Beyond Physical Habitat; Session 2: Productivity in Recovering Imperiled Salmonid Populations

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

- **Session Coordinators:**
  - Robert Lusardi, Ph.D., *UC Davis Center for Watershed Sciences*

This session will delve into understanding how prey availability may influence the growth and fitness of salmonids and will identify productive ecosystems or habitats that may assist in the recovery of imperiled populations. We will also explore ecosystems, including highly managed ecosystems, that have the ability to improve productivity or prey availability at broader spatial scales and in an overall effort to improve habitat heterogeneity across the landscape.

Presentations

Slide 4 - **How Physical Habitat and Prey Abundance Interact to Shape the Growth Opportunities of Salmonids: Examples from Bristol Bay to the Klamath Basin,** Jonny Armstrong., *Oregon State University*

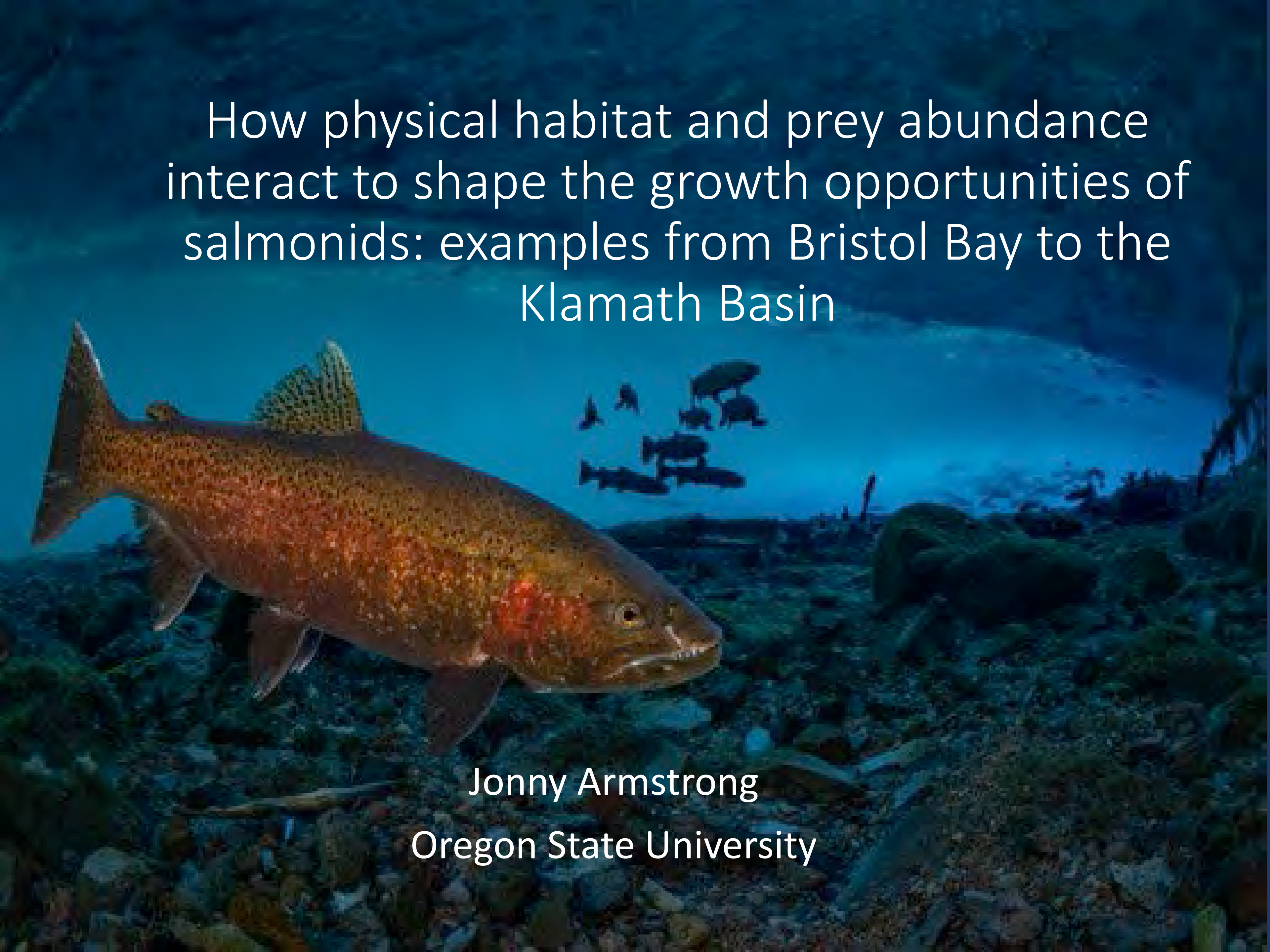
Slide 35 - **Making a Living in a Seasonal Lagoon: Interactions Among Water Temperature, Prey Availability, and Juvenile Salmonid Growth,** Kwanmok Kim, *UC Santa Cruz and NOAA Affiliate*

Slide 72 - **Puddle Power and the Pivot to Process: A Landscape-scale Recipe to Allow the Sacramento Valley to Make Salmon Again,** Jacob Katz, *Ph.D., Cal Trout*

Slide 110 - **Coupling Habitat and Prey Supply with Juvenile Chinook Salmon Growth and Production in the San Joaquin River Restoration Project,** Steve Blumenshine, Ph.D., *CSU-Fresno CA Water Institute*

Slide 149 - **Defining a Basin-scale Restoration Framework to Recover an Endangered Species. An Optimization- Simulation Approach using a Life Cycle Model,** Dr. Francisco Bellido-Leiva, *UC Davis*

Slide 198 - **Foodscapes as Reference States: Reconnecting Salmon with the Productive Capacity of Their Watershed,** Gabriel Rossi, Ph.D., *UC Berkeley*

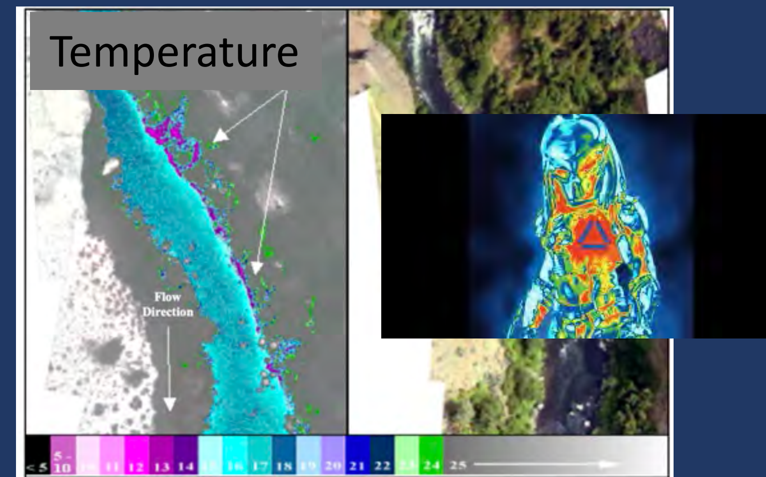


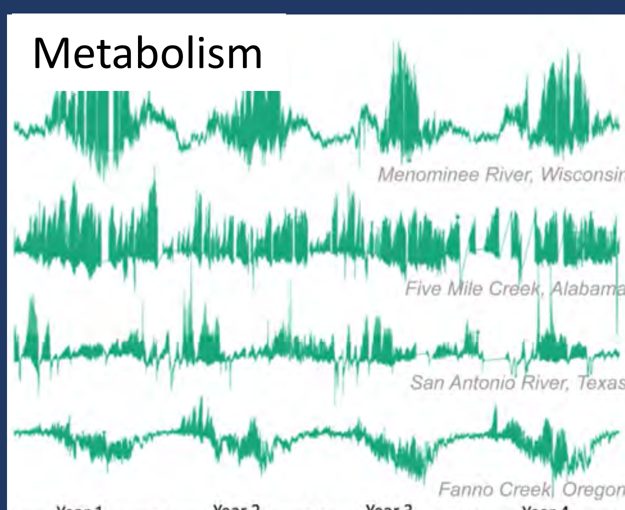
How physical habitat and prey abundance interact to shape the growth opportunities of salmonids: examples from Bristol Bay to the Klamath Basin

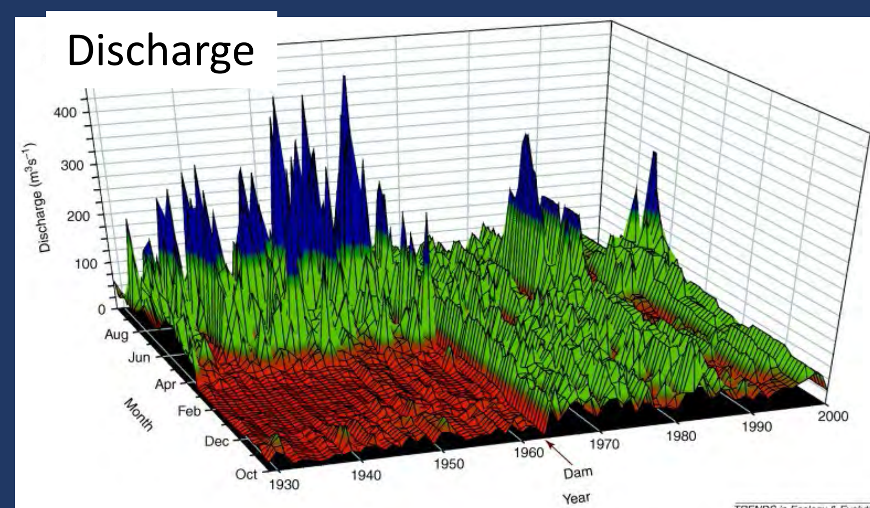
Jonny Armstrong

Oregon State University

What a time to be a fish ecologist!

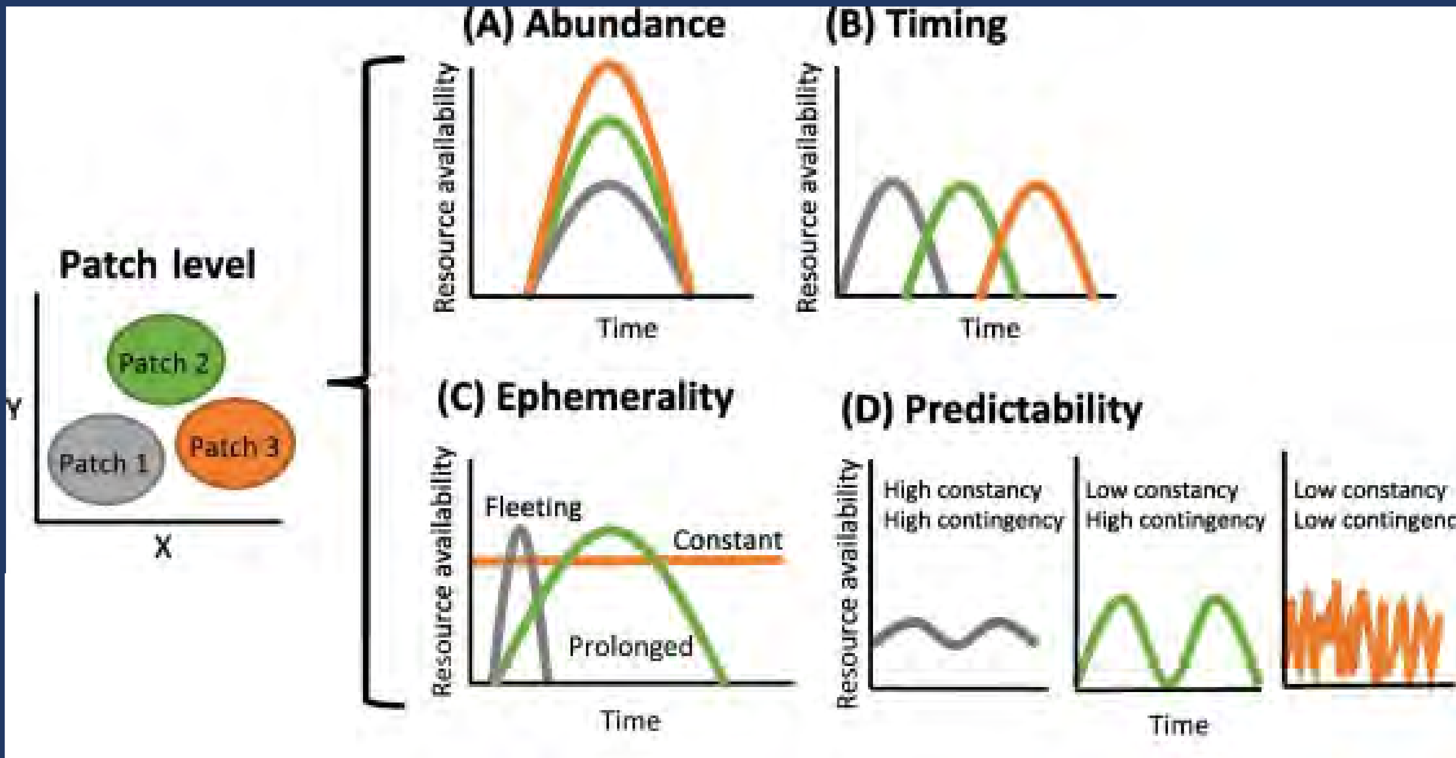






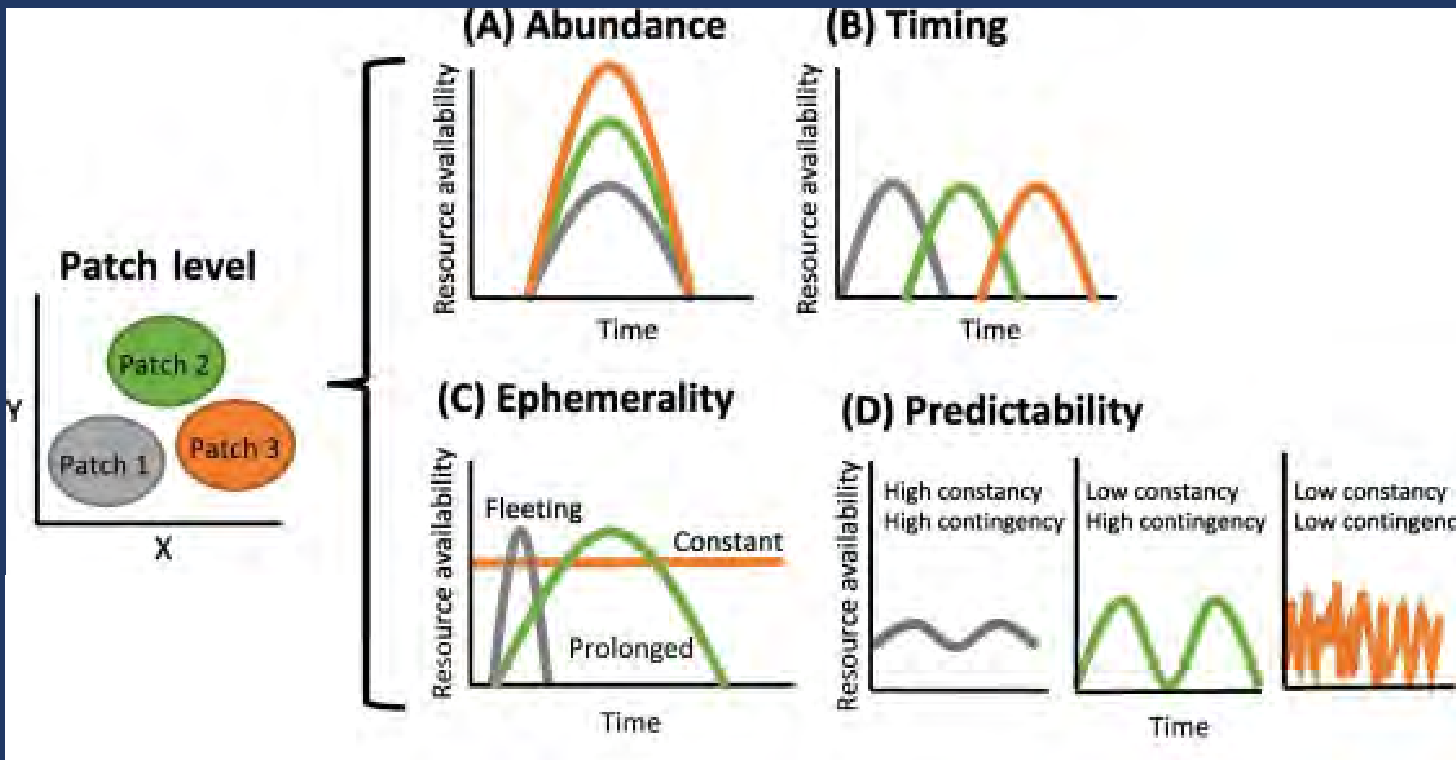
We know much less about food and foraging

Attributes of food sources



Mueller and Fagan 2008 *Oikos*
Abrahms et al. et al. 2021 *TREE*

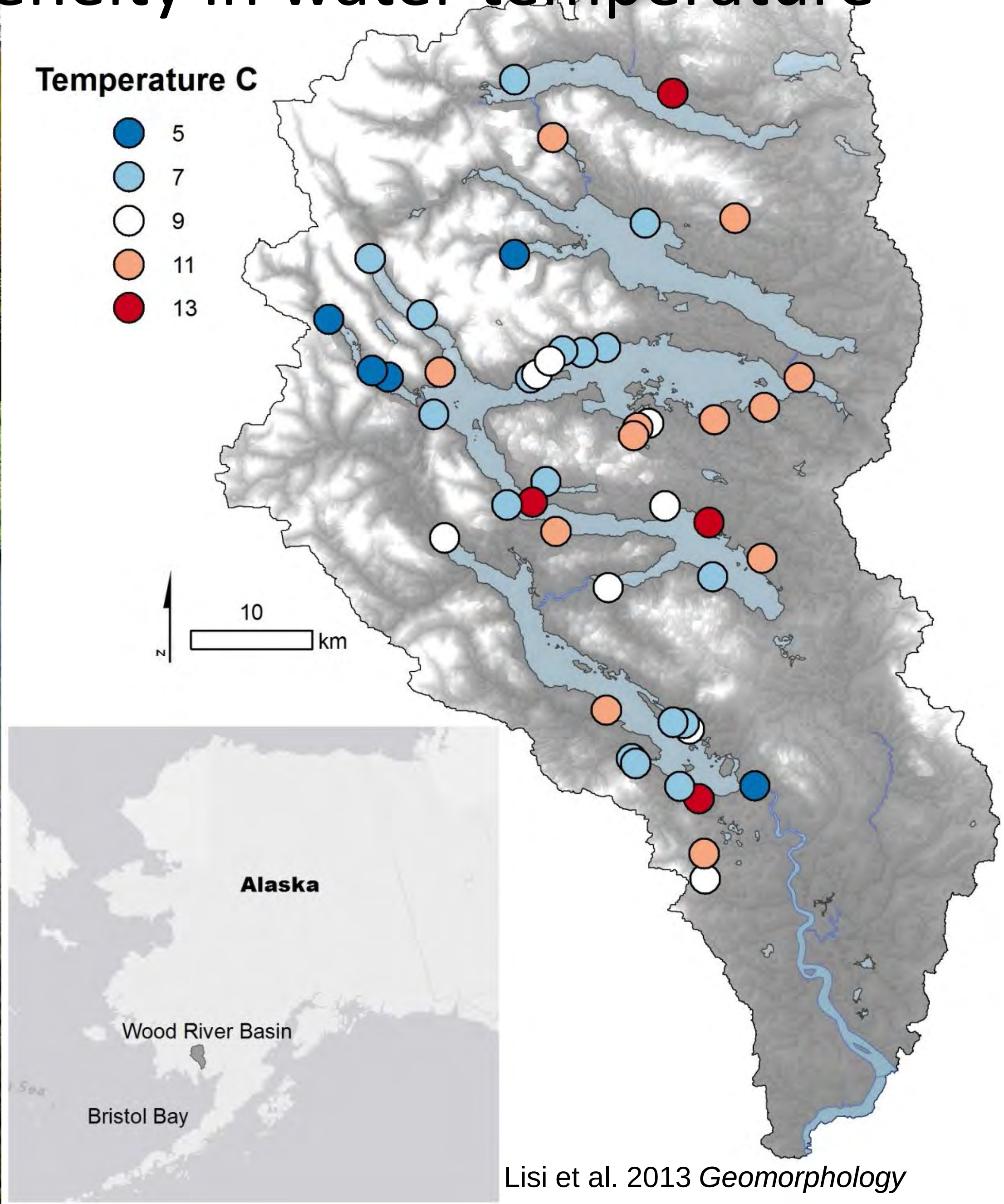
Timing of ephemeral resources



Mueller and Fagan 2008 *Oikos*
Abrahms et al. et al. 2021 *TREE*

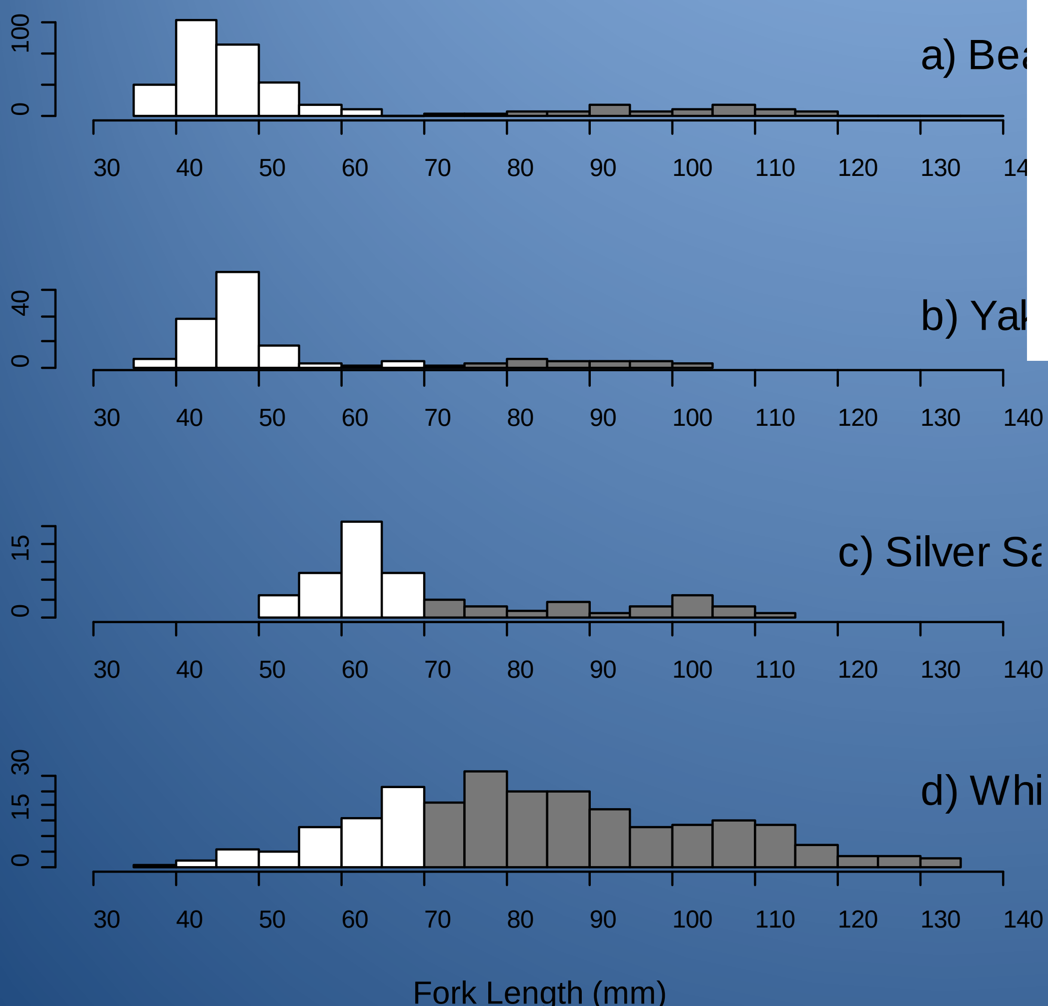
Pulsed salmon subsidies in Alaska

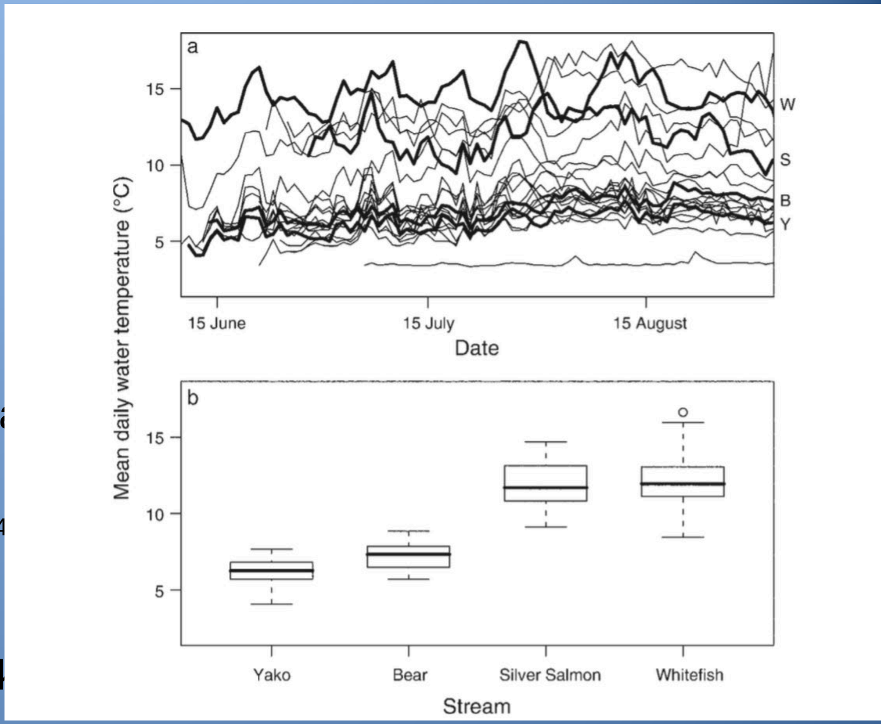
Spatial heterogeneity in water temperature



Lisi et al. 2013 *Geomorphology*

Fork length in August



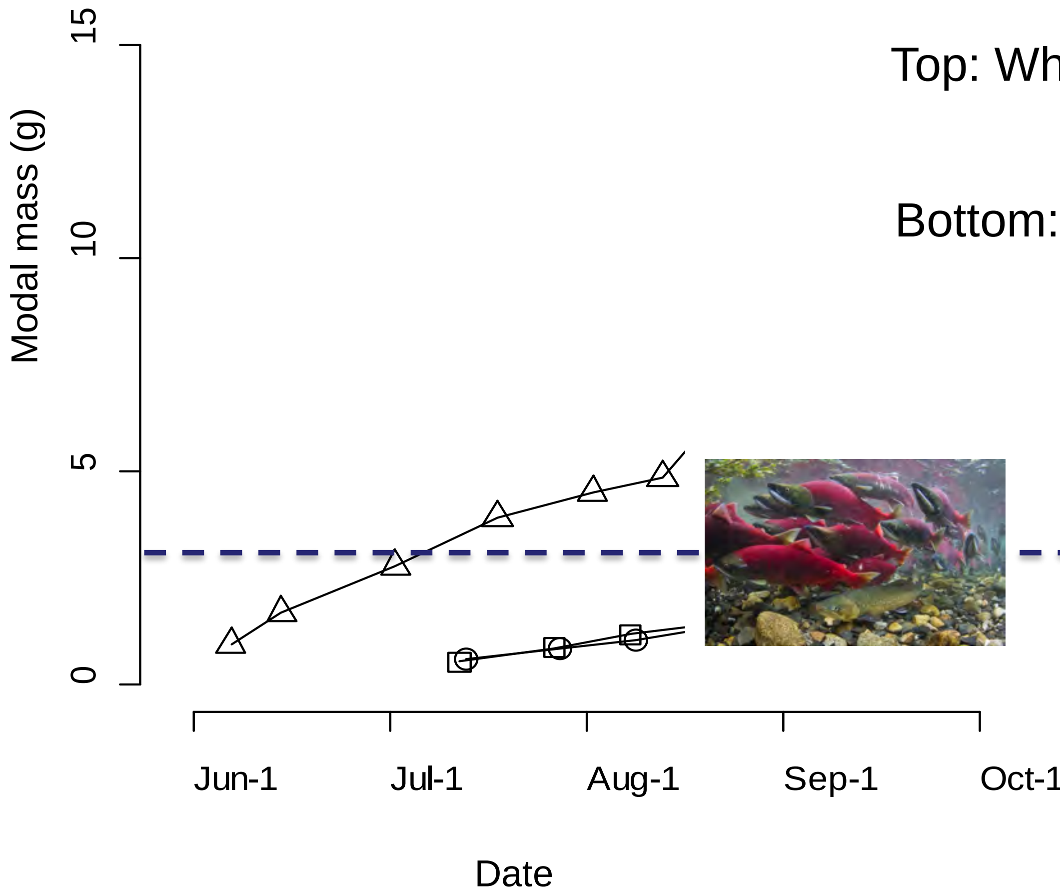


Armstrong et al. 2010 *Ecology*

Gape limit and temperature mediate effects of subsidy

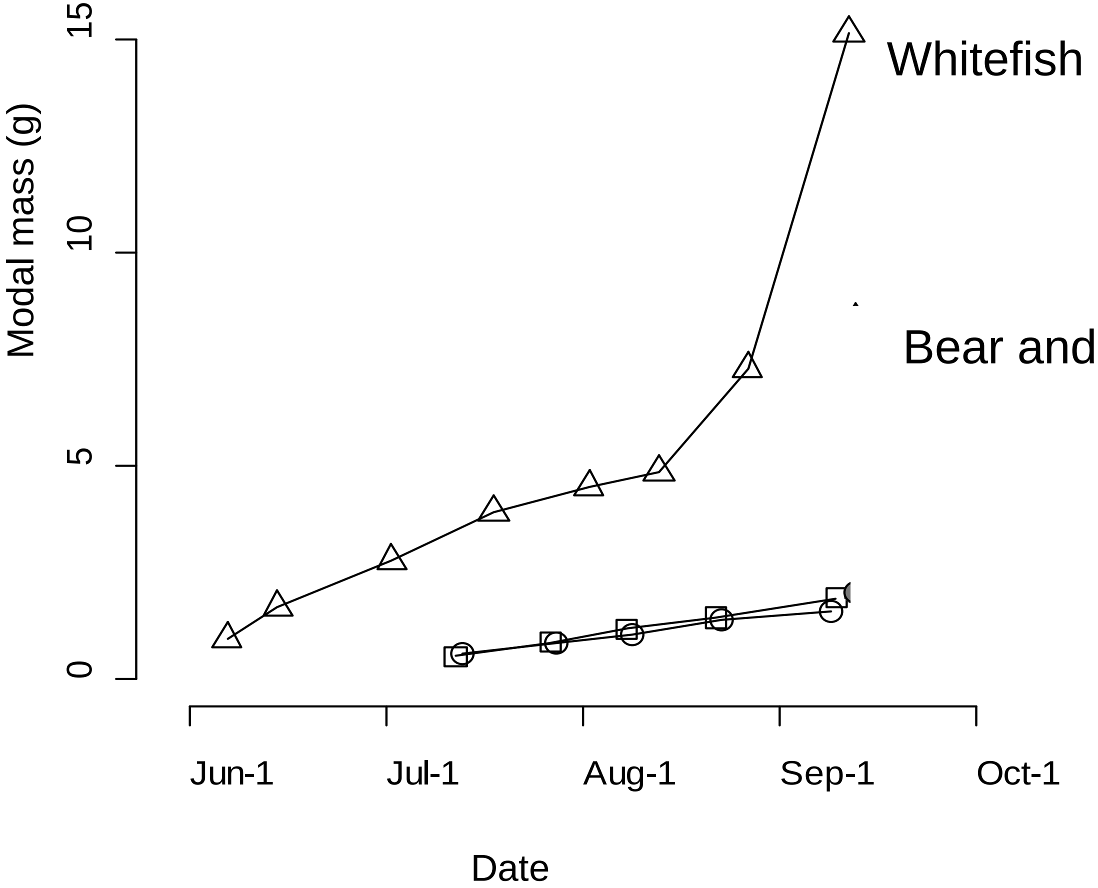
Top: Whitefish Ck. (warm)

Bottom: Bear and Yako Ck. (cold)

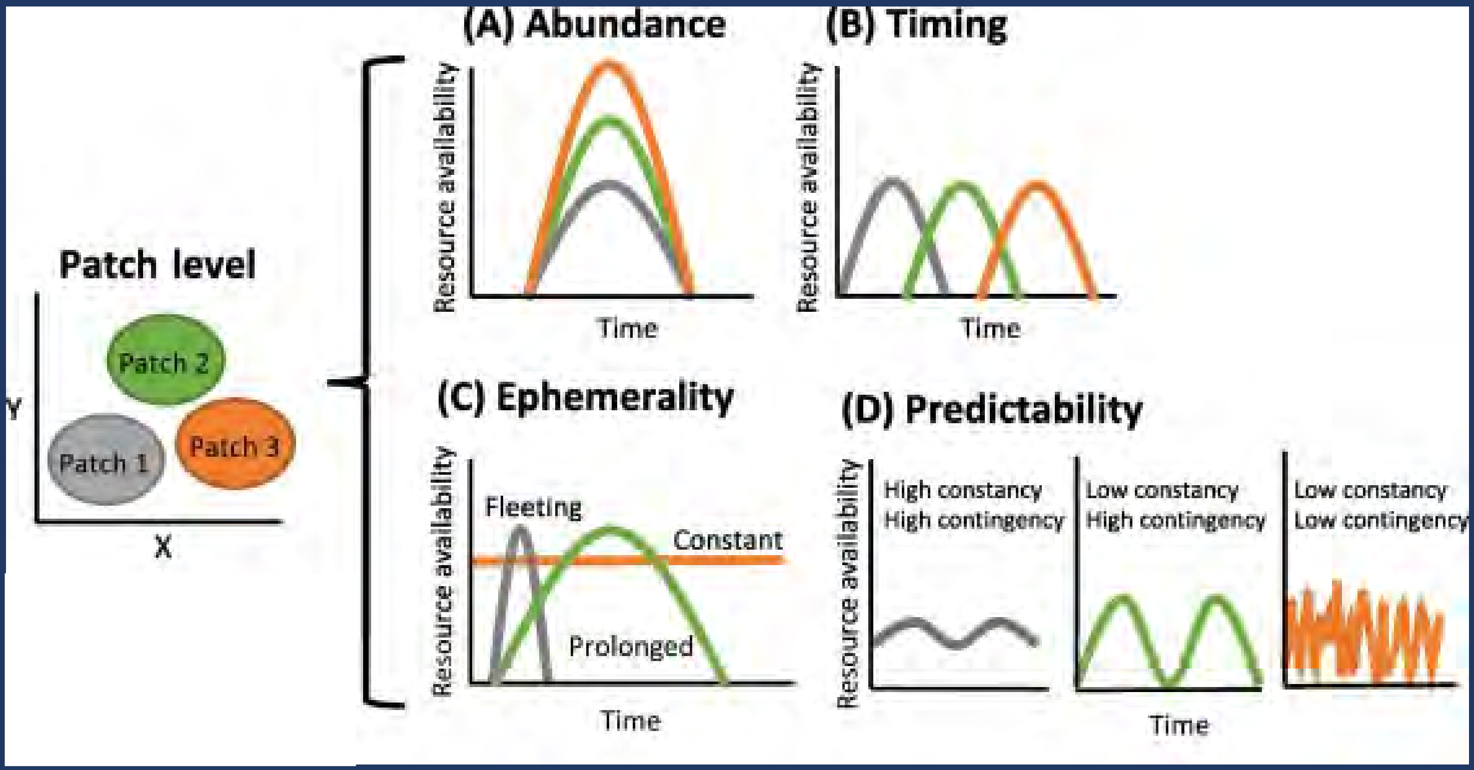


Warmer streams have earlier emergence, later salmon subsidies, and higher growth potential, so fish more likely to grow past 70 mm

Gape limit and temperature mediate effects of subsidy

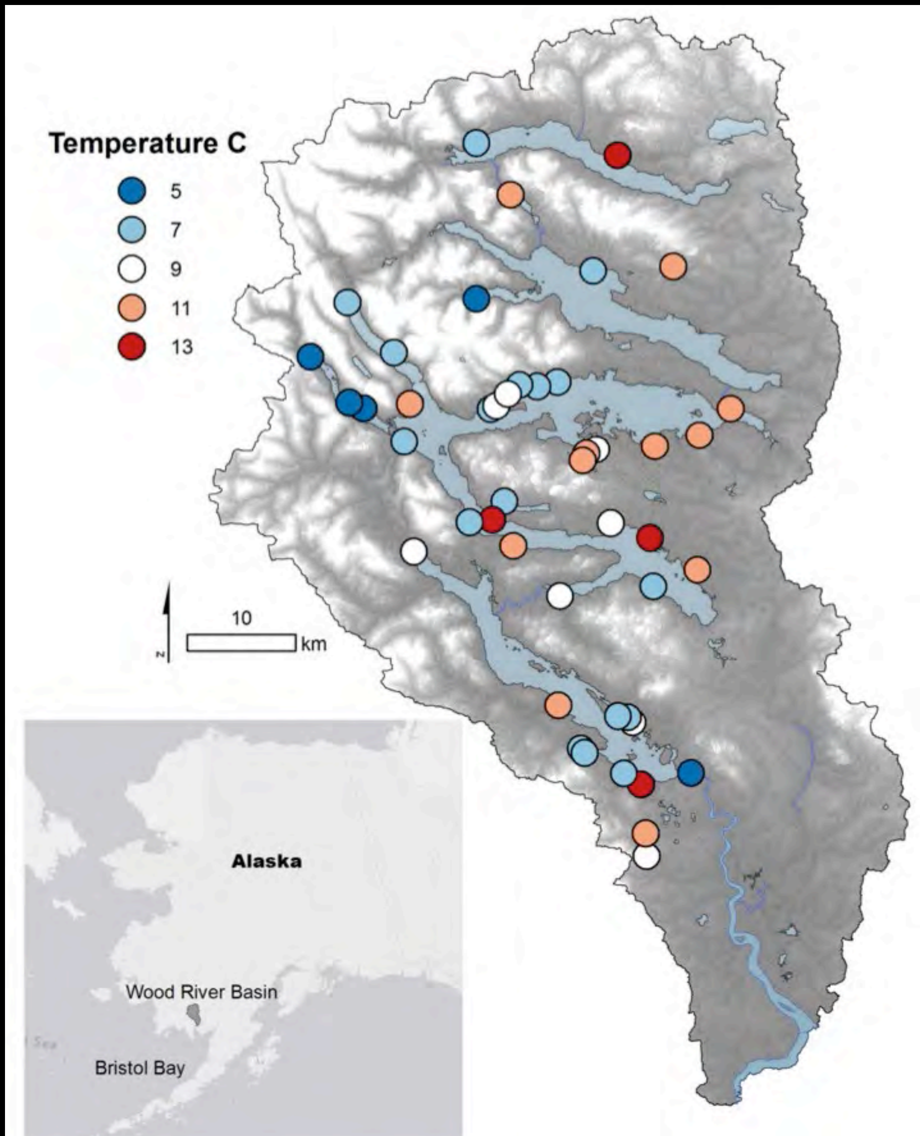


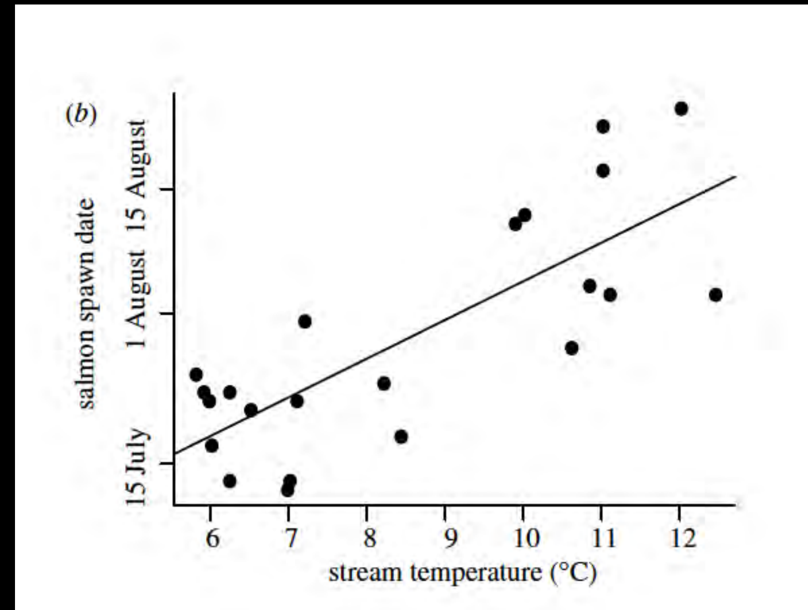
What about the timing across patches?



Mueller and Fagan 2008 *Oikos*
Abrahms et al. et al. 2021 *TREE*

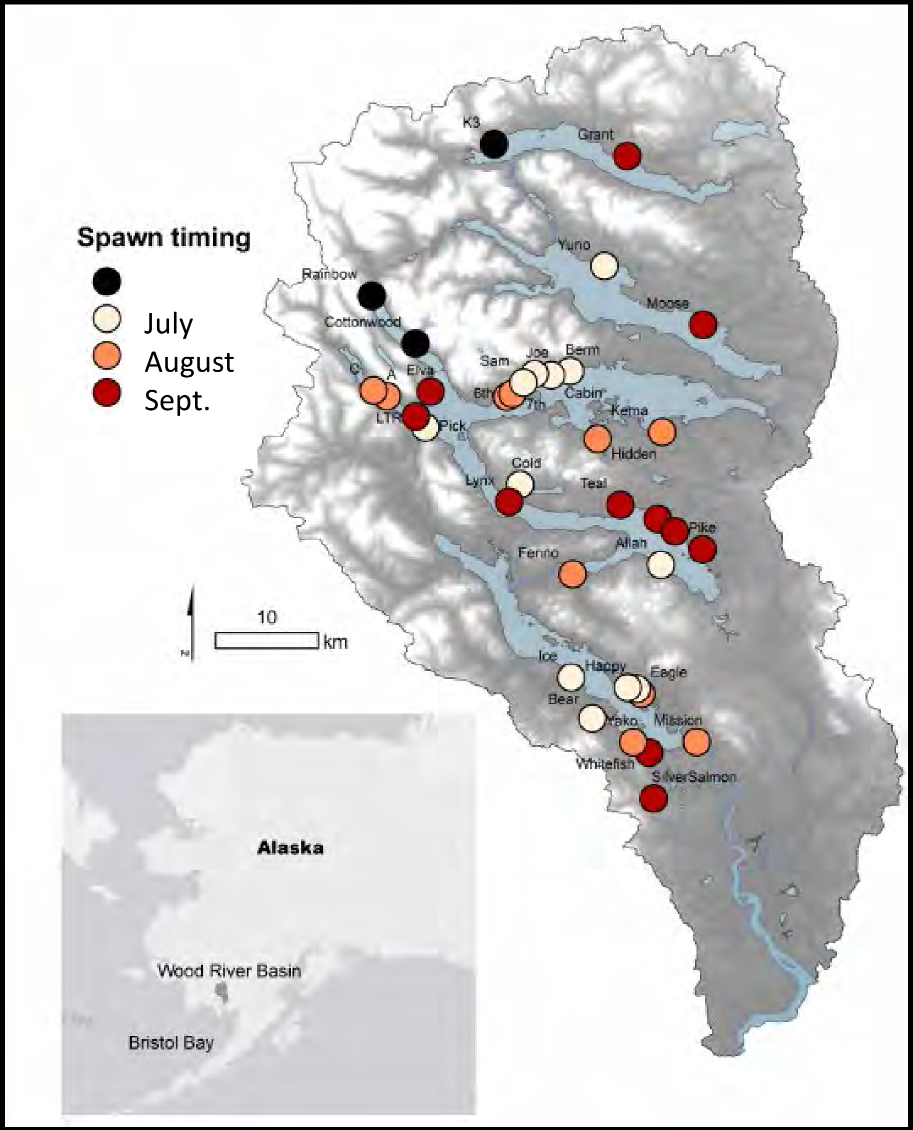
Thermal variation = phenological variation



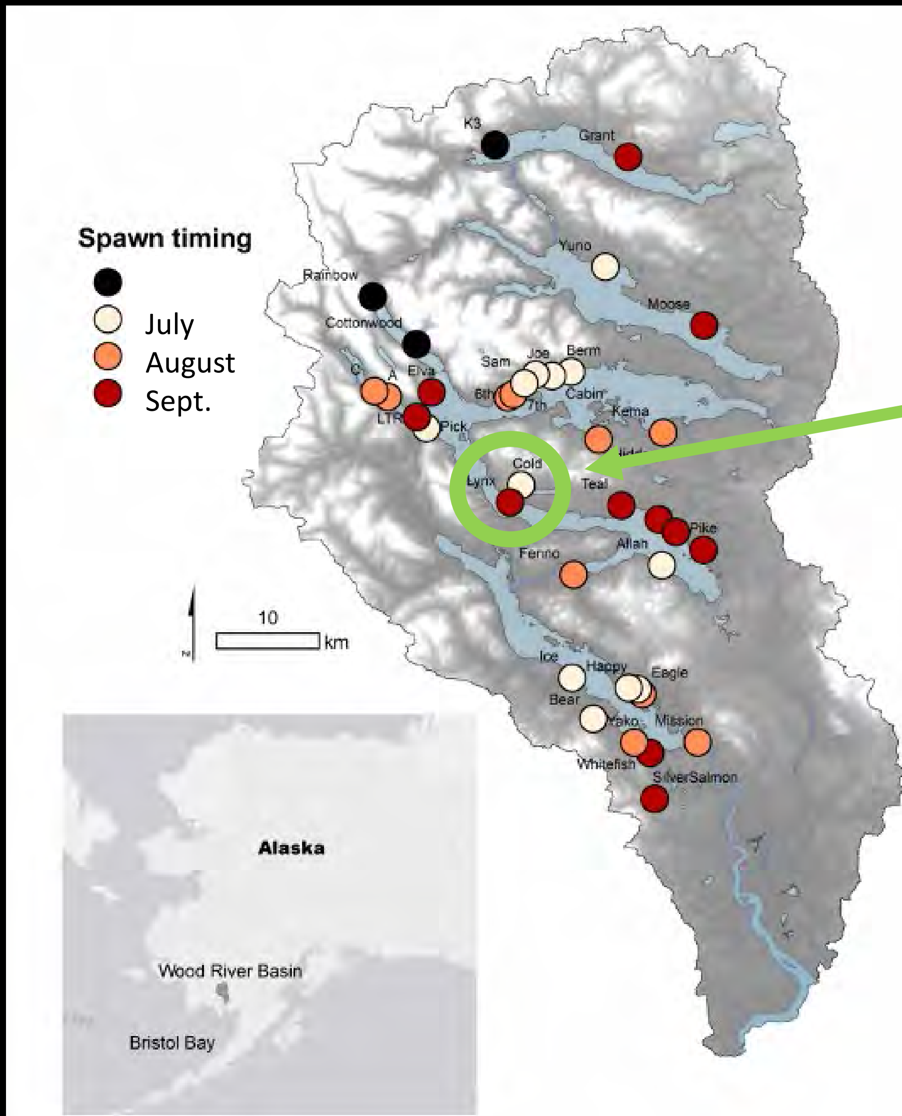


Lisi et al. 2013 *Geomorphology*

Implications depend on the consumer



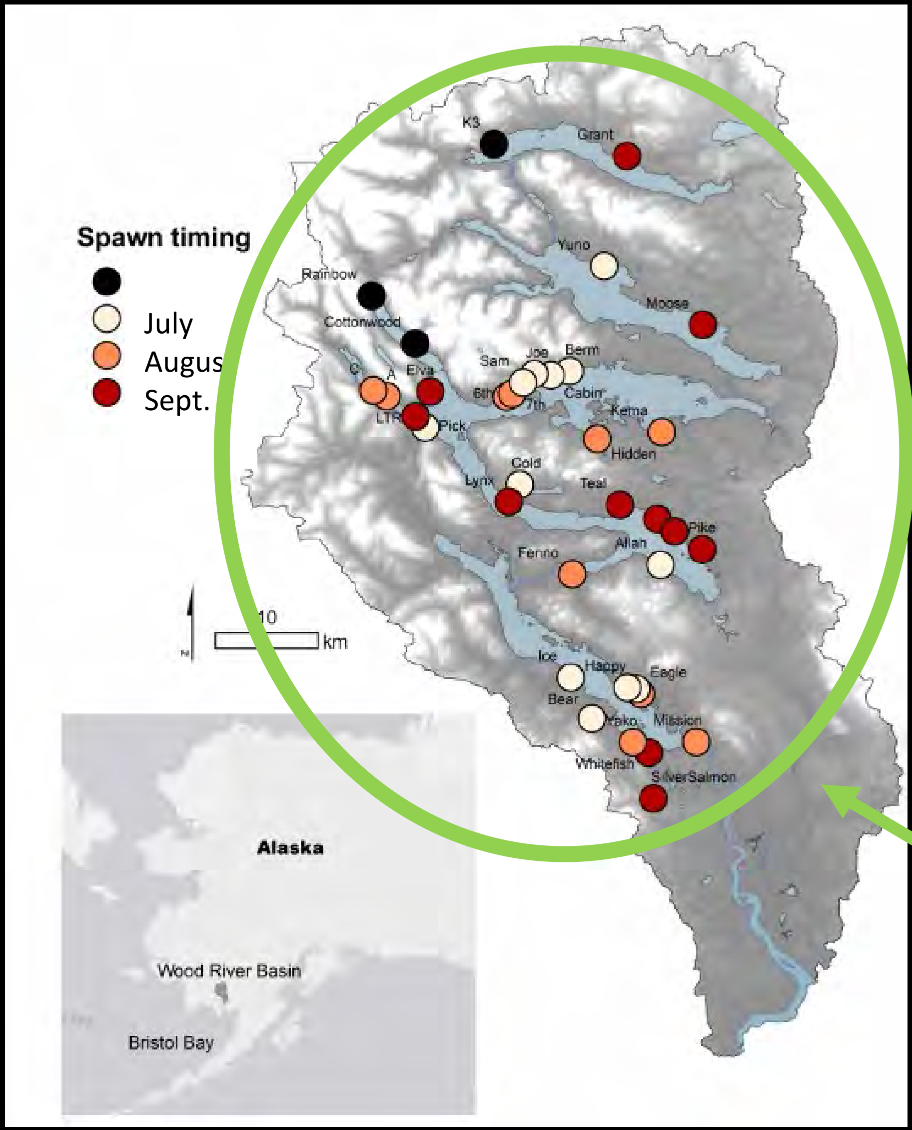
Phenological diversity protracts the availability of resource pulses



- Rainbow trout

Ruff et al. 2010 *Ecology*

Phenological diversity protracts the availability of resource pulses



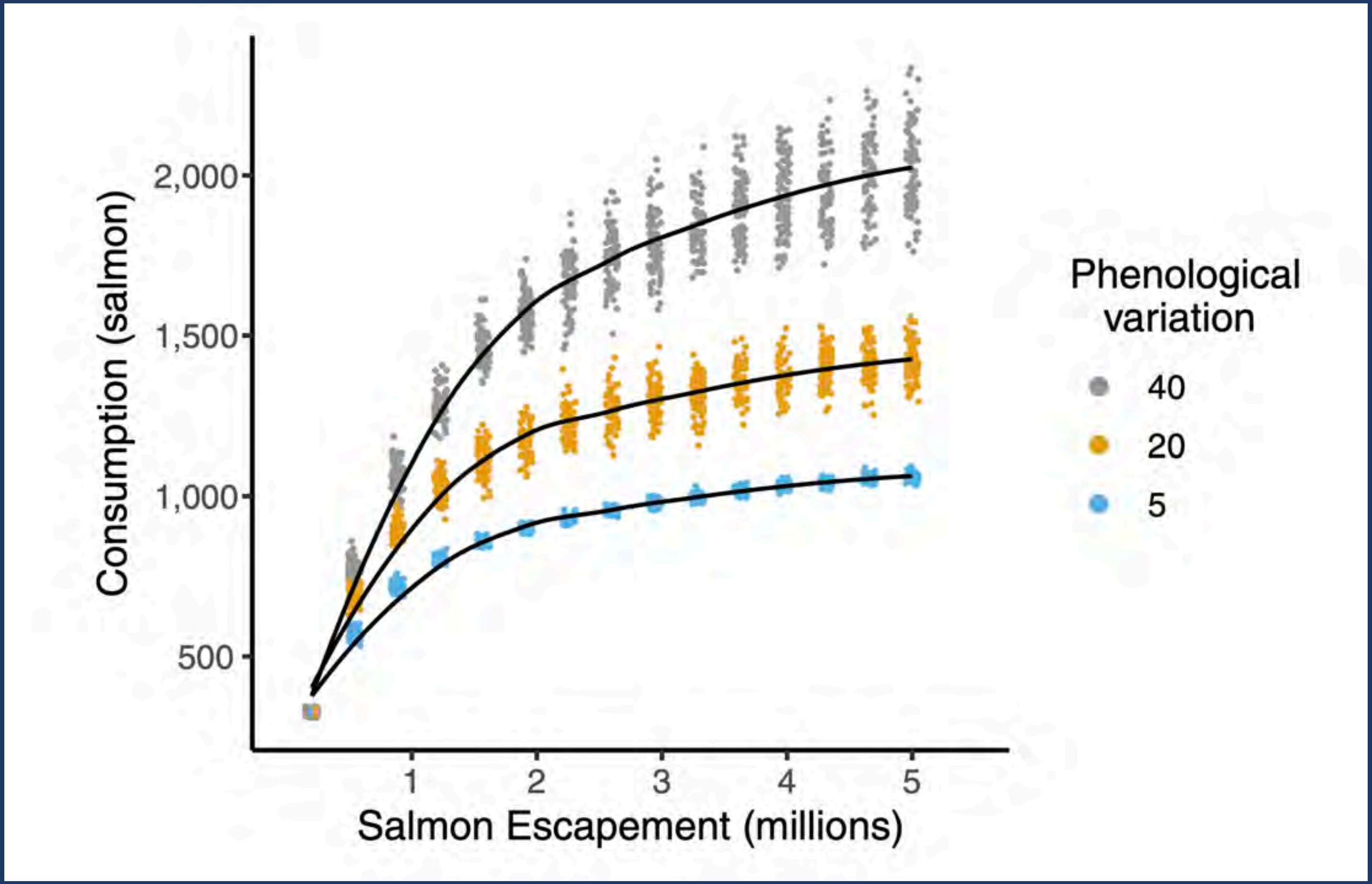
- Rainbow trout

Ruff et al. 2010 *Ecology*

- Bears, gulls, eagles

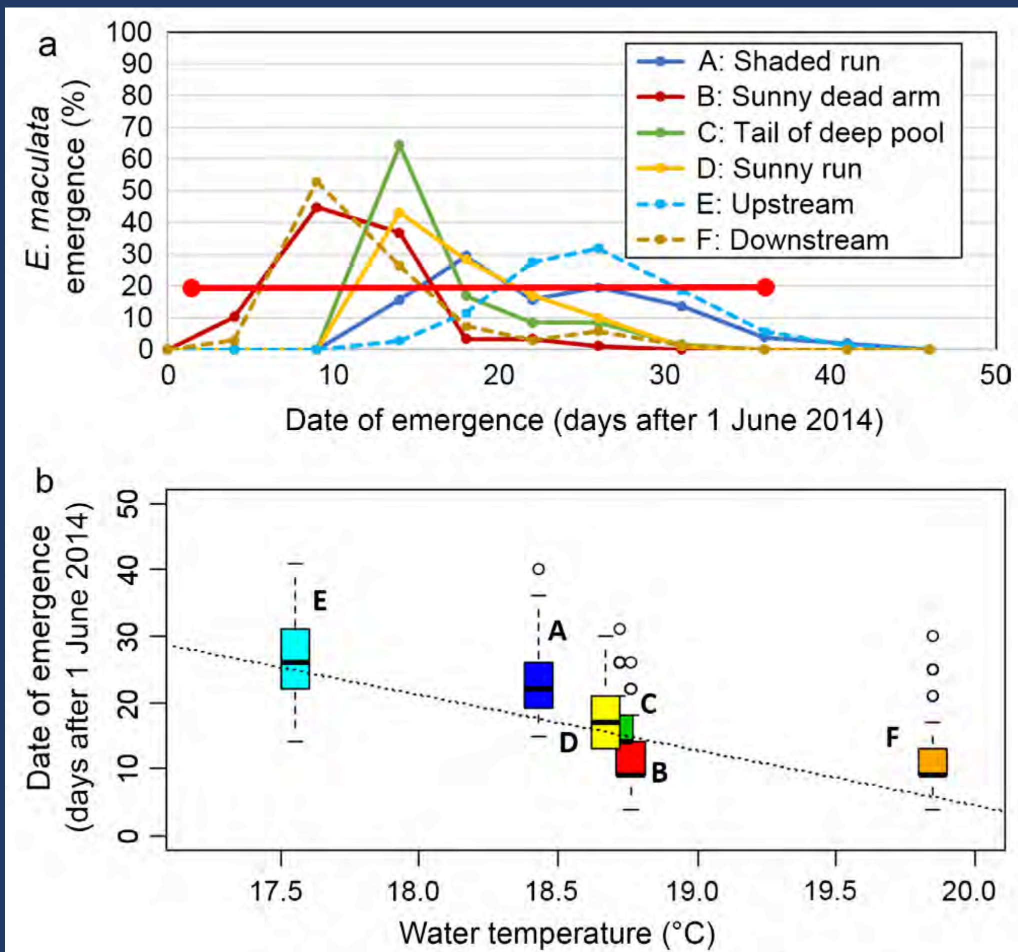
Schindler et al. 2013 *Biology Letters*

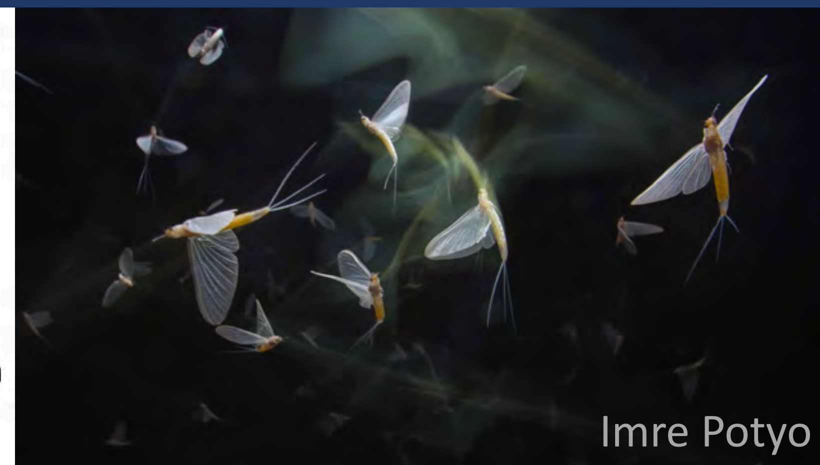
Key result from study of resource waves: phenological diversity magnifies the benefits of resource abundance



Armstrong et al. 2020 *Cons. Letters*

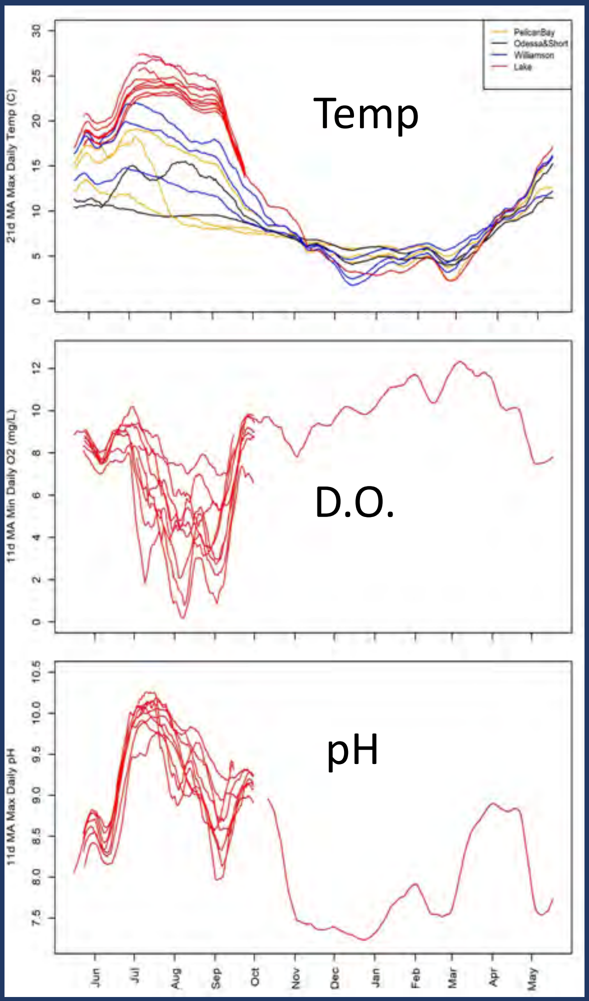
In branched linear networks, consumers may not have to move to exploit phenological diversity



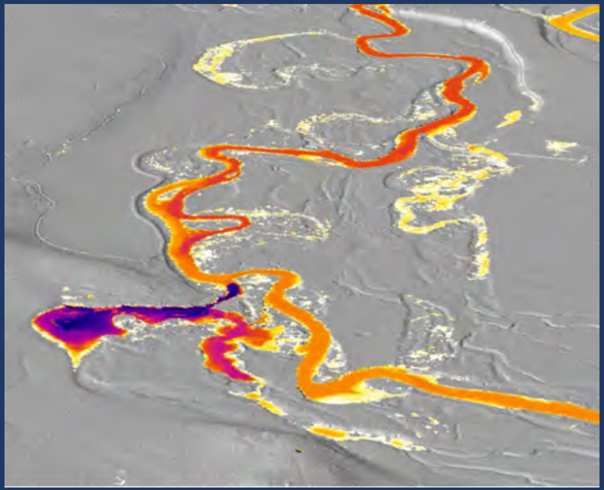


Uno 2016 *Ecology*

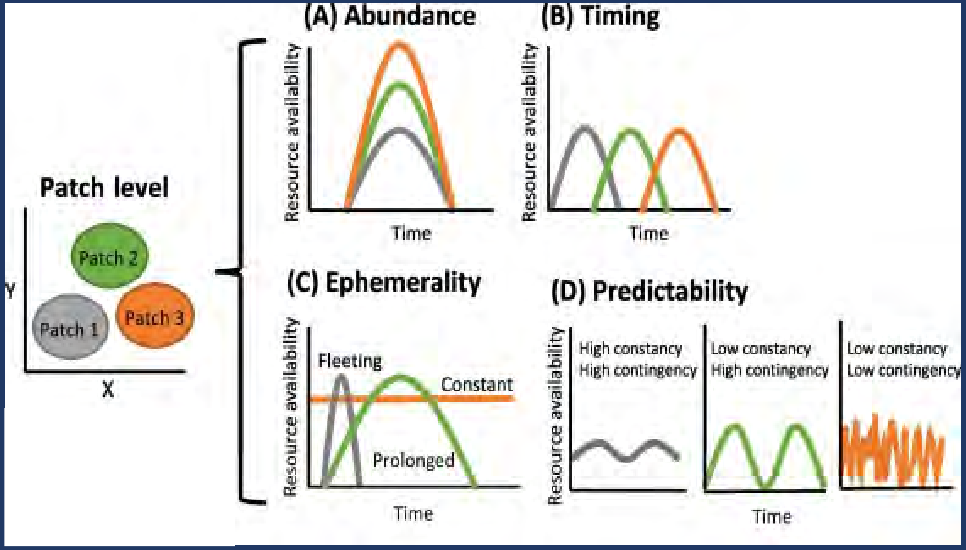
Food in suboptimal habitat



Habitat - time



Habitat - space



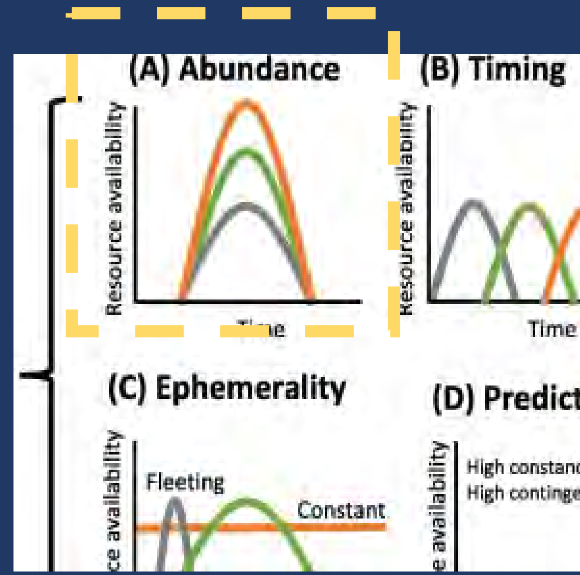
Feeding forays – dine and dash

Central mudminnow: feeds in anoxic hypolimnion
Rahel and Nutzman 1994 Ecology

Kokanee, coho, sculpin: feed in cold habitat, digest warm
Wurtsbaugh and Neverman 1988 Nature

Lake trout feed at dawn in warm littoral zone,
Morbey et al. 2006 J. Fish Biology

Feeding forays – dine and dash



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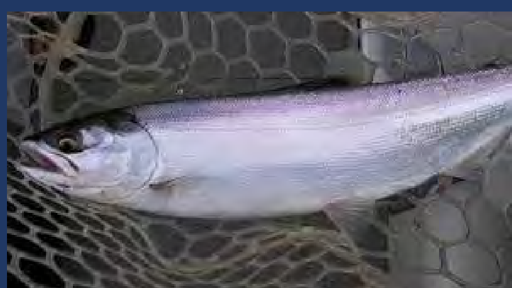

Kokanee, coho, sculpin: feed in cold habitat, digest warm
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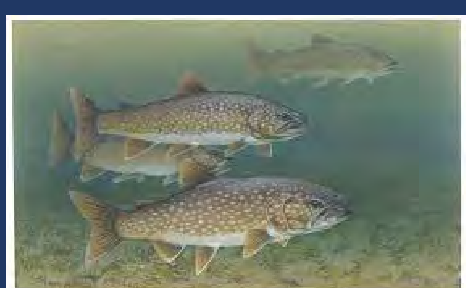
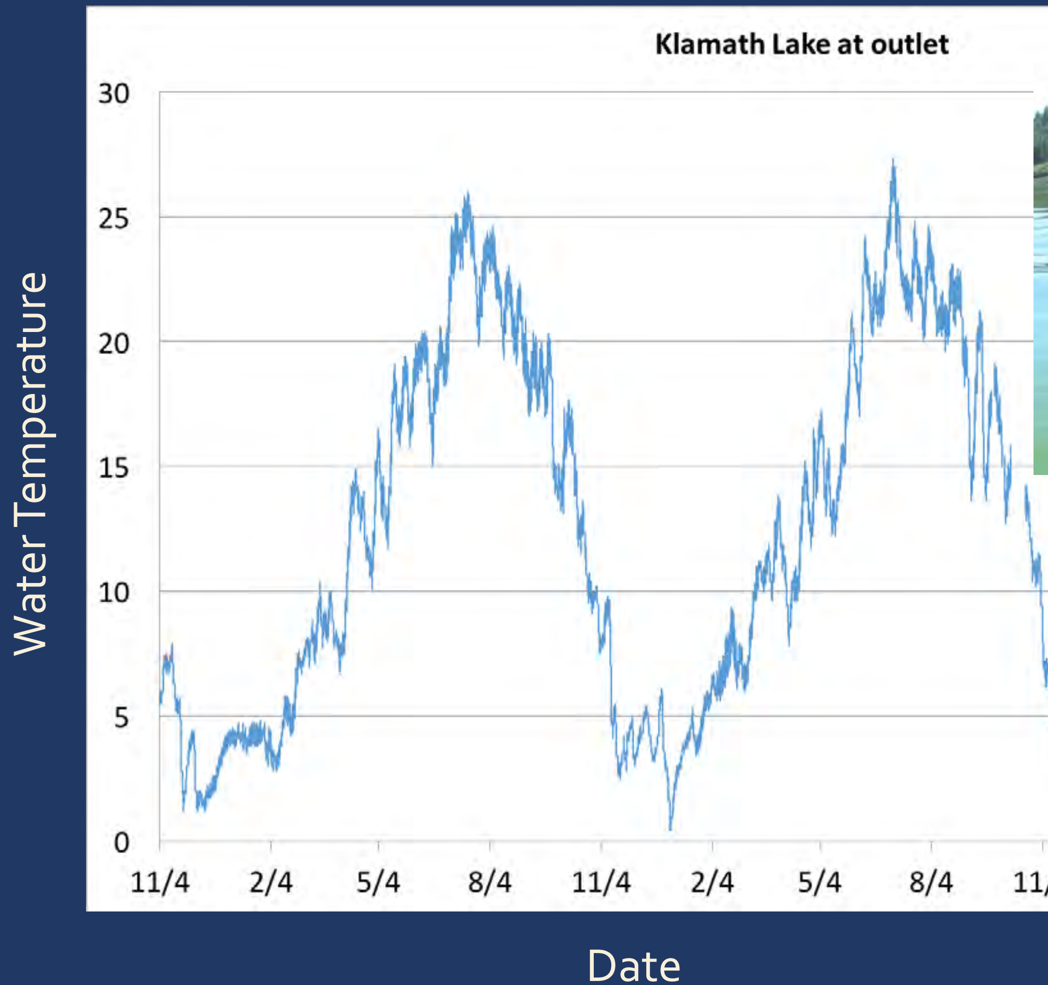
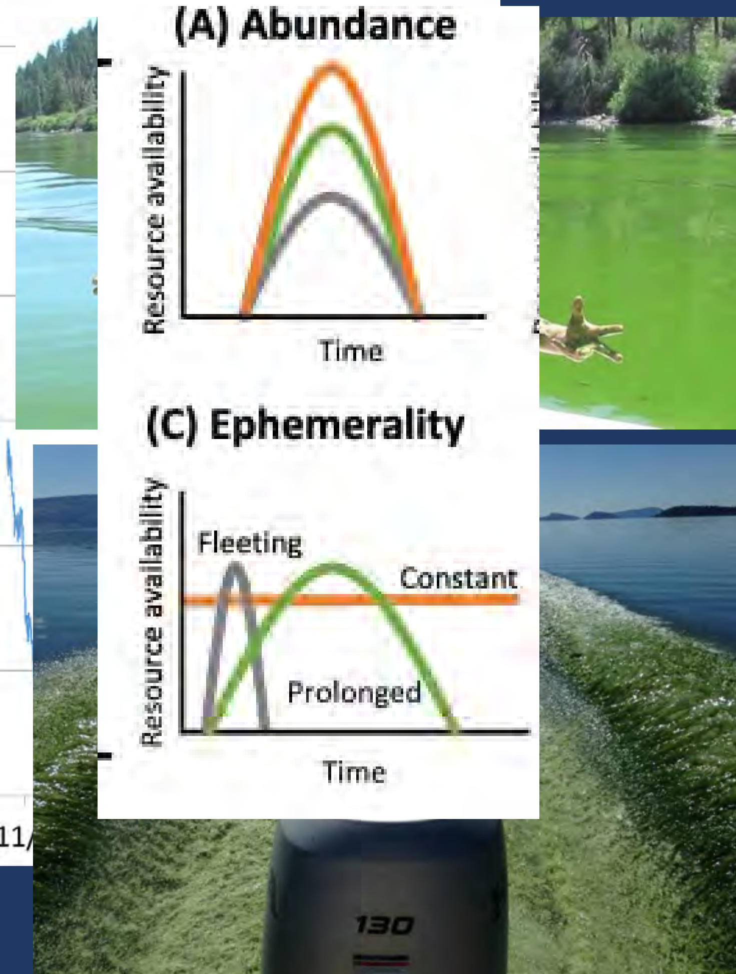


Lake trout feed in warm littoral zone, Morbey et al. 2006 J. Fish Biology

Sometimes nasty: U. Klamath Lake

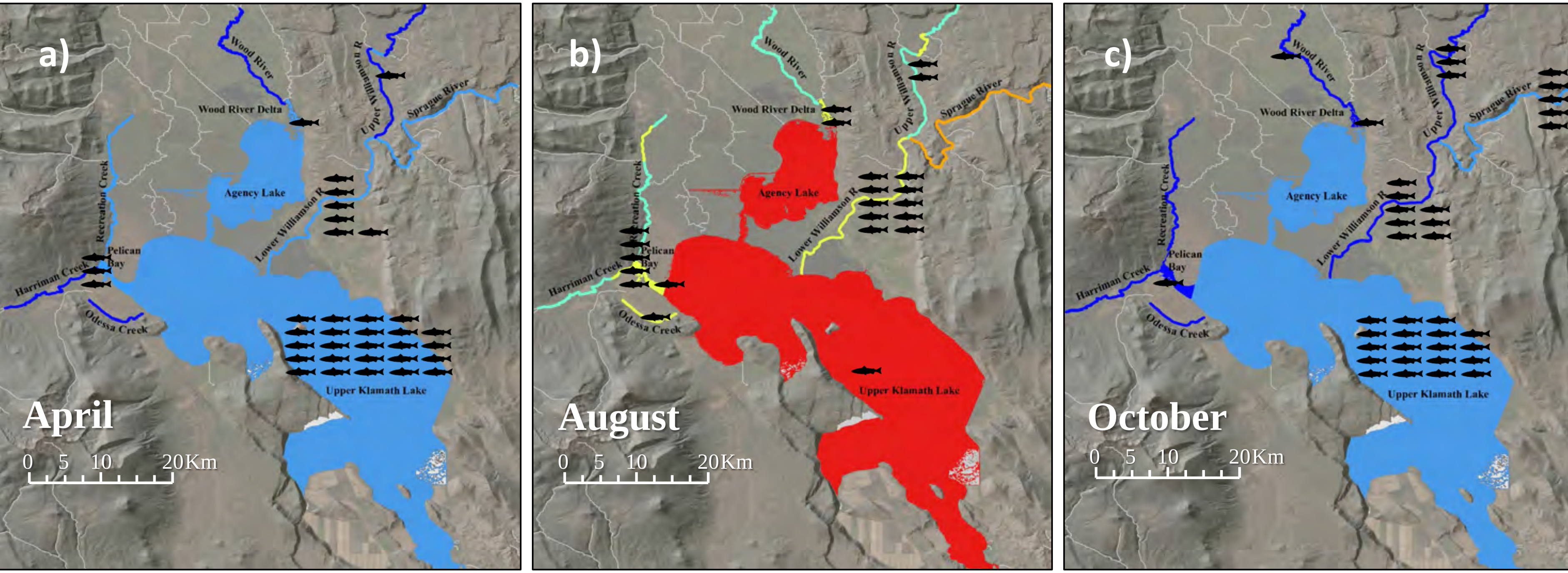
Sometimes nasty: U. Klamath Lake





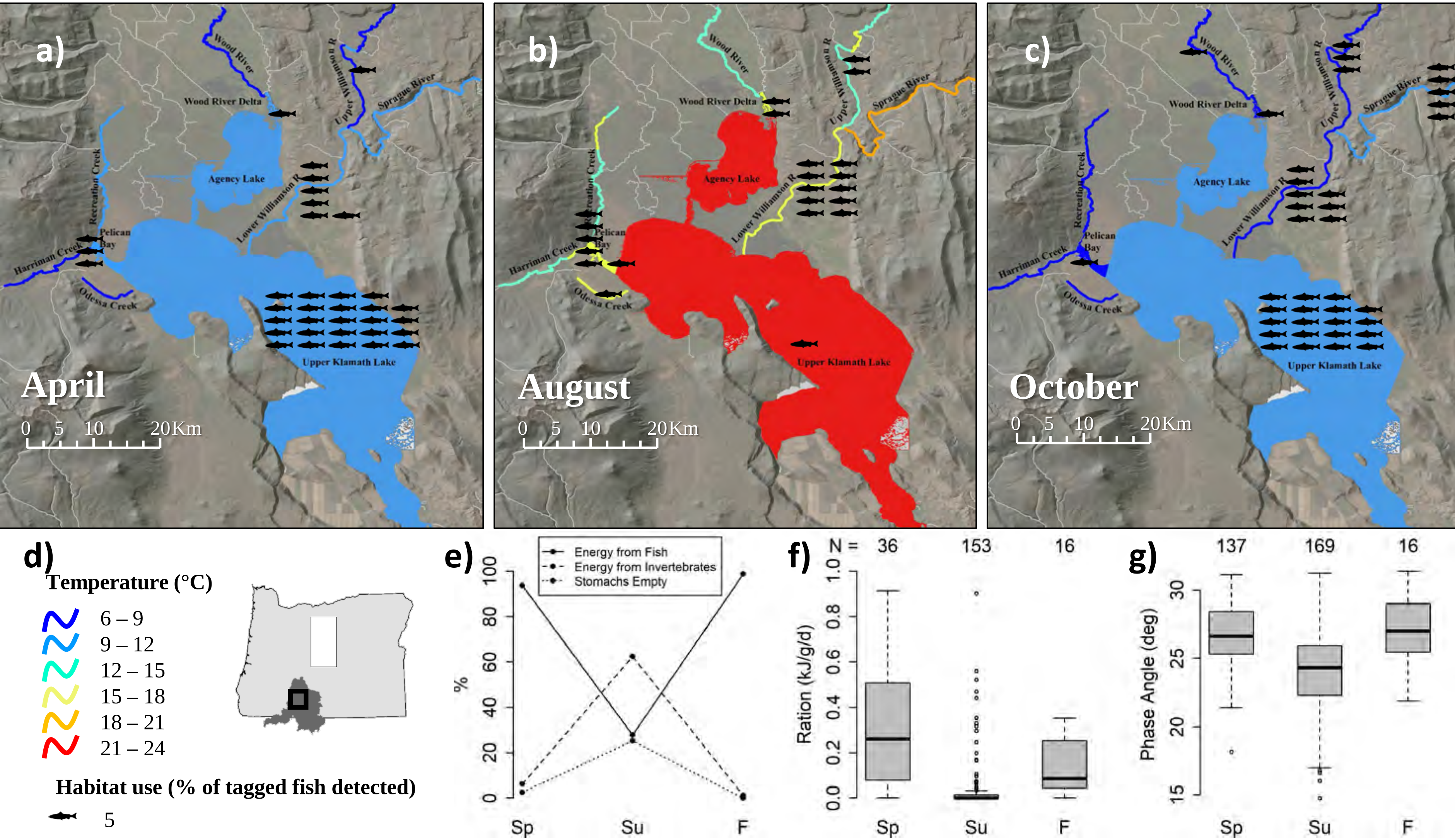
Summer: trout in cool tributaries

Redband trout use the lake in fall and spring

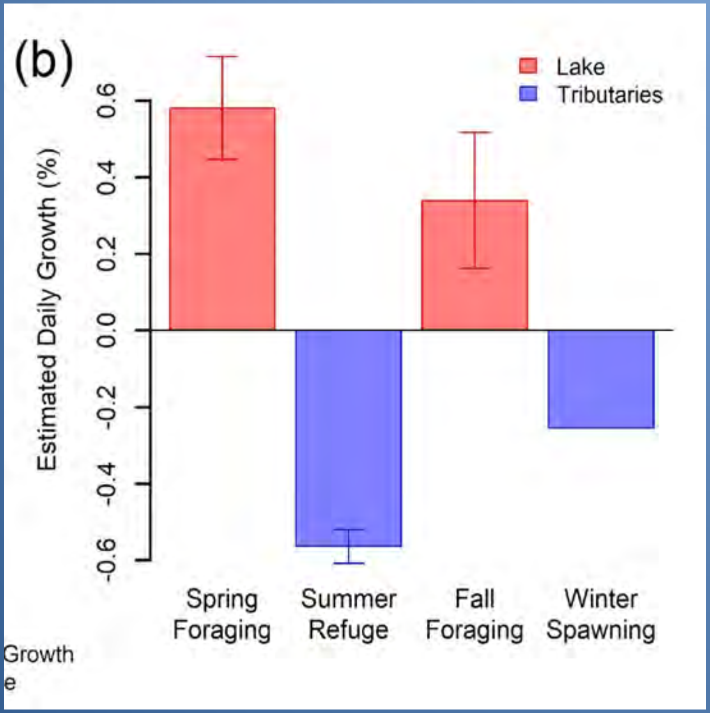


Sculpin from 1 diet sample

Trout pour on energy in the lake, lose energy on summer refuges



Seasonal energy budget: warm water pays the bills for adult trout



- Emphasizes importance of complementary habitats types
- Shows how productive warm habitat can provide pulses of growth during shoulder seasons

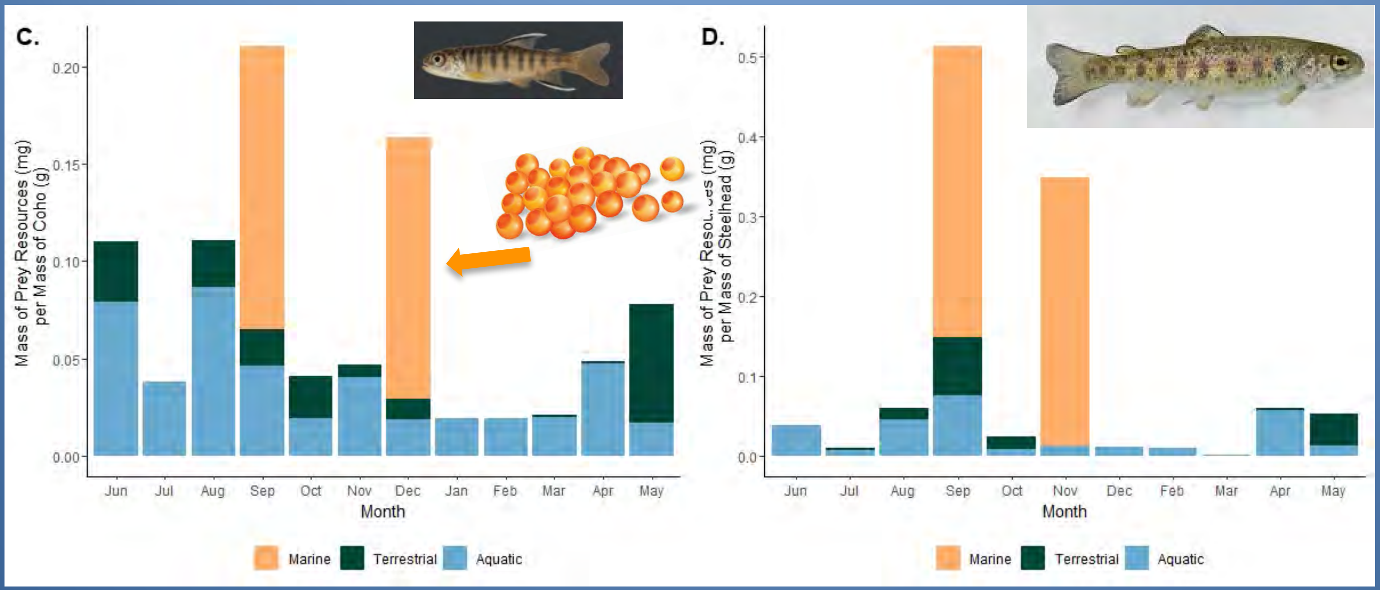
Conclusions

- Food abundance may not always translate into foraging opportunity
- The timing of food availability can be important
- Seemingly lethal habitat can sometimes play a role in fueling fish populations
- Accounting for these food X time interactions can alter how we rank habitats in conservation prioritization

Thanks!

