Sacramento River Science Partnership (SRSP)
Floodplain Science & Management Symposium

The Juvenile Experience

Eric Holmes, UC Davis
Carson Jeffres, UC Davis
Dave Smith, USACE
Anna Sturrock, University of Essex
Adam Pope, USGS
Rachel Johnson, SWFCS, NMFS

How juvenile salmon use Central Valley floodplains

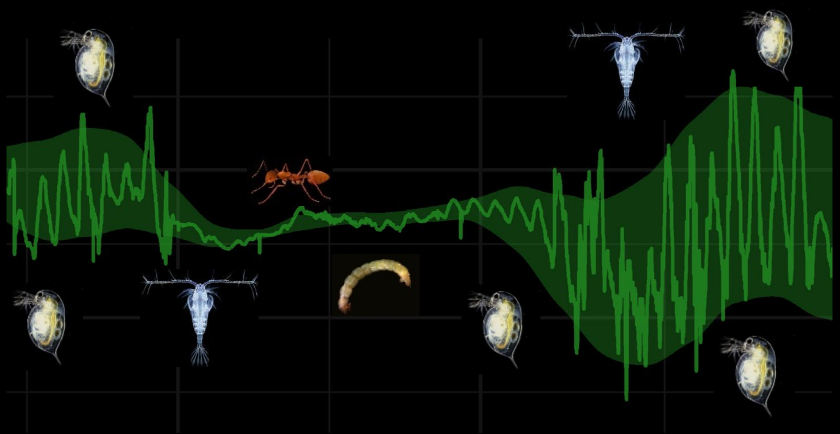
By Eric Holmes

Floodplain Symposium - October, 2021

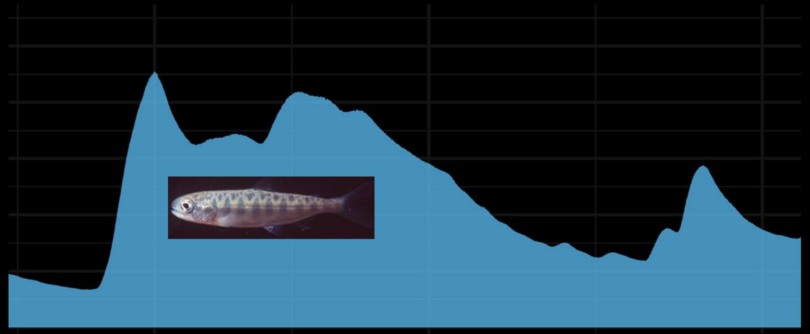
UC DAVIS CENTER FOR WATERSHED SCIENCES

Key points

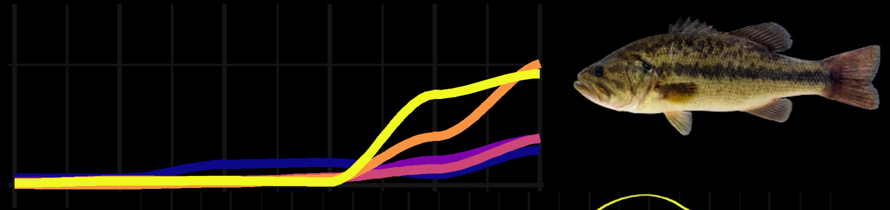
- The floodplain is a dynamic habitat



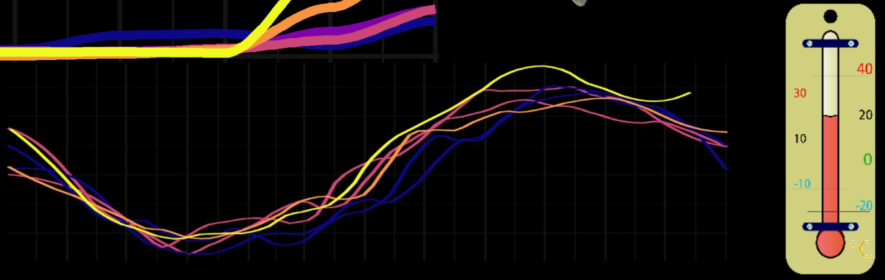
- Flow pulses distribute salmon during the flood season



- Salmon diets vary with location and flow conditions – salmon are opportunivores

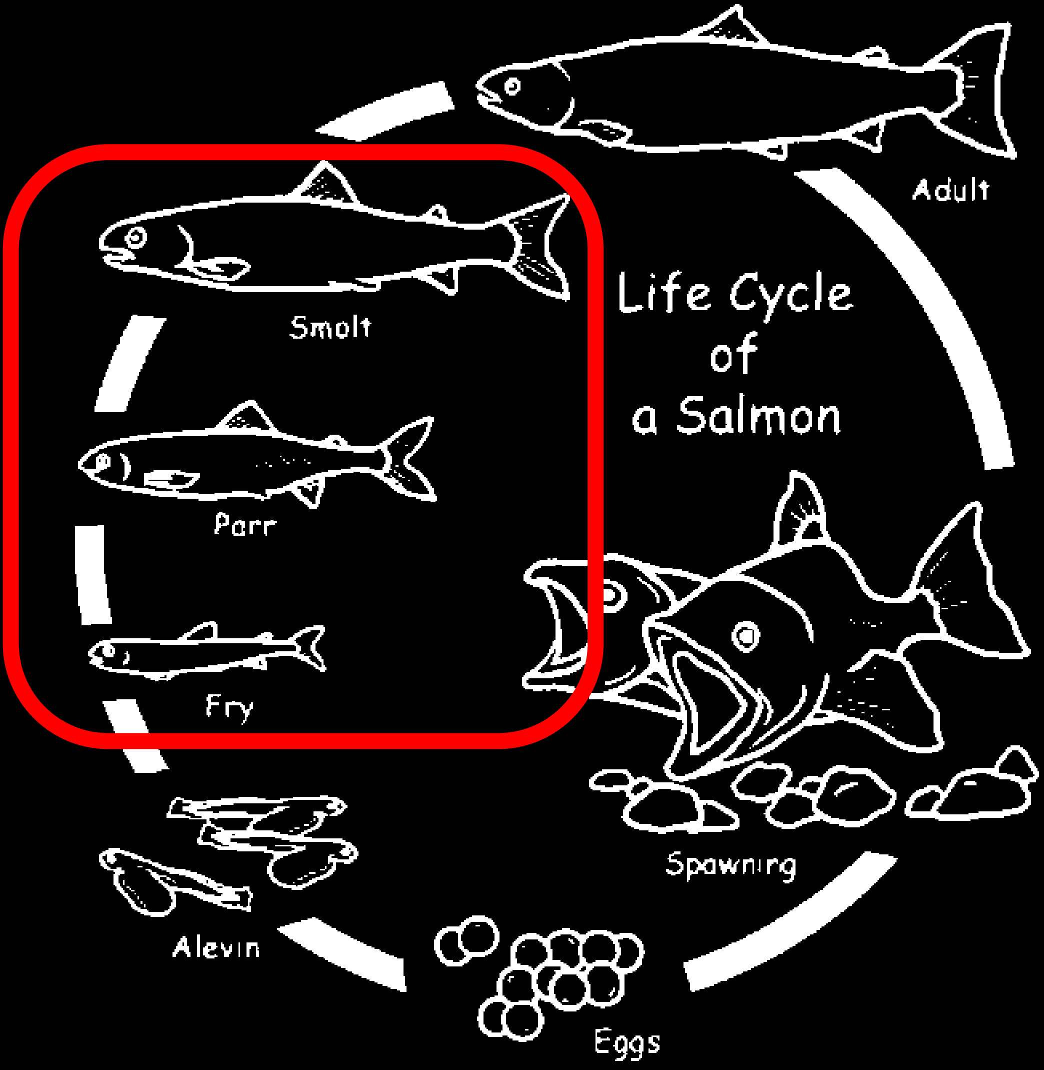


- Consequences of slow growth



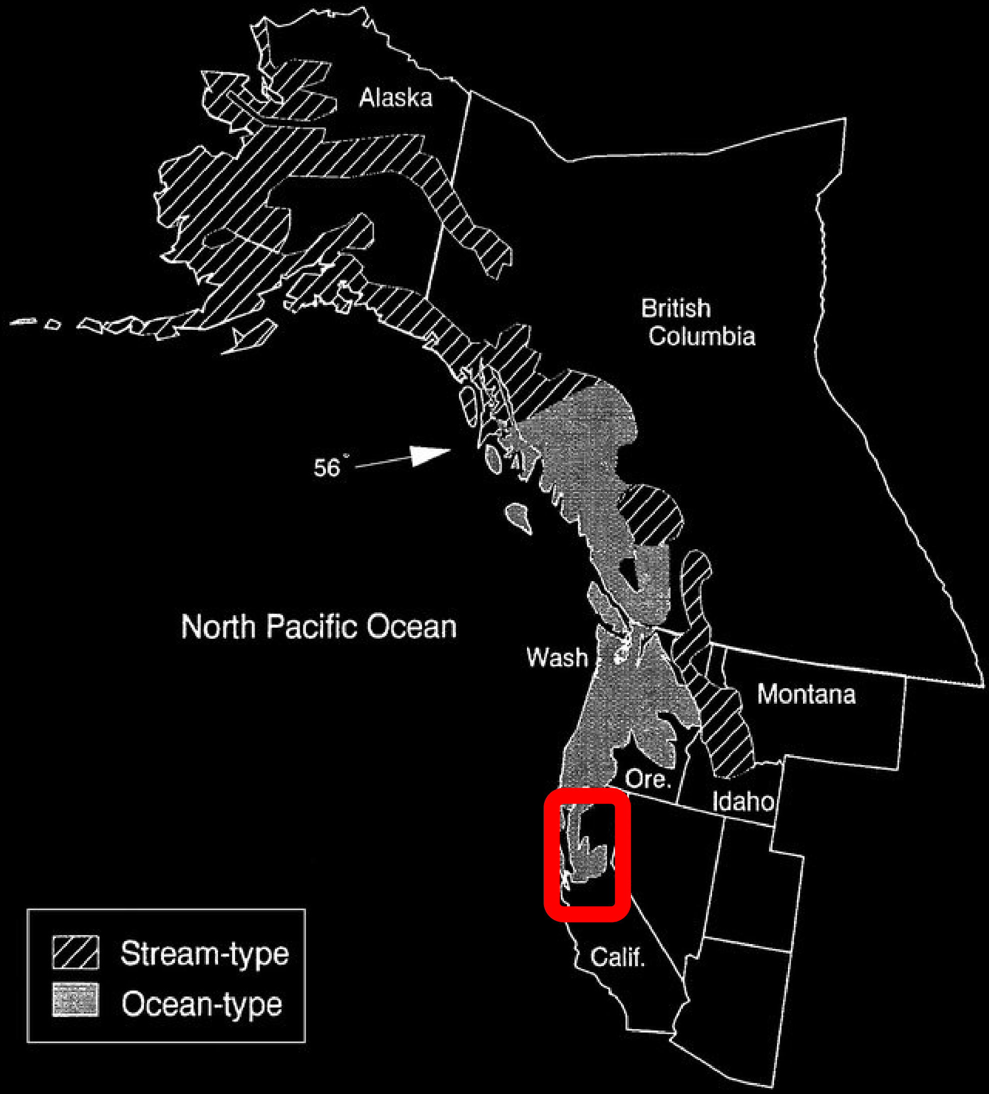
Chinook Salmon

Anadromous life cycle



Life cycle model from umpquawatersheds.org

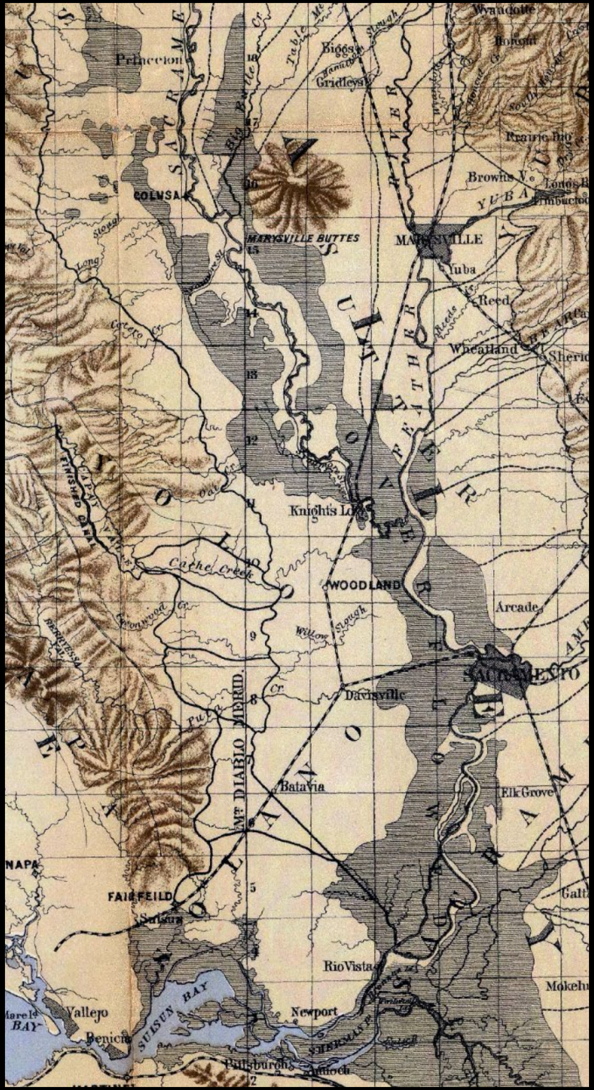
Endemic range in N. America



Range map from Brandon et al. 2010

Four salmon runs in the California Central Valley

Chinook Salmon life history diversity



Source: www.davidrumsey.com

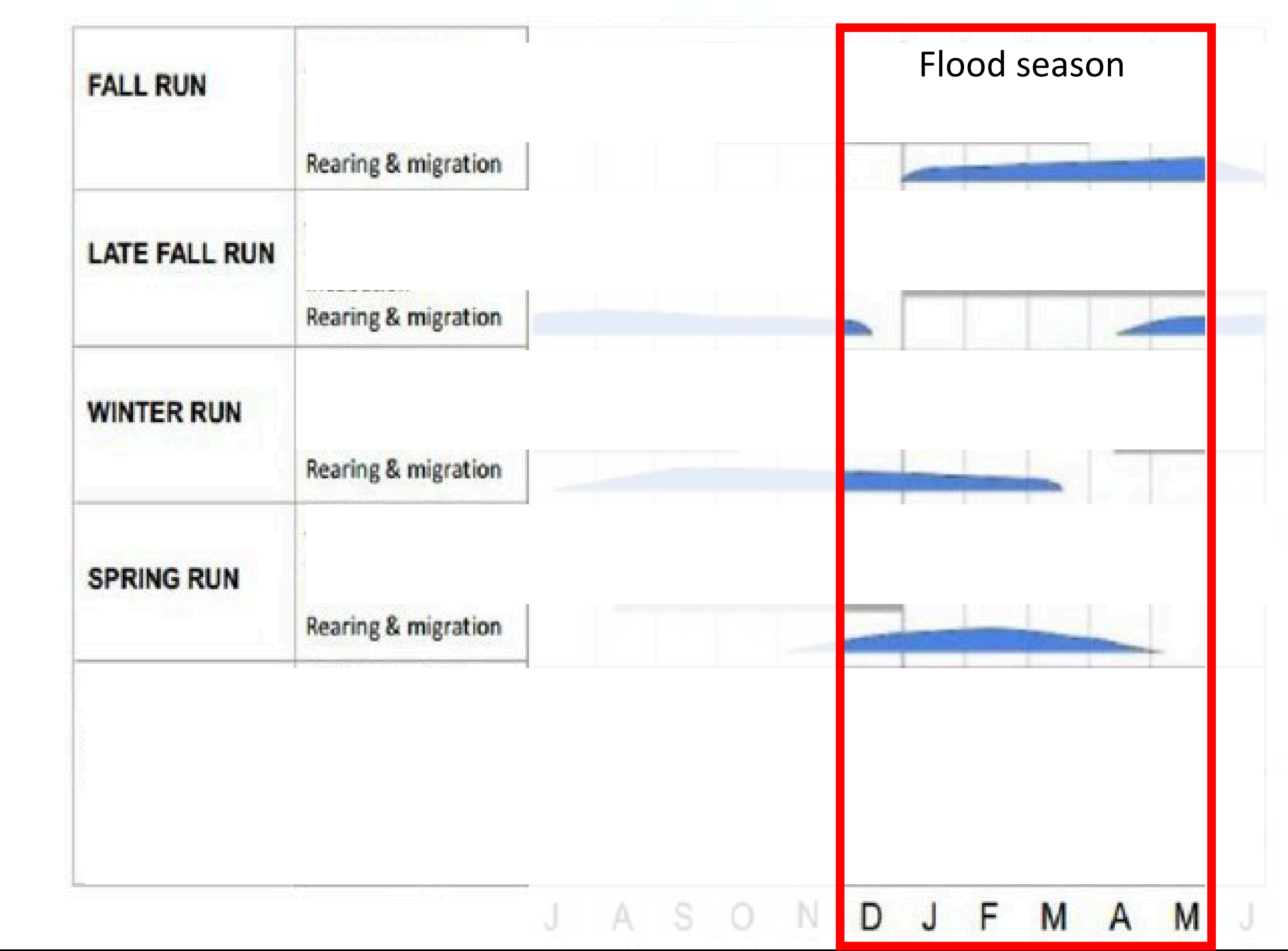


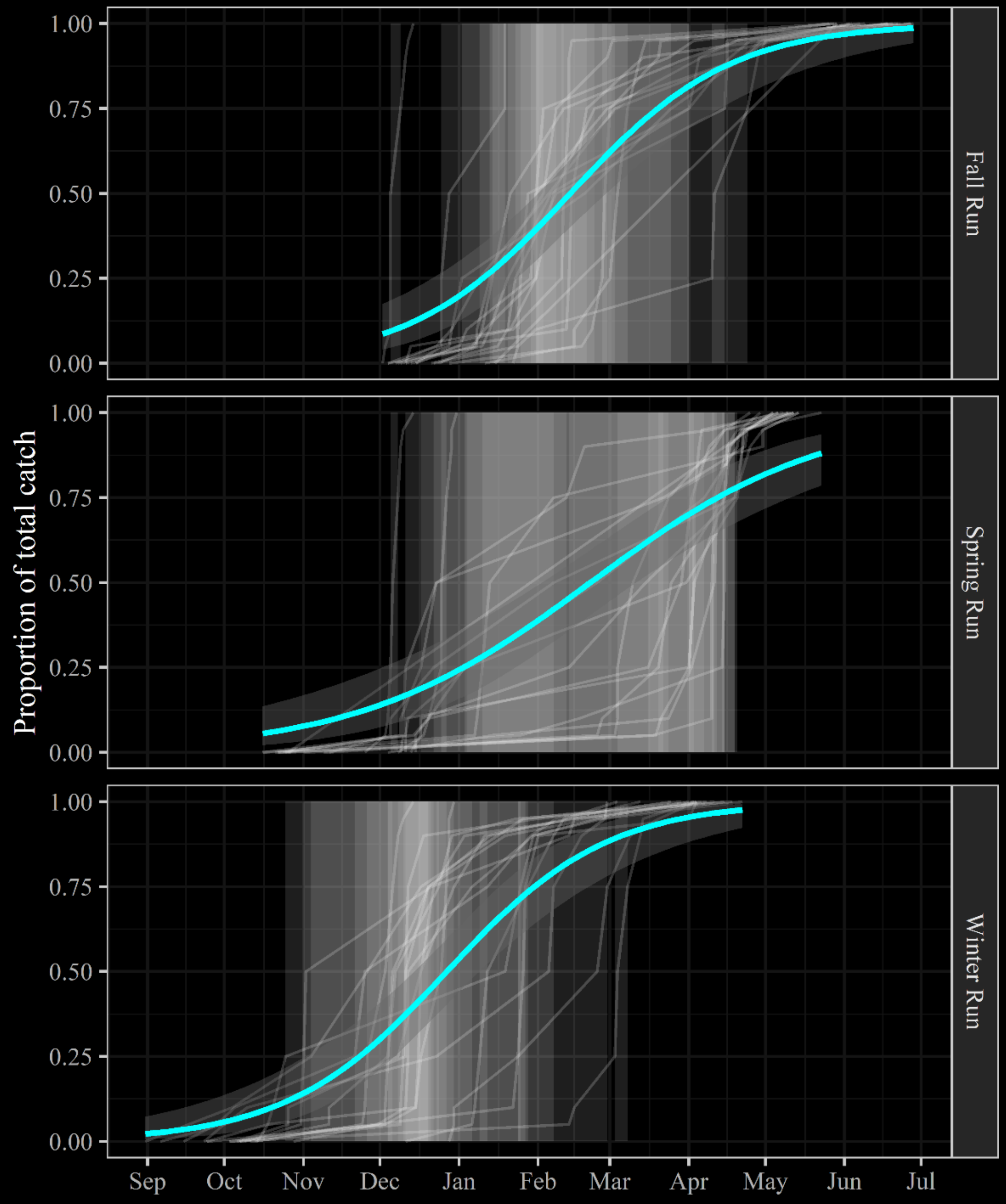
Figure from Herbold et al. 2018

Juvenile chinook migration timing

Empirical cumulative distribution functions for unmarked juvenile salmon from brood years 2004-2019 caught at Knights landing rotary screw trap

Migration timing primarily Dec-April

Image from calfish.org



Data source: SacPAS at www.cbr.washington.edu

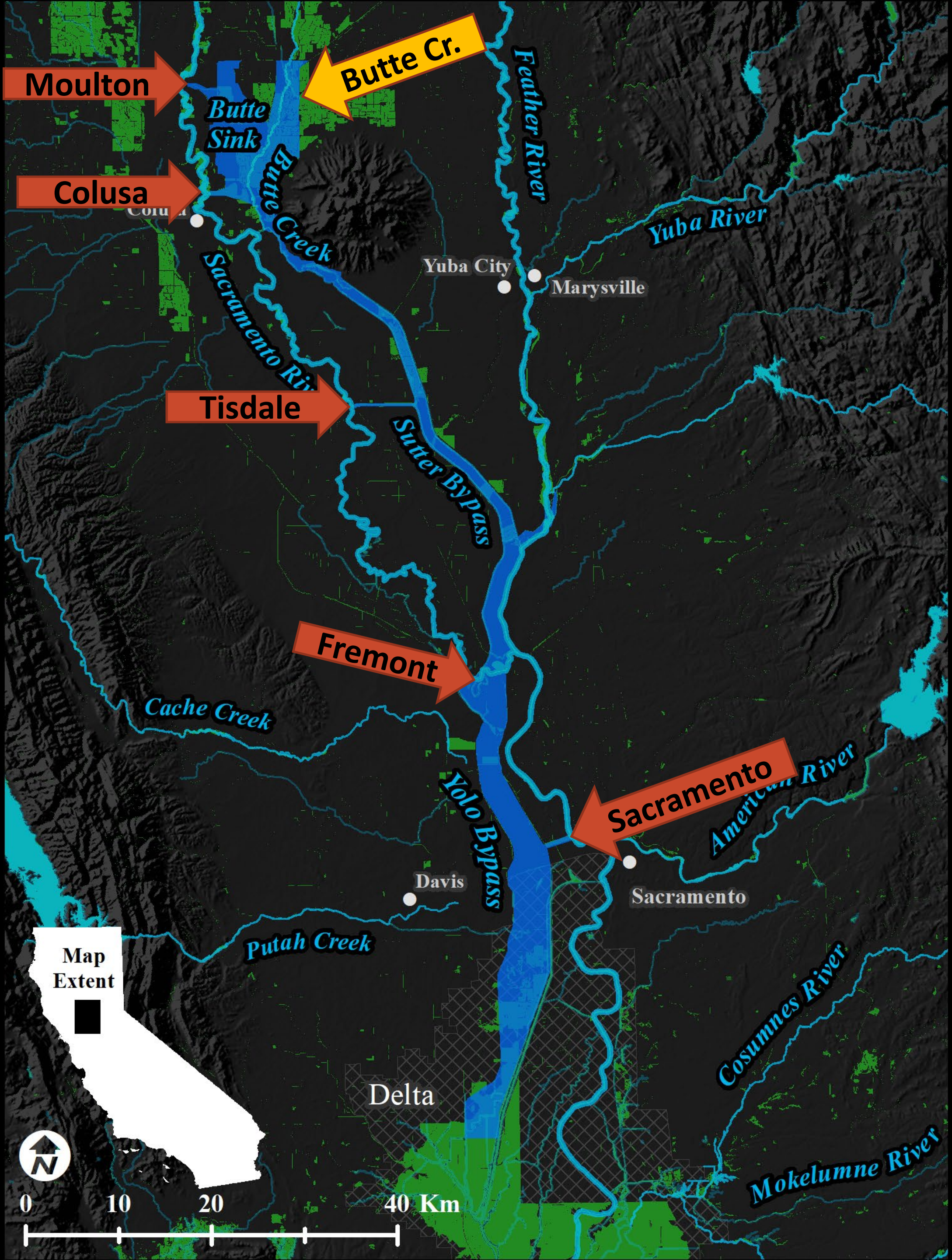
Historic:

- Chinook evolved rearing on floodplains

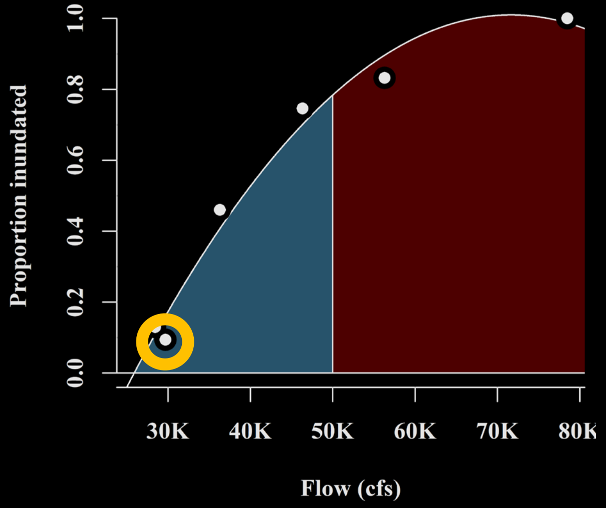
Today:

Pre 1900 Riparian, wetland and other floodplain habitat data
Source: Chico state historic veg mapping project (2003)
National Wetlands Inventory dataset (2018)

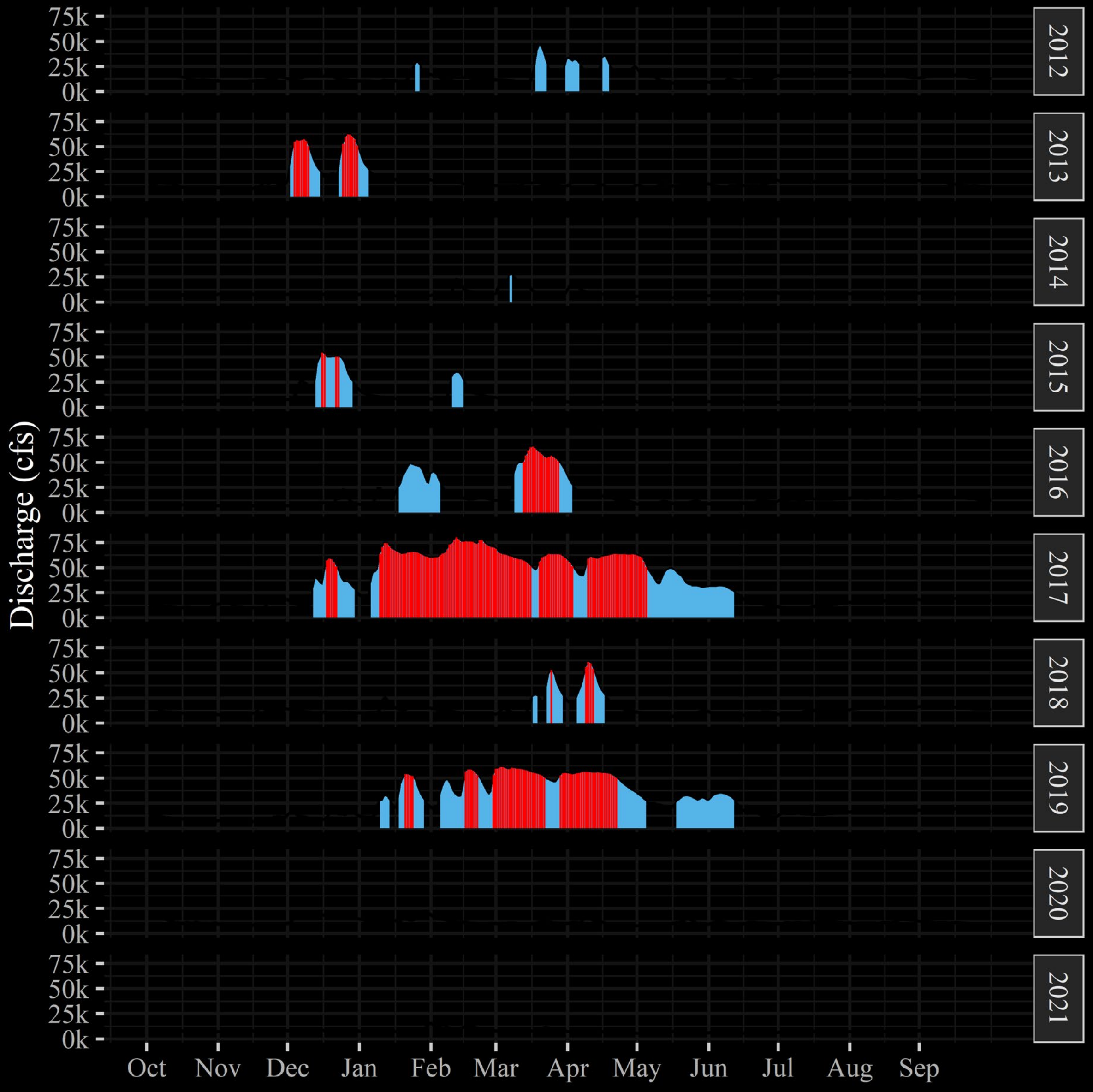
- ~95% of wetlands lost
- Remnant off-channel habitat in flood bypass system composed of agriculture and wetland substrates.
- Accessible to salmon via weir system
- Butte Creek salmon have connected river-wetland corridor



Flow inundation relationship



Sacramento River hydrology



Discharge data from the Sacramento River at Verona USGS gauge: 11425500

DWR Sacramento Valley Water Year Hydrologic Classification Index

Source: https://cdec.water.ca.gov

Below normal

Dry

Critical

Critical

Below normal

Wet

Below normal

Wet

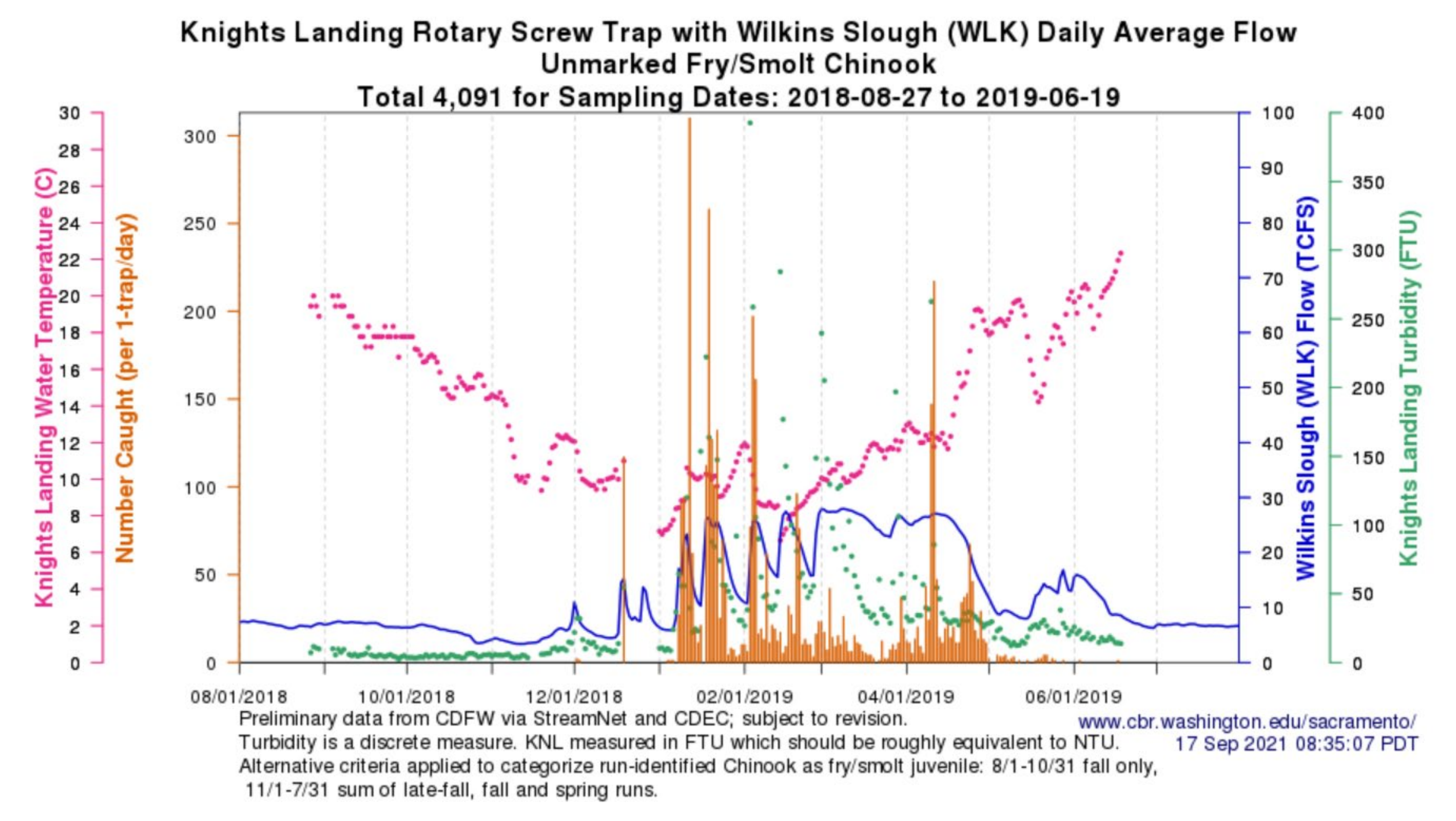
Dry

Critical*

*Anticipated by me

The bypass floodplain is dynamic

Flow distributes juvenile salmon

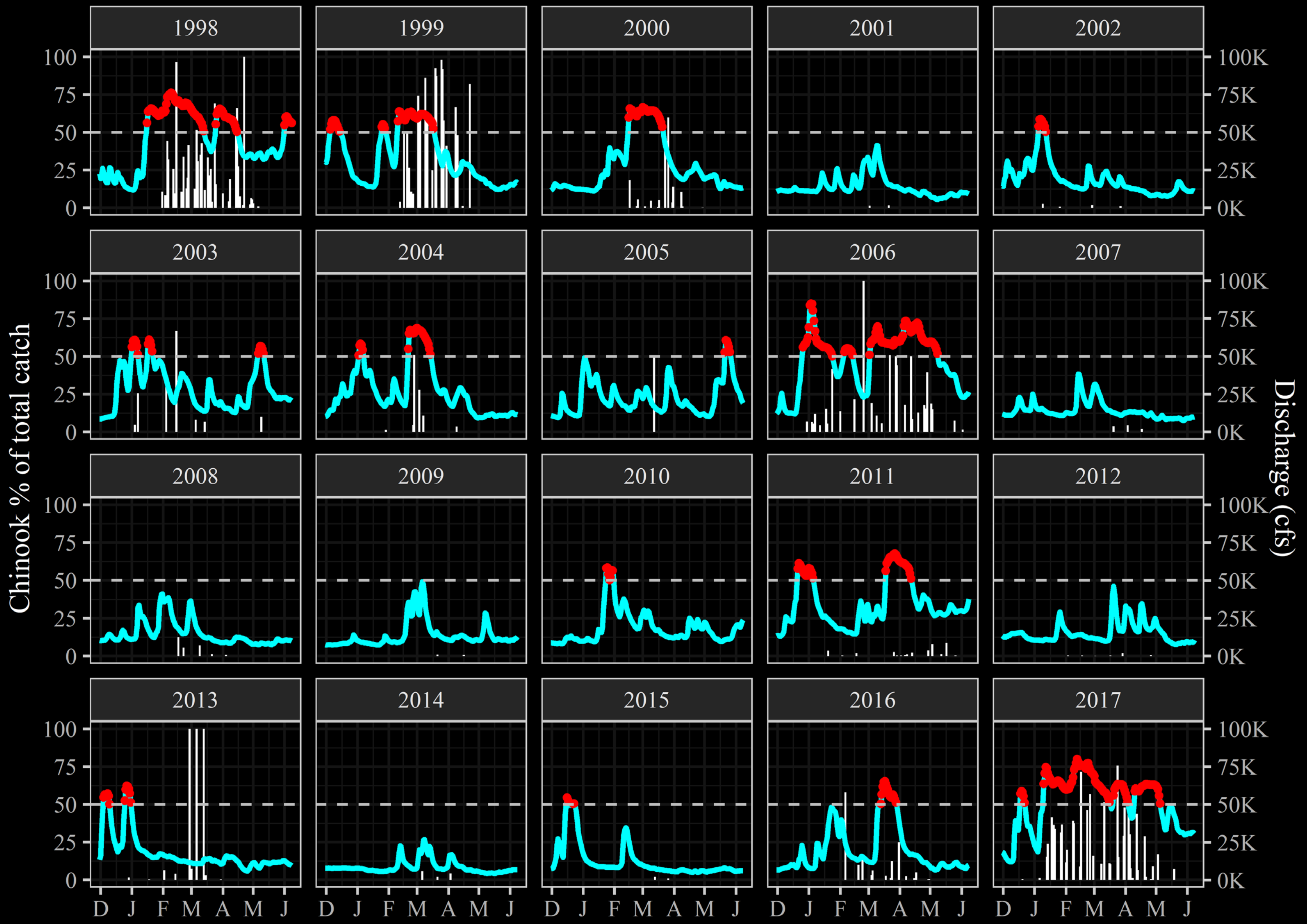


Source: SacPAS at www.cbr.washington.edu

Flow distributes juvenile salmon

Salmon numerically dominate the total catch in the Yolo Bypass during and after winter overtopping events

DWR crew sampling via beach seine for the Yolo Bypass fish monitoring project
Photo credit: Jared Frantzich



Data source: IEP https://portal.edirepository.org/nis/mapbrowse?packageid=edi.233.2

Wild fish sampling from Yolo (2016-17) and Sutter (2018-21) Bypasses

Methods:

- Opportunistic sampling during and after flood events using beach seines and fyke net traps
- Fin clips taken for genetic run identification

Limitations:

- Access limited to margins during flood events
- Low take of listed runs on permits
- Diets based on fall run sized fish only

Image credit: Kit Tyler

Image credit: UC Davis

Wild fish sampling from Yolo (2016-17) and Sutter (2018-21) Bypasses

Methods:

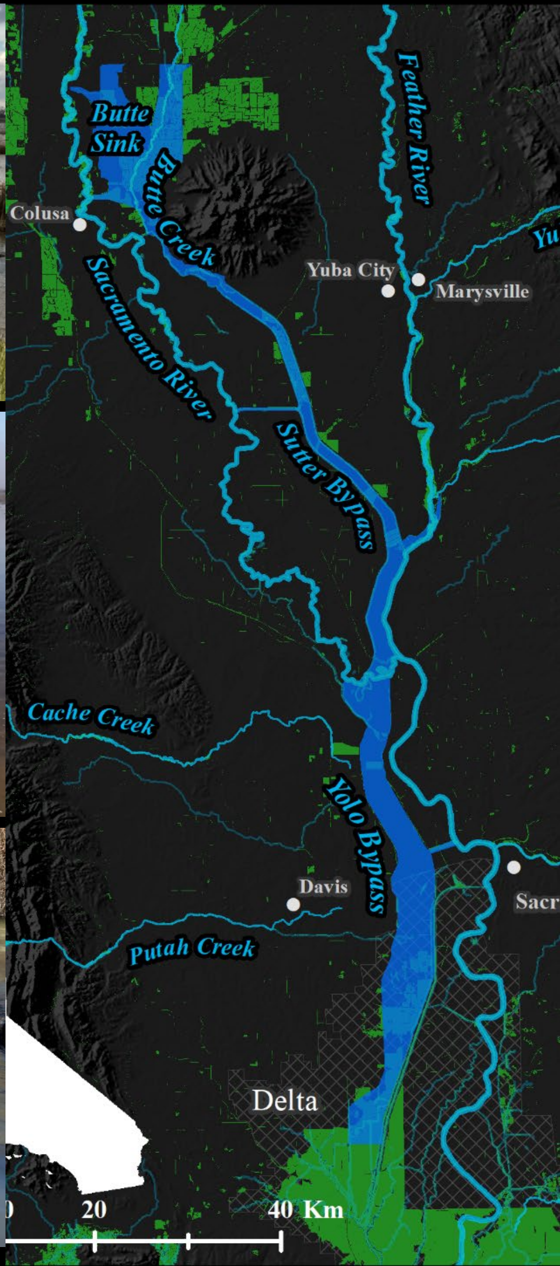
- Opportunistic sampling during and after flood events using beach seines and fyke net traps
- Fin clips taken for genetic run identification

Limitations:

- Access limited to margins during flood events
- Low take of listed runs on permits
- Diets based on fall run sized fish only

Habitats sampled:

- Wetlands
- Agricultural fields
- Bypass canals
- Weirs



Wild caught salmon from Sutter and Yolo Bypasses 2016-2021

General patterns:

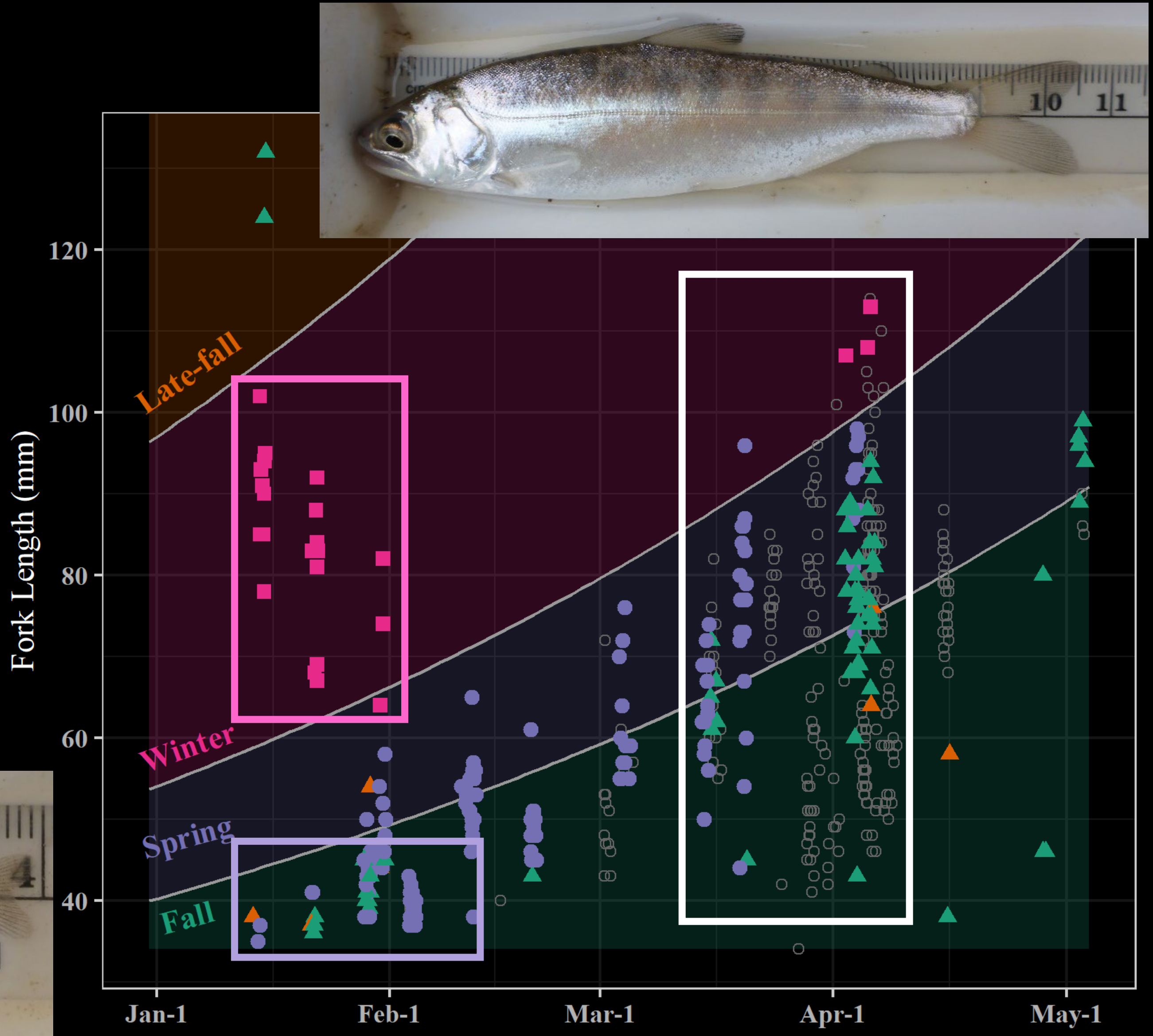
- All 4 runs observed in the Bypasses

- **Winter** run salmon accessing the bypasses primarily early in the flood season

- Small **spring** and **fall** run observed in the bypasses early in the flood season

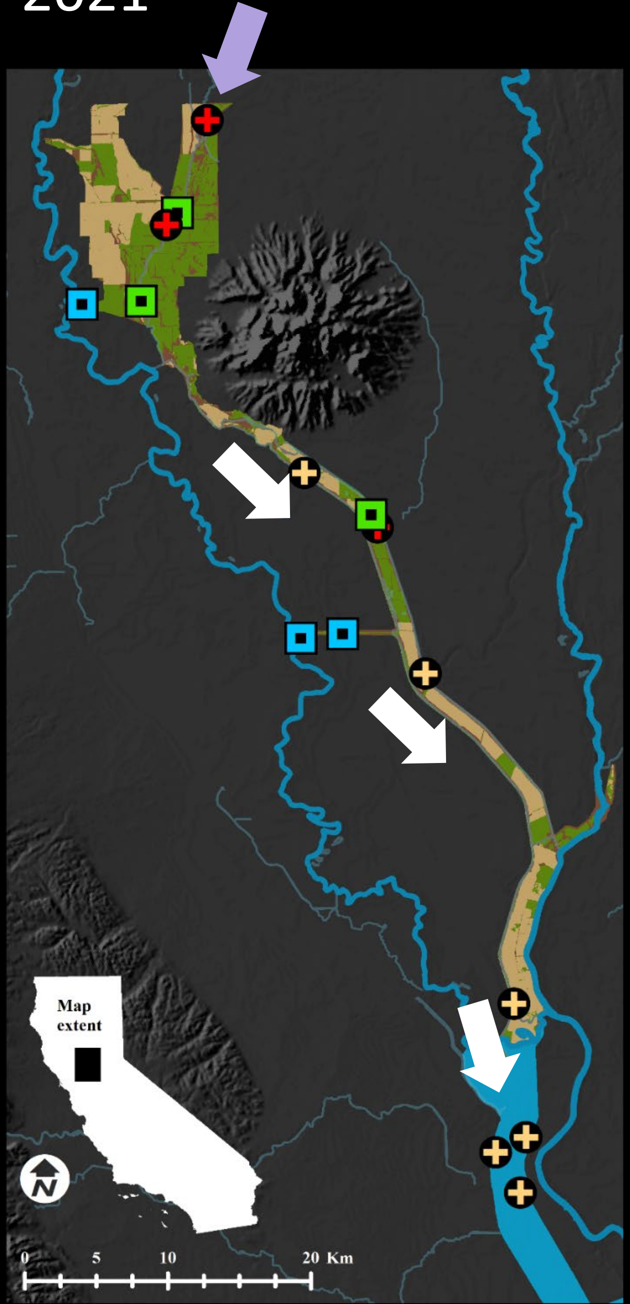
- High degree of size variation observed later in the season

Genetic ID	n
Fall	69
Late-fall	7
Winter	25
Spring	141
Unknown	269
Total	**511**



Wild caught salmon from Sutter and Yolo Bypasses 2016-2021

	Fall	Late-fall	Winter	Spring	Unknown	Total
Wetland	1	0	0	93	9	**103**
Agriculture	46	5	6	28	125	**210**
Canal	1	1	0	17	116	**135**
Weirs	21	1	19	3	19	**63**



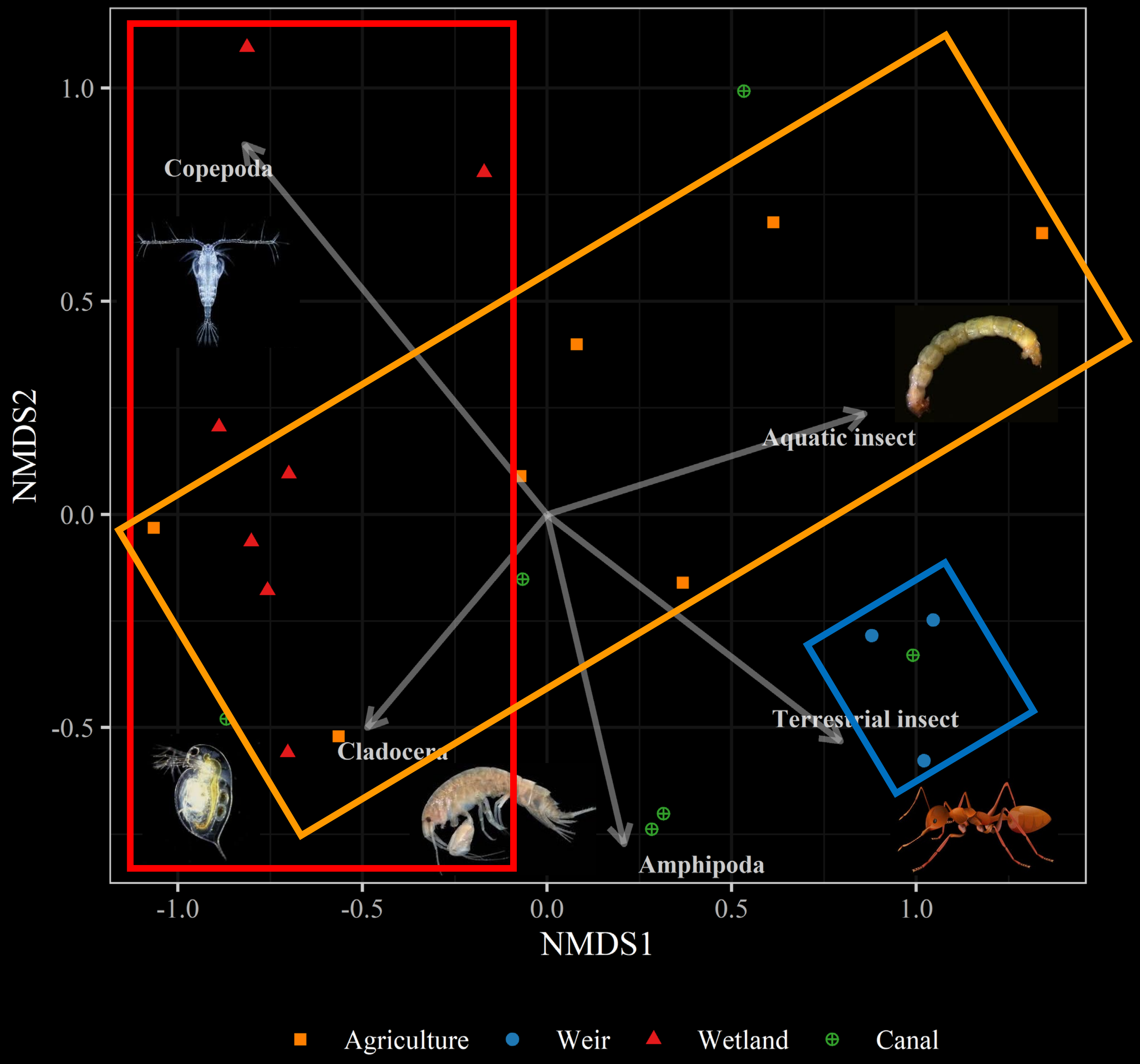
Diet composition

General patterns:

- Salmon caught in wetland habitats showed zooplankton dominated diets

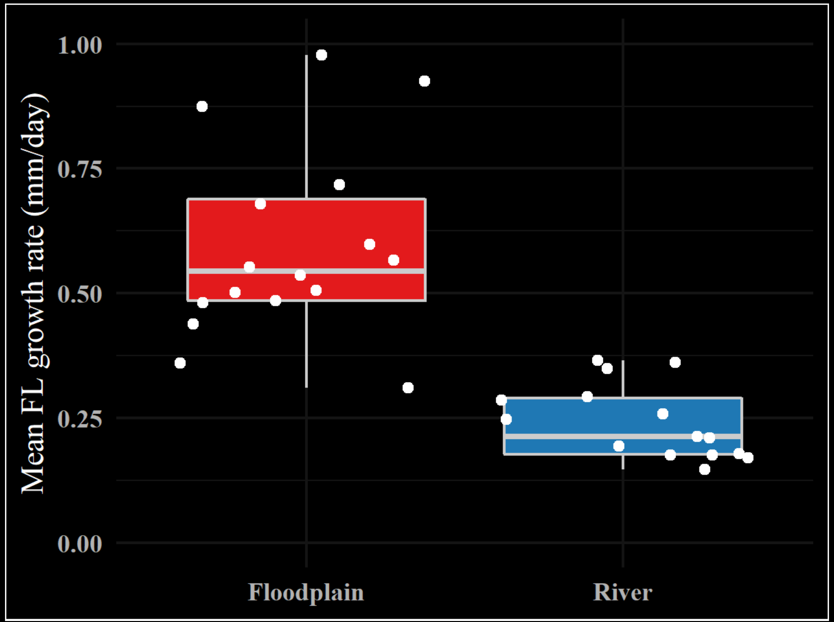
- Salmon caught in bypass agricultural and canal habitats had variable diets depending on water conditions

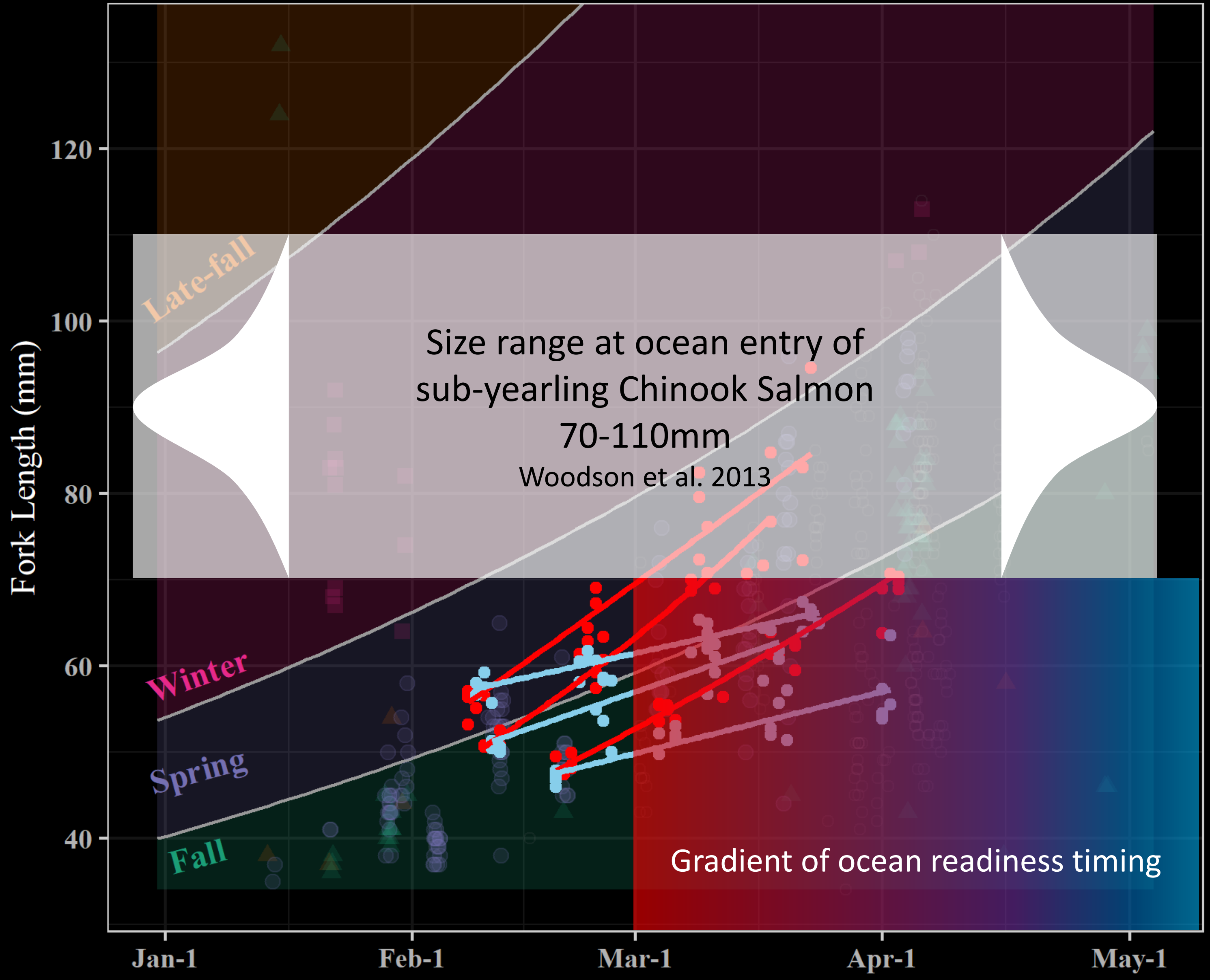
- Salmon caught entering the bypasses at the weirs had diets dominated by aquatic and terrestrial insects



Growth rate variation results from diverse rearing habitats

Enclosure reared salmon in Sutter Bypass
2019-2021 experiments





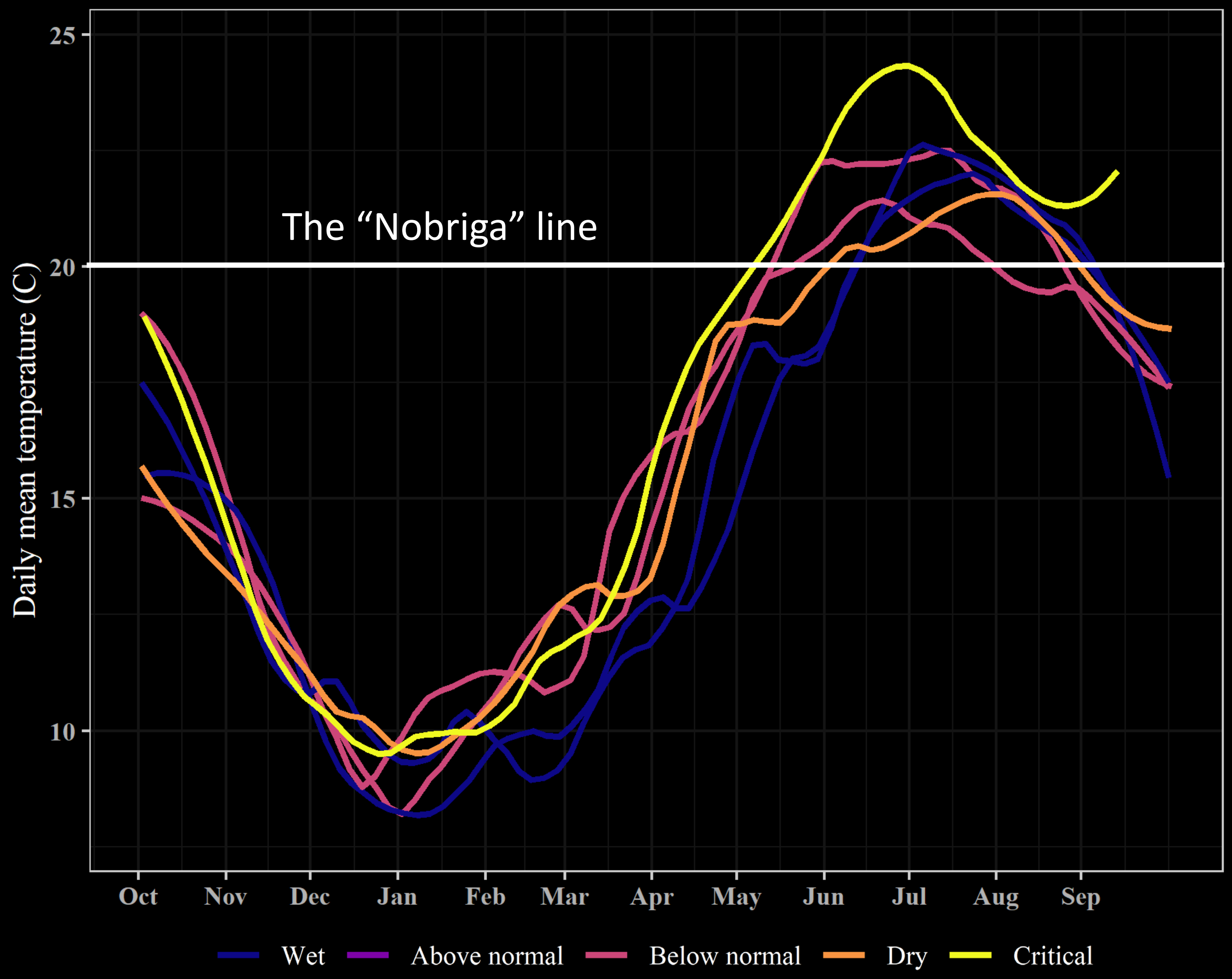
Challenges for late season migrants

Seasonal rise in Sacramento River and Delta water temperatures in the spring

Daily mean water temperature at Sherwood Harbor
Data source: cdec.water.ca.gov

“Chinook Salmon smolts must transit the Delta before water temperature reaches 20°C or mortality will be nearly 100%”

- Nobriga et al. 2021

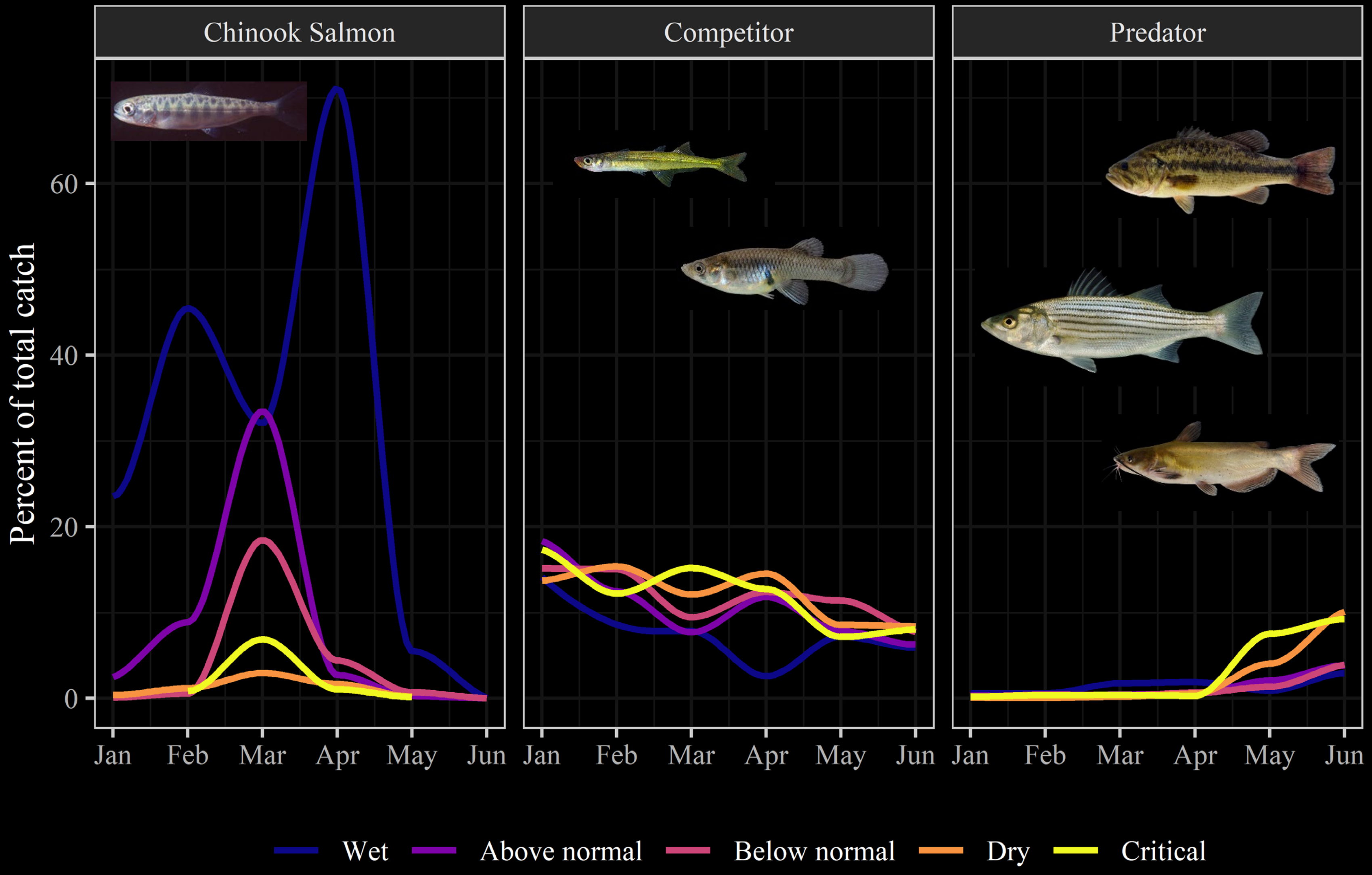


Challenges for late season migrants

Yolo Bypass fish monitoring program data (1998 – 2018)

Rotary screw trap

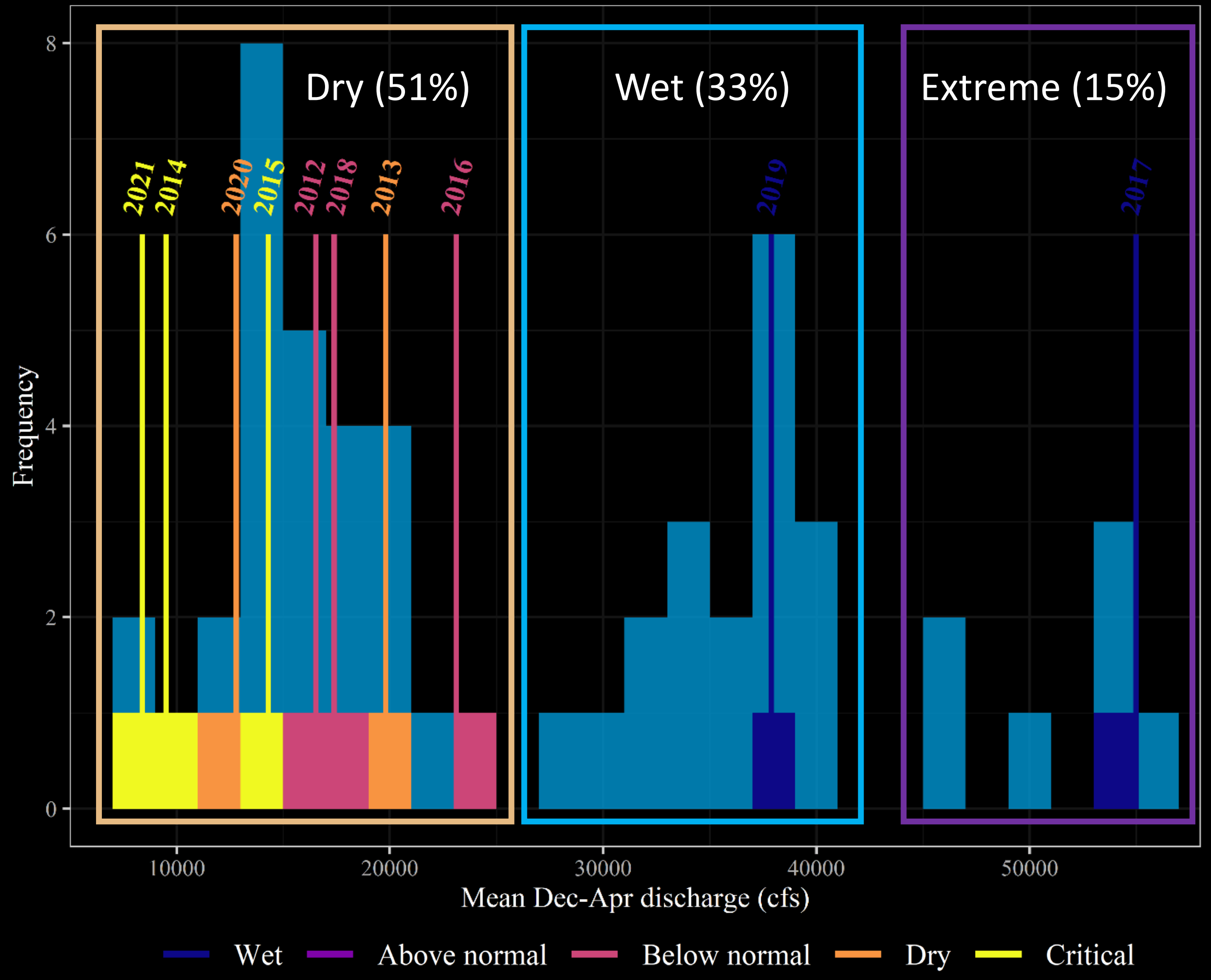
Image from water.ca.gov



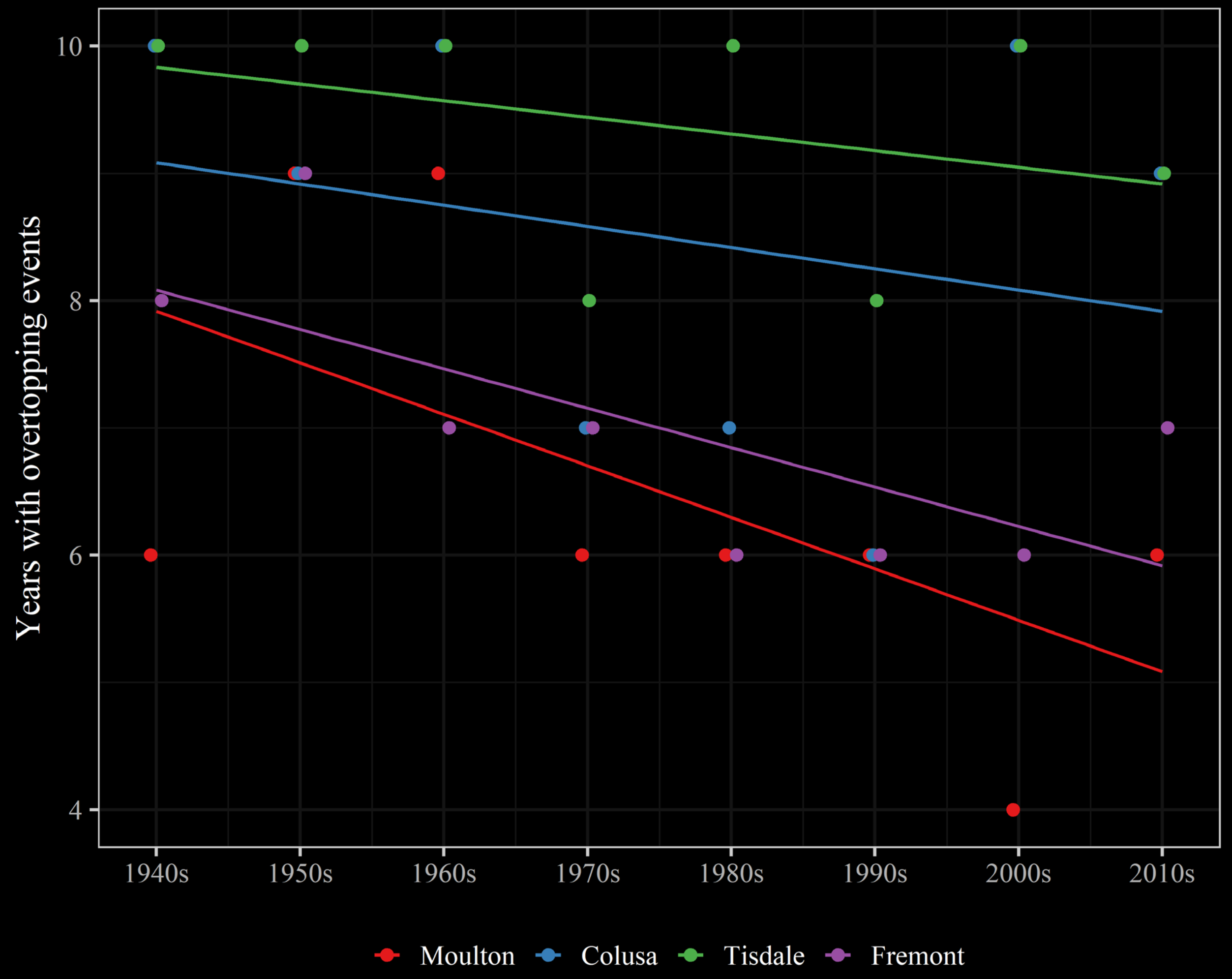
Source data: https://portal.edirepository.org/nis/mapbrowse?packageid=edi.233.2

Using the past to predict the future

Histogram of mean Dec-Apr runoff at Verona since completion of the Oroville Dam (1968)



Decreasing trend in water years per decade with at least one overtopping event



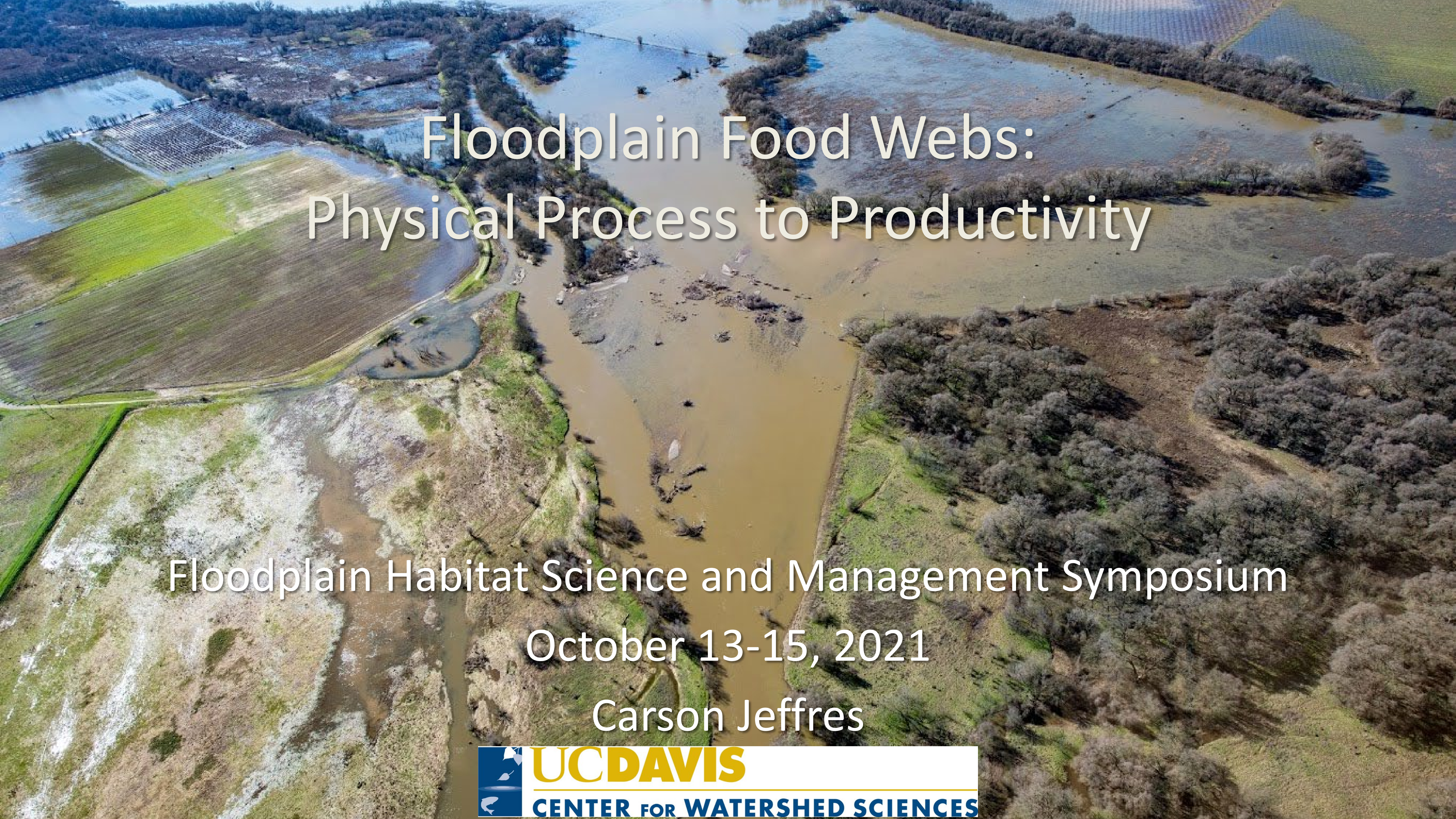
It takes two to make the seine go

Agency partners/funders
&
Private landowners

Knaggs Ranch   Davis Ranches   Next Generation Foods

Staff/collaborators

Carson Jeffres, Rachel Johnson, Flora Cordoleani, Matthew Salvador, Miranda Bell-Tilcock, Gabriel Saron, Mollie Ogaz, Nicholas Corline, Rosa Cox, Emma Cox, and many more!



