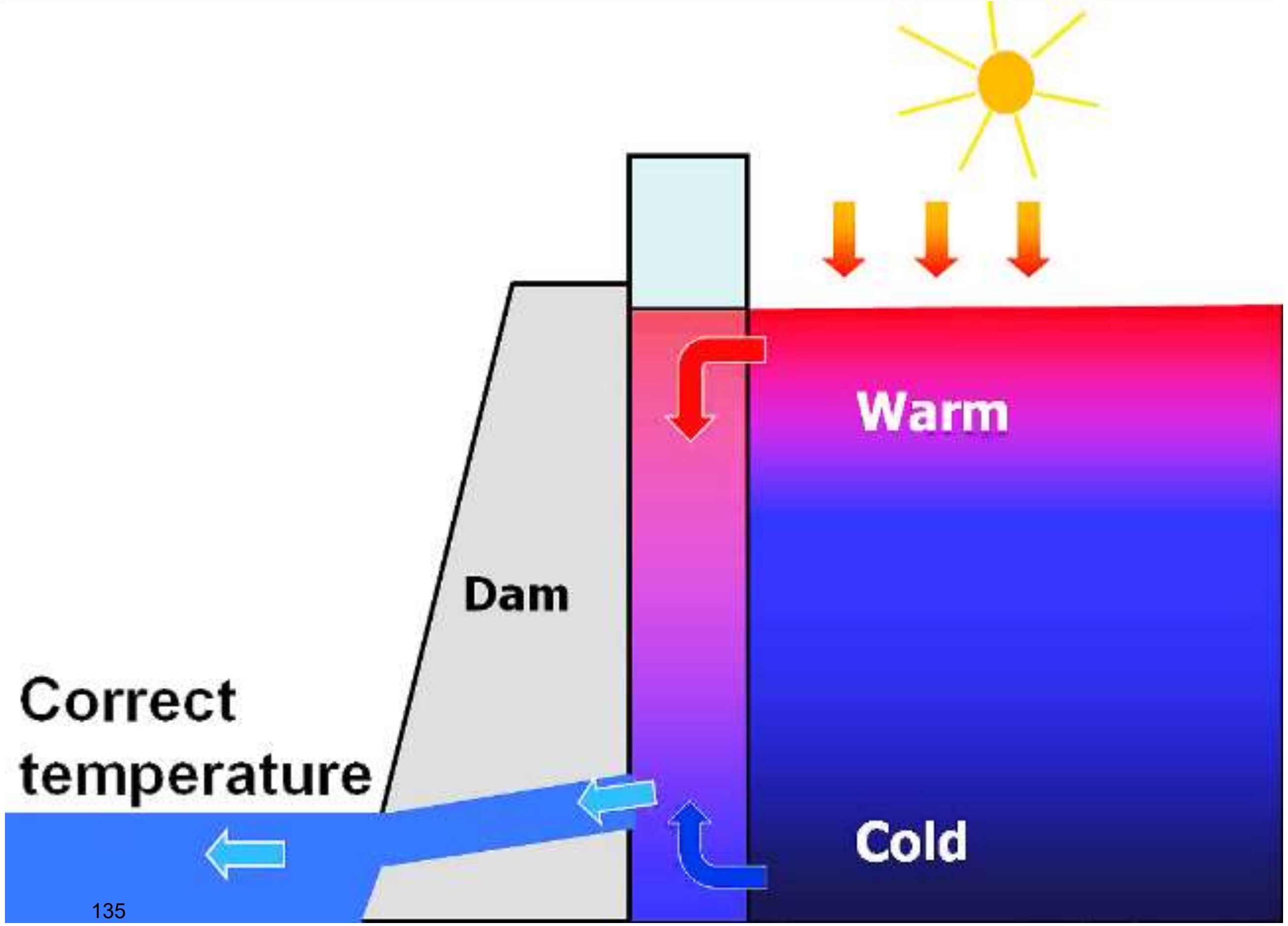




Study Site: South Fork McKenzie (SFMK)

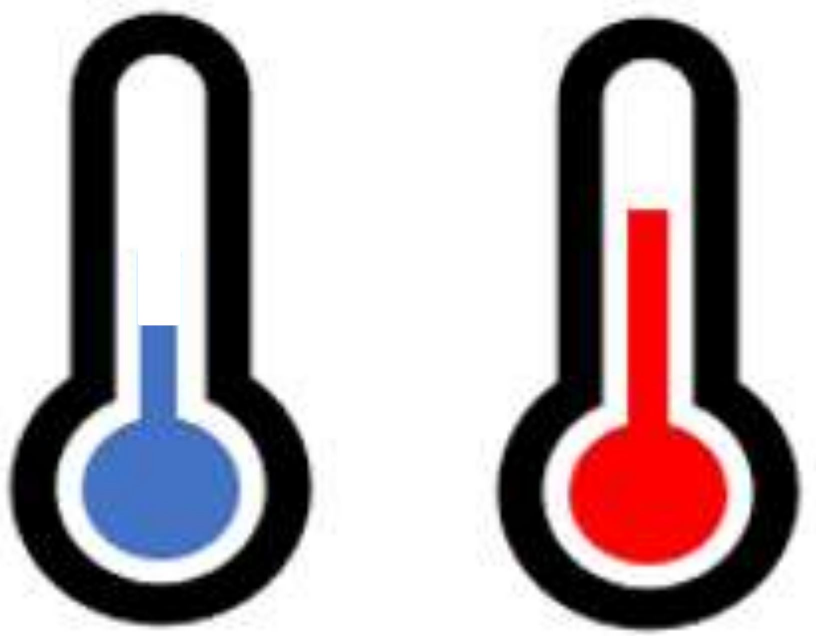
Cougar Dam Temperature Control Tower

- Upstream of study reach
- Temperature Control Tower installed in 2005
- 2020: Judge ruled operations violated Endangered Species Act
  - New operational measures initiated in winter 2022



Future Stream Temperatures

- NorWEST Stream Temperature Approximations
  - 2080: 22% increase in mean August stream temperature
- Monte-Carlo Analysis: 25% increase



inSALMO Model

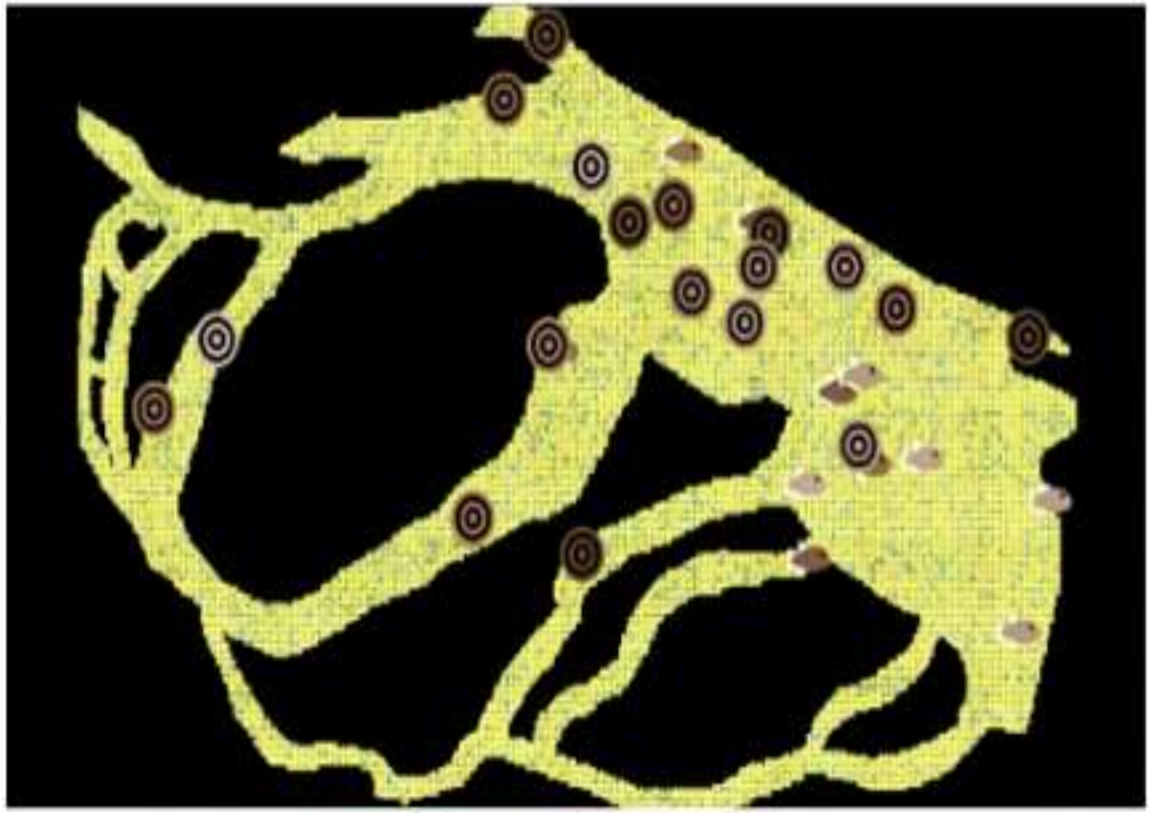
- Bioenergetics model for salmon spawning and rearing
- Simulated river environment
- Outputs acts like the ultimate screw trap

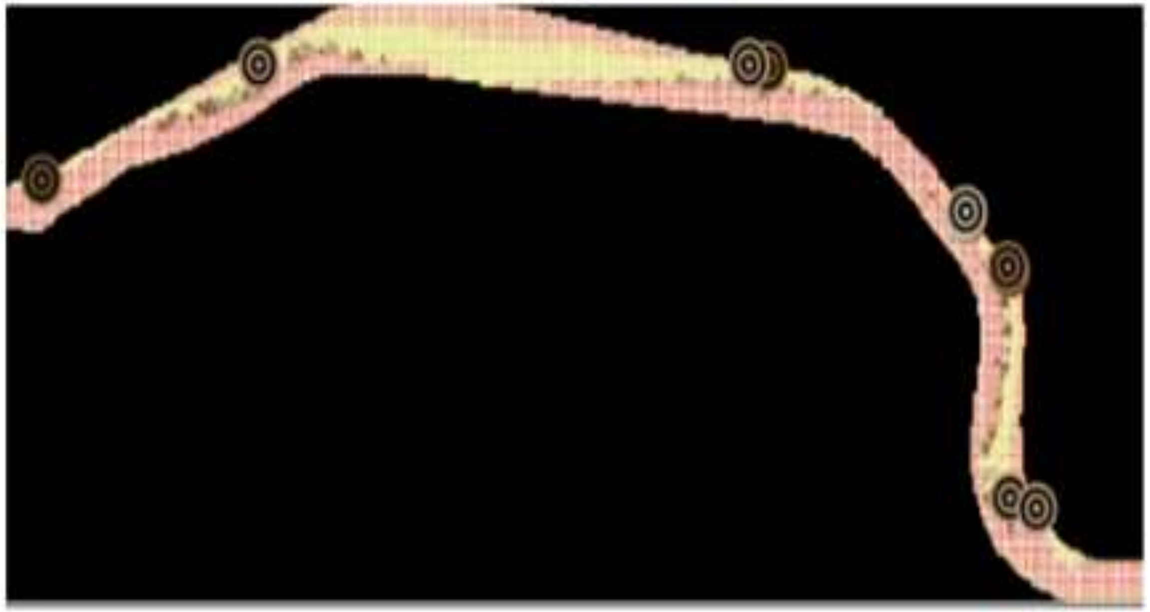
Methods

- **Collected hydraulic profiles and habitat characteristics**

Methods

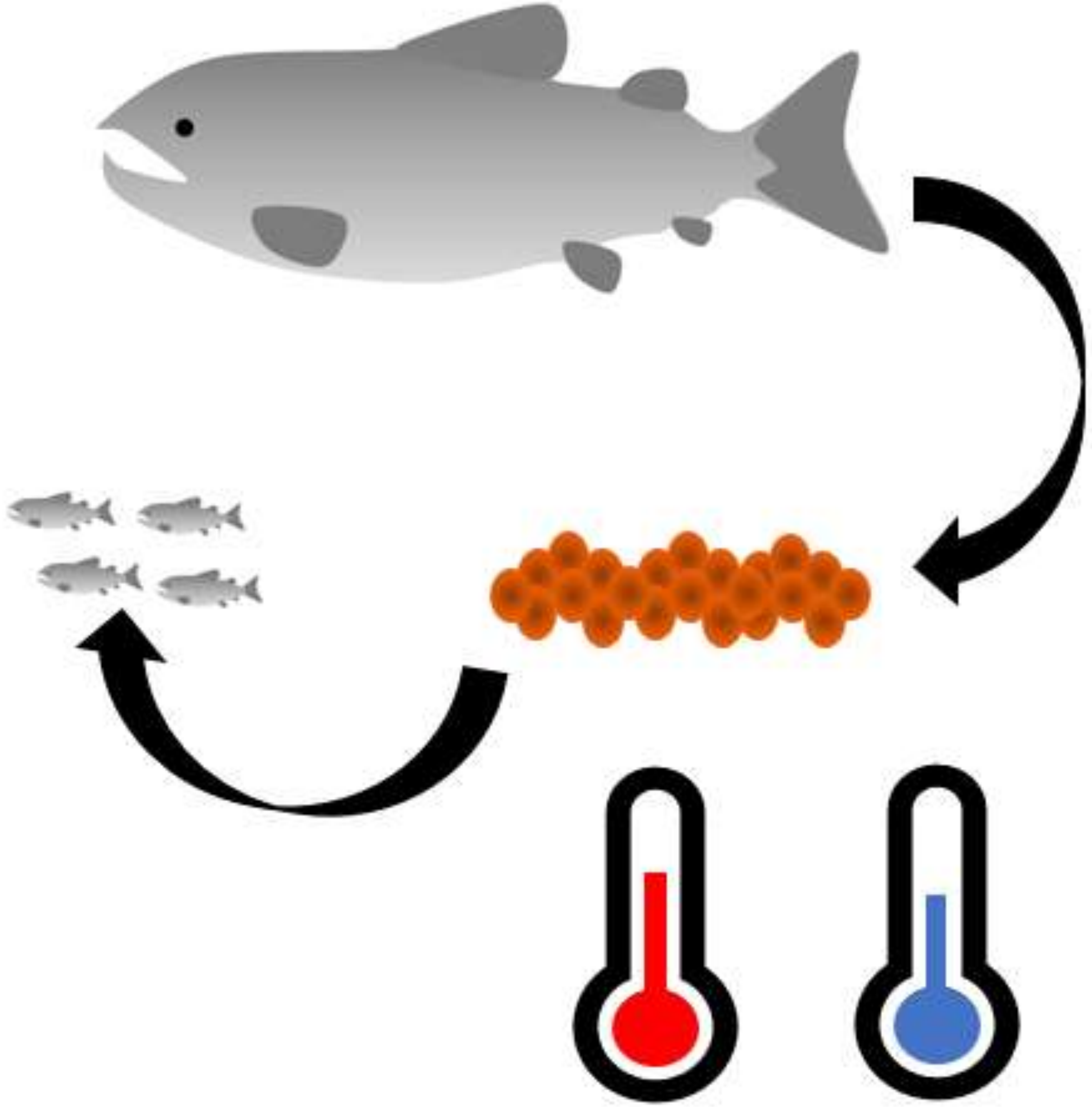
- Collected hydraulic profiles and habitat characteristics
- **Developed and calibrated inSALMO models for SFMK pre- and post-treatment**





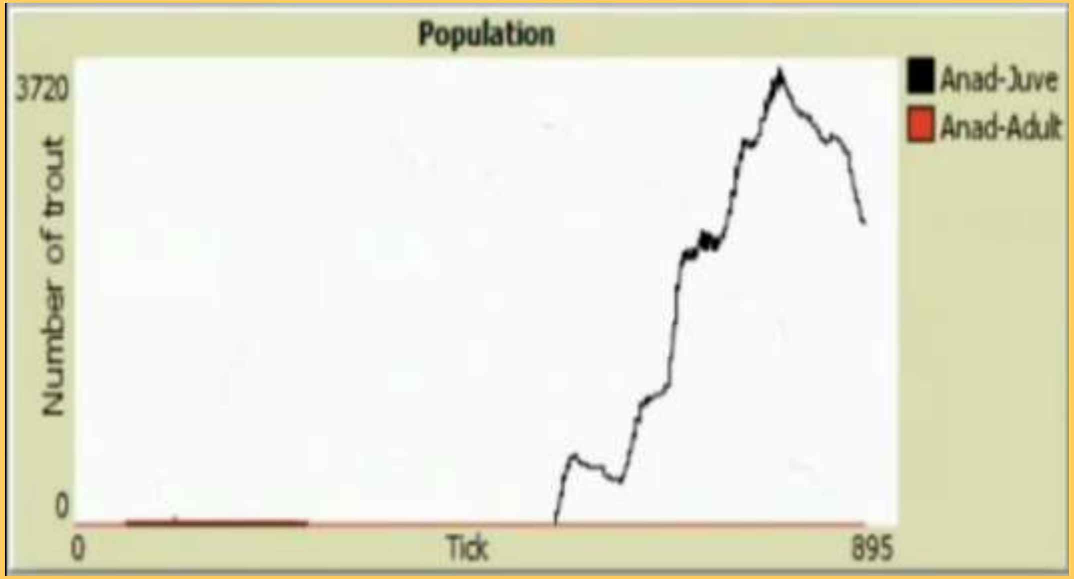
Methods

- Collected hydraulic profiles and habitat characteristics
- Developed and calibrated inSALMO models for SFMK pre- and post-treatment
- **Run models and sensitivity analysis**



Methods

- Collected hydraulic profiles and habitat characteristics
- Developed and calibrated inSALMO models for SFMK pre- and post-treatment
- Run models and sensitivity analysis
- **Analyze juvenile Chinook outmigrants**

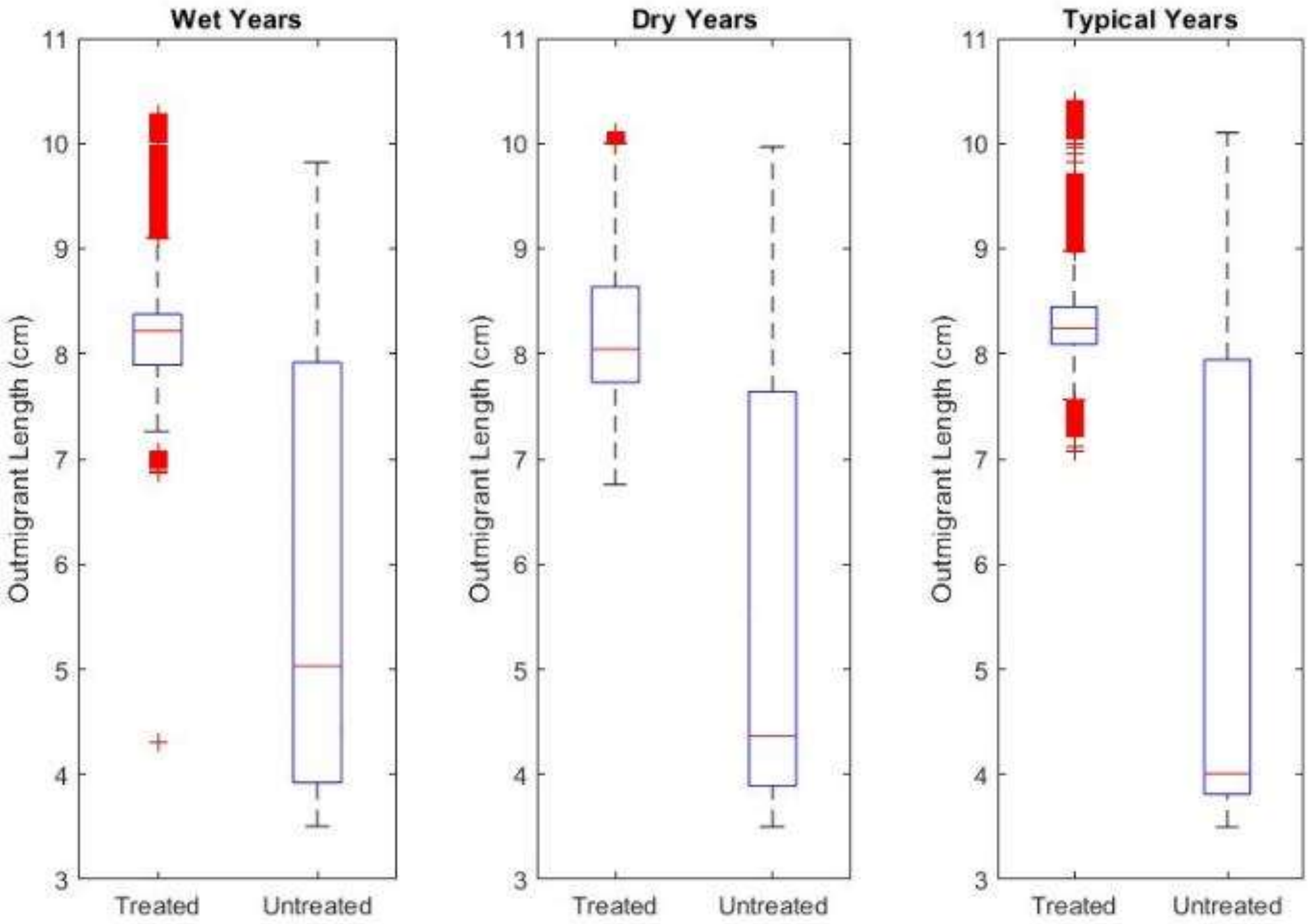


Treated vs Untreated

How does Stage 0 impact juvenile length and abundance among different hydrological years?

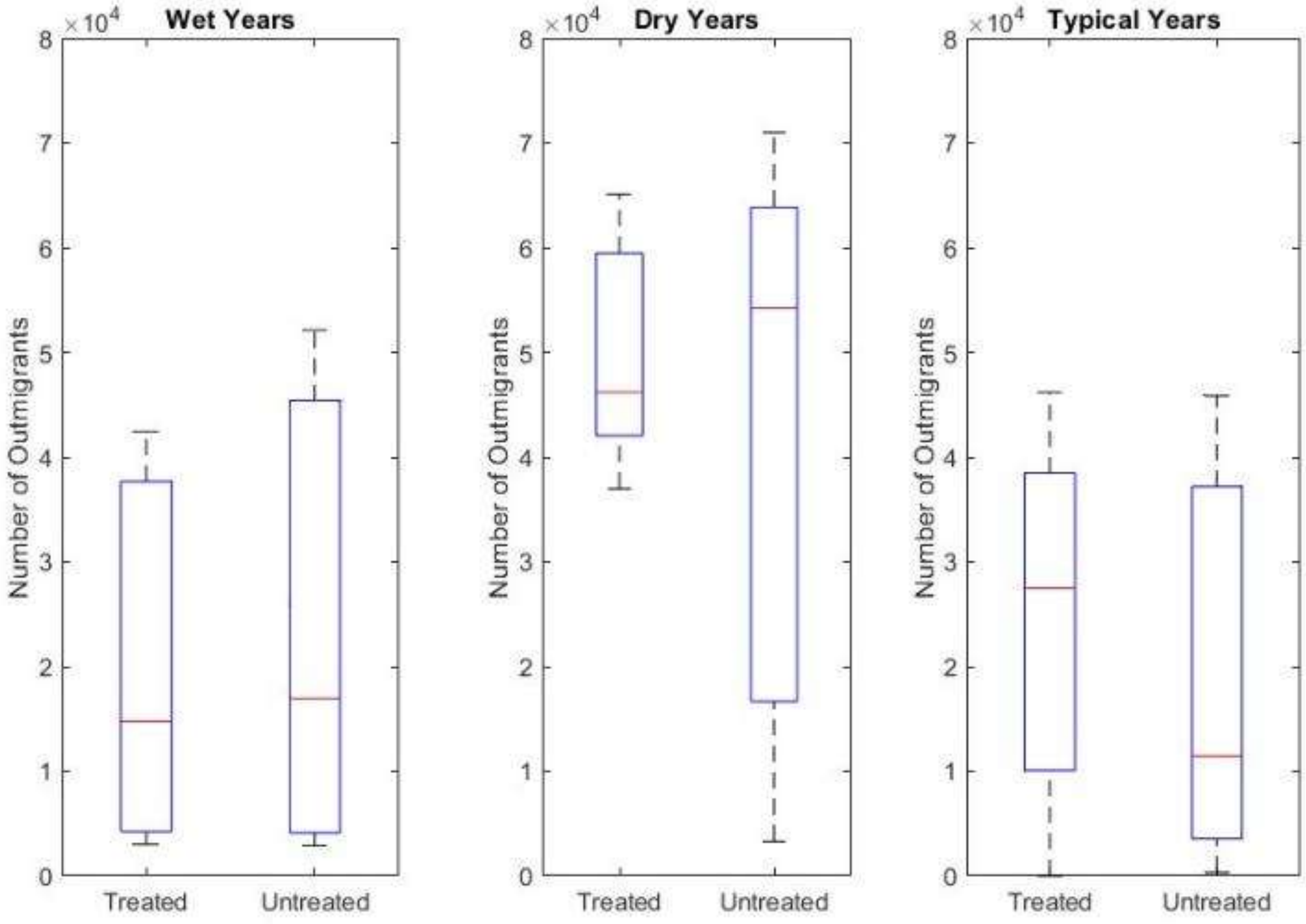
How does Stage 0 treatment impact juvenile length?