- Rob for inviting me
- Our research group
- NW CASC
- ODFW, Klamath Tribes, TU
- Schindler Lab and ASP
- Bristol Bay Native Corporation

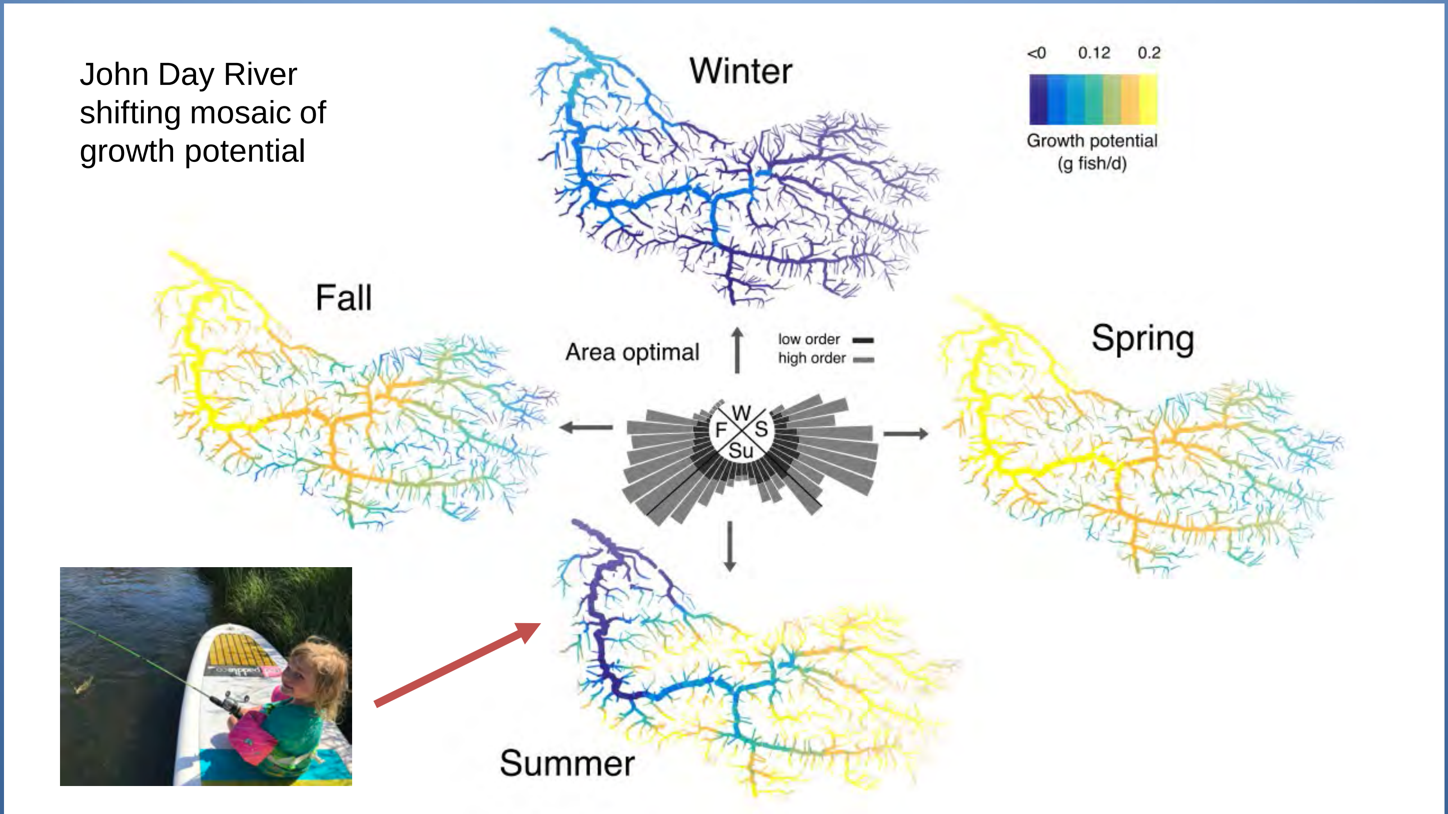
Depressed salmon runs can still trigger resource pulses



Monthly diet sampling
Skokomish River, WA

Megan Brady MS thesis in prep.

"Warm" habitat drives a massive expansion/contraction in the area of thermally optimal habitat



Making a living in a seasonal lagoon:

interactions among water temperature, prey availability, and juvenile salmonid growth.

Rosealea M. Bond, Cynthia H. Kern, Ann-Marie K. Osterback, Alexander E. Hay, Joshua M. Meko, Jeffrey M. Perez, Miles E. Daniels, and Joseph D. Kiernan

SRF 2022

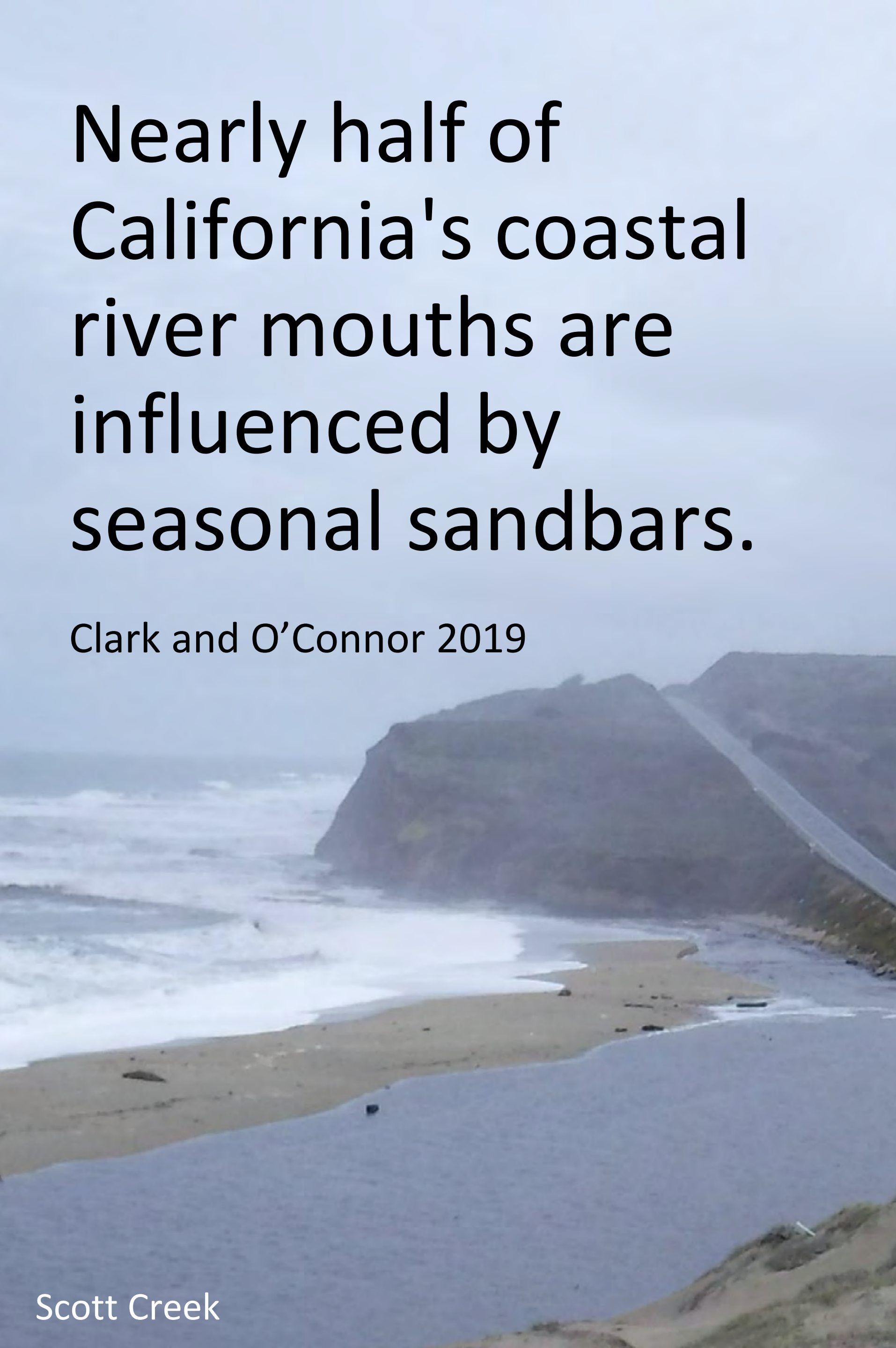
Land Acknowledgement

UCSC and Scott Creek are part of "the unceded territory of the Awaswas-speaking Uypi Tribe. The Amah Mutsun Tribal Band, comprised of the descendants of indigenous people taken to missions Santa Cruz and San Juan Bautista during Spanish colonization of the Central Coast, is today working hard to restore traditional stewardship practices on these lands and heal from historical trauma."

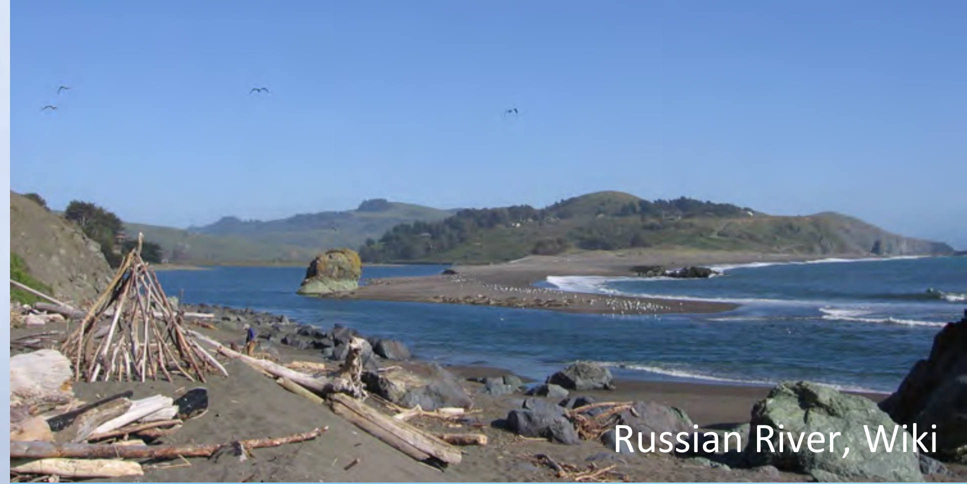

Columbia River, Wiki

Nearly half of California's coastal river mouths are influenced by seasonal sandbars.

Clark and O’Connor 2019



Scott Creek

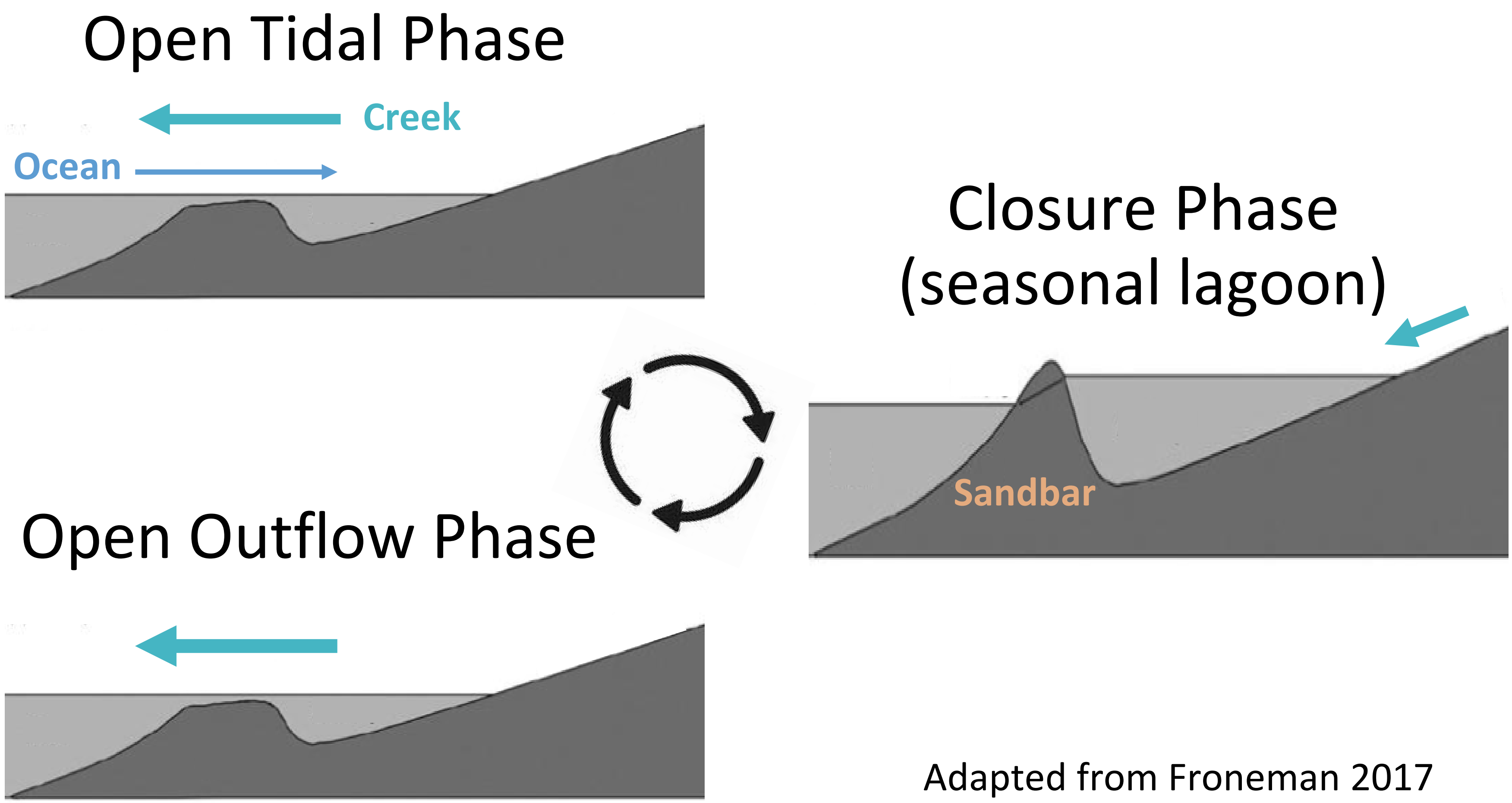


Russian River, Wiki

Pescadero Creek, SM RCD

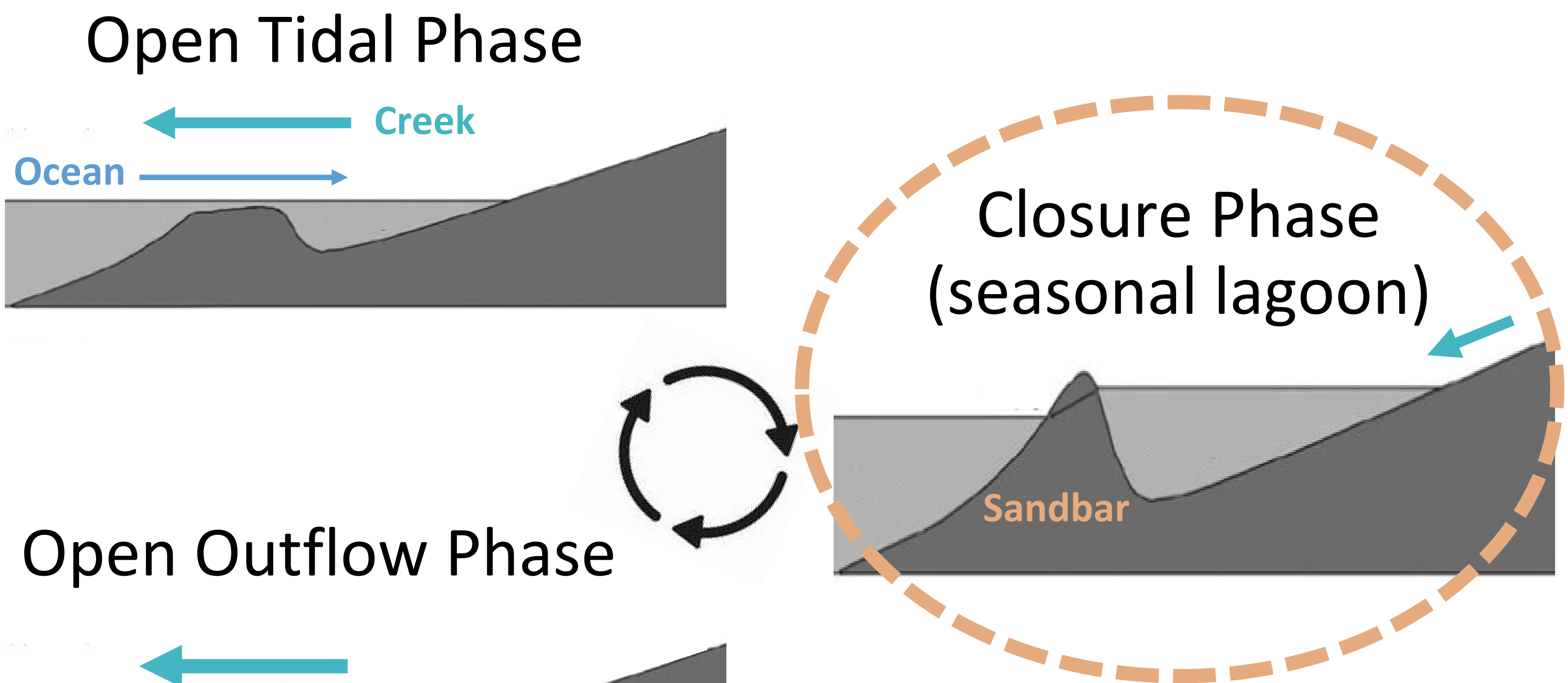
Carmel River, State Parks

River mouth open-close cycle



Adapted from Froneman 2017

River mouth open-close cycle



Adapted from Froneman 2017

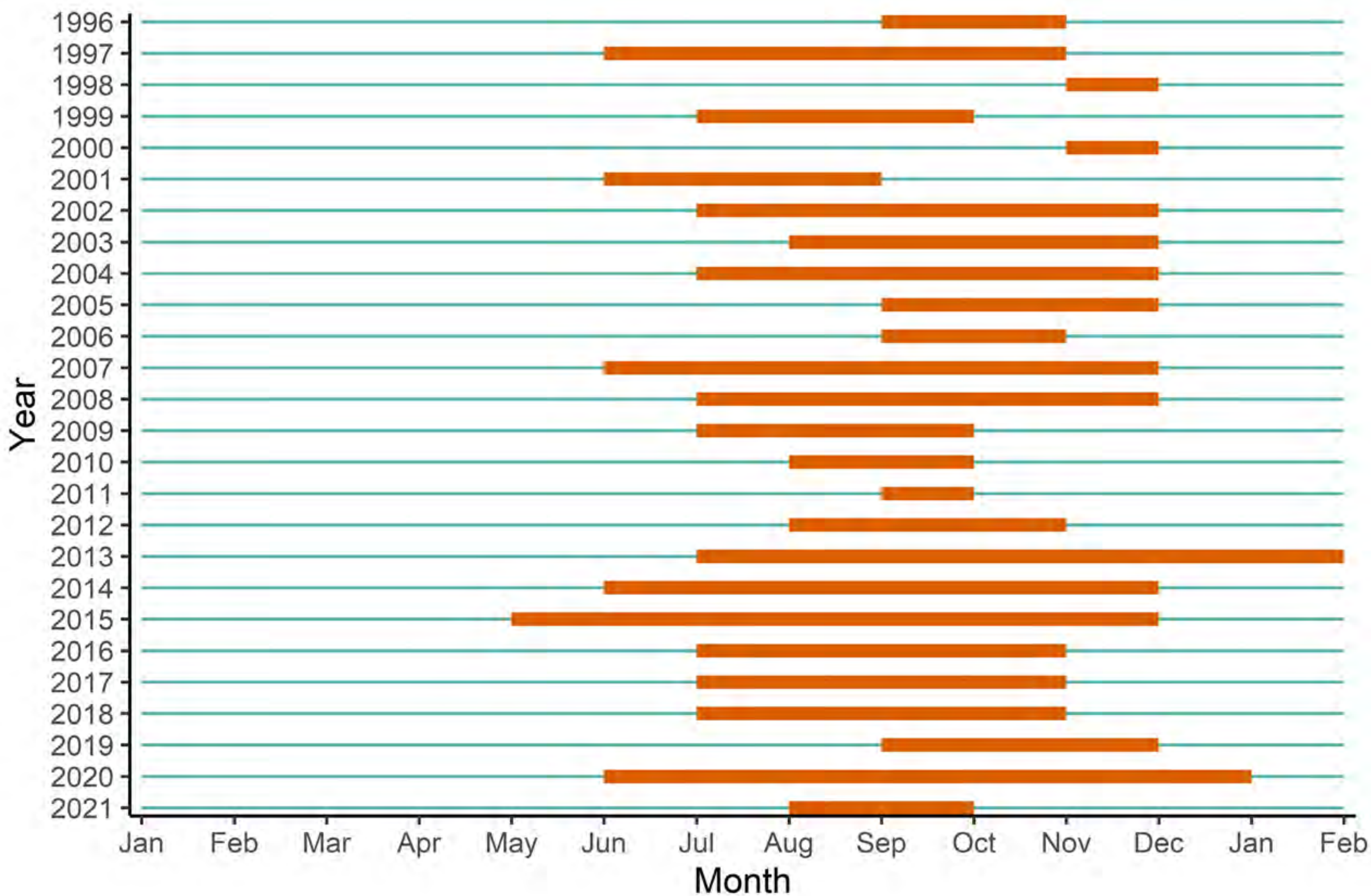
Scott Creek Estuary/Lagoon

Santa Cruz County Parks

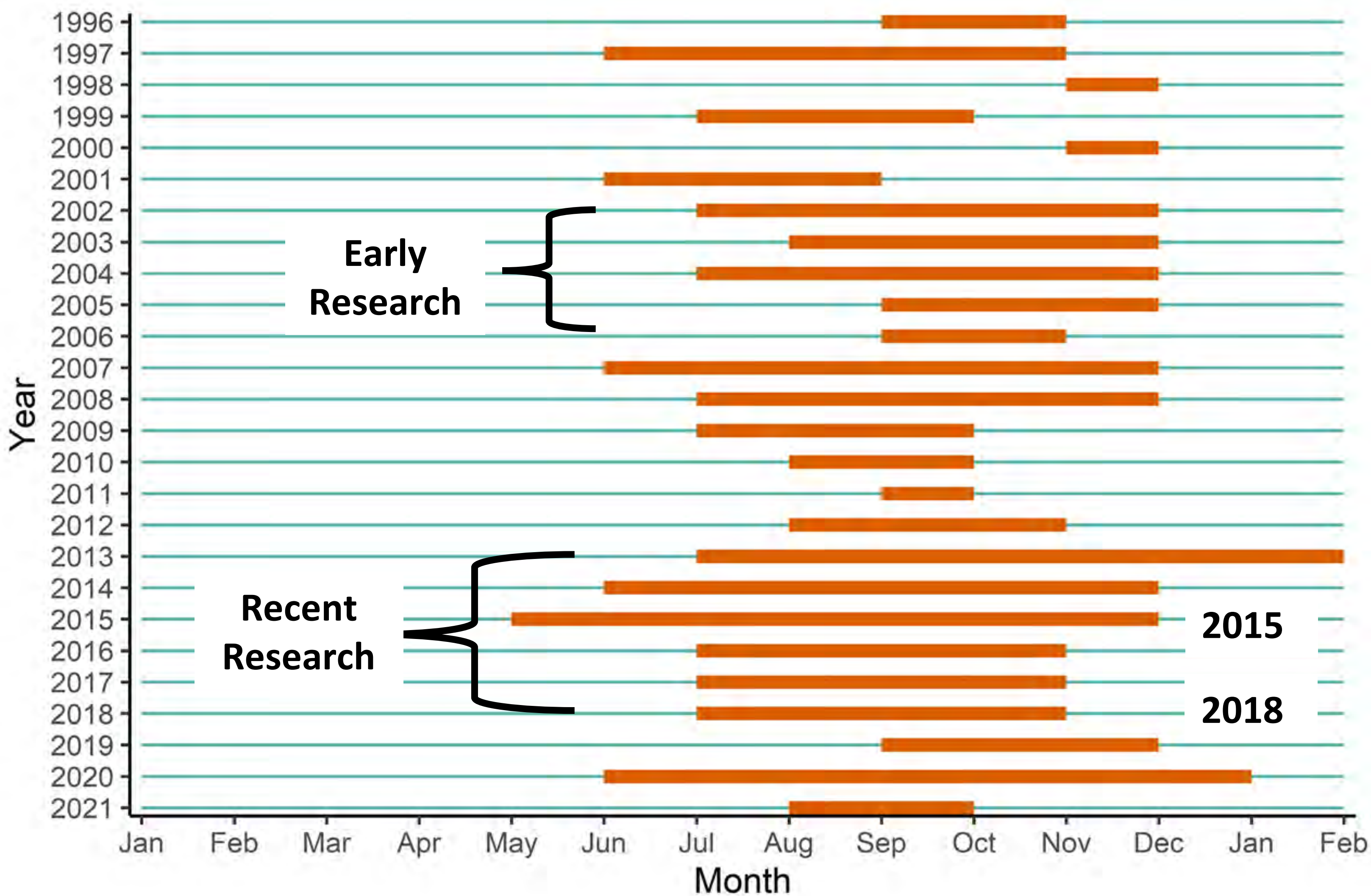

Riverine
Lagoon
Google Earth


Right photos © Kenneth & Gabrielle Adelman
www.californiacoastline.org

Scott Creek Mouth Closure Period

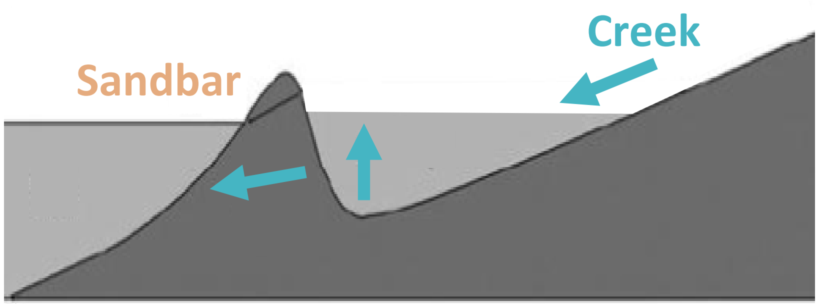


Scott Creek Mouth Closure Period

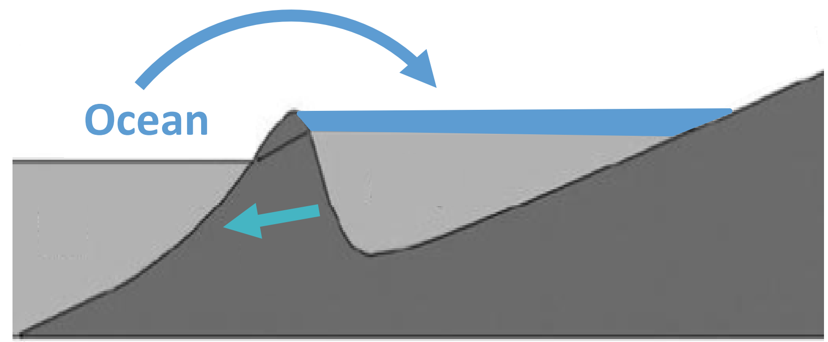


More emphasis on lagoon processes

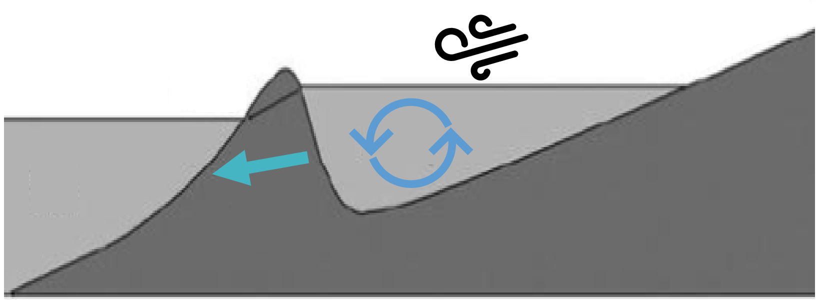
Lagoon Filling



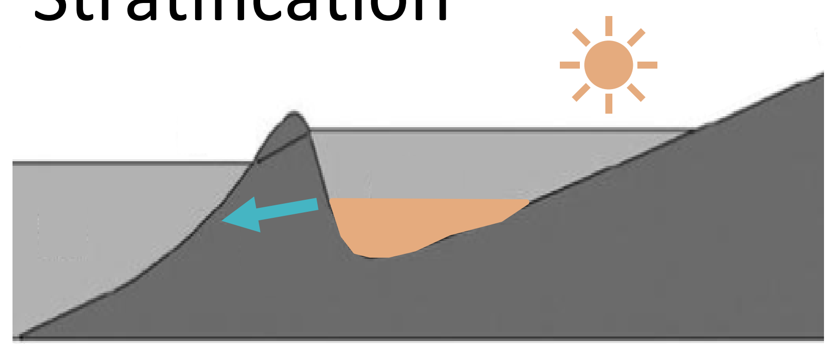
Overwash Events



Wind driven mixing



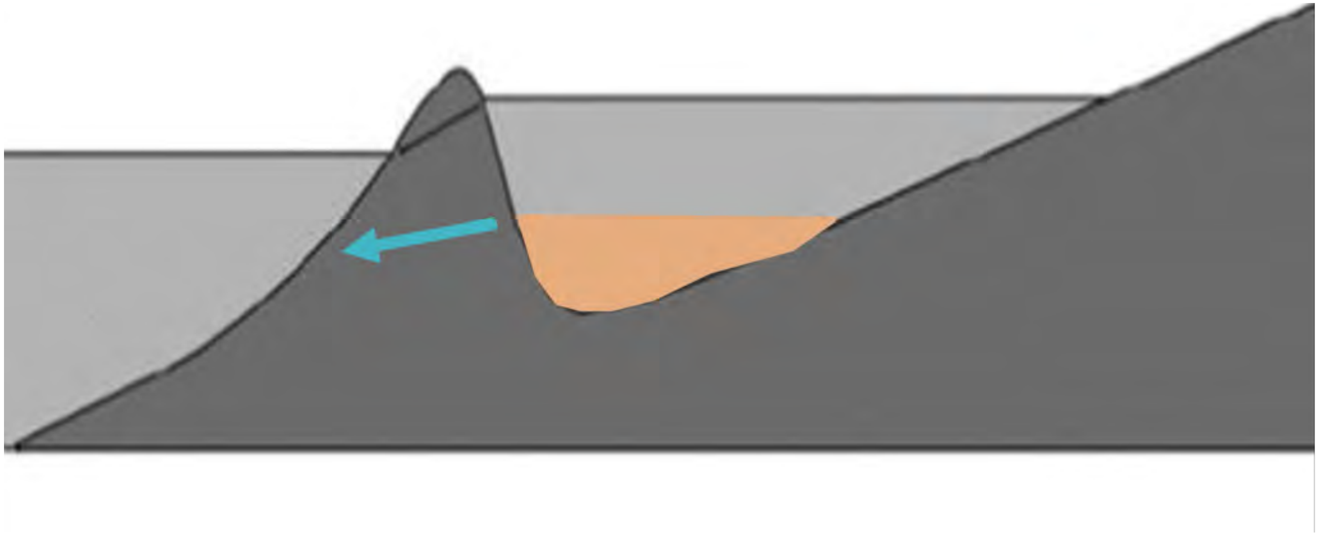
Stratification



Inspired by Behrens et al. 2013; Behrens, Bombardelli & Largier 2015

Stratification is a key stressor for salmonids

- Becoming more commonplace with drying climate,
- Low dissolved oxygen concentrations,
- Approach or exceed thermal limits,
- Affect large areas due to habitat homogeneity.



Community structure and food web dynamics

Juvenile Steelhead
(*Oncorhynchus mykiss*)

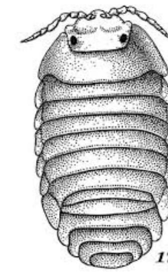
Juvenile coho salmon
(*Oncorhynchus kisutch*)

Tidewater goby
(*Eucyclogobius newberryi*)

Threespine stickleback
(*Gasterosteus aculeatus*)

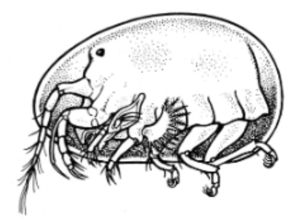
Pacific staghorn sculpin
(*Leptocottus armatus*)

Amphipoda
(*Eogammarus* sp.)

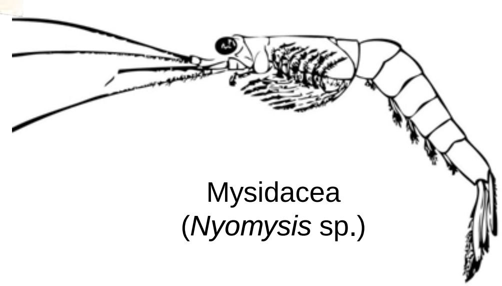


Isopoda
(*Gnorimosphaeroma* sp.)

Amphipoda
(*Americorophium* sp.)



Ostracod



Mysidacea
(*Nyomysis* sp.)

Credit: M. Bond, OSU, J. Sartore, C. Gross, Park Service, and others.

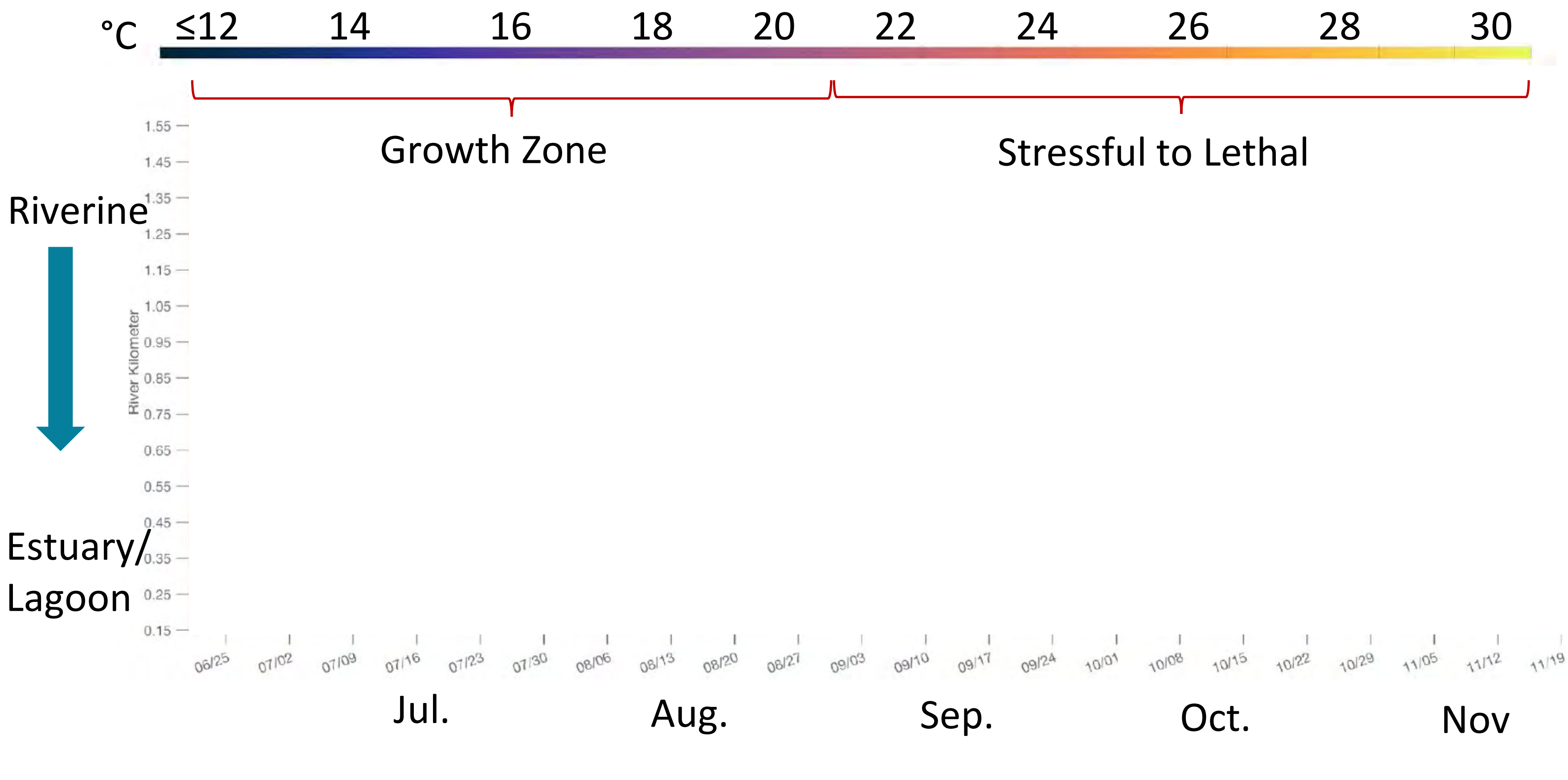
2018 STUDY

Our goals were to:

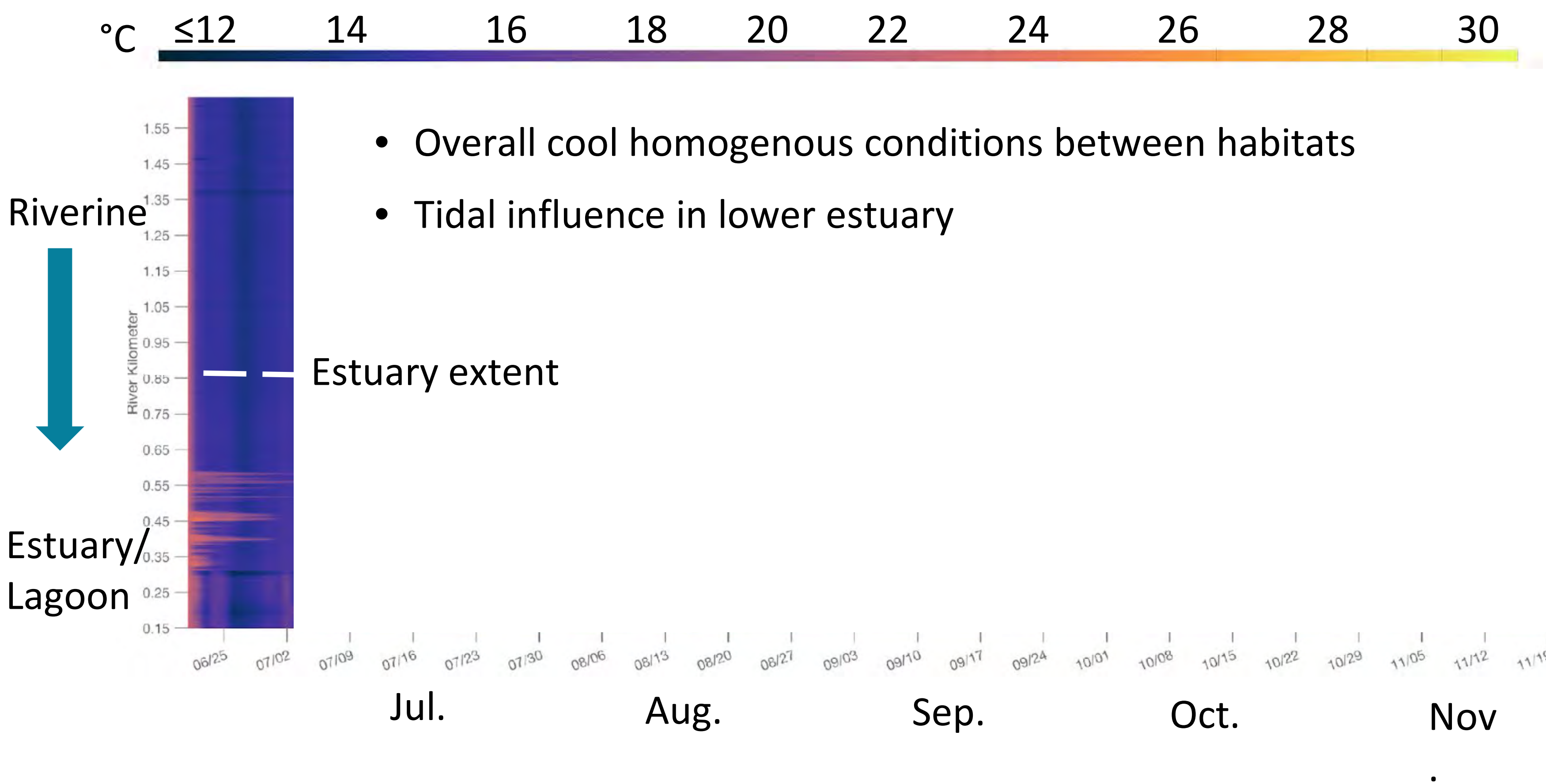
1. Characterize thermal environment over space and time,
2. Quantify juvenile steelhead performance (abundance and growth),
3. Investigate movement patterns within and among habitats.

Distributed Temperature Sensing: Fine-grained temperature monitoring

DTS revealed dynamic conditions within the lagoon



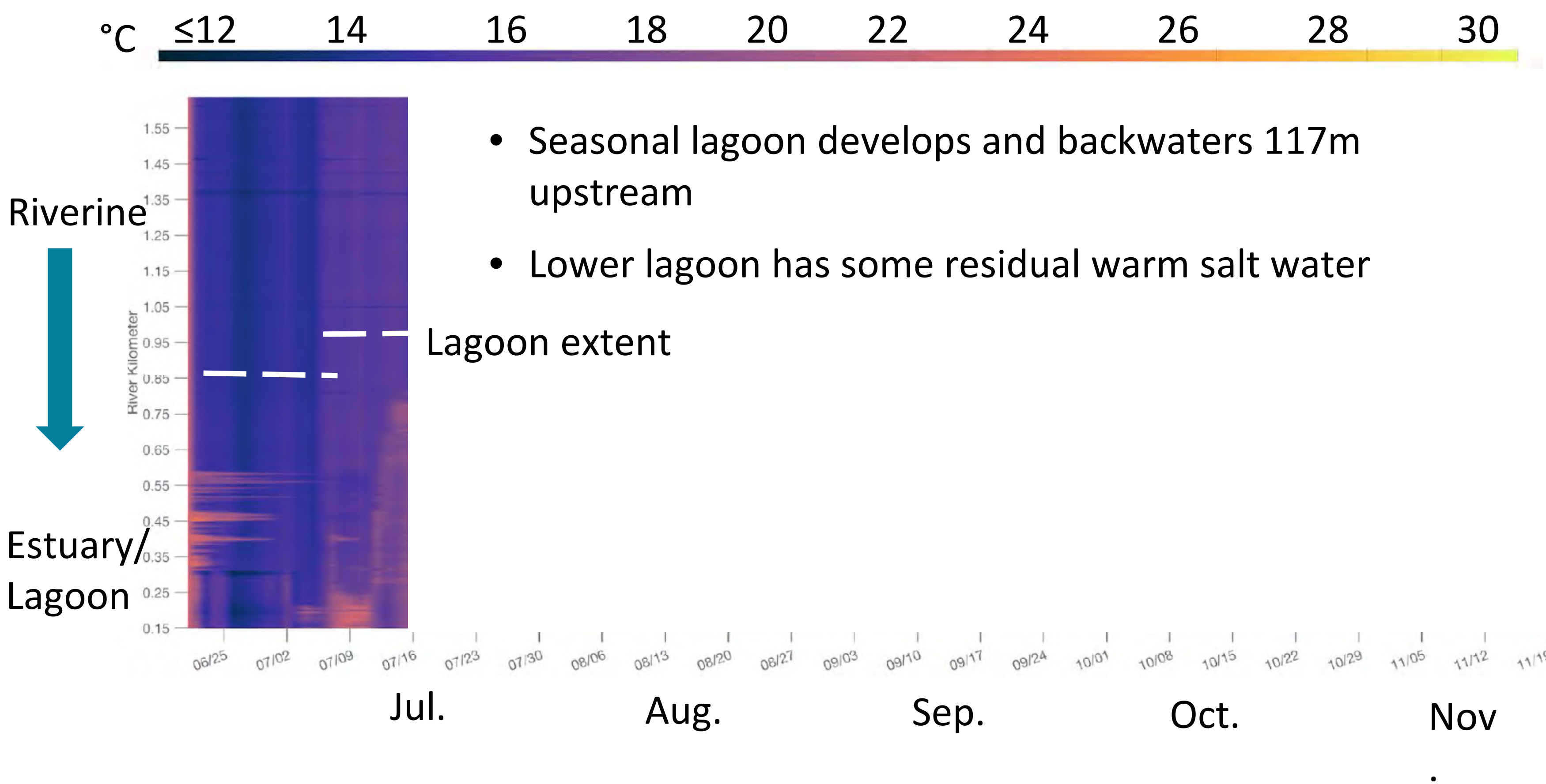
Tidal phase (pre-sandbar)



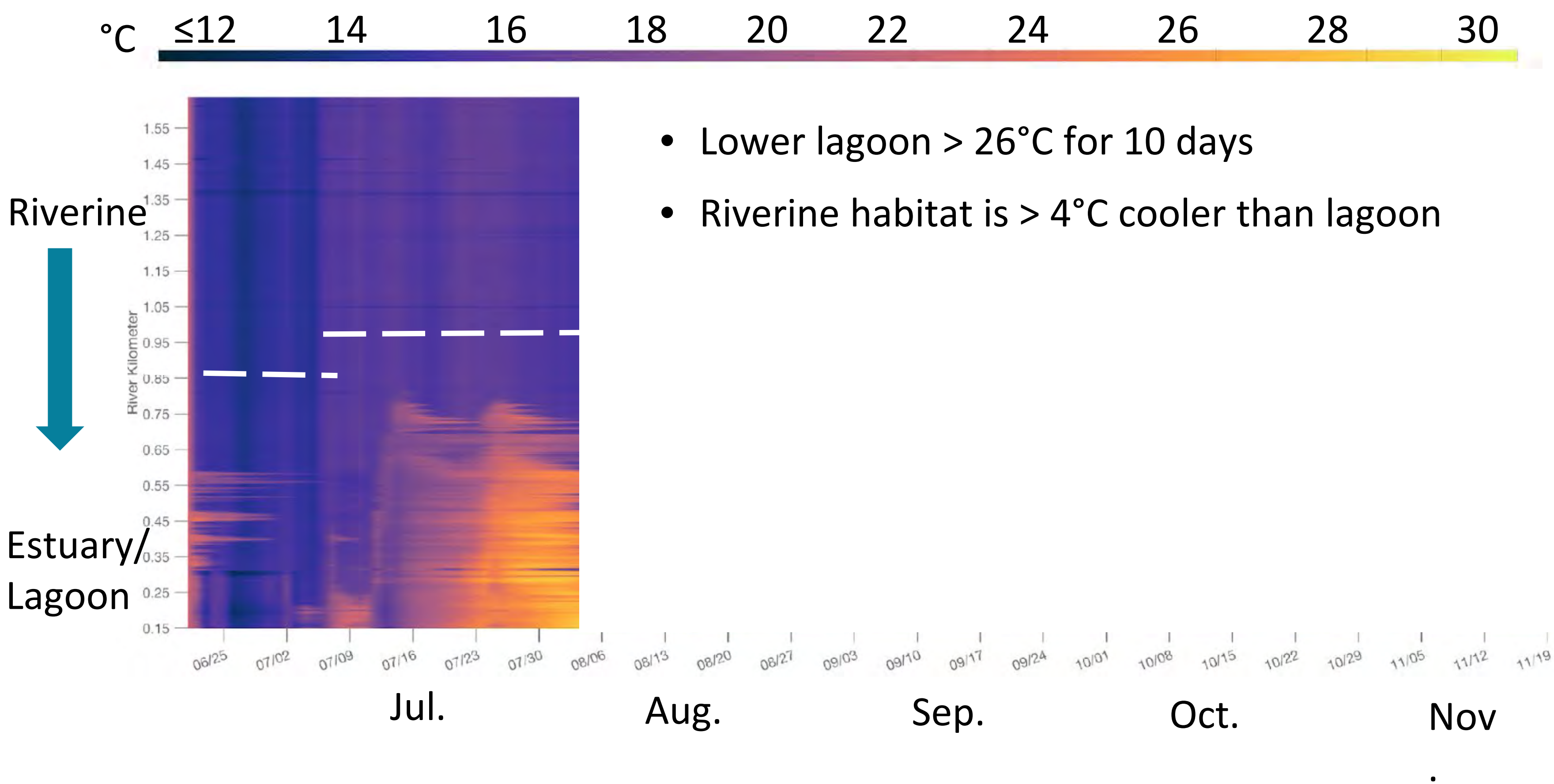
- Overall cool homogenous conditions between habitats
- Tidal influence in lower estuary

Sandbar Formation

- Seasonal lagoon develops and backwaters 117m upstream
- Lower lagoon has some residual warm salt water



Wave overwash leads to stratification



- Lower lagoon > 26°C for 10 days
- Riverine habitat is > 4°C cooler than lagoon

Wave overwash leads to stratification

- Lower lagoon > 26°C for 10 days
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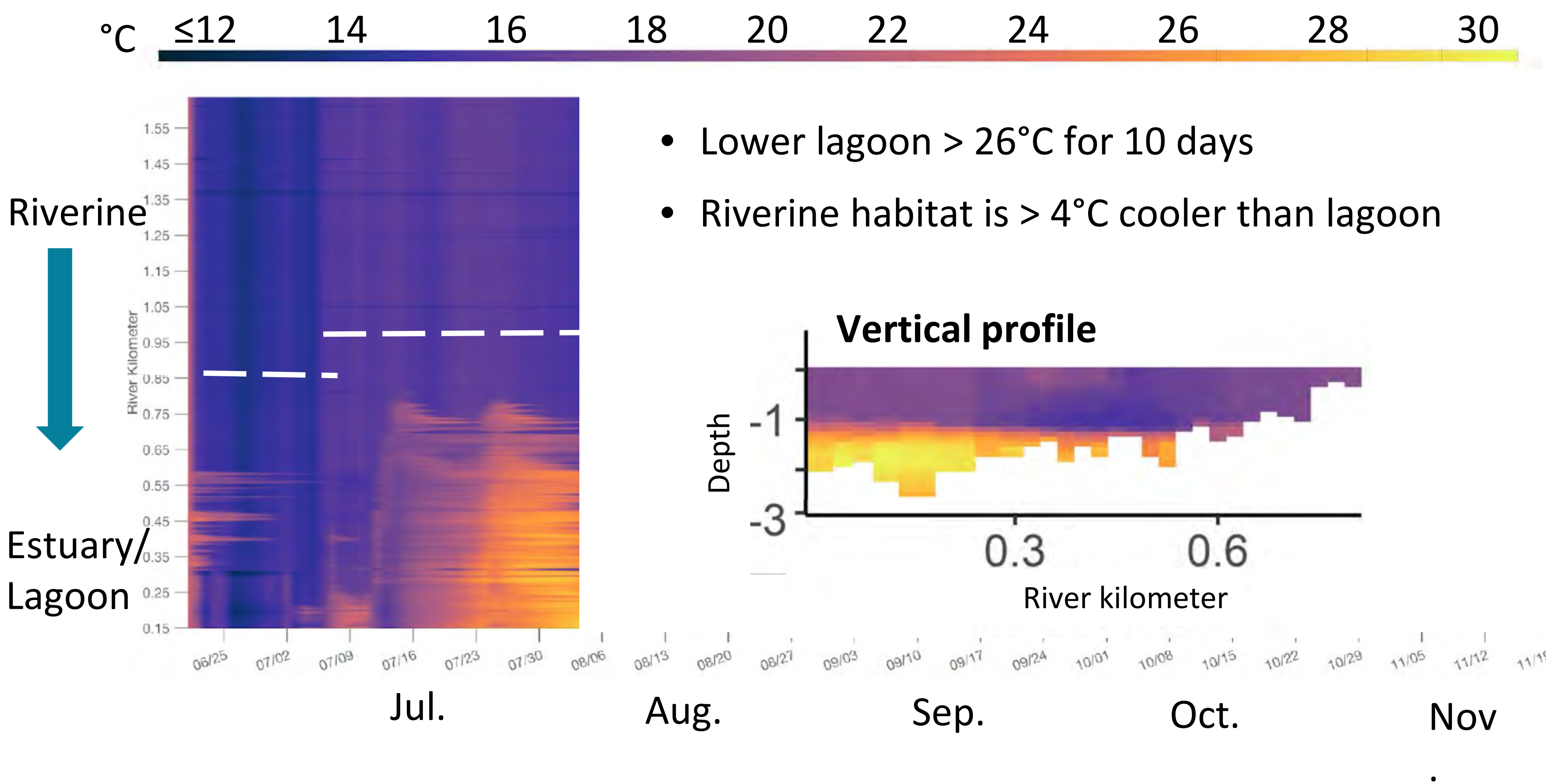
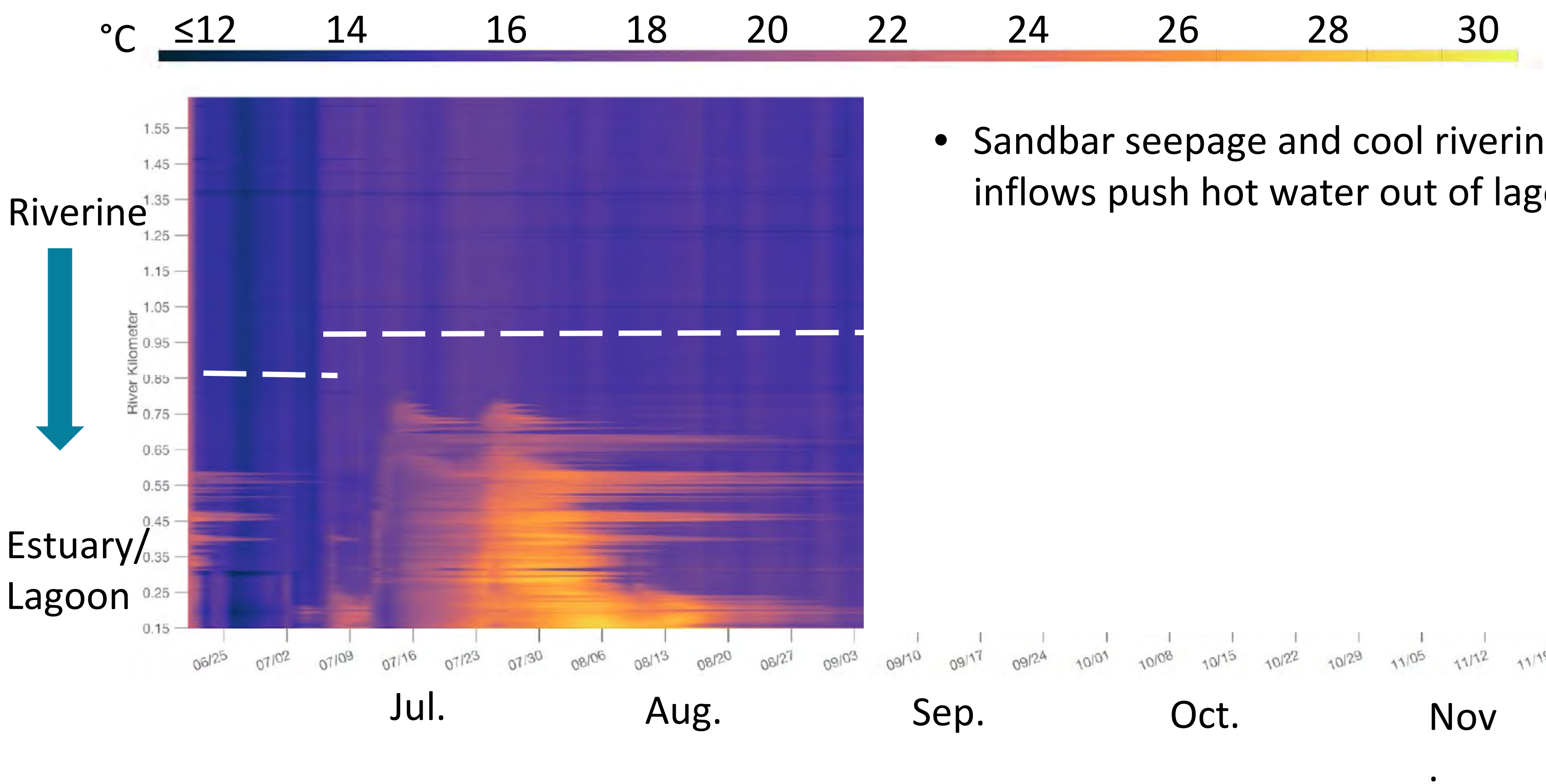
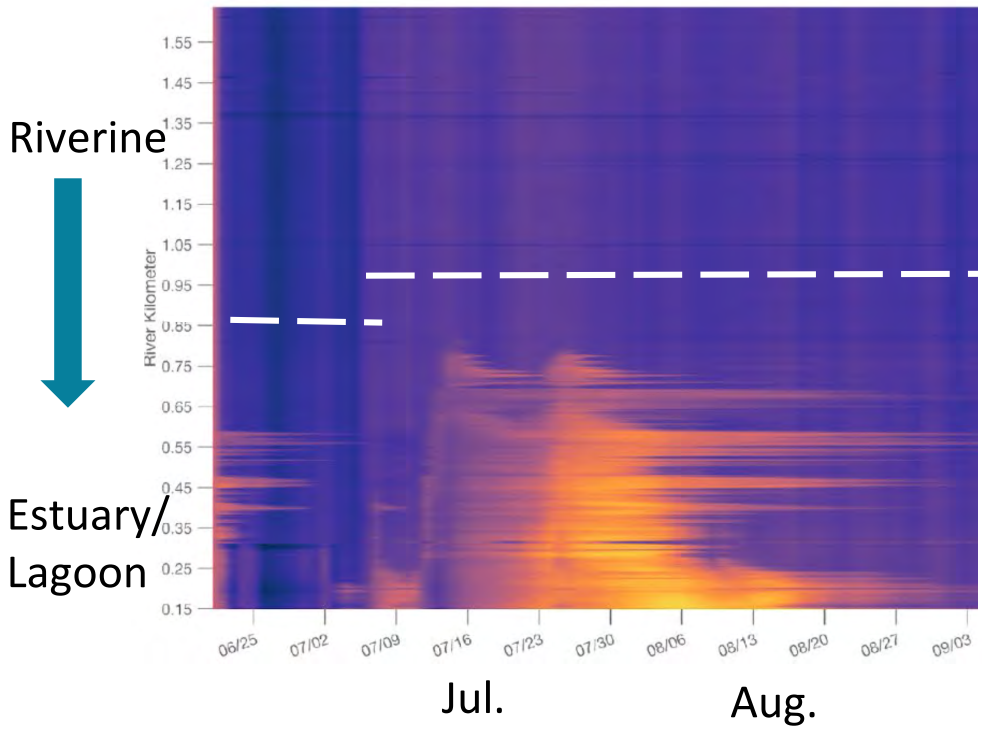


Late Summer Transition



- Sandbar seepage and cool riverine inflows push hot water out of lagoon

Late Summer Transition



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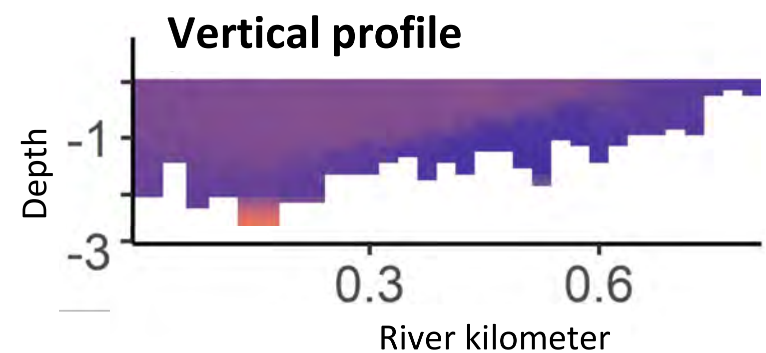
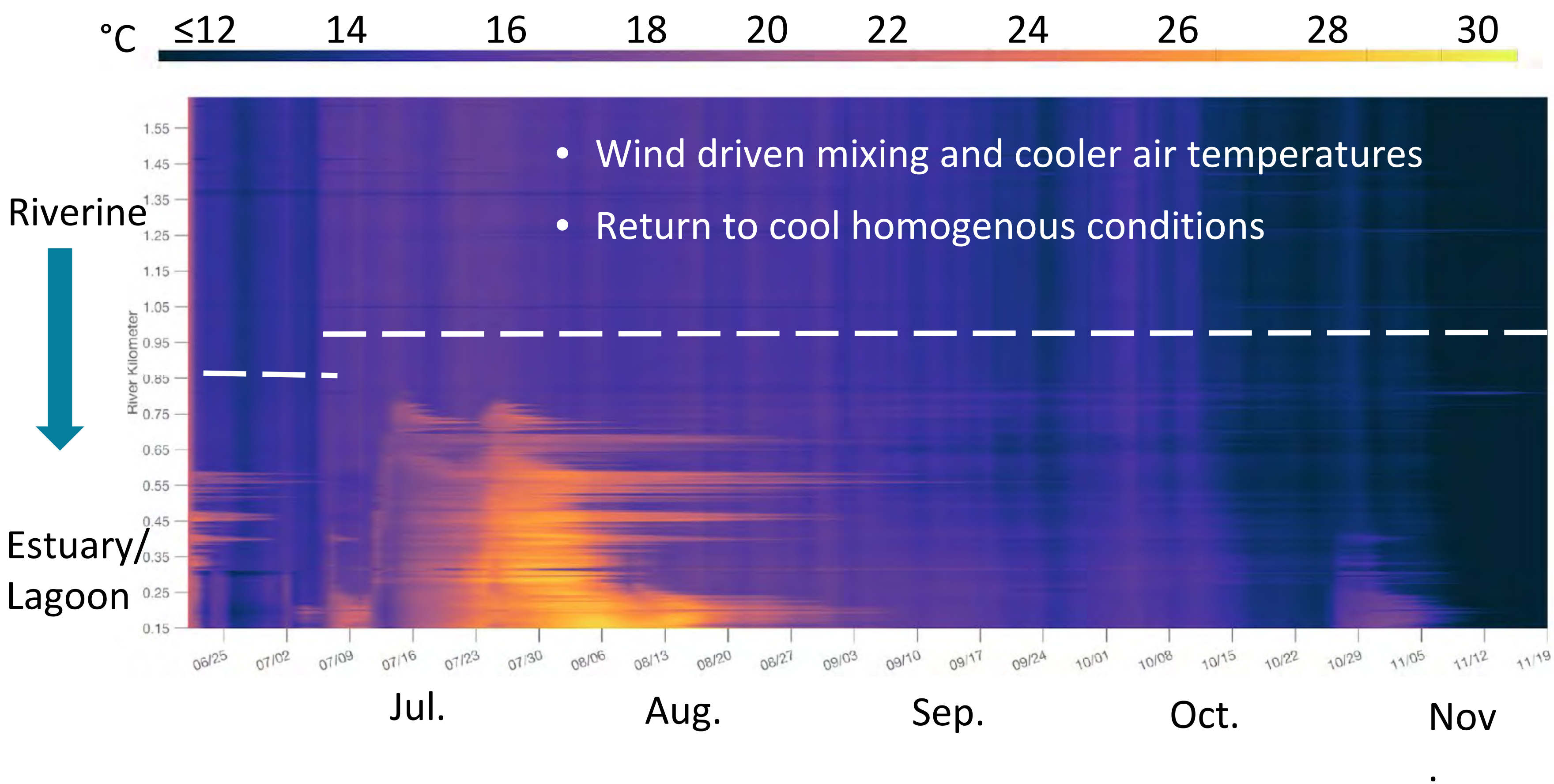
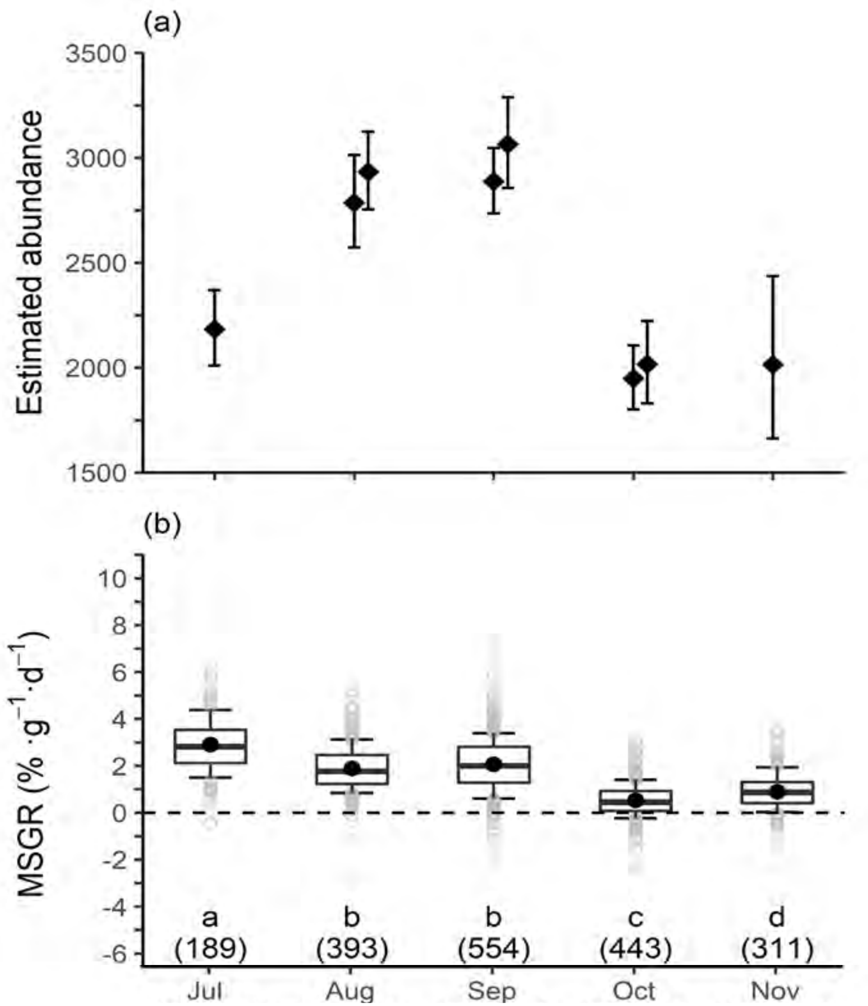


Autumn Cooling

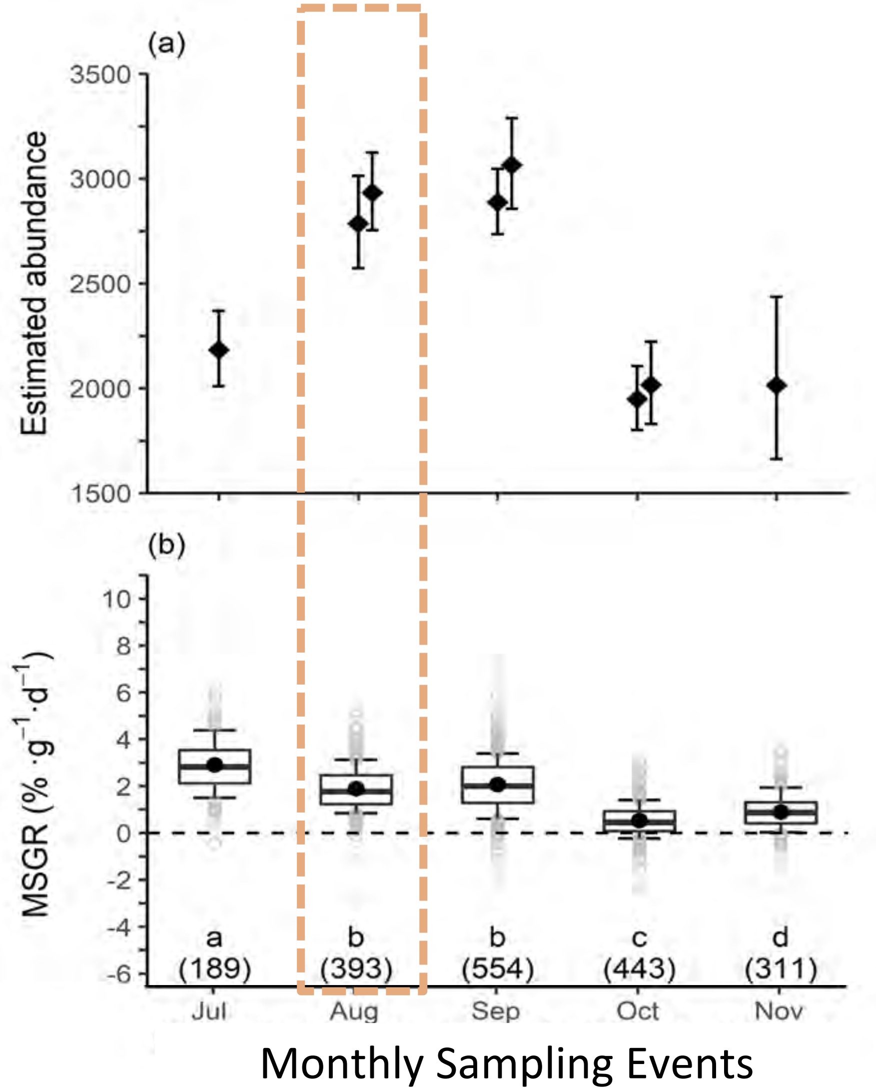


Juvenile steelhead were abundant!

