Managing Non-native Predatory Fish in California's Salmon Bearing Streams

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

- **Session Coordinator:**
  - Dr. Philip Georgakakos, UC Berkley
  - Dr. Gabriel Rossi, UC Berkeley
  - Abel Brumo, Stillwater Sciences

Ordering and prioritizing recovery actions for California's endangered salmon and steelhead is a dizzying challenge. Instream flow, habitat alteration, genetic bottlenecks, and hatchery management each have a claim as a priority for our attention and recovery dollars. In this pantheon of insults to native salmonids, the effects of invasive predatory fish are sometimes assumed to be an unavoidable and unmanageable reality of California's modern landscape. However, non-native predatory fish are affecting the survival, distribution, abundance, and life history patterns of native salmonids. And the impacts of many non-native predatory fish are increasing with climate change. Here we seek to look deeper at the types of interactions between non-native predatory fish and native salmon in California, their ecological implications for salmon recovery, and management tools to reduce the effects of non-native predatory fish on native salmonids.

River ecosystems contain mosaics of linked food webs. Therefore managers must carefully consider both the immediate and cascading effects of actions which remove predators or alter predator-prey dynamics. But given the critical state of our salmon populations it is necessary to make these considerations now, and carefully weigh the benefits and risks of different approaches. This session will include talks on the ecology of interactions between non-native predatory fish and Pacific Salmon, the success and failures of methods to manage non-native predatory fish in salmon-bearing streams, and novel and traditional management strategies for the future. The session will conclude with a round table discussion on how to proceed with the management of non-native predatory fish in California's salmon-bearing streams.

Presentations

Slide 5 - **Landscape-scale and Habitat-level Drivers of Fish Predation in the Sacramento-San Joaquin Delta**, Cyril Michel, *NOAA*

Slide 54 - **Spring Temperature Predicts Timing of Seasonal Upstream Migration of Invasive Sacramento Pikeminnow in South Fork Eel River**, Philip Georgakakos, *UC Berkeley*

Slide 100 - **Shade Affects Magnitude and Tactics of Juvenile Chinook Salmon Antipredator Behavior in the Migration Corridor**, Megan Sabal, *Oregon State University*

Slide 115 - **Tracking (and Trying to Stop) the Invasion of Sacramento Pikeminnow in the North Fork Eel River**, Zane Ruddy, *BLM*

Slide 143 – **Chorro Creek: A Big Success in a Small Watershed**, Ken Jarrett, *Stillwater Sciences*

Slide 163 - **Informing Management Strategies for Non-native Predatory Fishes Through Applied Ecological Studies: Lessons Learned from the Stanislaus River**, Matthew Petersen, *FISHBIO*

Managing Non-native Predatory Fish in California’s Salmon Bearing Streams

Landscape-scale and Habitat-level Drivers of Fish Predation in the Sacramento-San Joaquin Delta

Cyril Michel, NOAA Fisheries

Spring Temperature Predicts Upstream Migration Timing of Invasive Sacramento Pikeminnow in a Salmon-bearing River

Philip Georgakakos, UC Berkeley

Shade Affects Magnitude and Tactics of Juvenile Chinook Salmon Antipredator Behavior

Megan Sabal, Oregon State University

---*Break: 10:30 -10:45 am*--

Tracking (and Trying to Stop) the Invasion of Sacramento Pikeminnow in the North Fork Eel River

Zane Ruddy, BLM

Pikeminnow Suppression: A Big Success in a Small Watershed

Ken Jarrett, Stillwater Sciences

Informing Management Strategies for Non-native Salmonid Predators Through Applied Ecological Studies: Lessons Learned from the Stanislaus River

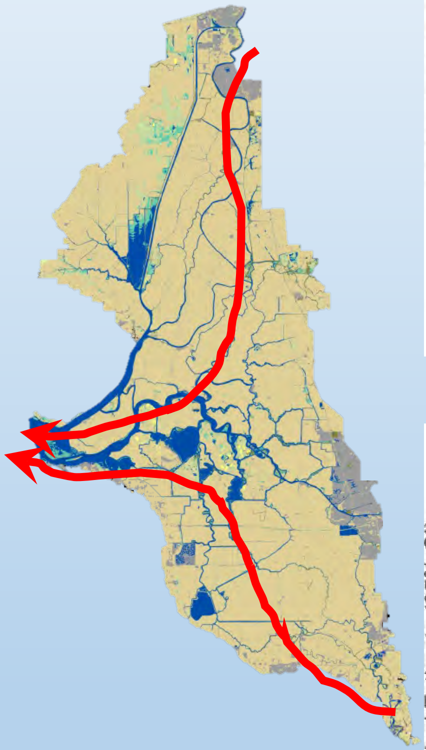
Matthew Petersen, FISHBIO

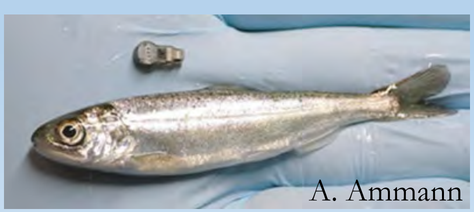
Landscape-scale and habitat-level drivers of fish predation in the Sacramento-San Joaquin Delta

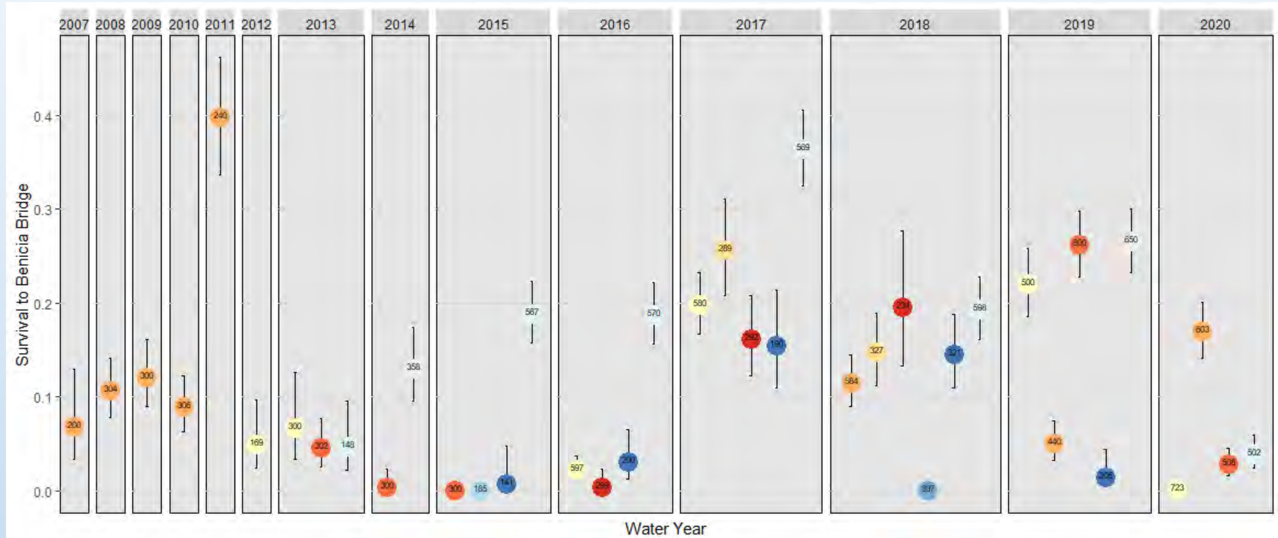
Cyril Michel[1], T. Reid Nelson[2], Nicholas Demetras[1], Brendan Lehman[1], Meagan Gary[1], Chris Loomis[3], Mark Henderson[3], Joseph Smith[4], David Huff[4]

[1]University of California Santa Cruz/NMFS
[2]George Mason University
[3]USGS/Humboldt State University
[4]NMFS

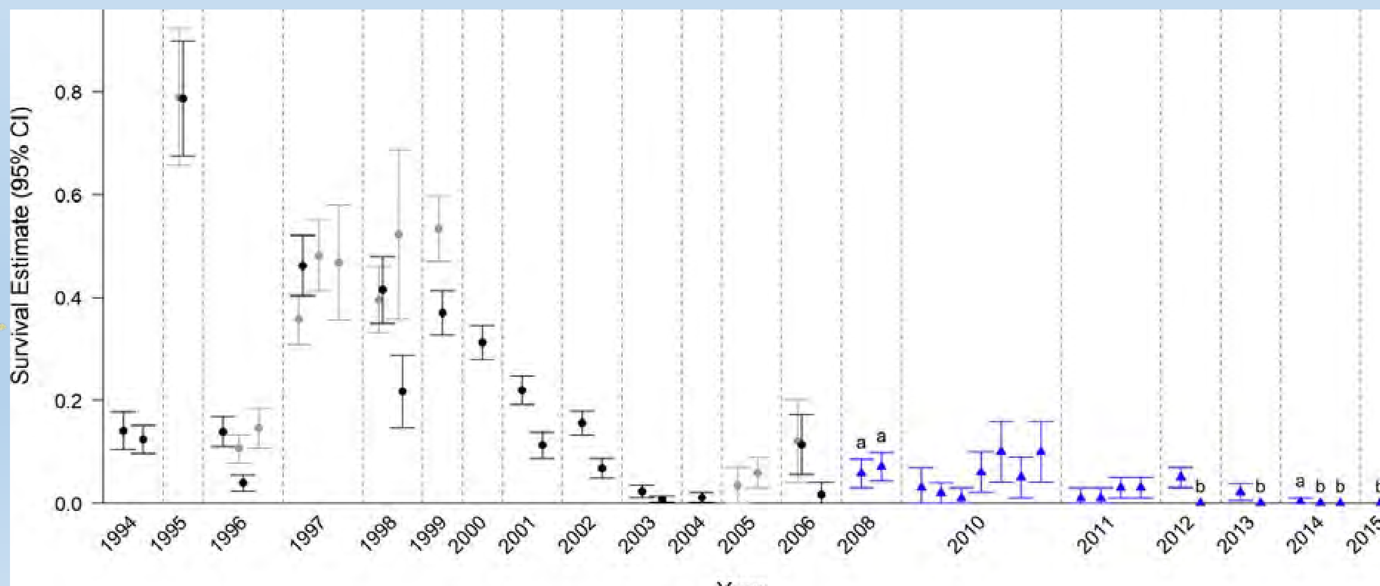
Low Outmigration Survival





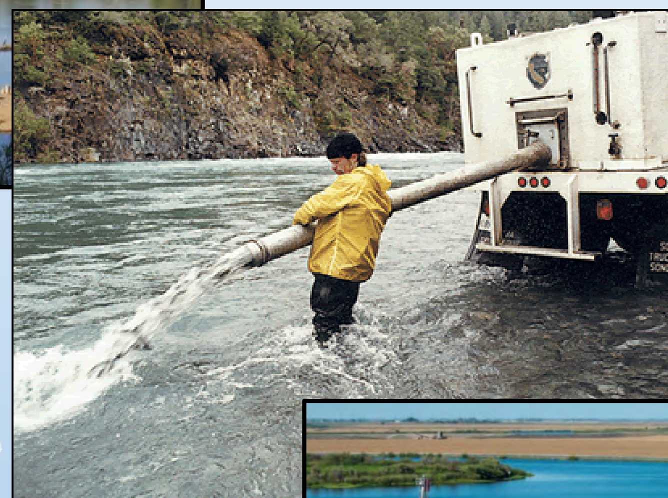


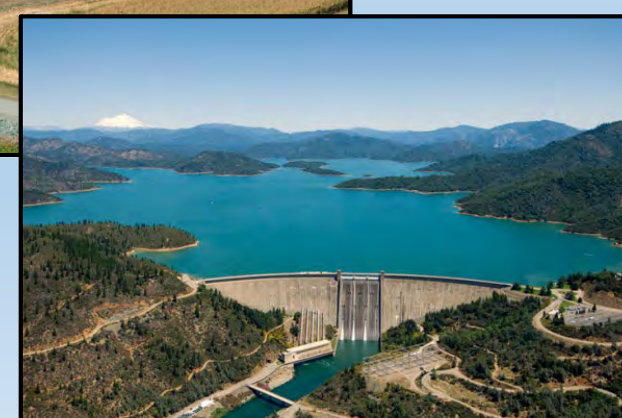
Michel, unpublished



Buchanan et al., 2018

Why is juvenile survival so low?

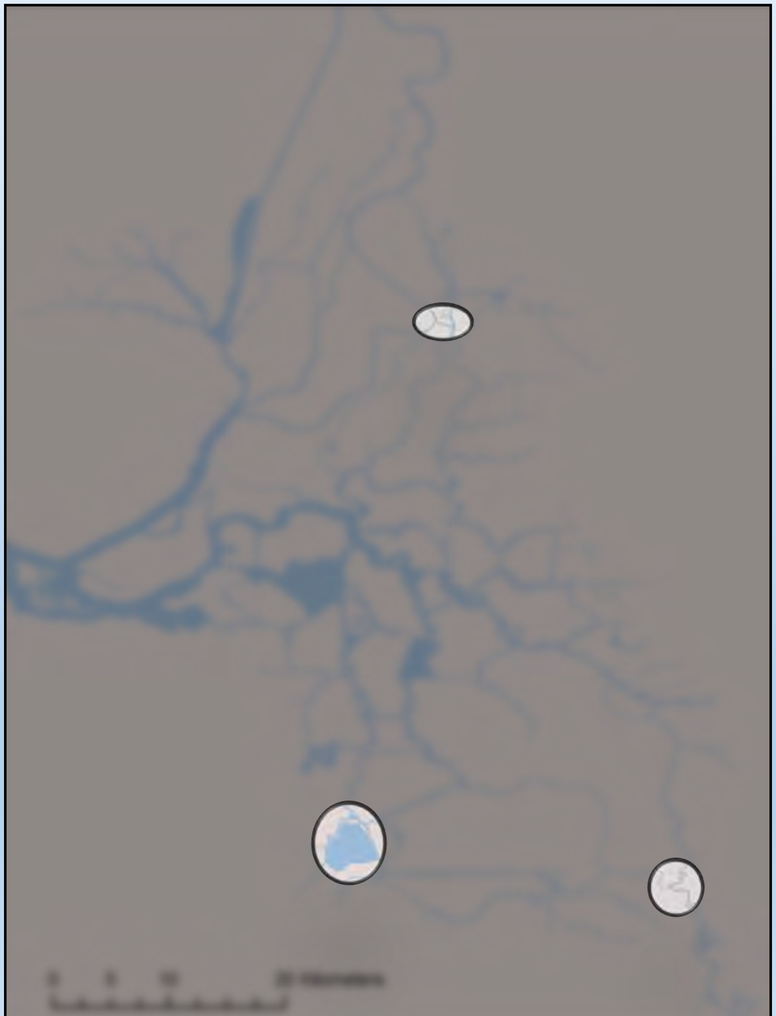




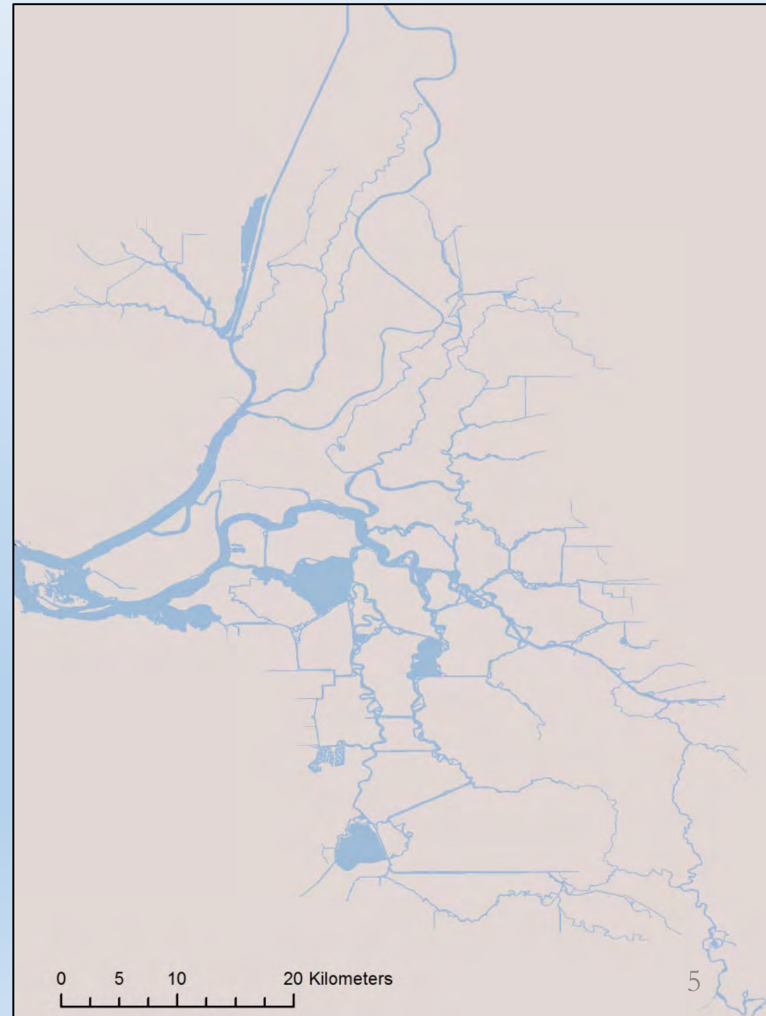
Why is juvenile survival so low?

Mismatch in scale between predation research, and the management it informs

RESEARCH



MANAGEMENT



We need to zoom out and study predation holistically

1. Identify drivers of predation most **important and common** across the estuary

2. Predict when and where they may be having the biggest impact on juvenile salmon

3. Predict landscape-level impacts and success of potential mitigation measures

Outline

1. Landscape-scale drivers of Predation Risk

2. Habitat-level drivers of Predation Risk

3. Management Applications

Outline

1. Landscape-scale drivers of Predation Risk
   A. South Delta Predation - 2017

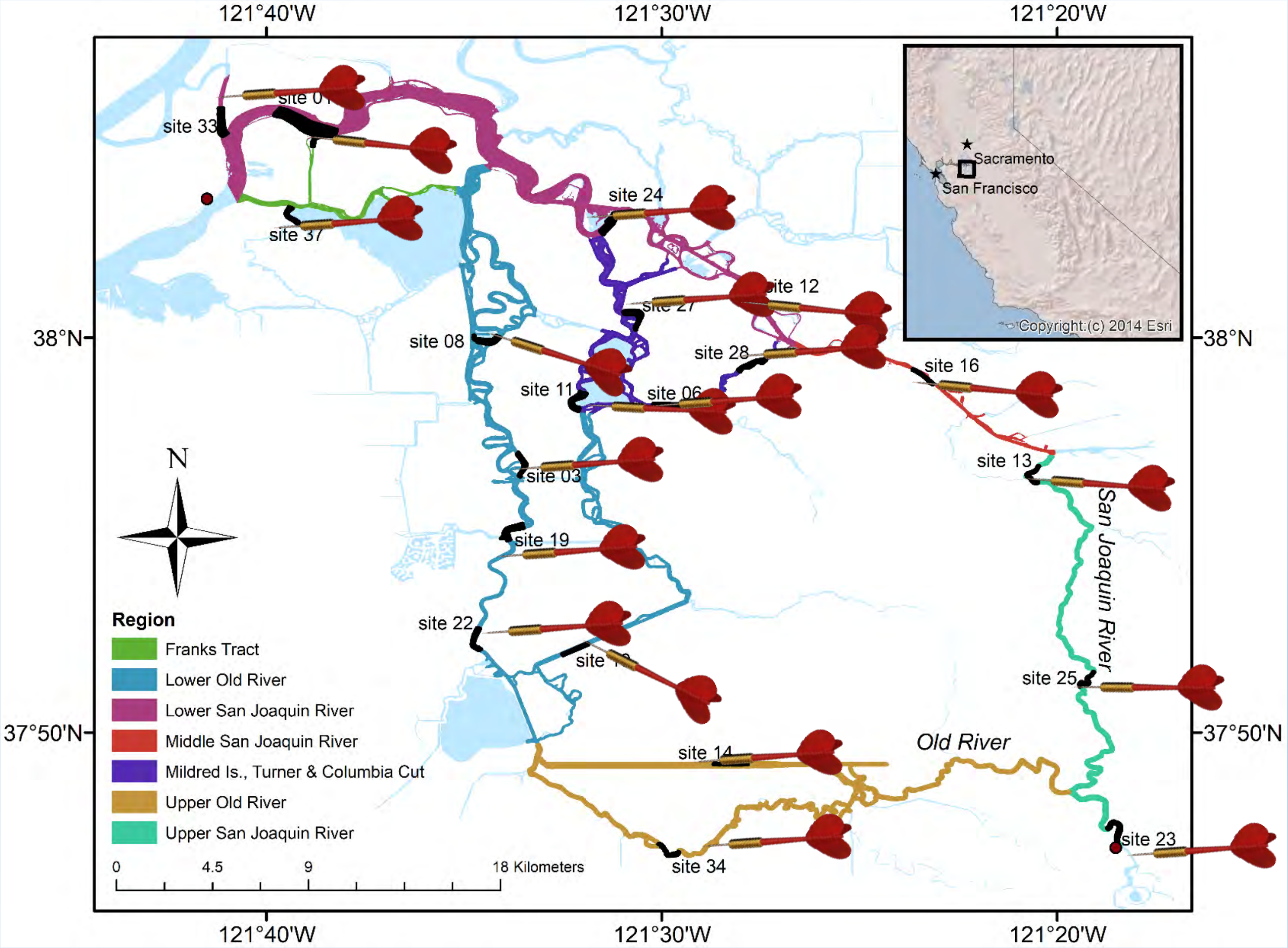
2. Habitat-level drivers of Predation Risk

3. Management Applications

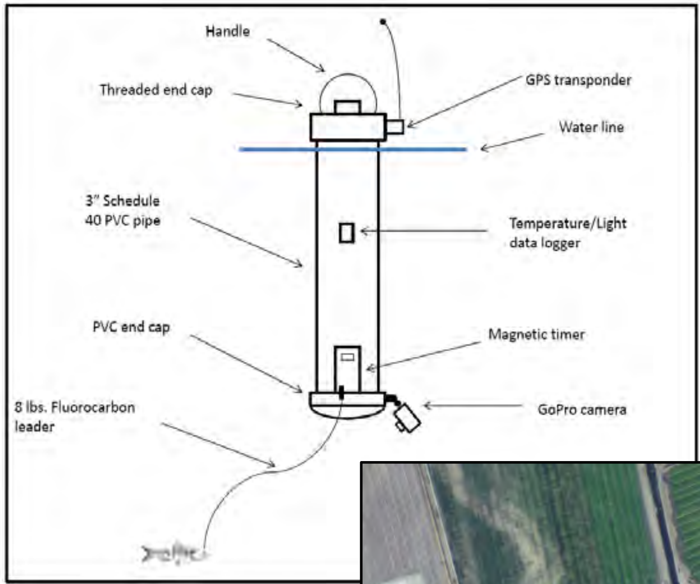
Central challenge: how to collect finite information on predation that can be reasonably extrapolated to landscape scale

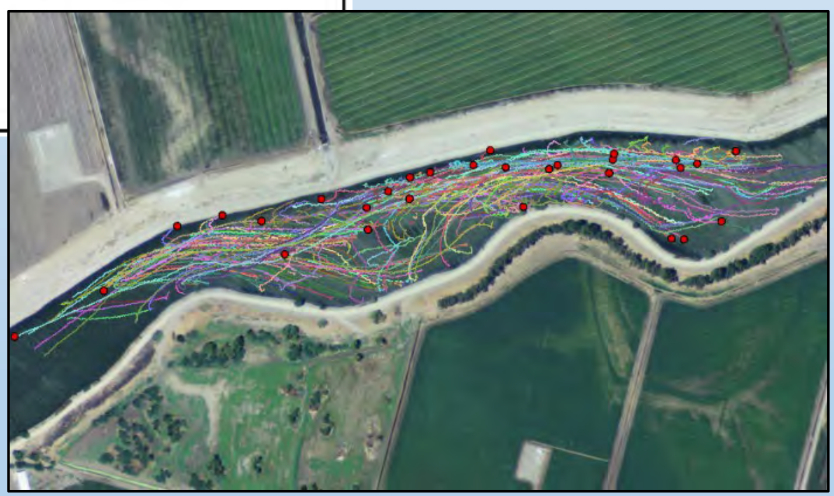
- GRTS: Generalized Random Tesselation Stratified

Stevens and Olsen 2004, *Journal of the American Statistical Association*



The tools: Predation Event Recorders "PERS"

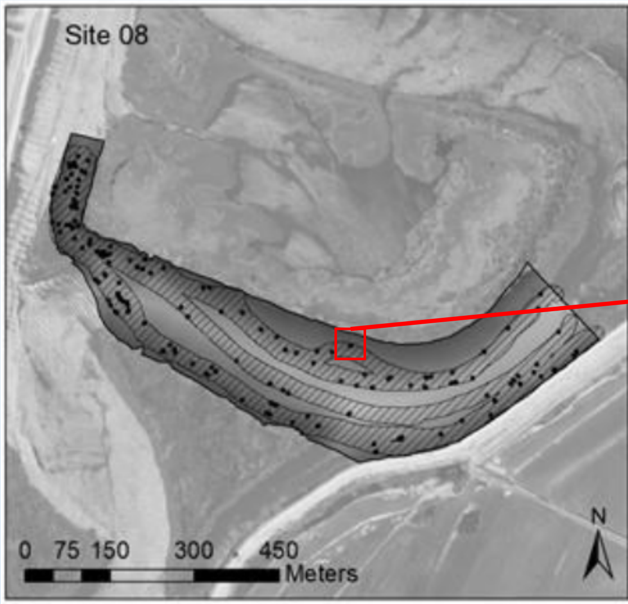


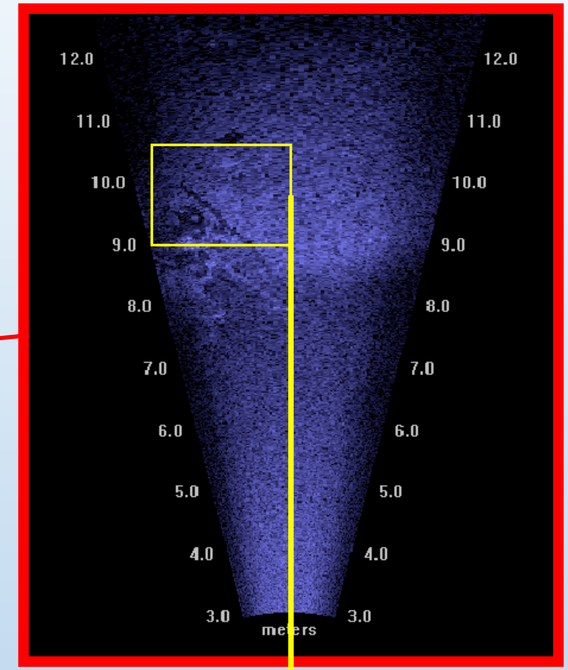


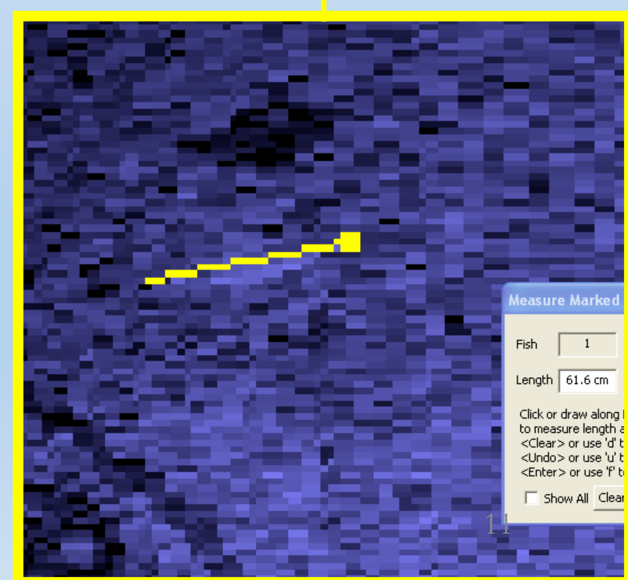
Easily repeatable standardized monitoring unit

Demetras et al. 2016 *Fishery Bulletin*

The tools: DIDSON cameras







Environmental/habitat variables

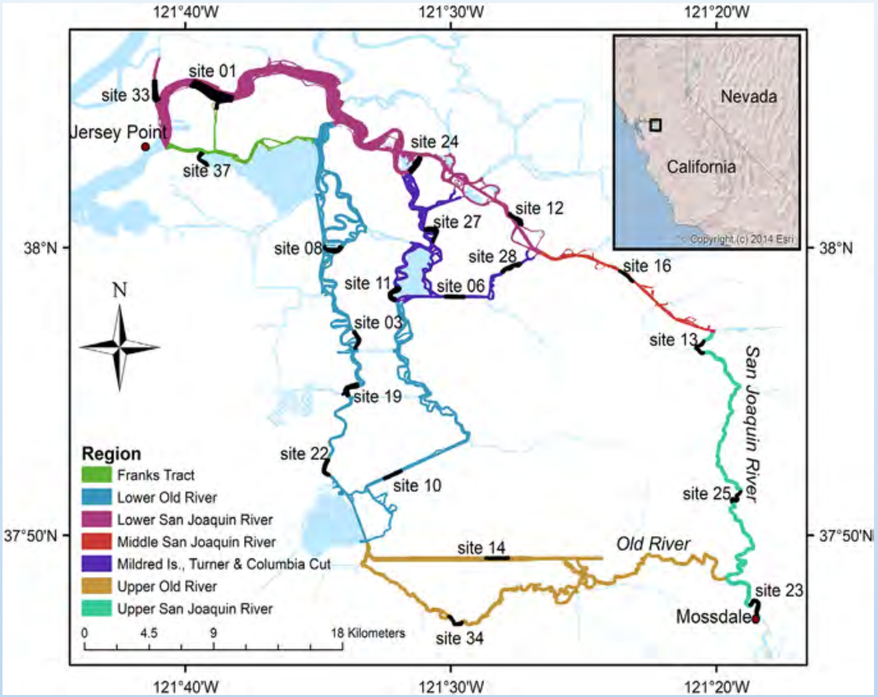
- Temperature
- Dissolved oxygen
- Turbidity

} Water quality sonde

- Depth (10m x 10m DEM*), and:
  - Bottom roughness (CV of depth)
  - Bottom slope
- Submerged Aquatic Vegetation (side-scan sonar)
- Predator Density (from DIDSON cameras)
- Water velocity (PER speed)
- Distance to shore
- Time to sunset

* Fregoso, T.A., Wang, R-F, Alteljevich, E., and Jaffe, B.E. 2017. San Francisco Bay-Delta bathymetric/topographic digital elevation model (DEM): US Geological Survey data release https://doi.org/10.5066/F7GH9G27.

South Delta Study in 2017



- 21 sites randomly selected sites visited, incl. 3 repeat sites, over 6 consecutive weeks during spring
- Sampled from 3 hours before sunset to 1.5 hours after to amplify predation signal
- Total of 1,670 PER deployments, overall PER predation rate of 15.7%.

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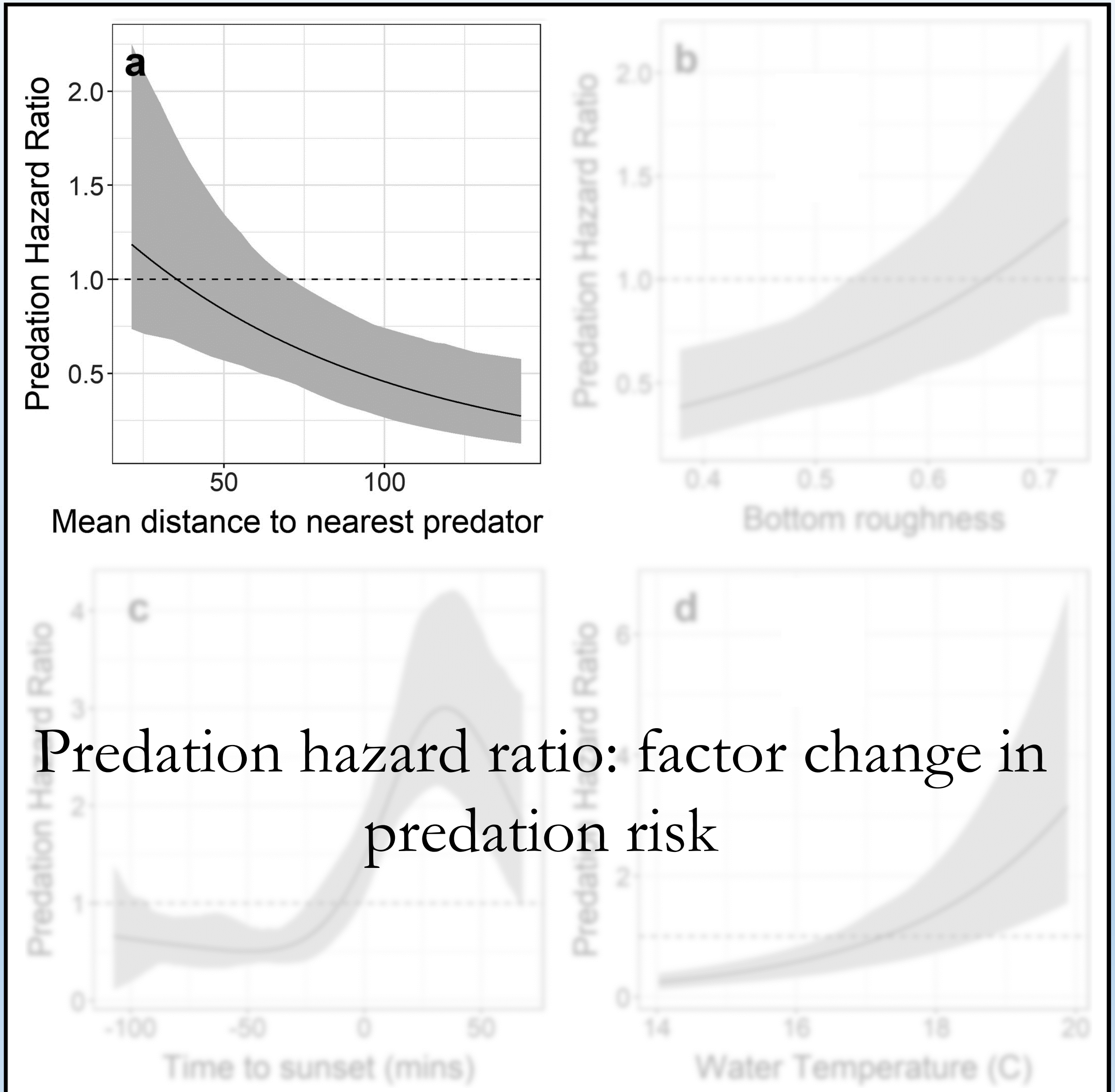
Fish predation on a landscape scale

Cyril J. Michel, Mark J. Henderson, Christopher M. Loomis, Joseph M. Smith, Nicholas J. Demetras, Ilysa S. Iglesias, Brendan M. Lehman, David D. Huff

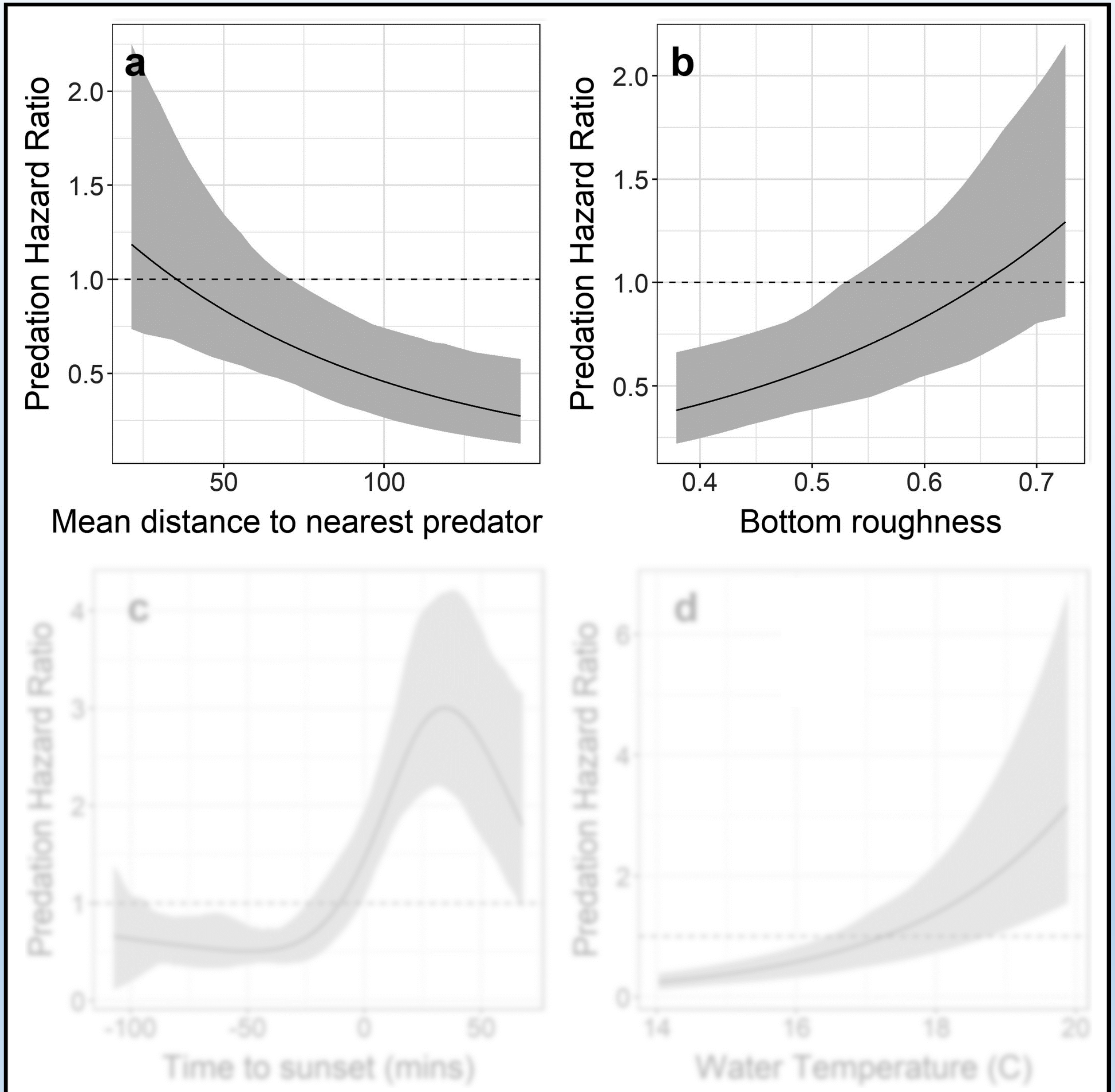
Published 2020

Top predictive covariates of landscape-scale predation



Predation hazard ratio: factor change in predation risk

Top predictive covariates of landscape-scale predation



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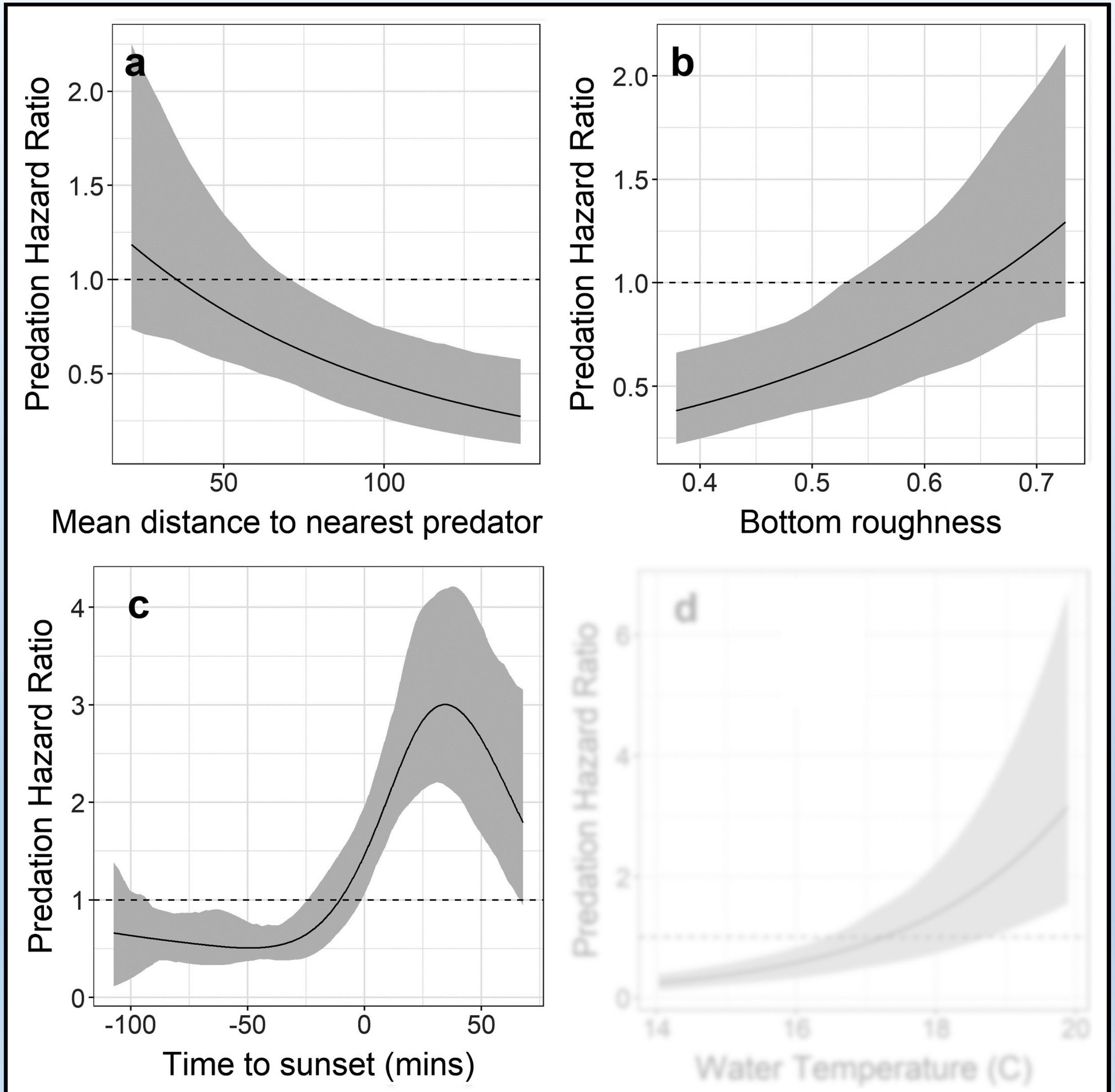
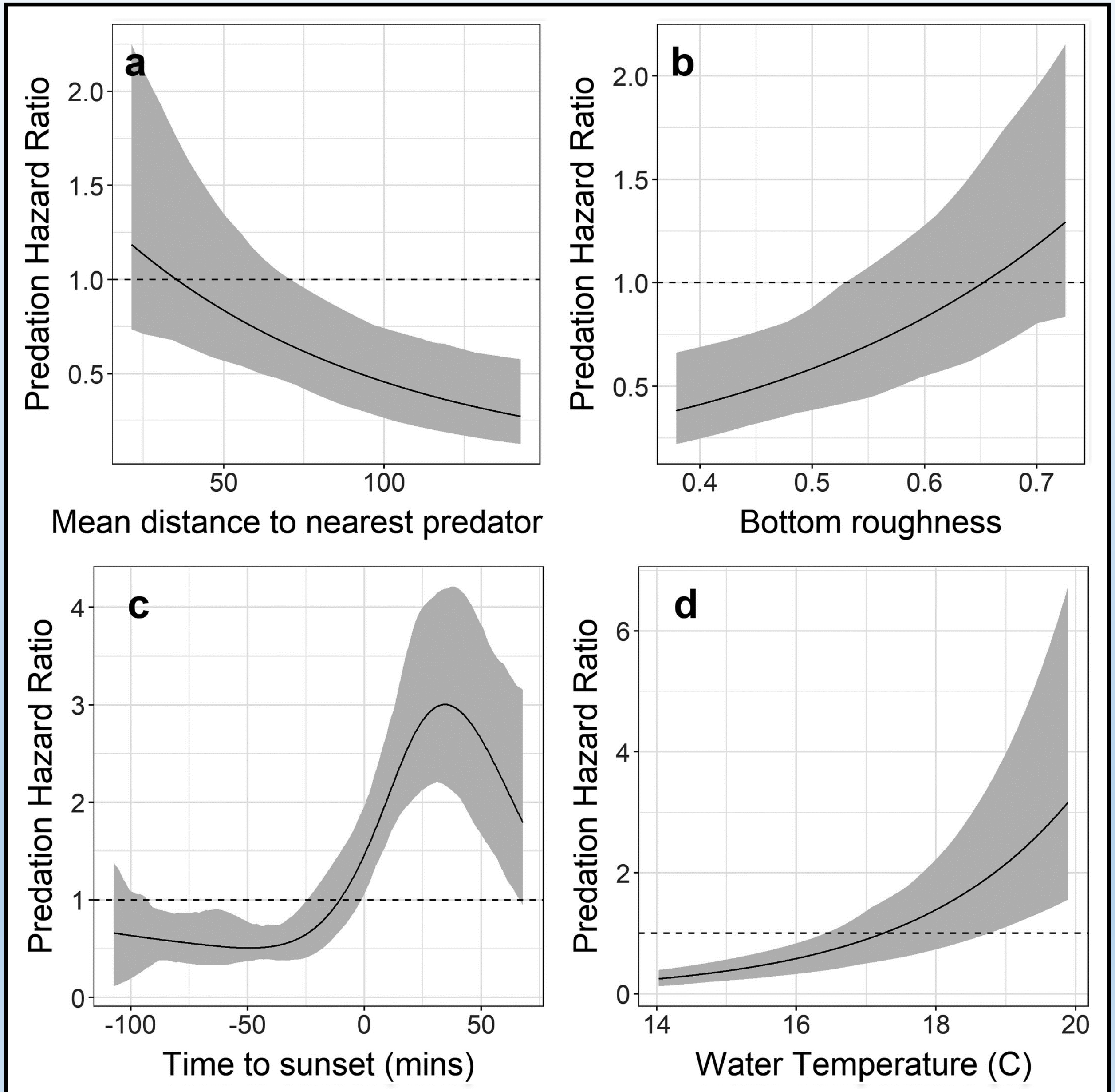


Top predictive covariates of landscape-scale predation



Outline

1. Landscape-scale drivers of Predation Risk
    A. South Delta Predation - 2017

2. Habitat-level drivers of Predation Risk
    A. Contact point literature review - 2018

3. Management Applications

Contact point literature review - 2018

SAN FRANCISCO ESTUARY & WATERSHED SCIENCE
Sponsored by the Delta Science Program and the UC Davis Muir Institute

POLICY AND PROGRAM ANALYSIS

Where Predators and Prey Meet: Anthropogenic Contact Points Between Fishes in a Freshwater Estuary

Brendan M. Lehman*[1], Meagan P. Gary[1], Nicholas J. Demetras[1], Cyril J. Michel[1]

Contact points are habitat features that are the result of human alterations to the riverscape, and that may locally increase the probability of juvenile salmon being predated upon

Contact point	Predator aggregation	Prey aggregation	Predator–Prey interaction	Predator efficiency	Prey vulnerability
Submerged aquatic vegetation	S[4] Q[14] P[5]	S[4,8,36] Q[27] P[5]	S[3,4,8,12,17,18,38,39,40,47] Q[9] P[5]	S[3,17,39,40] P[5,12,15,18,38,41]	S[3,10,17,36,39,40] P[5,12,15,18,38,41]
Artificial light	S[1,7]	S[1,7,11,43,45] P[32]	S[1,11,28,29,34,43] P[23,32]	S[11,20,28,29,49] P[7,32]	S[11] P[7,29,32,35]
Docks and piers	S[1,6,19]	S[1,6,19,30,31,33,42]	P[1,6,19,30]	P[6,19,24,30]	P[6,19,24,30,33]
Riprap	S[46] P[26,44]	S[44,46,48]	P[22,26,46]	P[21,26,44]	P[21,26]
Scour holes	P[2,25]	P[2,25]	P[2,25]	P[25]	
Diversions	S[37] Q[13] P[16]	S[16]	P[37] P[16]	P[16]	P[16]

a. Sources:

1 Able et al. (2013)
2 Allouche (2002)
3 Anderson (1984)
4 Annett (1998)
5 Baras and Nindaba (1999)
6 Barwick et al. (2004)
7 Becker et al. (2013)
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39 Savino and Stein (1982)
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43 Tabor (2001); Tabor et al. (2004)
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45 Tabor et al. (2017)
46 Tiffan et al. (2016)
47 Tsunoda and Mitsuo (2018)
48 Venter et al. (2008)
49 Vogel and Beauchamp (1999)

Published 2019

Outline

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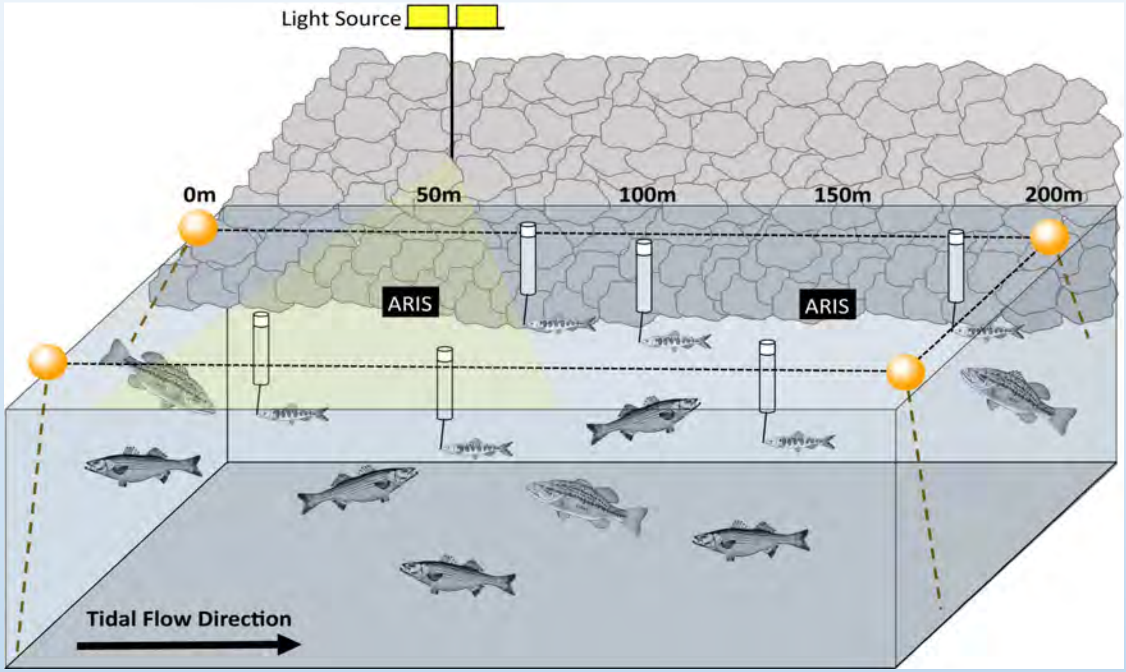
2. Habitat-level drivers of Predation Risk
   A. Contact point literature review - 2018
   B. Artificial light at night (ALAN) - 2019

3. Management Applications

ALAN Study in 2019



- 6 sites were sampled from April and May of 2019
- Sampled from 1 hour after sunset to 5 hours after
- 1518 PERs were deployed, overall PER predation rate of 16.9%.