- Mean length of juveniles significantly increased for all water years ($p<0.05$) in the treated reach.
- Stage 0 habitat conditions produced larger fish.
- Bigger is better!



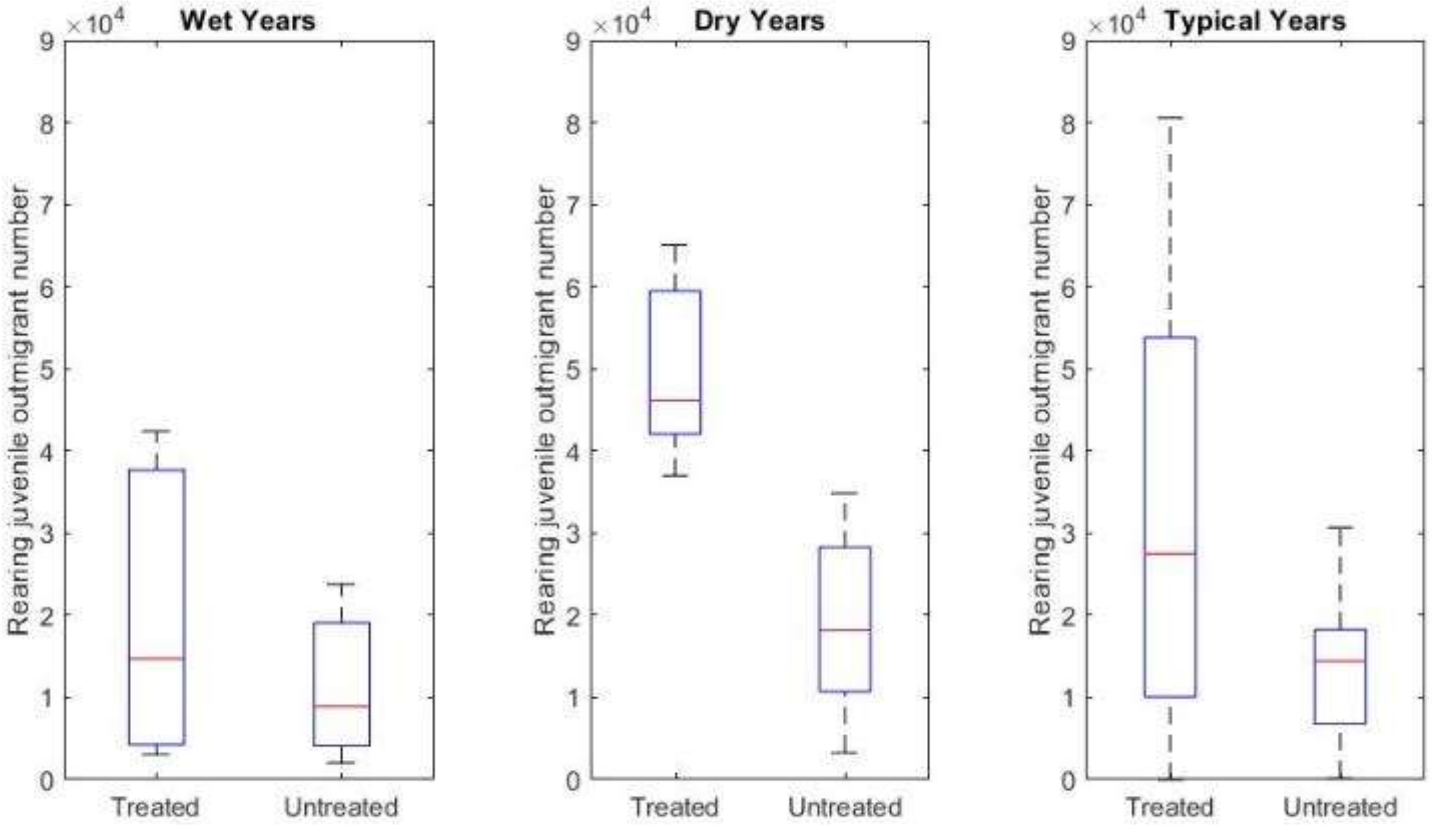
How does Stage 0 treatment impact number of juveniles?

- Statistically insignificant change ($p>0.05$) across all water years.
- Increase in habitat does not increase number of juveniles.



How does Stage 0 treatment impact number of *rearing* juveniles?

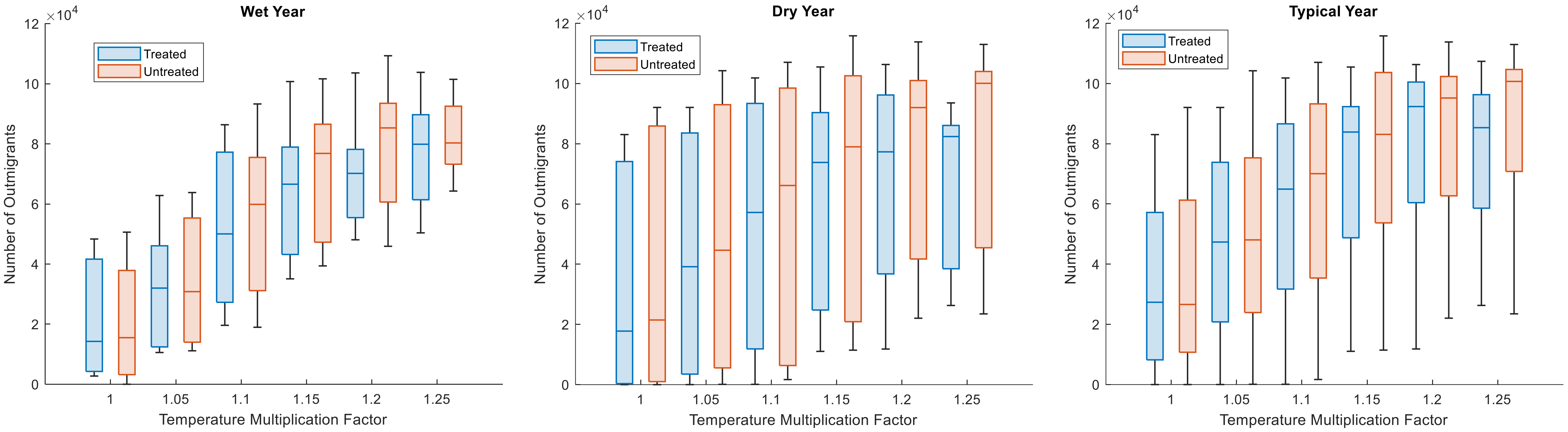
- Statistically significantly increase ($p<0.05$) across dry and typical water years.
- Site after treatment has increased habitat suitable for rearing.



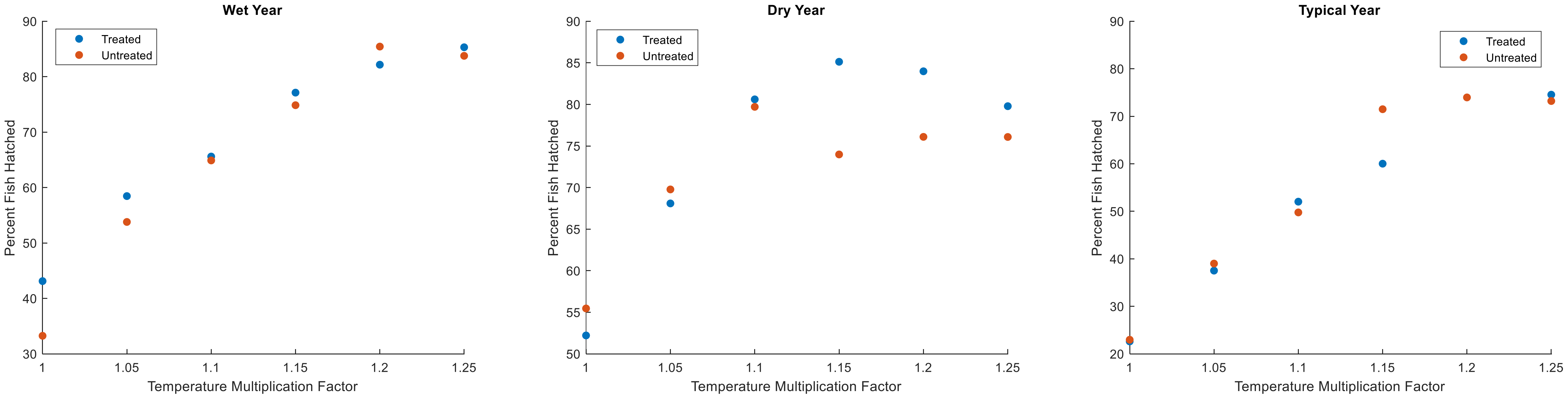
Future Climate Scenarios

How does Stage 0 impact juvenile length and abundance among different hydrological years?

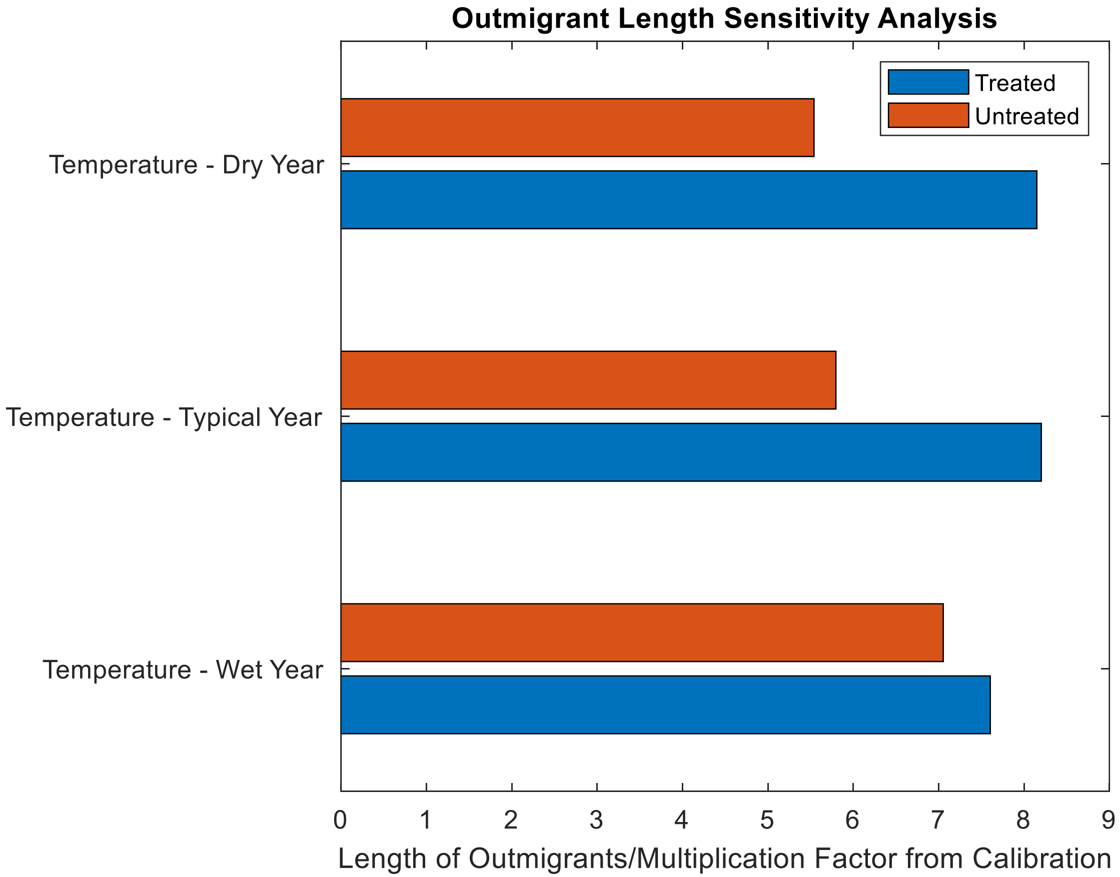
How do future temperatures impact number of outmigrants?



Approximations of historic stream temperature may not be ideal temperatures for incubating redds.



How do future temperatures impact mean length of outmigrants?



Conclusions

01

Larger juveniles in Stage 0 site but not an increase in abundance

02

Greater rearing juveniles in Stage 0 site indicative of favorable rearing conditions

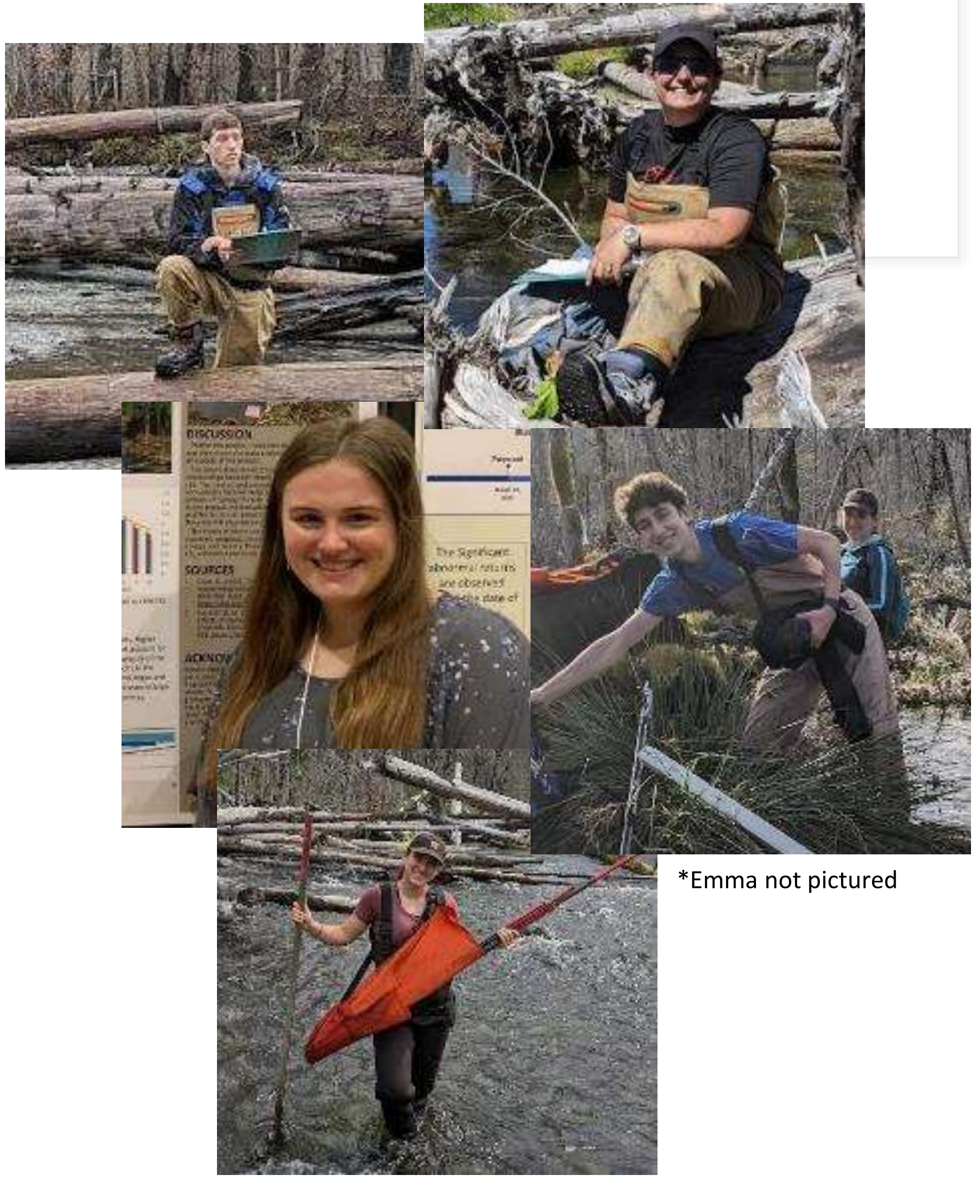
03

Increased temperatures under climate change may approach, then exceed ideal incubation temperatures

Thank You!

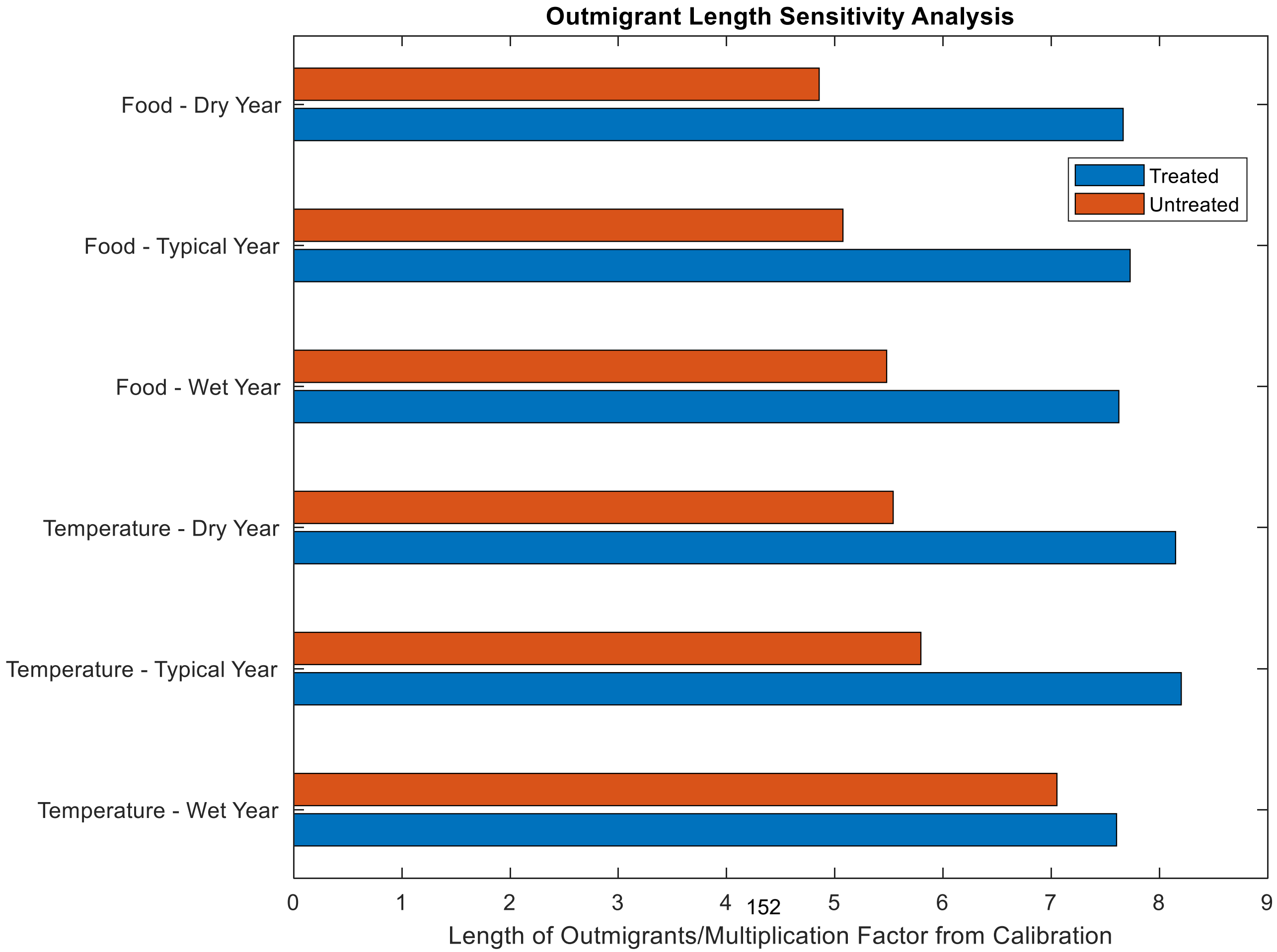
Many thanks to the following:

- USFS
- Committee: Desiree Tullos, Steve Railsback, Guillermo Giannico
- Amazing Undergraduate Researchers
    - Ceiba, Jonah, Bryce, Adalgisa, Abby, & Emma



*Emma not pictured

Sensitivity Analyses for food and temp



Streams Across Landscapes (SAL)

A NEW METHOD FOR MODELING STREAM FLOW IN SMALL WATERSHEDS

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ARCATA, CALIFORNIA, USA

JULIA PETRESHEN

THOMAS GAST & ASSOCIATES ENVIRONMENTAL CONSULTANTS

ARCATA, CALIFORNIA, USA

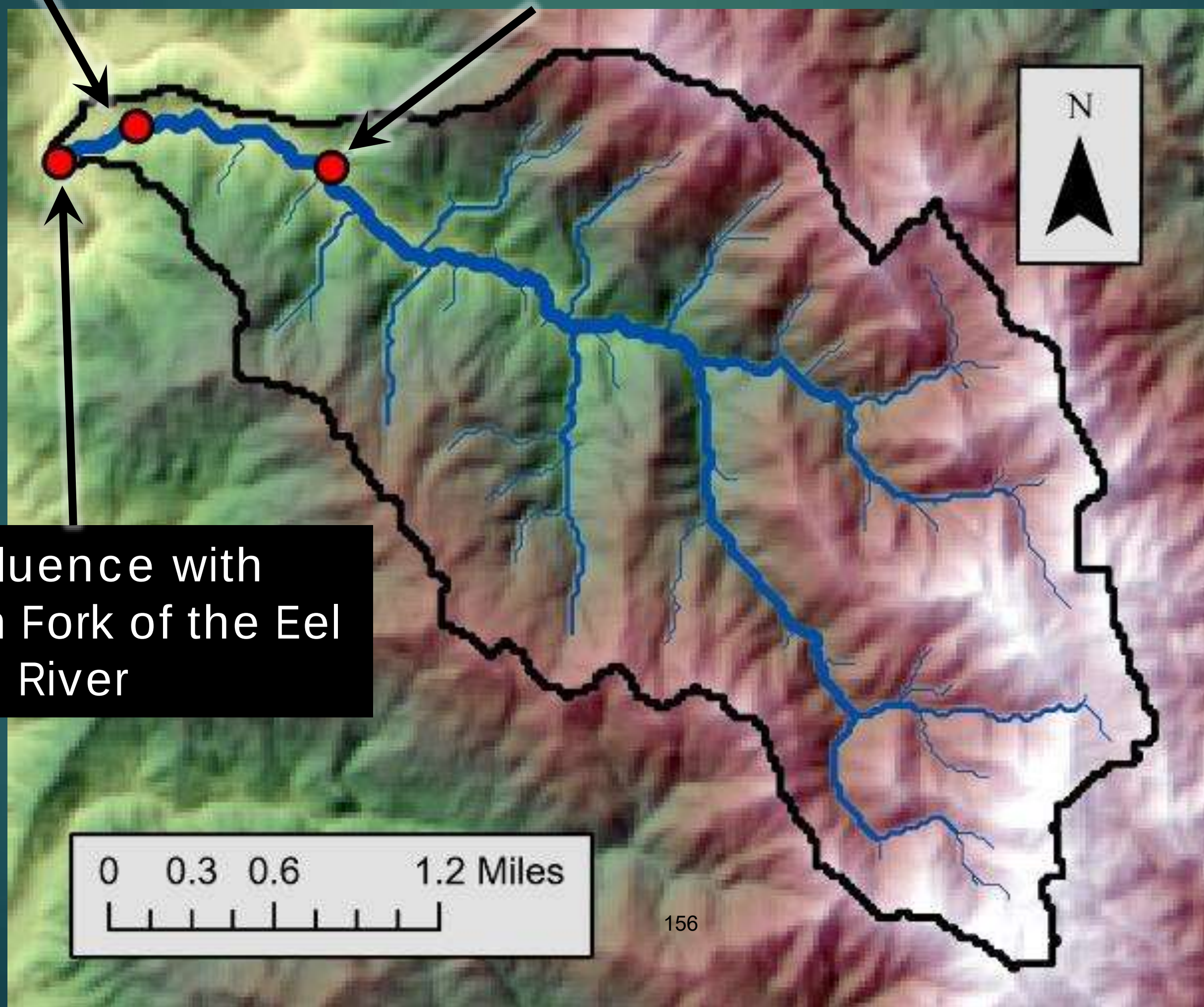
Background & Goals

- The amount of water, and it's characteristics, are key to determining emigration, spawning, rearing, and out migration potential for salmonids.
- Modeling allows us to recreate historic stream flow and predict future stream flow.
- Existing stream flow modeling approaches require calibration to a stream flow gauge.
  - Not always available
  - Shifts model off reality unless diversions are accounted for
- Goals are to create a modeling approach that:
  - Does not require calibration to a stream gauge hydrograph
  - Includes impacts of forest management, diversions and lakes

Eel River Watershed

- Wiya't in the Wiyot language.