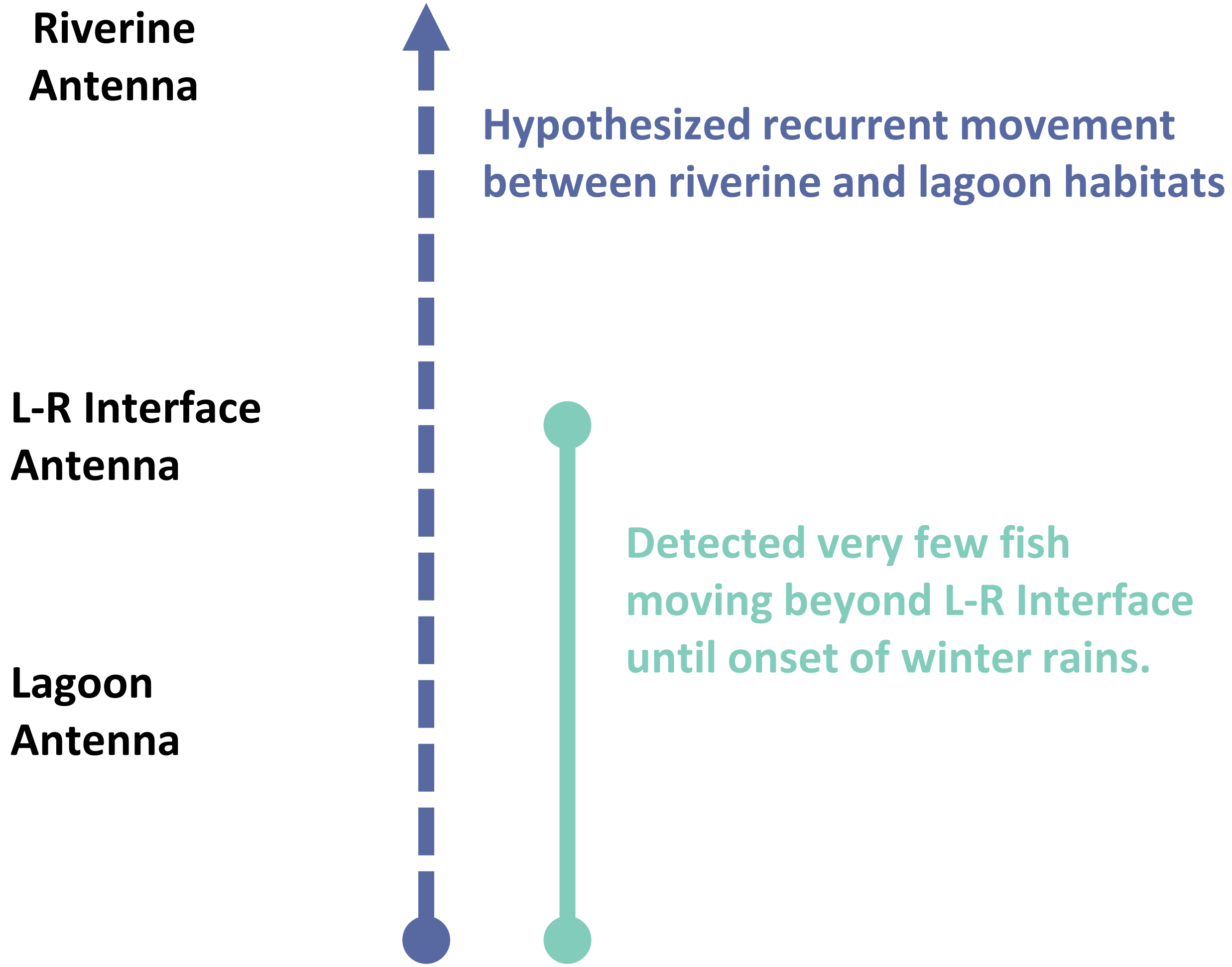


Monthly Sampling Events

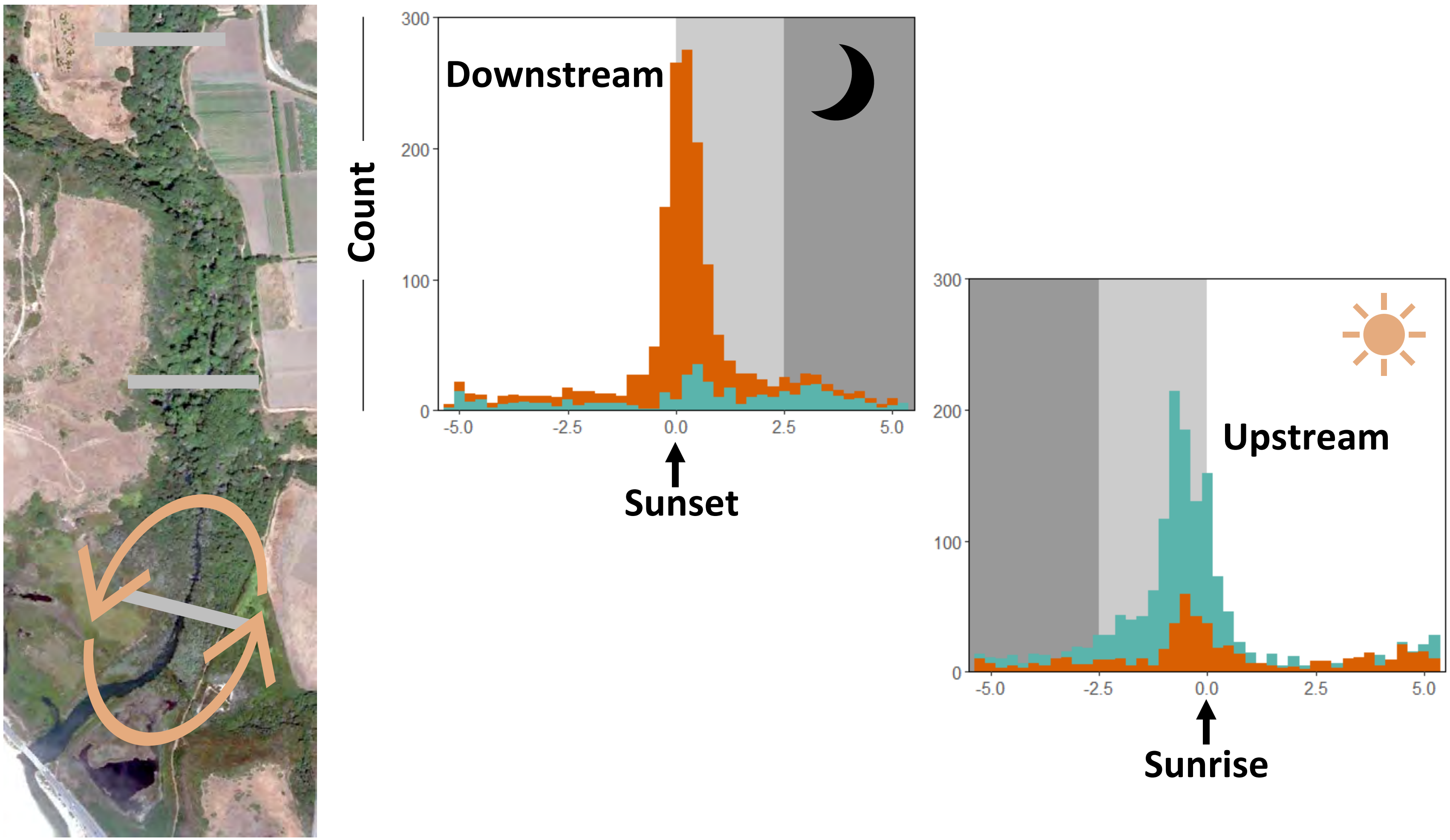
Juvenile steelhead were abundant!



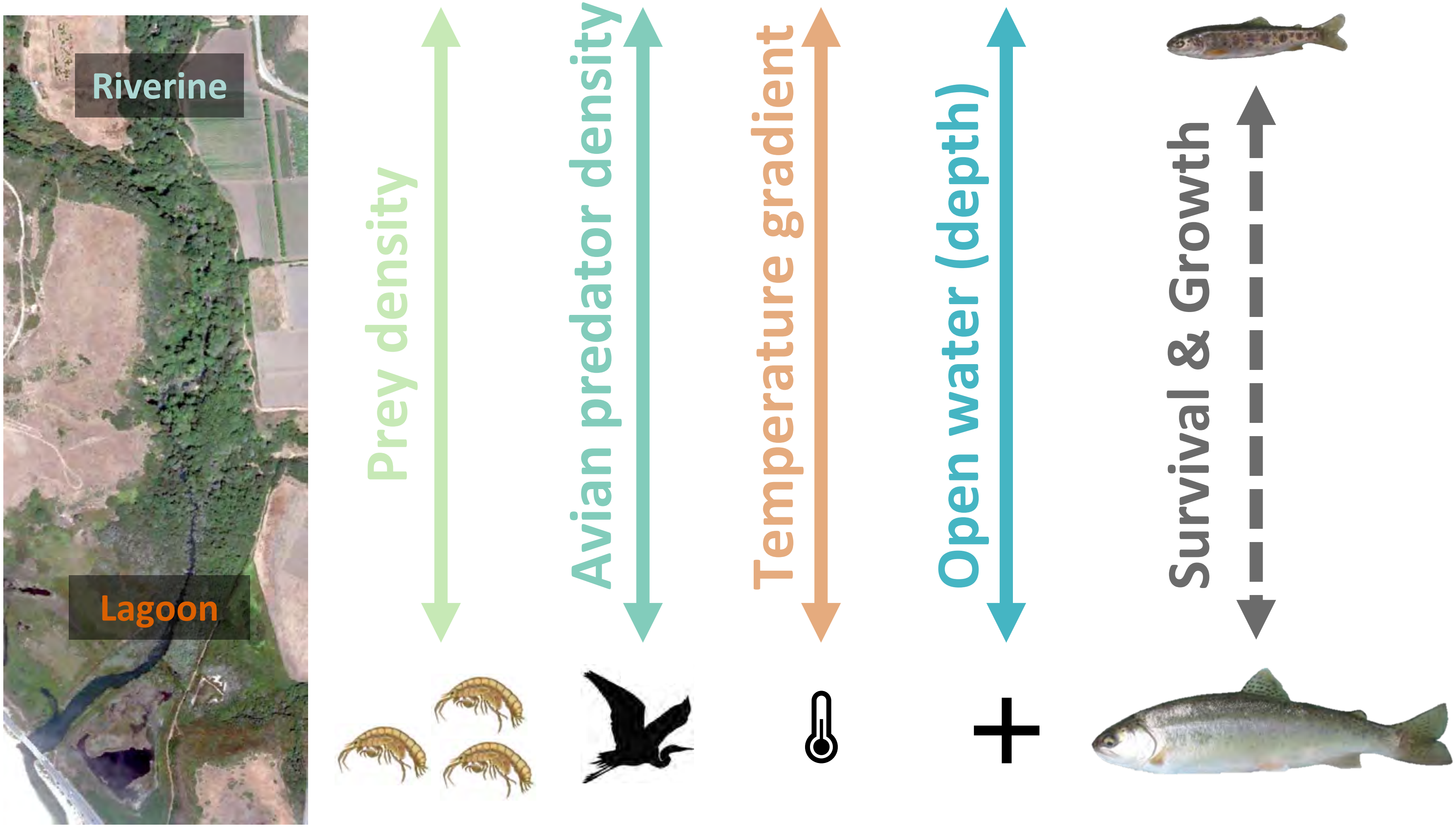
Juveniles remained in the lagoon.



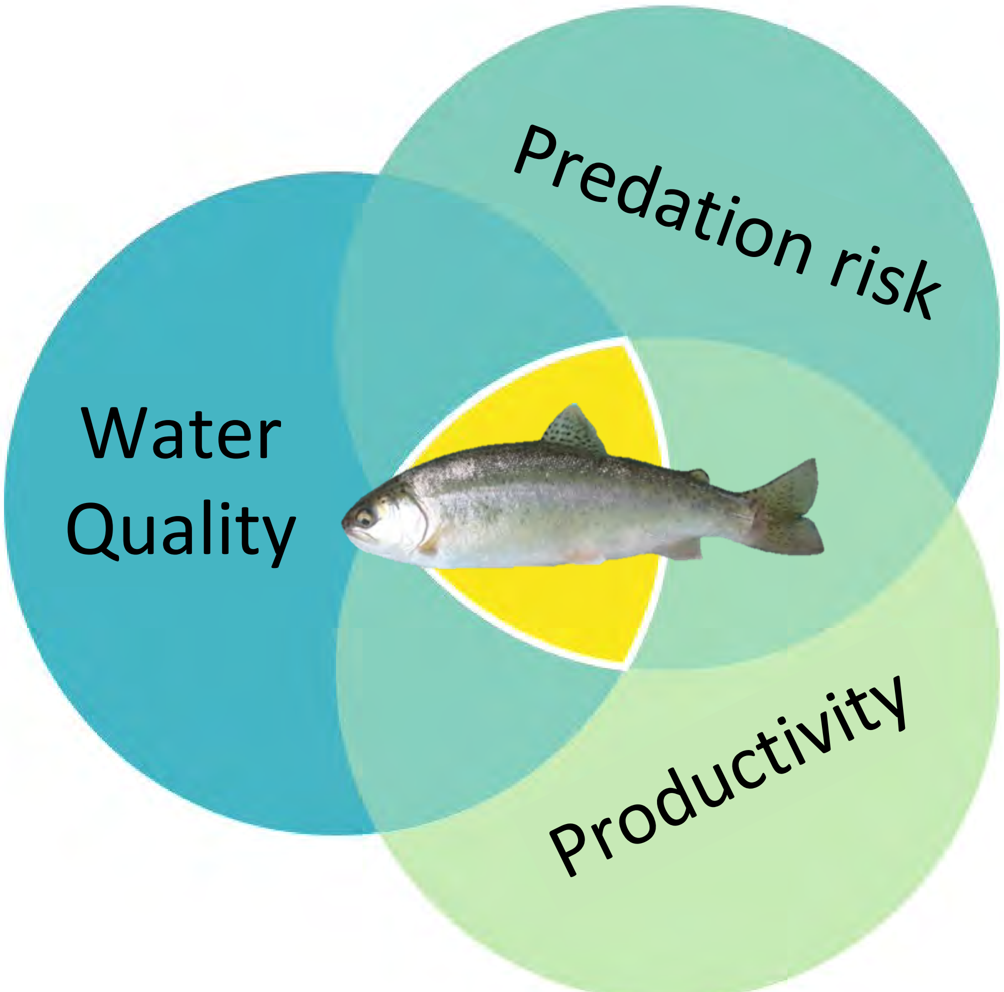
Diel movement patterns in the lower lagoon.



Lagoon rearing trade-offs



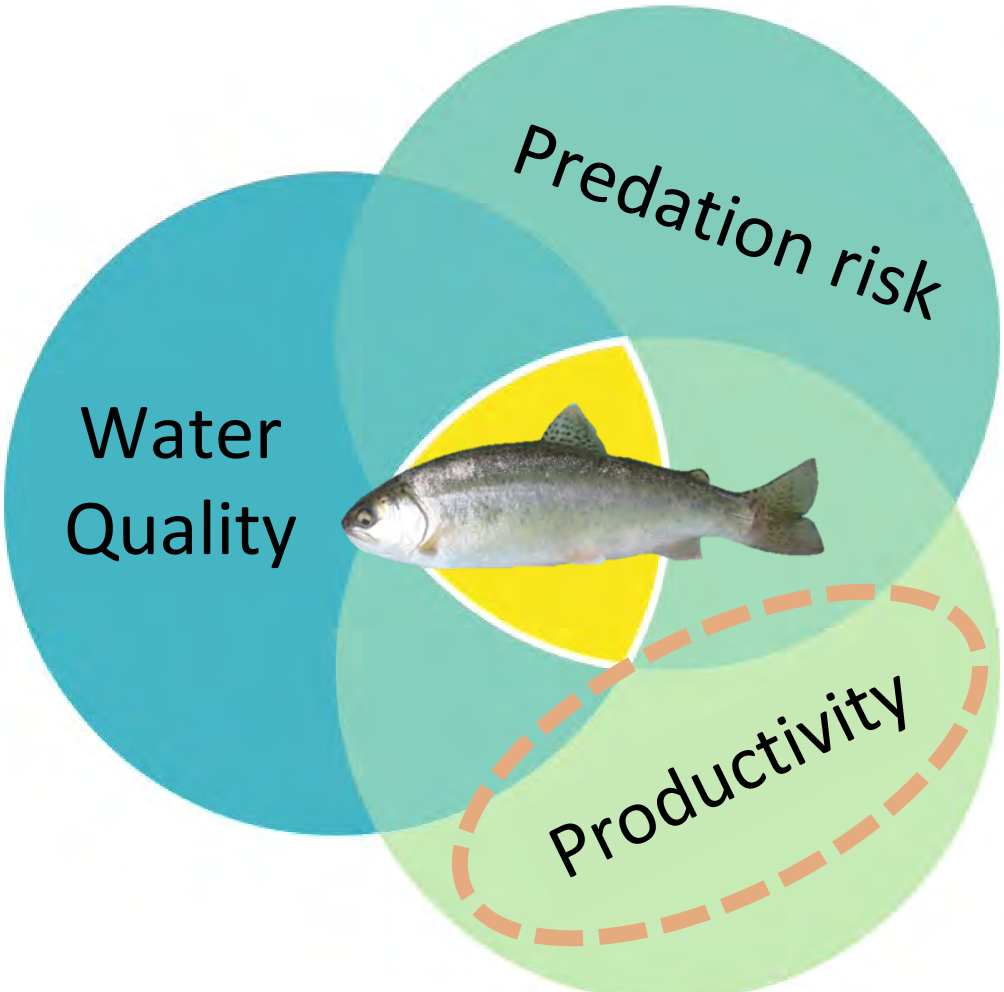
Updating our thinking: Shifting Spheres of influence



- Movement timing
- Foraging strategies
- Habitat use

Inspired by Boughton et al. 2017

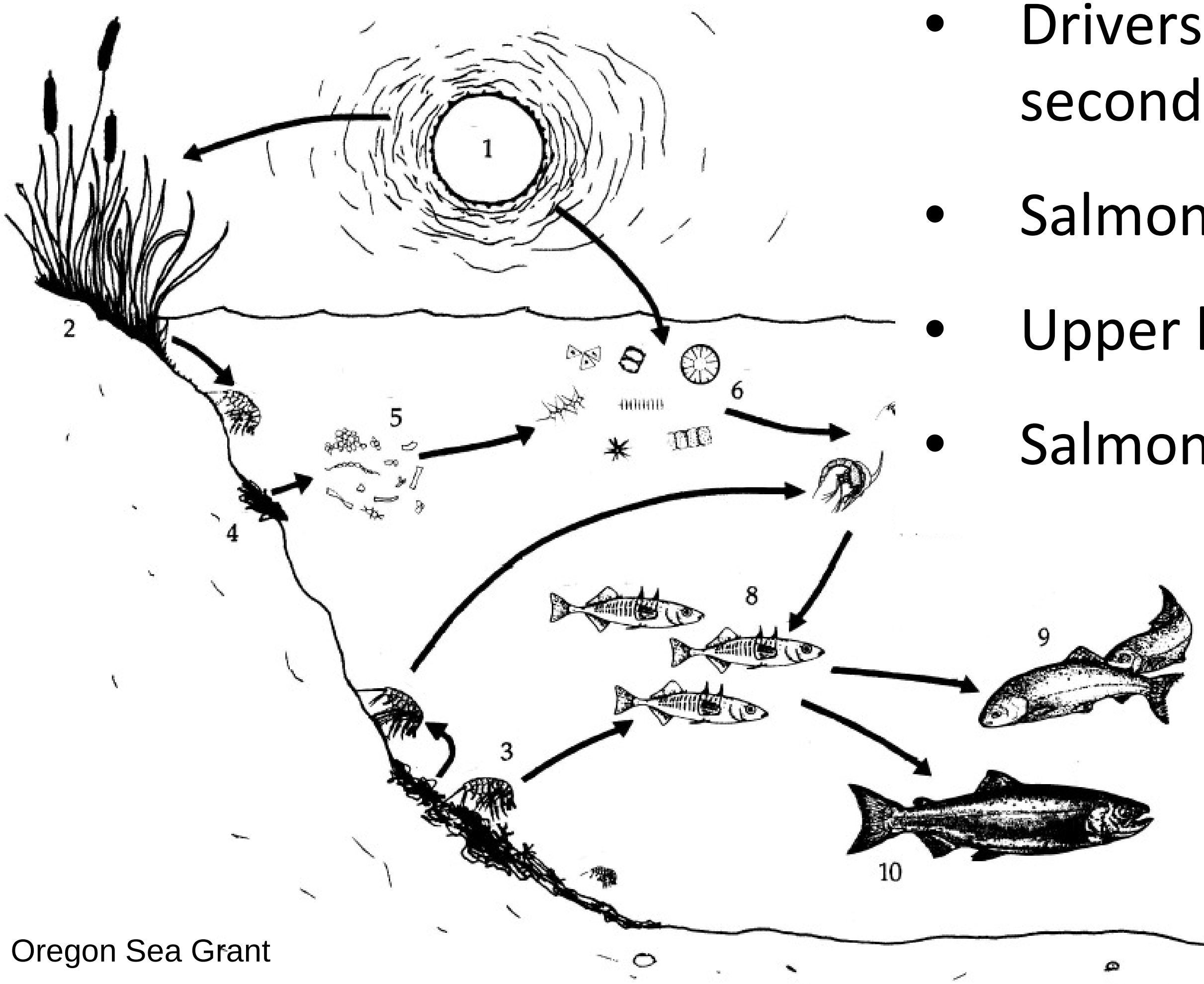
Updating our thinking: Shifting Spheres of influence



- Movement timing
- Foraging strategies
- Habitat use

Inspired by Boughton et al. 2017

Emerging themes/questions



Oregon Sea Grant

- Drivers of primary and secondary productivity
- Salmonid foraging strategies
- Upper lagoon habitat use
- Salmonid bioenergetics

This work is a huge collaborative effort.

NOAA FISHERIES
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
West Coast Region

THE UNIVERSITY OF CALIFORNIA 1868

SWANTON PACIFIC RANCH CAL POLY

CALIFORNIA DEPARTMENT OF FISH & WILDLIFE

CALIFORNIA CONSERVATION CORPS EST. 1976

AmeriCorps California

WSP

CALIFORNIA VOLUNTEERS
Office of the Governor

CTEMPs
Center for Transformative Environmental Monitoring Programs

Thank you

- Environmental conditions are getting more extreme. Is there a tipping point in the Scott Creek lagoon?
- In 2018, juvenile steelhead remained within lagoon habitat and thrived despite protracted periods of poor water quality.
- Lagoon physiochemistry, productivity, and predation pressure are key drivers of salmonid lagoon-rearing potential.

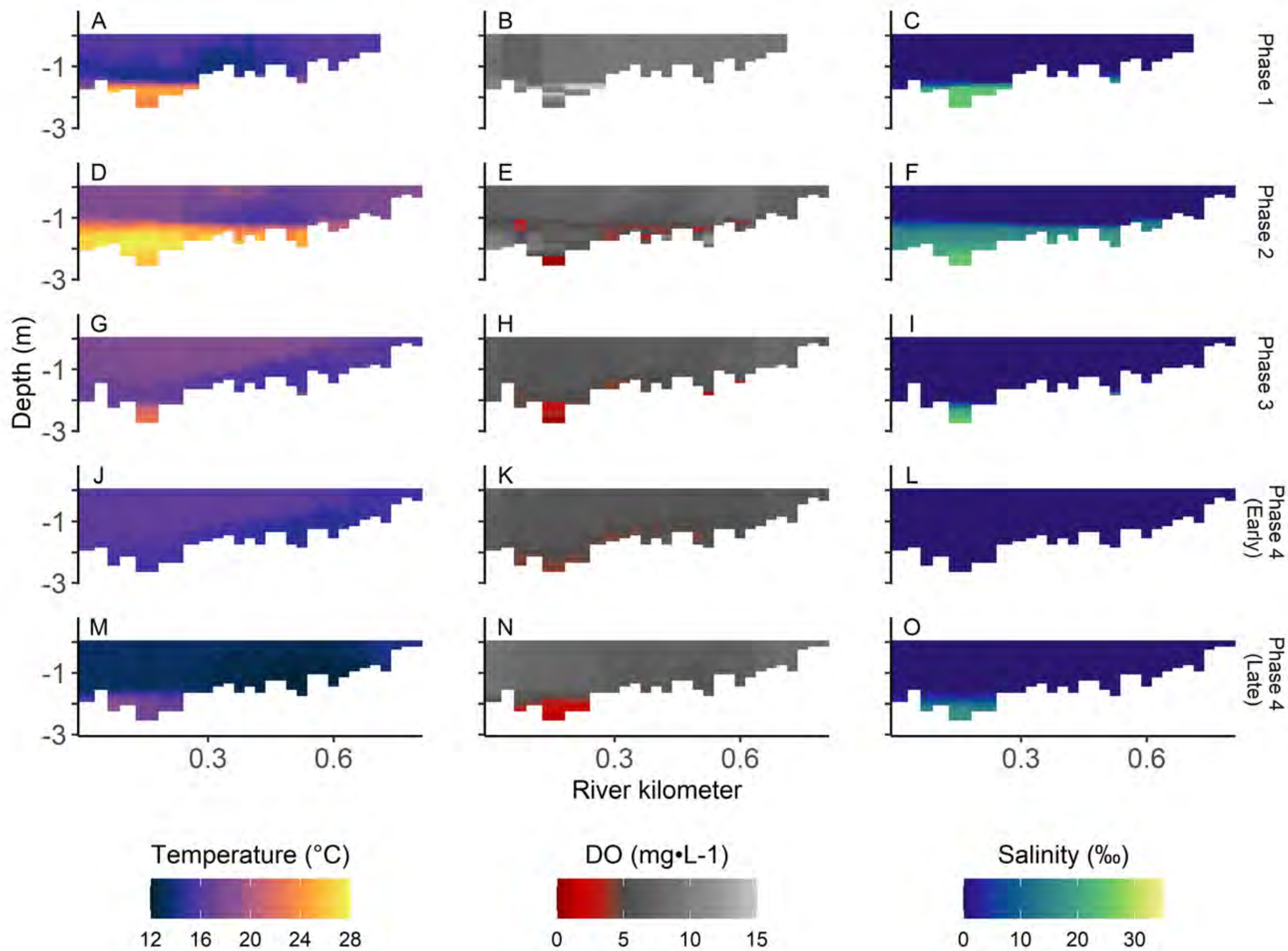
Contact Info:

Rosealea Bond Joseph Kiernan

RBond@ucsc.edu Joseph.Kiernan@noaa.gov

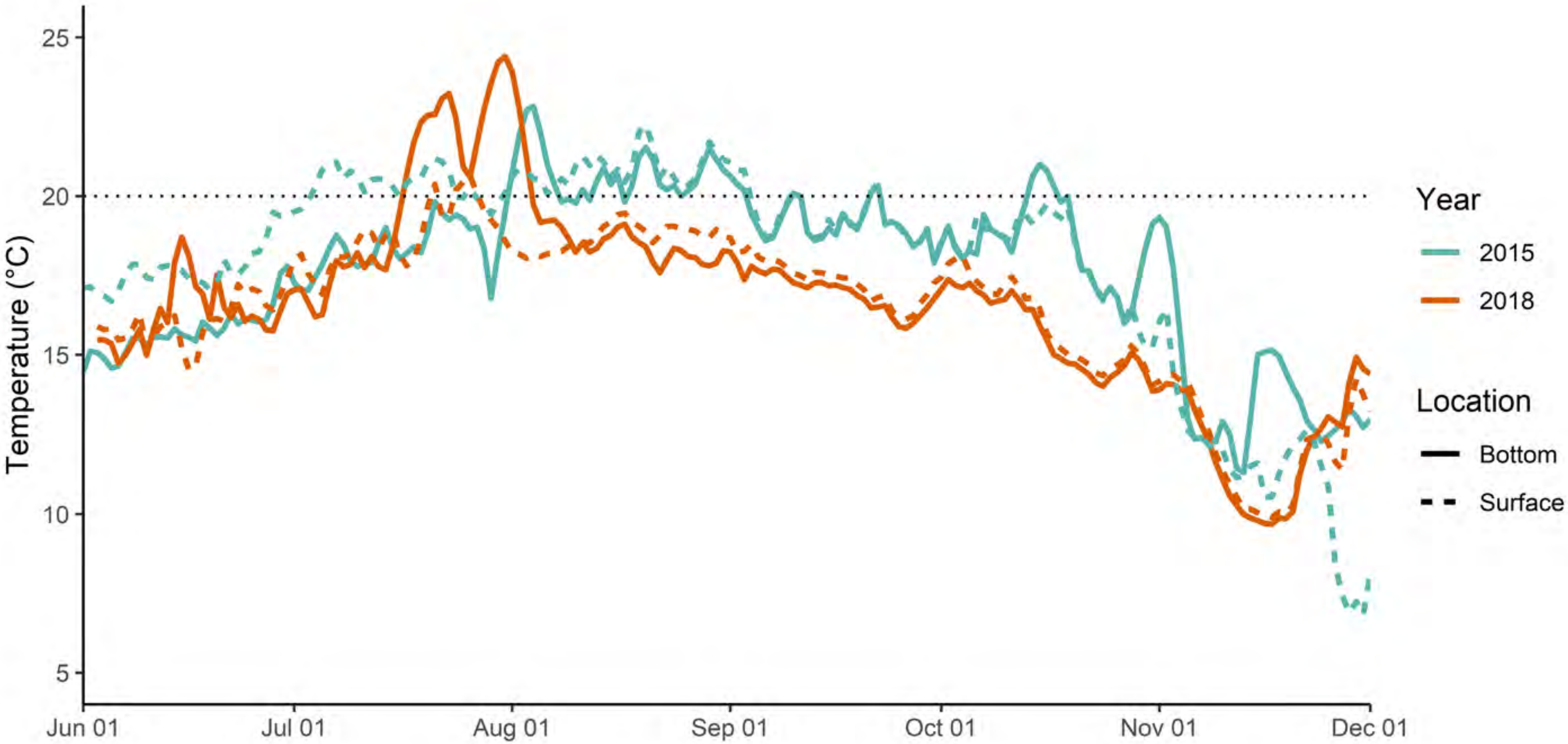
Artwork by Lindsay Hansen

Question Slides

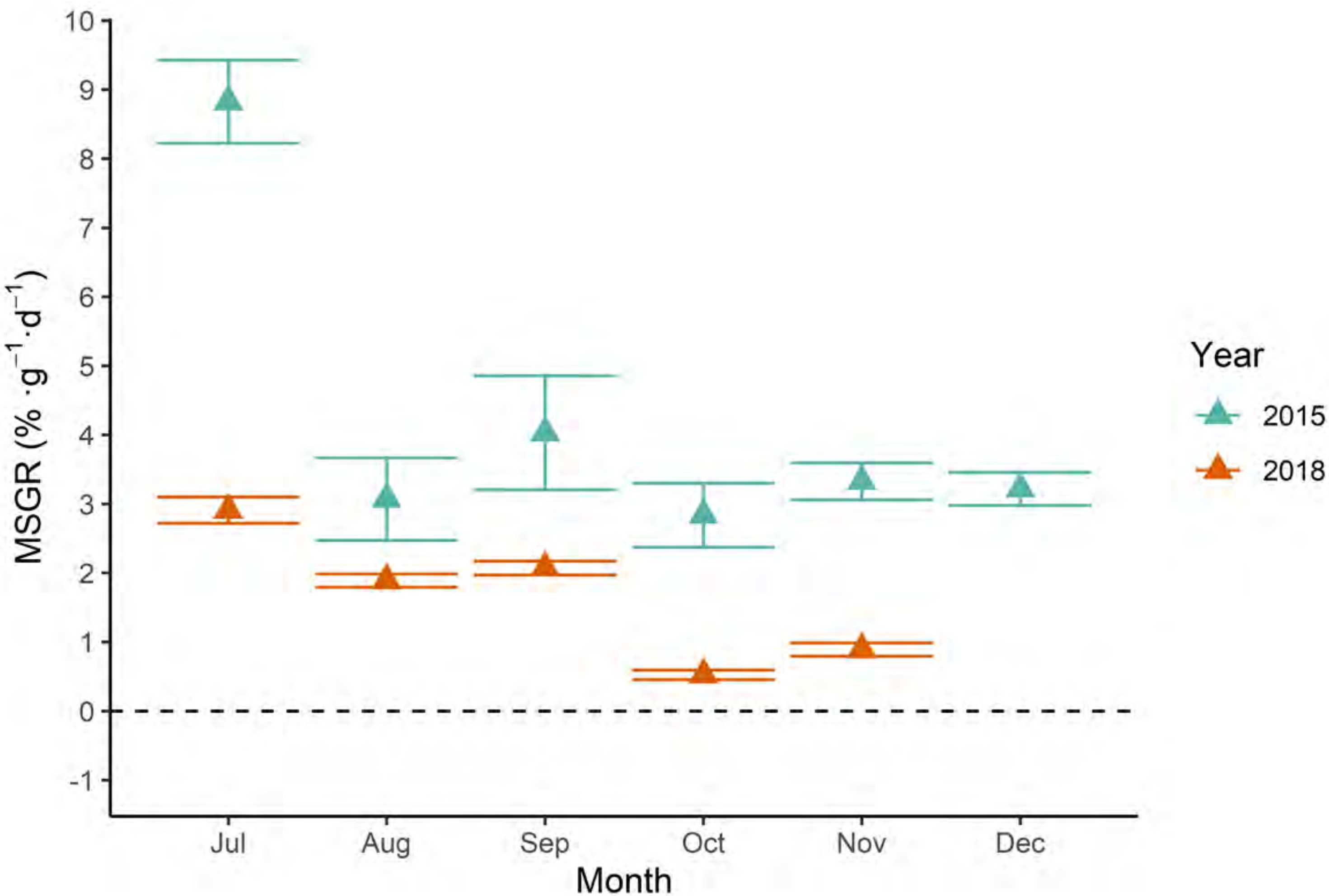


A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
Phase 1
Phase 2
Phase 3
Phase 4 (Early)
Phase 4 (Late)
Depth (m)
-1
-3
0.3
0.6
River kilometer
Temperature (°C)
12
16
20
24
28
DO (mg•L-1)
0
5
10
15
Salinity (‰)
0
10
20
30

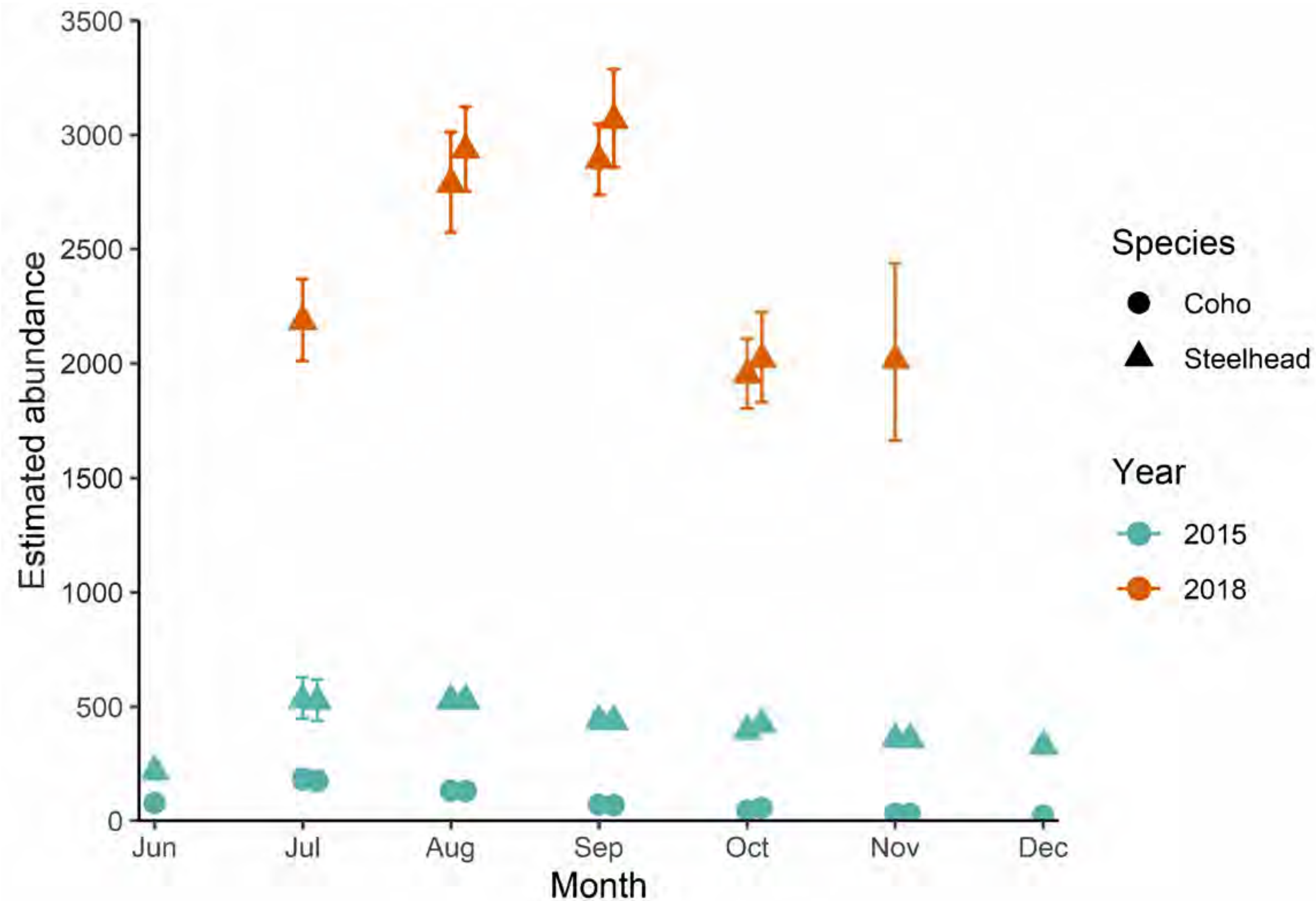
Mean Daily Water Temp



Steelhead Mass Specific Growth Rates



Lagoon Population Size



The Pivot to Process

CALIFORNIA TROUT

FISH · WATER · PEOPLE

Jacob Katz – California Trout

Process-Based Reconciliation

Integrating a working knowledge of natural process, into management of natural resources

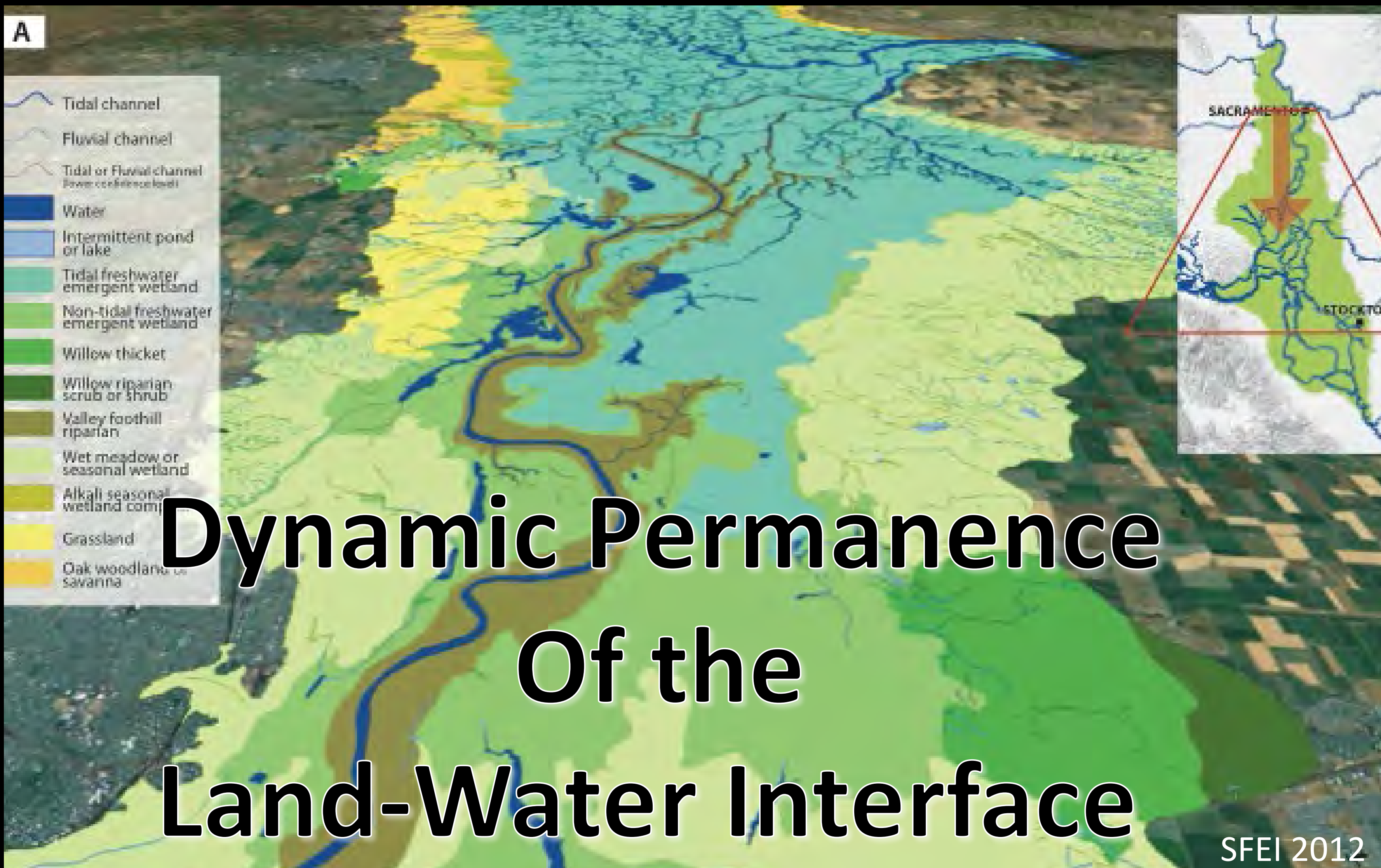



Fish belong in the river…

…and the river belongs in its banks.

Wetland–River Corridors

Whol et al. 2021



Sacramento Valley

Development

13,000 miles of levees

The Land Divorced from the Water

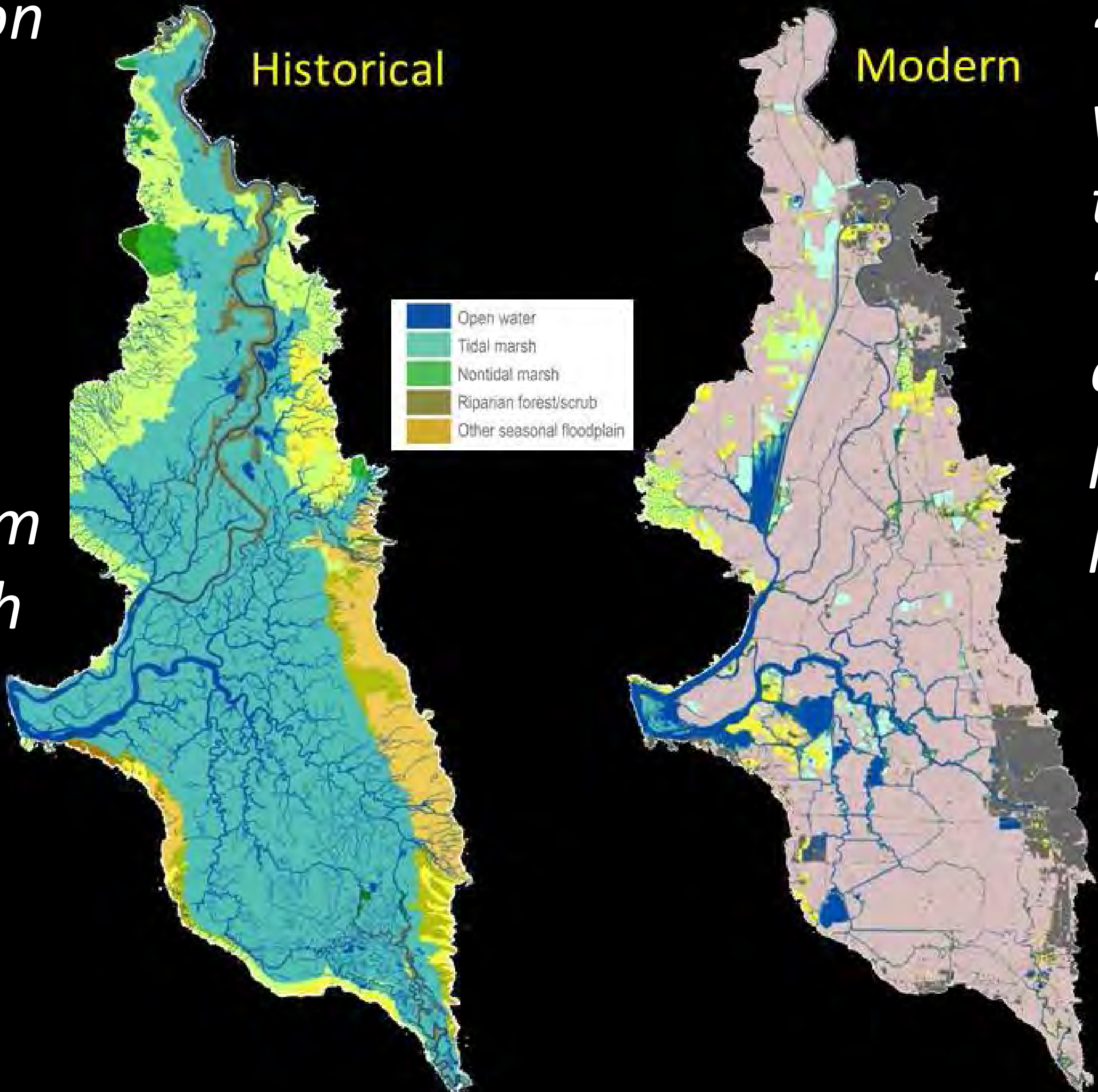
Ubiquitous Drainage

95%

Central Valley wetlands lost

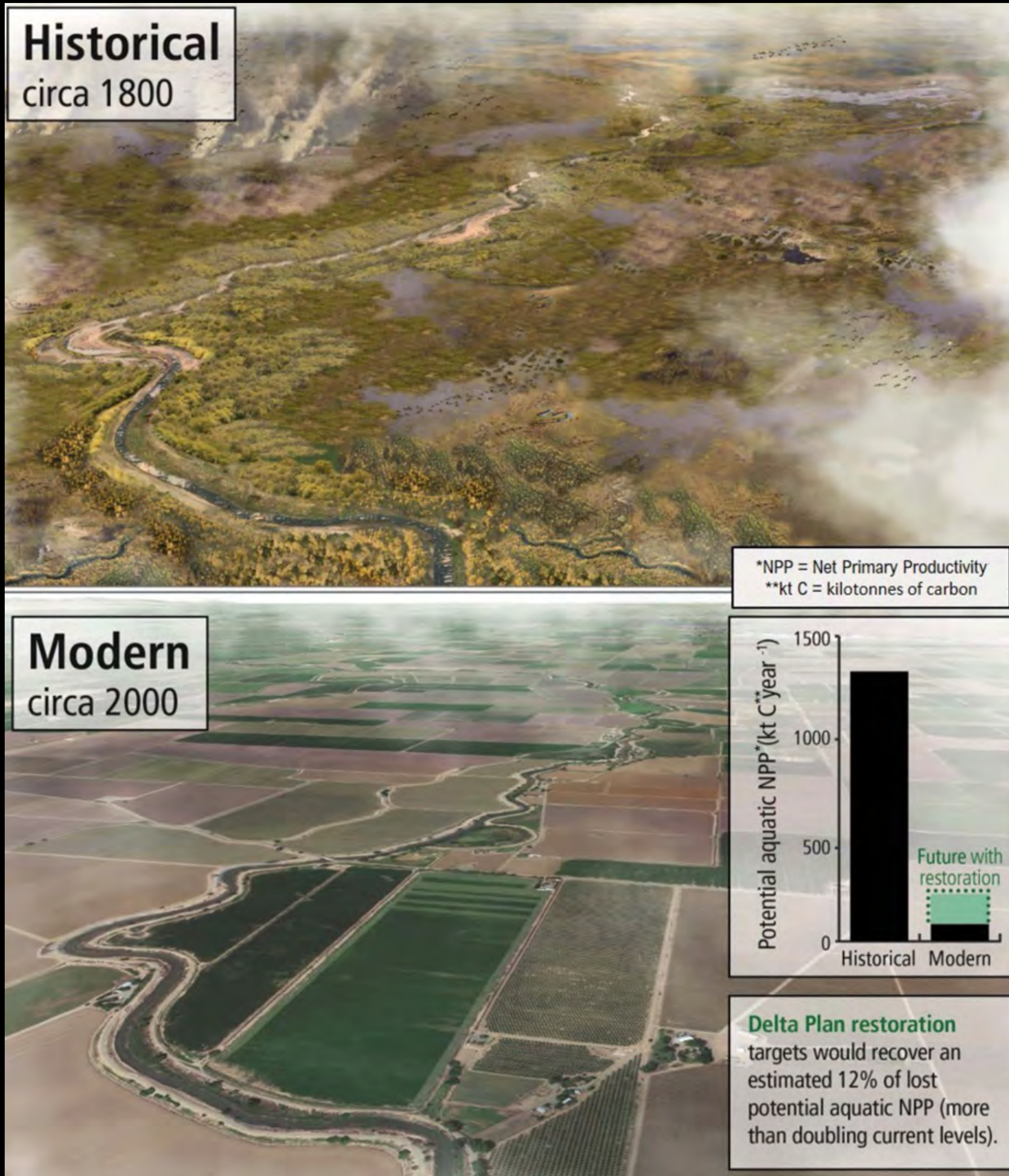
DELTA

95% of net production in the historical Delta aquatic food web came from the marsh



conversion of ~98 % of wetlands led to reduction of ~90% of ecosystem net primary production

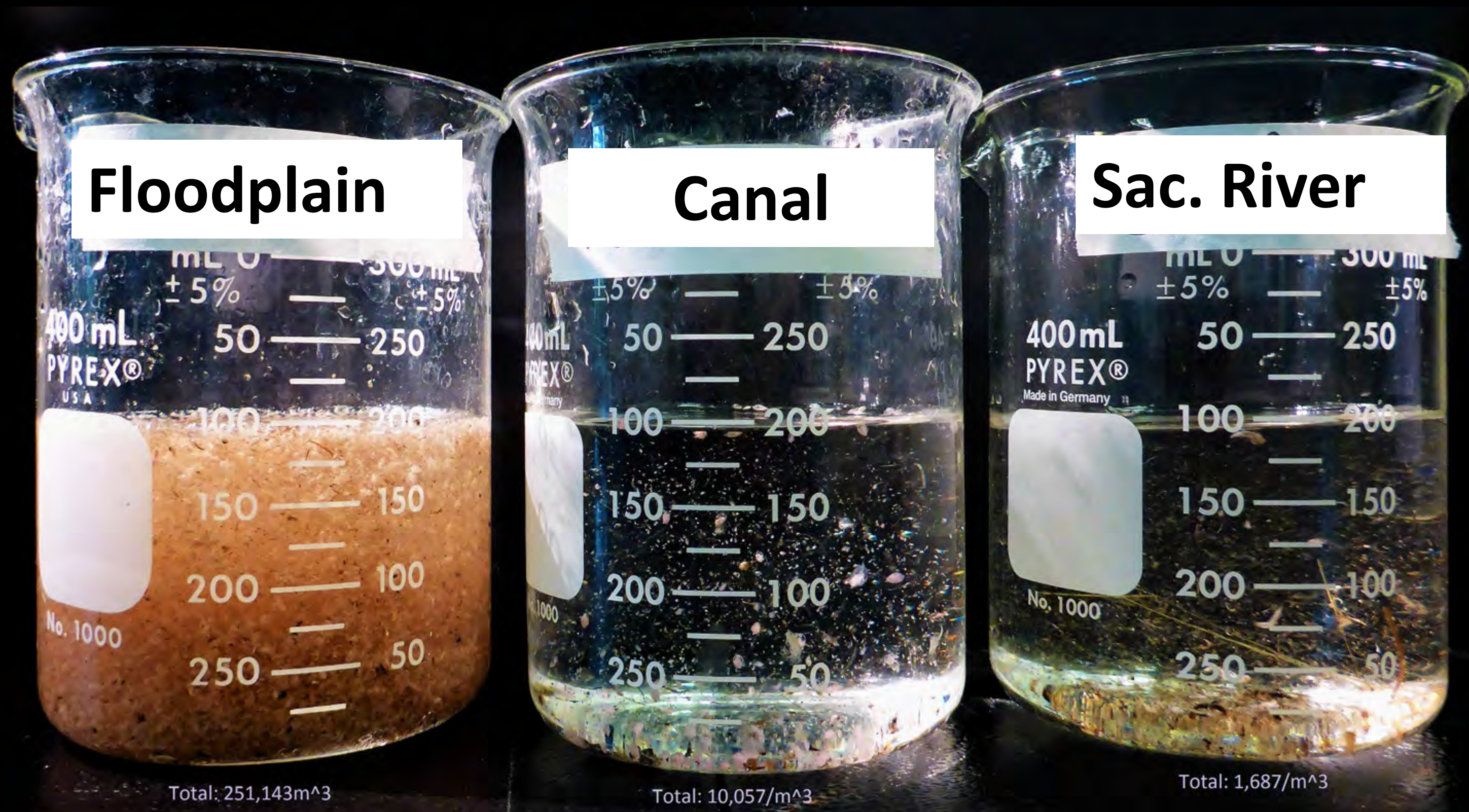
Cloern et al. 2021: *On the human appropriation of wetland primary production*



Land use alters energy flow through the landscape

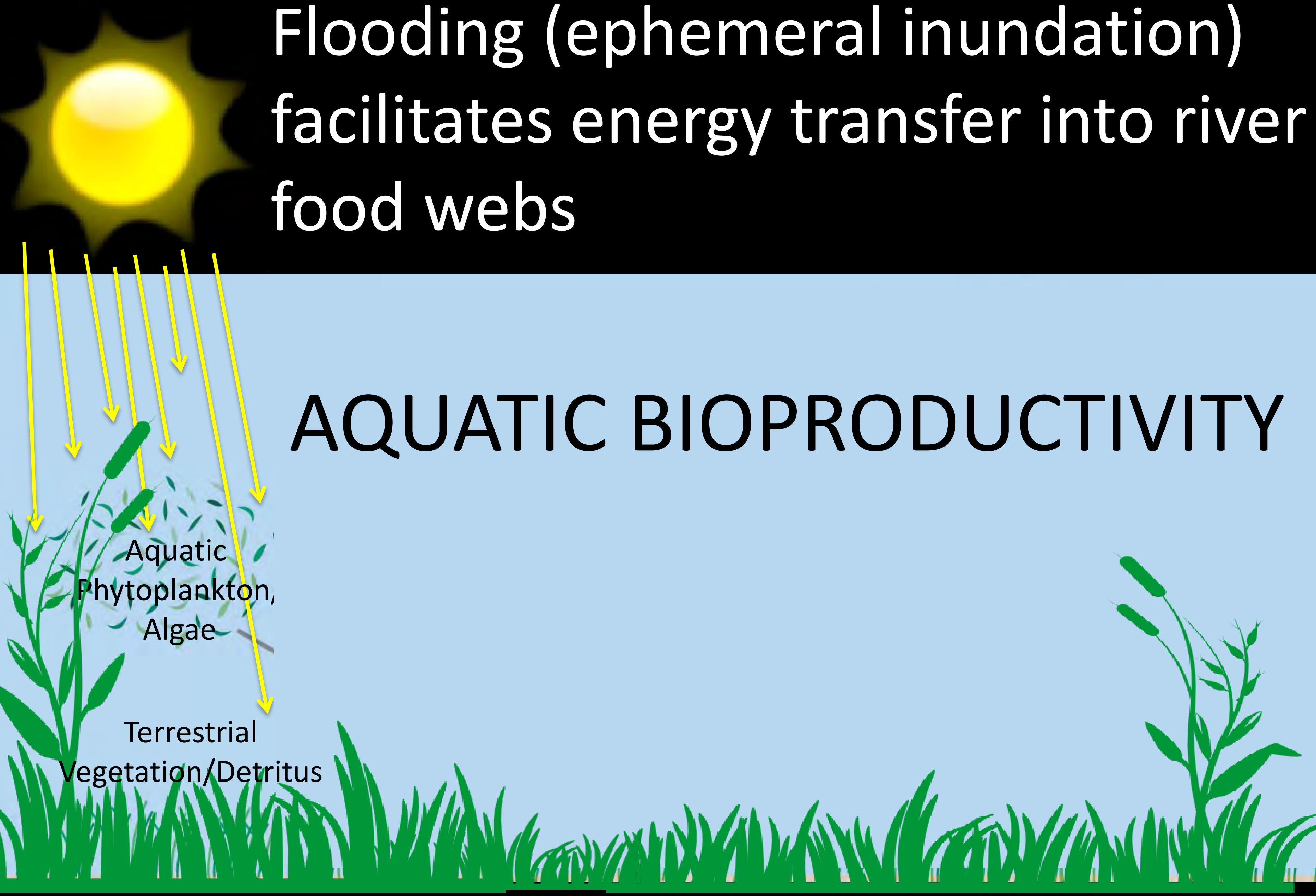

River
Floodplain

The Food is on the Floodplain

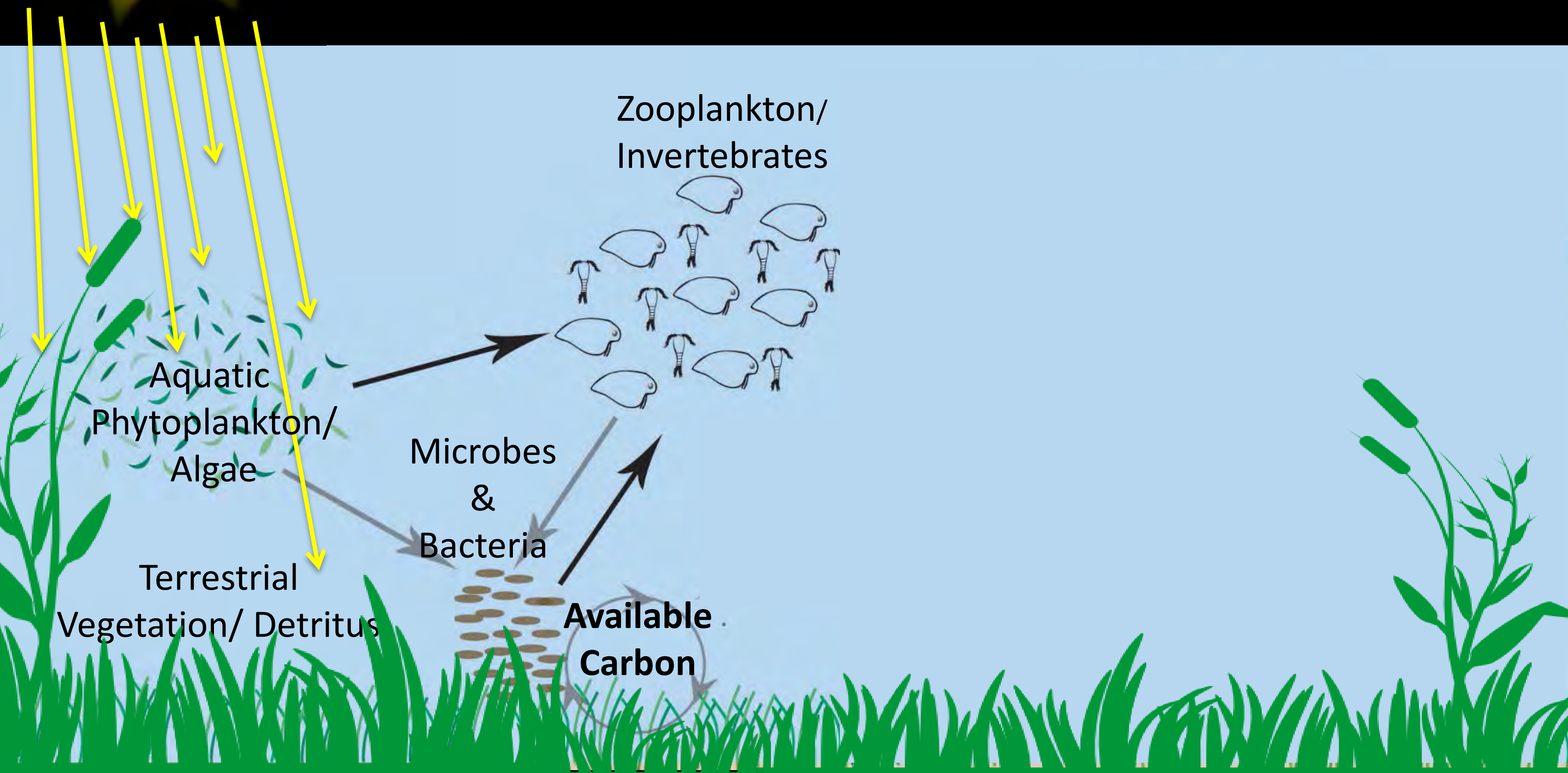


Bug Density 149x 6x x

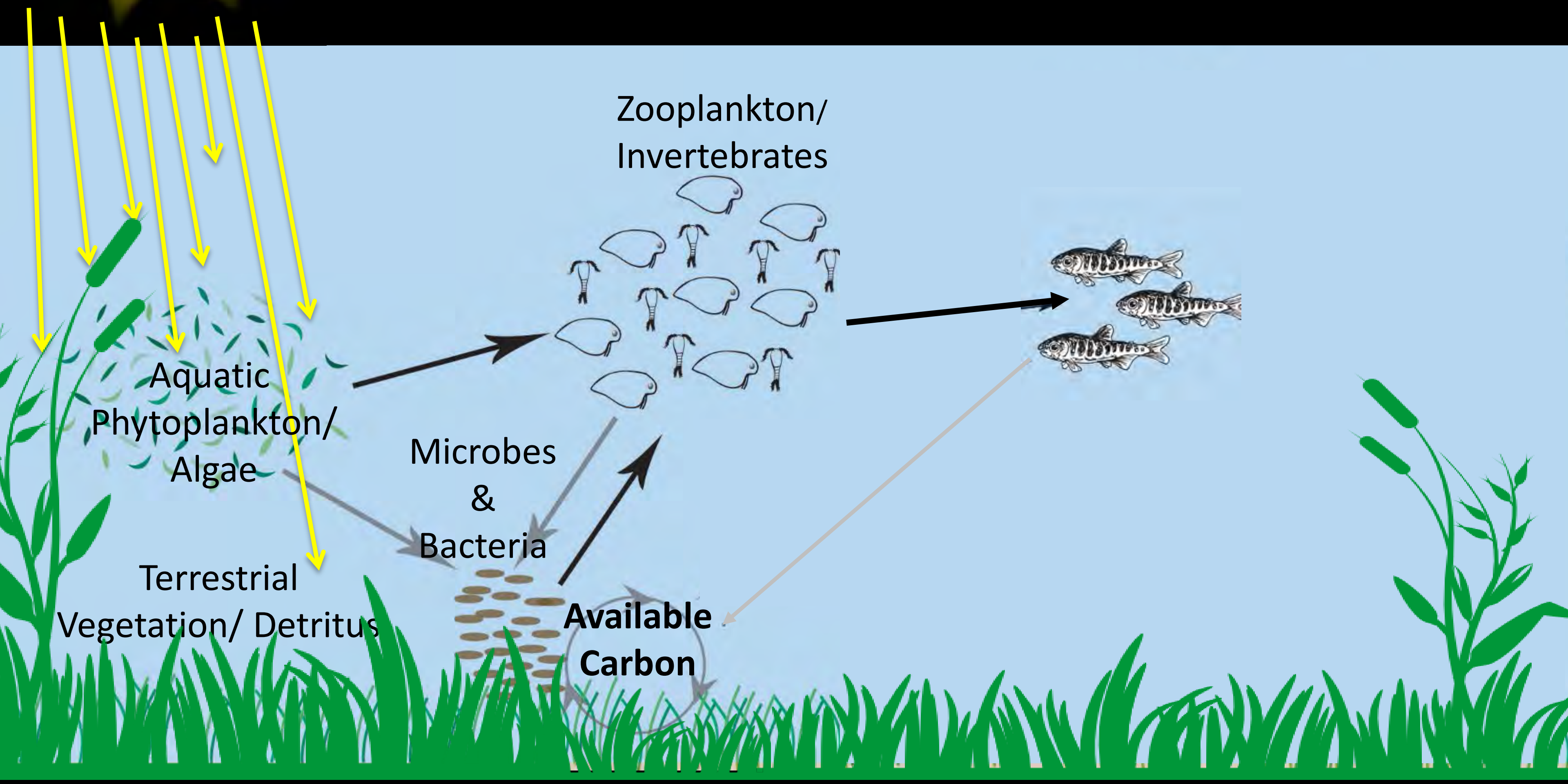
Flooding (ephemeral inundation) facilitates energy transfer into river food webs



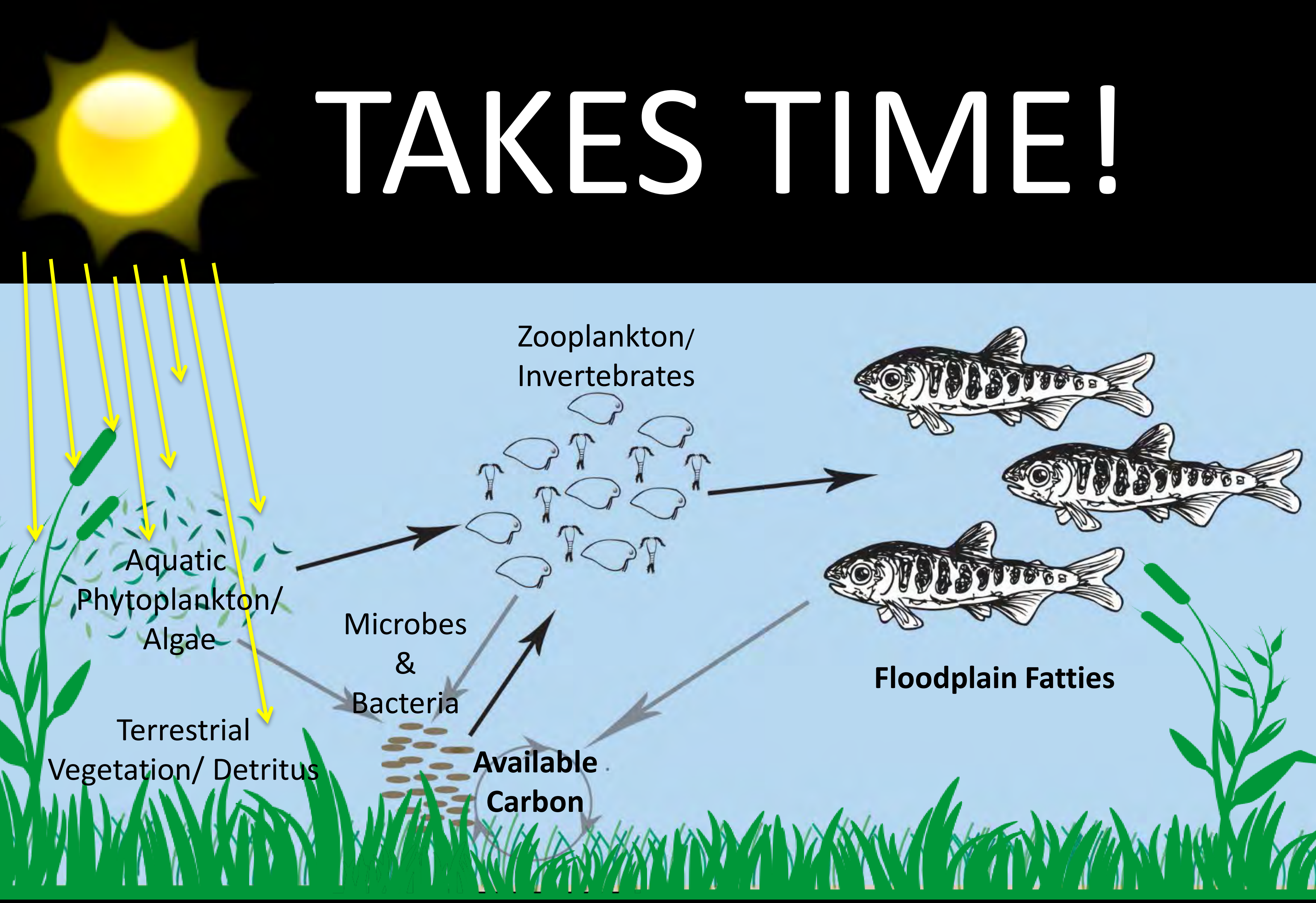
The Process Doesn't Happen Instantaneously



MAKING FISH


Zooplankton/
Invertebrates
Aquatic
Phytoplankton/
Algae
Microbes
&
Bacteria
Terrestrial
Vegetation/ Detritus
Available
Carbon

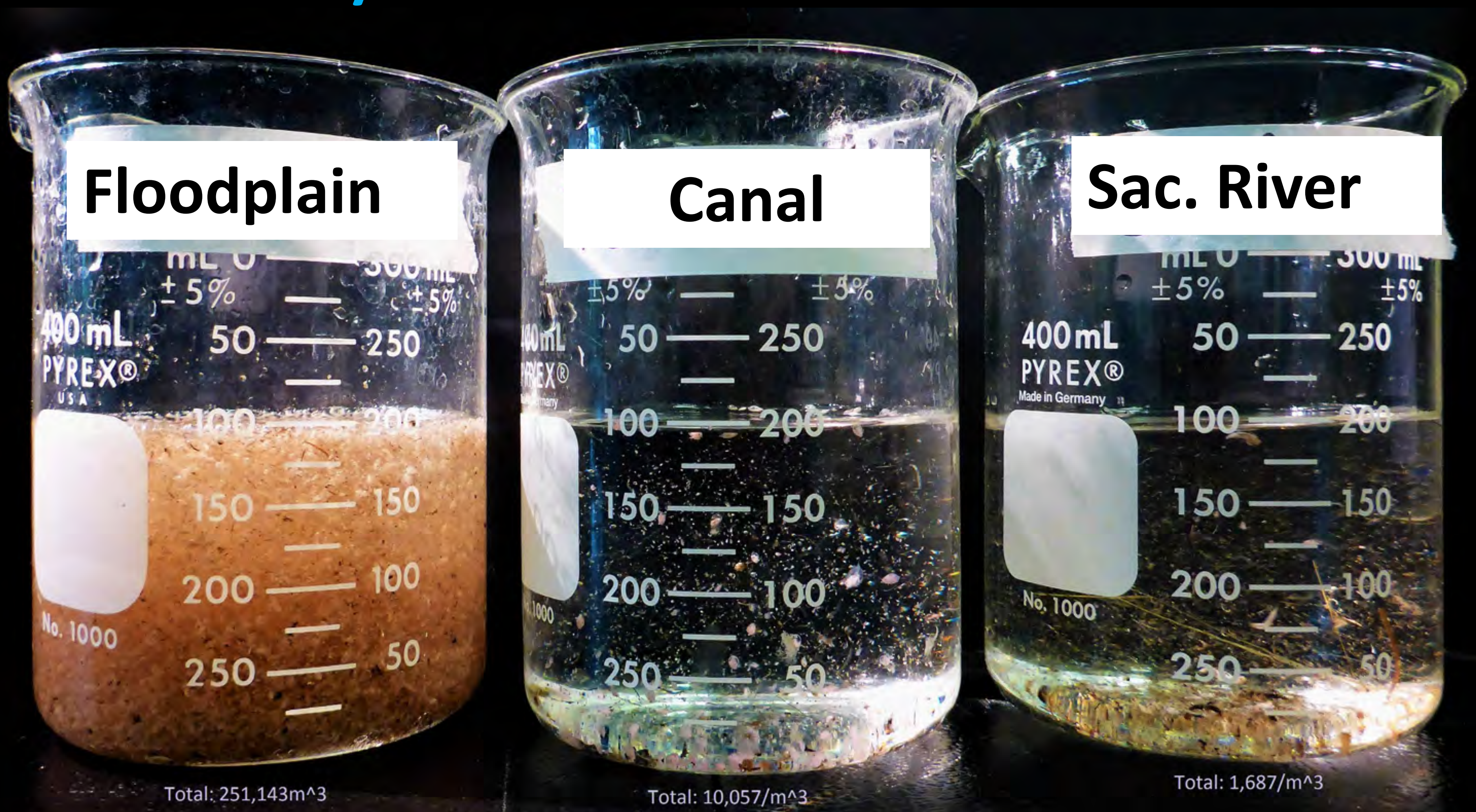
TAKES TIME!