Transactions of the American Fisheries Society

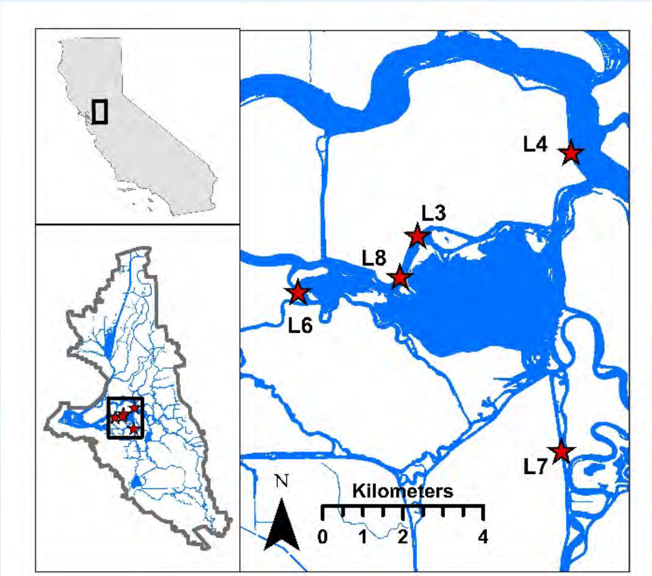
Article | Open Access

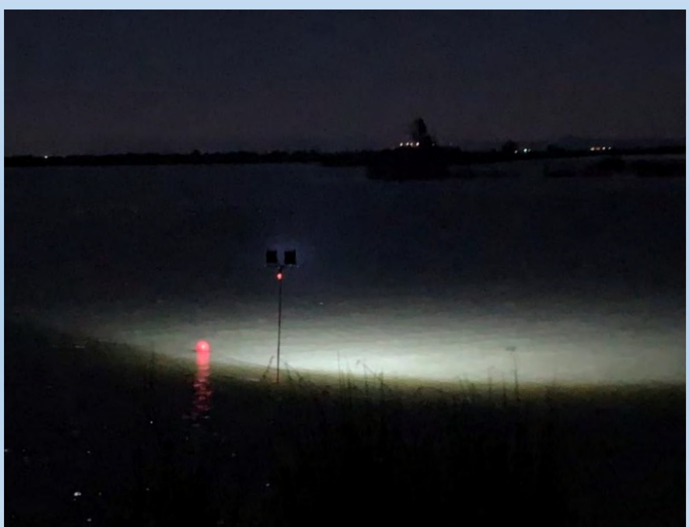
Effects of Artificial Lighting at Night on Predator Density and Salmonid Predation

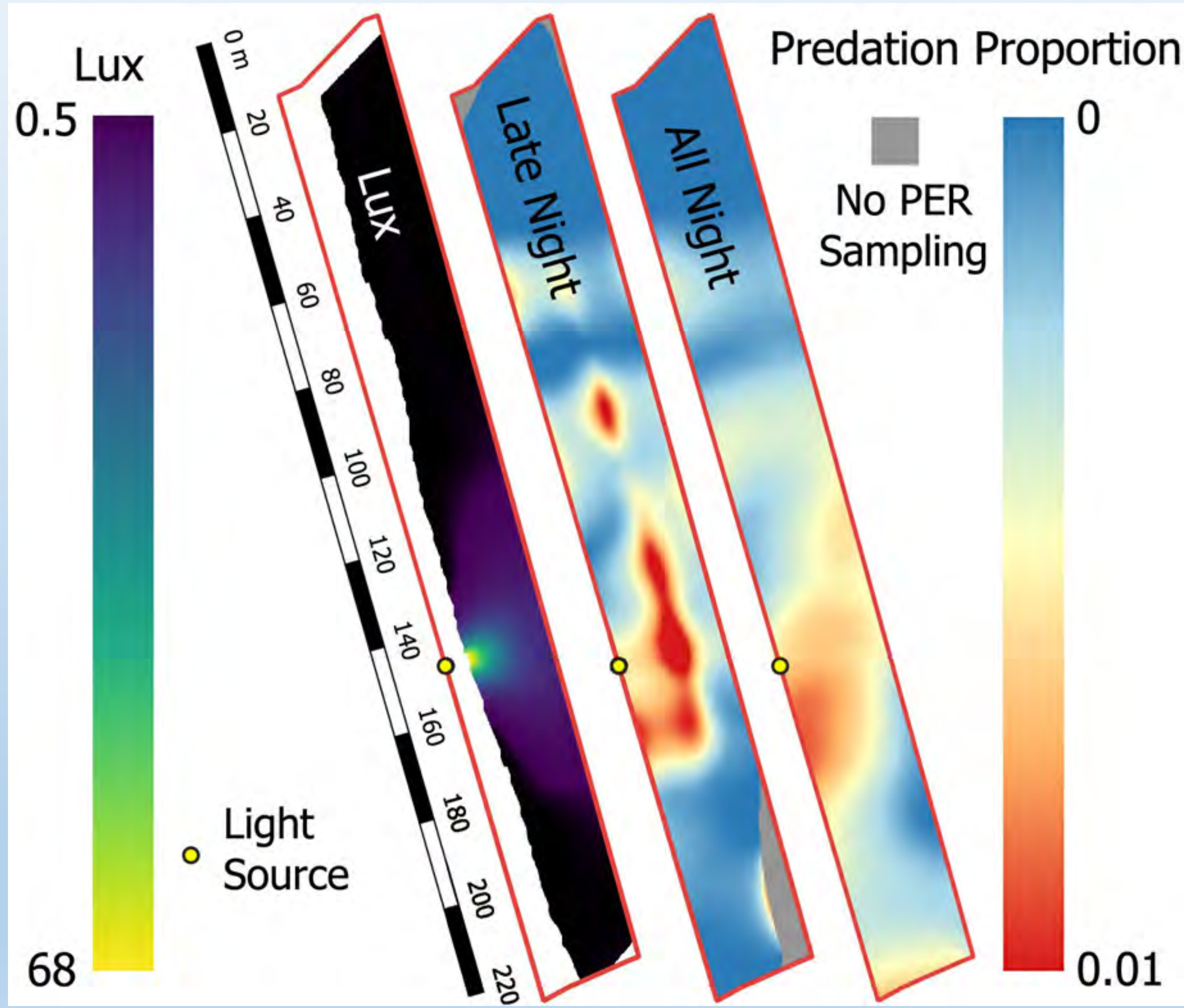
Thomas Reid Nelson, Cyril J. Michel, Meagan P. Gary, Brendan M. Lehman, Nicholas J. Demetras, Jeremy J. Hammen, Michael J. Horn

Published 2021

ALAN Study in 2019

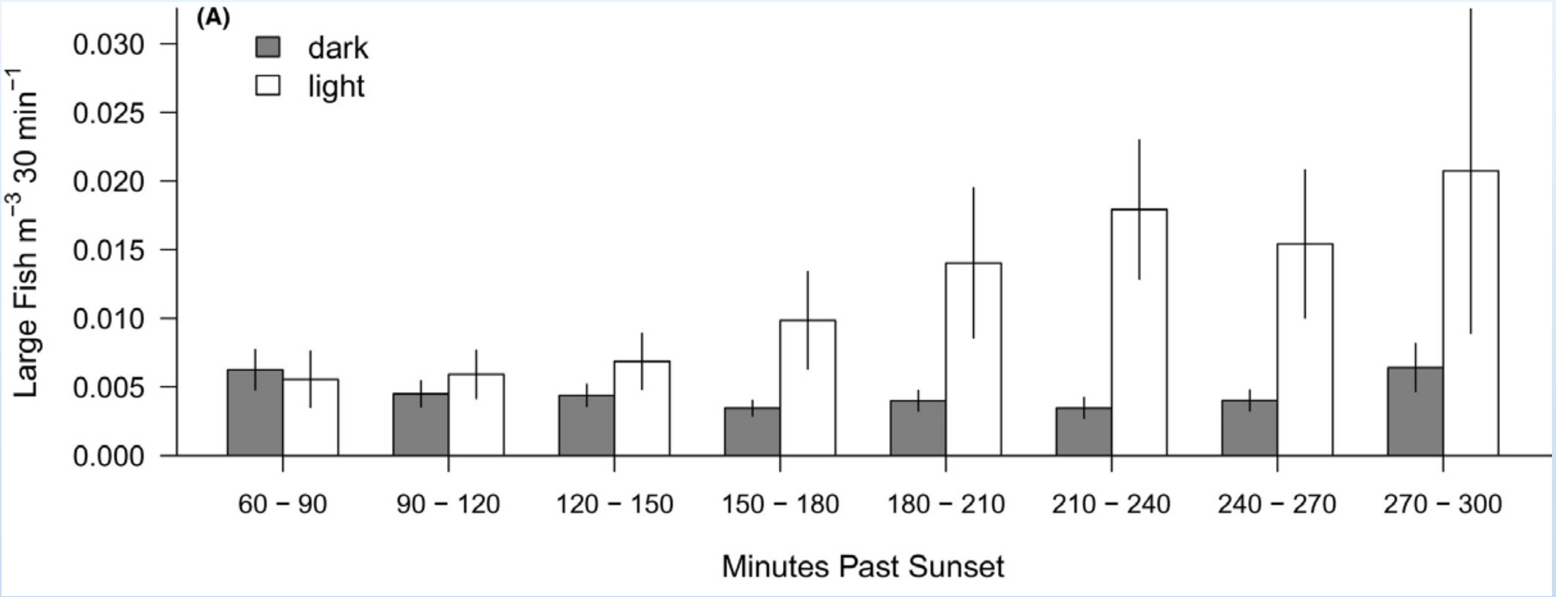




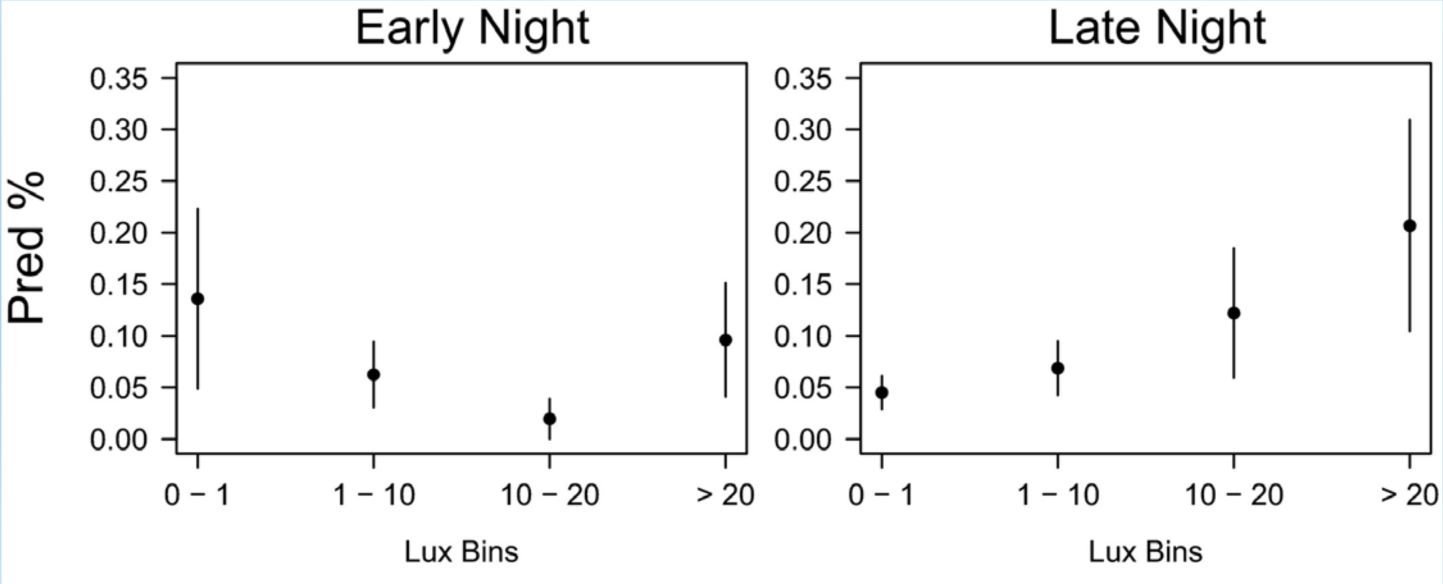


ALAN Study in 2019

- Predator abundances



- Predation risk



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    A. South Delta Predation - 2017

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    A. Contact point literature review - 2018
    B. Artificial light at night (ALAN) – 2019
    C. Water diversion structures - 2021

3. Management Applications

Diversion Study in 2021

SAN FRANCISCO ESTUARY & WATERSHED SCIENCE

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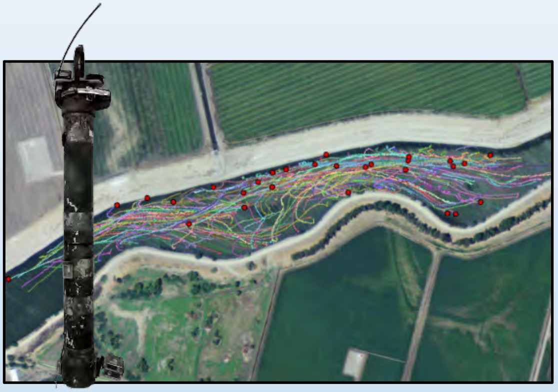
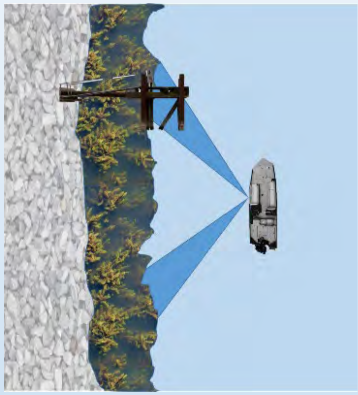
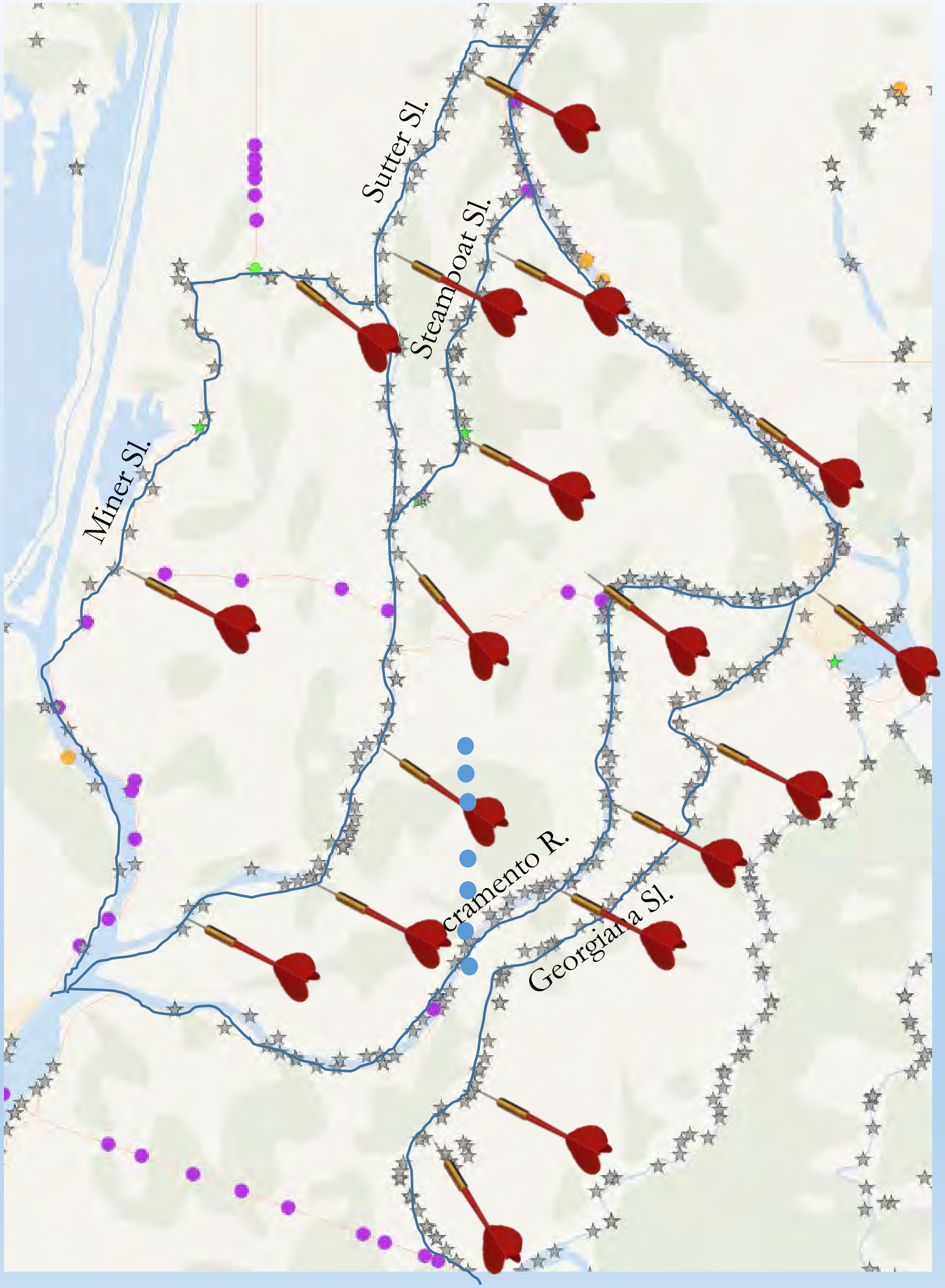
Diversion Study in 2021





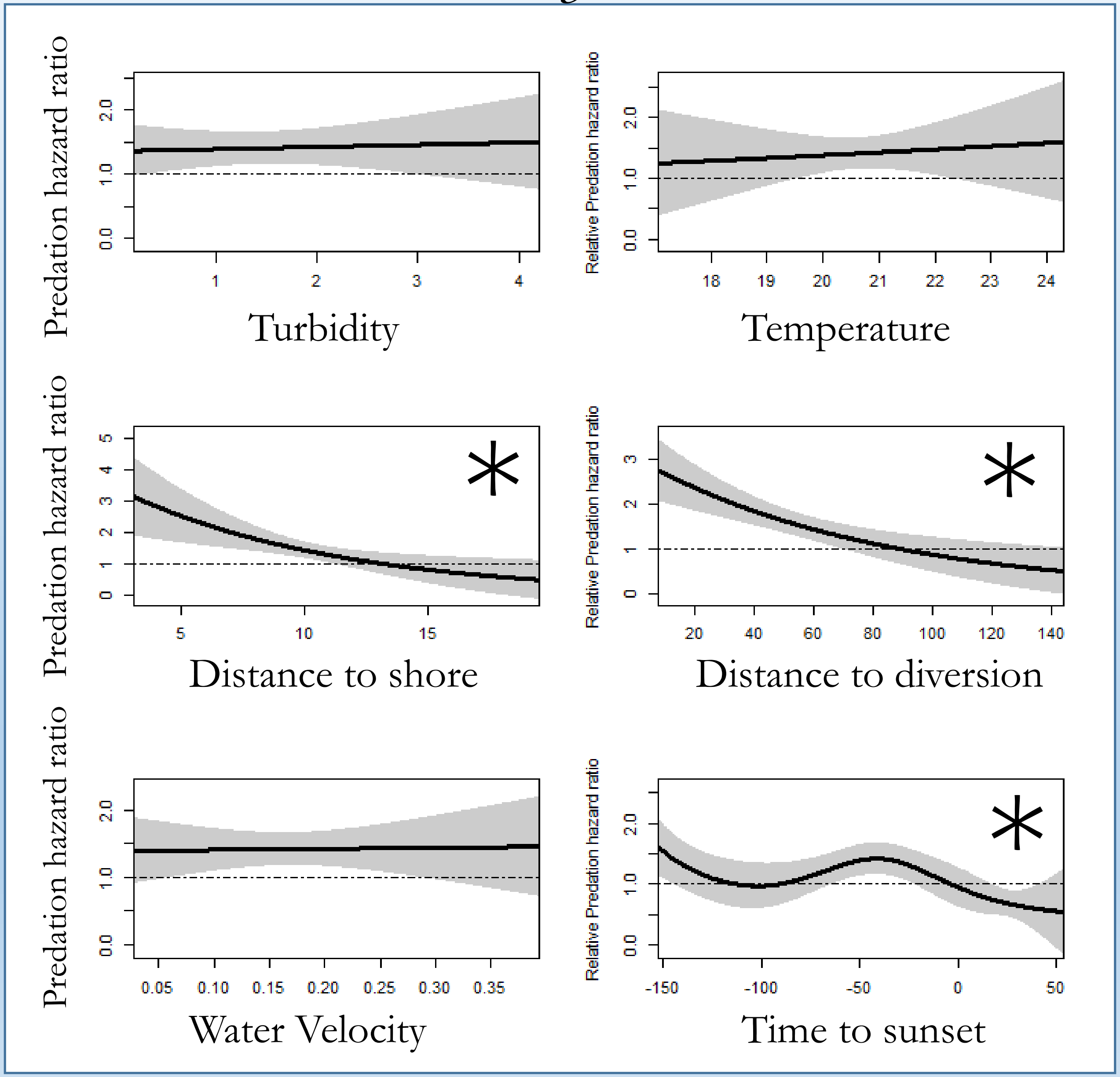


Diversion Study in 2021

- 30 sampling days in April and May
  - 10 in Steamboat Sl.
  - 10 in mainstem Sac
  - 10 in Georgiana Sl.
- Each site contained an operational diversion
- 2277 PERs were deployed, overall PER predation rate of 15.1 %.
- Paired ARIS cameras deployed every night, 1 trained on diversion, 1 trained on control area

Diversion Study in 2021

Preliminary results



Diversion Study in 2021

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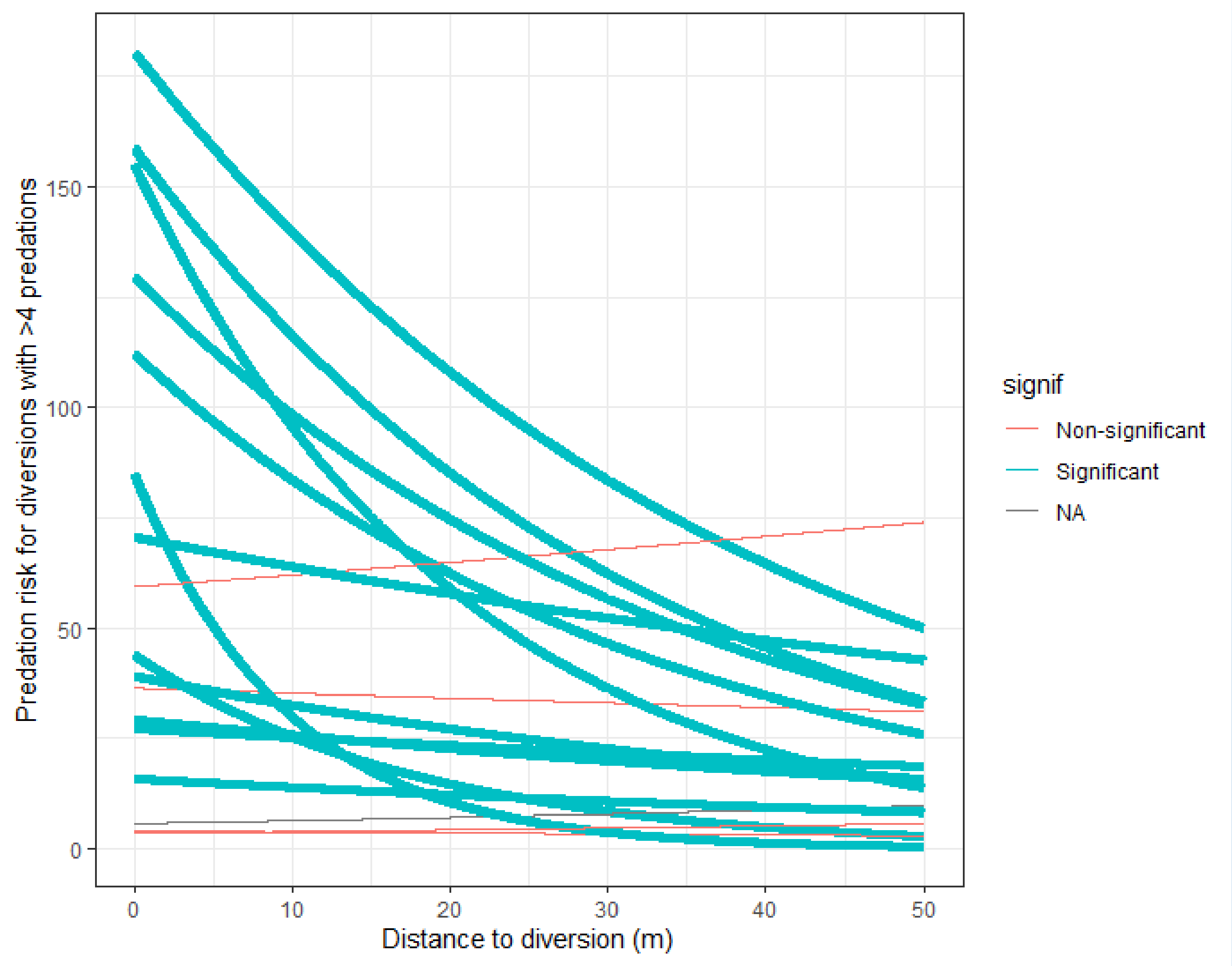

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2. Habitat-level drivers of Predation Risk
   A. Contact point literature review - 2018
   B. Artificial light at night (ALAN) – 2019
   C. Water diversion structures – 2021
   D. Submerged aquatic vegetation (SAV) - 2022

3. Management Applications

Diversion Study in 2021

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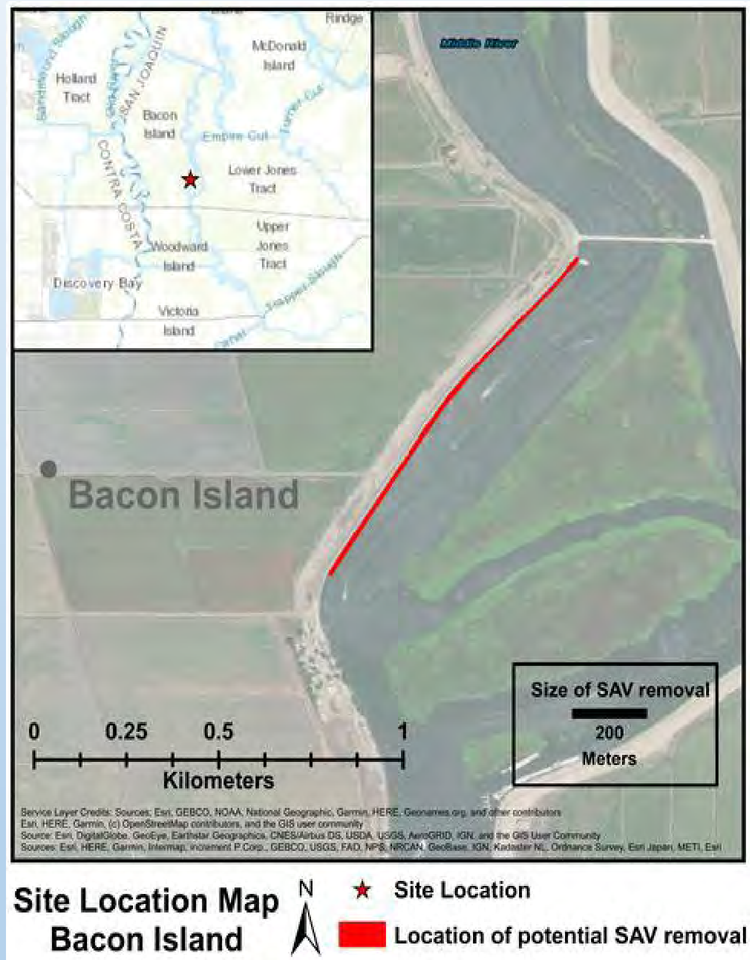
Docks and piers	S[1,6,19]	S[1,6,19,30,31,33,42]	P[1,6,19,30]	P[6,19,24,30]	P[6,19,24,30,33]
Riprap	S[46] P[26,44]	S[44,46,48]	P[22,26,46]	P[21,26,44]	P[21,26]
Scour holes	P[2,25]	P[2,25]	P[2,25]	P[25]	
Diversions	S[37] Q[13] P[16]	S[16]	P[37] P[16]	P[16]	P[16]

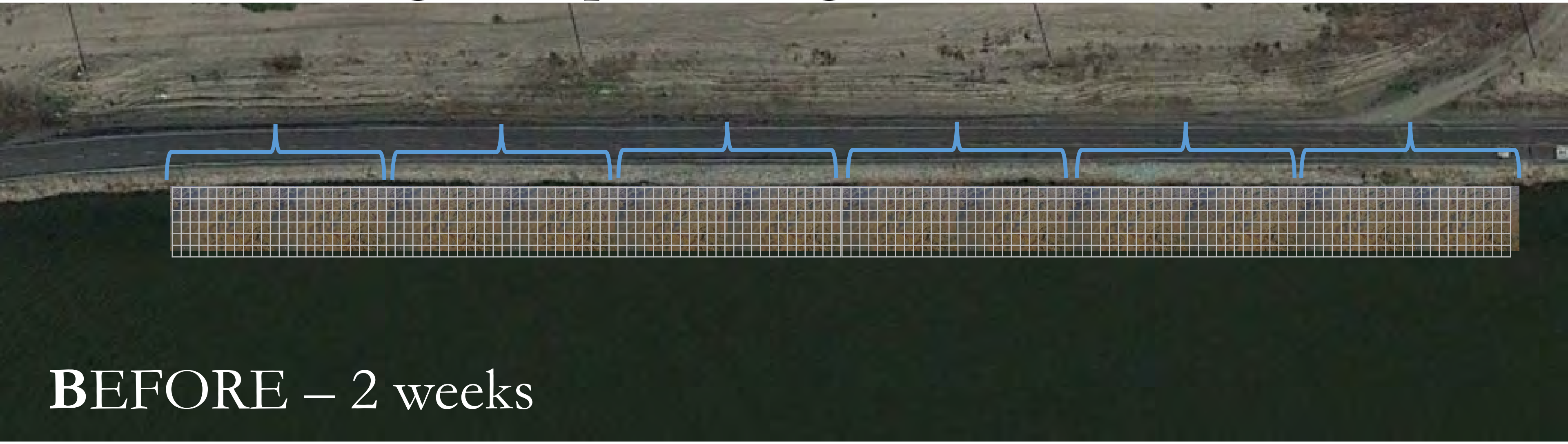
a. Sources:
1 Able et al. (2013)
2 Allouche (2002)
3 Anderson (1984)
4 Annett (1998)
5 Baras and Nindaba (1999)
6 Barwick et al. (2004)
7 Becker et al. (2013)
8 Bettoli et al. (1992)
9 Buckel and Stoner (2000)
10 Camp et al. (2012)
11 Cerri (1983)
12 Chacin and Stallings (2016)
13 de Mutsert and Cowan (2012)
14 de Mutsert et al. (2017)
15 Ferrari et al. (2014)
16 Floyd et al. (2007)
17 Gotceitas and Colgan (1987)
18 Gregory (1996)
19 Grothues et al. (2016)
20 Hansen et al. (2013)
21 Heerhartz and Toft (2015)
22 Jorgensen et al. (2013)
23 Kehayias et al. (2018)
24 Kemp et al. (2005)
25 Kinzli and Myrick (2010)
26 Kornis et al. (2017)
27 Lazzari (2013)
28 Mazur and Beauchamp (2003)
29 Mazur and Beauchamp (2006)
30 Moore et al. (2013)
31 Munsch et al. (2017)
32 Nightingale et al. (2006)
33 Ono and SimenstadSchool (2014)
34 Petersen and Gadomski (1994)
35 Riley et al. (2015)
36 Rozas and Odum (1988)
37 Sabal et al. (2016)
38 Sammons and Maceina (2006)
39 Savino and Stein (1982)
40 Savino and Stein (1989)
41 Shoup et al. (2003)
42 Southard et al. (2006)
43 Tabor (2001); Tabor et al. (2004)
44 Tabor (2011)
45 Tabor et al. (2017)
46 Tiffan et al. (2016)
47 Tsunoda and Mitsuo (2018)
48 Venter et al. (2008)
49 Vogel and Beauchamp (1999)

2022: Submerged Aquatic Vegetation study

- Perform SAV removal to measure impact of SAV on predation risk
- Redesign PERs to allow sampling within SAV beds -> **pole mounted PERs**

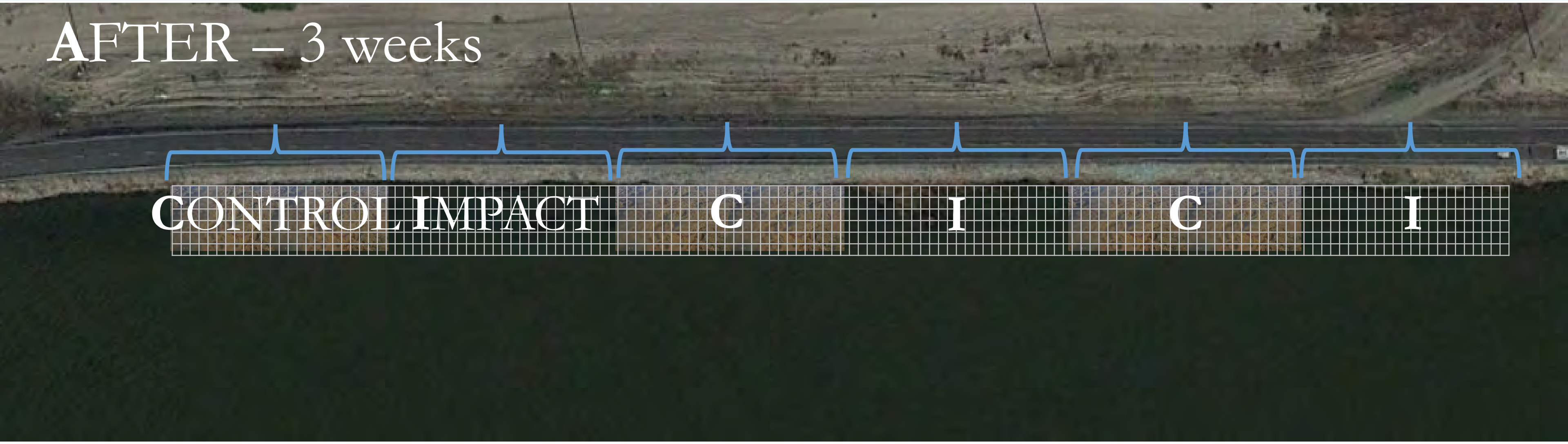


2022: Submerged Aquatic Vegetation study



Sampling methods

1. Pole PERs
2. Electrofishing



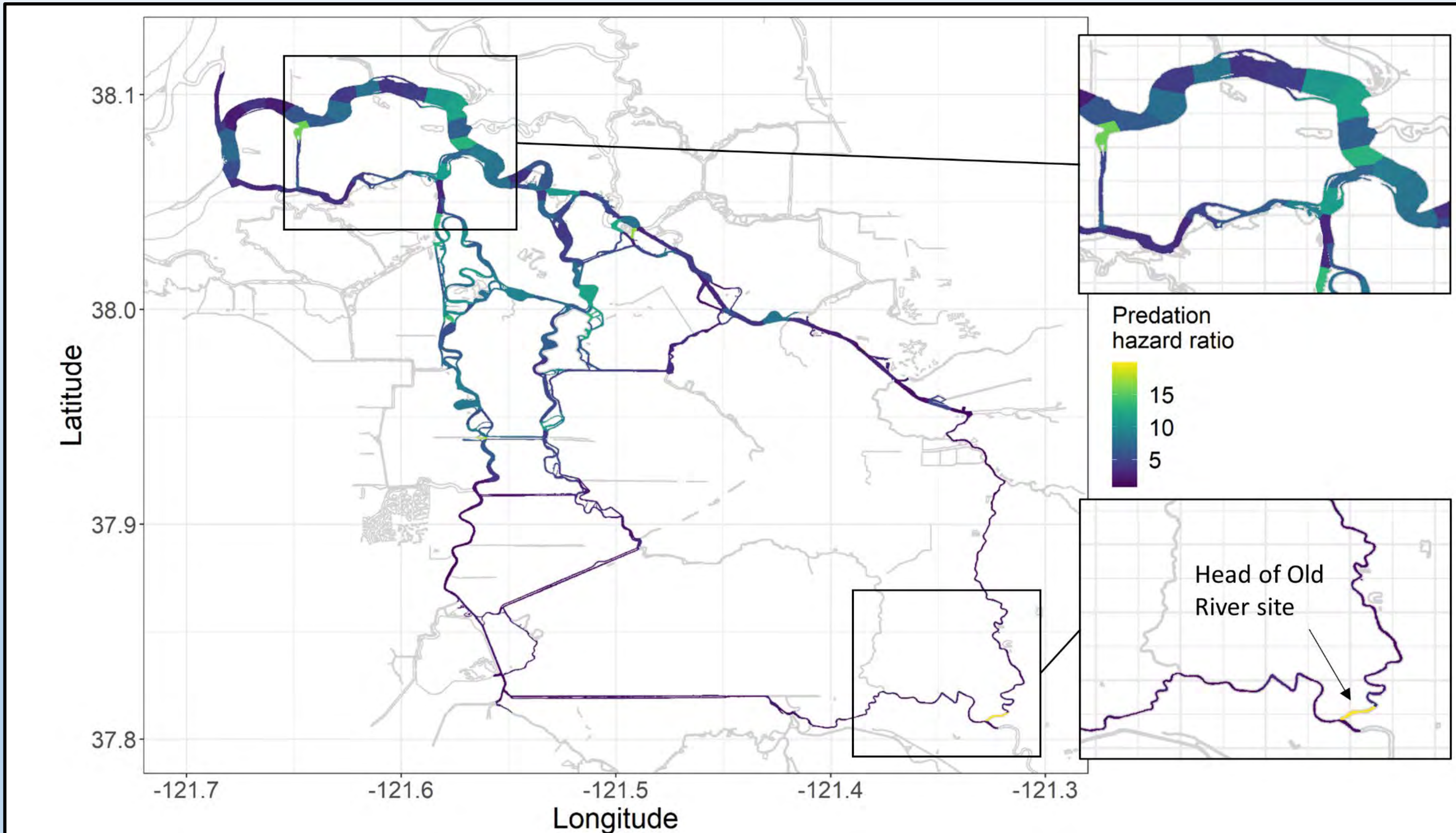
Outline

1. Landscape-scale drivers of Predation Risk
   A. South Delta Predation - 2017

2. Habitat-level drivers of Predation Risk
   A. Contact point literature review - 2018
   B. Artificial light at night (ALAN) – 2019
   C. Water diversion structures – 2021
   D. Submerged aquatic vegetation (SAV) - 2022

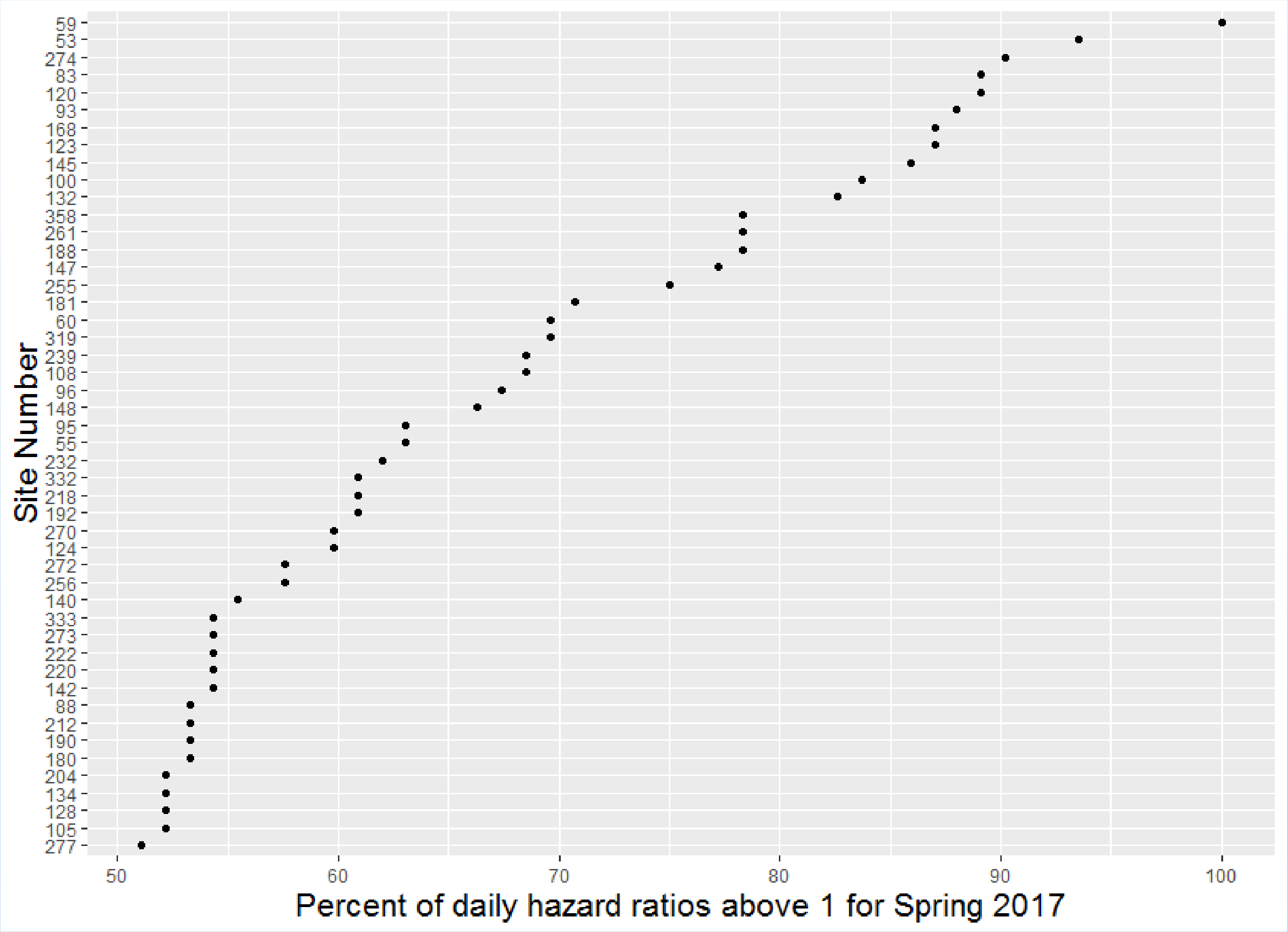
3. Management Applications
   A. Landscape-scale predation risk predictions

Explore spatial heterogeneity in predation risk



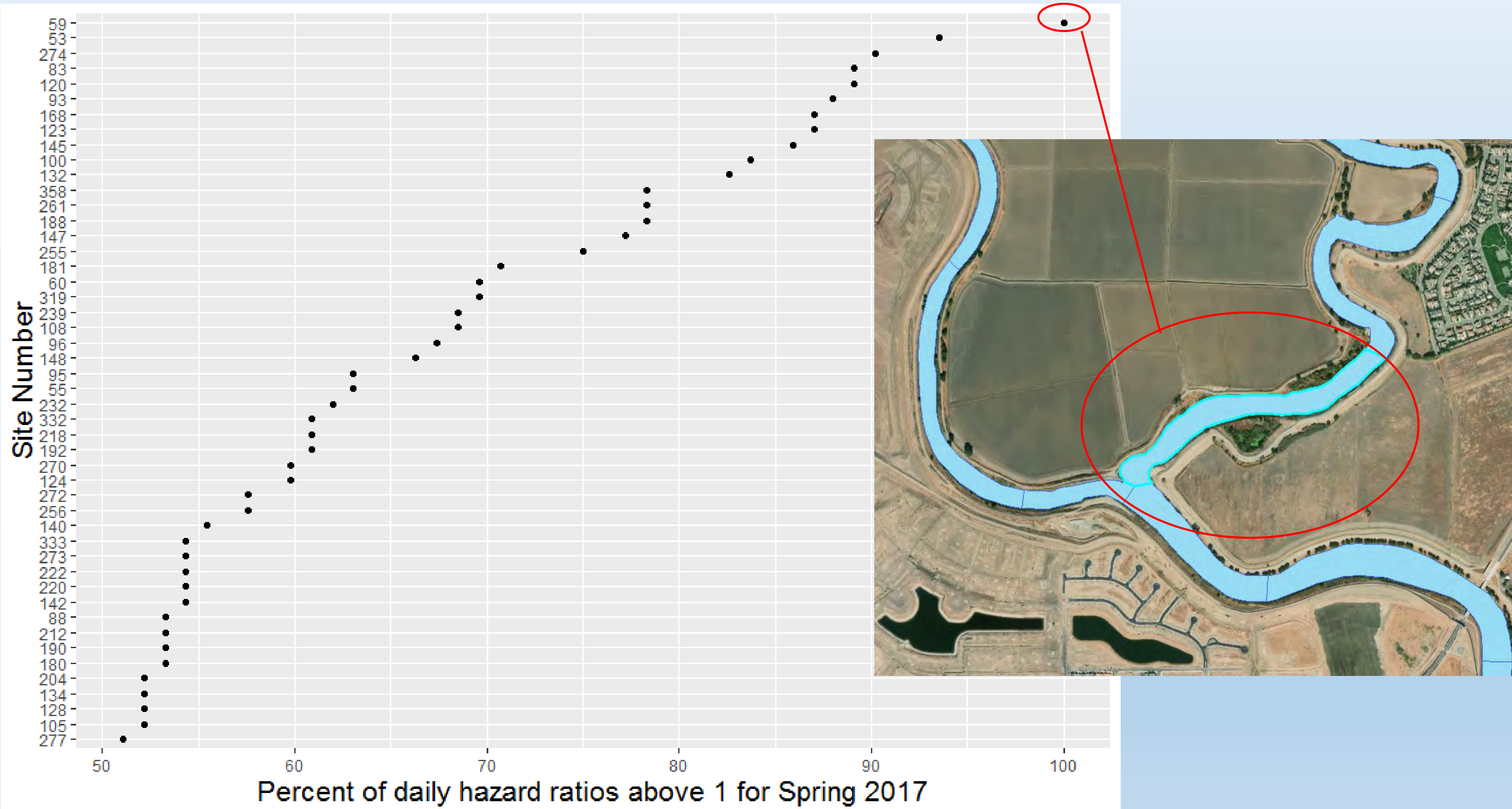
Objectively determine areas of persistently high predation risk

- Predation "hotspot" ➡ Focus mitigation efforts?