Elder Creek Watershed



Approach

- Created within BlueSpray
  - GIS application originally from SchoonerTurtles, Inc.
  - Combines open source libraries with custom code to create a flexible development environment
- Java based application
  - Runs on MS-Windows, UNIX, Linux, Mac
- Standard file formats for inputs and outputs
  - TIFF, Shapefiles, CSVs, etc.
- Outputs CSV files and web pages to visualize results

Data

- Digital Elevation Model (DEM)
  - 30 meters works well
  - All cells within the watershed, except lakes, flow to the pour point
- Pour Point for Watershed
- Weather Data
  - Precipitation
  - Required for Evaporation and Transpiration (ET): Wind, Temp, Humidity
    - Solar Radiation: provided or automatic
- Stream Gauge Data (optional)
- Cover Data (optional)
  - Parameters provided for National Land Cover Data (NLCD) types
- Soil Data (optional)
  - BlueSpray includes features to create soil layers from SSURGO polygons

Flexibility

- Any spatial resolution:
  - 30 meters seems to work well
- Weather and discharge input data at 5 minutes to daily
- Any number & depth of soil layers:
  - 4-6 layers for first 2 meters
- Options for dominate soil type or averaged soil values, etc.

Time	Air Temp	Rainfall	Humidity	Solar Radiation	Wind Speed
1/1/2022 0:00	-0.842	0	94	0	0.501
1/1/2022 0:10	-0.881	0	94.1	0	0.343
1/1/2022 0:20	-0.869	0	94.2	0	0.723
1/1/2022 0:30	-0.802	0	94.1	0	0.779
1/1/2022 0:40	-0.792	0	94.1	0	0.328
1/1/2022 0:50	-0.769	0	94.1	0	0.017
1/1/2022 1:00	-0.787	0	94	0	0.397
1/1/2022 1:10	-0.841	0	93.9	0	0.183
1/1/2022 1:20	-0.977	0	93.7	0	0.258
1/1/2022 1:30	-0.978	0	93.6	0	0.146
1/1/2022 1:40	-0.915	0	93.8	0	0.227
1/1/2022 1:50	-0.906	0	93.7	0	0.209
1/1/2022 2:00	-0.968	0	93.3	0	0
1/1/2022 2:10	-1.035	0	93.1	0	0.069
1/1/2022 2:20	-1.096	0	92.9	0	0.022
1/1/2022 2:30	-1.136	0	92.8	0	0.033
1/1/2022 2:40	-1.15	0	92.8	0	0.339
1/1/2022 2:50	-1.191	0	93	0	0.231
1/1/2022 3:00	-1.171	0	93.1	0	0.014
1/1/2022 3:10	-1.199	0	93.2	0	0.174
1/1/2022 3:20	-1.21	0	93.3	0	0.376
1/1/2022 3:30	-1.243	0	93.3	0	0.789
1/1/2022 3:40	-1.282	0	93	0	0.455
1/1/2022 3:50	-1.239	0	92.8	0	0.113
1/1/2022 4:00	-1.268	0	92.6	0	0.037
1/1/2022 4:10	-1.272	0	92.3	0	0.257
1/1/2022 4:20	-1.311	0	91.9	0	0.368
1/1/2022 4:30	-1.303	0	91.7	0	0
1/1/2022 4:40	-1.365	0	91.4	0	0.018
1/1/2022 4:50	-1.429	0	91.3	0	0.18
1/1/2022 5:00	-1.559	0	91.6	0	0.39
1/1/2022 5:10	-1.66	0	91.4	0	0.063
1/1/2022 5:20	-1.624	0	91.5	0	0.293
1/1/2022 5:30	-1.583	0	91.9	0	0.027
1/1/2022 5:40	-1.698	0	91.6	0	0.069
1/1/2022 5:50	-1.674	0	91.7	0	0.292
1/1/2022 6:00	-1.623	0	91.7	0	0.28
1/1/2022 6:10	-1.682	0	91.7	0	0.181
1/1/2022 6:20	-1.799	0	91.6	0	0.089
1/1/2022 6:30	-1.817	0	91.9	0	0.037

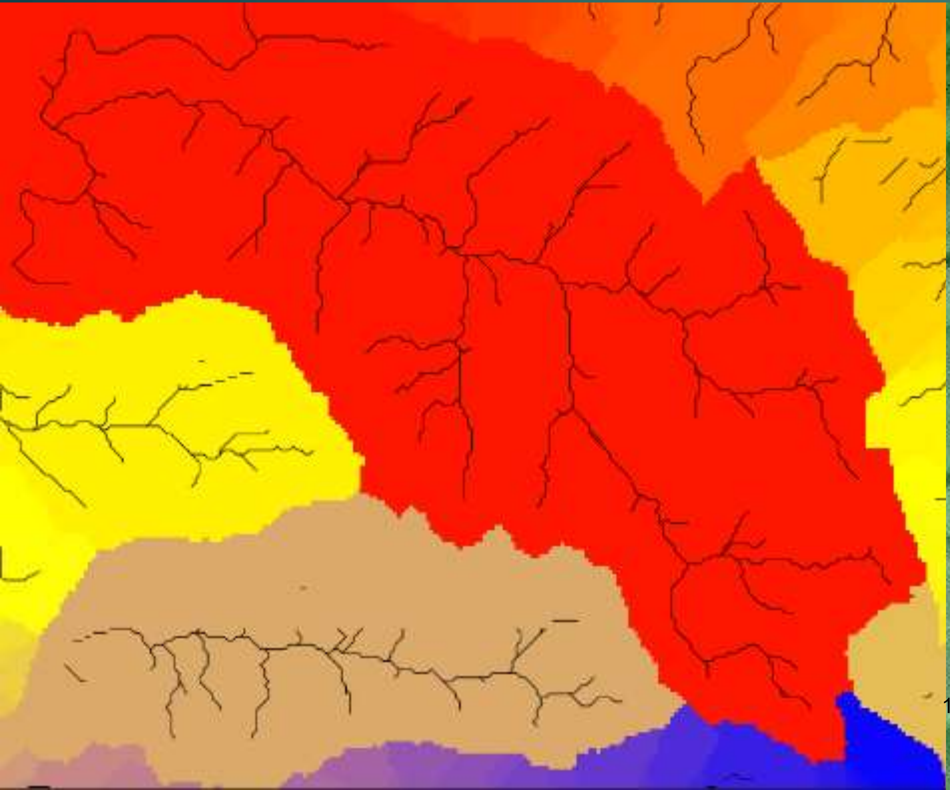
Elder Creek Model

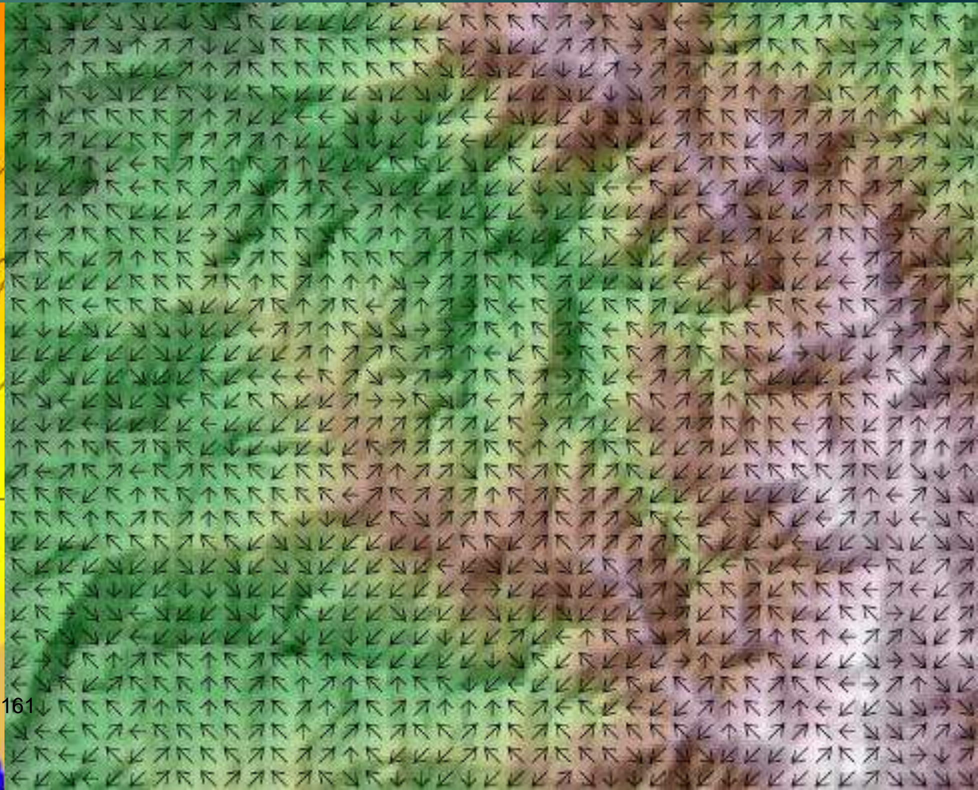
- Part of the Angelo Reserve
- Complete weather data at 15 minute intervals
  - Precip, Temp, Wind Speed, Humidity, Solar Radiation
- USGS stream gauge at 10 minute intervals resampled to 15 minute
- DEM from USGS
- Cover data from NLCD
- Soil Data from SSURGO
- Field work for characterizing the channel

Water Transforms

- Flow Direction
- Pour Points
- Watersheds
- Accumulation

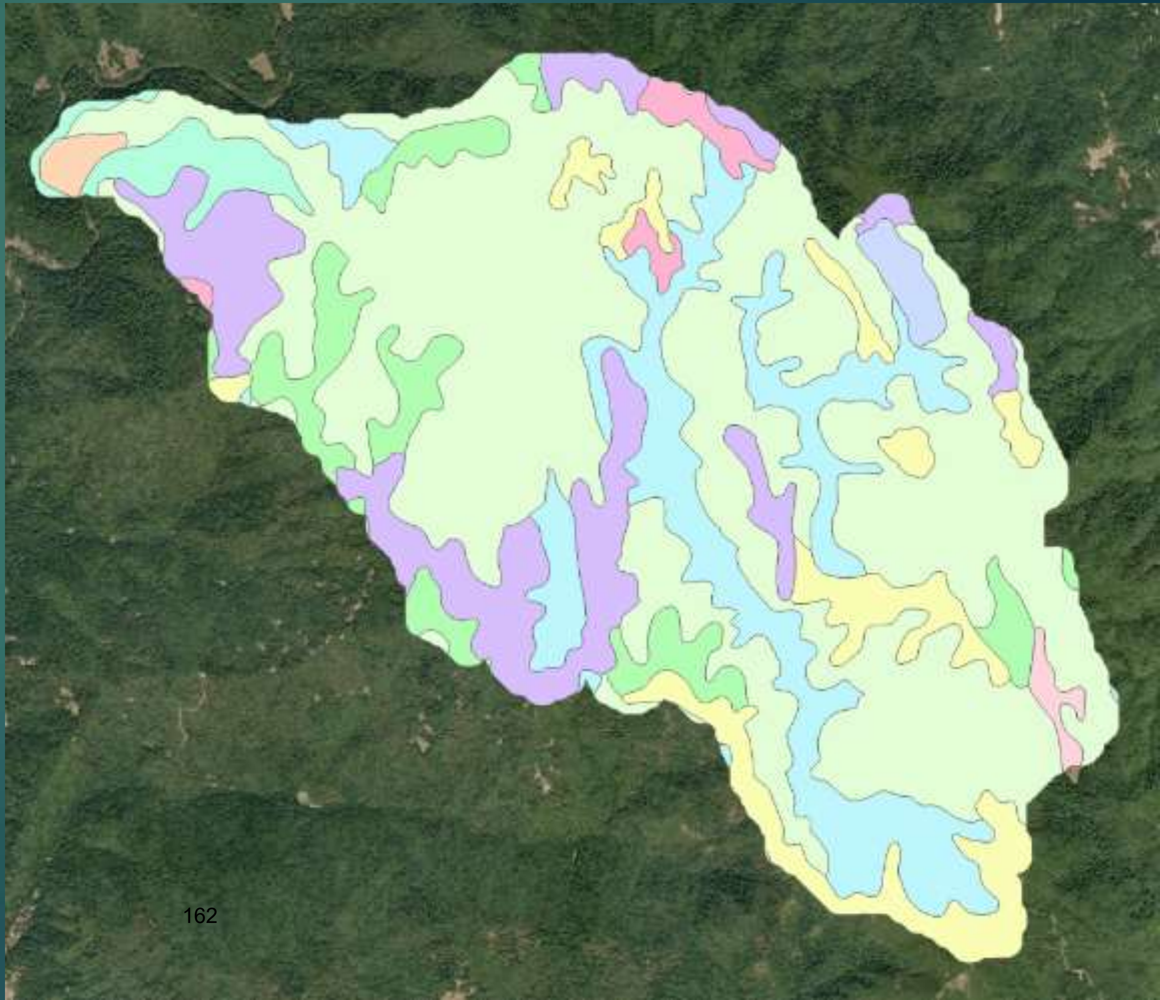
- Create a DEM where all pixels flow to a pour point



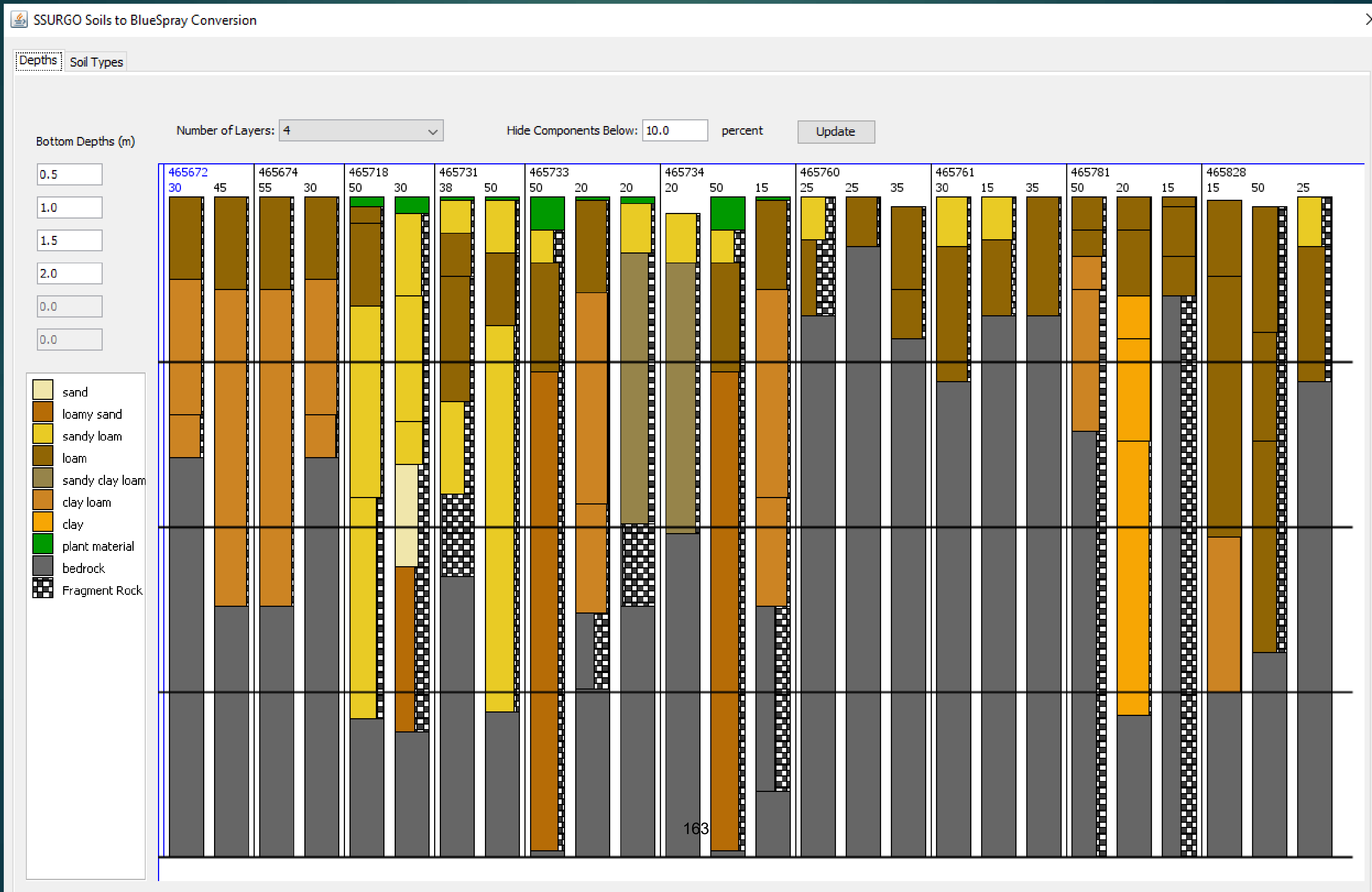


Soil Data from SSURGO

- Each Polygon contains a Map Key
- Each Map Key is associated with a number of components
- Each component has unique soil horizons
- Each horizon defines the soil type and soil parameters

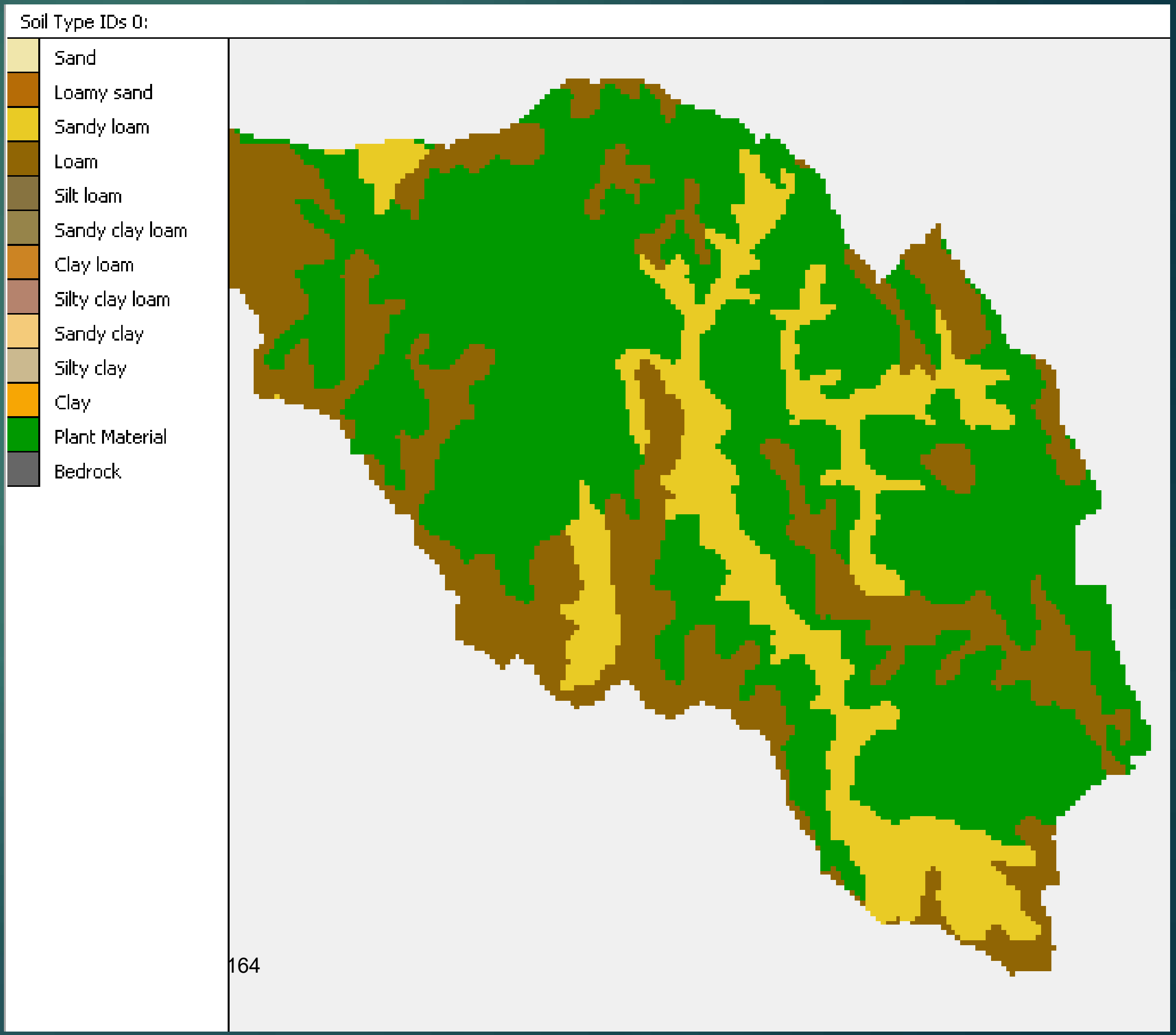


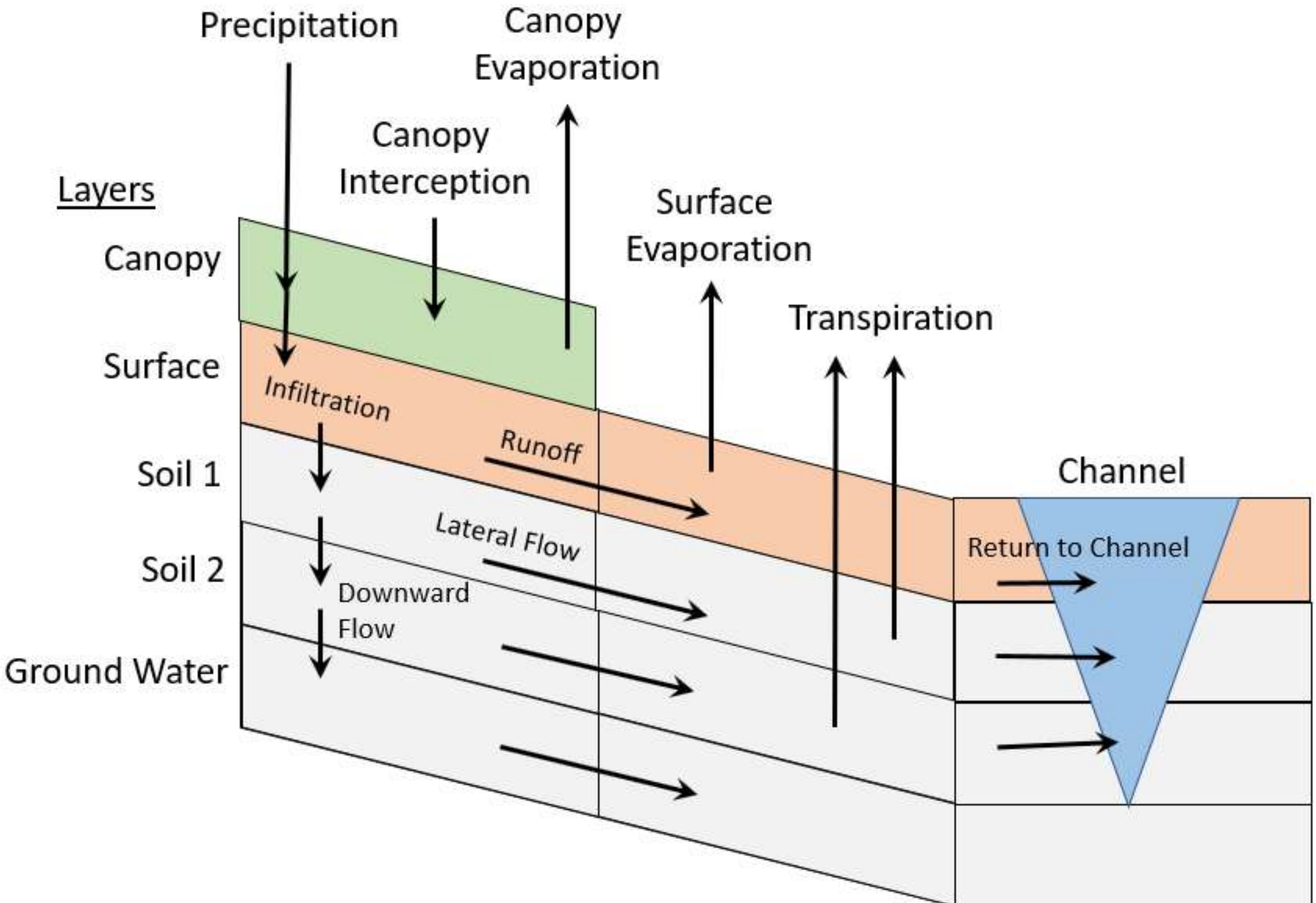
SSUGRO Layer Tool



SSURGO Soil Type Data

- Each soil type has different properties for moving water
- First soil layer is typically dominated by plant material