Zooplankton/
Invertebrates
Aquatic
Phytoplankton/
Algae
Microbes
&
Bacteria
Terrestrial
Vegetation/ Detritus
Available
Carbon
Floodplain Fatties

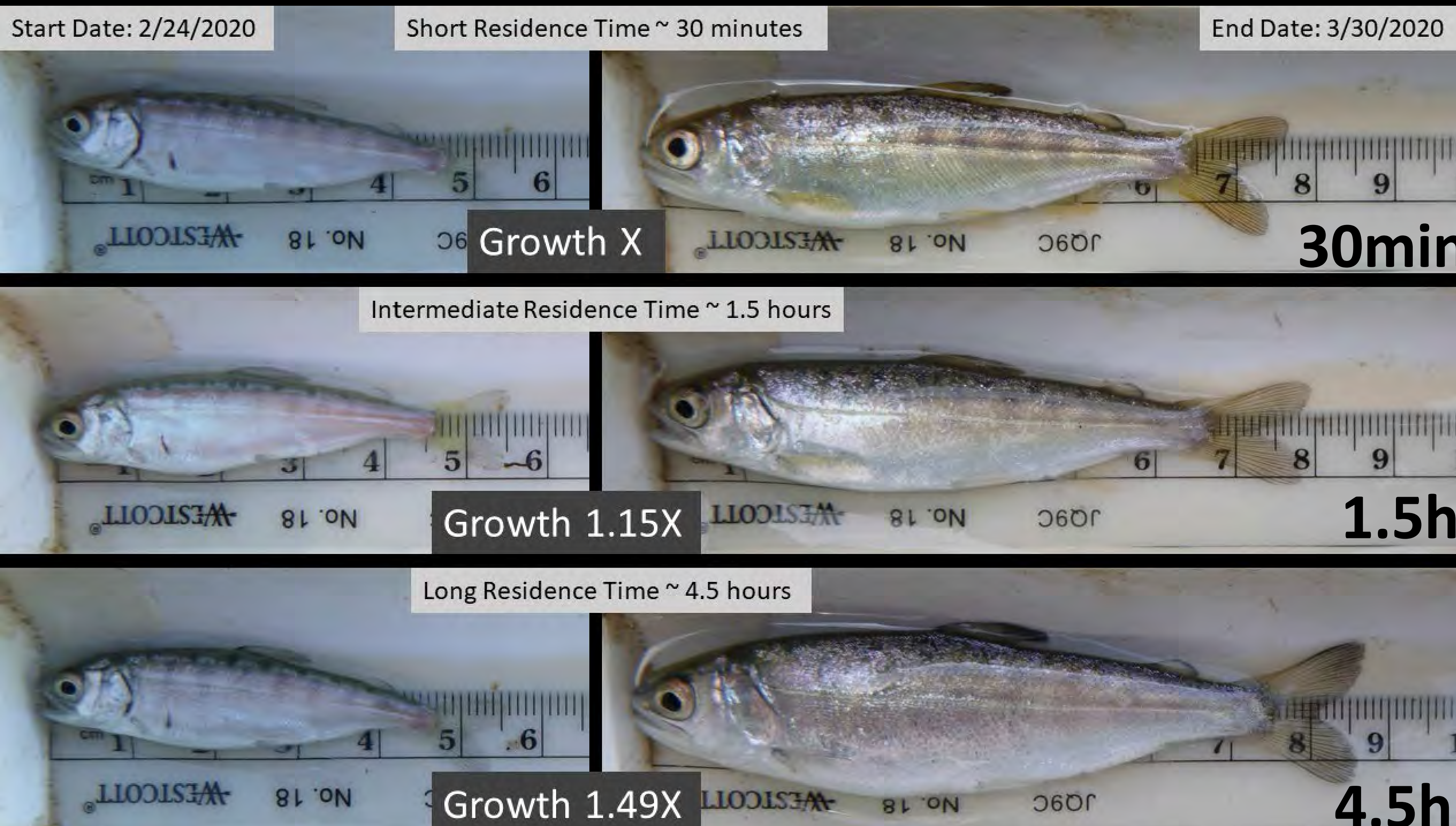
Residence Time of Water

2.15 days | 23.5 sec | 1.7 sec




Floodplain
Canal
River
inch 1 2 3 4 5 6
These fish were the same size 3 weeks prior to photo
Photo: J. Katz
3-11-2016

Slow it = Grow it



Spread it–Slow it–Sink it–Grow it

Harnessing Puddle Power

Reactivating Floodplains in the Sacramento River Basin

The Nigiri Project

Conaway Preservation Group

Lundberg Family Farms

Montna Farms

River Garden Farms

Llano Seco

Ducks Unlimited

UC Davis Center for Watershed Sciences

American Rivers

Sacramento River Forum

California Trout

108

The Nature Conservancy

Point Blue

River Partners

Sustainable Conservation

Trout Unlimited

EDF Environmental Defense Fund

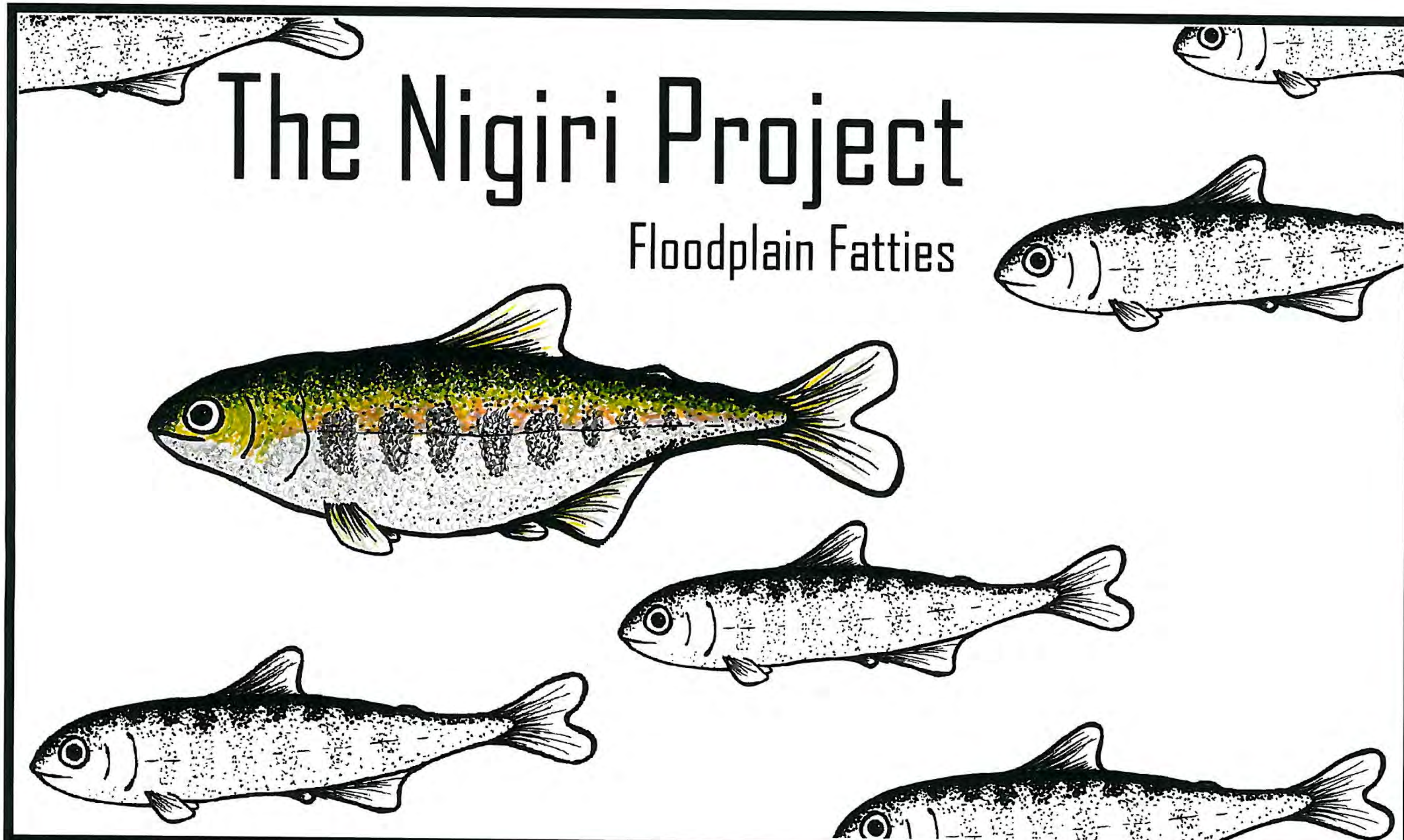
NCWA

RCRC

Audubon California

California Rice

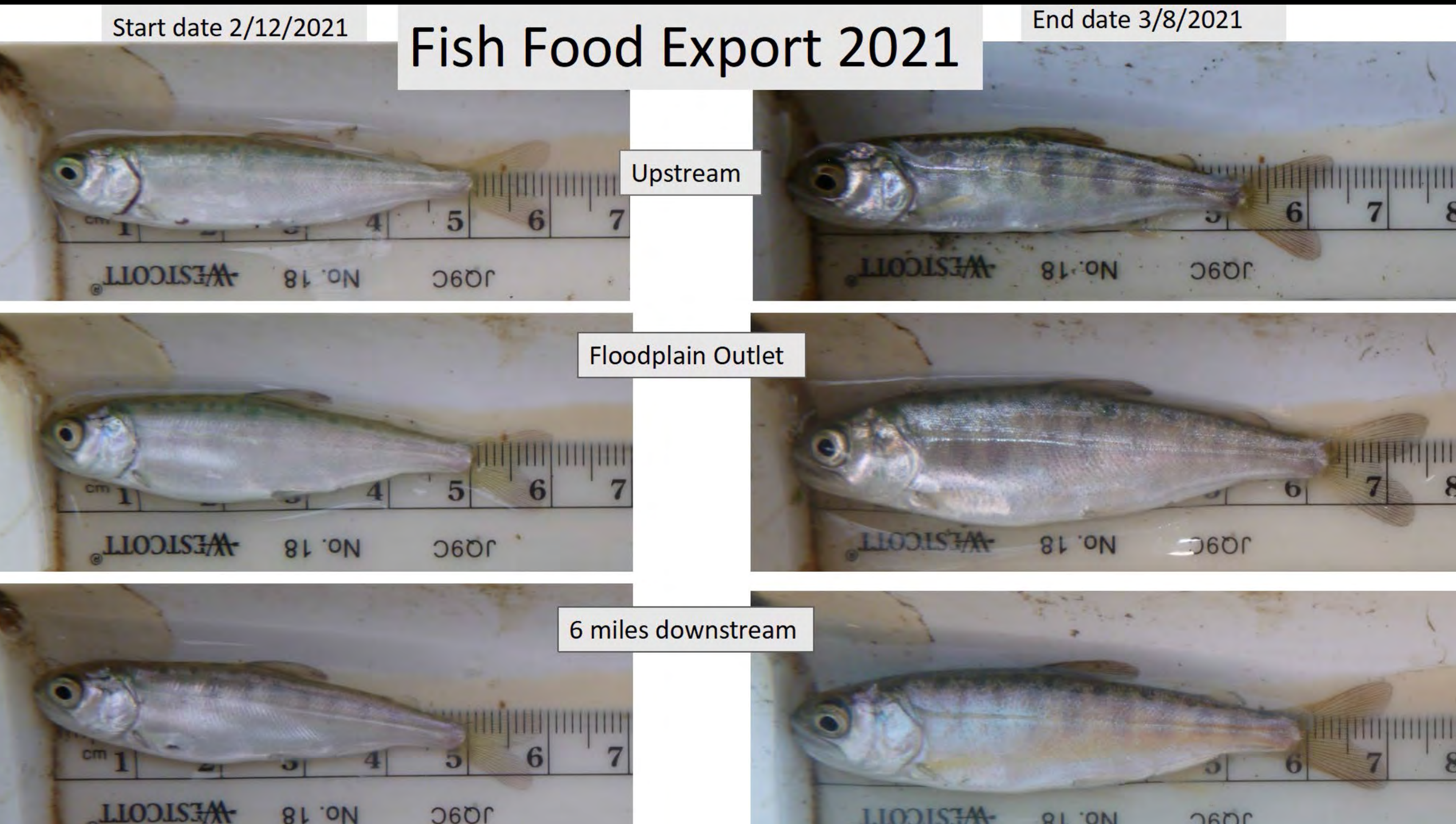
Wet Side



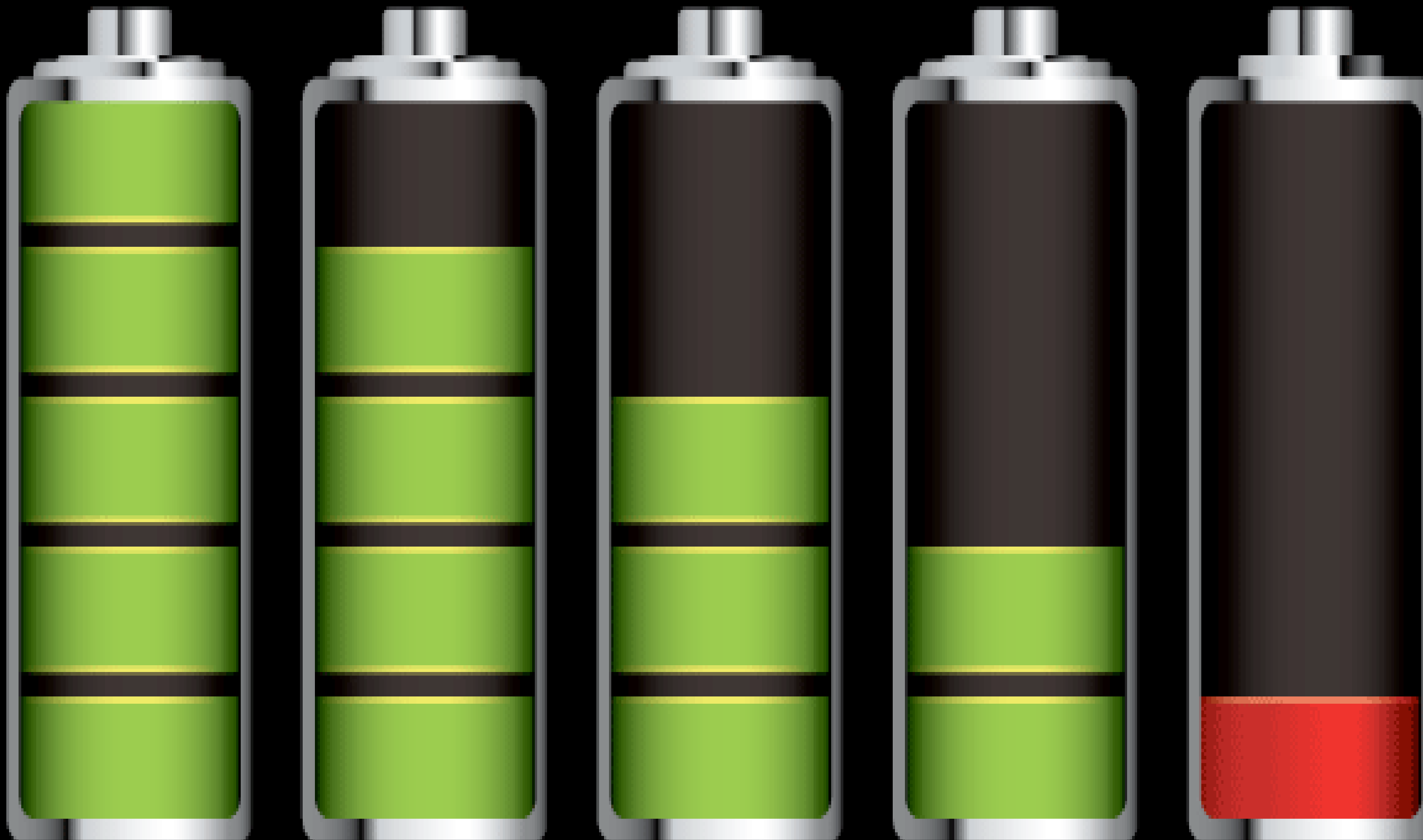
Dry-side: Implementing the solution at the SCALE of the Problem


M.Wier

Floodplain-derived food web subsidy to River channel habitats

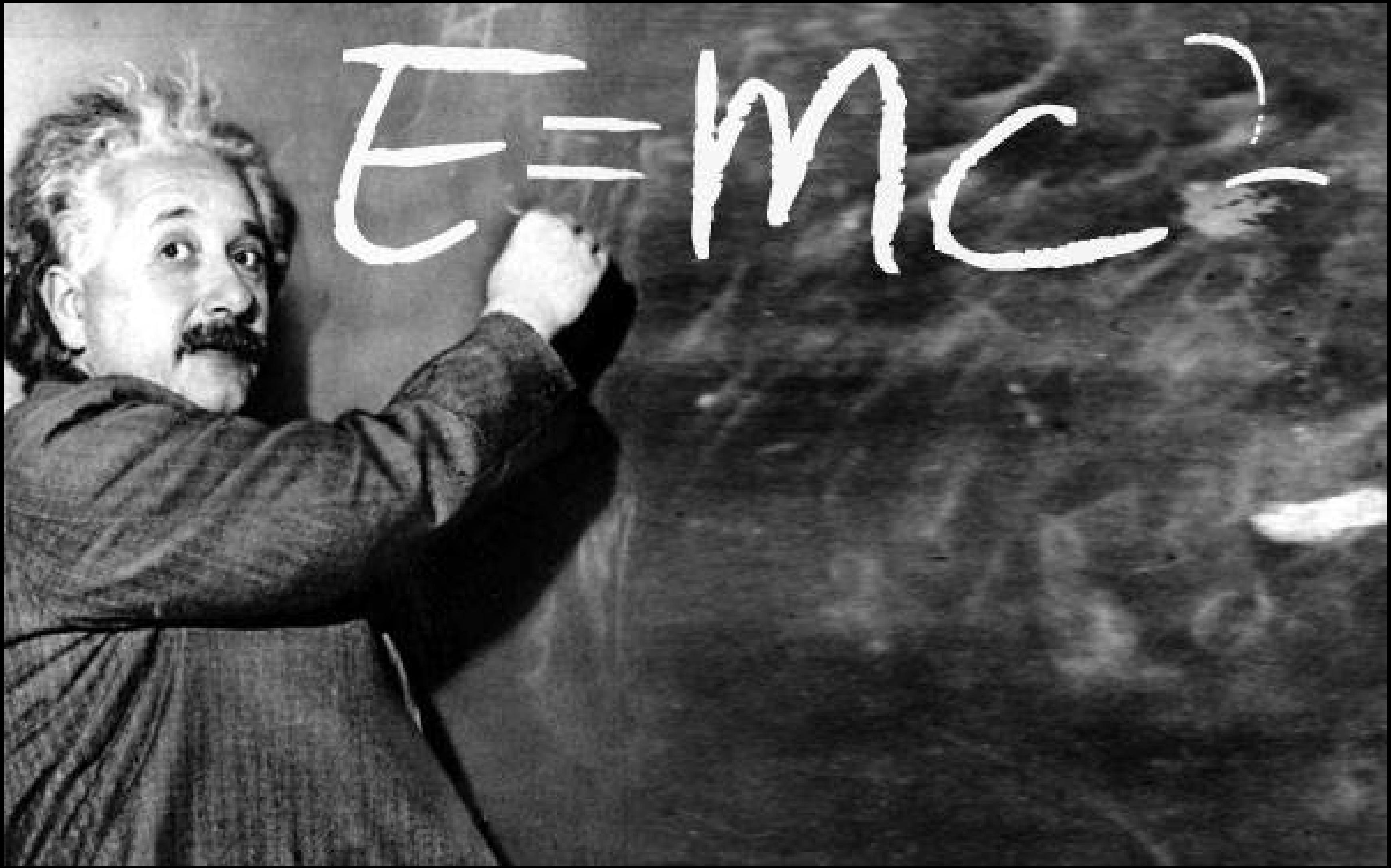


Energy in **Biomass out**



Pre-development ——— Today

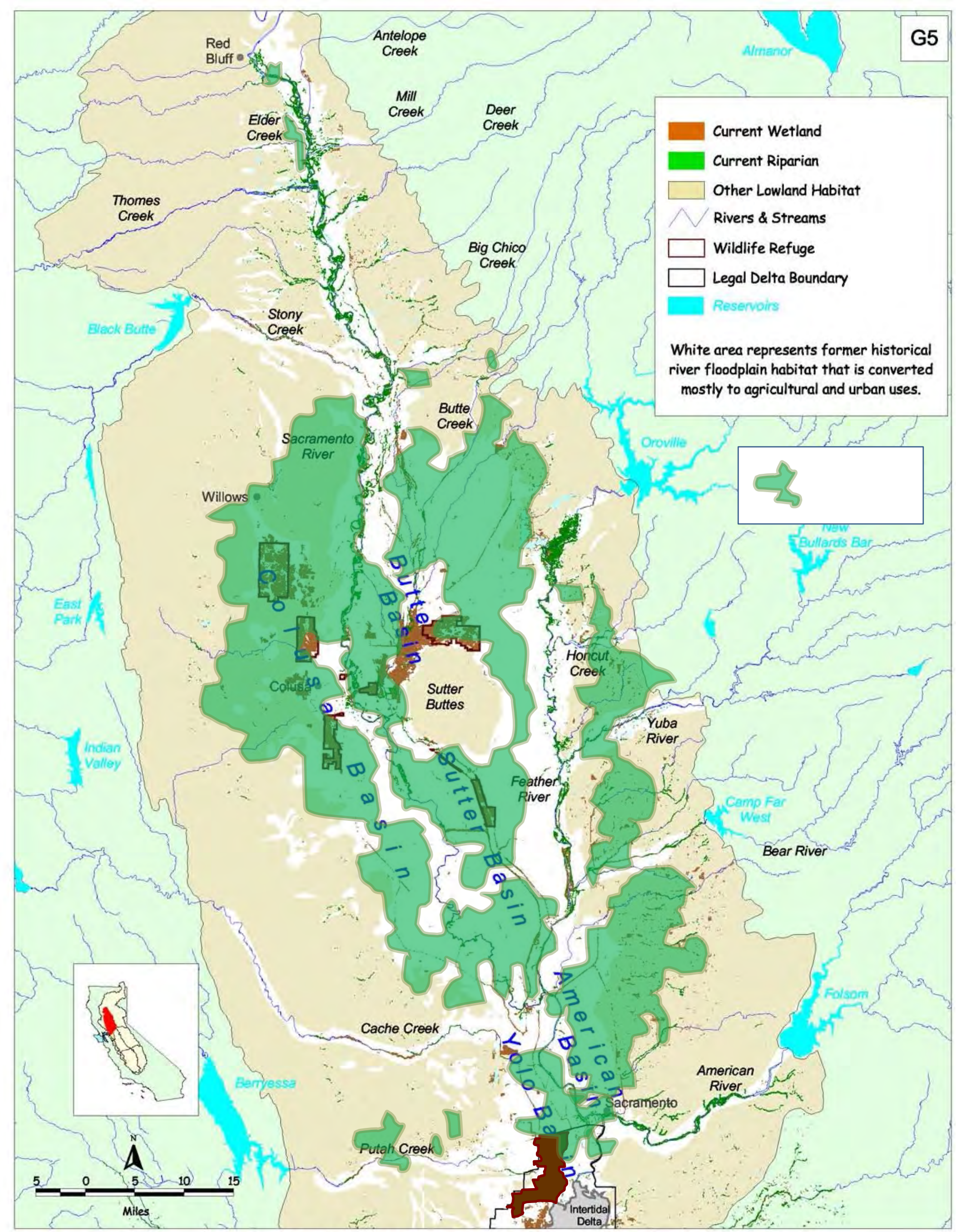
Loss of Seasonally Inundated Floodplain



The mathematics of recovery

When we cut off
95% loss of
activated
floodplains,

why are we
surprised
to find that we have
only approximately
5% of native
fish biomass?

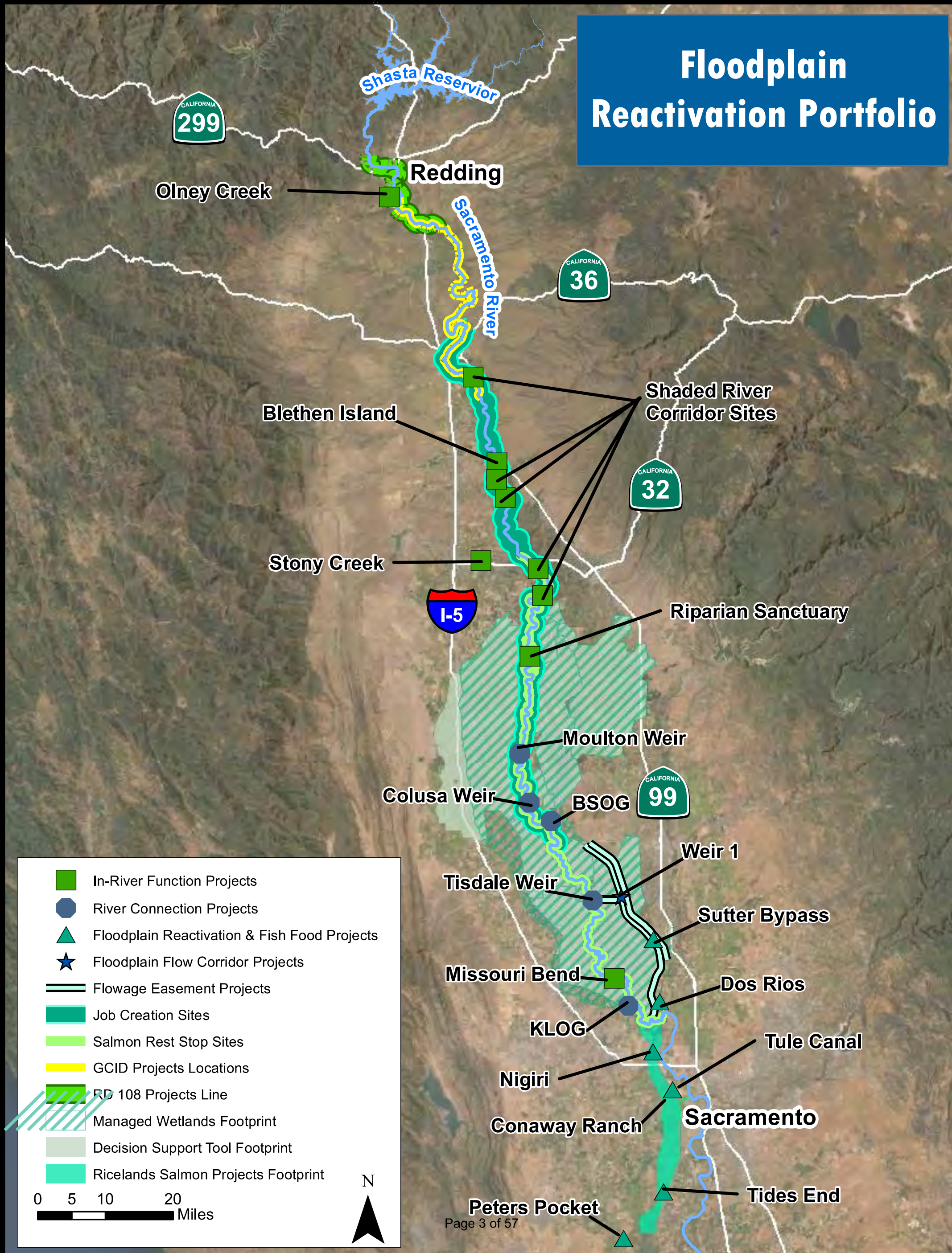


Sacramento Valley Current River Floodplain Ecosystem

Big, Early.

Science into Action

CA Water Solutions



Fish Don't Swim in Paper Rivers

Turning Science into Action - Fish Don’t Swim in paper Rivers

- Fish population resilience is predicated on biocomplexity which is in turn built on diverse aquatic habitats in time and space.

- Do our best to mimic the natural processes which create and sustain diverse habitat mosaics at landscape scale

- Attempt to re-expose native fish populations to an approximation of the patterns of biophysical conditions under which they evolved and to which they are adapted – Give fish rivers they can recognize!

- Every link in the chain! All life stages and the habitats on which they they depend are needed in order for a population to express the life-history diversity on which resilience to inevitable environmental change is predicated

- Management objectives should be aimed at diversifying the portfolio of size and timing at ocean entry

Process-Based Reconciliation

Integrating a working knowledge of natural process, into management of natural resources


09/21/2021 00:30:06

Coupling habitat and prey supply with juvenile Chinook Salmon growth and production in the San Joaquin River Restoration Project

Steve Blumenshine
CA Water Institute
Fresno State Univ

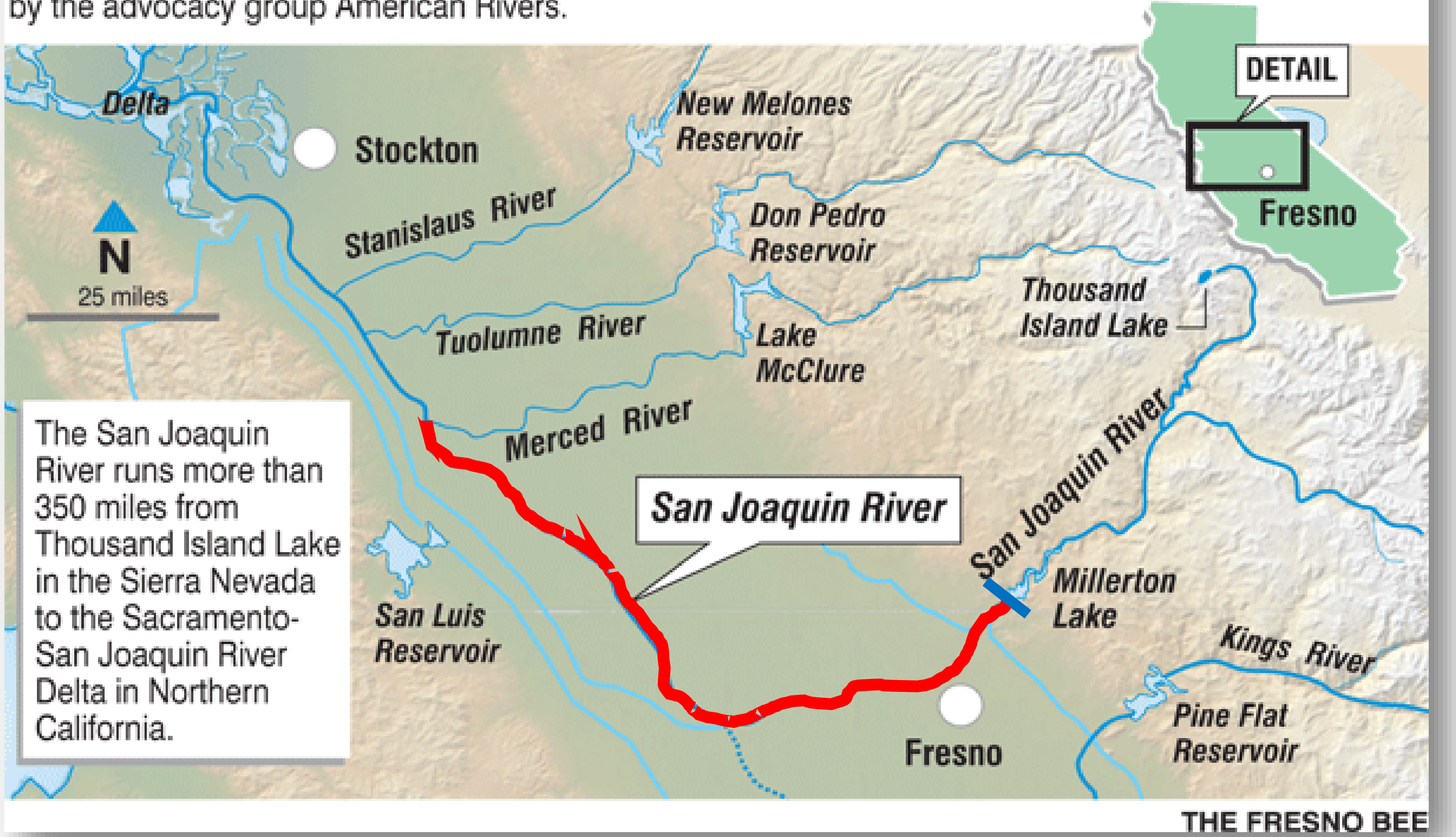
Images American Rivers

Chinook Salmon Restoration: San Joaquin River, CA

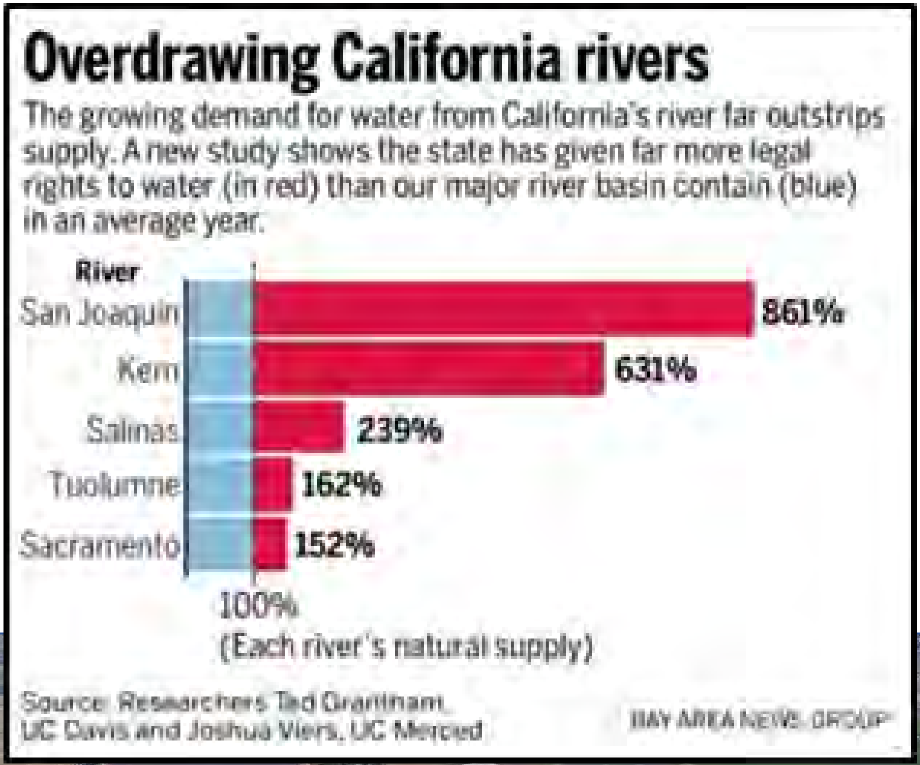
SAN JOAQUIN RIVER RESTORATION PROGRAM

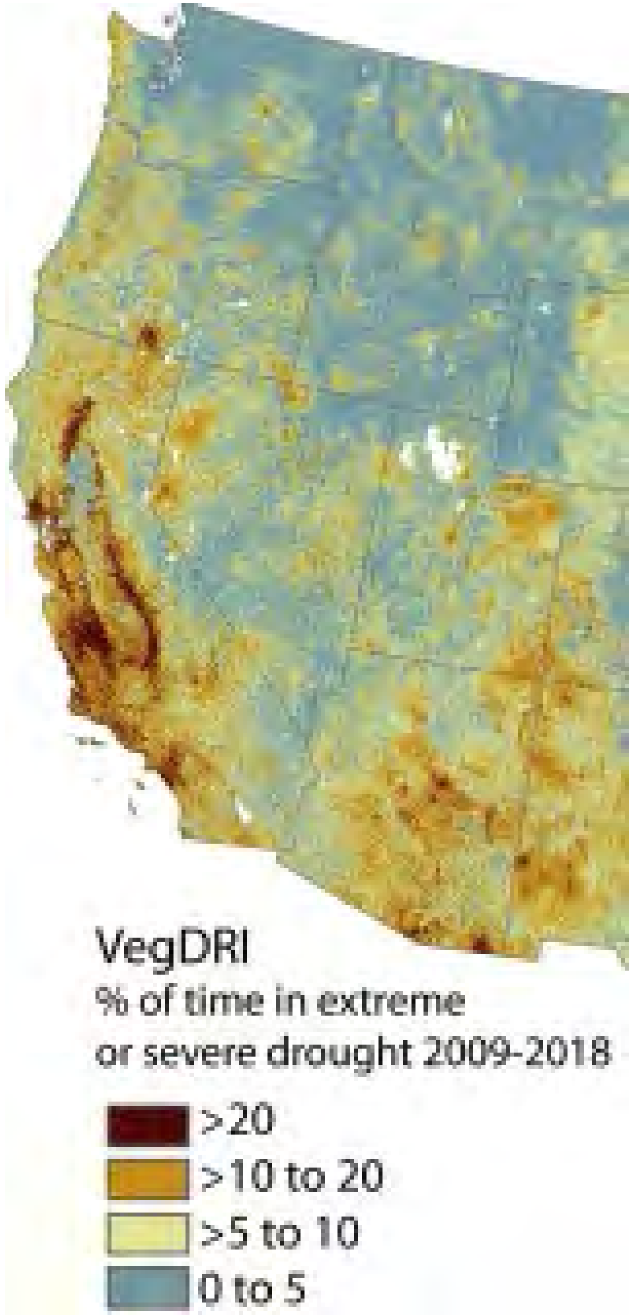
Endangered river

The San Joaquin has been named the most endangered river in the United States by the advocacy group American Rivers.



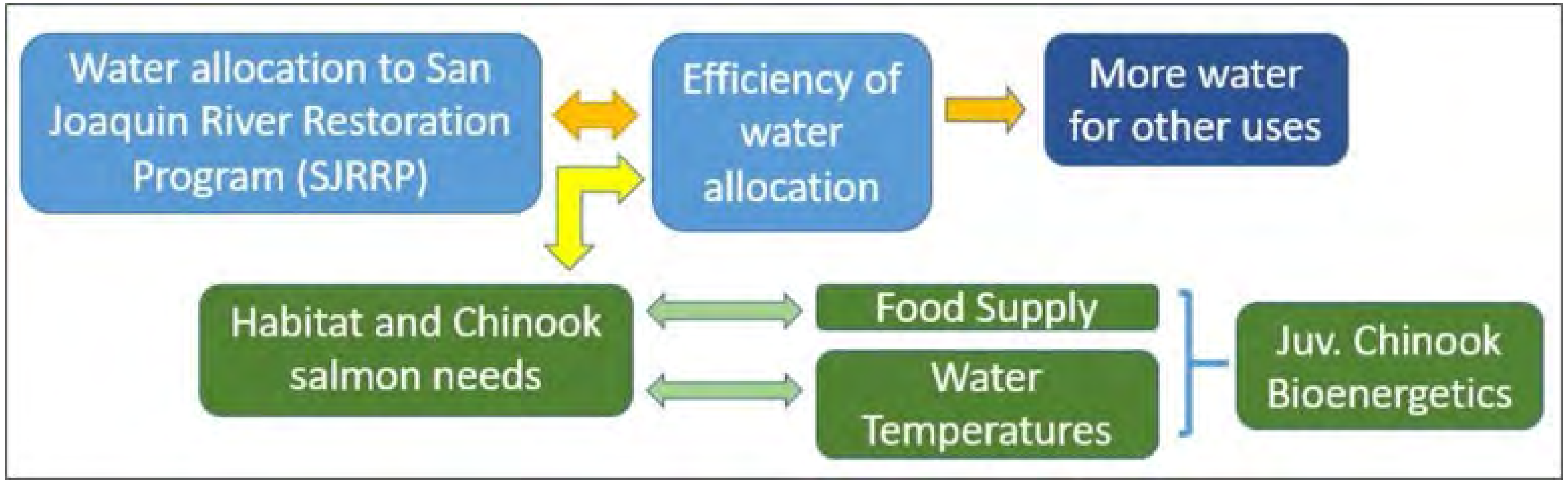
- **Highly Altered**
- **Overprescribed Water Demand**

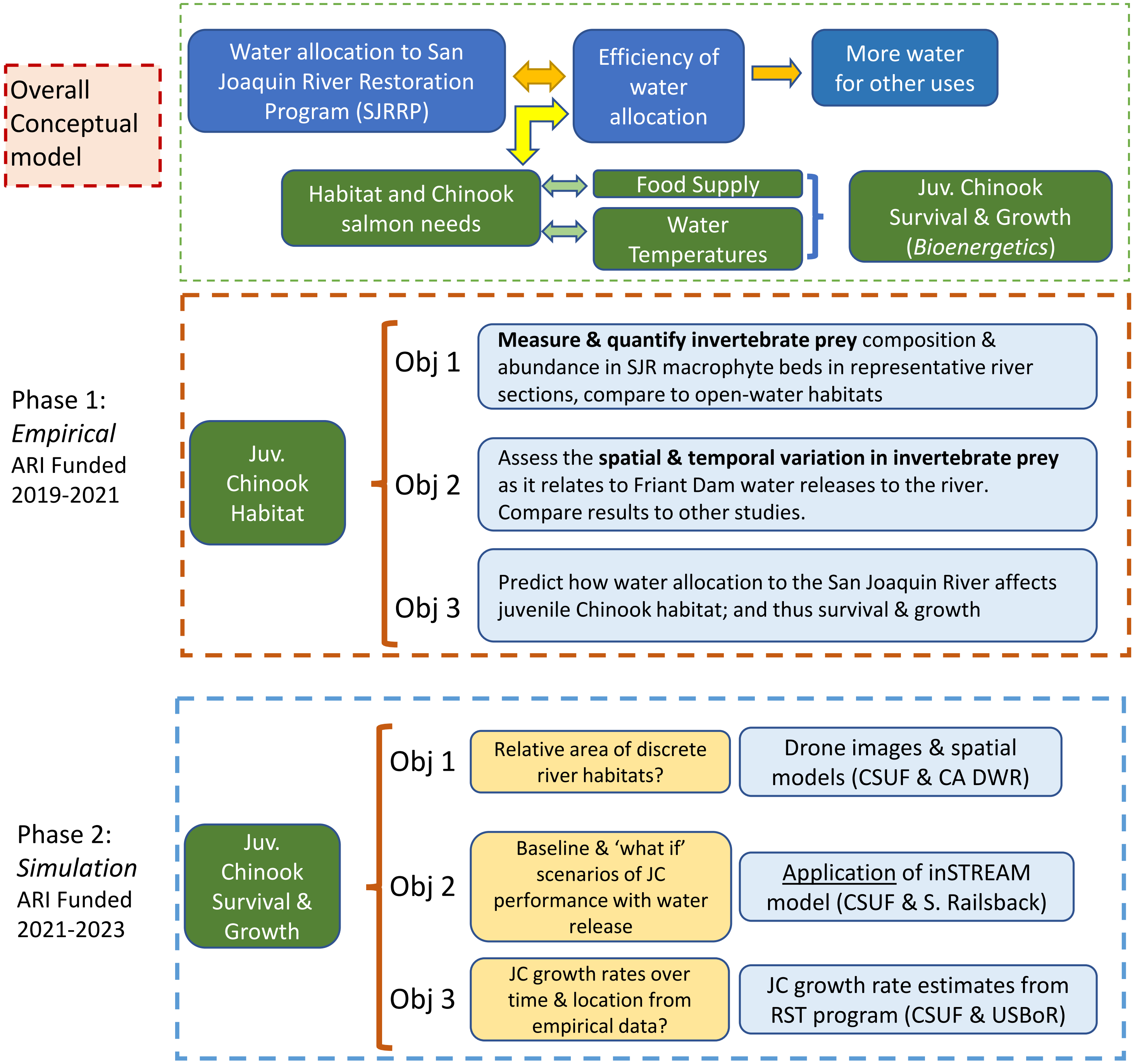




(Crausbay et al. 2020)

Conceptual Model (for project funding):
Bioenergetics Applications to Habitat & Species Management



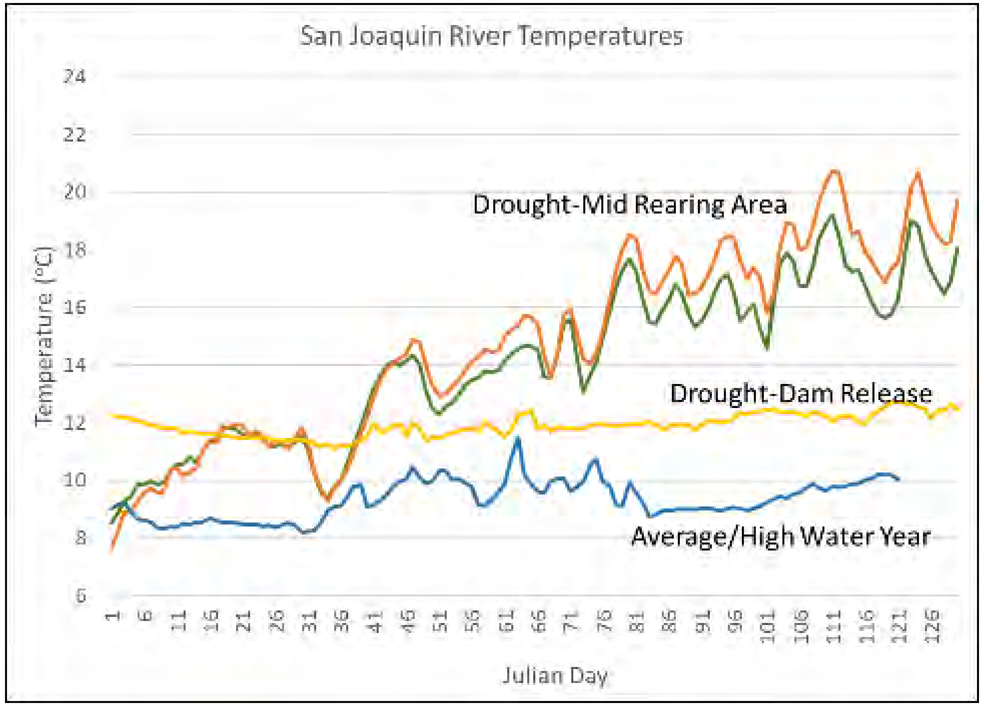


Funding: CSU-Ag Research Institute,
CA Water Boards,
CSU WRPI-USDA Intership Prog

Partners/Collaborators: USBoR, CDFW,
CDWR, Steve Railsback,
CSU-Fresno (Civil Engin, Biology, Plant Sci)

Water Year [1]	Unimpaired Runoff [2] (Natural River)	SJRRP Water Year Type [3]
1995	3,876,370	Wet
1996	2,200,707	Normal-Wet
1997	2,817,670	Wet
1998	3,160,759	Wet
1999	1,527,040	Normal-Wet
2000	1,735,653	Normal-Wet
2001	1,065,318	Normal-Dry
2002	1,171,457	Normal-Dry
2003	1,449,954	Normal-Dry
2004	1,130,823	Normal-Dry
2005	2,826,872	Wet
2006	3,180,816	Wet
2007	684,333	Dry
2008	1,116,790	Normal-Dry
2009	1,455,379	Normal-Wet
2010	2,028,706	Normal-Wet
2011	3,304,824	Wet
2012	831,582	Dry
2013	856,626	Dry
2014	509,579	Critical-High
2015	327,410	Critical-Low
2016	1,300,986	Normal-Dry
2017	4,395,400	Wet
2018	1,348,979	Normal-Dry
2019	2,734,772	Wet
2020	886,025	Dry

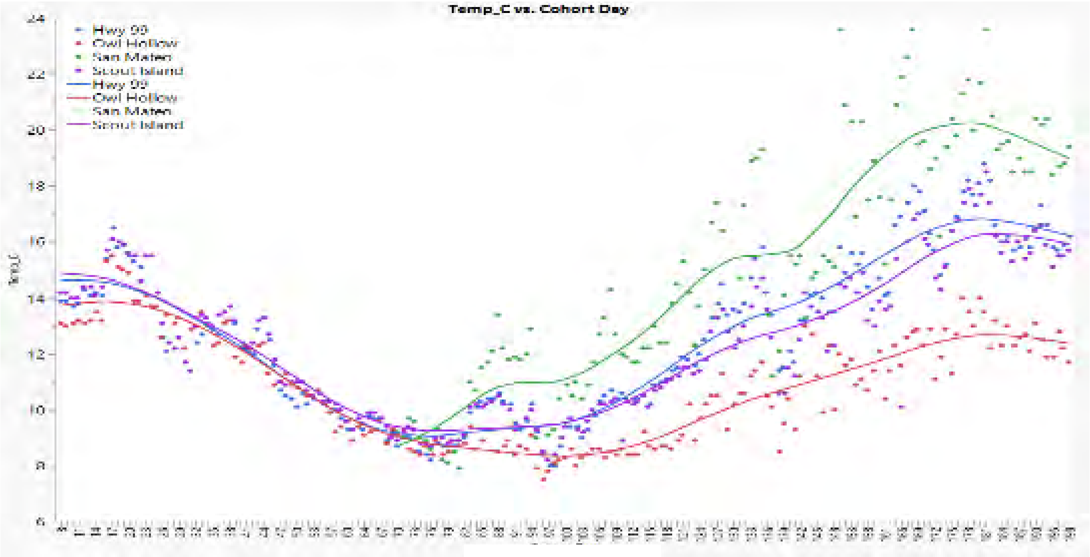
Water Releases to SJF Across Years



Water-Year Type, Temperature Regimes

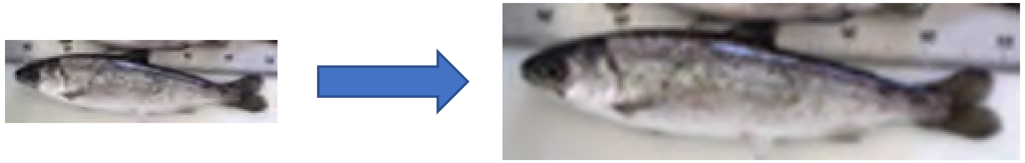
"Goldilocks Effects"?

Temperatures; Location * Time interaction

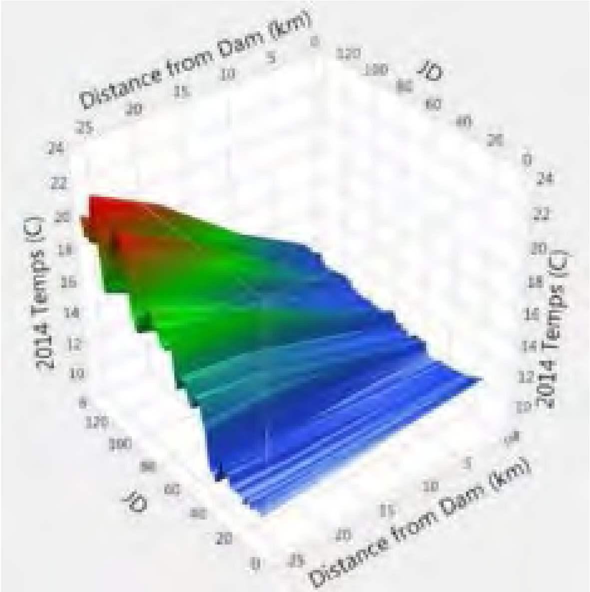


Nov 1 Cohort Day May 16

Juvenile Salmon Growth



- Thermal Environment + Prey Energy

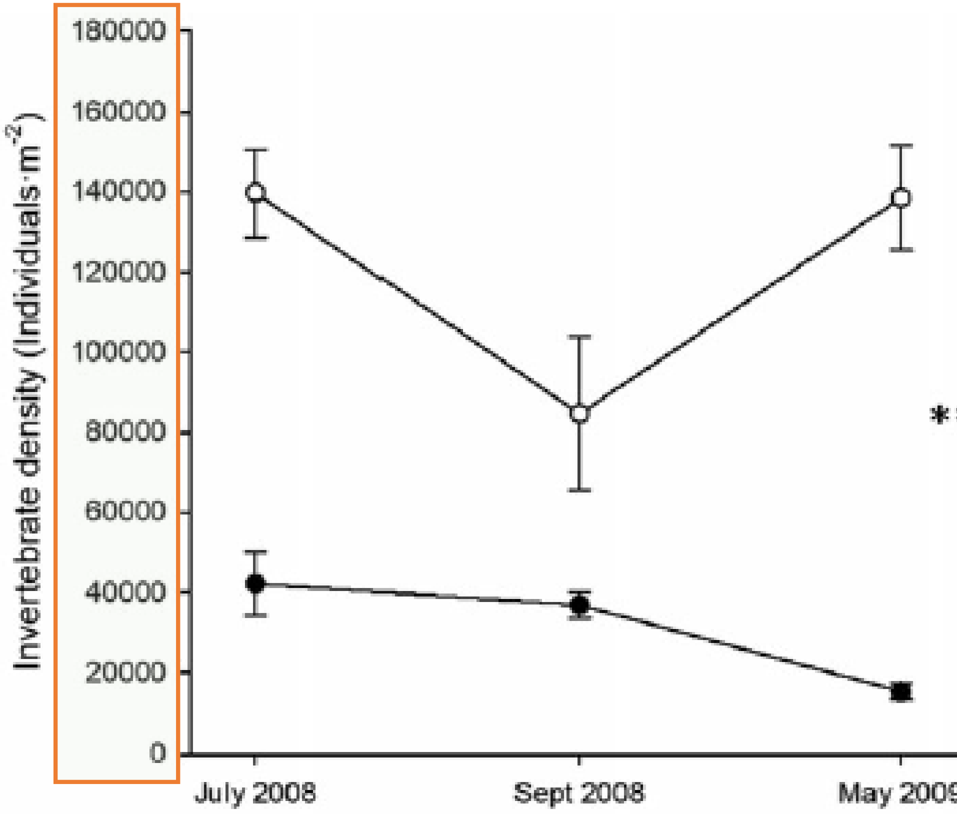


1. Empirical info
2. Simulations

(Simulations)
Bioenergetics IBM & inSTREAM/inSALMO

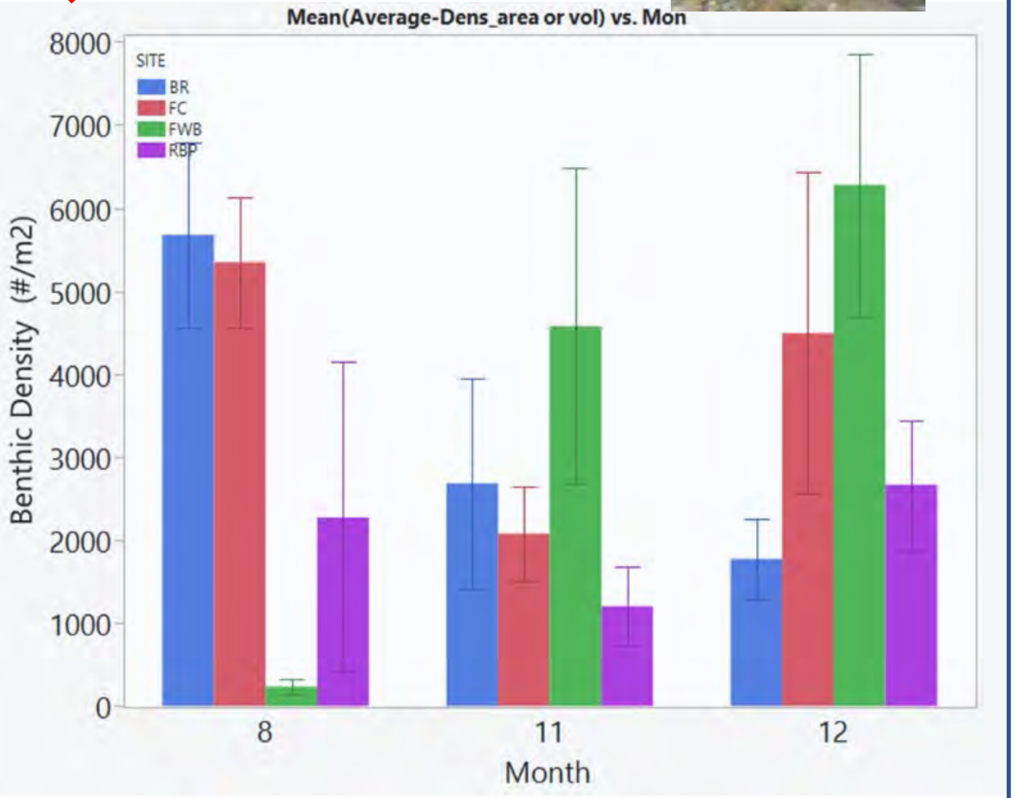
Stream macrophytes increase invertebrate production and fish habitat utilization in a California stream

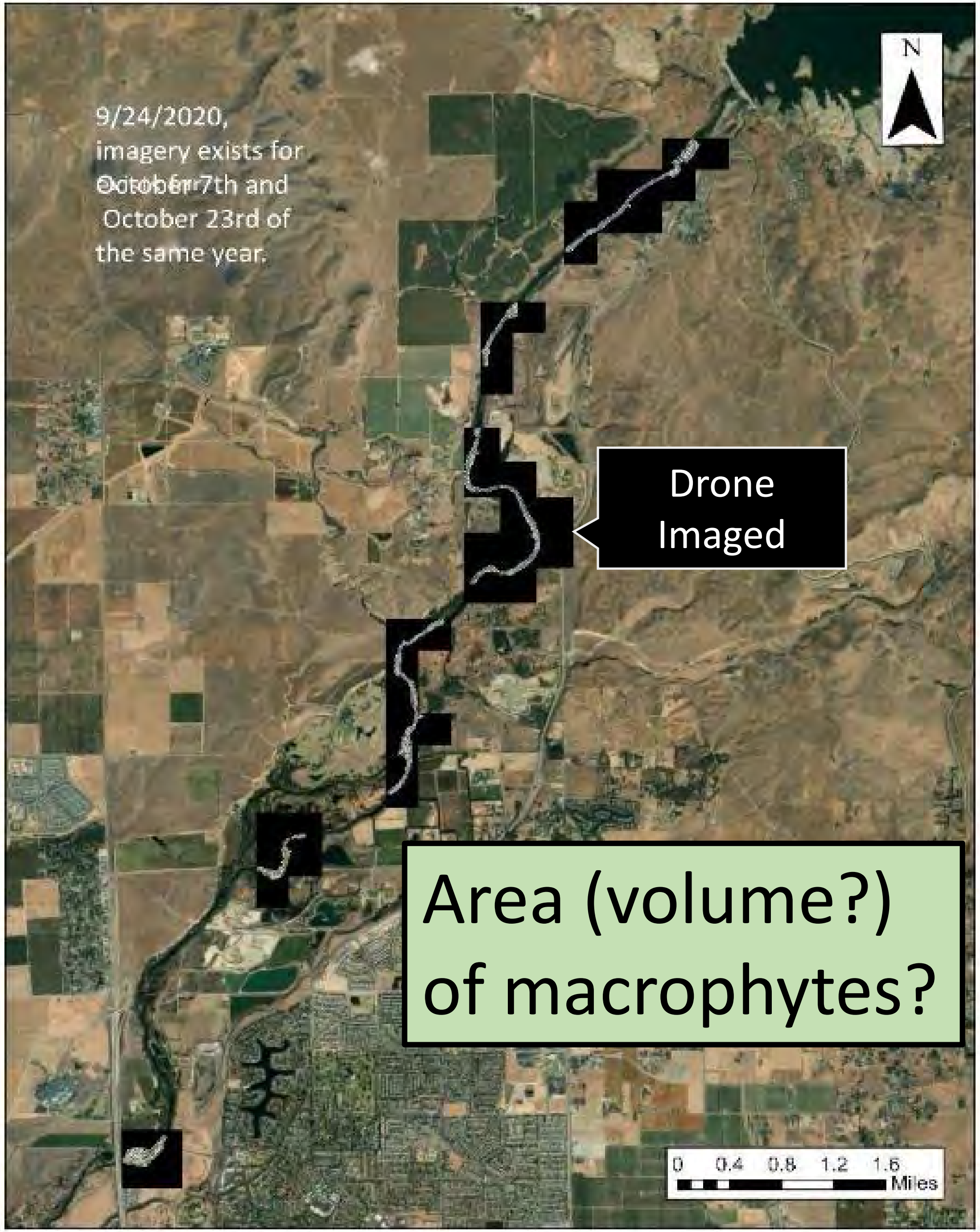
Robert A. Lusardi[1] | Carson A. Jeffres[2] | Peter B. Moyle[2]




Vancouver Observer

San Joaquin River;
JCS Rearing Area




N
9/24/2020,
imagery exists for
October 7th and
October 23rd of
the same year.
Drone
Imaged
Area (volume?)
of macrophytes?
0 0.4 0.8 1.2 1.6
Miles

Mike Grill

Is there enough prey to offset higher temps at lower water levels? (*where/when?)*

Plumb and Moffitt 2015
‘higher’ juvenile temp optima

Lusardi 2019, Sommer 2001
↑prey offsets high temperature metabolic costs

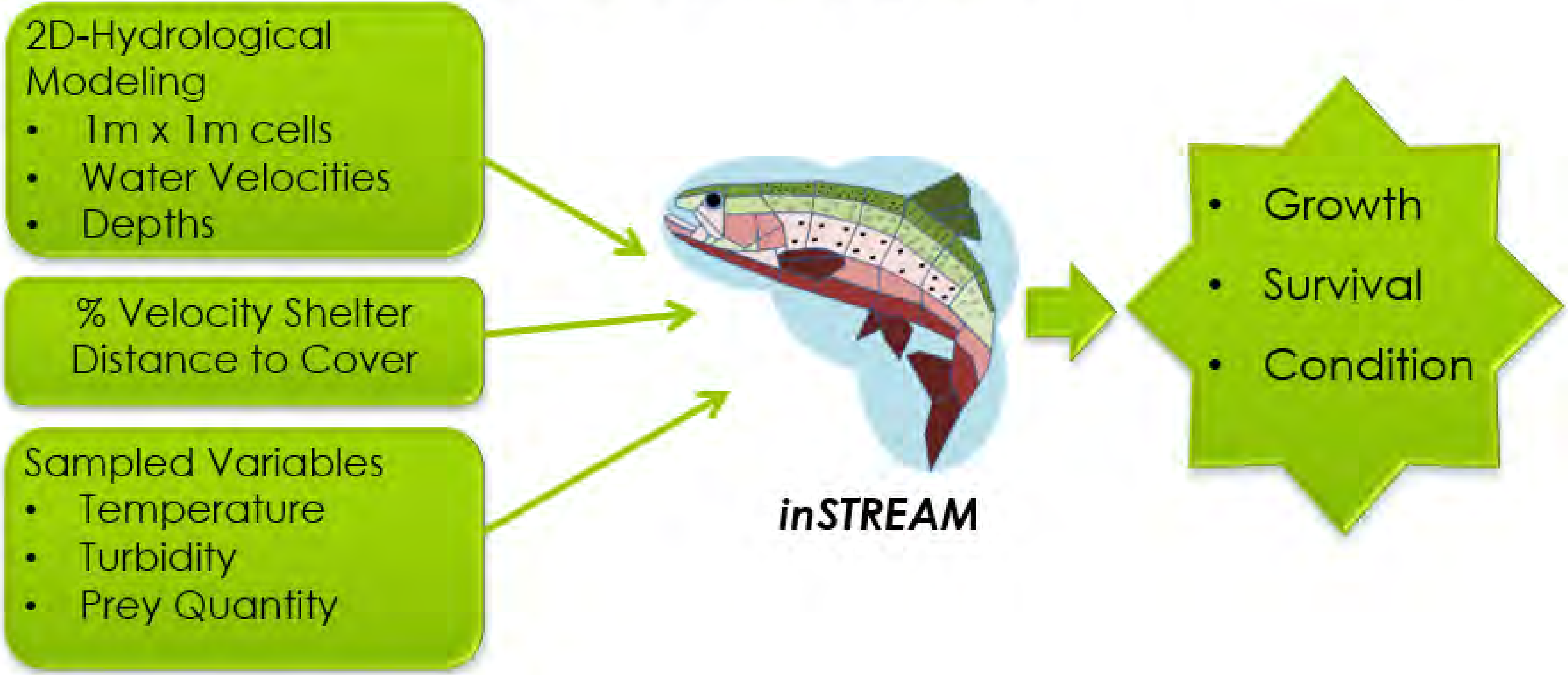
Spaulding 2016- ‘missing’ prey?