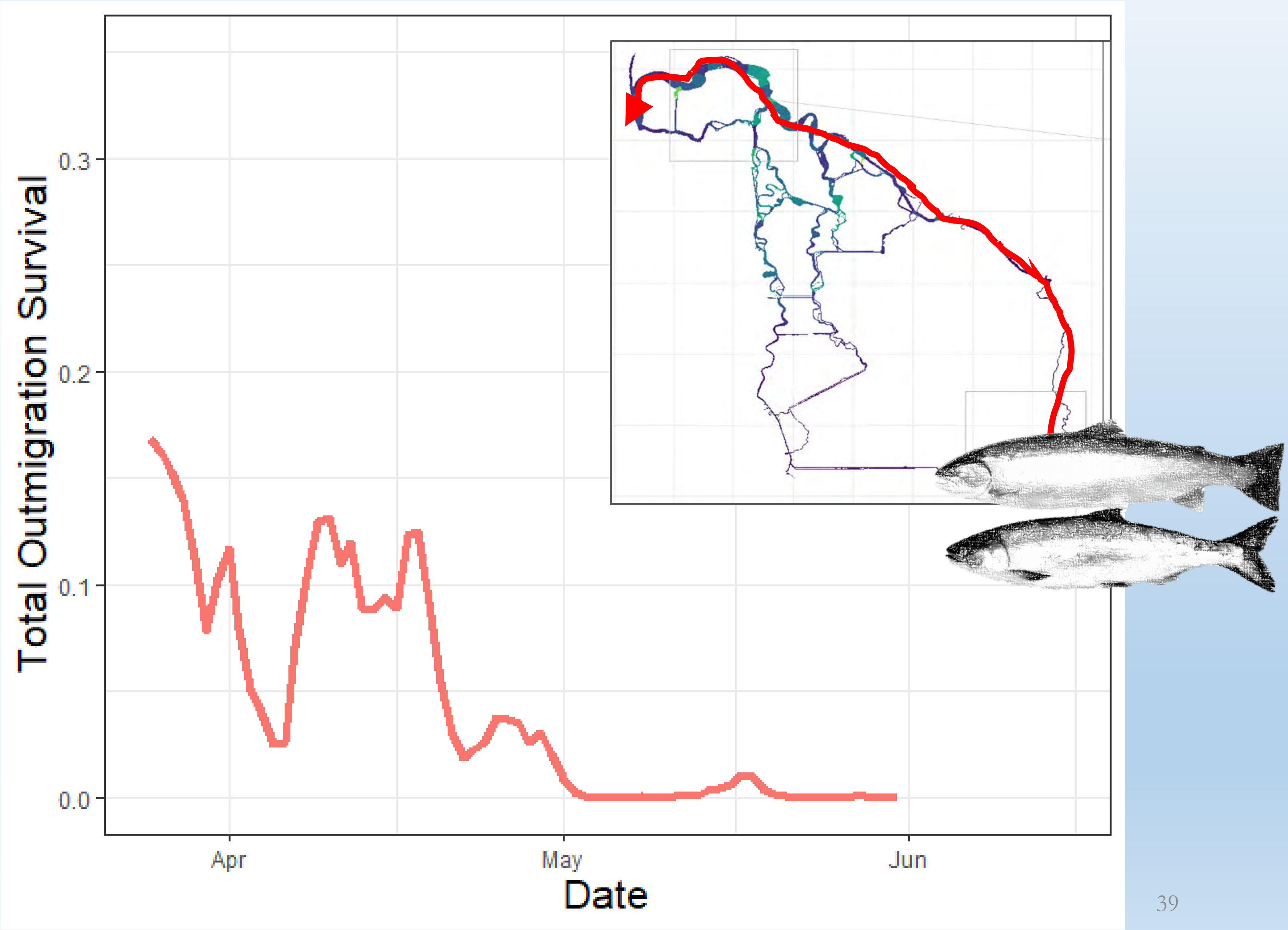


Objectively determine areas of persistently high predation risk

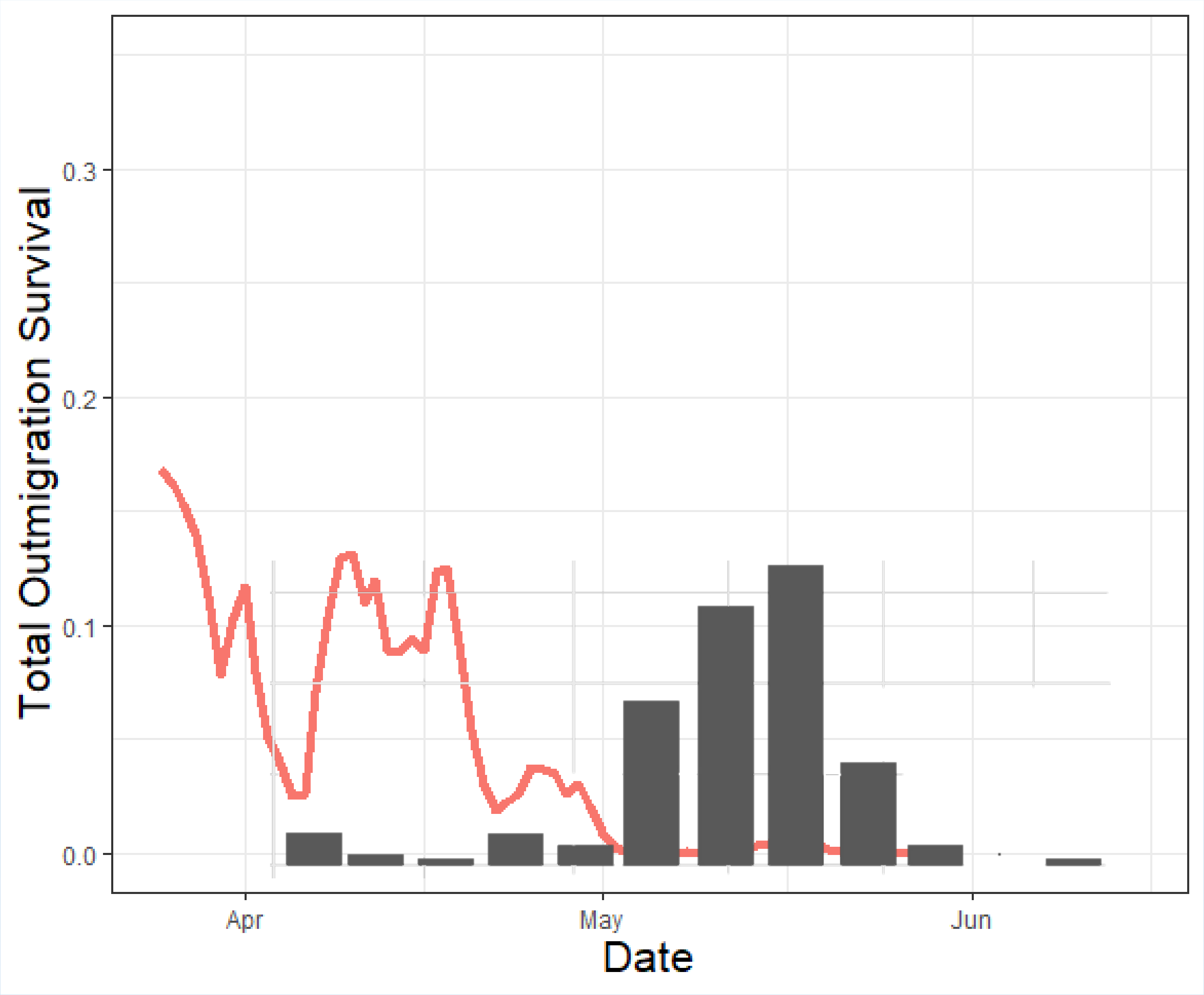
- Predation "hotspot" ➡ Focus mitigation efforts?



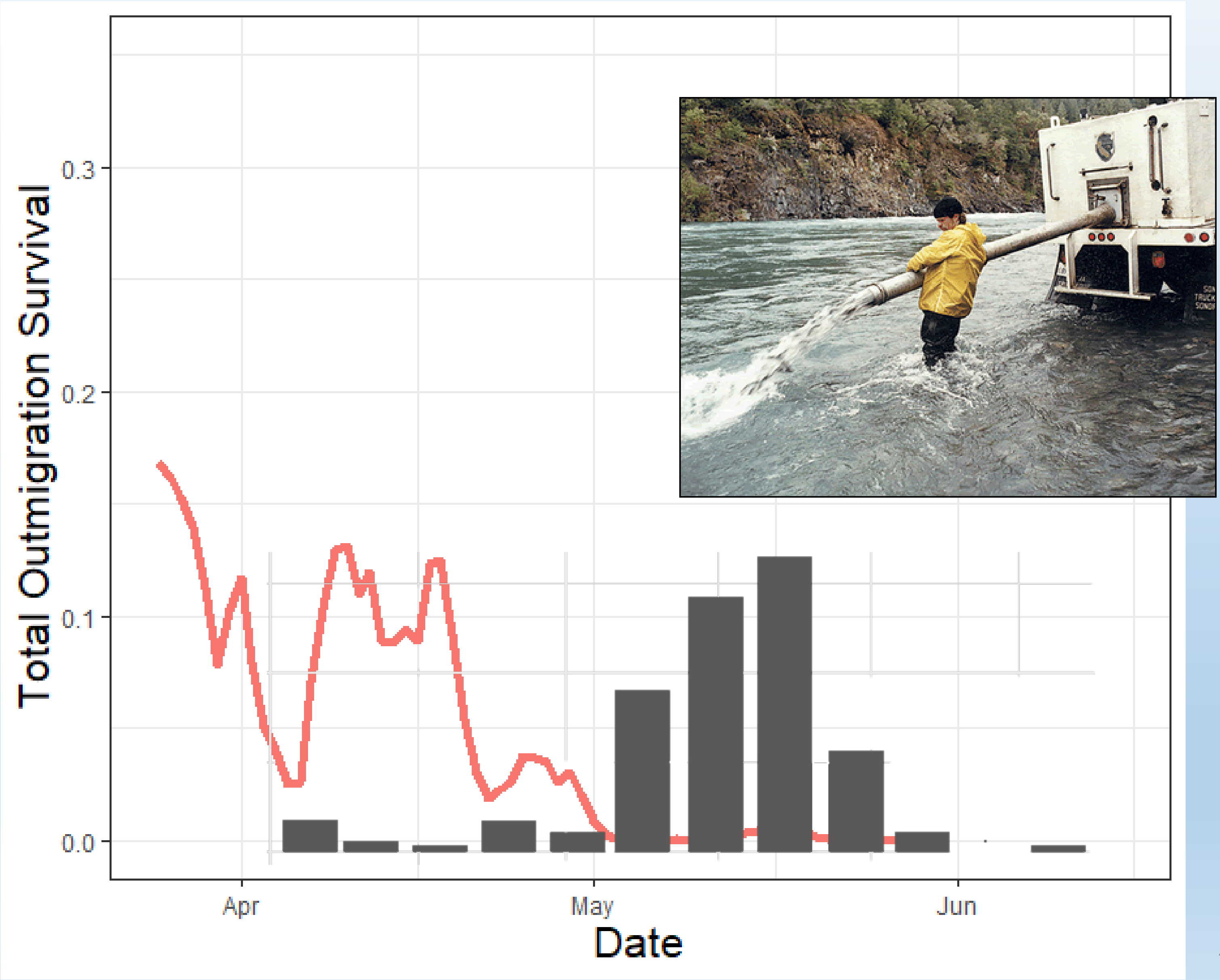
Landscape scale effects on populations



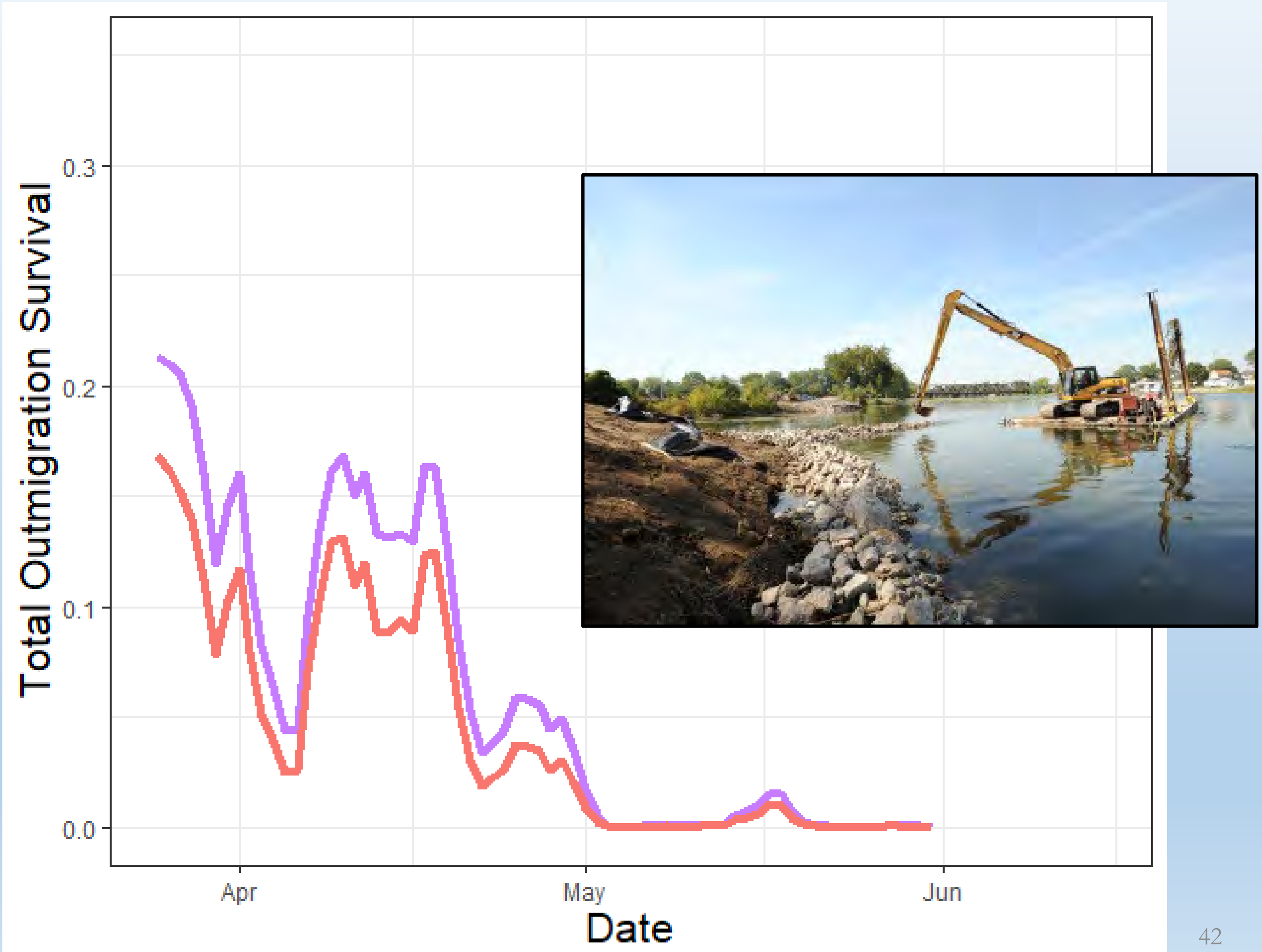
Landscape scale effects on populations



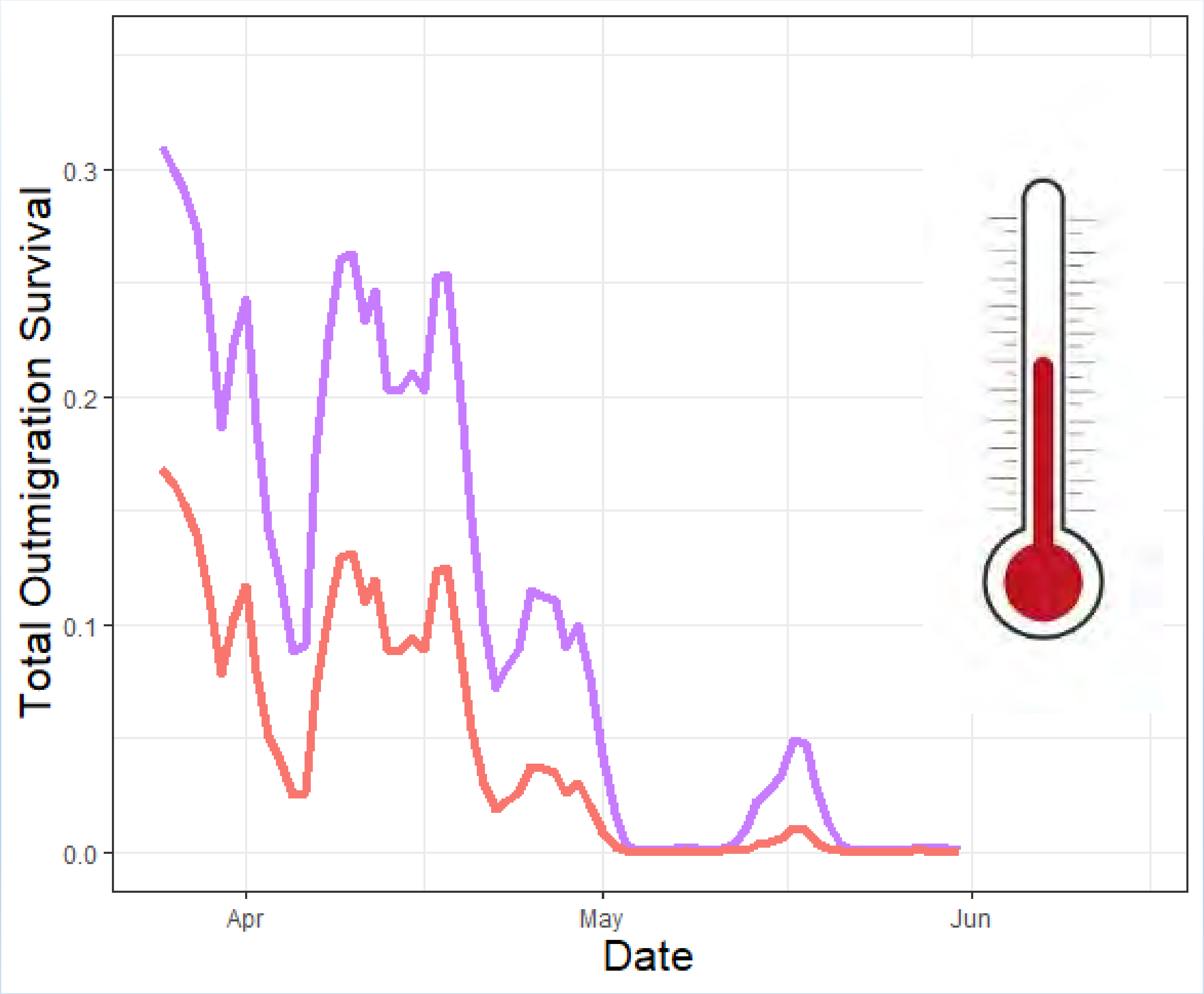
Hypothetical Management scenario #1: promote earlier migration



Hypothetical Management scenario #2: mitigate hotspot



Hypothetical Management scenario #3: manage temperature



Outline

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   D. Submerged aquatic vegetation (SAV) - 2022

3. Management Applications
   A. Landscape-scale predation risk predictions
   B. Habitat-level drivers: Artificial light at night

CVPIA Science Integration Team (SIT) Structured Decision Making Model

RESTORATION ECOLOGY
The Journal of the Society for Ecological Restoration

SER SOCIETY FOR ECOLOGICAL RESTORATION

RESEARCH ARTICLE | Open Access

Decision analysis for greater insights into the development and evaluation of Chinook salmon restoration strategies in California's Central Valley

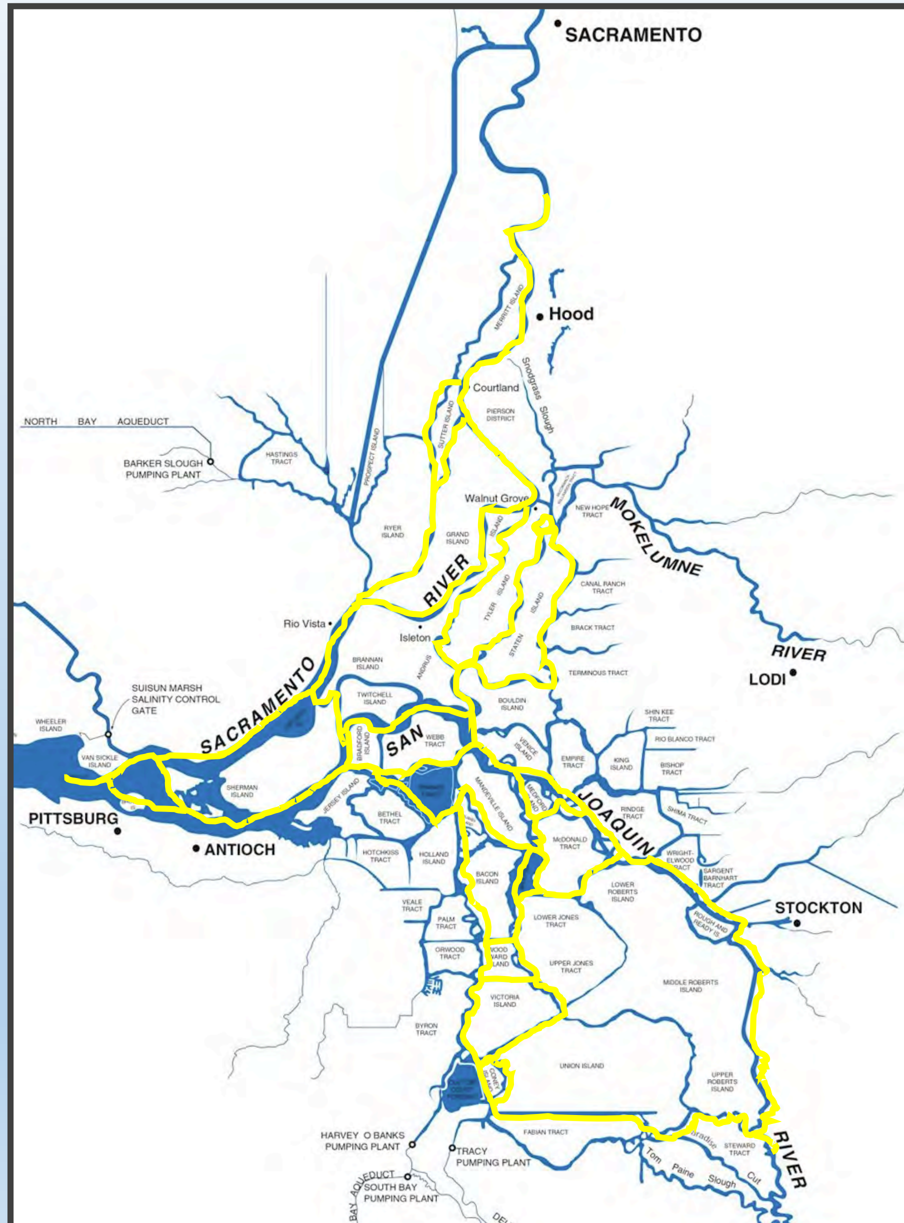
James T. Peterson, Adam Duarte

First published: 11 July 2020 | https://doi.org/10.1111/rec.13244 | Citations: 2

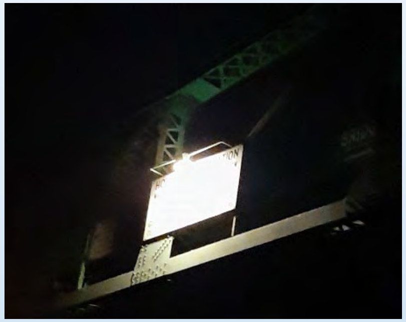
- Have already incorporated temperature impacts on predation risk as uncovered by 2017 project
- Next step will be to incorporate habitat-level drivers of predation risk
- In order to incorporate predation risk as a result of ALAN, we must first calculate overall extent of ALAN

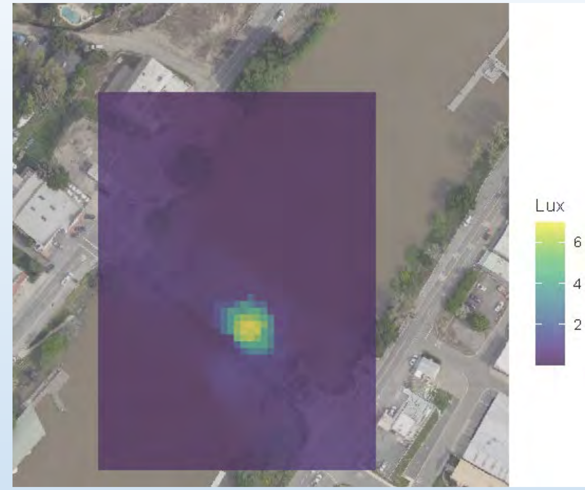
Delta illumination survey

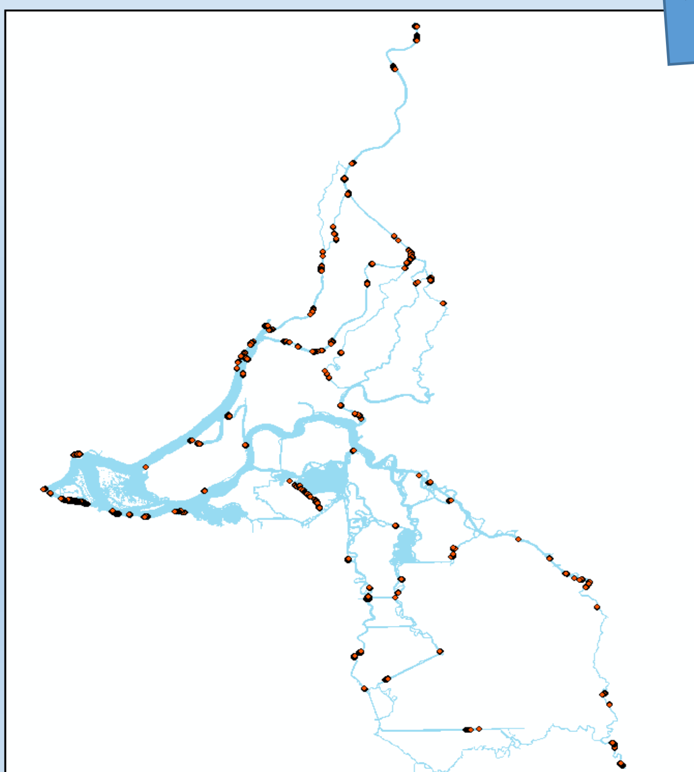
- Oct-Dec 2021

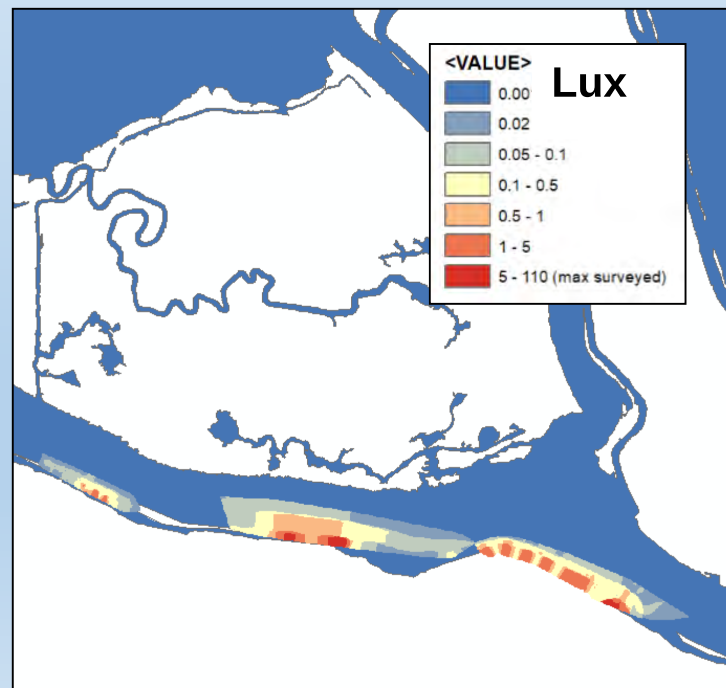


Delta illumination survey









Next steps

- Complete analysis from 2021 Diversion project
- Complete data collection and analysis from 2022 Submerged Aquatic Vegetation project
- Incorporate findings from artificial light, diversion, and aquatic vegetation studies into the CVPIA Science Integration Team SDM

Contact Info

Cyril.Michel@noaa.gov

Acknowledgements

- Funding support: CaDFW through 2014 Predation PSP, CVPIA/BOR
- Logistical support: NMFS-SWFSC Santa Cruz

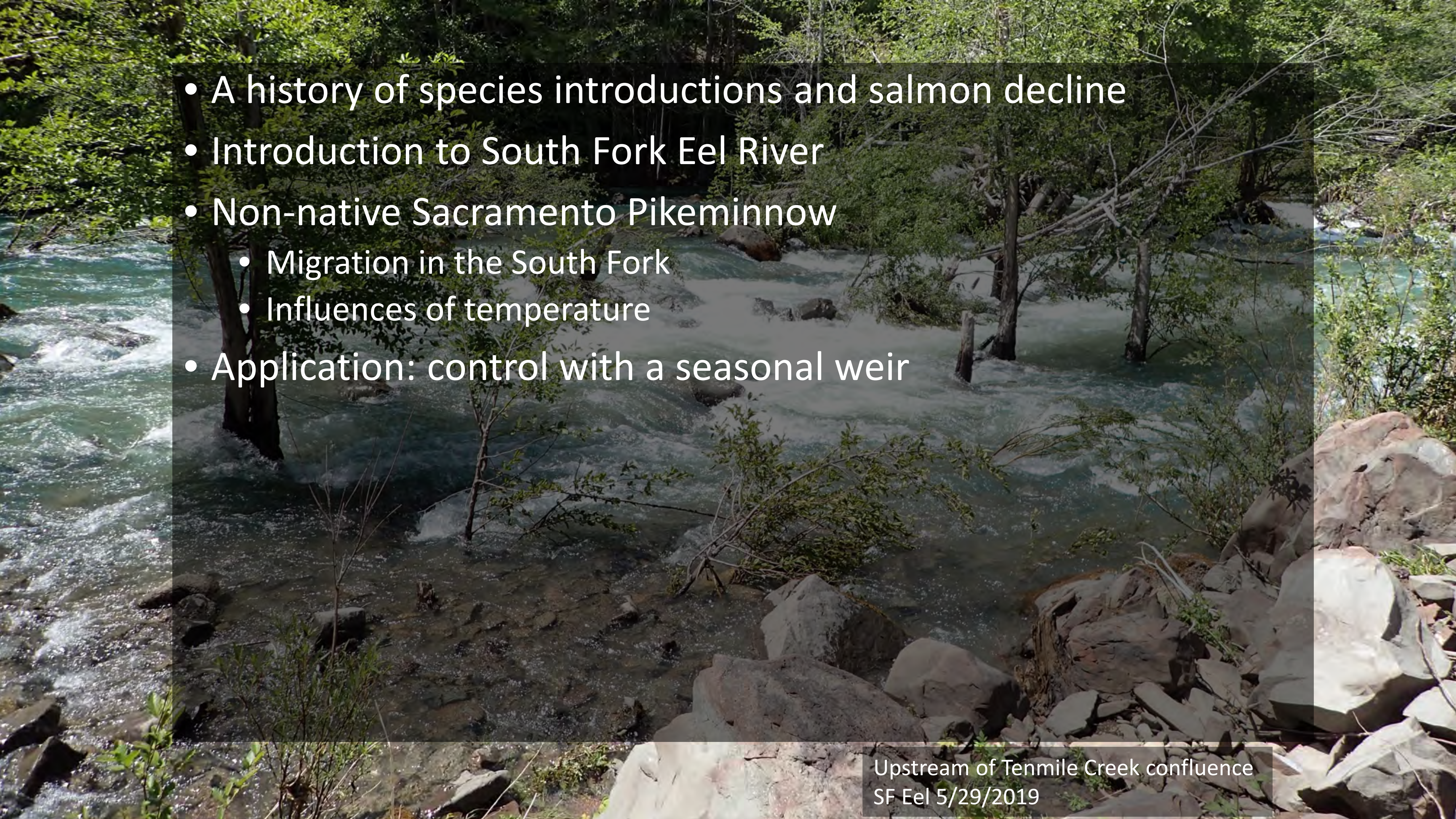
Spring temperature predicts timing of seasonal upstream migration of invasive Sacramento pikeminnow (*Ptychocheilus grandis*) in the South Fork Eel River

Salmon Restoration Federation
4-22-2022

Phil Georgakakos, David Dralle, Mary Power


Upstream of Tenmile Creek confluence
SF Eel 5/29/2019

- A history of species introductions and salmon decline
- Introduction to South Fork Eel River
- Non-native Sacramento Pikeminnow
  - Migration in the South Fork
  - Influences of temperature
- Application: control with a seasonal weir



Upstream of Tenmile Creek confluence
SF Eel 5/29/2019

History of freshwater fish introductions in California

- California has 67ish species of native freshwater and anadromous fishes
- As of 2002, 51 non-native species have established and 31 are piscivorous (Moyle 2002).
- 1st American Shad in 1871
  - Brook Trout, Brown Trout, Striped Bass, Largemouth Bass, Smallmouth Bass in the following decade

Photo of The Badger II: Mid-Continent Railway Gazette Volume. 2006. 39 : 4

Eel river and salmon decline

Early twentieth-century commercial seining operation on the Eel River near Rio Dell.

Lufkin, Alan, editor. 1991. *California's Salmon and Steelhead: The Struggle to Restore an Imperiled Resource.* Berkeley: University of California Press

- Historically returns of up to 1 million pacific salmonids (Genus *Oncorhynchus)* (Yoshiyama and Moyle 2010)
- Supported a cannery near the mouth
- Potentially 7 species
- Severe declines resulting from a combination of habitat degradation, channel widening and warming, overfishing, species introductions
- Currently 3 species occur regularly in the South Fork Eel
    - Coho *(O. kisutch),* Chinook *(O. tshawytscha),* and Steelhead *(O. mykiss)*

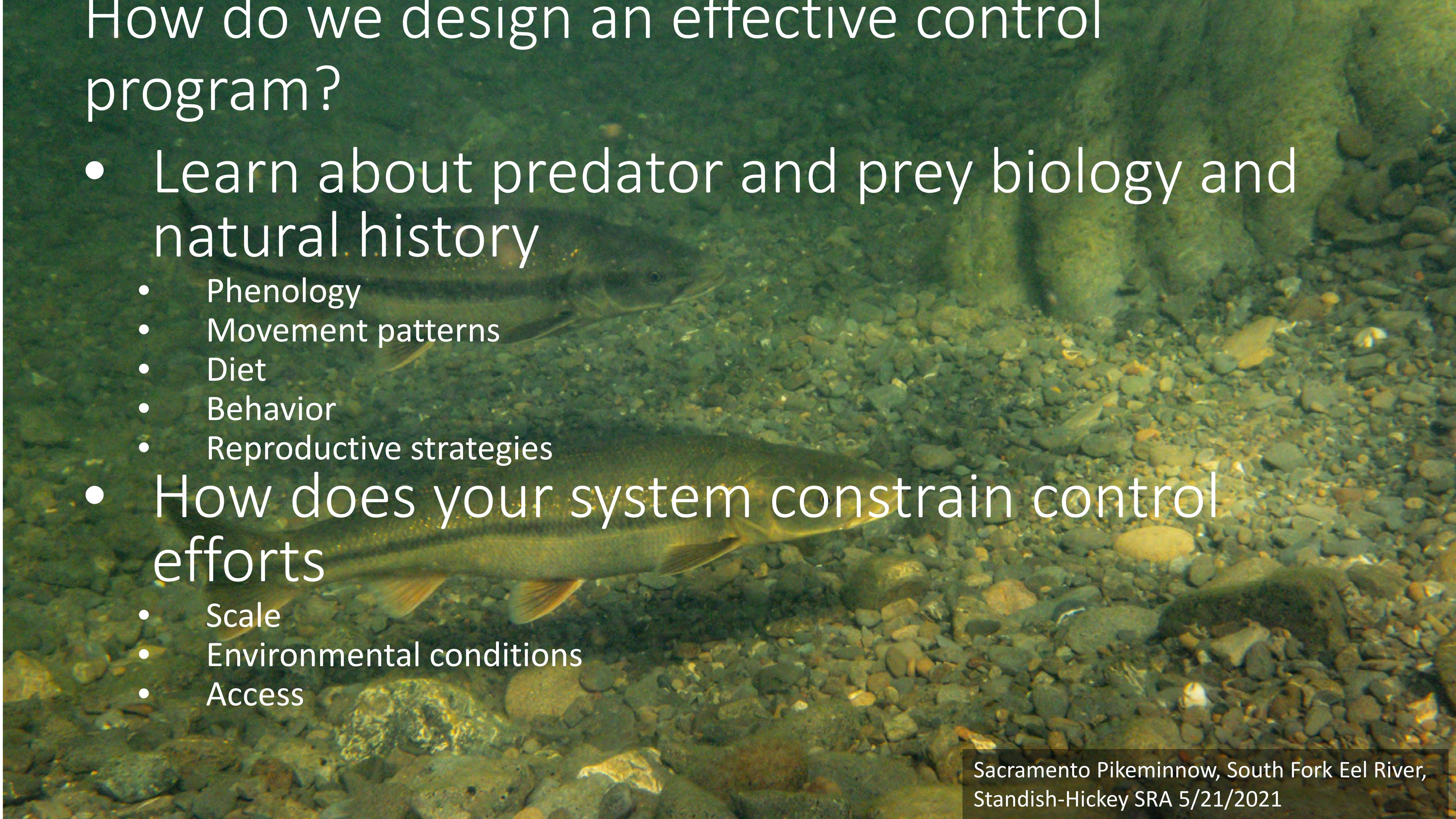
- SFER identified as a stronghold for Coho, but returns are well below historic numbers (Wild Salmon Center 2012)
- Pikeminnow one of the major hurdles to salmonid recovery is introduced non-native pikeminnow 2021 South Fork Eel River headwaters Salmon Habitat Restoration Priorities (SHARP)

How do we design an effective control program?

Sacramento Pikeminnow, South Fork Eel River, Standish-Hickey SRA 5/21/2021

How do we design an effective control program?

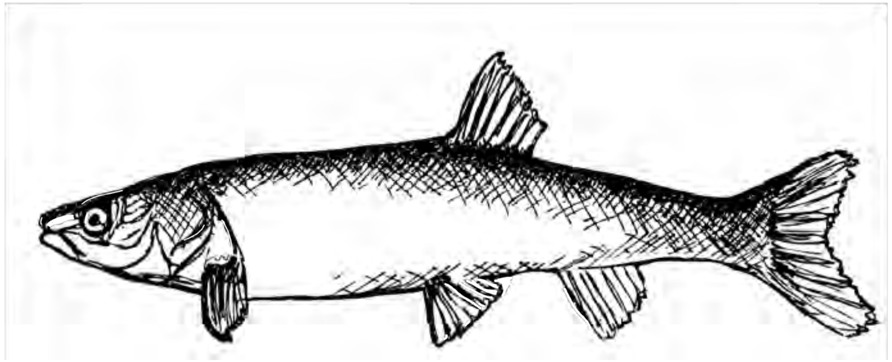
- Learn about predator and prey biology and natural history
  - Phenology
  - Movement patterns
  - Diet
  - Behavior
  - Reproductive strategies
- How does your system constrain control efforts
  - Scale
  - Environmental conditions
  - Access



Sacramento Pikeminnow, South Fork Eel River, Standish-Hickey SRA 5/21/2021

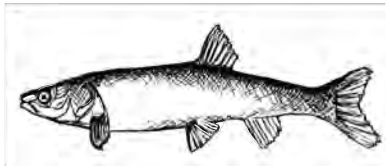
What is a pikeminnow?

- Genus *Ptychocheilus* contains 4 species and are the largest native cyprinids in North America
- Long-lived
- Can grow over 1m in length
- School in large pools in the summer
- Piscivorous as adults
- Spawn in tributaries in the spring
- Highly fecund
- Warm-adapted compared to native fishes
- Extremely Mobile (Harvey and Nakamoto 1999, Valentine et al. 2020)
- Sacramento Pikeminnow introduced into the Eel around 1979 from Clear Lake population

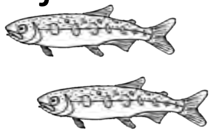


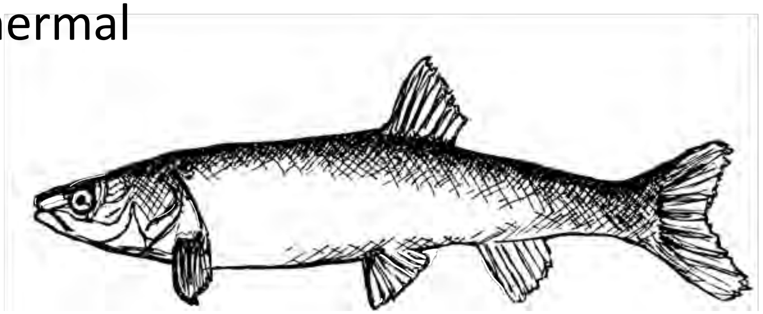
How to pikeminnow impact salmon?