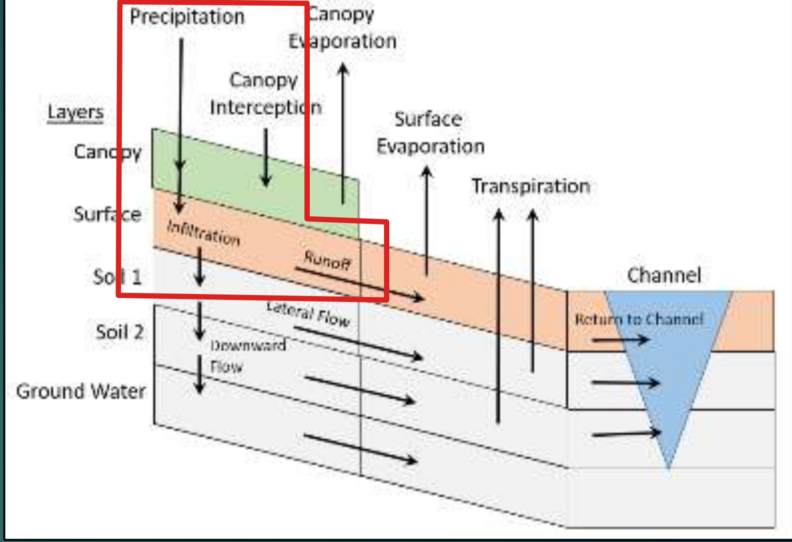



Precipitation
Canopy Evaporation
Canopy Interception
Layers
Canopy
Surface
Soil 1
Soil 2
Ground Water
Surface Evaporation
Transpiration
Infiltration
Runoff
Lateral Flow
Downward Flow
Channel
Return to Channel

Routing Water

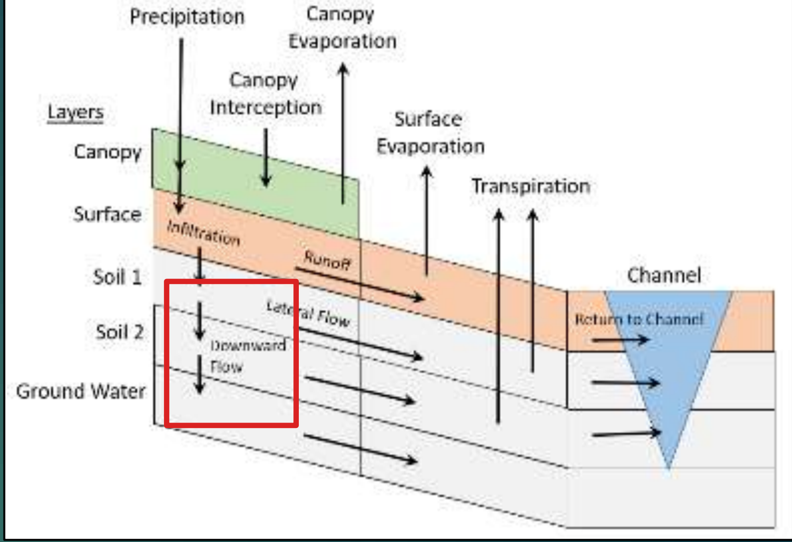
- Precipitation
  - Evenly distributed across watershed
- Canopy Interception
  - Canopy Interception = LAI * InterceptionFractionForLAI + SAI * InterceptionFractionForSAI (BROOK90)
- Soil Infiltration
  - K Saturation or K(Theta)
- Remainder -> Surface flow
- Surface flow:
  - Uniform-Flow Velocity (Dingman, 2015)

$$V = \frac{\sqrt[\frac{2}{3}]{D}}{n} * \sqrt{S}$$



USGS

Downward Flow



- Darcy's law for vertical unsaturated flow
  - q = Flow rate (distance /time)
  - $K(\theta)$ = Soil conductivity (distance/time)
  - $\psi\ (\theta)$ = Tension head (distance)
  - dx = Distance water moves

$$q = K(\theta) - K(\theta)\frac{d\psi(\theta)}{dx}$$

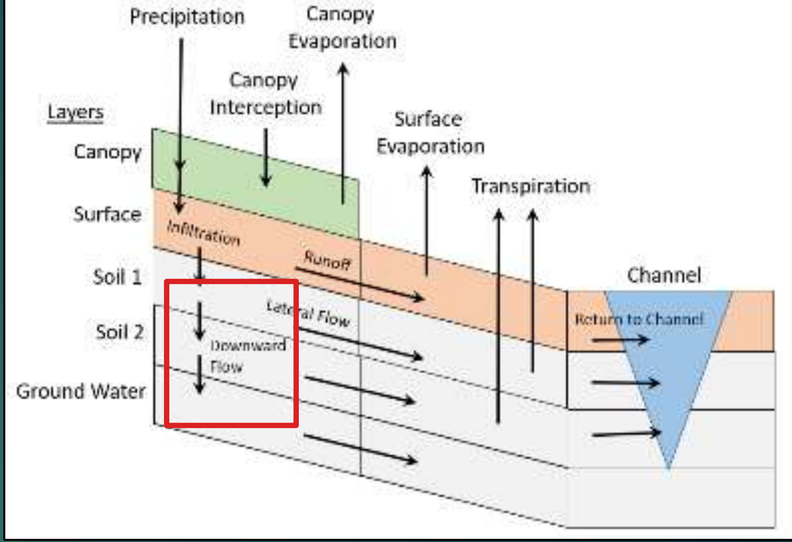
- Campbell's equations for tension head and conductivity
  - $\psi_{ae}(\theta)$ = Air Entry Tension
  - $K_{Sat}(\theta)$ = Soil conductivity when saturated
  - $\frac{\theta}{\phi}$ = Saturation
  - b = Parameter based on soil type

$$\psi(\theta) = |\psi_{ae}| * \left(\frac{\phi}{\theta}\right)^{b}$$

$$K(\theta) = K_{Sat} * \left(\frac{\theta}{\phi}\right)^{2*b+3}$$

- Dingman, 2015

Downward Flow



- Log weighted average of conductivity (BROOK90)
  - T_i= Thickness of layer
  - K_i= Conductivity of layer

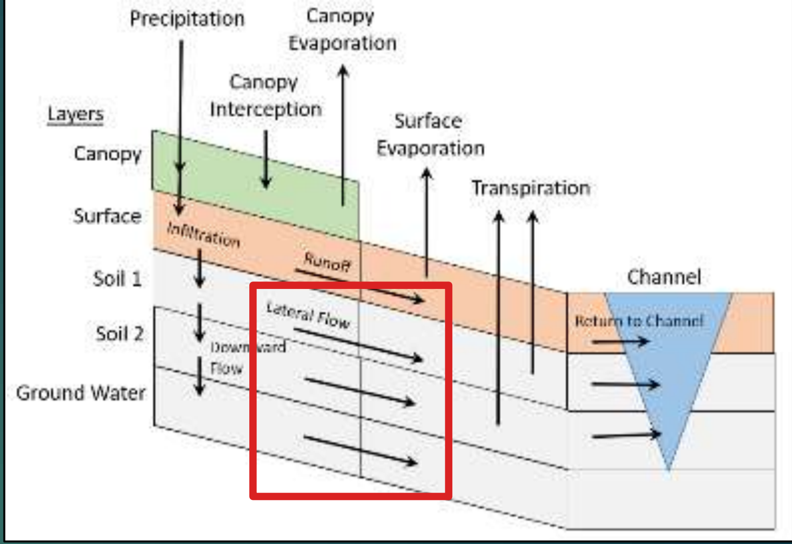
$$K_{Mean} = e^{\frac{T_i * \log(K_i) + T_{i+1} * \log(K_{i+1})}{T_i + T_{i+1}}}$$

- Darcy's law for vertical unsaturated flow
  - q = Flow rate (distance /time)
  - ψ_i= Tension head for each layer

$$Distance = \frac{T_i + T_{i+1}}{2}$$

$$q = K_{Mean} - K_{Mean} * \frac{\psi_i(\theta_i) - \psi_{i+1}(\theta_{i+1})}{Distance}$$

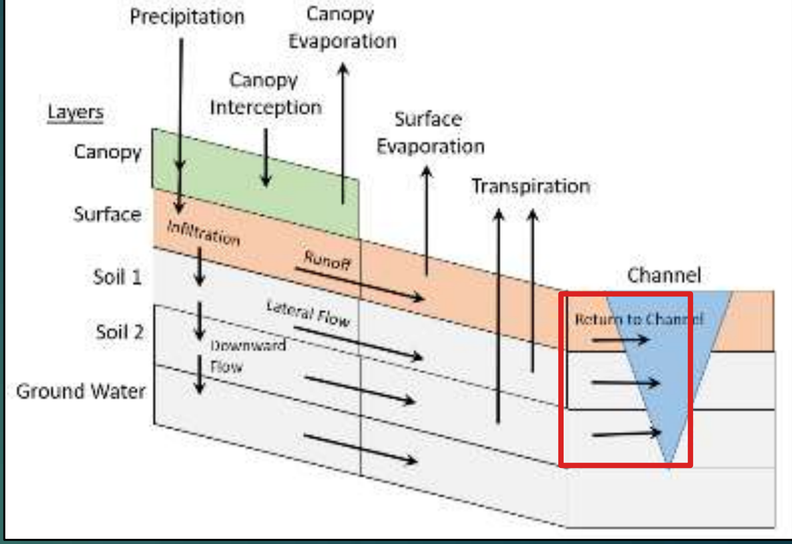
Lateral Flow



- Darcy’s law for unsaturated flow
  - dz = Vertical distance
  - dx = Distance water moves

$$q = -K(\theta)\frac{dz}{Distance} - K(\theta)\frac{d\psi(\theta)}{dx}$$

Return to Channel



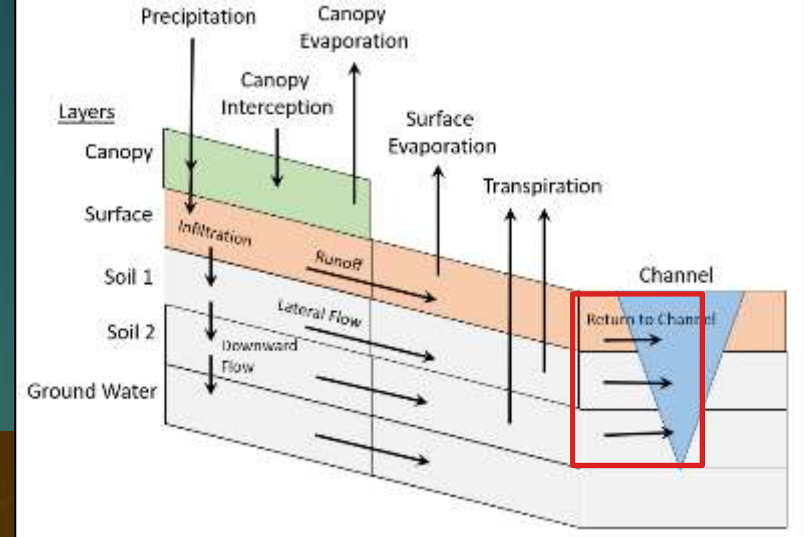
- Field measurements provide depth, and locations for:

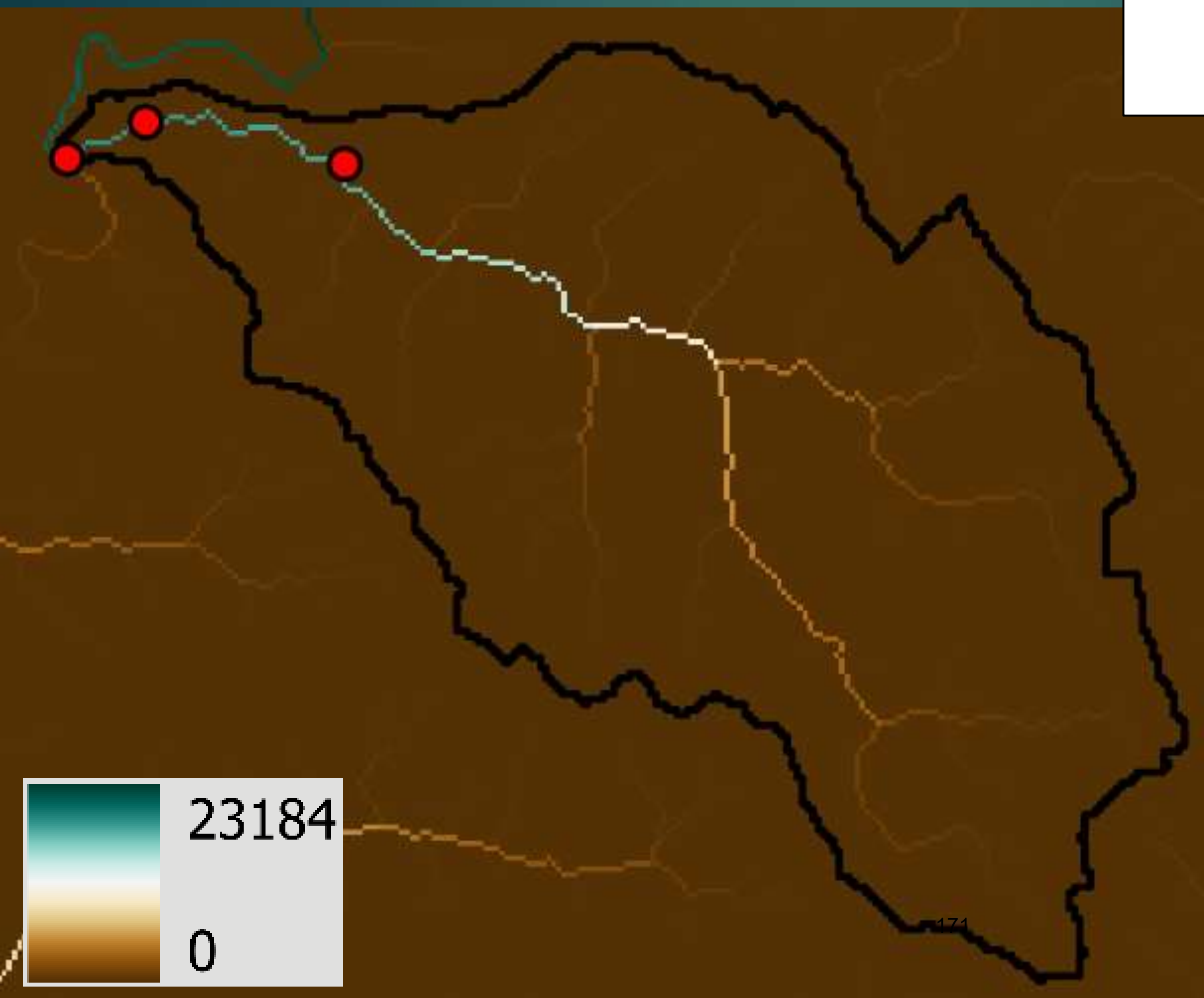
$$D = a * A^b$$

- Where D is depth of the channel, A is the accumulated area at the same location, and a and b are coefficients (Frasson et. al. 2019).
- Compute the minimum accumulation for each soil layer to be exposed to the stream channel.

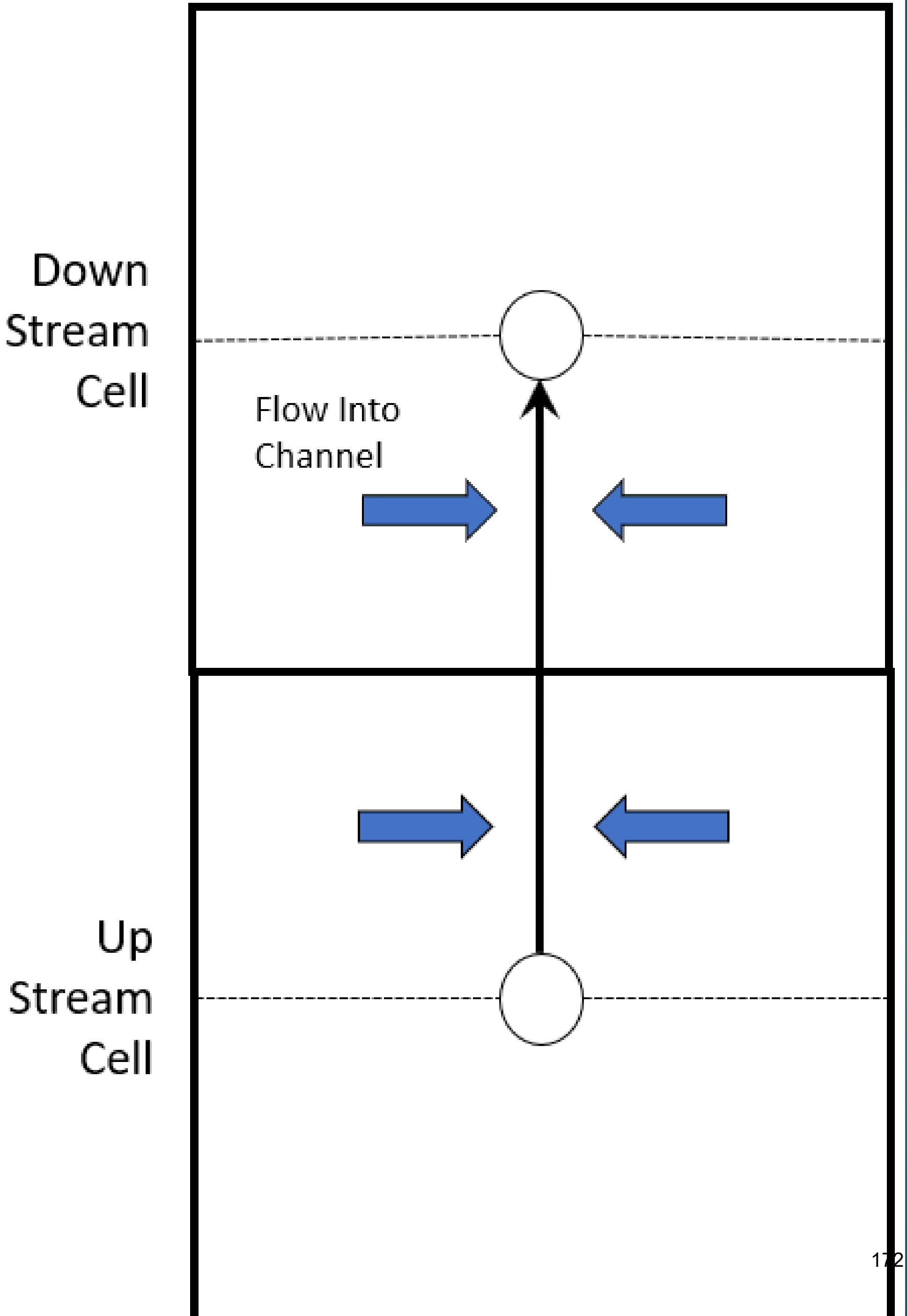
$$Minimum\ Accumulation_{SL} = \sqrt[b]{\frac{Depth_{SL}}{a}}$$

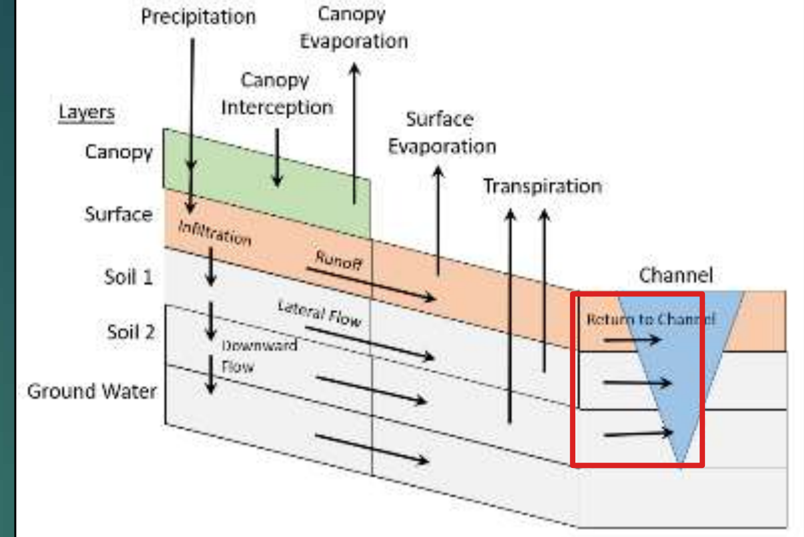
Accumulation





- Each cell contains the area that it drains.

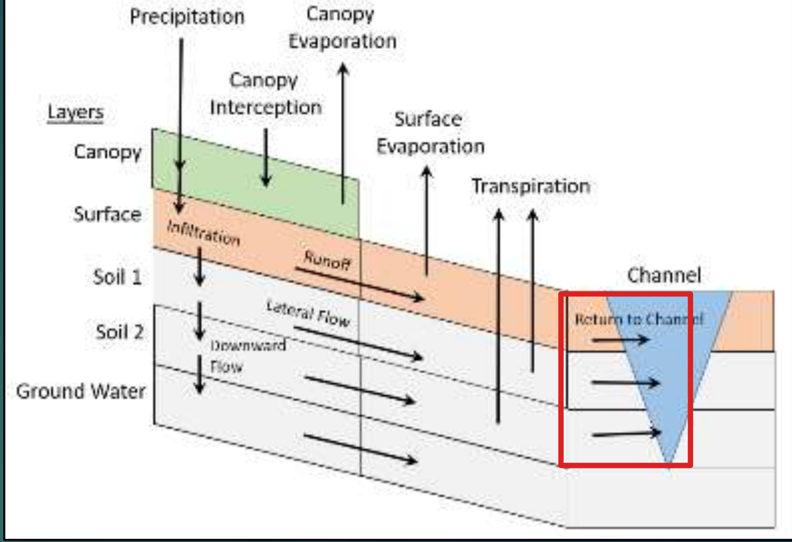




Return to Channel

- Water flows from cells into the stream channel

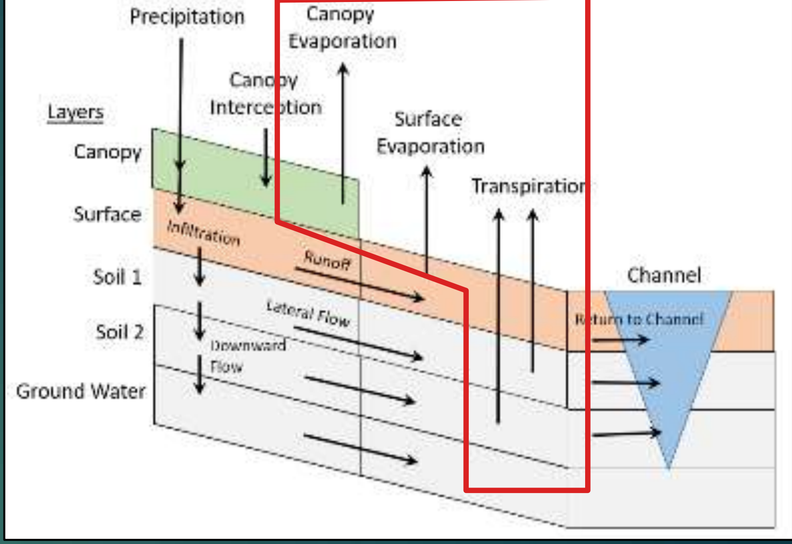
Channel Flow



- Uniform-Flow Velocity (Dingman, 2015)

$$V = \frac{\sqrt[\frac{2}{3}]{D}}{n} * \sqrt{S}$$

Evapotranspiration



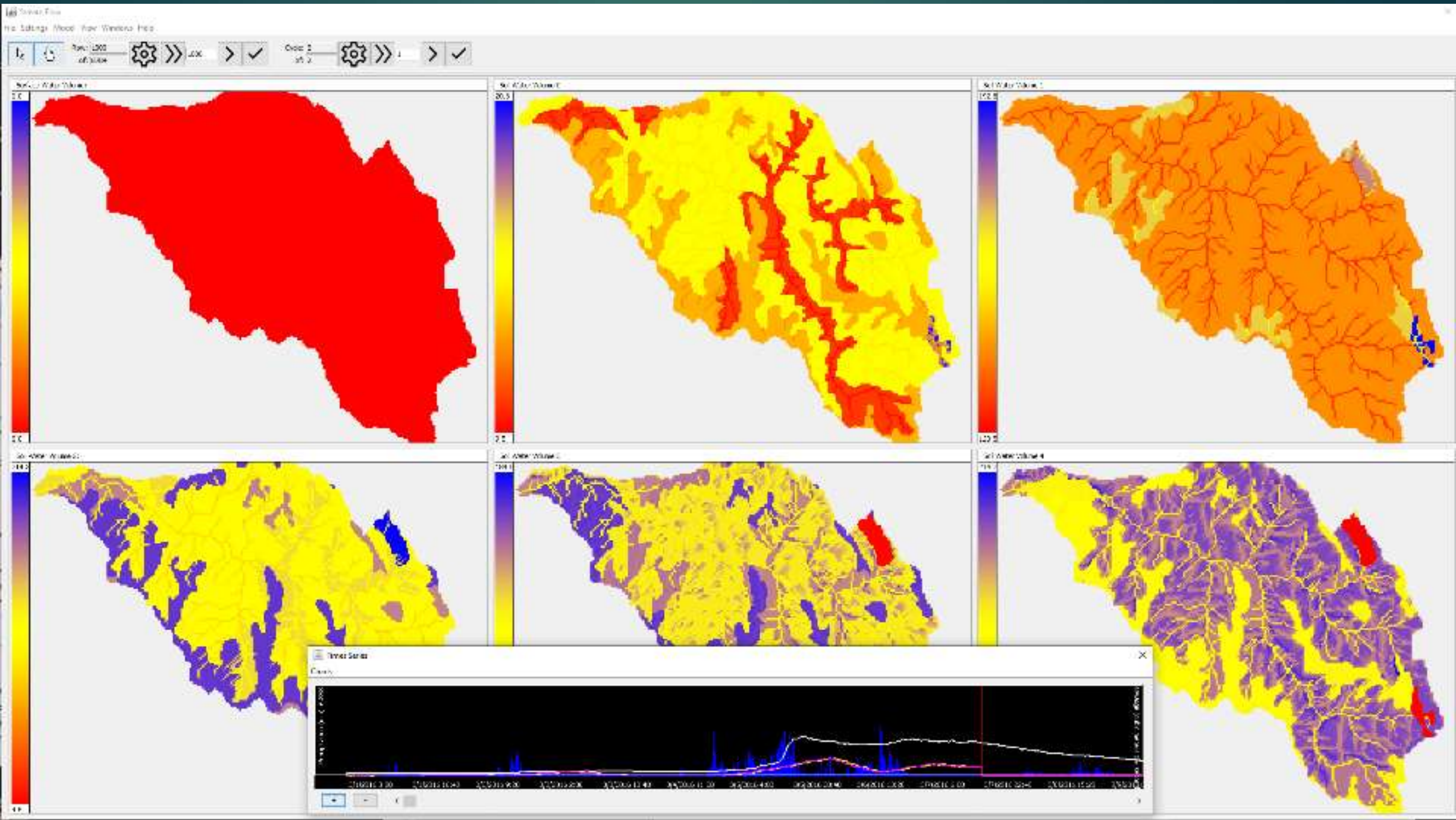
- Transpiration is computed based on the Penman Monteith equation (Dingman, 2015)

$$Transpiration = \frac{\Delta \cdot (K+L) + \rho_a \cdot c_p \cdot C_{at} \cdot e_a^* \cdot (1 - RH(z_m))}{\rho_w \cdot \lambda_v \cdot [\Delta + \gamma \cdot (1 + \frac{C_{at}}{C_{can}})]}$$