Lusardi 2018 – higher prey densities in macrophytes habitat (in-place & drift)

Modeling

Bioenergetics/Population Modeling

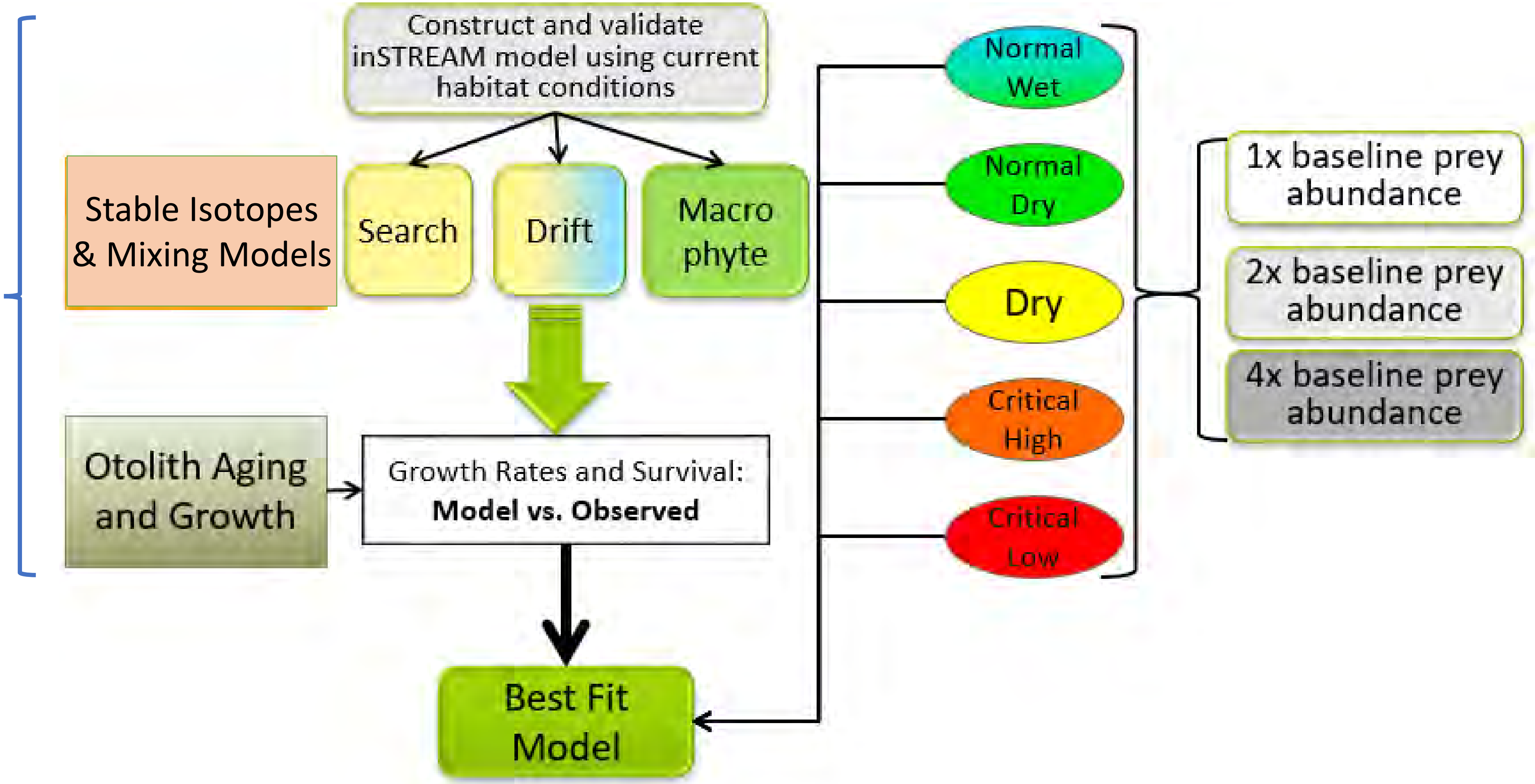
- Using inSTREAM (Steve Railsback and Bret Harvey), a Individual-Based Model (IBM) of whole populations, including birth, growth, migration, and death due to various events



Graphic: Taylor Spaulding

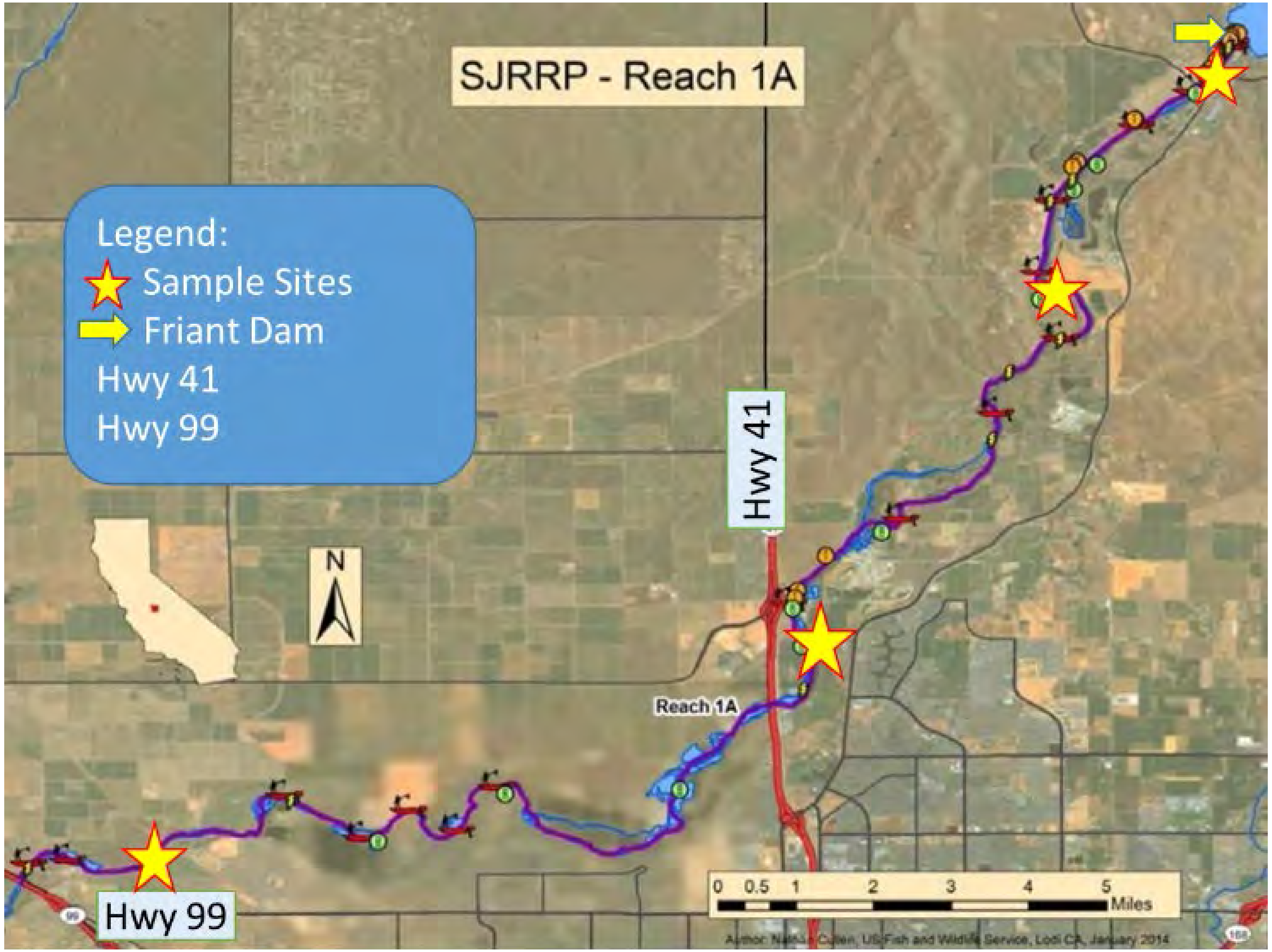
Scenarios of water/habitat & prey abundance

Tools to assess diet & growth

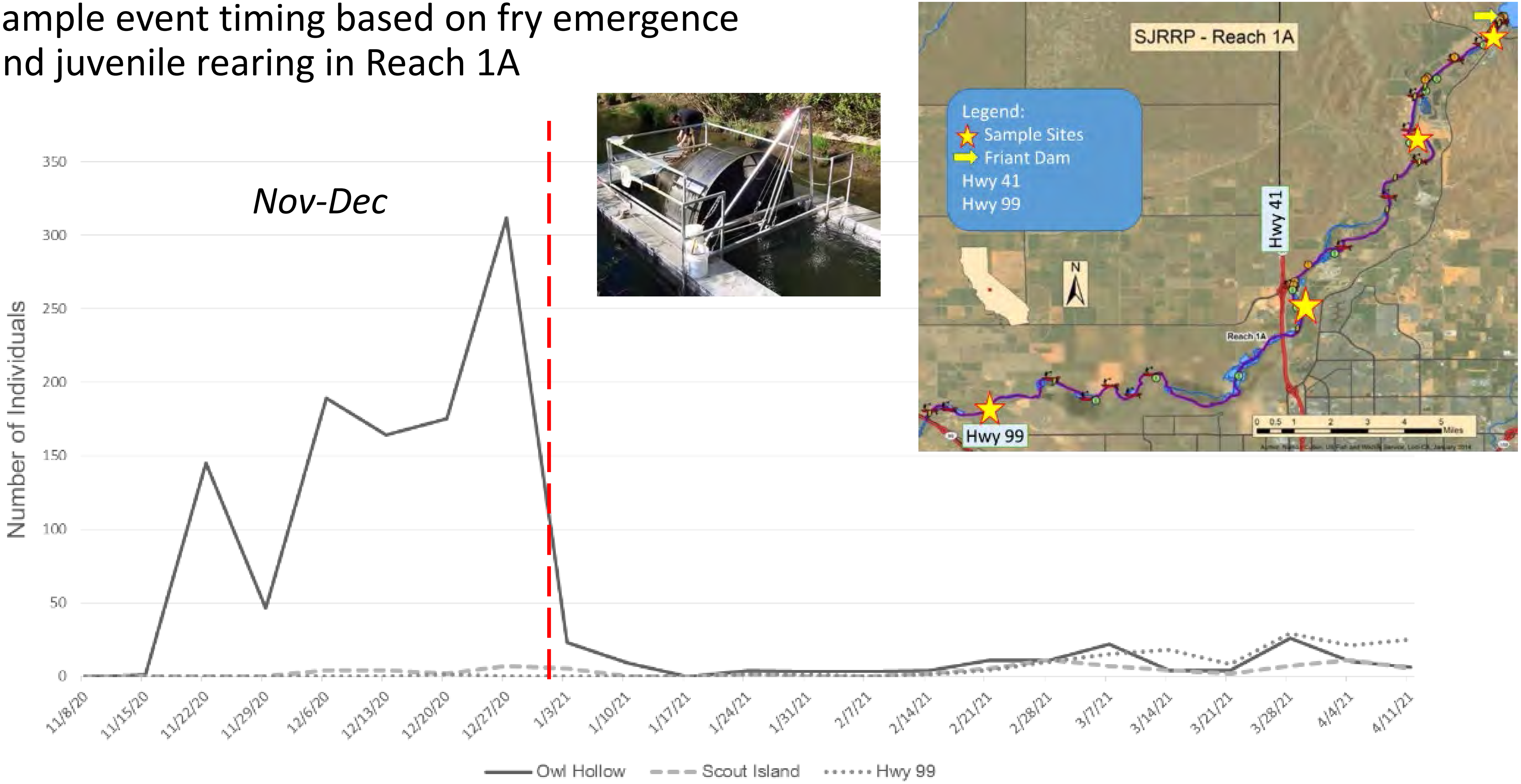


Graphic modified from Taylor Spaulding

Study sites and rotary screw traps



Sample event timing based on fry emergence and juvenile rearing in Reach 1A



Upriver Midriver Downriver

Sampling Coverage: Nested by: Time, Location, Habitat

Sample Events

Nov & Dec

Year 1– 2019-20

Year 2– 2020-21

Sites

1. Friant Cove
2. Ball Ranch
3. Sportsman's Club
4. Riverbottom Park

Habitats

Benthos

4 samples

Drift

3 net sets; 2 nets each: surface and riverbed

Macrophyte

2 beds; 3 samples each: upriver, margin, & downriver

Scaling Issues!

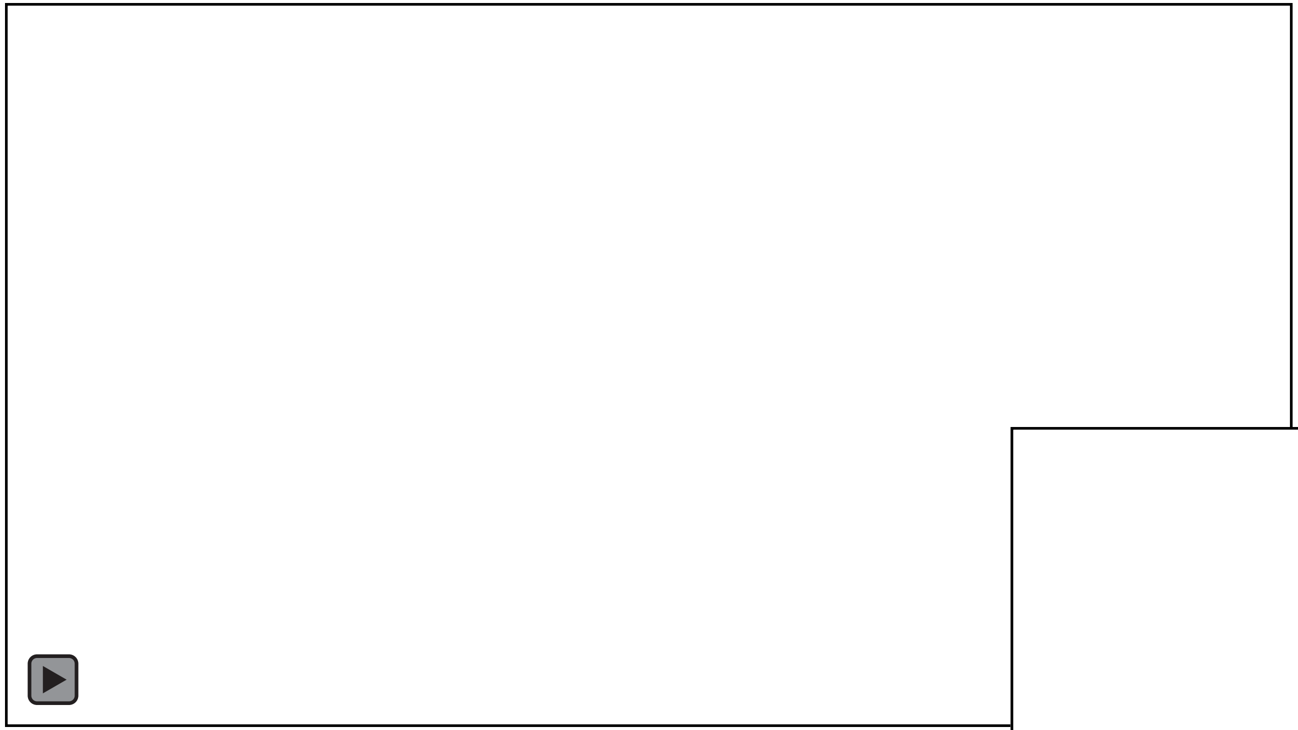
or g / m^2

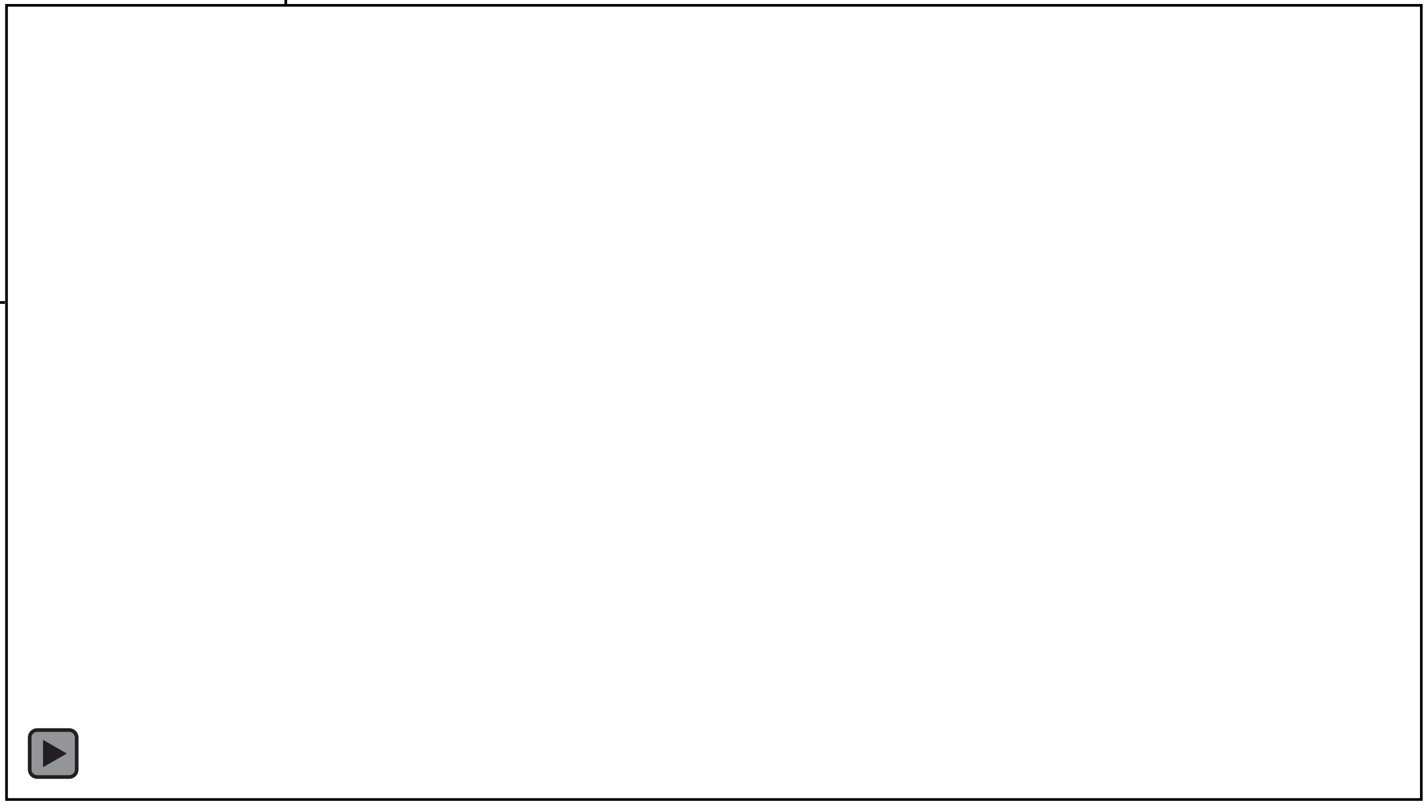
or g / m^3

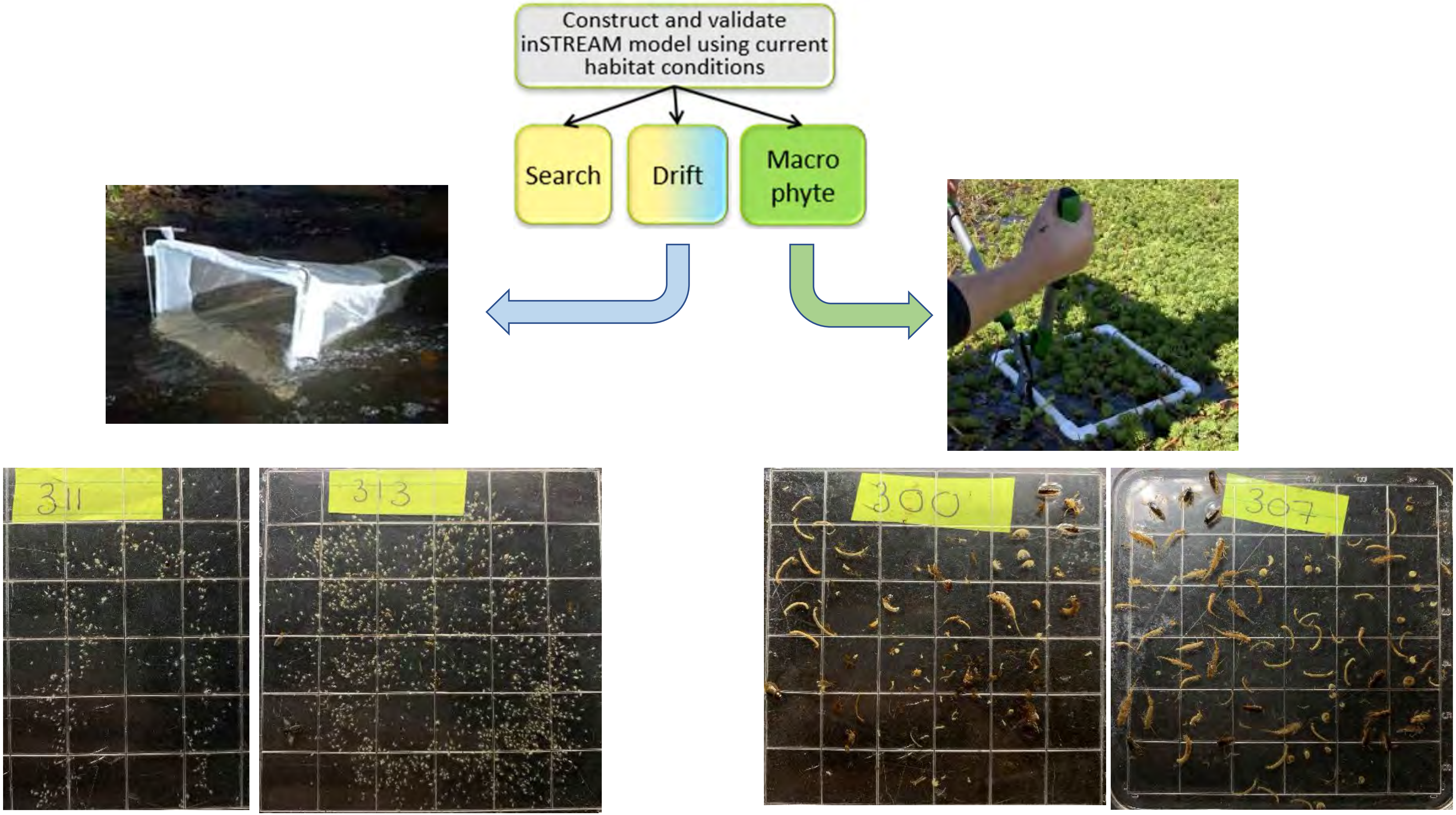
or g / m^2

or g / m^3

or g /g plant



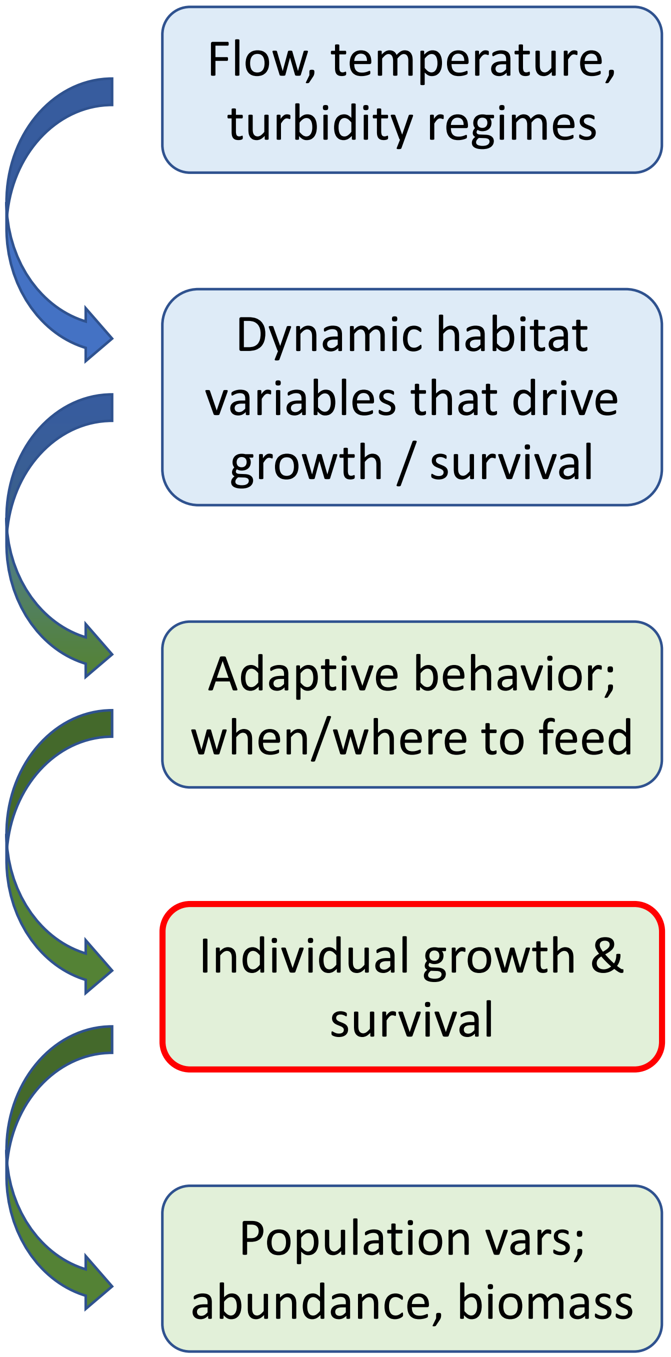



Construct and validate inSTREAM model using current habitat conditions
Search
Drift
Macro phyte
311
313
300
307

InSTREAM 7 User Manual: Model Description, Software Guide, and Application Guide (S. Railsback)

Version 7 of inSALMO was funded in part by the California State University, Fresno Foundation as part of the project *Influence and Impact of Water Allocation for Salmon Restoration*, directed by Dr. Steve Blumenshine.

To facilitate the San Joaquin River application, it also allows simulations to be initialized with juvenile salmon so model runs can focus only on juvenile rearing. This version and its documentation are now available. This version makes it very easy to represent macrophyte beds, either as separate "reaches" or by representing variables such as food availability as characteristics of individual cells instead of entire reaches. I plan to assist Dr. Blumenshine with application of the model to his study sites and their macrophyte beds.



inSTREAM model inputs include:

Light, Temperature

(some) Results

Sample Events

Nov & Dec

Year 1– 2019-20

Year 2– 2020-21

Sites

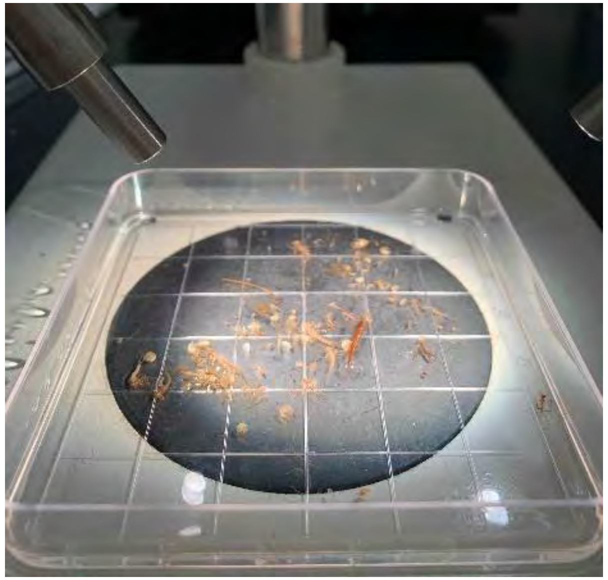
1. Friant Cove
2. Ball Ranch
3. Sportsman’s ub
4. Riverbottom rk

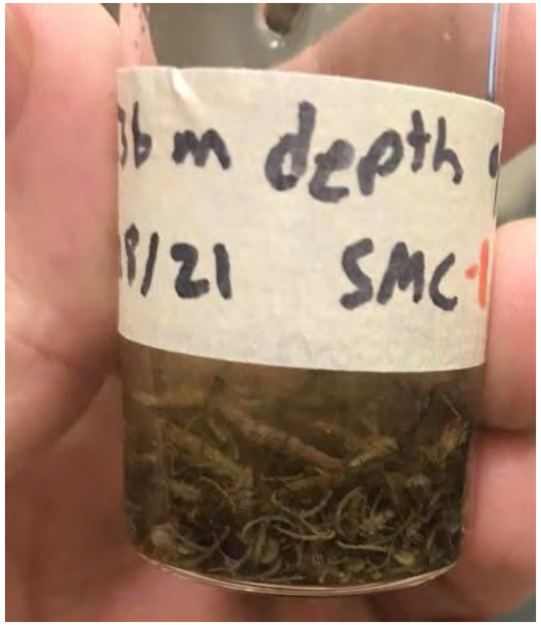
Habitats

Benthos
4 samples

Drift
3 net sets; 2 nets each: surface and riverbed

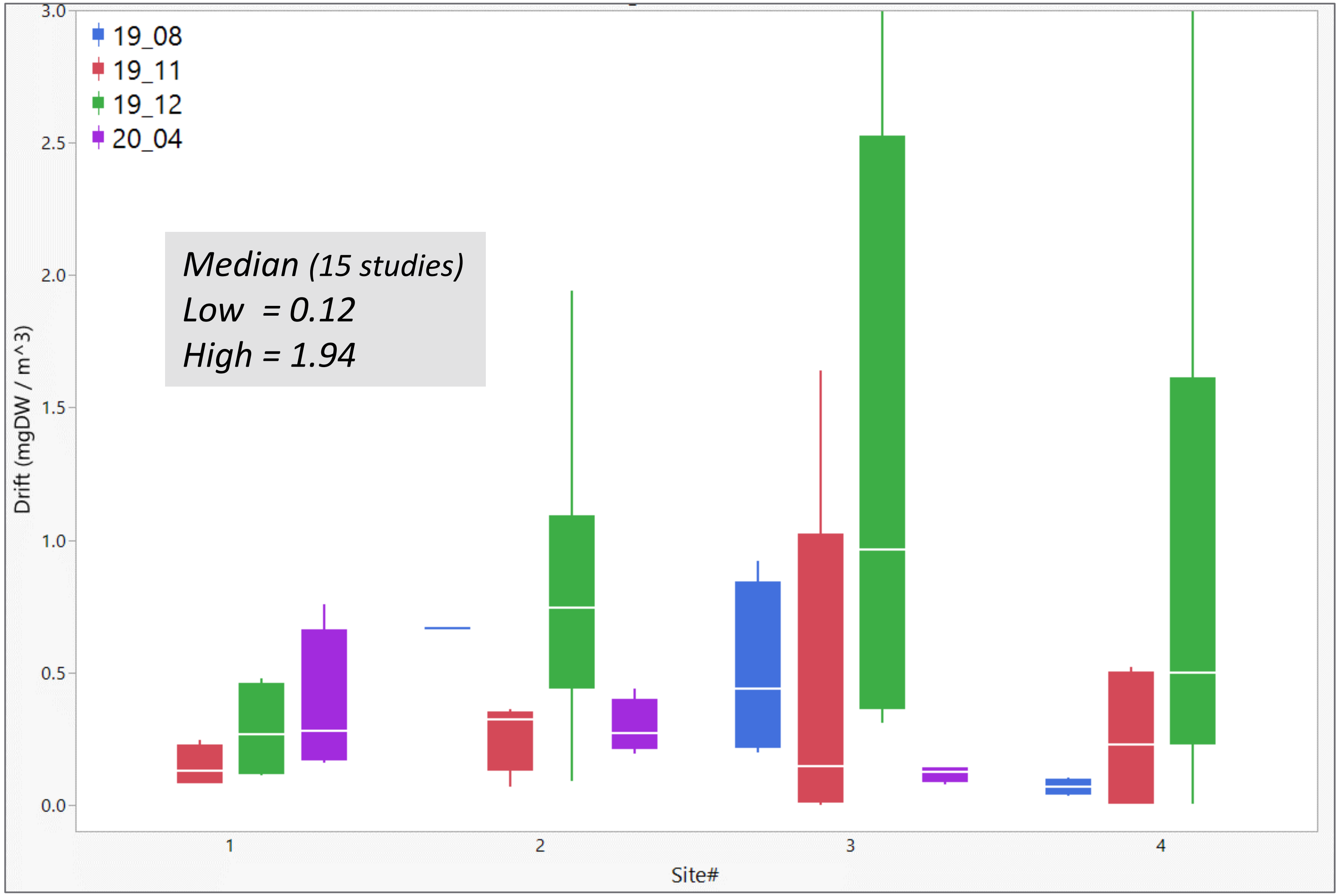
Macrophyte
2 beds; 3 samples each: upriver, margin, & downriver





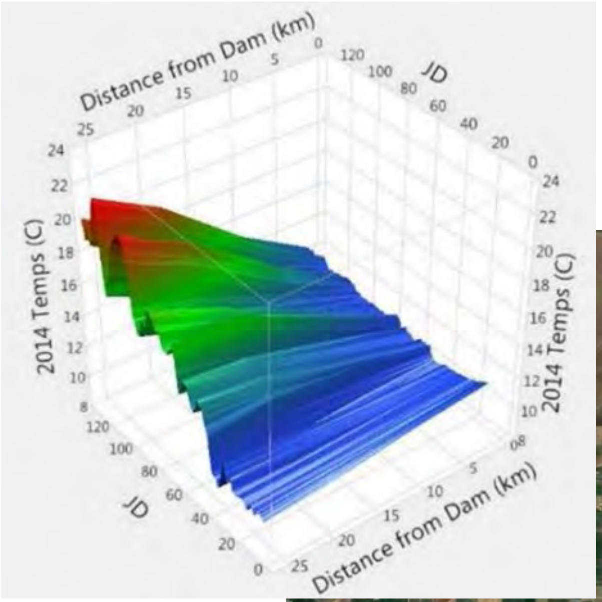
Drift
Biomass

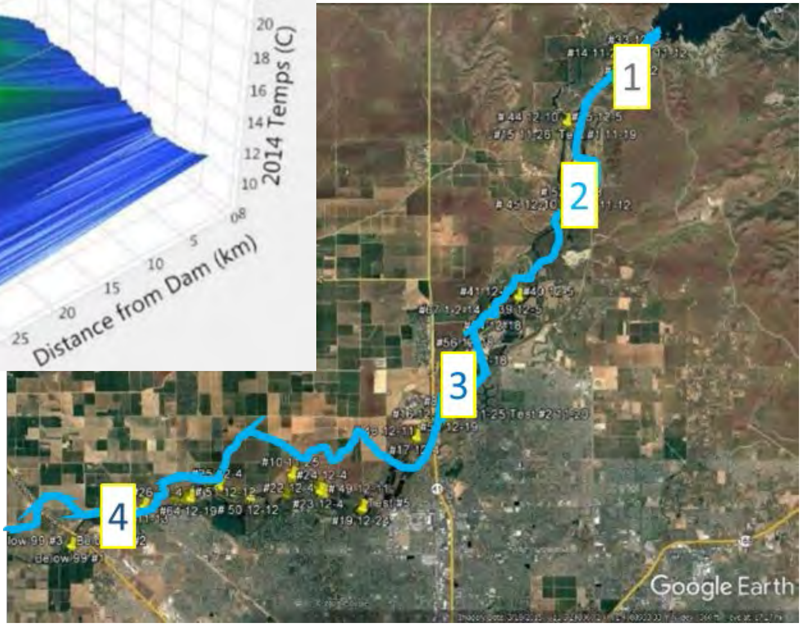
- Drift was higher (biomass / m^3) in Late December
- No difference among sites or site x month interaction

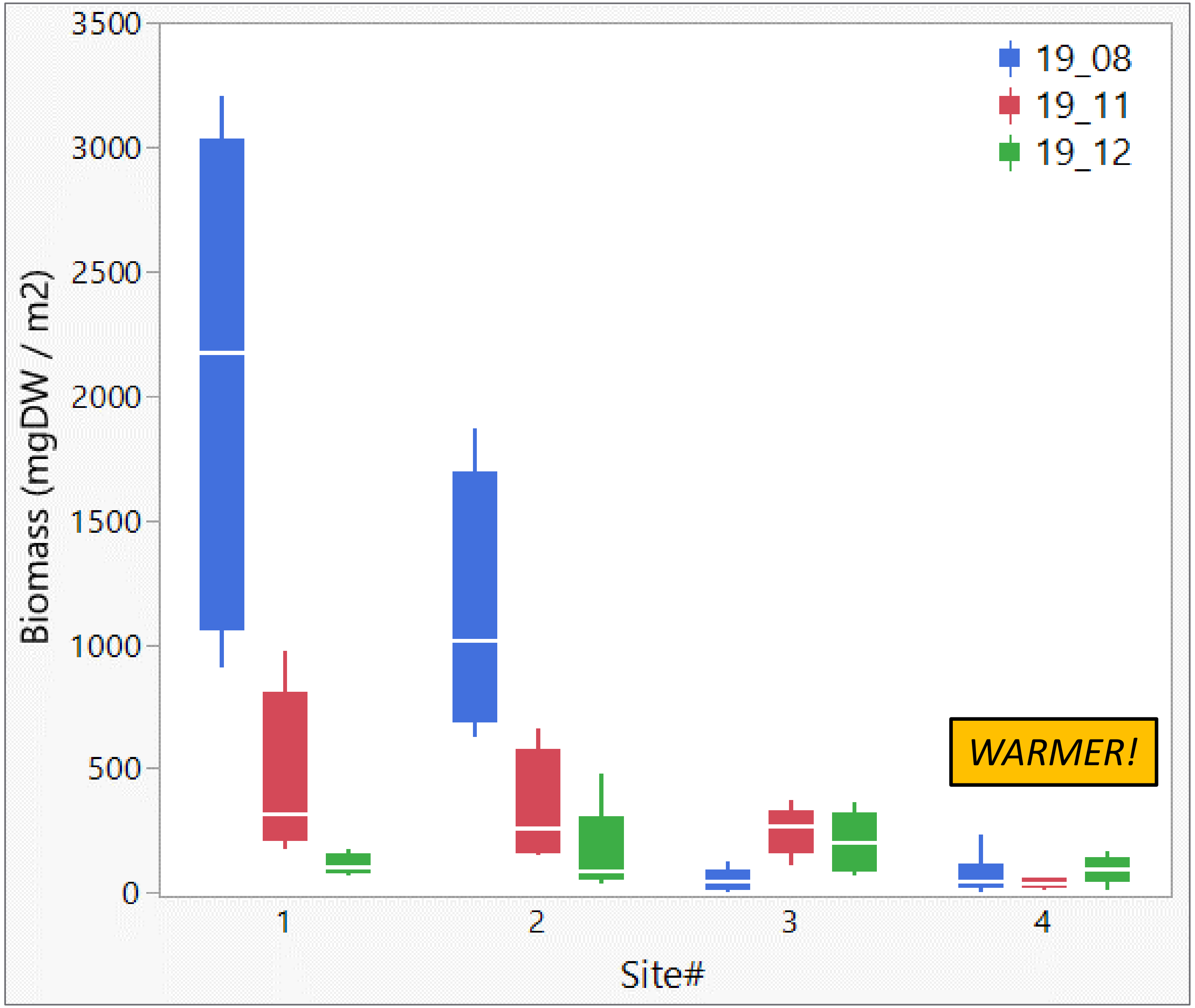


Benthos
Biomass

- Significant Month x Site interaction

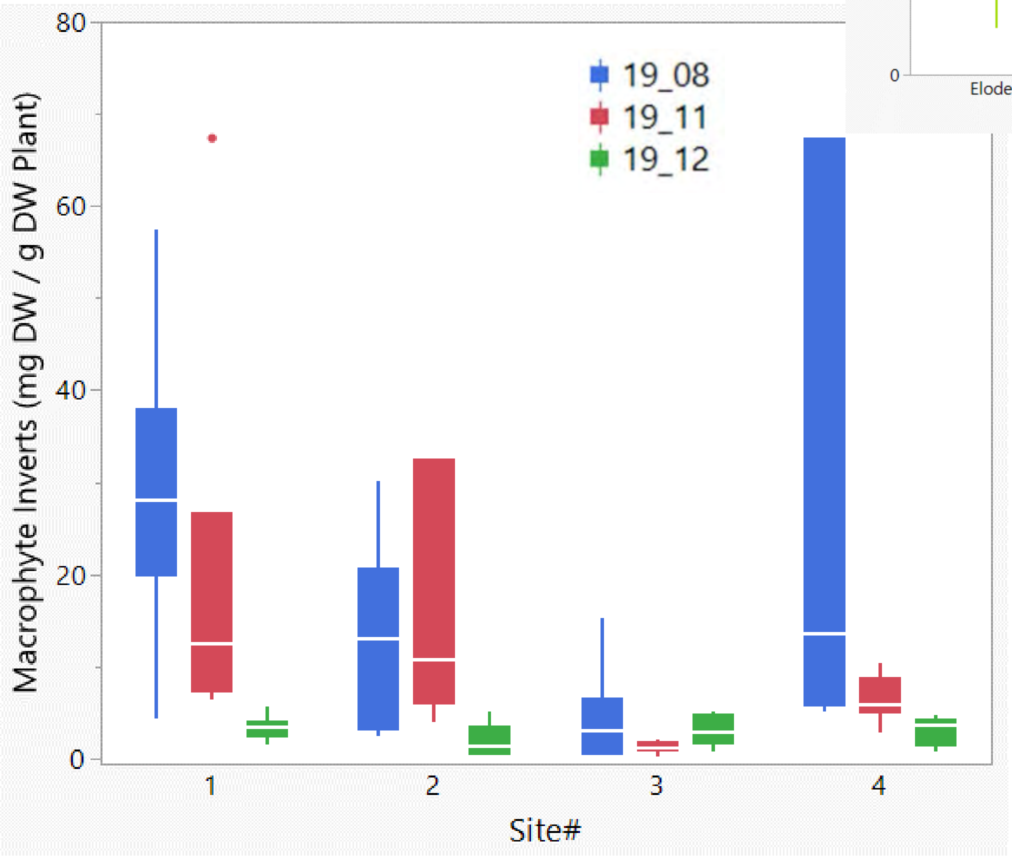


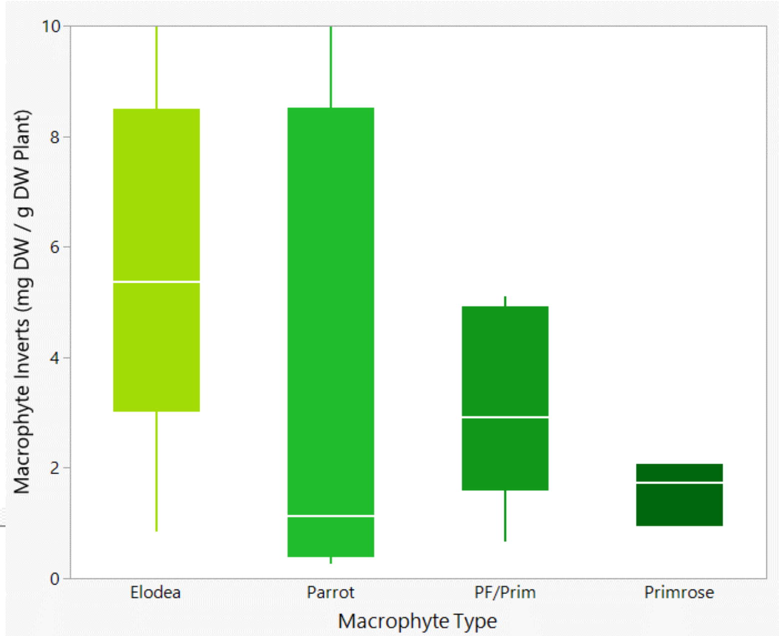




Macrophyte Invert Biomass

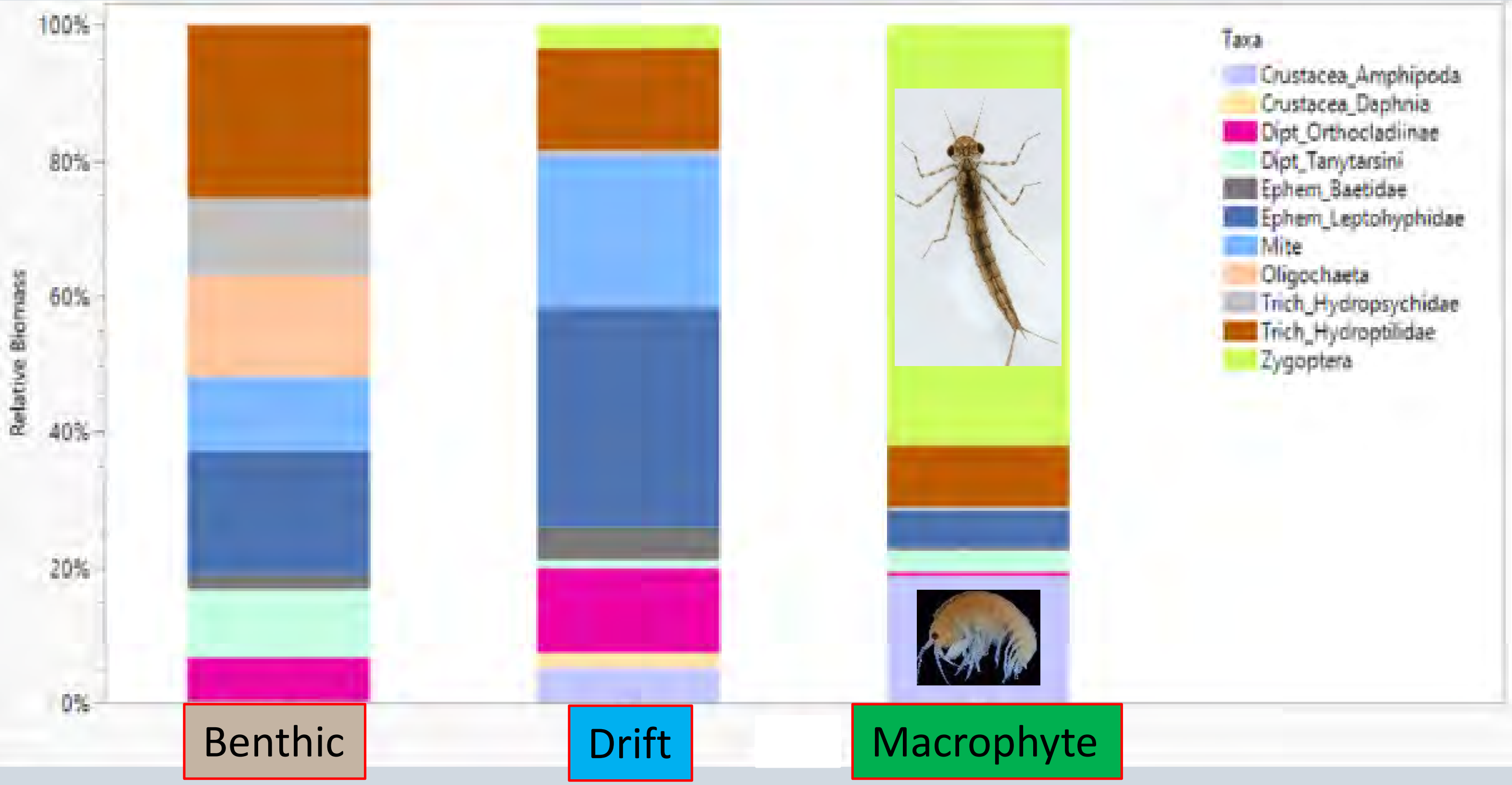
- Significant Month x Site interaction





Relative invertebrate biomass among habitats

(Additional Ordination and Discriminate Factor Analyses plots not covered today)

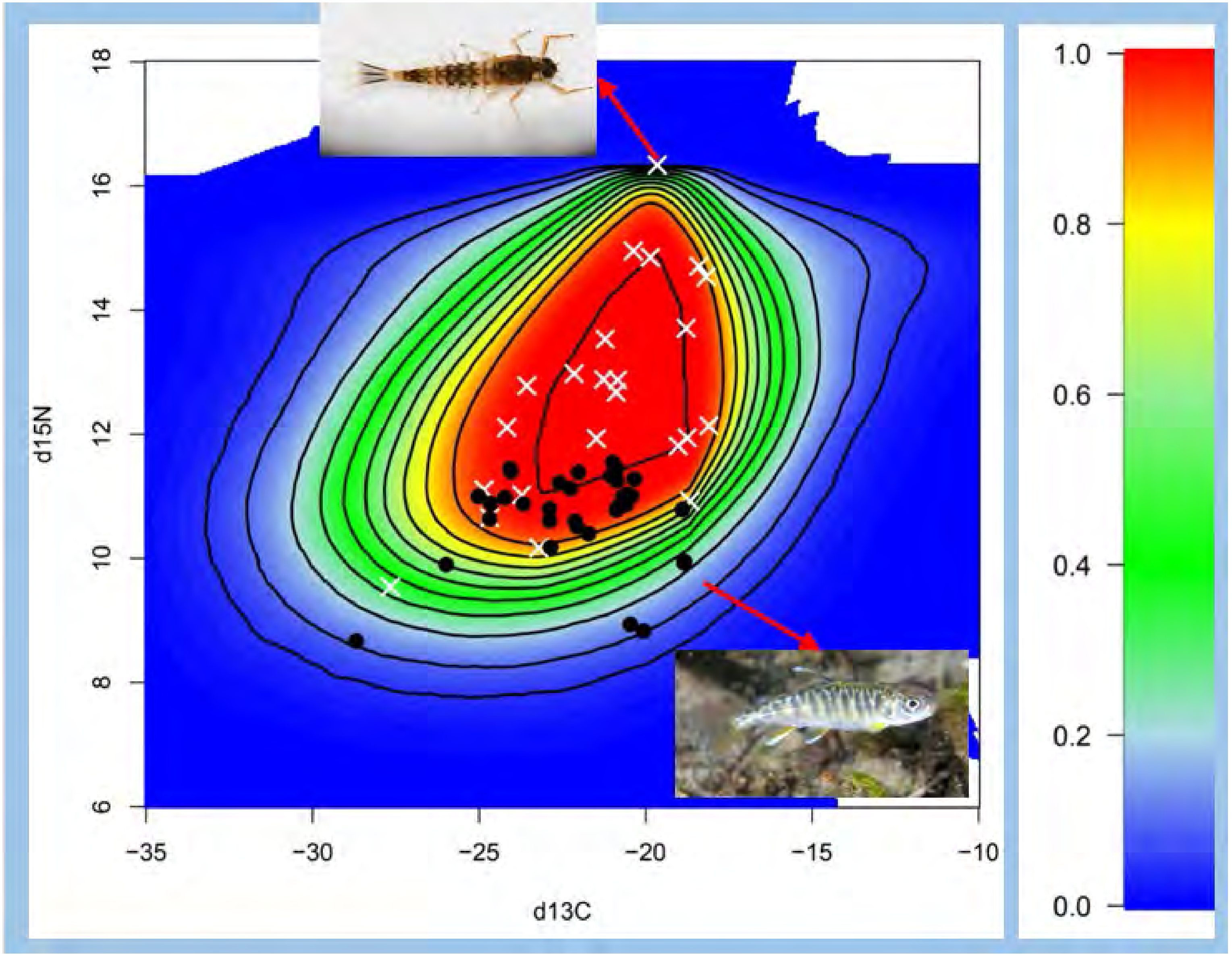


Year 1 Top 10 Relative Abundance- Taxa by Habitat (ind/sample)

Rank	Benthic (n=34)	Drift (n=52)	Macrophyte (n=47)
1	DIPT_ORTHO	CRUST_DAPH	DIPT_TARSINI
2	DIPT_TARSINI	DIPT_ADULT	CRUST_AMPHI
3	ANNELID_OLIGO	DIPT_ORTHO	ODONATA_ZYGOP
4	EPHEM_LEPT	ARACHNID_MITES	DIPT_ORTHO
5	ARACHNID_MITES	EPHEM_LEPT	ANNELID_OLIGO
6	TRICH_HYDROPT	CRUST_COPE	EPHEM_LEPT
7	OTHER	TRICH_HYDROPT	TRICH_HYDROPT

Resolution of Juv Chinook Prey Base: Did we run SIA on the correct taxa?

Stable Isotope Mixing Polygons

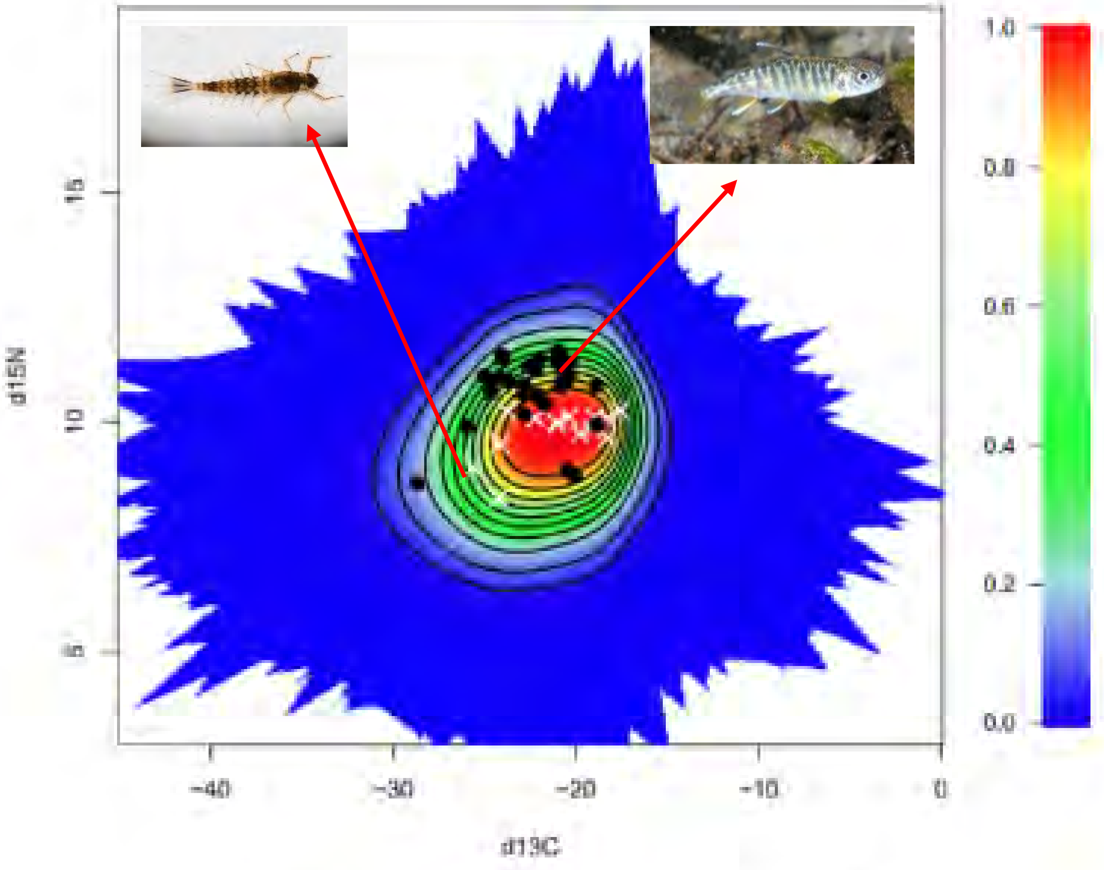


Quiz Time!

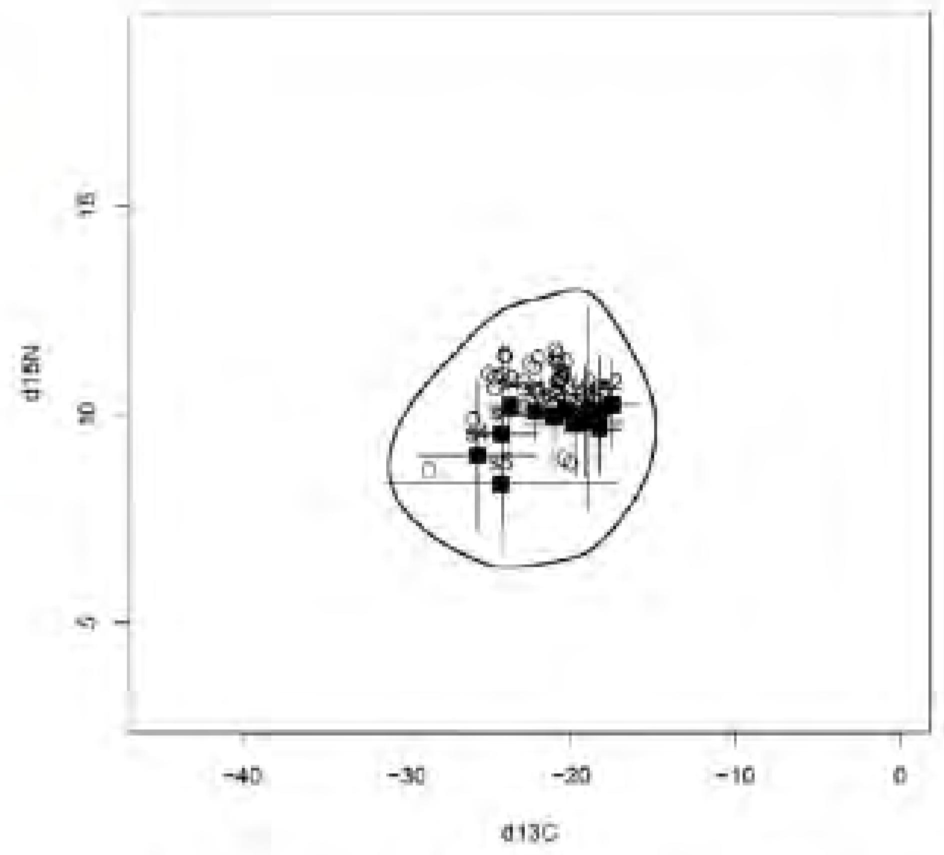
1. Is there an unexpected pattern in these data?

2. What might explain this?

Resolution of Juv Chinook Prey Base: Did we run SIA on the correct taxa?

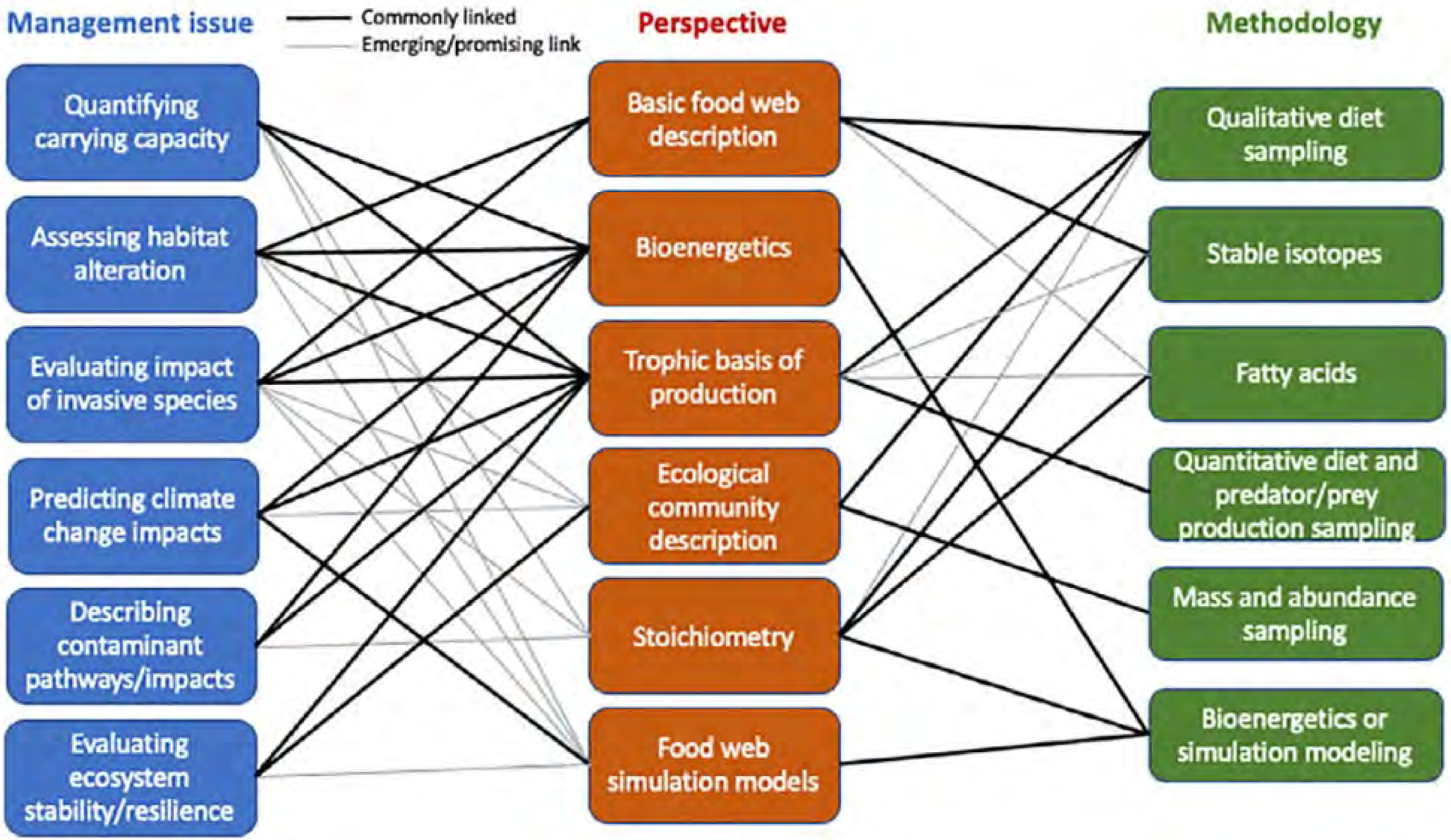


Consumer_Probabilities_Fish2020



Bi-plot with single 95 percent contour line

Naman, S. M., White, S. M., Bellmore, J. R., McHugh, P. A., Kaylor, M. J., Baxter, C. V., Danehy, R. J., Naiman, R. J., & Puls, A. L. (2022). Food web perspectives and methods for riverine fish conservation. WIREs Water, e1590



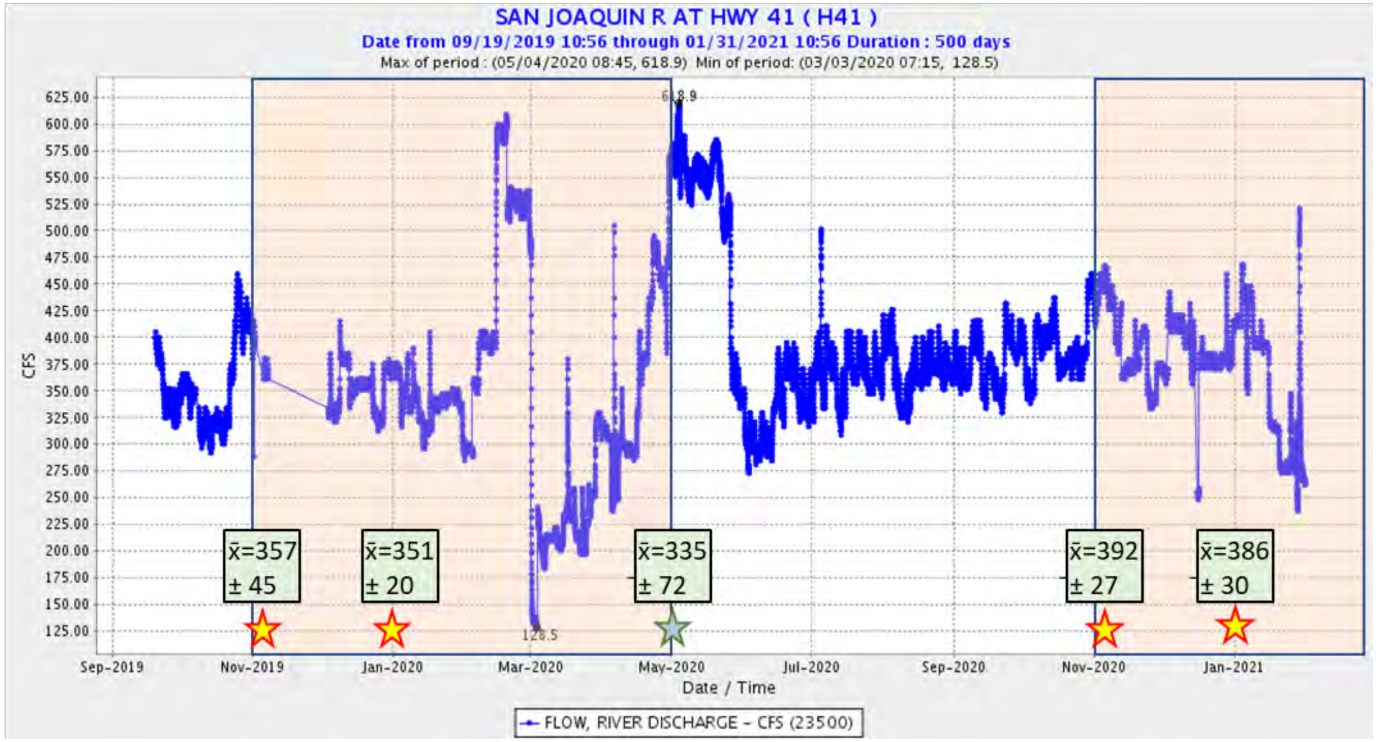
Summary:

- So how important is macrophyte habitat?
  -SIA mixing models
  -inSALMO simulations
- Thermal and energy source considerations
- Variation over space & time
- Use integrative energy-based approaches

2019-2021:
a) Generate empirical data for quantitative approaches
b) Expore available data from collaborators/colleagues

2021-2023:
a) Analyze habitat & water release patterns using simulation tools, etc.
b) Communicate output & results to SJRRP & water interests

SJR discharges (cfs @ 15min intervals) @ Hwy 41 during the study period. Shaded rectangles represent the JCS rearing period in the study reach (Friant Dam to Hwy 99). Start are study sampling periods for JCS habitats & invertebrates. Numbers are mean and ± s.d. for discharges 30 d prior to sampling events.



Acknowledgements:

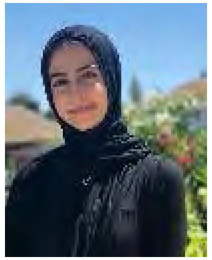
CDFW; Fresno & Friant Hatchery

U.S. Bureau of Reclamation

USFWS, CDWR

CSU-Fresno Aquatic Ecology Lab Contributors:

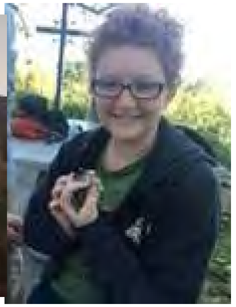
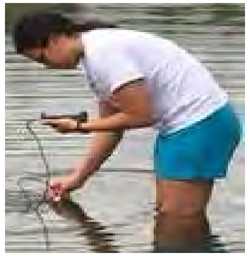
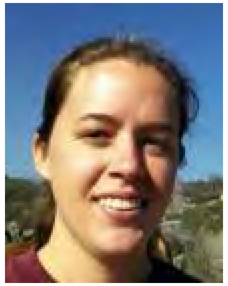
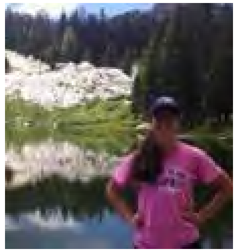
Michelle Reynaud, Raj Gill, Stephen Winsor, Yugjeet Grewal, Ameerah Jawad, Ray Jaclidone, Sierra Evans, Caoilinn Hardy, Amy Hernandez, Kiara Hill, Marcelo Vidal, Eli Rosenthal, Mike Grill, Jamie Castro, Karen Boortz, Dennis Whittington, Monet Gomes, Dalia Dull, Michael Bravo, Akusha Kaur, Skylar Nguyen, Emily Ramirez, Efrain Jimenez, Anu Gunawardane, Gabby Vang, Jackson Xiong, Guillermo Coronado, Sidney Marek, Devon Lee, Christian Cunningham, Matthew Cavaletto, James Peterson, Joey Salazar, Tshaaj Her, Rochelle Dumrauf, Brianna Koop

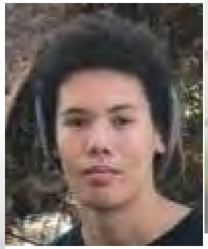
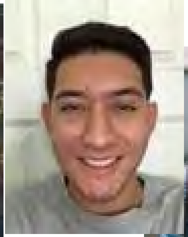
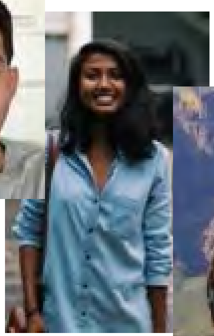







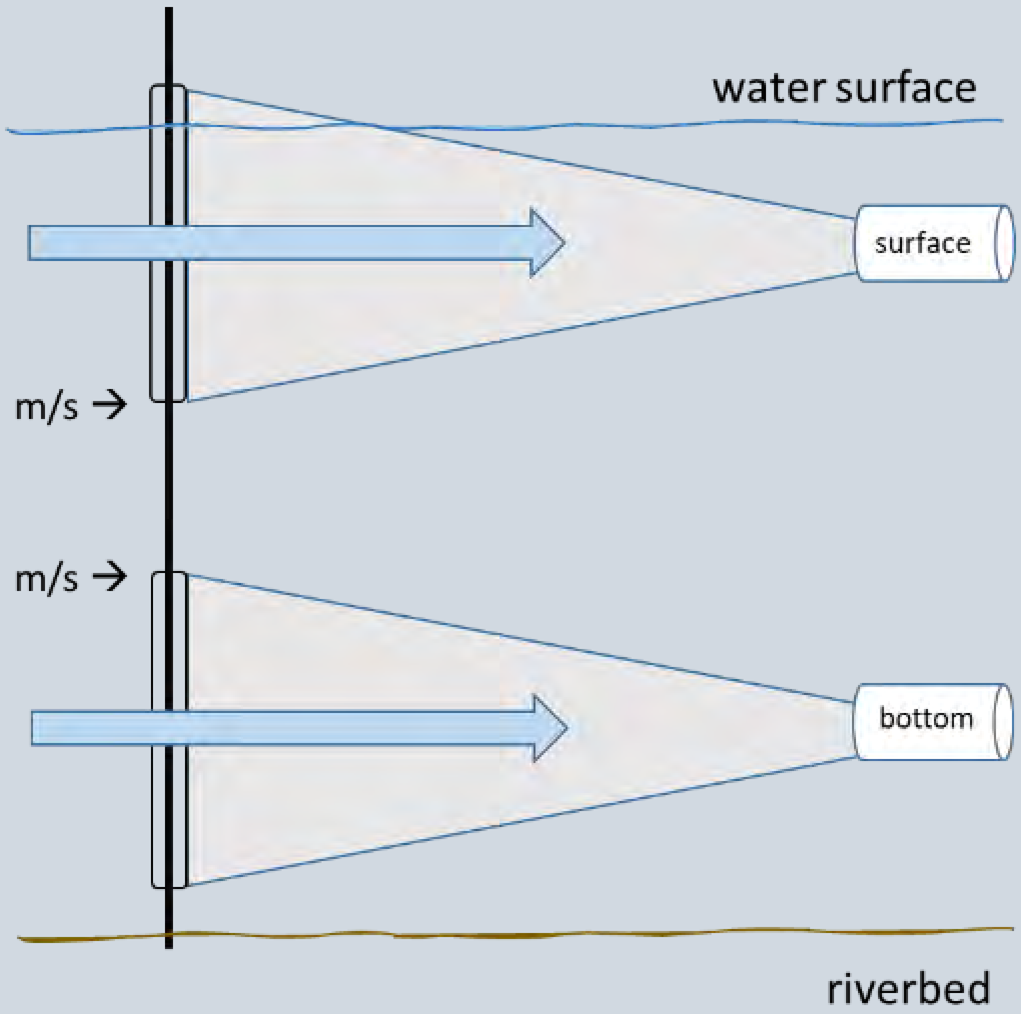


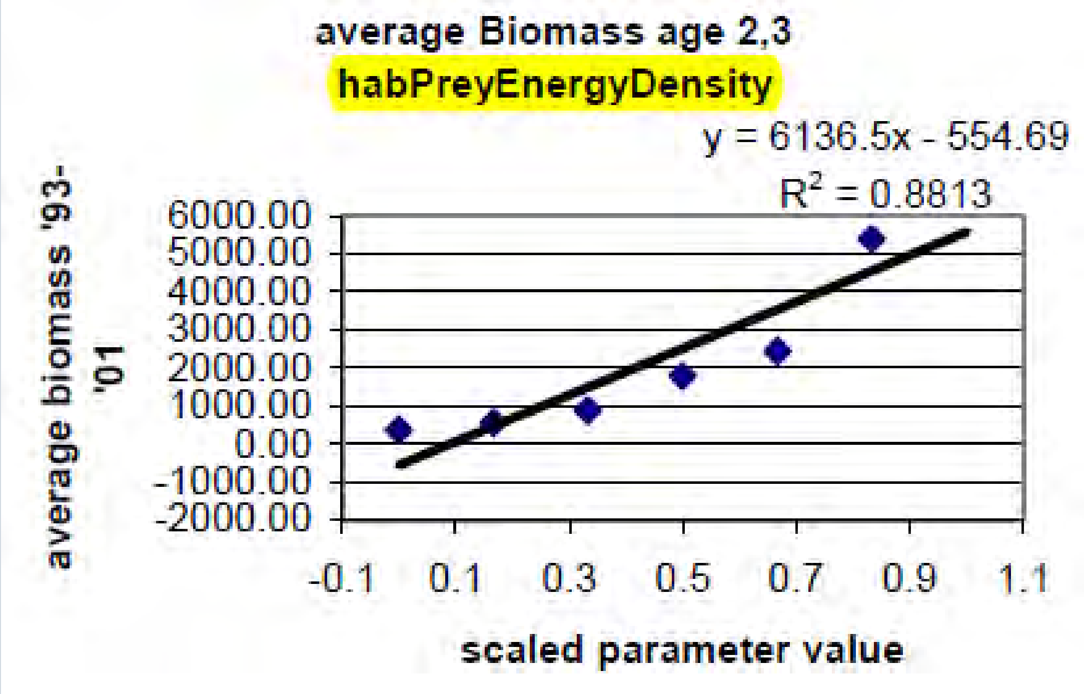

Double drift net setup

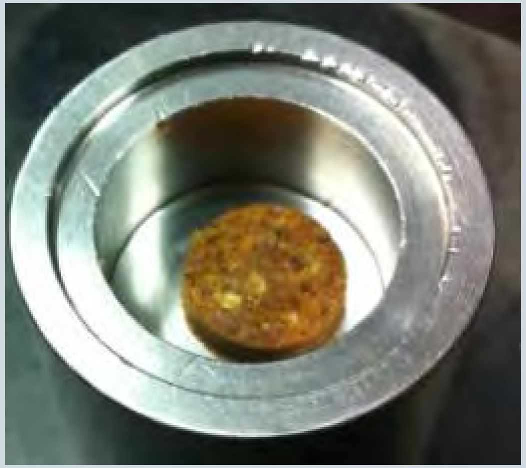
Deviation: Year 1 November– only Riverbed net samples, no Surface net

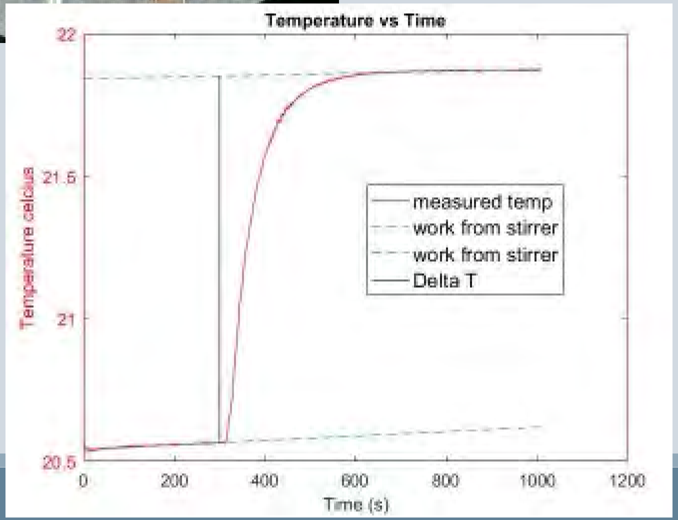


A SENSITIVITY ANALYSIS OF AN INDIVIDUAL-BASED TROUT MODEL
Cunningham 2007
MS Thesis, Humboldt State

Main Point:
inSTREAM estimation of salmonid production
Is most sensitive to prey energy density (cal/g)

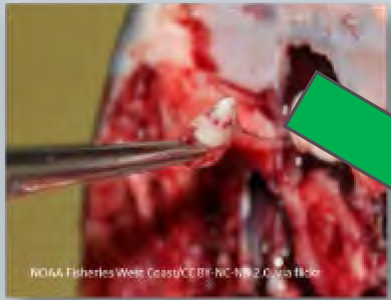






Methods/Approach:

$$SGR\ (\%\ body\ wt.gain/day) = \frac{(lnW_t - lnW_0)}{t} \times 100$$



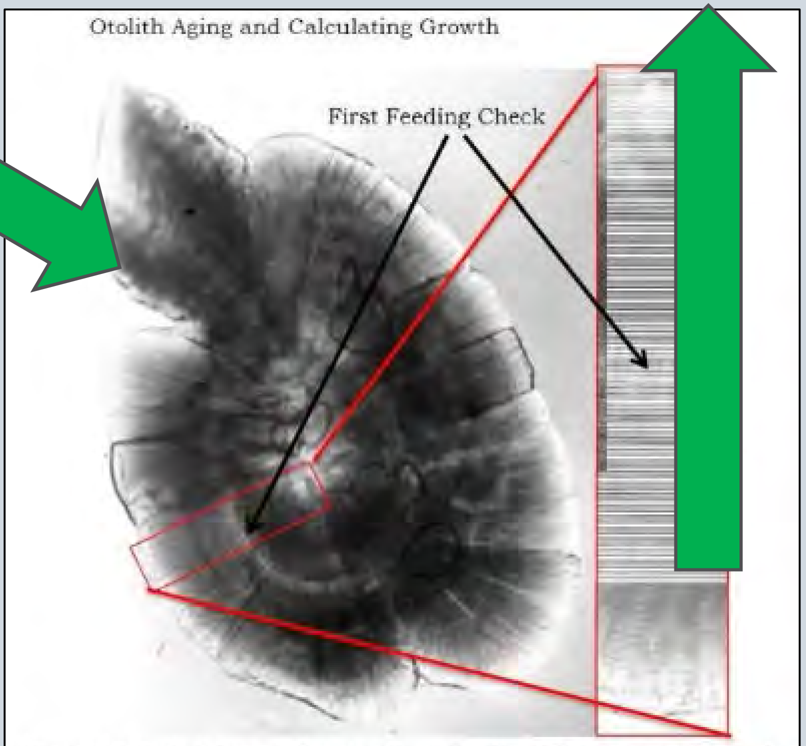
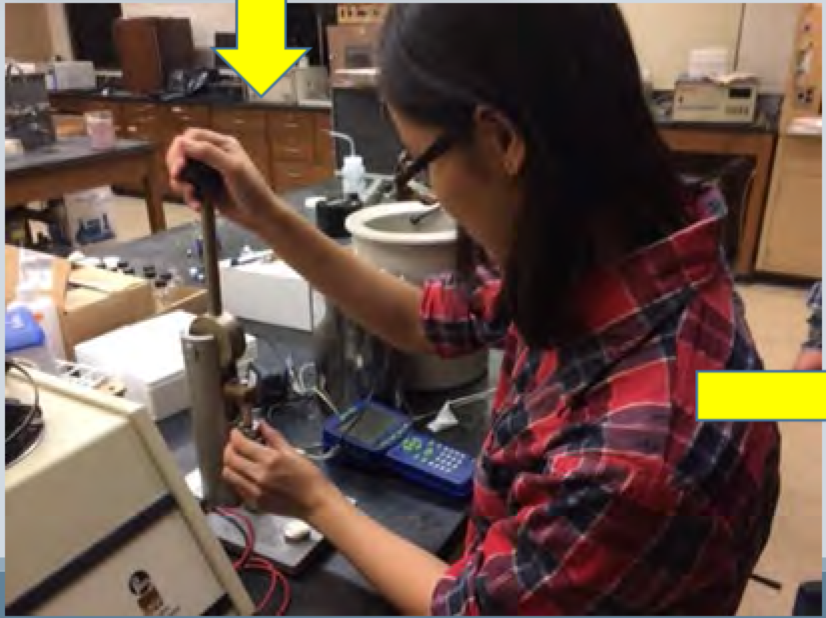
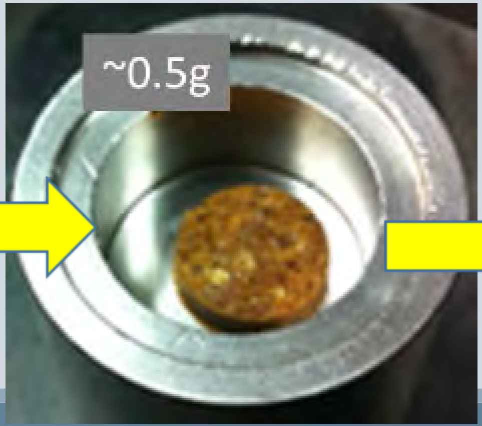
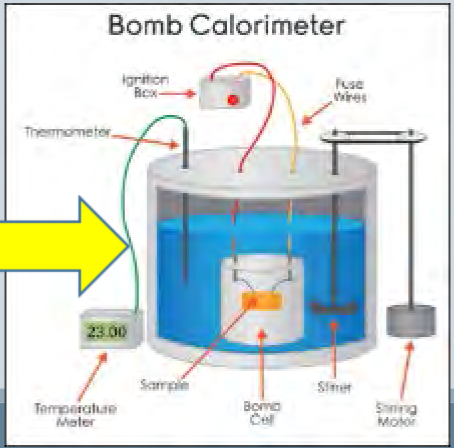


Figure 10 Otolith Image Showing First-Feeding Check (Image by Taylor Spaulding)







Integrating approaches to estimate fish growth and the importance of energy densities

Fish and habitat restoration projects should focus on fish growth and production as integrative variables to evaluate restoration success under varying hydrologic and habitat conditions…….