- Compete with size-matched salmonids and are more effective competitors at higher temperatures (Reese and Harvey 2002)



- Consume native all SFER fishes at some life stage (Nakamoto and Harvey 2003).
- Prey on fish approximately 1/3 their length (Nakamoto and Harvey 2003).
- More impactful predators at higher temps (Vondracek 1987).
- Change potential prey’s microhabitat use (Brown and Moyle 1991; Brown and Brasher 1995)
  - Limit access to key habitats like stratified deep pools which act as the thermal refugia during summer (Nielson 1994)
  - Reduce foraging opportunities and thus growth potential for juvenile salmonids in mainstems





Historic Food Web

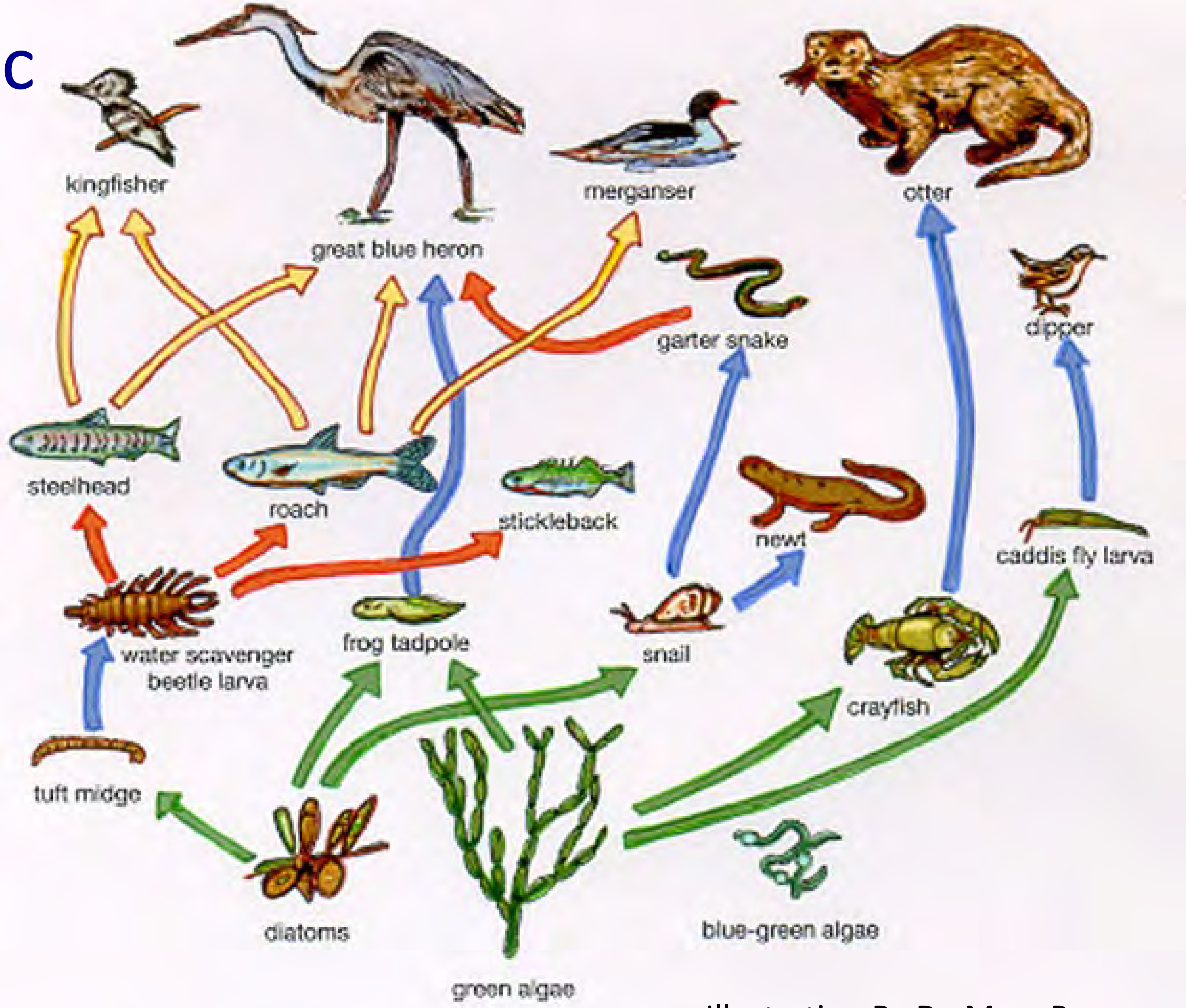


Illustration By Dr. Mary Power

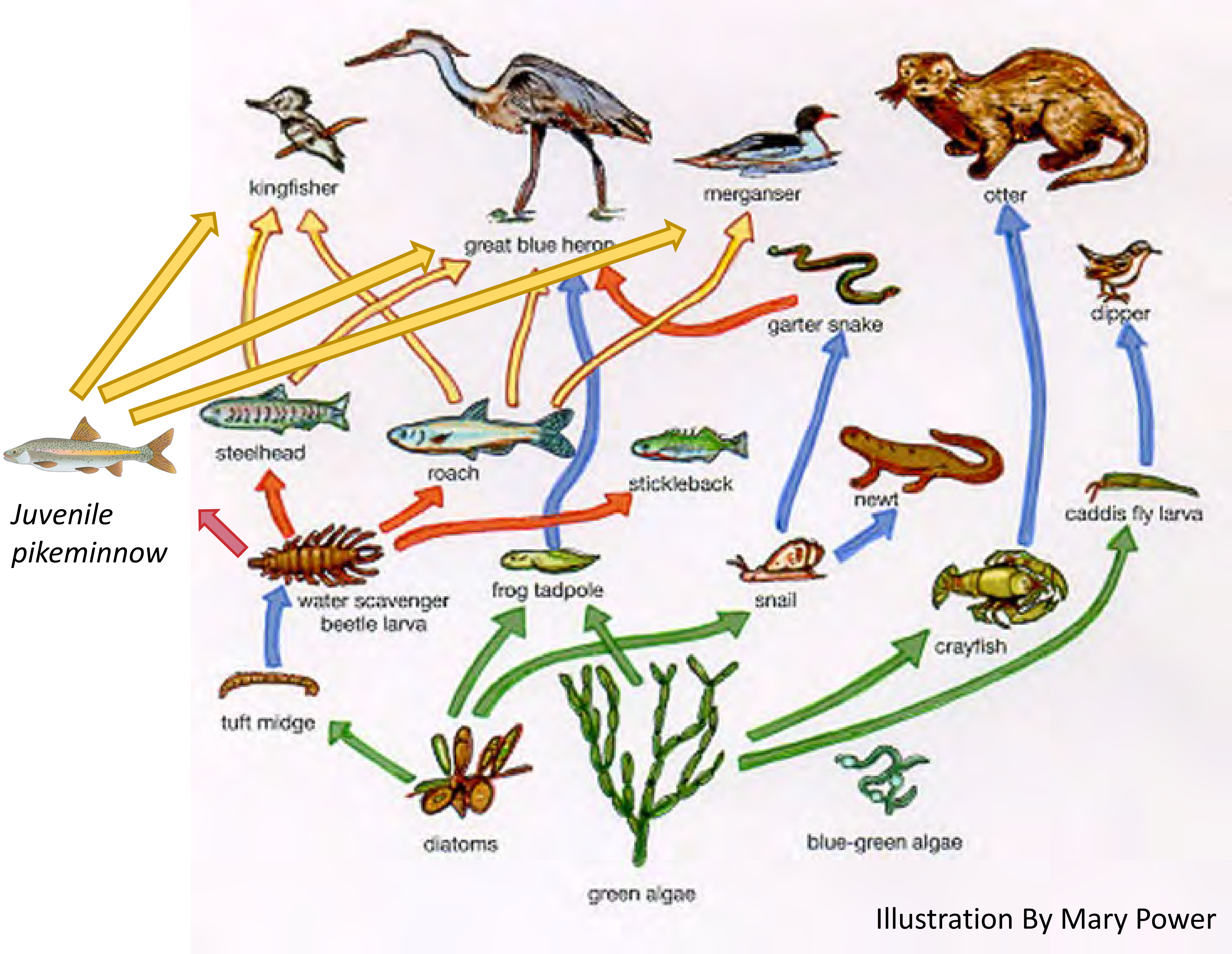


Illustration By Mary Power

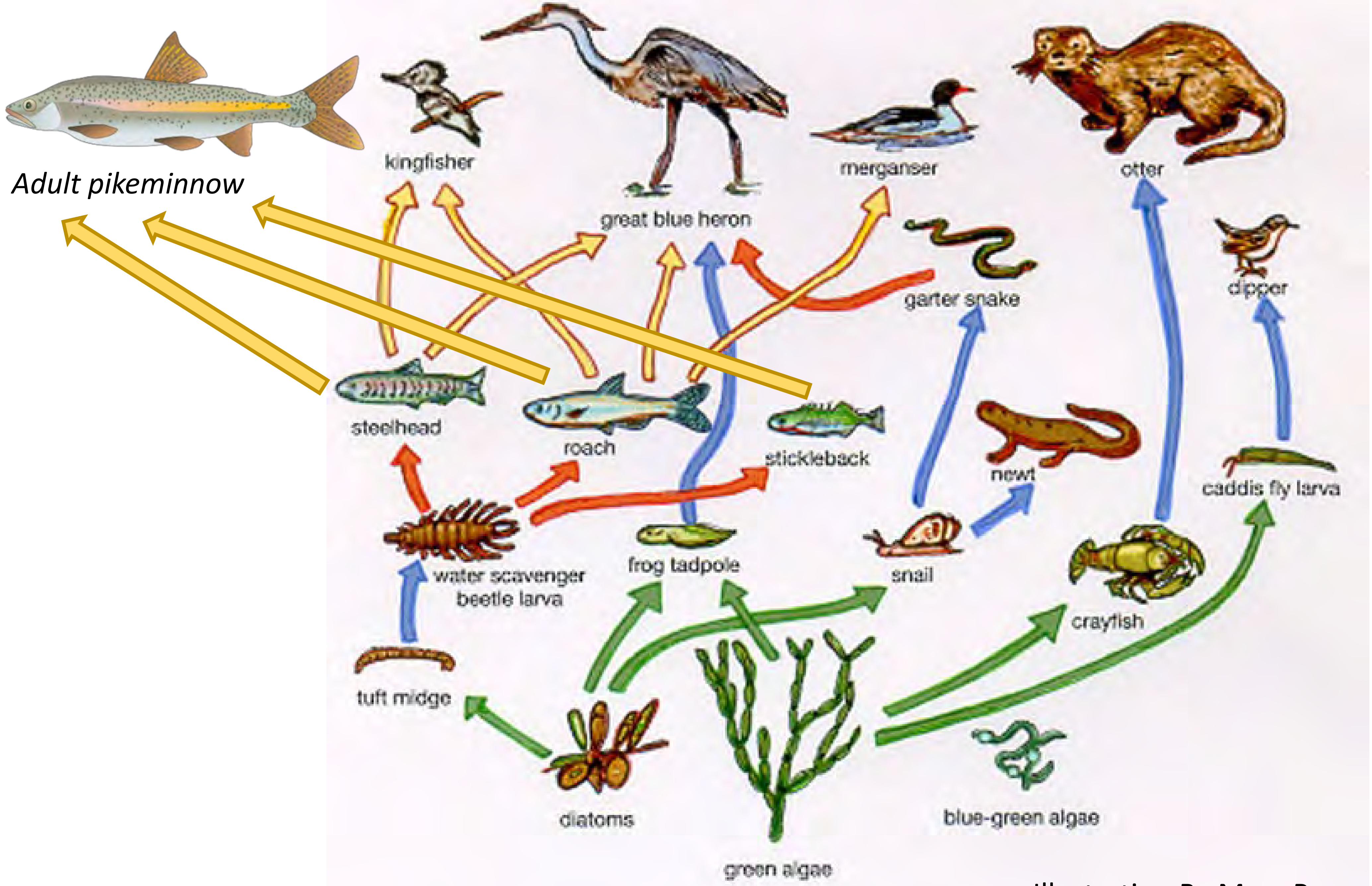


Illustration By Mary Power

Hunter's Pool, South Fork Eel, September 9, 2020

Merganser, South Fork Eel,
July 4, 2020

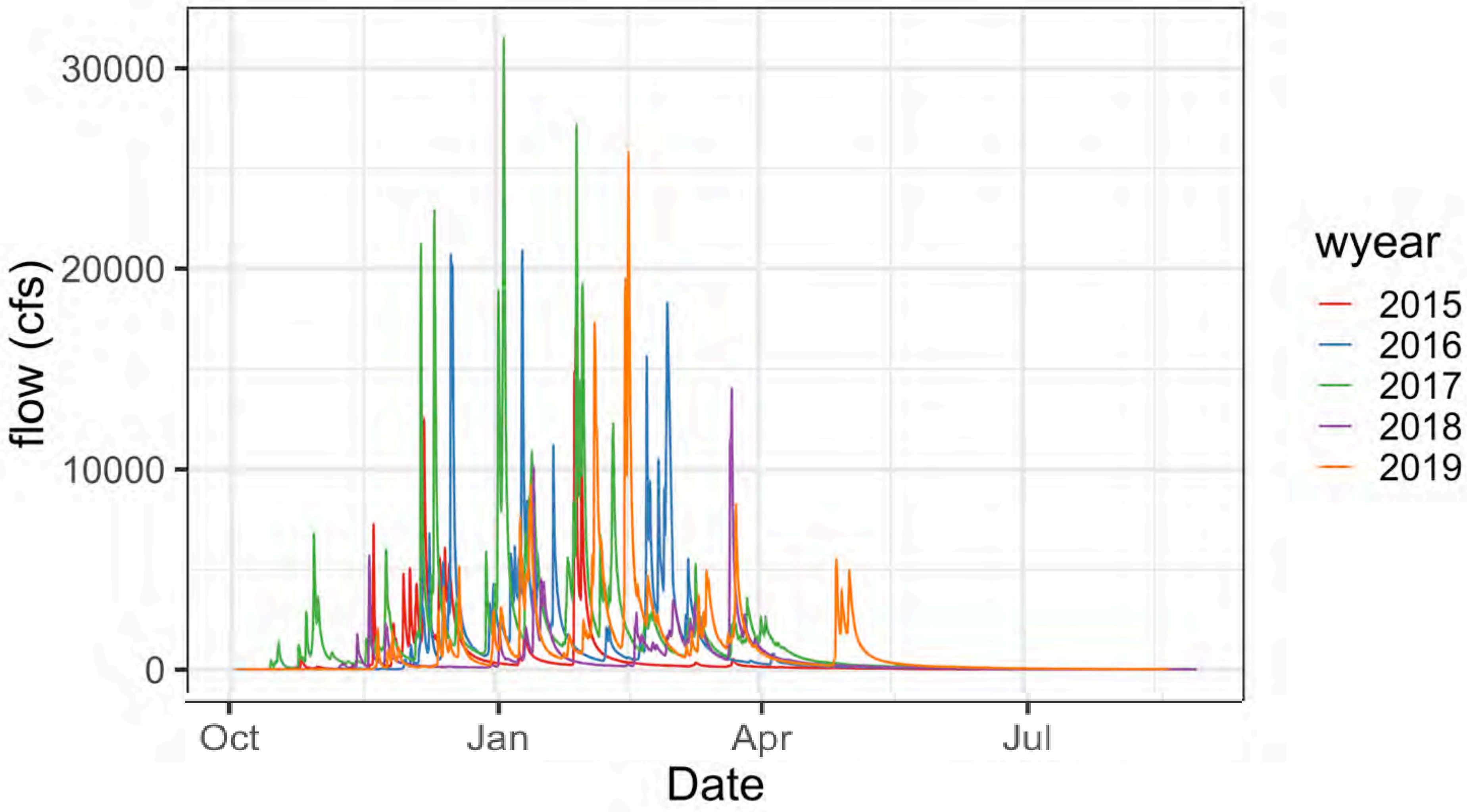
Alex Carey wades through *Cladophora*
Near the Environmental Science Center
SF Eel June 29, 2019

Coast Range Roach and *Podomageton*
SF Eel July 05, 2020

Steelhead and one Chinook parr,
Downstream of Tenmile Creek Confluence
SF Eel June 14, 2016

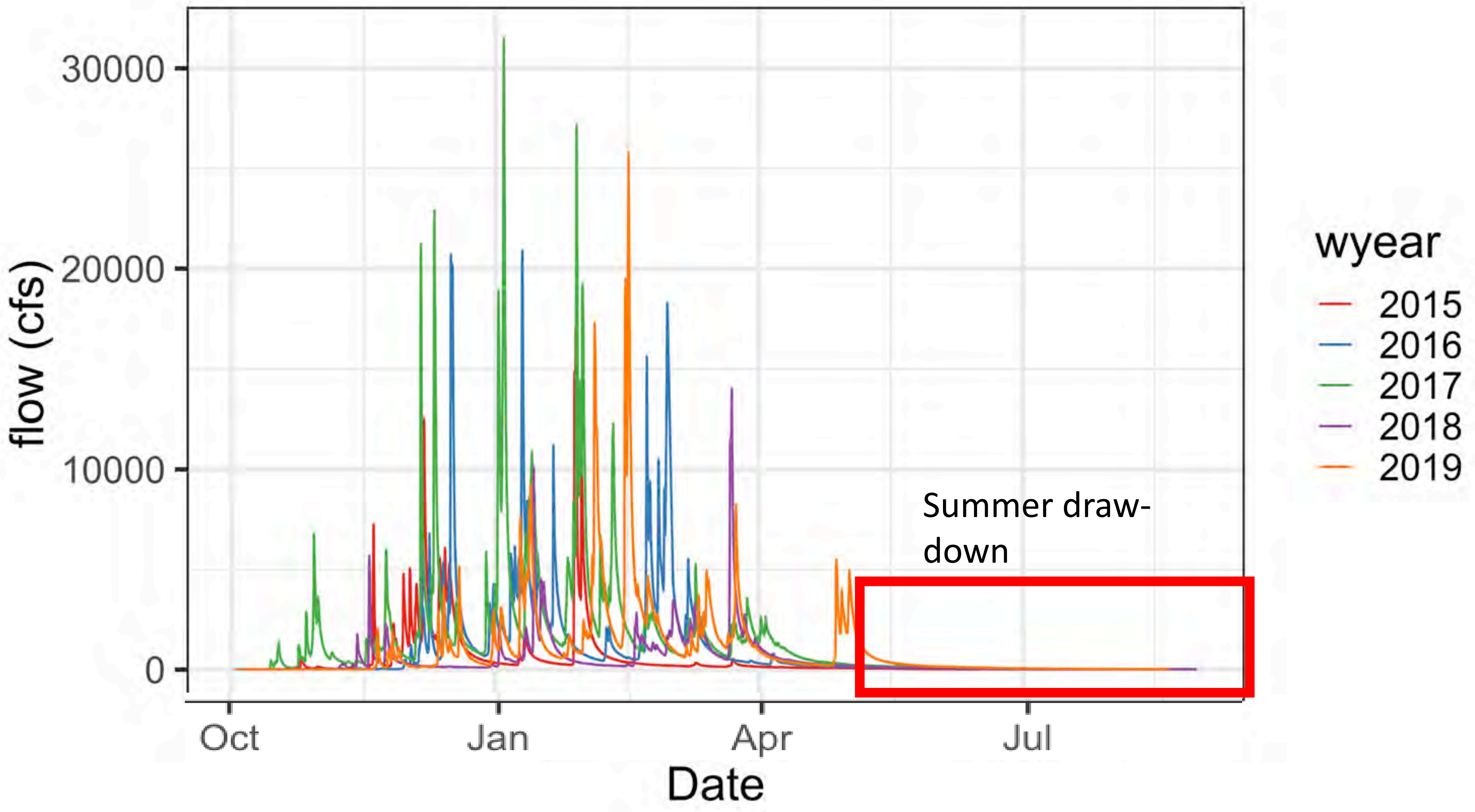

Sacramento Pikeminnow hunting smolts at a pool inflow
Standish-Hickey SRA, SF Eel May 15, 2021

South Fork Eel River: a Mediterranean Stream



USGS stream gauge 11475800. Legget, CA

South Fork Eel River: a Mediterranean Stream



USGS stream gauge 11475800. Legget, CA

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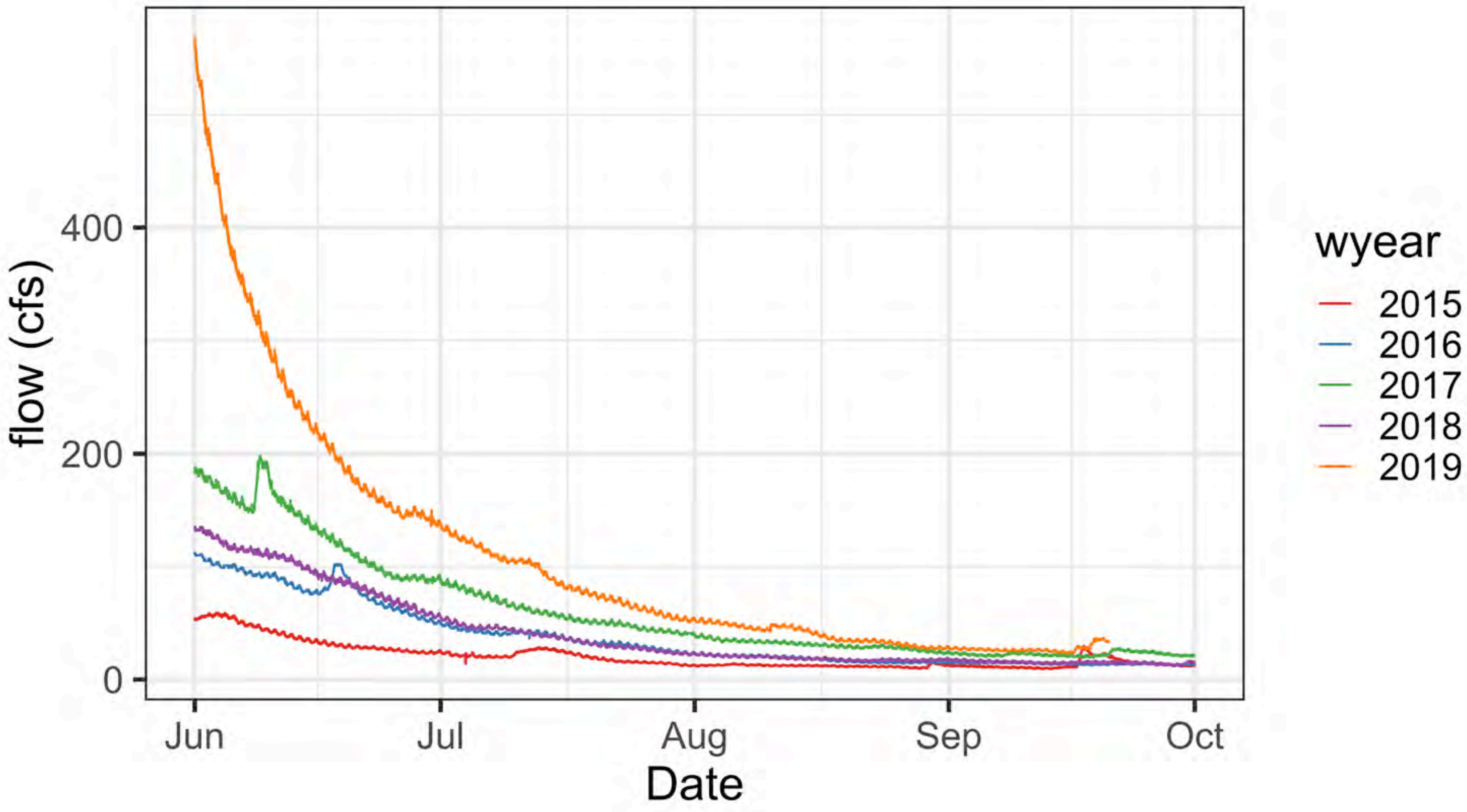
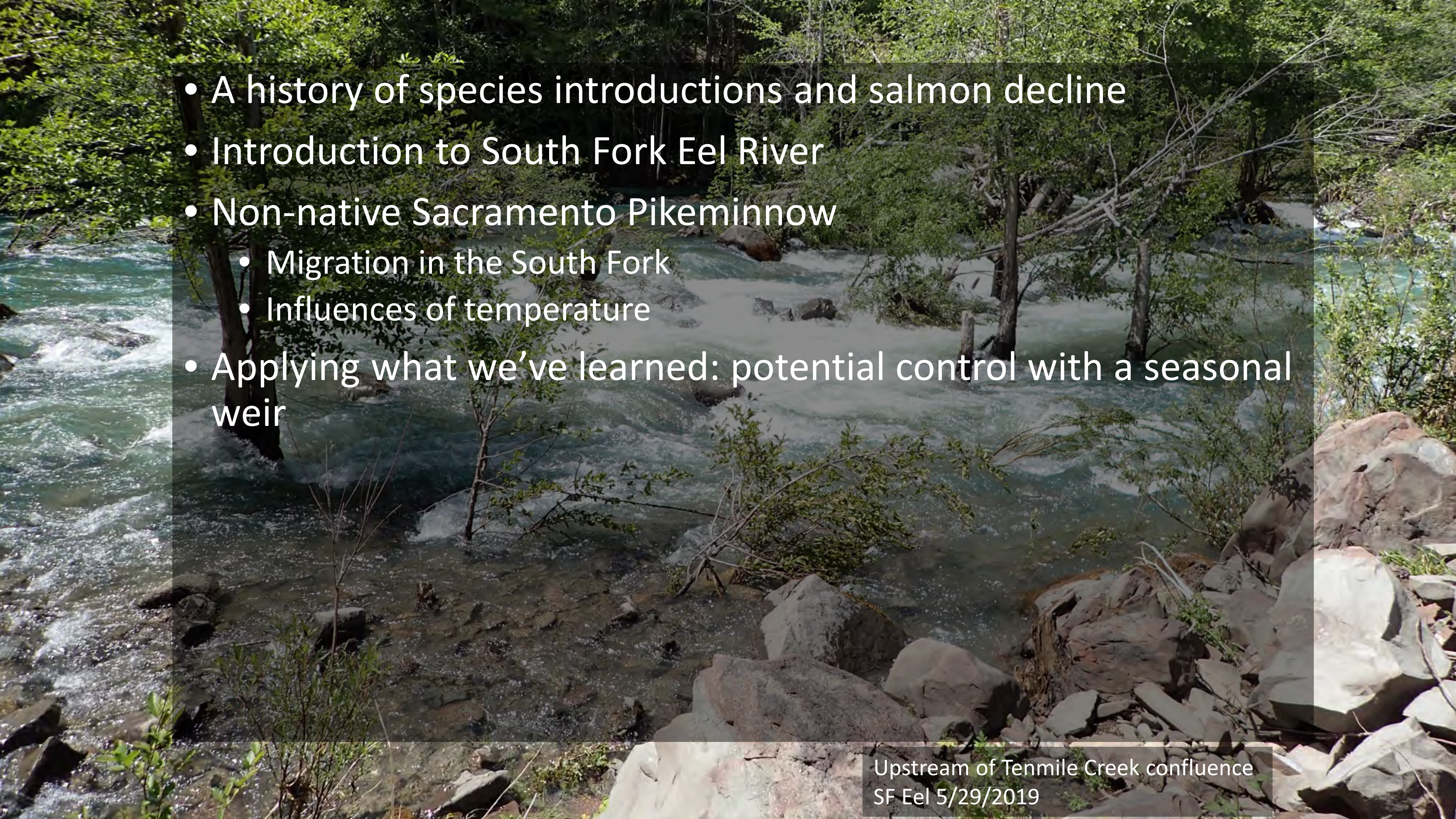


USGS stream gauge 11475800. Legget, CA

- A history of species introductions and salmon decline
- Introduction to South Fork Eel River
- Non-native Sacramento Pikeminnow
  - Migration in the South Fork
  - Influences of temperature
- Applying what we've learned: potential control with a seasonal weir

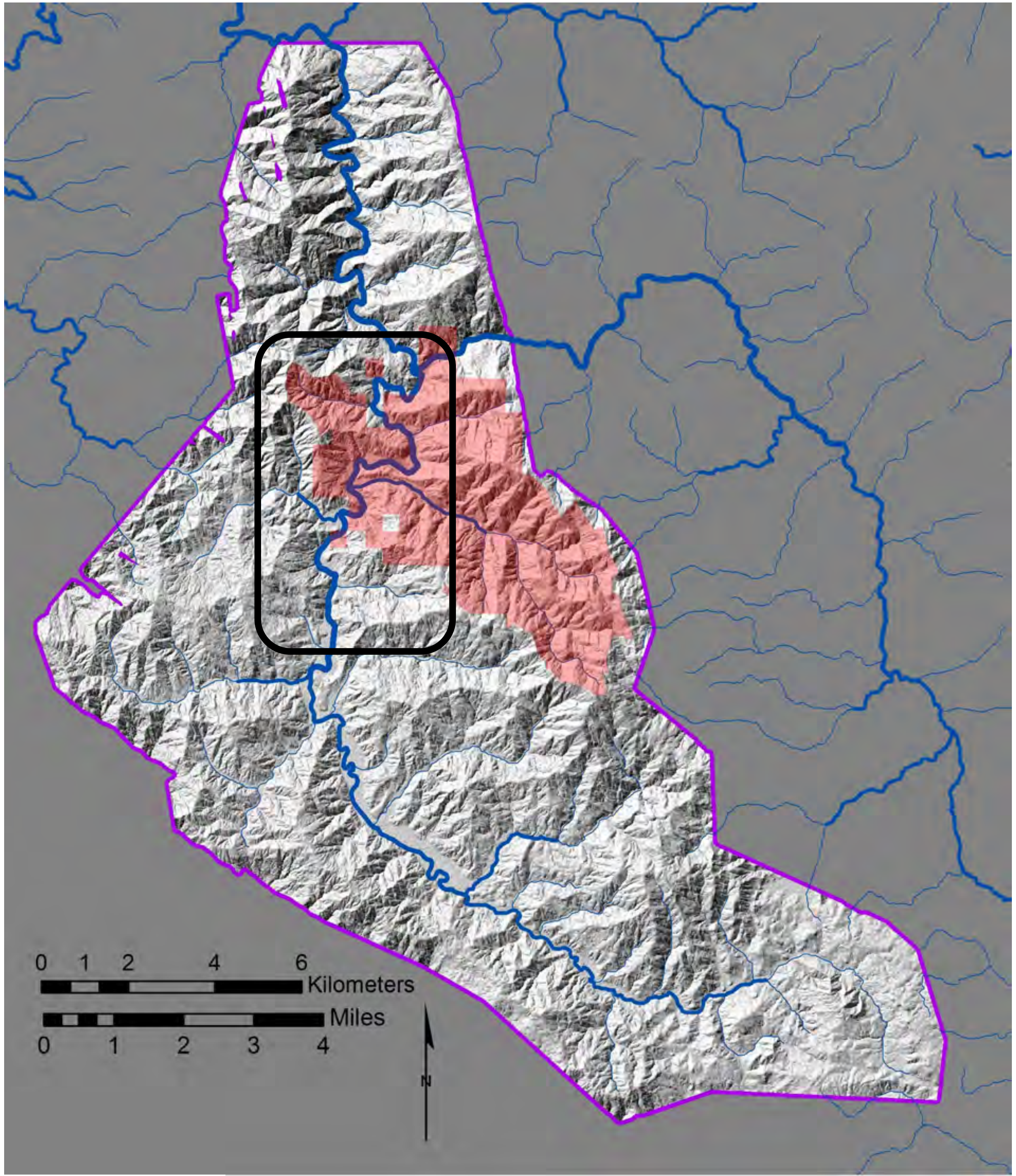


Upstream of Tenmile Creek confluence
SF Eel 5/29/2019

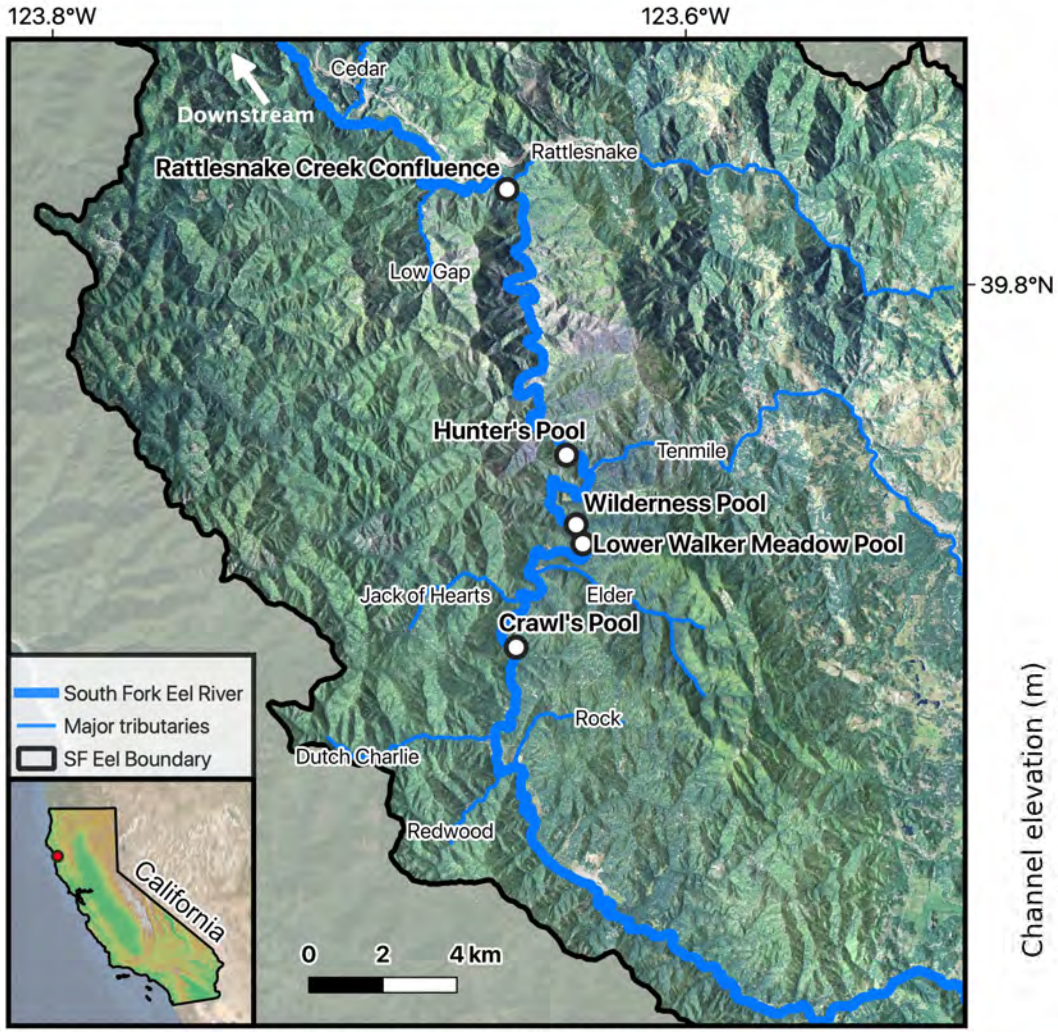
Angelo Coast Range Reserve

Snorkel Reach
Angelo Reserve
Lidar Boundary

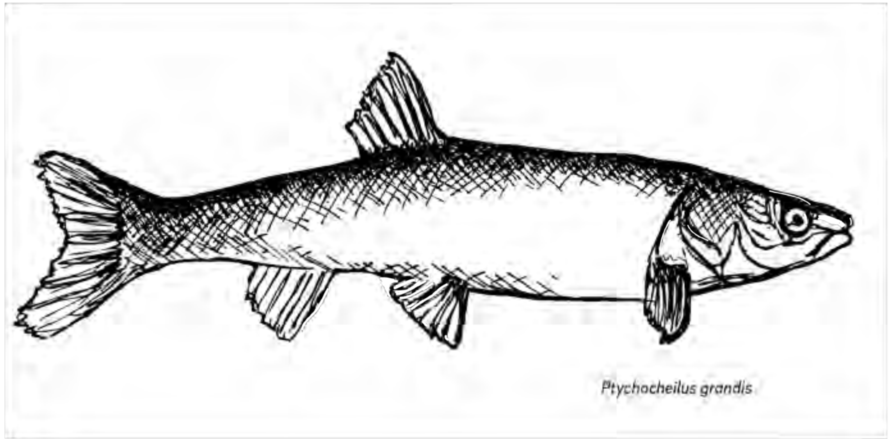
Data Sources: USGS and Lidar
Coordinate System: NAD 1983
UTM zone 10
Transverse Mercator

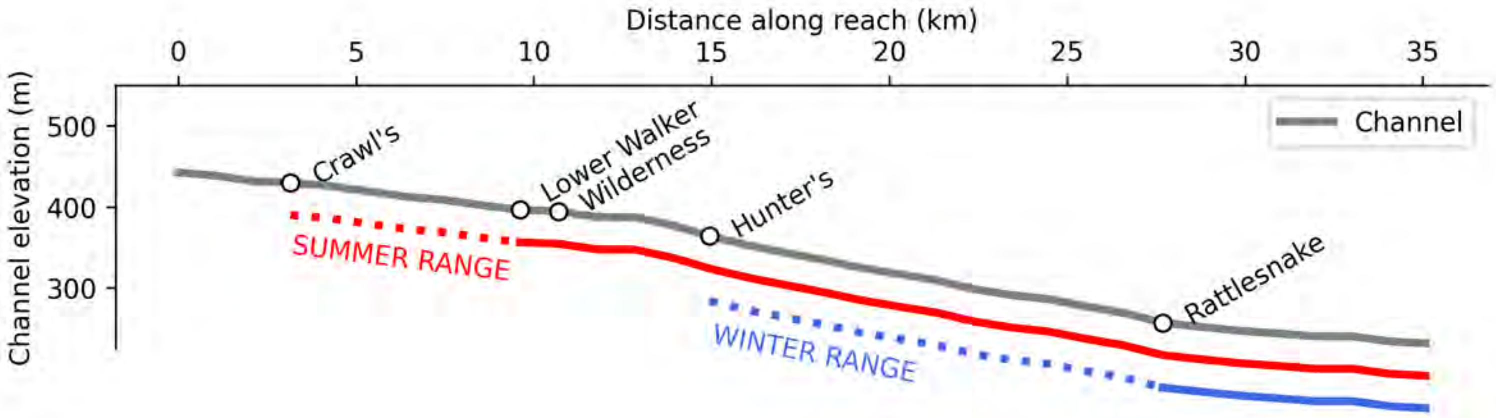


Pikeminnow Migrate in the Upper South Fork



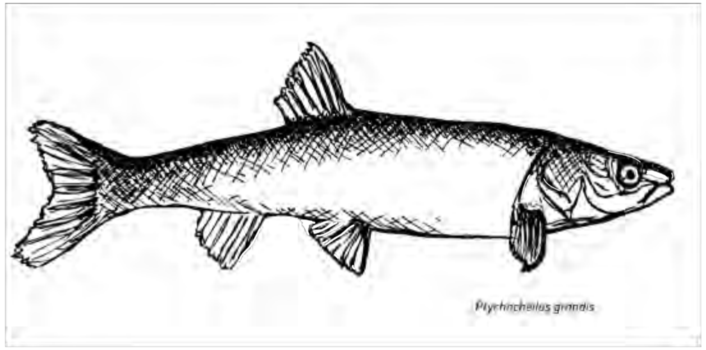
Color imagery from the National Agriculture Imagery Program, United States Department of Agriculture, Farm Service Agency





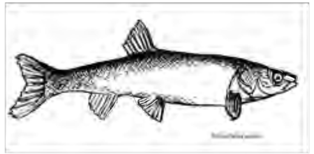
Research Questions

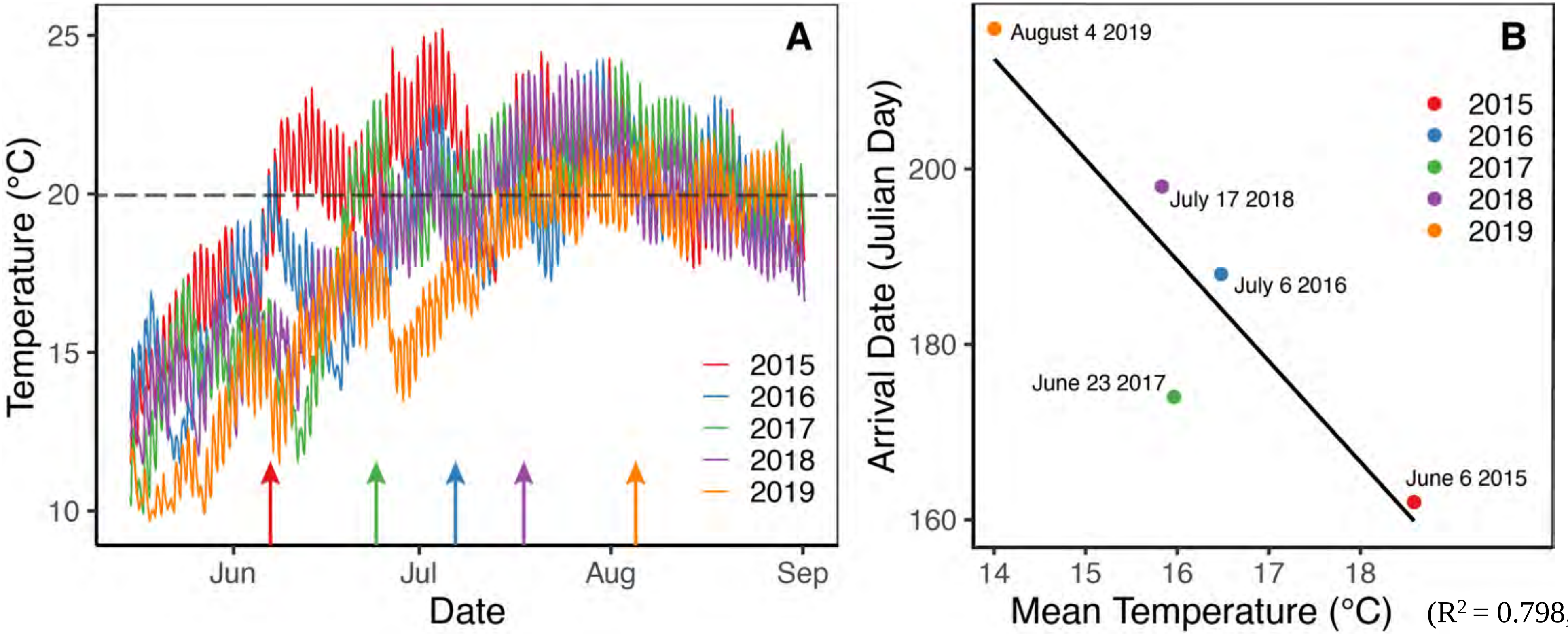
- Is there variation in the timing of Sacramento pikeminnow migration in the South Fork?
  - If so, what conditions predict that variation?
- What motivates migration in the South Fork?
- Are there conditions that might exacerbate the negative impacts of pikeminnow?



Application: How can we take advantage of pikeminnow biology to lessen their impacts for native salmonids

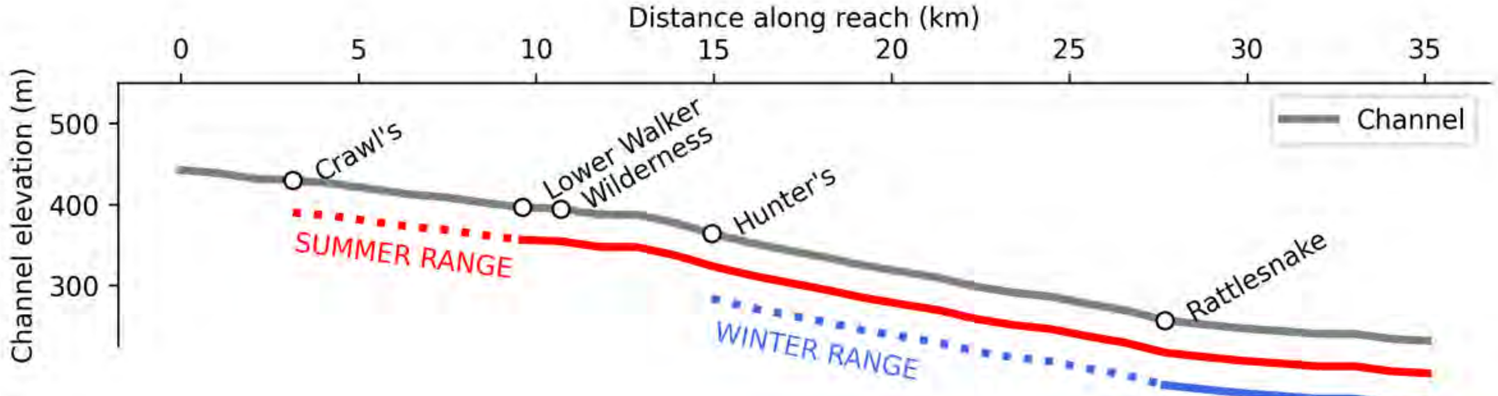
Migration Timing Varies With Temperature



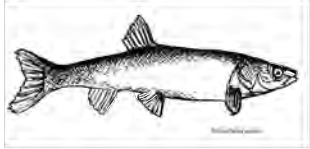


($R^2 = 0.798$, $p = 0.041$)

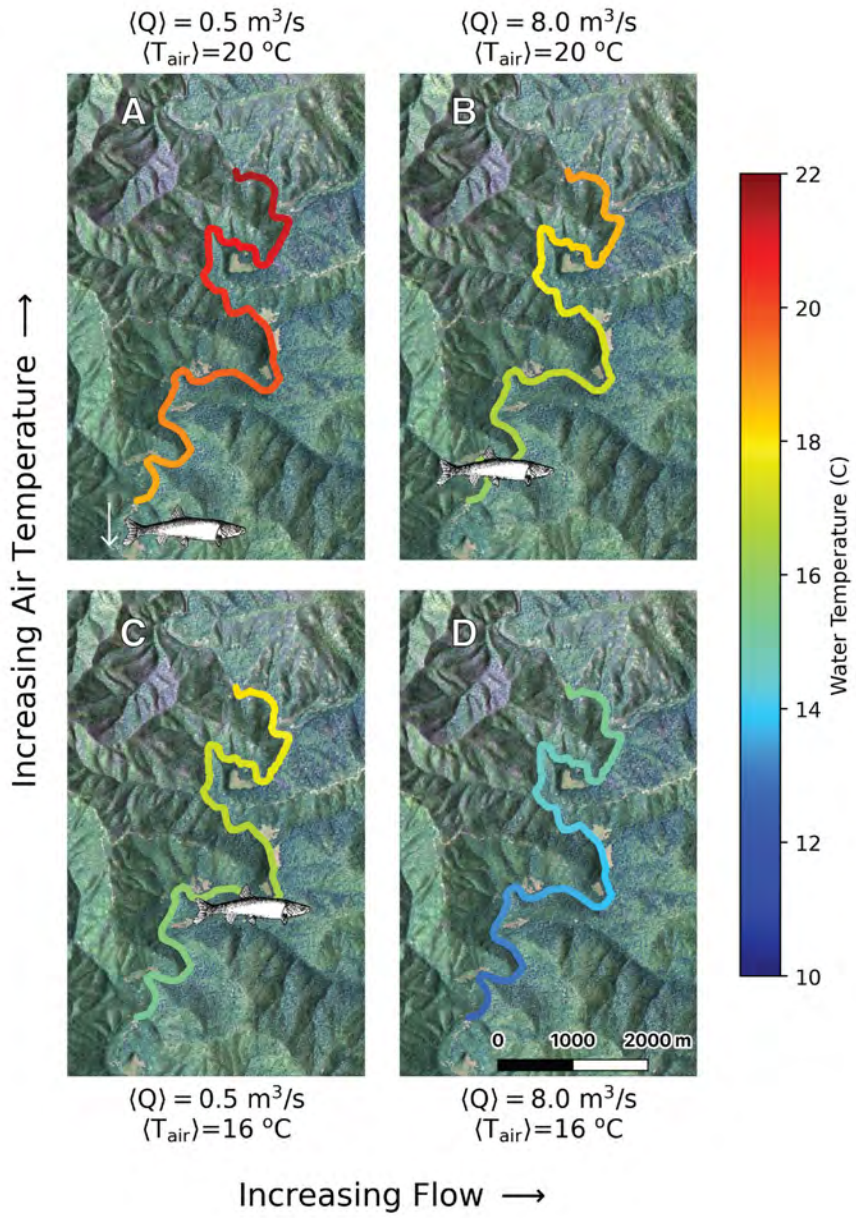
- 49 day difference between the warmest (2015) and coolest (2019) year
- Longer overlap with native prey
- Mean water temp from May 15- date of arrival 16.3°C (s.d. 0.78°C)
- Mean water temp the week prior to arrival 20°C (s.d. 0.75°C)
- (MWAT) across years was 21.7°C (s.d. 0.6°C).



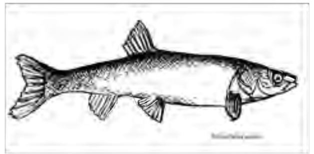
Do certain conditions promote earlier migration

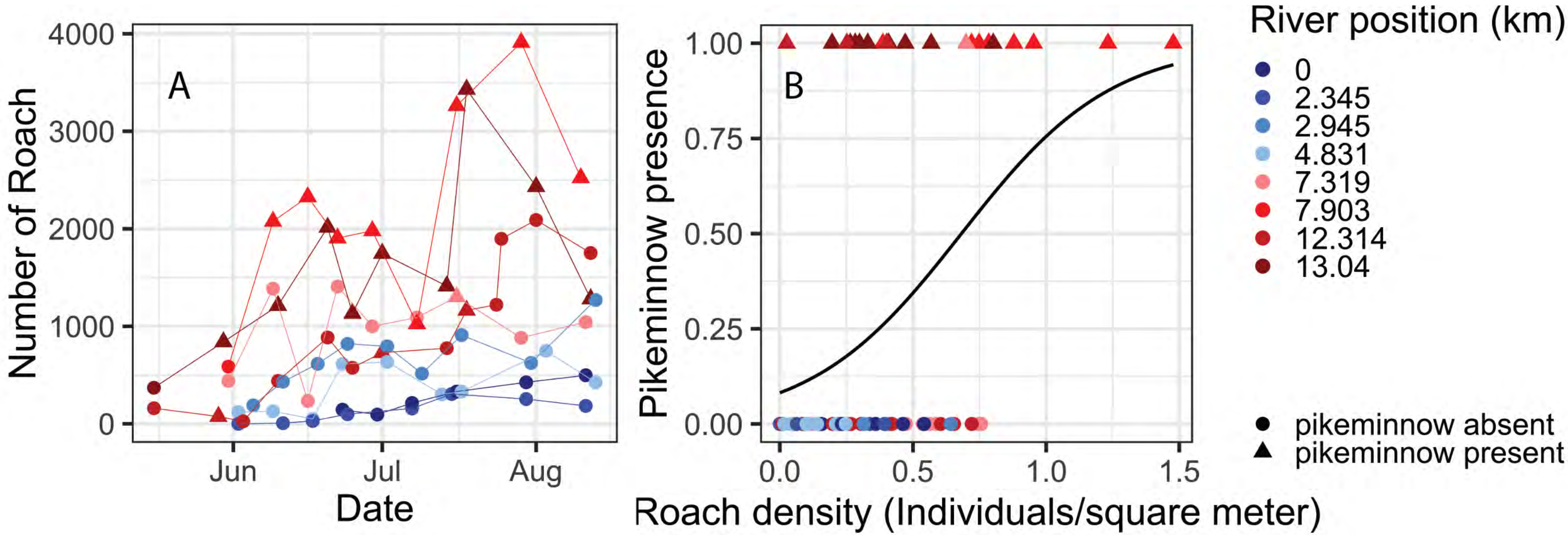


- Statistical temperature model (linear mixed-effect model)
  - Random effect of year
  - Fixed effects of air temperature, discharge, river position
  - All metrics for May 15 – July 1
- Using the parameter estimates from temp model we predicted temperature under 4 scenarios
  - 2 air temperatures: cool, 16°c or hot, 20°c
  - 2 discharges low, 0.5 m^3/s or high, 8 m^3/s
- Temp threshold 16.3 °C for pikeminnow arrival



Why migrate?