- Evaporation also based on Penman Monteith equation (Dingman, 2015)

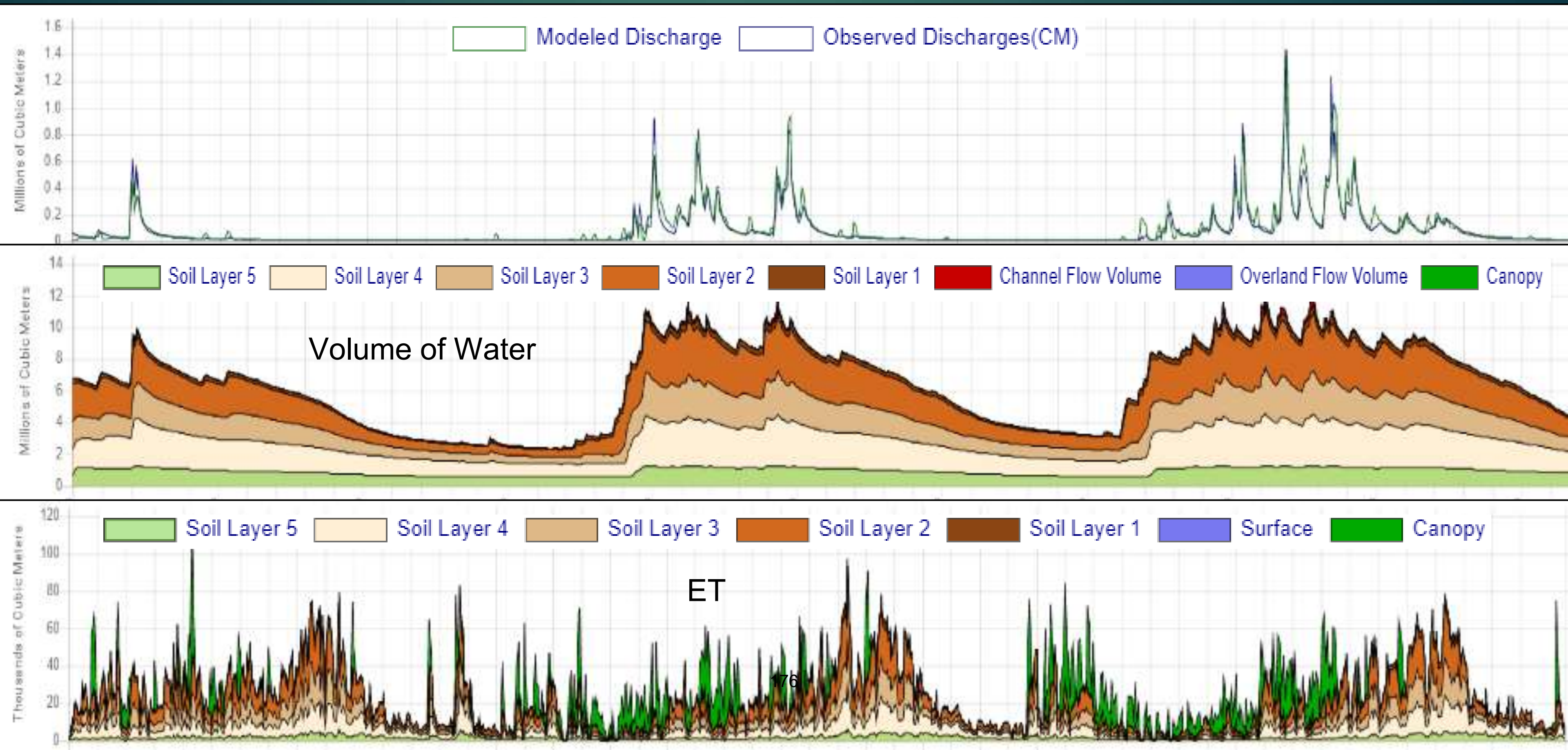
$$Evaporation = \frac{\Delta \cdot (K+L) + \rho_a \cdot c_p \cdot C_{at} \cdot e_a^* \cdot (1 - RH(z_m))}{\rho_w \cdot \lambda_v \cdot [\Delta + \gamma]}$$

Main Model Dialog



Results

- Best Nash–Sutcliffe Model Efficiency Coefficient:
  - 0.8764
  - For 2015 through 2017

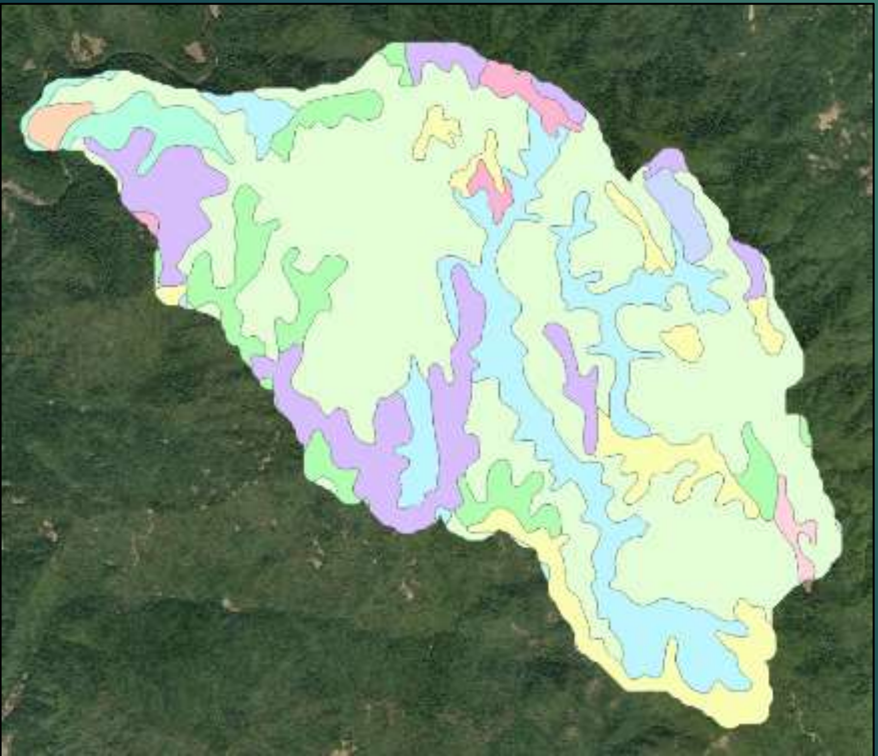


Additional features

- Diversions
  - Move water from streams and lakes to surface
- Modifications
  - Change rasters at any point in time
  - Simulate harvests, plantings
- Lakes
  - Simulate storage and evaporation

Uncertainty

- 30 meter cells
- Soil Water flow
    - SSUGRO polygons
    - Thickness of layers
- Cover data



Next Steps

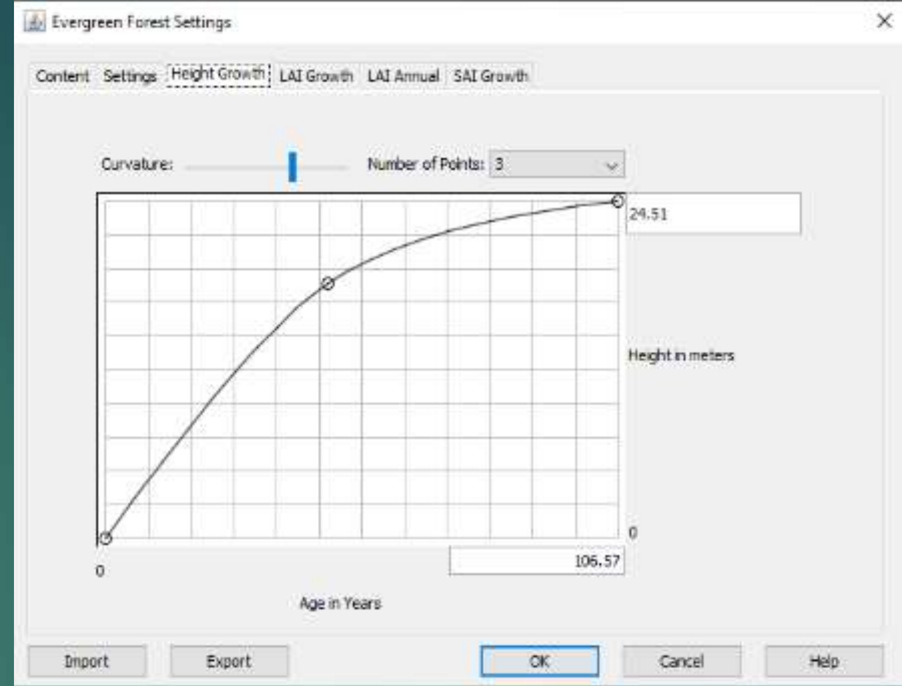
- Data:
  - Developing cover type based on LiDAR and NAIP data for entire Eel River watershed
  - Set of watersheds for testing including relatively dry watersheds
- Additional Future Features:
  - Macropores
  - Springs (upwelling)
  - Snow?
  - Fog absorption?
  - Ground water level?
- Testing, documentation improvements, etc.

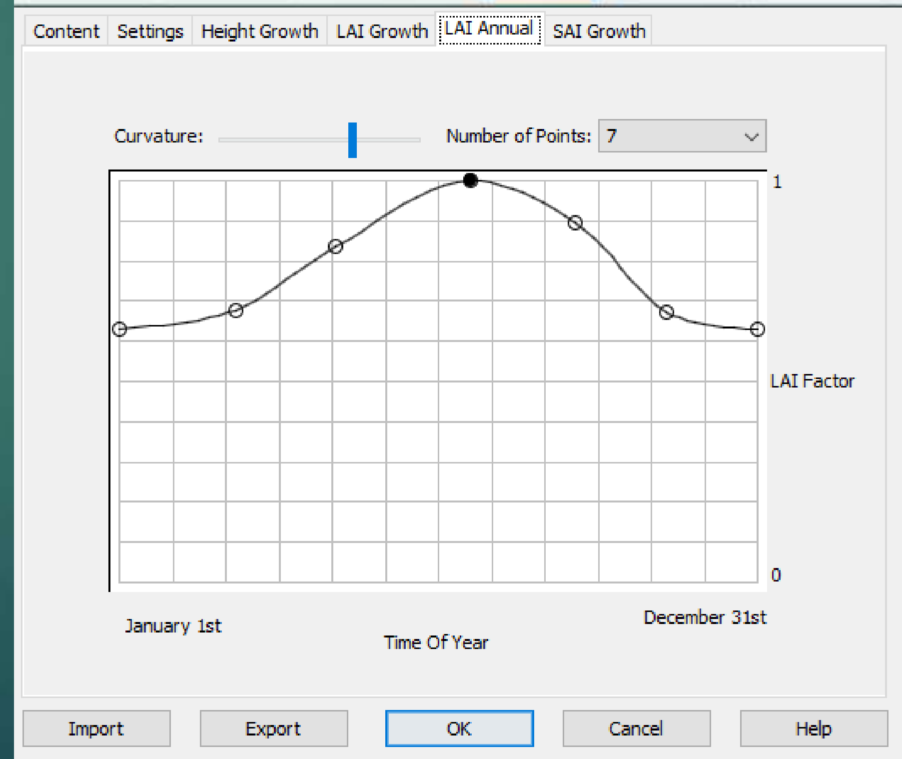
Acknowledgements

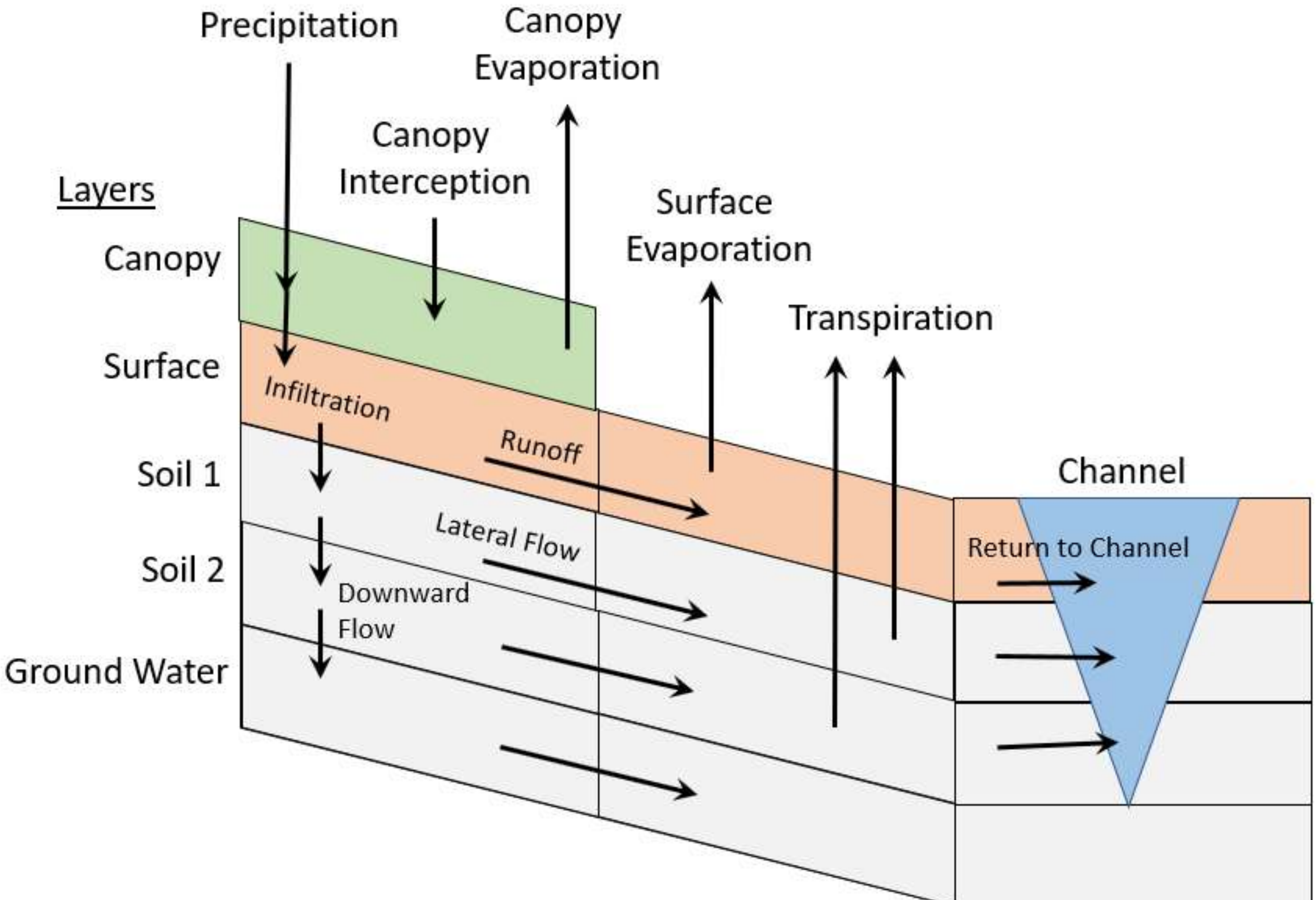
- Thanks to:
  - Eel River Recovery Project, State Coastal Commission for funding
  - Dr. Lawrence Dingman for the textbook Physical Hydrology
  - Angelo Coast Range Reserve:
    - University of California Natural Reserve System
  - VELMA team at the EPA
- Example Outputs:
  - http://gsp.humboldt.edu/websites/watersheds/ElderCreek/
- Web Site (under construction):
  - streamsacrosslandscapes.org
- Questions?
  - James.graham@humboldt.edu

Cover Types

- Based on National Land Cover Types
- Height: LEMMA AGE_DOM converted to height using growth curves
- LAI from Landsat using Google Earth Engine (Kang et. All., 2021
- Leaf Area Index (LAI) Annual curves : Landsat analyzed for 2 years for annual
- Stem Area Index (SAI): LEMMA BAH_GE_3

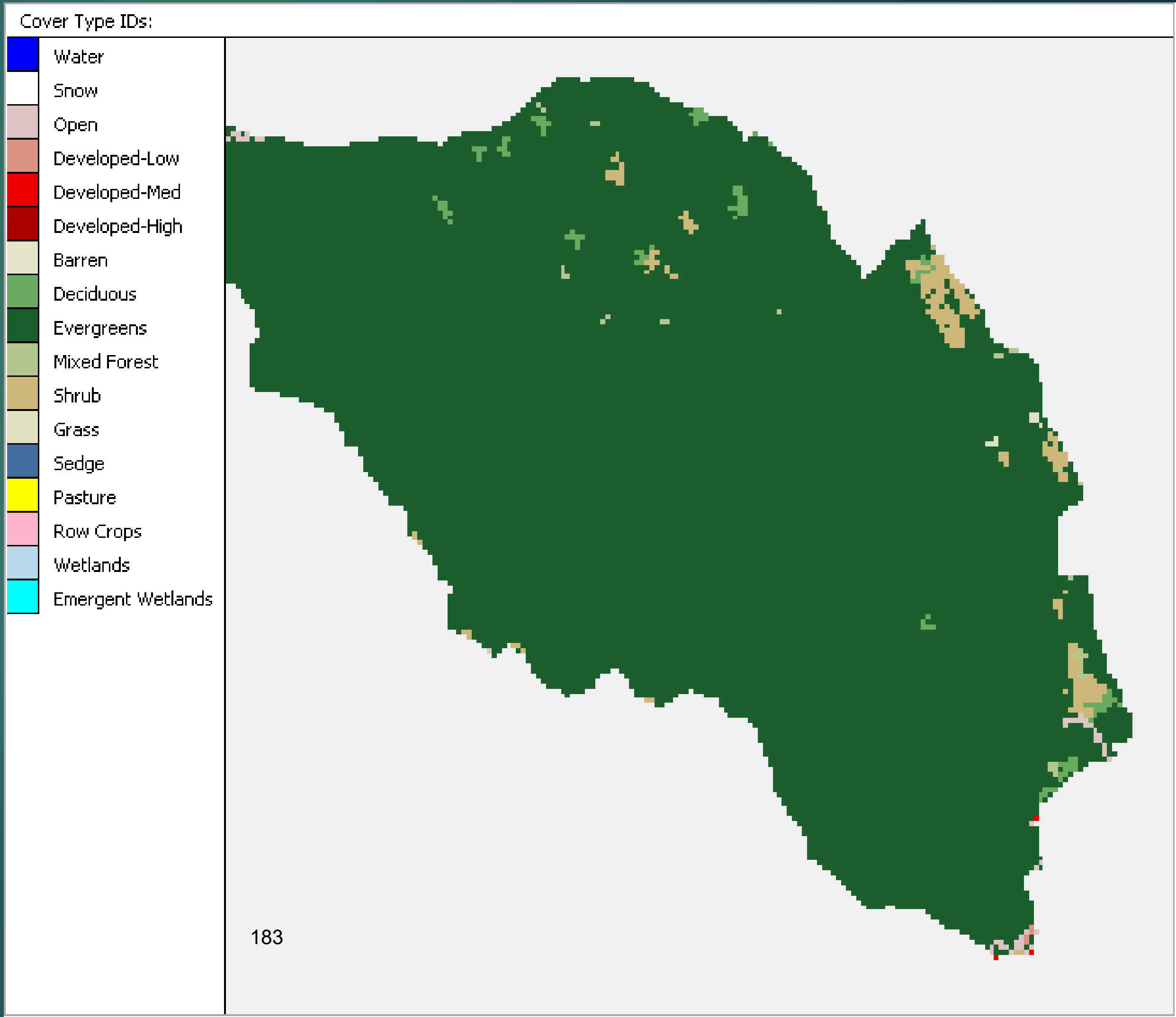





Precipitation
Canopy Evaporation
Canopy Interception
Layers
Canopy
Surface
Soil 1
Soil 2
Ground Water
Surface Evaporation
Transpiration
Infiltration
Runoff
Lateral Flow
Downward Flow
Channel
Return to Channel

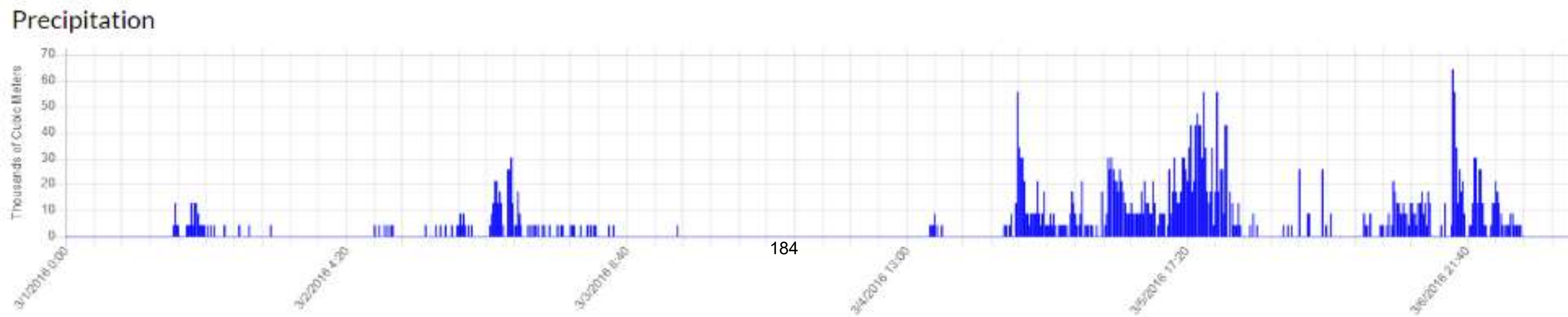
NLCD Cover Type Data

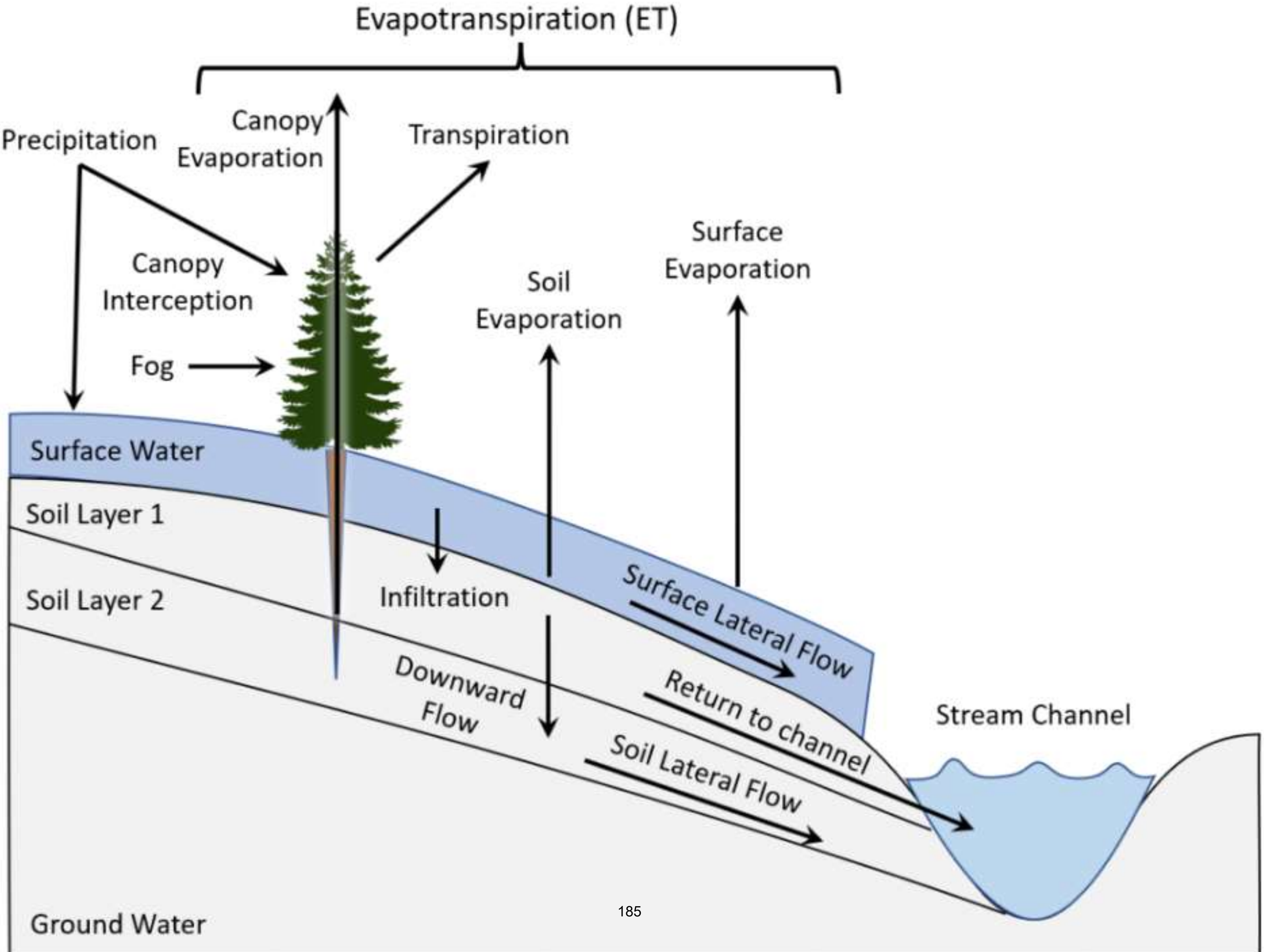
- Elder Creek is almost all evergreen forest