Secondly, several case studies of our research in three countries have independently highlighted the importance and influence of accurate estimates of predator and prey energy densities in evaluating both manifested and potential fish growth rates. Another example is from an **energy density based error in the simulation tool Fish Bioenergetics 4**, which produced erroneous specific growth rates of fish, but **the magnitude of this error was related to predator:prey energy density ratios.**

<u>Supporting Notes:</u>

NRG Density Issues; Examples

1) Israel: Lake Kinneret Cichlids & Peridinium; sustained mass & growth via high NRG density algae
2) USA_CA: San Joaquin River juvenile Chinook Salmon; direct measures NRG density via calorimetry
3) Germany: Lake Constance Sticklebacks (pop'n specific & seasonal variation in NRG density)

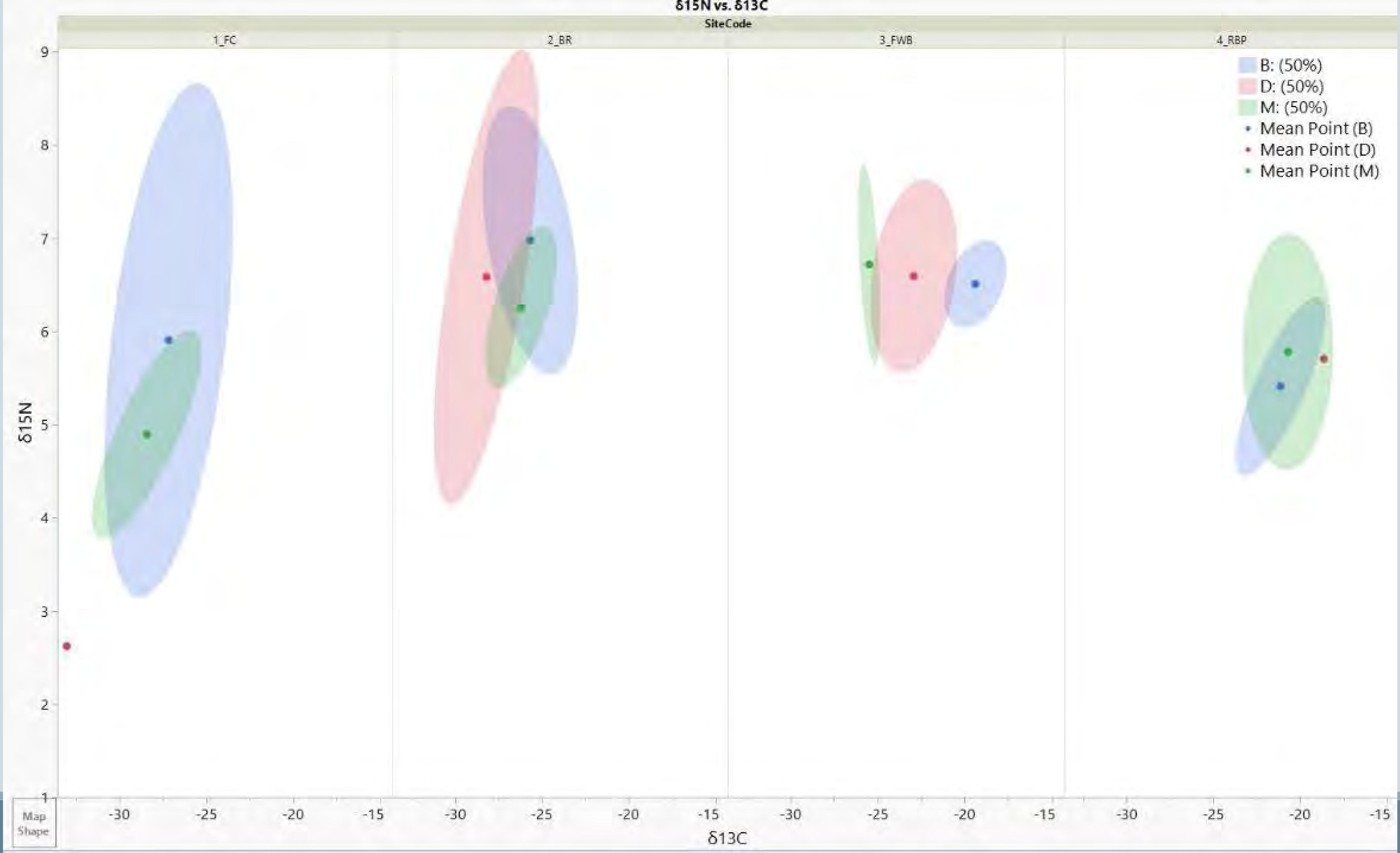
4) Fish Bioenergetics 4:

‘Latest version: FB4 v1.1.3. was released 5/26/2021. This version fixes an error in the reporting of Specific.Growth.Rate.g.g.d. Thanks to Steve Blumenshine for identifying and reporting this error.’

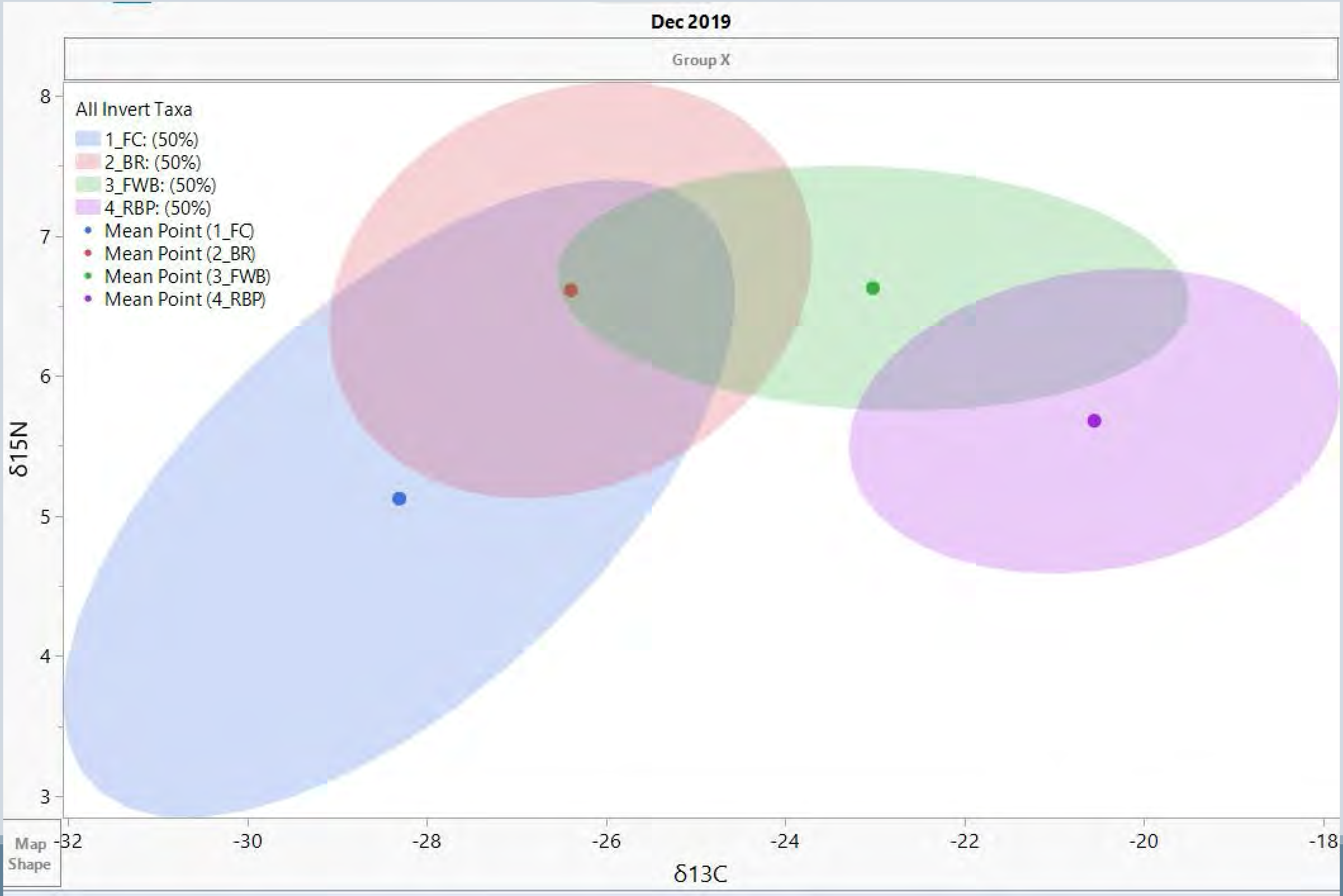
Pred:Prey energy density ~1:1; no (big) problem

Pred:Prey energy density >1:1; big problem in SGR & SCR

How much macrophyte habitat is there?



δ15N vs. δ13C
SiteCode
1_FC
2_BR
3_FWB
4_RBP
B: (50%)
D: (50%)
M: (50%)
Mean Point (B)
Mean Point (D)
Mean Point (M)
δ15N
9
8
7
6
5
4
3
2
1
-30
-25
-20
-15
δ13C
Map Shape


Dec 2019
Group X
All Invert Taxa
1_FC: (50%)
2_BR: (50%)
3_FWB: (50%)
4_RBP: (50%)
Mean Point (1_FC)
Mean Point (2_BR)
Mean Point (3_FWB)
Mean Point (4_RBP)
δ15N
8
7
6
5
4
3
-32
-30
-28
-26
-24
-22
-20
-18
δ13C
Map Shape

Defining a Basin-scale Restoration Framework to Recover an Endangered Species. An Optimization-Simulation Approach using a Life Cycle Model

F.J. Bellido-Leiva[1,3,*], R. Lusardi[2,3,4] and J.R. Lund[1,3]

[1]Department of Civil & Environmental Engineering, UC Davis
[2]Department of Wildlife, Fish and Conservation Biology, UC Davis
[3]Center for Watershed Sciences, UC Davis
[4]California Trout

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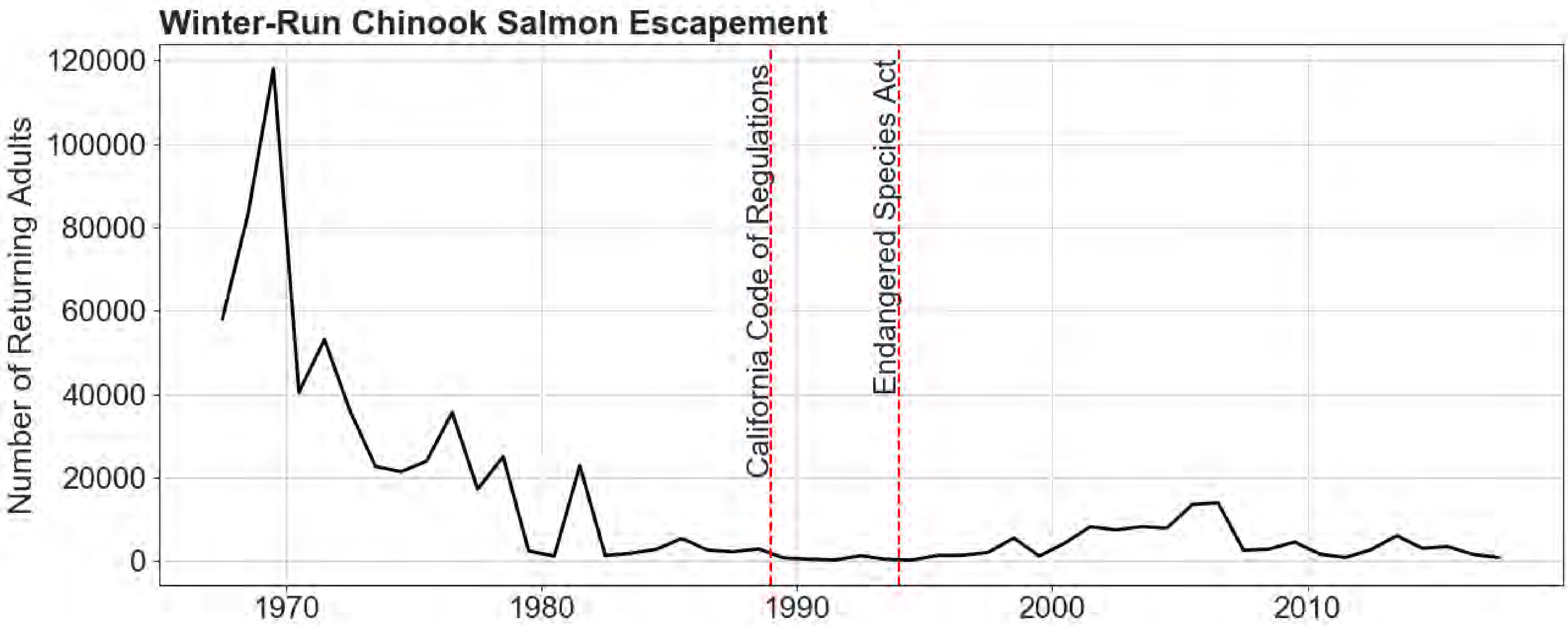
39th Annual Salmonid Restoration Conference

More than 90% decrease in returning adults since 1960s-1970s. Less than 975 adults in 2017



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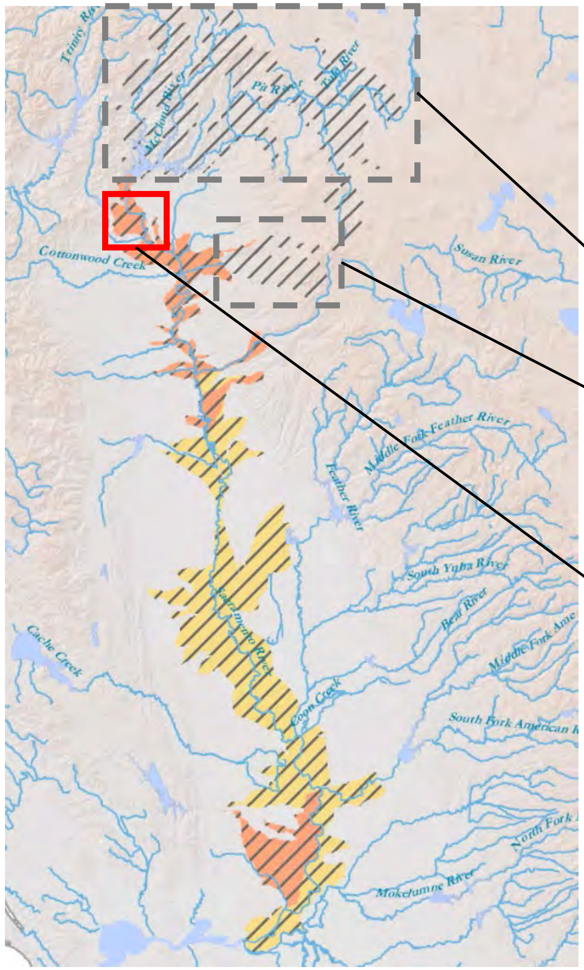
Declines from extirpation from historical spawning grounds



[PISCES, 2019]

Historical spawning grounds at cold, spring-fed rivers

McCloud

North Fork Battle Creek

Current spawning ground: below Keswick Dam

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Declines from habitat reduction and alteration of natural hydrograph

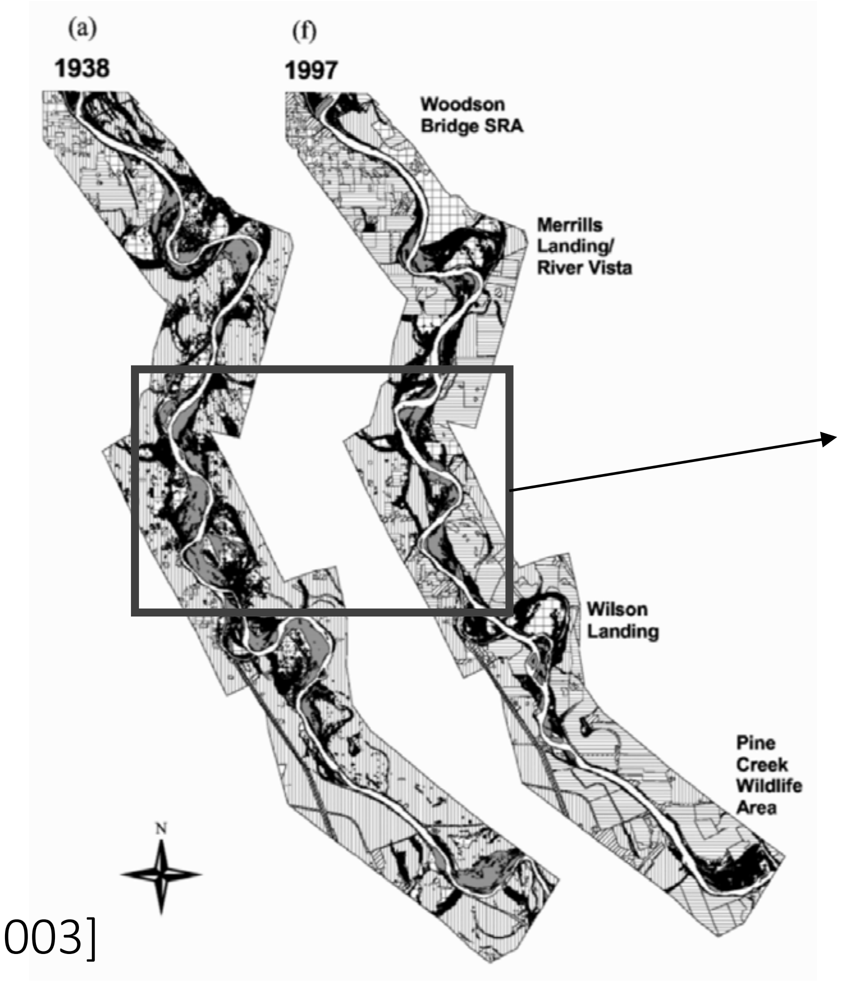
[PISCES, 2019]

Historical spawning grounds at cold, spring-fed rivers

McCloud, Pit

North Fork Battle Creek

Current spawning grounds: below Keswick Dam



[Greco and Plant, 2003]

Reduction of off-channel habitat

Declines from extirpation from historical spawning grounds, habitat reduction and alteration of natural hydrograph

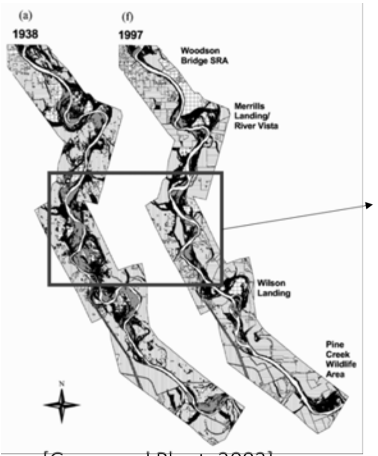
[PISCES, 2019]

Historical spawning grounds at cold, spring-fed rivers

McCloud, Pit

North Fork Battle Creek

Current spawning grounds: below Keswick Dam



Reduction of off-channel habitat

[Greco and Plant, 2003]

Habitat restoration efforts have been developed across many watersheds to mitigate for the loss of historically important habitats

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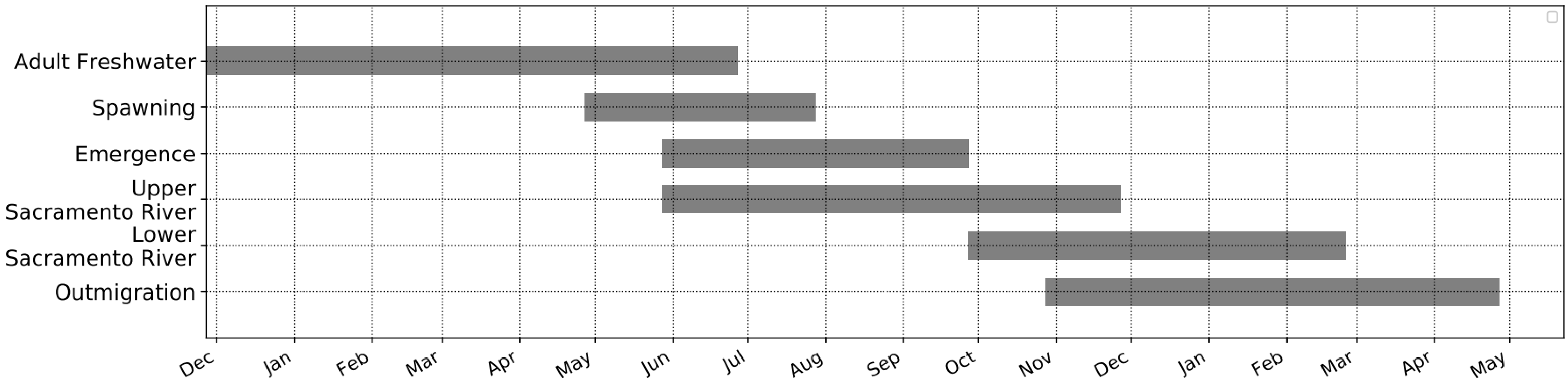
Especially difficult for anadromous species due to their geographical extent and different needs at each life stage



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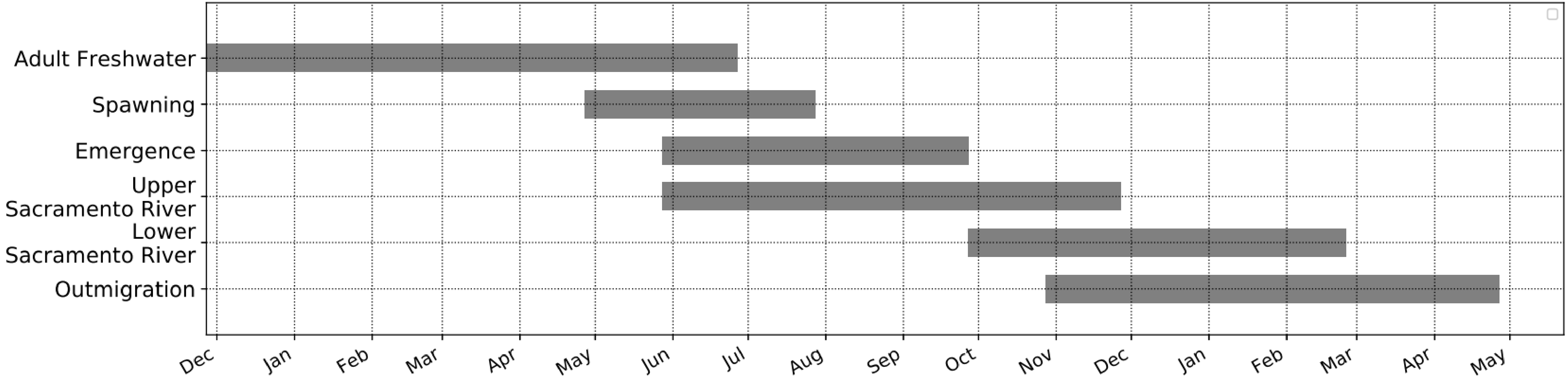
Especially difficult for anadromous species due to their geographical extent and different needs at each life stage



A formal methodology to help coordinate and structure such complex watershed-scale efforts

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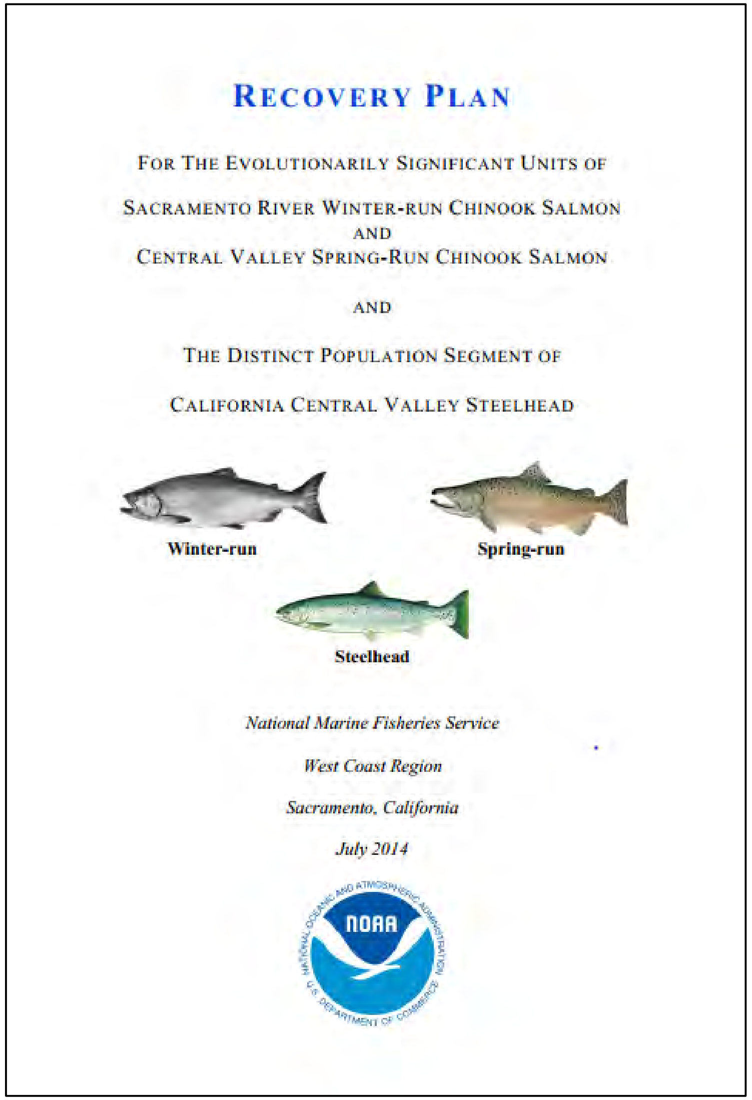
This methodology requires a diverse set of restoration actions covering multiple geographical areas and stressors

Restoration Action Portfolio

Management Actions	Cost	Modeled Effects	Variable Type
Fremont Weir Notch	Assumed at M$100-150	$\uparrow \alpha_{FLOOD}$	Discrete (binary)
Tisdale Weir Notch	Assumed at M$50	$\uparrow \alpha_{FLOOD}$	Discrete (binary)
Winter-run reintroduction plan in Battle Creek	Estimated at M$3,5	$\uparrow \gamma_{TRIB}$, T_{BC}	Discrete (binary)
Side Banks Habitat Restoration/Re-connection	$150K/mi	$\uparrow \beta_{MAIN}$, $\uparrow \beta_{S}$, $\uparrow r_{g,MAIN}$, $\uparrow \gamma_{OFF}$, $\uparrow \alpha_{OFF}$	Continuous (0-240 mi)
Tributaries Habitat Restoration	$27.5K mi^{-1}	$\uparrow \alpha_{TRIB}$, $\uparrow \gamma_{TRIB}$, $\uparrow \beta_{TRIB}$, $\uparrow r_{g,TRIB}$	Continuous (0-100 mi)
Winter-run Reintroduction over Shasta Dam	Estimated at M$50.2	$\uparrow \beta_{Fry}$, $\downarrow T_{SPAWN}$, $\uparrow r_{g,MAIN}$, $\downarrow \beta_{MAIN}$	Discrete (binary)
Gravel Augmentation Plan	Estimated at M$2.38	Decrease redd superimposition ($\uparrow \beta_{Fry}$)	Discrete (binary)

Comprehensive list of potential restoration actions along the Sacramento River

- NMFS 2014
- NOAA 2021



RECOVERY PLAN

FOR THE EVOLUTIONARILY SIGNIFICANT UNITS OF

SACRAMENTO RIVER WINTER-RUN CHINOOK SALMON
AND
CENTRAL VALLEY SPRING-RUN CHINOOK SALMON

AND

THE DISTINCT POPULATION SEGMENT OF

CALIFORNIA CENTRAL VALLEY STEELHEAD

Winter-run

Spring-run

Steelhead

National Marine Fisheries Service

West Coast Region

Sacramento, California

July 2014

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And a tool to help understanding the response of the population to changes in restored habitat (quality/quantity) and recovery actions

Restoration Action Portfolio

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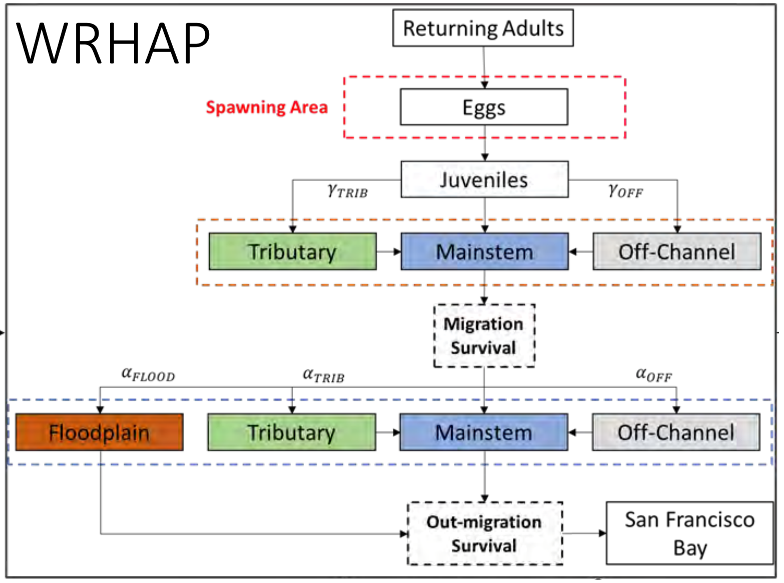

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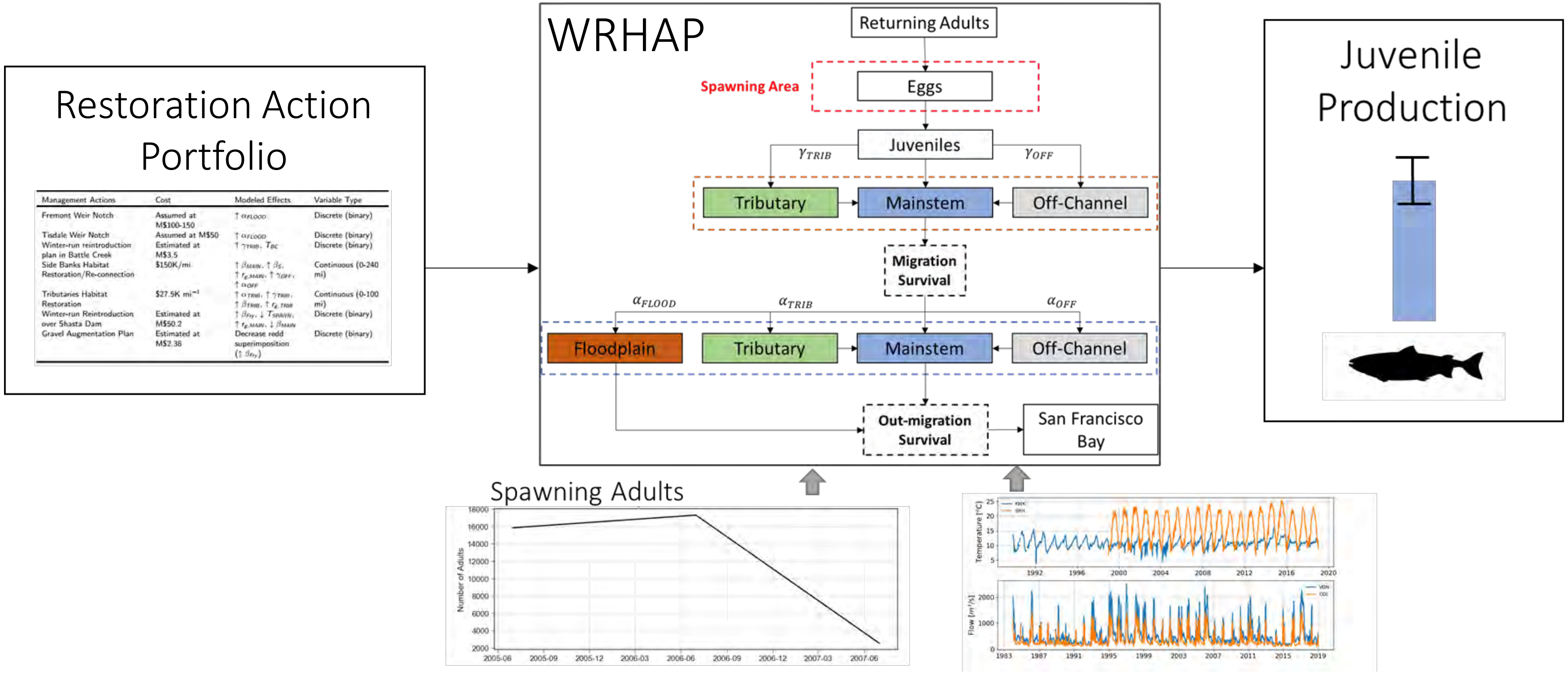
And a tool to help understanding the response of the population to changes in restored habitat (quality/quantity) and recovery actions



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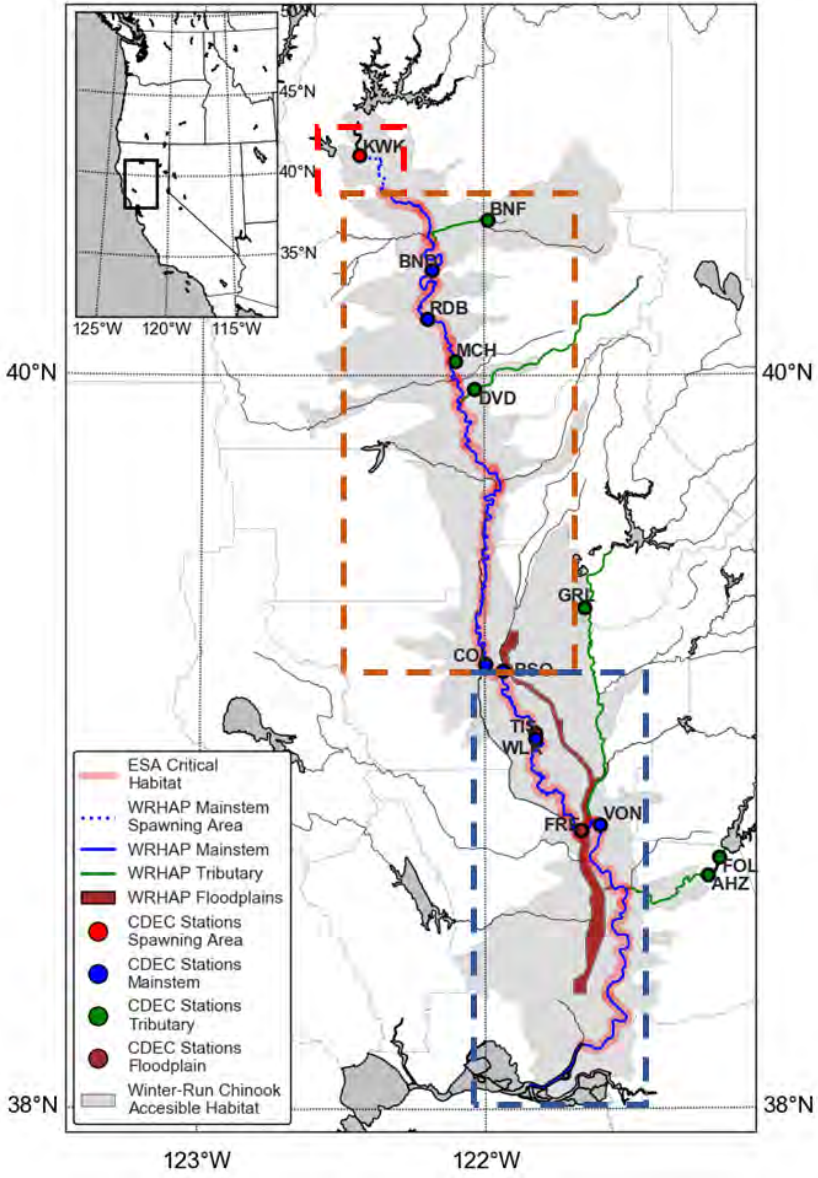
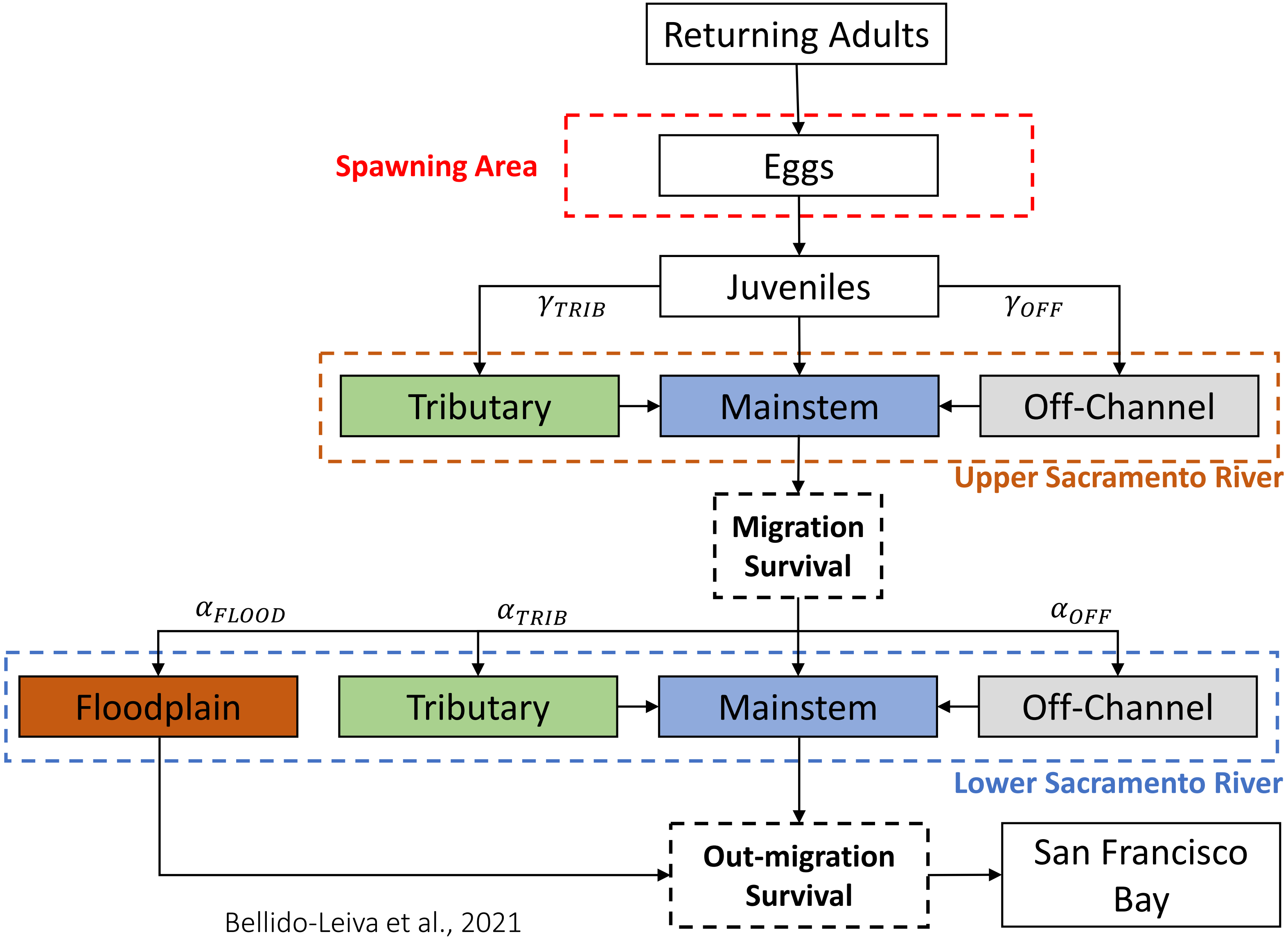
Side Banks Habitat Restoration/Re-connection	$150K/mi	$\uparrow \beta_{MAIN}$, $\uparrow \beta_{S}$, $\uparrow r_{g,MAIN}$, $\uparrow \gamma_{OFF}$, $\uparrow \alpha_{OFF}$	Continuous (0-240 mi)
Tributaries Habitat Restoration	$27.5K mi^{-1}	$\uparrow \alpha_{TRIB}$, $\uparrow \gamma_{TRIB}$, $\uparrow \beta_{TRIB}$, $\uparrow r_{g,TRIB}$	Continuous (0-100 mi)
Winter-run Reintroduction over Shasta Dam	Estimated at M$50.2	$\uparrow \beta_{Fry}$, $\downarrow T_{SPAWN}$, $\uparrow r_{g,MAIN}$, $\downarrow \beta_{MAIN}$	Discrete (binary)
Gravel Augmentation Plan	Estimated at M$2.38	Decrease redd superimposition ($\uparrow \beta_{Fry}$)	Discrete (binary)

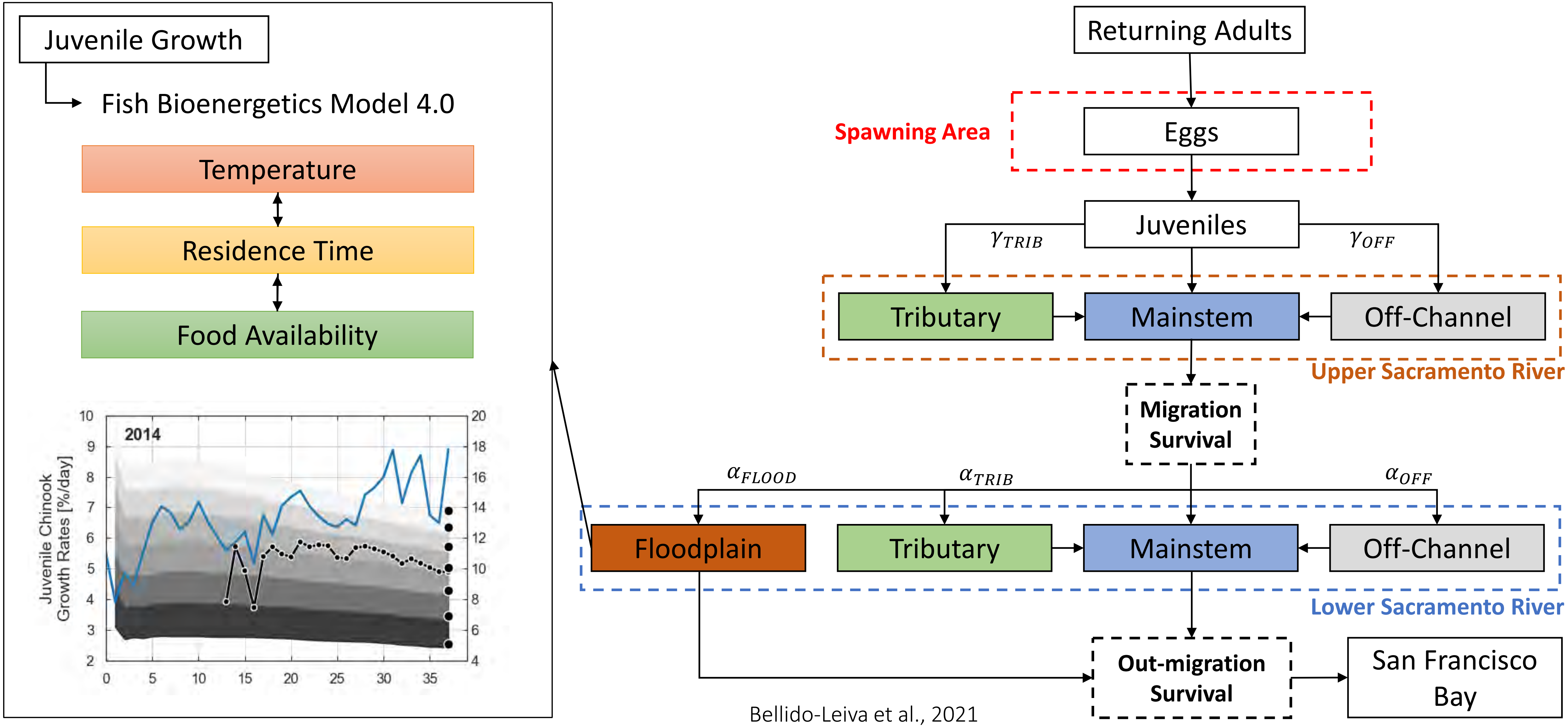
WRHAP is a conceptual juvenile production model that includes all available rearing habitats at each location along the Sacramento River





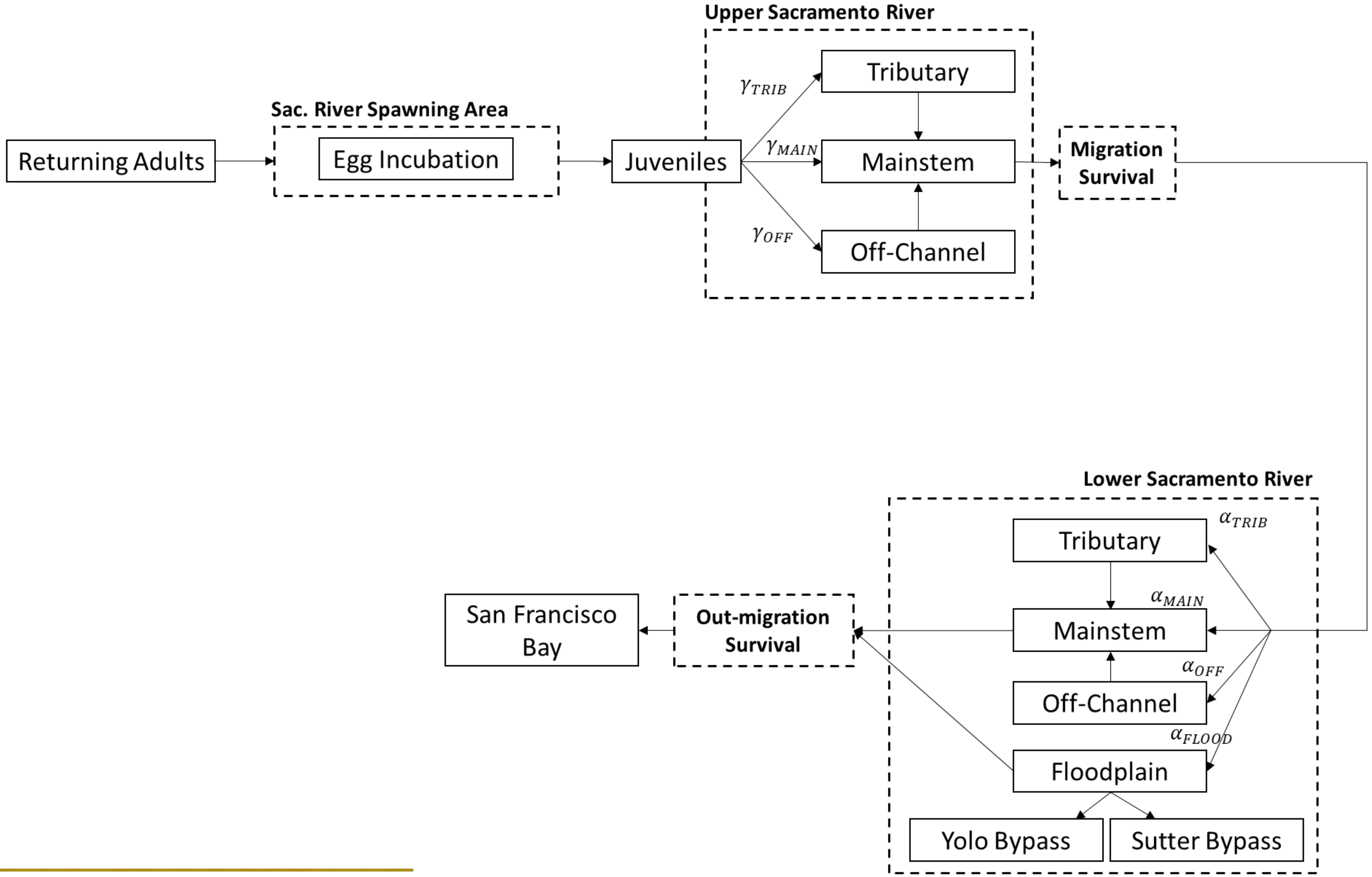
Bellido-Leiva et al., 2021

WRHAP structure allows to simulate the impact of residence times at floodplains on juvenile development and return success



Bellido-Leiva et al., 2021

The discontinuity between out-migrating smolts and returning adults neglects the longer-term effects of habitat conditions from one time period to future ones



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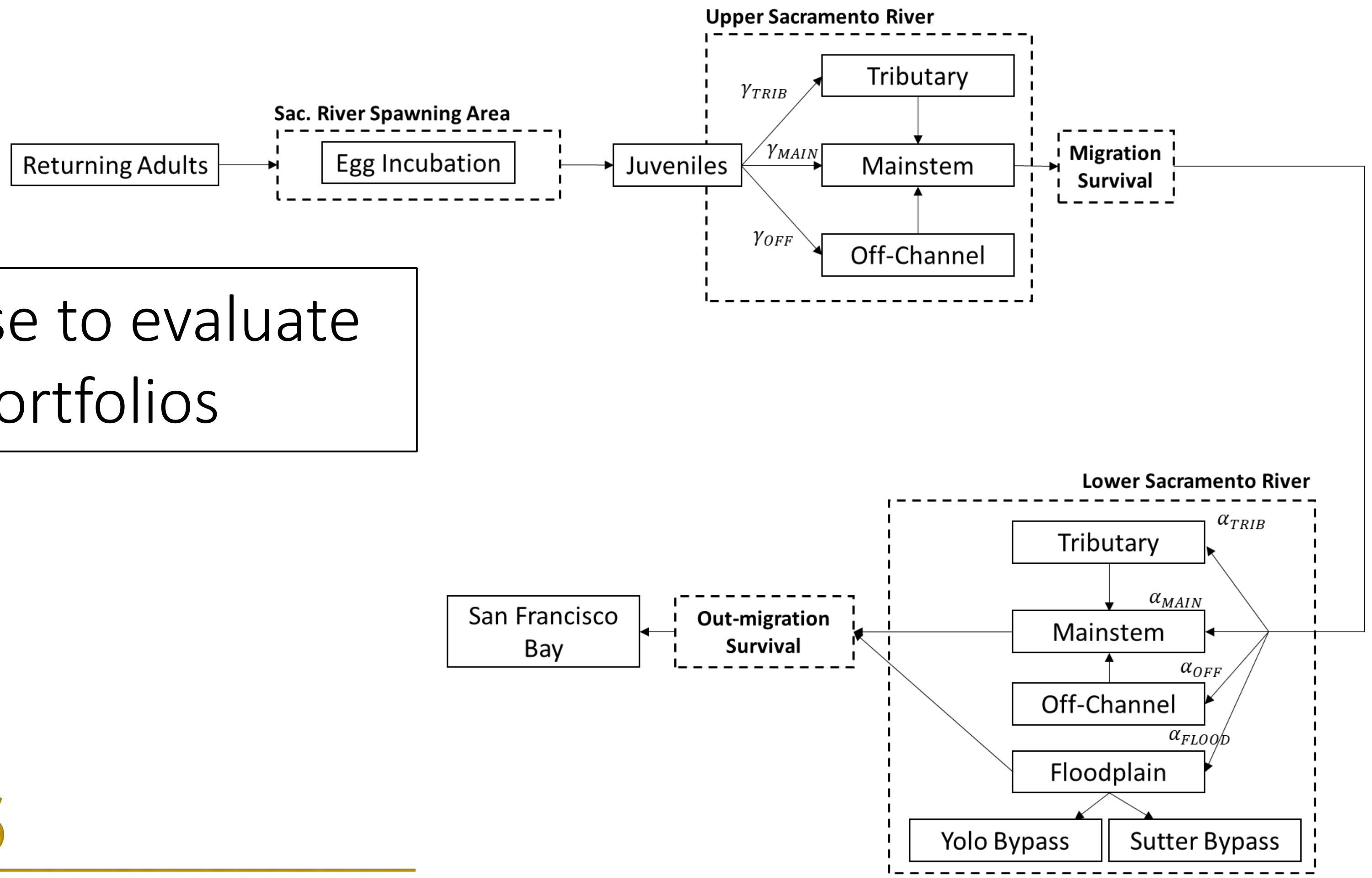

Hinders its use to evaluate restoration portfolios

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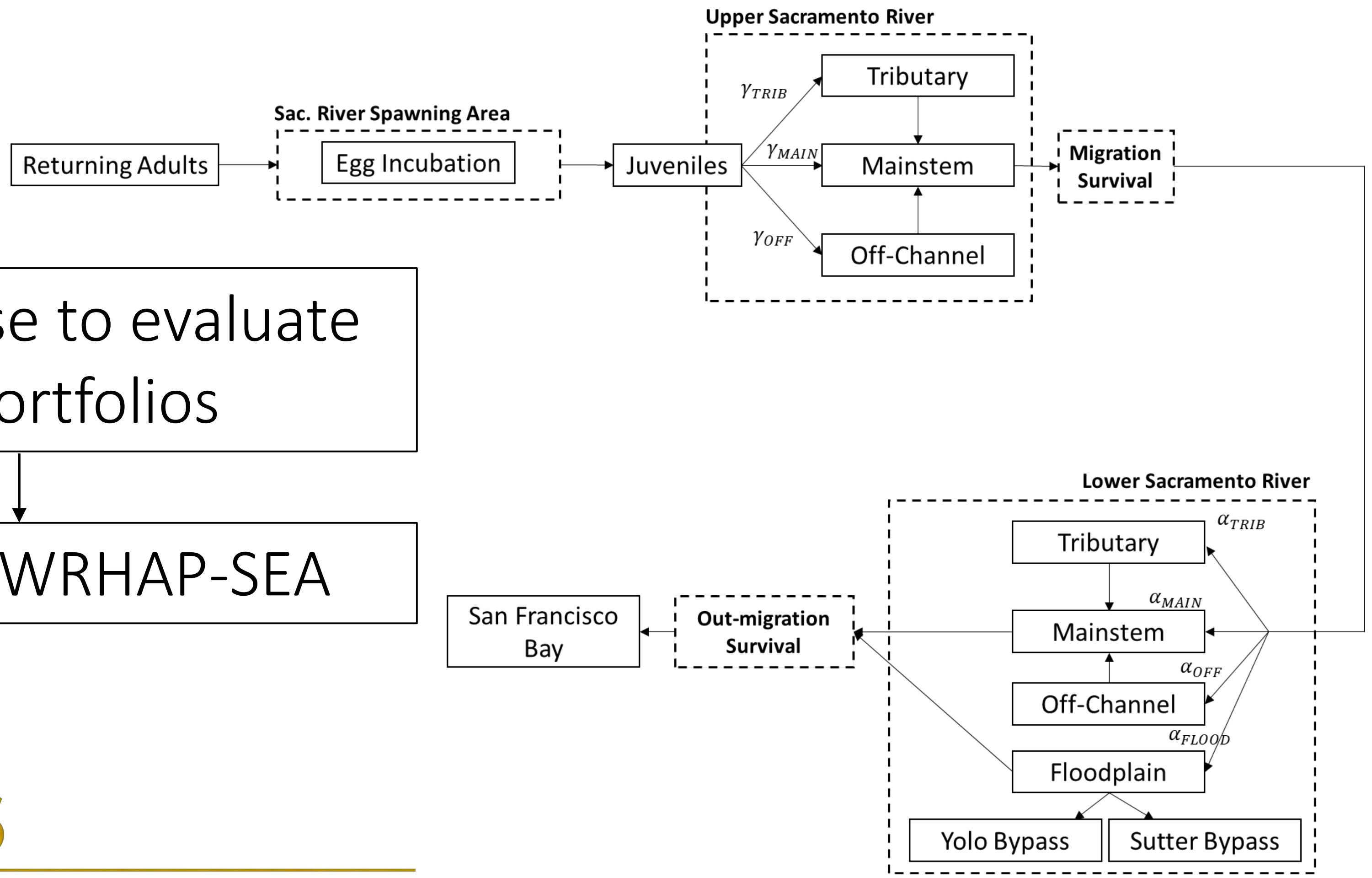

Hinders its use to evaluate restoration portfolios

Expanded to WRHAP-SEA

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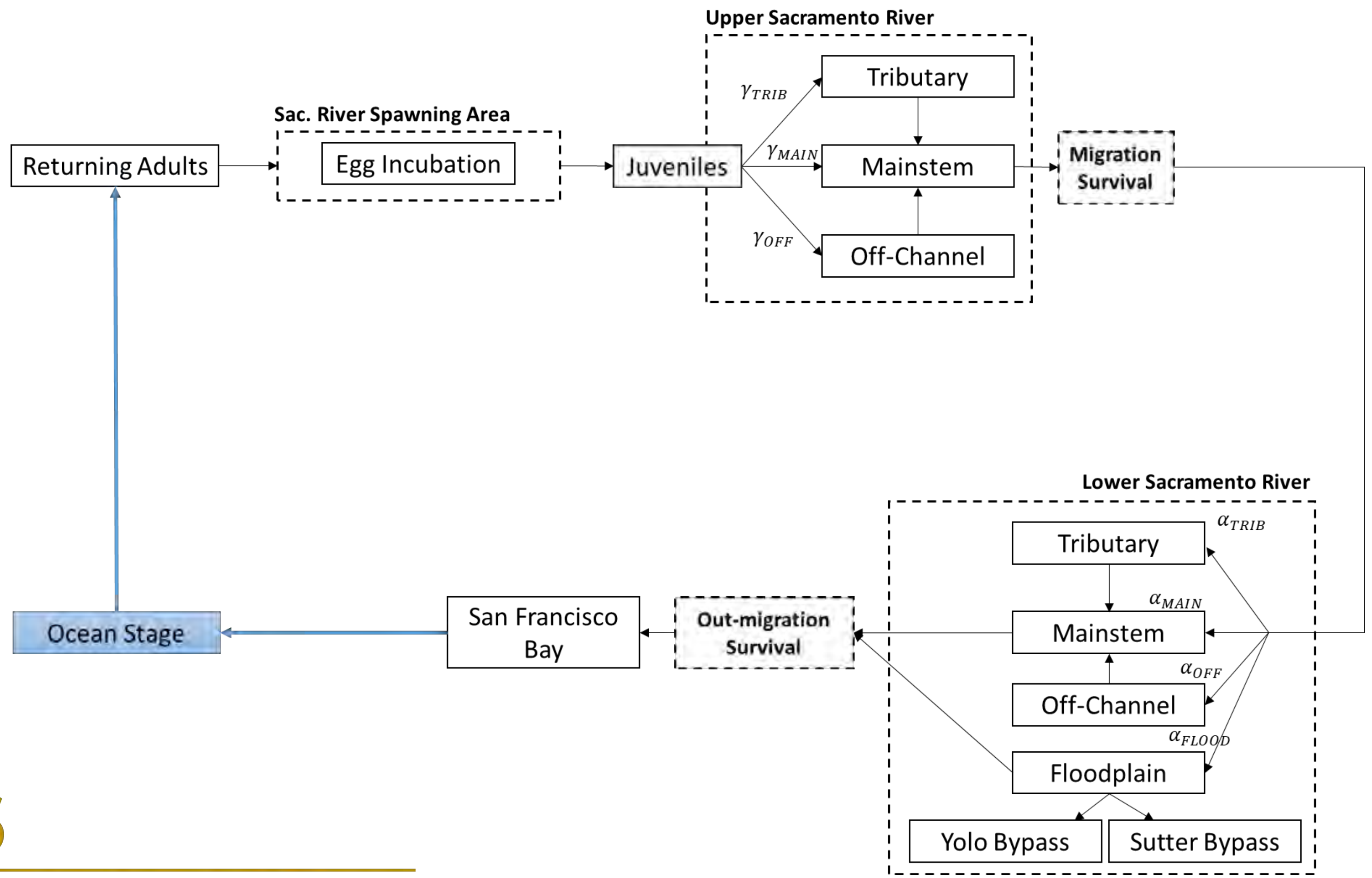
The ocean submodel is based on previous efforts in literature, including an early ocean survival as a function of smolt size at outmigration



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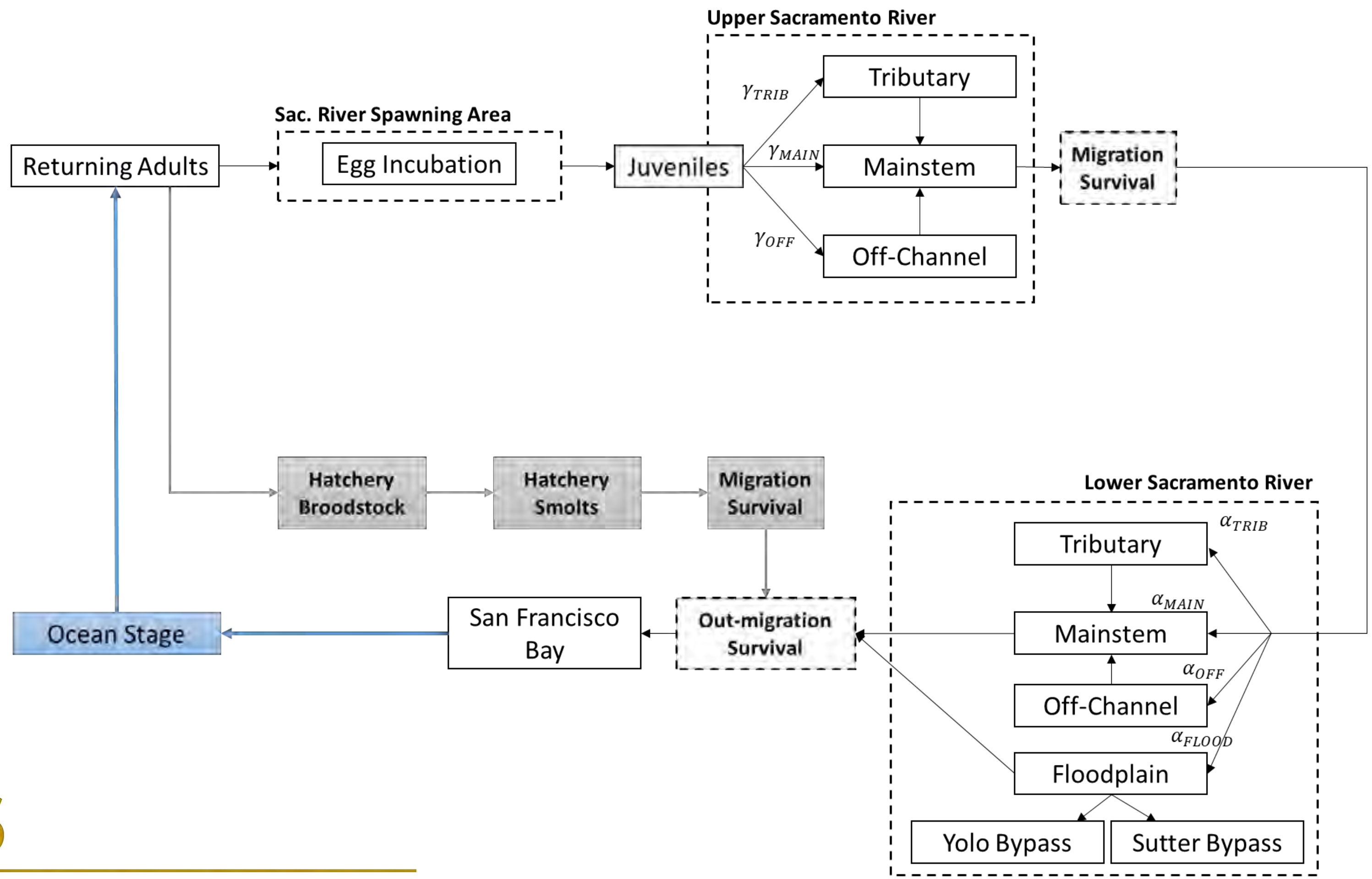
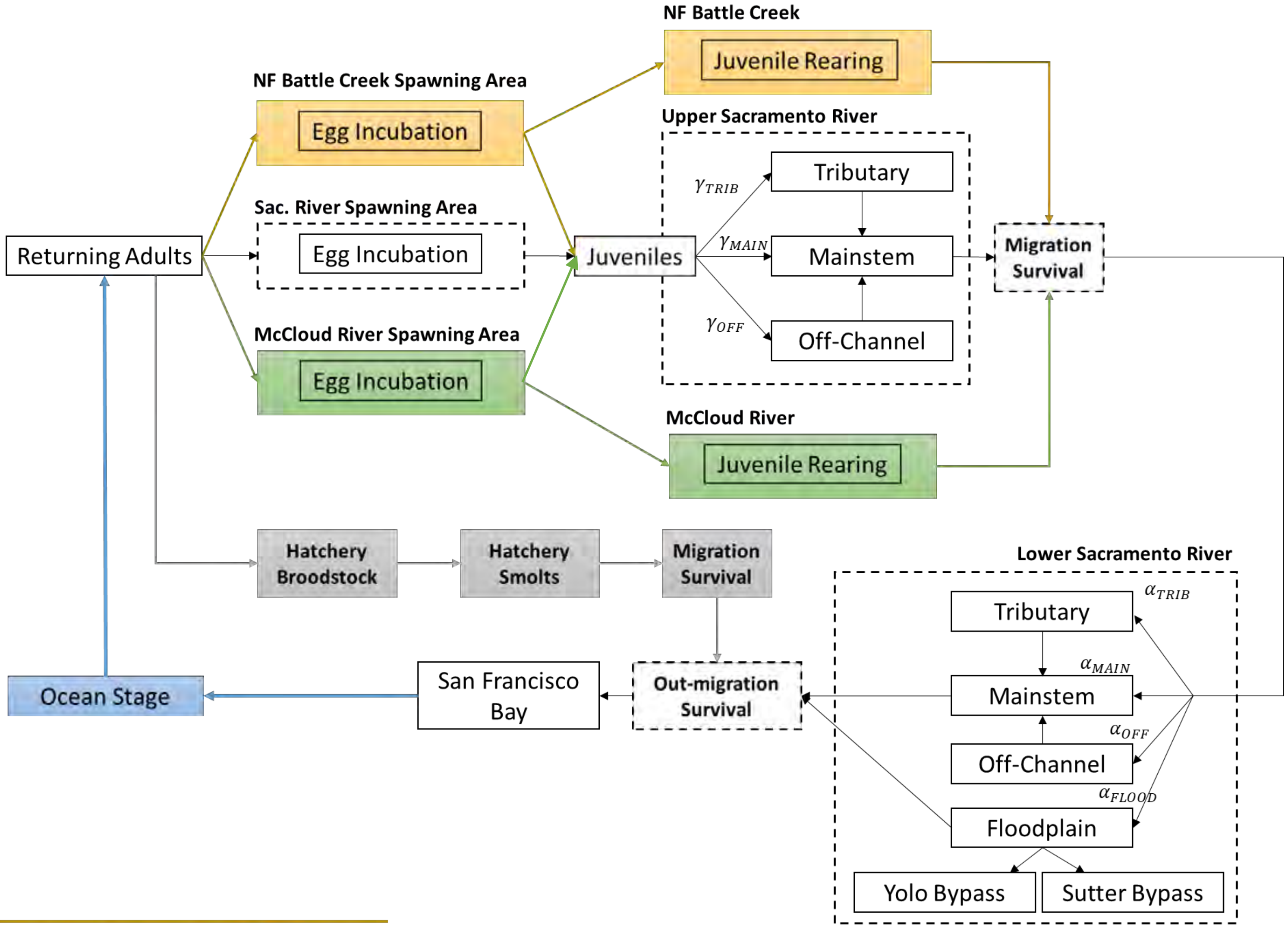
Hatchery operations are simulated based on Livingston Stone National Fish Hatchery Winter-run Program (USFWS 2012, 2013)



Submodels for the reintroduced populations at Battle Creek and McCloud River, assuming similar residence times in natal tributaries and along the Upper Sac.