Floodplain Food Webs: Physical Process to Productivity

Floodplain Habitat Science and Management Symposium

October 13-15, 2021

Carson Jeffres

UC DAVIS
CENTER FOR WATERSHED SCIENCES

Aquatic Food Webs

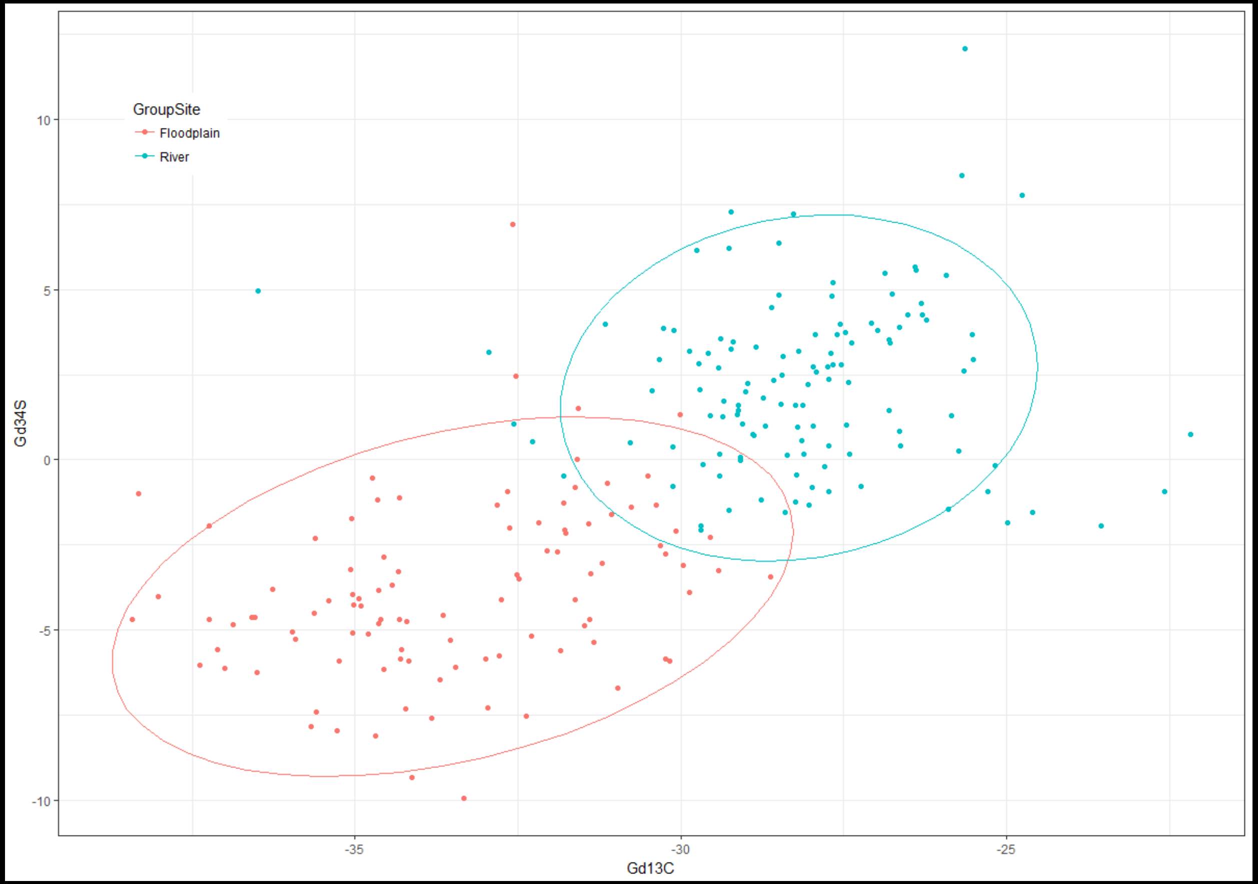
- What you observe in the aquatic food web is a product of the physical environment

Aquatic Food Webs

- What you observe in the aquatic ecology is a product of the physical environment
- Species in California have evolved to take advantage of a Mediterranean climate

Aquatic Food Webs

- What you observe in the aquatic ecology is a product of the physical environment
- Species in California have evolved to take advantage of a Mediterranean climate
- Understanding physical processes can help community composition and food web structure

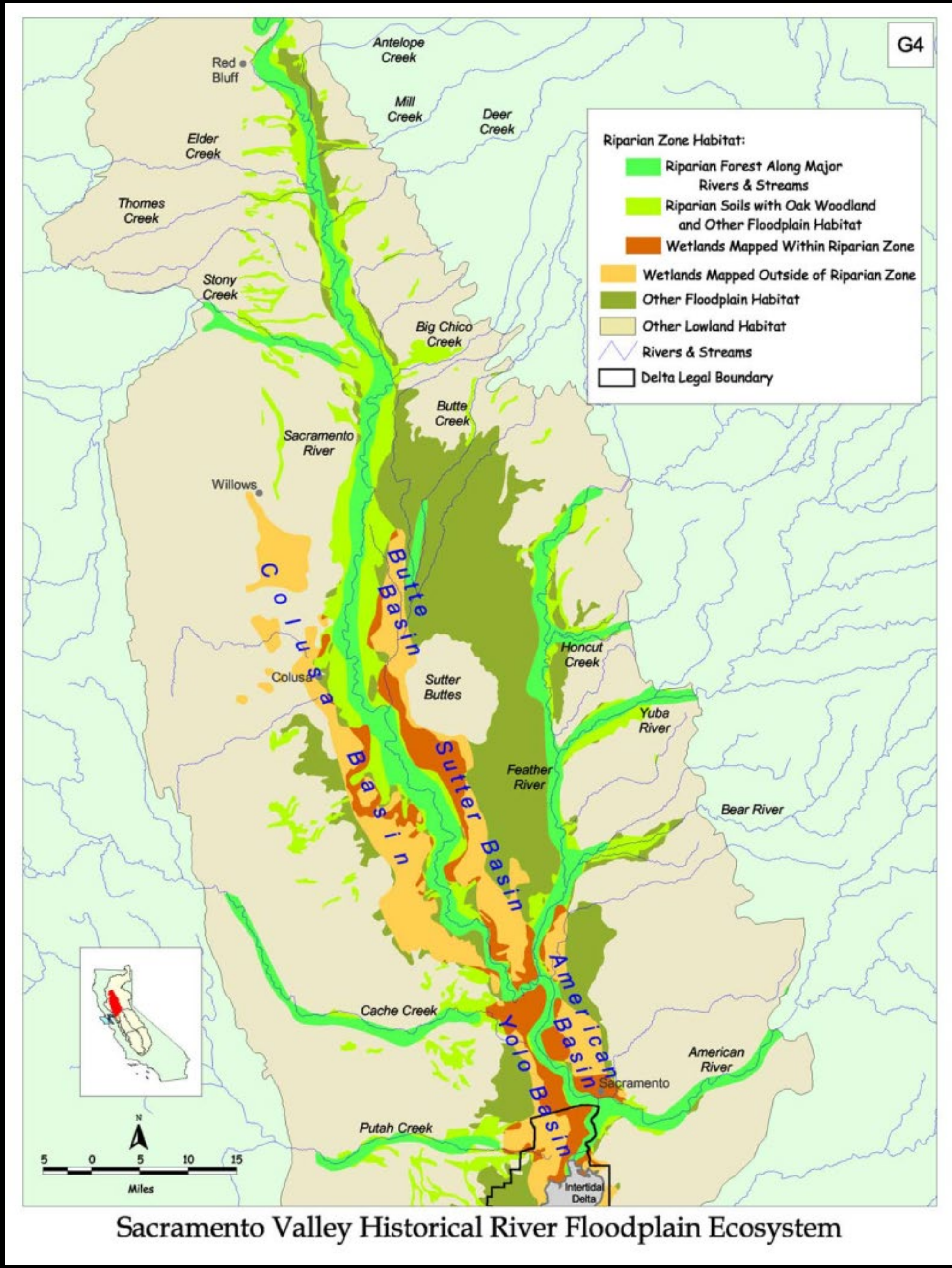


Floodplain: Land along a river subject to seasonal inundation

HISTORICALLY:

- Much of the Sacramento Valley was wetland and riparian habitat

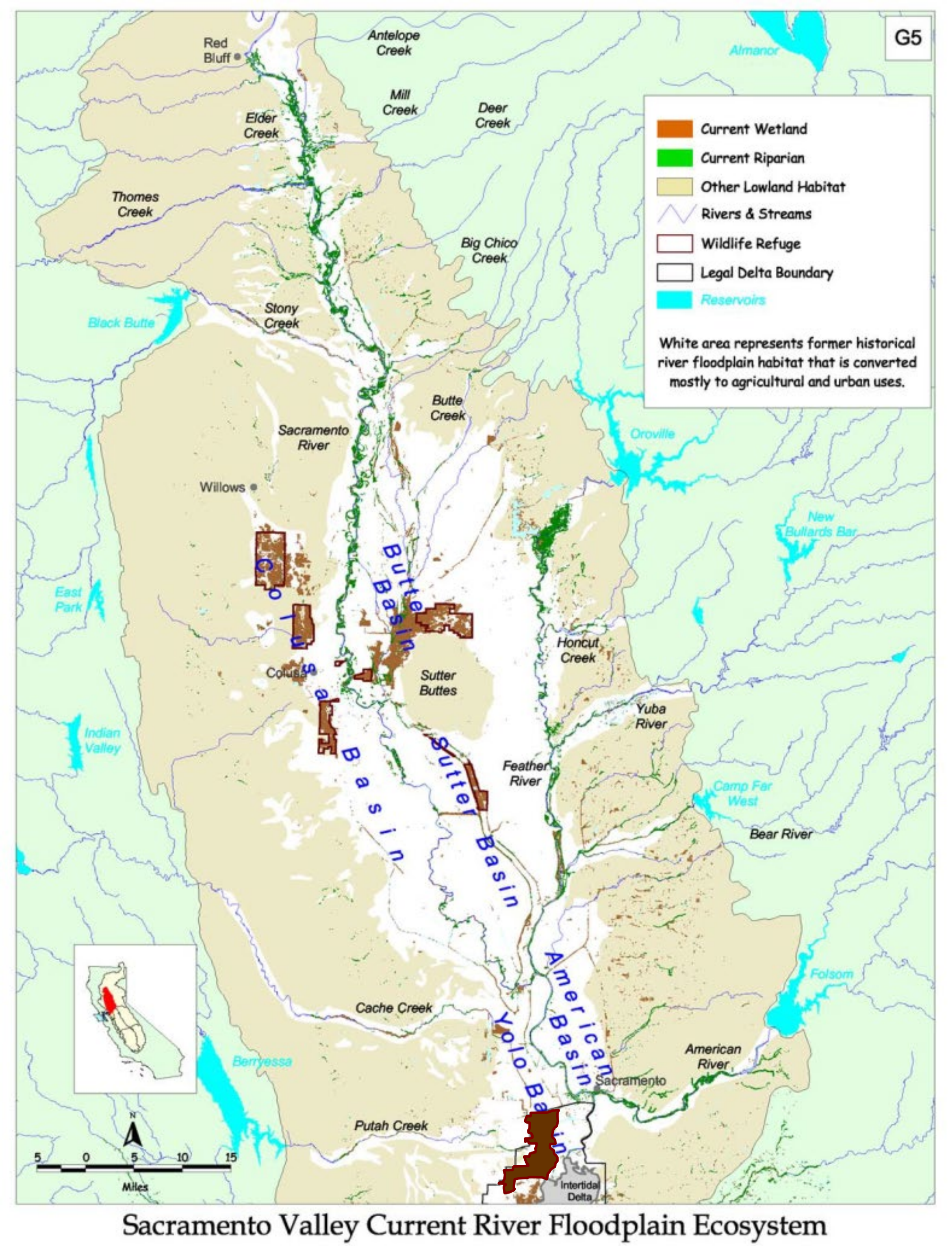
California State Library



The Bay Institute, 1998

TODAY:

- ~95% of floodplains are no long available
- Converted to agriculture and urban development.

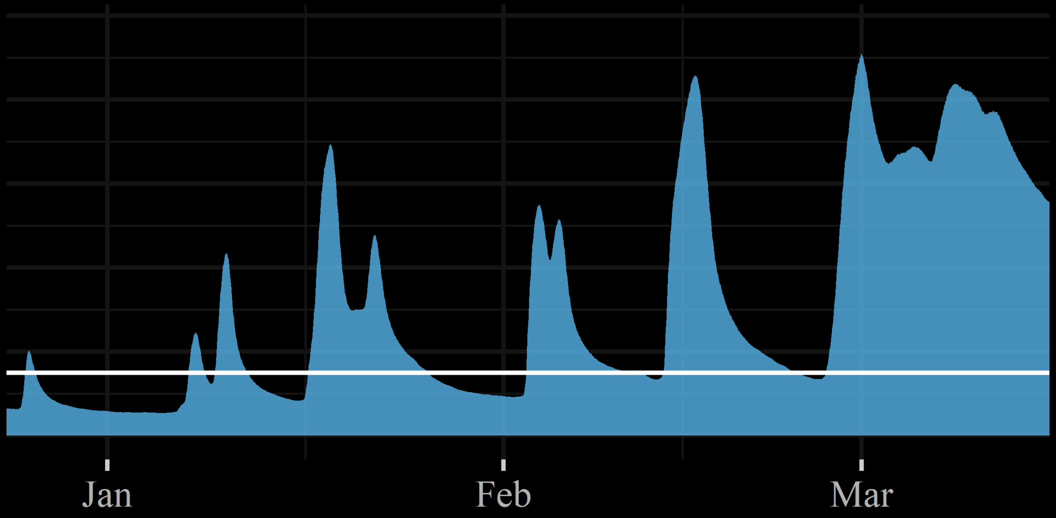


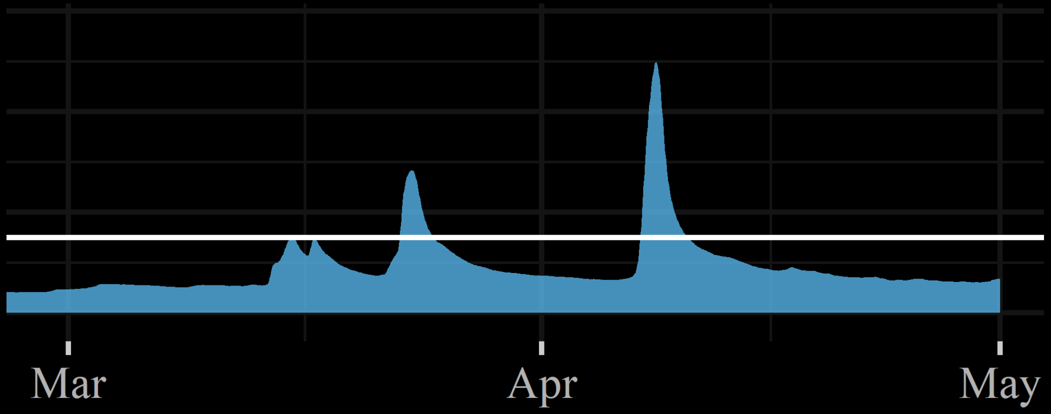
The Bay Institute, 1998

Floodplains in California

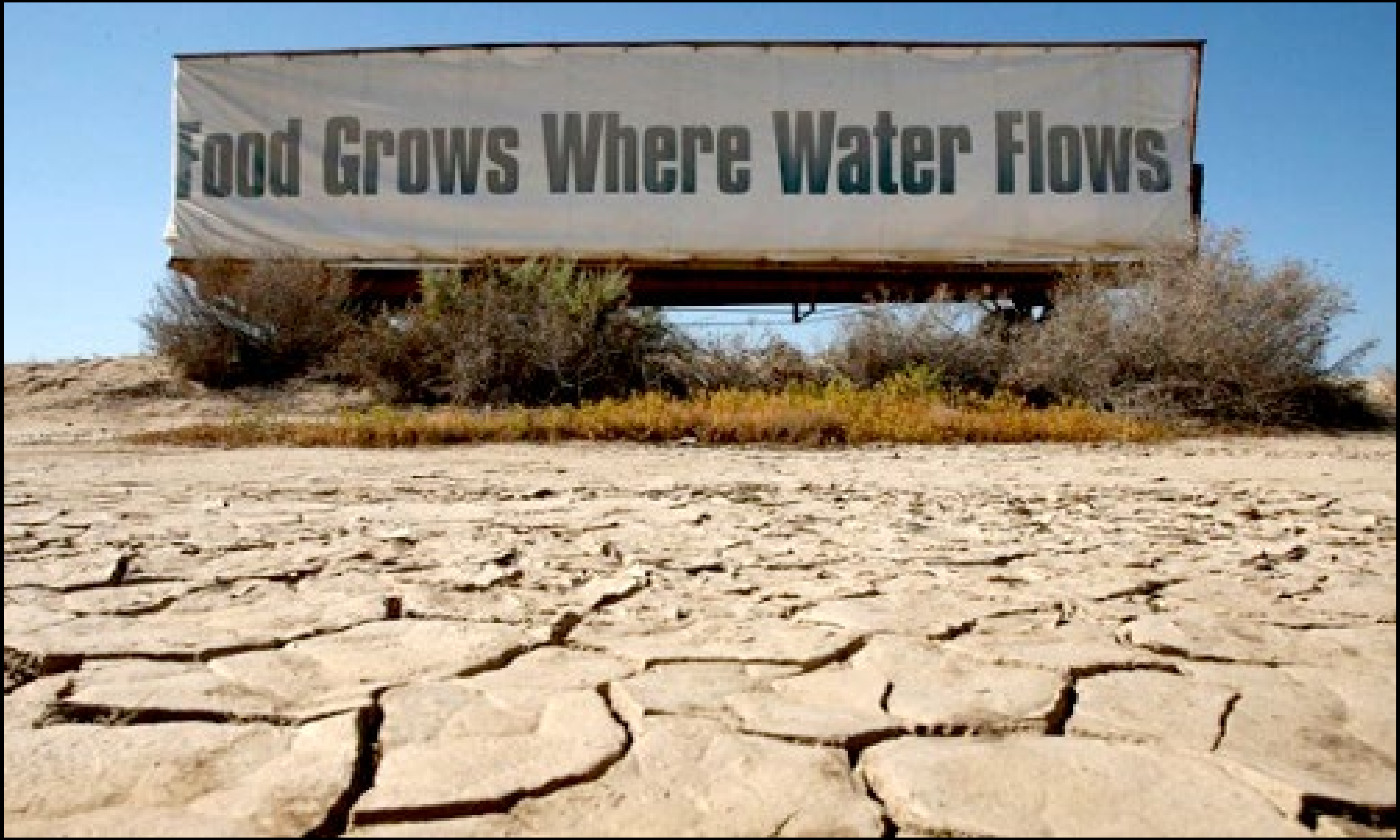
- Extent of floodplain habitat greatly reduced

- Hydrologic context
  - Flood timing, duration, and location dictate opportunities for food web abundance and composition.





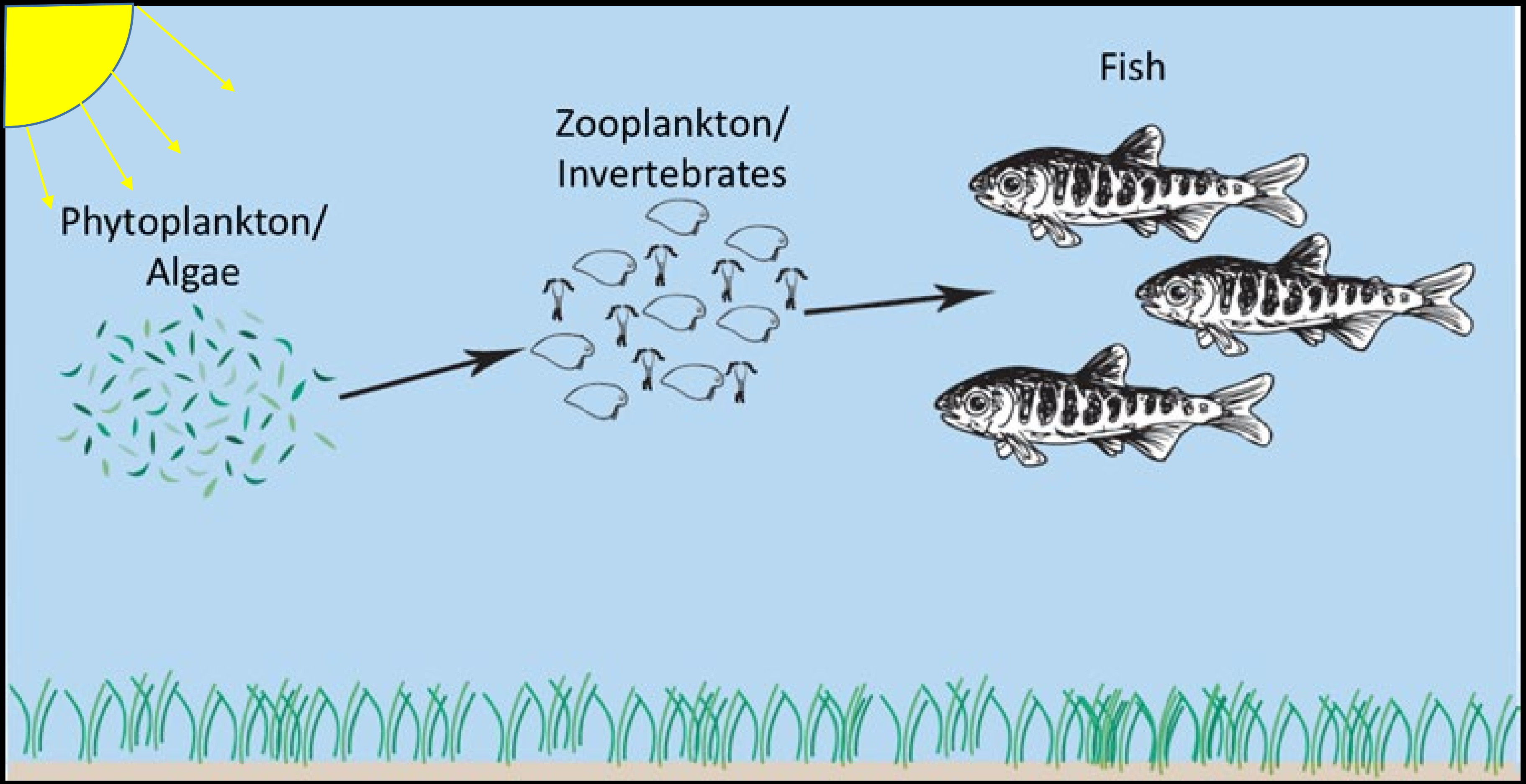
Floodplain Food Webs



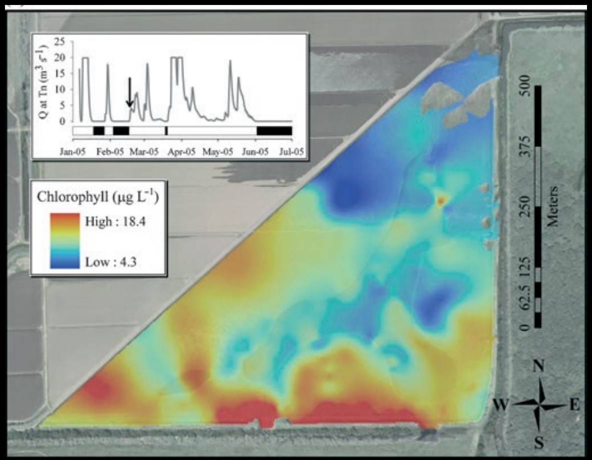
Floodplain Food Webs

Floodplain Food Webs

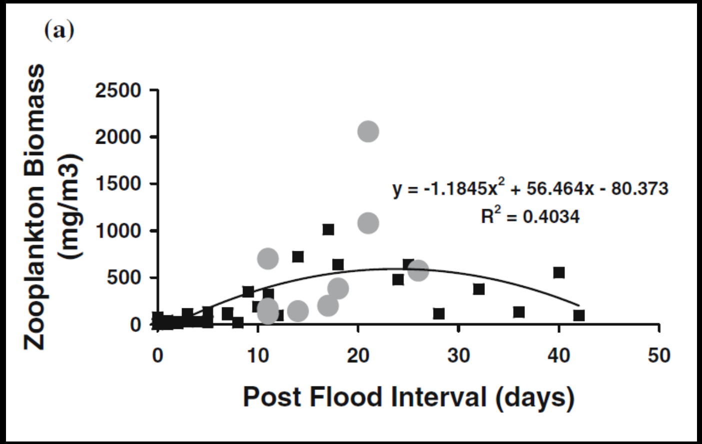
Conceptual Model of Floodplain Food Web



Cosumnes River Floodplain Food Web



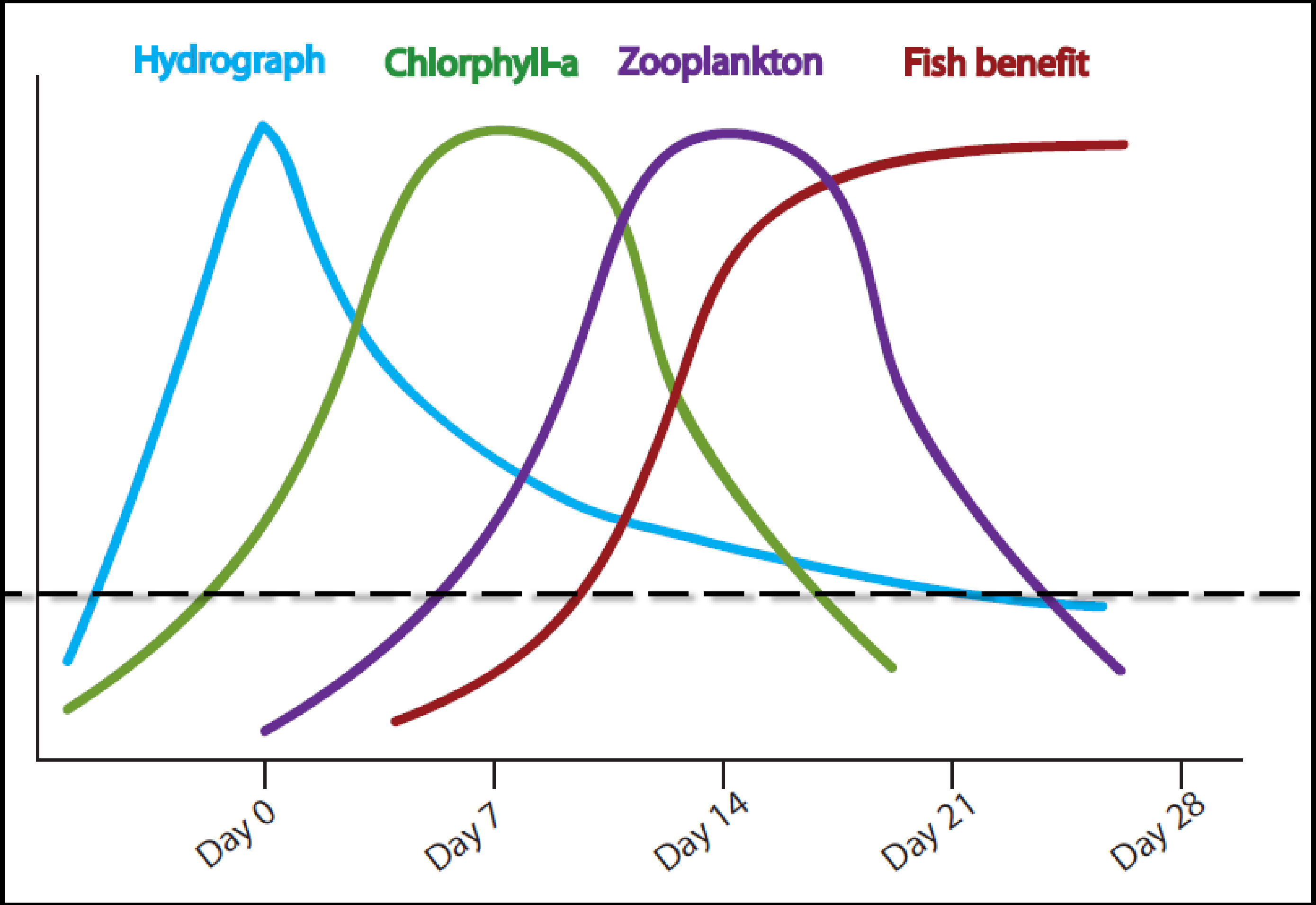
Ahearn et al. 2006



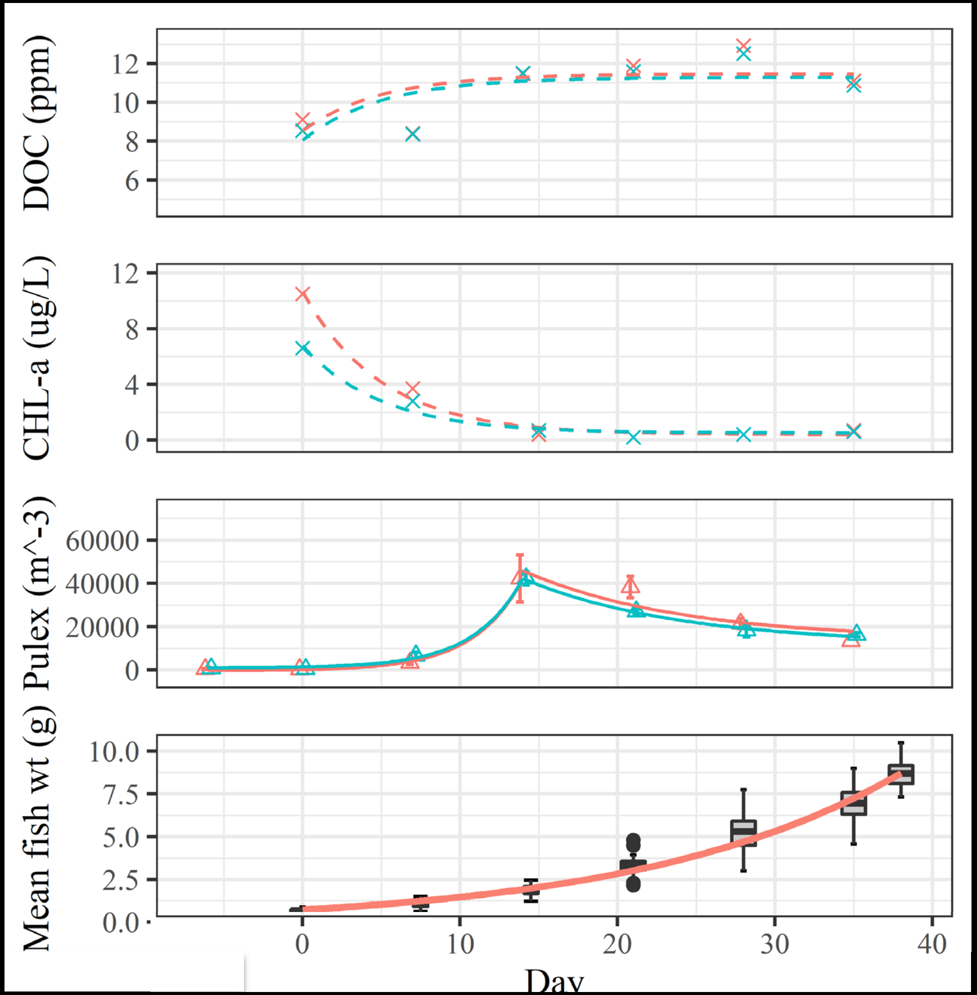
Grosholz and Gallo 2006

Jeffres et al. 2008

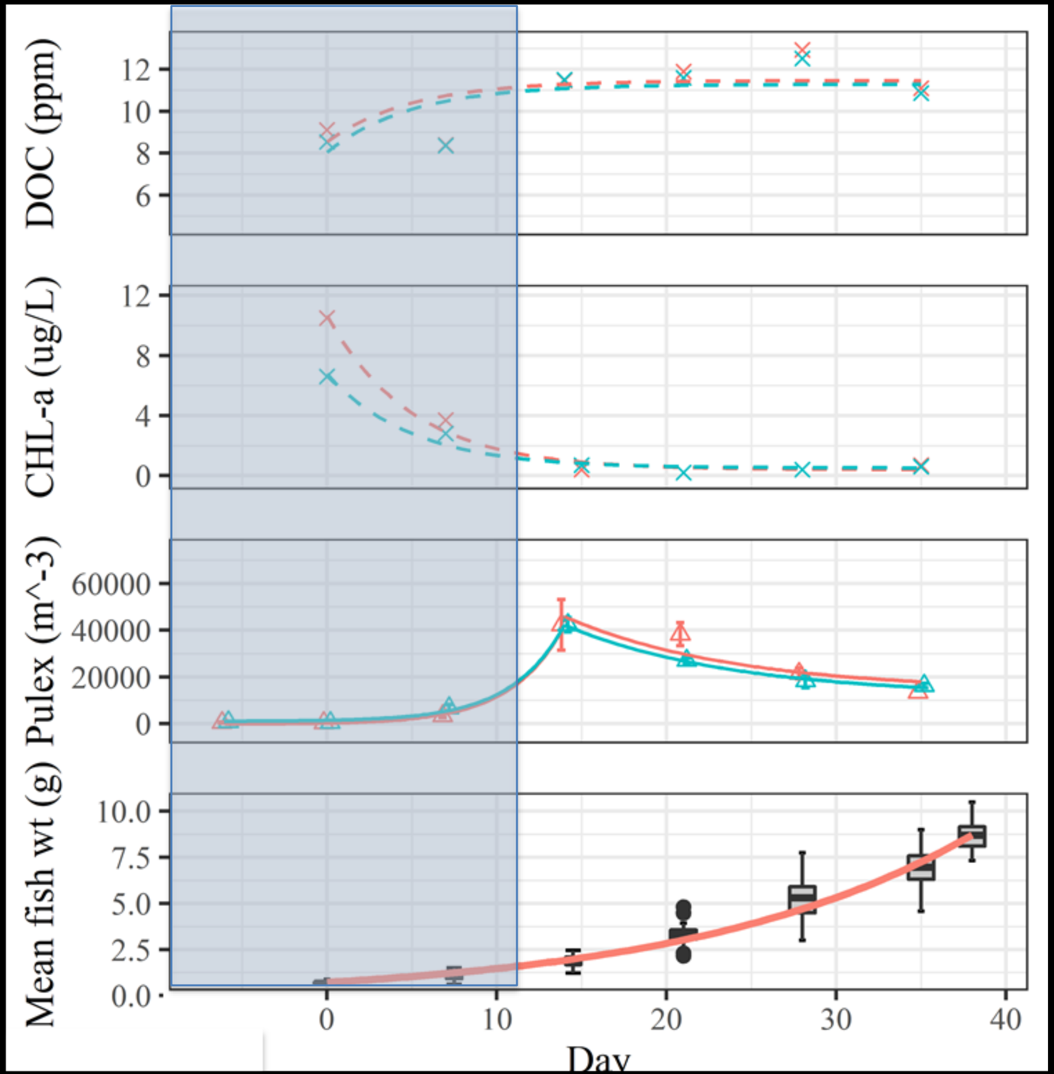
Food Web Over Time

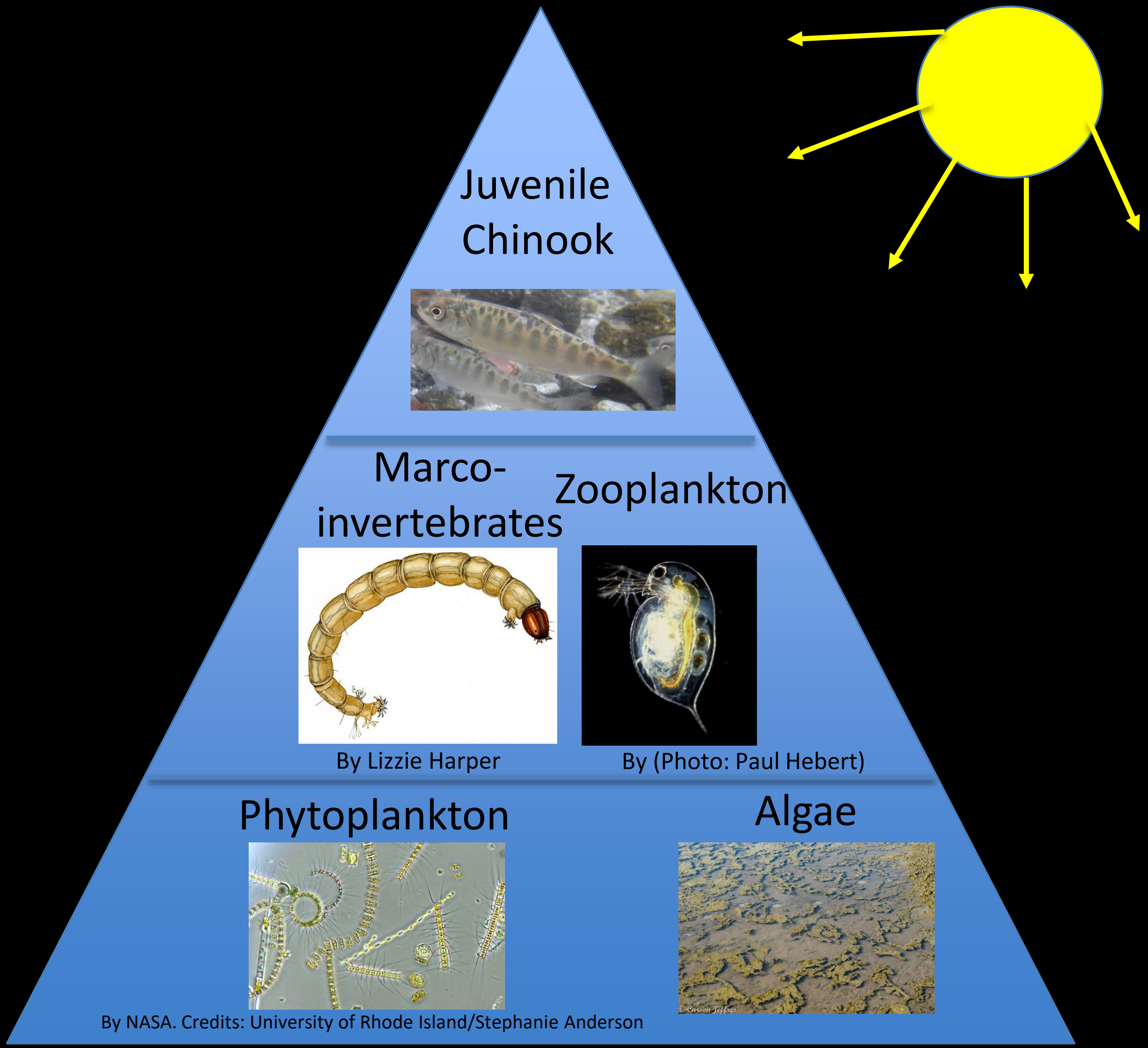


Food Web Over Time

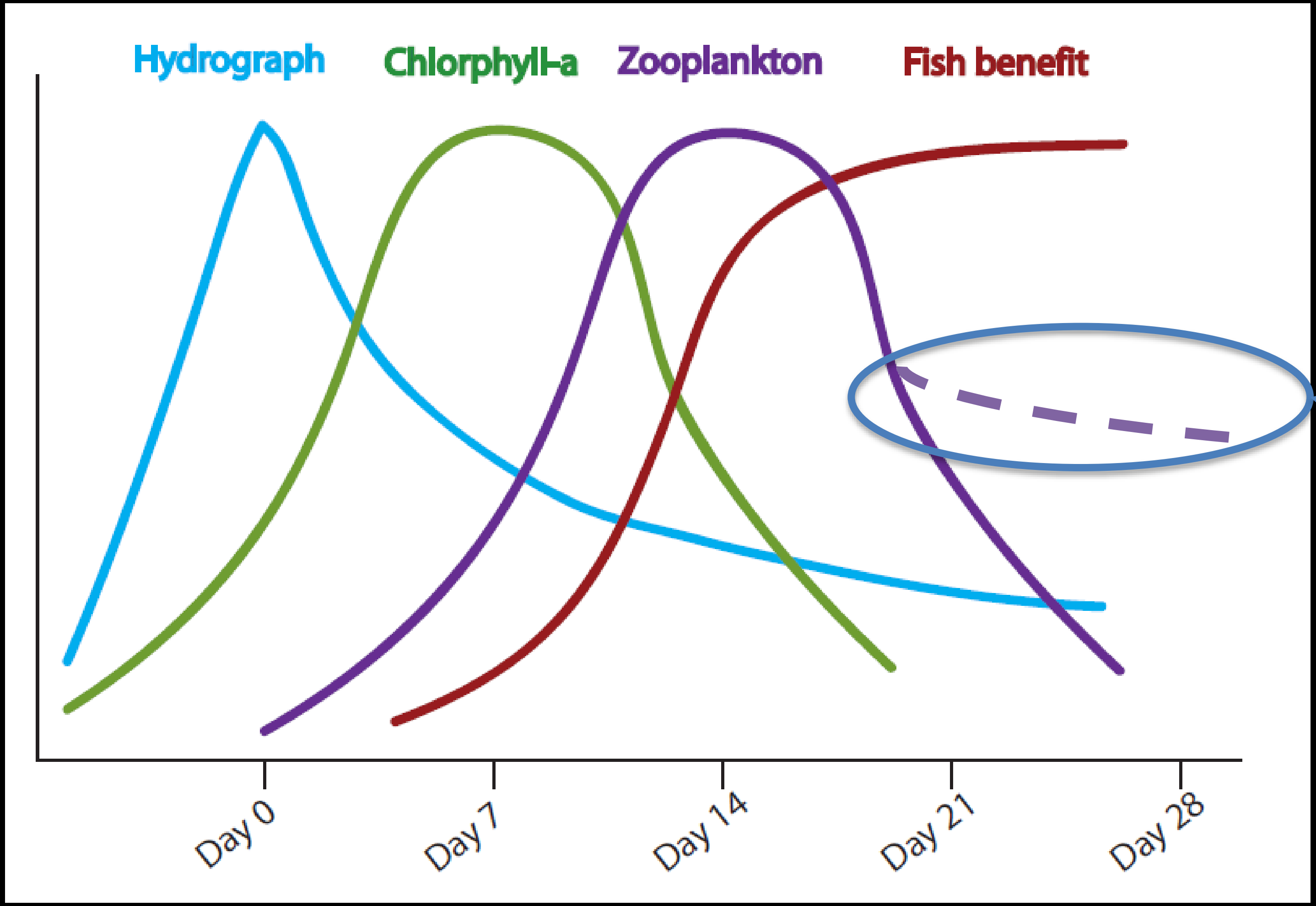


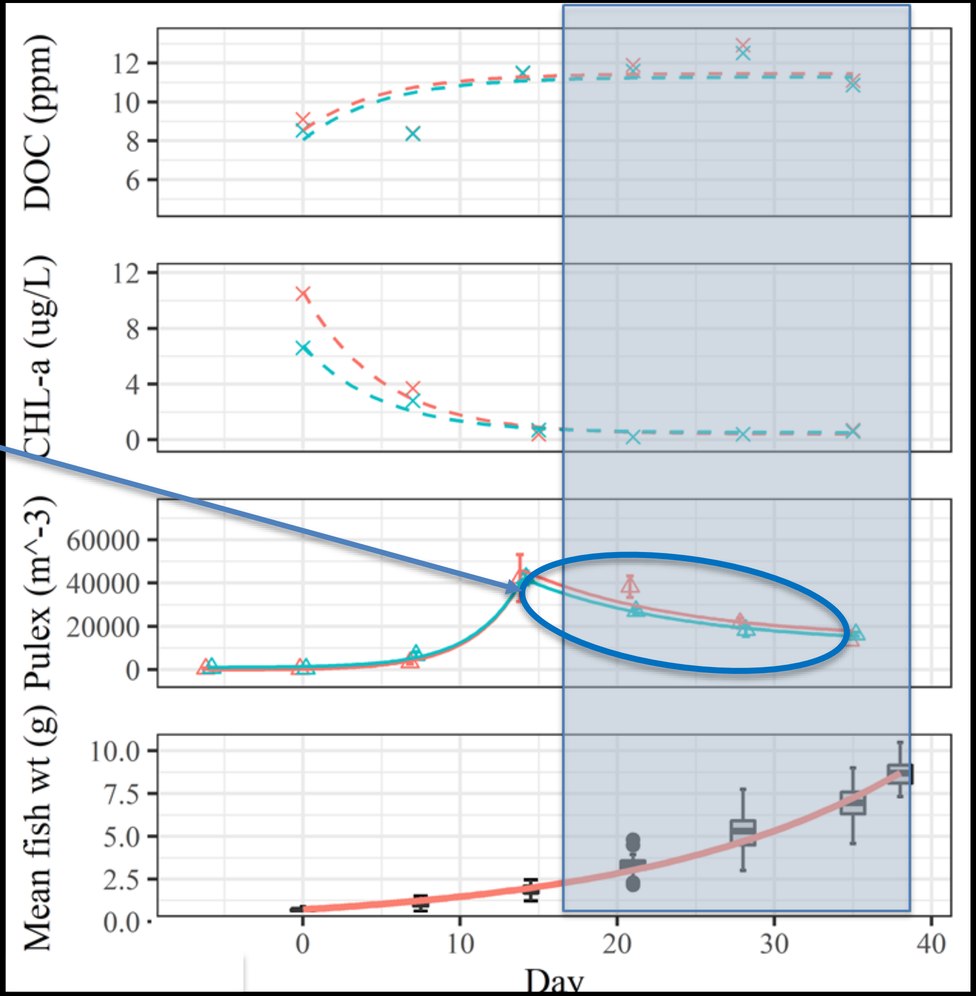
Sources of Carbon



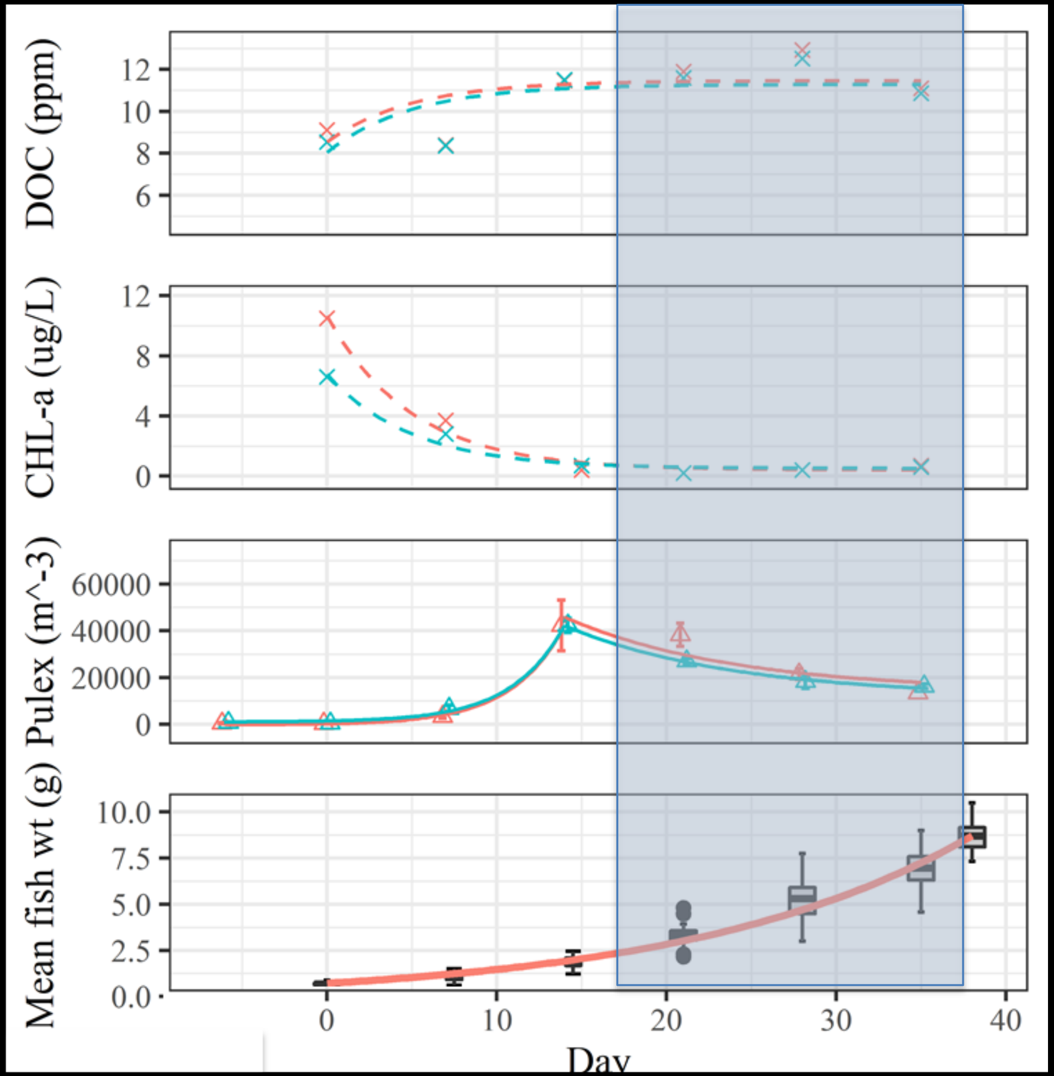


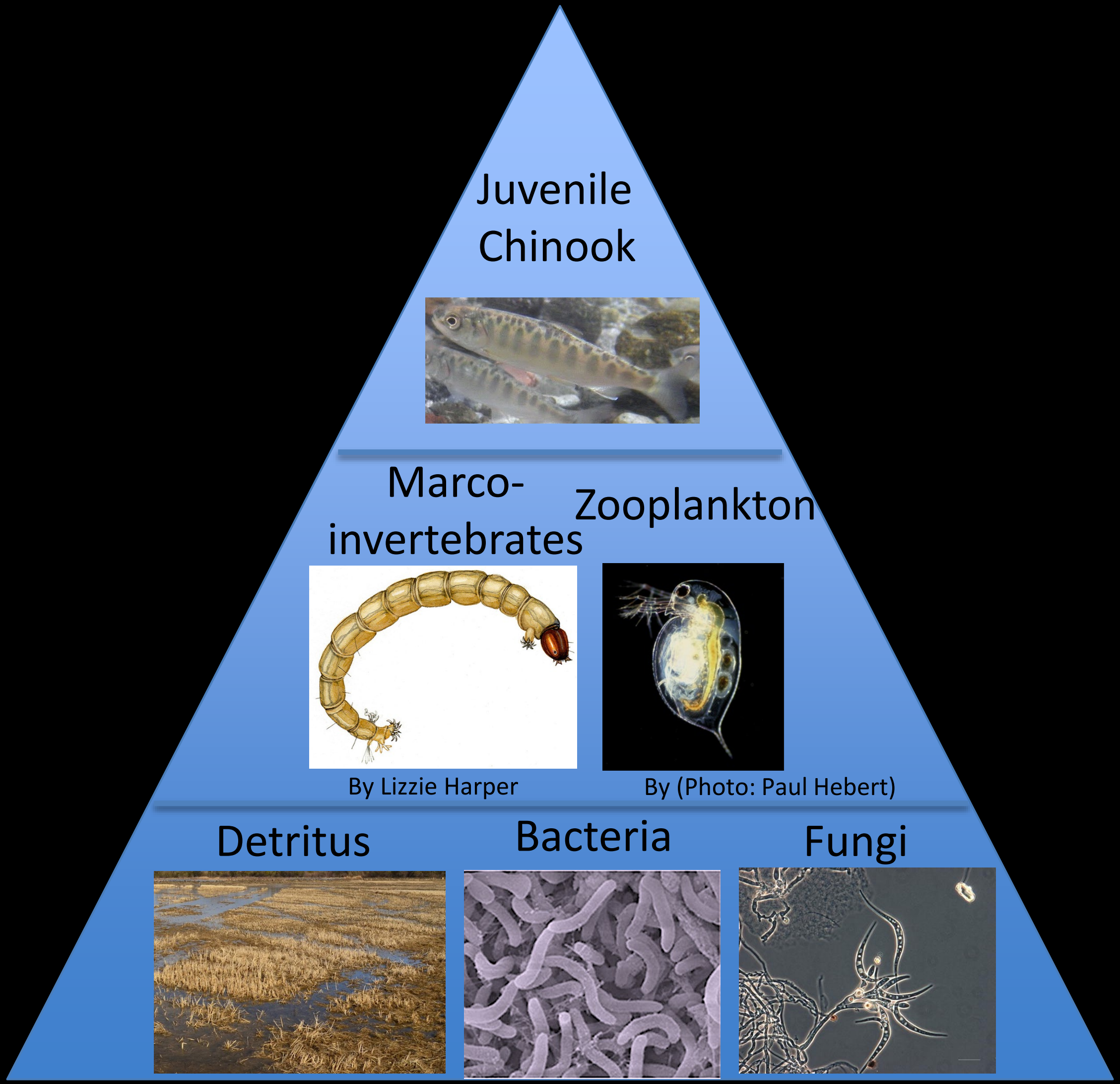
Food Web Duration





Sources of Carbon

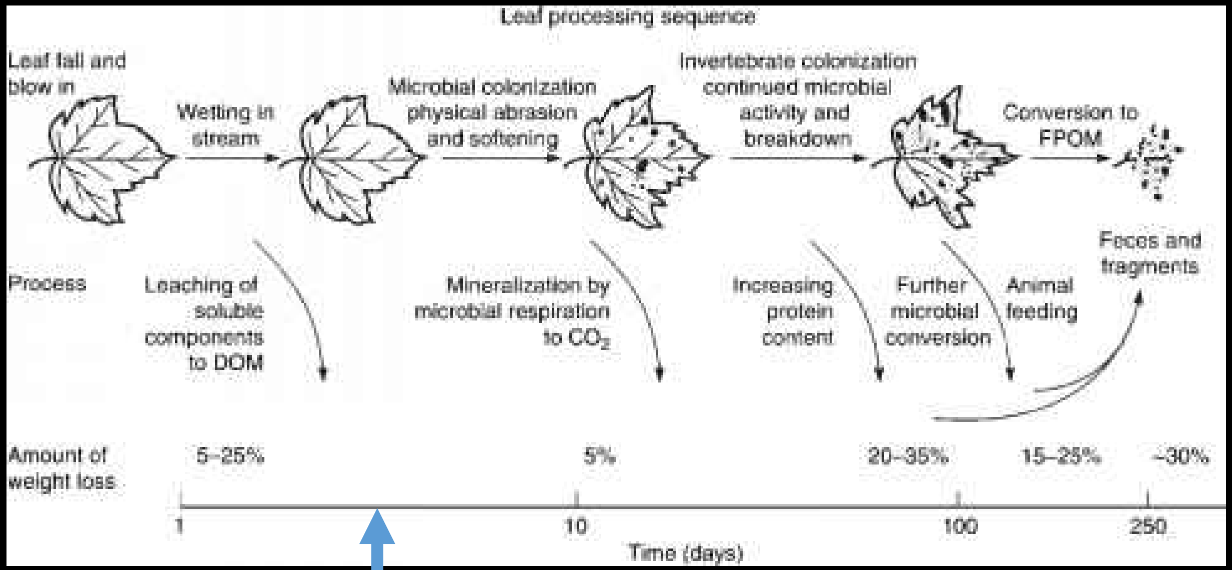


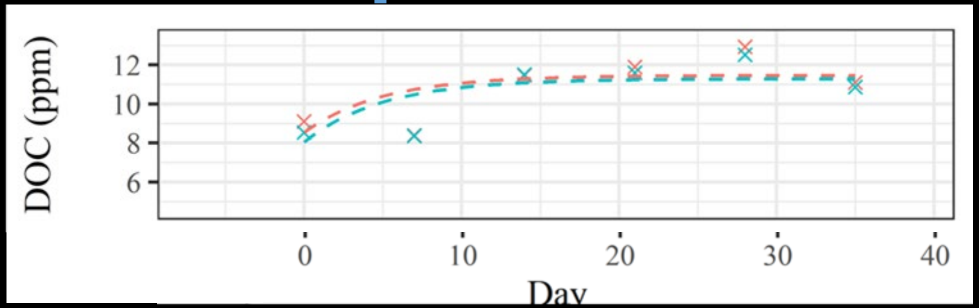


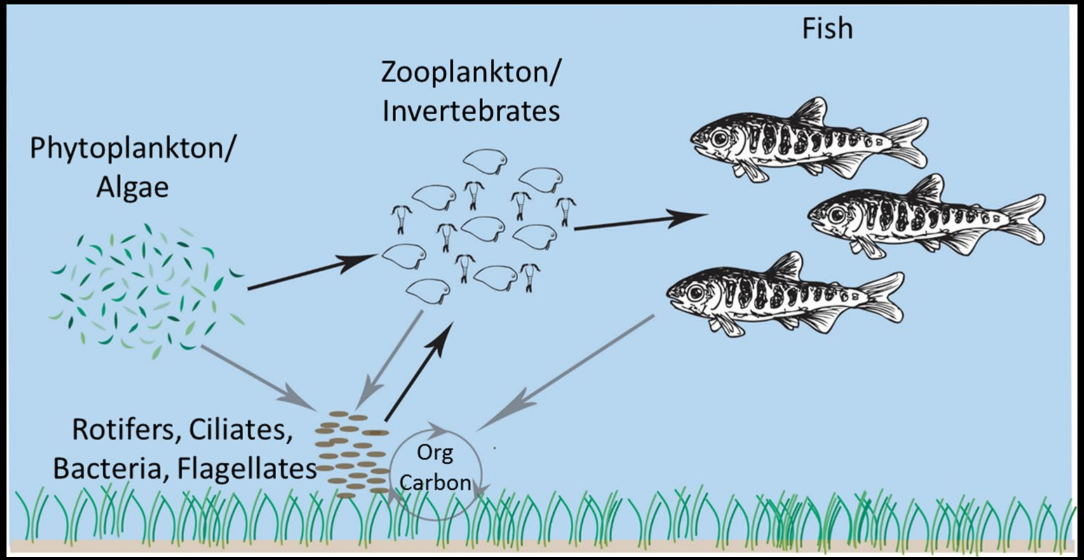
Steeping the Tea

=

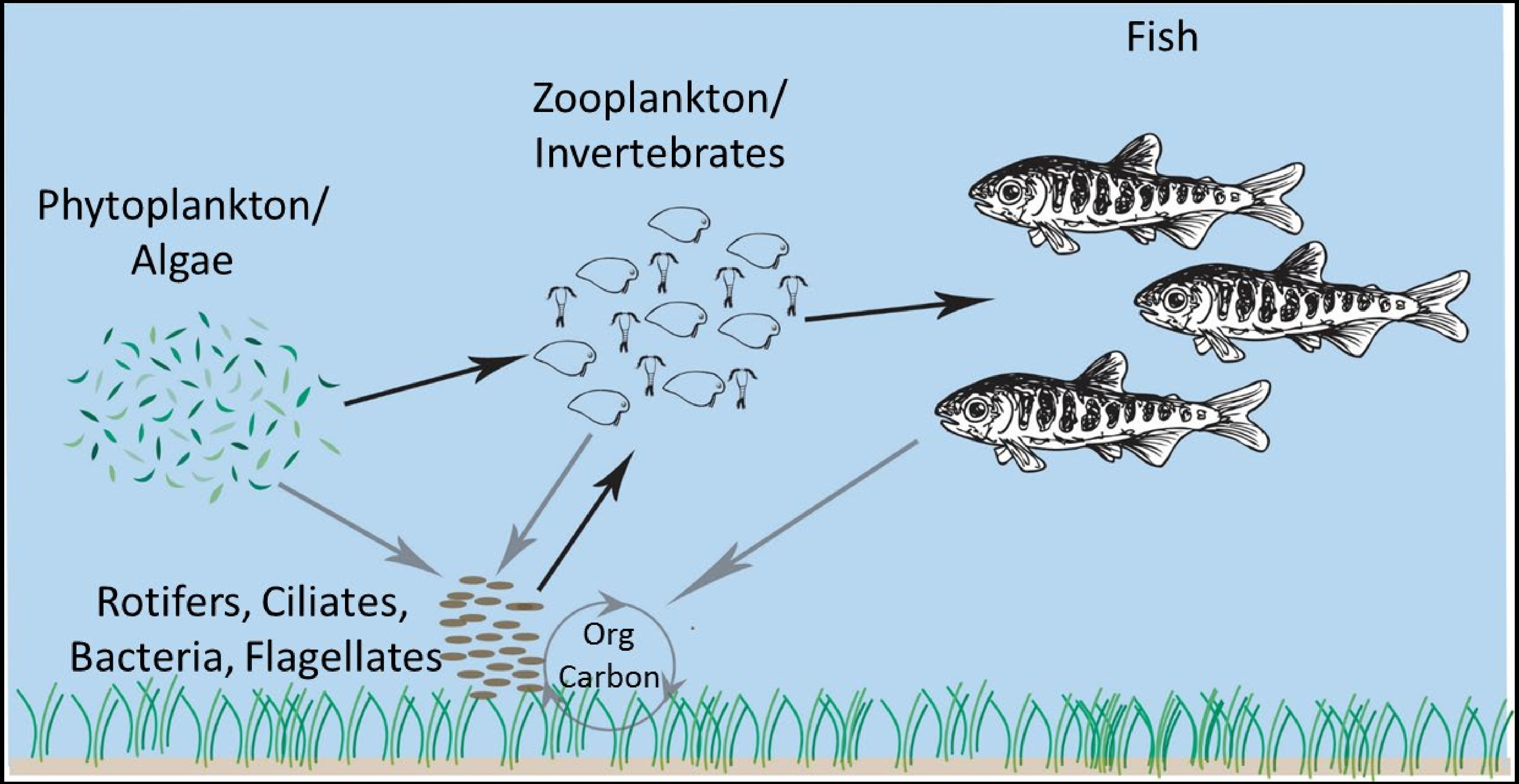
Steeping the Tea





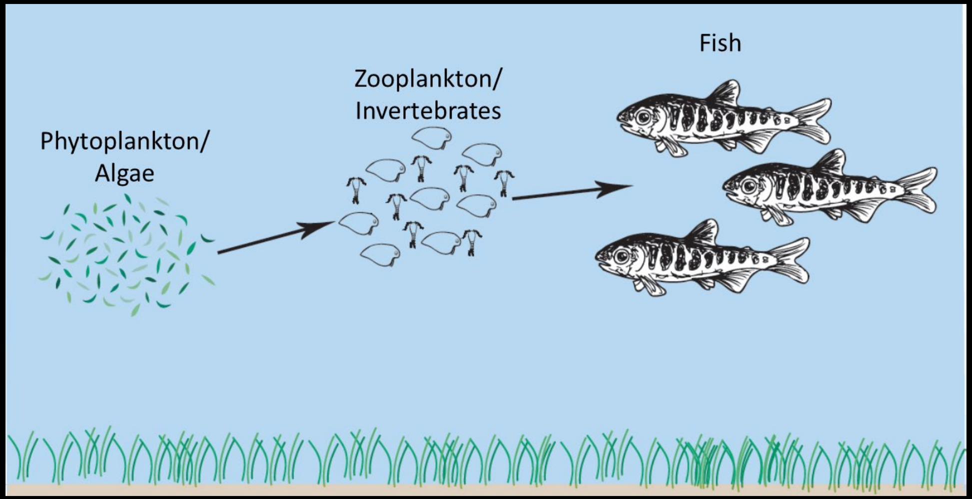


Floodplain Food Web

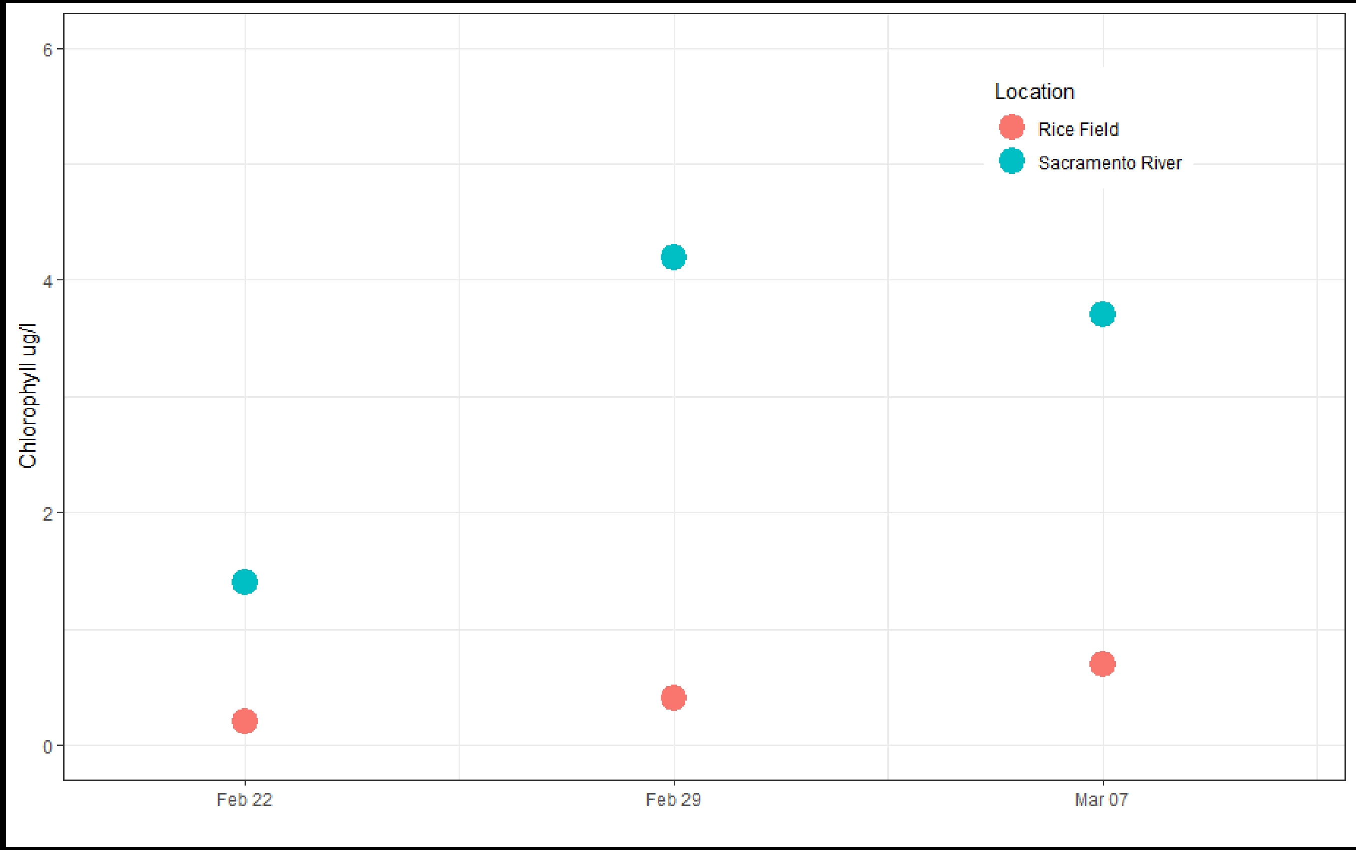


Floodplain vs River Food Webs

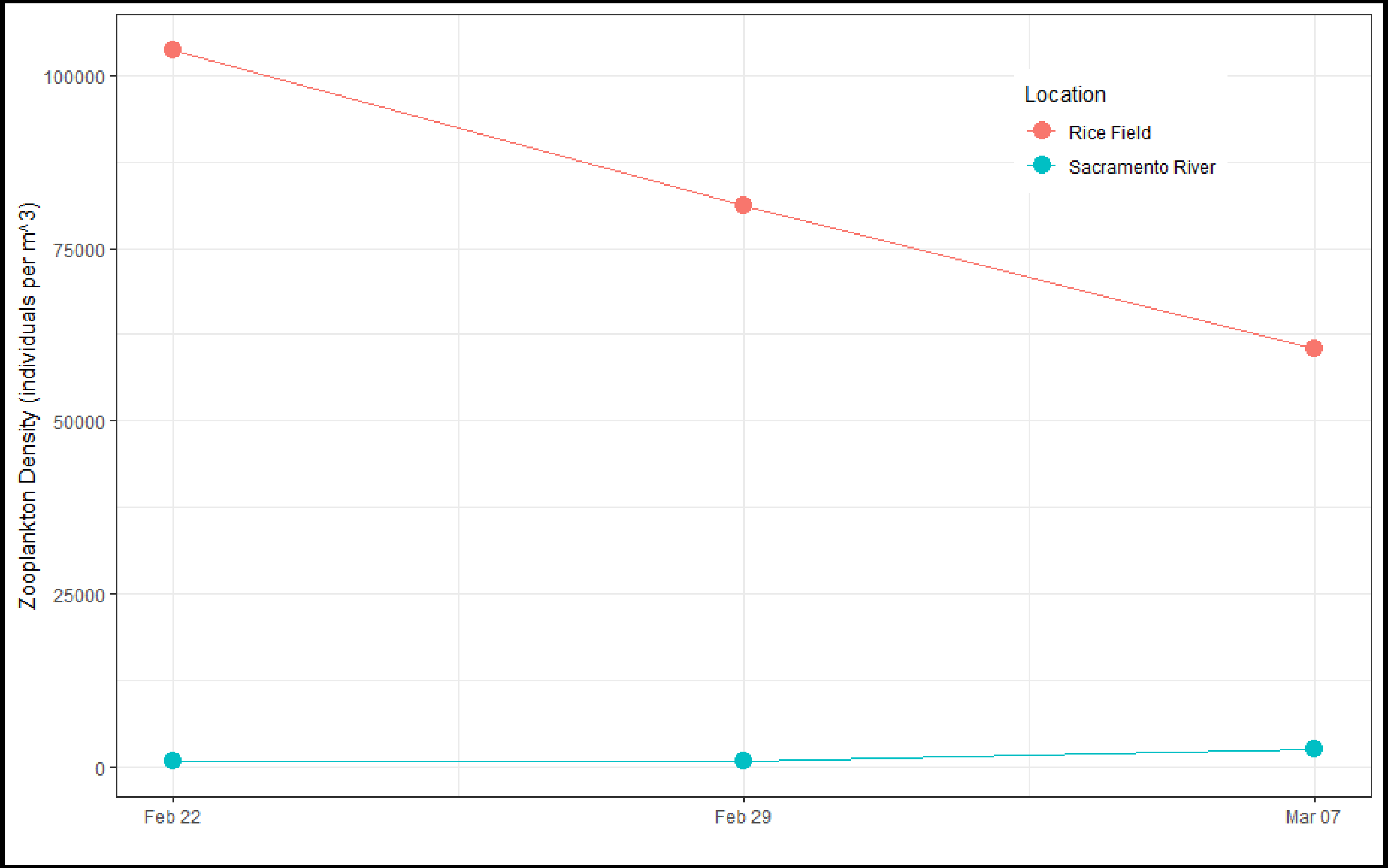
- Where does our "primary production" coming from?
- The Sacramento River follows traditional models of in situ photosynthesis.