Weather and Discharge Data

- Tools developed to:
  - Convert RAWs format
  - Interpolate to time intervals from 5 minutes to daily




Evapotranspiration (ET)
Precipitation
Canopy Evaporation
Transpiration
Canopy Interception
Fog
Soil Evaporation
Surface Evaporation
Surface Water
Soil Layer 1
Soil Layer 2
Infiltration
Surface Lateral Flow
Downward Flow
Return to channel
Soil Lateral Flow
Stream Channel
Ground Water

Setup

- Collect channel width and height for at least 2 locations (near pour point and small tributary)
- Weather data
  - Converted to SI units
  - Converted to desired time interval
- Define pour point
- Convert DEM to have all pixels, except lakes, flow to pour point
- Define soil layers with thickness and type
- Default cover type for the entire watershed

Approach

- Cover, surface, and soil modeled with grids made up of rectangular cells
  - Cover: Cover type, volume of water
  - Surface: Volume of water
  - Soil: Soil type, volume of water
- Stream channels modeled with line segments
  - Channel dimensions are much smaller than cells and increase toward pour point
  - Requires field data to model channel width and depth

Predicting Fish Movement near Infrastructure in Different River and Reservoir Environments

R. Andrew Goodwin, PhD, PE

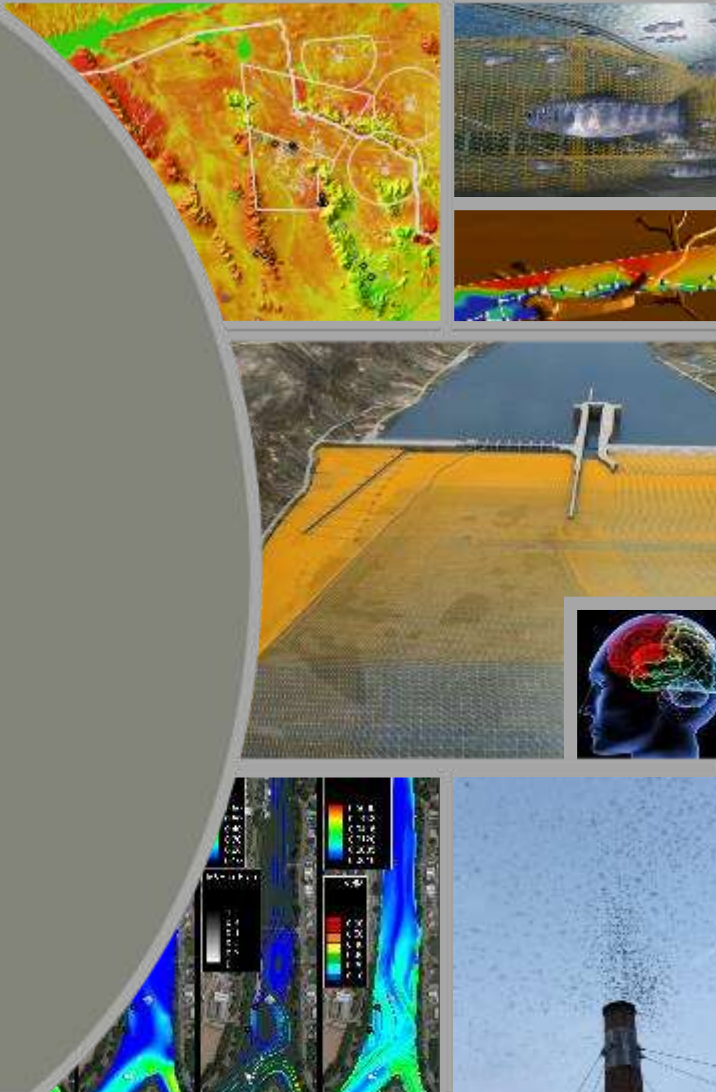
U.S. Army Engineer R&D Center

Portland, Oregon

Collaborators & Contributors

Many, many, …

27 April 2023



ERDC
Engineer Research and Development Center

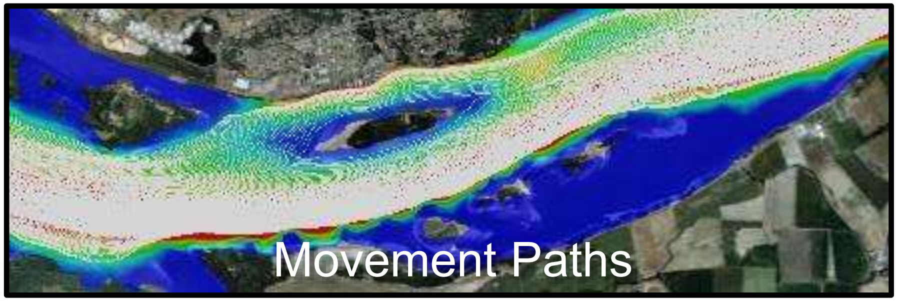
US Army Corps of Engineers

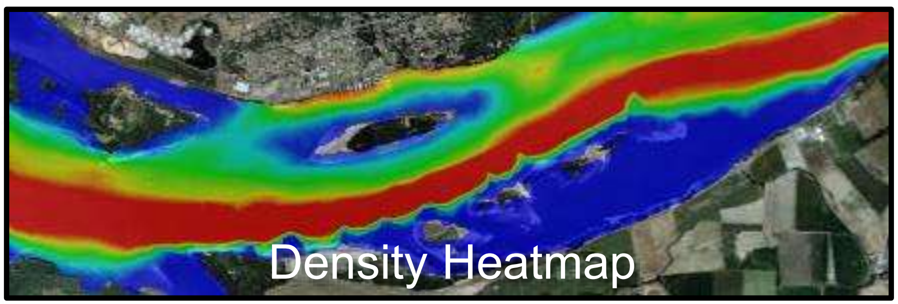
U.S. ARMY

Innovative solutions for a safer, better world

ELAM model: Peer-reviewed Fish Prediction

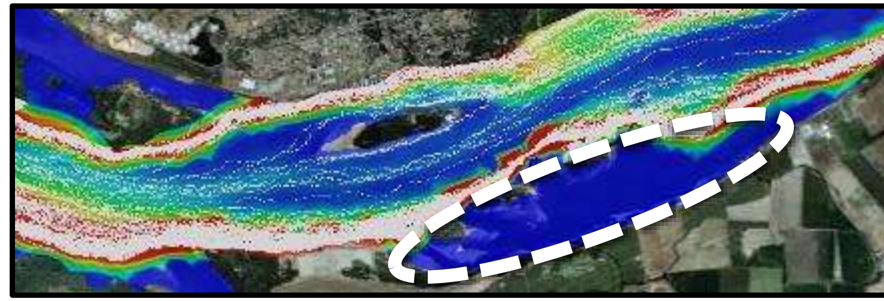
Water Flow Particles



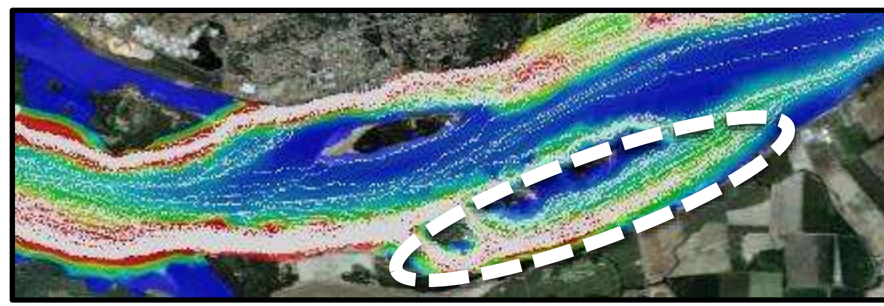


<u>Species Movement Forecast</u>

w/out engineered modification



w/engineered modification

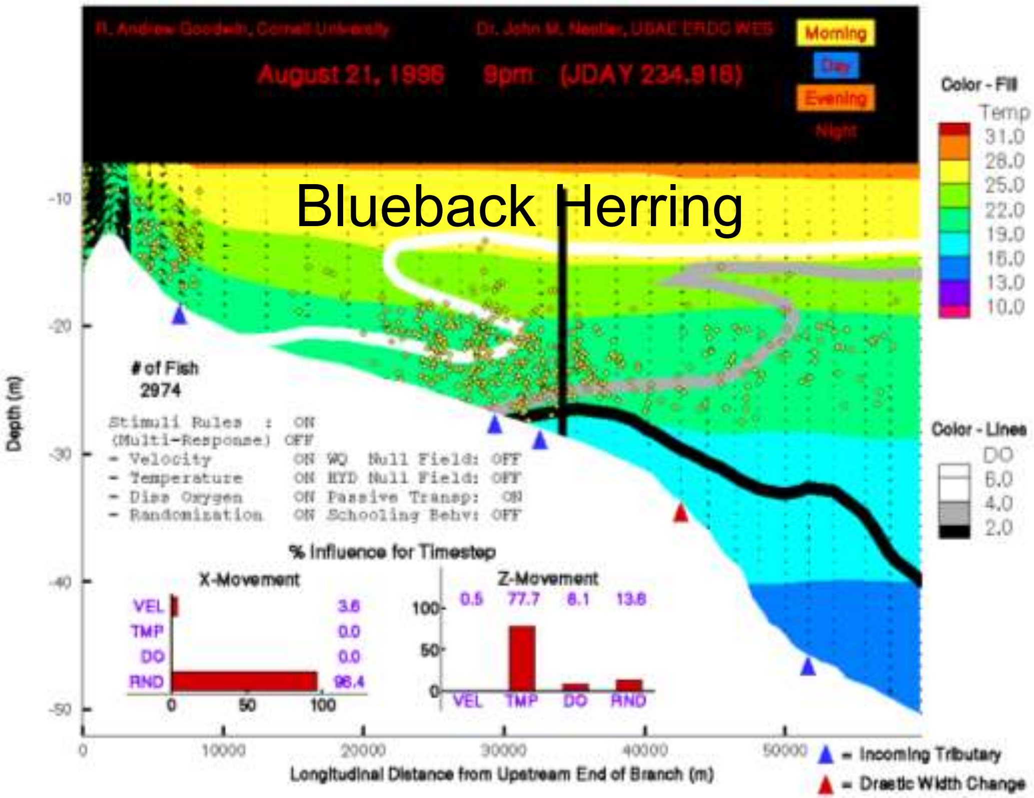


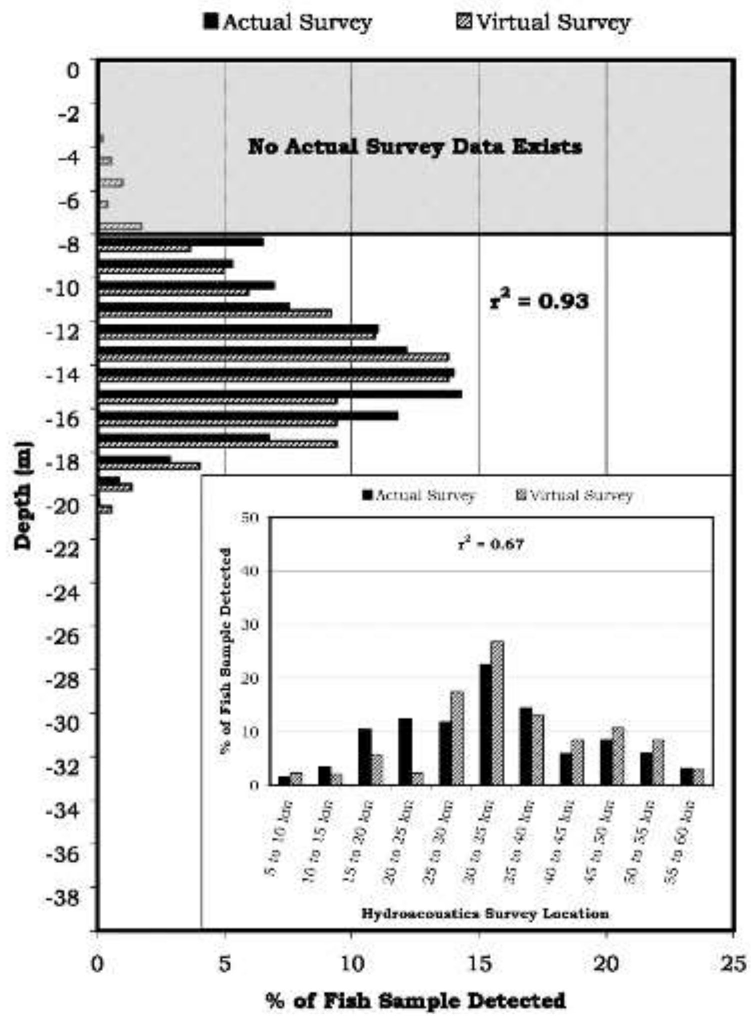
Habitat Selection / Species Distribution

~25 years ago

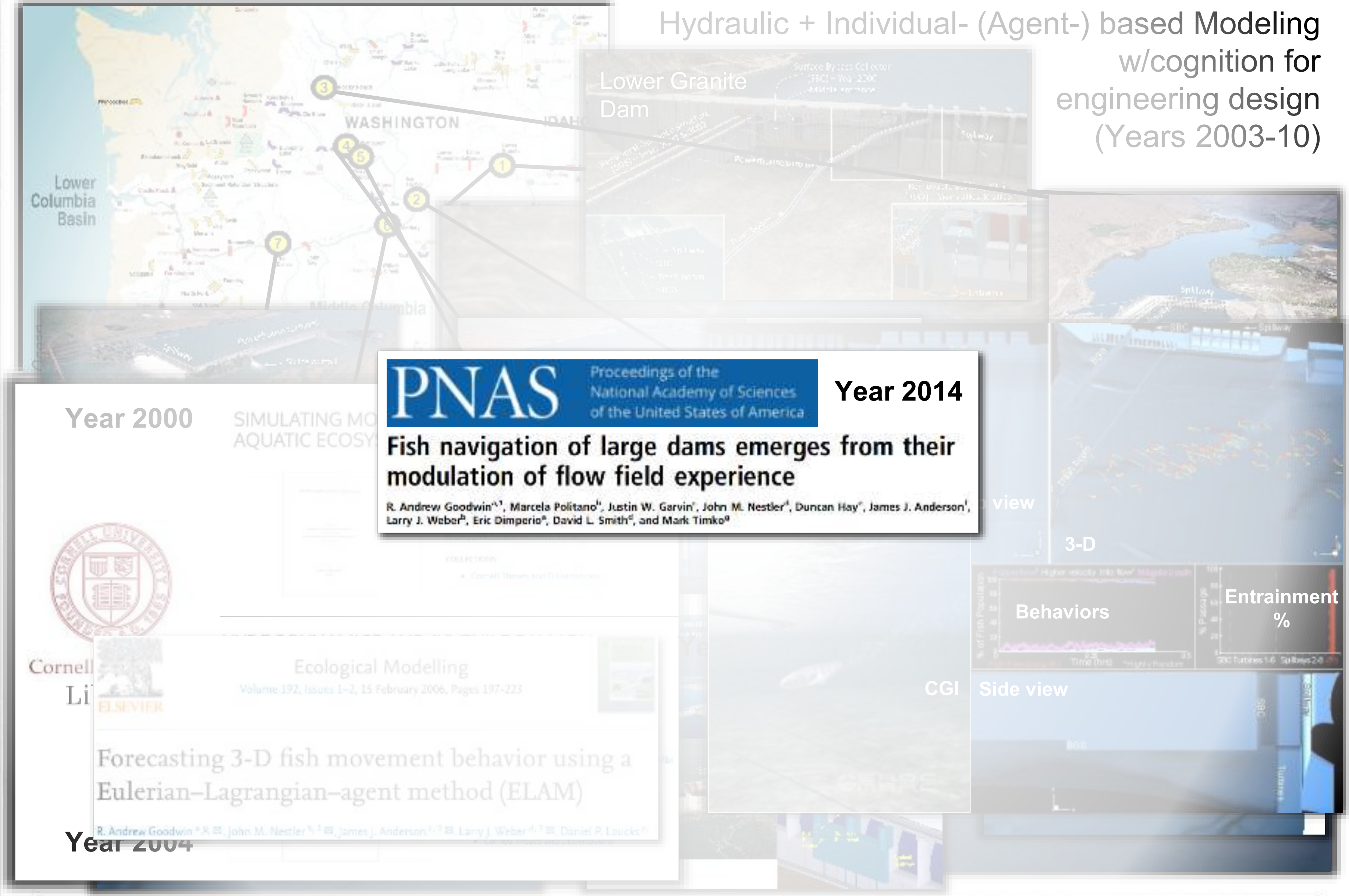
- Temperature
- Dissolved oxygen
- 2-D hydrodynamics

CE-QUAL-W2





25 Years: Out-of-Sample Fish 3-D Movement Prediction



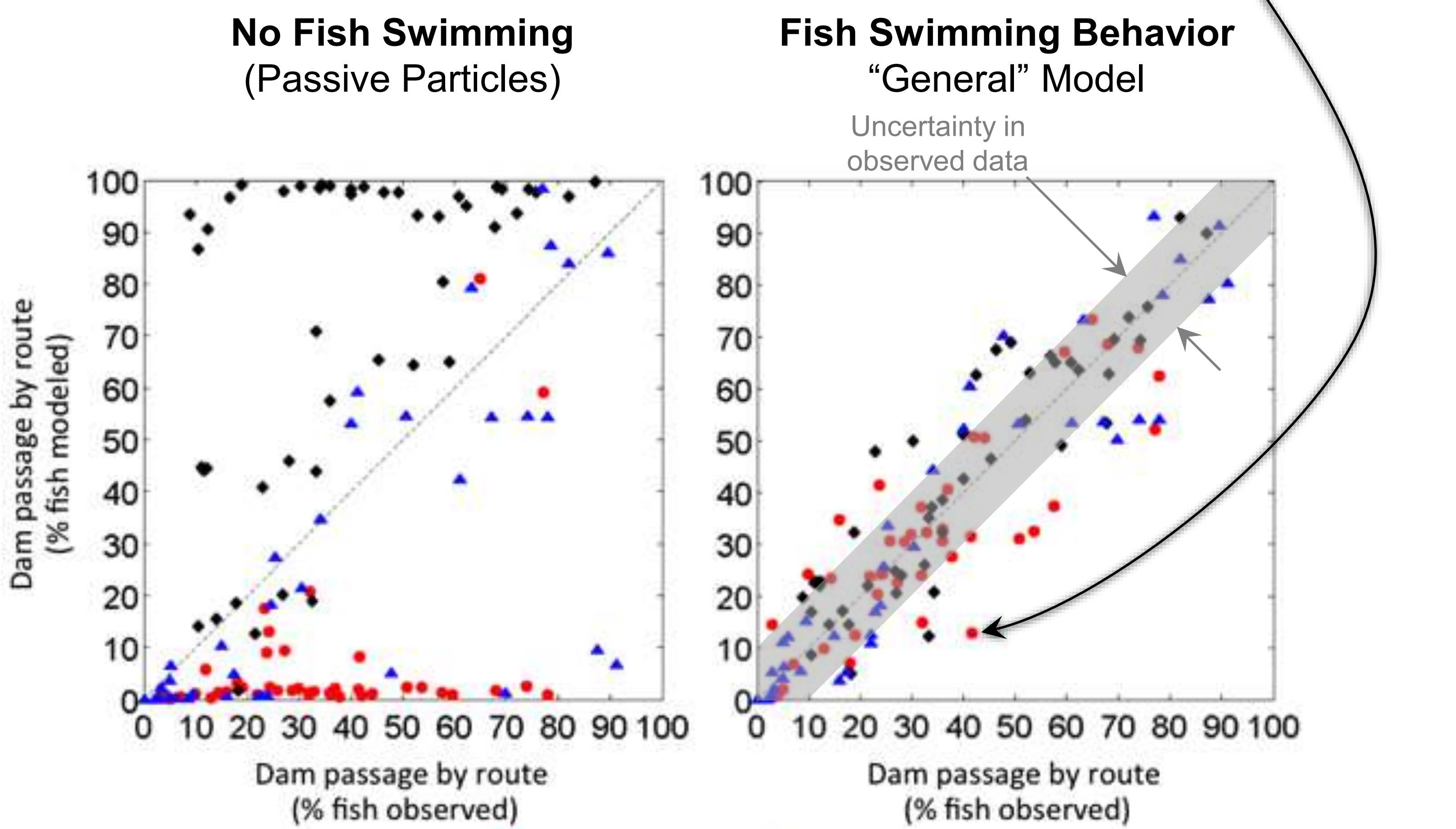
Accuracy Performance

of ELAM Model

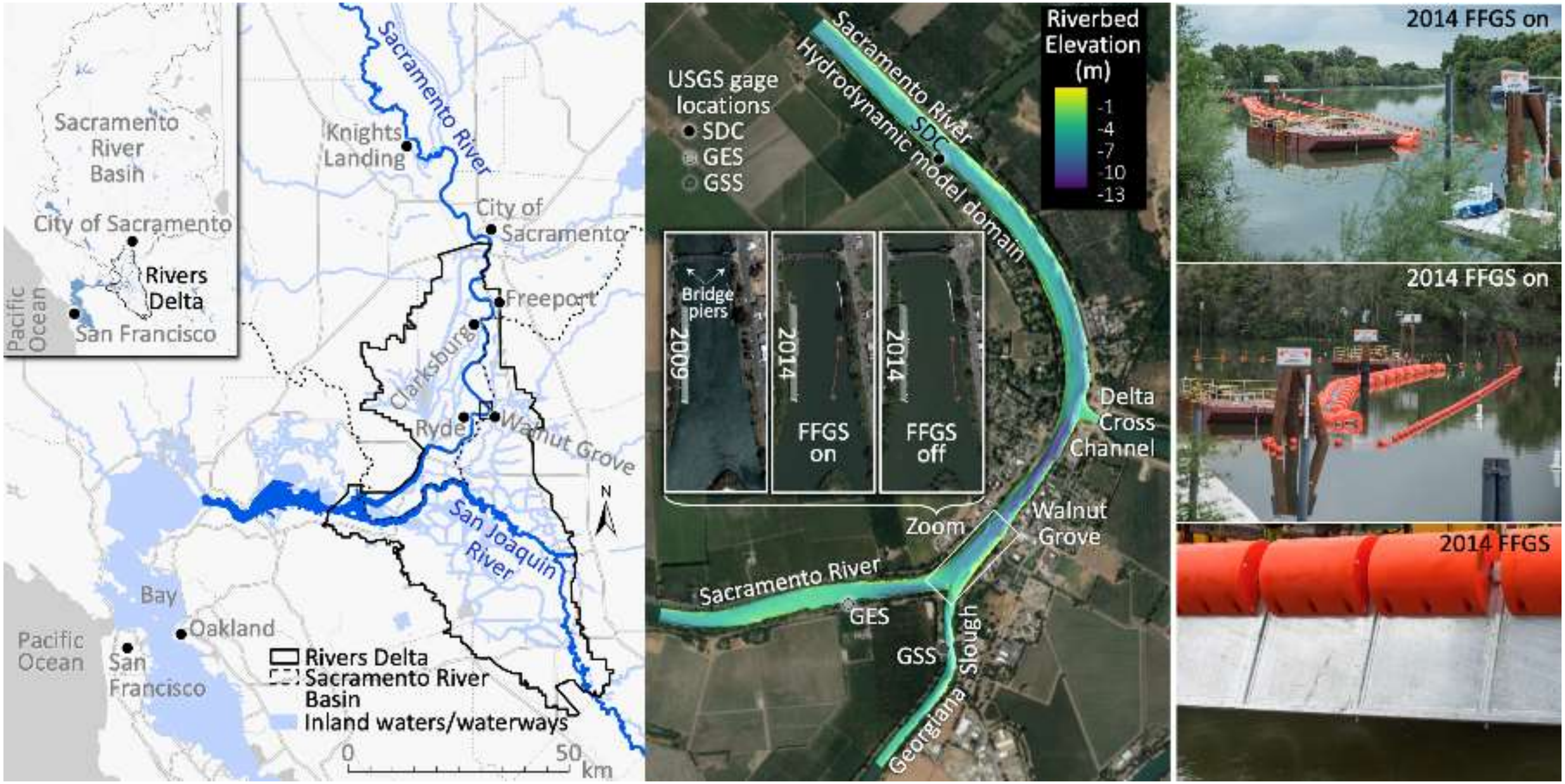
Describing Navigational Choice

● Bypass ◆ Turbines ▲ Spillway

Goodwin *et al.* (2014)