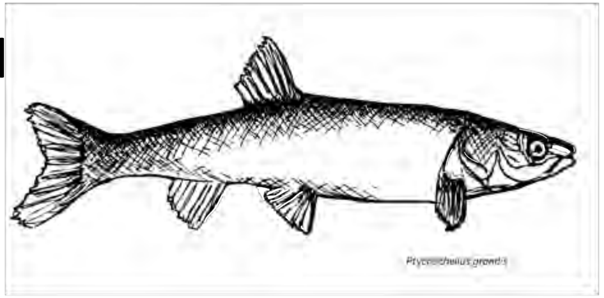


<u>Evidence supporting a foraging migration</u>

1. No Juvenile Pikeminnow ever seen in the upper South Fork
2. Migration timing coincides with seasonal increases in roach numbers
3. Pikeminnow occur in pools with greater numbers and higher densities of roach, Generalized linear mixed-effects models, $p = 0.03$, $p = 0.04$ respectively

Conclusions

- What controls the timing of Sacramento pikeminnow migration in the South Fork?
  - *Temperature*
- Are there conditions that might exacerbate the negative impacts of pikeminnow?
  - *Migration occurs earlier in warmer years and years with less flow*
  - Pikeminnow compete more effectively with steelhead in warmer temperatures (Reese and Harvey 2002).
  - Digest more prey in warmer temperatures (Vondracek 1987).
- What motivates migration in the South Fork?
  - *Probably food concentration*
- How can we take advantage of pikeminnow biology to lessen their impacts
- Next steps
  - Acoustic tagging study 2021 & 2022, collaboration with CDFW, Still Sciences and Wiyot Tribe
  - SF Eel River seasonal fish weir



Acoustic tagging project

Buddha Pool, Legget , SF Eel September 21, 2021

Acoustic tagging project

Buddha Pool, Legget , SF Eel September 21, 2021

Acoustic tagging project

- Acoustic tagging study 2021 & 2022, collaboration with Wiyot Tribe, CDFW, BLM, and Stillwater Sciences
- 12 acoustic receivers placed along the SF Eel River
- Downstream movement timing and extent
- Seasonality of movement
- Site fidelity
- Size class dependent movement patterns
- Individual decisions

Acoustic tagging project

- Tagged 79 pikeminnow in summer and fall 2021
- Detected 19 individuals with a combination of mobile tracking and stationary receivers
  - 8 moved downstream (larger fish)
  - 3 upstream (smaller fish)
  - 8 detected at tagging location
- Our team is concurrently tagging Steelhead and Coho to look at patterns of outmigration and overlap with pikeminnow
- Are there specific life histories more likely to be impacted?

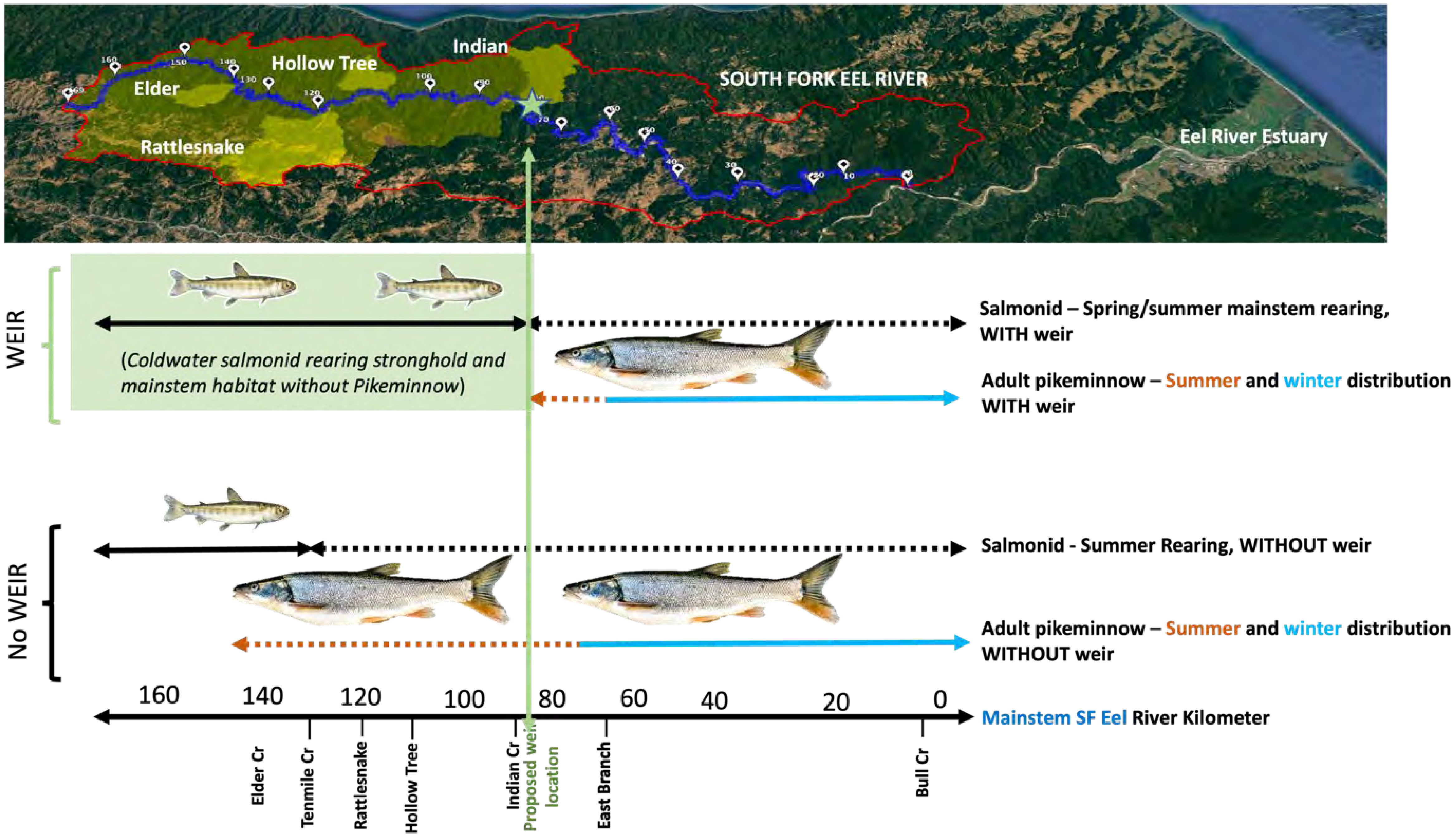
- Apply what we know and have learned about pikeminnow and prey biology
  - Seasonal upstream migration in spring
  - Take advantage of pikeminnow biology to maximize effort invested
  - Limit overlap between pikeminnow and salmonid prey
- Prioritize and protect key habitat (upper South Fork Eel)

Sacramento Pikeminnow hunting at a pool inflow
Standish-Hickey SRA, SF Eel May 15, 2021

The South Fork Eel River Seasonal Fish Weir

Segregation and removal of an invasive predatory fish to benefit recovering salmonids and other native fis

UC Berkeley; Wiyot Tribe; CalTrout; Stillwater Sciences; Cramer Fish Sciences


Indian
Hollow Tree
Elder
Rattlesnake
SOUTH FORK EEL RIVER
Eel River Estuary
WEIR
Salmonid – Spring/summer mainstem rearing, WITH weir
(Coldwater salmonid rearing stronghold and mainstem habitat without Pikeminnow)
Adult pikeminnow – Summer and winter distribution WITH weir
No WEIR
Salmonid - Summer Rearing, WITHOUT weir
Adult pikeminnow – Summer and winter distribution WITHOUT weir
160
140
120
100
80
60
40
20
0
Mainstem SF Eel River Kilometer
Elder Cr
Tenmile Cr
Rattlesnake
Hollow Tree
Indian Cr
Proposed weir location
East Branch
Bull Cr

Tenmile Creek Confluence Pool

non-native predators

- Understand predator and prey biology (phenology, movement patterns, diet, behavioral patterns)
- Direct control efforts to locations and times with high “Bang for our bucks”
- Use control methods that take advantage of predator behavior and limit impacts to native species
- Limit spatial and temporal overlap of non-native predators and native prey especially access to key habitats or vulnerable life stages
- Assess and employ multiple control strategies
  - Wiyot tribe and Stillwater Sciences are doing this, working towards a Pikeminnow Management plan
- Think about methods appropriate for your system

Tenmile Creek Confluence Pool


XCEL

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Peter Steel

Sharon and Dean Edell

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Natural Reserve System
UNIVERSITY OF CALIFORNIA

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Yoshiyama, R. M., and P. B. Moyle. 2010. Historical review of Eel River anadromous salmonids, with emphasis on Chinook salmon, Coho salmon and Steelhead. Report for California Trout. Center for Watershed Science.

Questions and Comments?

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Common Mergansers
Near Wilderness lodge
SF Eel 6/26/2019

Shade affects magnitude and tactics of juvenile Chinook salmon antipredator behavior in the migration corridor

Megan Sabal
Postdoctoral Scholar, Oregon State University

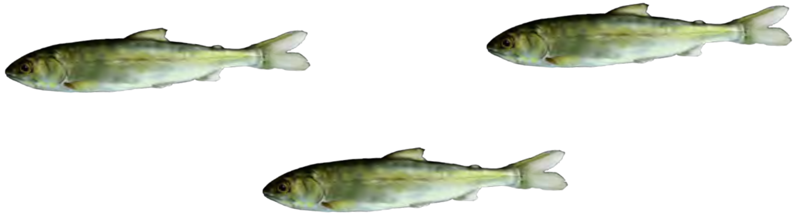
Oecologia
https://doi.org/10.1007/s00442-021-05008-4

BEHAVIORAL ECOLOGY – ORIGINAL RESEARCH

Shade affects magnitude and tactics of juvenile Chinook salmon antipredator behavior in the migration corridor

Megan C. Sabal[1] · Michelle L. Workman[2] · Joseph E. Merz[1,3] · Eric P. Palkovacs[1]

Sabal MC, Workman ML, Merz JE, Palkovacs EP. 2021. Shade affects magnitude and tactics of juvenile Chinook salmon antipredator behavior in the migration corridor. *Oecologia.* https://doi.org/10.1007/s00442-021-05008-4



How do predators affect their prey?

Eat prey
Mortality

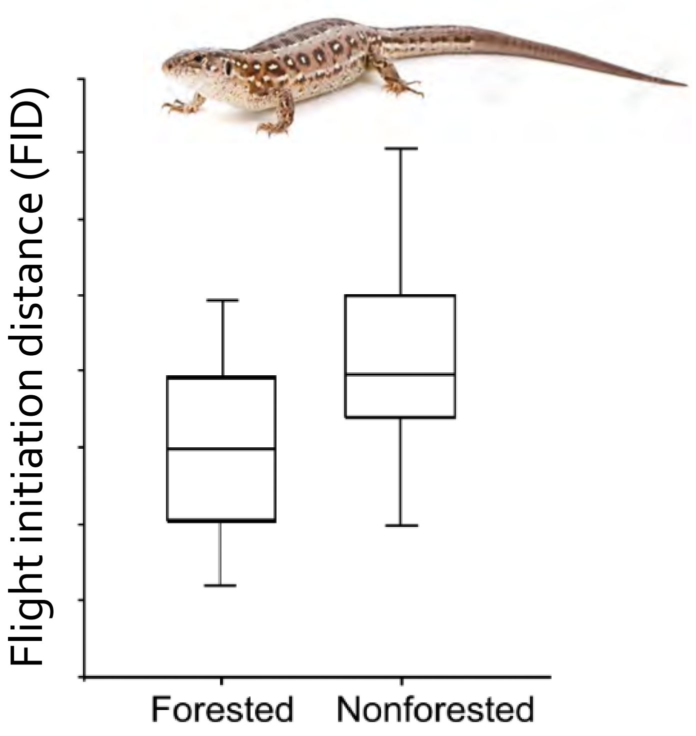
Scare prey
Prey behavior

Traits
Population sizes
Communities
Ecosystems

Habitat influences antipredator behavior

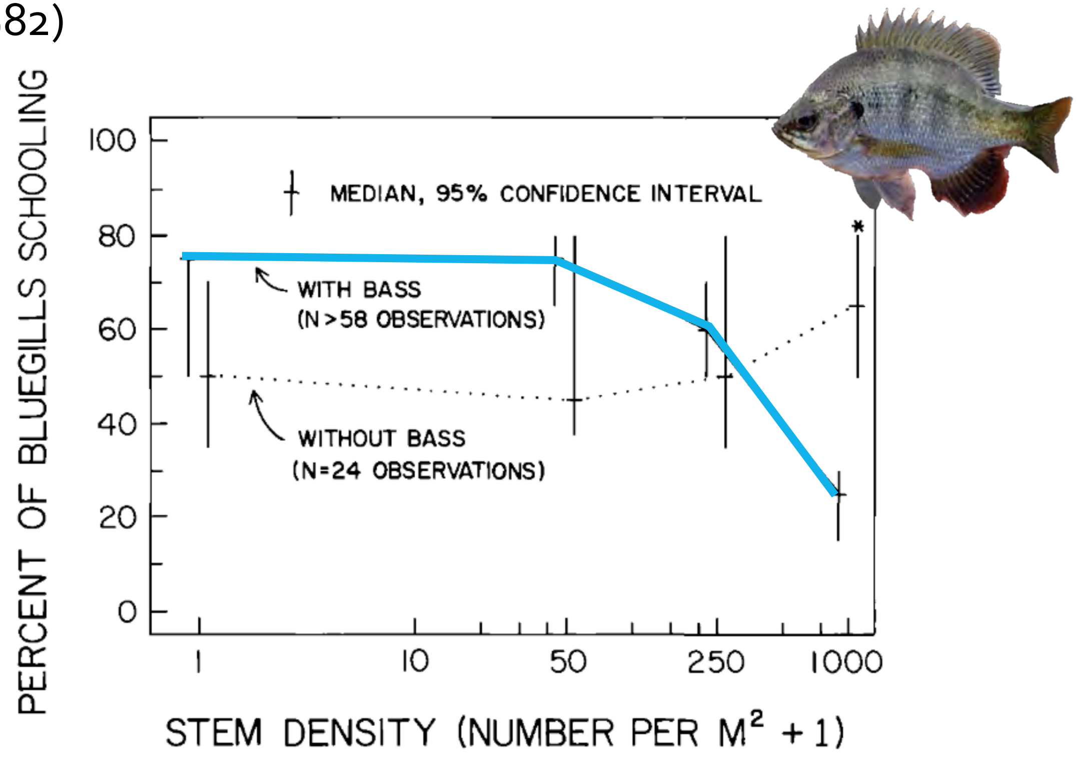
Magnitude

Animals engage in less antipredator behavior when closer to refuge (Stellatelli et al. 2015)



Escape tactic

Bluegill sunfish school when structure is absent, but hide when structure is present (Savino and Stein 1982)



Habitat influences antipredator behavior

When salmon are rearing upstream:
shade & structure as salmon refugia

<u>Structure</u>

- Riparian vegetation, woody debris
- Decrease risk

<u>Overhead shade</u>

- Correlated with structure
- Decreases risk

(McMahon and Hartman 1989; Reinhardt and Healey 1997; Korstrom and Birtwell 2006; Penaluna et al. 2015)

Habitat influences antipredator behavior

When salmon are actively migrating:
shade & structure as ???

<u>Structure</u>

- Woody debris & submerged aquatic vegetation

- Increase risk?
- Decrease risk?

<u>Overhead shade</u>

- Less correlated with structure (bridges, trees on bank)

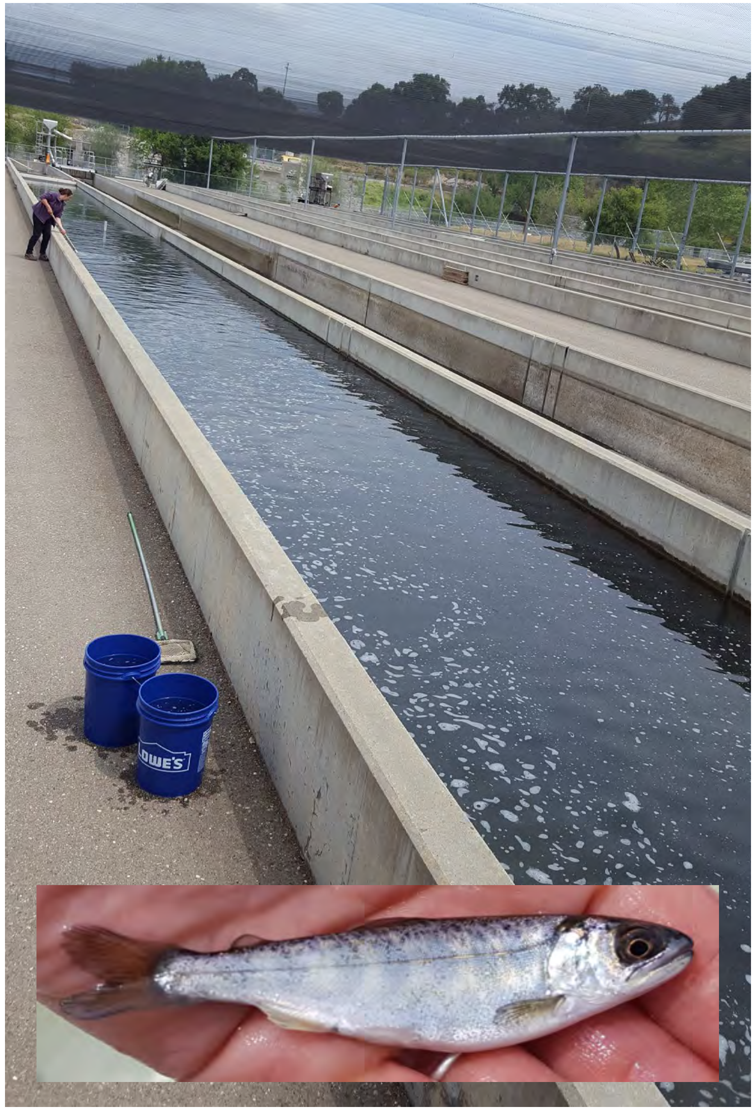
- Salmon avoid?
- Salmon prefer?

(Zajanc et al. 2013; Henderson et al. 2019; Kemp et al. 2005; Ono and Simenstad 2014; Hellmair et al. 2018)

Hatchery practices influence antipredator behavior

<u>Hatchery salmon</u>

- No prior predator experience
- Reduced antipredator behavior
- Increased mortality upon release



Measuring antipredator behavior in directionally moving animals

Antipredator behavior →	***Time to destination (travel speed)***
Hide Fight Be cryptic Increase vigilance Occupy sheltered habitat Wait to move at lower risk time	***Slow down***
Flee past	***Speed up***

Magnitude: how much prey change their speed = how much risk they perceive.

Direction: speed up vs. slow down = what escape tactic prey use.

Sabal MC, Merz JE, Alonzo SH, Palkovacs, EP. 2020. *Journal of Animal Ecology.*

Habitat, hatcheries, & salmon antipredator behavior

Questions

1. Do salmon change travel speed under predation risk?

2. If so, does the magnitude vary related to **structure**, **overhead shade**, and **origin**?

Behavioral assay to measure a change in travel speed

Time salmon swimming downstream with and without a predator

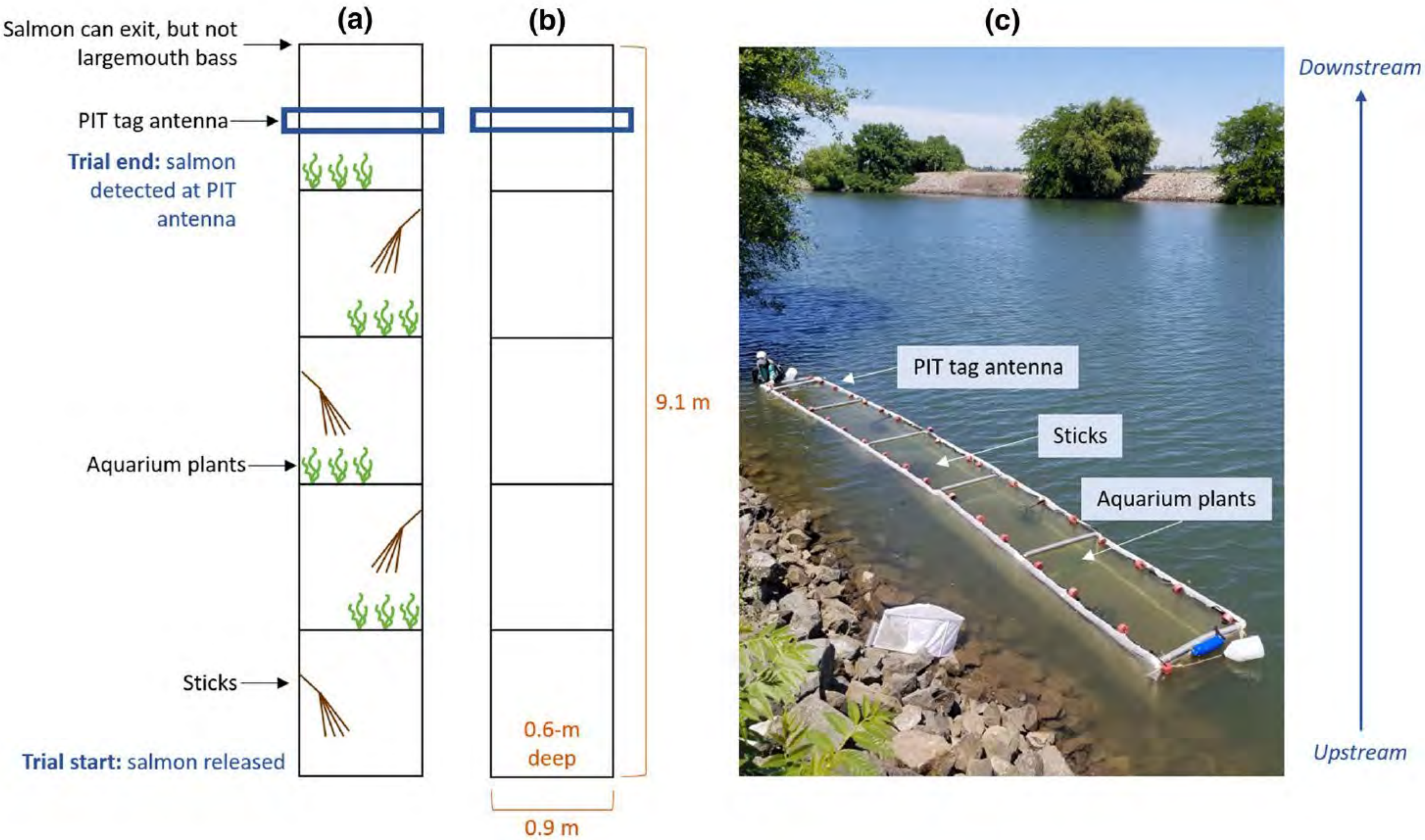
Live largemouth bass

PIT tagged salmon

EBMUD

Hatchery (N = 71), Wild (N = 73)

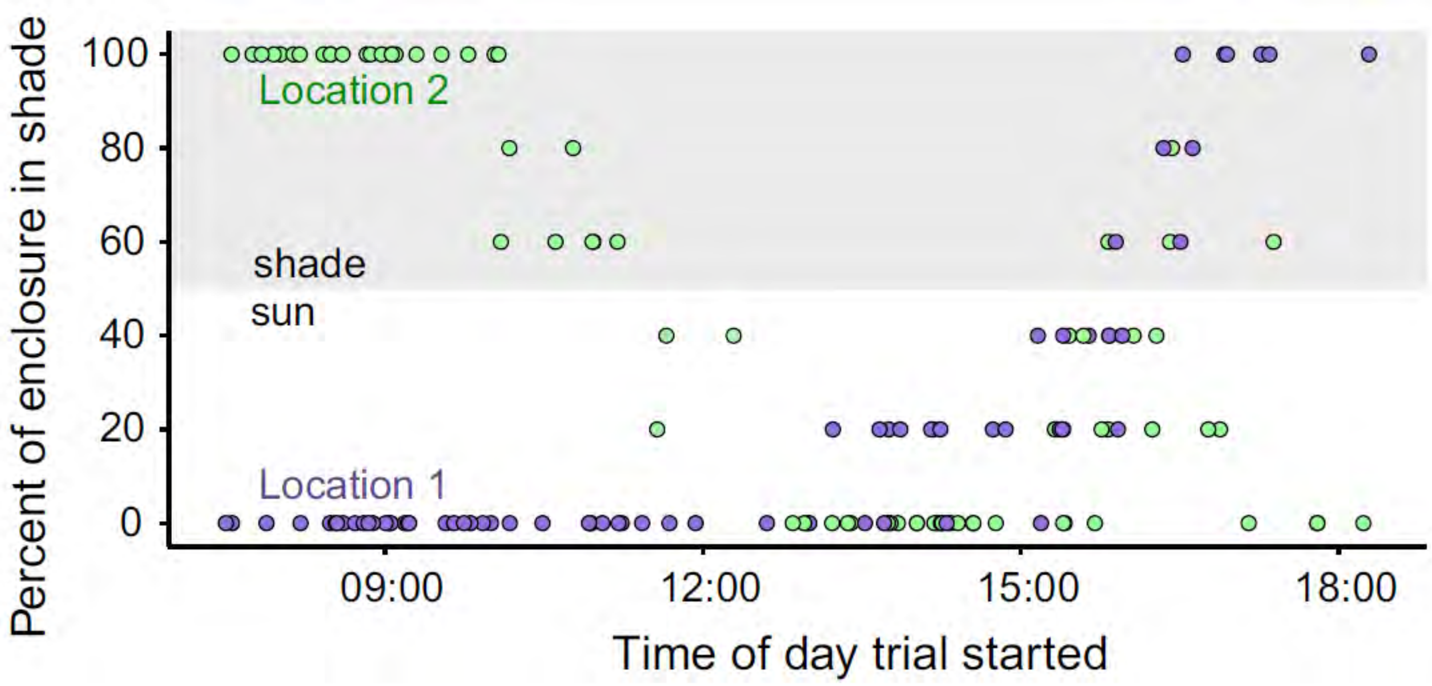
Structure

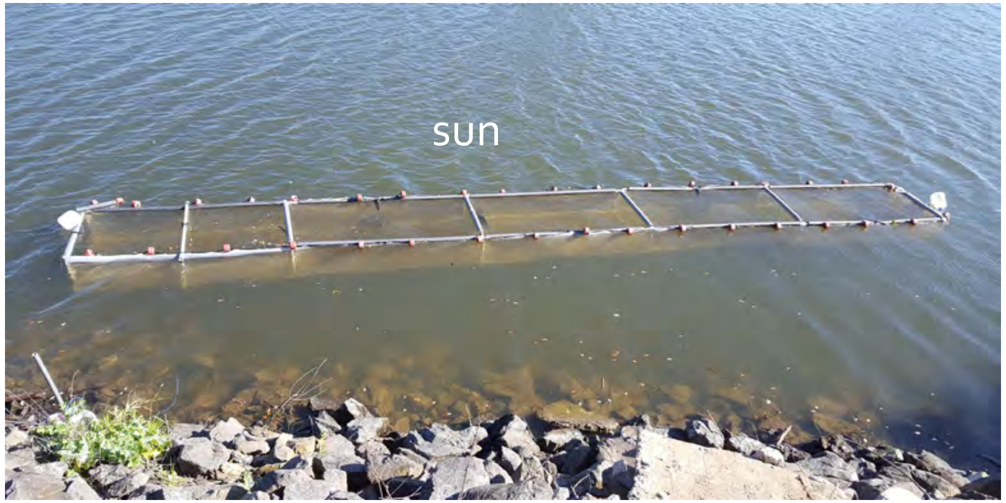


(a)
(b)
(c)
Salmon can exit, but not largemouth bass
PIT tag antenna
Trial end: salmon detected at PIT antenna
Aquarium plants
Sticks
Trial start: salmon released
9.1 m
0.6-m deep
0.9 m
PIT tag antenna
Sticks
Aquarium plants
Downstream
Upstream

Overhead Shade

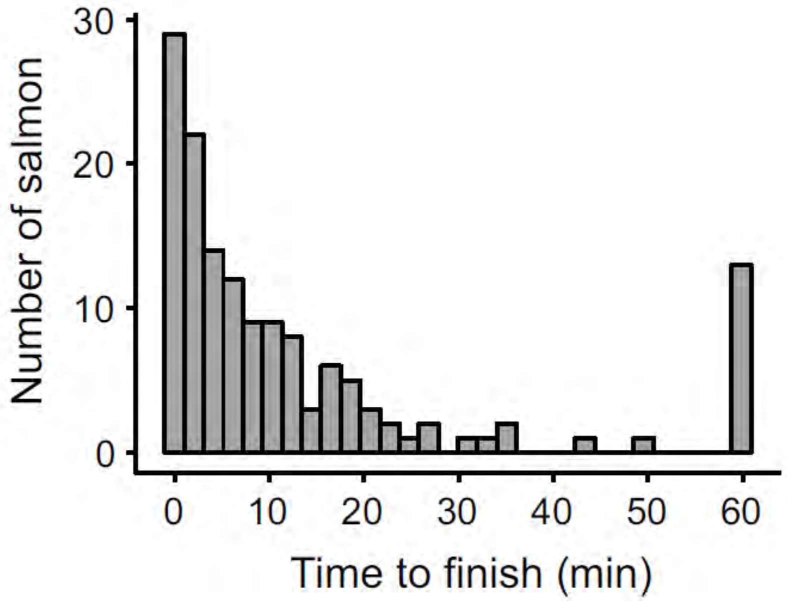
- Two enclosure locations with different shade regimes
- Ignored overcast days
- Categorized shade (> 50% enclosure in shade) and sun (< 50% enclosure in shade)





Results: shade influenced antipredator behavior

- 144 behavioral assays total
- Most (131/144) salmon reached the PIT antenna at the end of the enclosure in the allotted 60 min



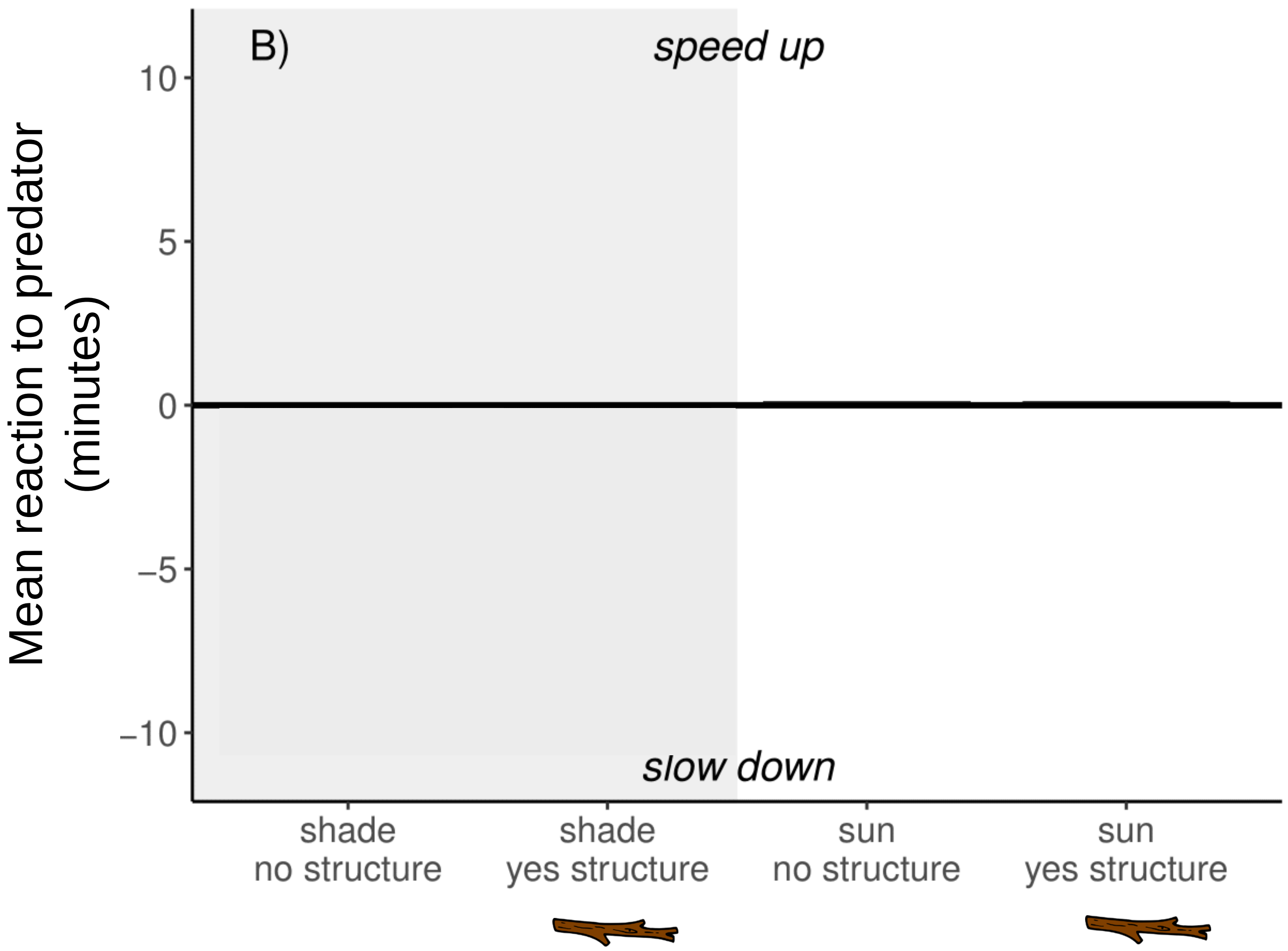
ANOVA on mixed-effects Cox model

Covariate	*df*	χ^2	*P*
Predator	1	7.58	0.006*
Shade	1	15.16	<0.001*
Structure	1	4.86	0.03*
Origin	1	2.42	0.12
Predator × shade	1	9.25	0.002*
Predator × structure	1	2.04	0.15
Predator × origin	1	0.39	0.53
Shade × structure	1	3.73	0.05†
Shade × origin	1	5.56	0.02*
Origin × structure	1	<0.001	0.99

*$p < 0.05$

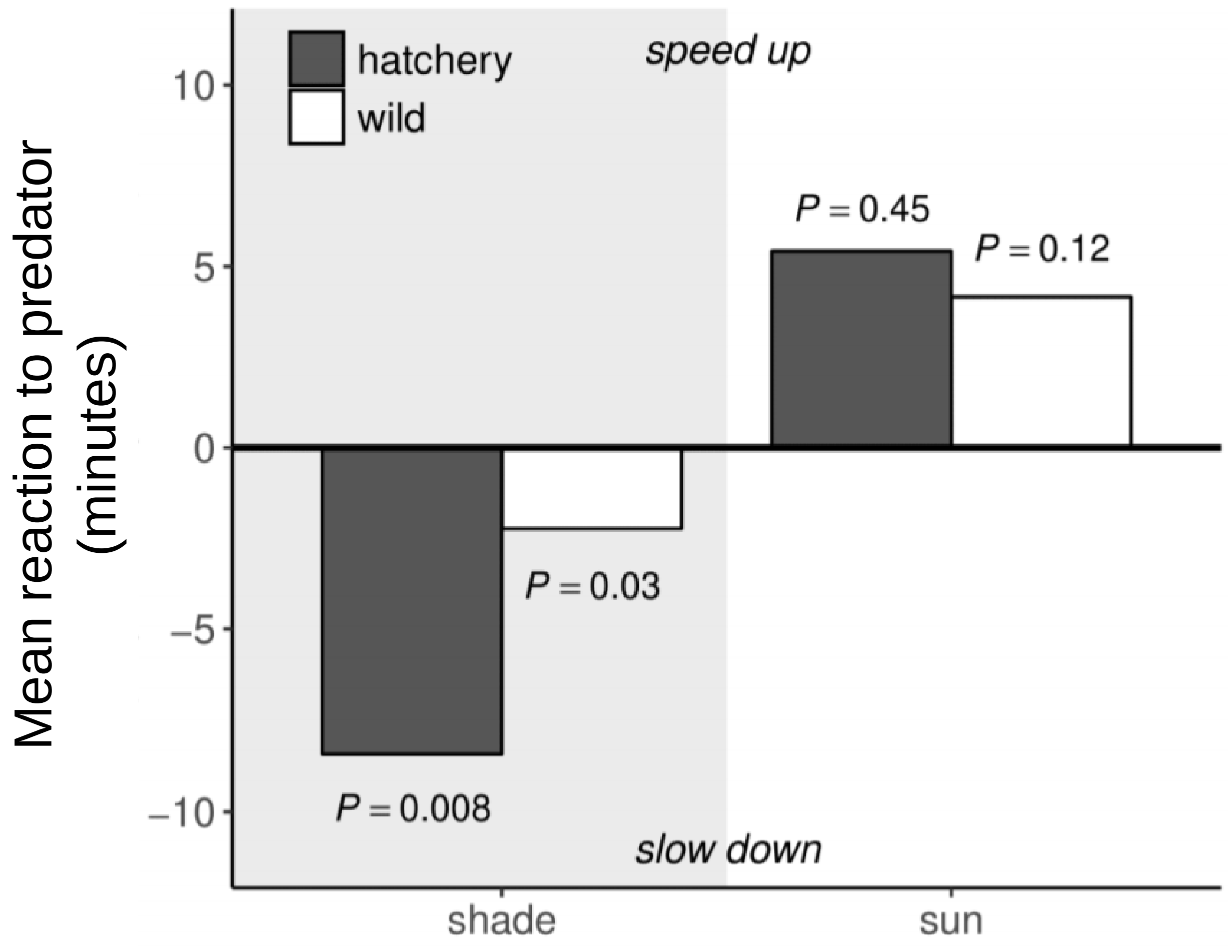
†$p < 0.1$

Results: shade influenced antipredator behavior



- Shade affected **magnitude**
  - Salmon perceived shade to be riskier than sun
- Shade affected **escape tactic**
  - Slowed down in shade
  - Sped up in sun
- Structure reduced risk in shade
  - Restoration: pair structure with shade?

Results: hatchery and wild salmon behaved similarly



- No major difference, but hatchery react more to predator in shade?!
- Hatchery & wild salmon = same shade patterns
  - Magnitude
  - Escape tactic

Conclusions

- Risky shade → magnitude & tactics
- Shade > Structure & Origin
- Rearing ≠ migratory life stages
- Familiarity?
  - Migration corridor = unfamiliar
  - Is unfamiliar structure a less valuable risk cue?

≠

Antipredator behavior is context-dependent

Implications

- Restoration: pair shade + structure?
- Don't assume info from rearing transfers to migratory life stages
- Don't underestimate shade! (anthropogenic structures, etc.)
- Behavior likely influences survival and is context-dependent!

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SWC

Sea Grant California

California Institute for Water Resources

The Nature Conservancy

CRAMER FISH SCIENCES®
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EBMUD

Thank you!
Questions?!

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Sabal et al. 2021. Shade affects magnitude and tactics of juvenile Chinook salmon antipredator behavior in the migration corridor. *Oecologia.* https://doi.org/10.1007/s00442-021-05008-4

U.S. Department of the Interior
Bureau of Land Management

Tracking (and Trying to Stop) the Invasion of Sacramento Pikeminnow in the North Fork Eel River

Zane Ruddy - BLM Arcata Field Office

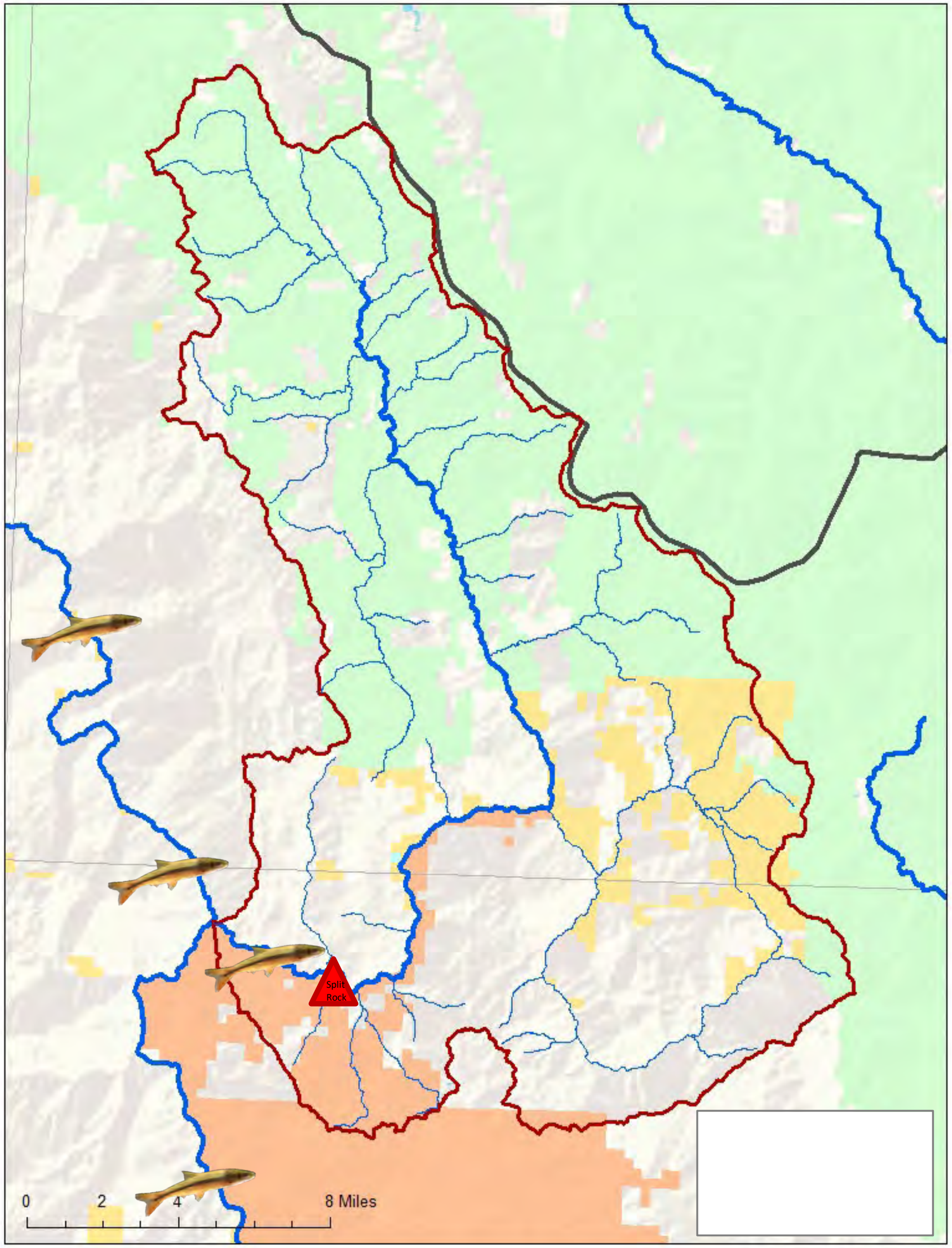
U.S. Department of the Interior
Bureau of Land Management

Eel River

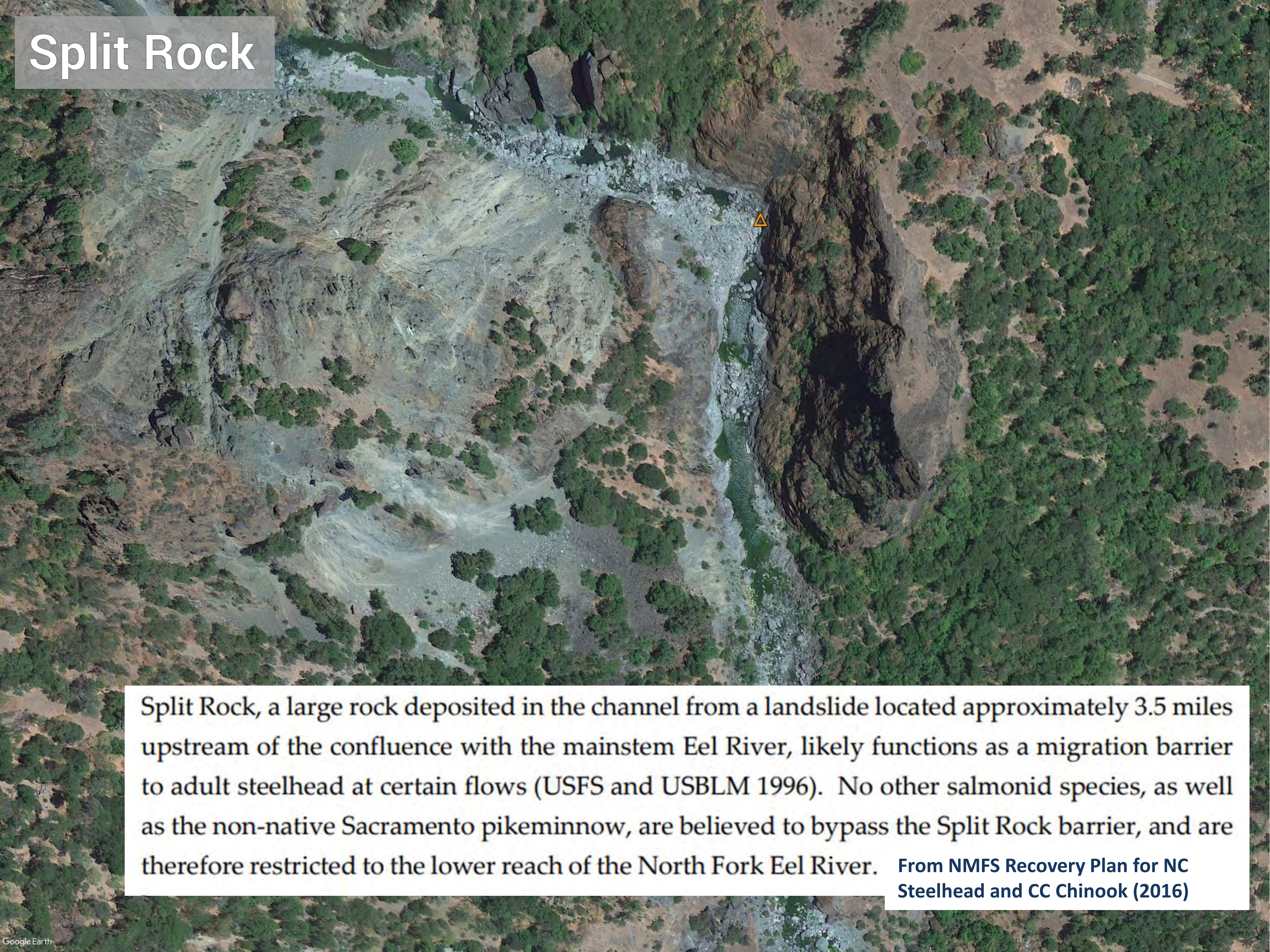
and

Sacramento Pikeminnow

North Fork Eel River



Split Rock

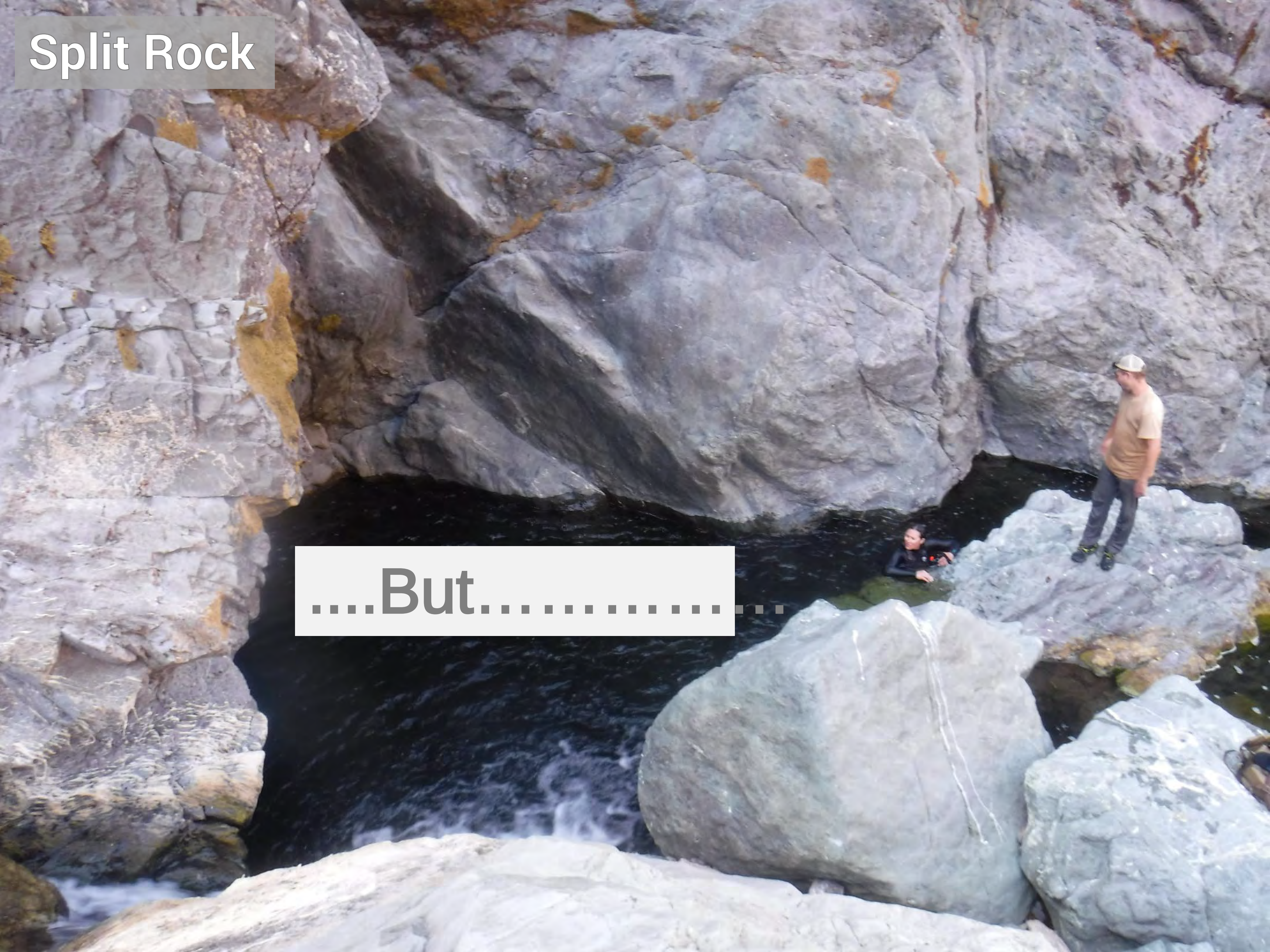


Split Rock, a large rock deposited in the channel from a landslide located approximately 3.5 miles upstream of the confluence with the mainstem Eel River, likely functions as a migration barrier to adult steelhead at certain flows (USFS and USBLM 1996). No other salmonid species, as well as the non-native Sacramento pikeminnow, are believed to bypass the Split Rock barrier, and are therefore restricted to the lower reach of the North Fork Eel River.