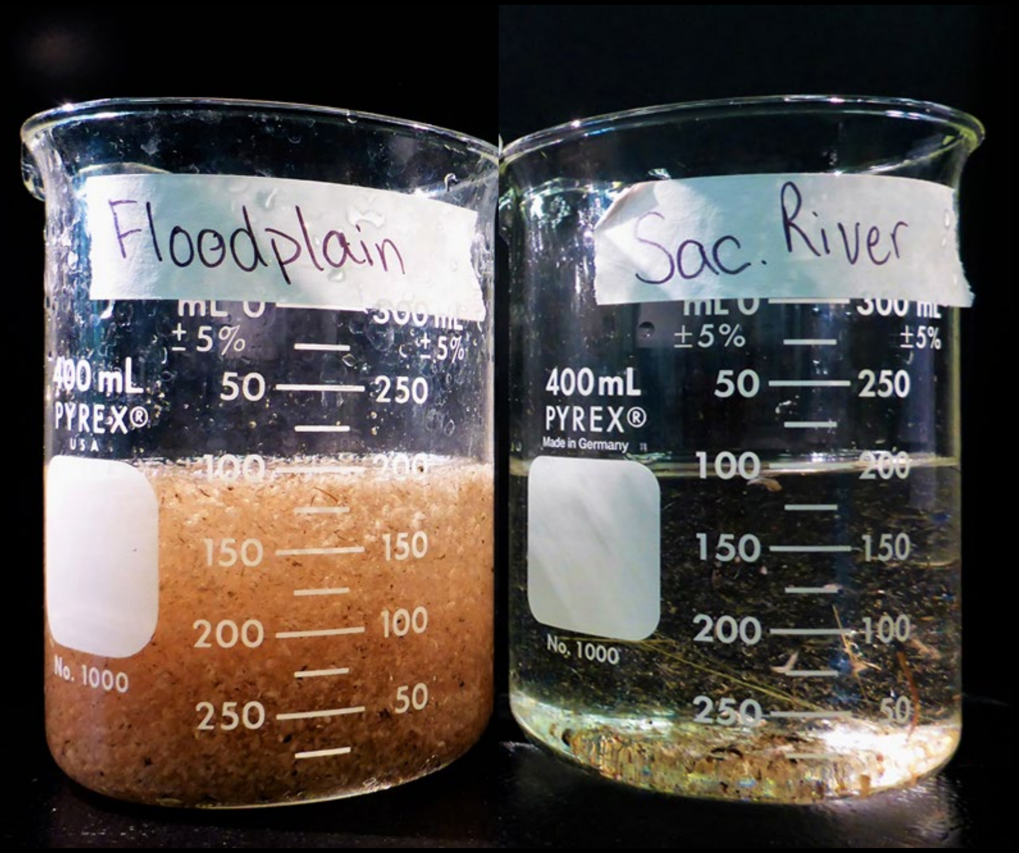


Chlorophyll

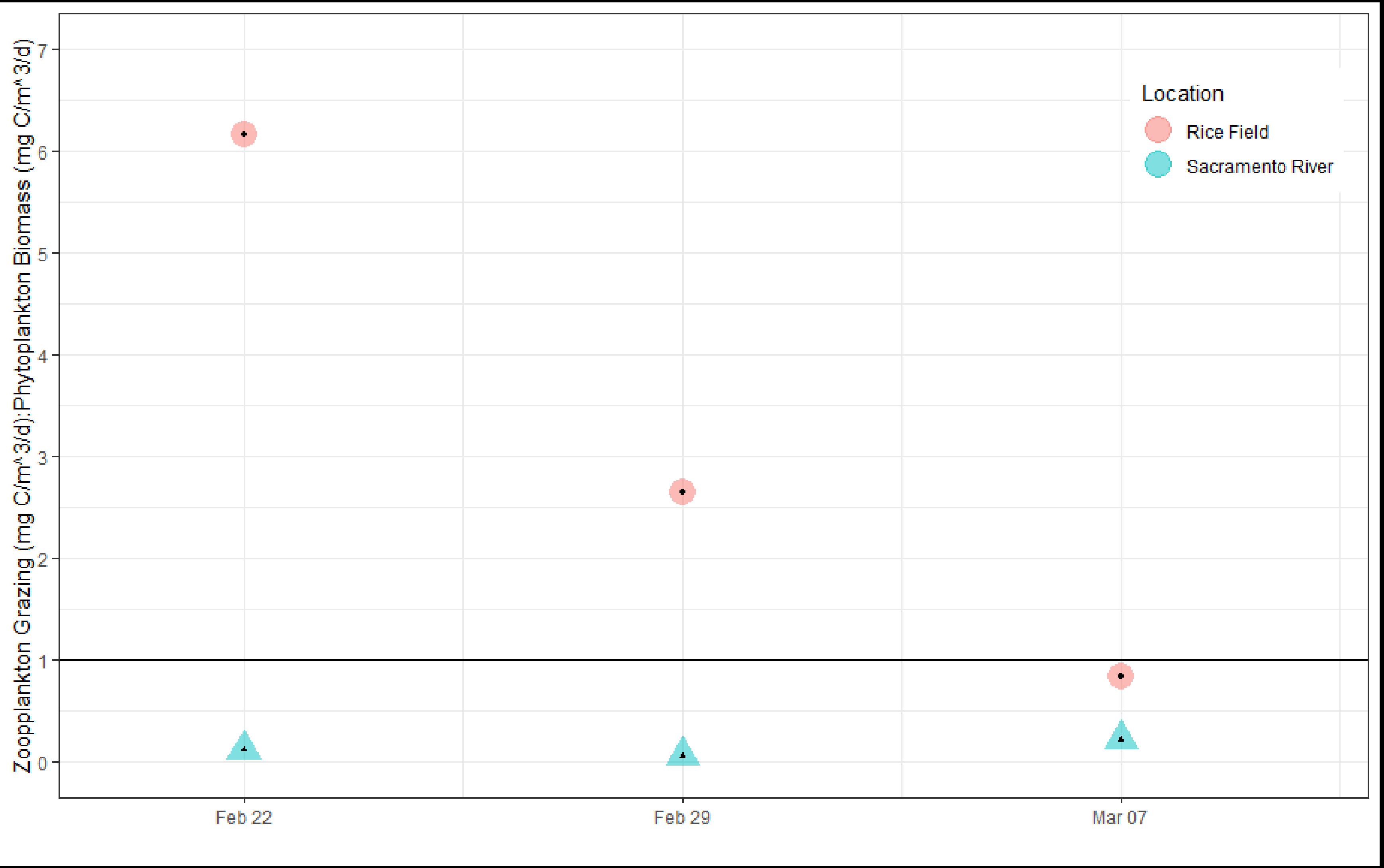


Food Web


Location
Rice Field
Sacramento River
Zooplankton Density (individuals per m^3)
100000
75000
50000
25000
0
Feb 22
Feb 29
Mar 07


Floodplain
Sac. River
400 mL
PYREX®
No. 1000

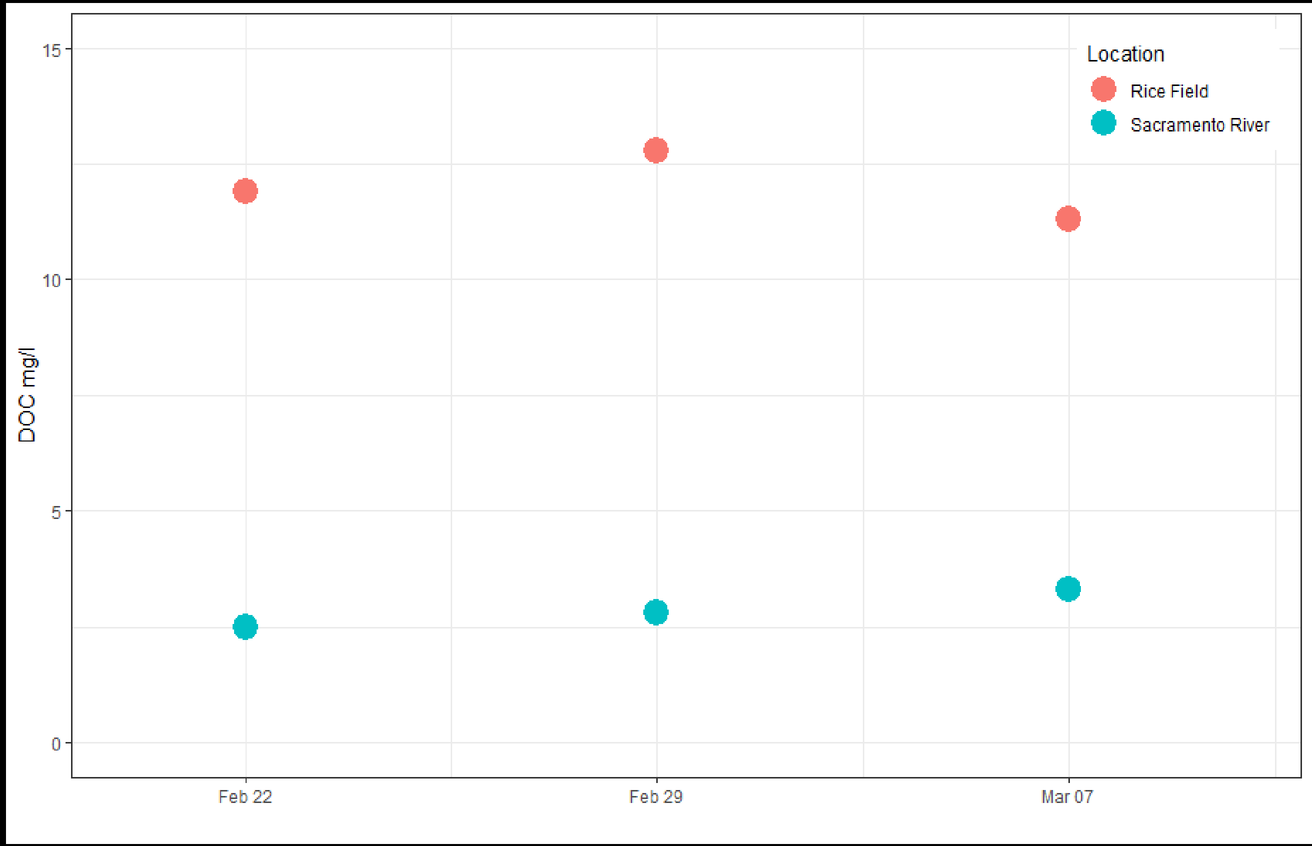
Grazing : Primary Production



Food Web

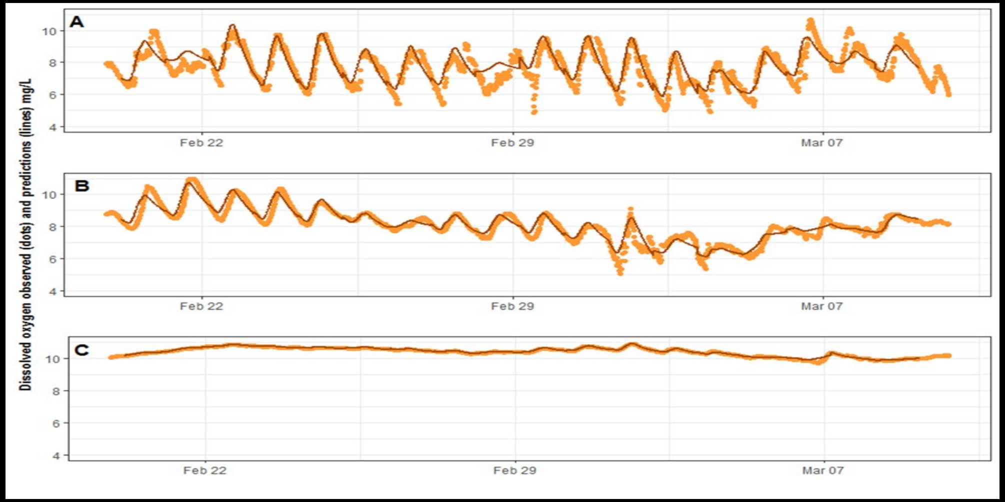
- Where is our basal carbon (aka energy) coming from?
- The Sacramento River follows traditional models of autotrophic production.
- Floodplain "fueled" by mix of autotrophic and heterotrophic food webs

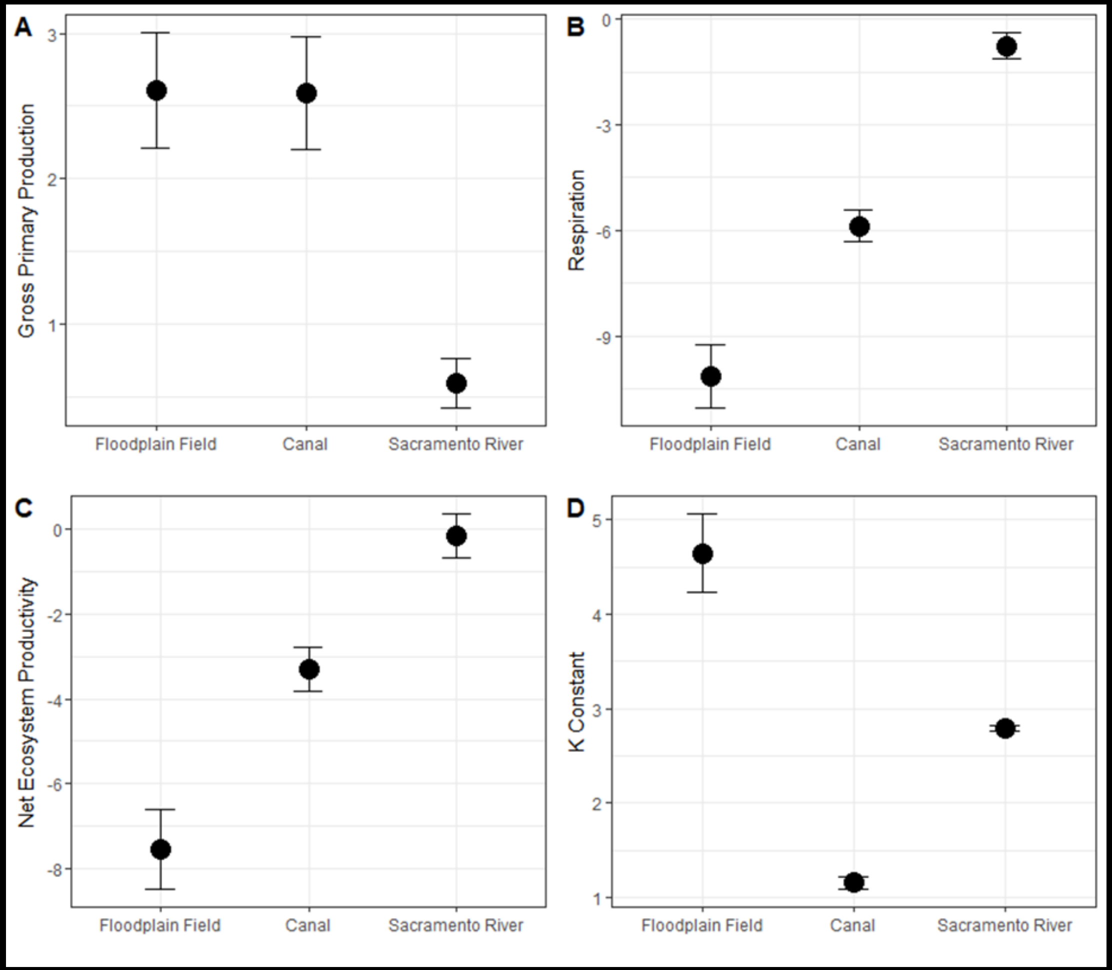
Dissolved Organic Carbon



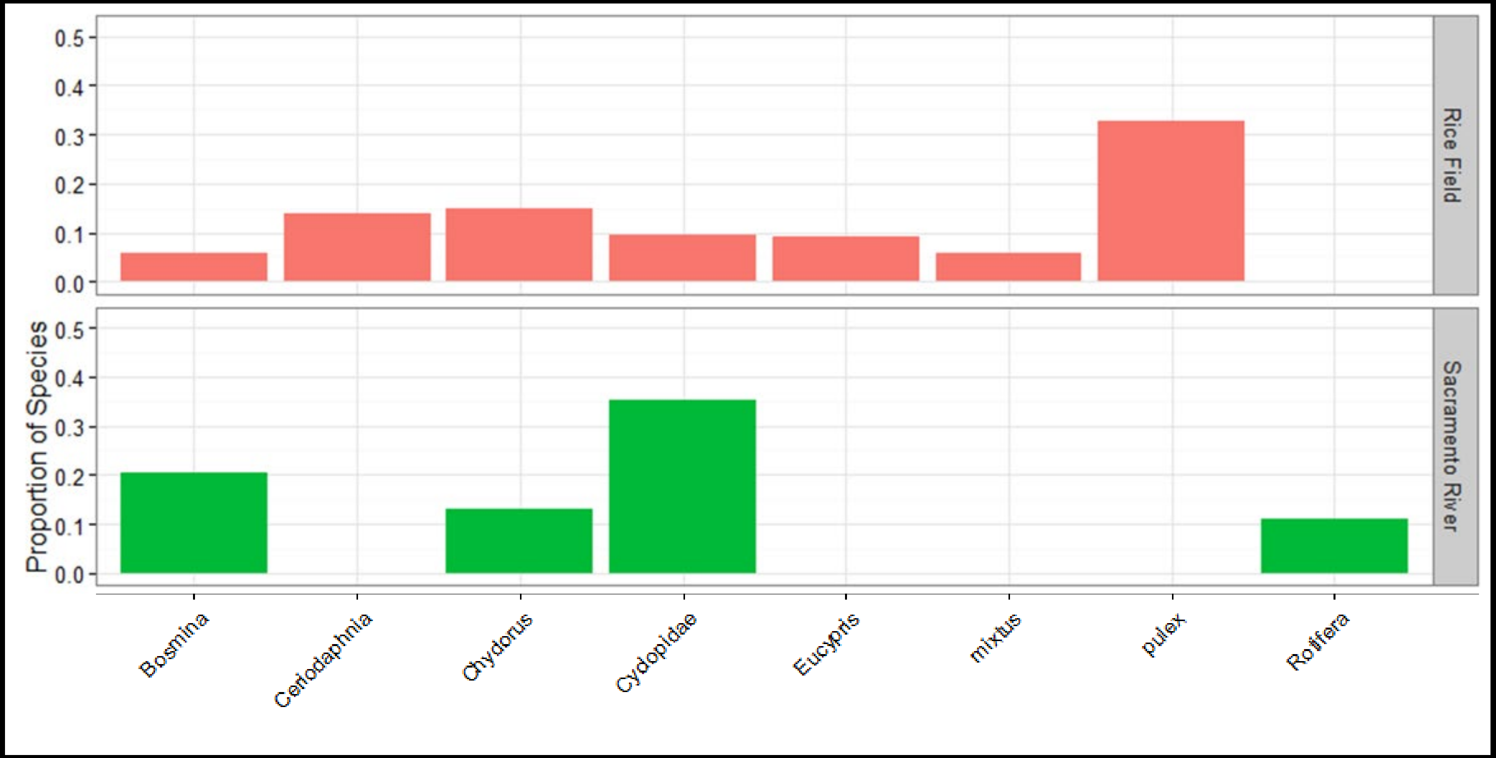
Detrital Sources in the Food Web

- Model developed using USGS Streammetabolizer package in R
  - uses inverse modeling to estimate aquatic metabolism (photosynthesis and respiration) from time series data on dissolved oxygen, water temperature, depth, and light.





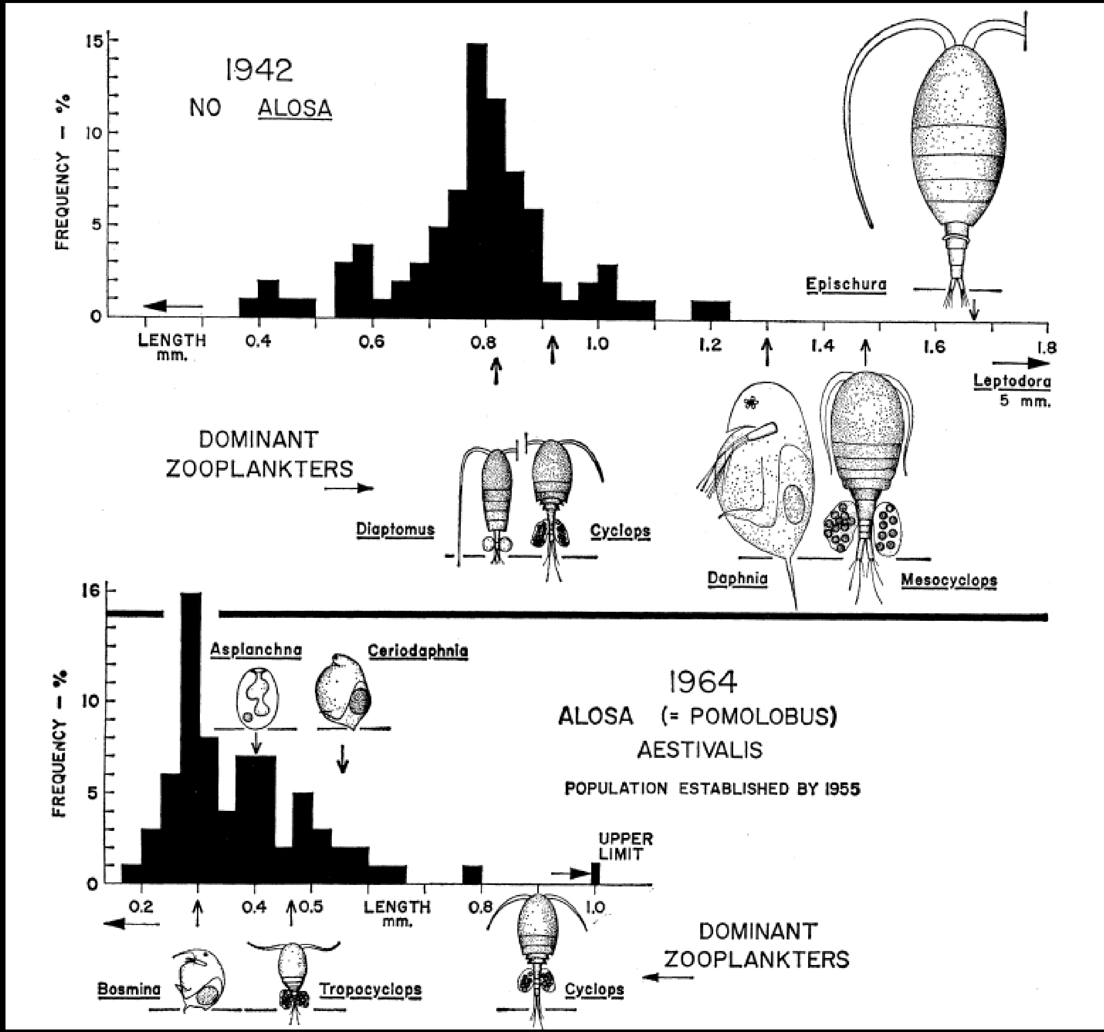
Food Web Composition



Lack of Permanent Fish Predators

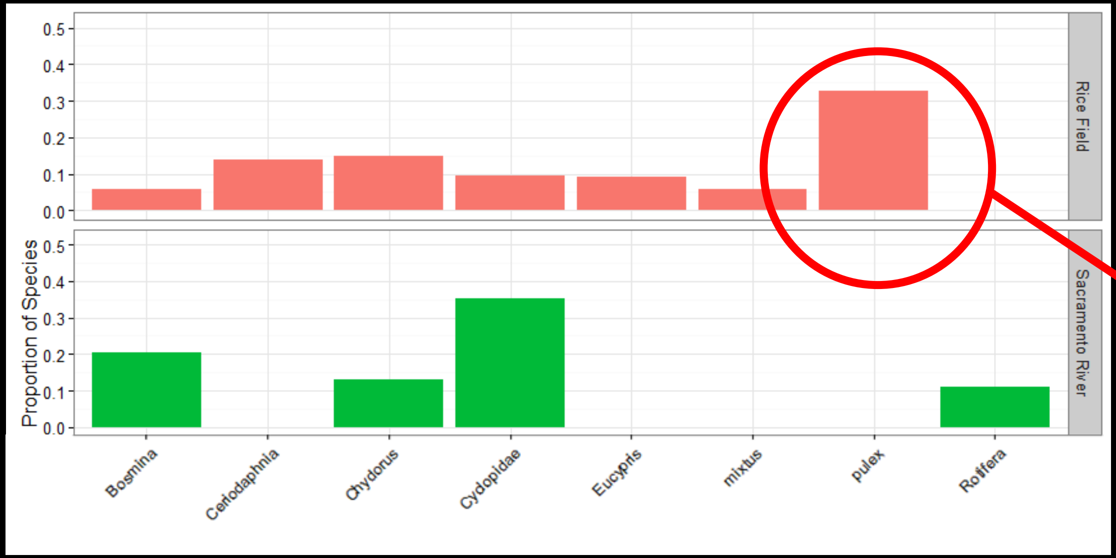
Without Fish

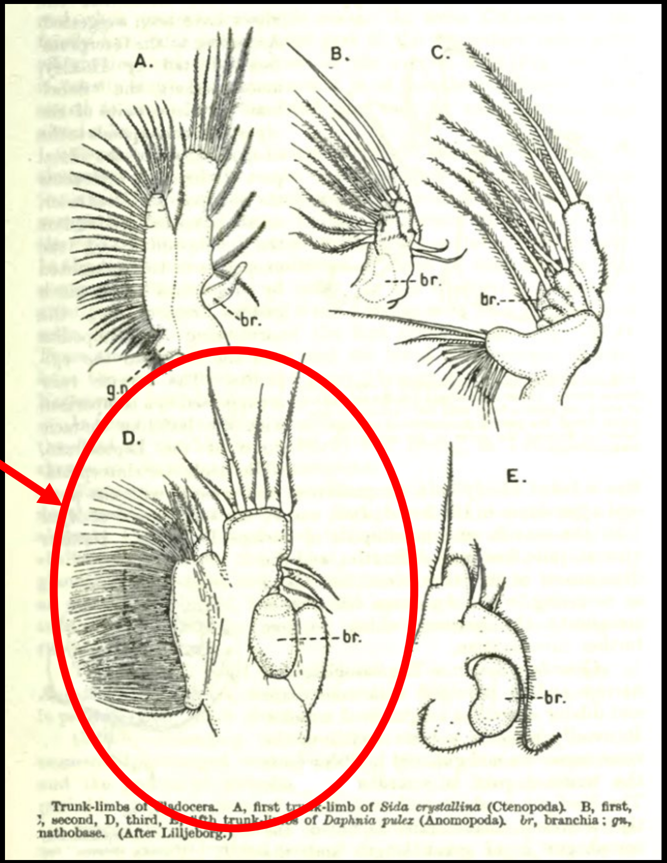
With Fish



Brooks and Dodson 1965

Food Web Composition





Cladocerans are Indicators of Off-Channel Habitats

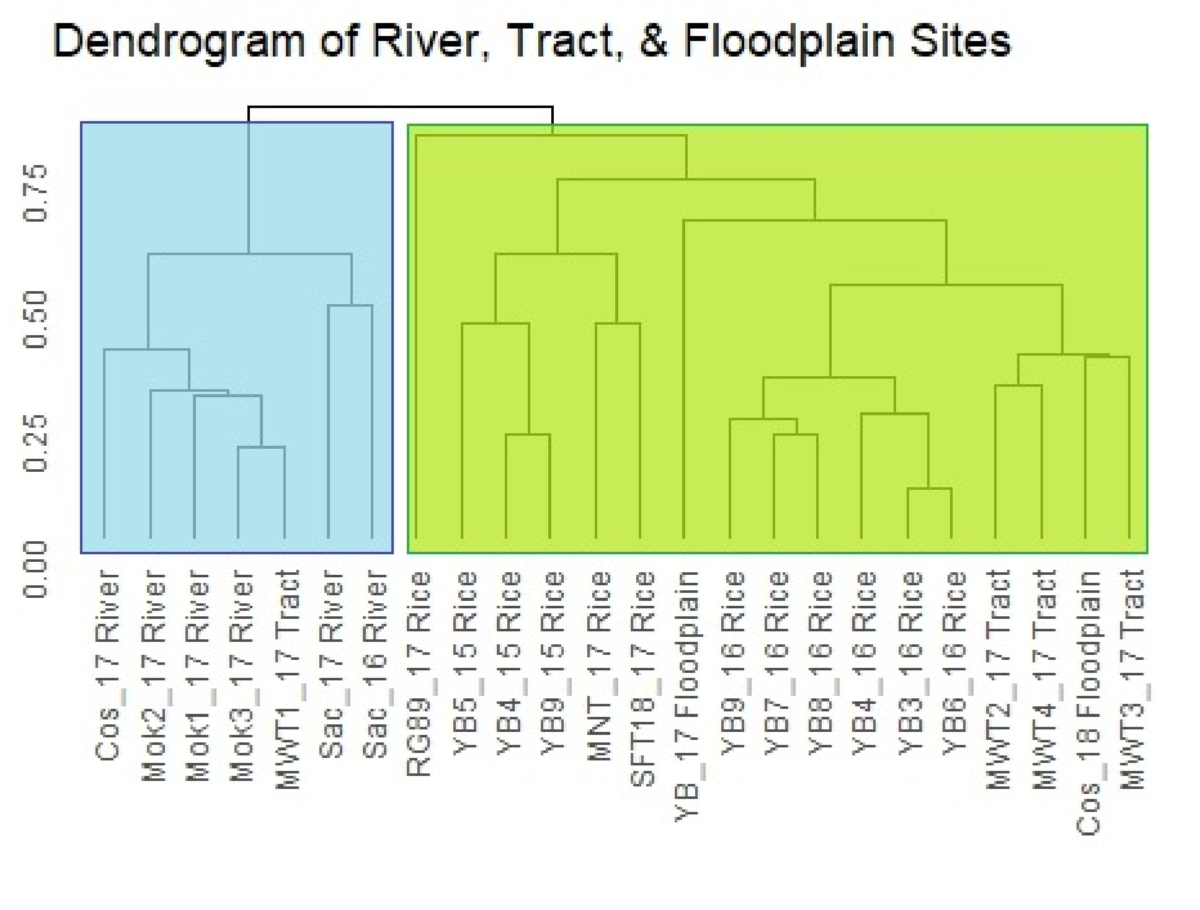
Off-Channel Habitat				River Habitat			
Species	Specificity	Fidelity	P-value	Species	Specificity	Fidelity	P-value
D. pulex	0.99	1.0	0.0001	*Ilyocryptus sp.*	0.74	0.67	0.043
Rotifera	0.98	1.0	0.0005				
Simocephalus sp.	0.96	1.0	0.0001				
Acanthocyclops sp.	0.96	1.0	0.0001				
Bosmina sp.	0.95	1.0	0.0007				
Ceriodaphnia sp.	0.95	1.0	0.0013				
Calanoid sp.	0.90	1.0	0.0070				
D. mendotea	0.99	1.0	0.0020				

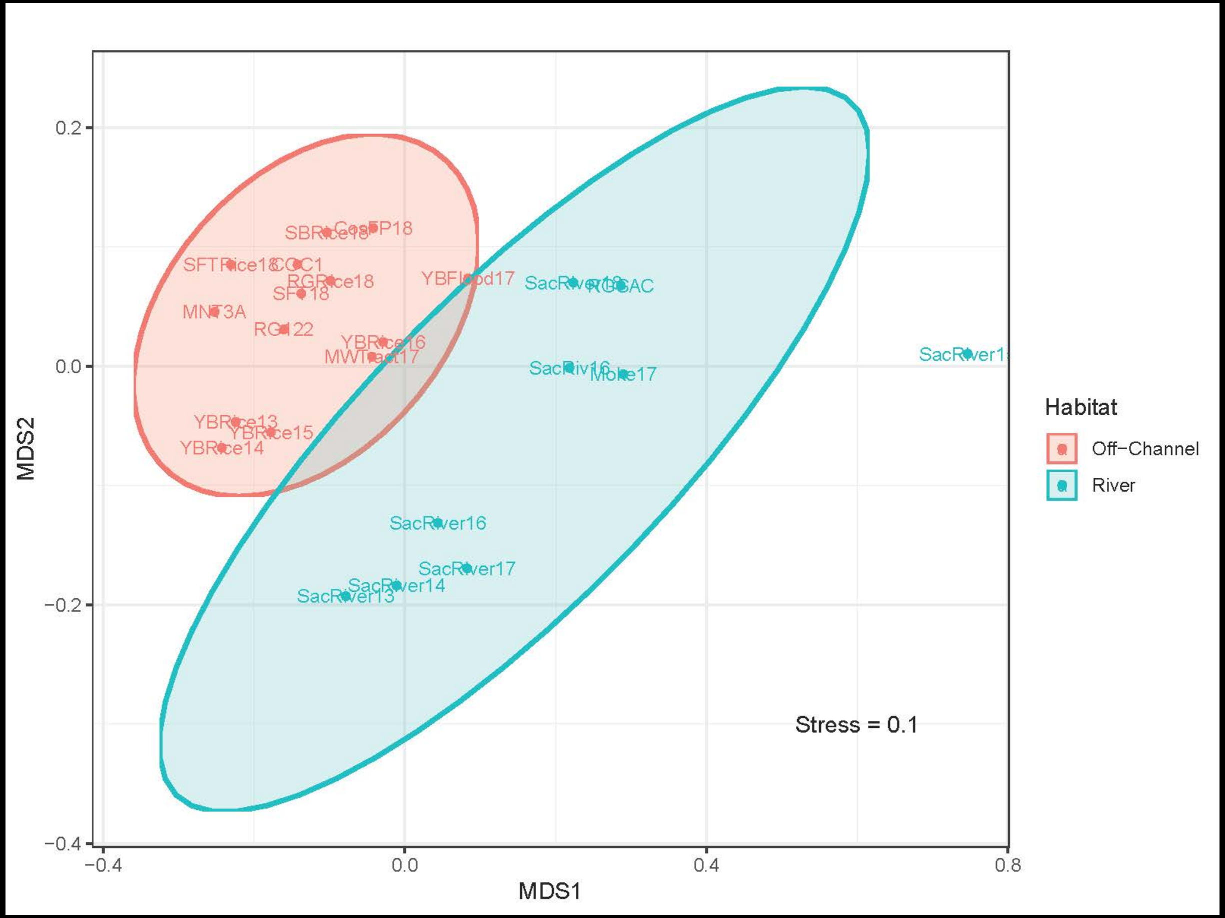
Corline et al. 2020

Specificity-How good a indicator the species is for the site group. Ex. We found D. pulex so we can be pretty certain that this sample is from a off-channel site.

Fidelity-Probability of finding the species in the said group. Ie if I go to a off-channel habitat what is my probability of finding D. pulex.

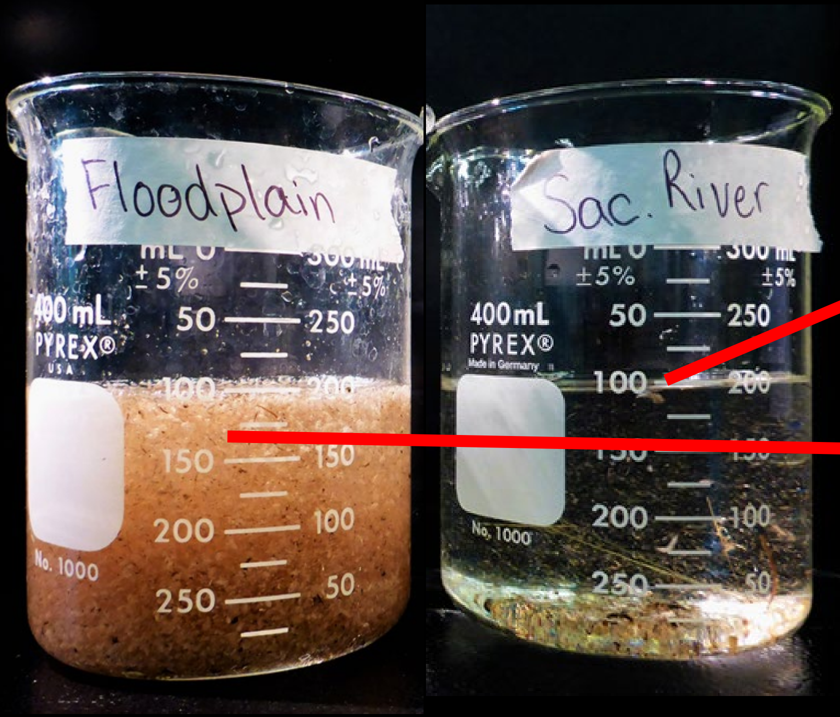
Similar Off-Channel Communities

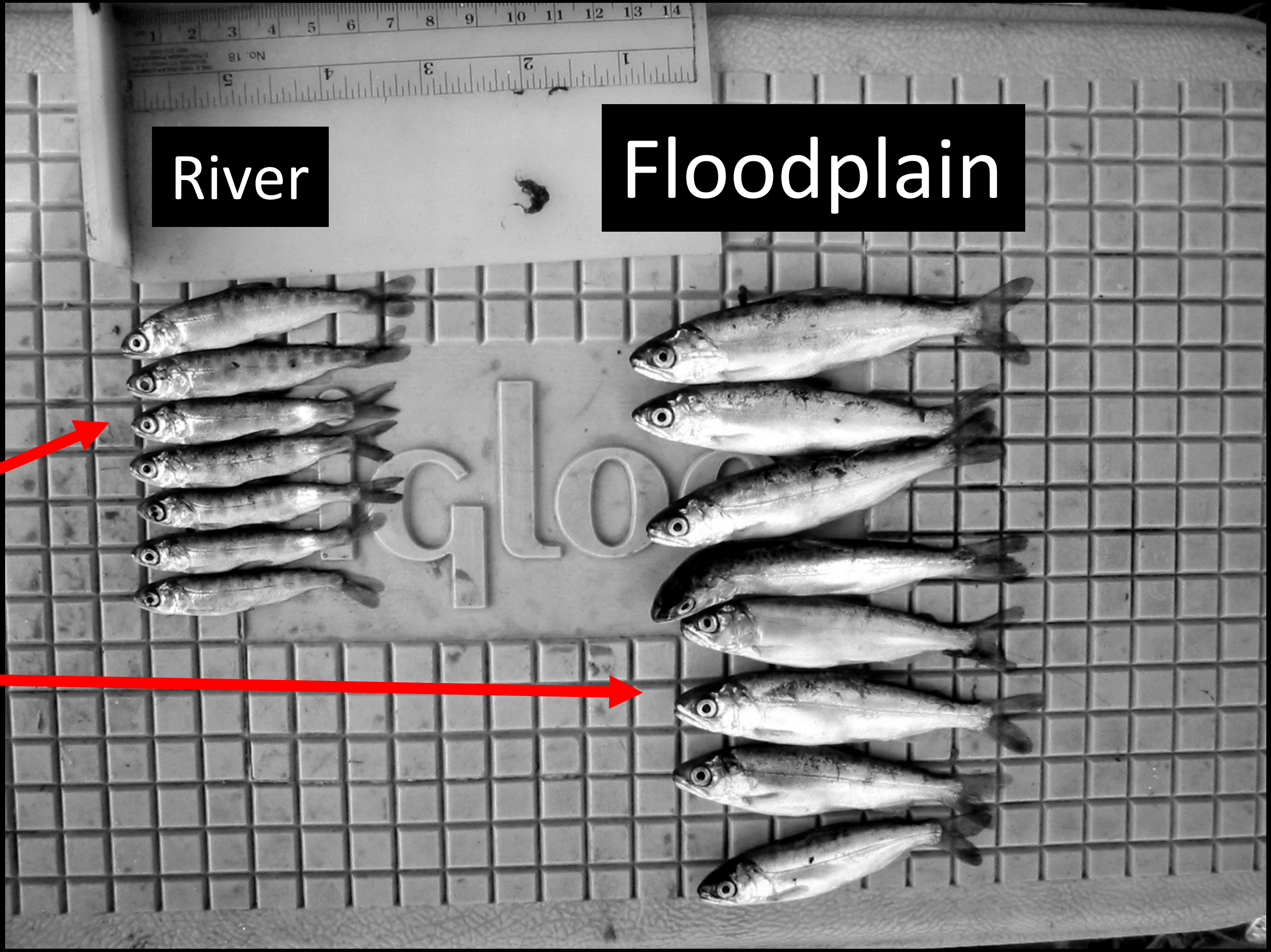




You Are What You Eat

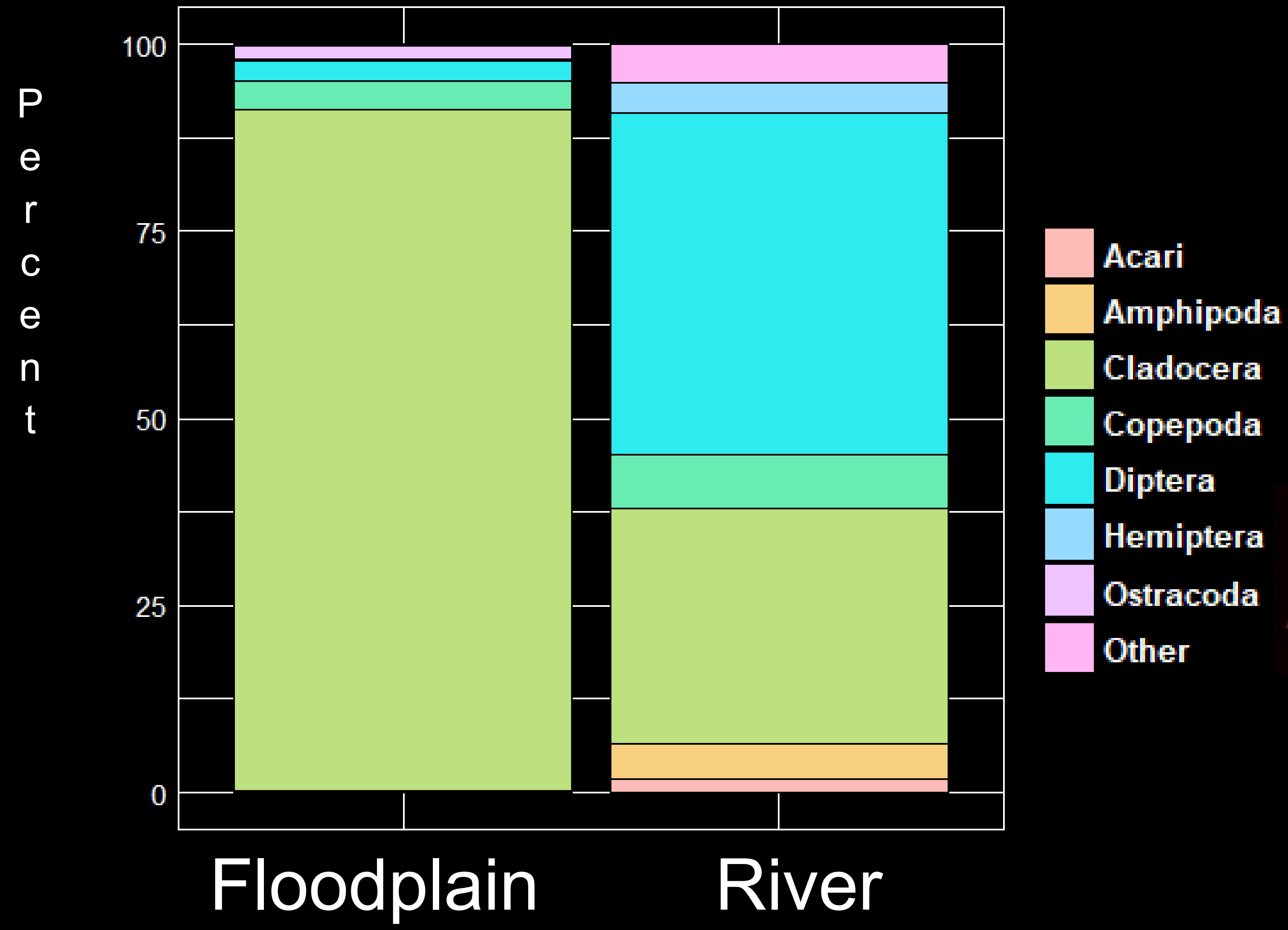
- Contents from a single salmon
  - ~1200 individual cladocerons





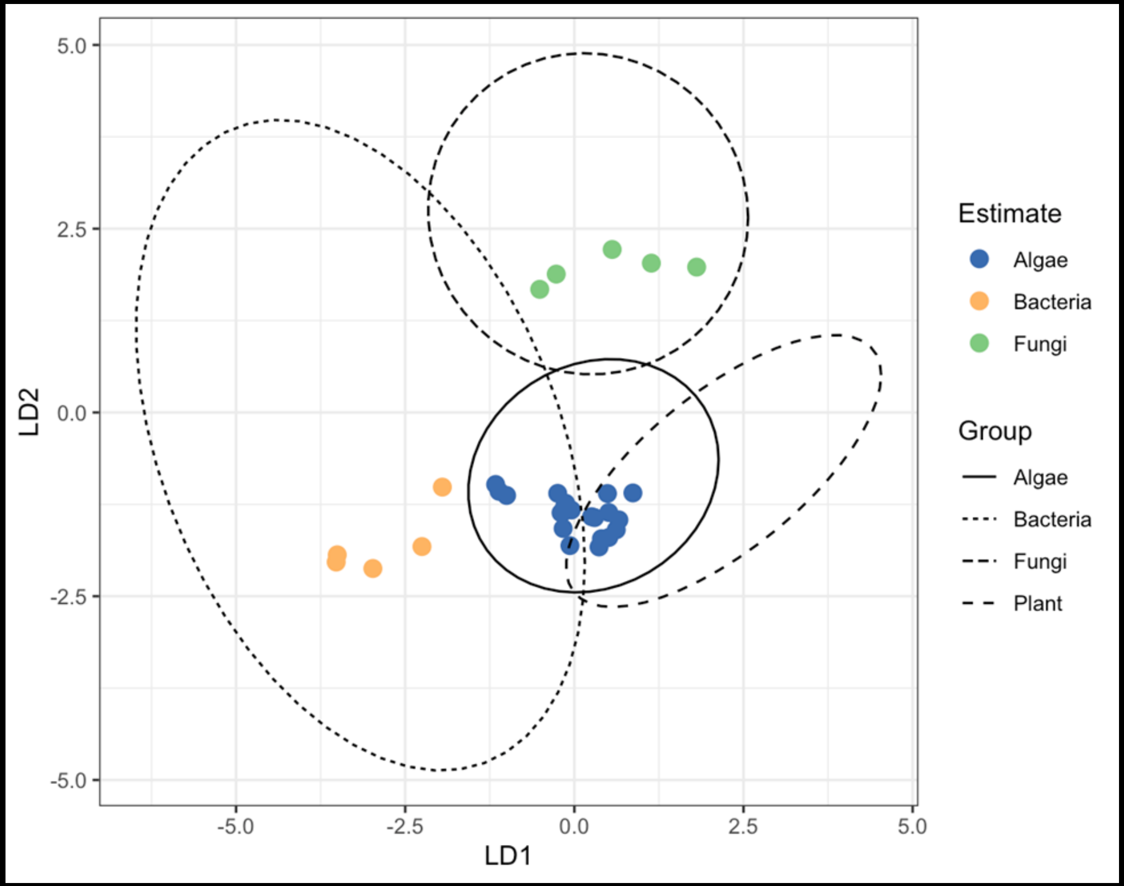
Jeffres et al. 2008

Stomach content of salmon (2014-16)

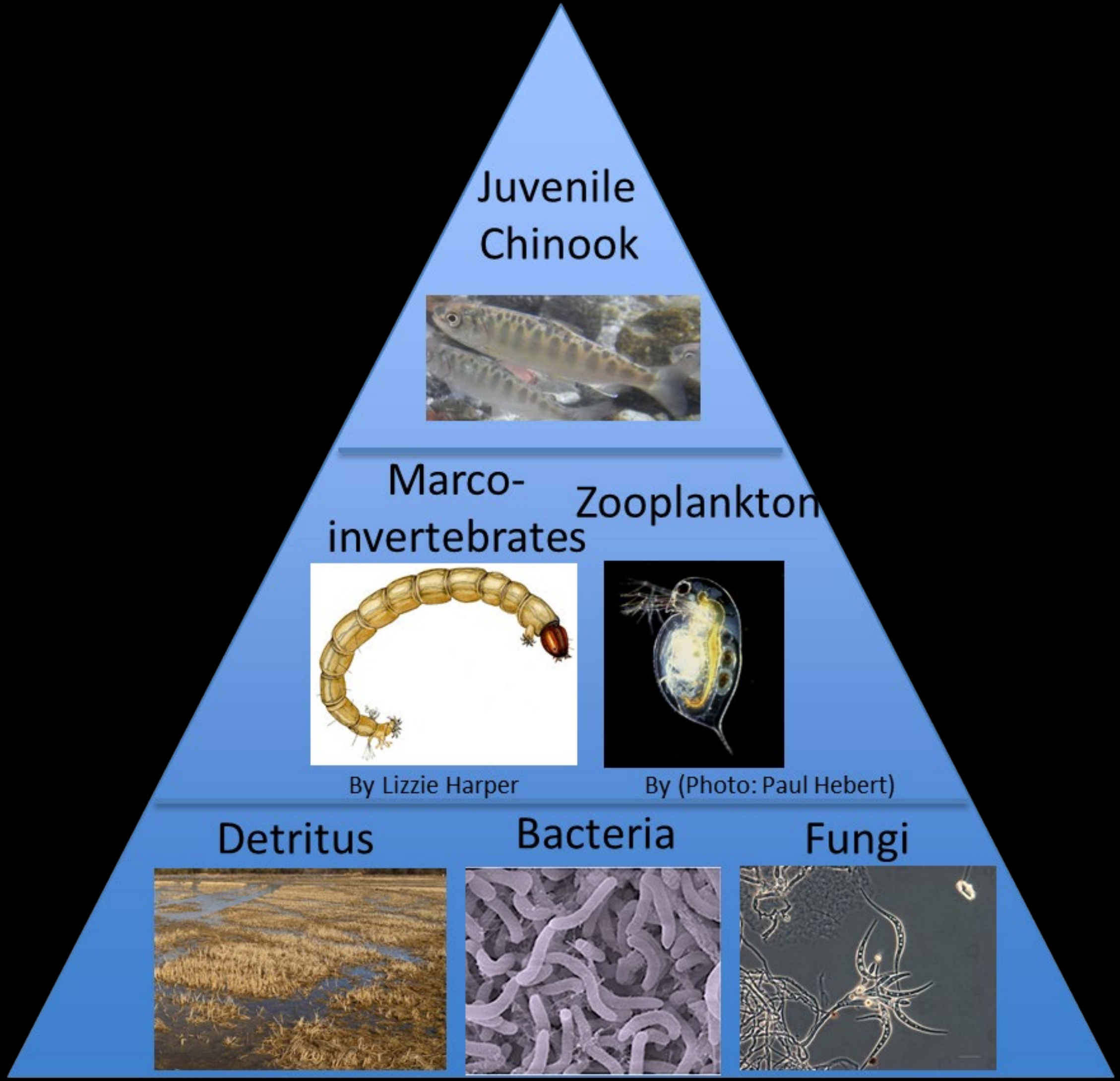


You Are What You Eat

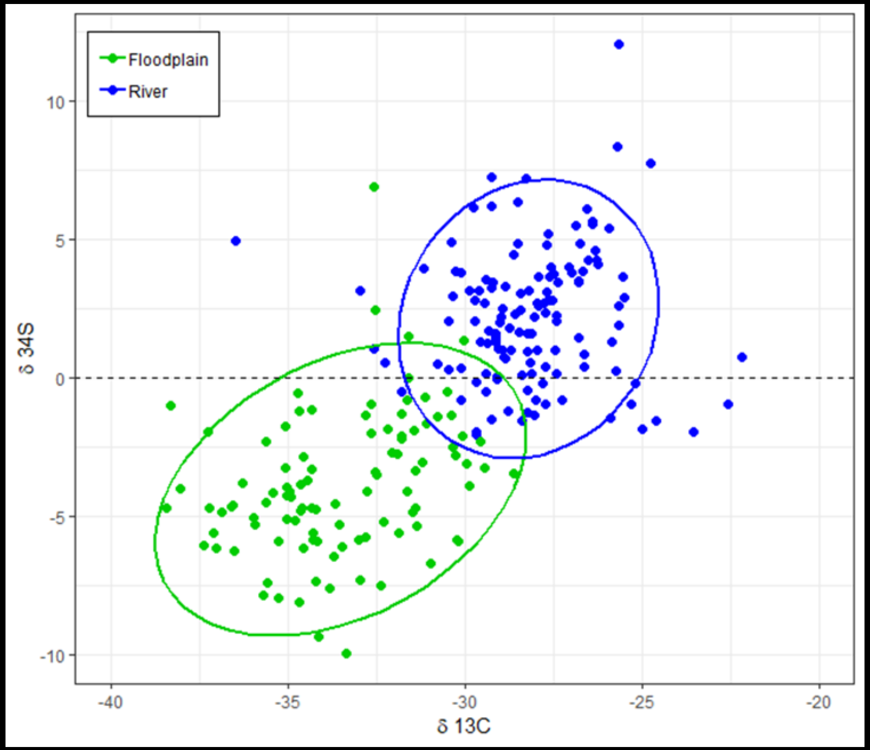
Dietary sources of amino acids in juvenile Chinook Salmon in CV habitats



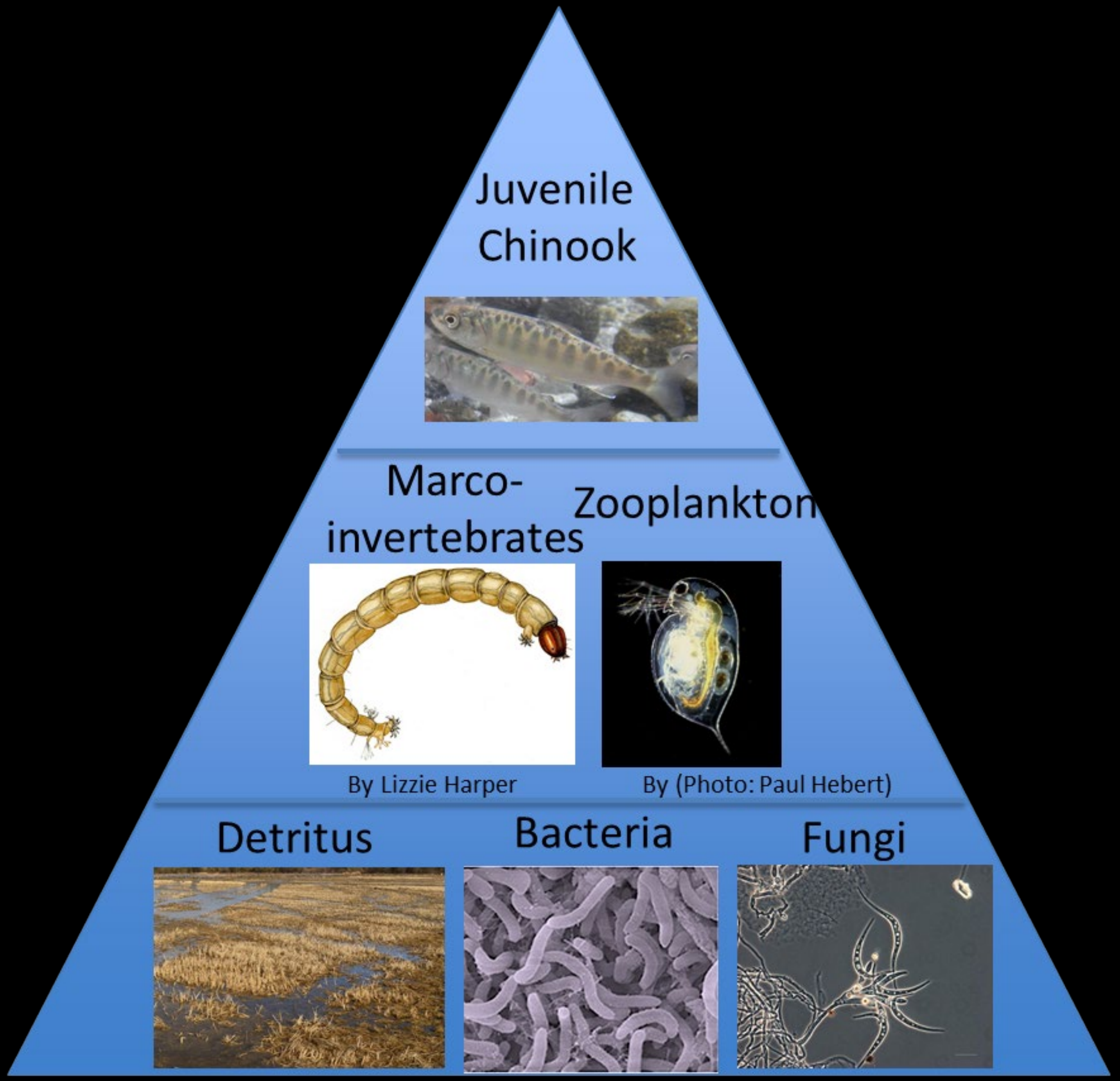
B. Nakamoto unpublished data



You Are What You Eat



Bell-Tilcock et al. in press



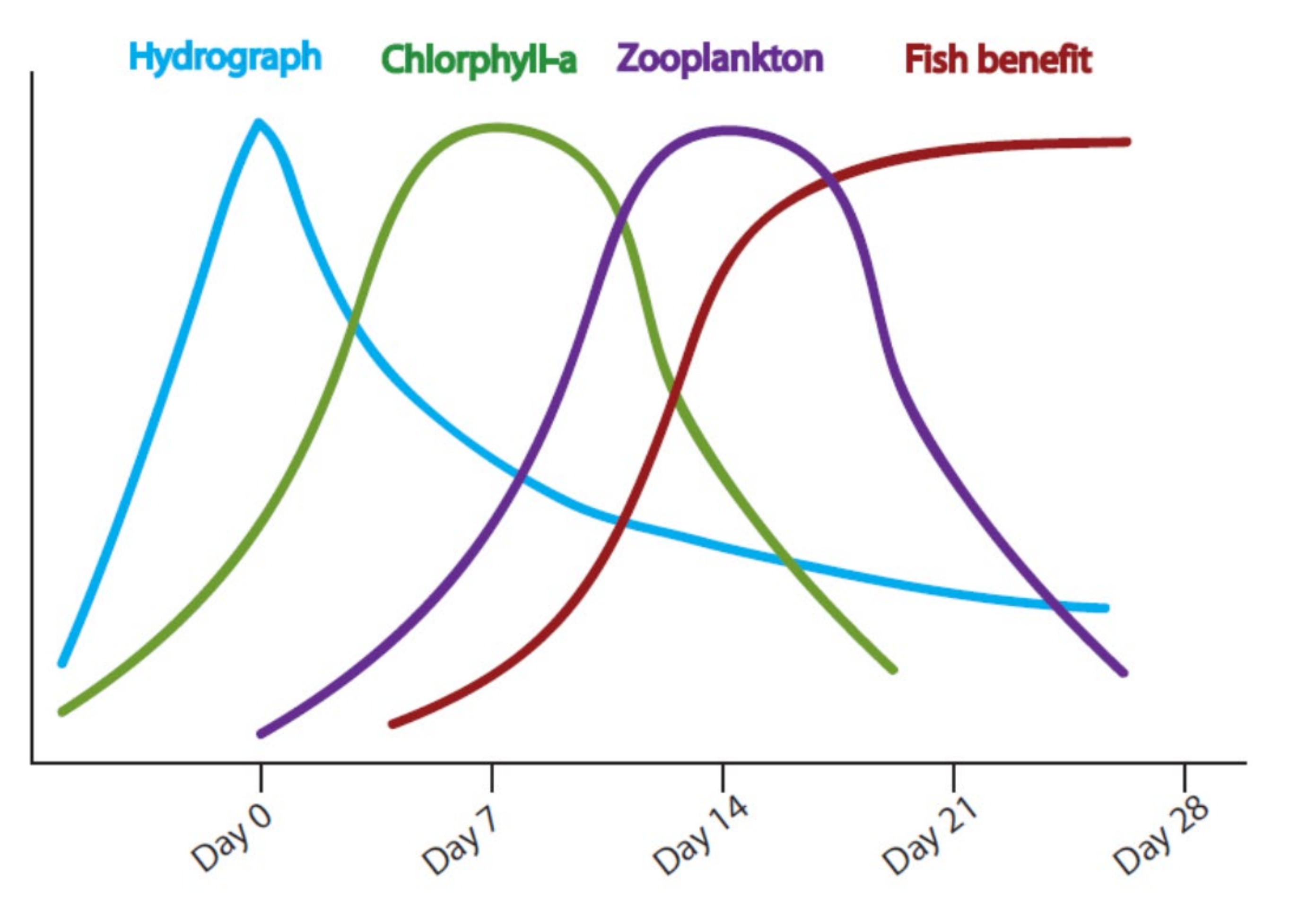
Food Web Considerations

- Timing
  - When flooding happens
- Duration
  - How long a flood lasts
- Magnitude
  - Volume of river discharge

Figure from Herbold et al. 2018

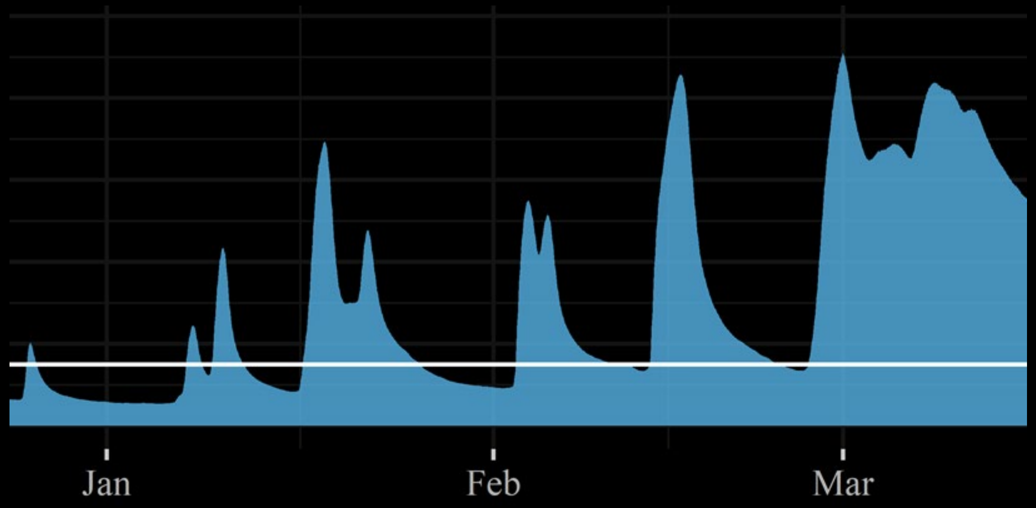
Food Web Considerations

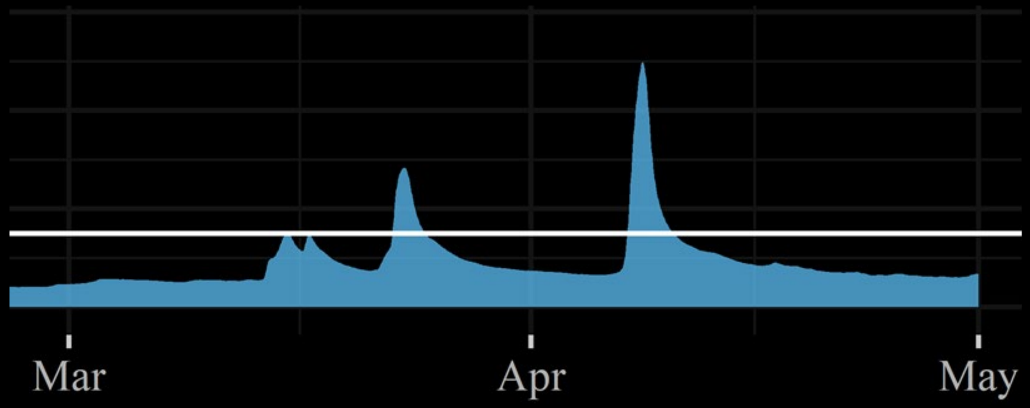
- Timing
  - When flooding happens
- Duration
  - How long a flood lasts
- Magnitude
  - Volume of river discharge



Food Web Considerations

- Timing
  - When flooding happens
- Duration
  - How long a flood lasts
- Magnitude
  - Volume of river discharge





Spring 1851

Satellite Imagery by Matt Clark

April 1, 2017

NASA.gov

Future of Food Webs

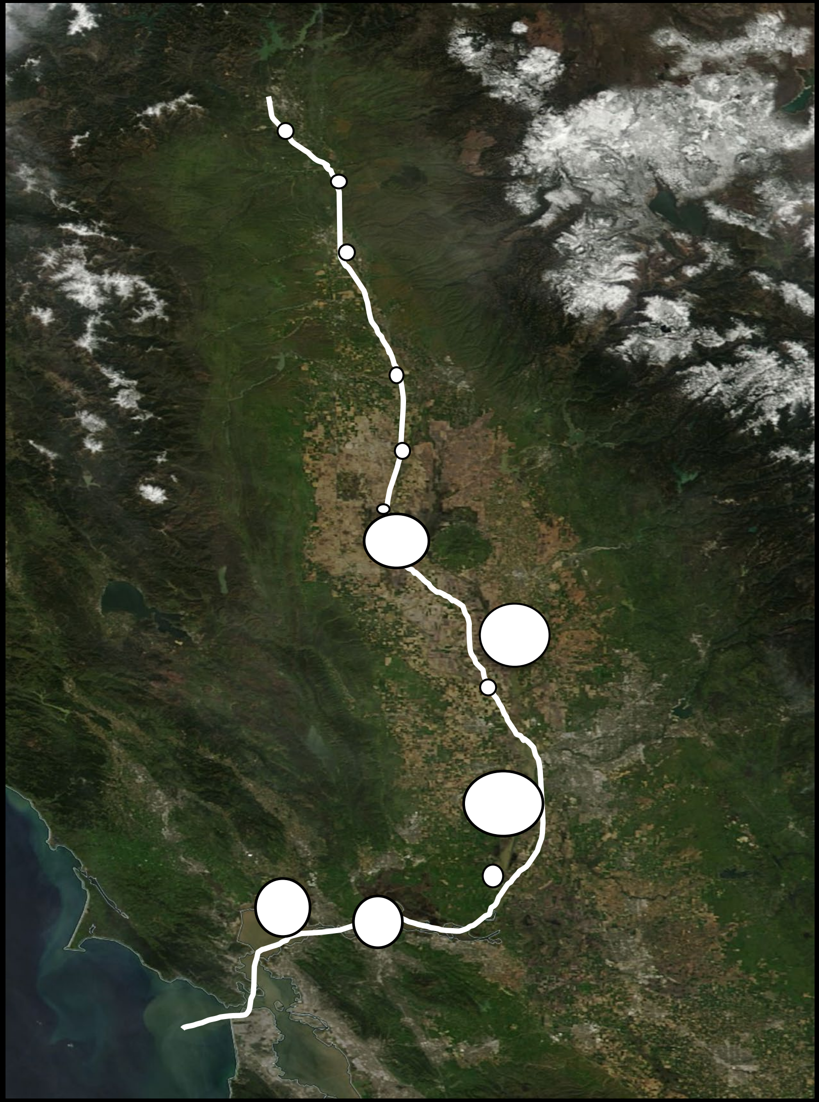
- Reconciled System
  - We are not going back
  - We ultimately control the system and decide how it functions
  - Restoration of processes

Future of Food Webs

- Reconciled System
  - We are not going back
  - We ultimately control the system and decide how it functions
  - Releases
  - Restoration of processes
- Diversity of habitat types
  - “natural” floodplains
  - Multi-benefit floodplains

Future of Sac Valley Food Webs

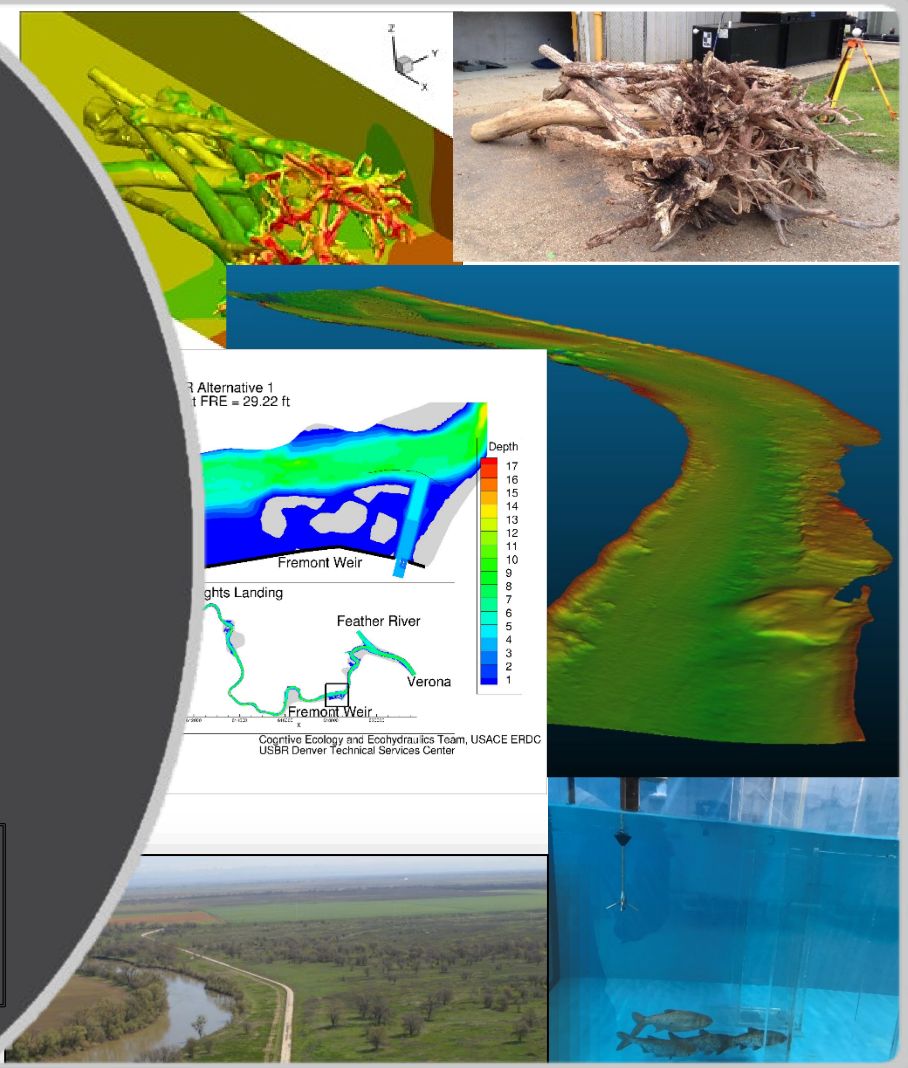
- Reconciled System
  - We are not going back
  - We ultimately control the system and decide how it functions
  - Releases
  - Restoration of processes
- Diversity of habitat types
  - "natural" floodplains
  - Multi-benefit floodplains
- String of Pearls
  - Connecting habitats throughout the system



Questions ?

Juvenile passage: fish movement onto the floodplain

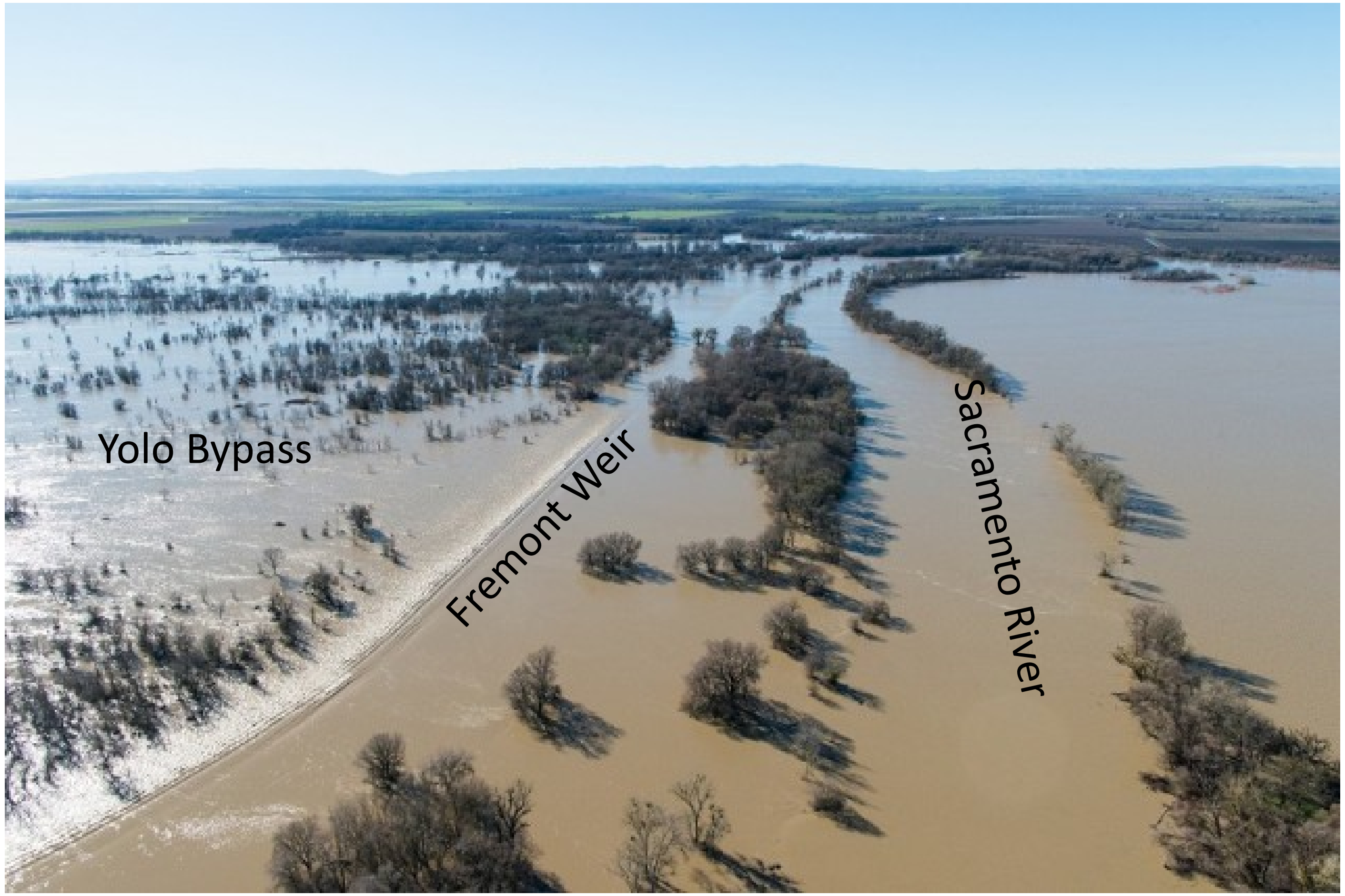
Dave Smith
USACE-ERDC



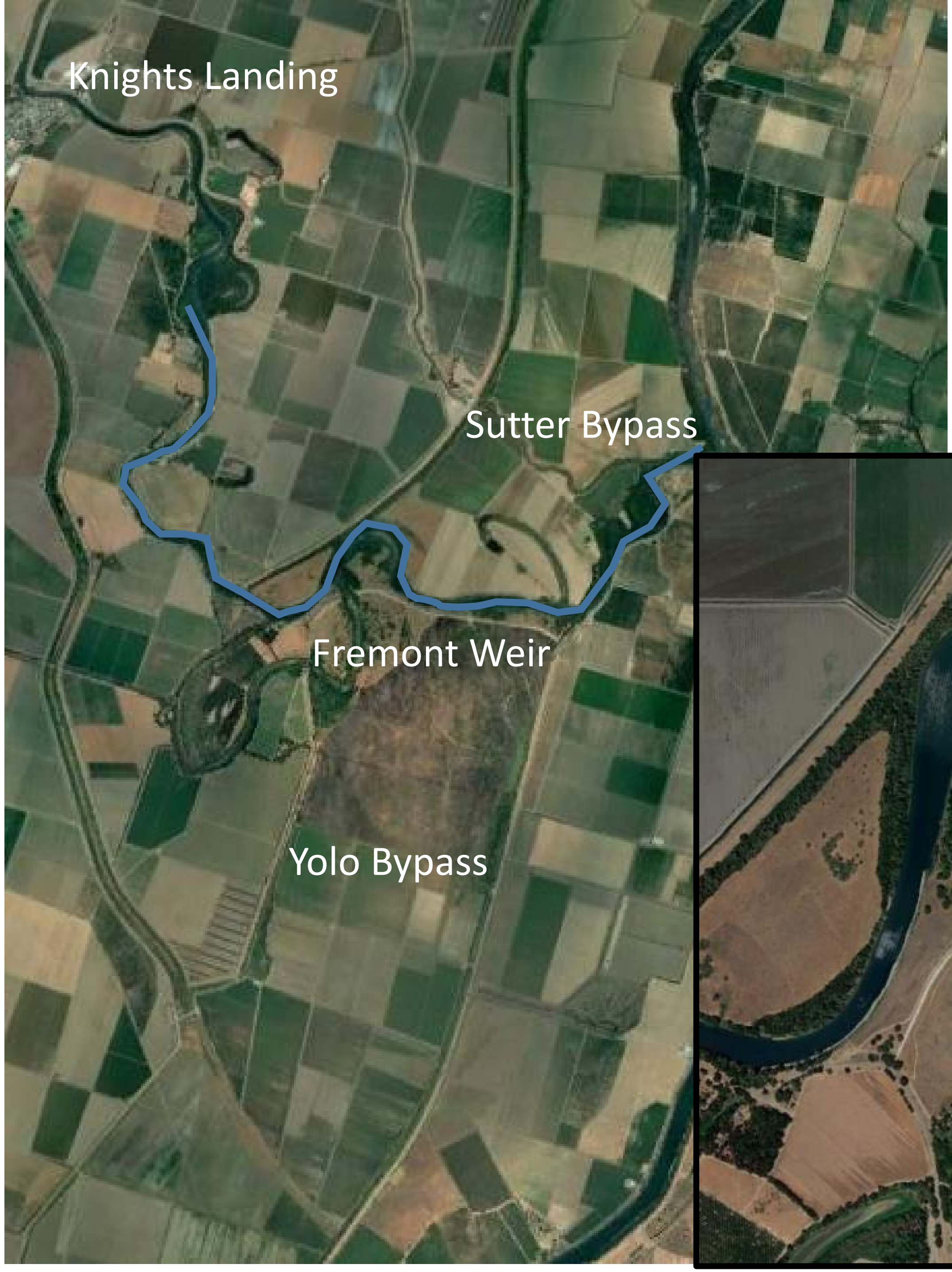
DISTRIBUTION STATEMENT HERE, e.g.,
Distribution A: Approved for public release. or
Distribution C: Distribution authorized to U.S. Government Agencies and their contractors; Vulnerability Information; January 2015. Other requests for this document shall be referred to US Army ERDC, ATTN: CEERD-GSV, 3909 Halls Ferry Rd., Vicksburg, MS 39180-6199.