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Bellido-Leiva et al., *in review*

An evaluation method that allows for a structured assessment of population changes as a response to restoration/recovery actions along the Sacramento River

Policy – Restoration Action Portfolio

Management Actions	Cost	Modeled Effects	Variable Type
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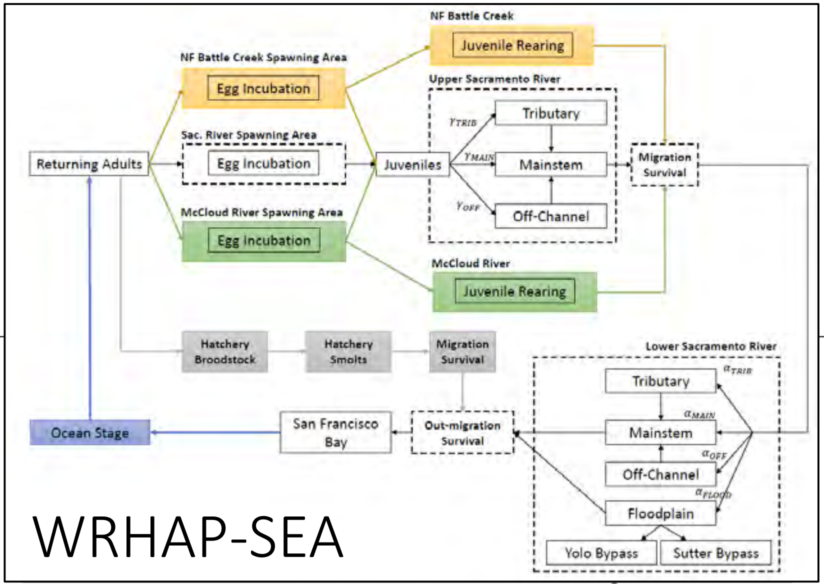
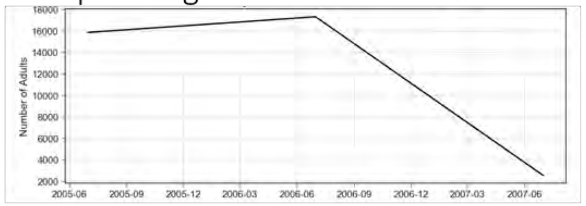
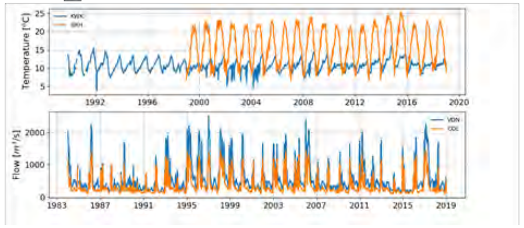


Adult Production

Spawning Adults





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Set of restoration/recovery actions cover available habitats during the freshwater stage of winter-run Chinook

Considered Restoration/Recovery Actions

- Fremont/Tisdale Weir Notching

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- Fremont/Tisdale Weir Notching

$\uparrow Passage,$
$\uparrow Resid.Time$

Set of restoration/recovery actions cover available habitats during the freshwater stage of winter-run Chinook

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$\uparrow Hab.\ Capacity$
$\uparrow Growth$
$\uparrow Rear\ Surv.$

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- Fremont/Tisdale Weir Notching
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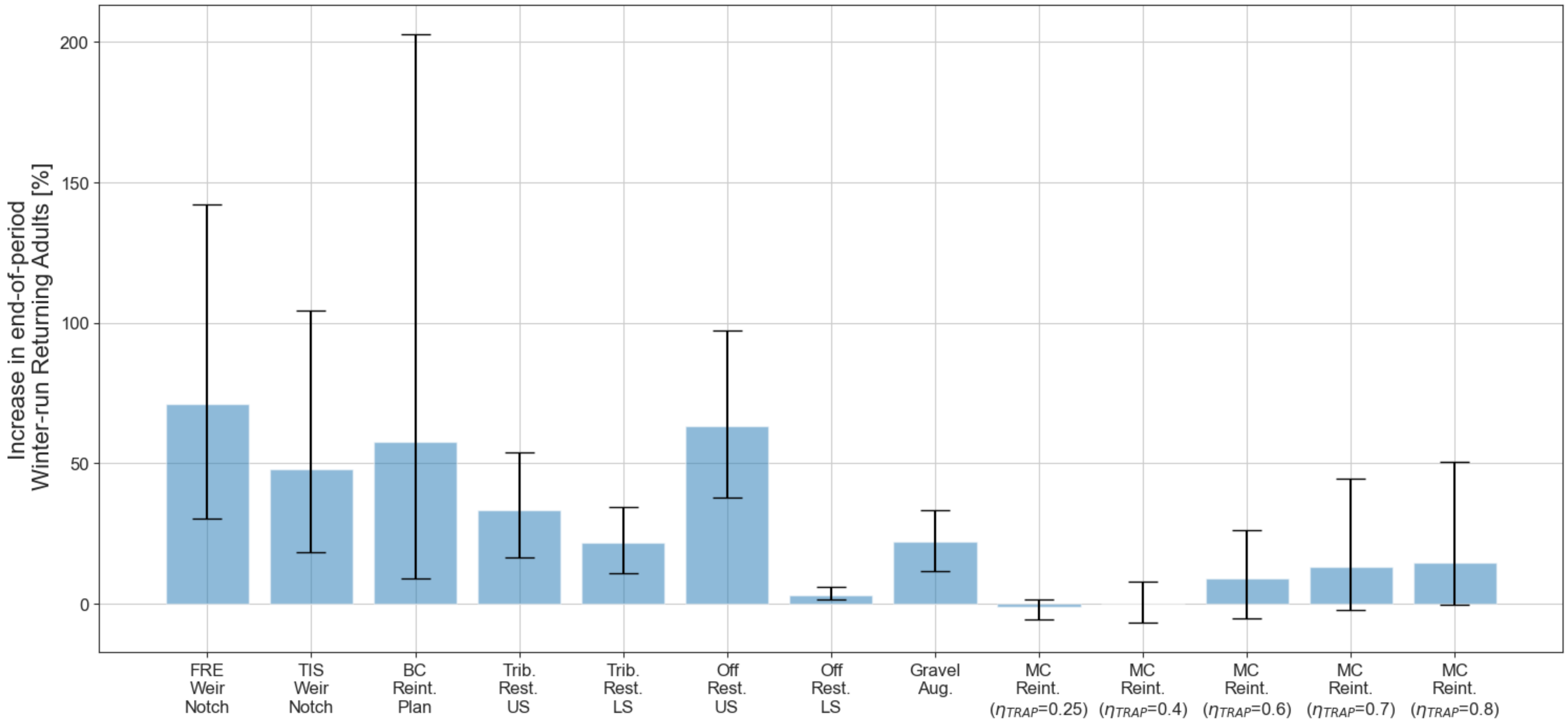
- Off-channel Habitat Restoration
- Gravel Augmentation Plan
- McCloud River Reintroduction Program (TH2)
- Battle Creek Reintroduction Program

Fast comparison between each restoration alternative when implemented individually. Range includes uncertainty in hydrology.



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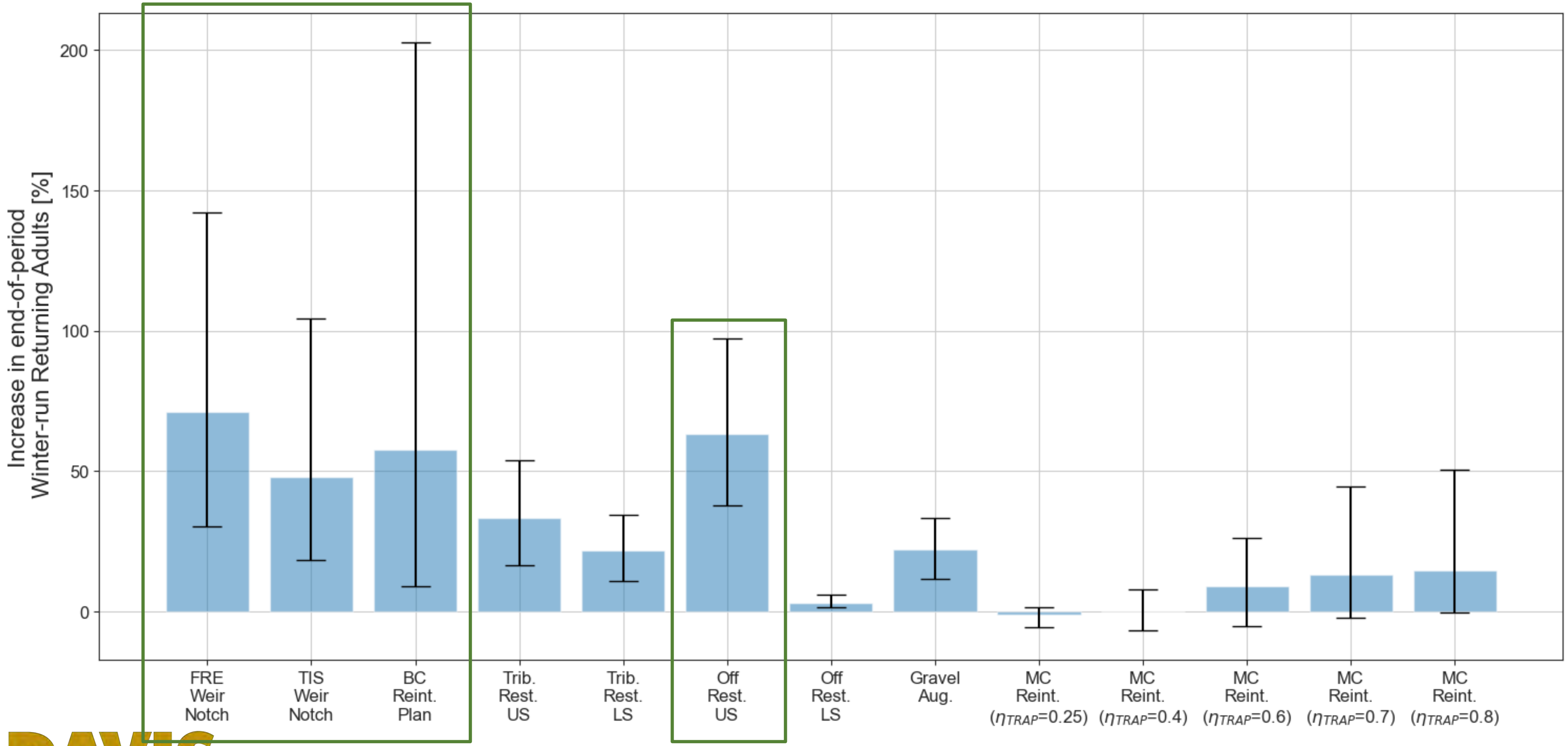
Bellido-Leiva et al., *in review*

Battle Creek reintroduction, bypass weir notching and off-channel restoration generated the greatest impacts on winter-run abundance



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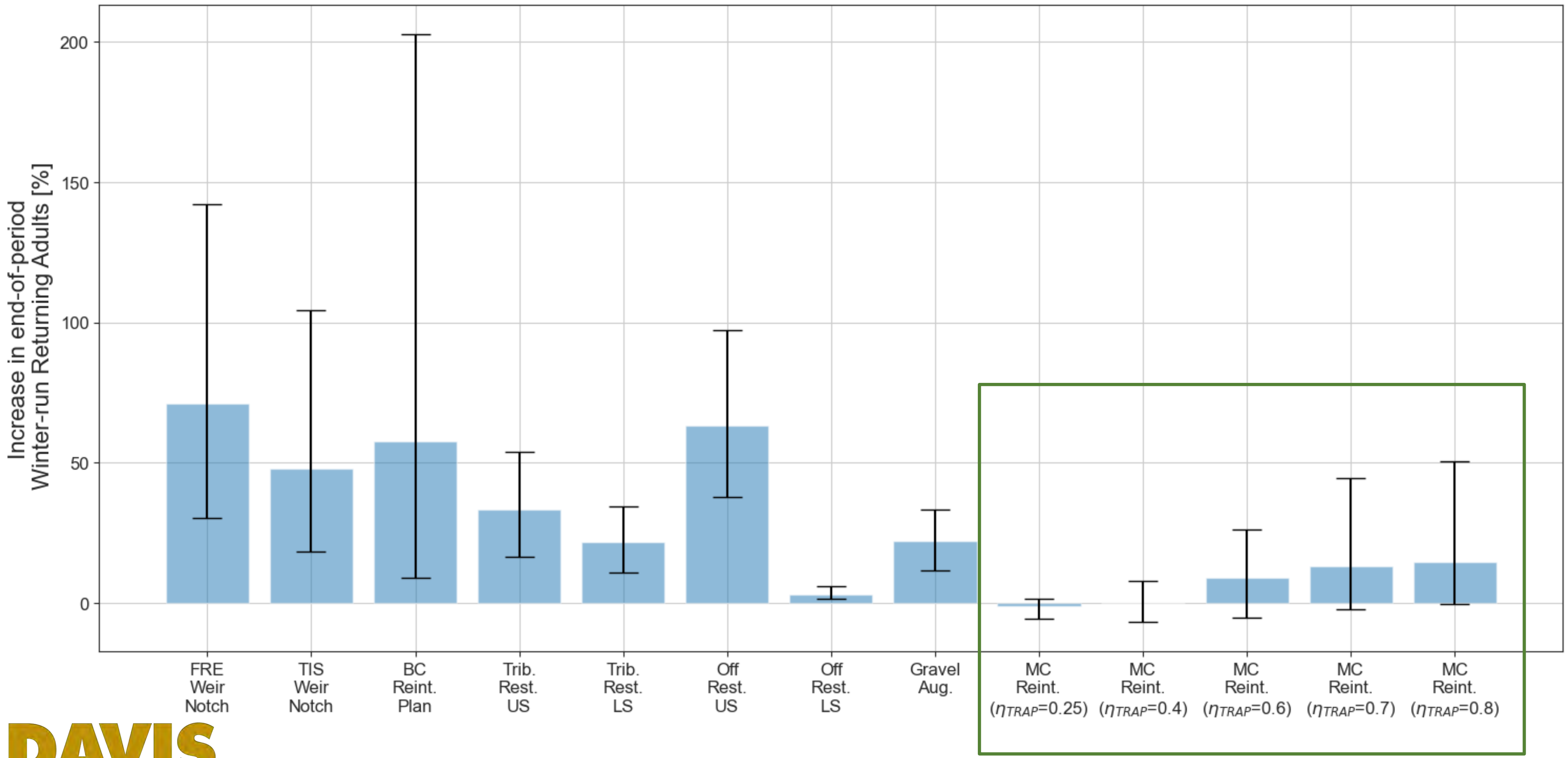
Bellido-Leiva et al., *in review*

Trap and haul performance greatly depends on achieved juvenile trapping efficiency, considering optimal handling and minimal delayed mortality



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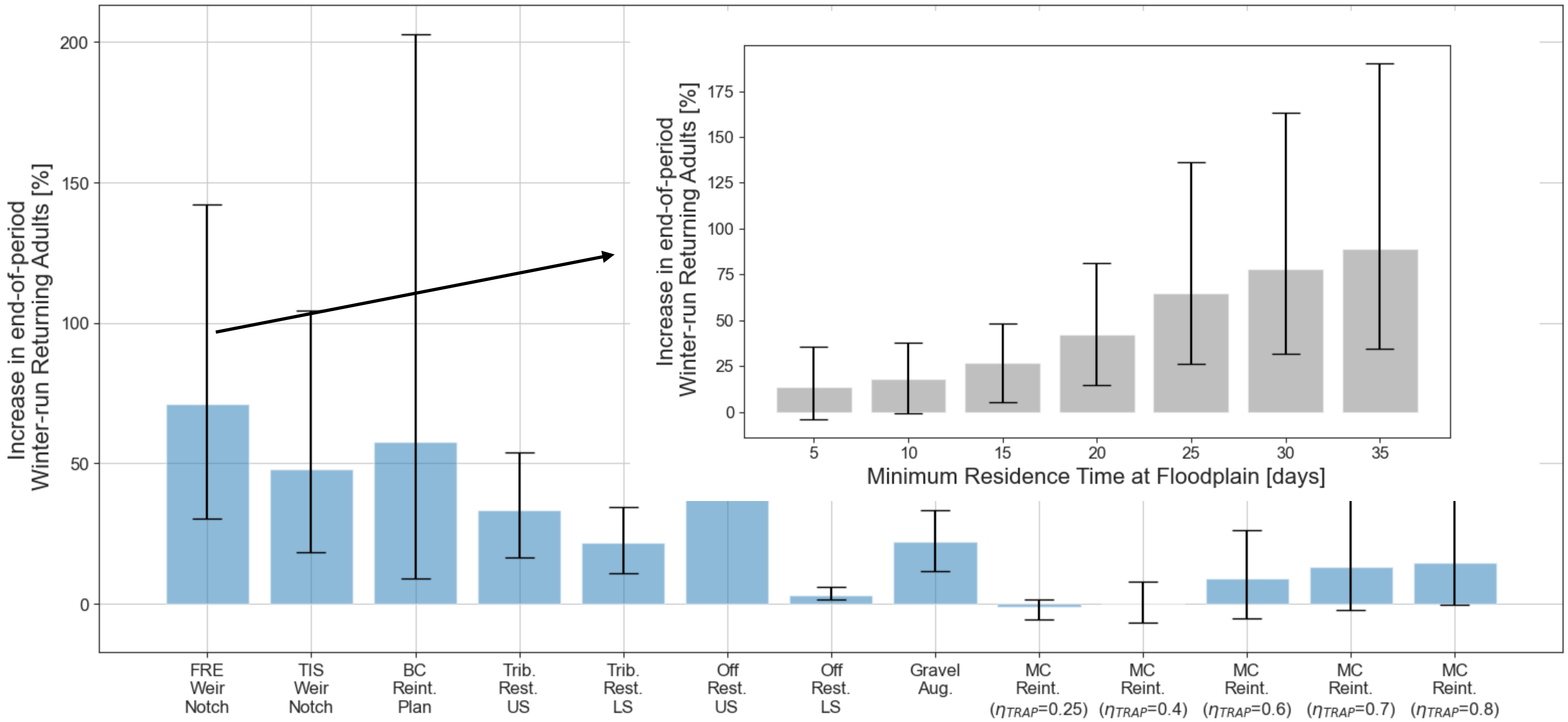
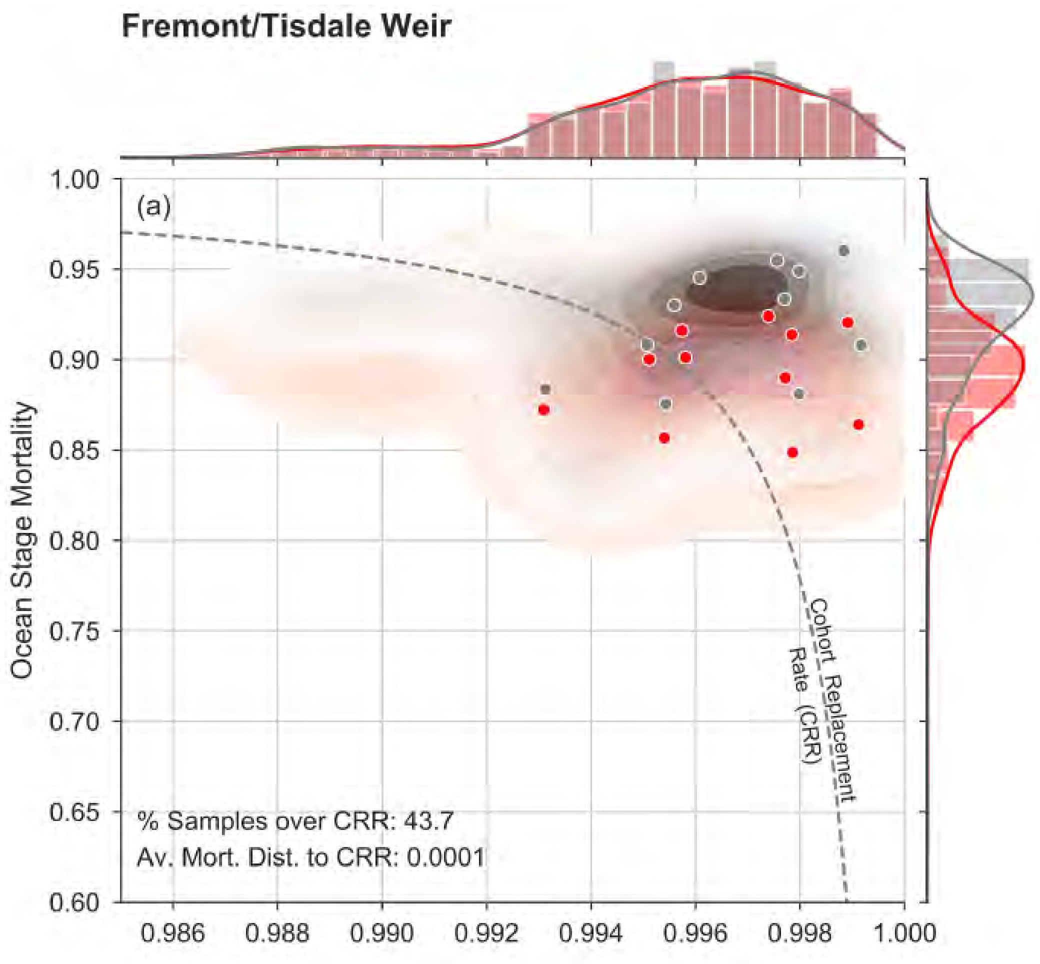
Bellido-Leiva et al., *in review*

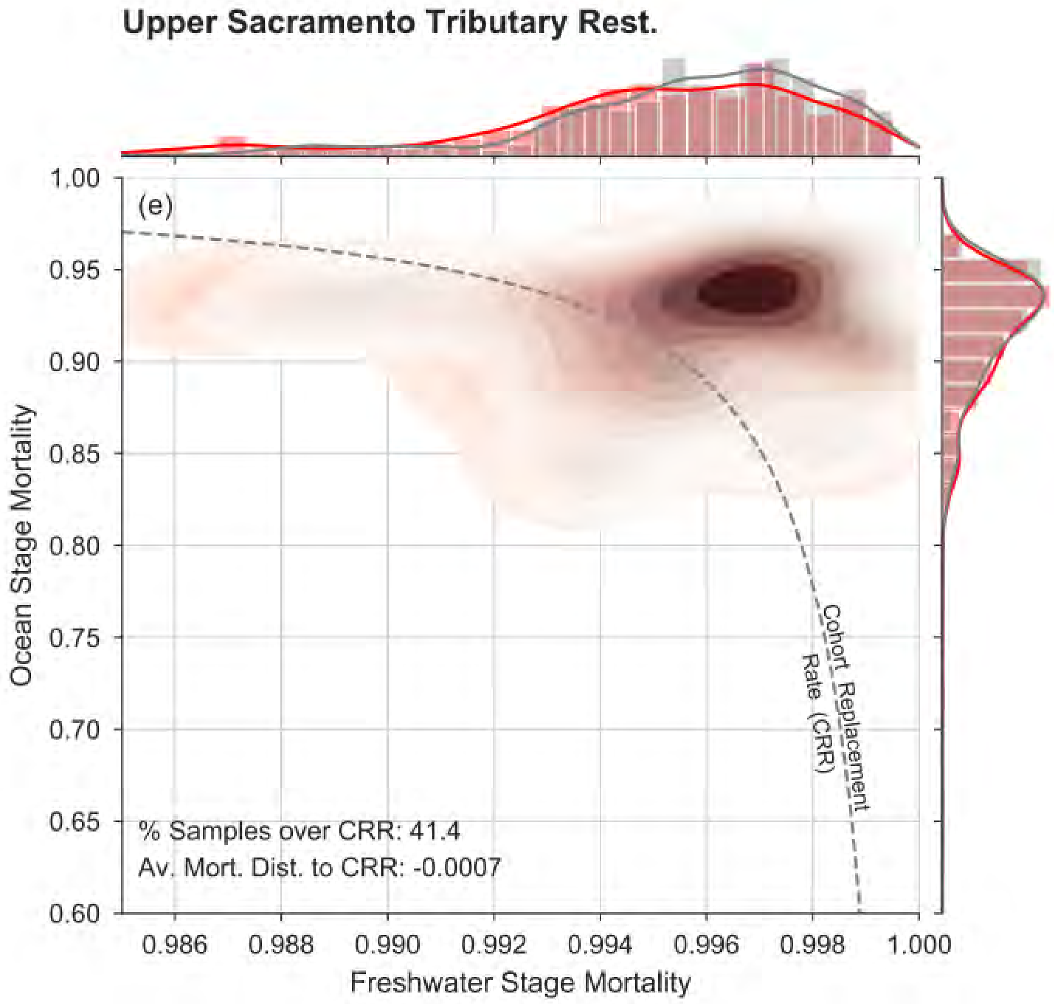
Allow us to explore additional aspects of the proposed restoration action. Importance of sustained bypass flooding inundation with notch operation



Bellido-Leiva et al., *in review*

Allows to analyze further population viability metrics, such as expected population growth after restoration





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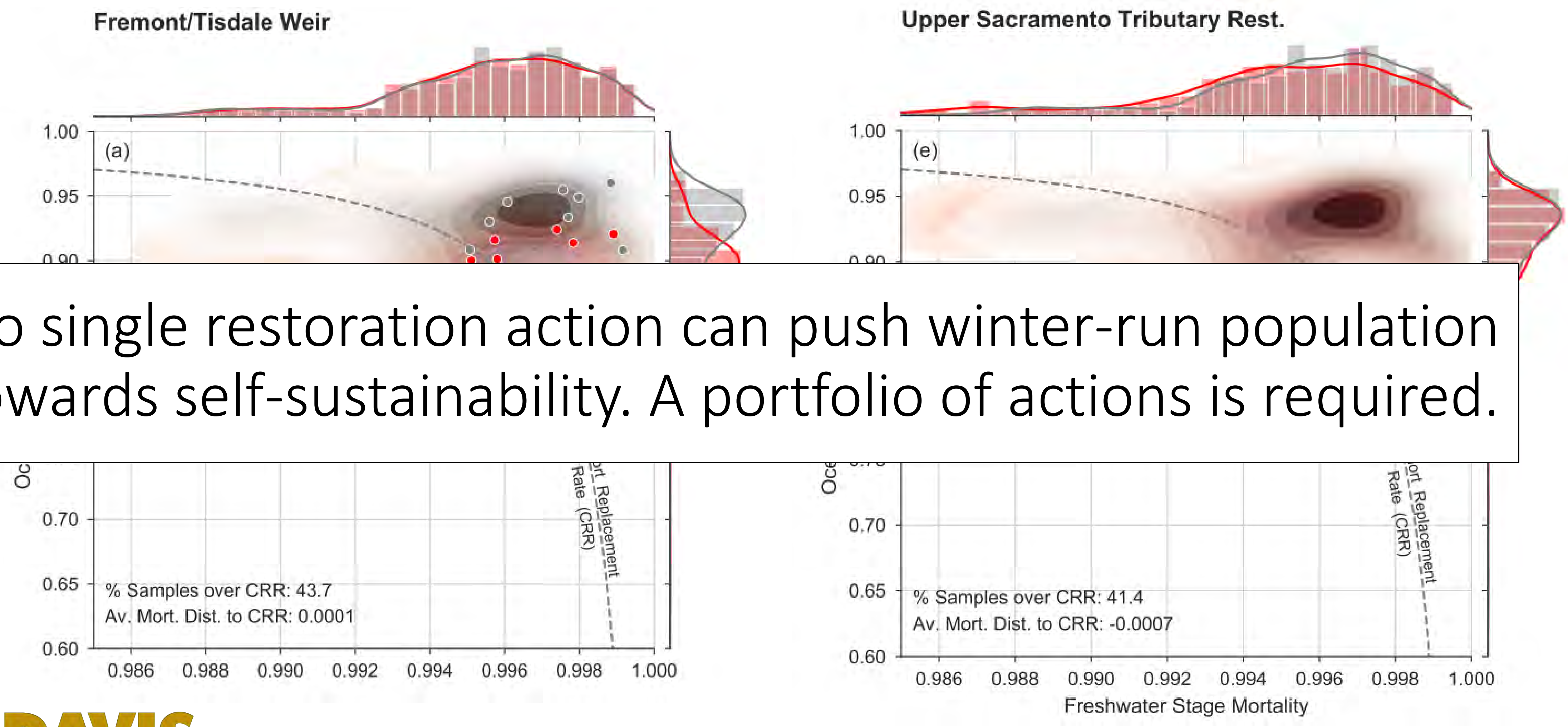

No single restoration action can push winter-run population towards self-sustainability. A portfolio of actions is required.

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Bellido-Leiva et al., *in review*

Formal optimization framework to prioritize conservation actions before investments, and help improving the likelihood of significant ecological benefits

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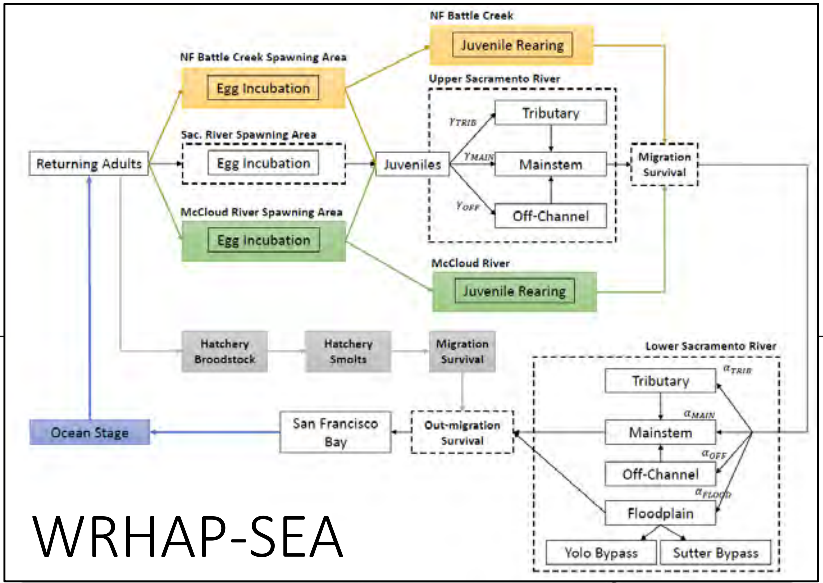
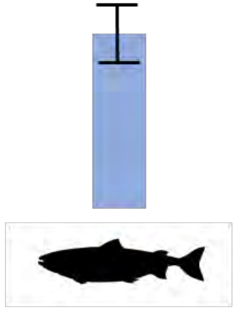
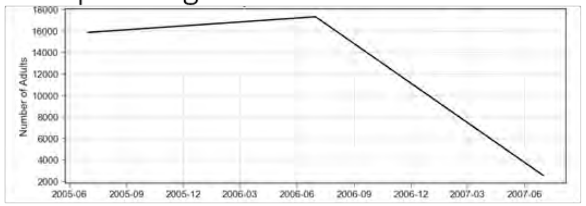
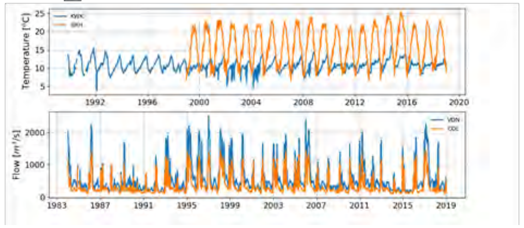


Adult Production



Spawning Adults





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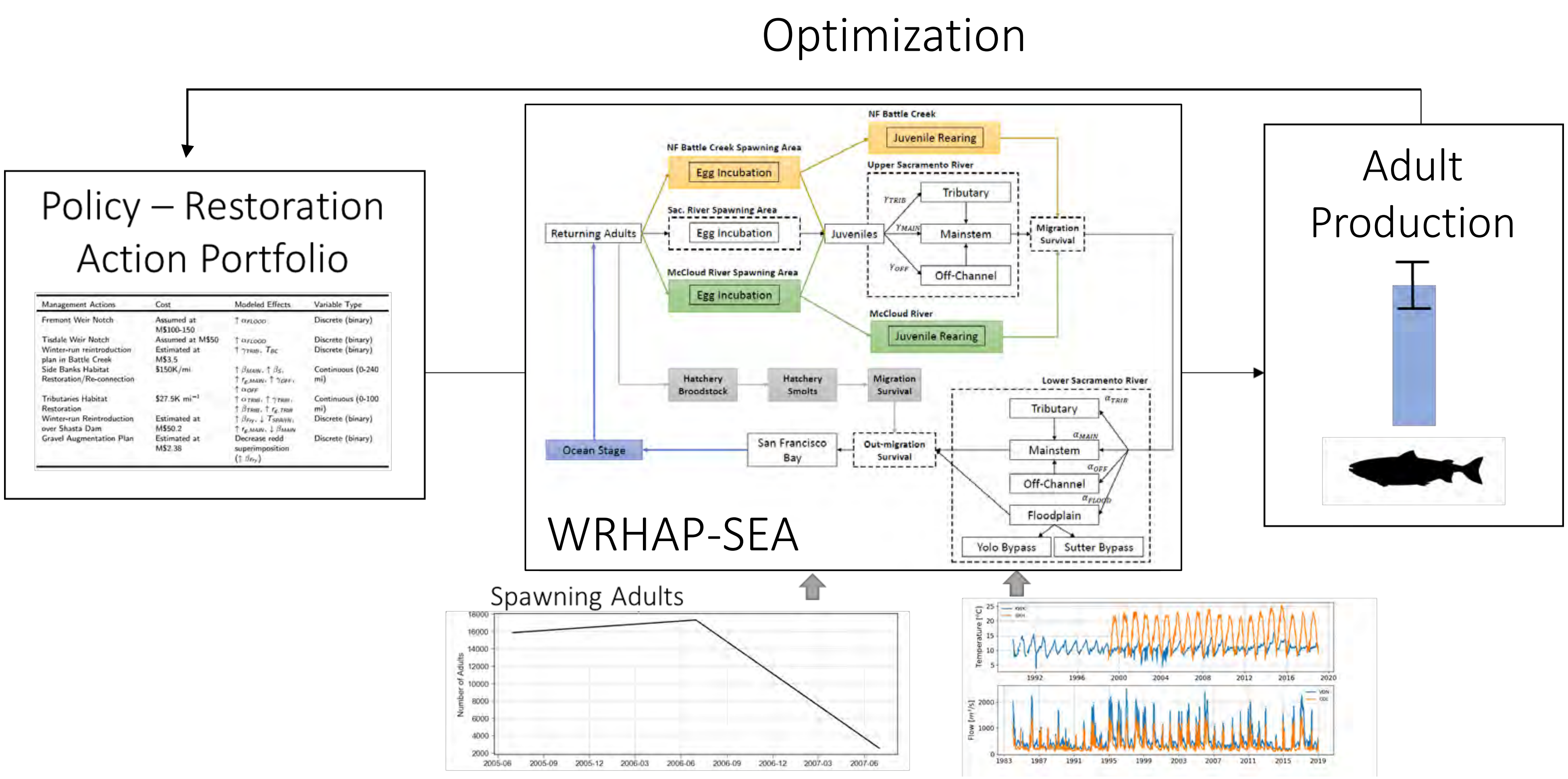
Formal optimization framework to prioritize conservation actions before investments, and help improving the likelihood of significant ecological benefits



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The optimization maximizes end-of-period winter-run Chinook spawner abundance (WRHAP-SEA output), constrained by available funds

$$Z_1 = \max \frac{1}{H} \sum_{H} \sum_{P} \sum_{j=T-2}^{T} N_{RA,P,j}^{NO}$$

$$\text{S.t.} \quad B \geq \sum_{j} X_j C_{RA,j}$$

$$\text{where} \quad N_{RA,P,j}^{NO} = F\left[N_{S,P,j}^{NO+HO}, \boldsymbol{Z}, \boldsymbol{X_j}\right] \quad \text{WRHAP-SEA output}$$

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Costs derived from previous efforts in other watersheds and values reported in literature (e.g., NMFS 2014)

Considered Restoration/Recovery Actions

- Fremont/Tisdale Weir Notching ($136m/$66.4m)
- Tributary Habitat Restoration ($430k/rmi)
- Off-channel Habitat Restoration ($115K/acre)
- Gravel Augmentation Plan ($2.6m)
- McCloud River Reintroduction Program (TH2) ($44.65m-$214m)
- Battle Creek Reintroduction Program ($13.8m)

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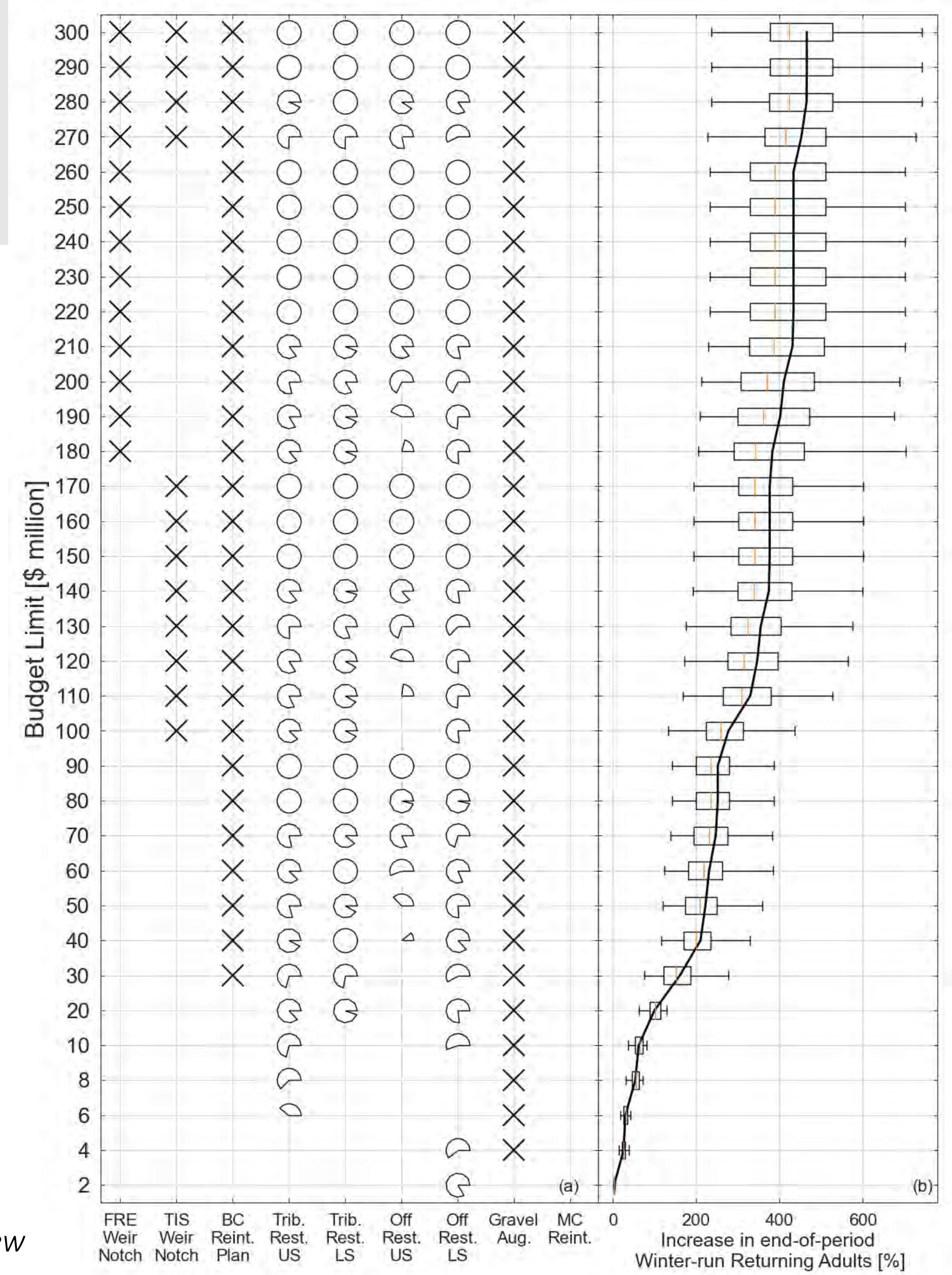
Optimized portfolios present several clear patterns as available funding changed



Bellido-Leiva et al., *in review*

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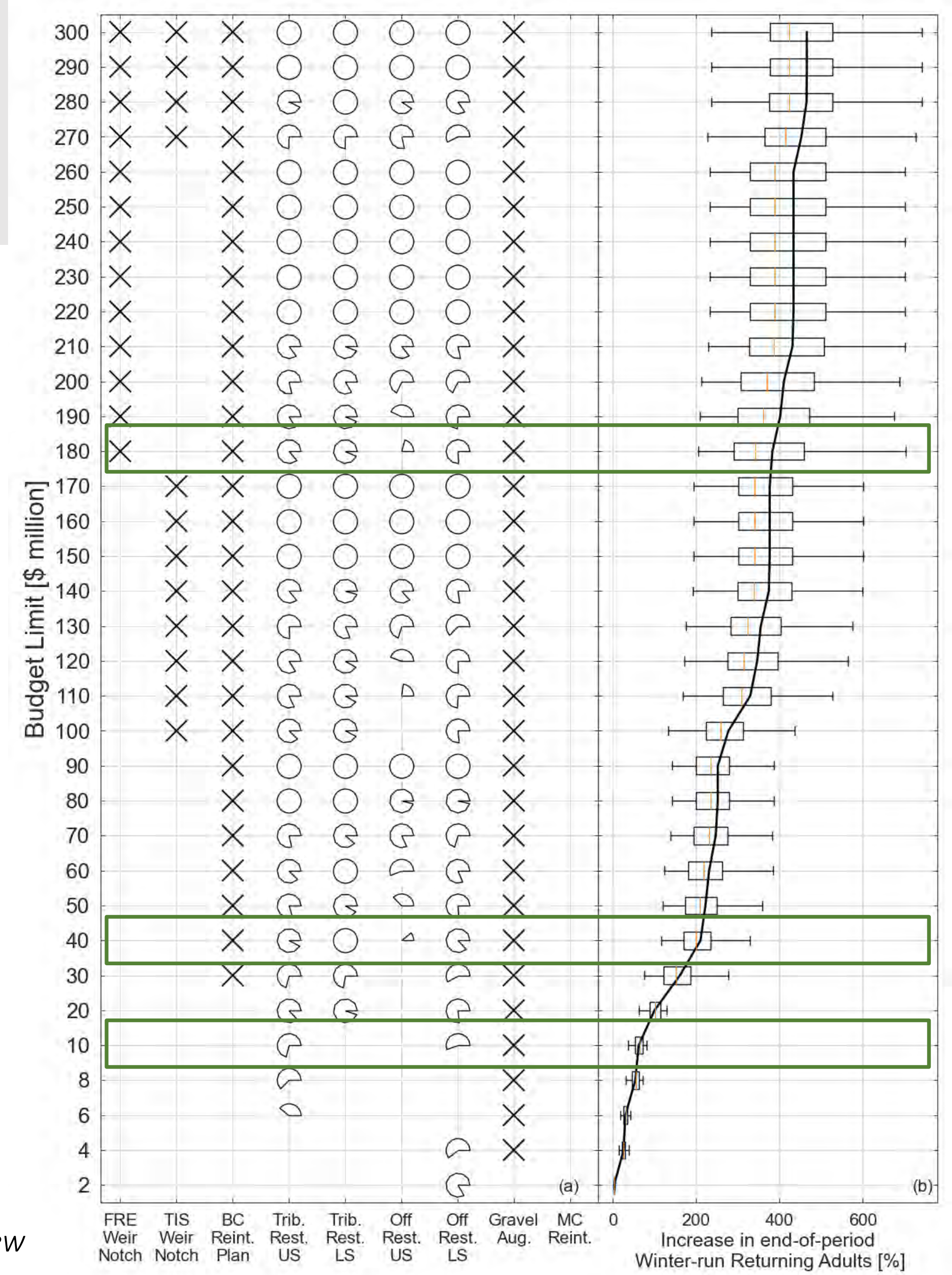
Optimized portfolios present several clear patterns as available funding changed

Optimization selects portfolios that target several locations and stages simultaneously



Bellido-Leiva et al., *in review*

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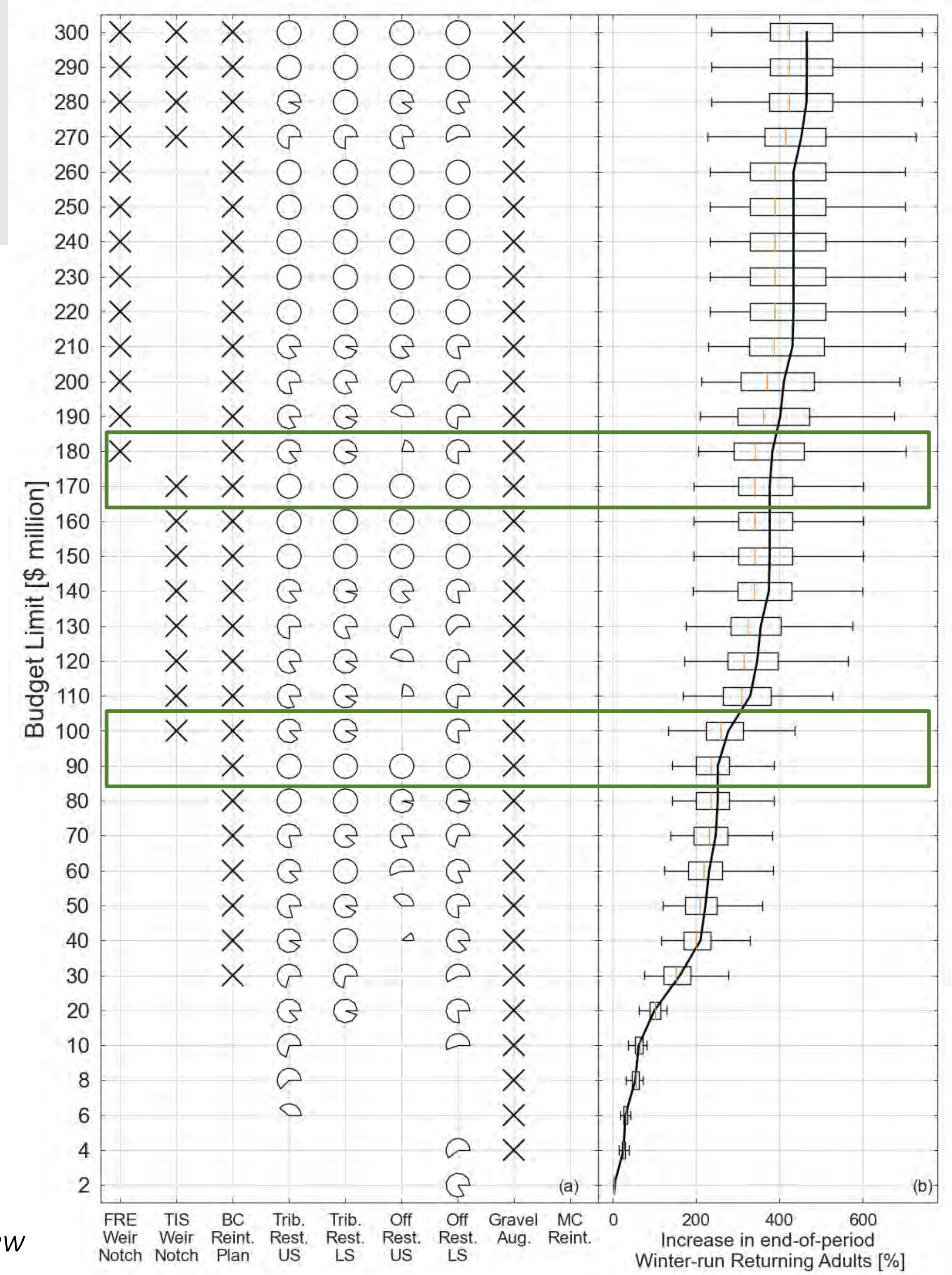
Bypass weird notching, off-channel and tributary restoration



Bellido-Leiva et al., *in review*

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Optimized portfolios present several clear patterns as available funding changed

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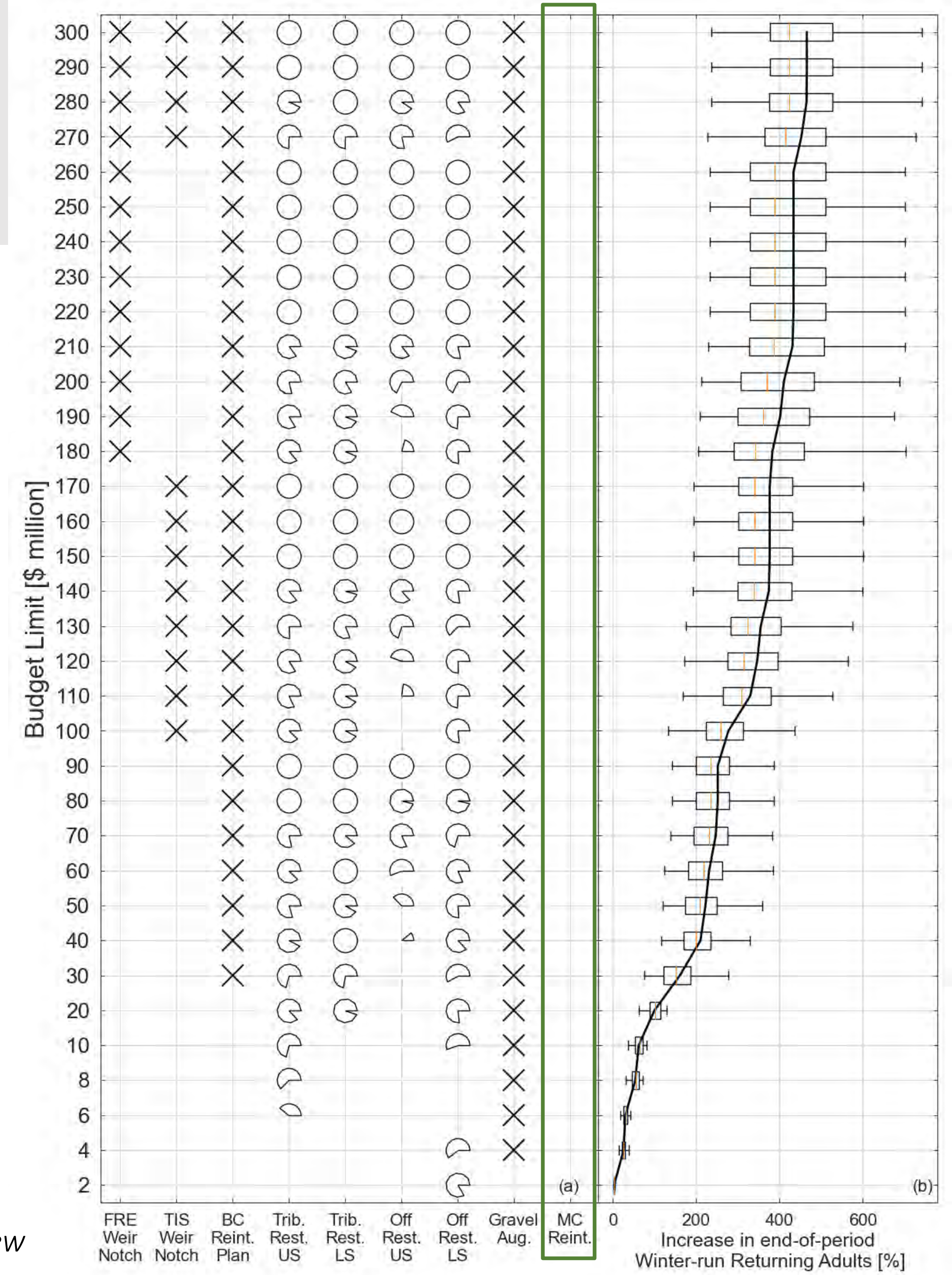
Bypass weird notching, off-channel and tributary restoration

McCloud River trap-and-haul program was not selected under any budget scenario



Bellido-Leiva et al., *in review*

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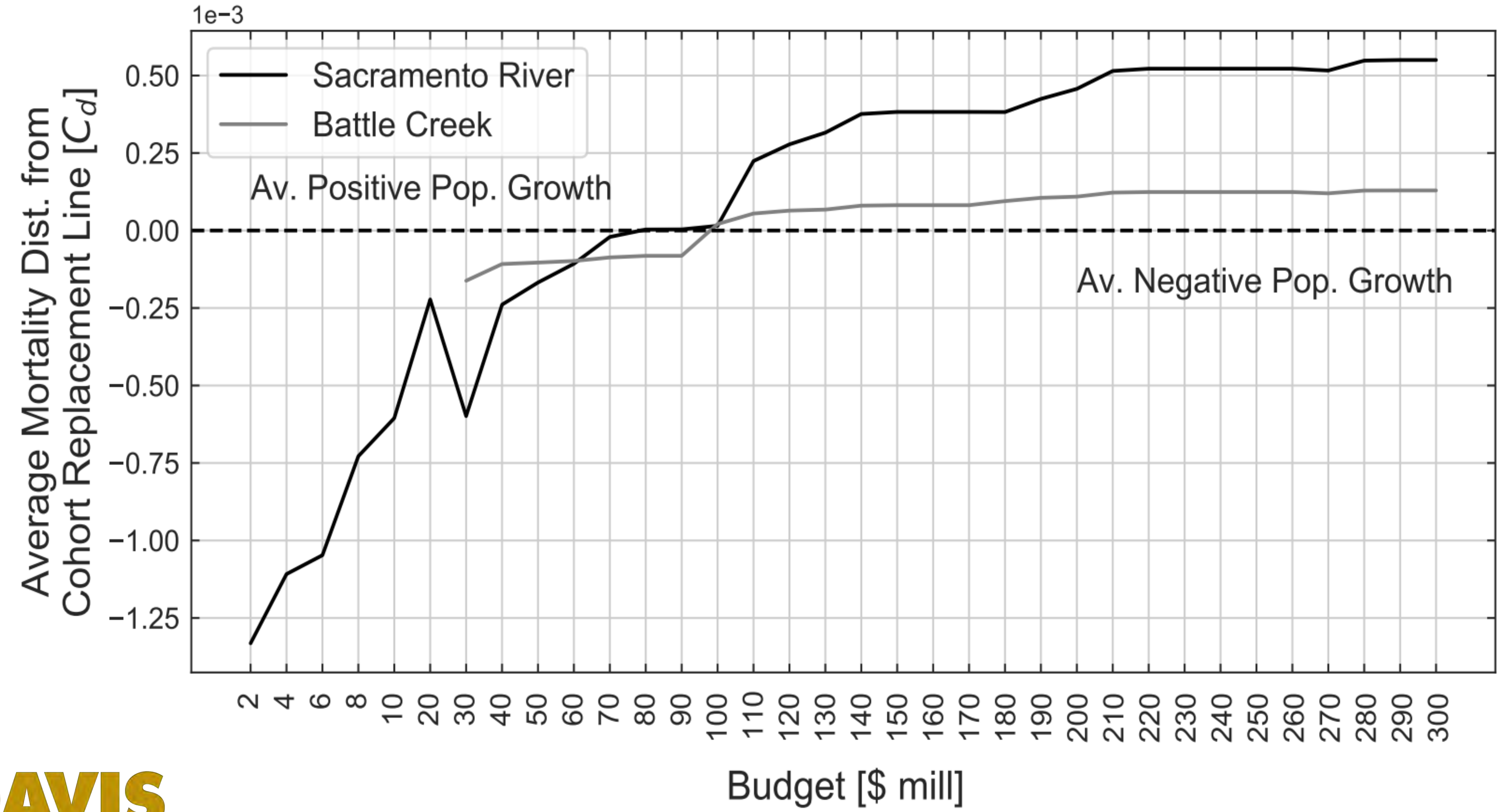
Positive expected population growth was not achieved until bypass floodplain weir notching was included in optimal portfolios



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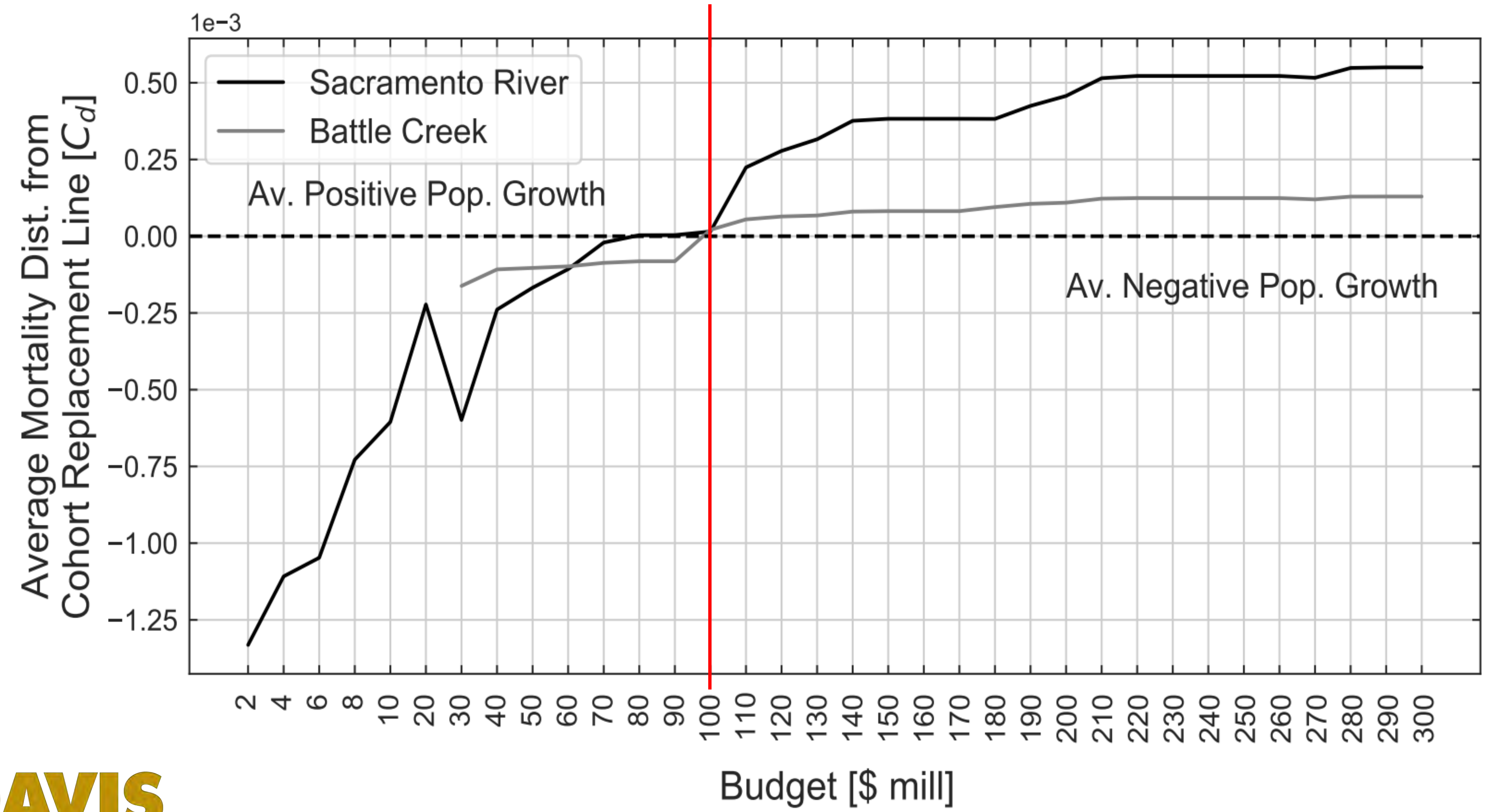

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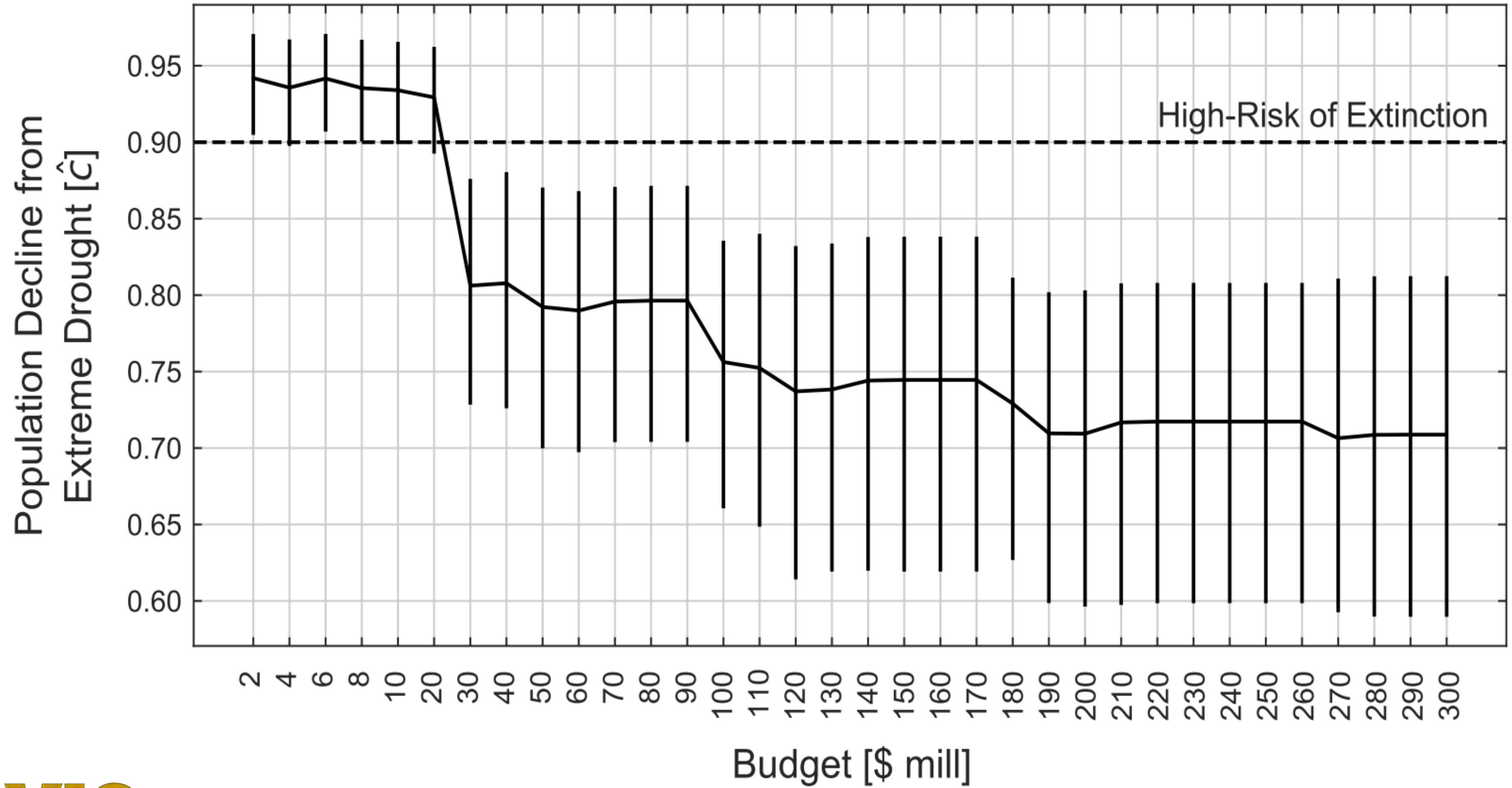
Bellido-Leiva et al., *in review*

Population decline from extreme drought was greatly reduced by Battle Creek reintroduction. Two-way trap and haul would also greatly improve this metric



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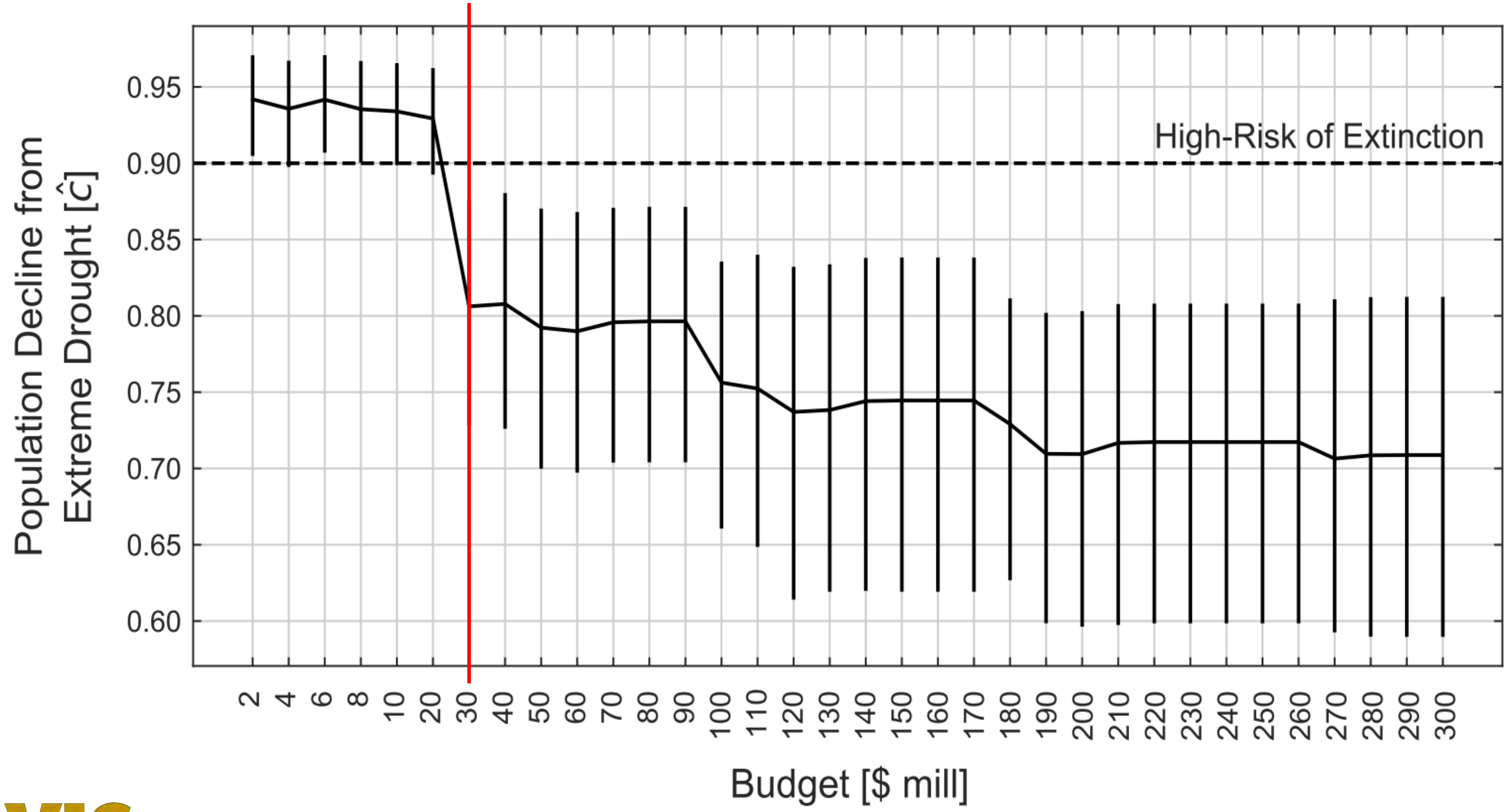

Bellido-Leiva et al., *in review*

Conclusions

- Formal optimization frameworks may help coordinate and structure complex watershed-scale efforts
- Allows exploring tradeoffs among a broad set of restoration options and identifies optimal portfolios to assist management for species recovery.
- Optimized portfolios, particularly those targeting multiple stressors at different locations, improved winter-run population viability
- Prominence of frequent and sustained floodplain activation to achieve a self-sustaining population
- Potential limitation of two-way trap and haul programs, constrained capture efficiency and low delayed mortality.

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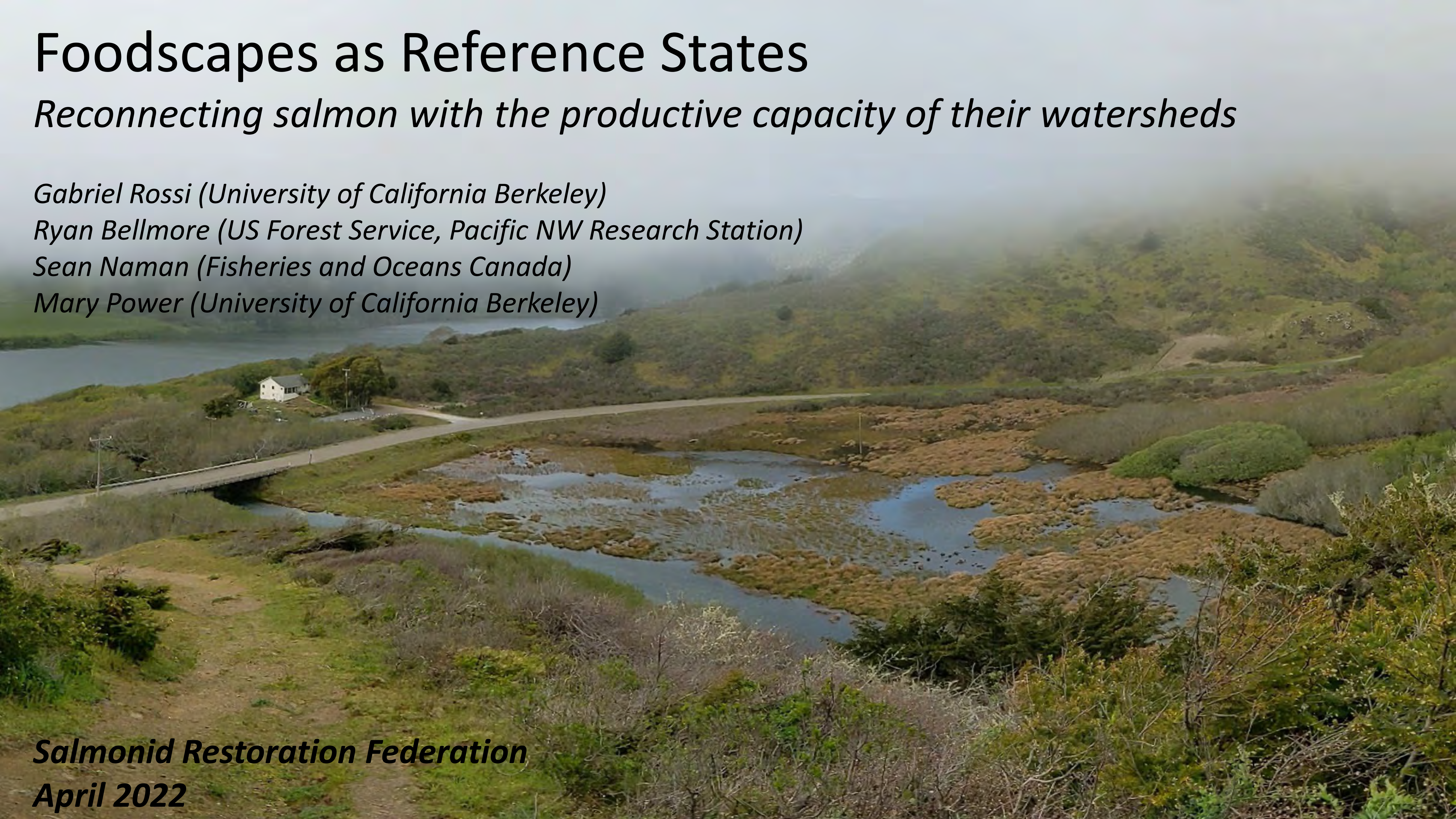
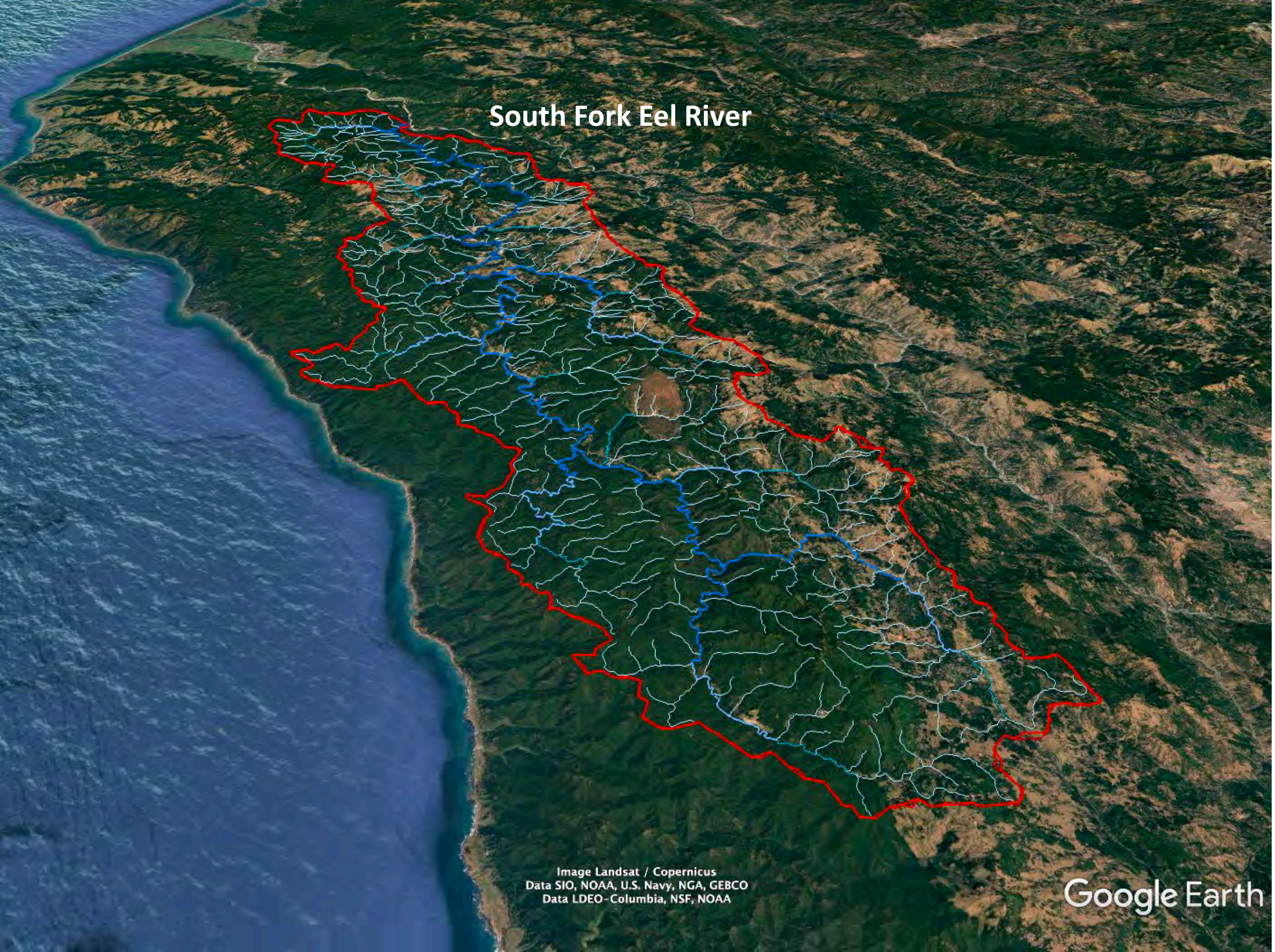
Foodscapes as Reference States

Reconnecting salmon with the productive capacity of their watersheds

Gabriel Rossi (University of California Berkeley)
Ryan Bellmore (US Forest Service, Pacific NW Research Station)
Sean Naman (Fisheries and Oceans Canada)
Mary Power (University of California Berkeley)



Salmonid Restoration Federation
April 2022



The case of the missing life histories

683 miles of stream channel in the South Fork Eel River; but less then 150* miles of cold, perennial, rearing habitat for over summering salmonids.

Based on SF Eel SHaRP 2021 Report

How many adult fish could these "ideal" rearing stream produce?

"Silly math for steelhead" (very inflated density and survival numbers!)