From NMFS Recovery Plan for NC Steelhead and CC Chinook (2016)

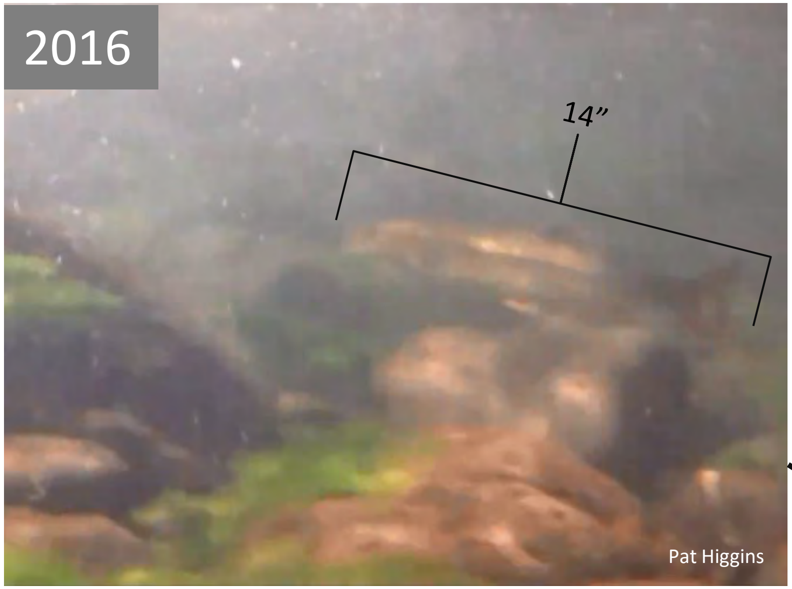
Split Rock

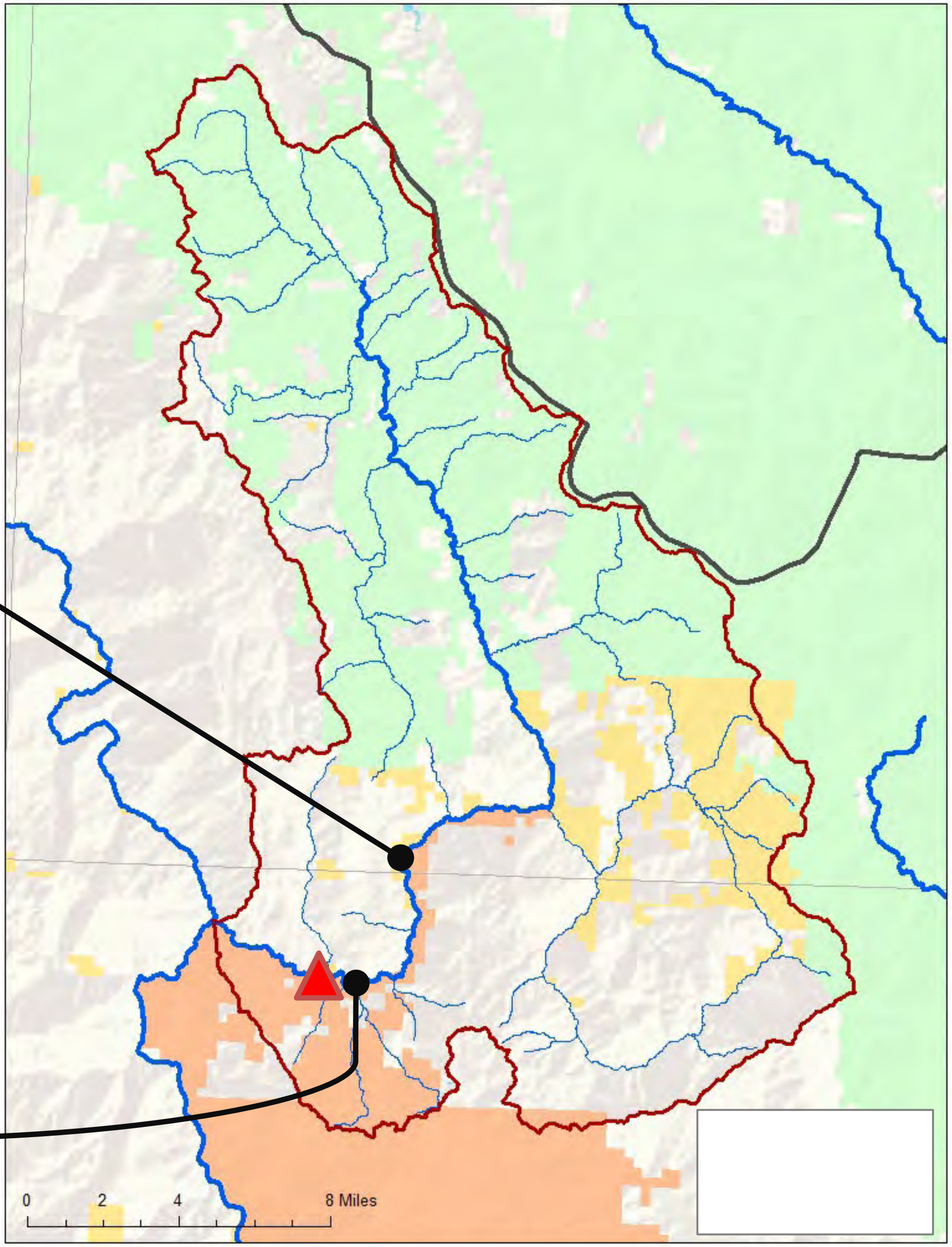

Split Rock



Split Rock
....But...................

....then....





2017 eDNA and snorkel surveys

Objective: Find out what's going on!

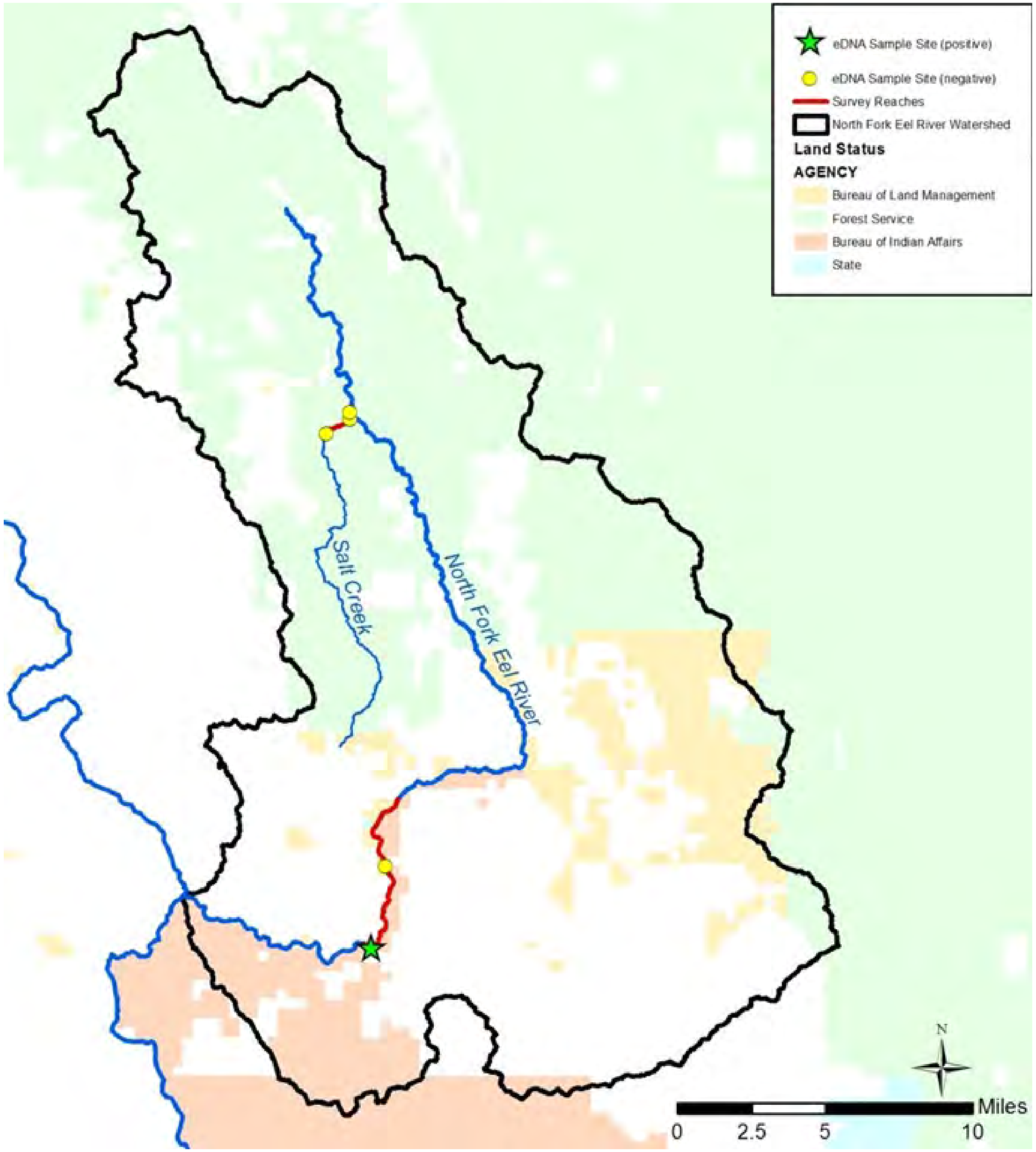
2017 Results

Snorkel survey – 7 miles

- No pikeminnow observed

eDNA survey

- 1 positive detection
- 4 negative detections



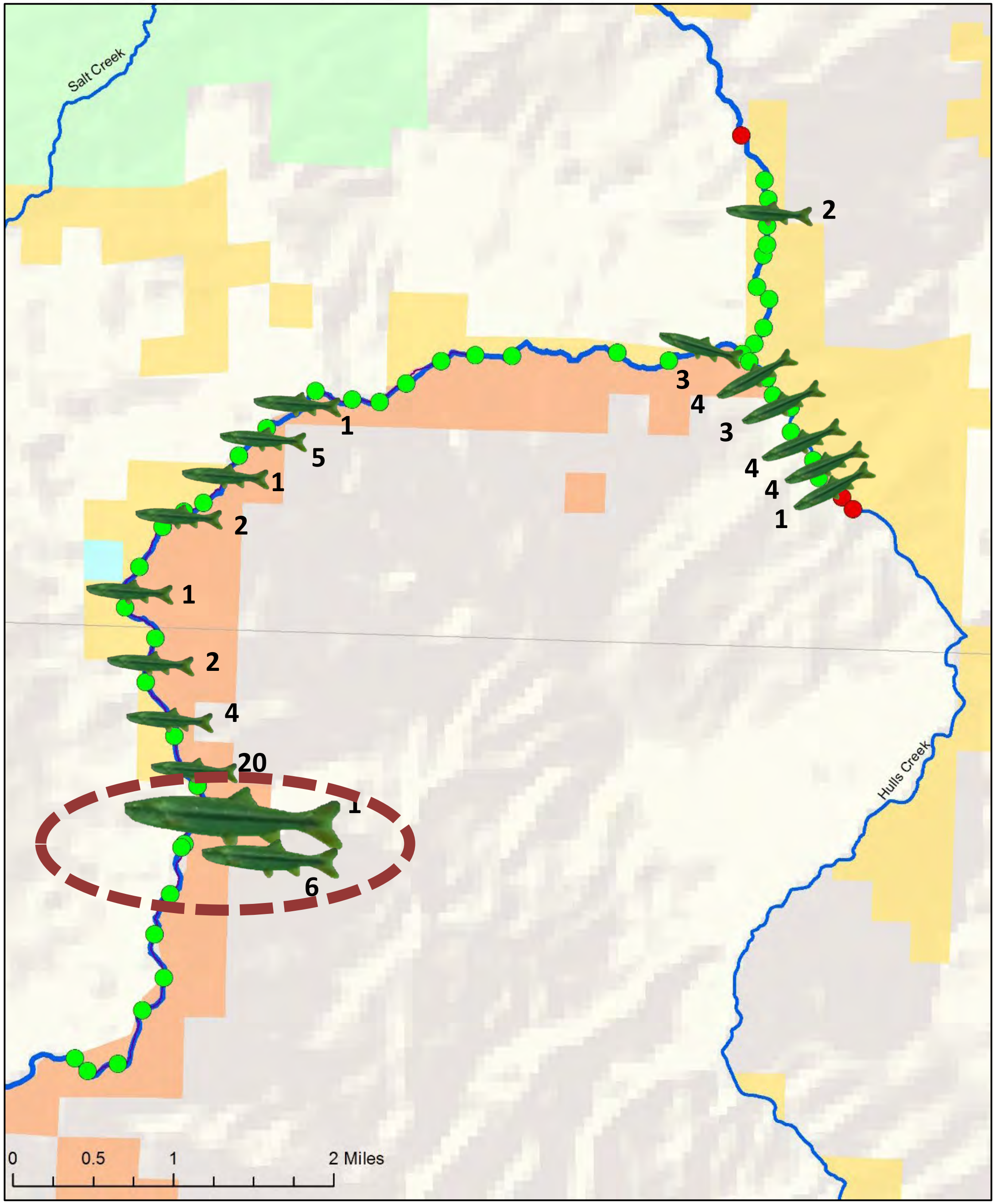
2018 Results

Snorkel survey – 15 miles

- Adults (>14"): 1
- Sub-adults (8-14"): 6
- Juveniles (4-8"): 60

eDNA survey

- 45 positive detections
- 3 negative detections



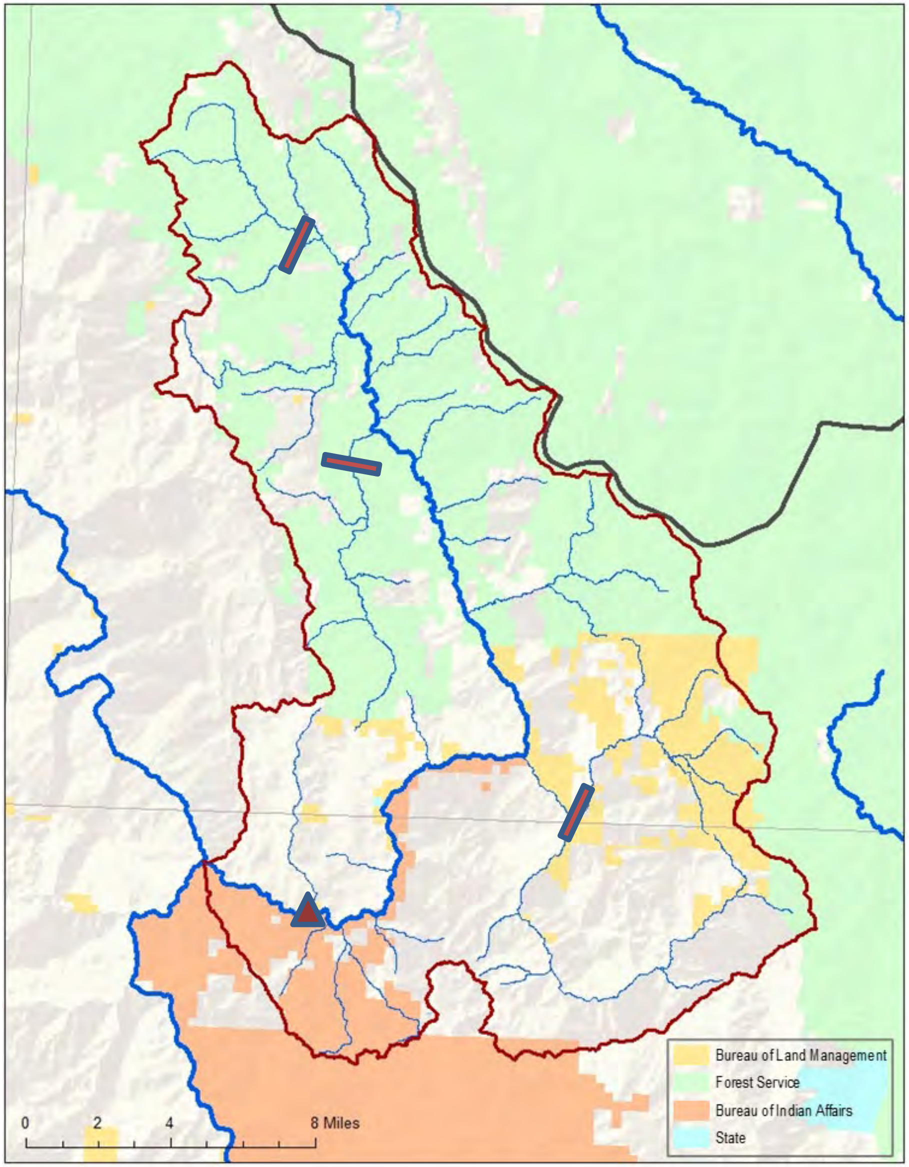
The challenge

Jacob Pounds

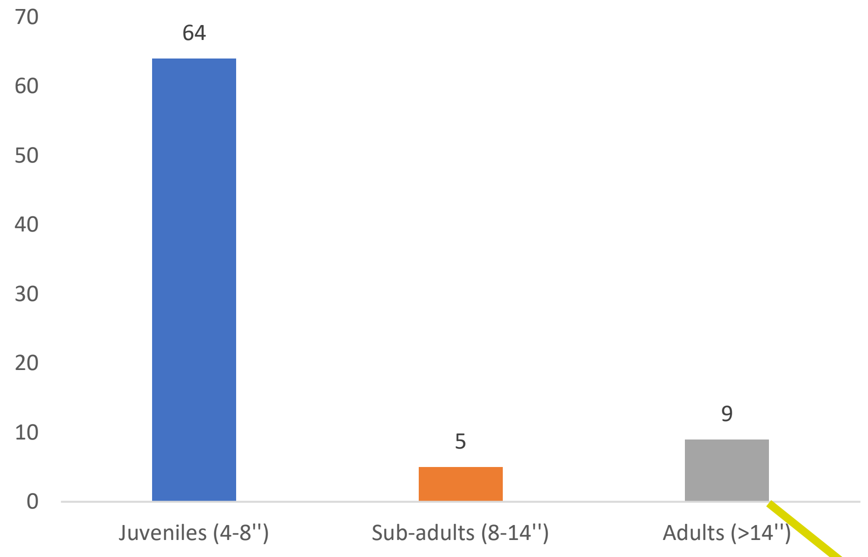
Typical juvenile habitat

2018 Results

Snorkel Surveys 2019 - 2021



2019 Results



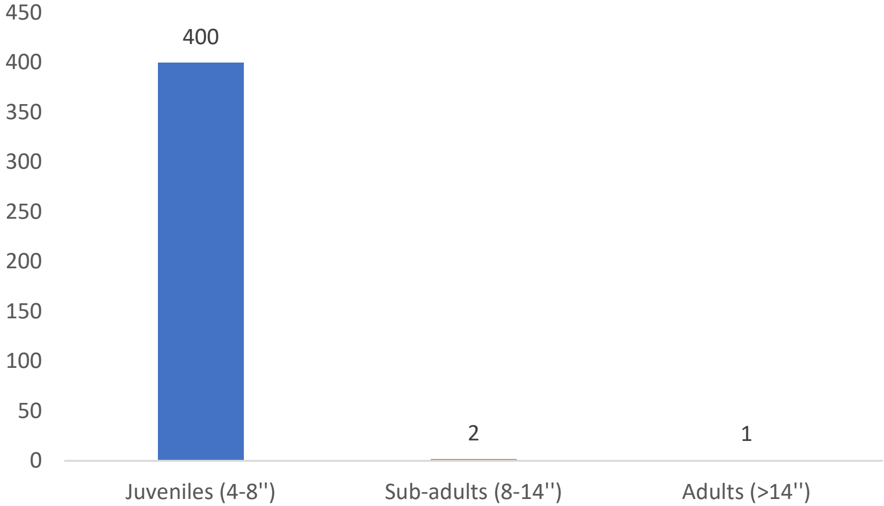
Access + Large fish =
Suppression!

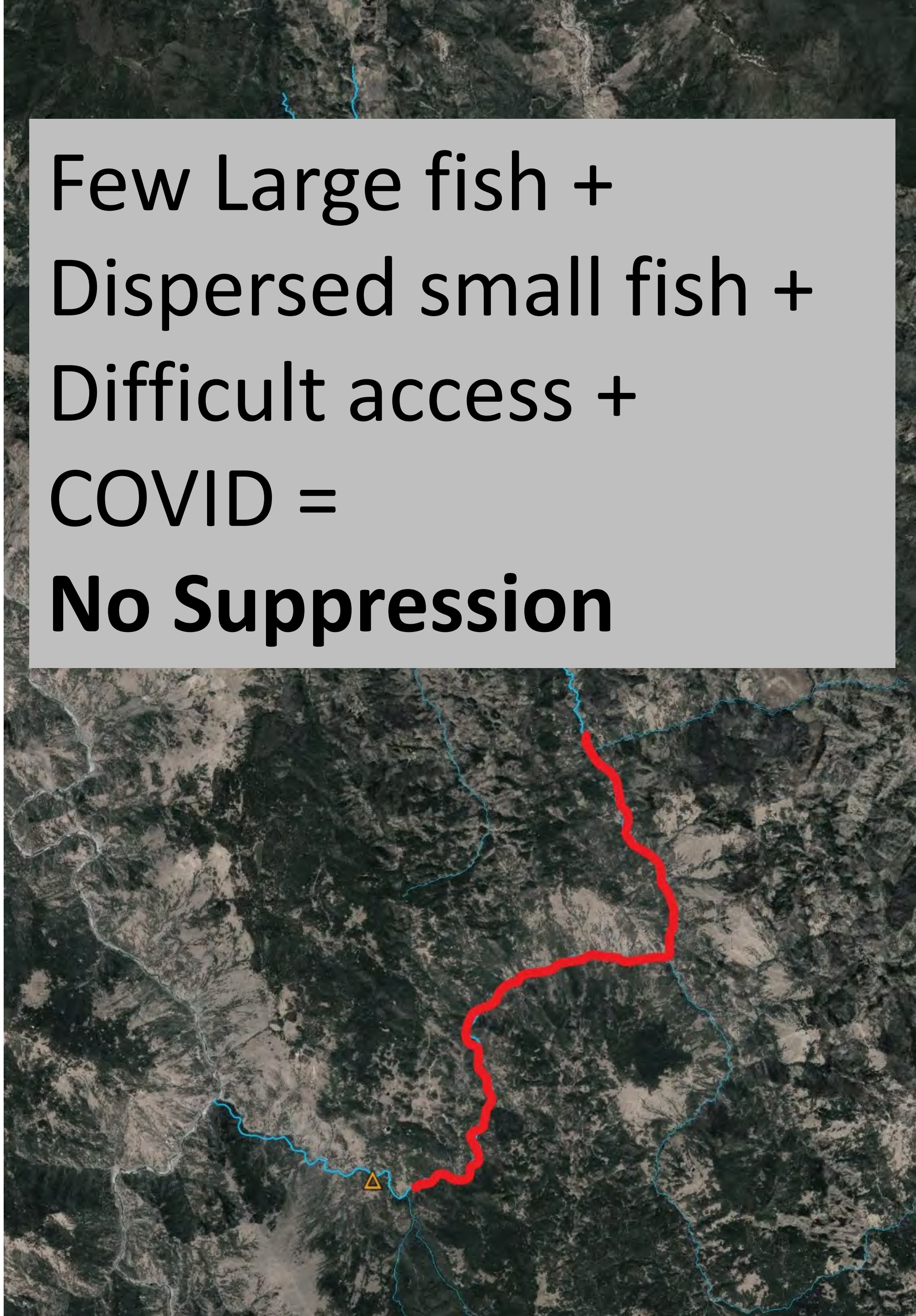

2019 Suppression


2019 Suppression

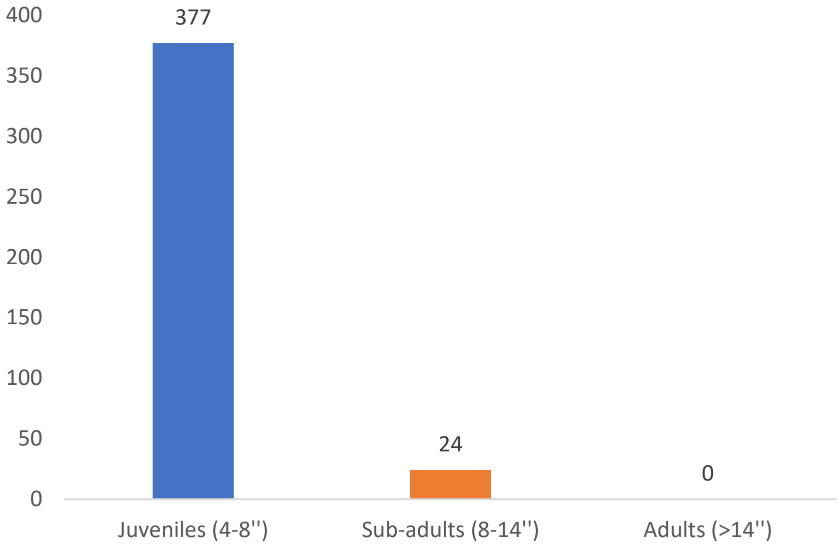
2019 Suppression

2020 Results





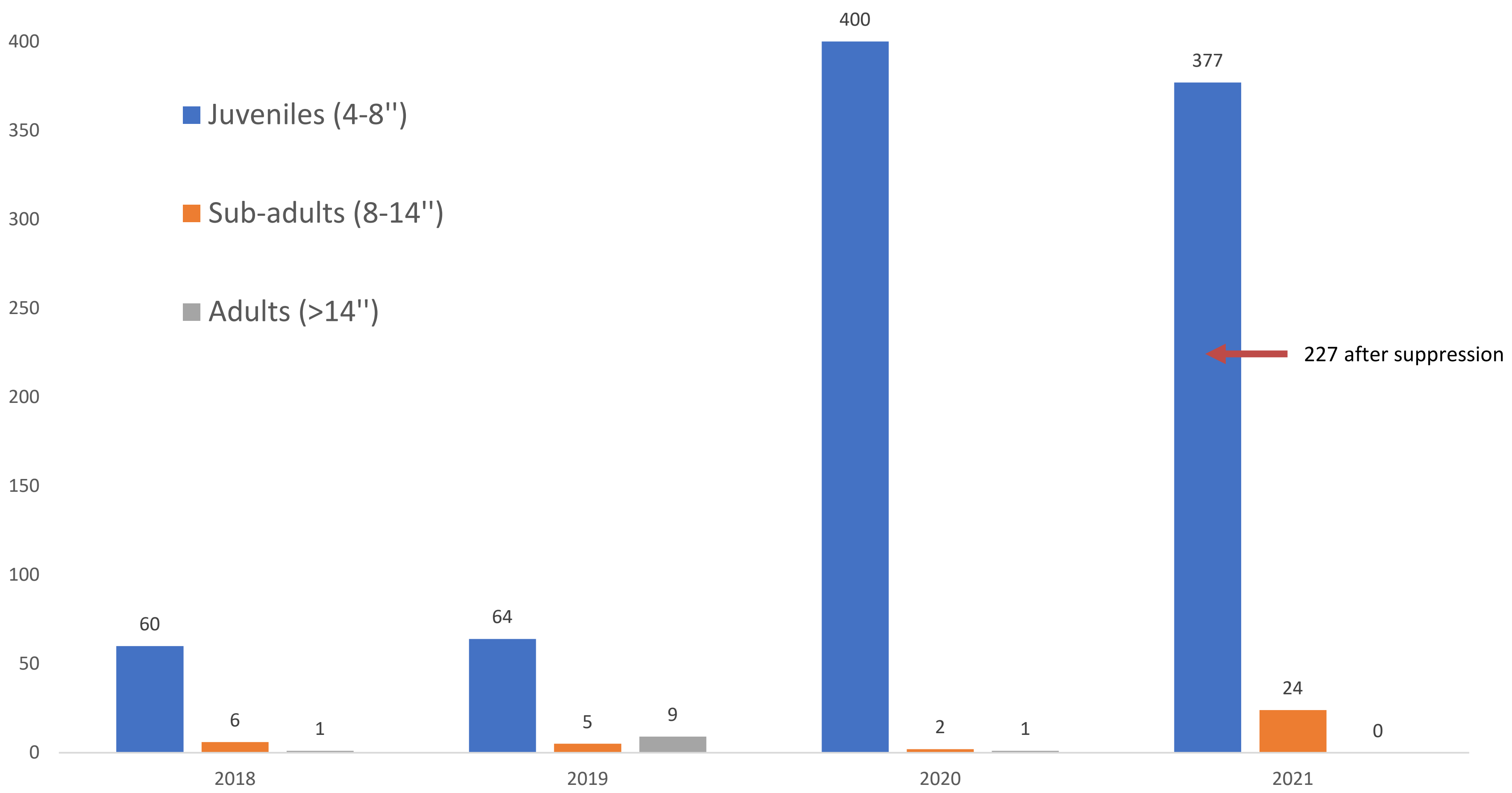
2021 Results




2021 Suppression

2021 Suppression

Results Summary



Conclusions

- Pikeminnow have reproduced above Split Rock several times
- Juvenile abundance increased over time
- Distribution varies year-to-year
- Adults rare and seem to prefer one reach of river
- Suppression possible but pikeminnow difficult to catch

Questions, Theories, and Guesses

- **Why aren't pikeminnow pervasive in NF Eel River after 40+ years in the Eel River basin?**

  Theory 1: Split Rock passed pikeminnow once (or maybe twice?)

  Theory 2: Small founding population = double-genetic bottleneck?

- **Why don't we see adults?**

  Theory 1: Split Rock acts as one-way valve for sub-adults that migrate downstream

  Theory 2: Big fish are sitting ducks for otters

- **Can suppression efforts prevent invasion?**

  Guess: Yes, if we do it every year and if the pattern of low reproduction continues

- **Could the problem take care of itself (and has it done so many times in the past)?**

  Guess: Probably not because pikeminnow have shown they can colonize from small number of founders. Must be vigilant while we have a chance.

- **Next Steps**
  - Continue snorkel survey monitoring efforts, expand to downstream of Split Rock
  - Figure out how to catch pikeminnow in remote settings (informed by Wiyot study)

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- CDFW Fortuna
- J.B. Lovelace & Associates
- Field Crew and Watershed Stewards Program Members
- NF Eel watershed and pikeminnow guidance
  - Pat Higgins, Dave Fuller, Karen Kenfield, Bret Harvey, Andrew Kinziger, Round Valley Indian Tribes, Wiyot Tribe, Blue Lake Rancheria, and Stillwater Sciences

Zane Ruddy
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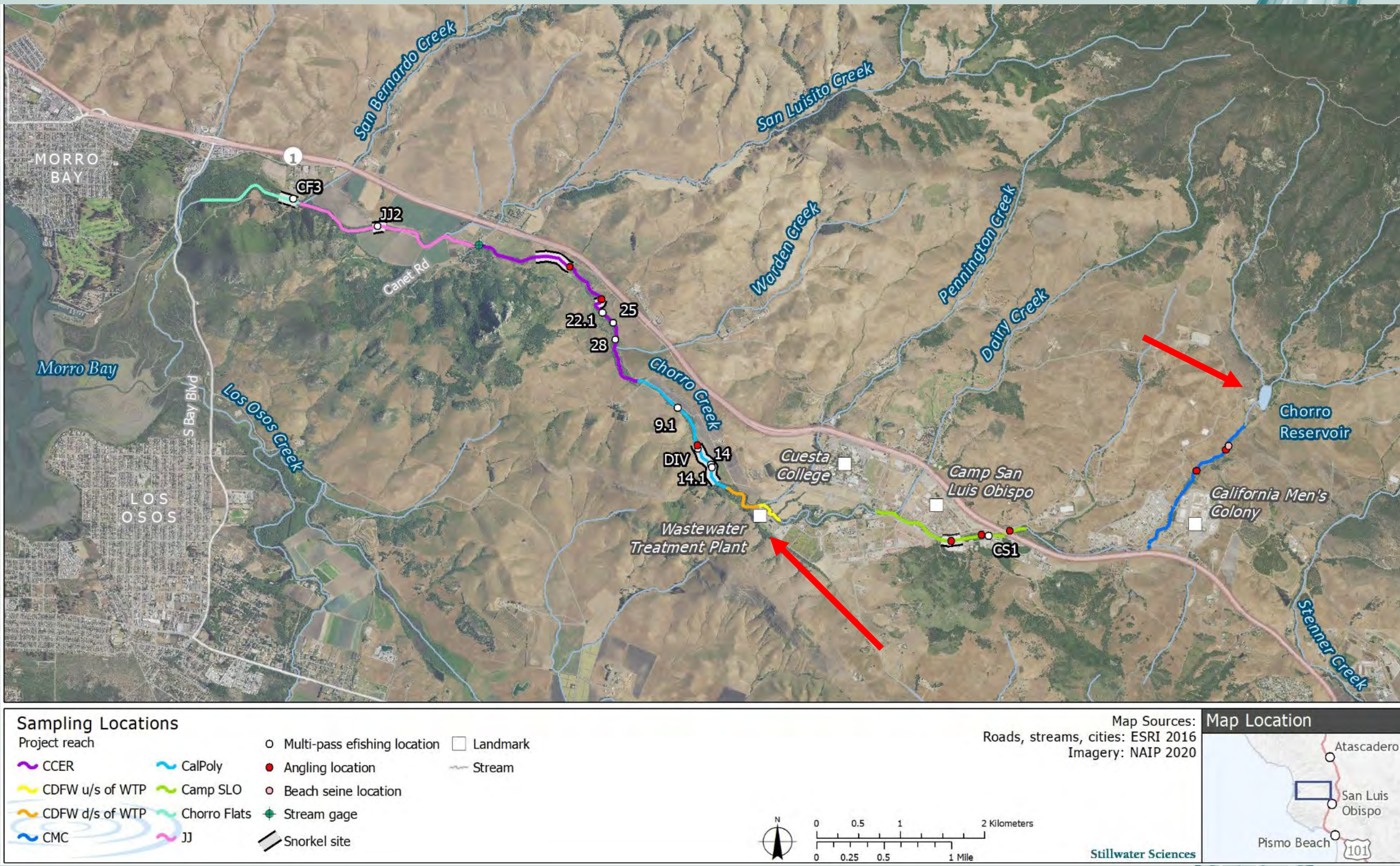
Chorro Creek: Big Success in a Small Watershed

Salmonid Restoration Federation Conference Santa Cruz, CA
April 22, 2022

Ken Jarrett, Matt McKechnie, Ethan Bell (Stillwater Sciences), and Carolyn Geraghty (MBNEP)

Stillwater Sciences

Chorro Creek

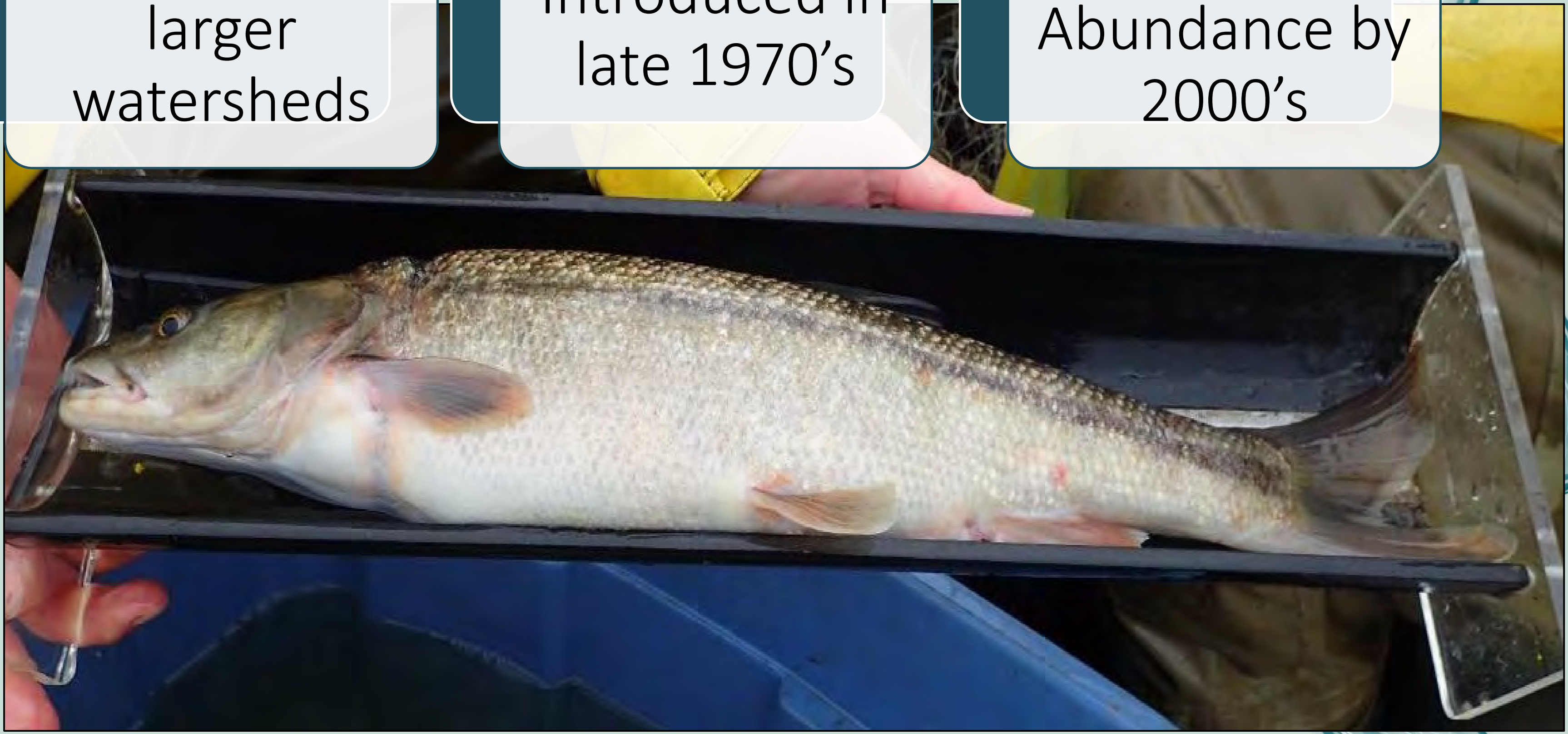


Sacramento Pikeminnow

Native to larger watersheds

Introduced in late 1970's

High Abundance by 2000's

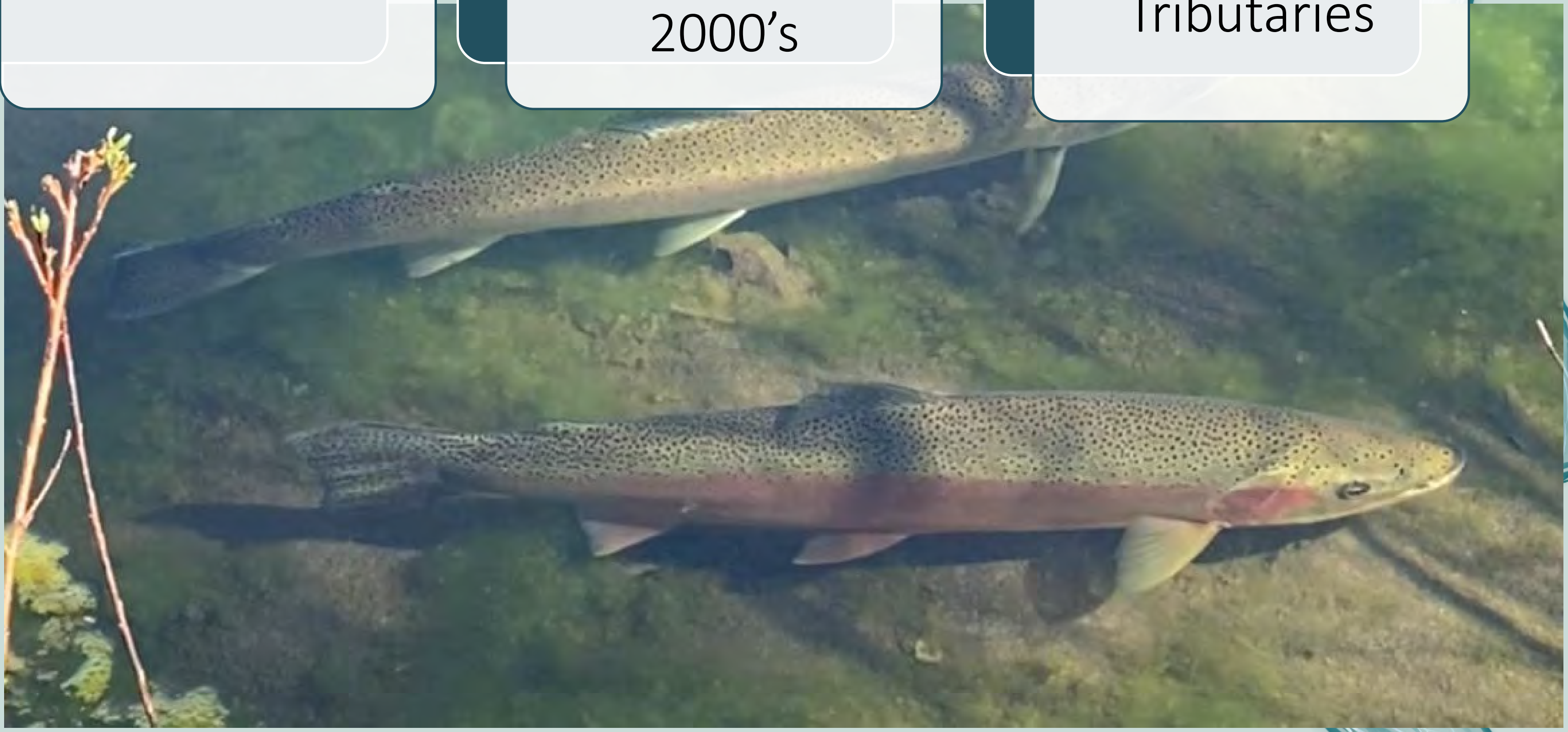


Steelhead

Threatened

Low Abundance in Mainstem in 2000's

Found Mainly in Tributaries



Background

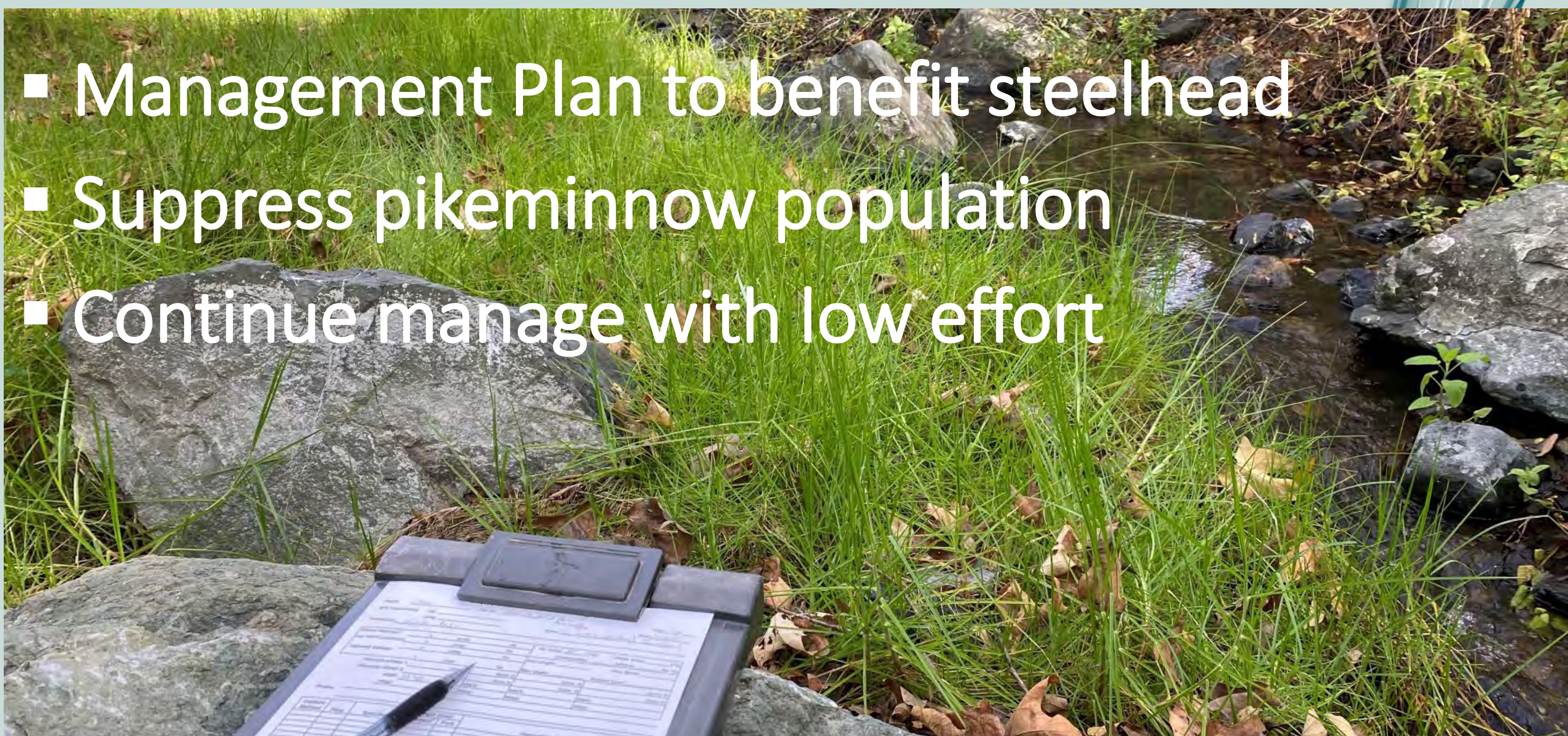
Pilot Suppression efforts

Occurred from 2005 – 2010

Helped to inform recent efforts

Study Goals

- Management Plan to benefit steelhead
- Suppress pikeminnow population
- Continue manage with low effort



Approach

- Develop management plan
- Confirm Predation
- Address reservoir source population
- Target all life stages
- Prioritize known hotspots
- Monitor steelhead response