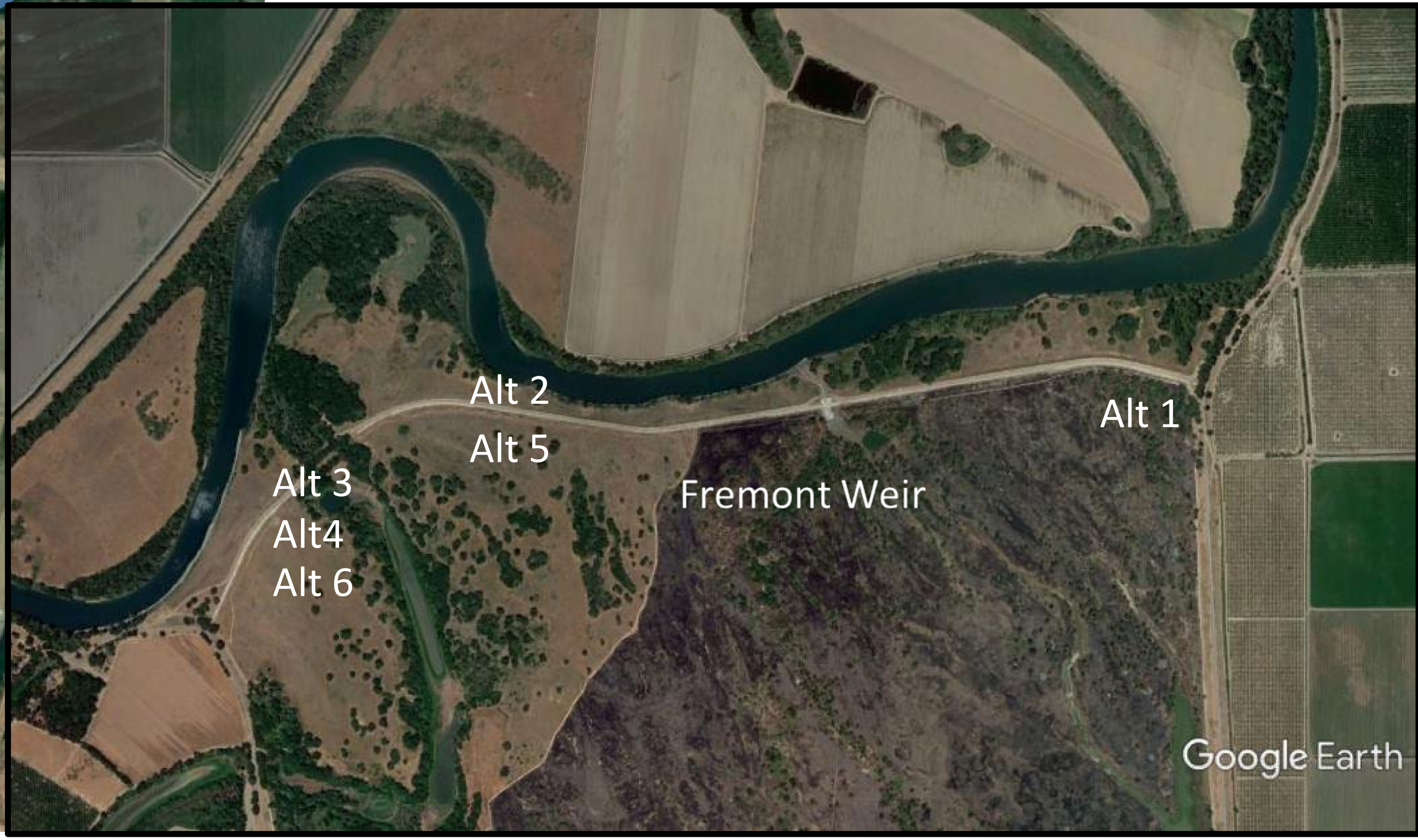
Project Objectives

- Use measured fish and hydraulic data to evaluate future conditions with a entrainment notch in place.
- Estimate <u>relative</u> entrainment for notch scenarios and alternatives and validate against other studies in Sacramento River.
- Describe notch features that influence entrainment (size, orientation, location, flow etc).
- Develop information for next phase (engineering and evaluation of accuracy and precision).



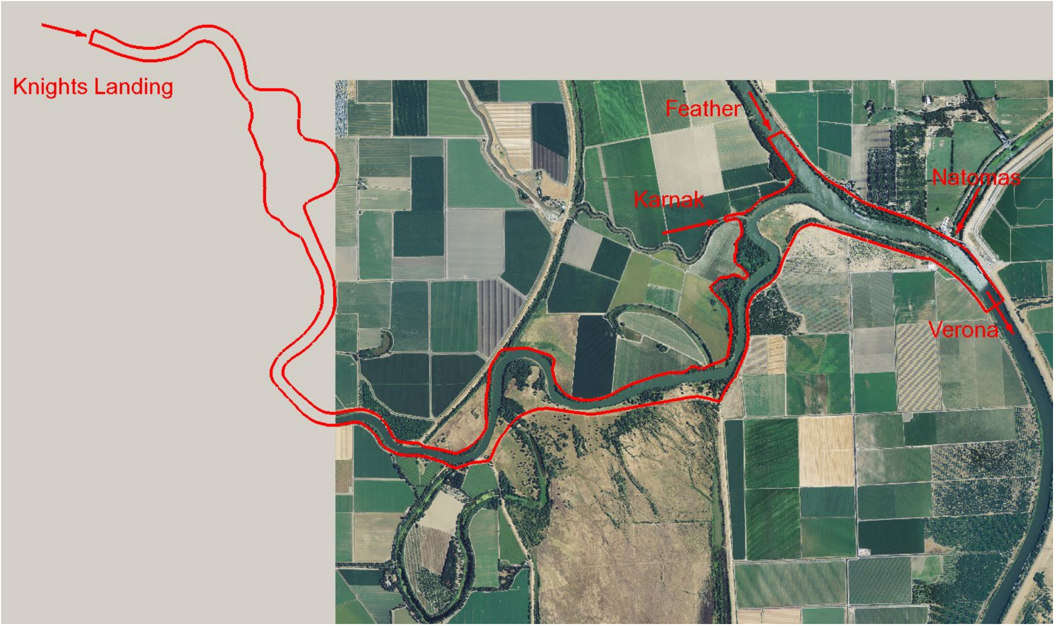
Alt 1. East 6,000 cfs Intake
Alt 2. Central 6,000 cfs Intake
Alt 3. West 6,000 cfs Intake
Alt 4. West 3k Intake - Managed Flow Capped at 3,000 cfs
Alt 5. Central Multi-Gate, 3,400 cfs
Alt 6. West 12,000 CFS, Intake

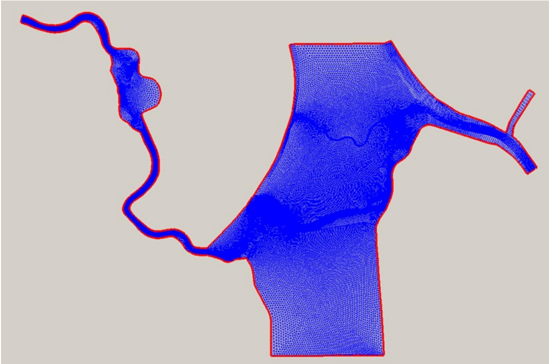




Model Domains

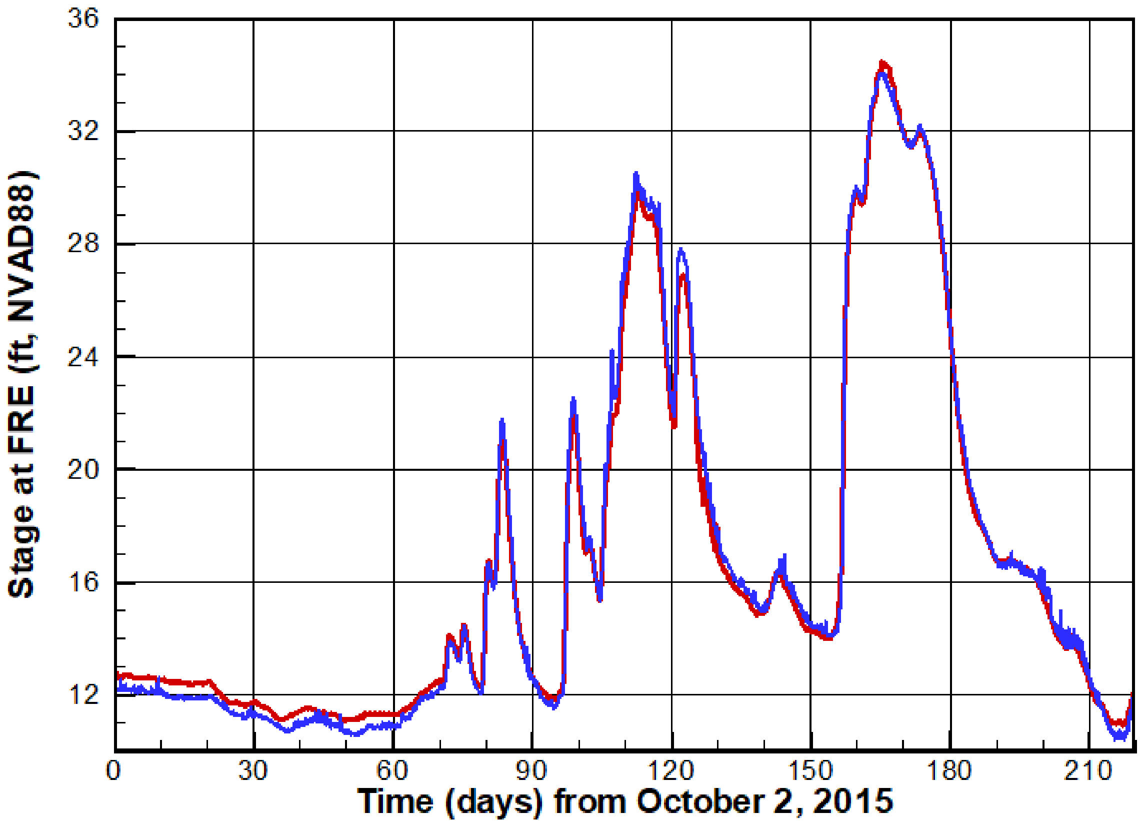
- Spatial and temporal overlap with fish telemetry data
- 2015 was contained within levees and did not contain Sutter or Yolo Bypass
- 2016 included Sutter inflows and Yolo outflows
- Boundary conditions provided by TUFLOW

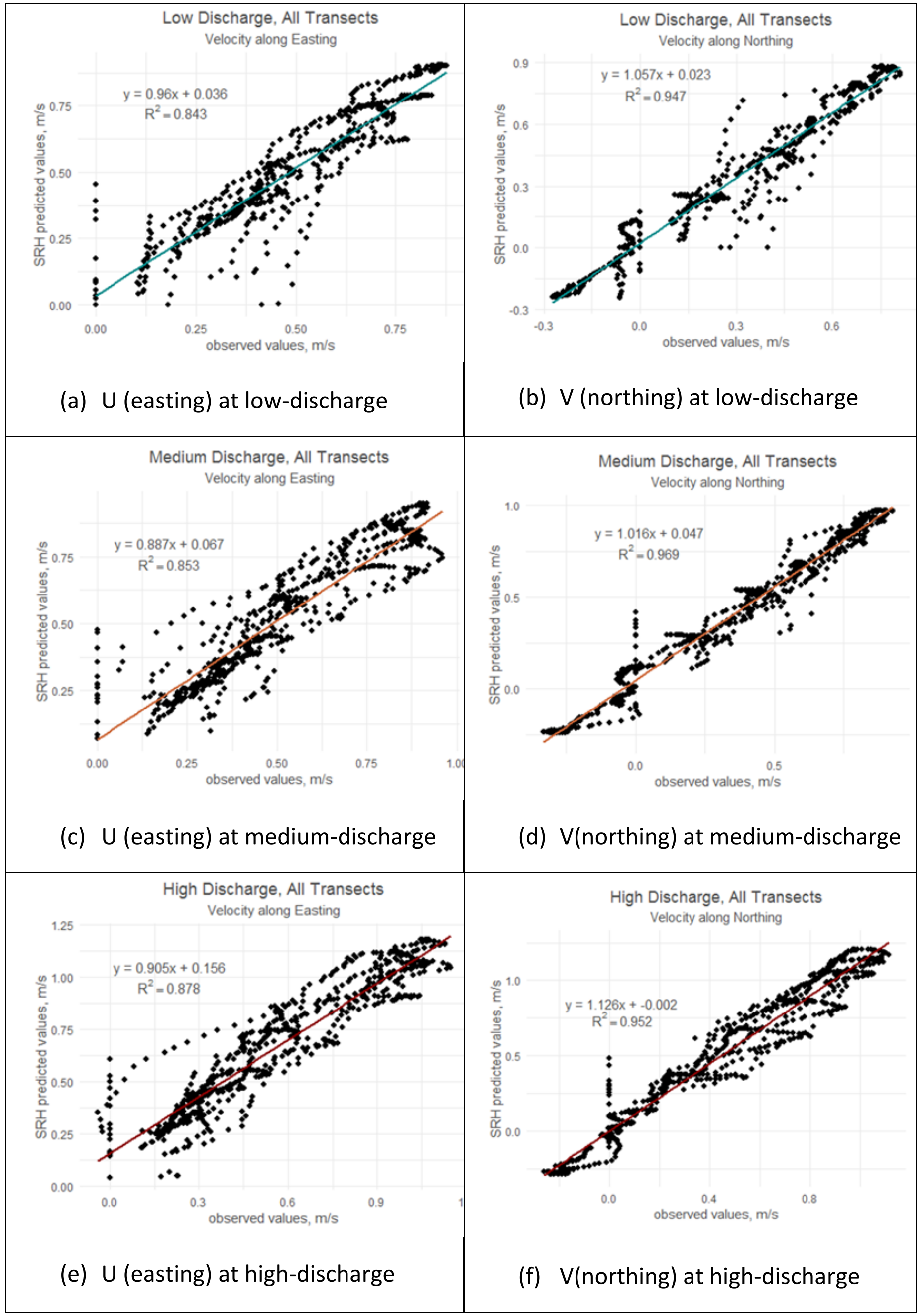




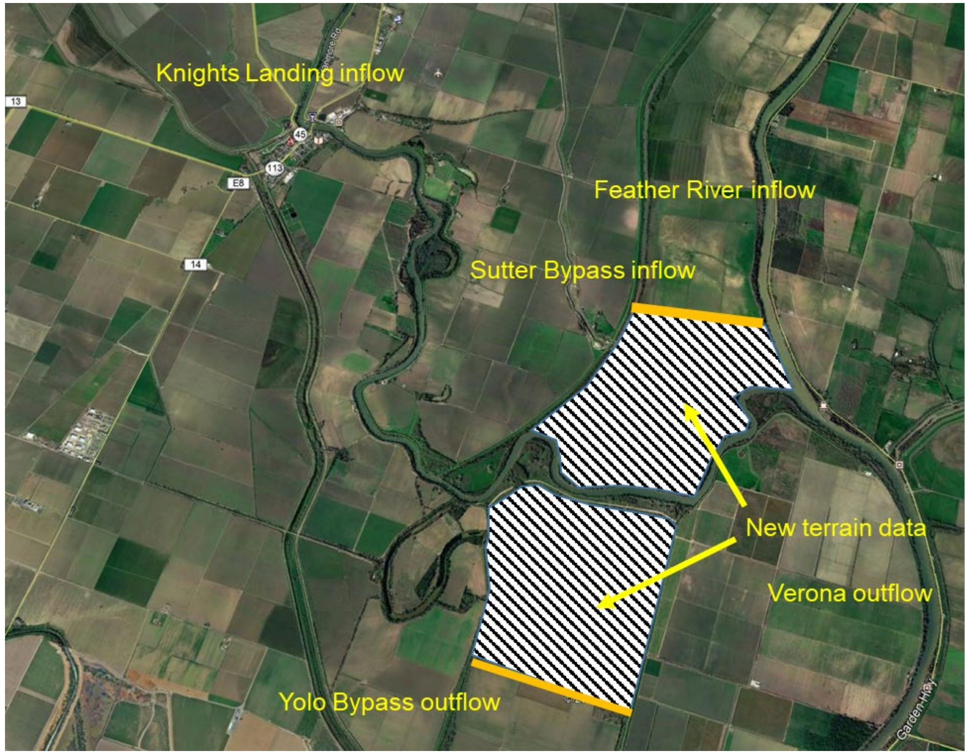
2D model calibration and validation

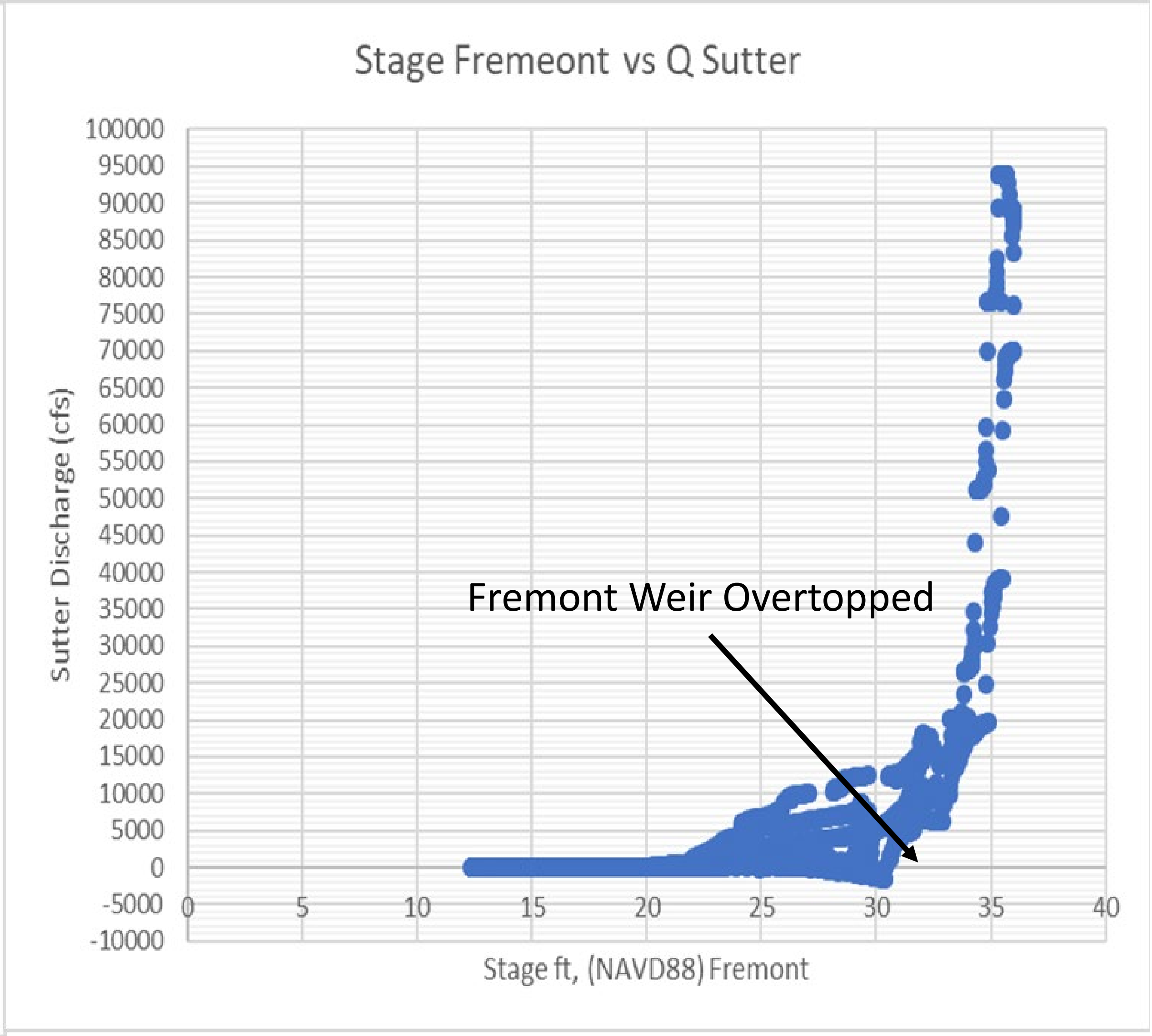
- Data for stage and velocity used





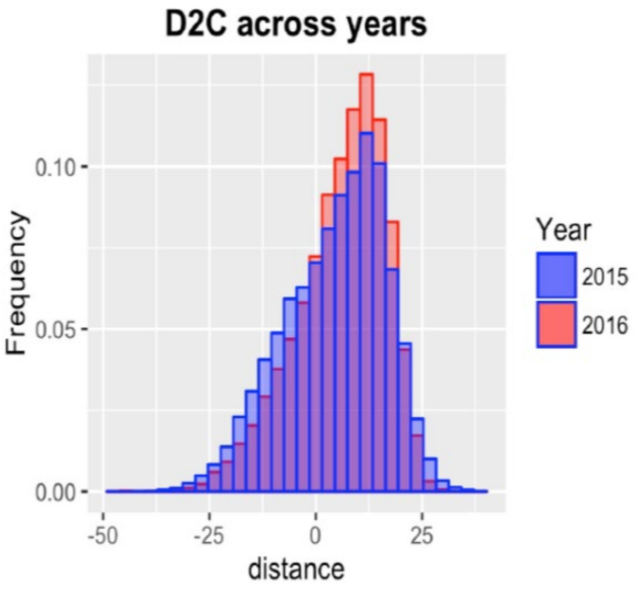
2016 Sutter Influence

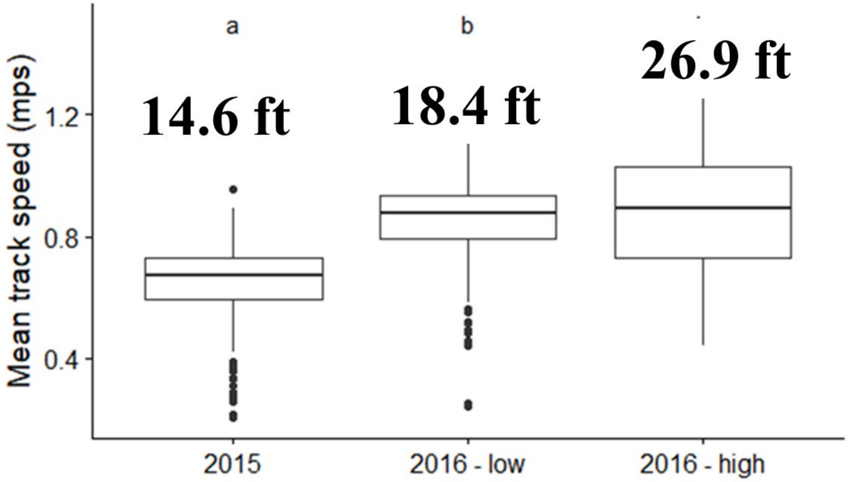


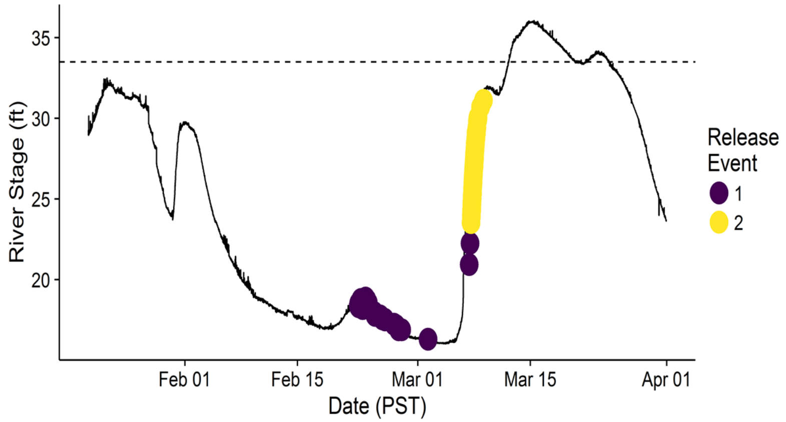


Fish telemetry

- 2015 (one release group) and 2016 (two release groups)
- 2015
  - 14.9 ft stage (low)
  - Late fall and winter Chinook
- 2016
  - 18.4 and 26.9 ft stage
  - Late fall Chinook
- Conclusions
  - Higher stage increases speed over ground
  - Fish are skewed toward the outside bend (D2C mean > 0)
  - Stage has small influence on spatial distribution





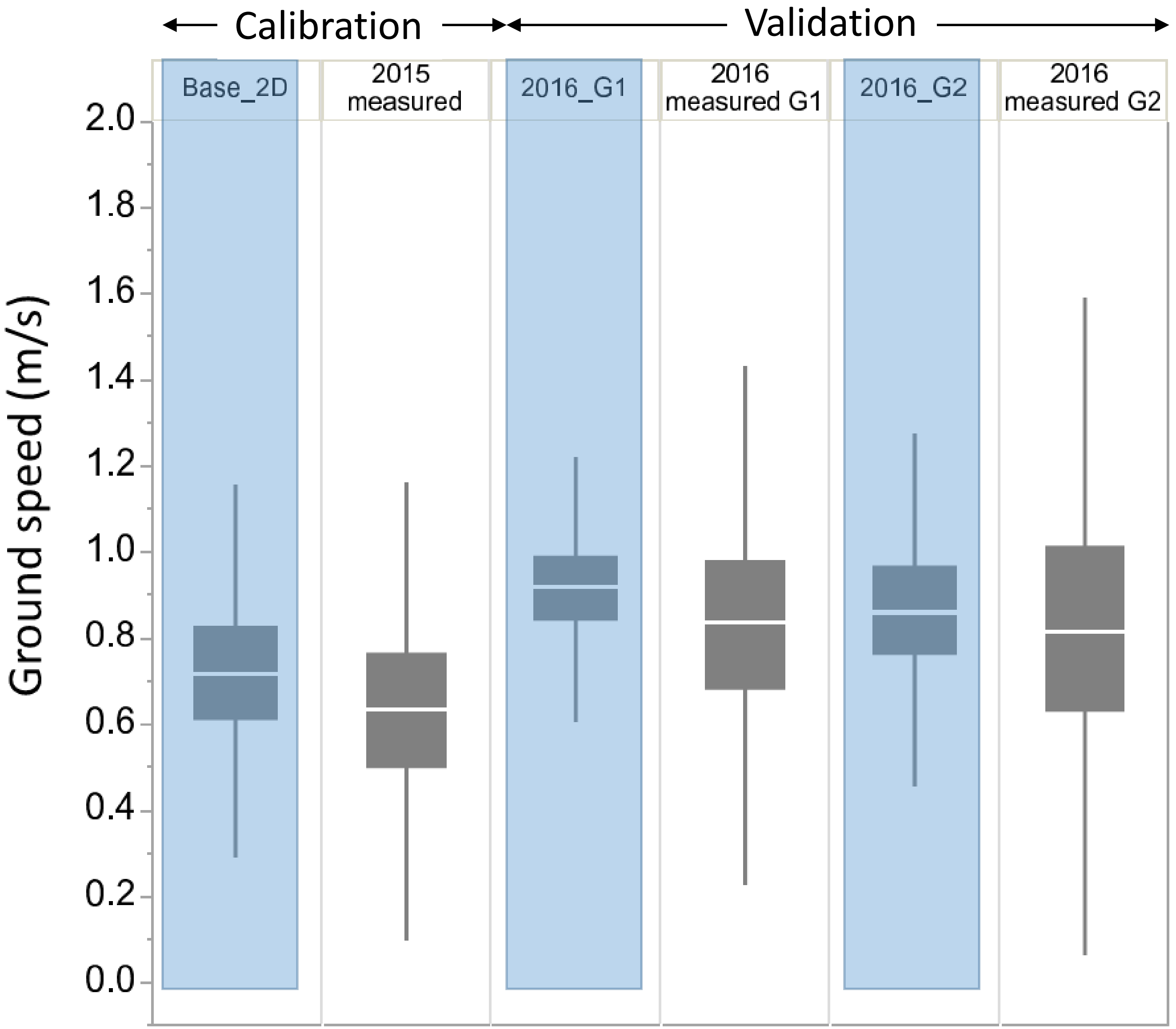


Calibration/Validation Approach

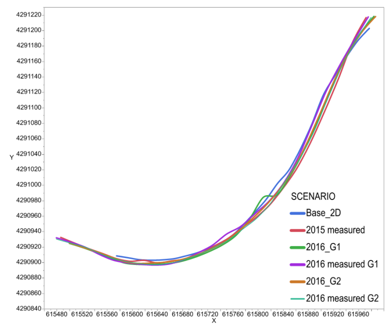
- Used 2015 telemetry and hydro data to calibrate to one stage (14.9 ft)
- Used 2016 telemetry data at higher stages to validate 2015 calibration
- Fish release/removal
  - 500 fish/run released at Knights Landing
- Ensemble development
  - Multiple runs with different behaviors
- Fish size/species
  - Fish size set at 124 mm, mean LFC/WC size in Steel et al (2017).
- Behavior rule
  - B1:Swim downstream at 1.5 BL/s ± σ
  - B2: Swim toward faster water, increased swim speed
  - B3: swim toward slower water (downstream direction), increased swim speed
- Stochasticity
  - Ornstein-Uhlenbeck (OU)
- Process
  - Compare measured Speed Over Ground, spatial distribution between measured and model and adjust stochasticity, behavior, and speed to match measured fish data
  - Calibrated model used B1 only with fixed OU coefficients

Results

- Speed Over Ground
- 2016 validation matched measured fish speed over ground
- No difference in measured ground speeds



Results – spatial distribution

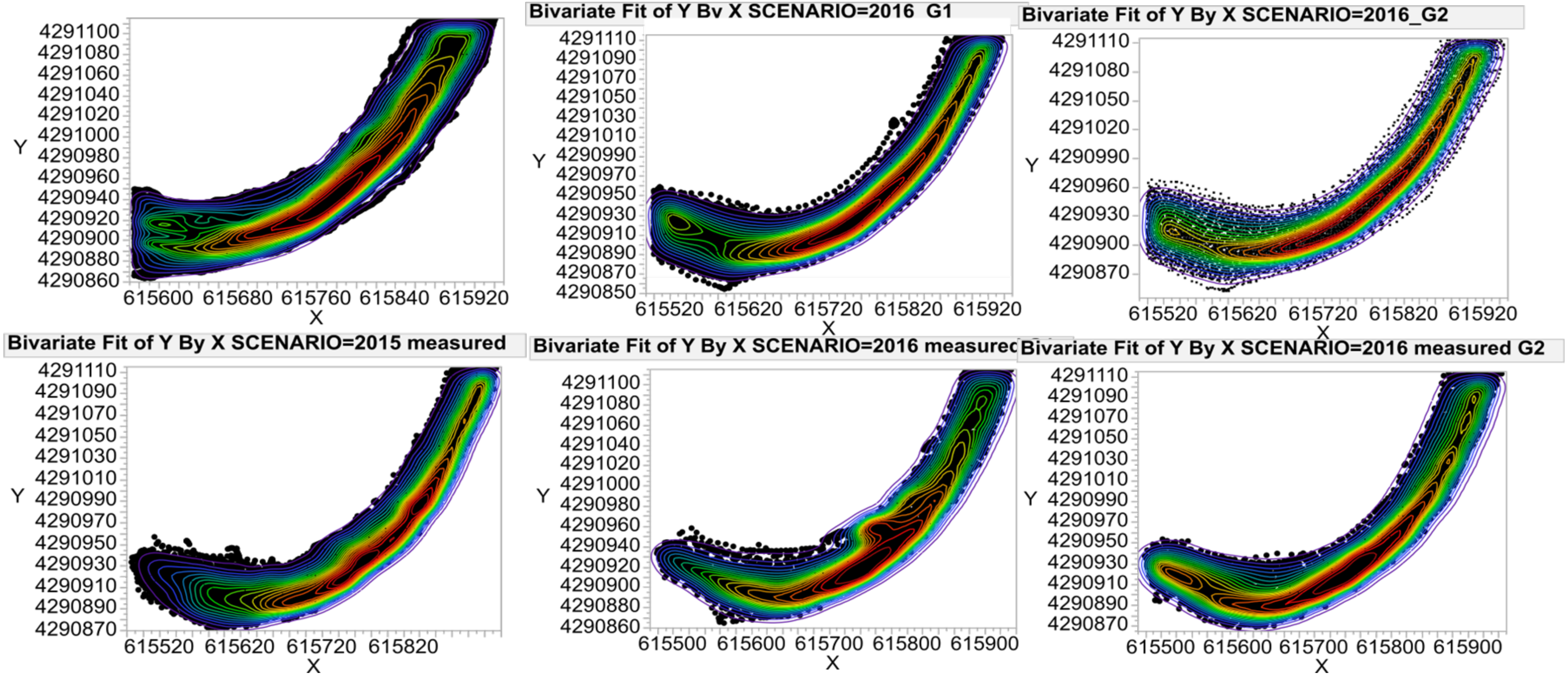


No measured difference in mean position

2015 | 2016_G1 | 2016_G2

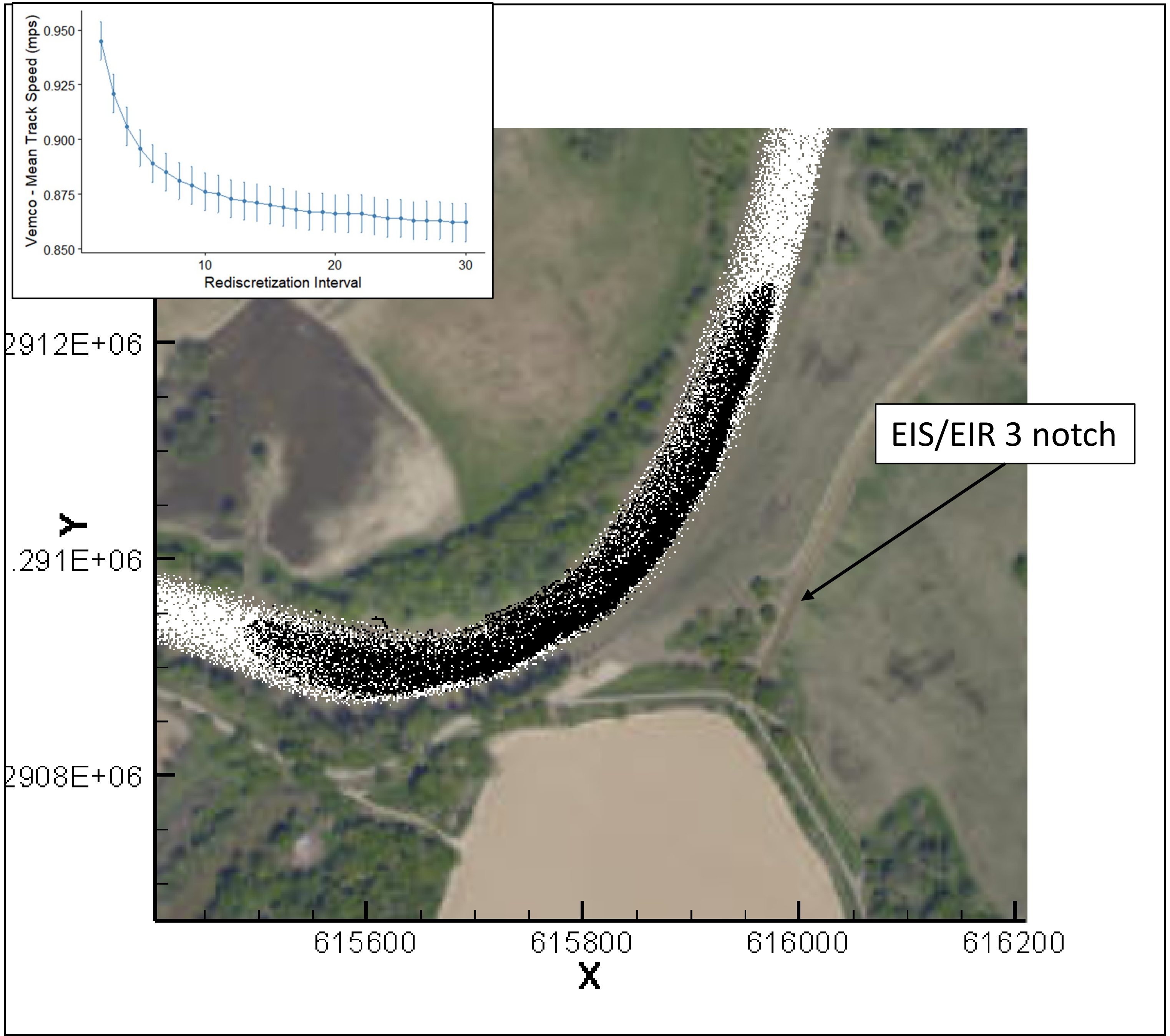
Modeled

Measured

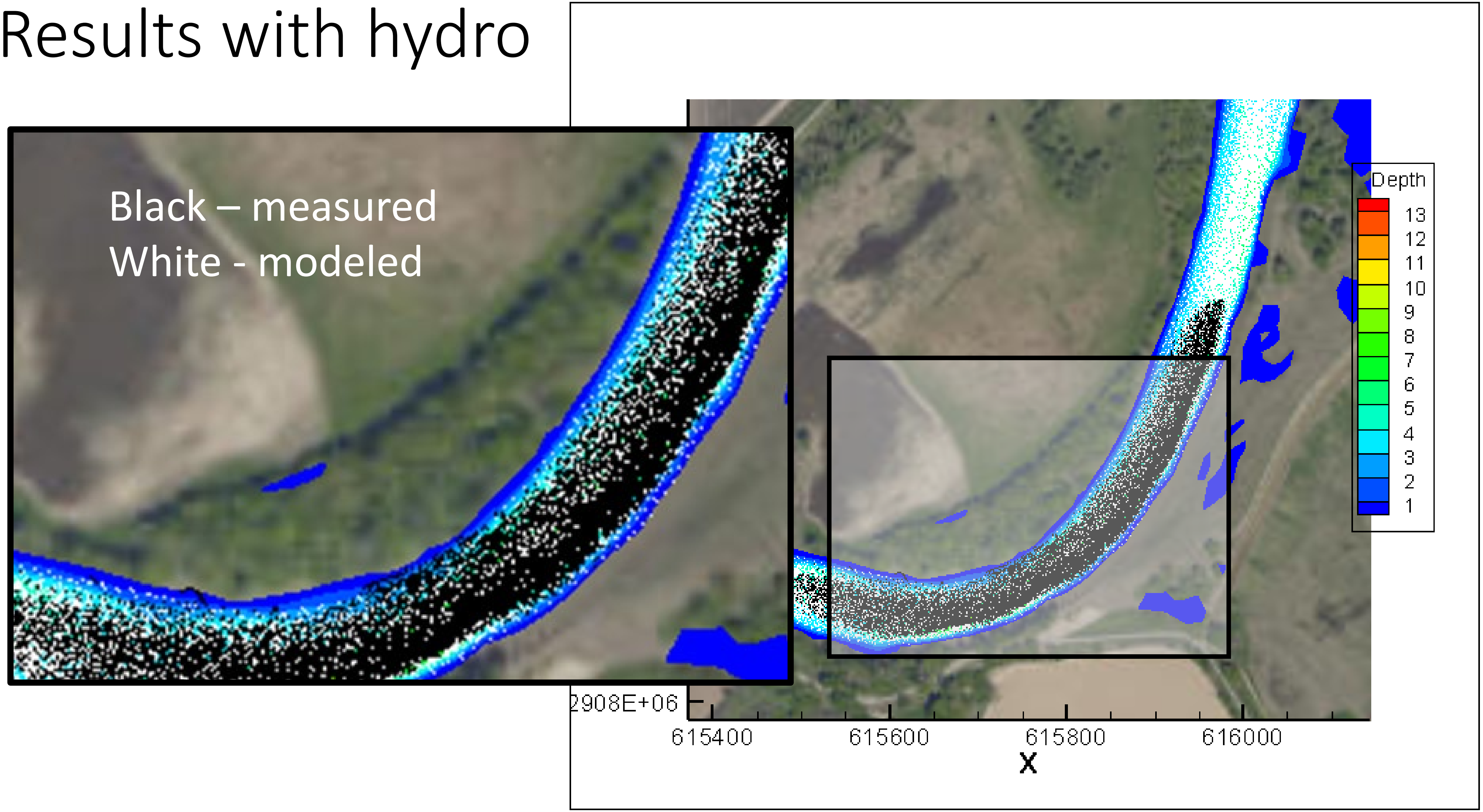


Results – spatial distribution

- Results represent cross channel fish distribution seen with measured fish
- 2015 final calibration shown in white points
- Both output at 20 seconds intervals
- Image is georeferenced (UTM Zone 10 N)
- Modeled points occupy wider channel cross section than measured
- Cross channel distribution well represented in model

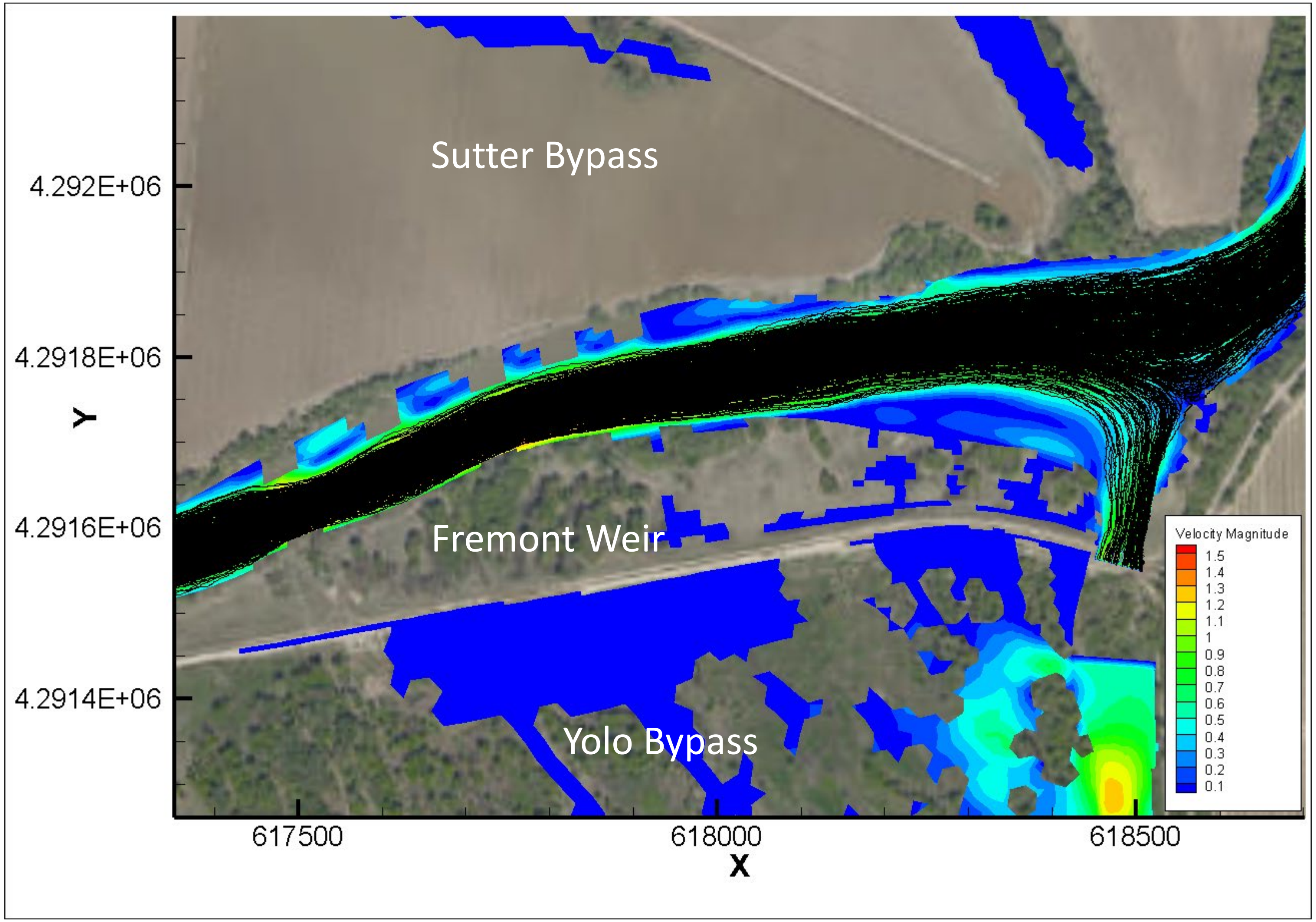


Results with hydro

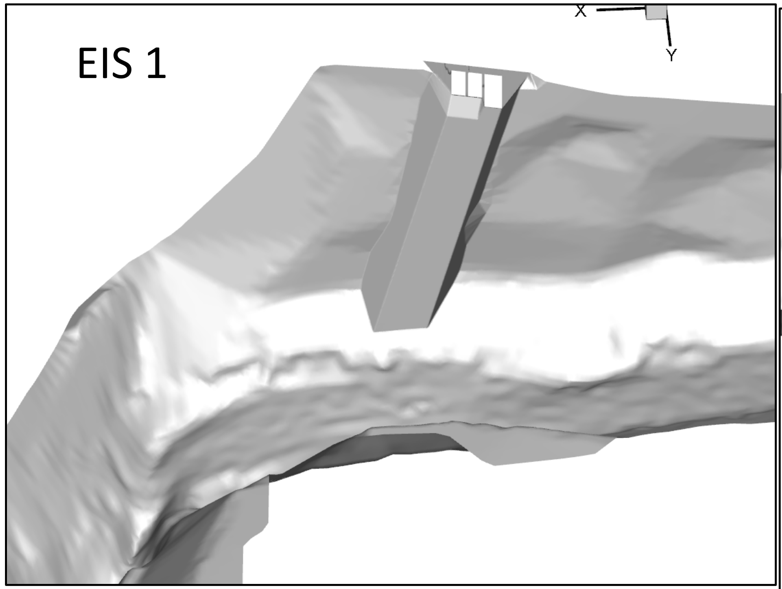


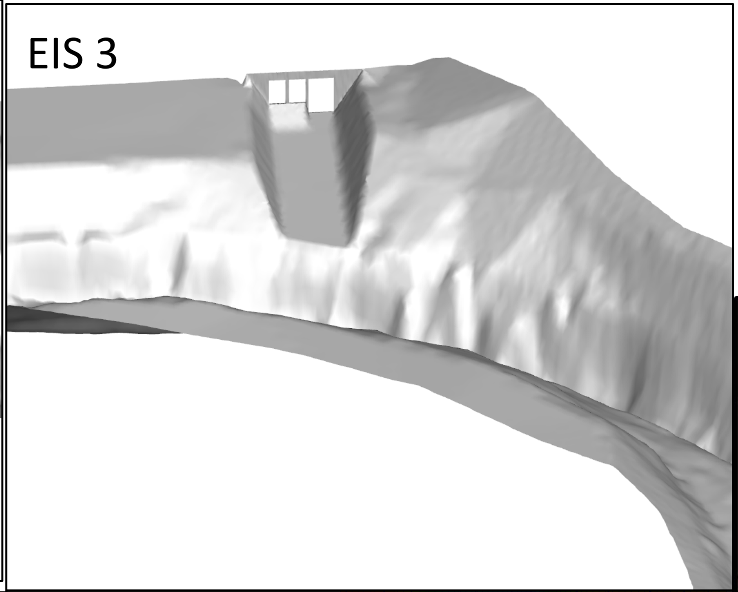
Using the calibrated/validated model

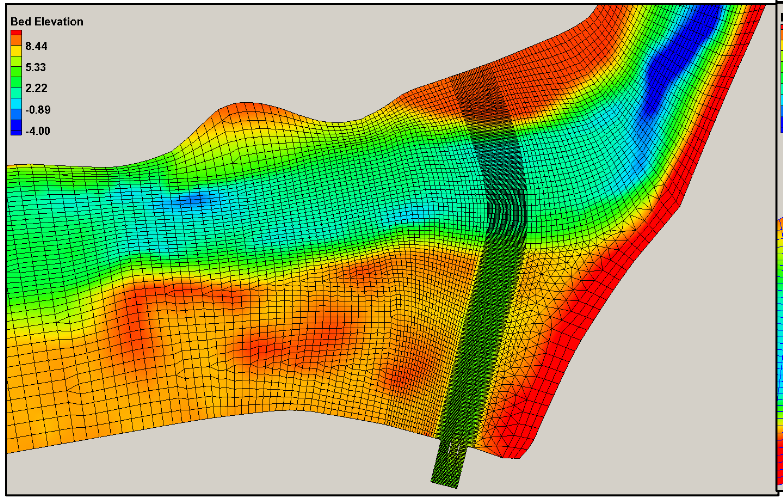
- Build 2D models for each EIS/EIR alternative for 6 stages representing6 notch flows
- Stages representative of wide range of hydrologic conditions at Fremont Weir
- Run and compute entrainment as percentage of fish versus ration of notch flow/river flow

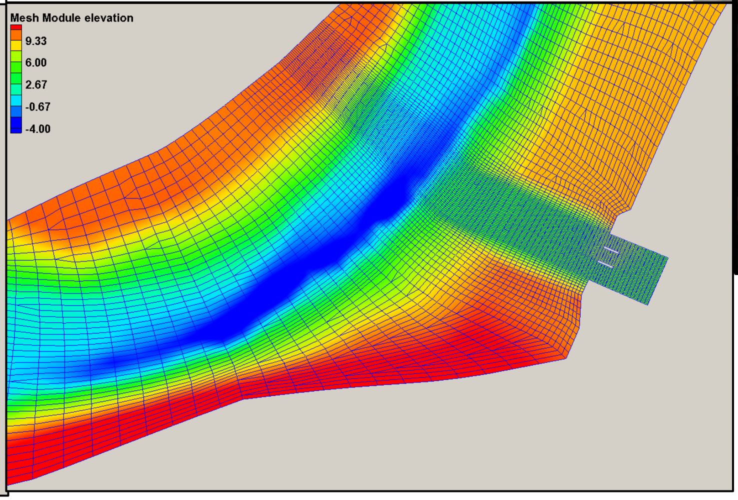


Examples: EIR/EIS 1 (East) and 3 (West)



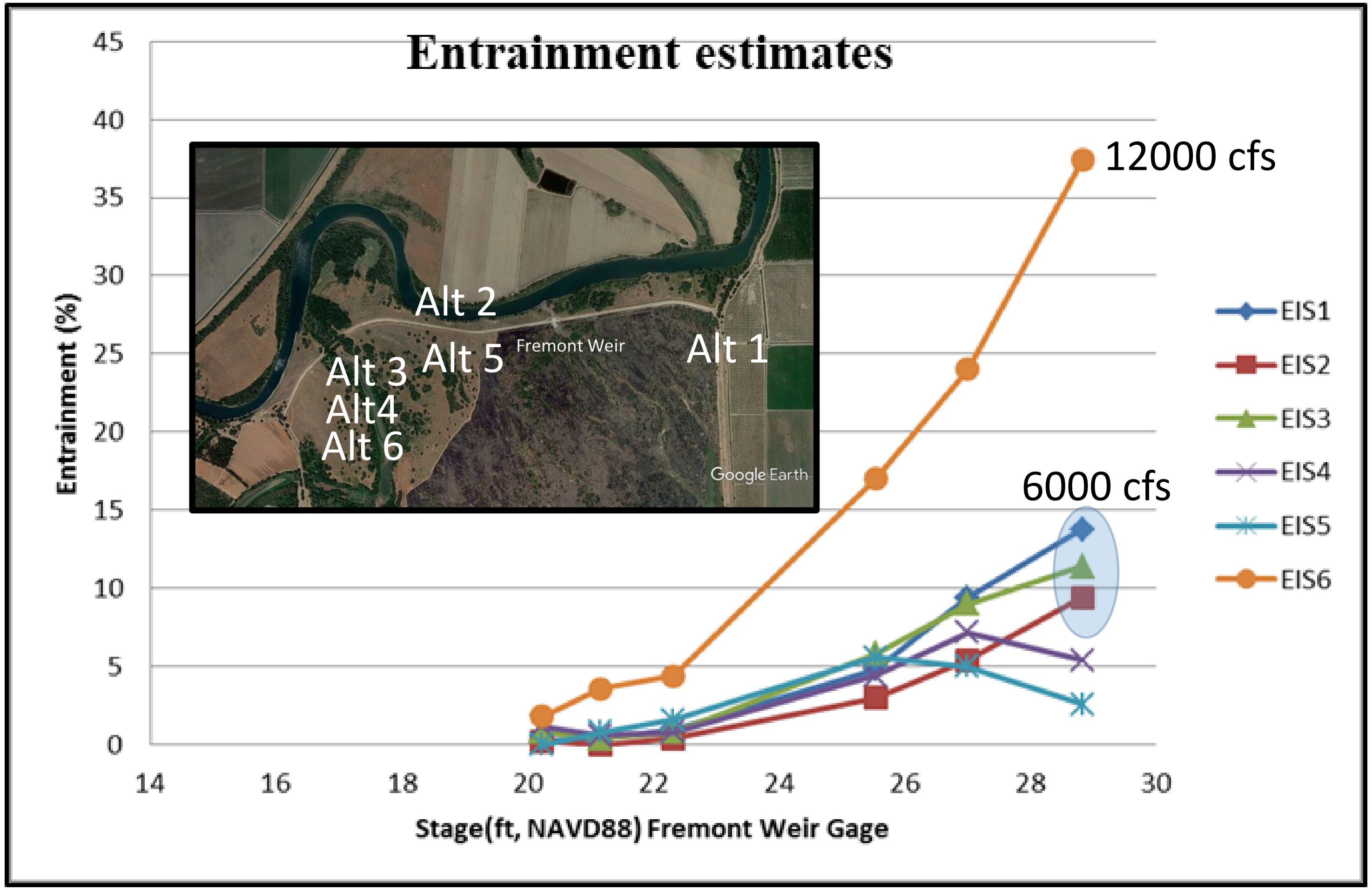






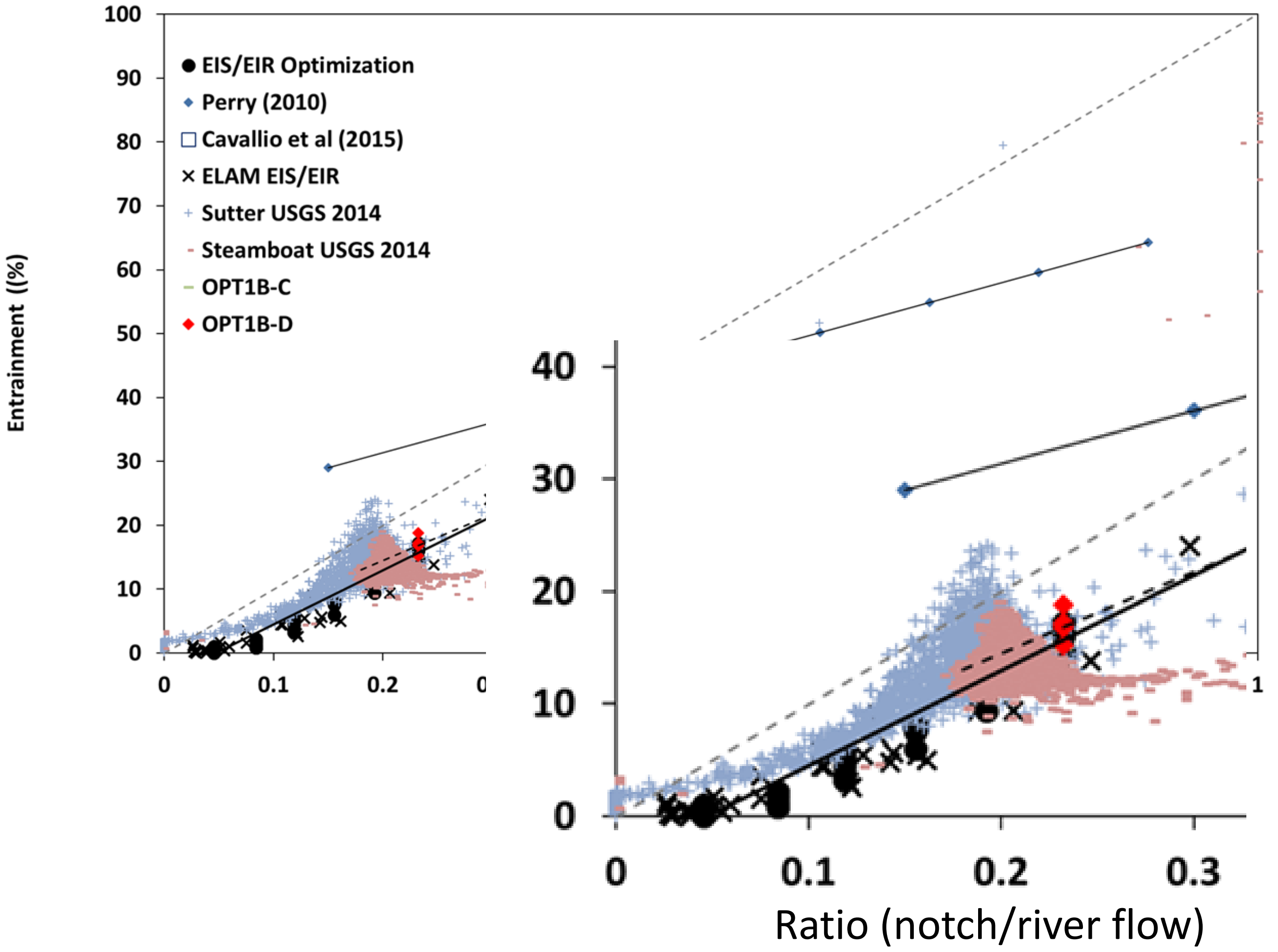
Entrainment results

- Across all stages, entrainment is 1 to 38%
- Higher flows at a given stage increases entrainment
- For a given flow/stage notch entrainment is insensitive to location
- Entrainment is dependent on fish location In cross section
- Entrainment is dominated by advection-suggest slower water or bigger fish will display more behavior



Building confidence in the entrainment estimates

- Used entrainment estimates elsewhere in Sacramento to gauge magnitude of expected entrainment as function of flow – Independent validation
- Plotted EIS 1 entrainment estimates on same scale as measured entrainment at Sutter and Steamboat Sloughs
- Suggest that entrainment estimates at Freemont Weir are realistic
- This is important – suggest accurate forecast are possible and that further engineering evaluation can improve entrainment



Floodplains

- Floodplains are the most impacted geomorphic feature of rivers
- Critical ecosystems services lost while other economic services gained
- Ecological forecast are not readily synchronized with engineering design – critical shortcoming
- How do you forecast ecological outcomes for conditions you cant measure?
  - This project is one method forward
  - Mechanistic with simple ecological outcomes (not populations)
  - Post construction validation is planned
- Fremont Weir/Yolo Bypass work suggest a measured approach to ecosystem services/economic services is possible

Acknowledgments

- Department of Water Resources (funding)
    - James Newcomb, Josh Urias, Josh Martinez, Edmond Yu, Manny Bahia, Rajet Saha, Ryan Reeves, Jacob McQuirk, Jim West, Ted Sommer, Trevor Greene, Brett Harvey
- USBR (funding agency)
    - Josh Israel, Traci Michel
- Crammer Fish Sciences
    - Travis Hinkelman
- UC Davis
    - Gabe Singer/Anna Steel
- CBEC
    - Chris Campbell
- USGS
    - Jason Romine, Paul Stumpner, Aaron Blake, Jon Burau
- USACE (funding)
    - Brian Mulvey, Mike Fong, David Colby, Brian Luke, Natalie Houghton
    - John Nestler (retired)
    - SacBank Team
- Staff of Livingstone Stone and Coleman National Fish Hatchery
- Fisheries Engineering Technical Team

Winter Chinook Tagging Event
Jan 22, 2015

Complicated relationships: Environmental drivers of salmon phenology & foodscapes

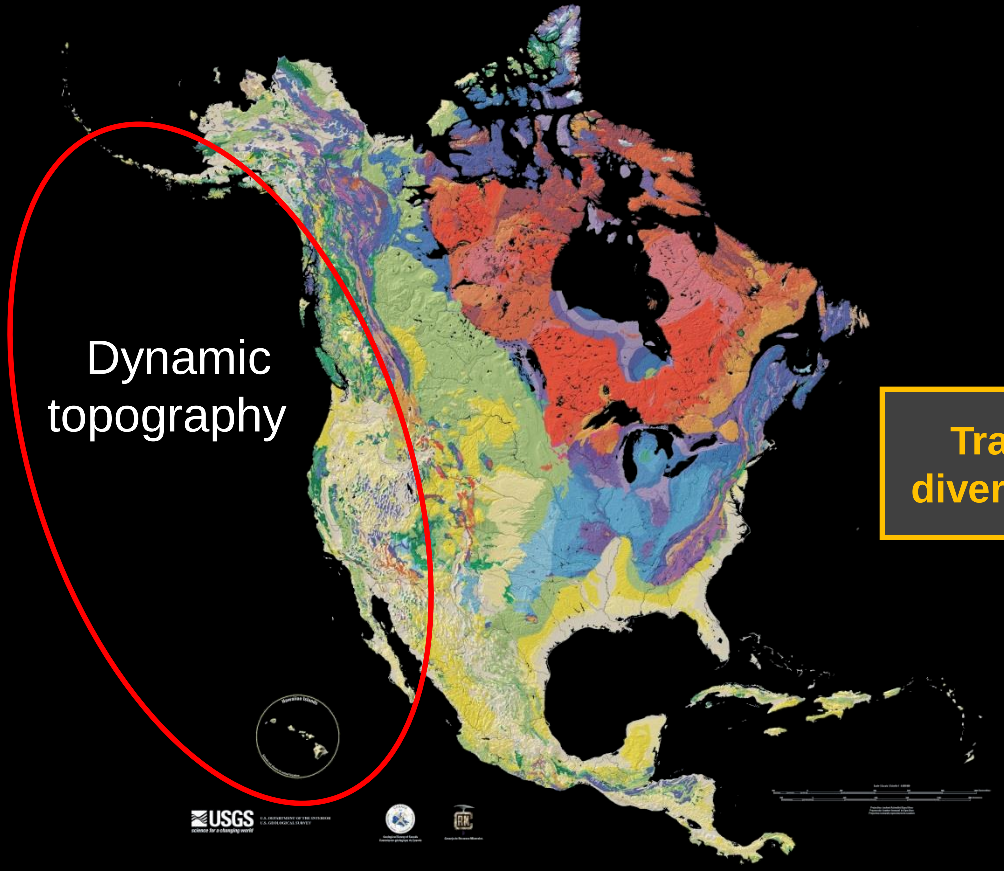
Anna M. Sturrock [1,2], Rachel Johnson [2,3], Stephanie Carlson [4], Flora Cordoleani [3,4], Corey Phillis [5], Pedro Morais [4], Carson Jeffres [2], Mollie Ogaz [2]

[1] University of Essex, School of Life Sciences, [2] UC Davis, Center for Watershed Sciences, [3] Southwest Fisheries Science Center, NMFS, [4] UC Berkeley, [5] UC Santa Cruz, [6] Metropolitan Water District

Presentation outline

- **Intro.** Evolutionary → recent history of salmon in the California Central Valley
- **Flow shaping.** *Sturrock et al. (2020) Global Change Biology. Unnatural selection of salmon life histories in a modified riverscape*
- **Habitat mosaic.** *Morais et al. (in prep) Climate variability and juvenile density drives migratory behavior and habitat use in an endangered salmon*
- **Thermal refugia.** *Cordoleani et al. (in press) Nature Climate Change Threatened salmon rely on a rare life history strategy in a warming landscape.*
- **Foodscapes** - The multifaceted benefits of floodplains to early migrants. *Sturrock, Ogaz et al. (in review) Floodplain trophic subsidies in a modified river network: Managed foodscapes of the future?*
- **Summary.**

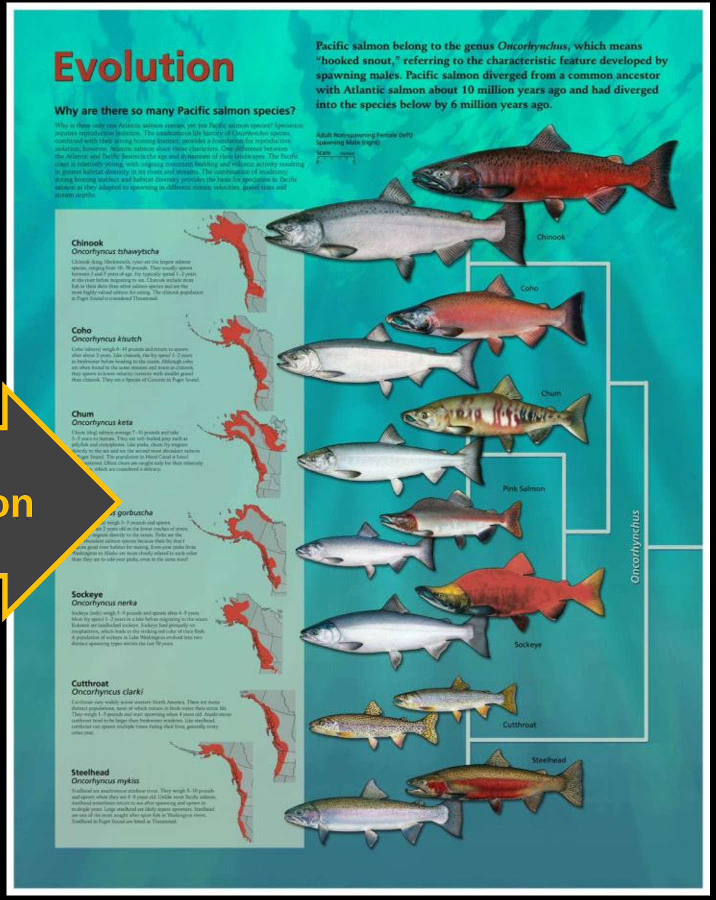
Evolutionary history of Pacific salmonids



Trait diversity

Photos courtesy of T. Quinn

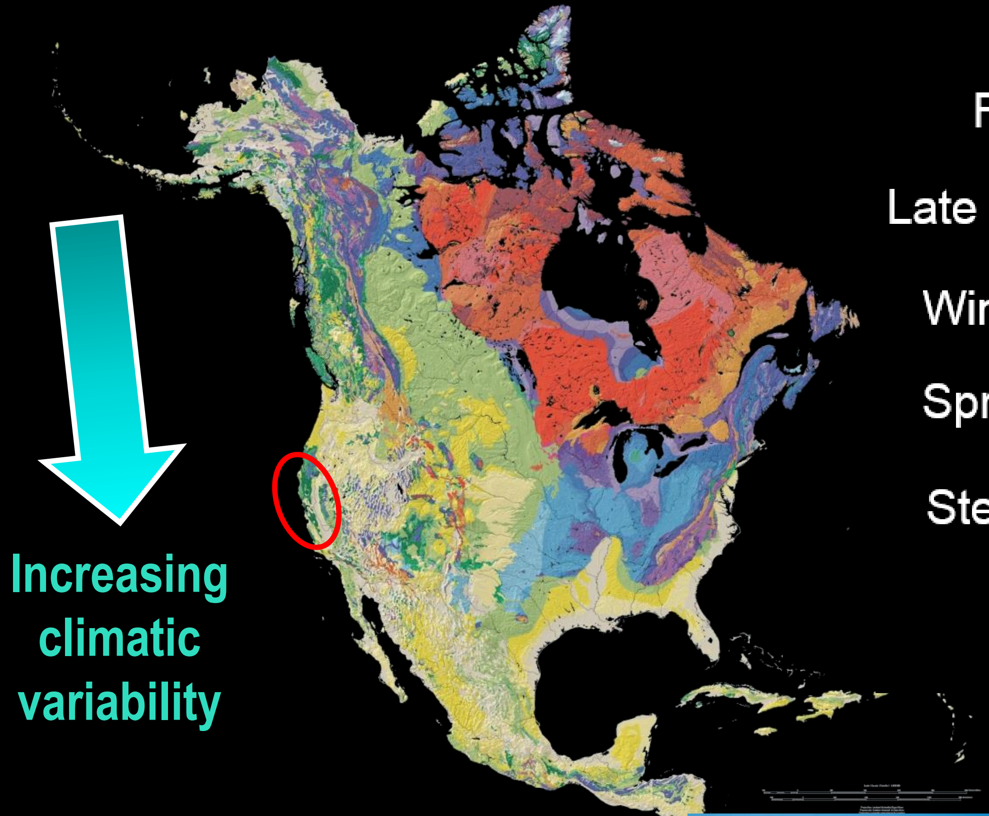
Speciation



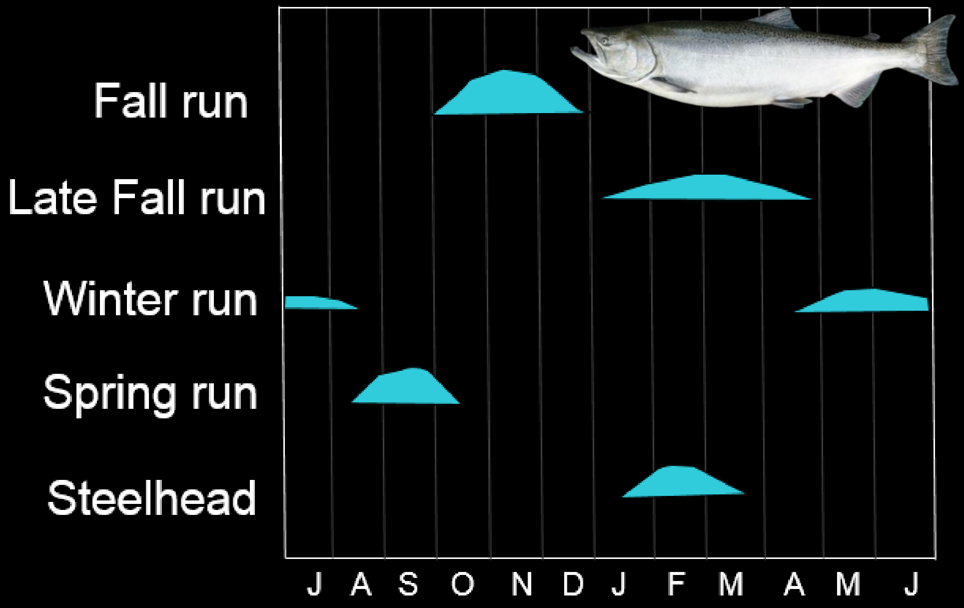
www.pugetsound.edu/files/resources/salmonevolution.jpg