~150 miles of stream;

2000 smolts per mile;

5% SAR

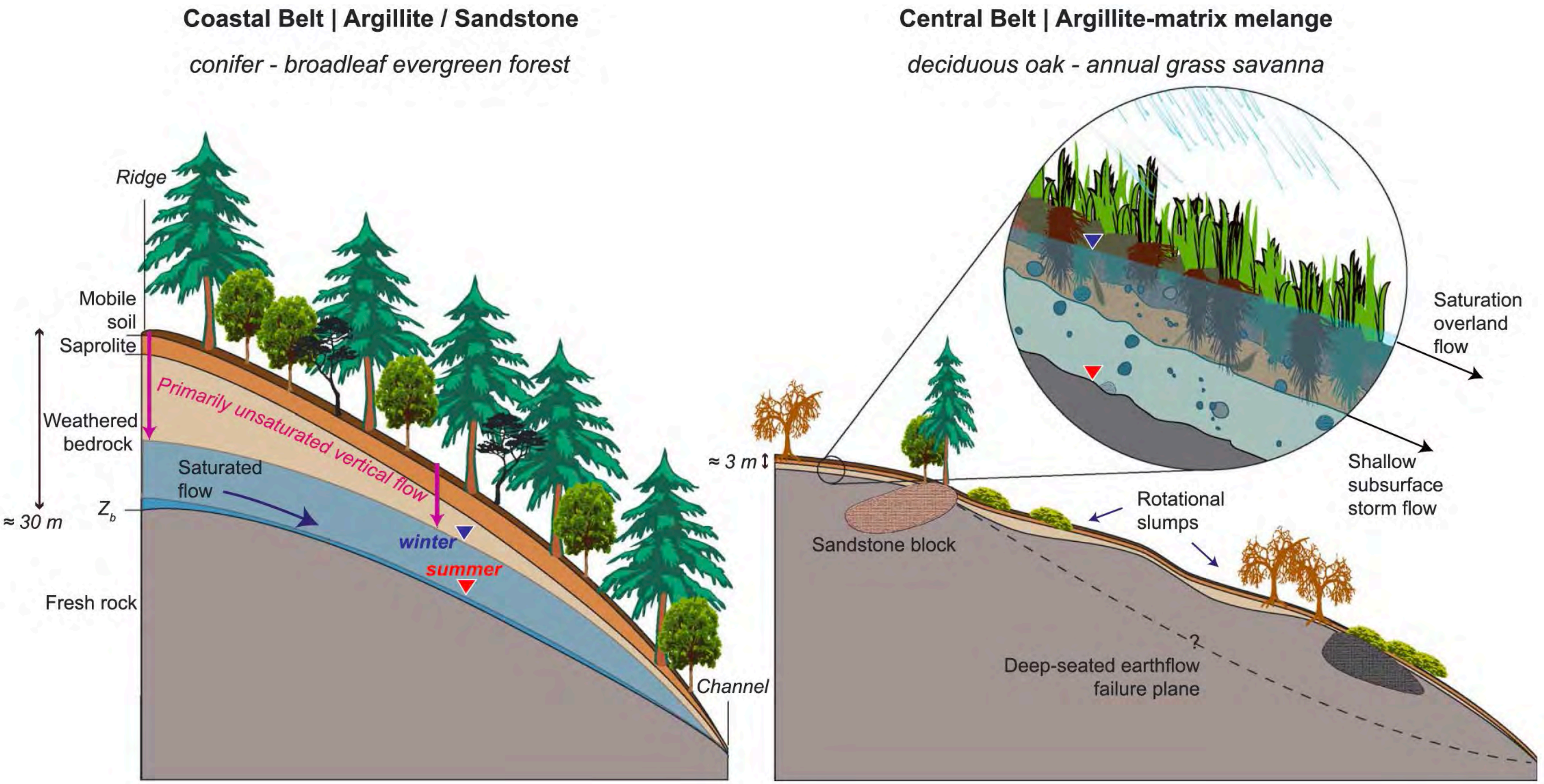
=

<u>300,000 smolts</u>

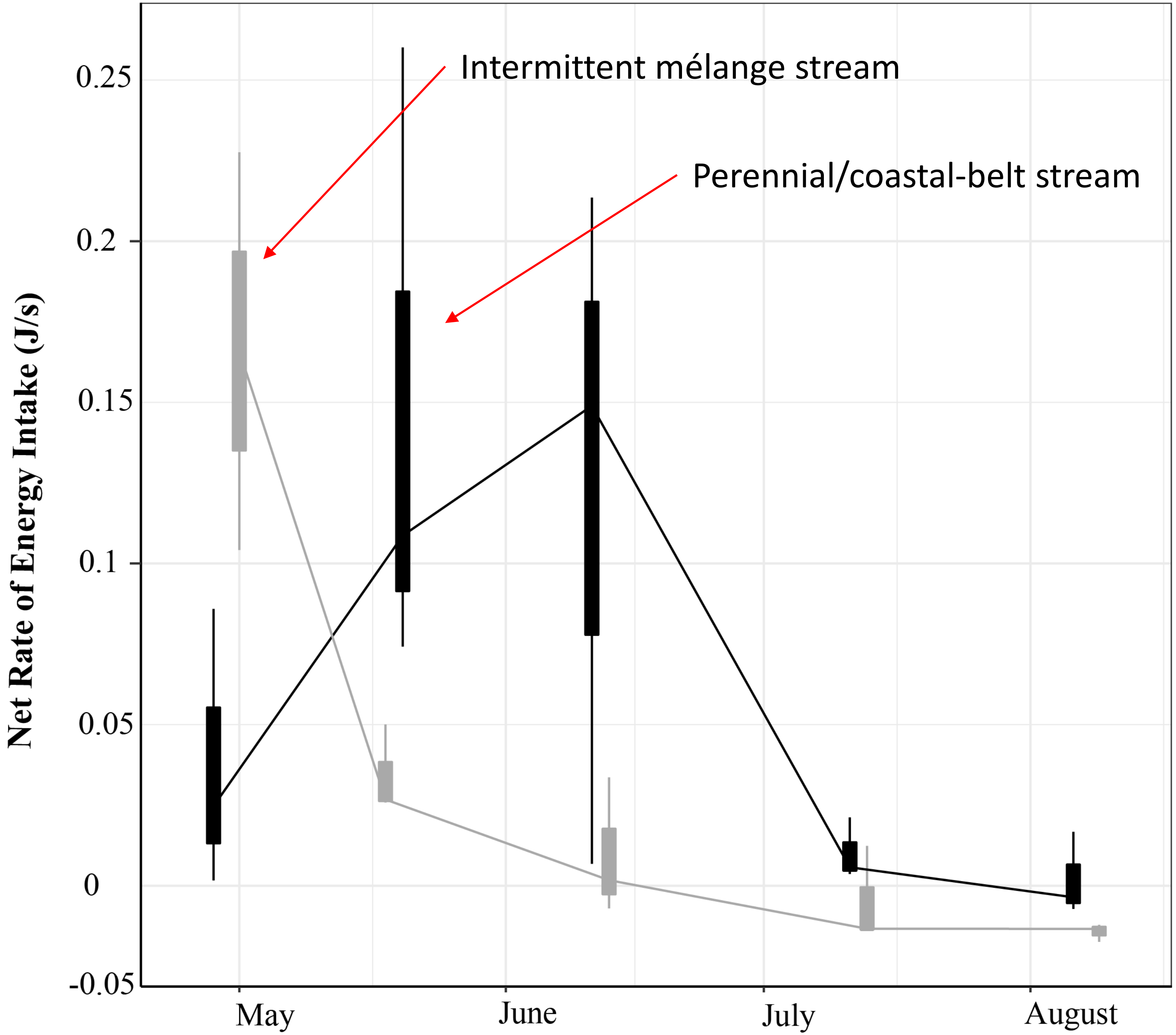
<u>15,000 adults</u>

But estimates are that the SF Eel River produced **3X this number of adult fish!** Where did they come from? How did they do it?

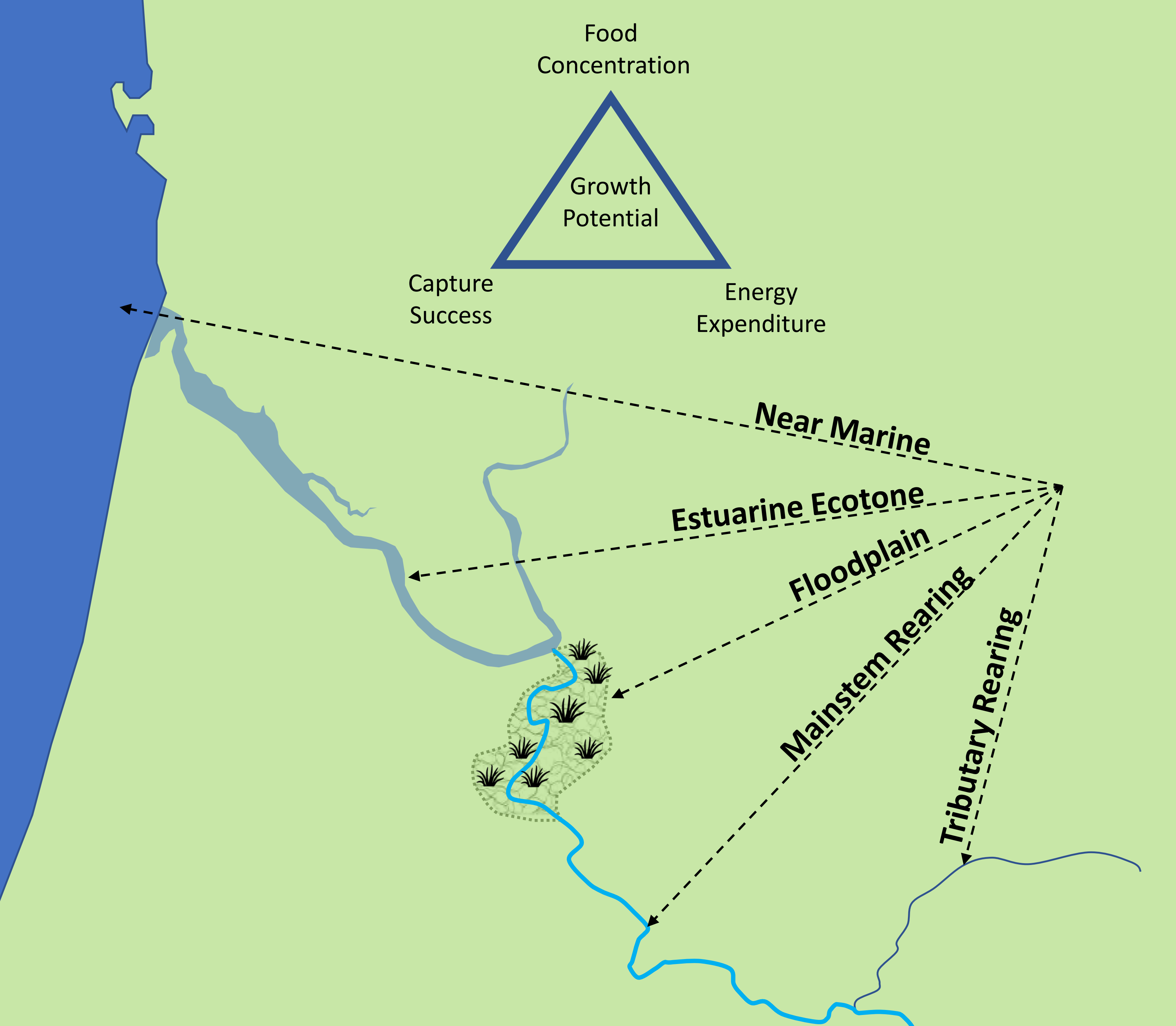
H1: They reared in, and occupied habitats that were only seasonally profitable and migrated to non natal habitat through an array of life histories that have been either extirpated or massively reduced. Tracking landscape scale growth potential. Ideal free/despotic fish??



Hahm, Rempe, Dralle, et al,. Water Resources Research, 2019



Rossi et al., *in review* at Ecosphere



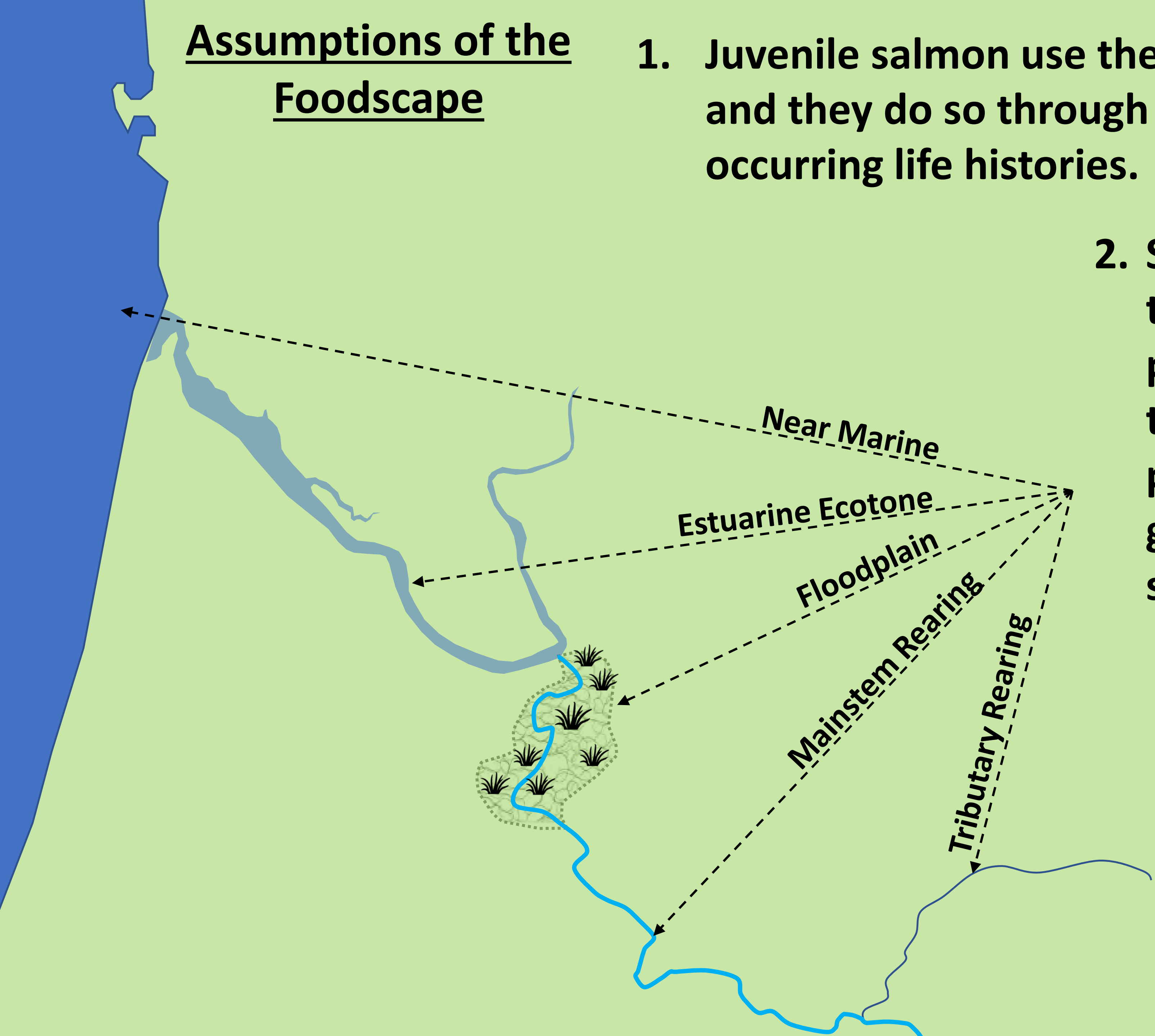
The "**foodscape**" is a mosaic of linked habitats with different growth potential phenologies that is exploited by mobile consumers and supports multiple life histories, often through asynchronies in resource availability.

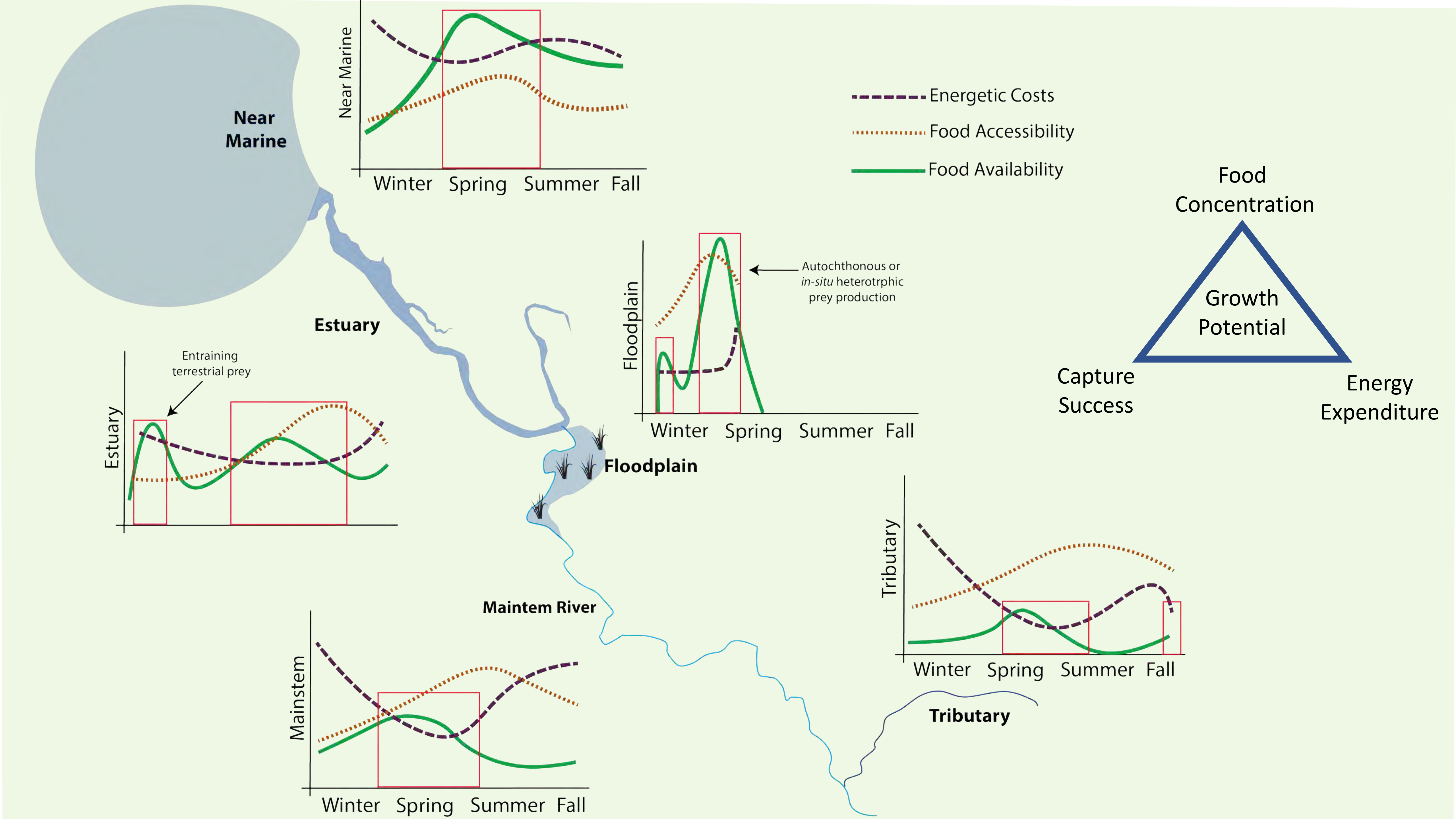
<u>Assumptions of the Foodscape</u>

1. Juvenile salmon use the whole watershed, and they do so through multiple, co-occurring life histories.

2. Salmon are fed by different trophic pathways in different parts of the watershed. And these different pathways produce asynchronous pulses of growth potential for juvenile salmonids in time, and space.

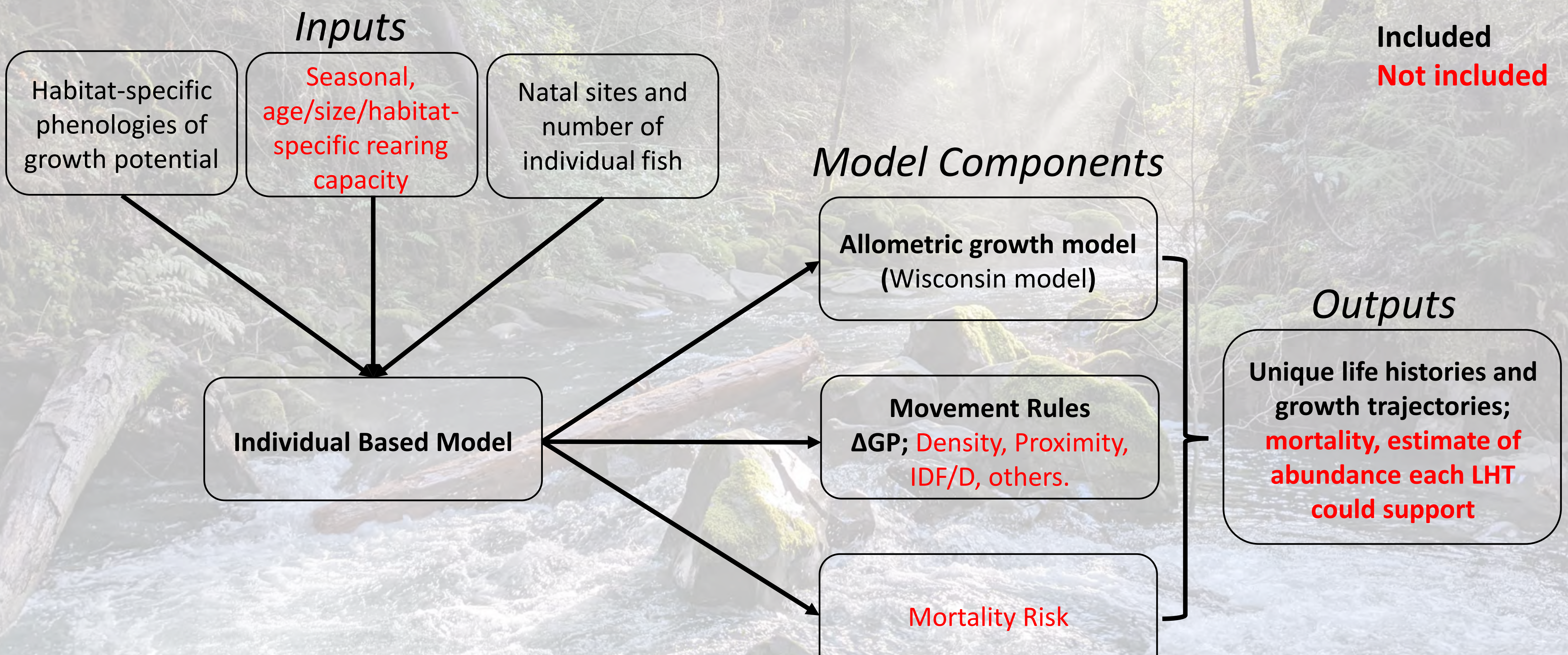
3. Salmon life histories are adapted to capitalize on the asynchronous pulses of growth that are unique to each watershed and perhaps water year.

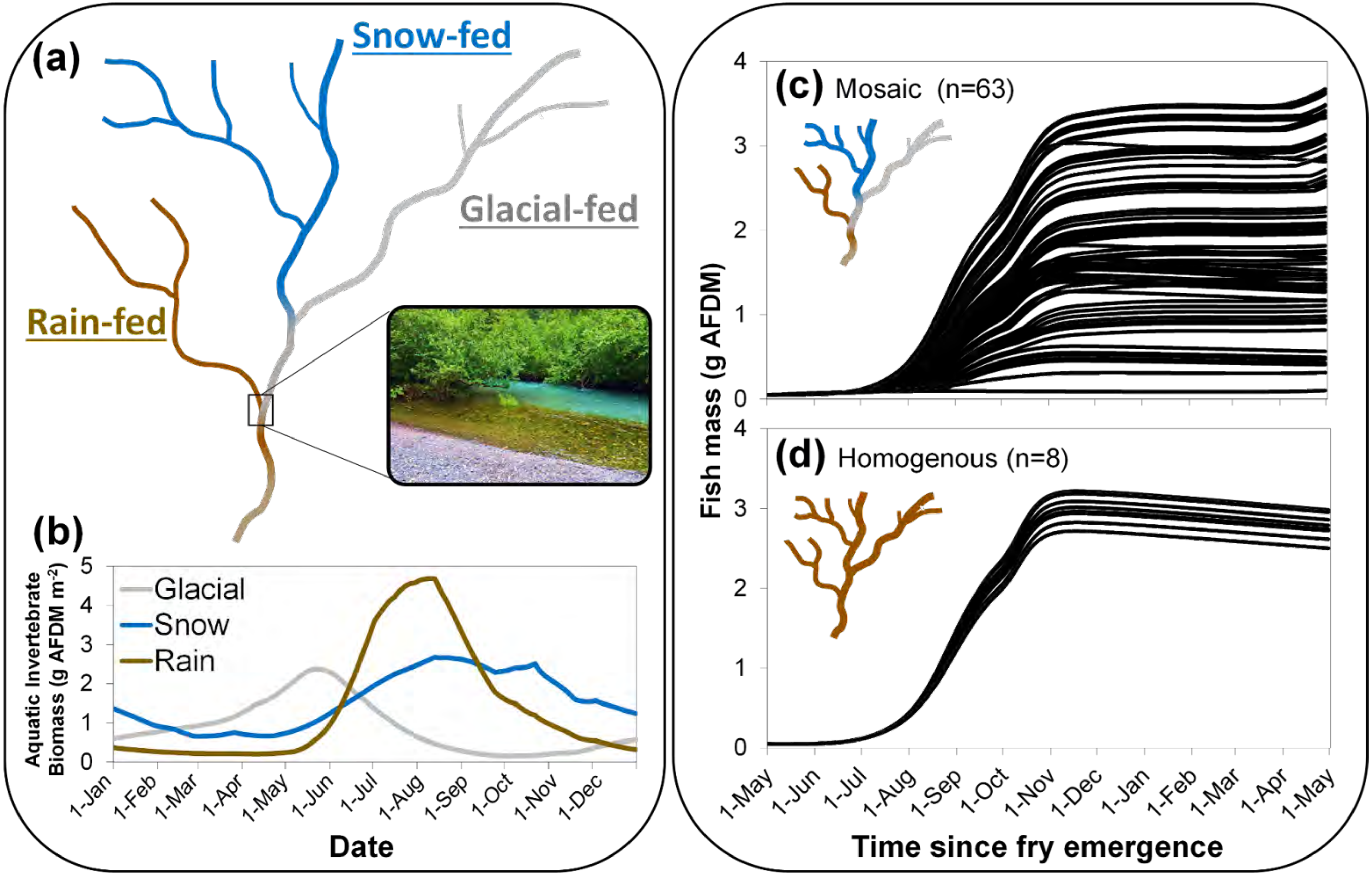



Near Marine
Near Marine
Winter Spring Summer Fall
Energetic Costs
Food Accessibility
Food Availability
Food Concentration
Growth Potential
Capture Success
Energy Expenditure
Estuary
Entraining terrestrial prey
Estuary
Floodplain
Autochthonous or *in-situ* heterotrphic prey production
Winter Spring Summer Fall
Floodplain
Maintem River
Mainstem
Winter Spring Summer Fall
Tributary
Winter Spring Summer Fall
Tributary

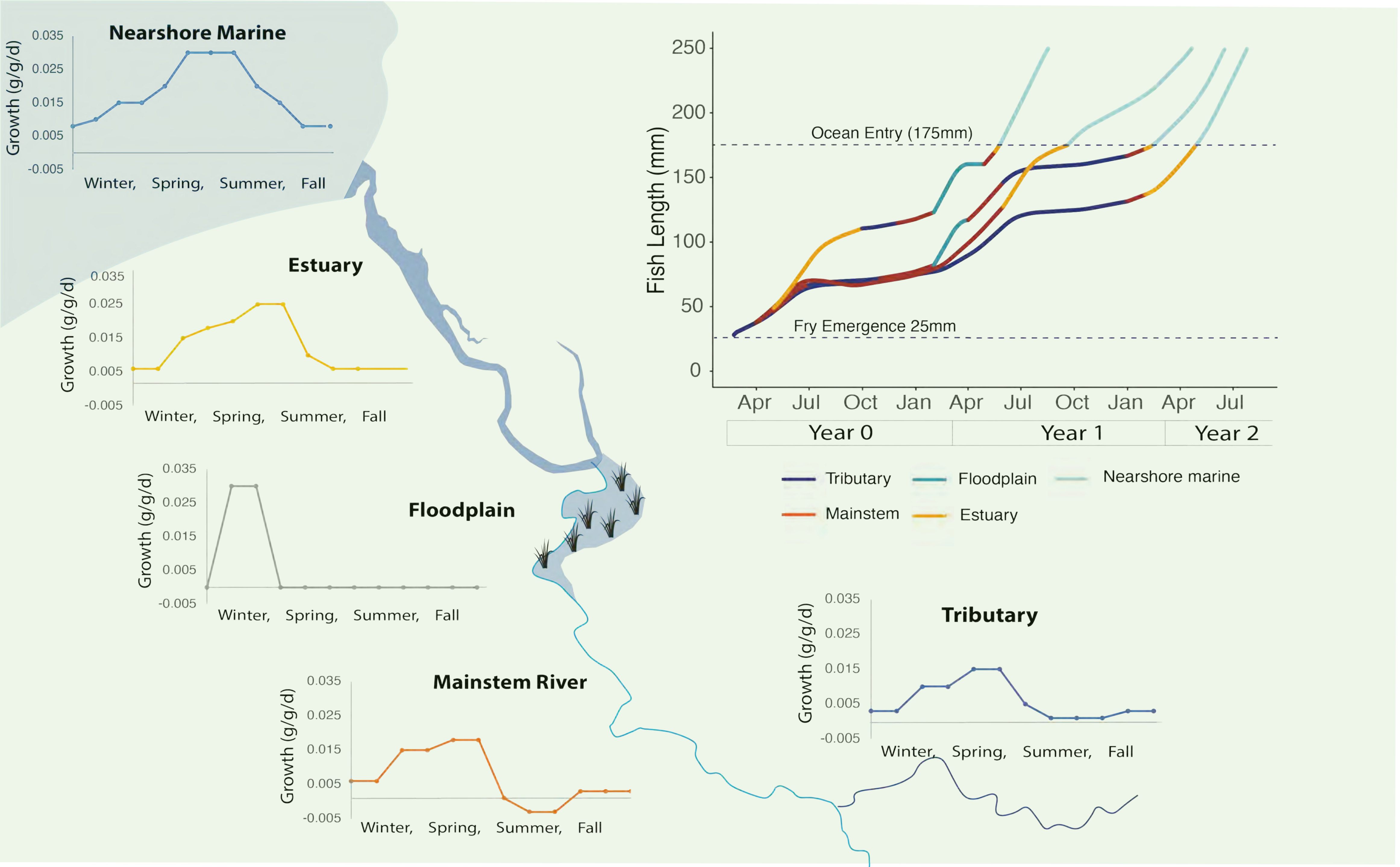
Problem -- How can we estimate critical life histories that are now absent from the landscape; and the spatio-temporal patterns of growth potential that supported them?

A Modeling Approach (with help from natural history, written history, and Indigenous knowledge)





Bellmore et al. 2022. *In review* at Global Change Biology



Nearshore Marine
Growth (g/g/d)
0.035
0.025
0.015
0.005
-0.005
Winter, Spring, Summer, Fall
Estuary
Floodplain
Mainstem River
Tributary
Fish Length (mm)
250
200
150
100
50
0
Ocean Entry (175mm)
Fry Emergence 25mm
Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul
Year 0
Year 1
Year 2
Tributary
Floodplain
Nearshore marine
Mainstem
Estuary

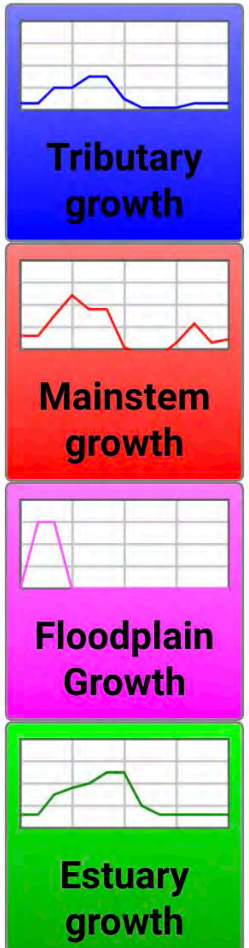
Not a slide:

Switch to online IBM model to illustrate different growth trajectories as seasonal growth potential changes across the landscape.

https://exchange.iseesystems.com/public/ryan-bellmore/fish-foodscape-ibm-example/index.html#page1

Run Model

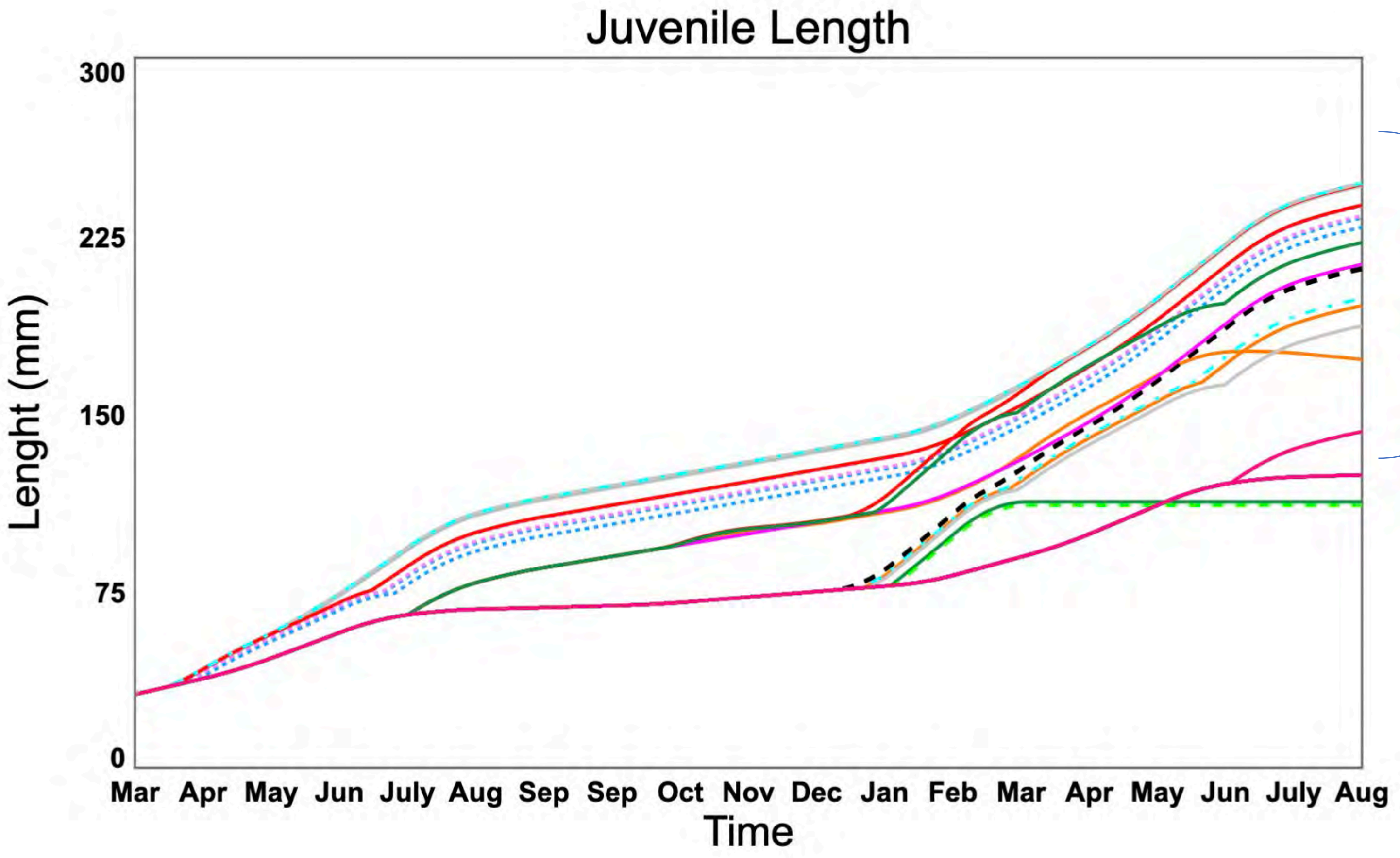
Restore All Inputs



Baseline Reference Model:

Habitats: 1 natal tributary; 1 mainstem, 1 floodplain, 1 estuary

100 fish; probability distribution, movement based on relative growth potential in adjacent habitats



~ 15 life histories emerge, with 2+ fish reaching 100mm-240mm

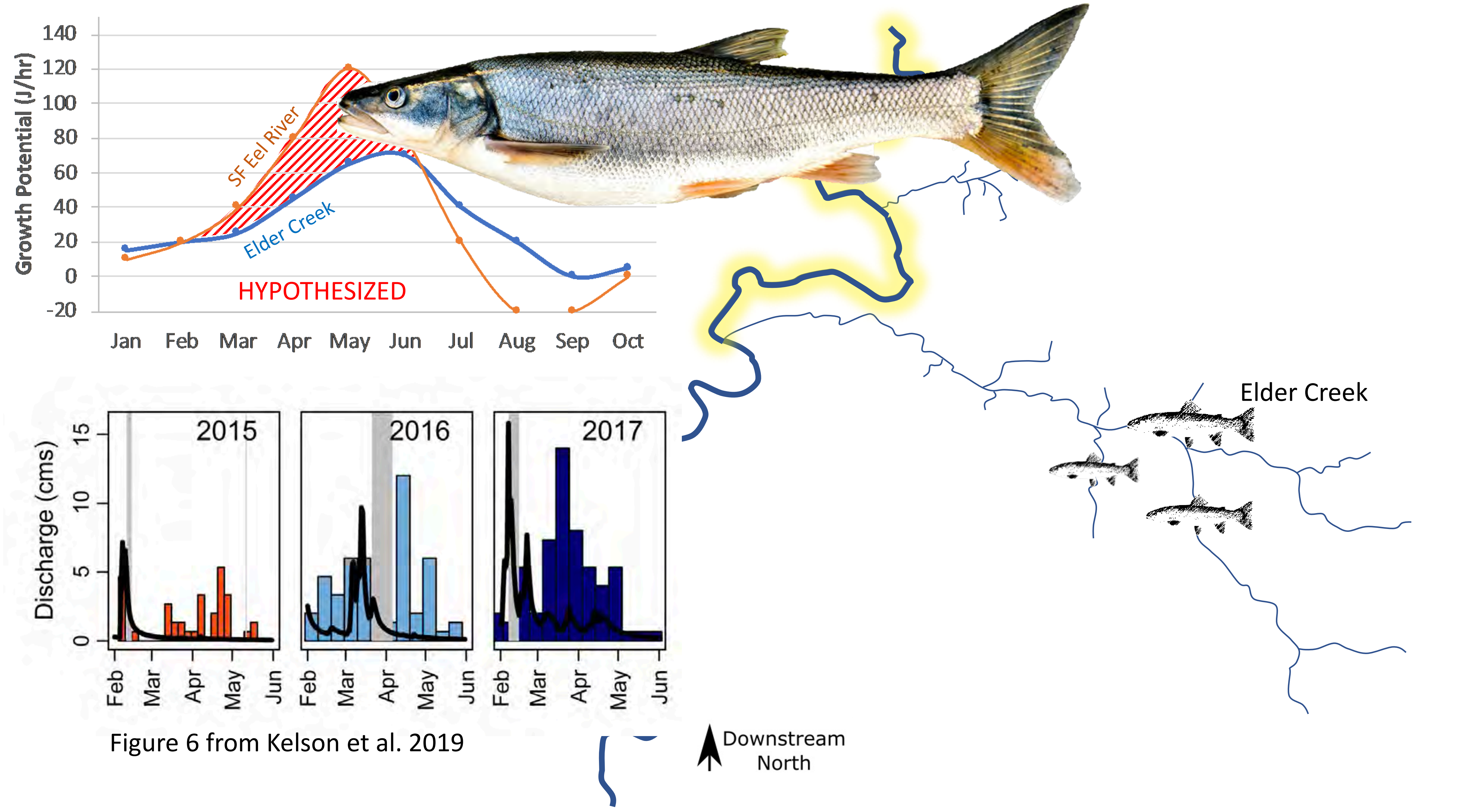
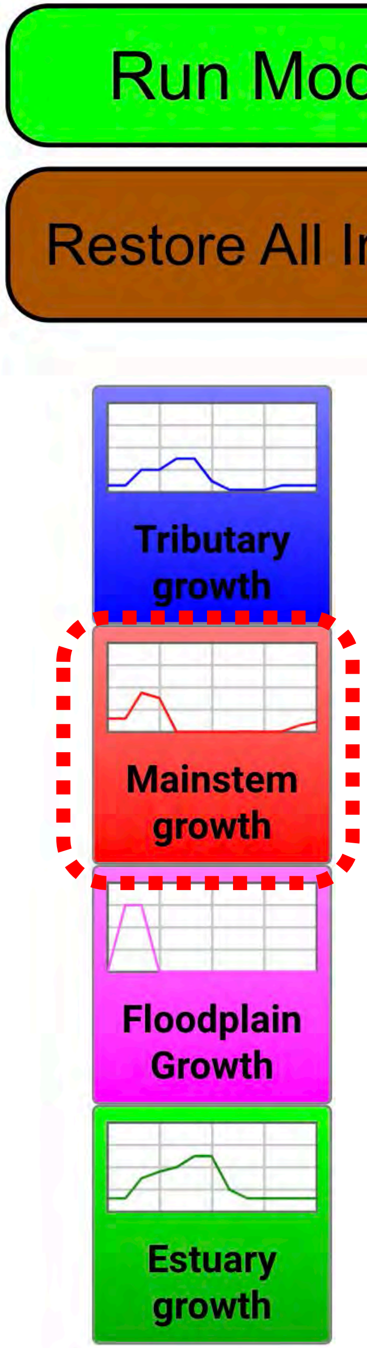


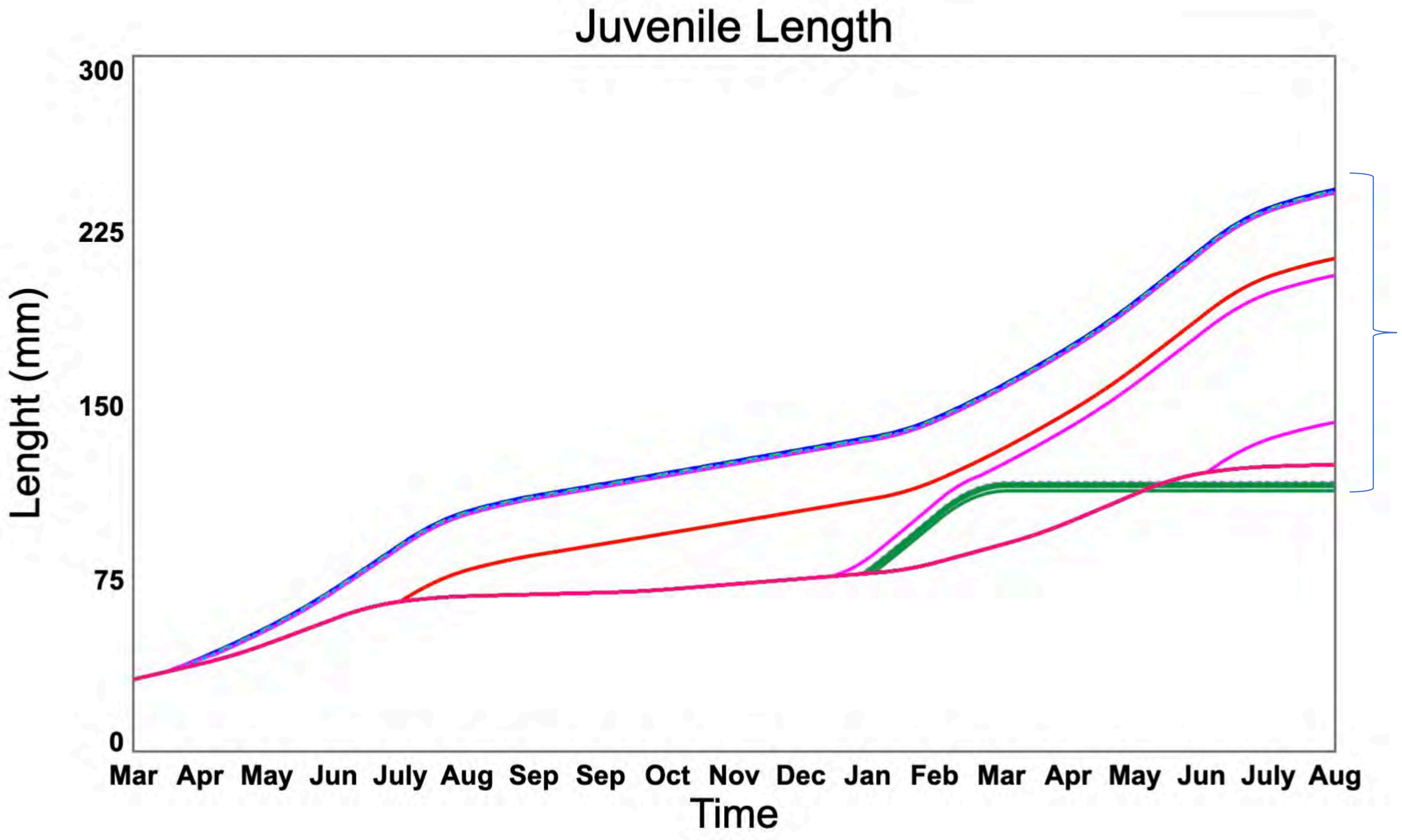
Figure 6 from Kelson et al. 2019

Pikeminnow impaired mainstem model:

Habitats: 1 natal tributary; 1 mainstem, 1 floodplain, 1 estuary

100 fish; probability distribution, movement based on relative growth potential in adjacent habitats

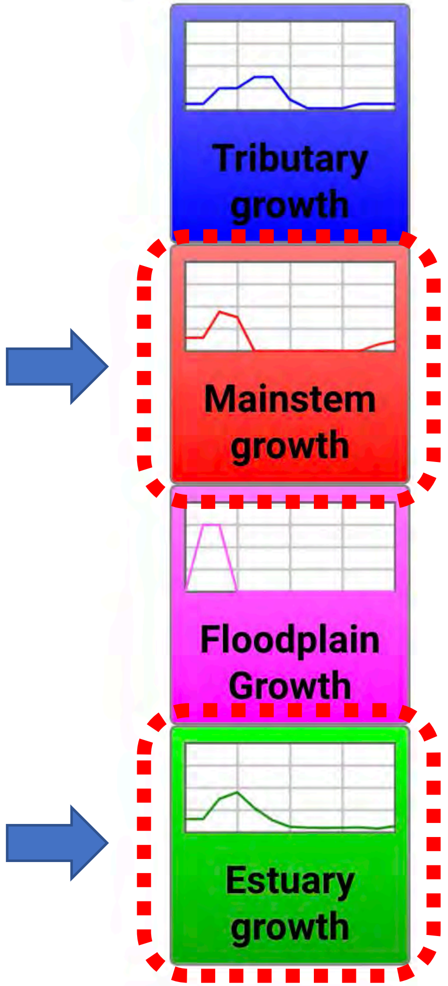




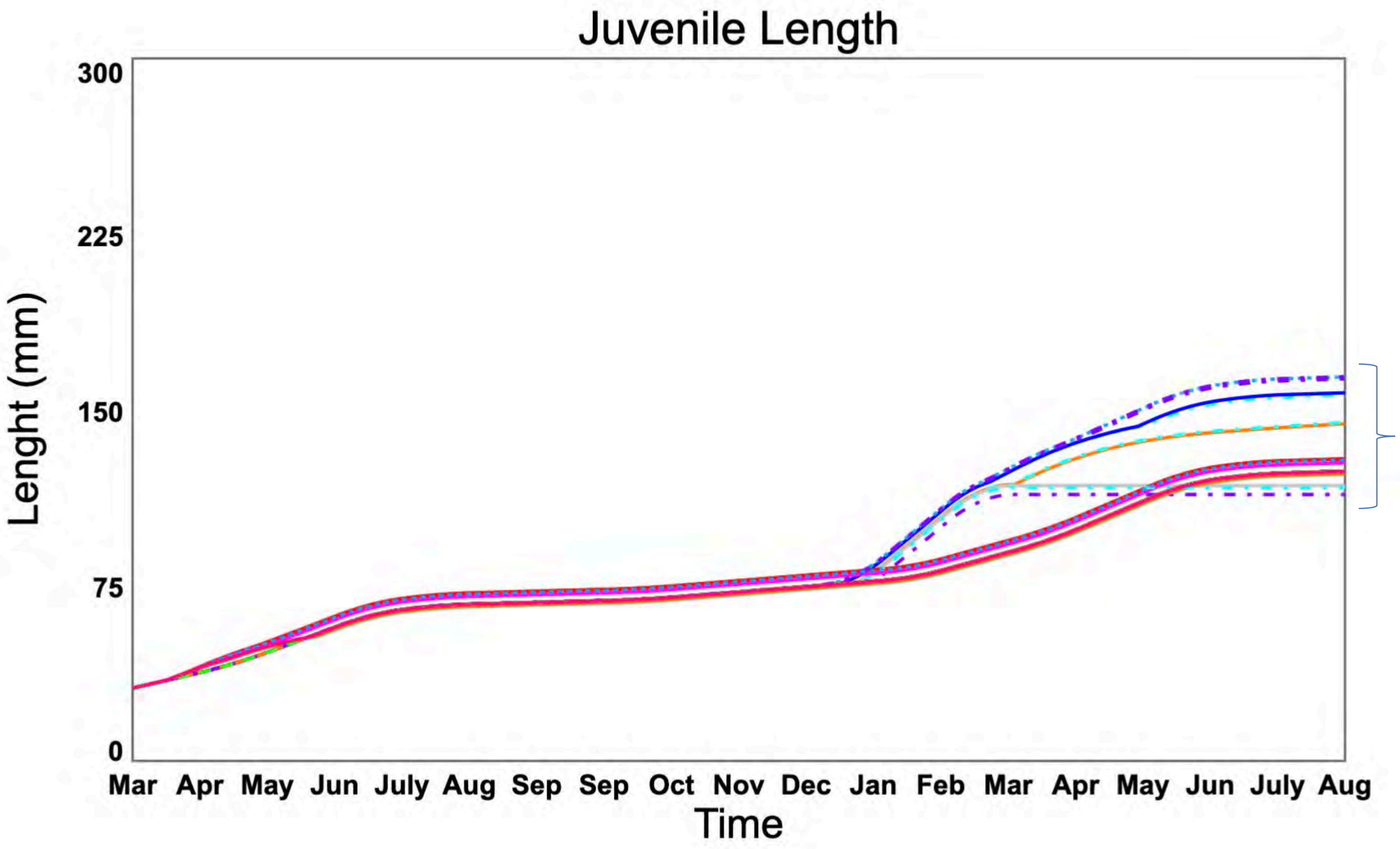
~ 6 life histories emerge, with 2+ fish reaching 90mm-230mm

Run Model

Restore All Inputs



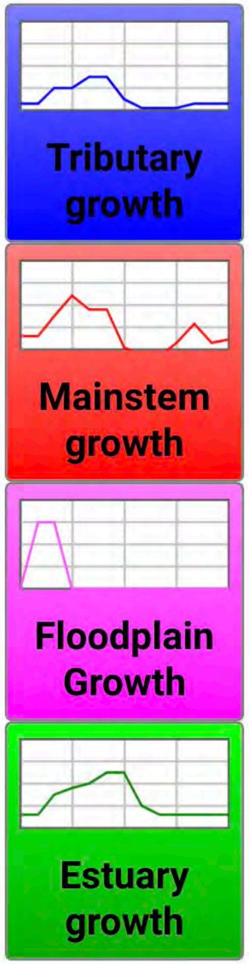
Pikeminnow impaired mainstem + impaired Estuary model:
Habitats: 1 natal tributary; 1 mainstem, 1 floodplain, 1 estuary
100 fish; probability distribution, movement based on relative growth potential in adjacent habitats



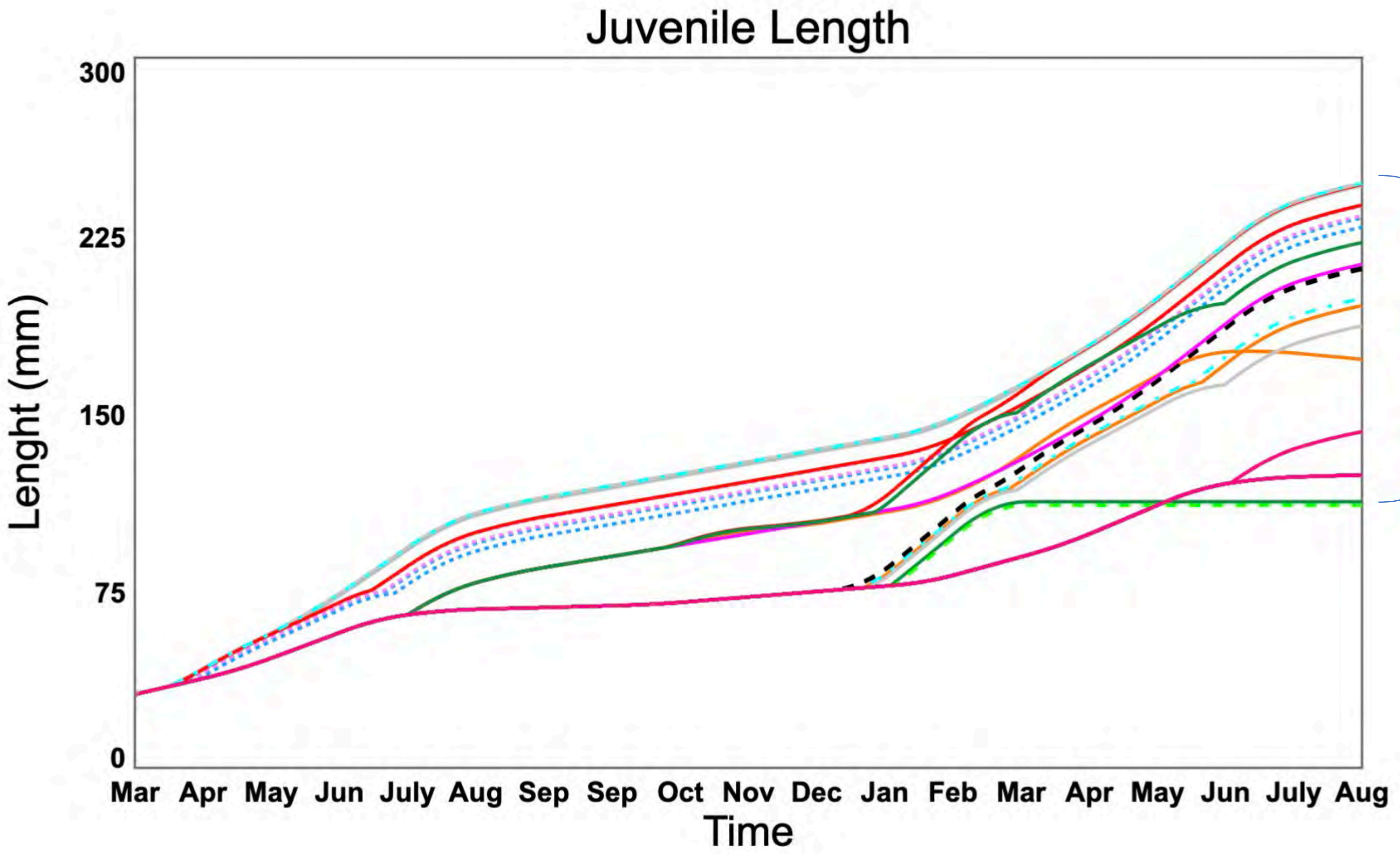
~ 7 life histories emerge, with 2+ fish reaching 90mm-160mm

Run Model

Restore All Inputs



Baseline Model:
Habitats: 1 natal tributary; 1 mainstem, 1 floodplain, 1 estuary
100 fish; probability distribution, movement based on relative growth potential in adjacent habitats



~ 15 life histories emerge, with 2+ fish reaching 100mm-240mm

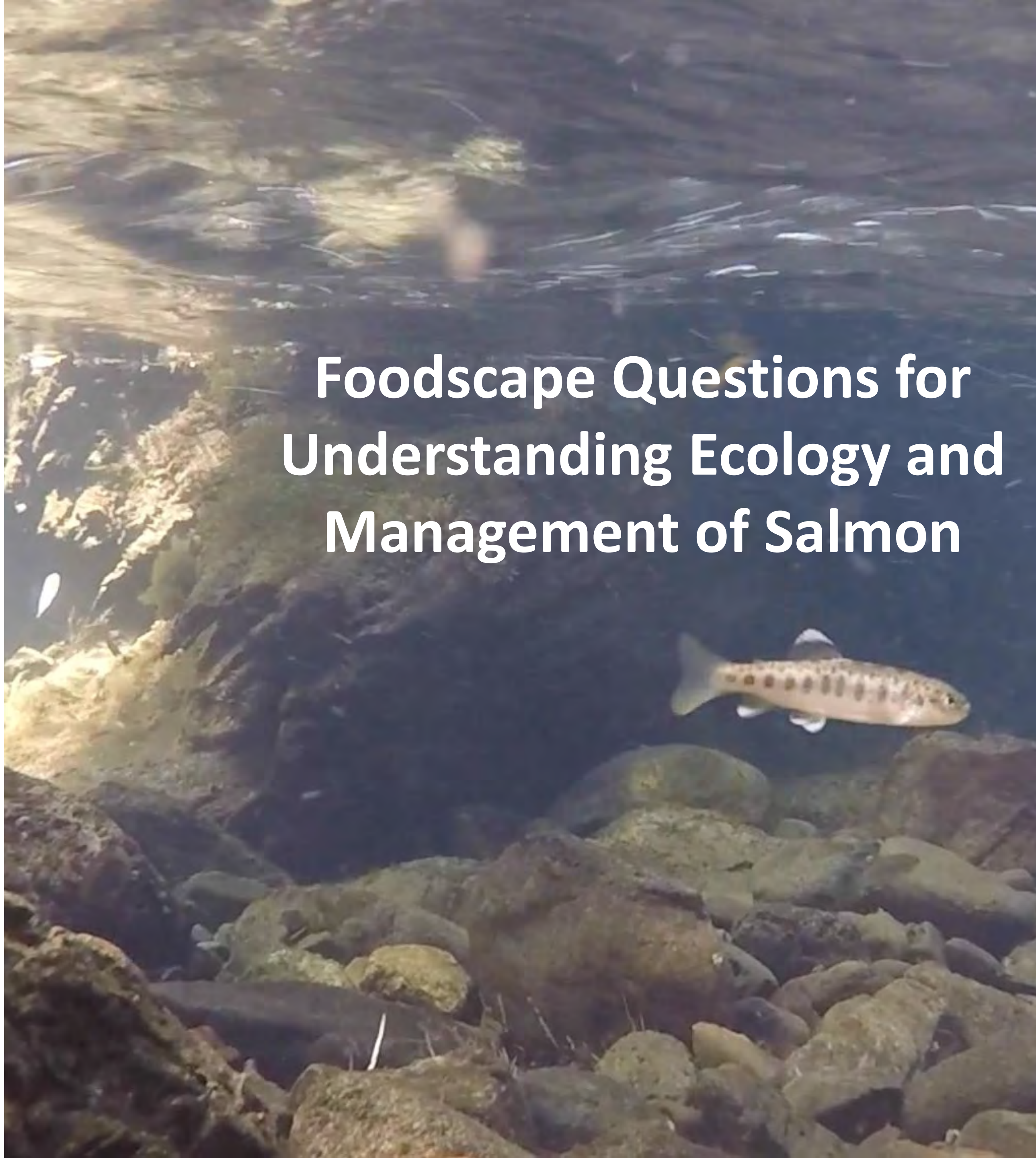
Foodscape Questions for Understanding Ecology and Management of Salmon

What contexts and drivers mediate the seasonal and spatial distribution of growth opportunity for juvenile salmon?

What are the most effective trophic pathways for feeding fish (in each part of the riverscape)… And what facilitates (or inhibits) those pathways?

How has modification of the riverscape changed the ability of a population of juvenile salmon to take advantage of asynchronous pulses of growth potential throughout the riverscape?

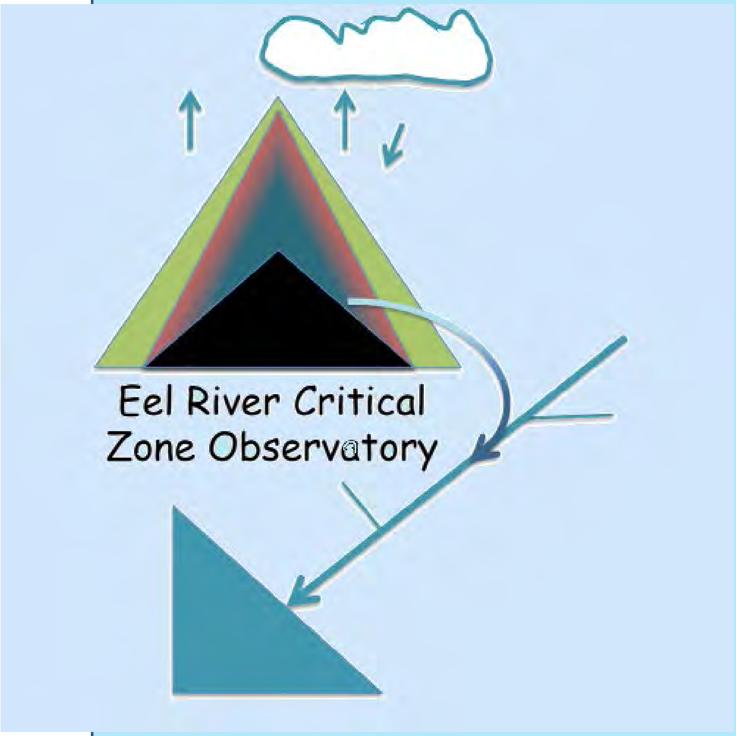
And how can we restore capacity to a salmon?



Acknowledgements

- **California Trout**
- **UC Natural Reserve System**

Stephanie Carlson, Ted Grantham, Carson Jeffres, Jonny Armstrong, Mathew Kaylor, Shelley Pneh, Keith Bouma-Gregson, Phil Georgakakos, Suzanne Kelson, Weston Slaughter, Keane Flynn, Kobie Boslough, Terrance Wang, Hannah Roodenrijs, Kate Stonecypher, Riley Brown, Emily Long, Jason Nueswanger, Samuel Larkin, Shannon Mckillop-herr, Blake Toney, Reed Hamilton.

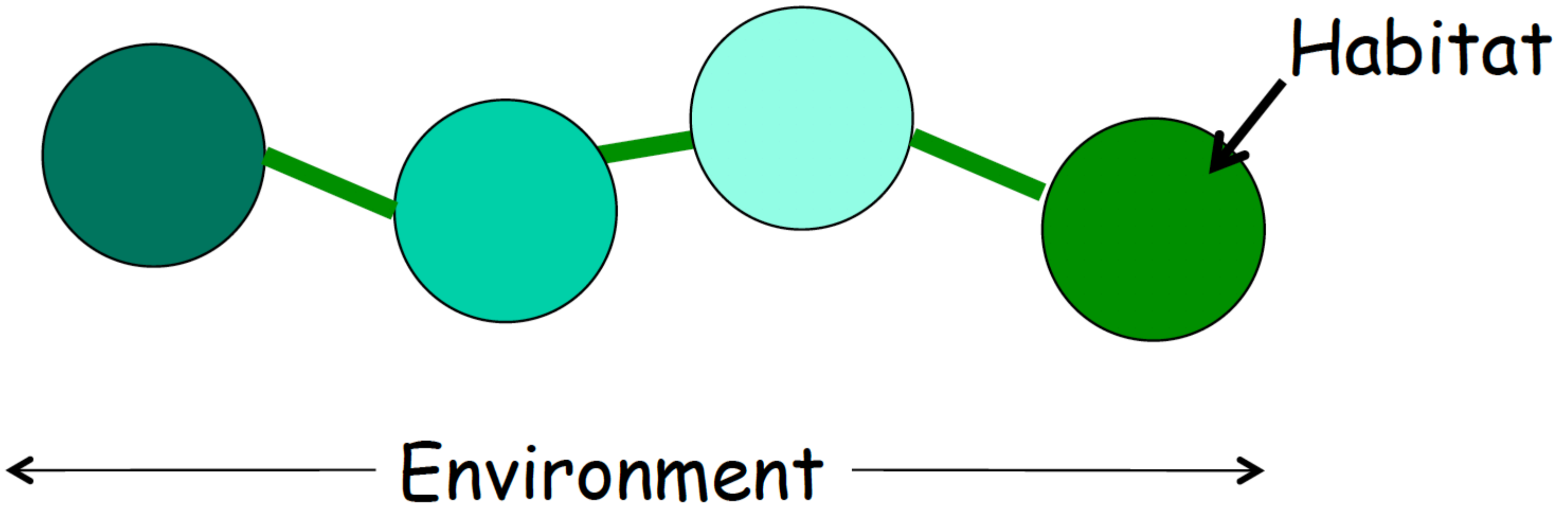



Questions?

Ideal Free Distribution (Fretwell and Lucas 1970, Fretwell 1972)

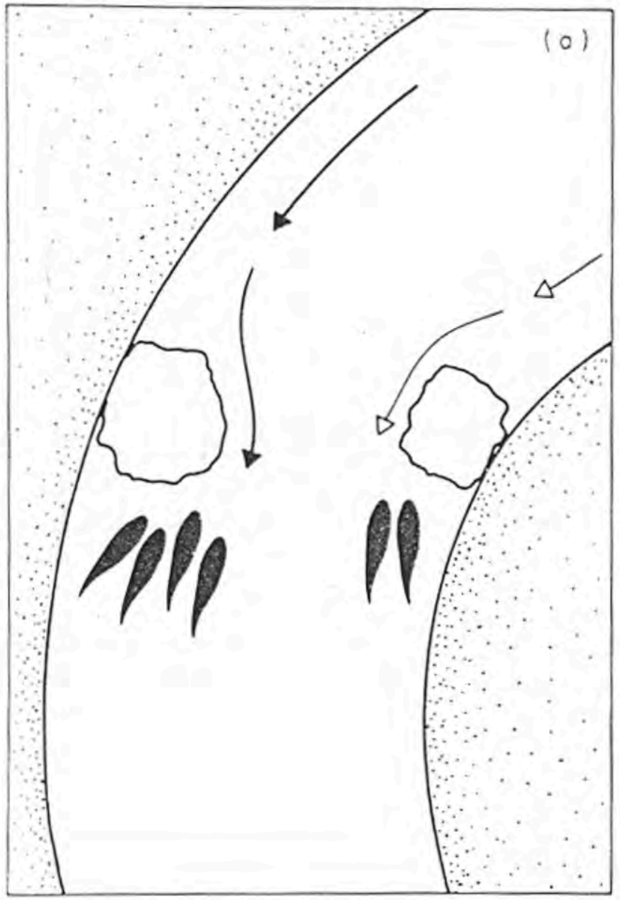
- Close spatial tracking by organisms of habitat quality (e.g. of **renewal rates** of a limiting food that **renews** at different rates in different habitats .....)

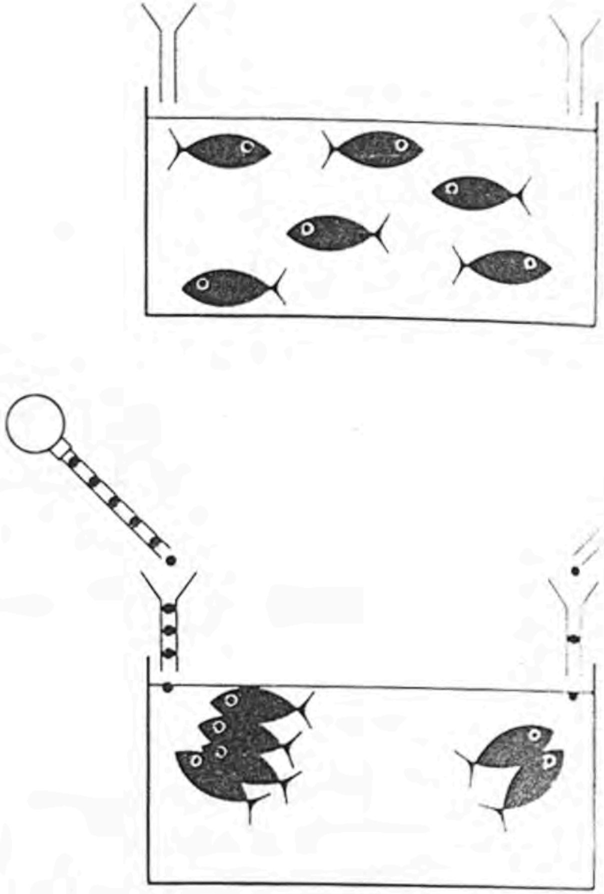
- Assumptions:
  - forager is "ideal" (has perfect knowledge of habitat quality over heterogeneous environment;
  - Forager is "free" to feed from the best habitat at any given time....)



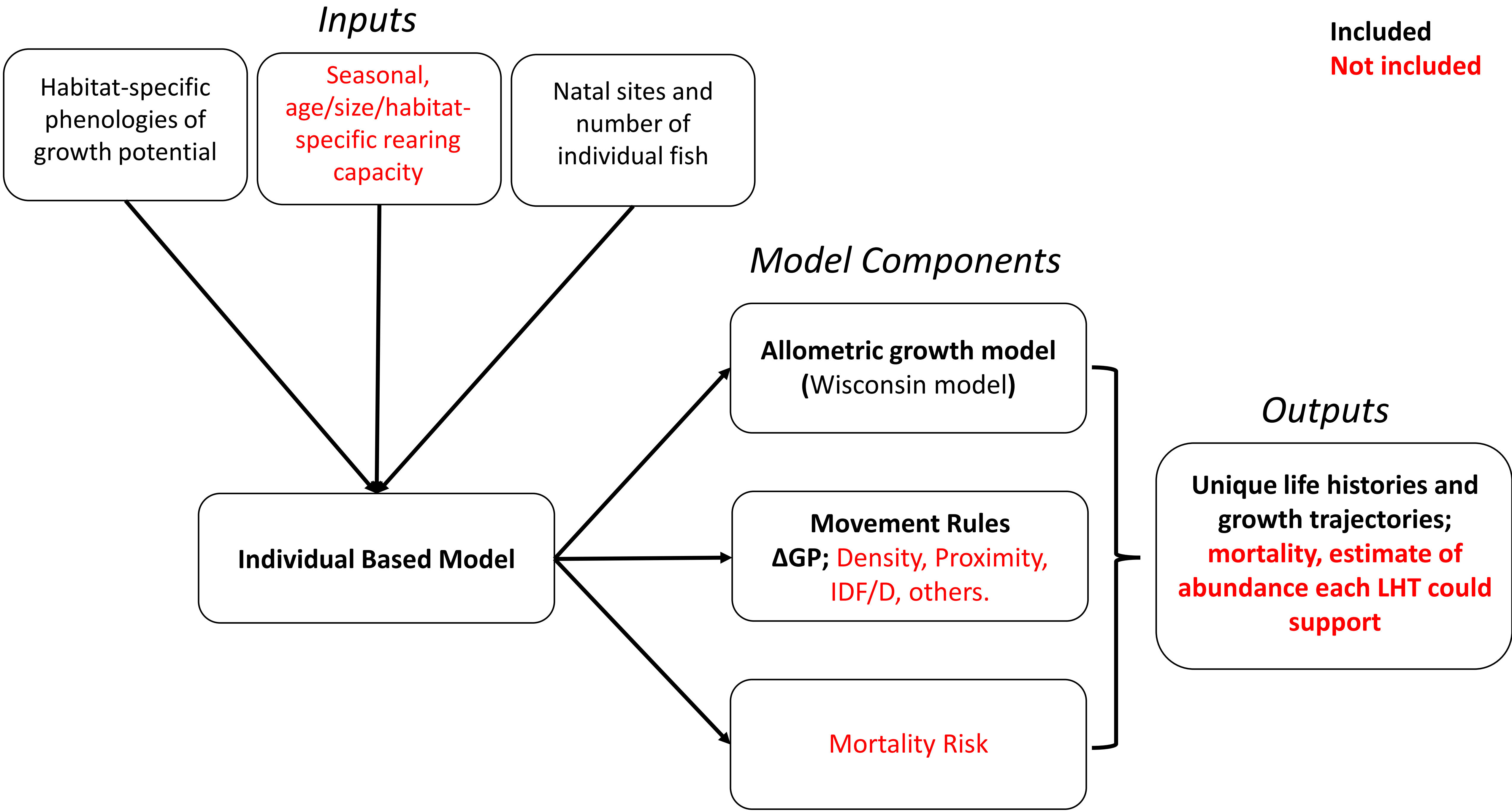
Prediction: When the environment is saturated, the density of consumers should match the **productivity*** of the habitats (if food is all that matters). The standing crop of the food, and the fitness of the consumers, should be equal across all habitats. (Consumer fitness and food equilibrial standing crop should be equal in productive, crowded habitats, and unproductive, less crowded habitats).

*Productivity = food renewal rate (biomass area^{-1} time^{-1}) or (biomass volume^{-1} time^{-1})





M. Power Ecology Lectures 2018


Inputs
Included
Not included
Habitat-specific phenologies of growth potential
Seasonal, age/size/habitat-specific rearing capacity
Natal sites and number of individual fish
Model Components
Individual Based Model
Allometric growth model (Wisconsin model)
Movement Rules ΔGP; Density, Proximity, IDF/D, others.
Mortality Risk
Outputs
Unique life histories and growth trajectories; mortality, estimate of abundance each LHT could support