Predation Assessment

Genetic testing gut contents

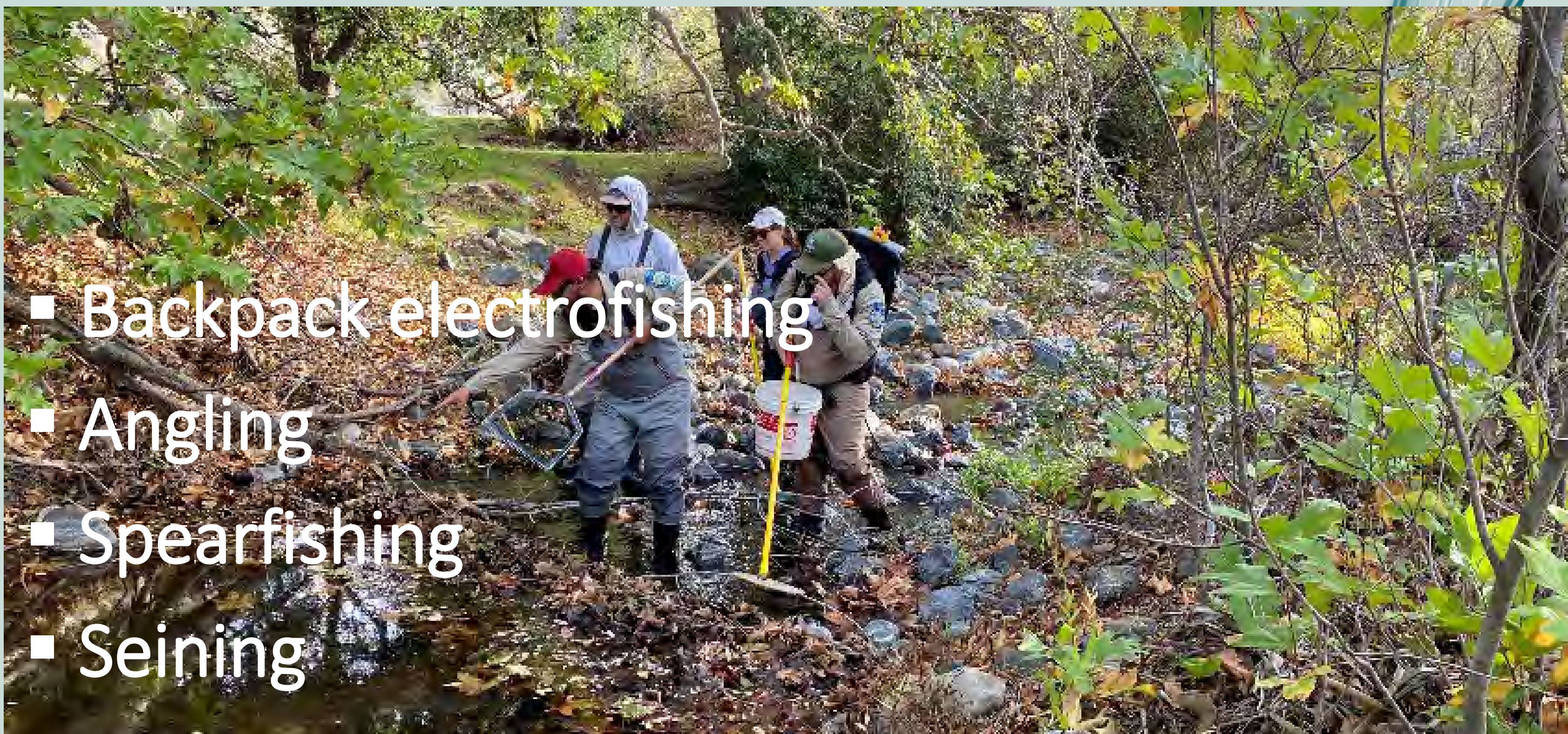
Versus

Visual analysis

Reservoir Methods

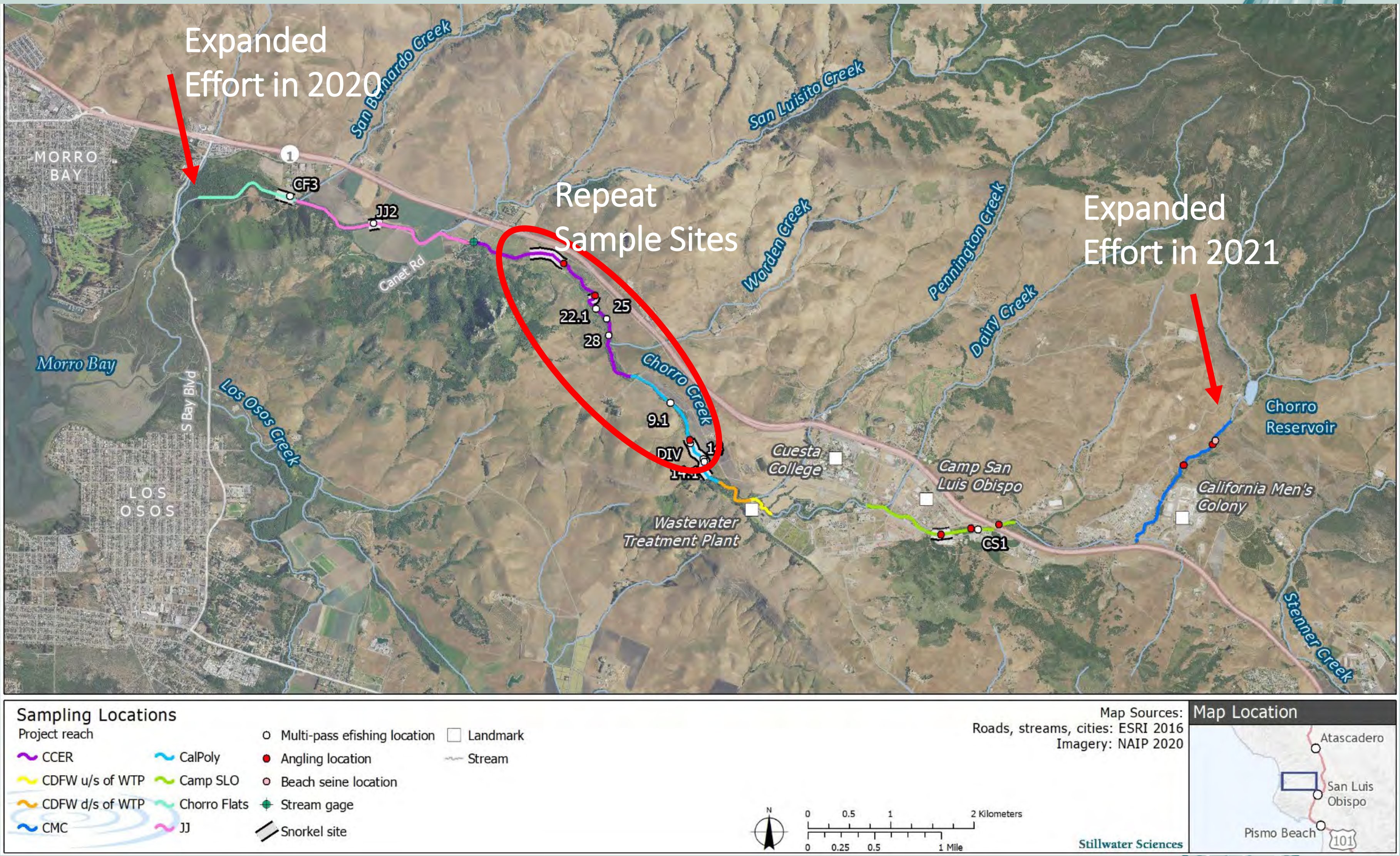
- Gill netting
- eDNA sampling

Stream Methods

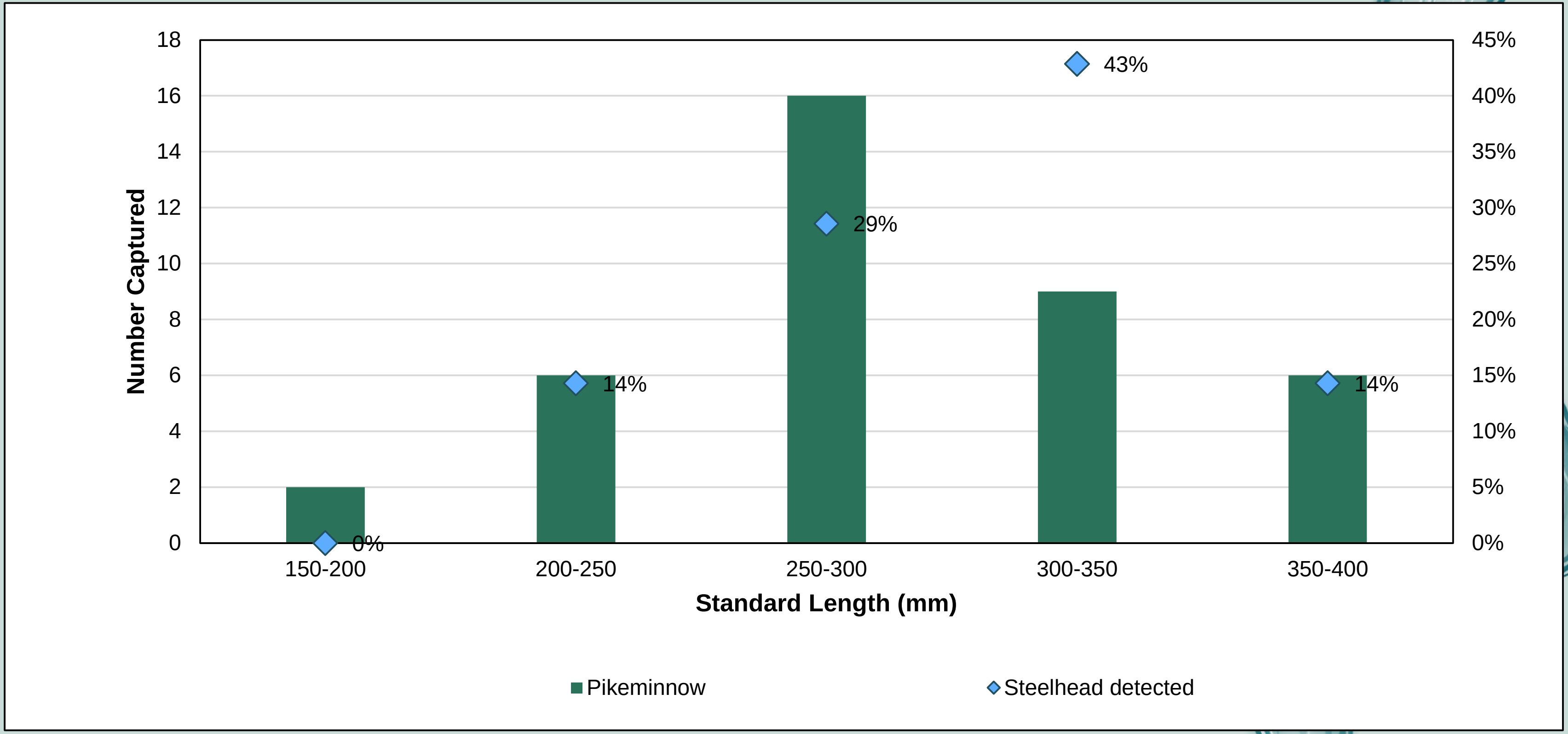


- Backpack electrofishing
- Angling
- Spearfishing
- Seining

Sample Sites



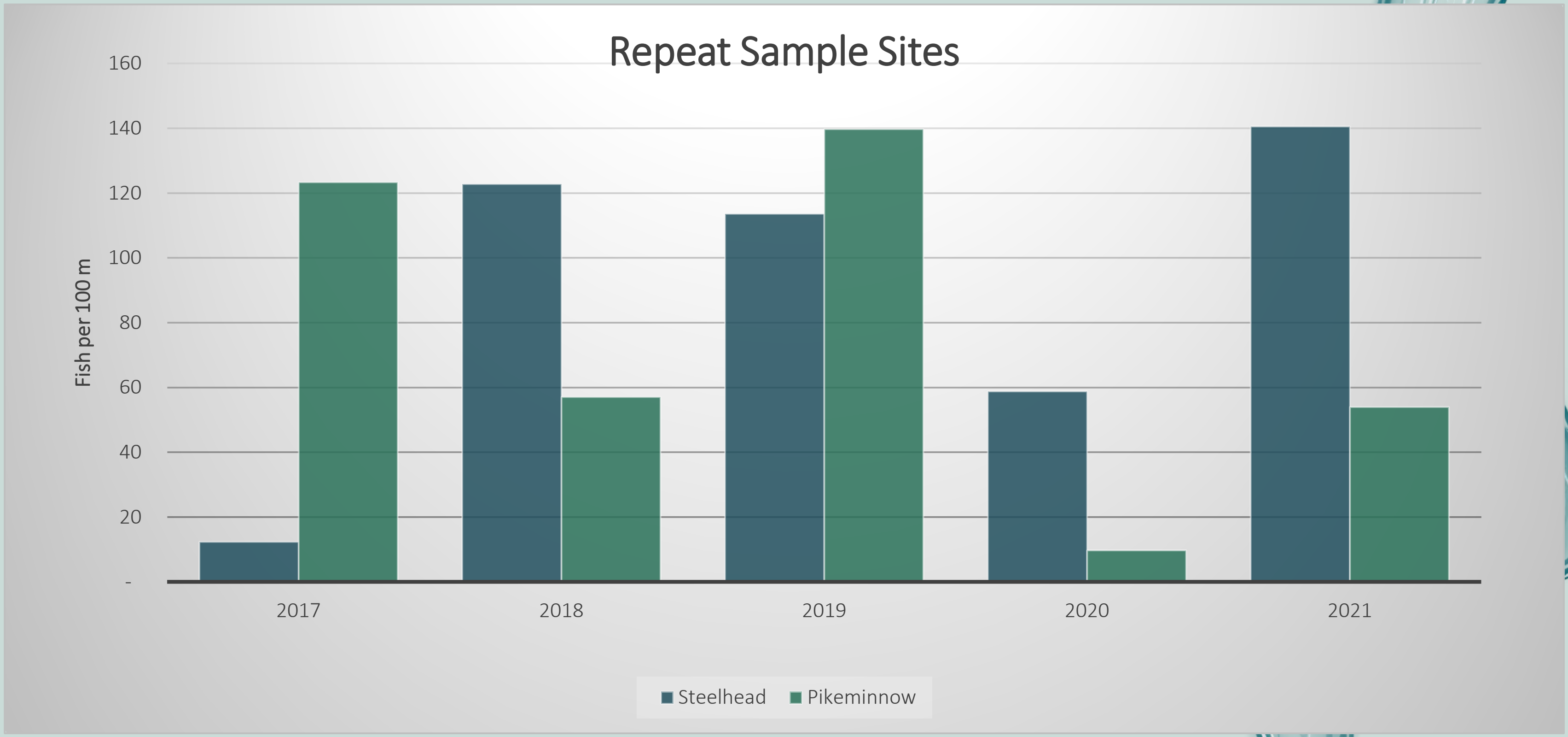
Predation Assessment



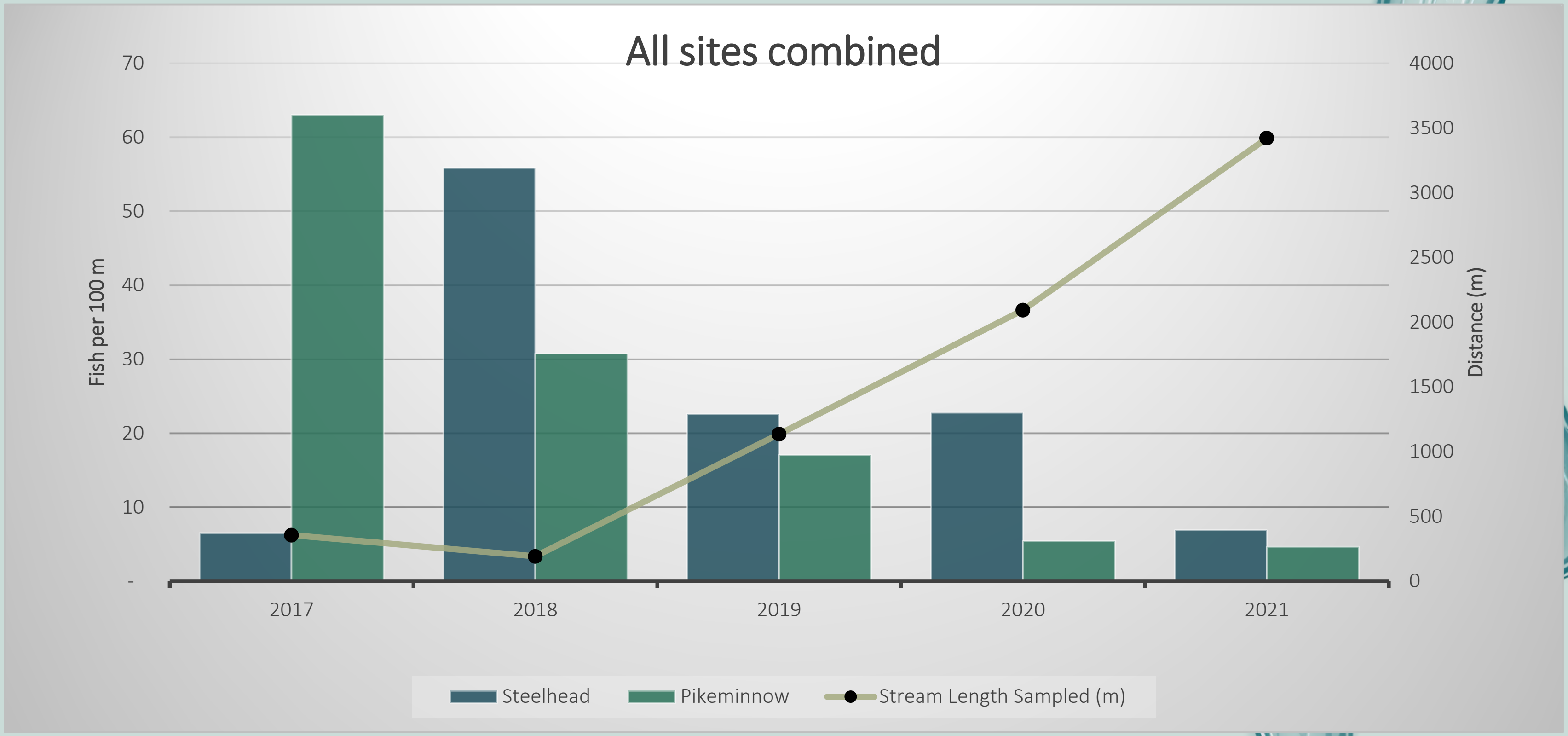
Reservoir Results

Season	Year	Pikeminnow Captured	Nets Deployed	Hours Sampling	Catch per unit effort
Fall	2005*	9	6	47	0.77
Fall	2006	19	6	264	0.29
spring	2007	5	9.5	240	0.05
Fall	2007	5	10.5	312	0.04
spring	2008	2	14.5	408	0.01
spring	2017	1	8.6	99	0.03
spring	2022	0	8.3	92	0.00

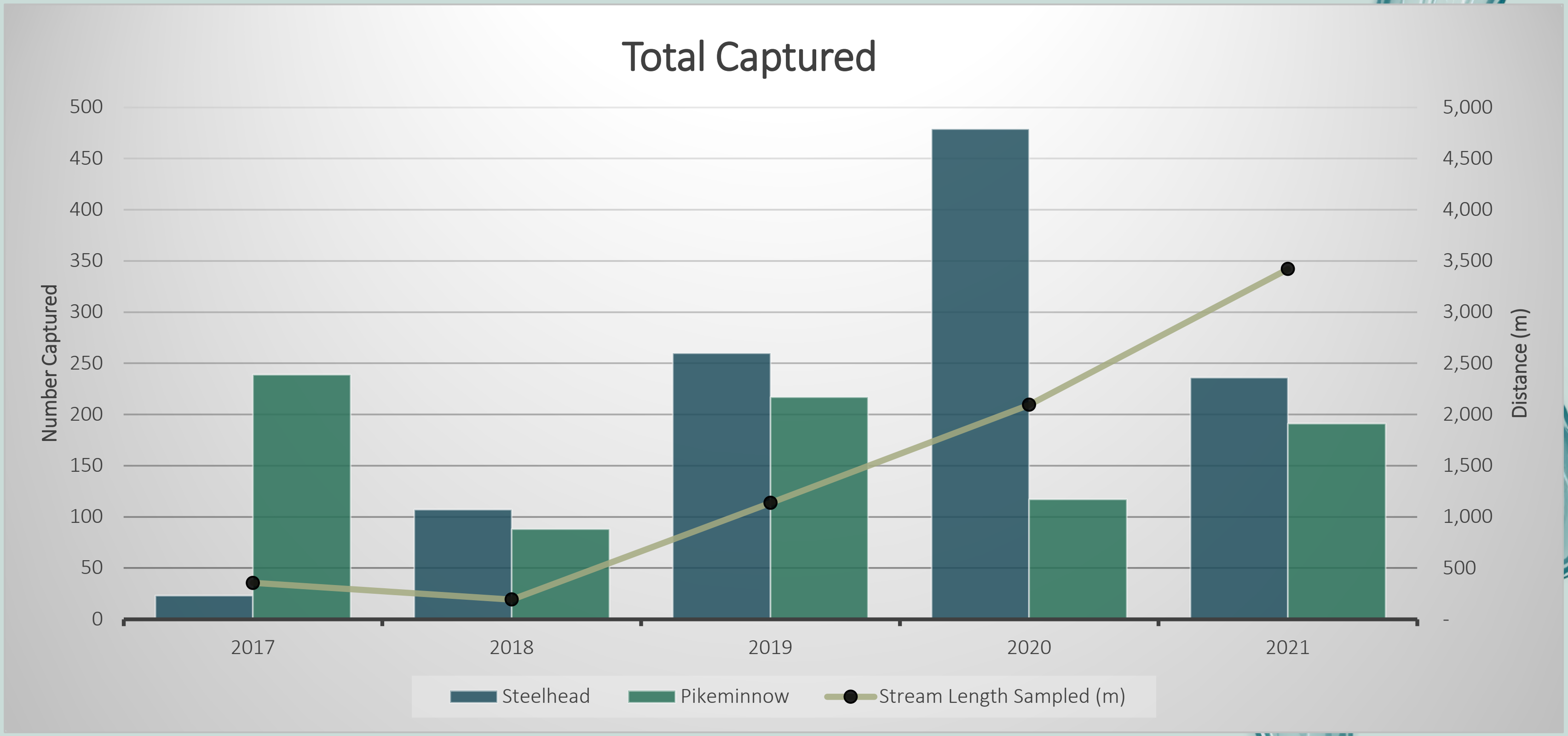
Stream Suppression Results



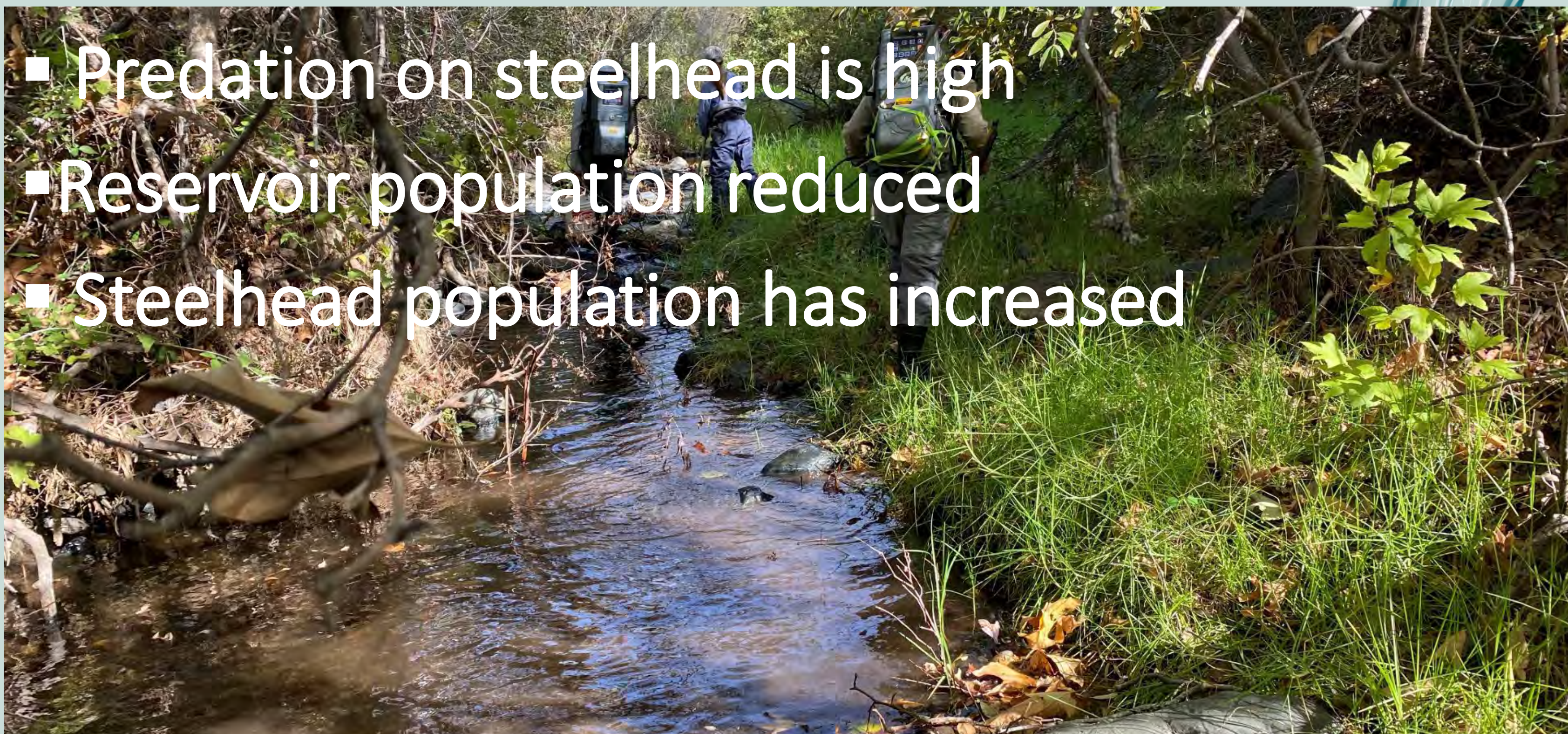
All Sites Combined



Total Captured



Summary



- Predation on steelhead is high
- Reservoir population reduced
- Steelhead population has increased

Discussion - Methods

- Backpack electrofishing
- Angling
- Spearfishing
- Seining

Next Steps

Acknowledgements

Morro Bay National Estuary Program

California Conservation Corps

NOAA Vets

Watershed Stewards Program

CDFW Prop 1 Funding

Informing management strategies for non-native predatory fishes through applied ecological studies

Lessons learned and insights from the Stanislaus River (2018 – 2022)

Salmonid Restoration Federation Conference, Santa Cruz, CA

April 19-22, 2022

Presenter: Matt Peterson

Co-Authors: Jason Guignard, Tyler Pilger, and Andrea Fuller

Acknowledgements

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Key Collaborators: NOAA Fisheries (California Central Valley Office and Southwest Fisheries Science Center), California Department of Fish and Wildlife (Region 4 and Fisheries Branch)

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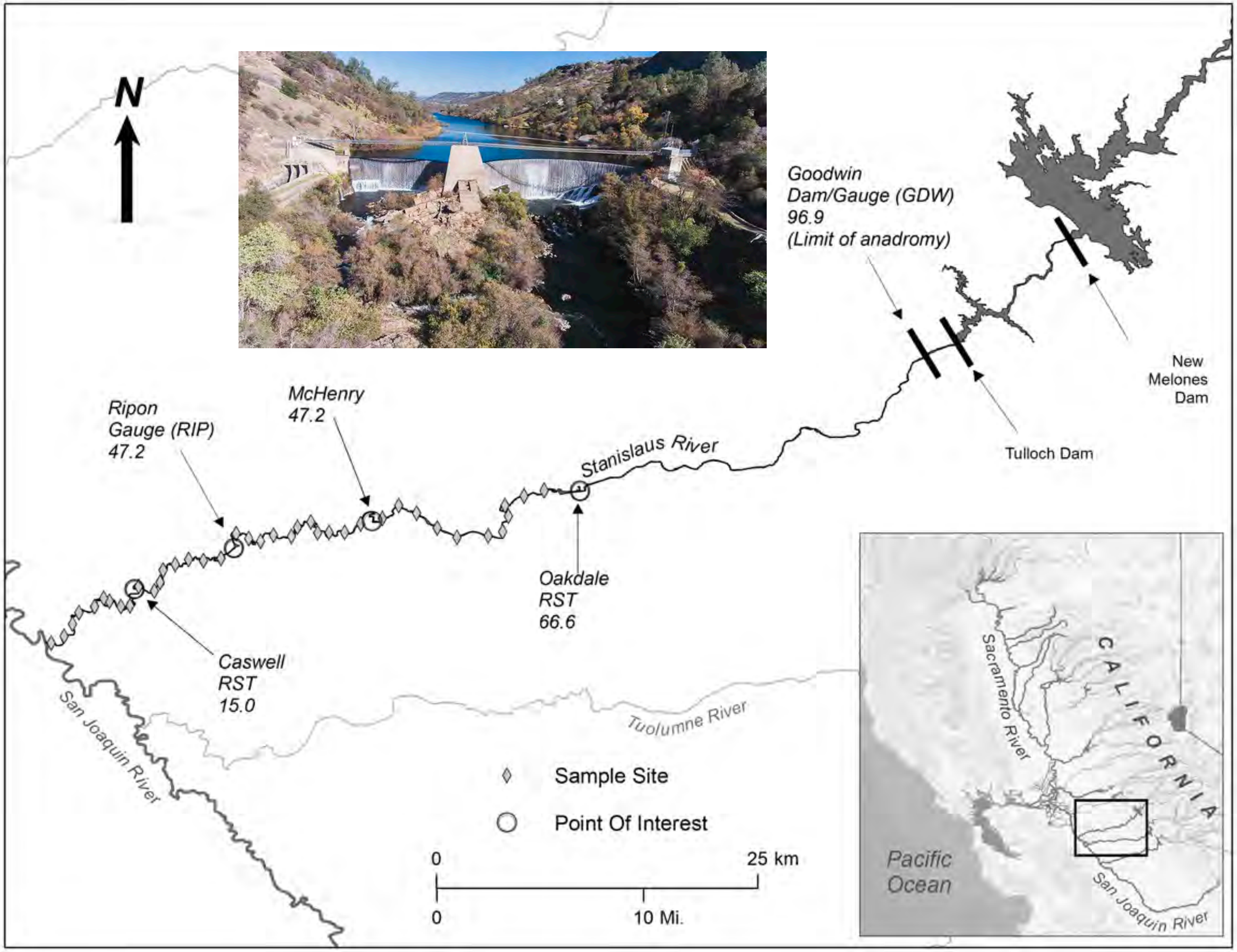
N
Goodwin
Dam/Gauge (GDW)
96.9
(Limit of anadromy)
New
Melones
Dam
Tulloch Dam
Ripon
Gauge (RIP)
47.2
McHenry
47.2
Stanislaus River
Oakdale
RST
66.6
Caswell
RST
15.0
San Joaquin River
Tuolumne River
Sample Site
Point Of Interest
0
25 km
0
10 Mi.
Sacramento River
CALIFORNIA
Pacific
Ocean
San Joaquin River

Low Survival of Native Fish

- Fall-run Chinook salmon
  - Anadromous
  - Juveniles outmigrate to ocean in winter/spring
  - Many CA CV populations experience low survival during this life stage

High mortality due to predation?

- Growing concern among fisheries researchers and managers
- Need for understanding **ecology** and use what we learn to inform **management** strategies

Three Main Questions For Today

1. Where are the predators located in the Stanislaus River?
2. When, where, and in what conditions does predation on Chinook salmon occur?
3. How can we use this rich dataset to inform management strategies and identify challenges?

Sampling Methods

- Boat electrofishing primary collection method at 39 300-m long sites that were repeatedly visited
- Fork length, scales, diet, PIT tag, release

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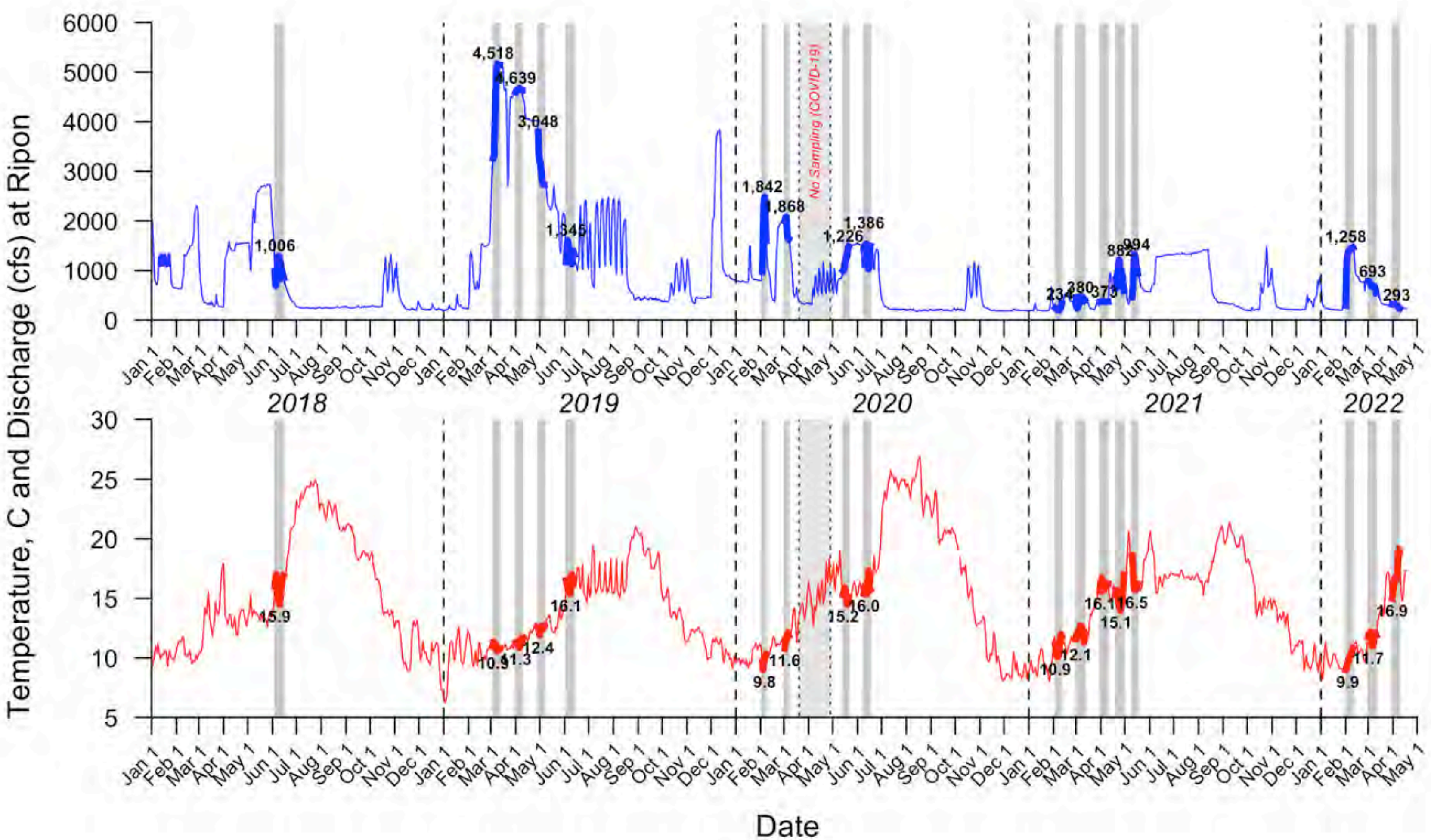
Sampling Conditions (2018-2022)



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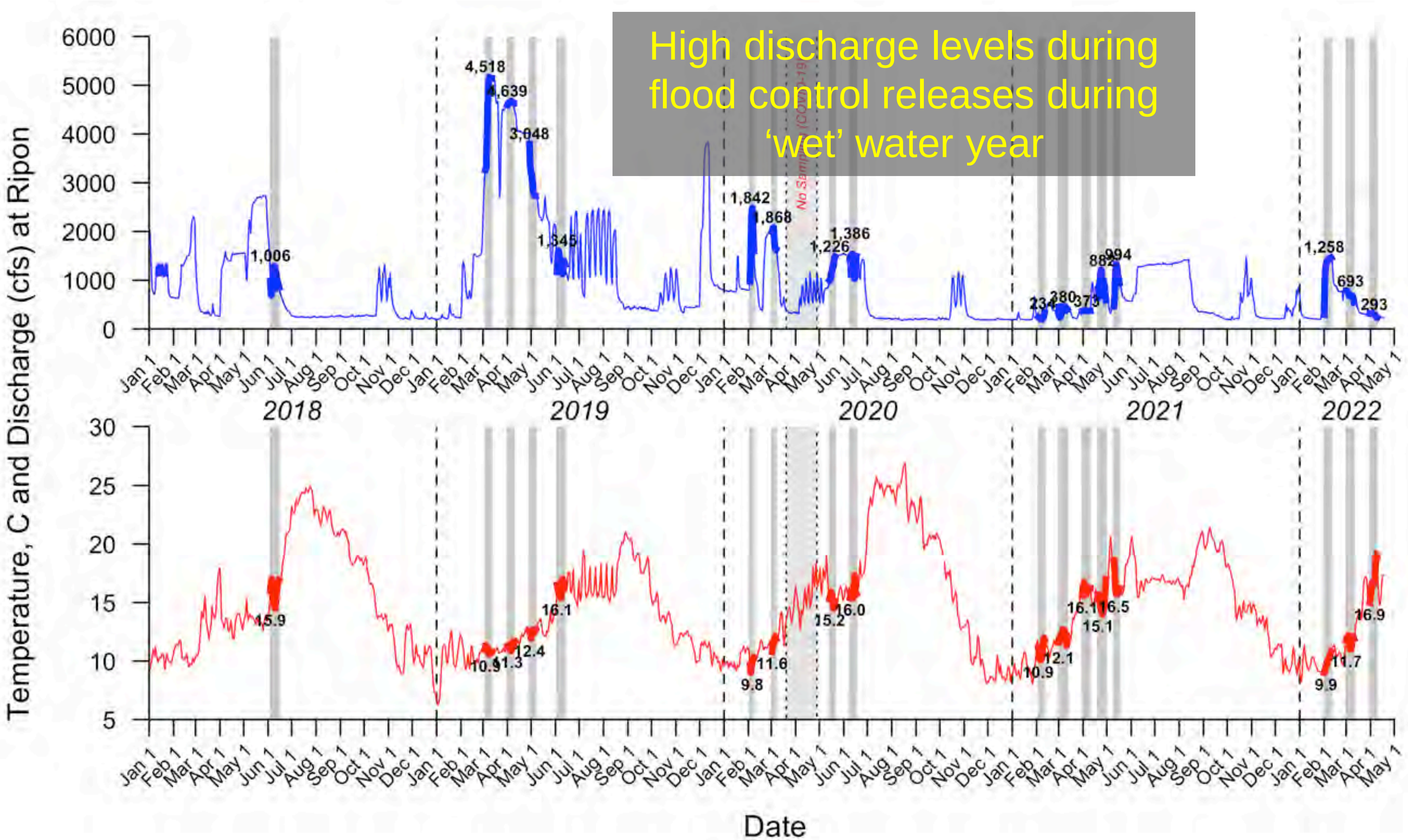

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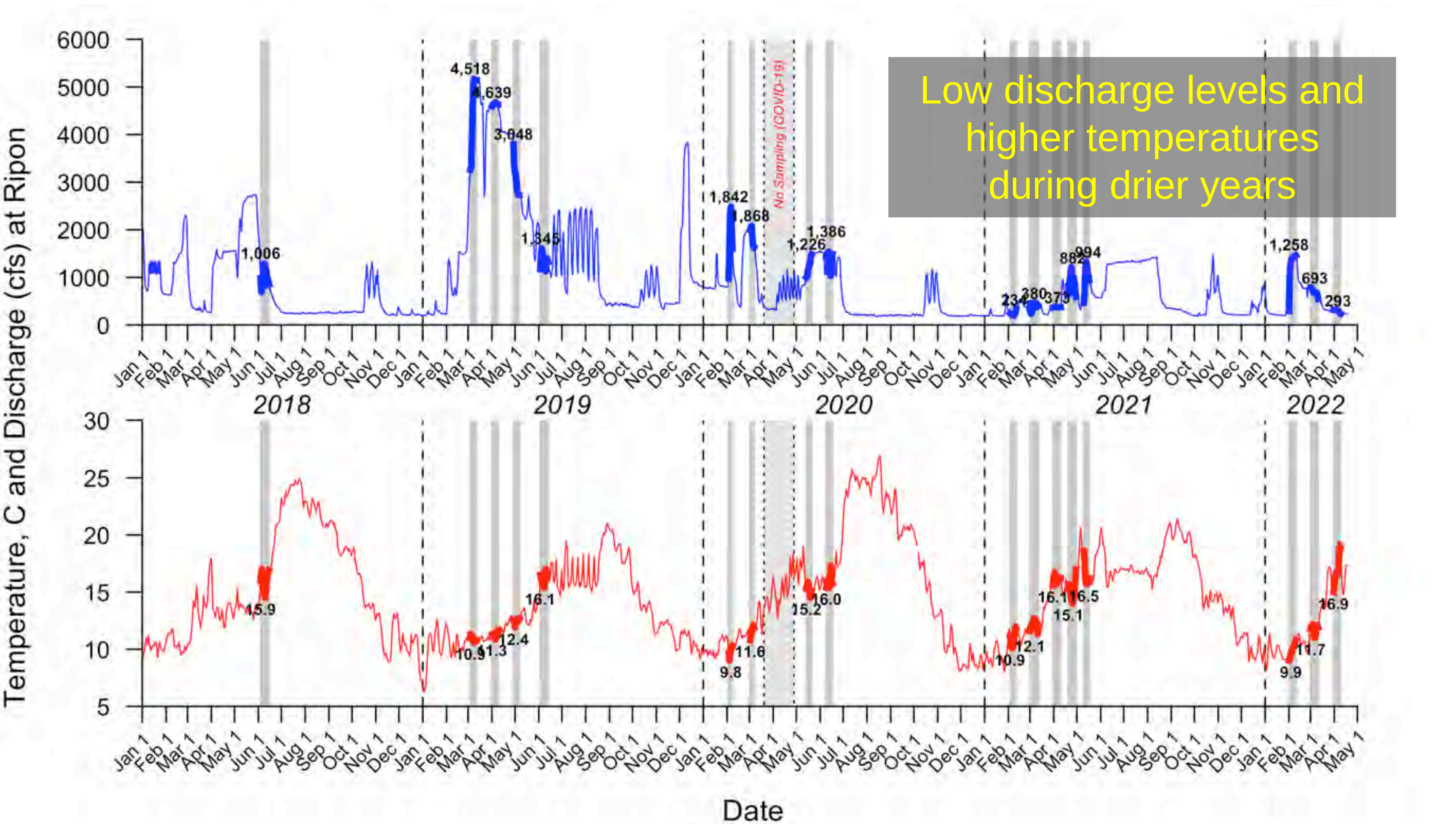
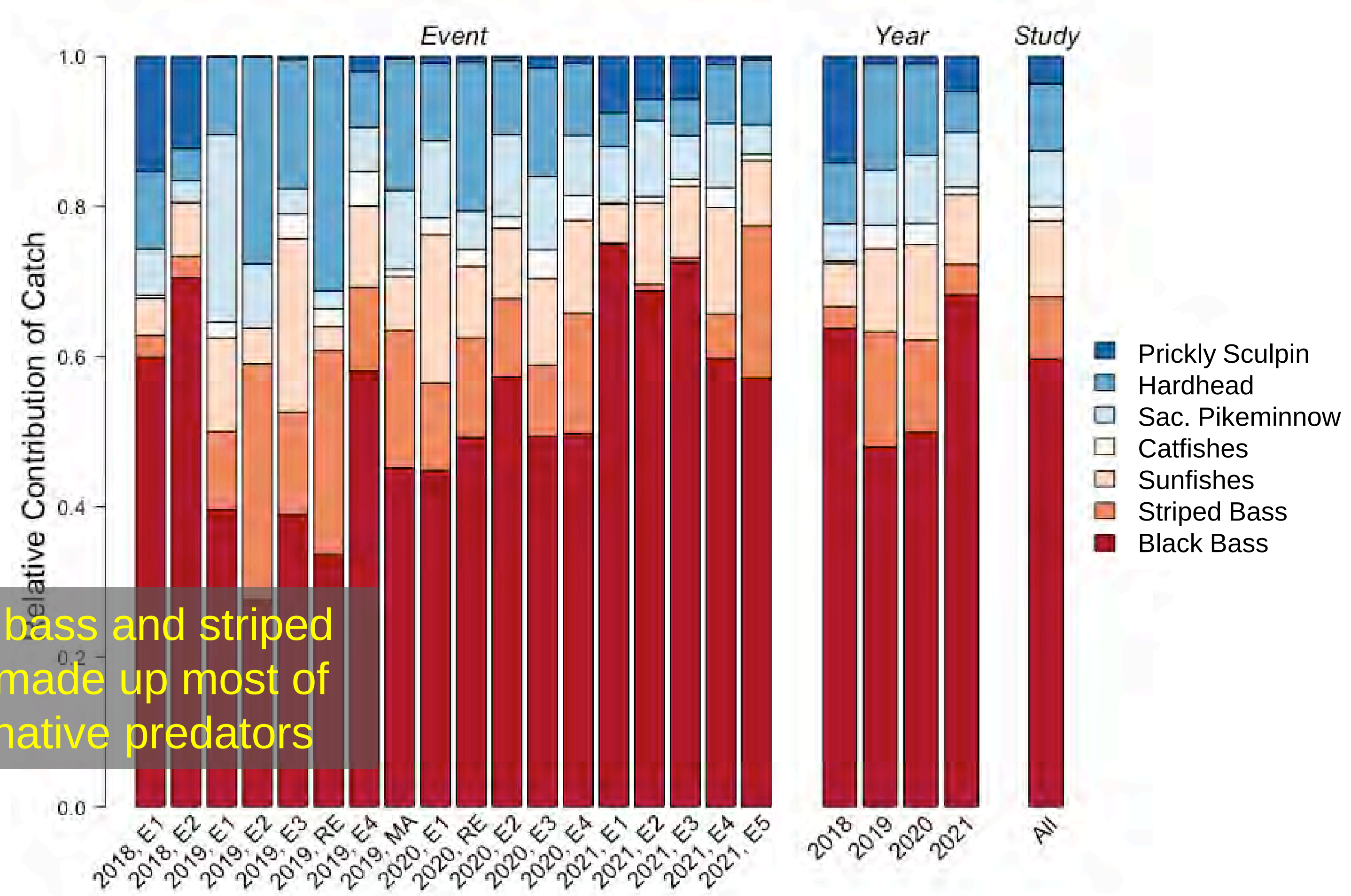
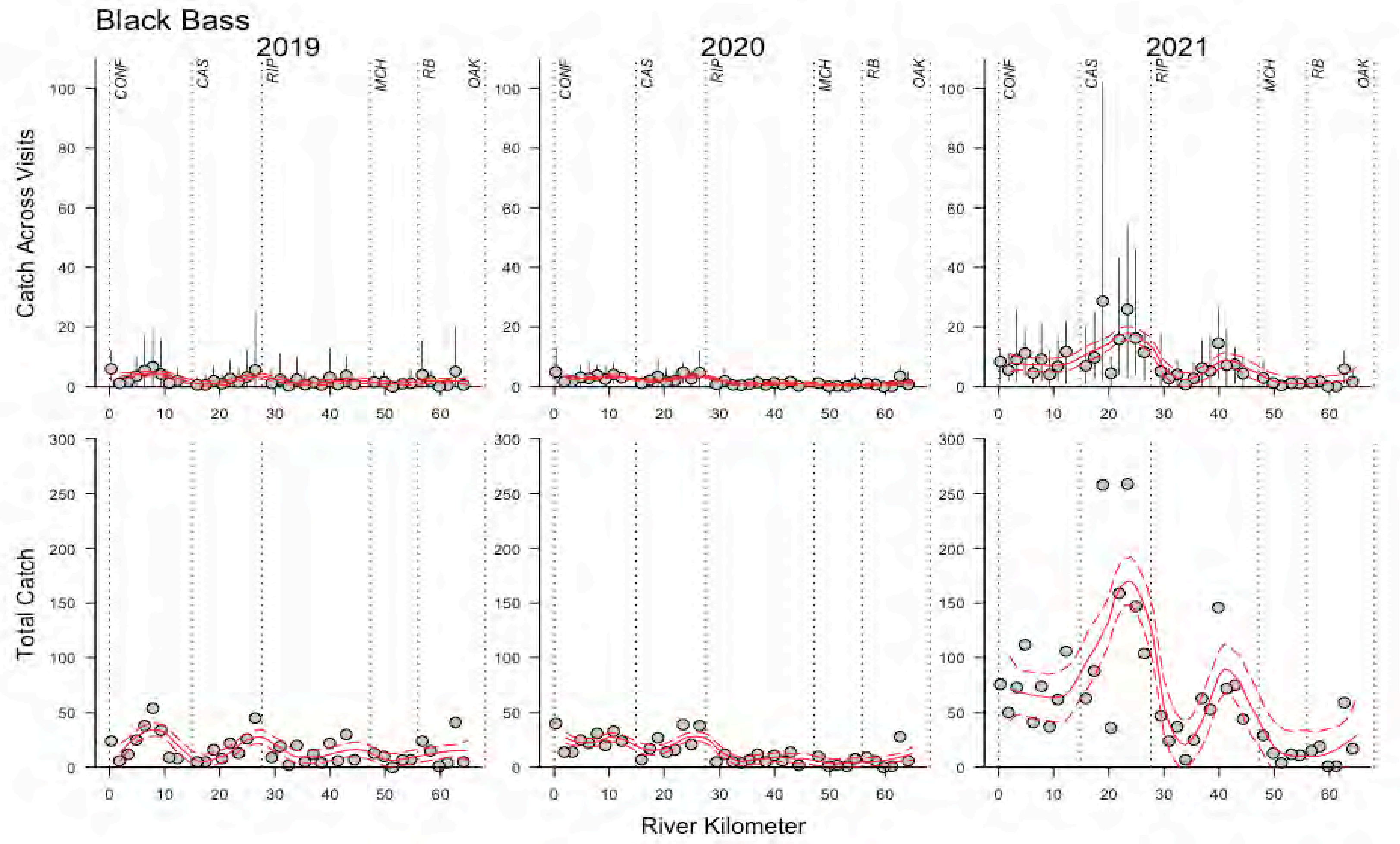