+ disturbance regimes
+ natal homing and local adaptation

Evolutionary history of Pacific salmonids in California

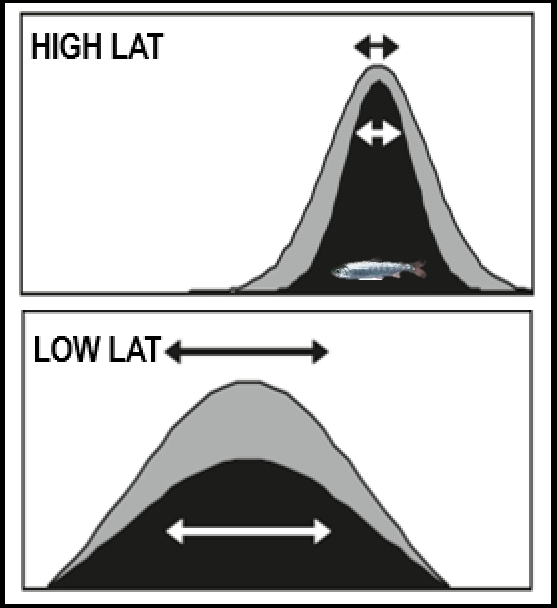


ADULT RETURN TIMING

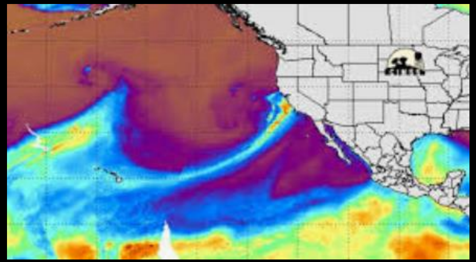


Data sources: Vogel and Marine, 1991; Hallock, 1983; CDFG, 1993

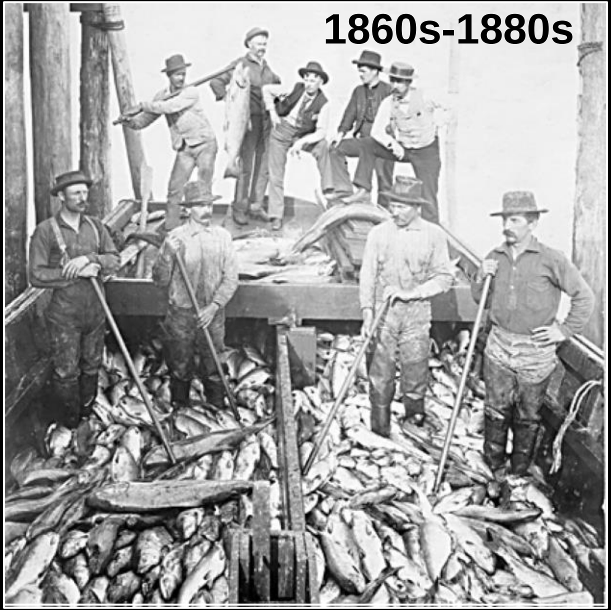
JUVENILE EMIGRATION TIMING

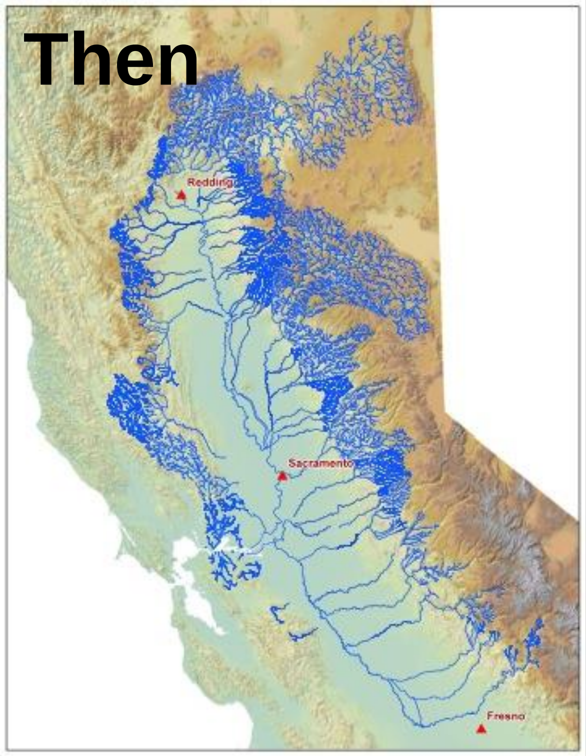


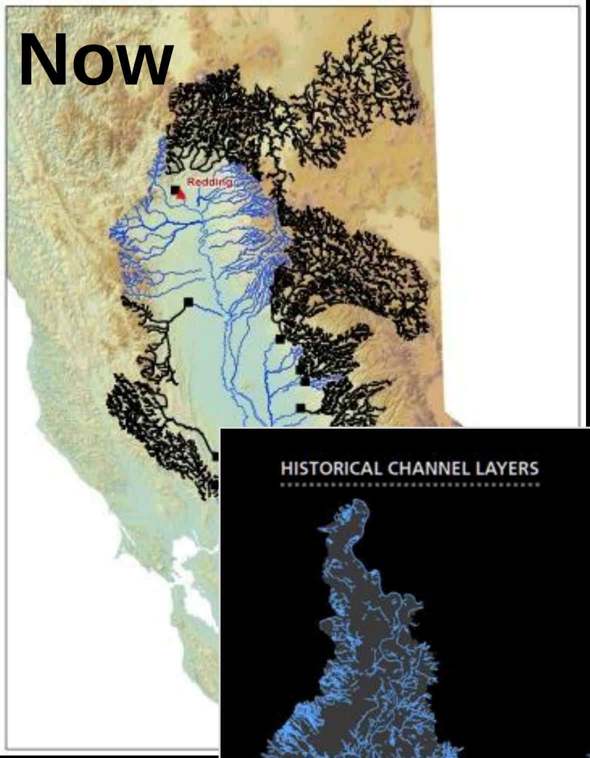
Spence & Hall (2010). CJFAS 67: 1316-1334

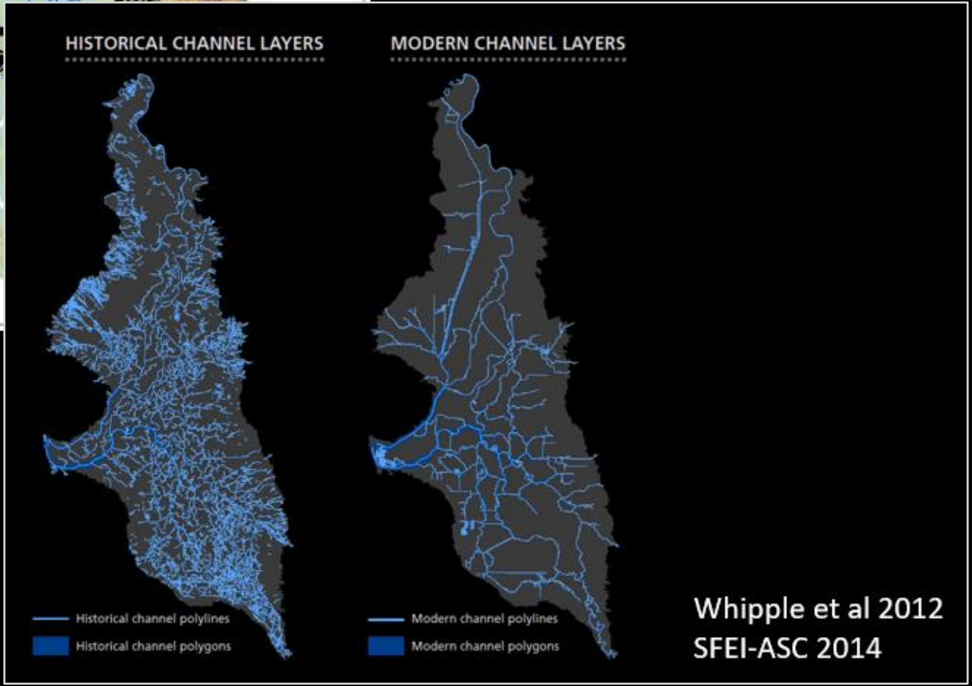


Recent history of salmonids in California

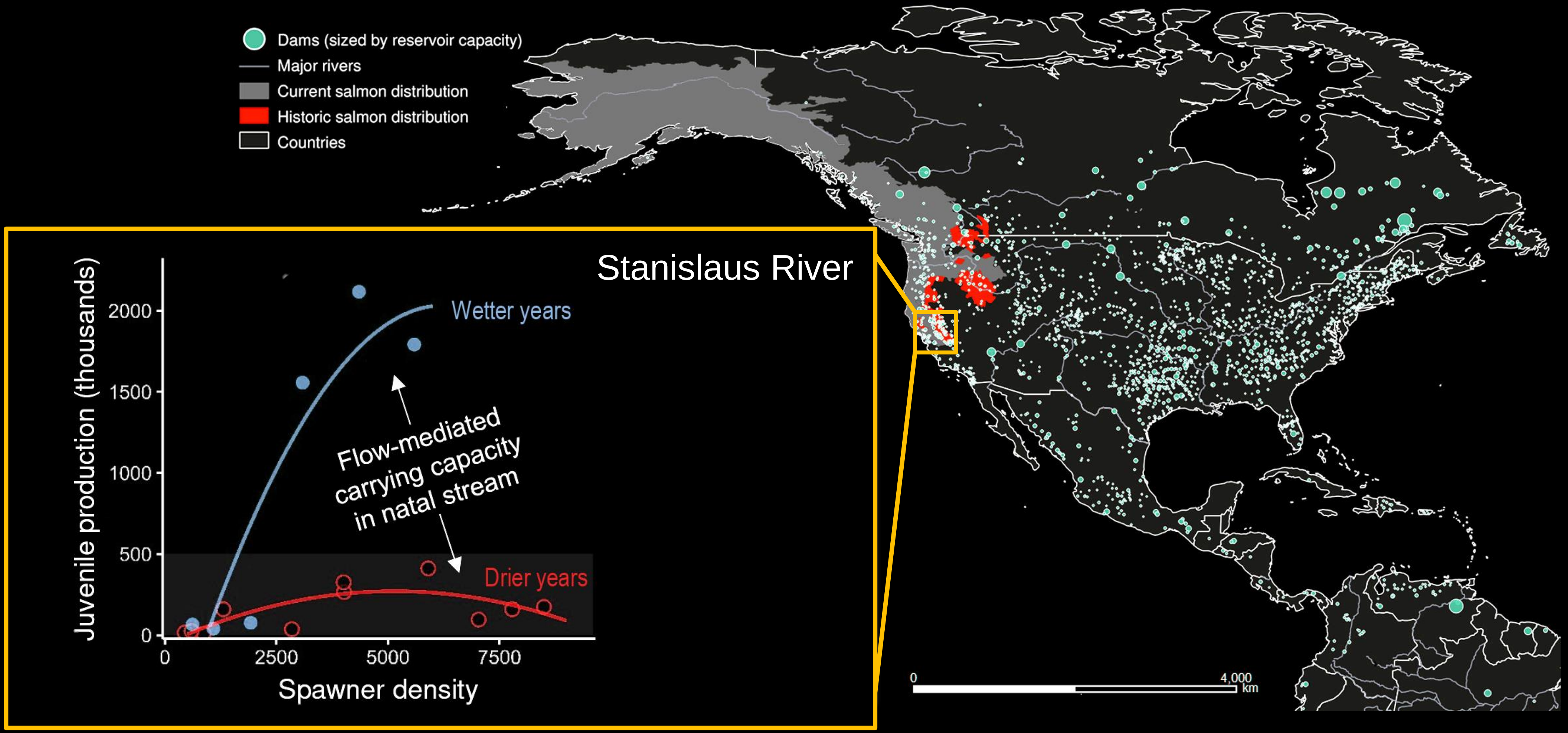






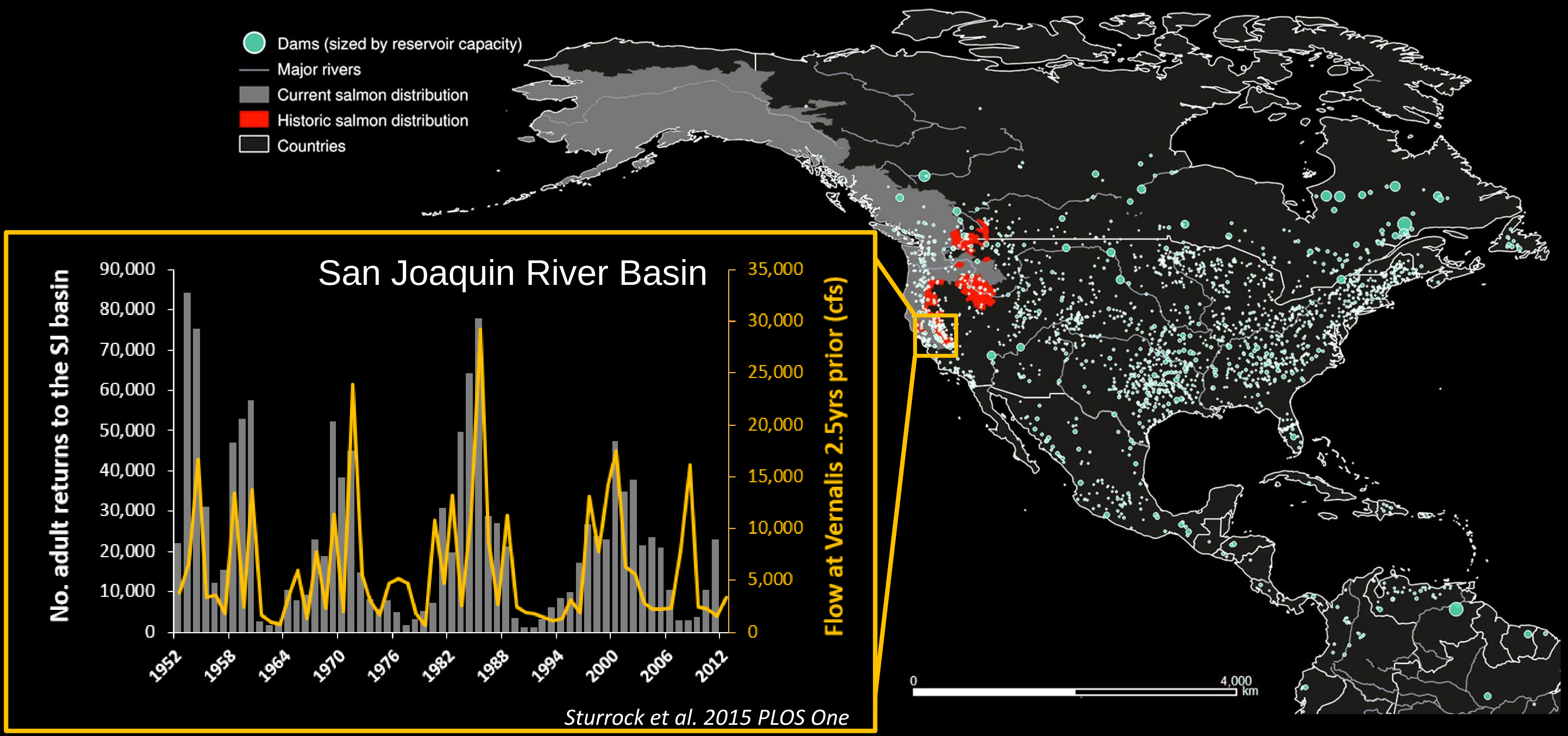


Low flows associated with increased juvenile mortality



Sturrock et al. 2020 Global Change Biology - Unnatural selection of salmon life histories in a modified riverscape

Low flows associated with increased juvenile mortality



Sturrock et al. 2020 Global Change Biology - Unnatural selection of salmon life histories in a modified riverscape

Flows also affect emigration timing and selection patterns

Yearling

Smolt
>75mm

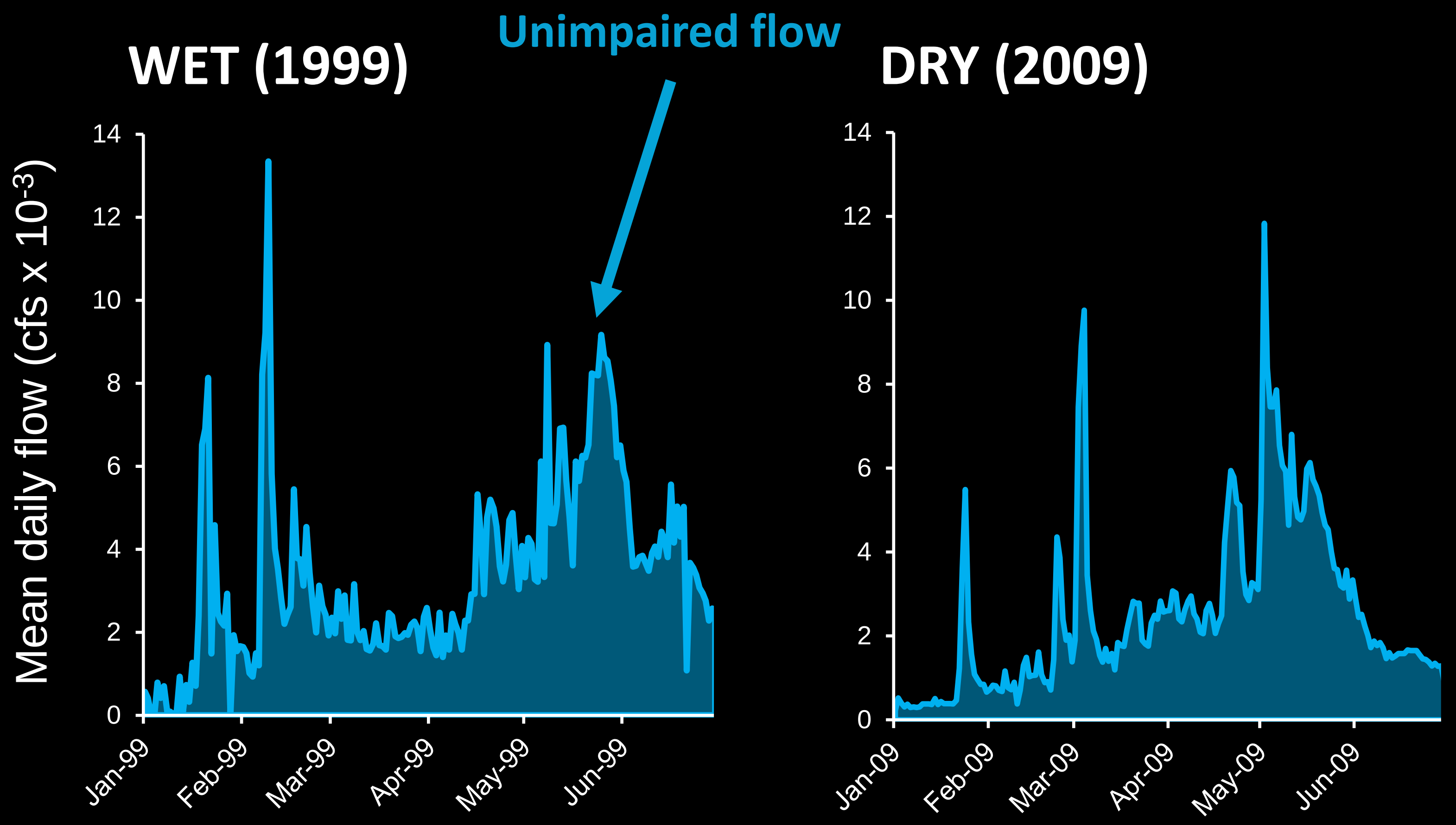
Parr
55-75mm

Fry
<55mm

Leave late

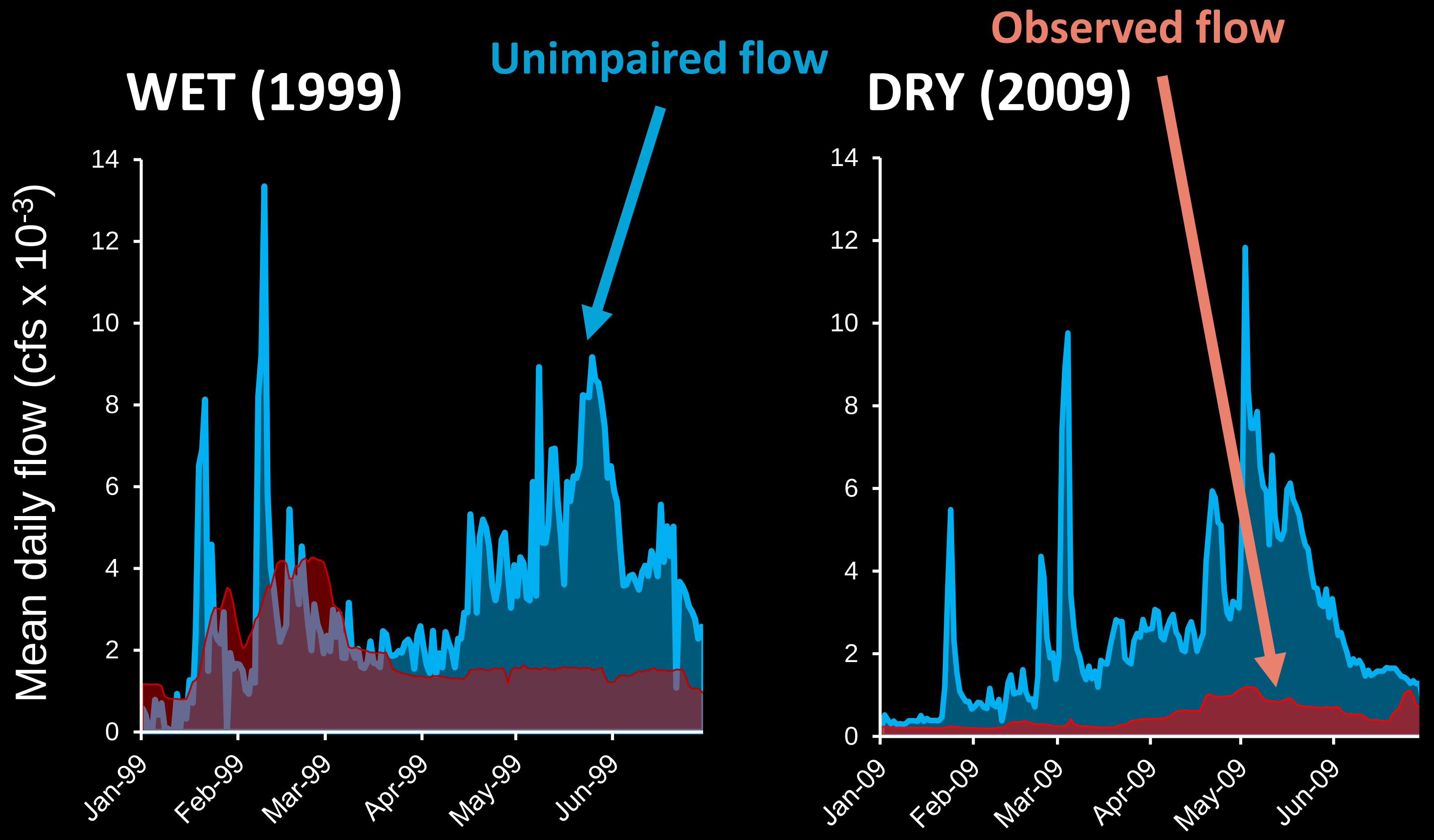
Leave early

Suppressed winter flow cues delay emigration timing



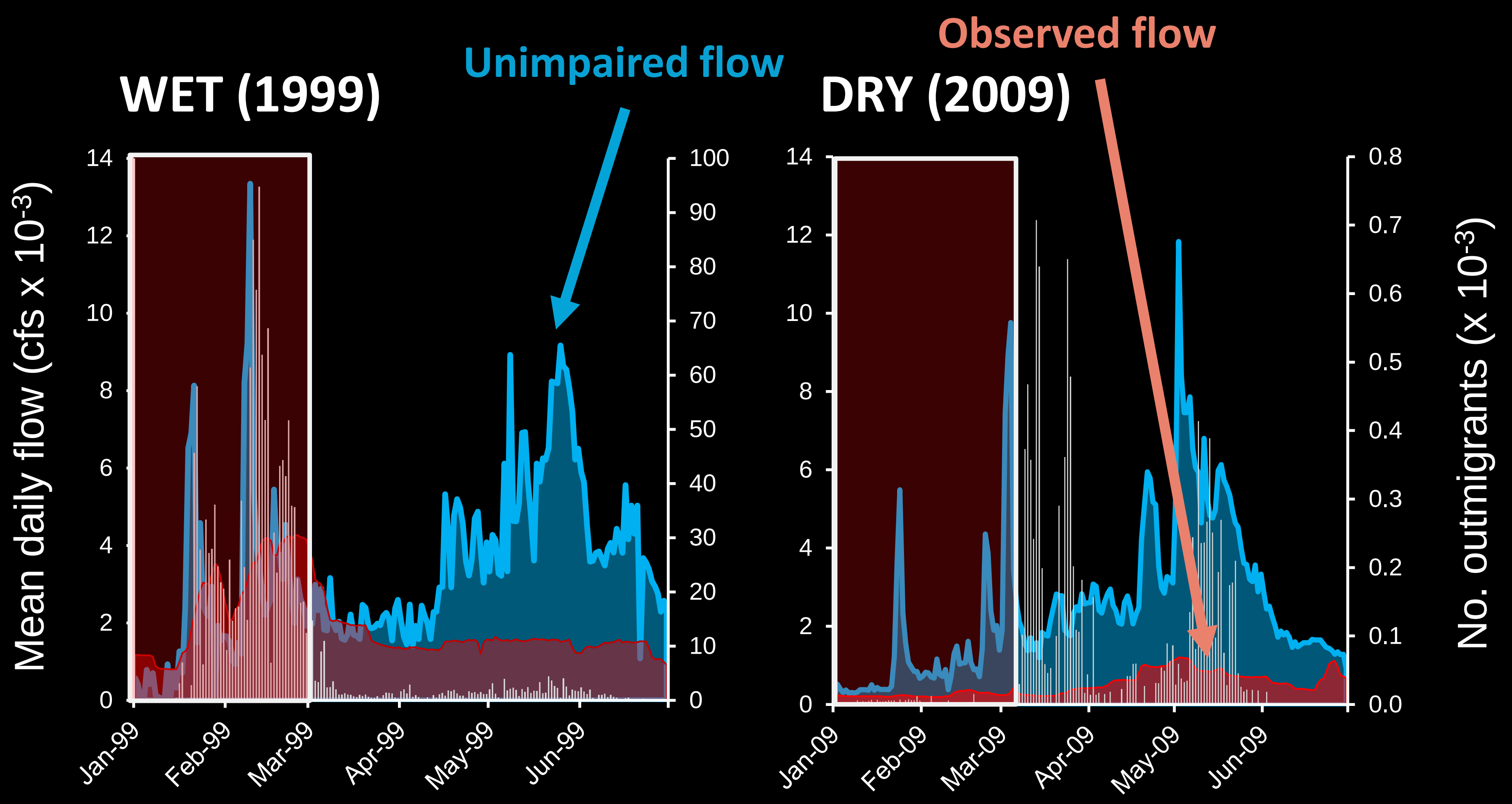
Sturrock et al. 2020 Global Change Biology - Unnatural selection of salmon life histories in a modified riverscape

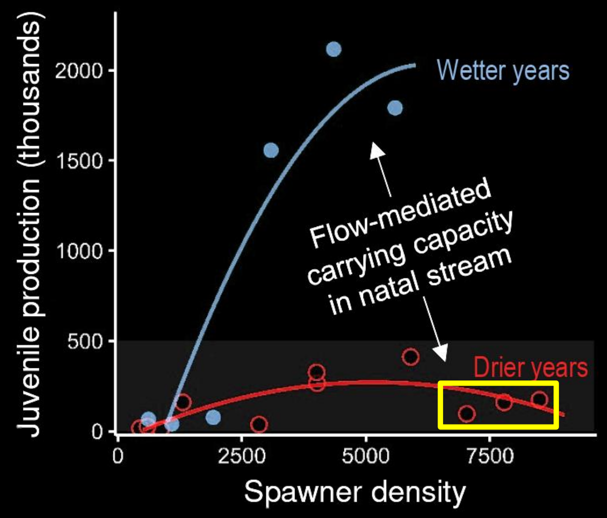
Suppressed winter flow cues delay emigration timing



Sturrock et al. 2020 Global Change Biology - Unnatural selection of salmon life histories in a modified riverscape

Suppressed winter flow cues delay emigration timing



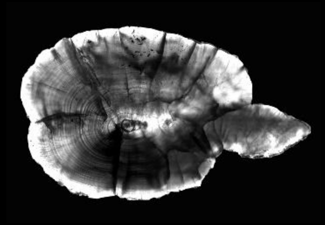


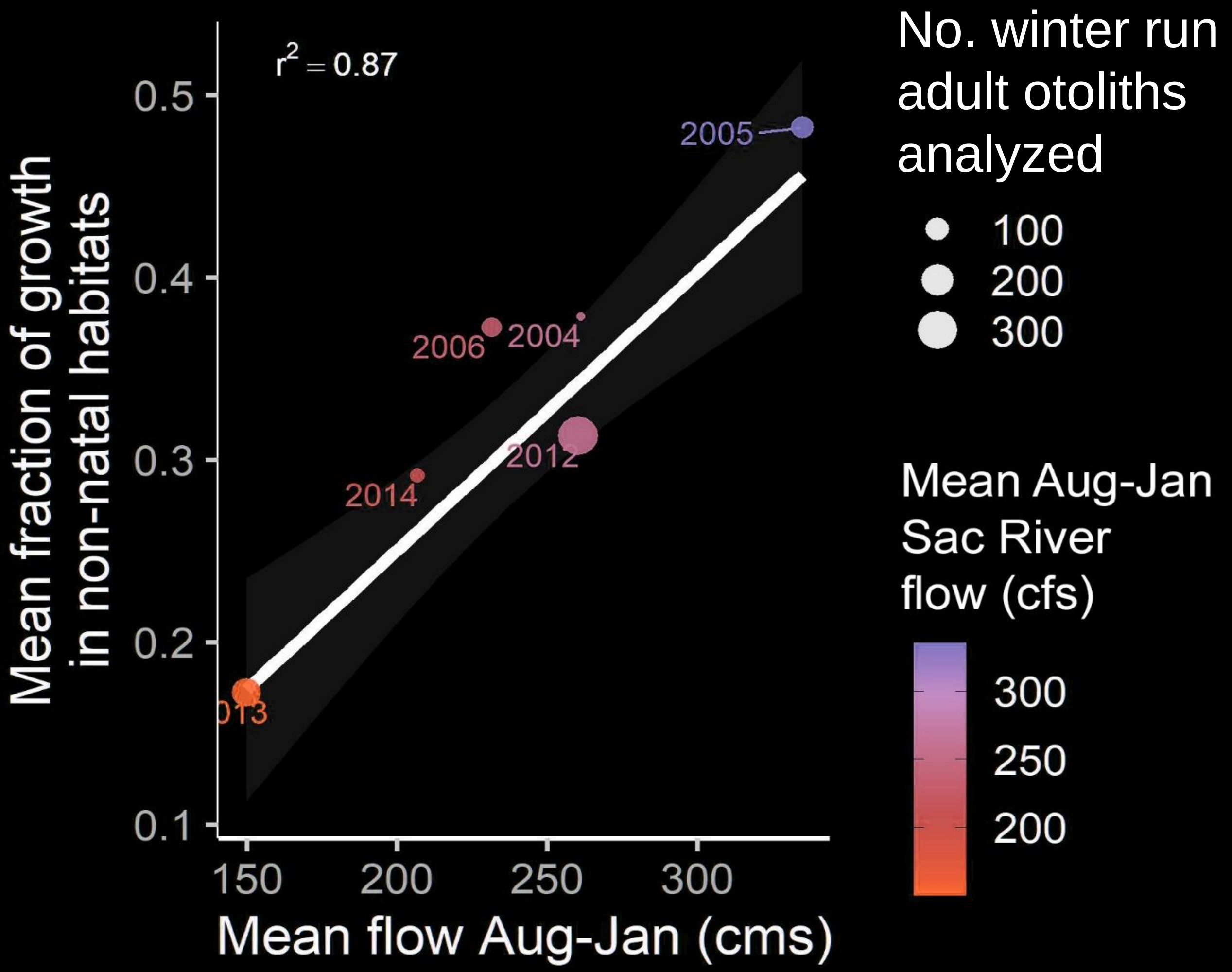
Sturrock et al. 2020 Global Change Biology - Unnatural selection of salmon life histories in a modified riverscape

High flows are associated with increased non-natal rearing

Hypothesized mechanisms:

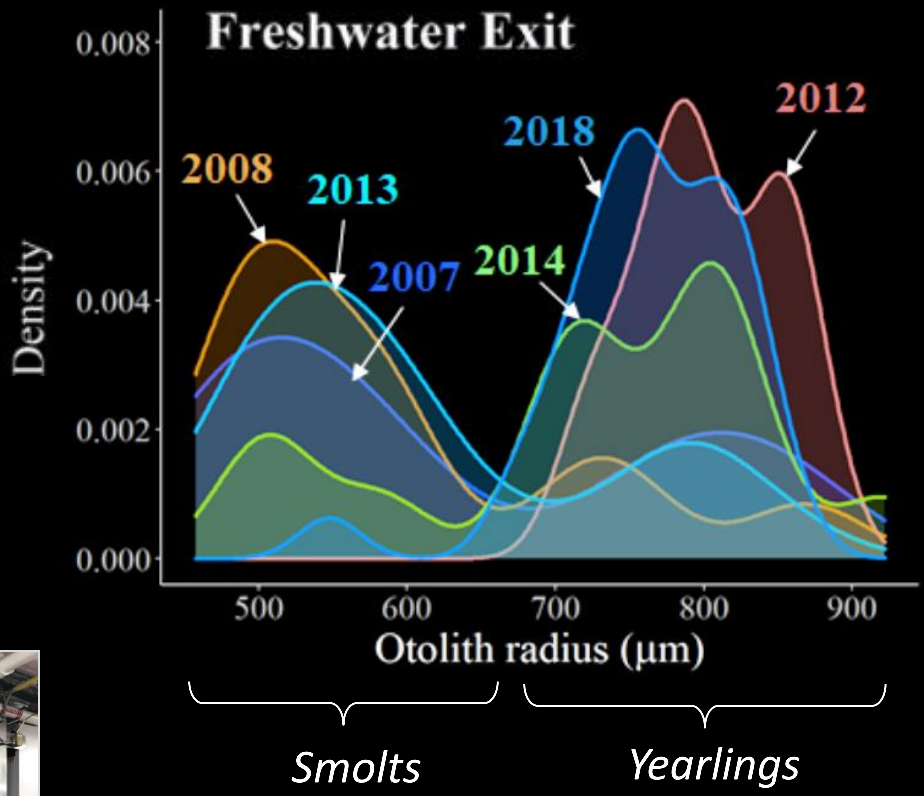
- *Increased lateral connectivity*
- *Earlier/larger freshets (emigration cues)*
- *Greater need for low velocity rest stops*

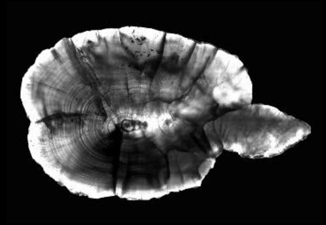




Morais et al. (in prep) Climate variability and juvenile density drives migratory behavior and habitat use in an endangered salmon

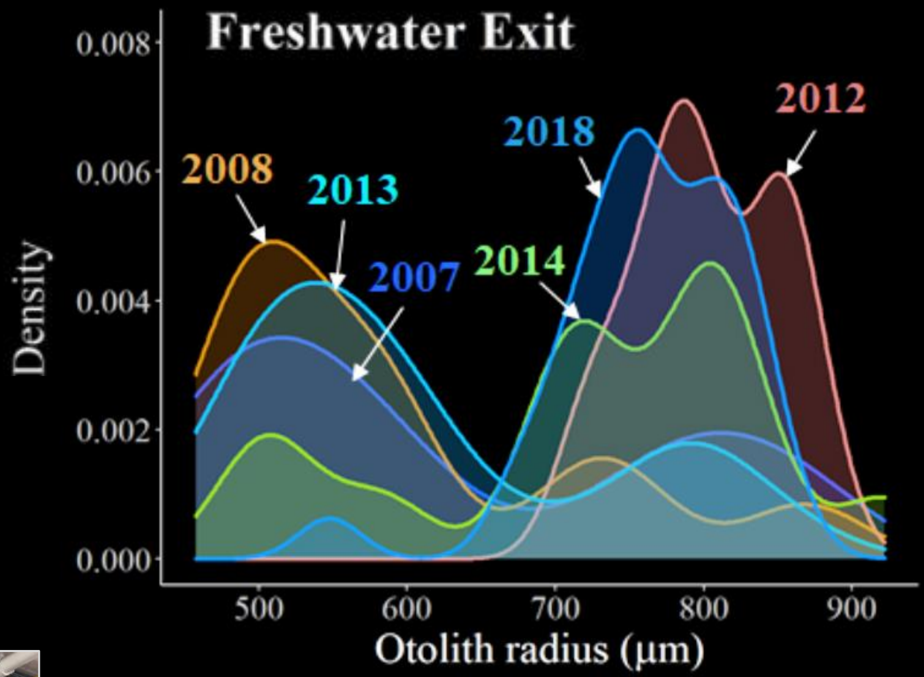
Yearlings perform disproportionately well in droughts



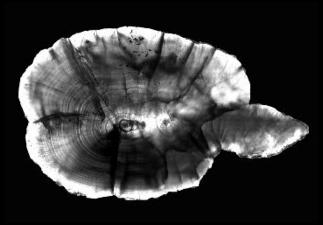


Cordoleani et al. (in press) Nature Climate Change - Threatened salmon rely on a rare life history strategy in a warming landscape

Yearlings perform disproportionately well in droughts

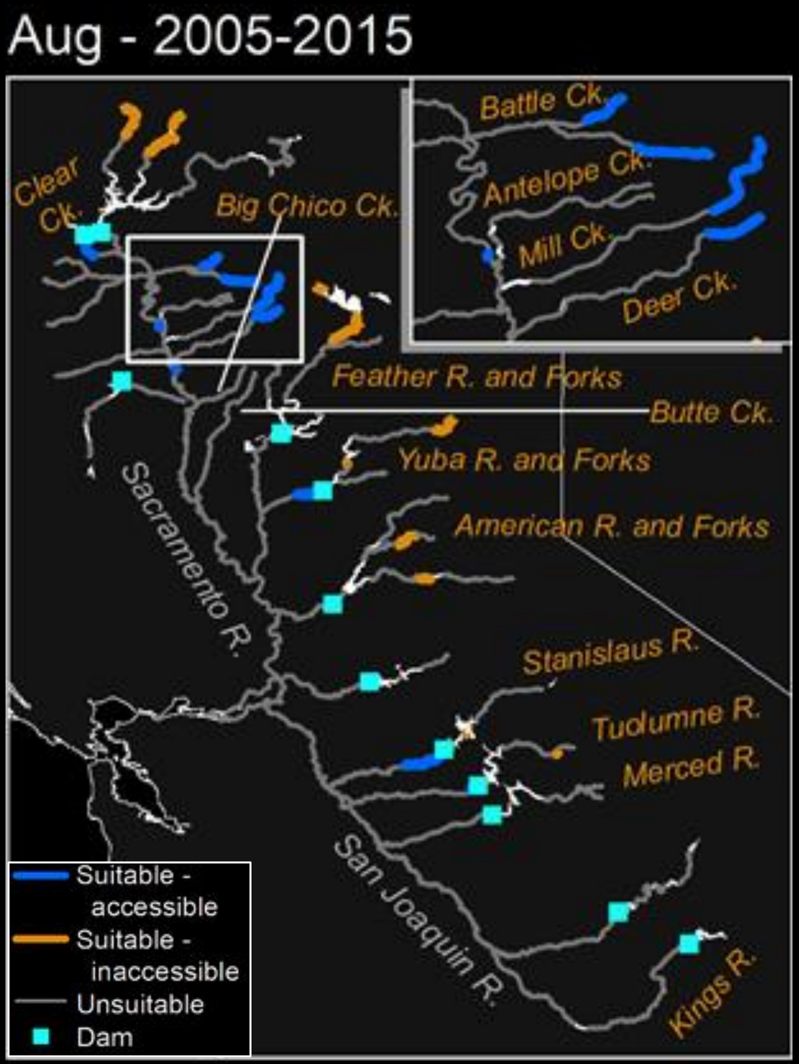


Smolts *Yearlings*

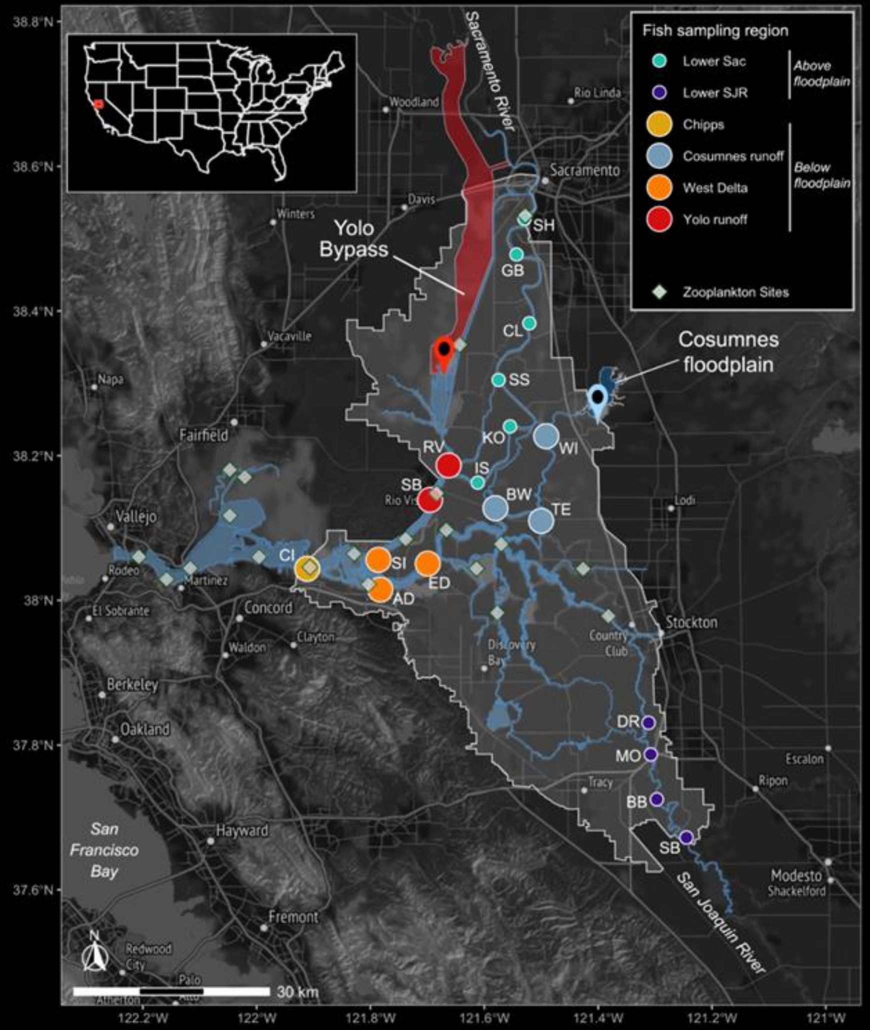


Cordoleani et al. (in press) Nature Climate Change - Threatened salmon rely on a rare life history strategy in a warming landscape

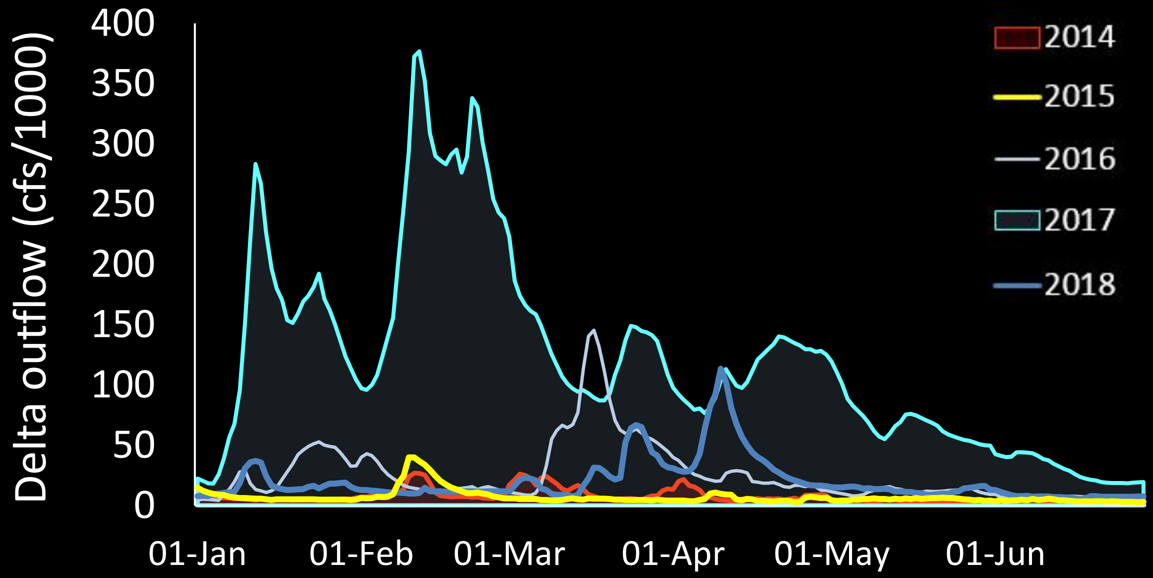
But thermal refugia to enable over-summering are limited and shrinking rapidly…



Floodplains provide trophic subsidies to salmon in the Delta

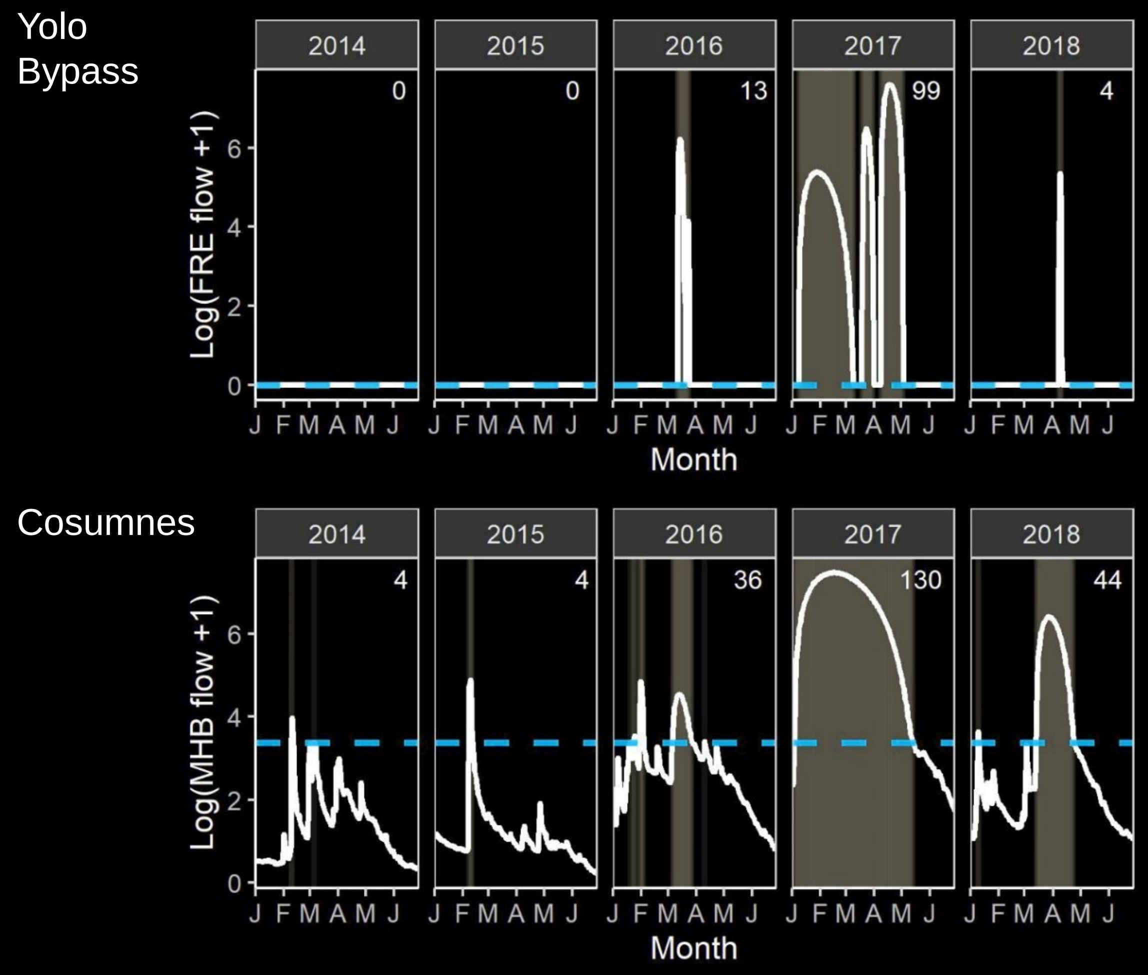


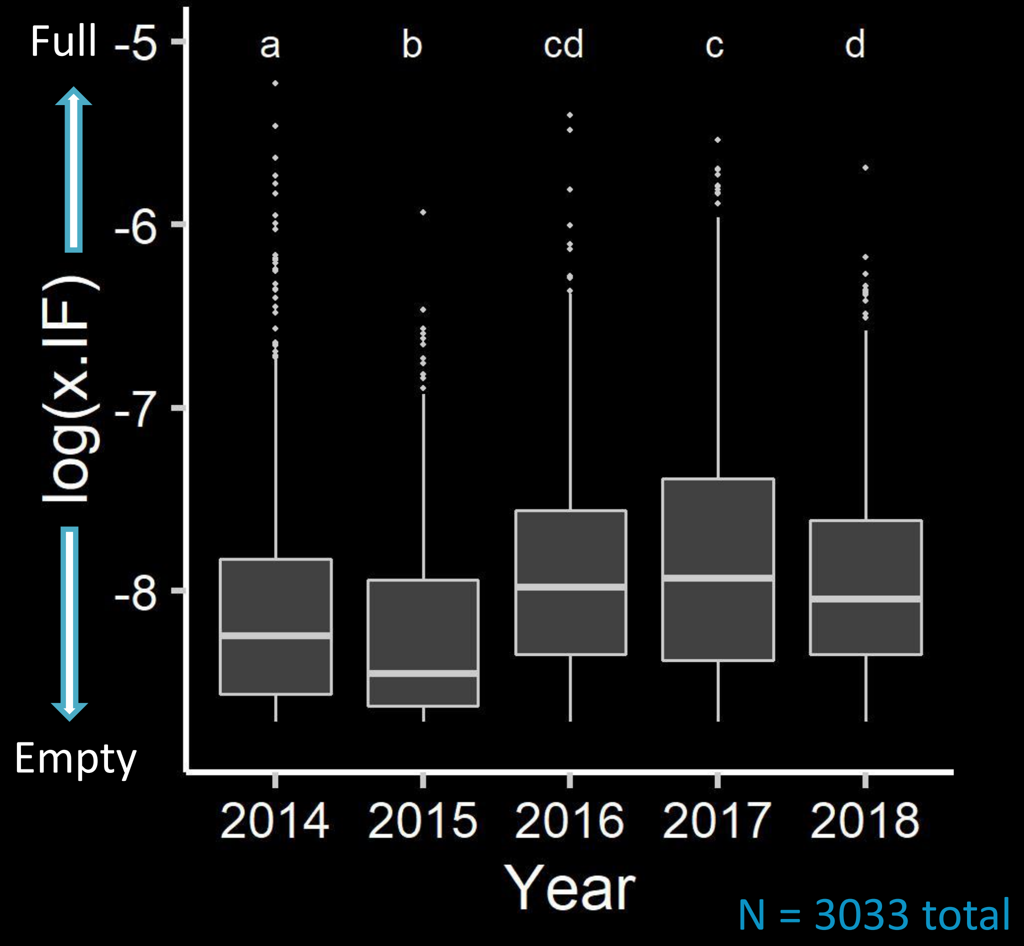
Juvenile salmon sampled by Kodiak Trawl, beach seines and midwater trawl in 2014 – 2021 (showing 2014-18 here).



Sturrock, Ogaz et al. (in review) Floodplain trophic subsidies in a modified river network: Managed foodscapes of the future?

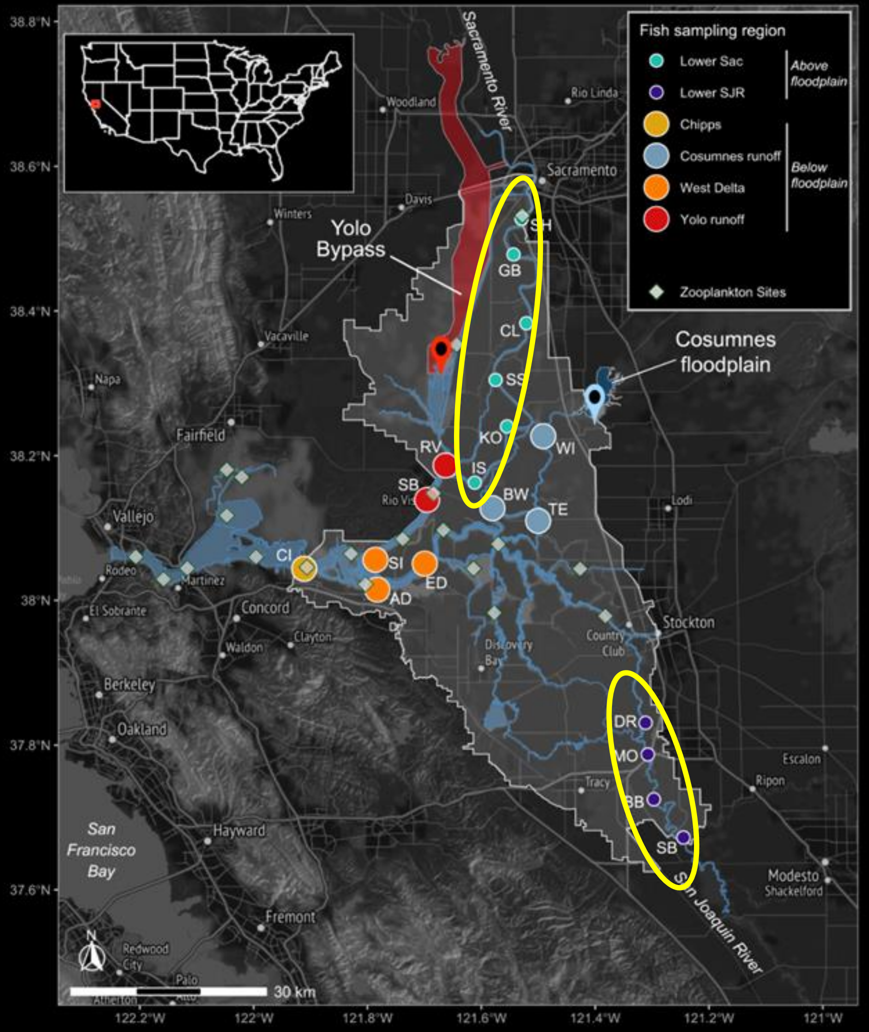
Floodplains provide trophic subsidies to salmon in the Delta

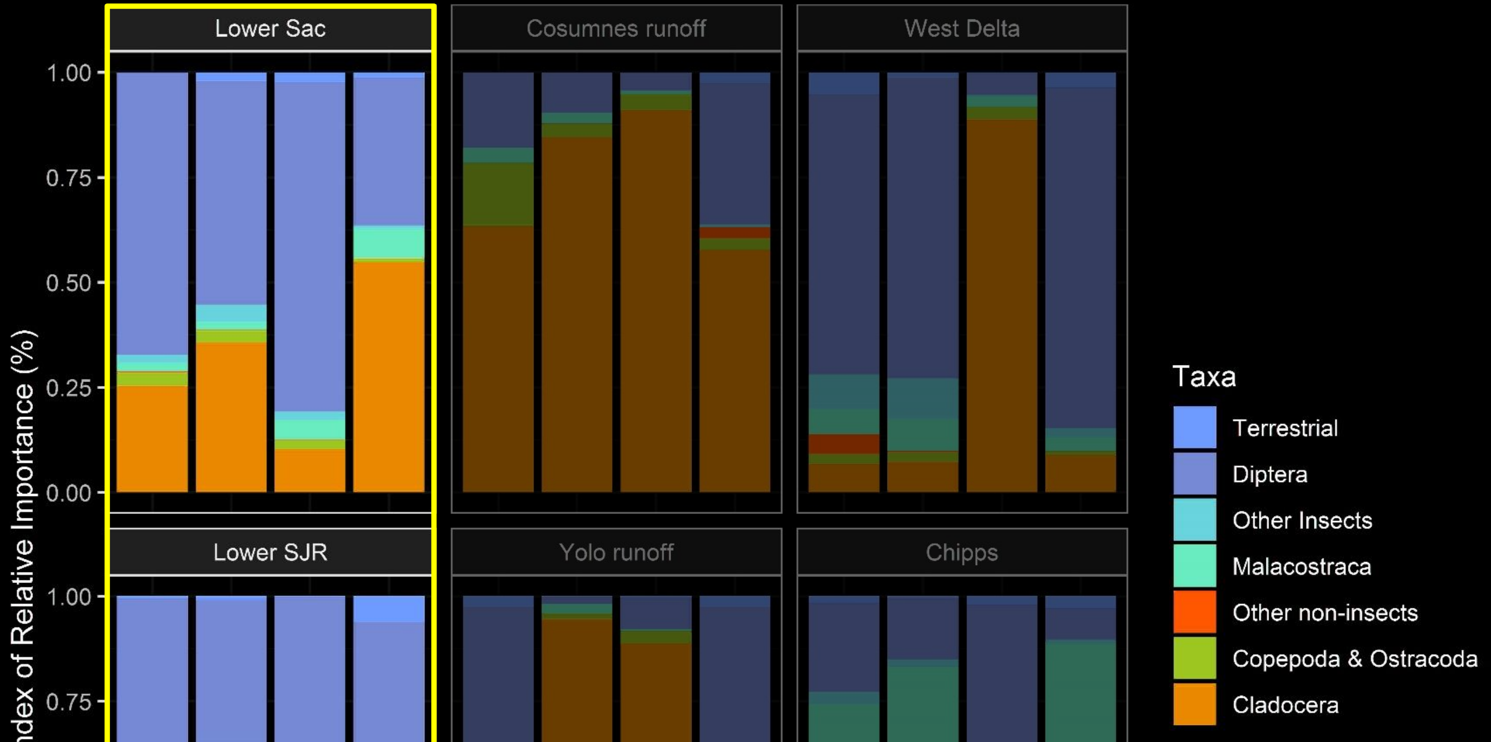




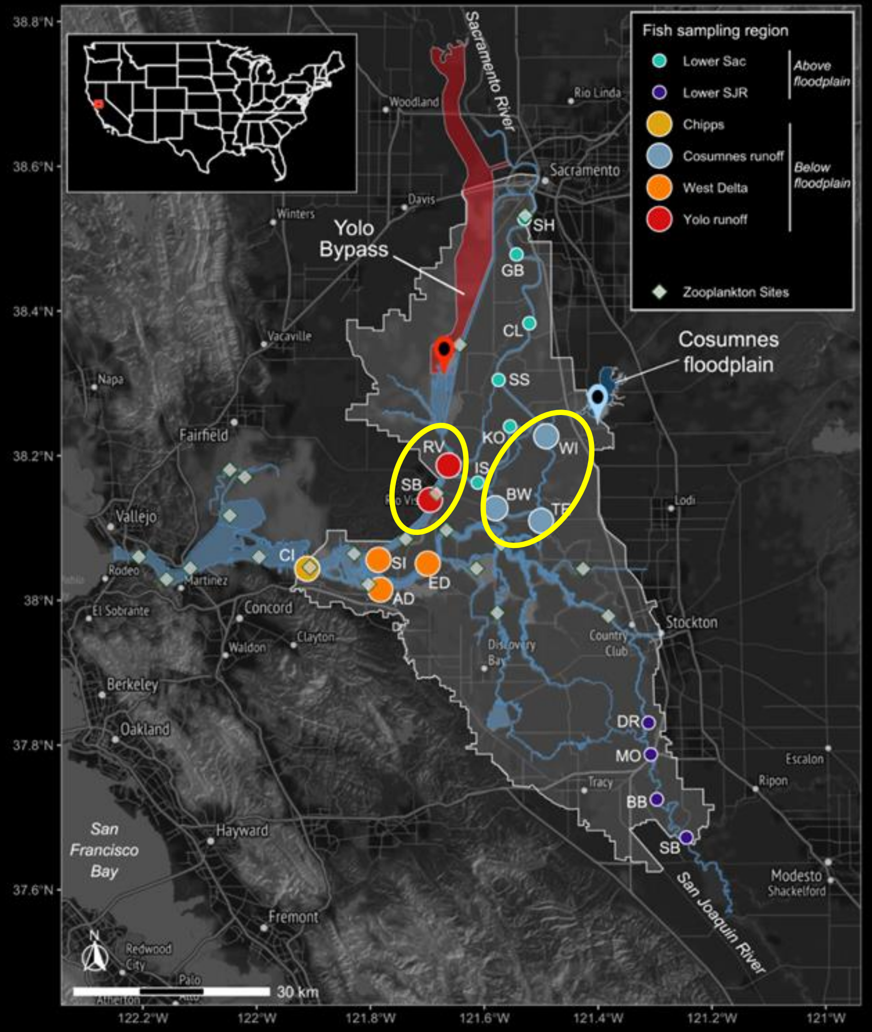
Sturrock, Ogaz et al. (in review) Floodplain trophic subsidies in a modified river network: Managed foodscapes of the future?

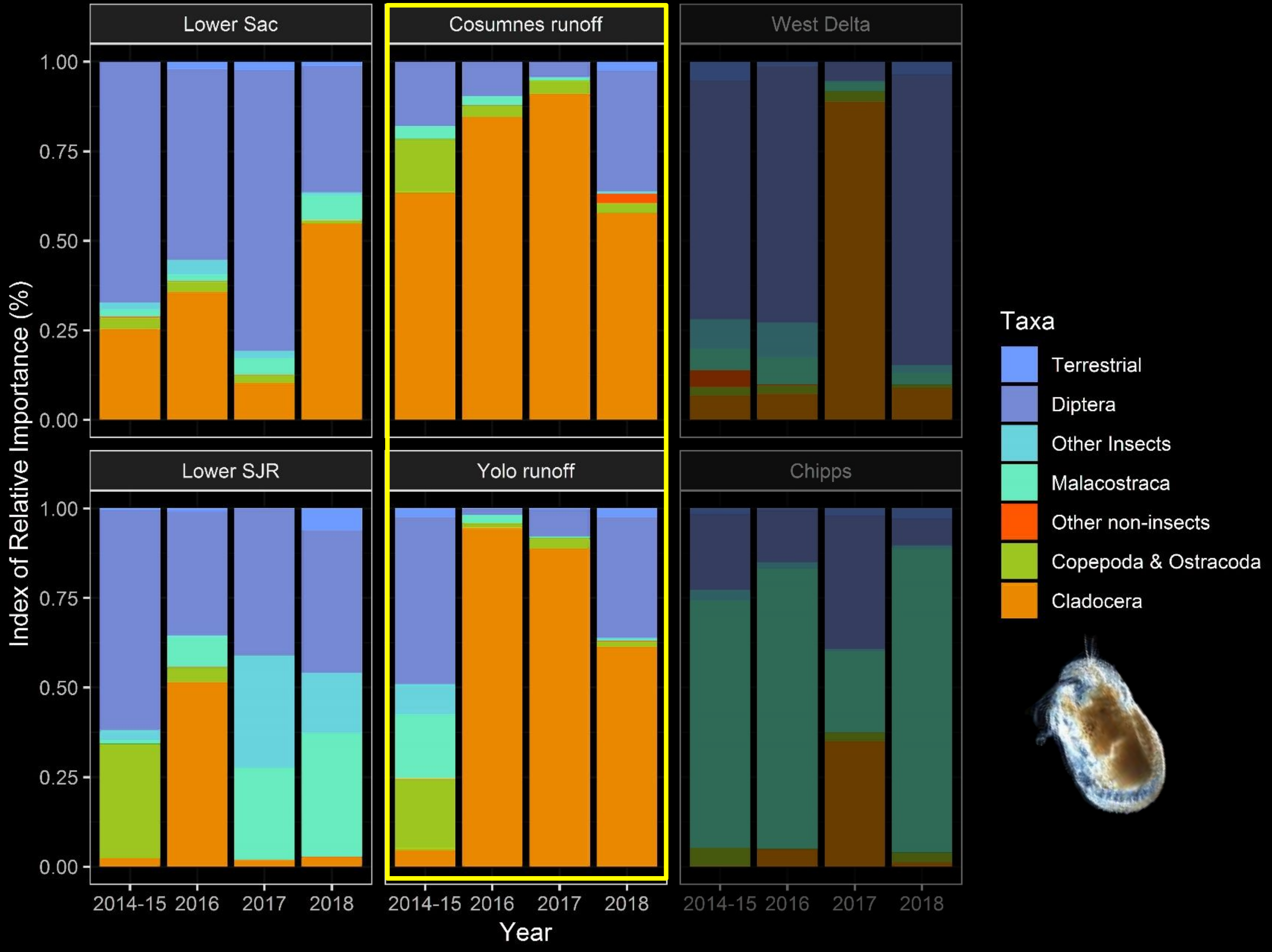
Floodplains provide trophic subsidies to salmon in the Delta



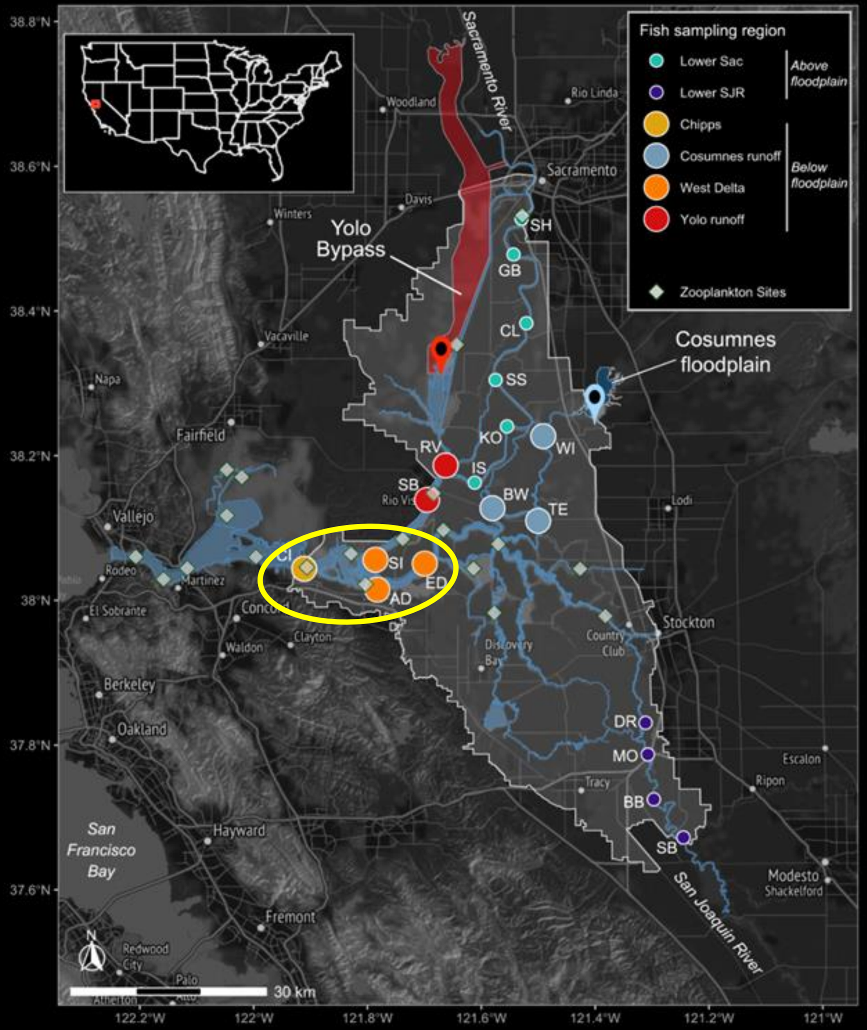


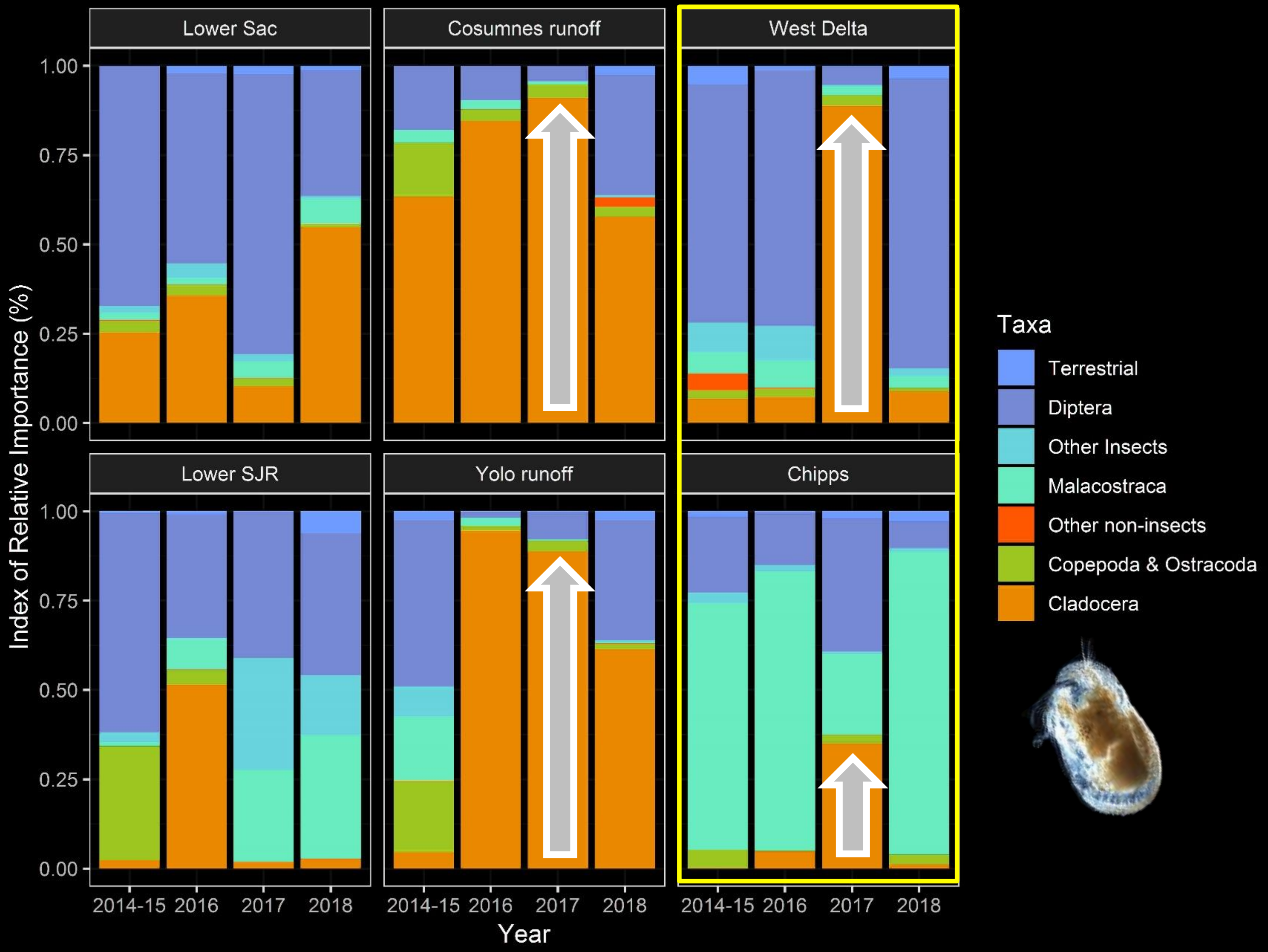
Floodplains provide trophic subsidies to salmon in the Delta