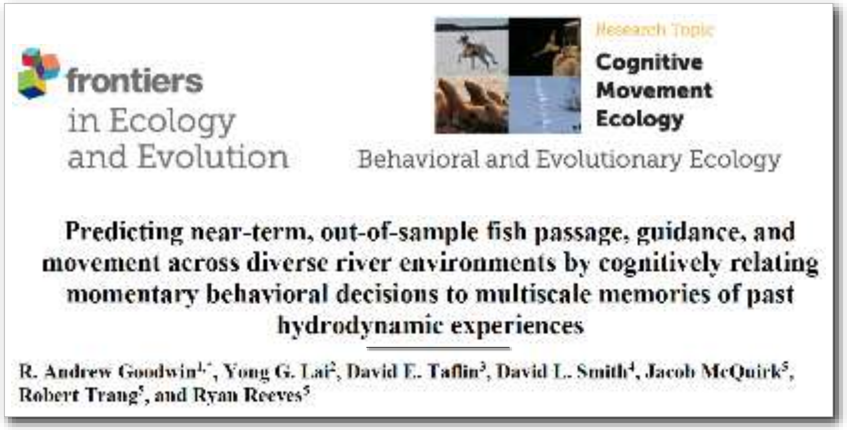


Tidal Sacramento River at Georgiana Slough



Tidal Sacramento River at Georgiana Slough

Year 2023 (in 2nd review)


frontiers in Ecology and Evolution

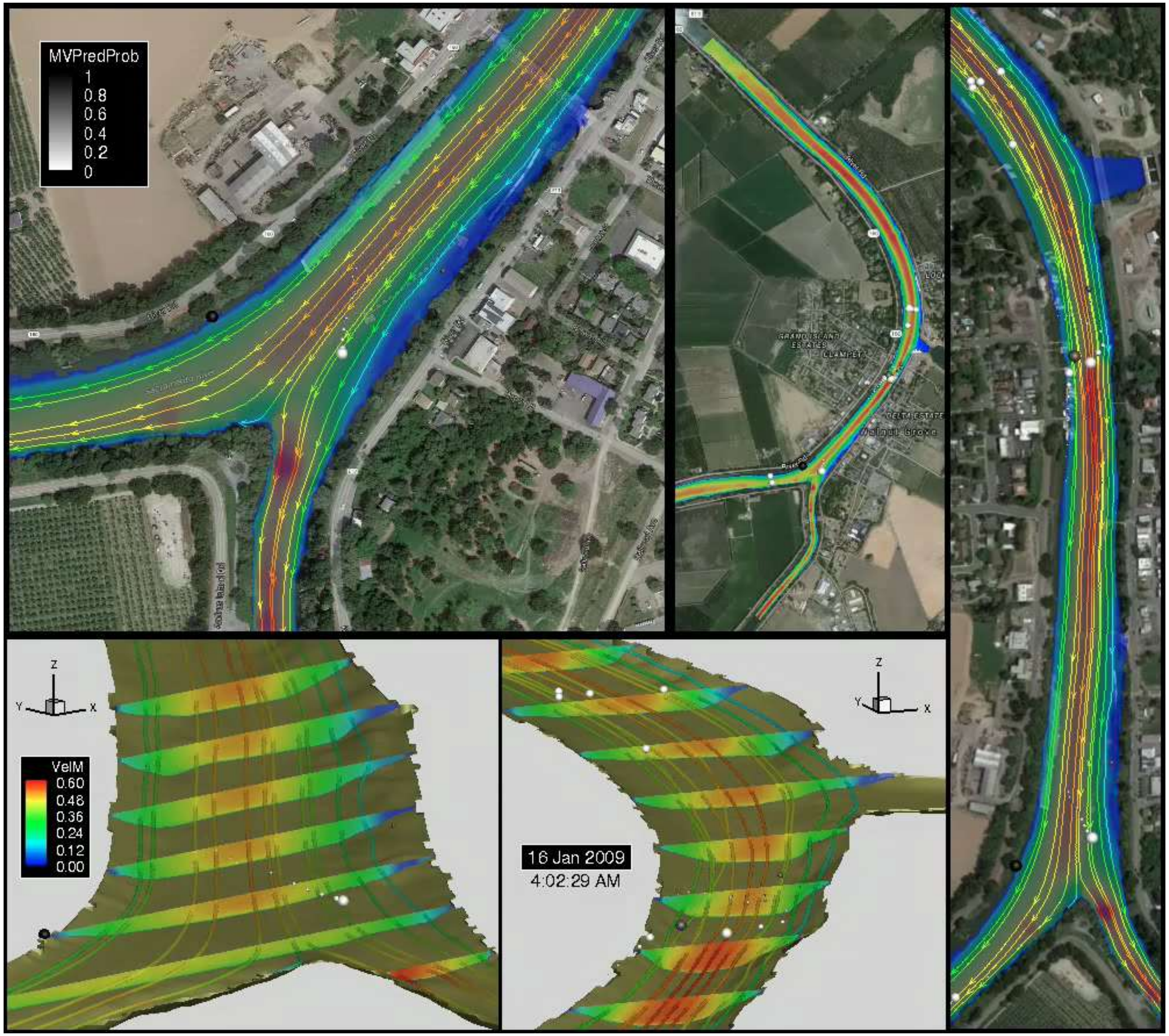
Research Topic
Cognitive Movement Ecology
Behavioral and Evolutionary Ecology

Predicting near-term, out-of-sample fish passage, guidance, and movement across diverse river environments by cognitively relating momentary behavioral decisions to multiscale memories of past hydrodynamic experiences

R. Andrew Goodwin[1,*], Yong G. Lai[2], David E. Taflin[3], David L. Smith[4], Jacob McQuirk[5], Robert Trang[5], and Ryan Reeves[5]

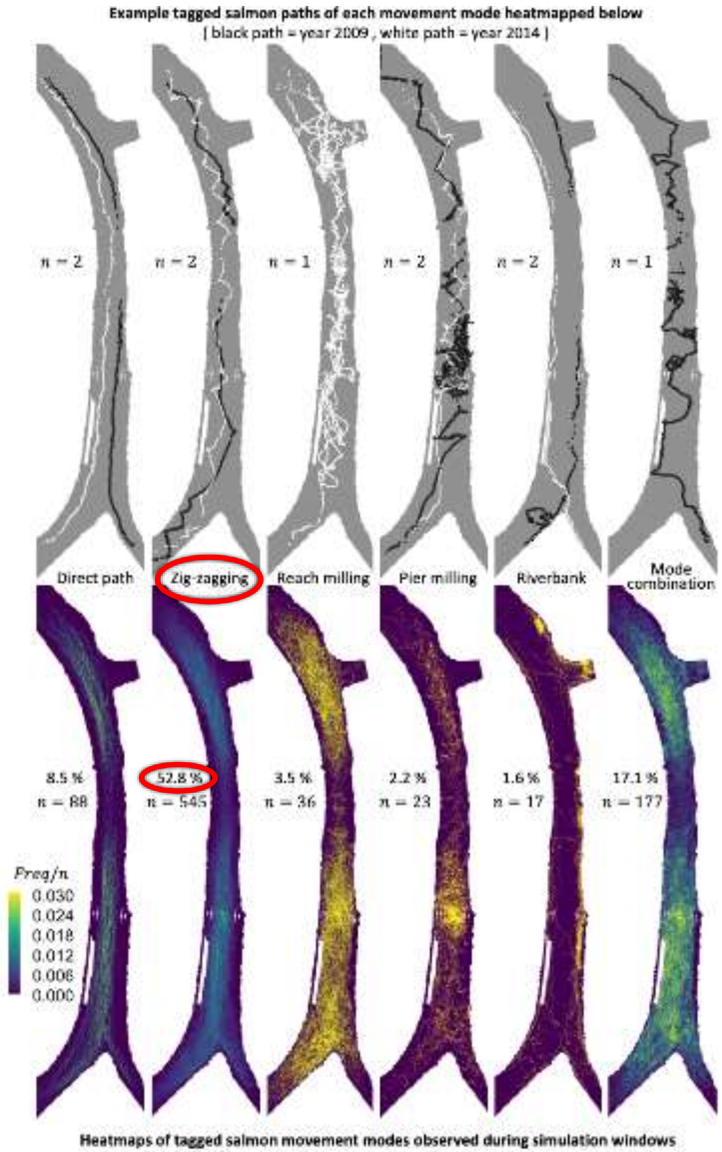
- Updated cognitive-based algorithms for predicting fish movement, guidance, and entrainment
- Simplest formulation of many evaluated
- Behaviors emerge from animal's recent past experience (environmental context)
- Selective tidal stream transport a superset of the behaviors at large hydropower dams – potential for unified prediction model

Tidal Sacramento River at Georgiana Slough

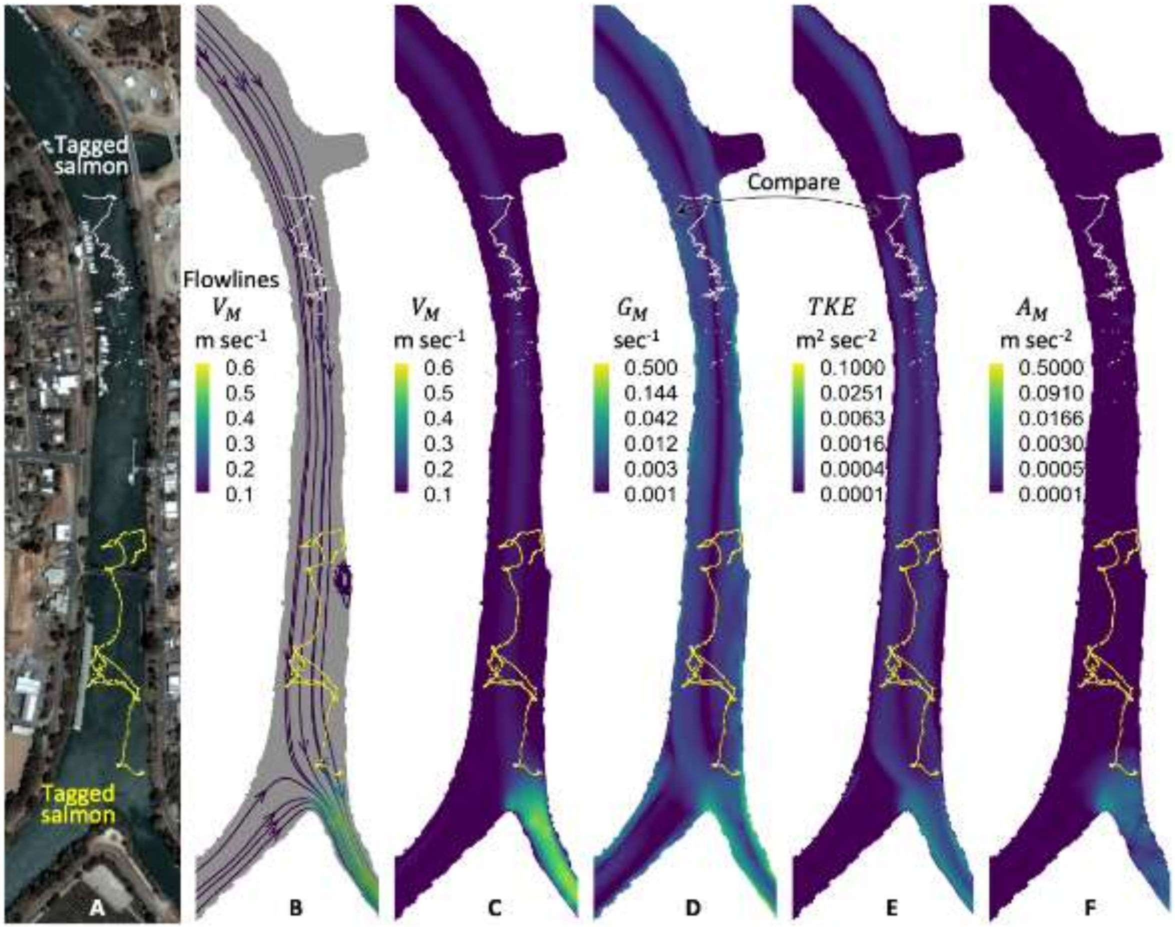


U2RANS CFD – Yong Lai, USBR // Acoustic-tag Telemetry – USGS

Fish Behavior is Complex – Different Movement Modes



Hydrodynamic Behavioral Stimuli

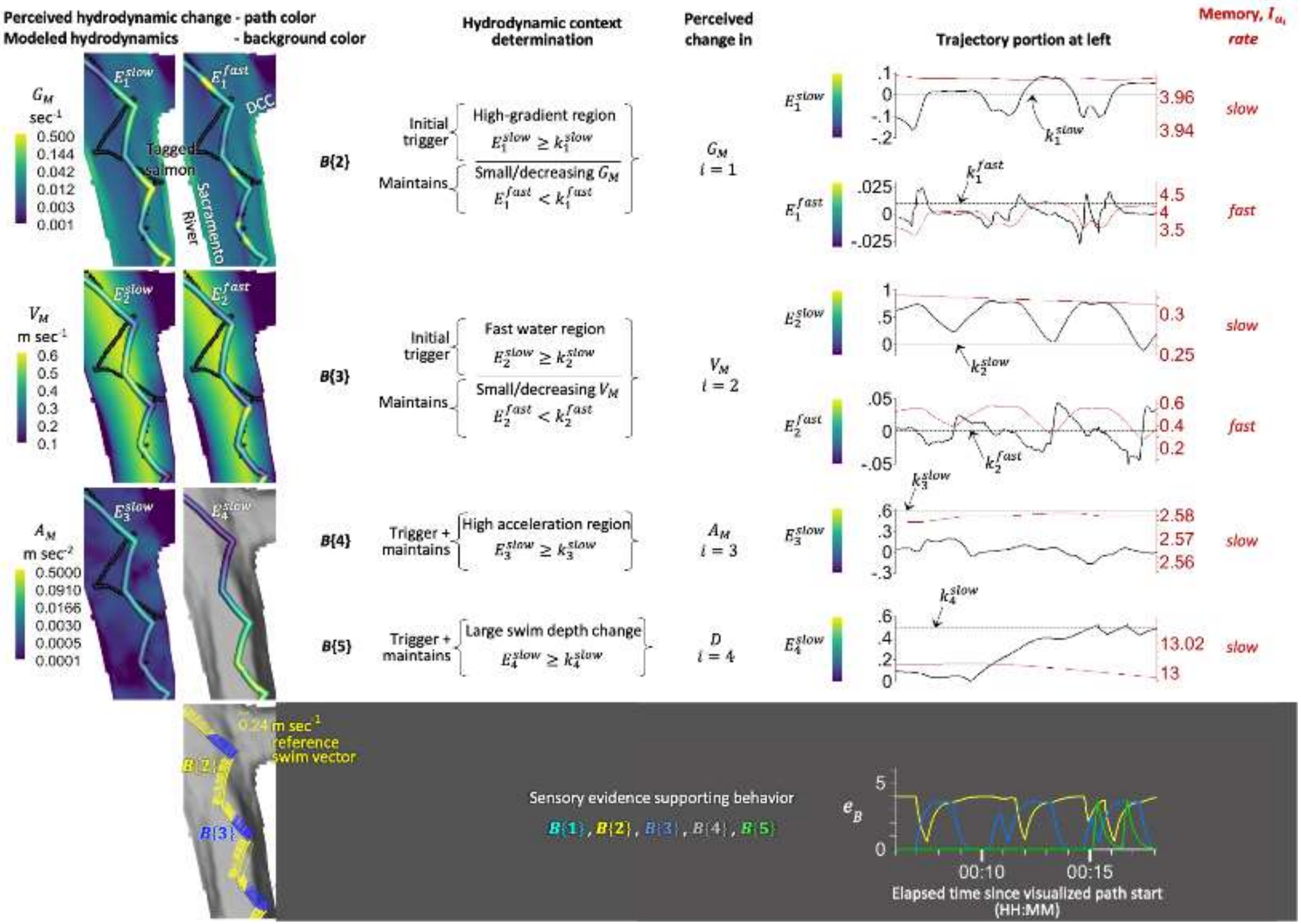


Engineering design relevance	**Orientation** Alignment Attraction Repulsion Modulation	**Trigger** Accumulated sensory evidence, e_R, indicates
Guide salmon with bulk water flow	**Flowline alignment** swim with flow	Absence of other triggers
Guide salmon away from bulk water flow	**Velocity (V_M) attraction** swim toward fastest water	Small or decreasing perceived change in spatial gradient of water speed G_M ($\downarrow E_2^{fast}$) in large G_M ($\uparrow E_1^{slow}$)
	Gradient (G_M) attraction swim toward largest spatial gradient in water speed	Small or decreasing perceived change in water speed V_M ($\downarrow E_2^{fast}$) in fast water ($\uparrow E_2^{slow}$)
Repulse salmon	**Acceleration (A_M) repulsion** swim against flowline, away from large A_M	Large perceived change in water acceleration/deceleration A_M ($\uparrow E_3^{slow}$)
In deep environments Guide salmon away from bulk water flow	**Pressure (depth, D) modulation** swim toward habituated/acclimatized depth	Large perceived change in swim bladder pressure or depth D ($\uparrow E_4^{slow}$)

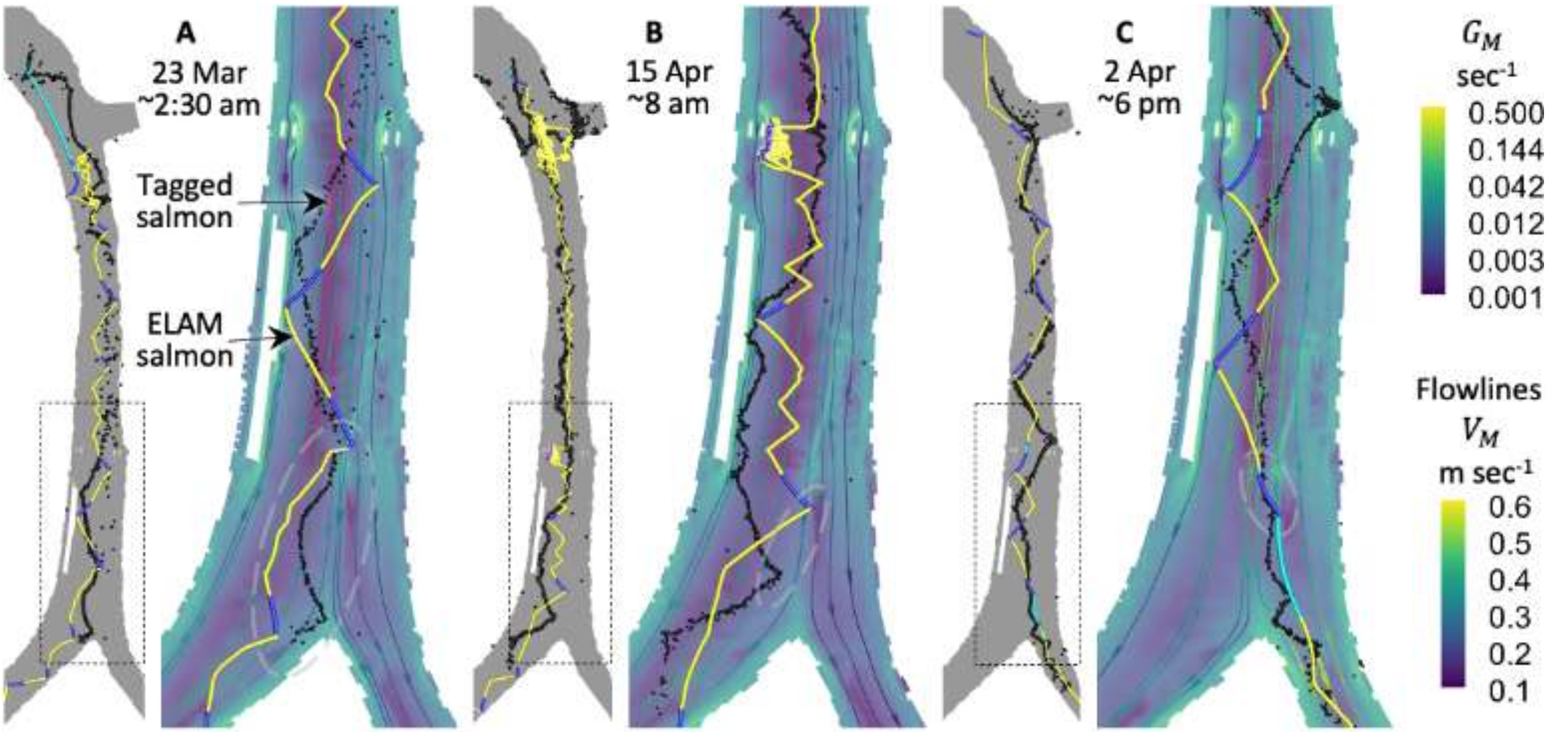
N/A = not applicable.

↓ = small or decreasing values; ↑ = large values.