Consistent Predator Composition

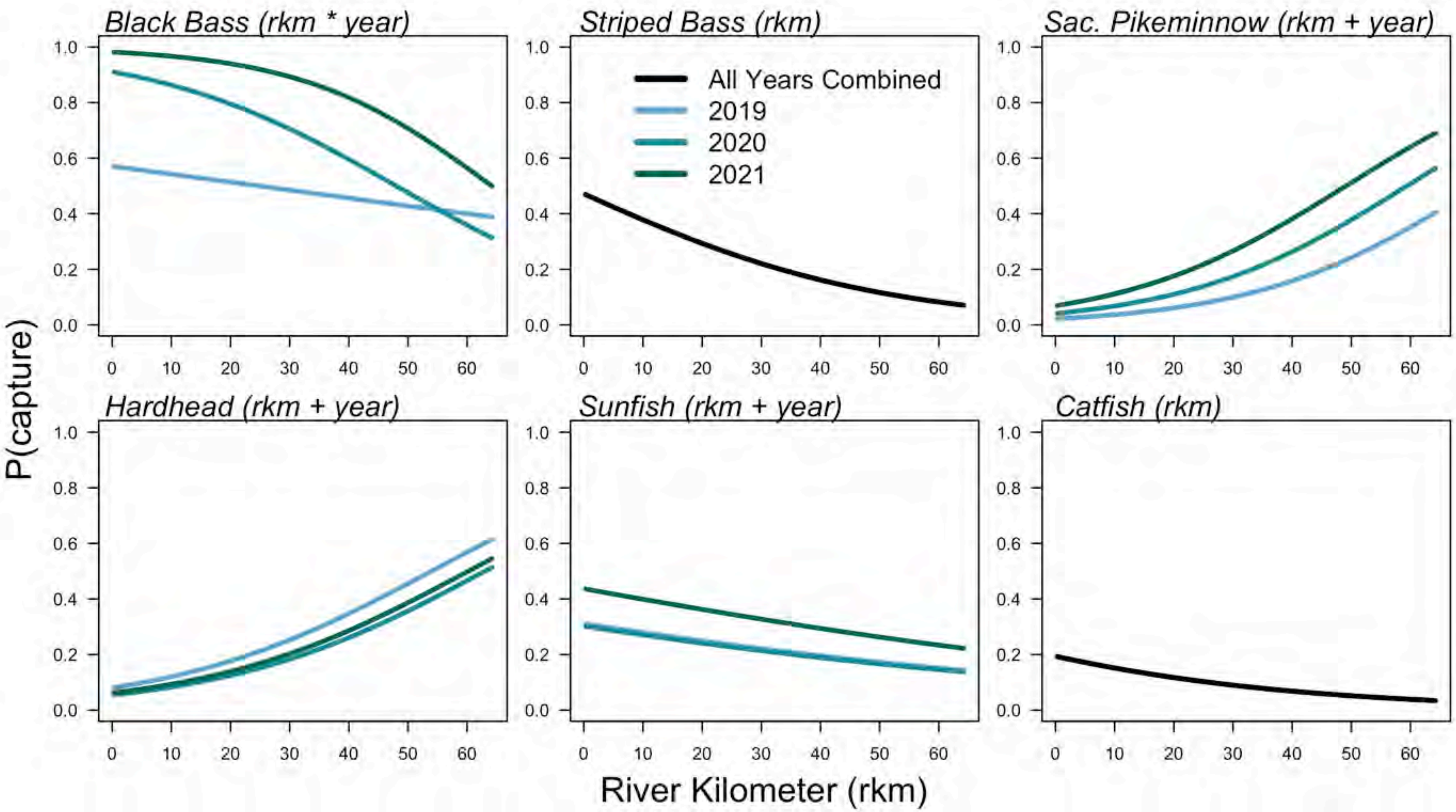


Black bass and striped bass made up most of non-native predators

Widespread Distribution of Black Bass



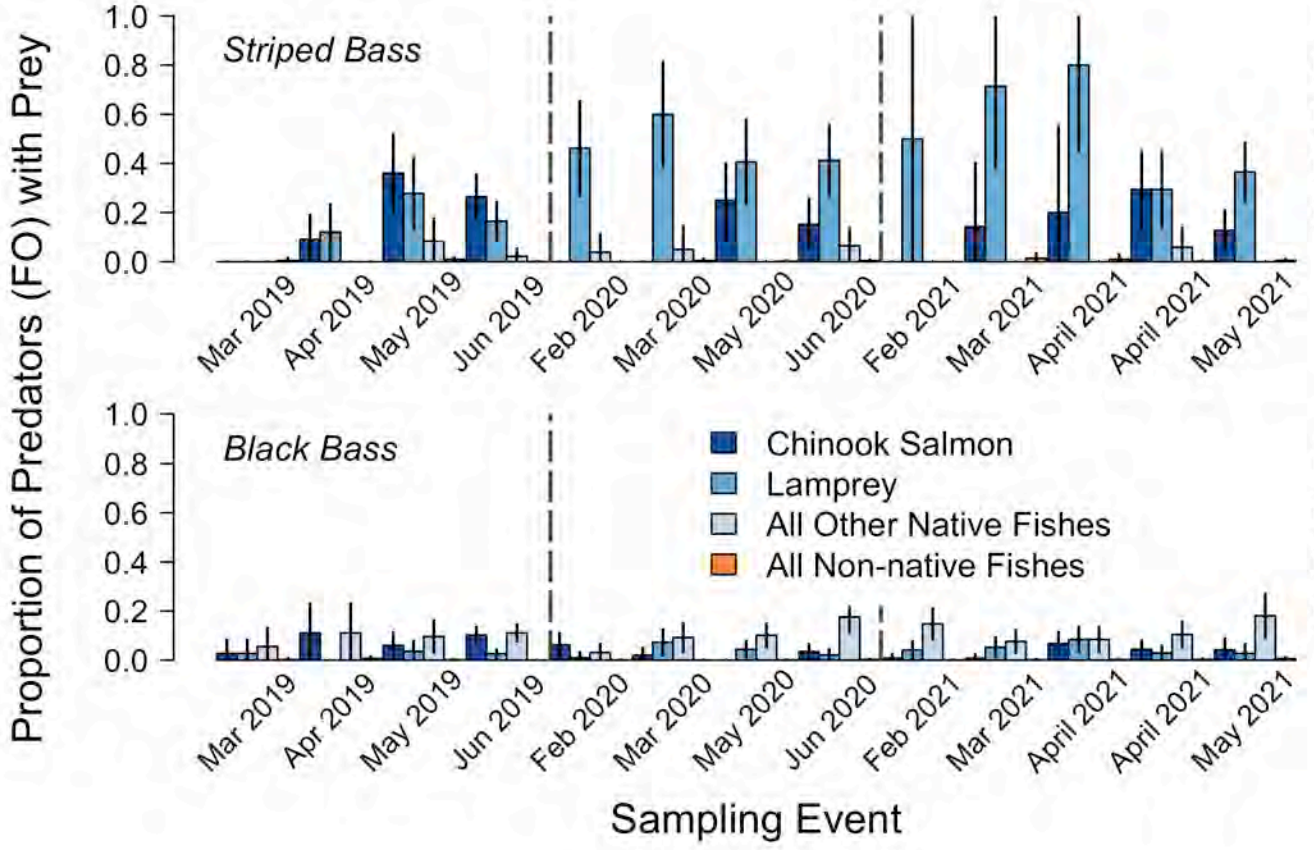
Differing Distributions Between Native and Non-Native Predators



Diet Composition

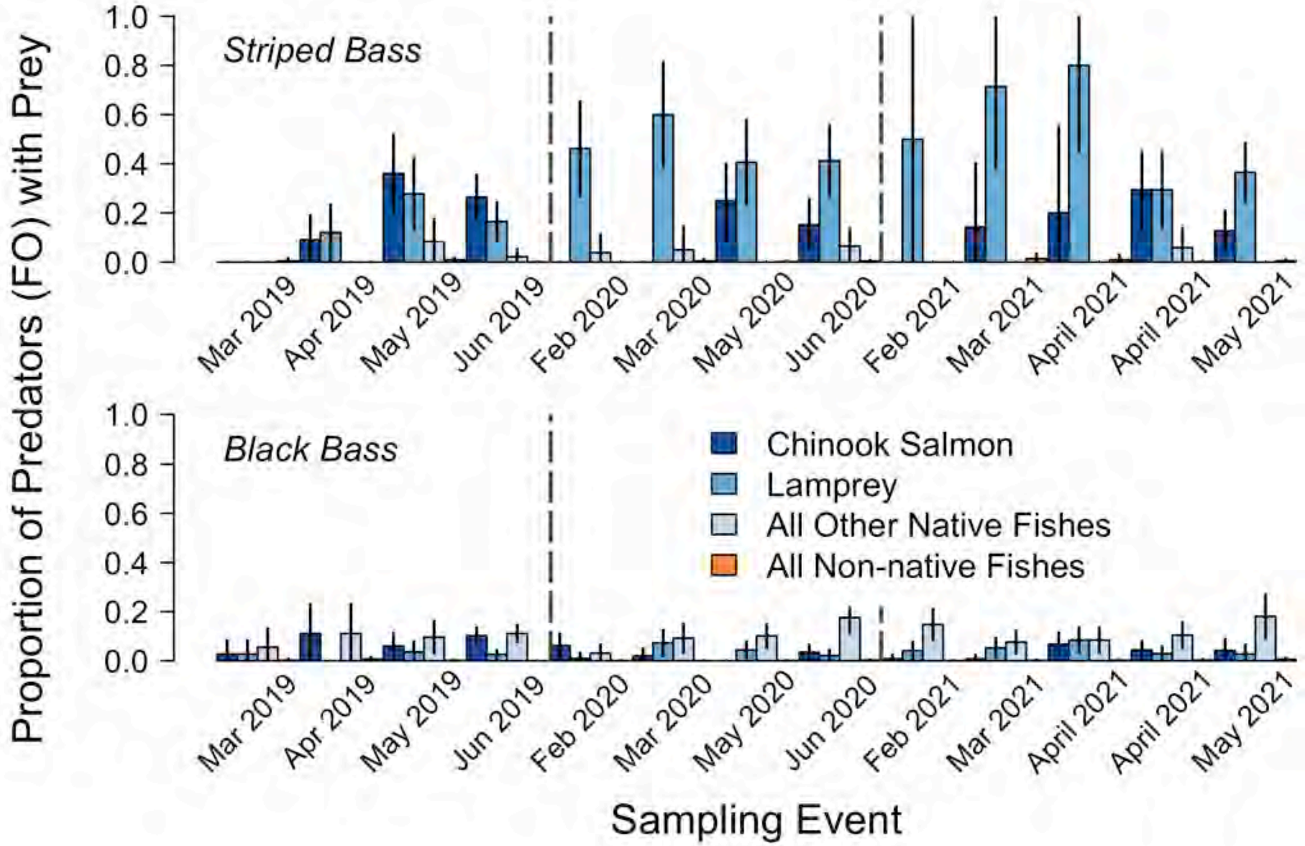
- Visual identification for all diet items
- For fish or suspected fish, used visual & genetic methods
- Used Frequency of Occurrence (FO) as primary metric
  - aka, a proportion

Consumption of Chinook salmon and other fishes



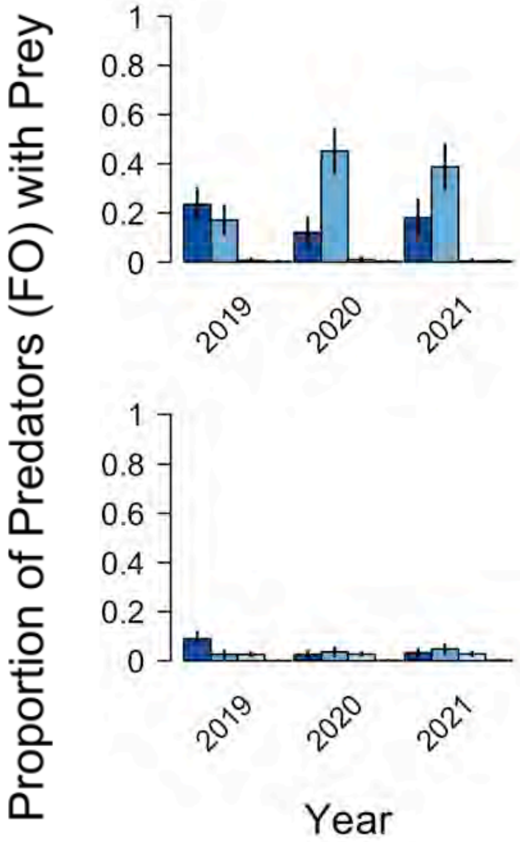
Across events, Chinook salmon consumed during every event with seasonal trend

Consumption of Chinook salmon and other fishes



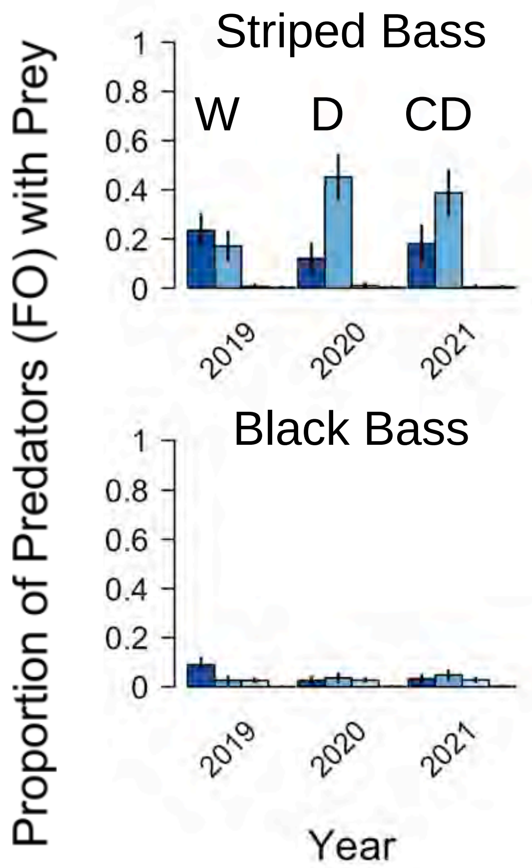
Native fishes consumed at higher frequencies than non-native fishes

Low Interannual Variation in FO for Striped Bass and Black Bass



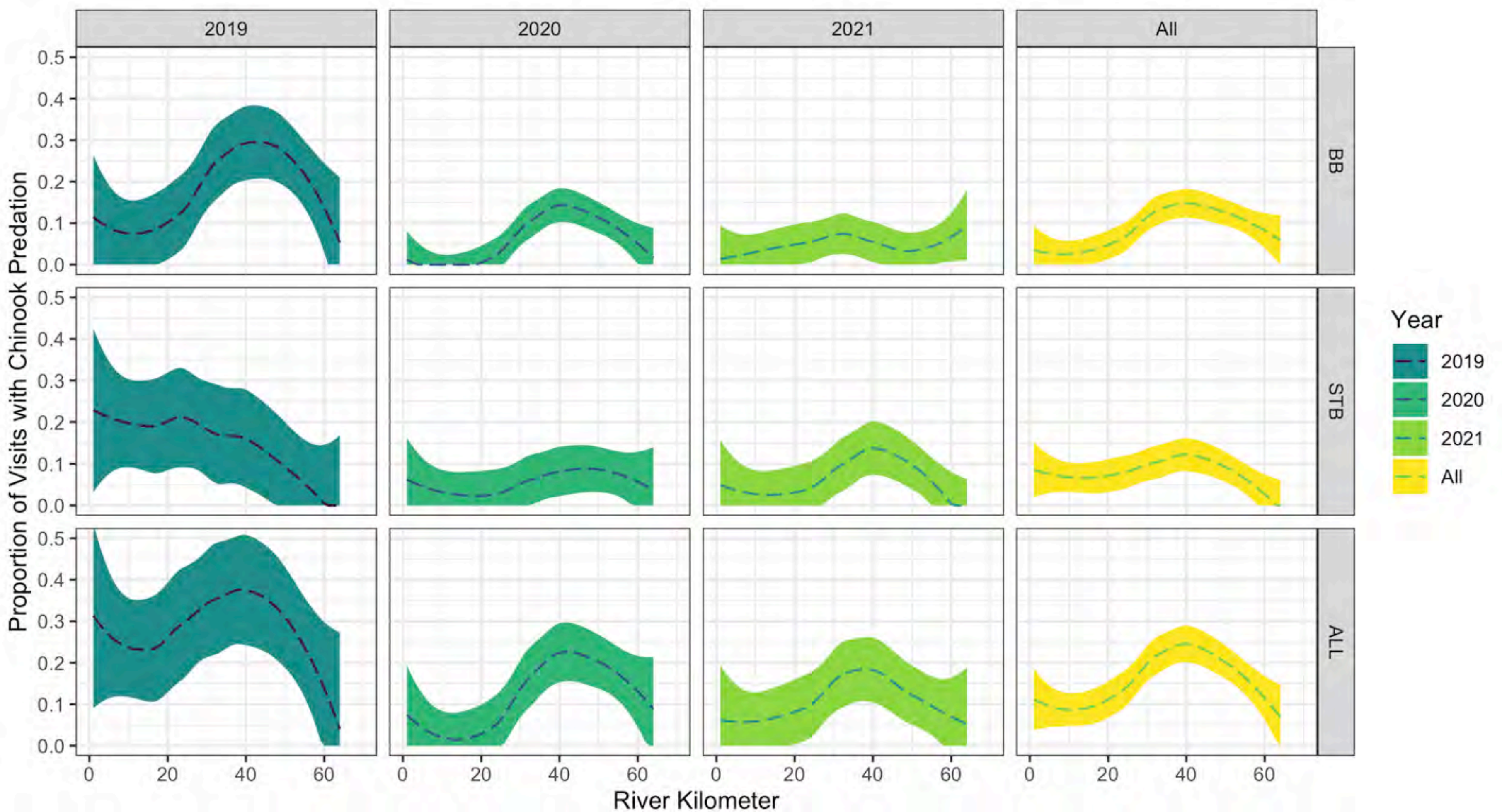
Striped bass consumed Pacific Lamprey at higher frequency than Chinook salmon

Low Interannual Variation in FO for Striped Bass and Black Bass



Higher frequency of Chinook salmon in 2019 (a wet year) vs. 2020 and 2021 (drier years)

Spatial Variation in Chinook Salmon Consumption



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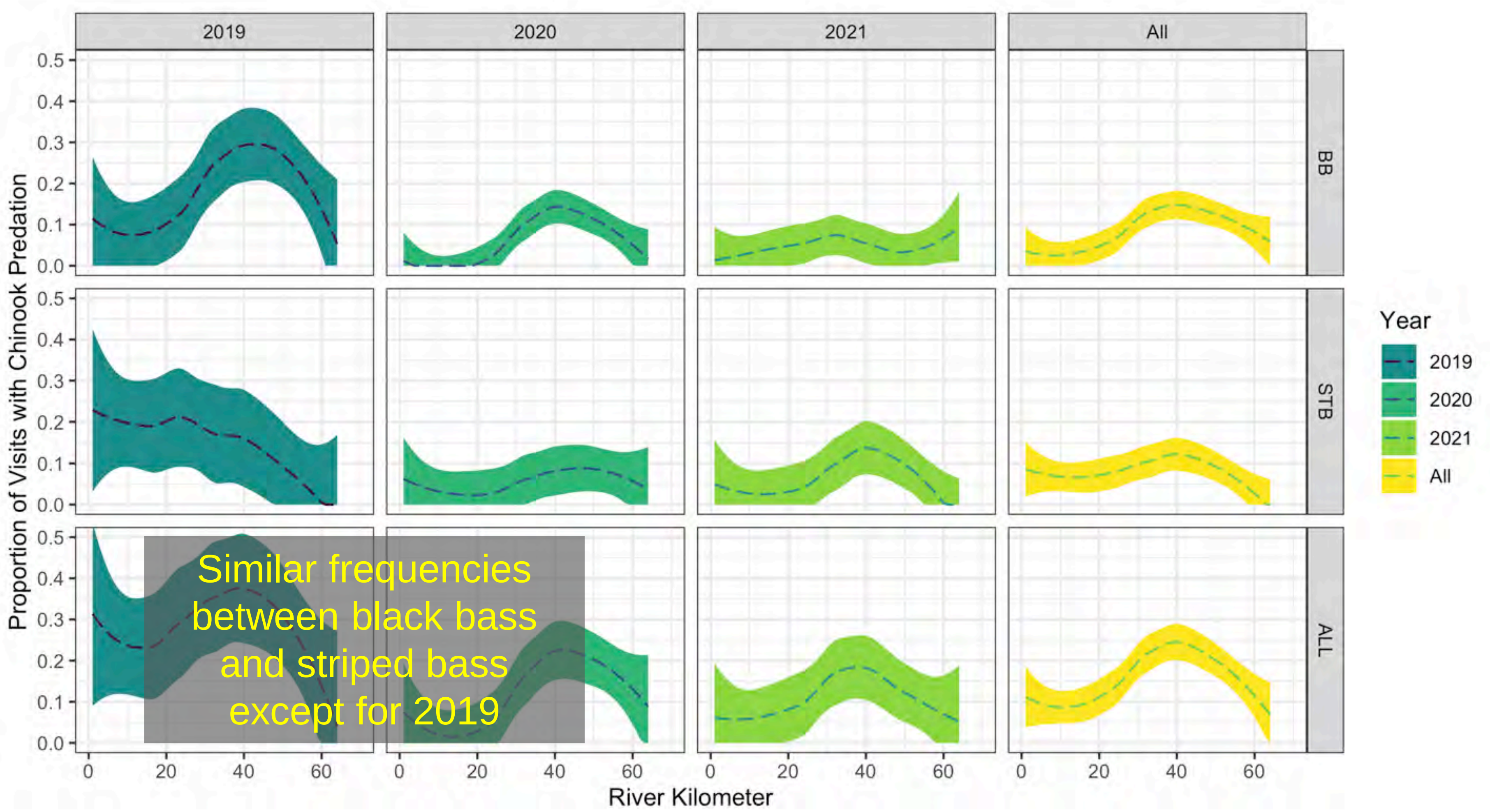

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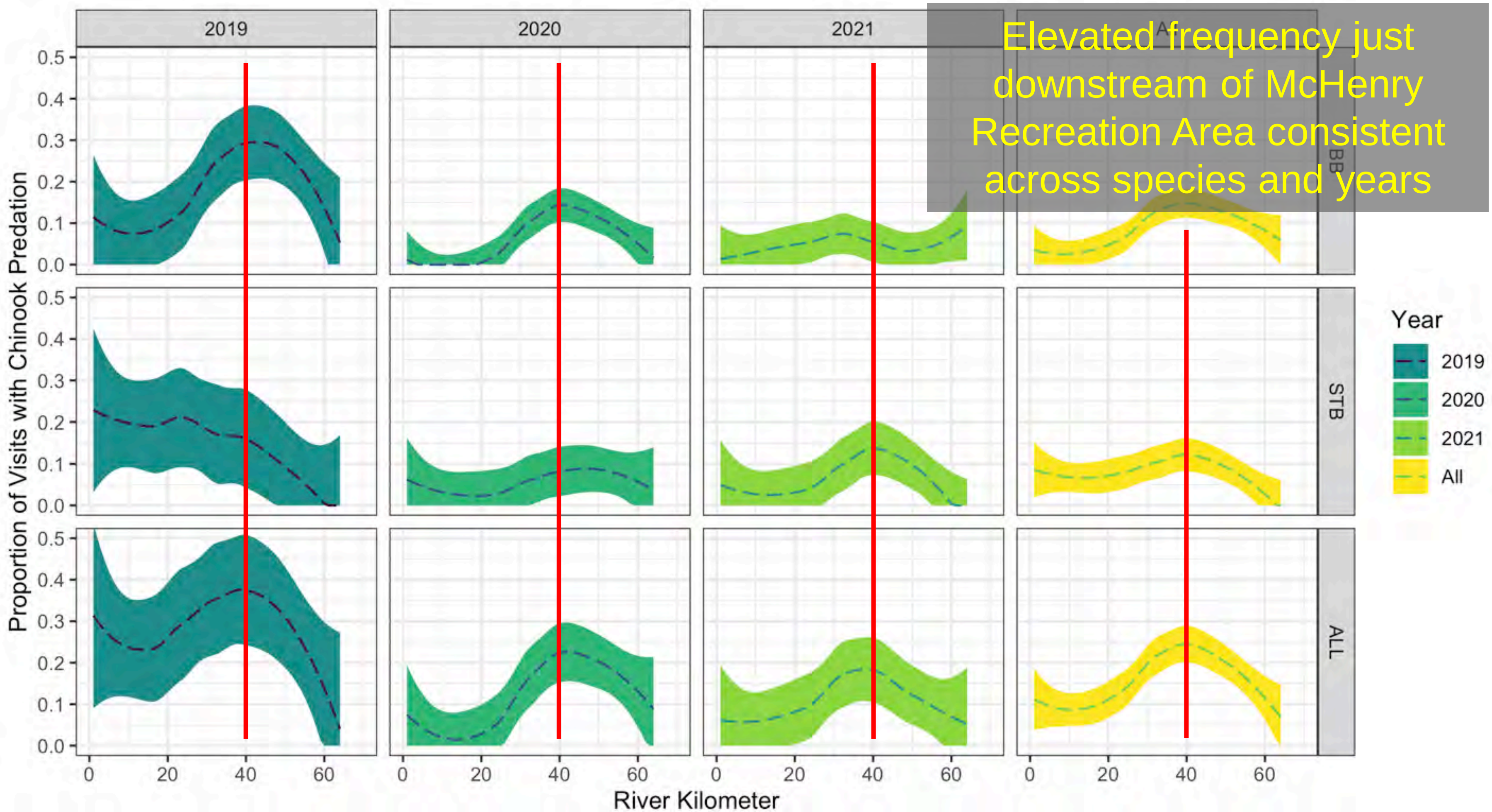
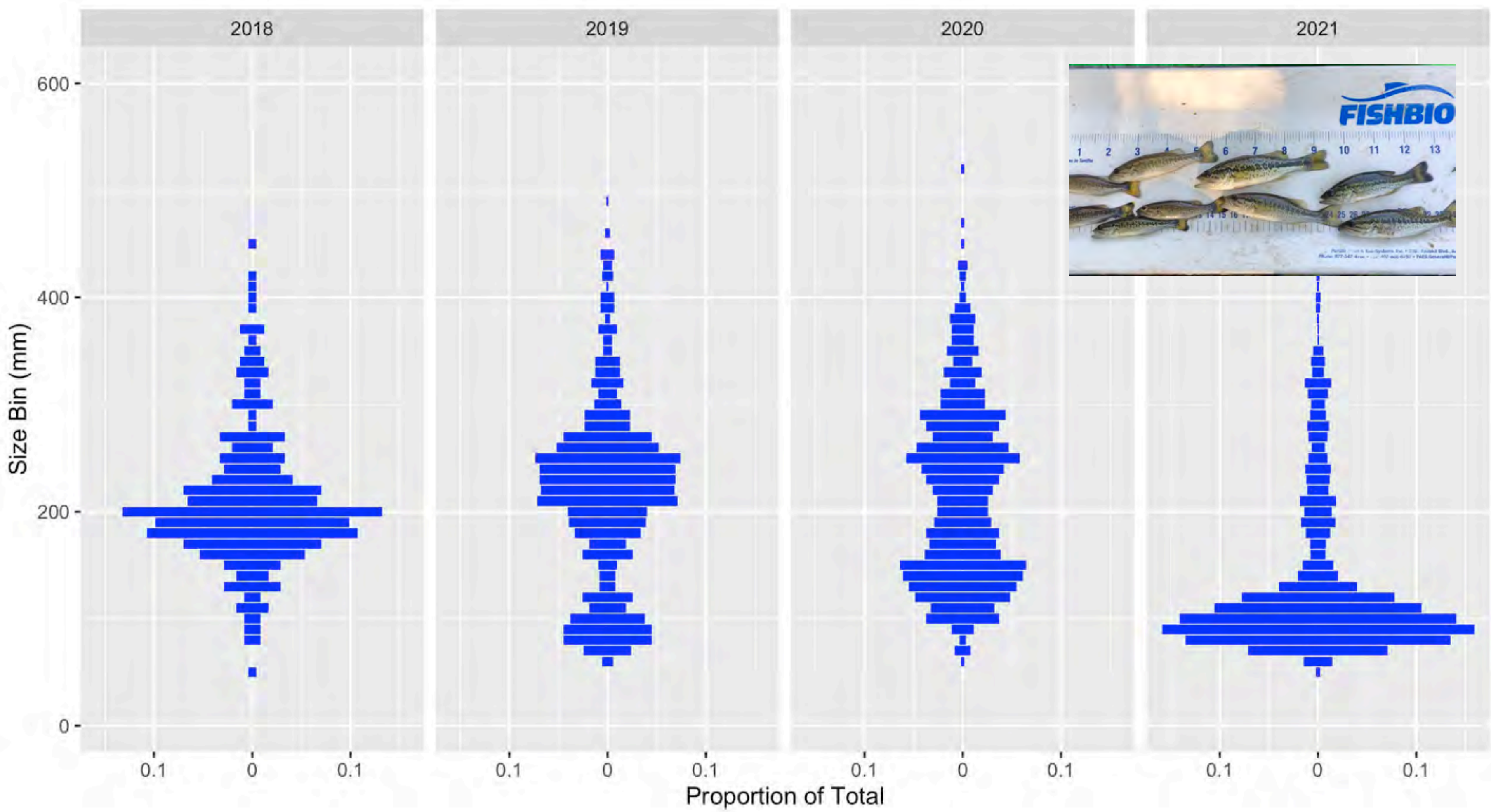


Elevated frequency just downstream of McHenry Recreation Area consistent across species and years

Large Recruitment Event of Black Bass



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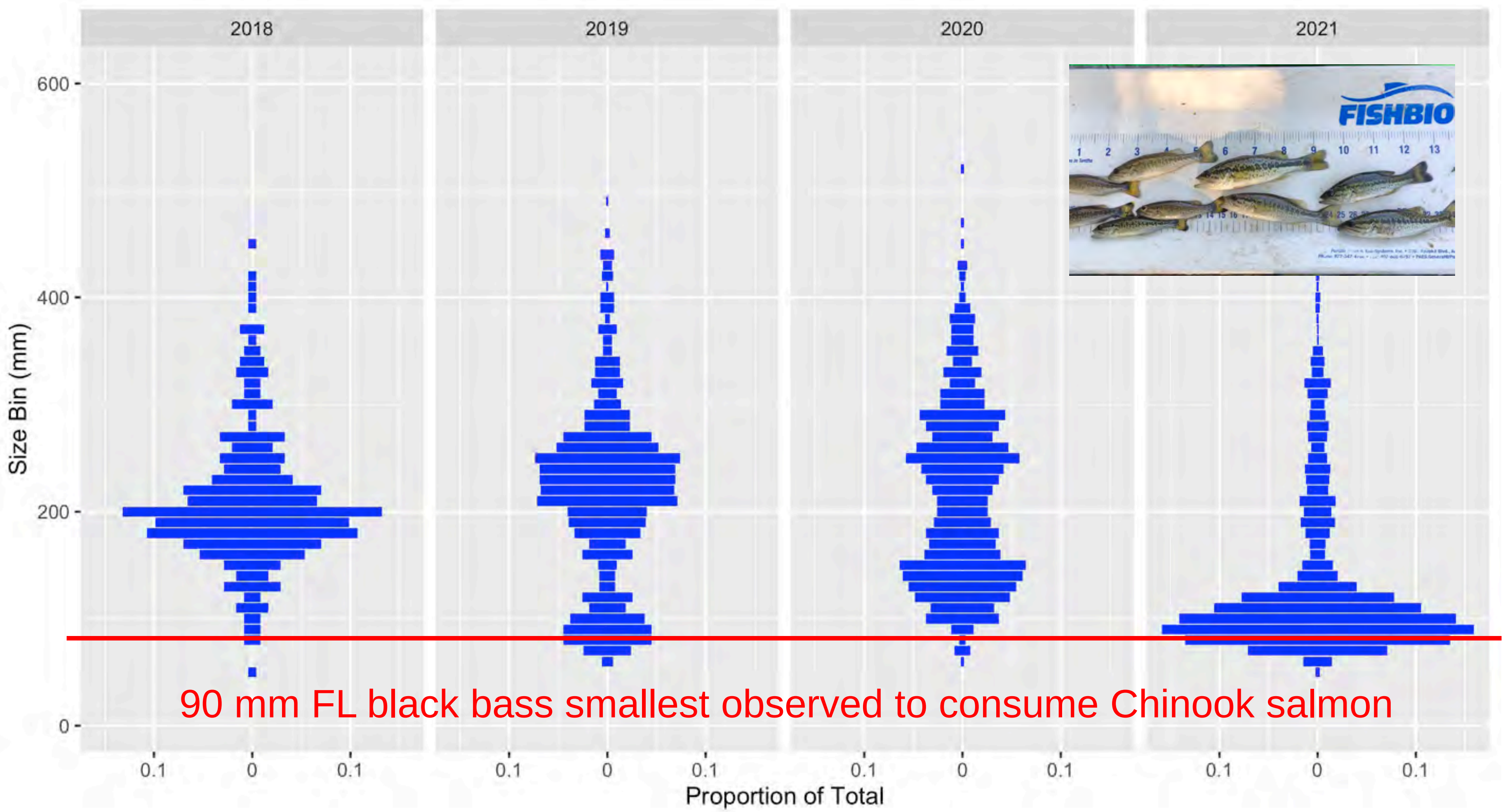
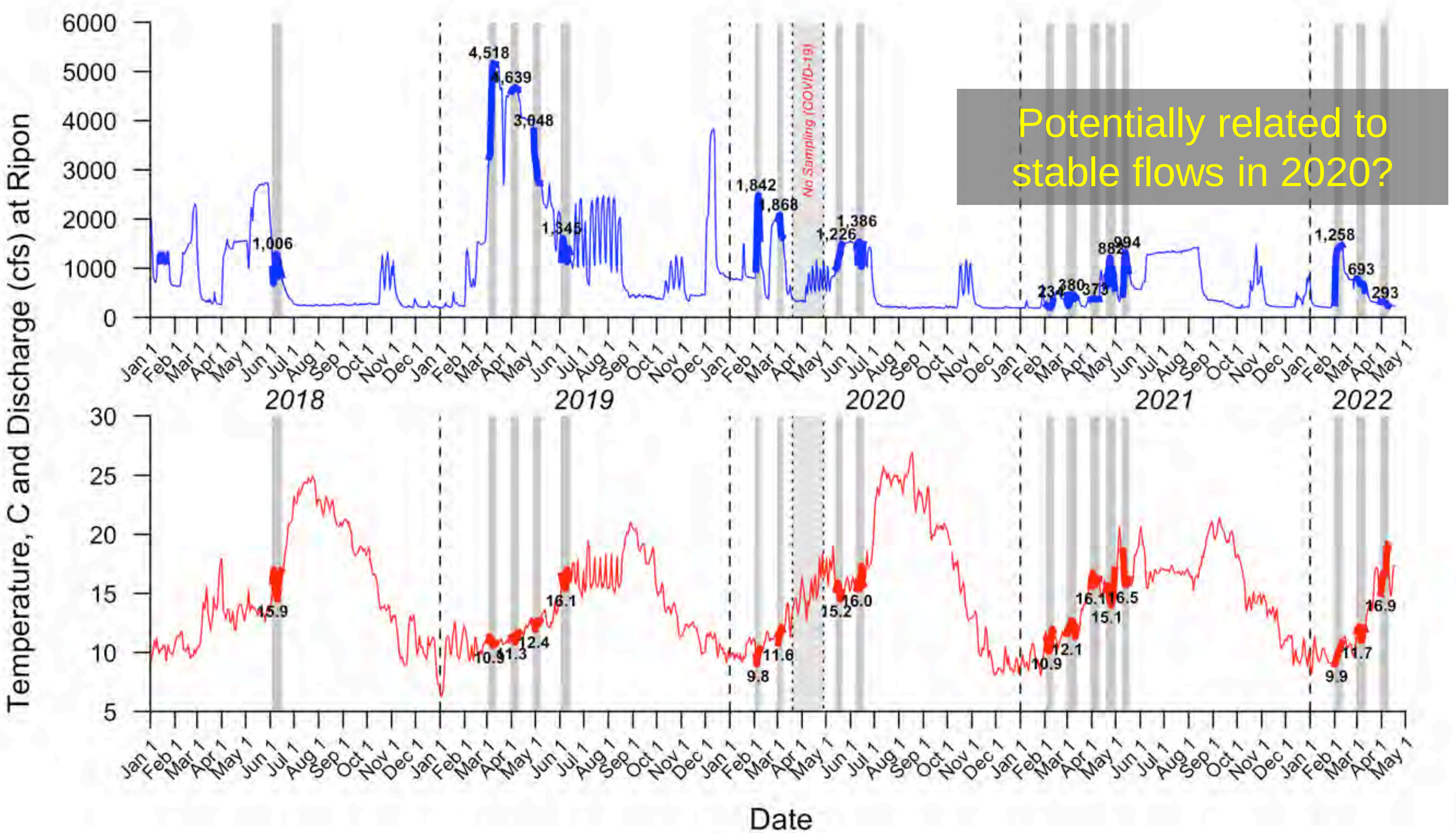


Sampling Conditions (2018-2022)



Potentially related to stable flows in 2020?

Take Home Points

First Question: Where are the predators located in the Stanislaus River?

- *Non-native predators more frequent downstream, native predators more frequent upstream*

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- *Black bass ubiquitous throughout study reach*

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Second Question: When, where, and in what conditions does predation on Chinook salmon occur?

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Second Question: When, where, and in what conditions does predation on Chinook salmon occur?

- *Predation on Chinook salmon observed during every sampling event*
- *Most frequent just below McHenry Recreation Area (rkm 40)*
- *Clear seasonal trend, but occurred across all discharge and temperatures*

Take Home Points

Third Question: How can we use this rich dataset to inform management strategies and identify challenges?

- *Two main predators with widespread distributions and different recruitment patterns*
- *Multiple native, anadromous prey species*
    - *Steelhead, Chinook salmon, and Pacific lamprey*
- *Dynamic population-level processes of predator and prey species*

Take Home Points

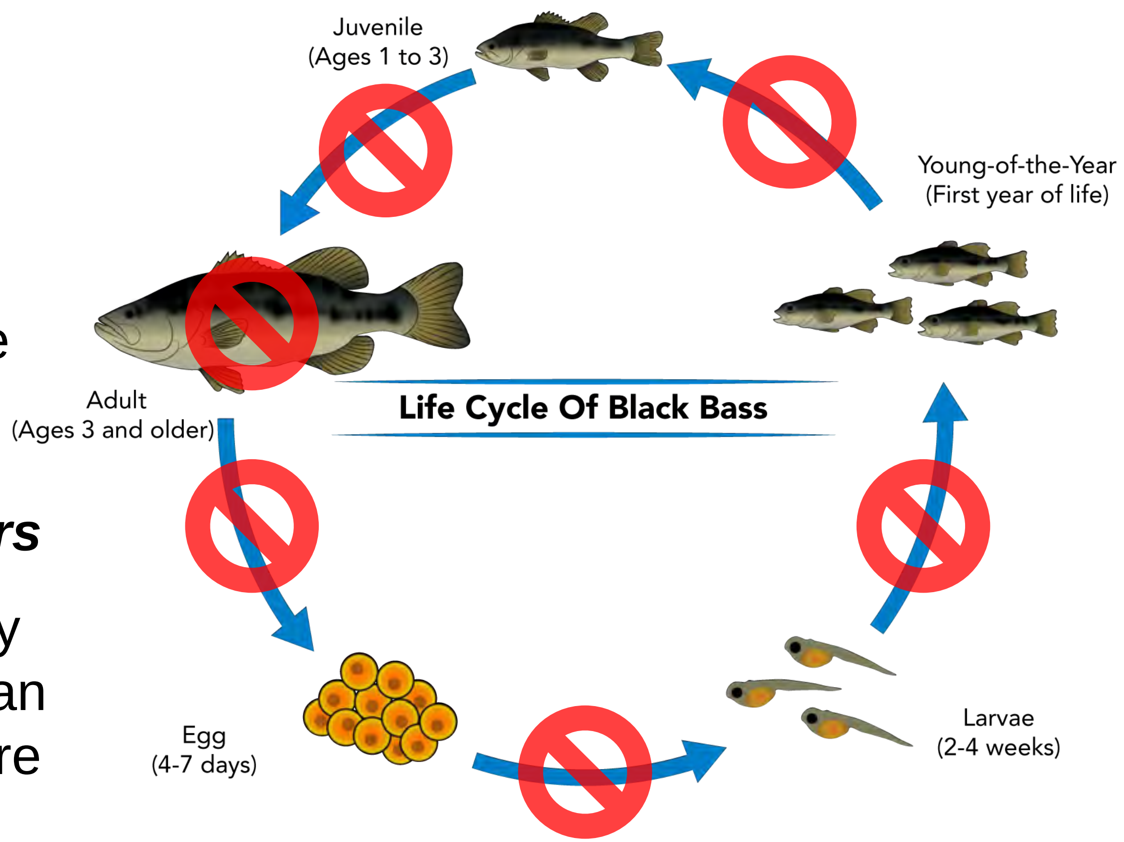
Third Question: How can we use this rich dataset to inform management strategies and identify challenges?

- *Multiple predators with widespread distributions and different recruitment patterns*
- *Multiple native, anadromous prey species*
  - *Steelhead, Chinook salmon, and Pacific lamprey*
- *Dynamic population-level processes of predator and prey species*

Large-scale, holistic, short- and long-term management actions that are adaptive through time and account for variable conditions

Short- and Long-Term Actions

- Targets today's predators ***and the demographic processes*** (e.g., survival from egg to larvae) that determine abundance and impact to juvenile Chinook salmon in ***future years***
- Depending on efficacy of targeted actions, can tailor approach to more effectively suppress predator populations



Questions?

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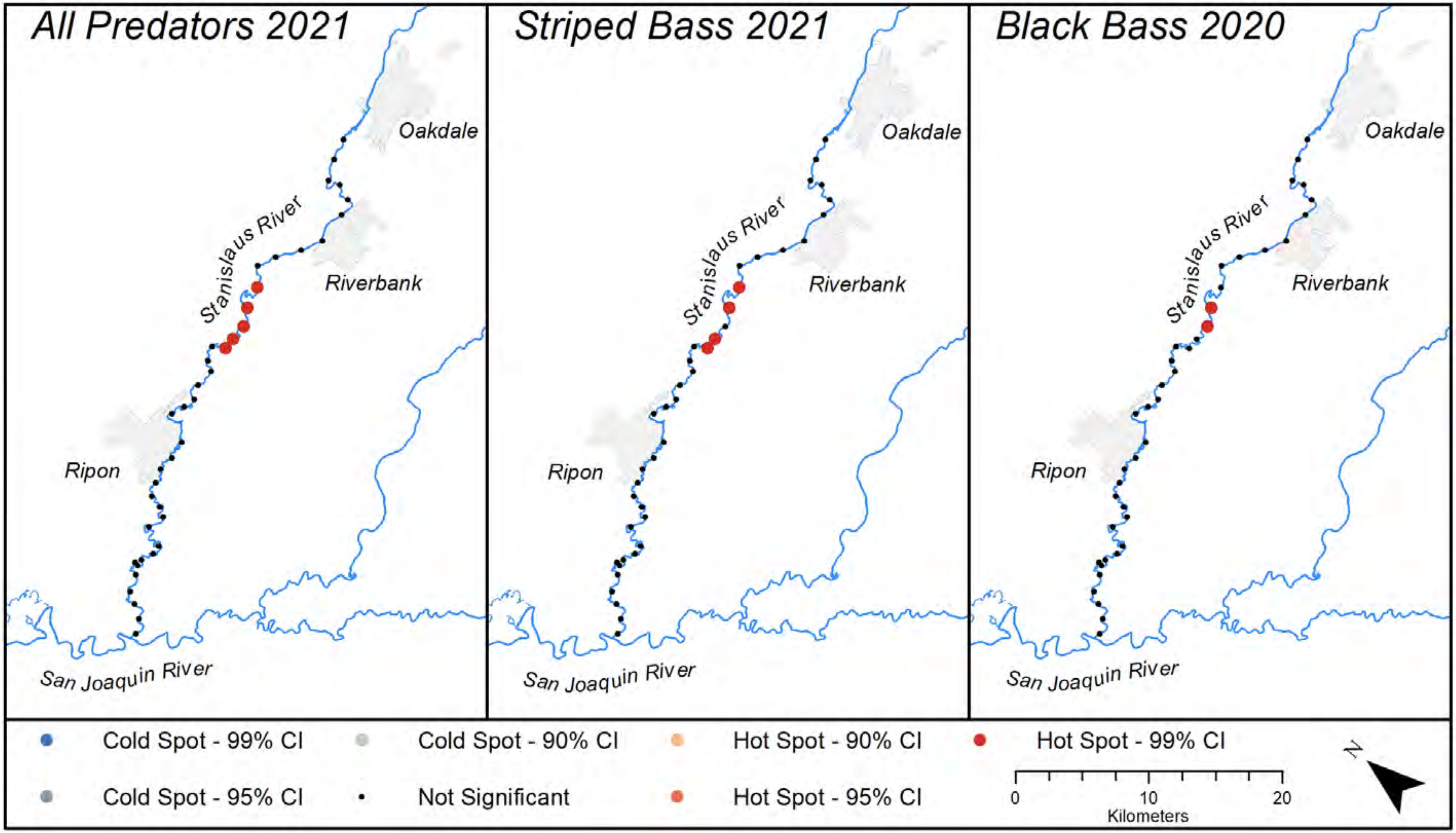
WIIN Act of 2016

Key Requirements of Predator Research Program:

- Evaluation of how predator populations are affecting juvenile Chinook salmon survival
- Establish removals of predatory fish
- Assess how removals affect juvenile Chinook salmon survival
- Develop research questions jointly with NOAA Fisheries
- Conduct research from 2017 to 2021

Evidence for Predation Hotspots?



Potential Actions

- *Physical removals + actions to reduce spawning success*
- Potential methods include:
- Spawning disruption
- Nest destruction
- Targeted pulse flows to disrupt spawning (also may benefit Chinook salmon)
- Removal of males that guard nests