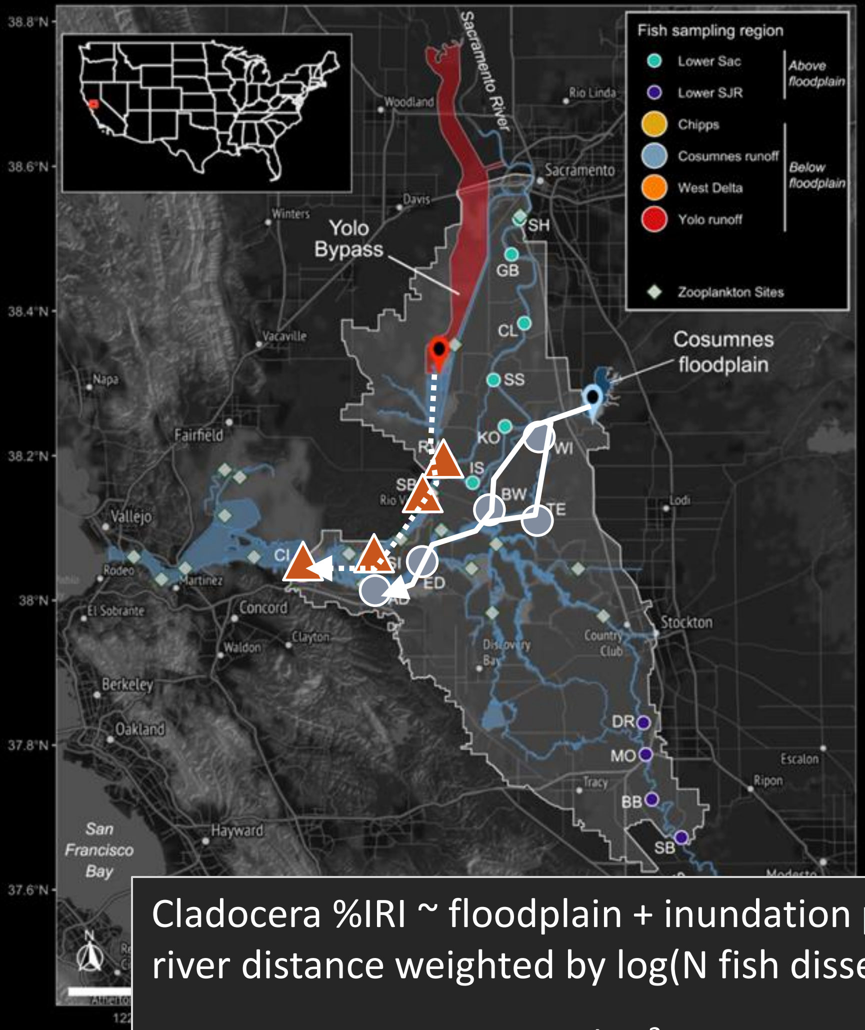


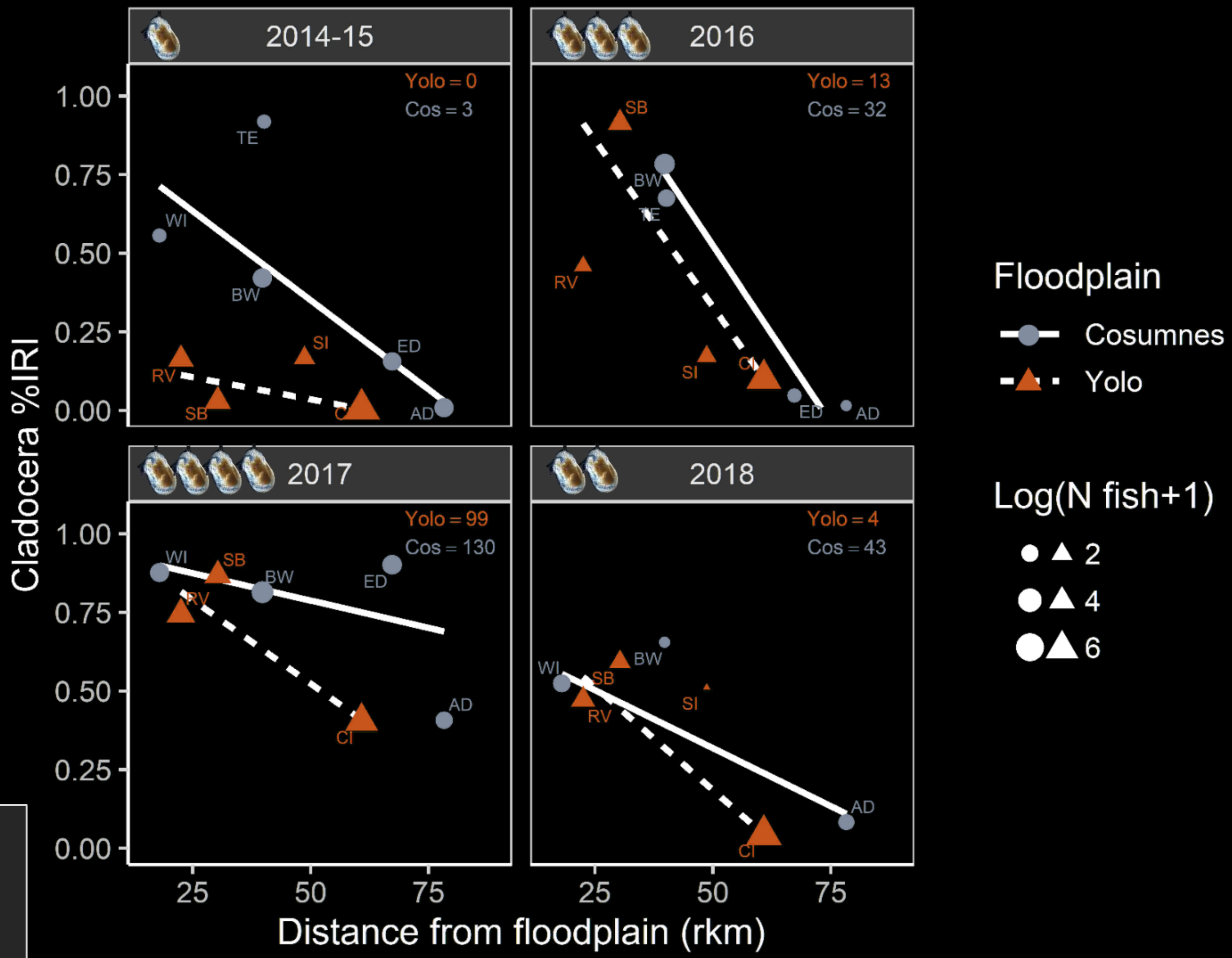
Floodplains provide trophic subsidies to salmon in the Delta





Floodplains provide trophic subsidies to salmon in the Delta

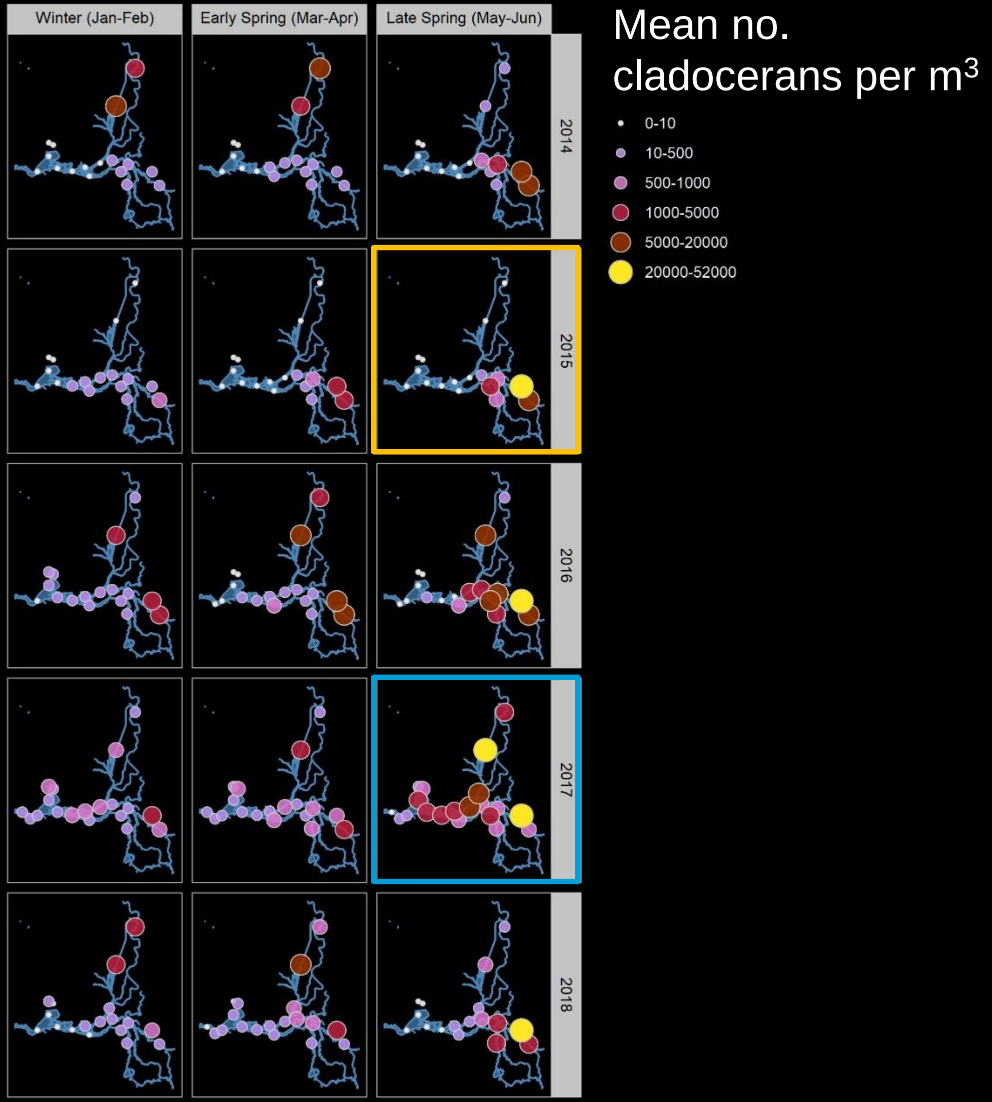


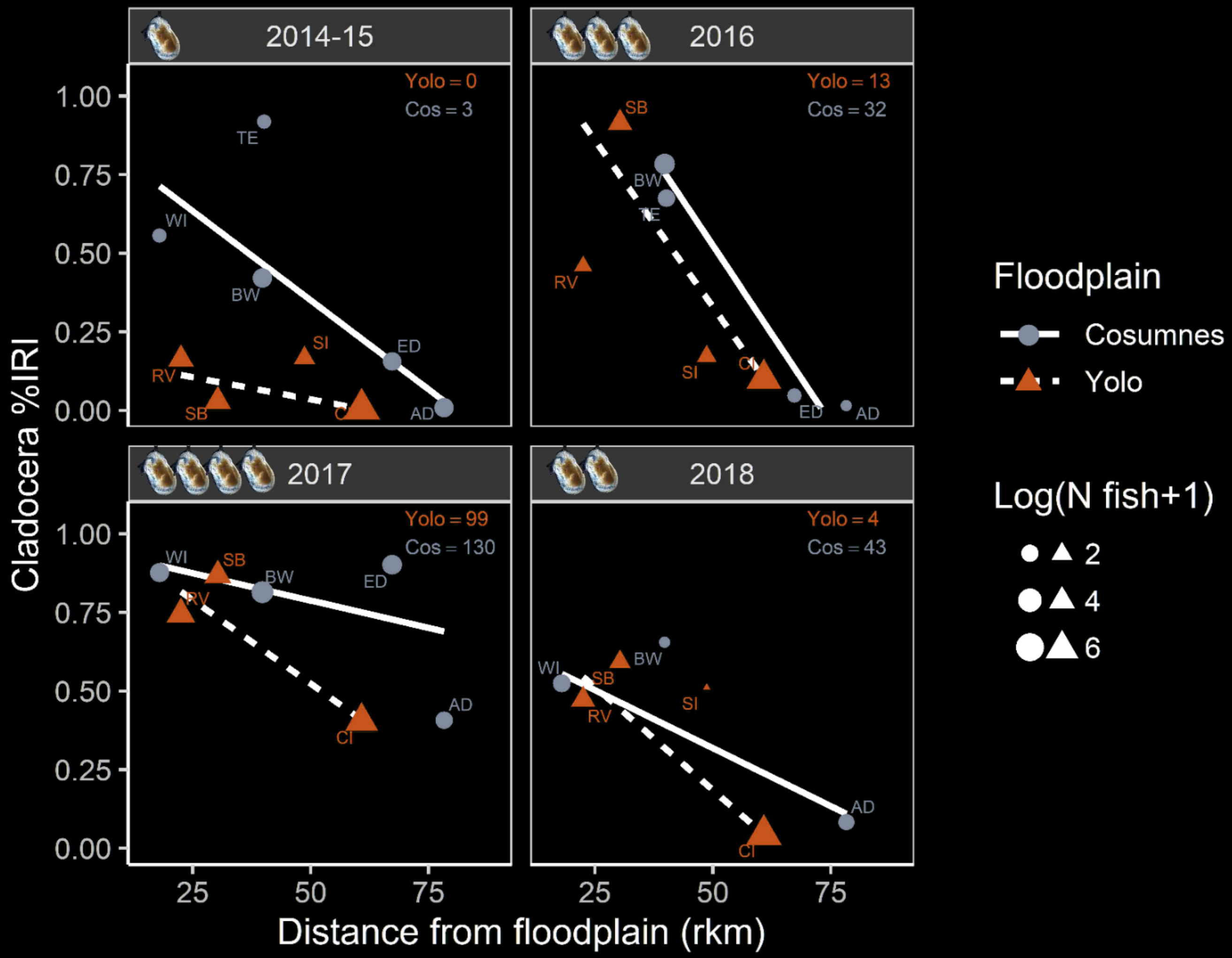


Cladocera %IRI ~ floodplain + inundation period + river distance weighted by log(N fish dissected)

$F_{3,27} = 63.4$, $p < 0.0001$, adj. $r^2 = 0.67$

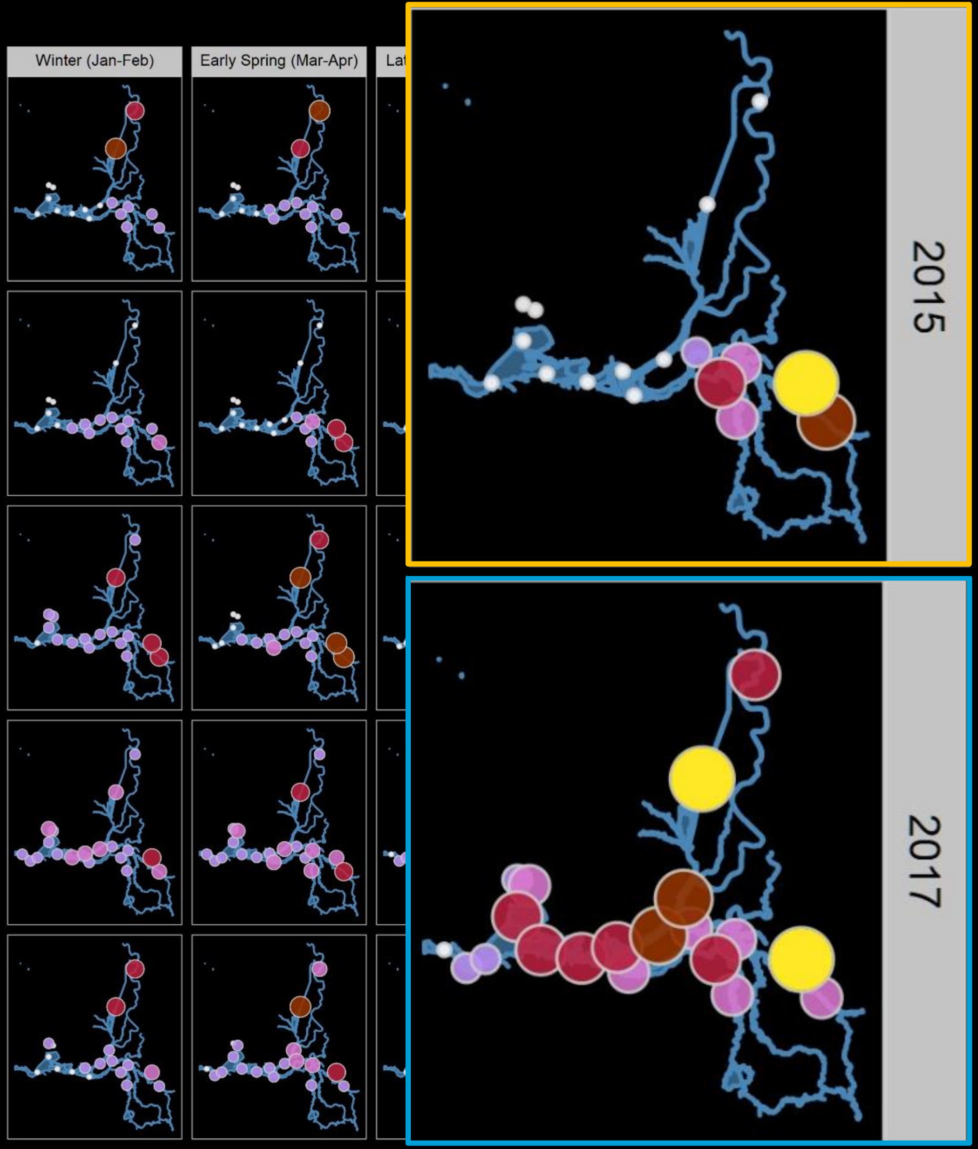
Floodplains provide trophic subsidies to salmon in the Delta

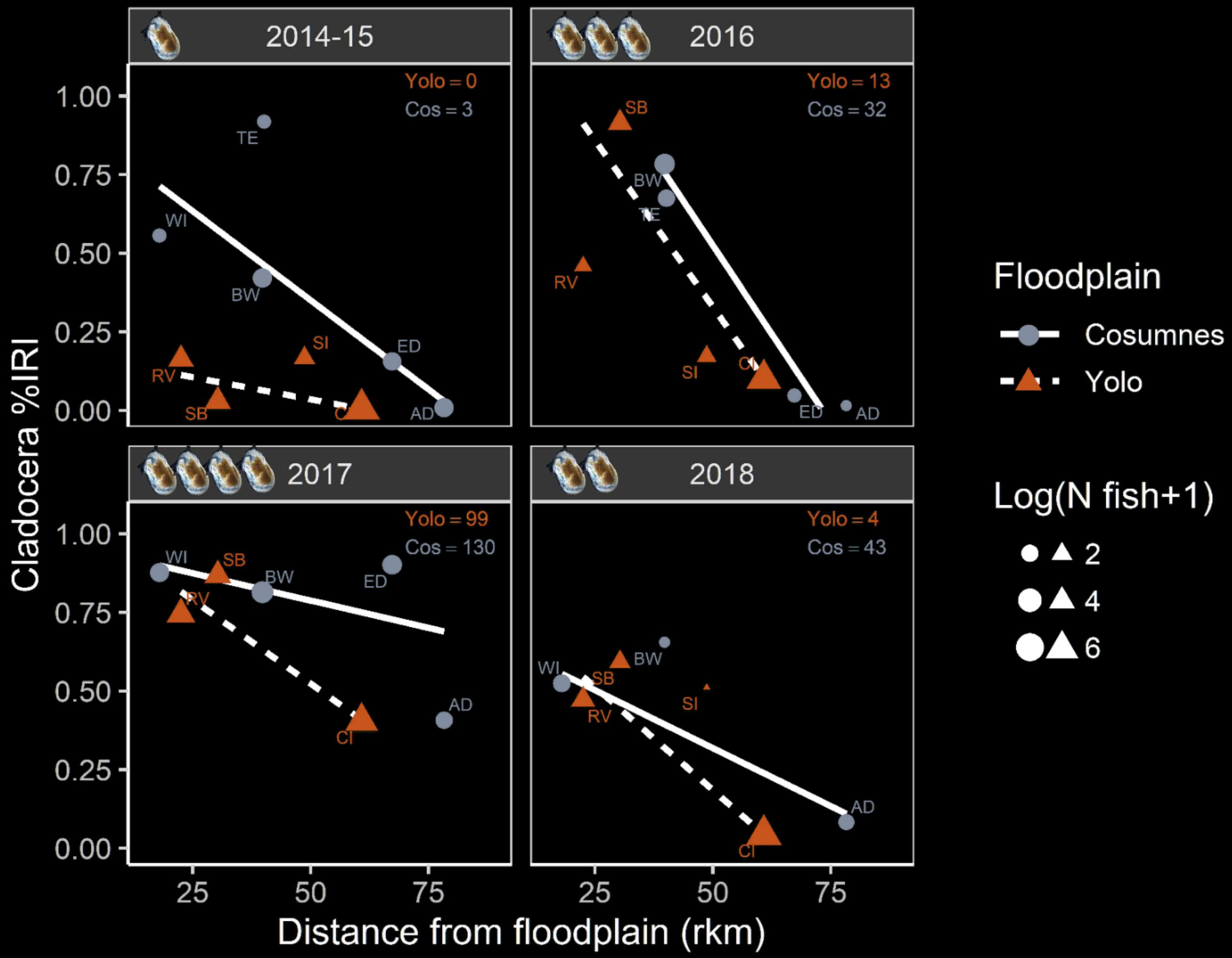




Data provided by CDFW (IEP) & DWR

Floodplains provide trophic subsidies to salmon in the Delta





Summary

- Maintaining / diversifying habitat mosaics and foodscapes from source (*e.g.* upstream thermal refugia to support yearlings) to the sea (*e.g.* restoring marshes & downstream floodplains to support fry) will broaden emigration window and help maintain adaptive capacity – critical for salmon resilience in a changing climate.
- Important to consider both longitudinal connectivity (*e.g.* pulse flows to cue emigration and to transport zooplankton from floodplains downstream) and lateral connectivity (*e.g.* increasing floodplain inundation periods and increasing accessibility to fish) and in coordinated flow and habitat management plans.
- Fry can successfully rear in non-natal habitats (including floodplains, Delta, other tributaries) so long as

  (a) the strategy is expressed in the first place

  (b) there is sufficient habitat & food
- In the latter study, the inundation of a managed floodplain (or lack of) played a pivotal role in shaping the juvenile salmon Central Valley foodscape (*sensu* Rossi 2020).
- Floodplain restoration that increases the extent and productivity of the foodscape is especially important given rising temperatures and projections of more rain/less snow (*i.e.,* increased reliance on early migrants).

THANK YOU FOR LISTENING! Also many thanks to..

Will Satterthwaite (NMFS), JD Wikert (USFWS), Joe Merz (CFS), Tim Heyne (CDFW), Sébastien Nusslé (UCB), Hugh Sturrock (UCSF)

Alyssa Fitzgerald (UCSC), Peter Weber (LLNL), George Whitman (UCD), Anthony Malkassian (MIO), Matt Johnson (CDFW)

Nick Corline, Ryan Peek, Kelly Neal, Dana Myers, Sierra Schluep, Marissa Levinson (UCD)

Cory Graham, Jack Ingram, Patt Brandes, Jeff McClain, Matt Dekar, Denise Barnard and all DJFMP crews (USFWS)

Travis Hinkelman & Steve Zeug (CFS) and all Cramer Fish Sciences RST operators

Laura Coleman, Keiko Mertz, Krista Schmidt, Bradyn O'Connor, Amanda Gonzales, Matt Salvador, Gabe Saron,

Justin Glessner, Miranda Tilcock, Amber Manfree, Malte Willmes, Cathryn Lawrence, Mike Miller (UCD)

Steve Tsao, Gretchen Murphey, Crystal Sinclair, Shelly Schubert and everyone on the Mossdale Trawls (CDFW)

All crews on the Stanislaus River, Sacramento River and Mill/Deer Creek Carcass Surveys

Ted Sommer, Brian Schreier, Jared Frantzich, Brett Harvey, Mallory Bedwell (DWR)

Louise Conrad, Pascale Goertler, Annika Keeley (DSC)

Alison Whipple, April Robinson and Letitia Grenier (SFEI)

CDFW Proposition 1 Grant (Ecosystem Restoration Program and the Water Quality, Supply, and Infrastructure Improvement Act of 2014, CWC §79707[g]) funded the Delta study

anna.sturrock@essex.ac.uk
@otolithgirl

University of Essex

Center for Watershed Sciences

UC Davis – University of California

Cramer Fish Sciences – Oregon • California • Washington • Idaho • Alaska

AFRP

Delta Stewardship Council

USGS
science for a changing world

Survival, travel time, and entrainment of juvenile salmon smolts migrating within Yolo Bypass

Adam C. Pope
Russell W. Perry
Dalton J. Hance
Western Fisheries Research Center

13 October 2021

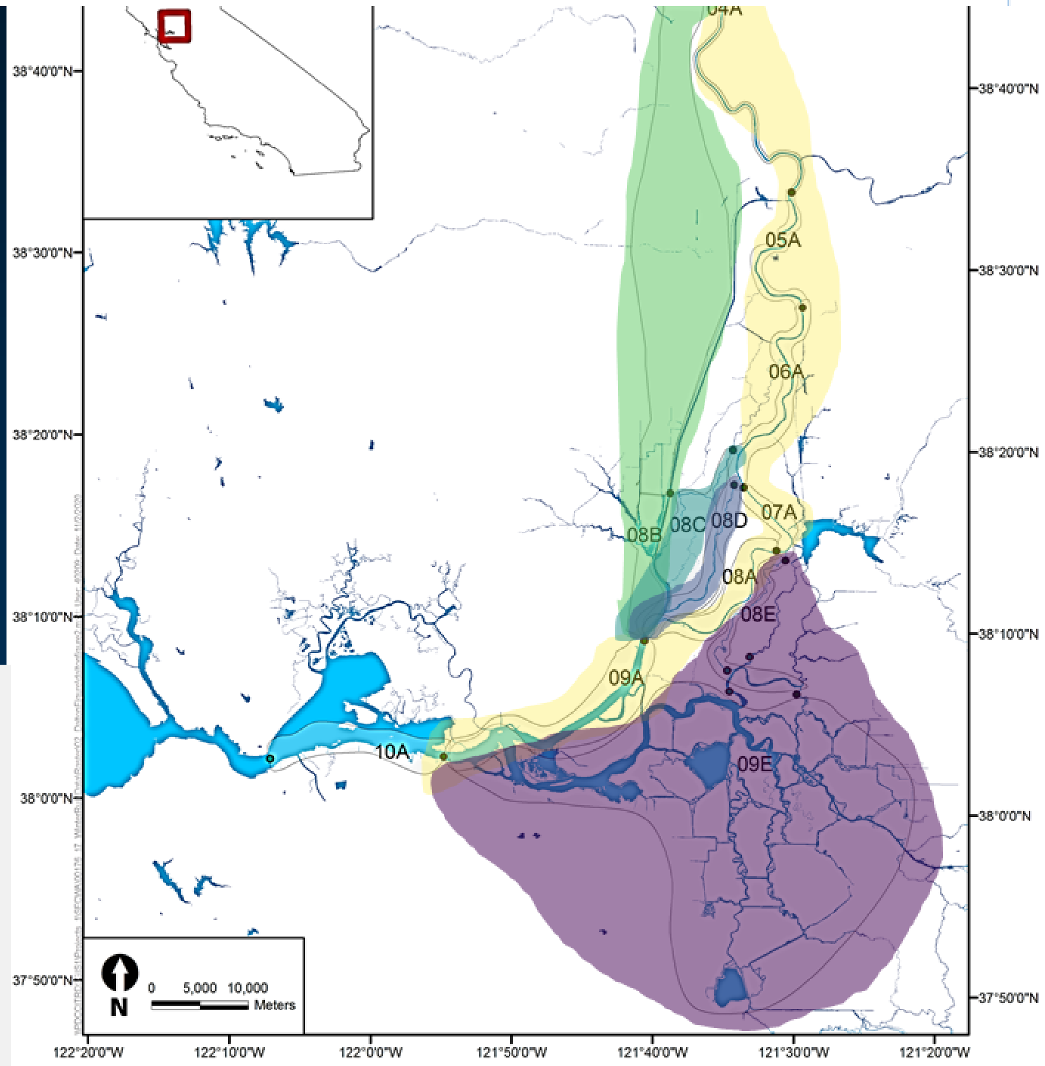
AUGUST 2018

SAN FRANCISCO ESTUARY & WATERSHED SCIENCE

Sponsored by the Delta Science Program and the UC Davis John Muir Institute of the Environment

Survival of Juvenile Chinook Salmon in the Yolo Bypass and the Lower Sacramento River, California

Myfanwy E. Johnston[1], Anna E. Steel[2], Matthew Espe[3], Ted Sommer[4], A. Peter Klimley[5], Philip Sandstrom[6], and David Smith[7]



North American Journal of Fisheries Management 25:1493–1504, 2005

DOI: 10.1577/M04-208.1

[Article]

Habitat Use and Stranding Risk of Juvenile Chinook Salmon on a Seasonal Floodplain

TED R. SOMMER,* WILLIAM C. HARRELL, AND MATTHEW L. NOBRIGA

California Department of Water Resources, Sacramento, California 95816, USA

Two Case Studies

- 2016 – late fall run
  - 3 releases at various points across a flood event
  - Releases into Yolo before and after overtopping
- 2014-18 – winter run
  - 5 years of data
  - Fish enter Yolo volitionally

Transactions of the American Fisheries Society

Article | Full Access

Juvenile Chinook Salmon Survival, Travel Time, and Floodplain Use Relative to Riverine Channels in the Sacramento–San Joaquin River Delta

Adam C. Pope, Russell W. Perry, Brett N. Harvey, Dalton J. Hance, Hal C. Hansel,

First published: 05 January 2021 | https://doi.org/10.1002/tafs.10271

From drought to deluge: spatiotemporal variation in migration routing, survival, travel time and floodplain use of an endangered migratory fish

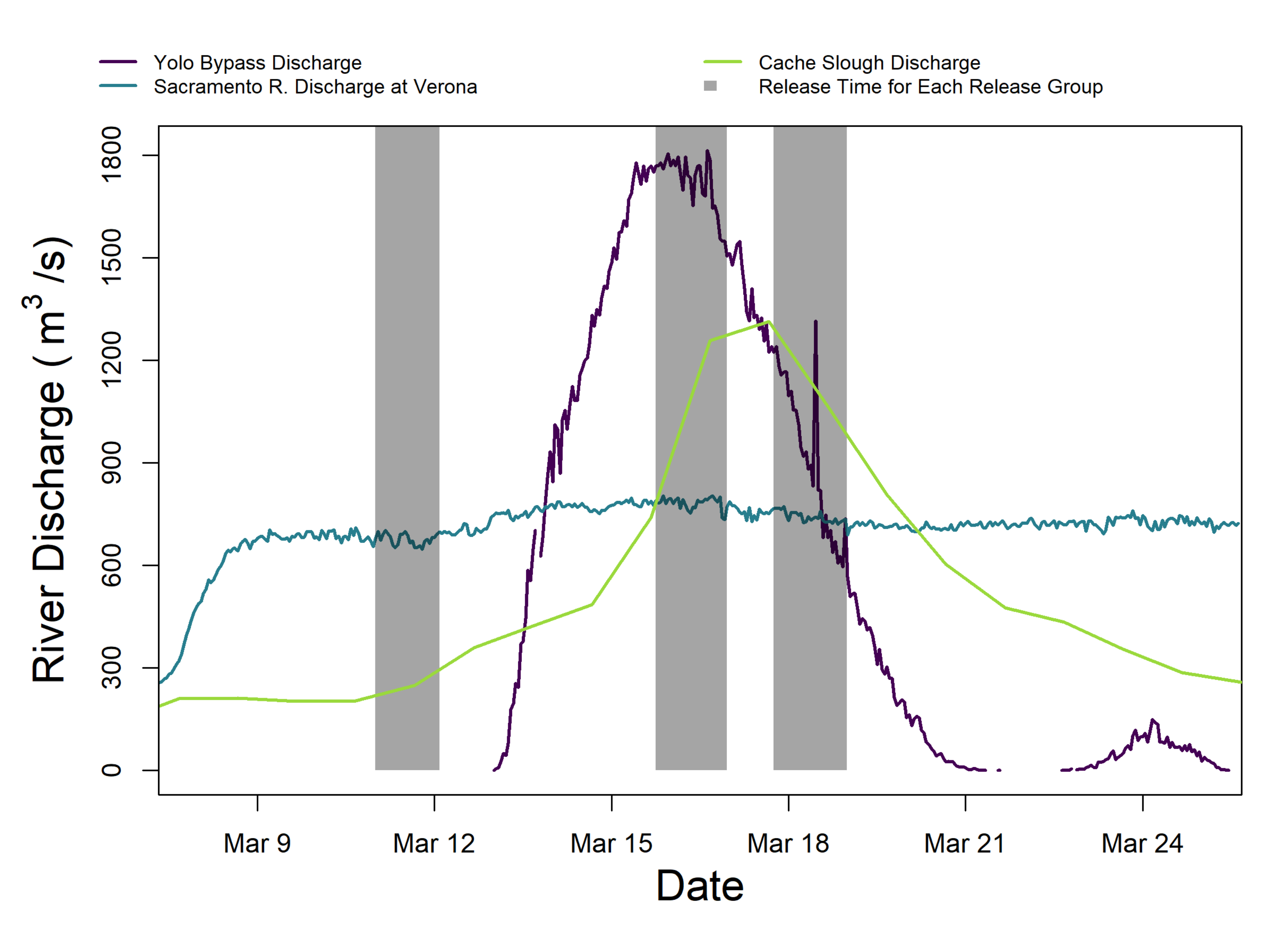
Authors: Dalton J Hance, Russell W Perry, PhD, Adam C Pope, Arnold J Ammann, Jason L. Hassrick, and Gabriel Hansen | AUTHORS INFO & AFFILIATIONS

Publication: Canadian Journal of Fisheries and Aquatic Sciences • 11 August 2021 • https://doi.org/10.1139/cjfas-2021-0042

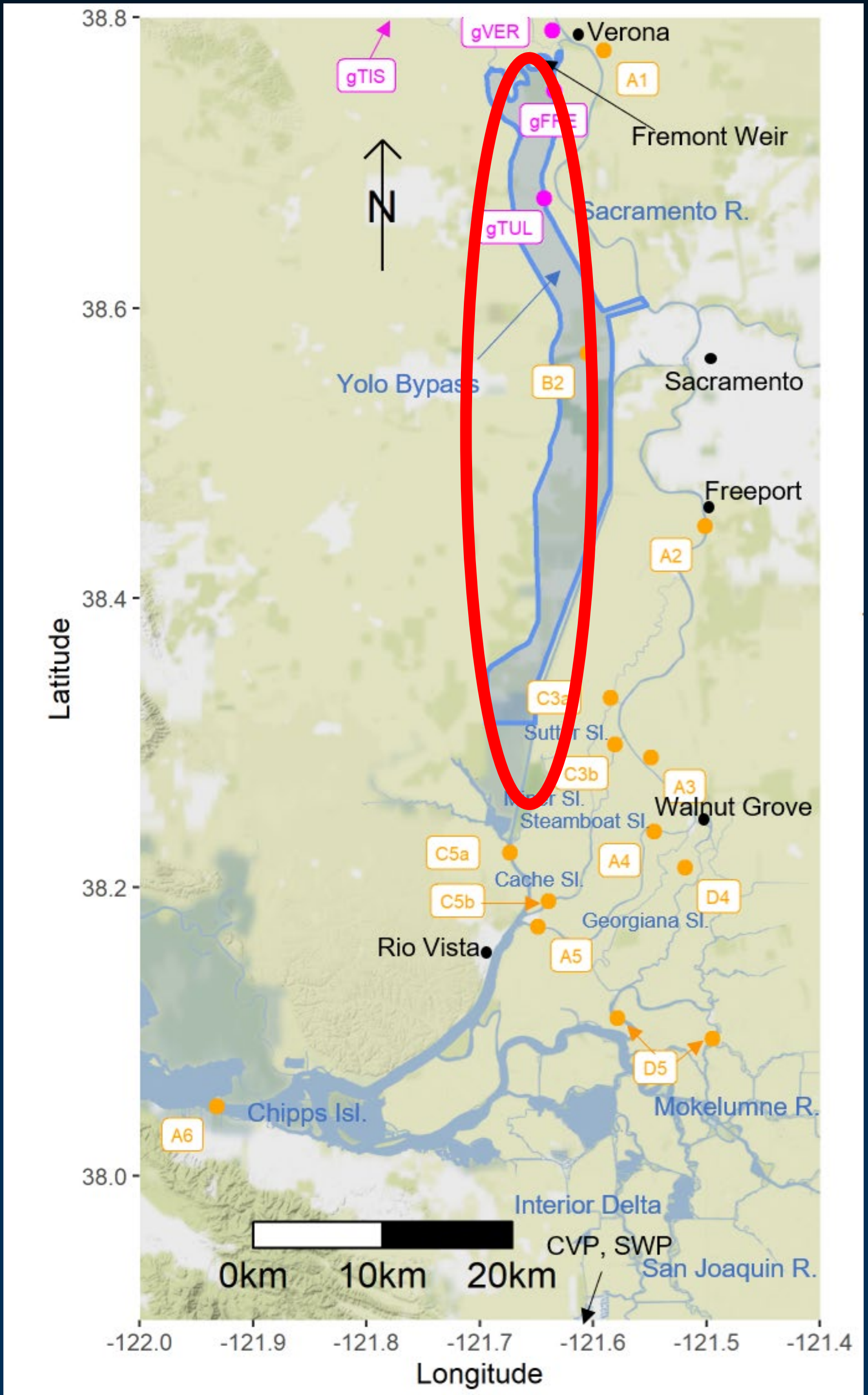
Telemetry data and Sacramento River flow – 2016

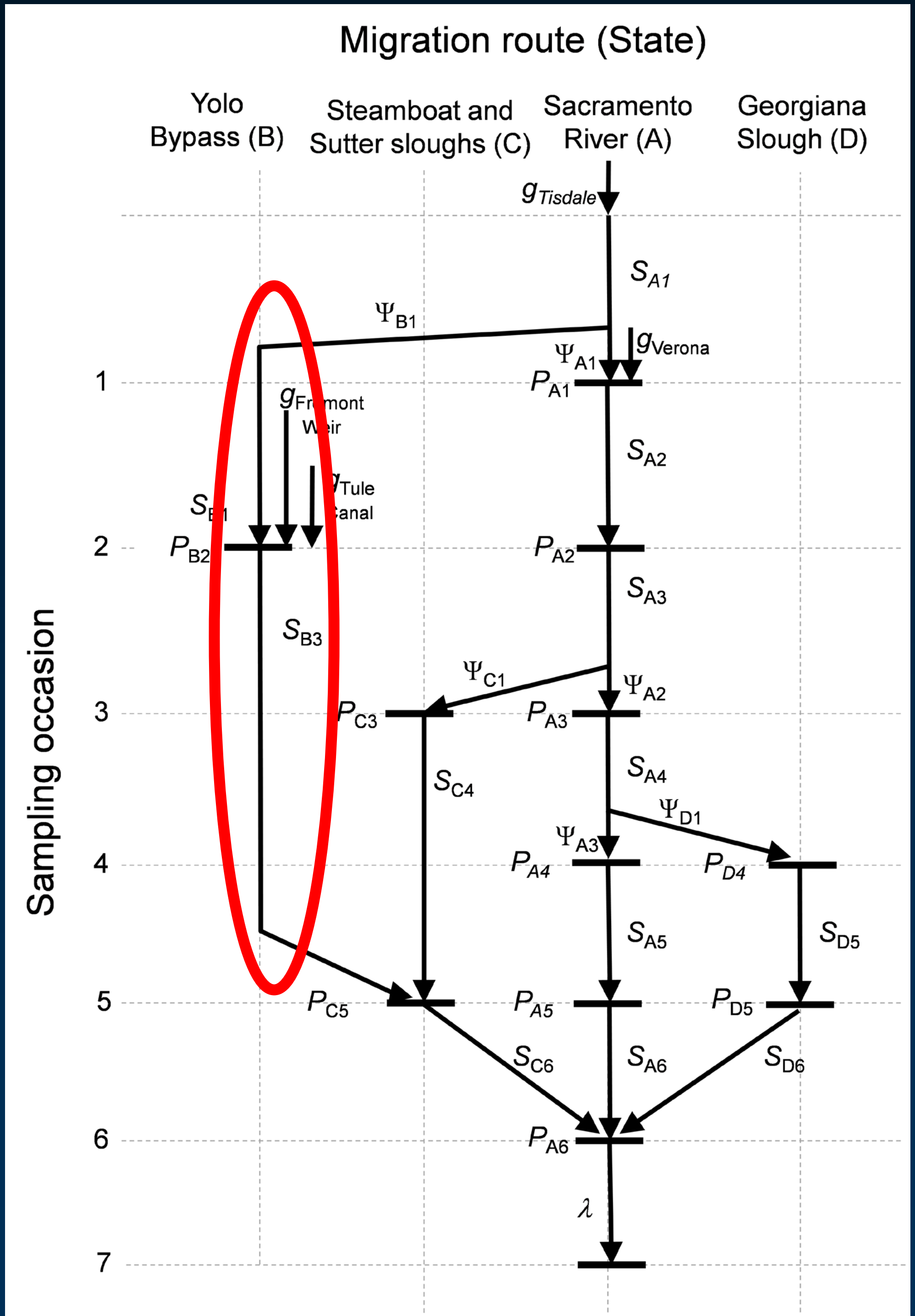
- 711 total released late fall Chinook

Release Date	Release location	n
March 11–12	Tisdale	141
	Yolo Bypass	99
	Verona	0
March 15–16	Tisdale	40
	Yolo Bypass	100
	Verona	100
March 17–18	Tisdale	40
	Yolo Bypass	98
	Verona	99



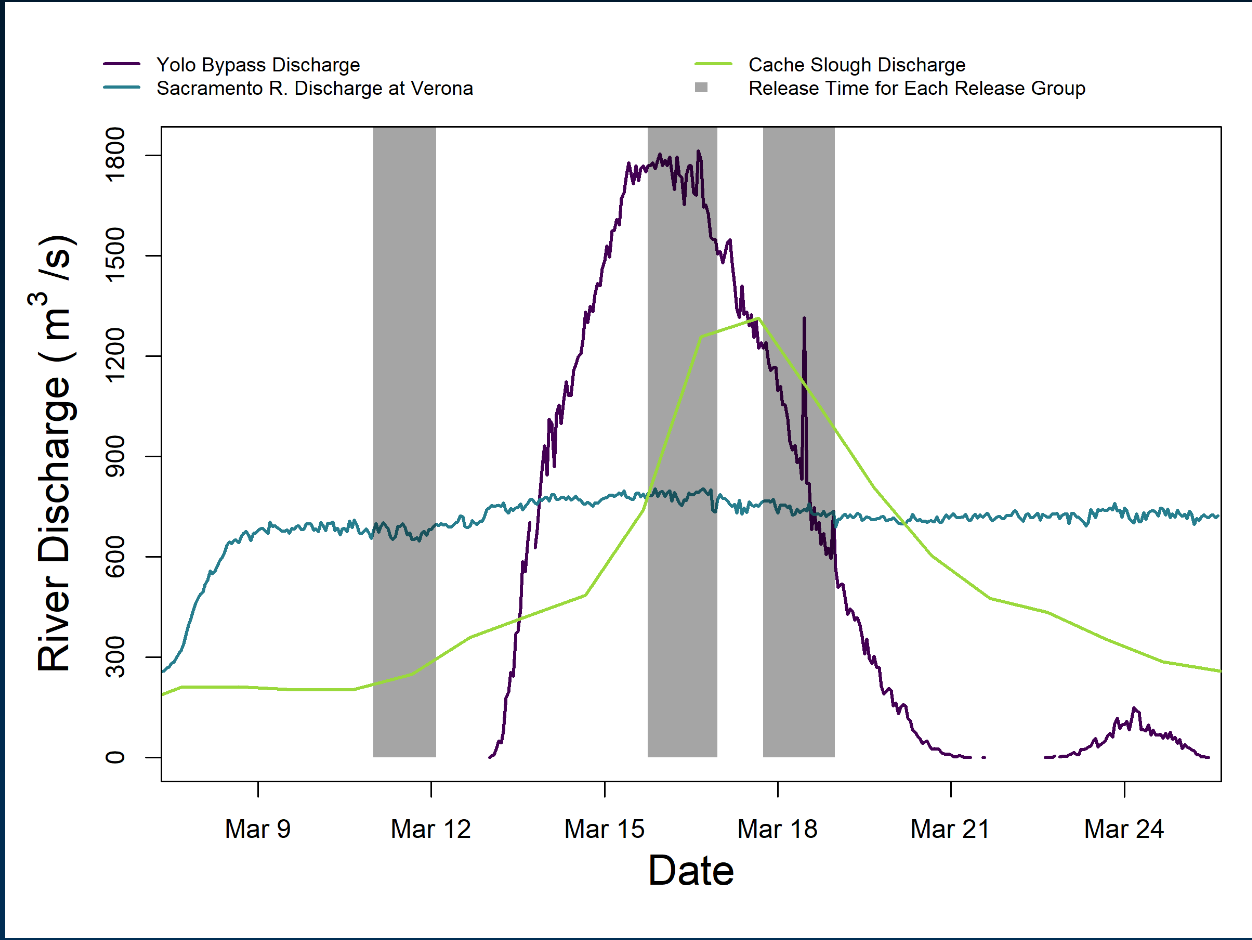
USGS

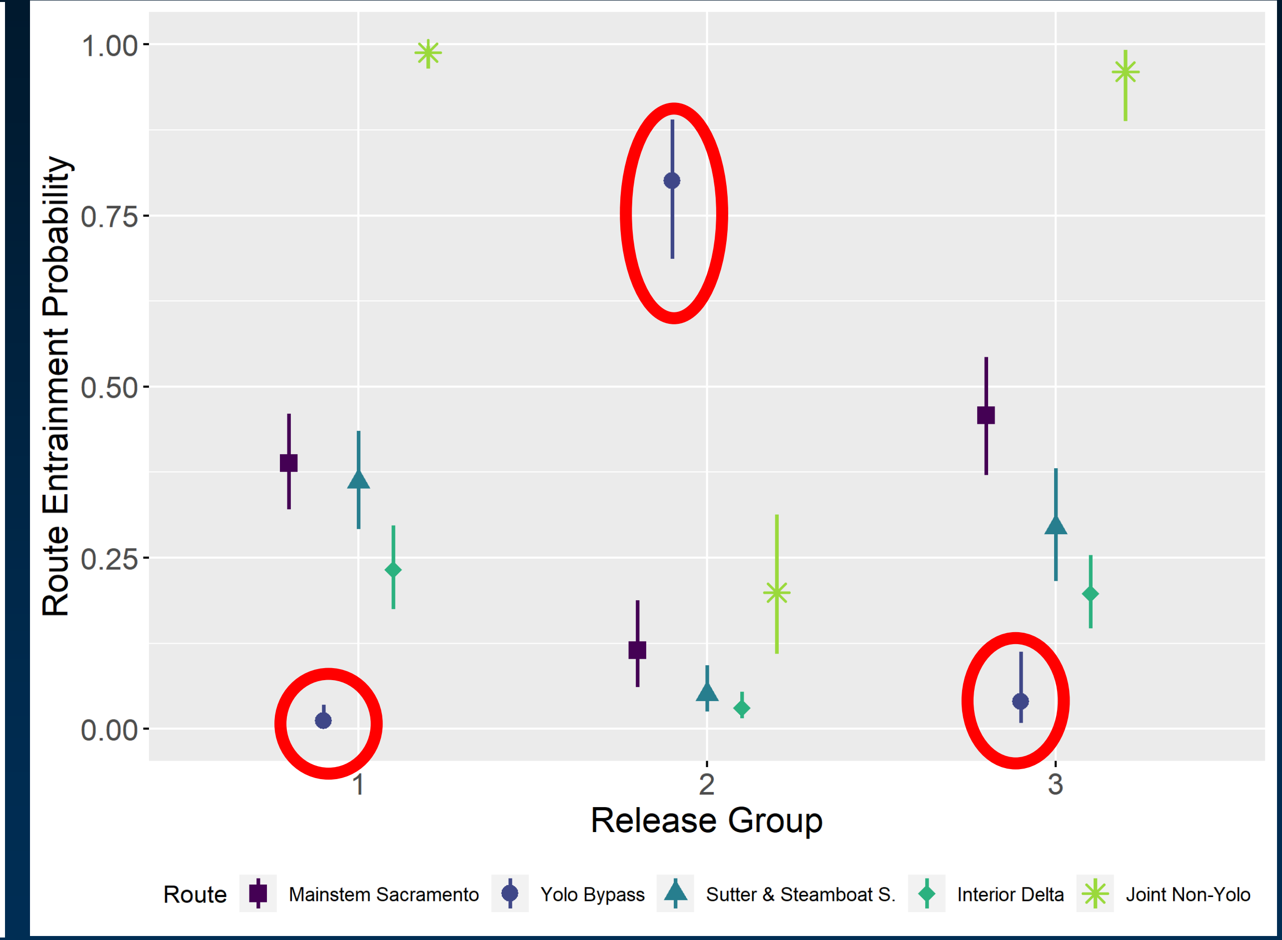

gTIS
gVER
Verona
A1
gFRE
Fremont Weir
N
Sacramento R.
gTUL
Yolo Bypass
B2
Sacramento
Freeport
A2
Latitude
38.8
38.6
38.4
38.2
38.0
C3a
Sutter Sl.
C3b
A3
Walnut Grove
Steamboat Sl.
C5a
A4
Cache Sl.
C5b
D4
Georgiana Sl.
Rio Vista
A5
D5
Chipps Isl.
Mokelumne R.
A6
Interior Delta
CVP, SWP
San Joaquin R.
0km
10km
20km
-122.0
-121.9
-121.8
-121.7
-121.6
-121.5
-121.4
Longitude


Migration route (State)
Yolo Bypass (B)
Steamboat and Sutter sloughs (C)
Sacramento River (A)
Georgiana Slough (D)
Sampling occasion
1
2
3
4
5
6
7
g_Tisdale
S_A1
Ψ_B1
g_Verona
Ψ_A1
P_A1
S_A2
P_B2
P_A2
S_A3
S_B3
Ψ_C1
Ψ_A2
P_C3
P_A3
S_C4
S_A4
Ψ_D1
Ψ_A3
P_A4
P_D4
S_A5
S_D5
P_C5
P_A5
P_D5
S_C6
S_A6
S_D6
P_A6
λ

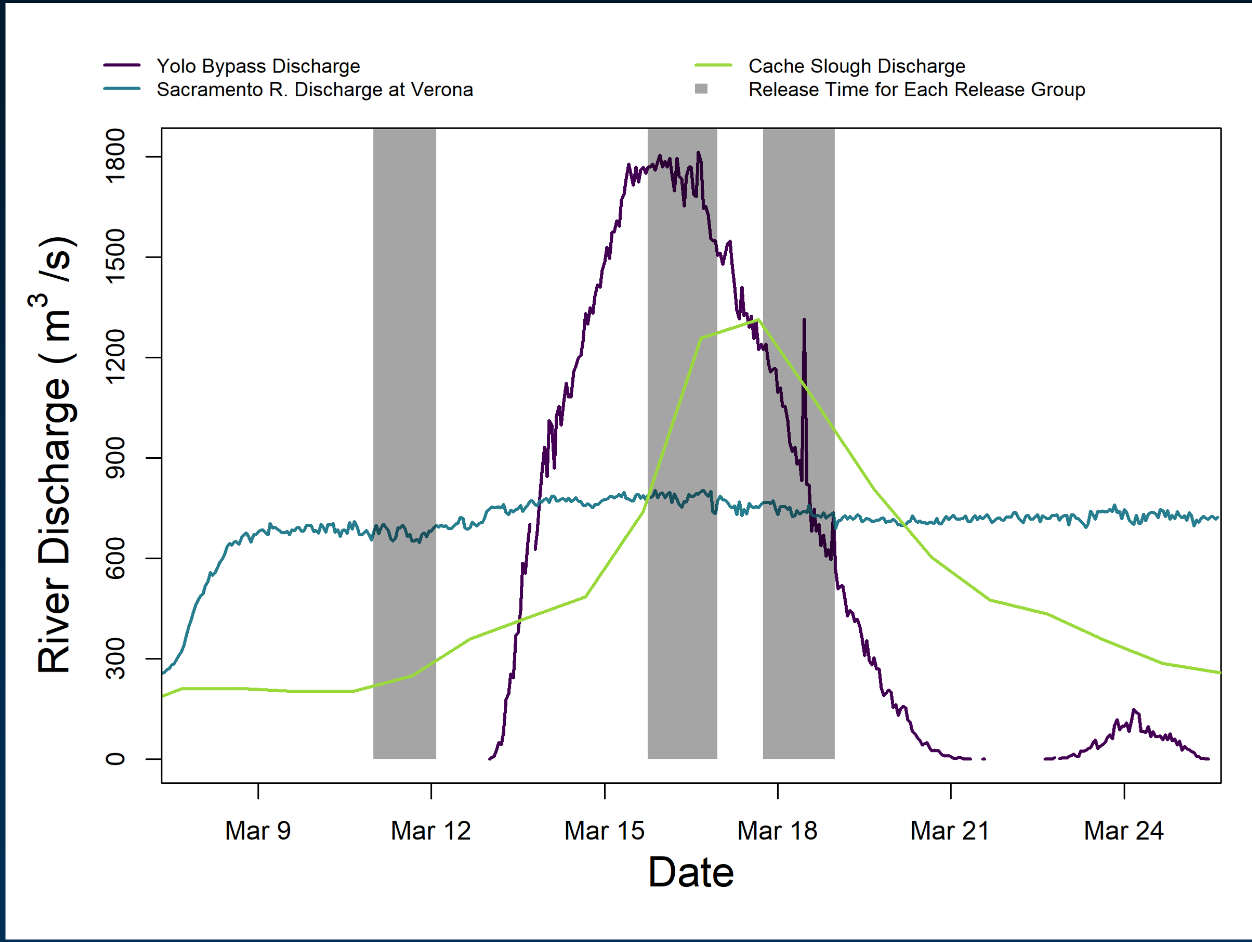
USGS

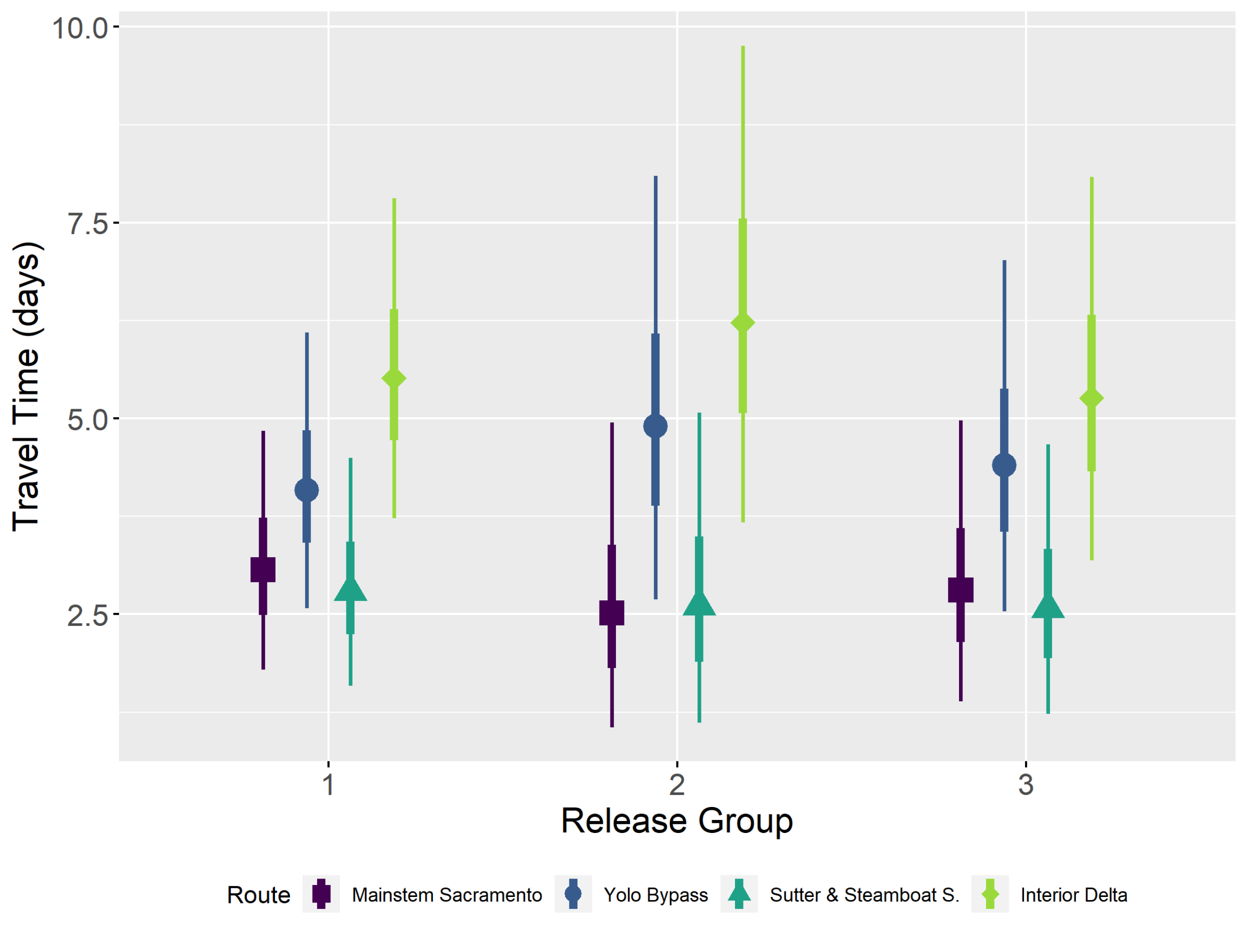
2016 Late Fall Run – Entrainment





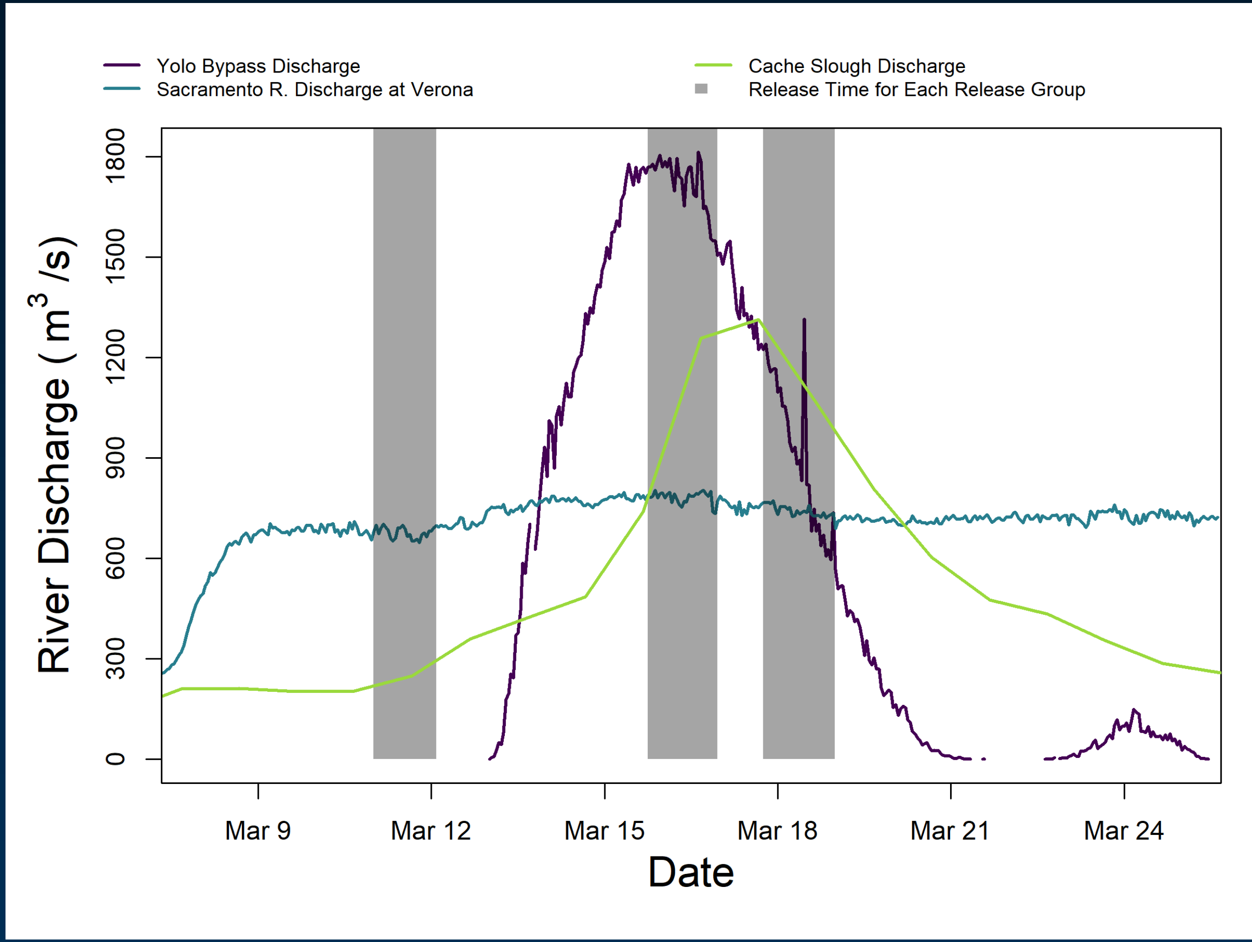
2016 Late Fall Run – Travel Time

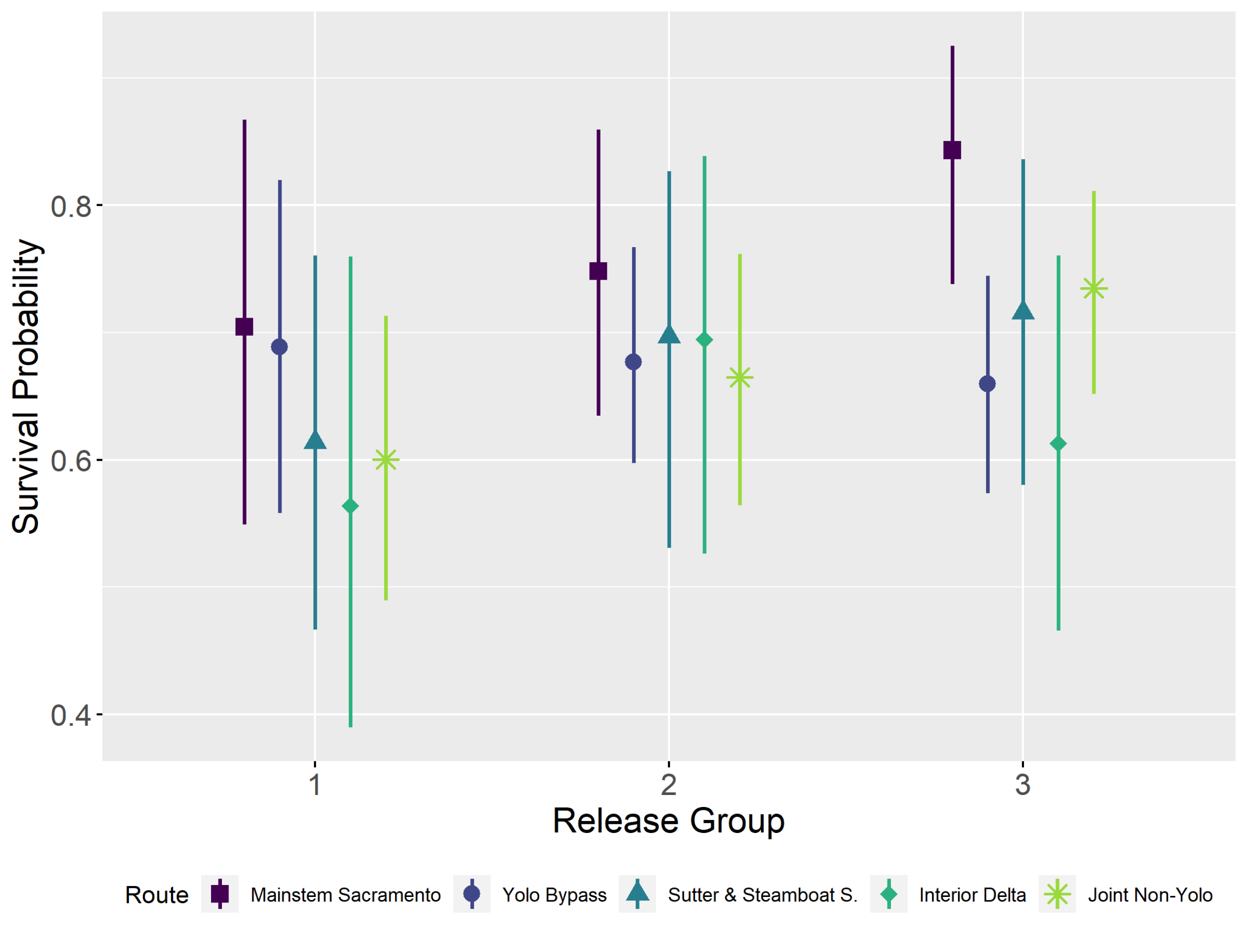




USGS

2016 Late Fall Run – Survival



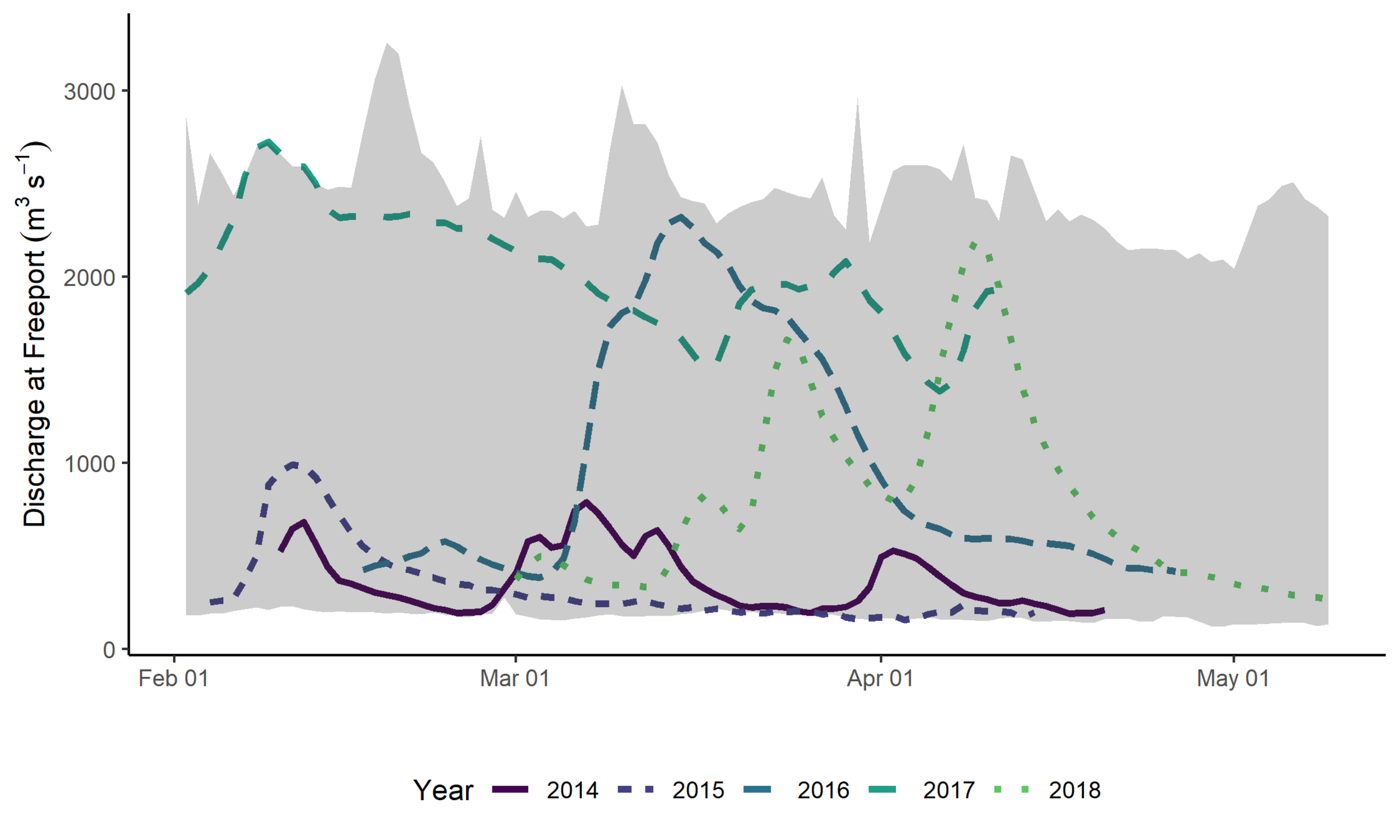


USGS

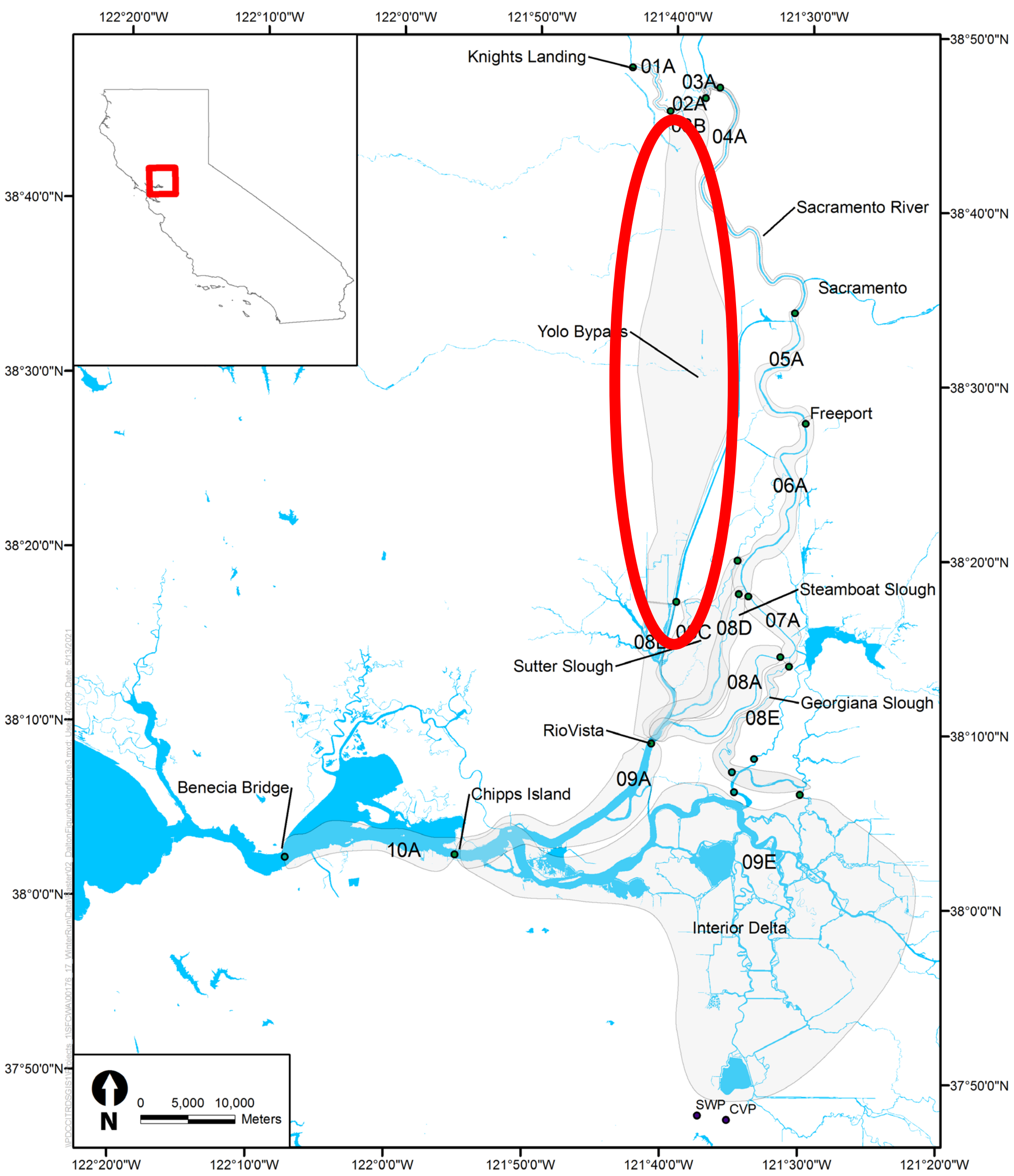
Telemetry data – 2014-18

- 2,662 total released winter run Chinook

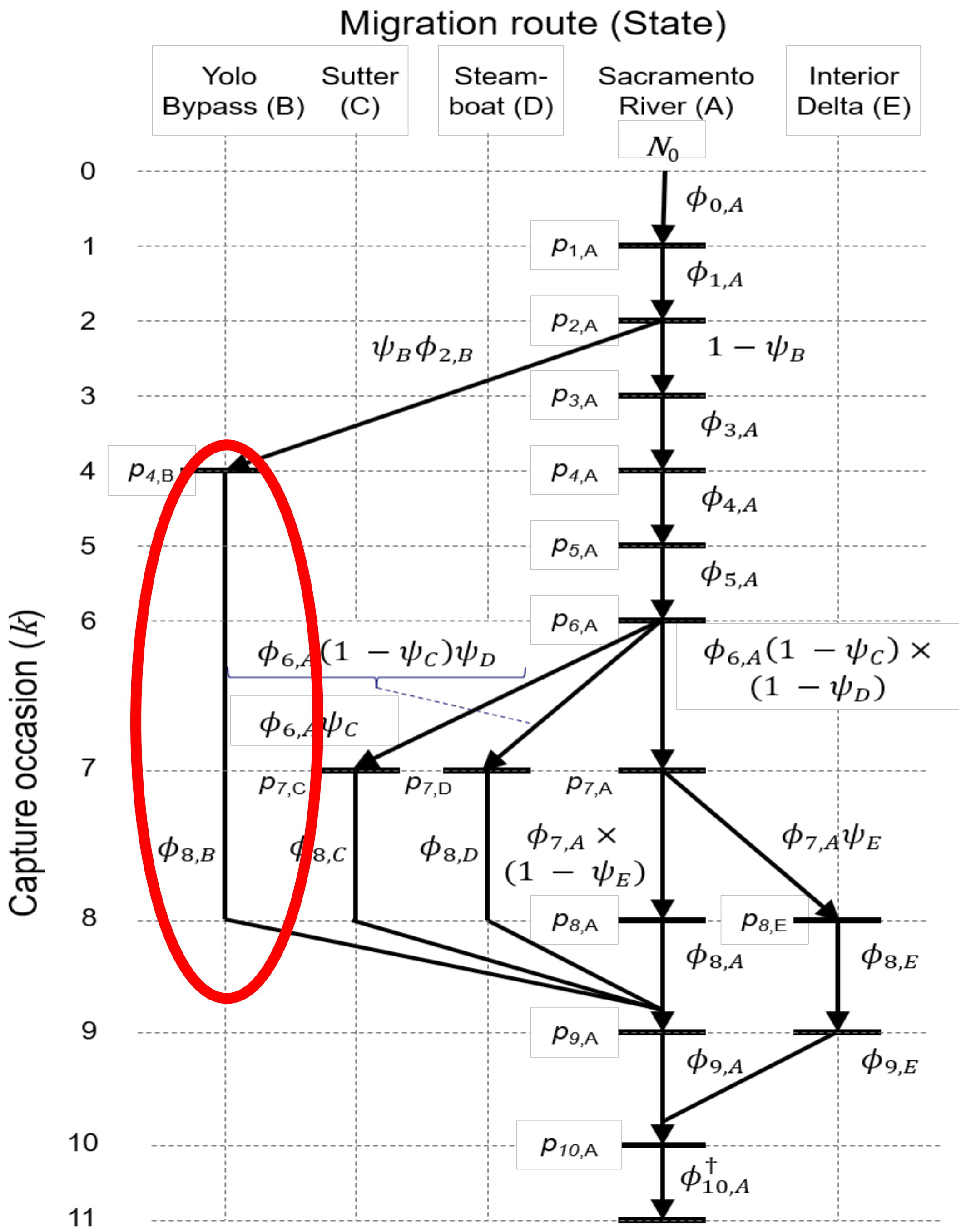
Year	Release Date	n
2014	Feb 10	358
2015	Feb 04	249
2015	Feb 06	318
2016	Feb 17	285
2016	Feb 18	285
2017	Feb 02	569
2018	Mar 01	361
2018	Mar 13	237