Perceptual Decision-Making (Cognition)

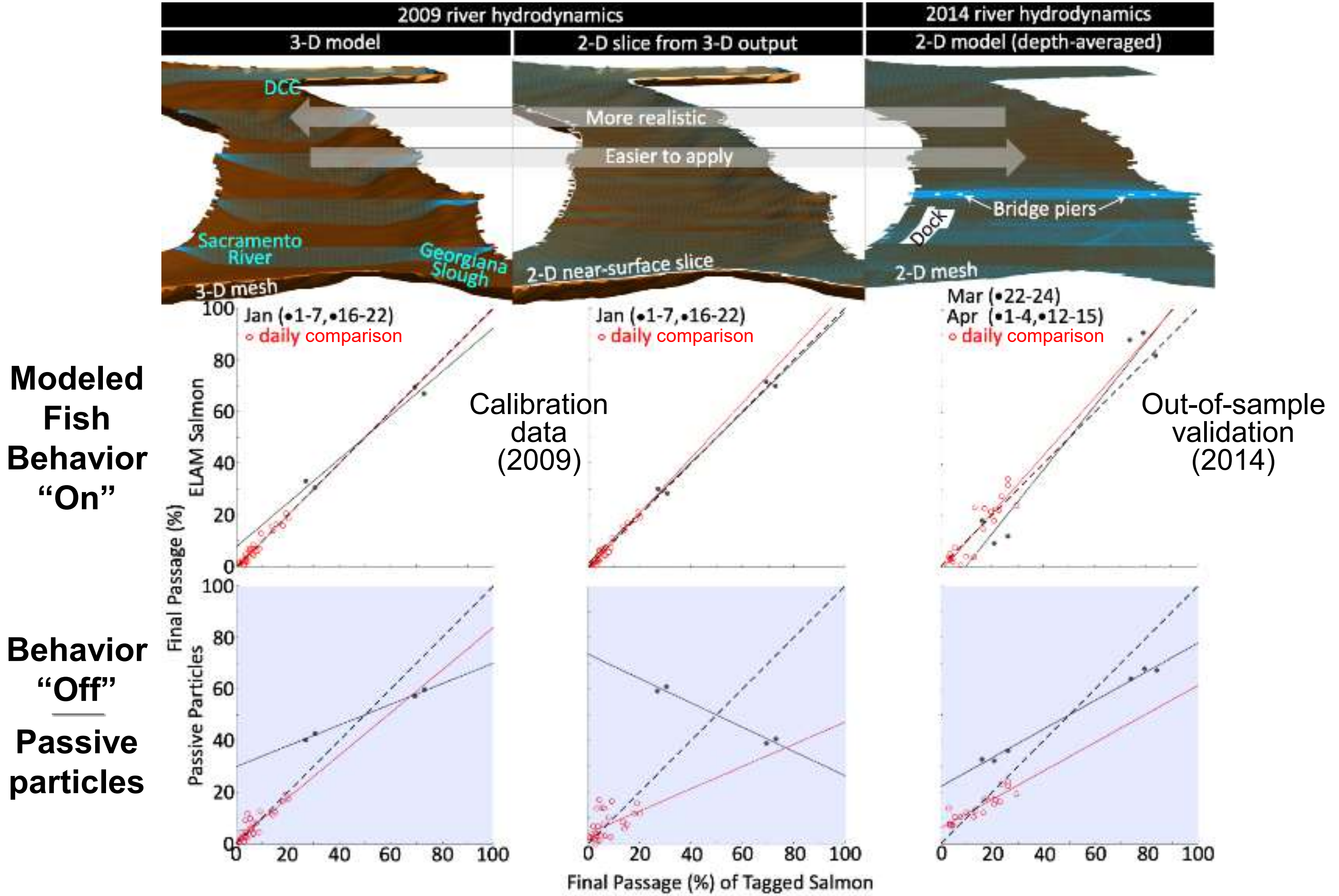


Out-of-Sample Movement Prediction

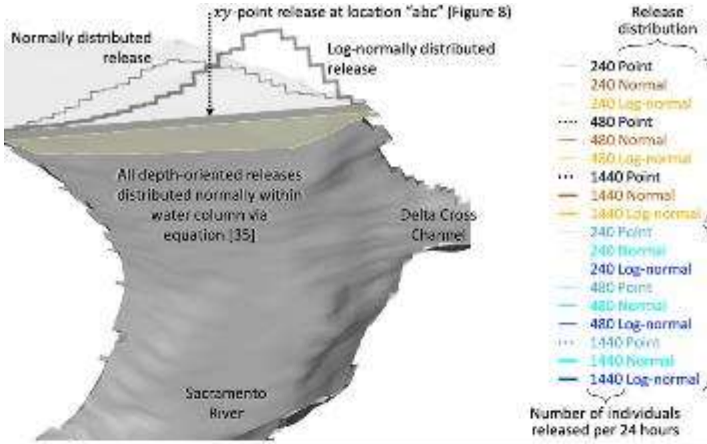


$B\{1\}$: flowline alignment | $B\{2\}$: velocity (V_M) attraction | $B\{3\}$: gradient (G_M) attraction | $B\{4\}$: acceleration (A_M) repulsion

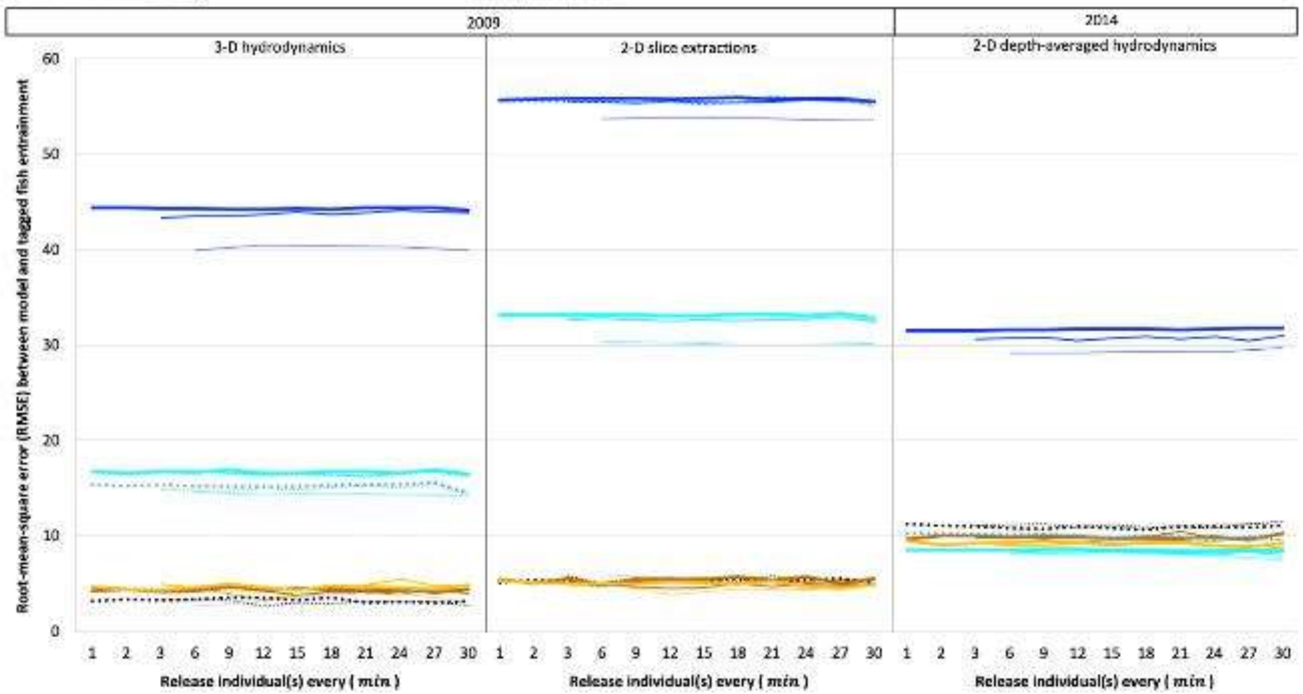
Predicting Out-of-Sample Guidance/Entrainment



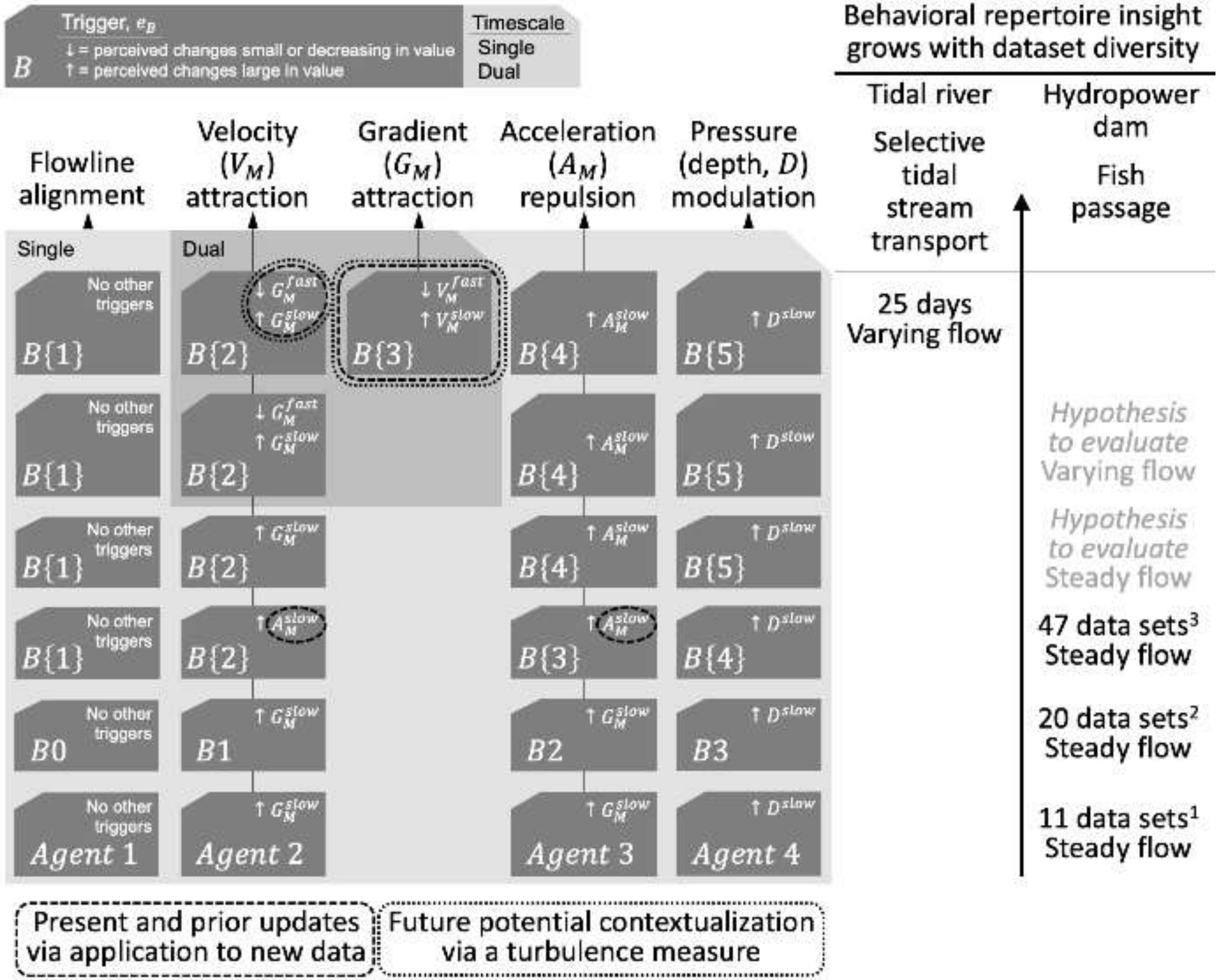
Prediction Accuracy
(not knowing where/when salmon enter domain)



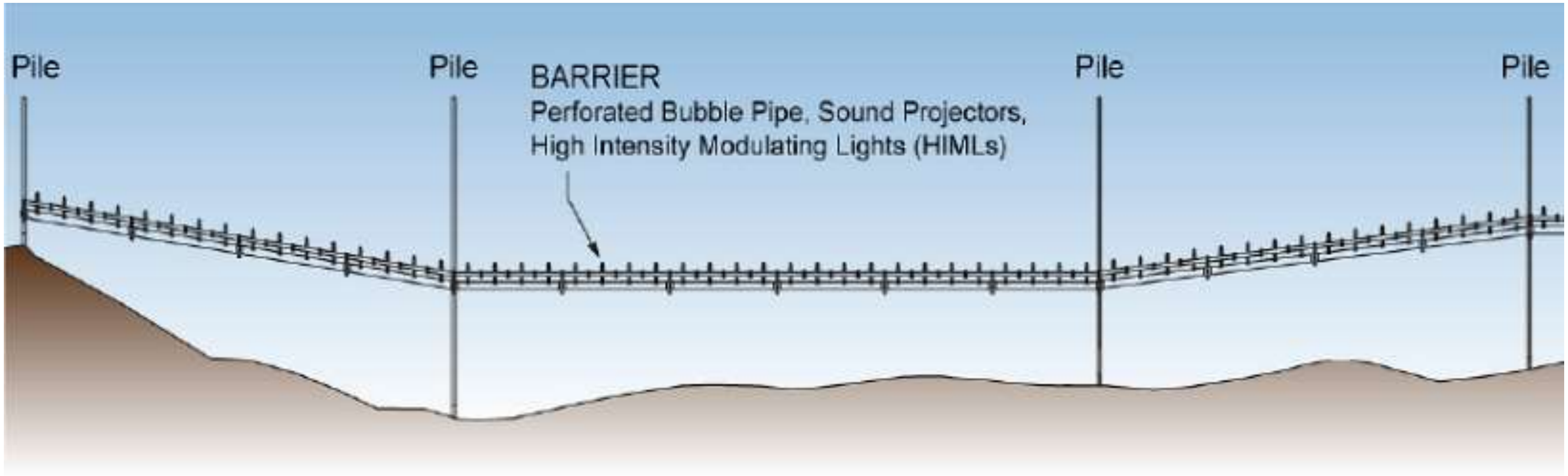
Release individual(s) every (min)	Number of releases per 24 hours	Number of individuals per release	Number of individuals released per 24 hours	Number of individuals per release	Number of individuals released per 24 hours	Number of individuals per release	Number of individuals released per 24 hours
1	1440					1	1,440
2	720					2	1,440
3	480			1	480	3	1,440
6	240	1	240	2	480	6	1,440
9	160			3	480	9	1,440
12	120	2	240	4	480	12	1,440
15	96			5	480	15	1,440
18	80	3	240	6	480	18	1,440
21	68.6			7	480	21	1,440
24	60	4	240	8	480	24	1,440
27	53.3			9	480	27	1,440
30	48	5	240	10	480	30	1,440



What $65+ Million of Telemetry & CFD is Saying



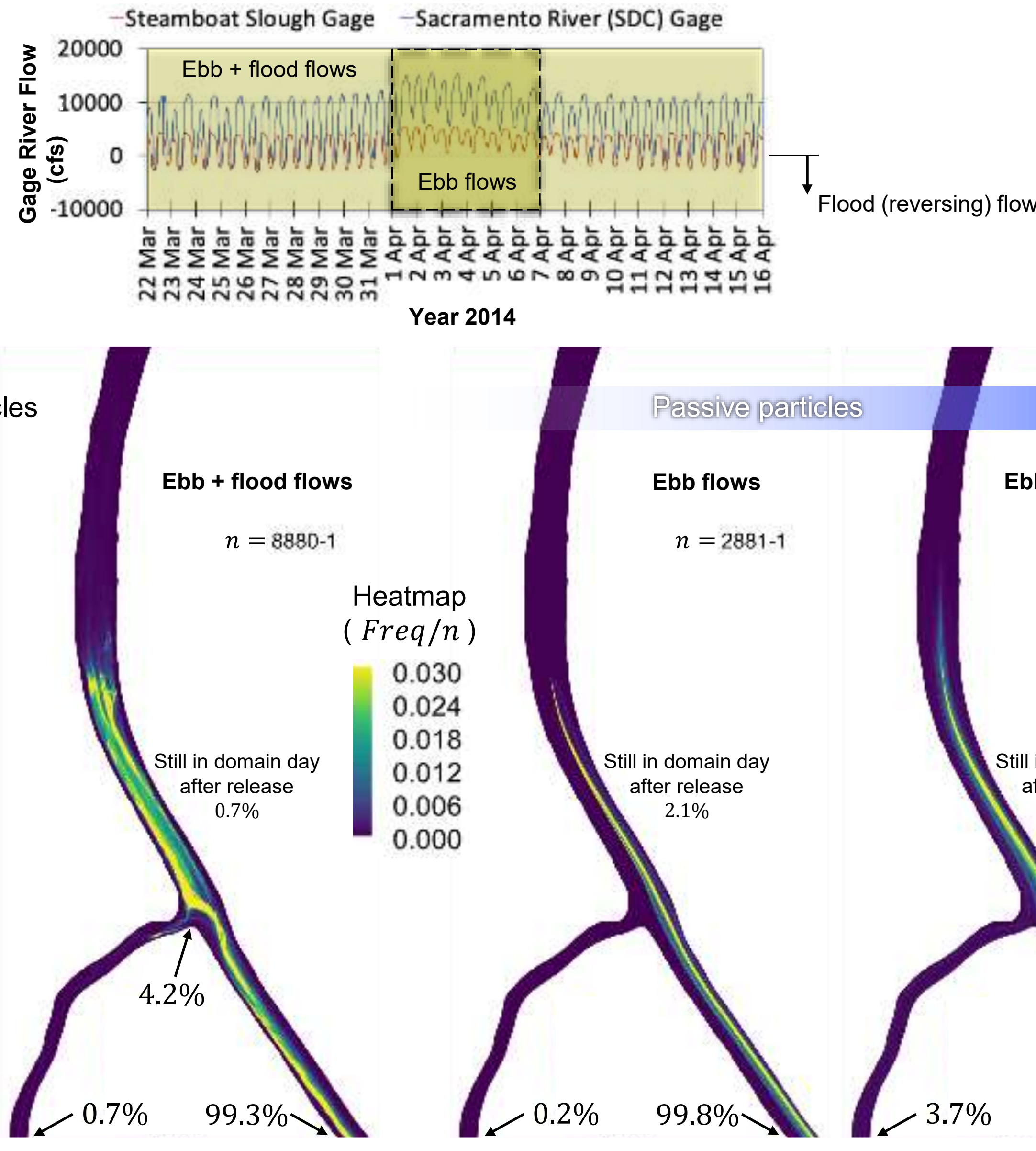
Bubbles, Acoustic, Light Stimuli Guidance/Occlusion



Source: Data provided by Fish Guidance Systems and adapted by AECOM in 2012

Predicting Out-of-Sample Guidance/Entrainment

Base case

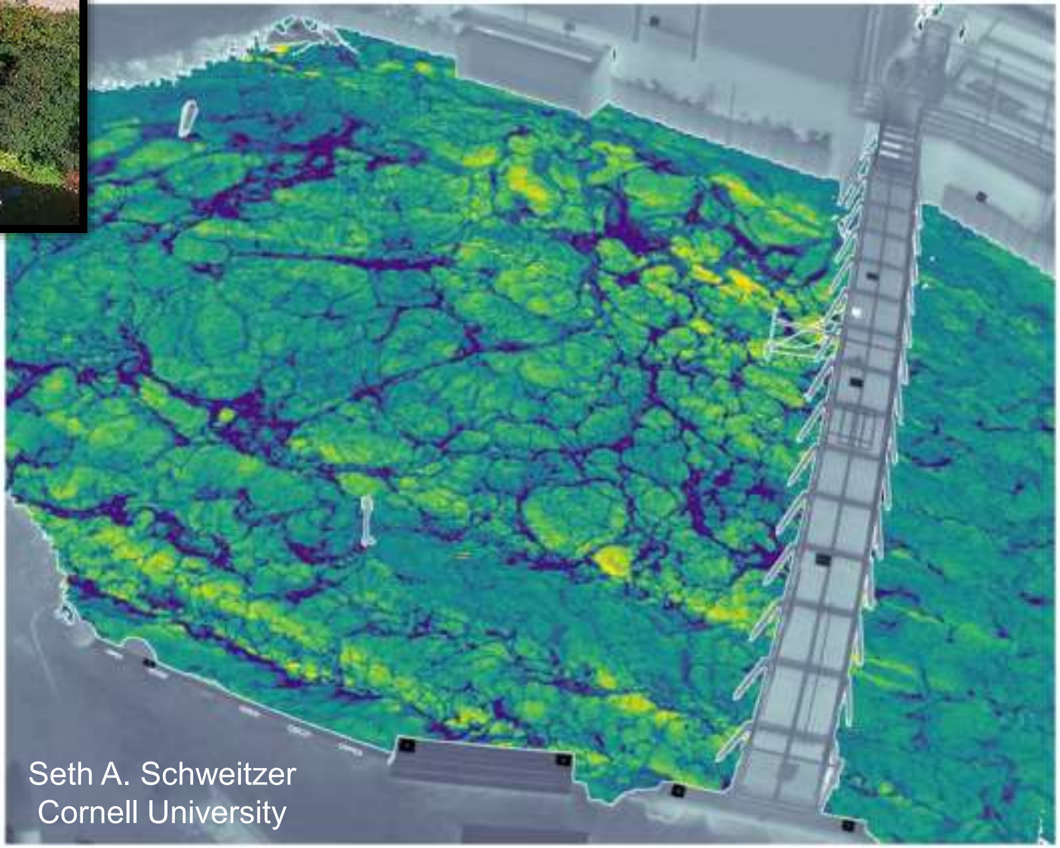


ELAM Theory-Informed Machine Learning

Real-time Fish Trajectory Prediction

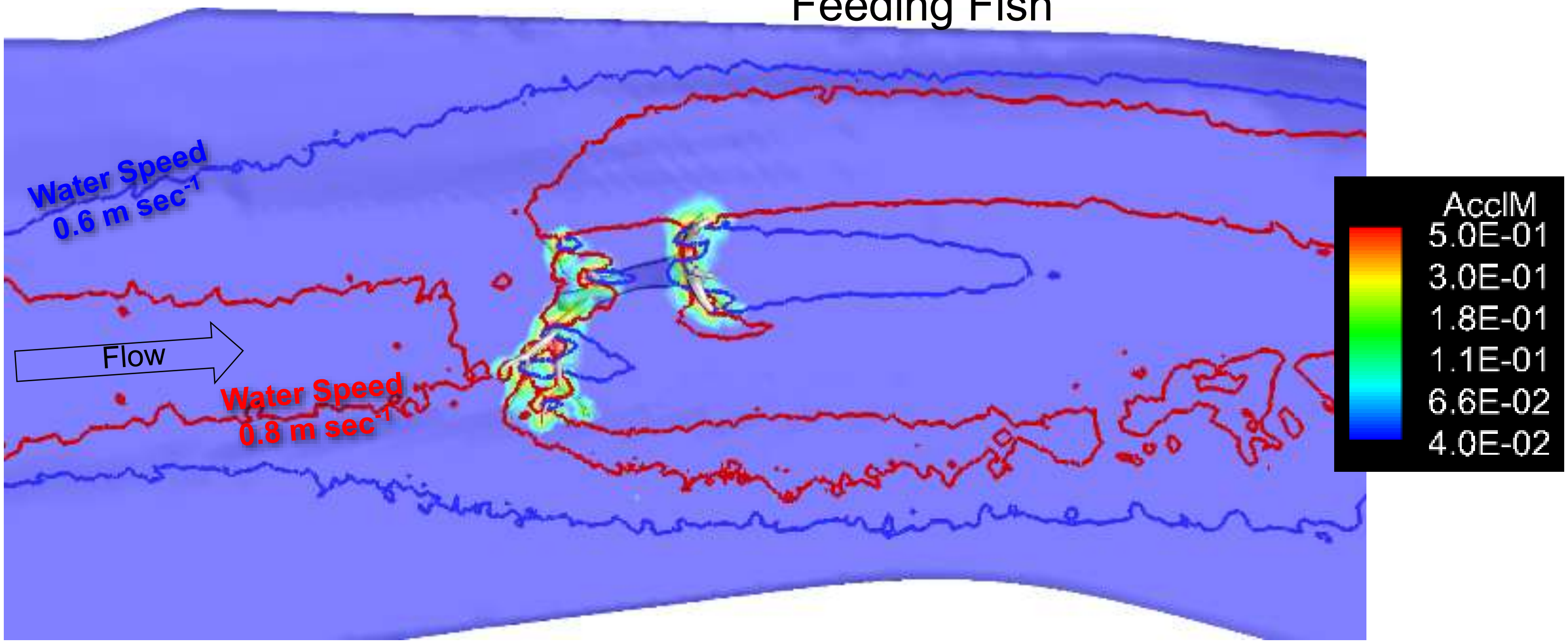
Boardman River, Michigan
Great Lakes Fishery Commission

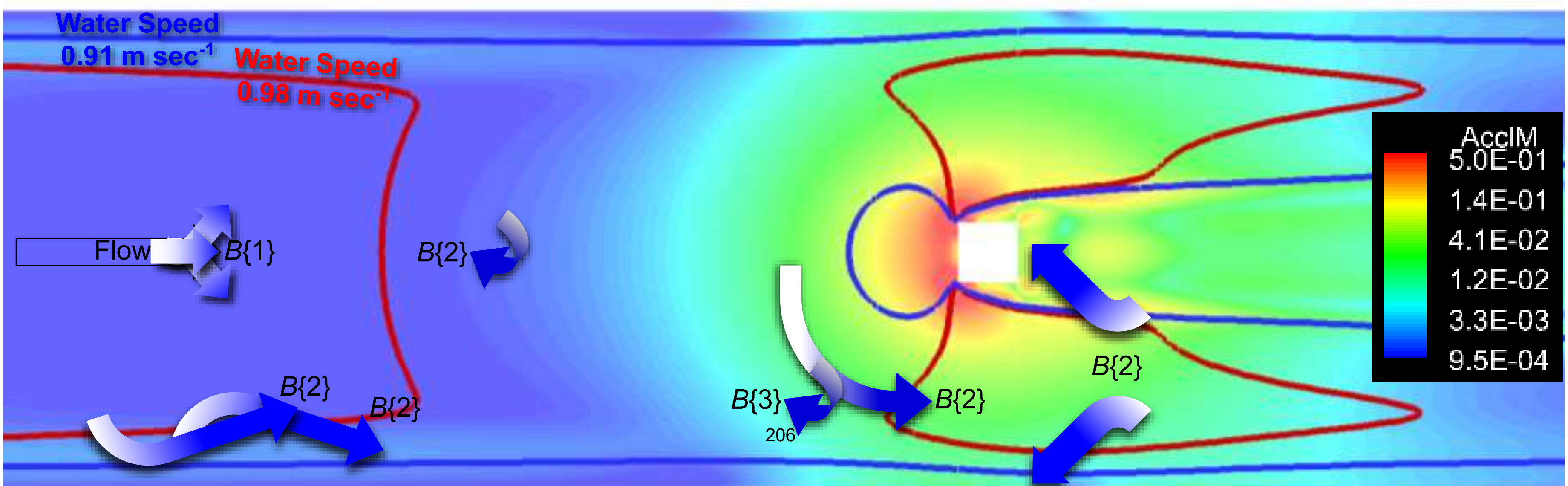
Bi-directional, selective fish passage



Seth A. Schweitzer
Cornell University

Hypothesis Reversal for: Upstream-migrating Fish
Resident Fish
Feeding Fish





Drift-feeding & Bioenergetics