USGS



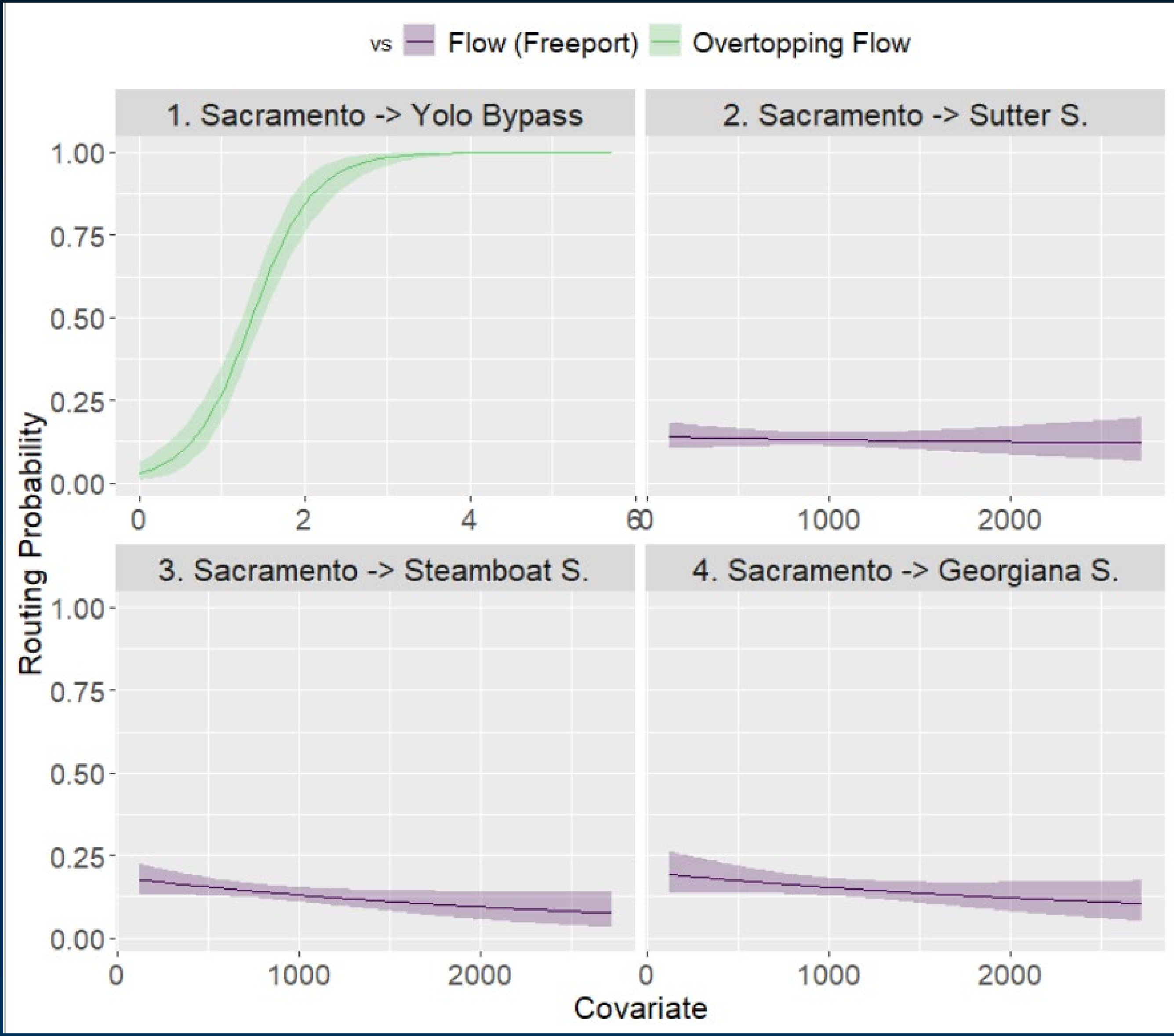
122°20'0"W
122°10'0"W
122°0'0"W
121°50'0"W
121°40'0"W
121°30'0"W
121°20'0"W
38°50'0"N
38°40'0"N
38°30'0"N
38°20'0"N
38°10'0"N
38°0'0"N
37°50'0"N
Knights Landing
01A
03A
02A
04A
Sacramento River
Sacramento
Yolo Bypass
05A
Freeport
06A
Steamboat Slough
07A
08D
Sutter Slough
08A
Georgiana Slough
08E
RioVista
09A
Benecia Bridge
Chipps Island
10A
09E
Interior Delta
SWP
CVP
N
0 5,000 10,000
Meters

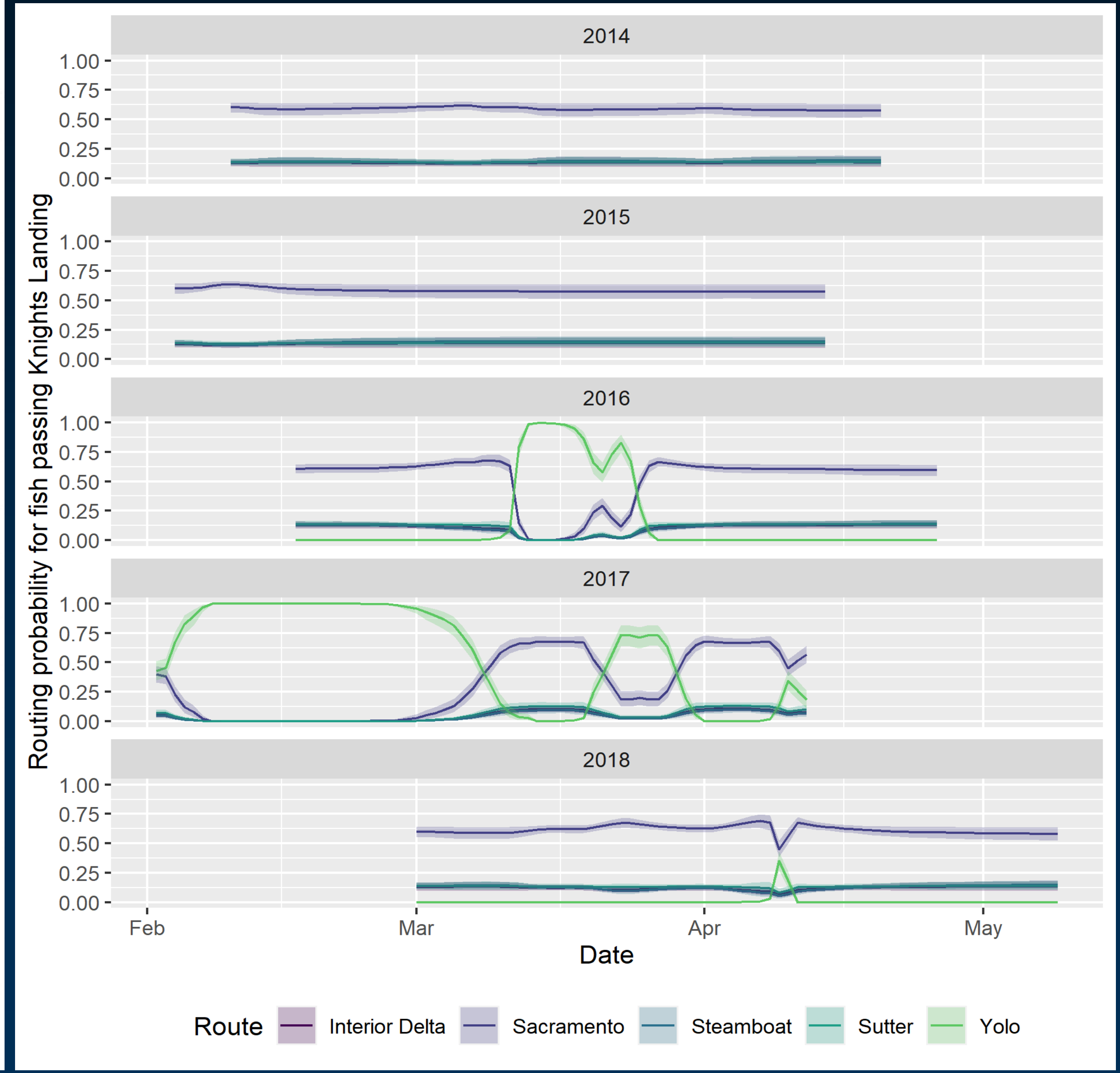


Migration route (State)
Yolo Bypass (B)
Sutter (C)
Steam-boat (D)
Sacramento River (A)
Interior Delta (E)
Capture occasion (k)
0
1
2
3
4
5
6
7
8
9
10
11
N_0
$\phi_{0,A}$
$p_{1,A}$
$\phi_{1,A}$
$p_{2,A}$
$\psi_B \phi_{2,B}$
$1 - \psi_B$
$p_{3,A}$
$\phi_{3,A}$
$p_{4,B}$
$p_{4,A}$
$\phi_{4,A}$
$p_{5,A}$
$\phi_{5,A}$
$p_{6,A}$
$\phi_{6,A}(1 - \psi_C)\psi_D$
$\phi_{6,A}(1 - \psi_C) \times (1 - \psi_D)$
$\phi_{6,A}\psi_C$
$p_{7,C}$
$p_{7,D}$
$p_{7,A}$
$\phi_{8,B}$
$\phi_{8,C}$
$\phi_{8,D}$
$\phi_{7,A} \times (1 - \psi_E)$
$\phi_{7,A}\psi_E$
$p_{8,A}$
$p_{8,E}$
$\phi_{8,A}$
$\phi_{8,E}$
$p_{9,A}$
$\phi_{9,A}$
$\phi_{9,E}$
$p_{10,A}$
$\phi^{\dagger}_{10,A}$

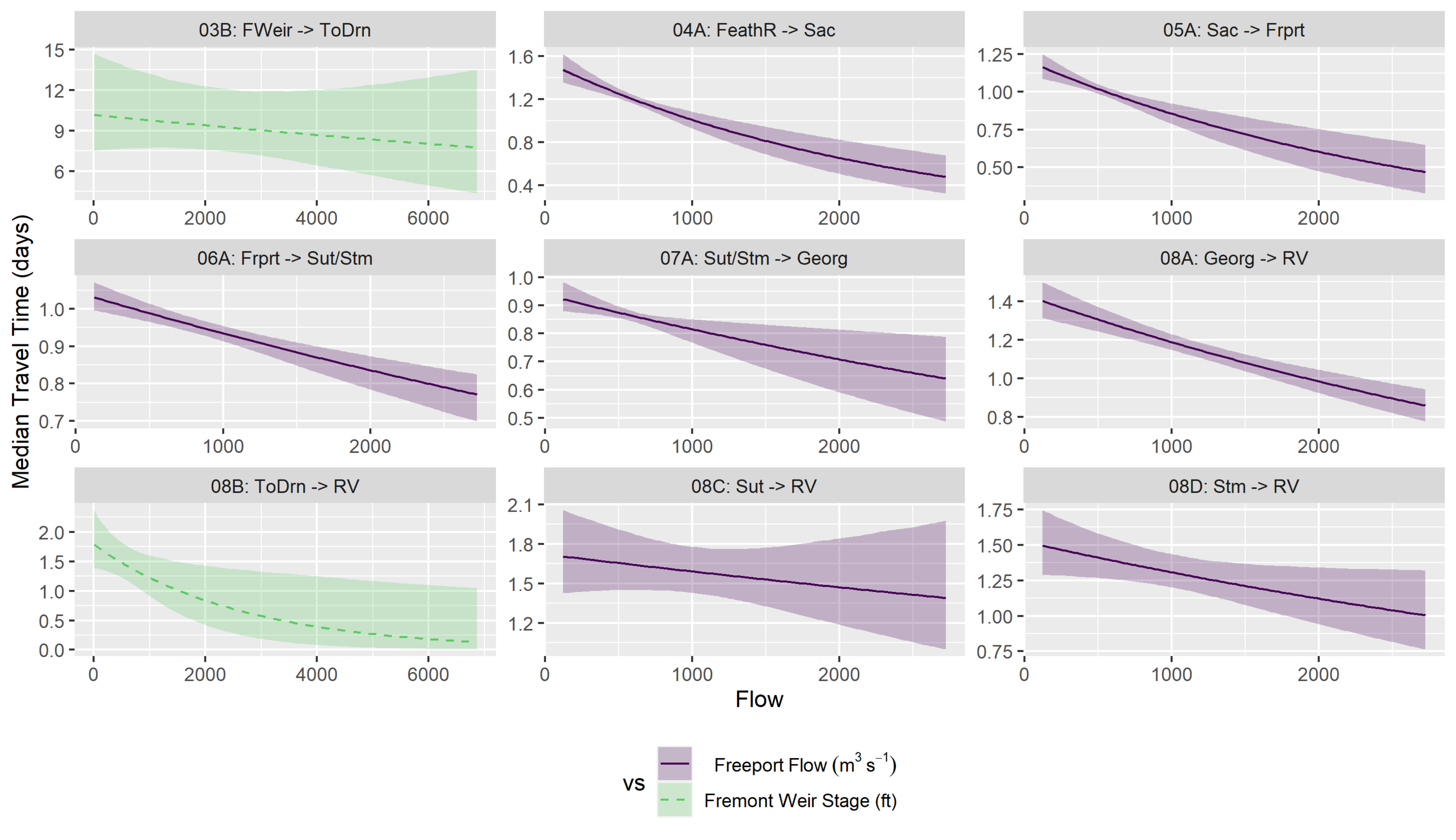
USGS

2014-18 Winter Run – Entrainment

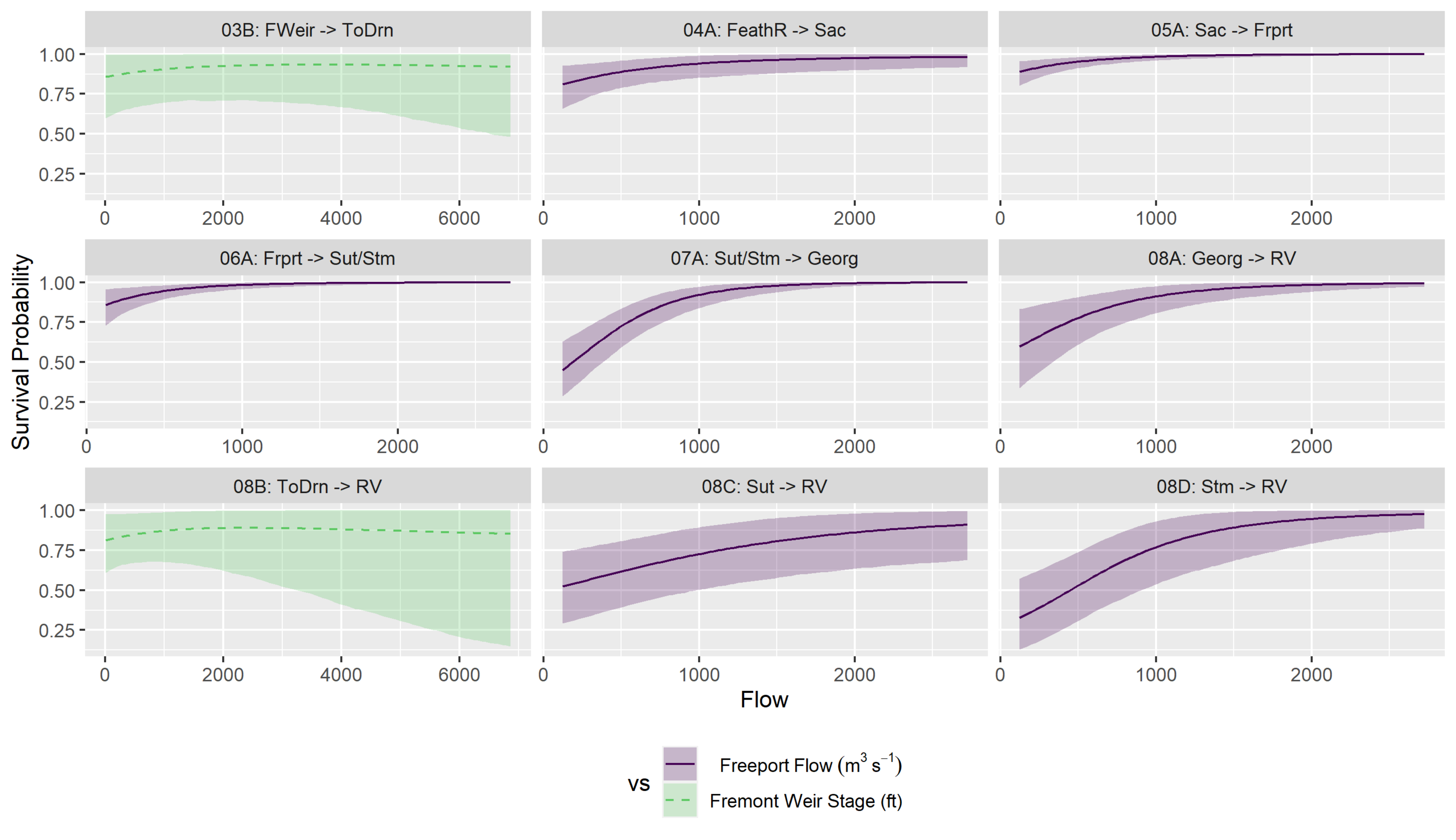




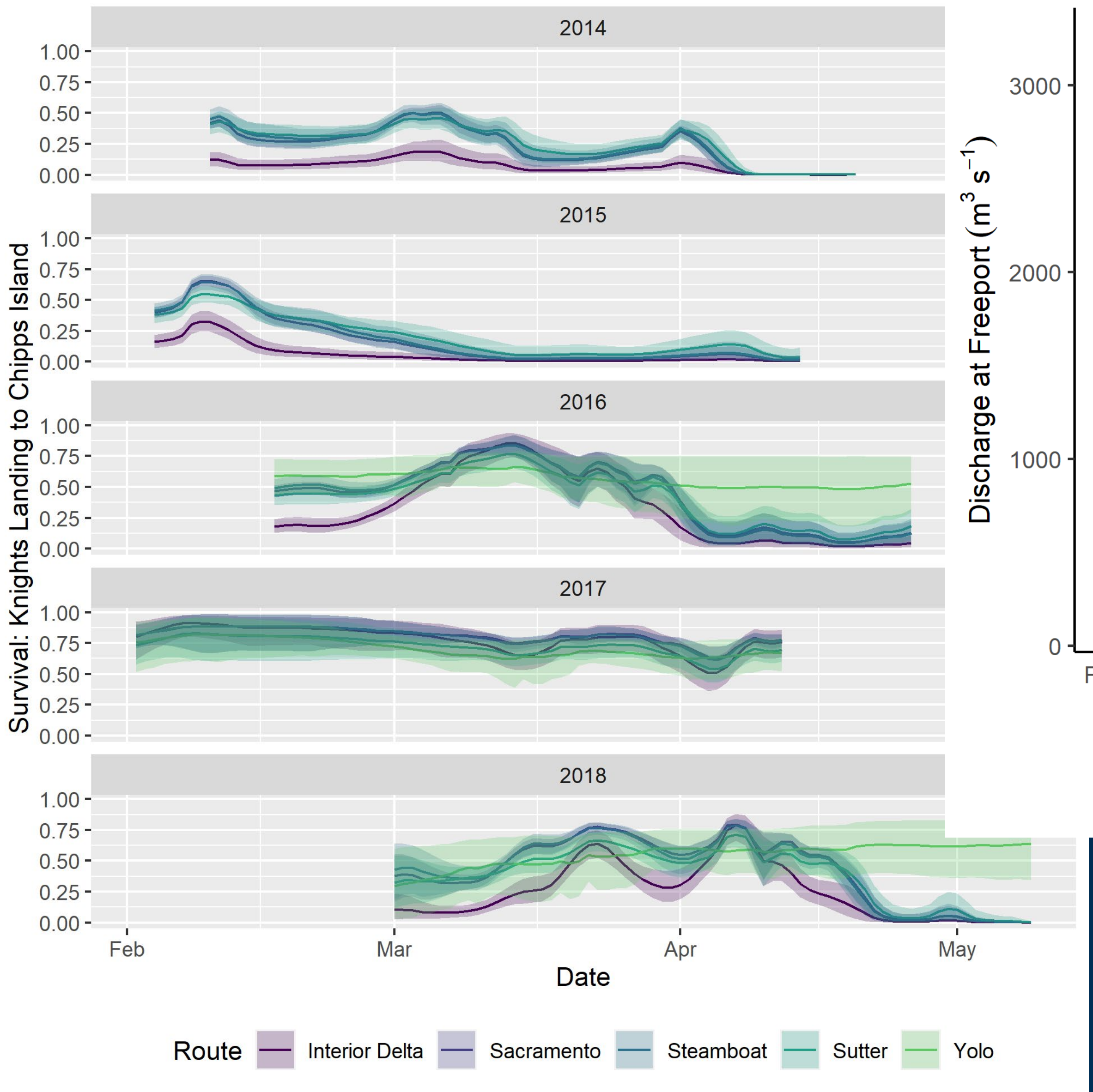
2014-18 Winter Run – Travel Time

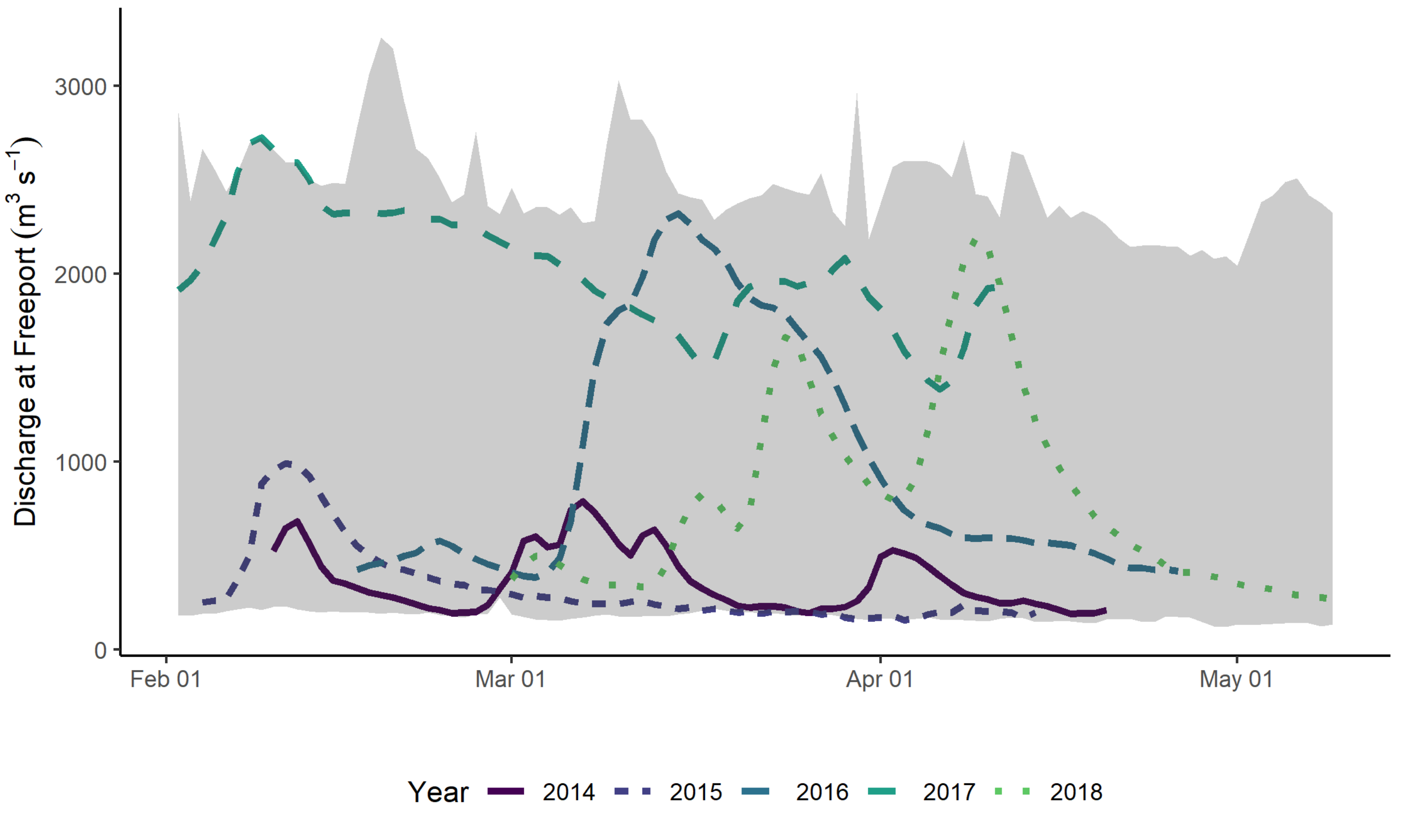


2014-18 Winter Run – Survival



2014-18 Winter Run – Survival





Summary

- Compare and contrast migration behavior from 2 studies
  - Wide differences in flow within a single year versus among years
  - Volitional survival and covariates in multiyear study; survival and travel time estimates at very low flows in single year study

Summary

- Compare and contrast migration behavior from 2 studies
- Both survival and travel times are high in Yolo Bypass
  - Little change with changing flow in Yolo, unlike in the Sacramento River
  - Need more research at very low flows – could survival still be high in Yolo in dry years?
  - “Portfolio effect” – later outmigration through Yolo

USGS

Summary

- Compare and contrast migration behavior from 2 studies
- Both survival and travel times are high in Yolo Bypass
- Entrainment into Yolo Bypass exhibits "step" change behavior
  - Few fish entrained unless stage is a foot or more above Fremont Weir
  - Implications for "notch"?

Summary

- Compare and contrast migration behavior from 2 studies
- Both survival and travel times are high in Yolo Bypass
- Entrainment into Yolo Bypass exhibits “step” change behavior
- Questions remain
  - Fine scale behavior – rearing among migrating smolts?
  - Is survival really high at sub-overtopping flows?

USGS

Questions/Discussion

USGS

* Final data expected January 2022. Final data available upon request Rachel.Johnson@noaa.gov

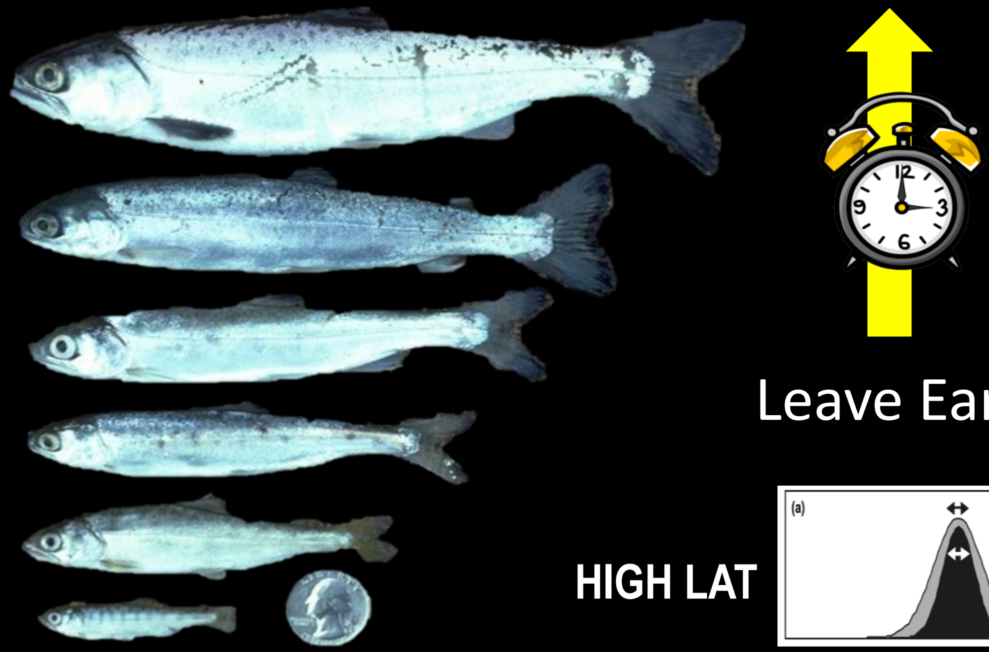
Quantifying the role of floodplain rearing to salmon populations

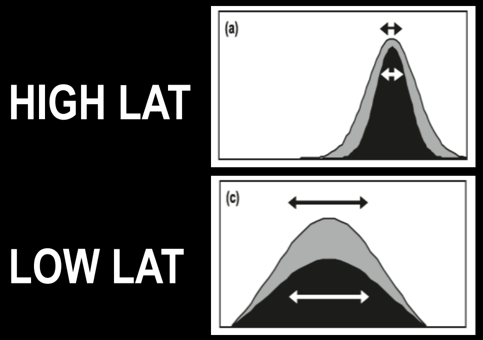
Rachel Johnson[1,2], Miranda Bell-Tilcock[2], Anna Sturrock[3], Alexandra Chu[2], Danhong Ally Li[2], Carson Jeffres[2]

1 NOAA
2 UC DAVIS CENTER FOR WATERSHED SCIENCES
CALIFORNIA DEPARTMENT OF FISH & WILDLIFE
U.S. FISH & WILDLIFE SERVICE
3 University of Essex

Salmon evolved to use a mosaic of connected habitats

Art by Linda Glass

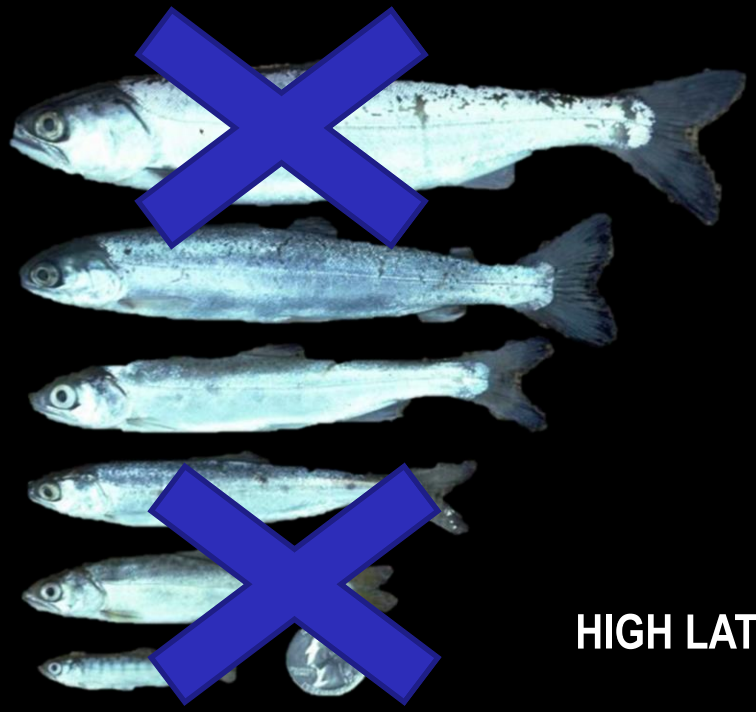




Spence and Hall 2010

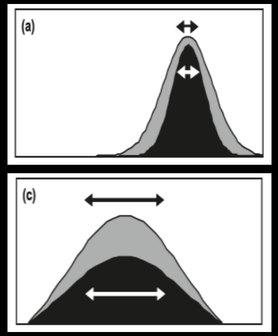
Salmon evolved to use a mosaic of connected habitats

Art by Linda Glass



Leave Late

Leave Early

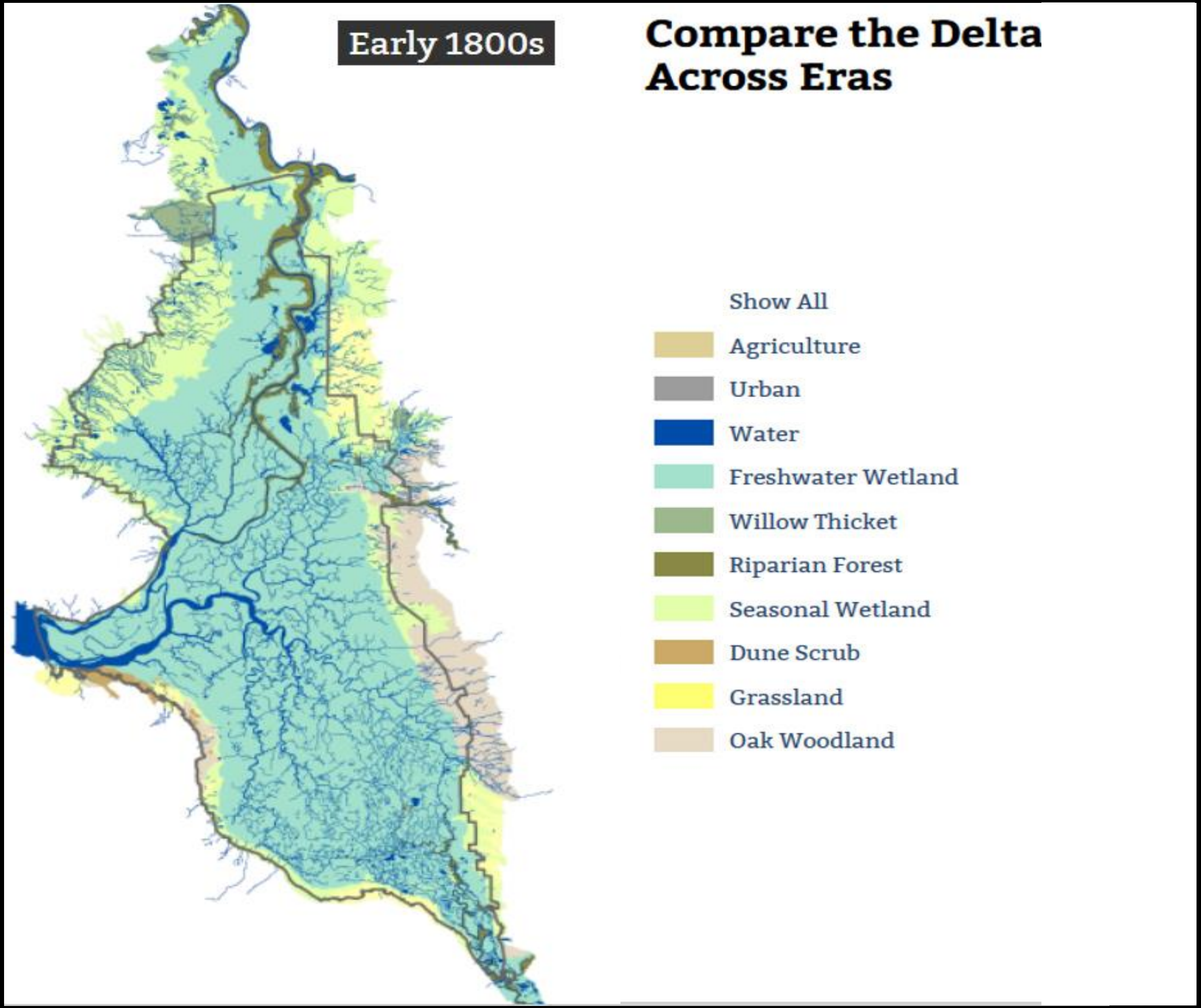


Spence and Hall 2010

Weakened portfolio effect in a collapsed salmon population complex

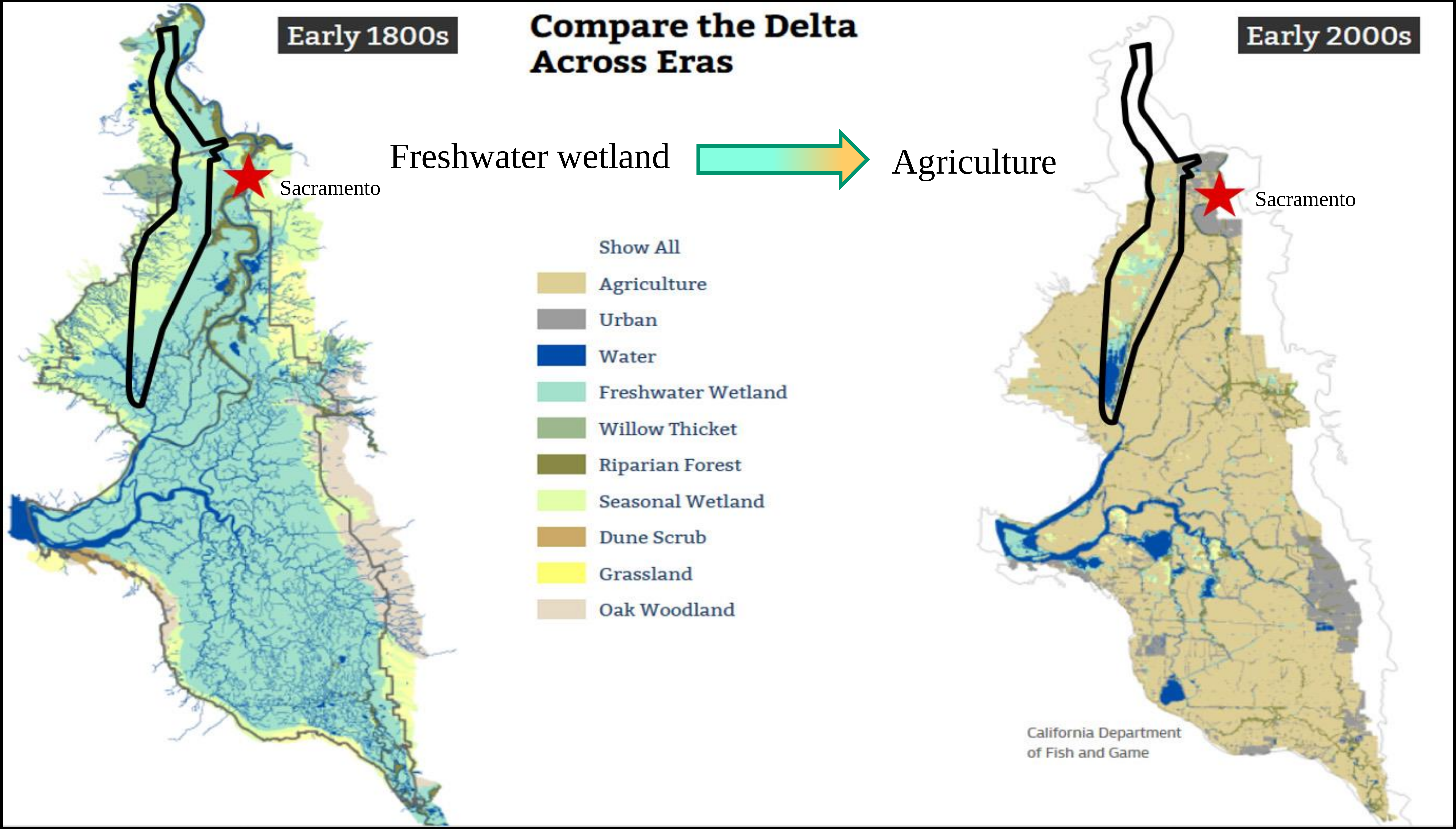
Stephanie Marie Carlson and William Hallowell Satterthwaite

Altered rearing habitats



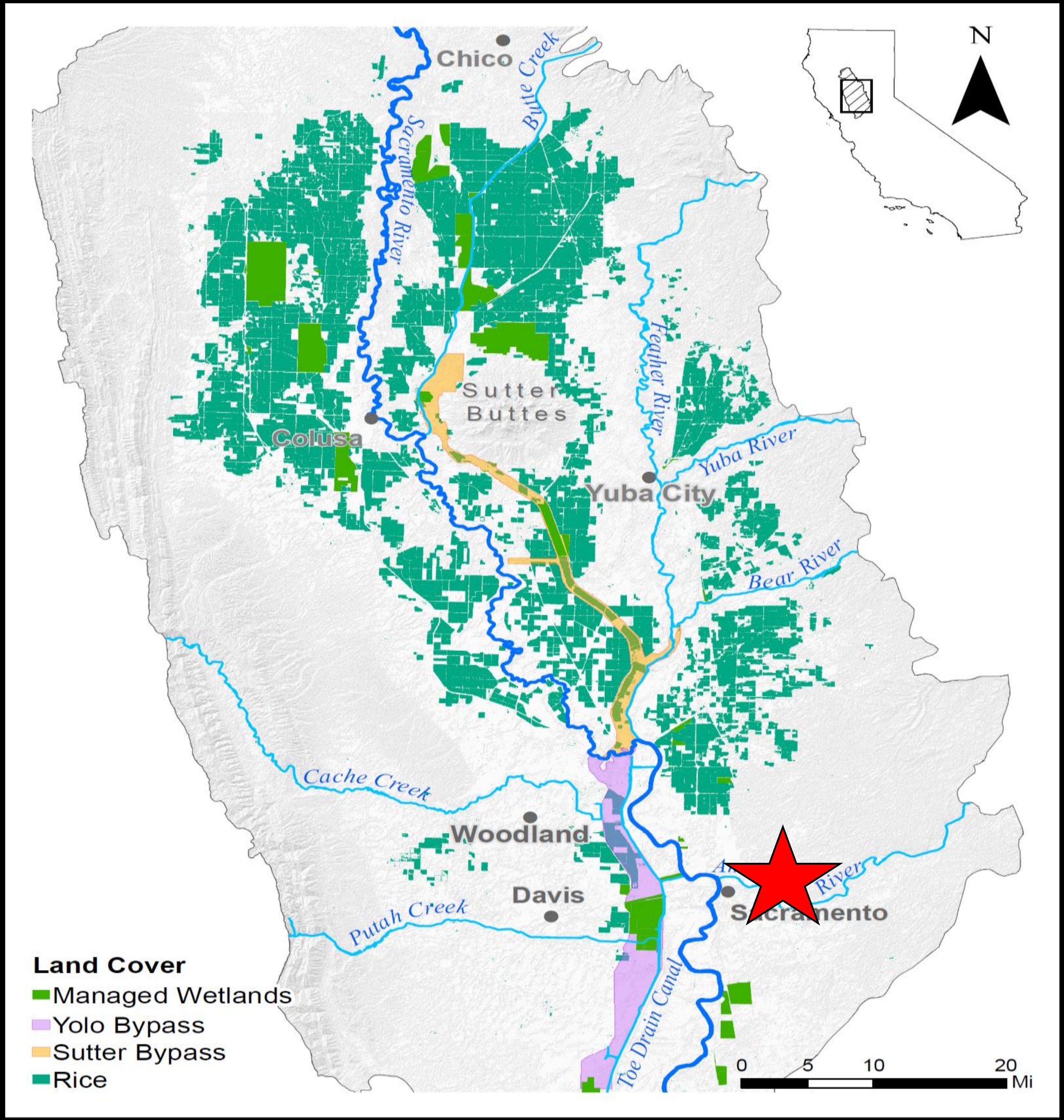
Data source: San Francisco Estuary Institute

Altered rearing habitats



Data source: San Francisco Estuary Institute

Managed wetlands & rice



California Rice Commission, Map courtesy of Gabriel Saron, UCD

Rearing habitat matters

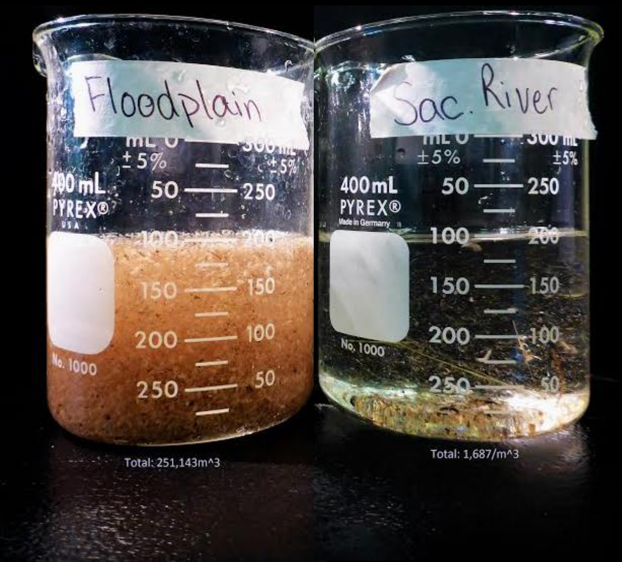
Courtesy of Carson Jeffres

River

4 days difference in age

Managed Floodplain

March 25, 2016



Vol. 487: 163–175, 2013
doi: 10.3354/meps10353

MARINE ECOLOGY PROGRESS SERIES
Mar Ecol Prog Ser

Published July 30

FREE ACCESS

Size, growth, and origin-dependent mortality of juvenile Chinook salmon *Oncorhynchus tshawytscha* during early ocean residence

Lindsay E. Woodson[1,*], Brian K. Wells[1], Peter K. Weber[2], R. Bruce MacFarlane[1], George E. Whitman[3], Rachel C. Johnson[3,4]

Freshwater growth & condition influences early ocean survival

(Woodson et al 2013)

Nursery Role Concept

BioScience

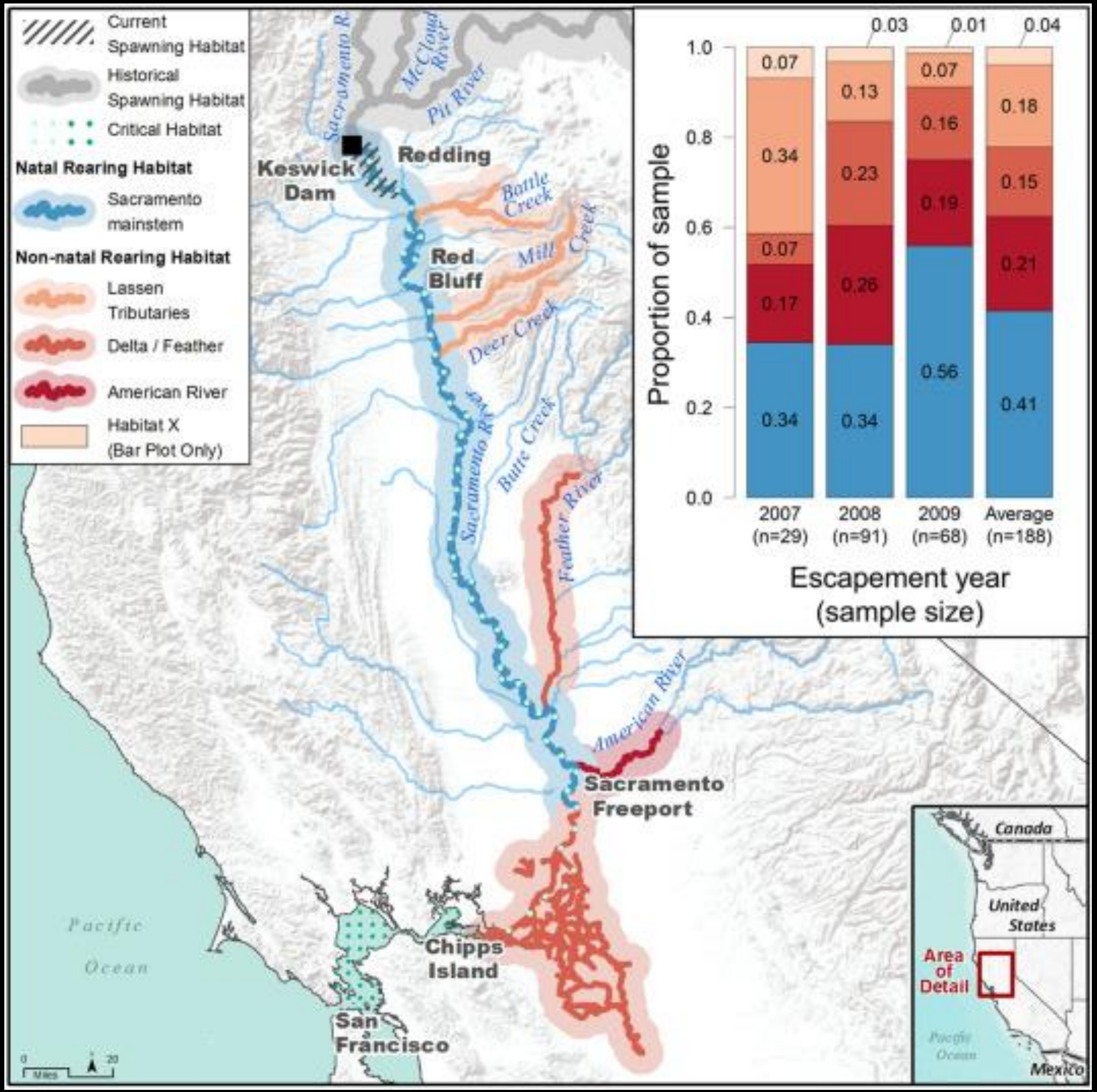
The Identification, Conservation, and Management of Estuarine and Marine Nurseries for Fish and Invertebrates

MICHAEL W. BECK, KENNETH L. HECK, JR., KENNETH W. ABLE, DANIEL L. CHILDERS, DAVID B. EGGLESTON, BRONWYN M. GILLANDERS, BENJAMIN HALPERN, CYNTHIA G. HAYS, KAHO HOSHINO, THOMAS J. MINELLO, ROBERT J. ORTH, PETER F. SHERIDAN, AND MICHAEL P. WEINSTEIN

"A habitat is a nursery for juveniles if its contribution [per unit area] to the production of individuals that recruit to adult populations is greater, on average, than production from other habitats in which juveniles occur"

Are managed flood bypasses nurseries for Central Valley salmon?

Critical habitats can be a mystery



ELSEVIER

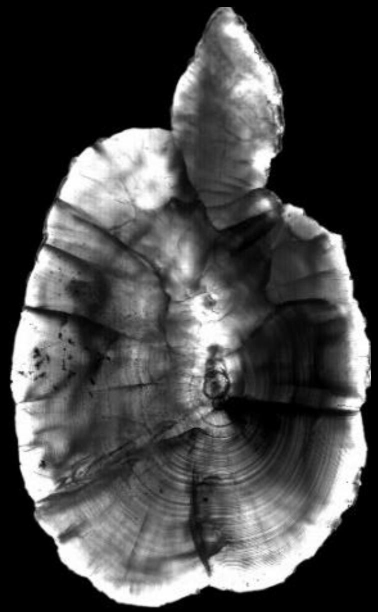
Biological Conservation

Volume 217, January 2018, Pages 358-362

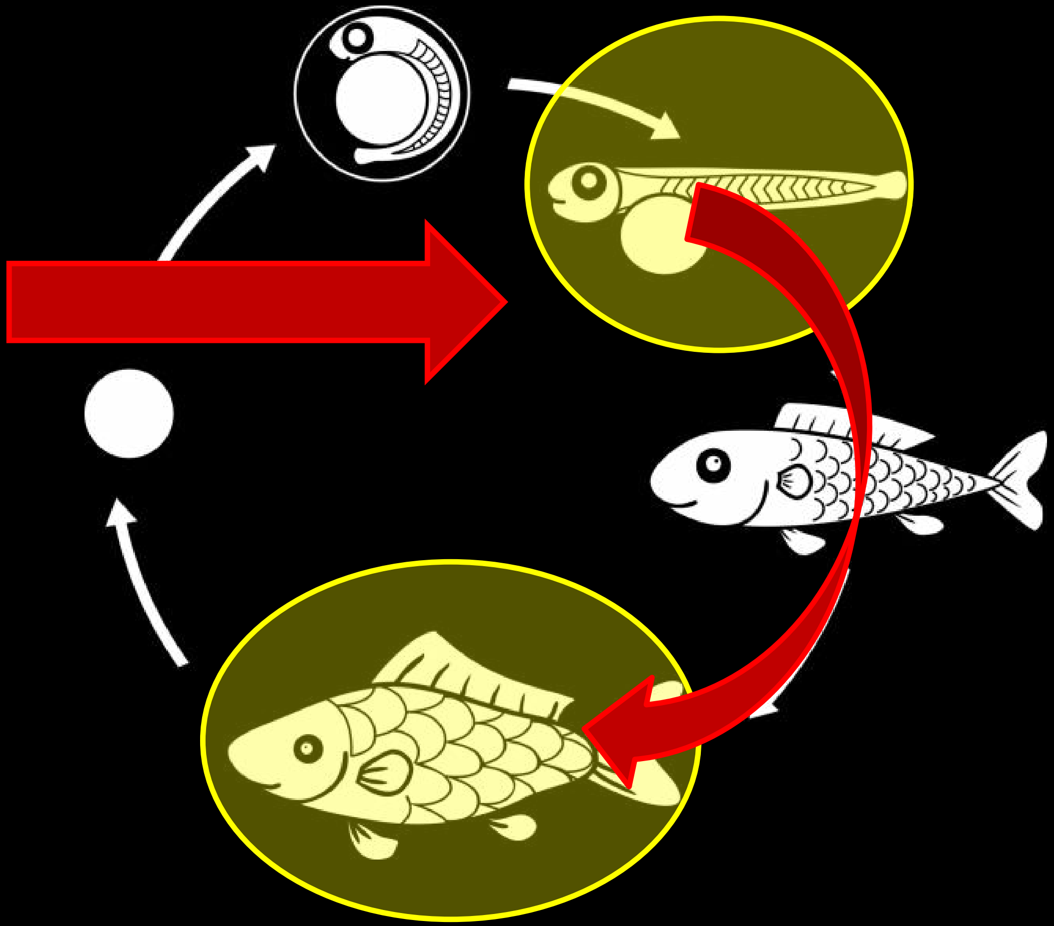
Short communication

Endangered winter-run Chinook salmon rely on diverse rearing habitats in a highly altered landscape

Corey C. Phillis [a], Anna M. Sturrock [b], Rachel C. Johnson [b, c], Peter K. Weber [d]



Linking habitat use across life stages is hard



1) Unique habitat signature

2) Preserved in archival tissue

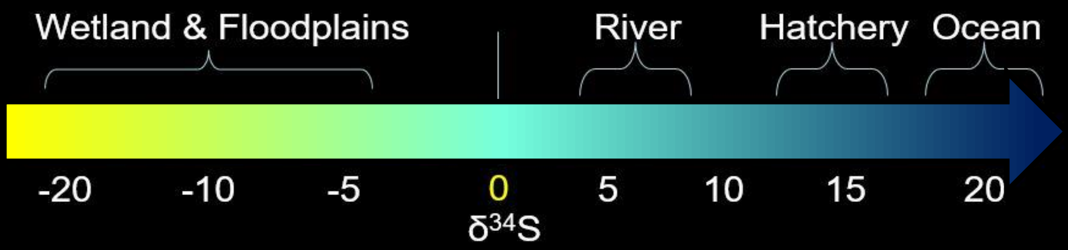
SEGMENT | 11:59

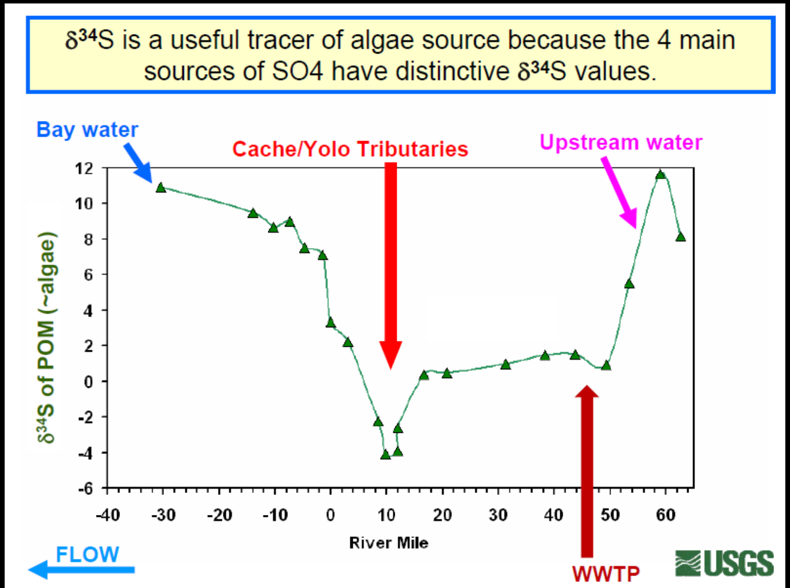
Seeing The World Through Salmon Eyes

Dissecting eyes is helping measure what fish eat—and the value of different habitats.

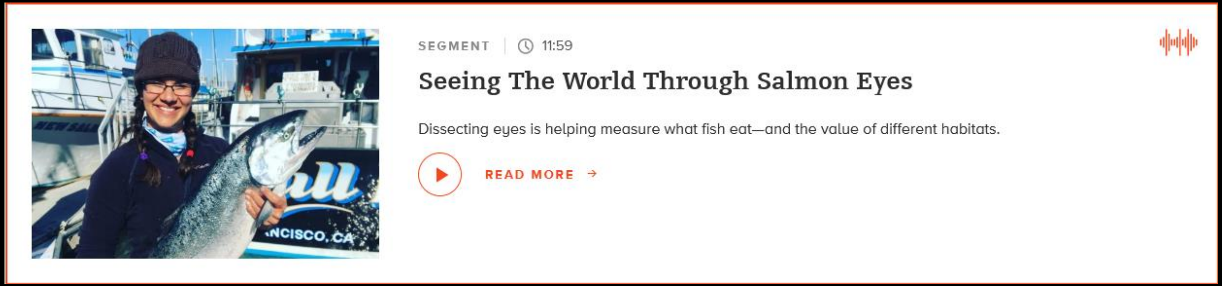
READ MORE →

2
0
1
6

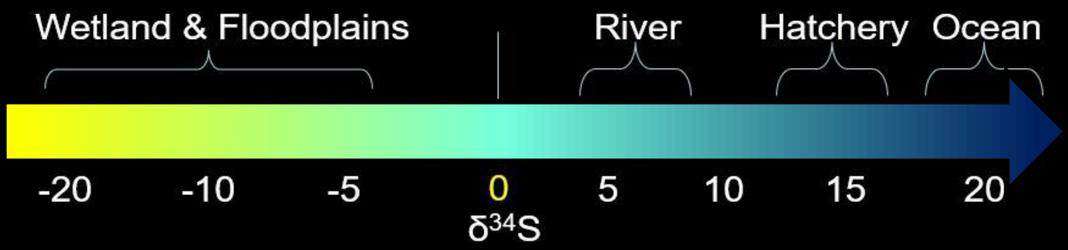


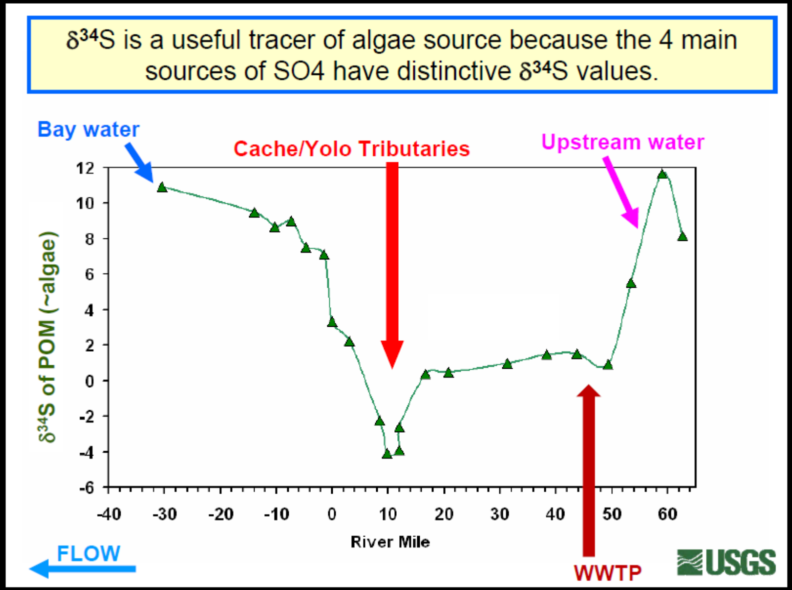


Courtesy of Carol Kendall, BDSC 2010



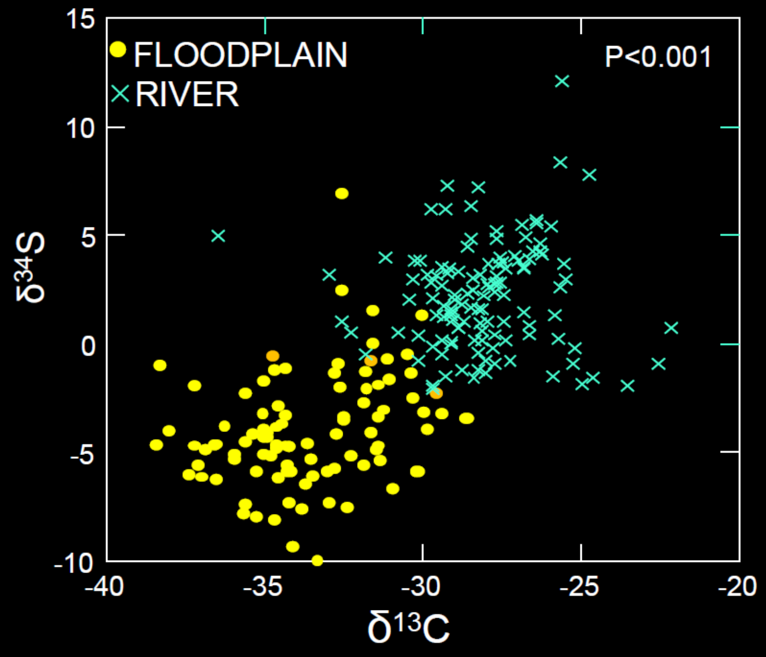
2016



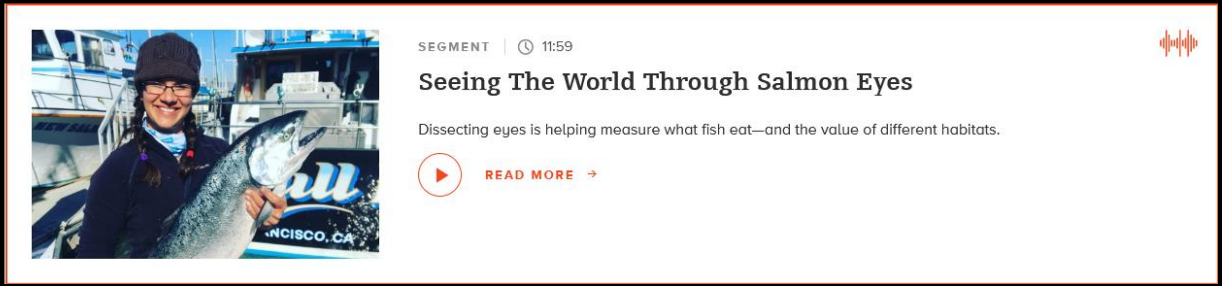


Courtesy of Carol Kendall, BDSC 2010

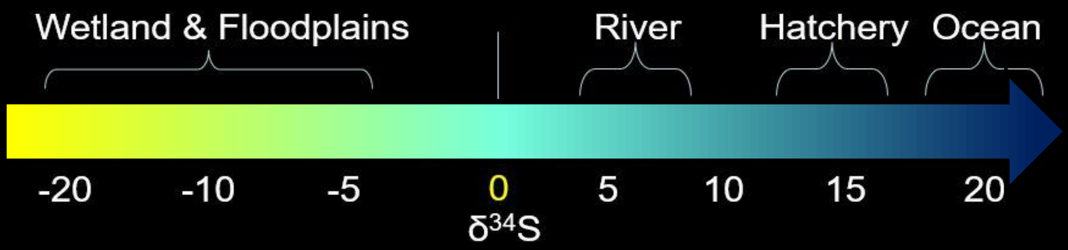
Stomach content $\delta^{34}S$ and $\delta^{13}C$

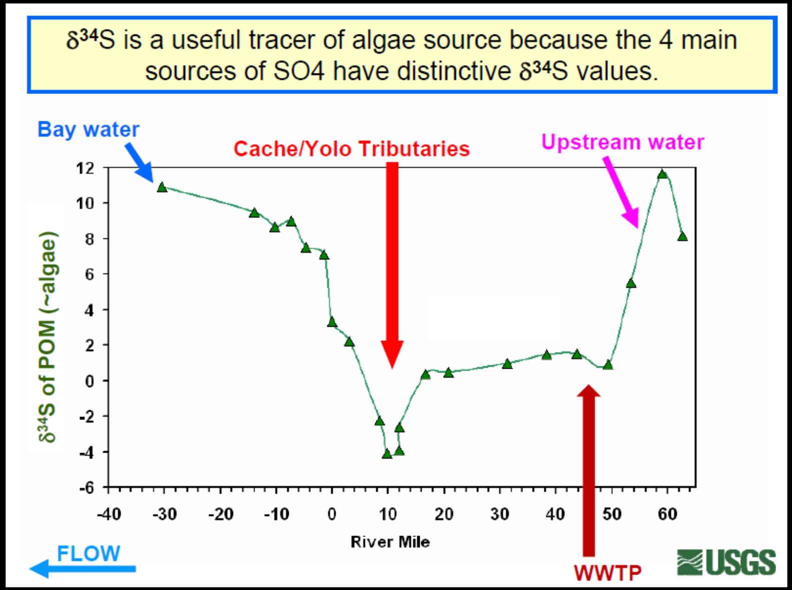


Bell-Tilcock et al. 2021



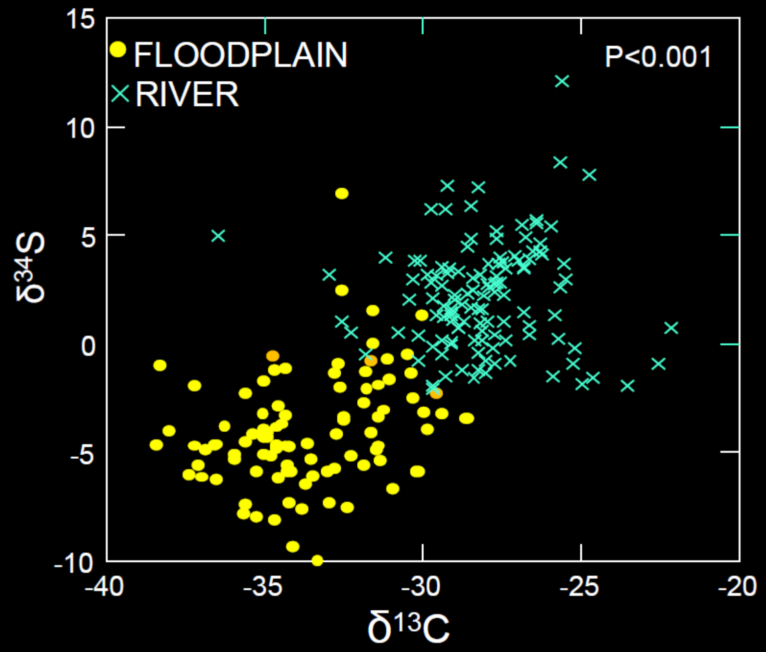
2016





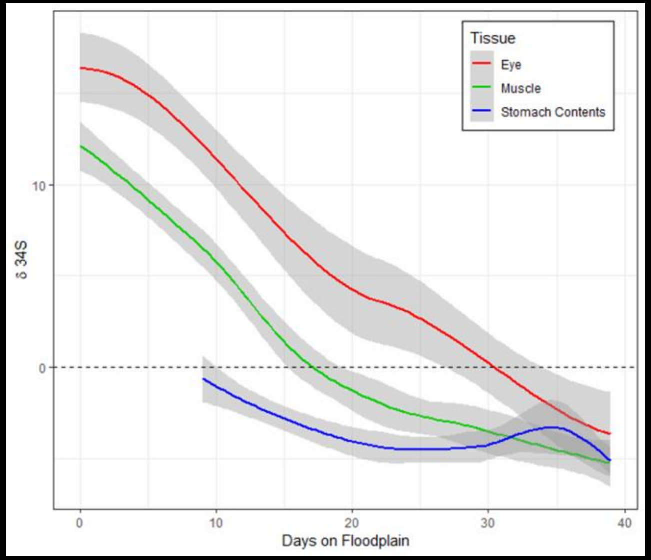
Courtesy of Carol Kendall, BDSC 2010

Stomach content $\delta^{34}S$ and $\delta^{13}C$



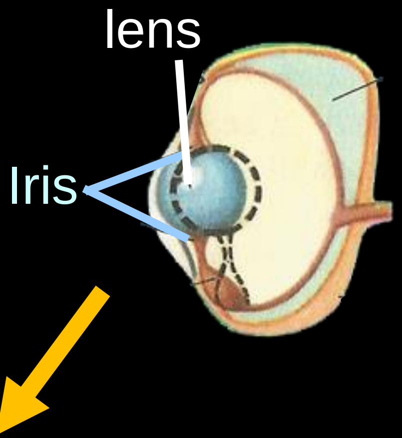
Bell-Tilcock et al. 2021

Sulfur in salmon tissues

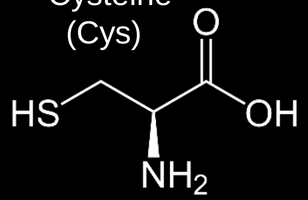


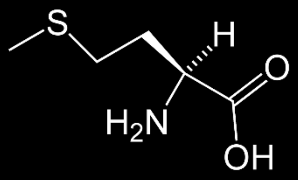
Bell-Tilcock et al. 2021

Eye lenses as diet archive

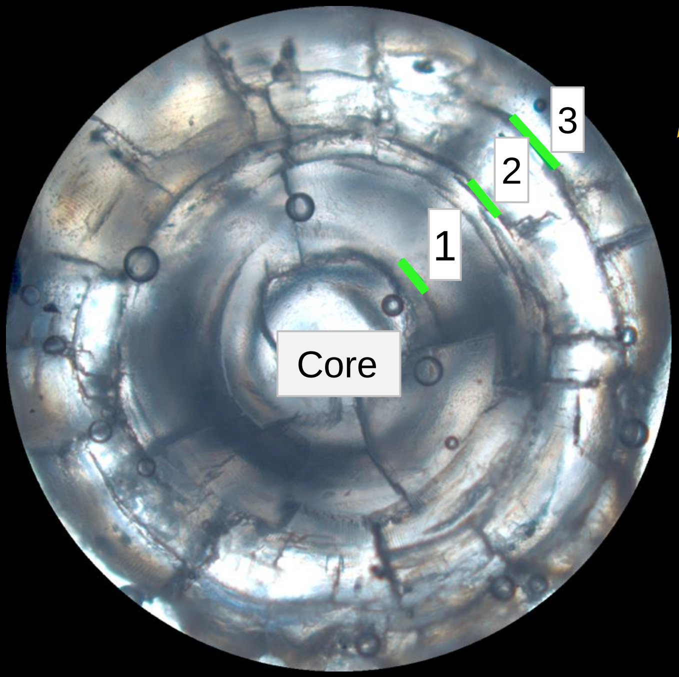


Cysteine
(Cys)





Methionine
(Met)

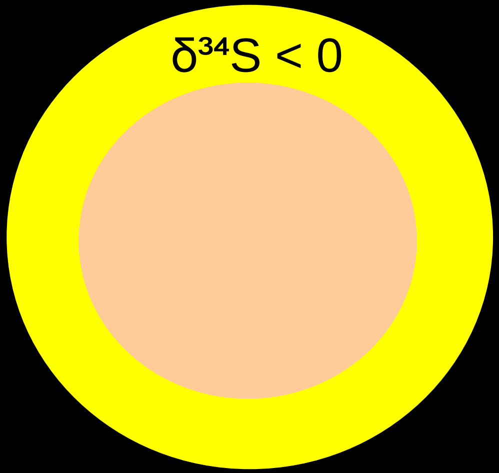


Juvenile salmon eye lens

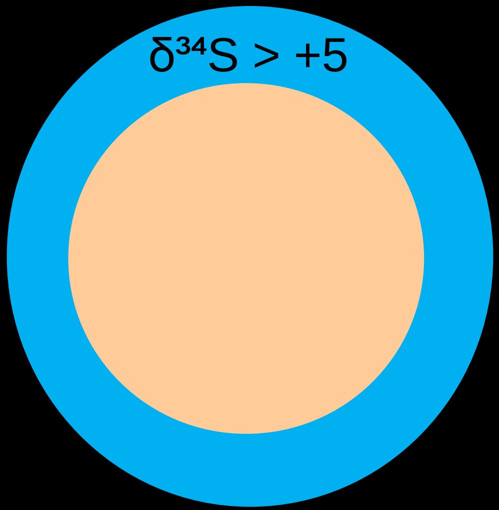
Lenses look like an onion

Lens formation and diet reconstructions

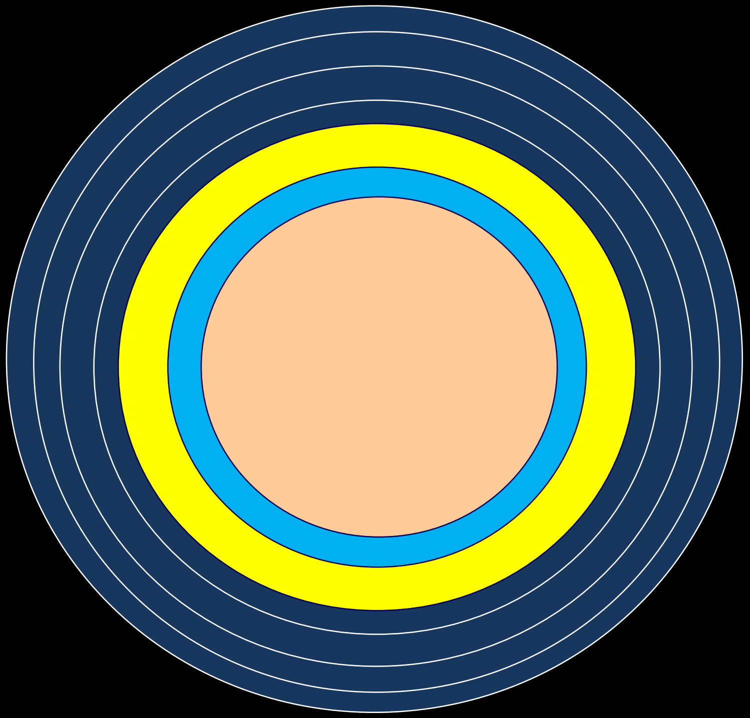
Floodplain

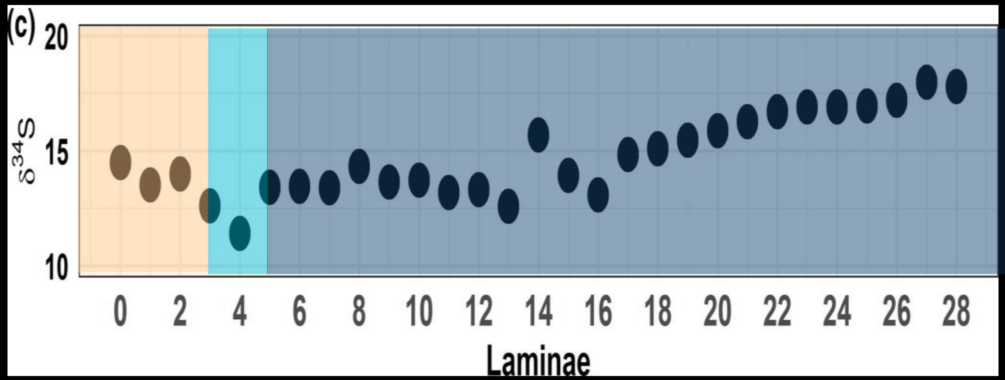


River



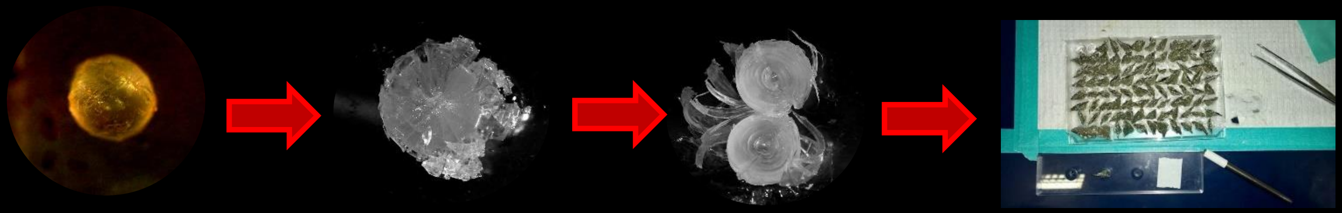
Multiple habitats



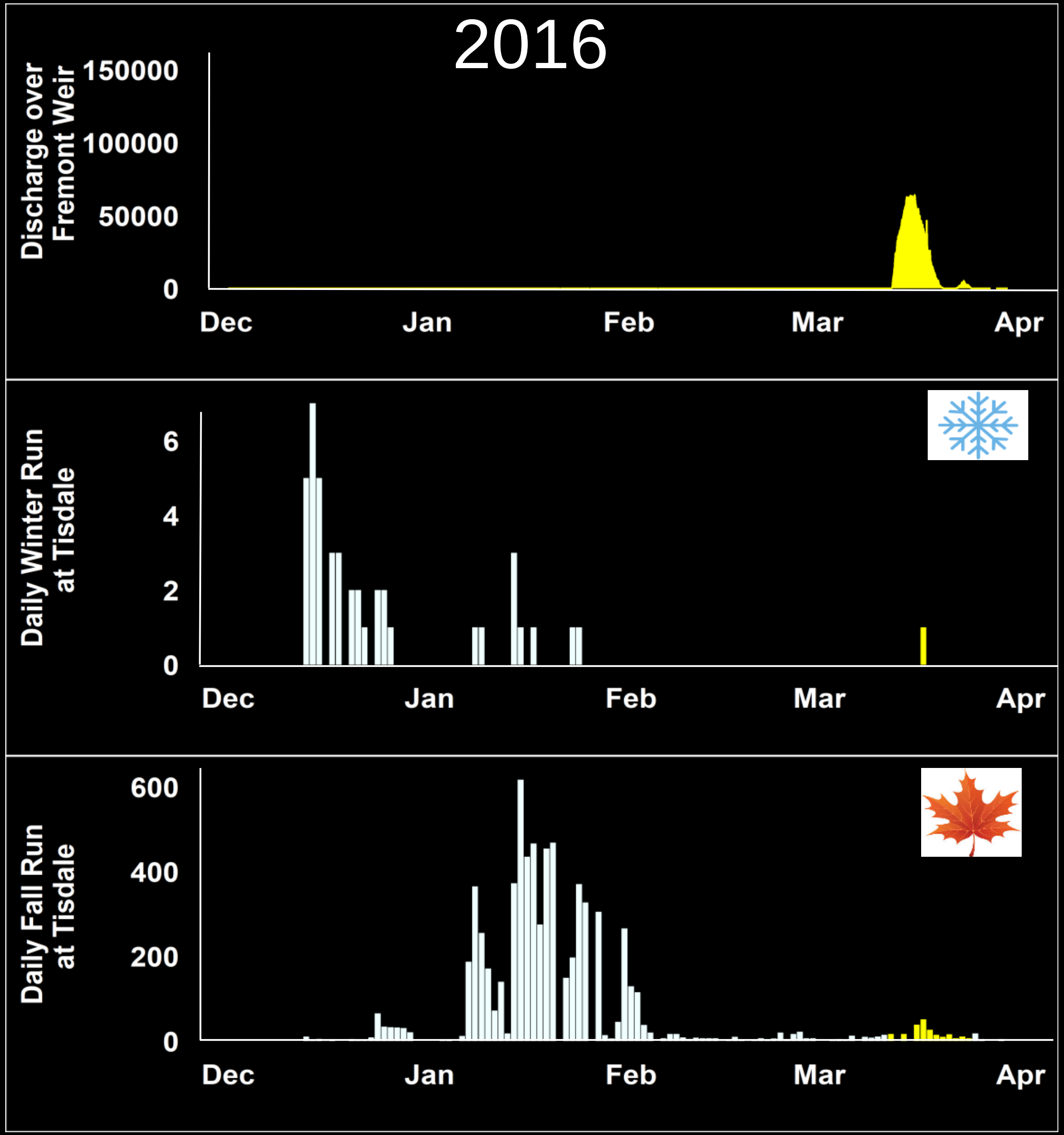


Bell-Tilcock et al. 2021

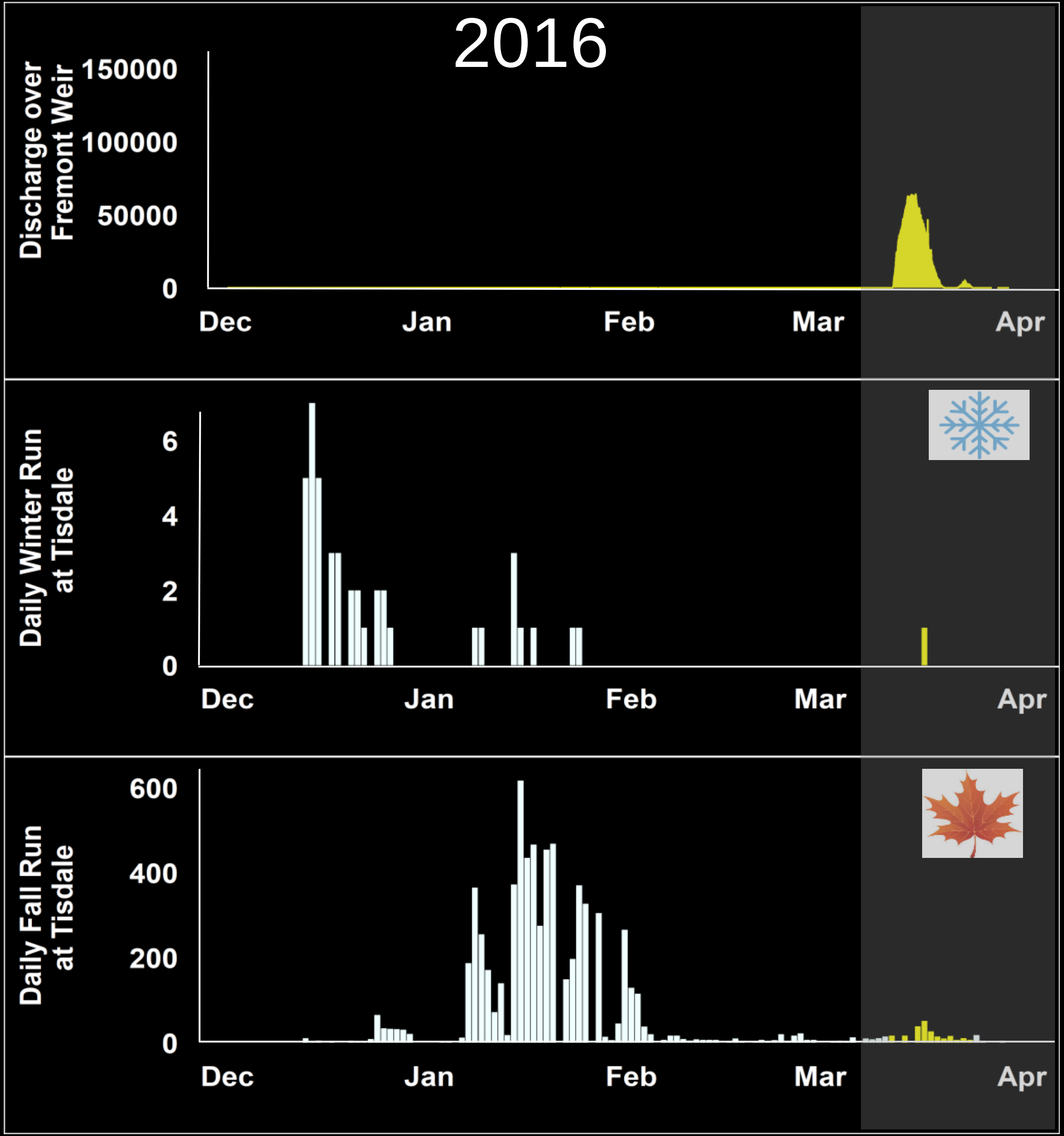
Delamination



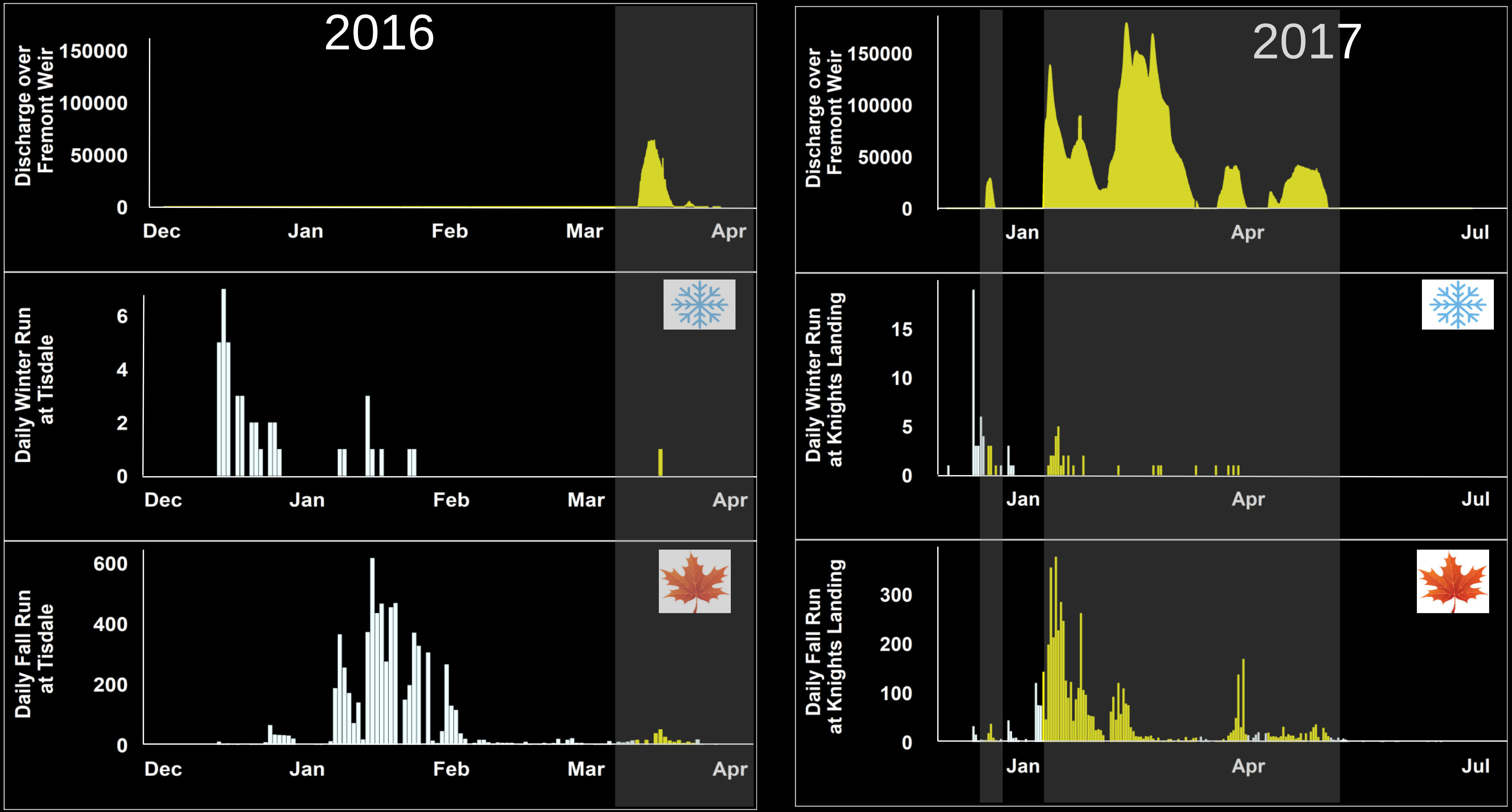
Floodplain opportunity



Floodplain opportunity



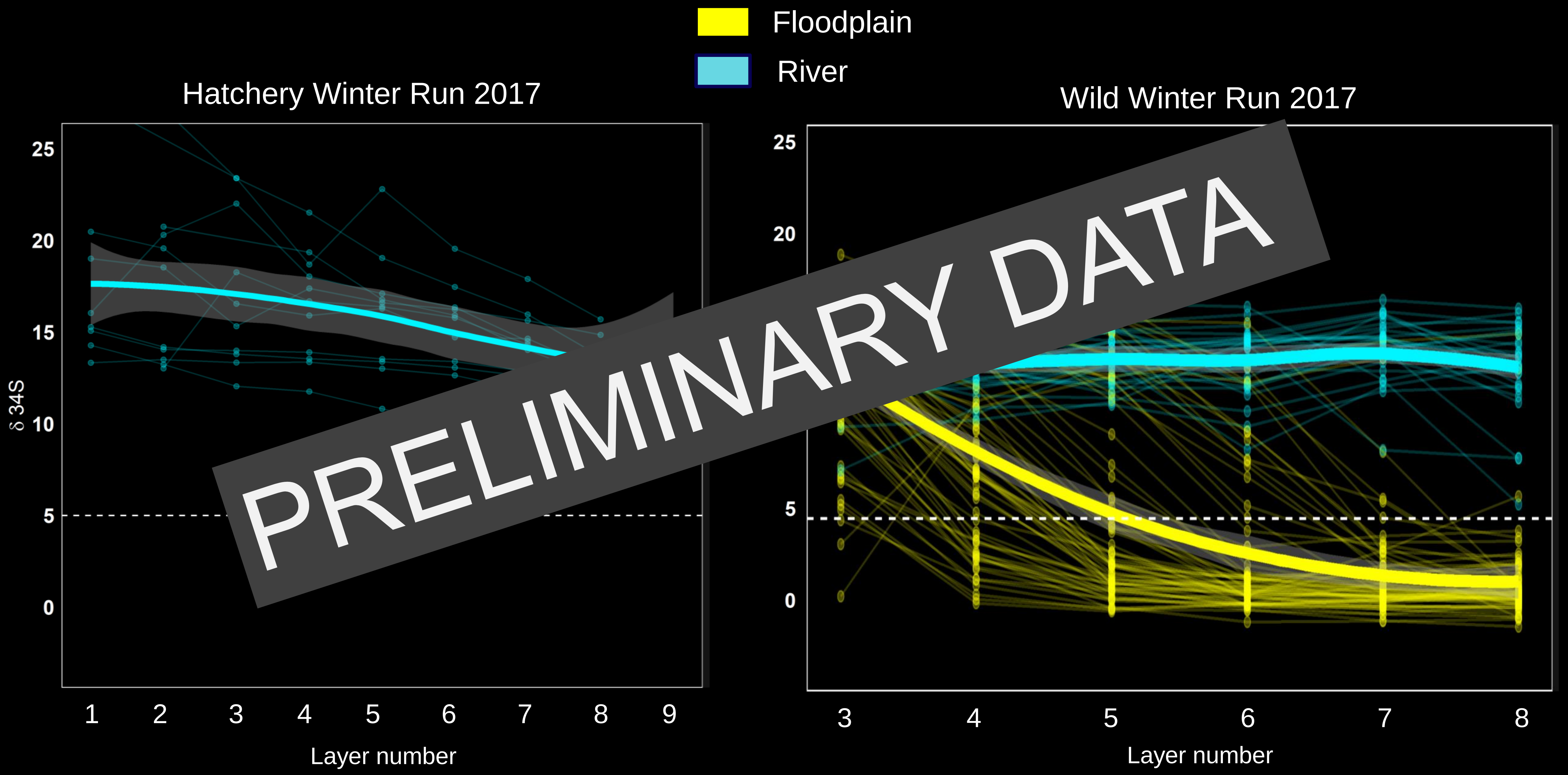
Floodplain opportunity



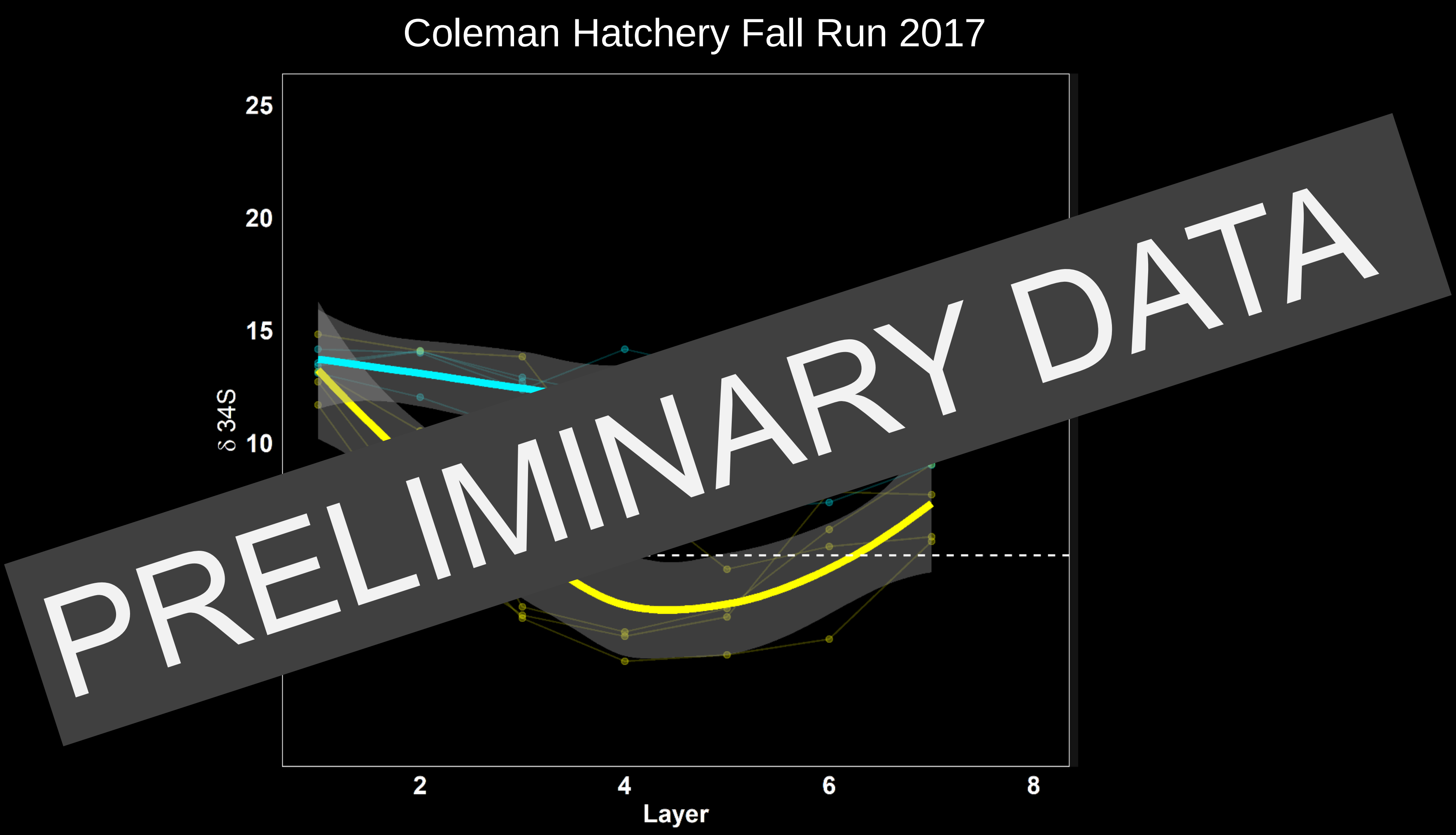
Adult Survivors: Eyes and Ears

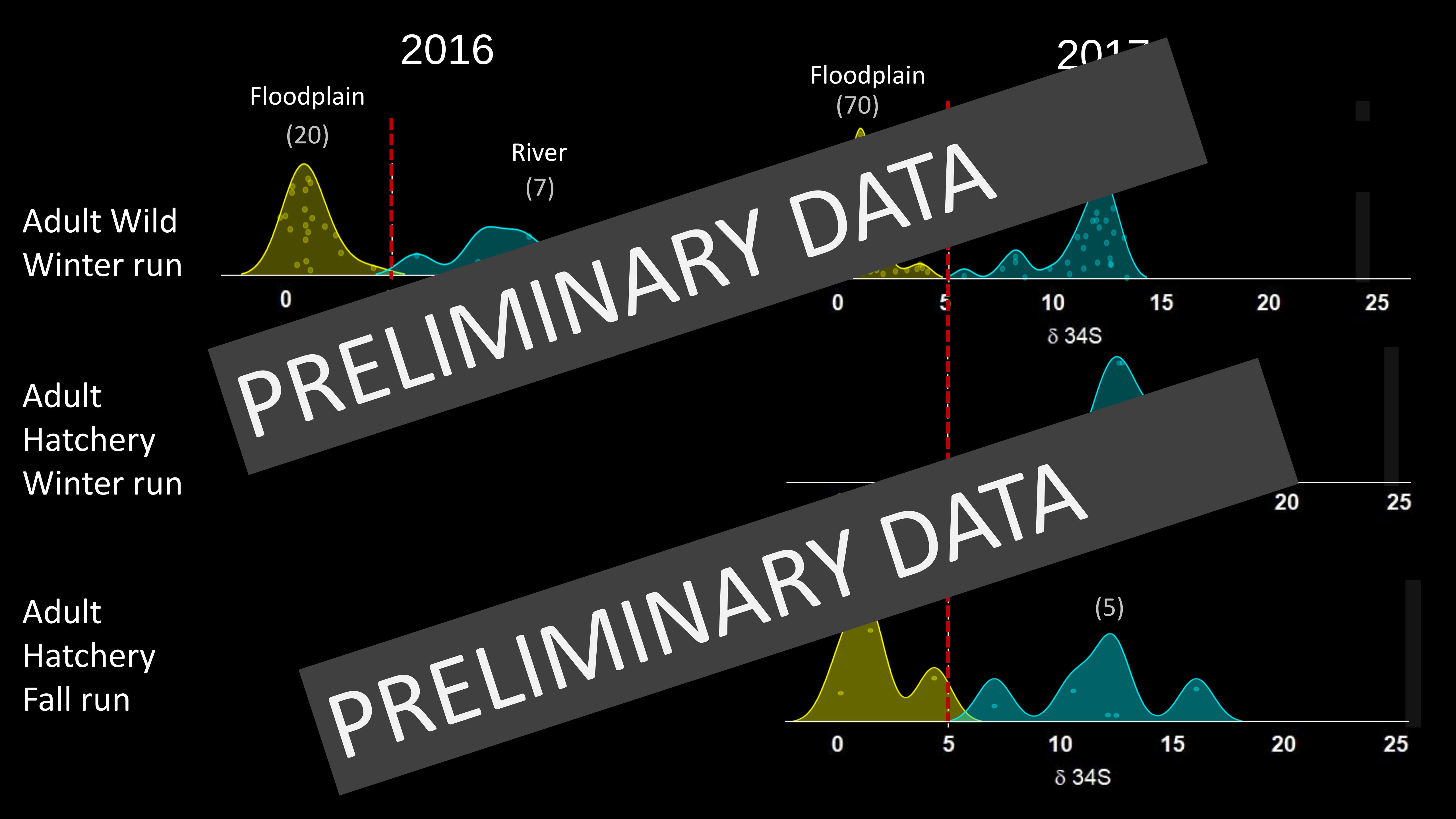
- Upper Sacramento winter and fall run
- Outmigration years 2016 and 2017
- Escapement years 2018 and 2019

Evidence for floodplain rearing in winter run

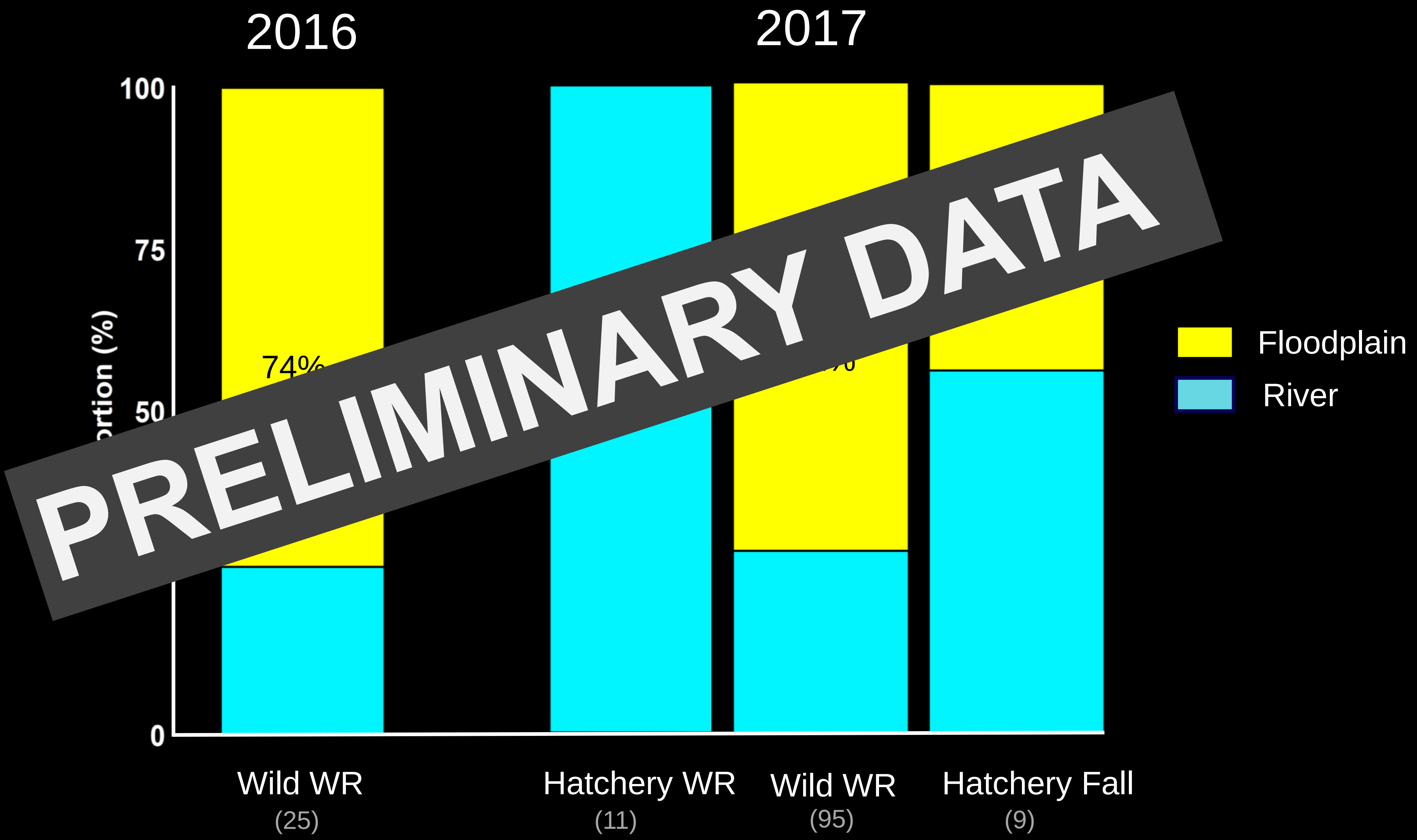


Evidence for floodplain rearing in fall run

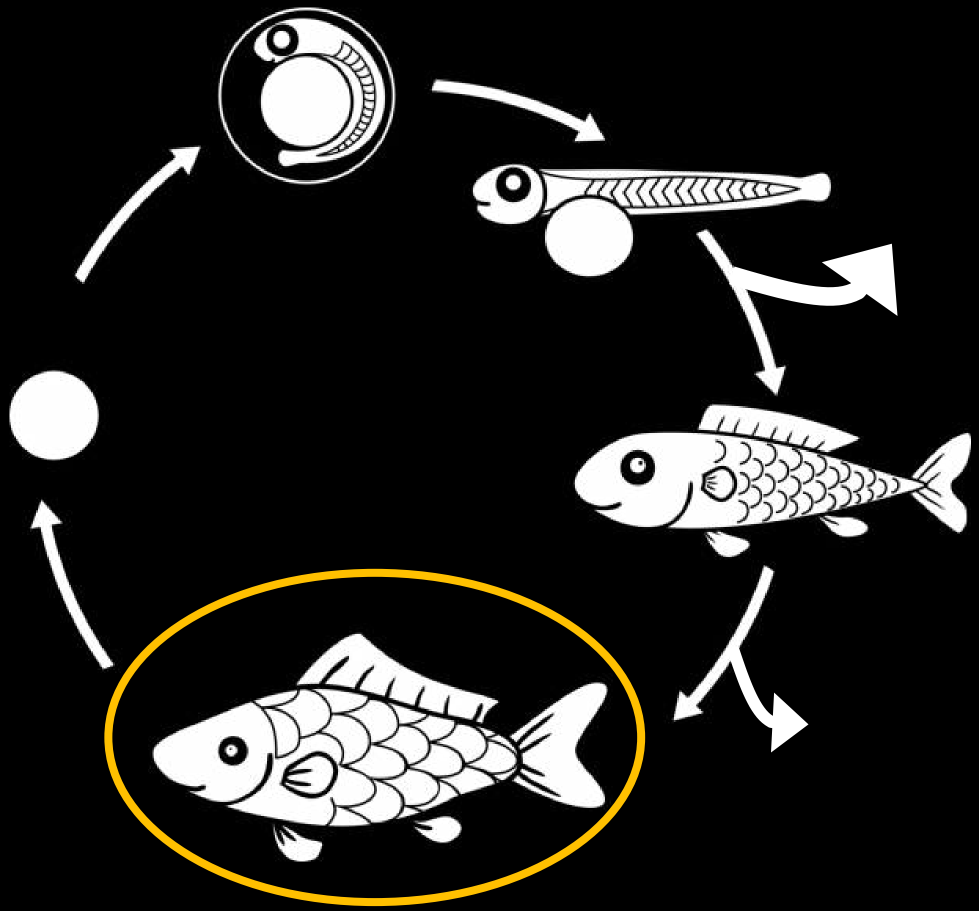



2016
Floodplain
(20)
River
(7)
Adult Wild
Winter run
Adult
Hatchery
Winter run
Adult
Hatchery
Fall run
Floodplain
(70)
(5)
0
5
10
15
20
25
δ 34S
PRELIMINARY DATA
PRELIMINARY DATA

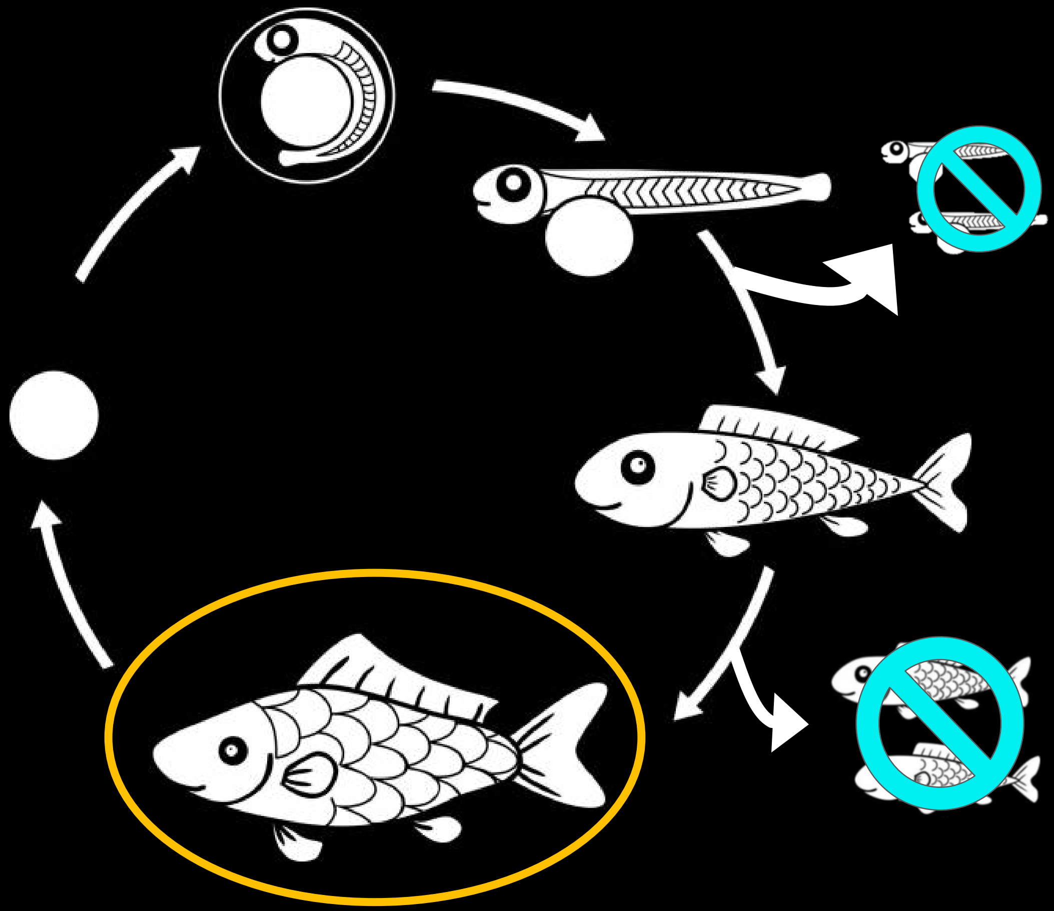
Proportion of adults that used floodplains



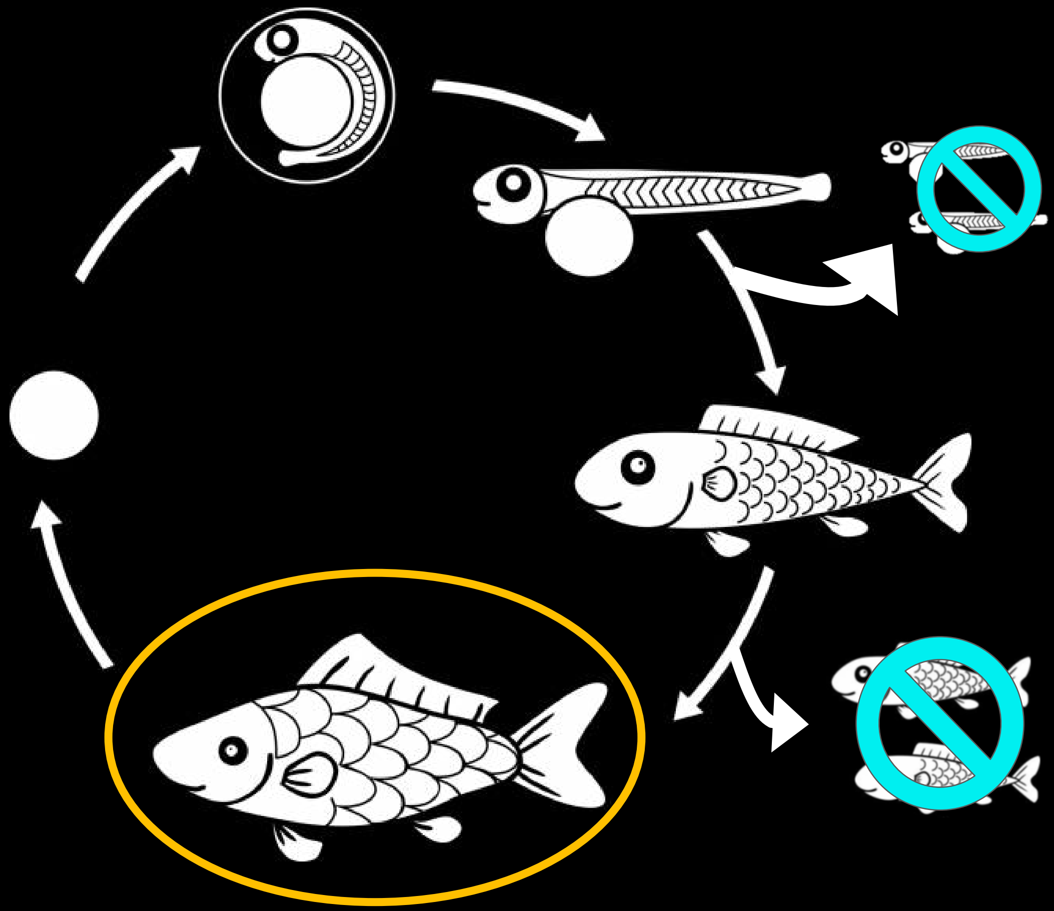
Survivor Bias

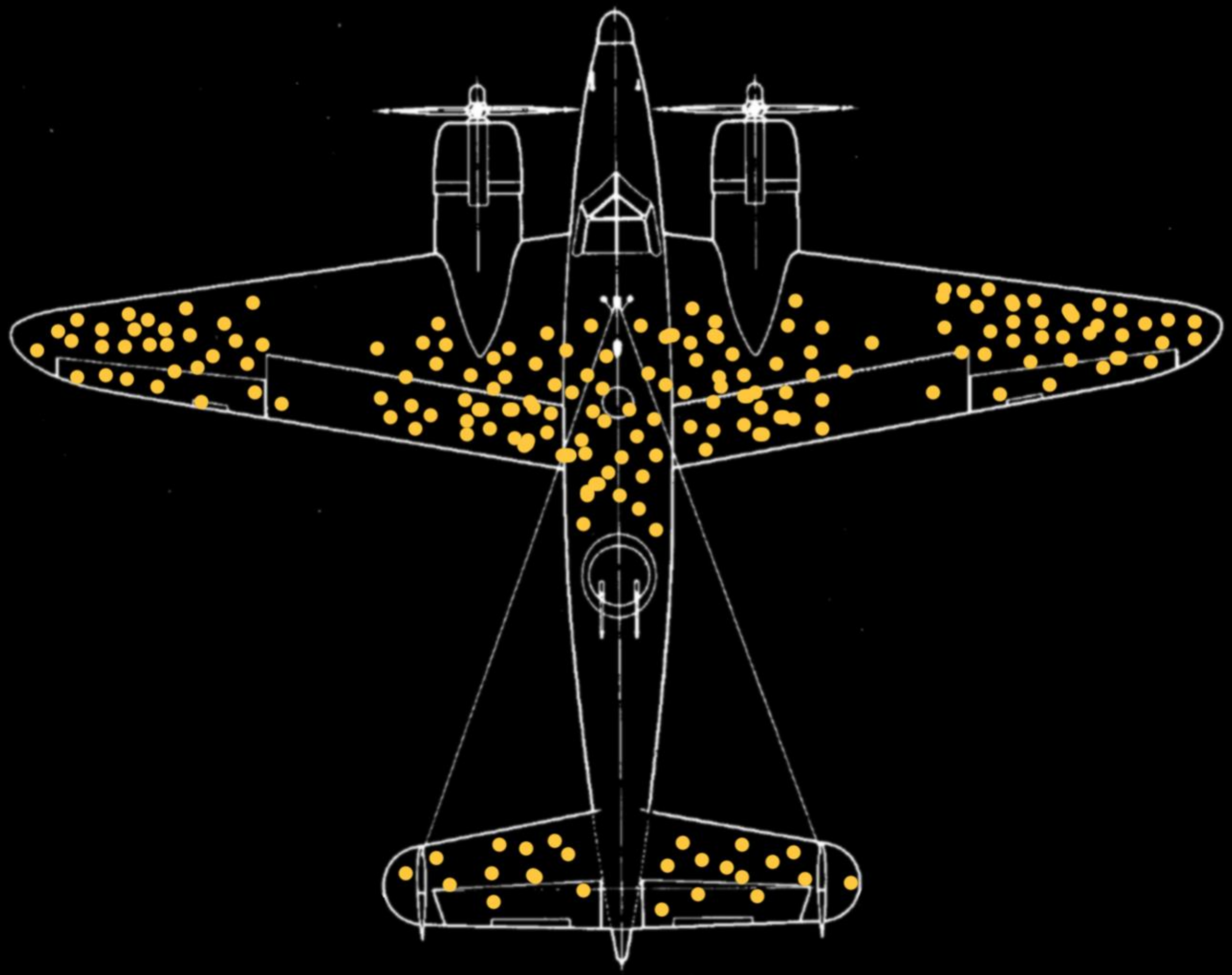


Survivor Bias

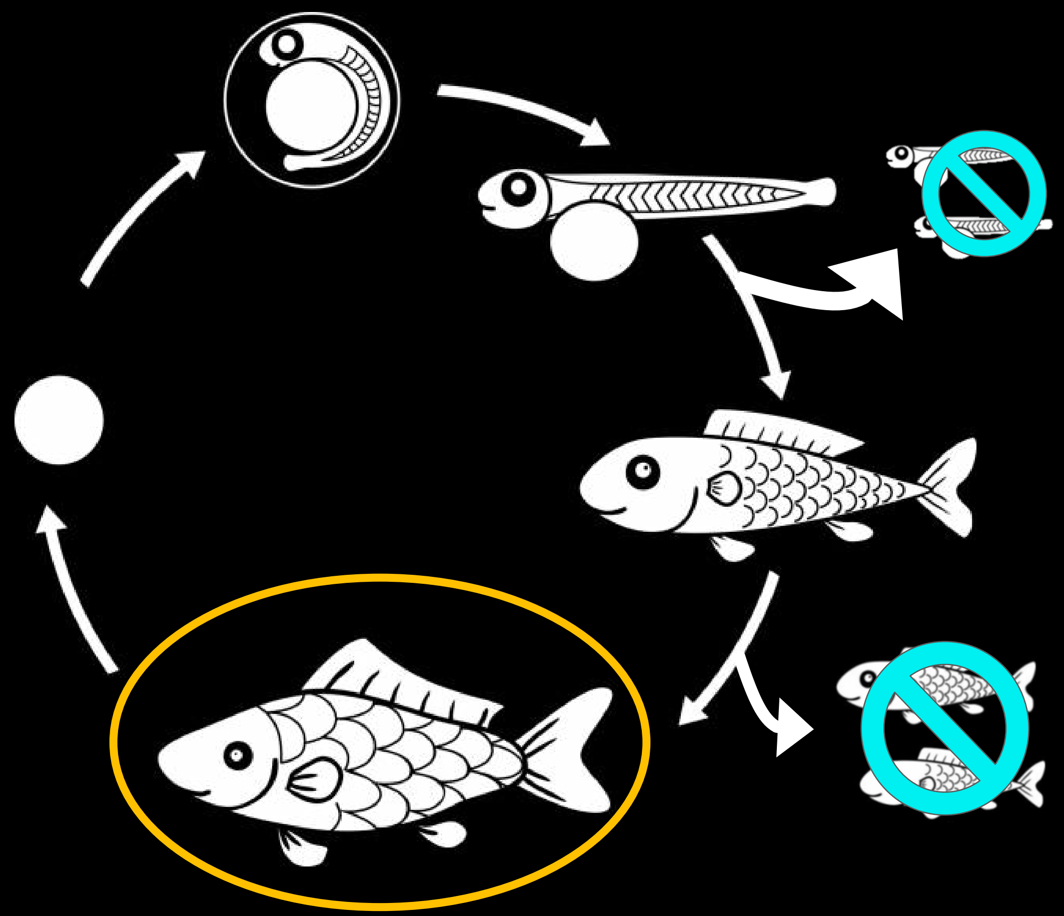


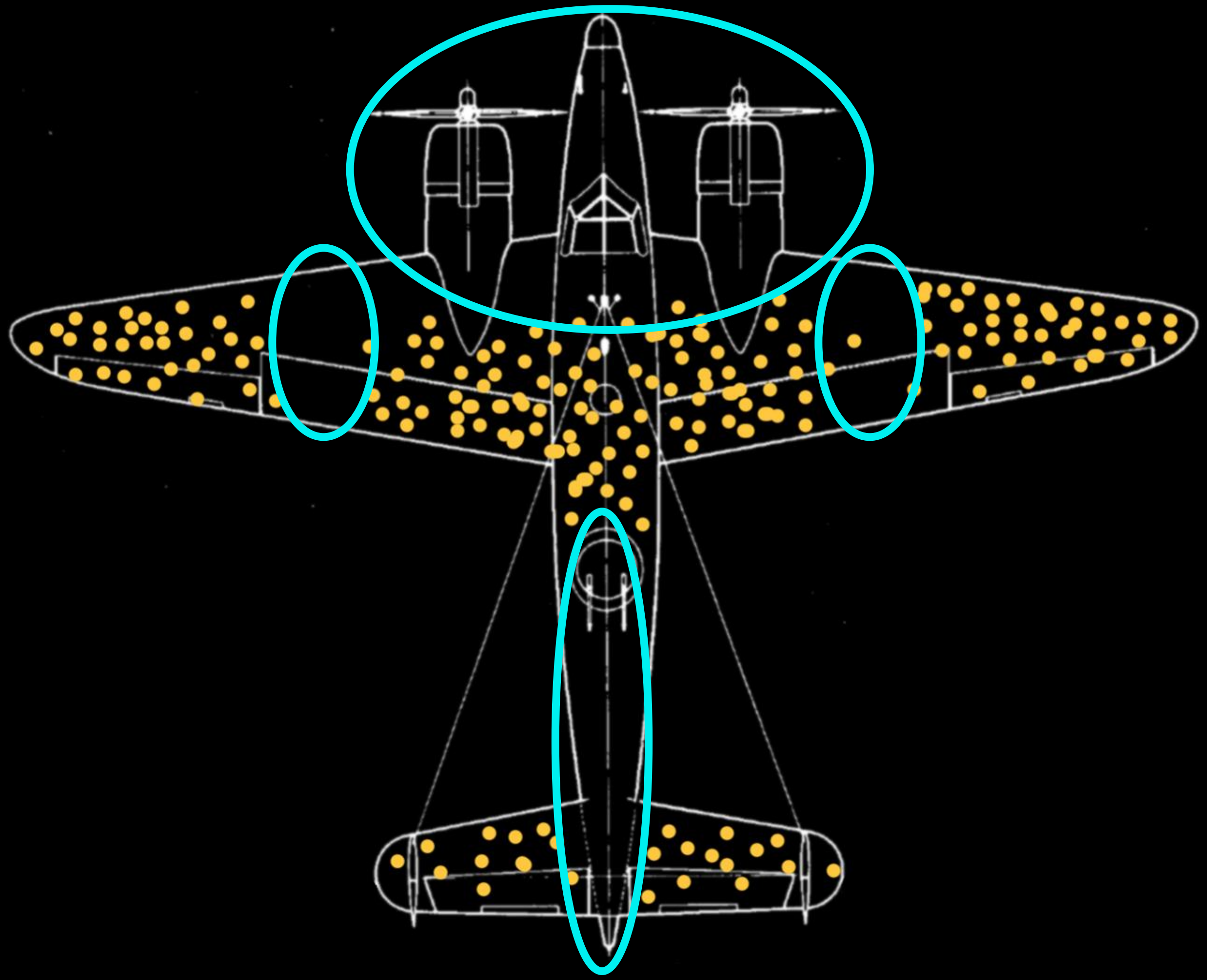
Survivor Bias



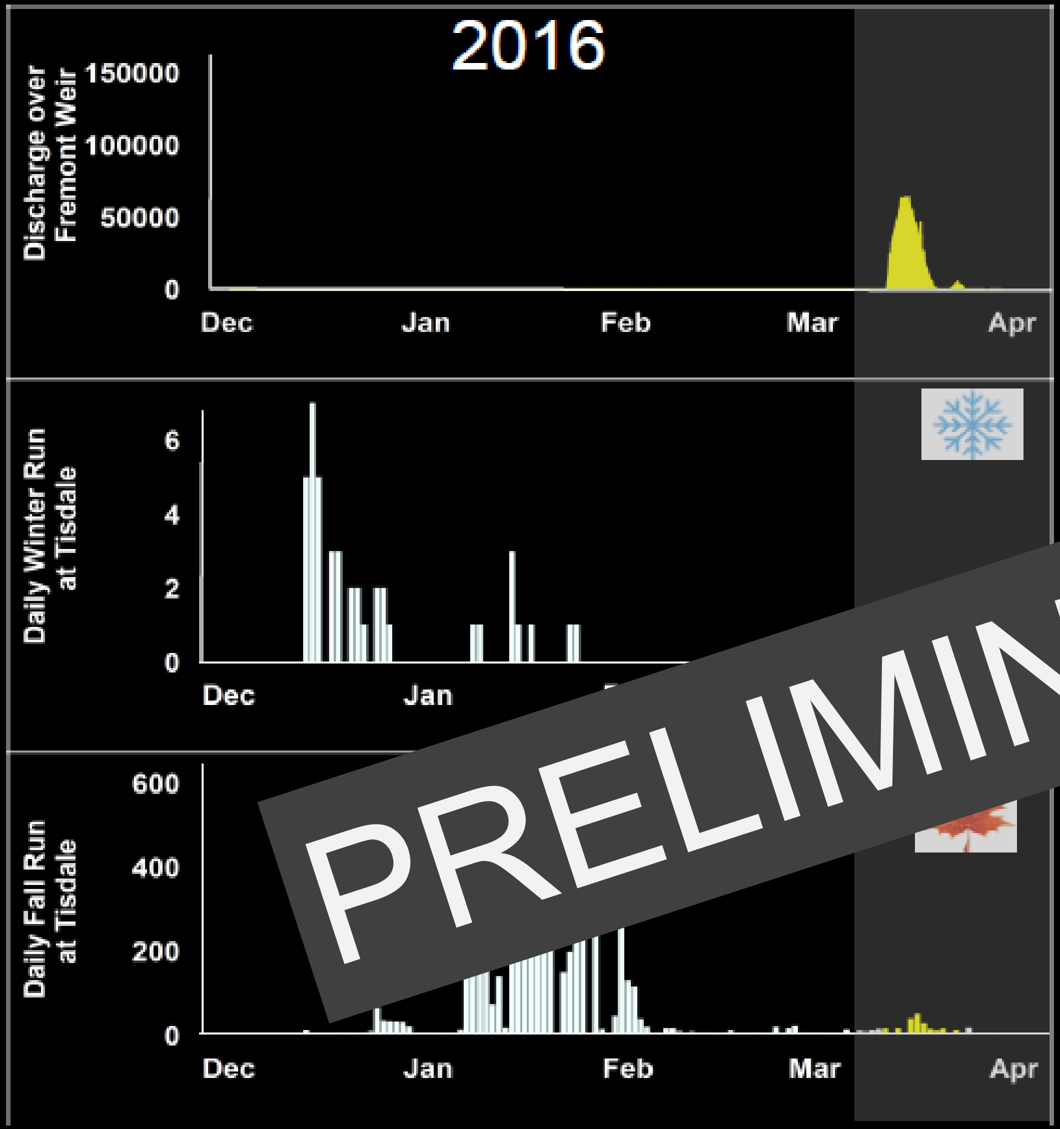


Survivor Bias

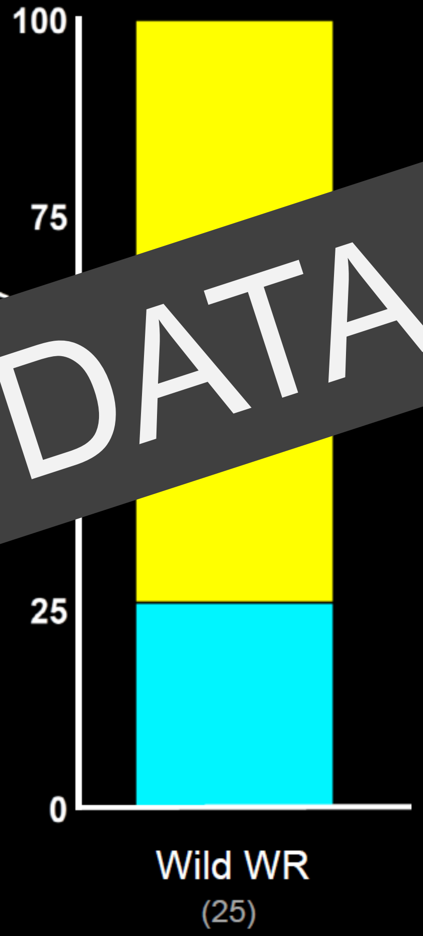




Floodplain opportunity

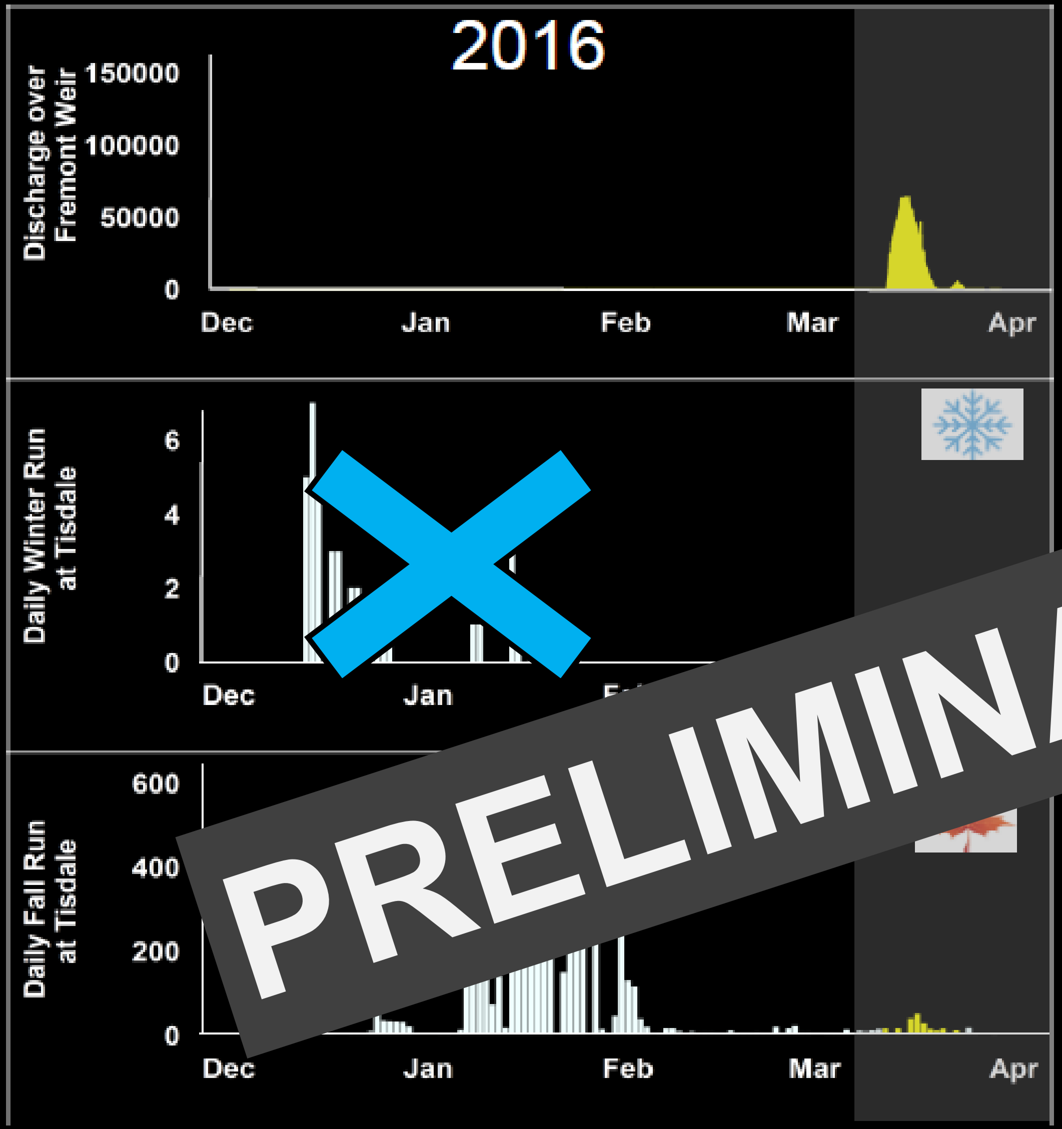


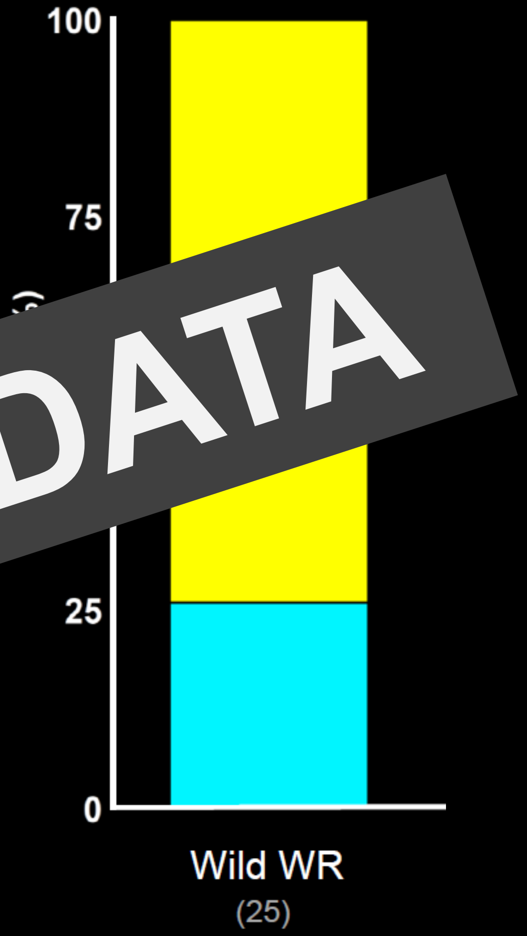
Survivors



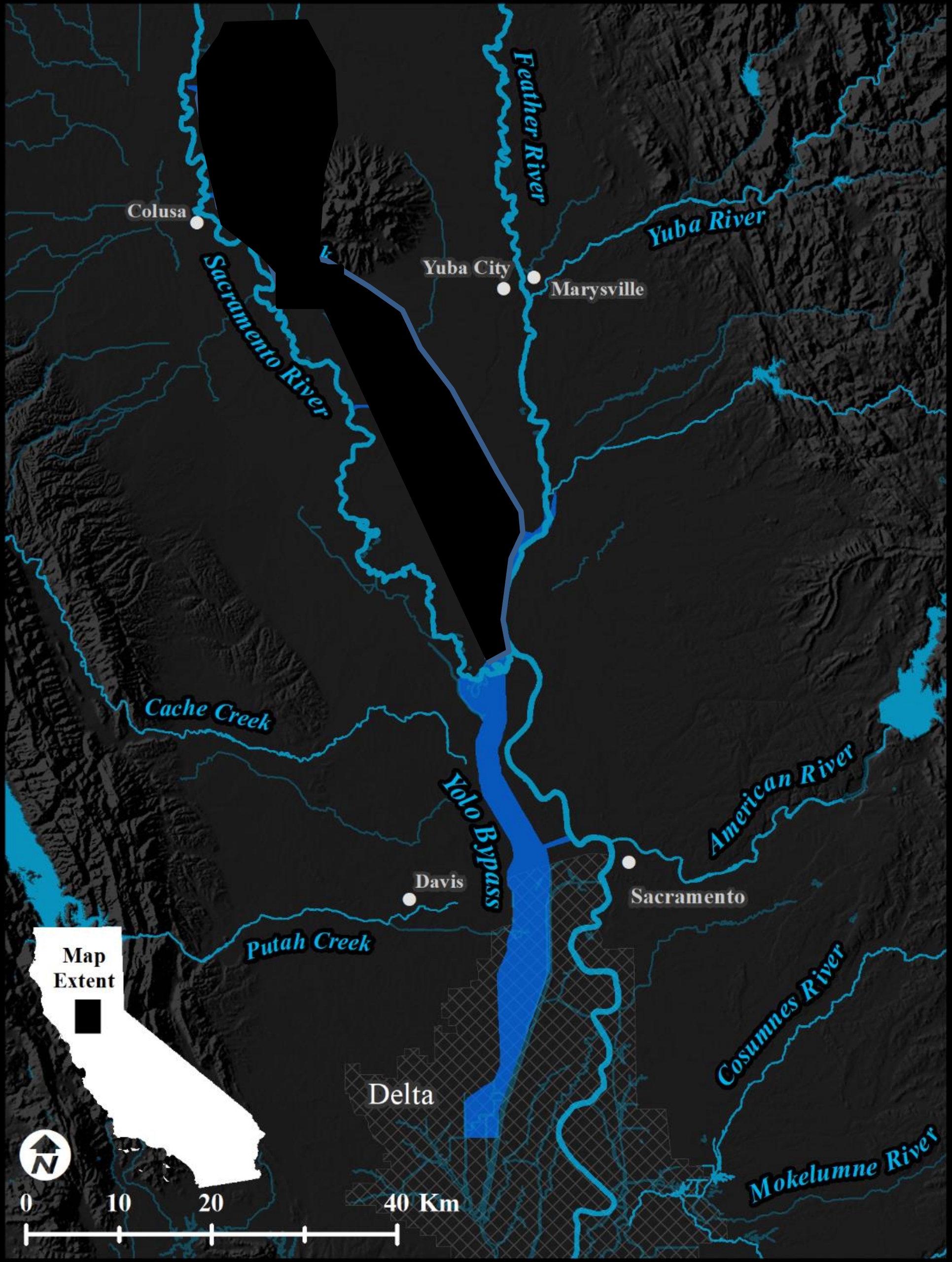
Floodplain opportunity

Survivors



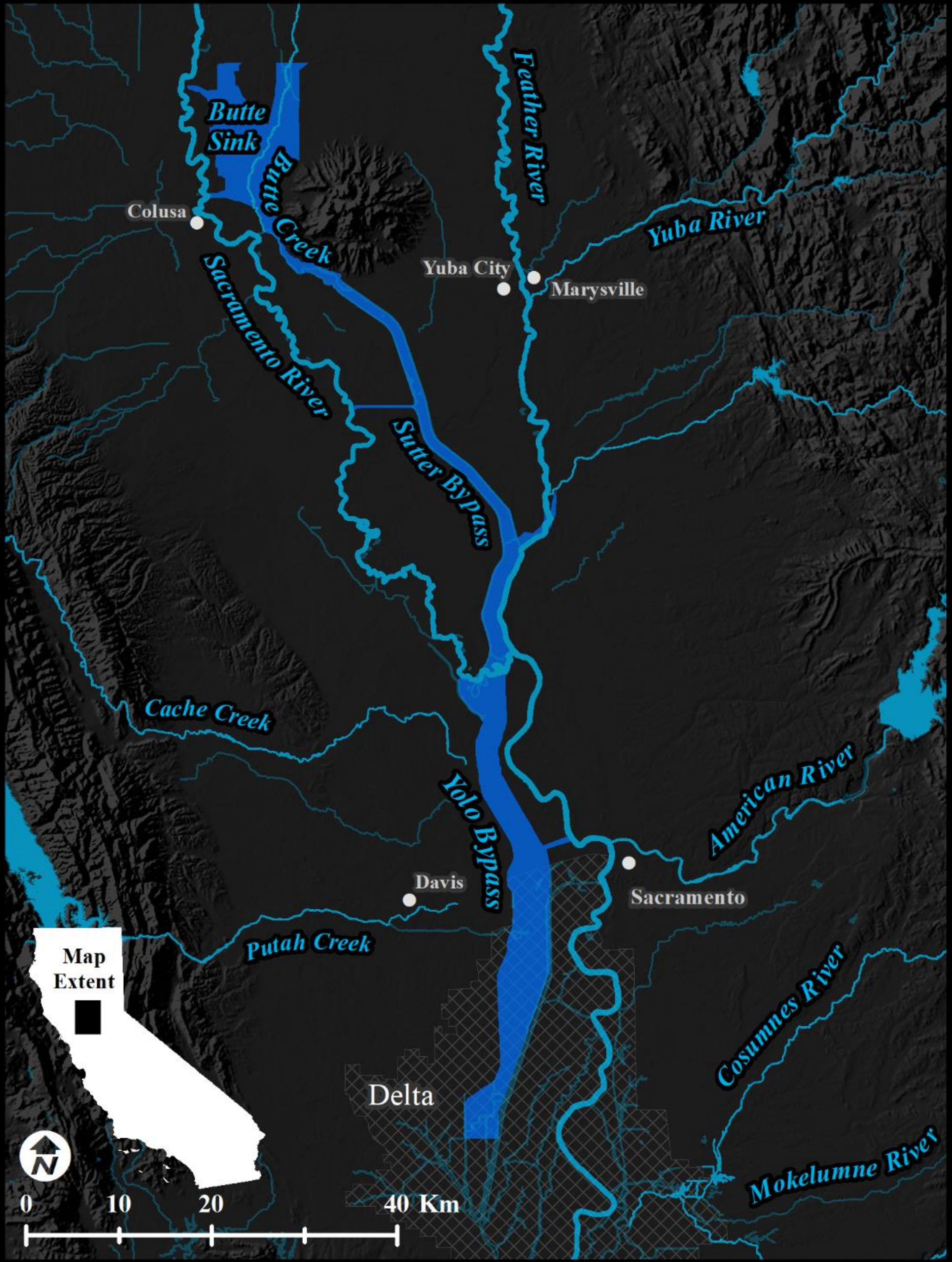


The Forgotten Bypass
Sutter



Map courtesy of Eric Holmes

The Forgotten Bypass
Sutter



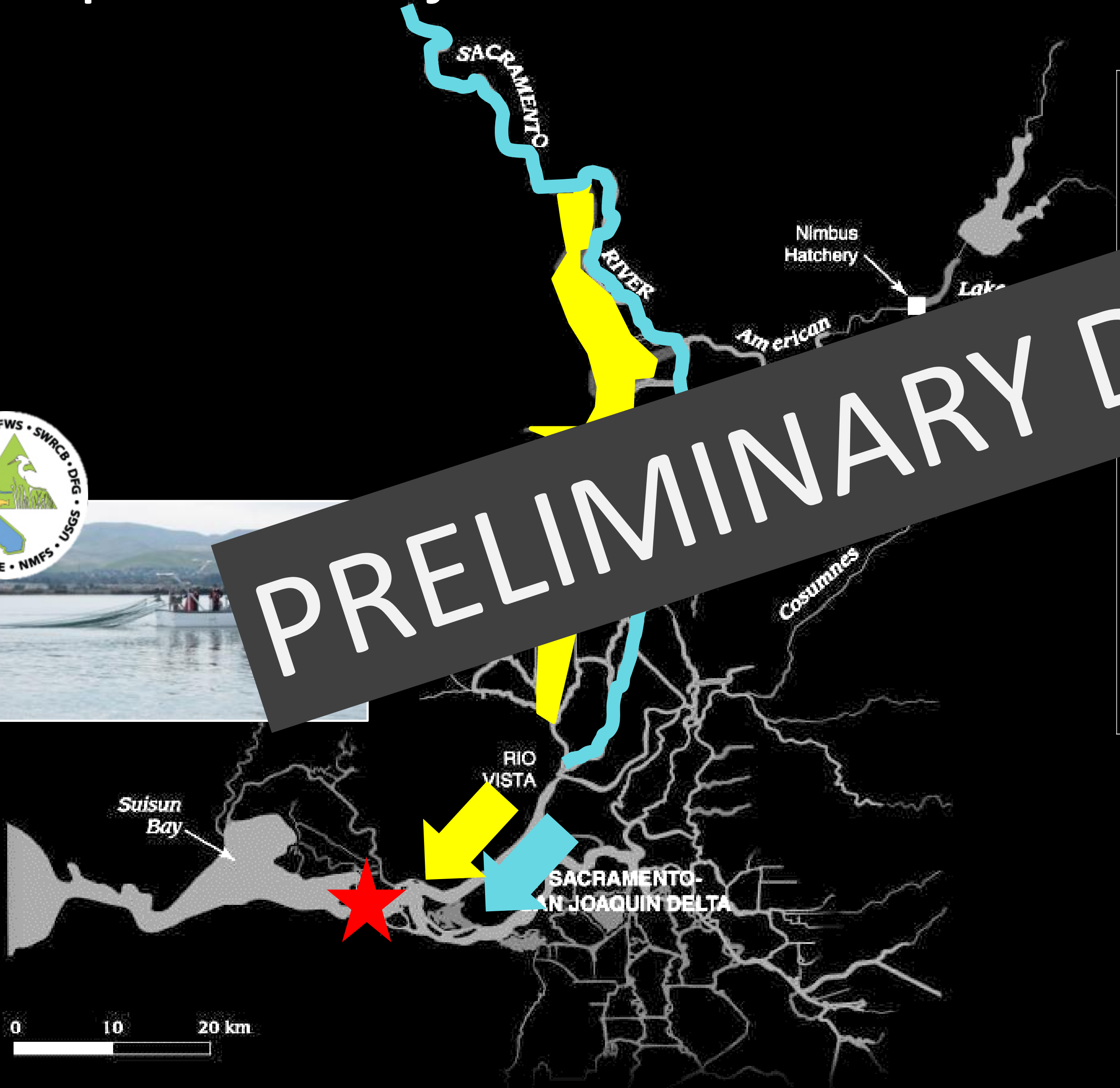
Map courtesy of Eric Holmes

Imagery from planet.com

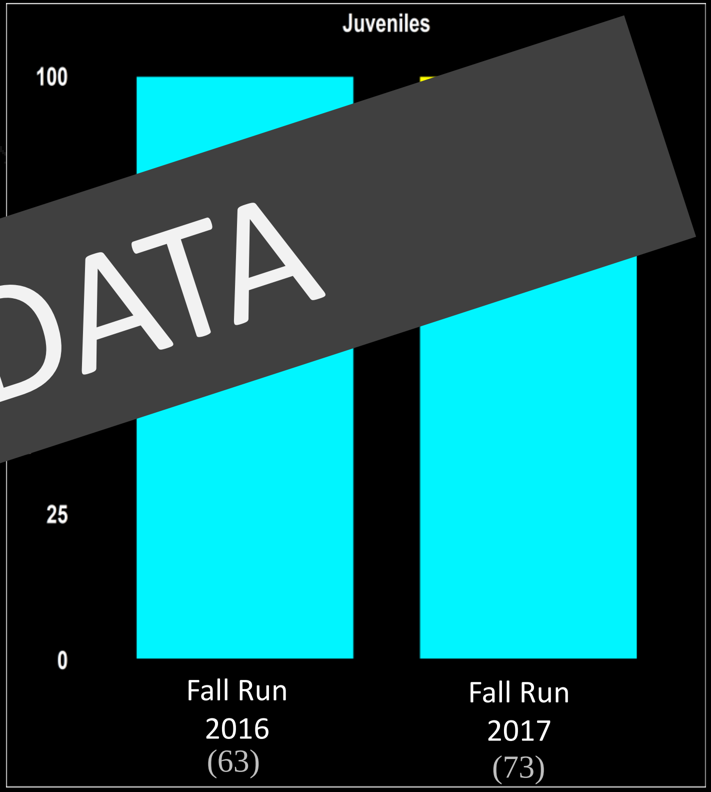
Proportion of juveniles that used floodplains

Floodplain

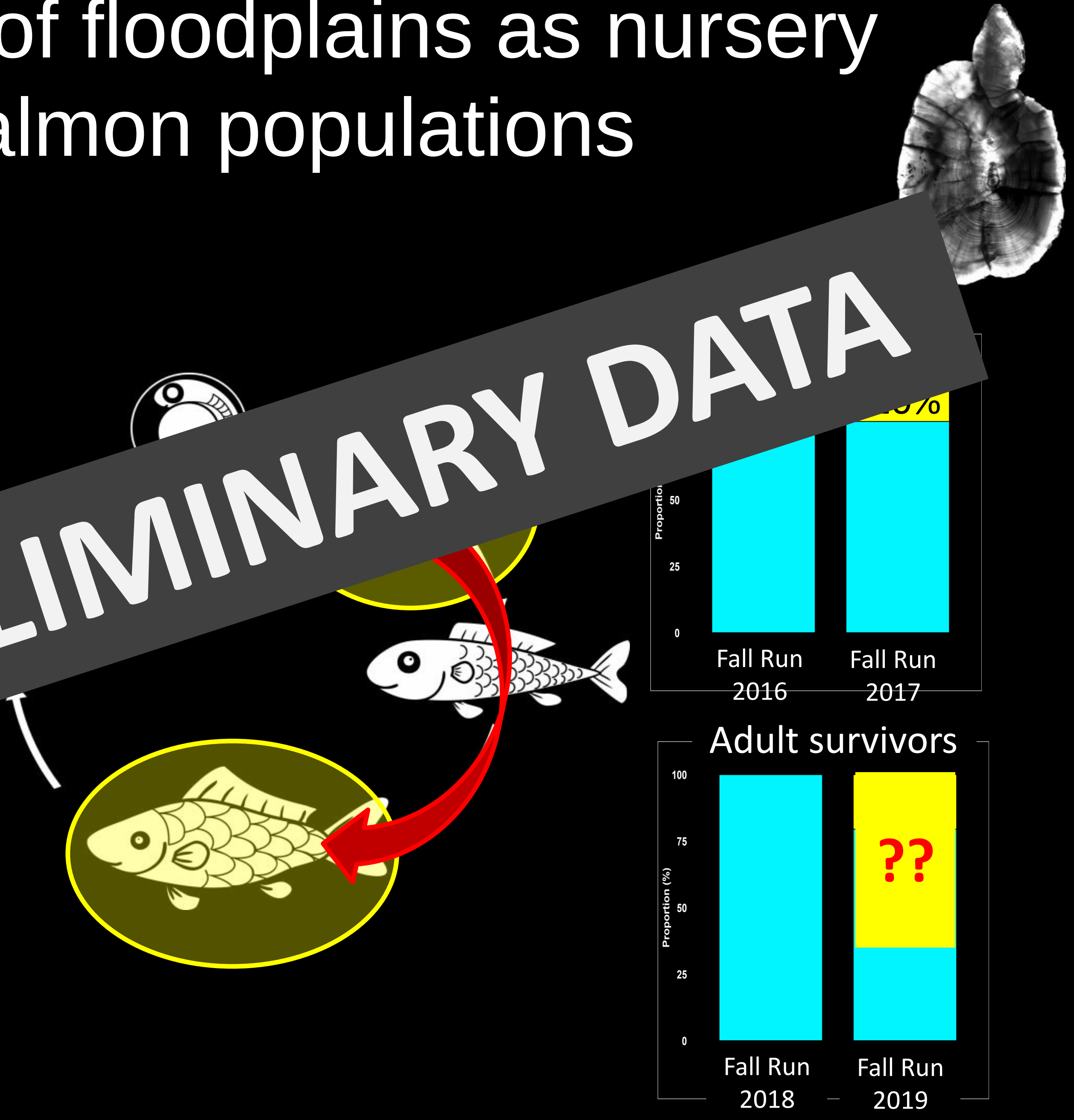
River



PRELIMINARY DATA



Quantifying the role of floodplains as nursery habitats for salmon populations



Many management applications

Photos courtesy of USFWS

Next Steps

- Establish differential benefit of off-channel access across more populations (Butte Creek Spring Run)

- Better understand how timing of outmigration, habitat use, & survival are related

- Scale up the technique to better understand how management/ restoration actions affect population dynamics.

Thank you !

Funding provided by: CDFW
Proposition 1 Grant # P1896030

- CDFW
  - Doug Killam and the Carcass Crew
- USFWS
  - Kevin Niemela and the Carcass Crew
  - DJFMP Chips Island Trawl Crew
- UCD –
  - Team Ears – George Whitman
  - Joy Mathews – UCD SIF
  - Team carcass survey- Laura Coleman, Marissa Levinson, Gabriel Saron