Thiamine Deficiency in California Salmon and Steelhead

A Concurrent Session at the 41st Annual Salmonid Restoration Conference
Santa Rosa, California, March 26-29, 2024

Session Coordinator: Nate Mantua, *Southwest Fisheries Science Center*

Thiamine deficiency was first detected in California's Central Valley Chinook salmon fry in early 2020, and has since been documented in at least some of California's steelhead, coho and Chinook salmon populations every year since then. This session invited presentations on any aspects of thiamine deficiency relevant to this emergent stressor on California's salmon and steelhead.

Presentations

Widespread thiamine deficiency found in California salmon

Nate Mantua, NOAA, Southwest Fisheries Science Center Santa Cruz, CA
nate.mantua@noaa.gov

NOAA: **Rachel Johnson**, Nate Mantua, John Field, Steve Lindley, Tommy Williams, Jeff Harding
USFWS: Taylor Lipscomb, Scott Foot, William Ardren
USGS: **Donald Tillitt, Dale Honeyfield**, Freya Rowland, David Walters, Catherine Richter
CDFW: Kevin Kwak, Mark Adkison, Brett Kormos
SUNY: State University of New York Brockport, **Jacques Rinchard,** Jarrod Ludwig
DWR: Jason Kindopp
Idaho State University: Bruce Finney
Moss Landing Marine Laboratory and CICESE: Iliana Ruiz-Cooley
Monterey Bay Aquarium Institute: Steve Litvin
UC Santa Cruz: Miles Daniels
UC Davis: Anne Todgham, Carson Jeffres, Nann Fangue, Heather Bell, Dennis Cocherell, Sage Lee, Peggy Harte, Ryan Meyer, Abigail Ward
Oregon State University: Rick Colwell, Chris Suffridge, Kelly Shannon
Anglers: New Sea Angler, New Rayann, Erick Owens, Dick Ogg, Keith Parker Yurok Tribe
Salmon in the Classroom: Teachers and Students!

Management Team

NOAA West Coast Region: Amanda Cranford, Charlotte Ambrose

Thiamine deficiency in California's salmonids

Unusually high egg-to-fry mortality rates, fry with coagulated yolks, corkscrew swimming patterns, and anorexia 2-4 weeks after ponding observed in multiple CV Chinook salmon hatcheries in 2020

Scott Foott, USFWS CA-NV Fish Health Center Memo from Jan 23, 2020:

- FHC, CDFW and UC Davis assays found *"fry loss not associated with infectious agent";* **thiamine bath** treated fry swimming normally and feeding soon after

Thiamine deficient Lake Trout fry

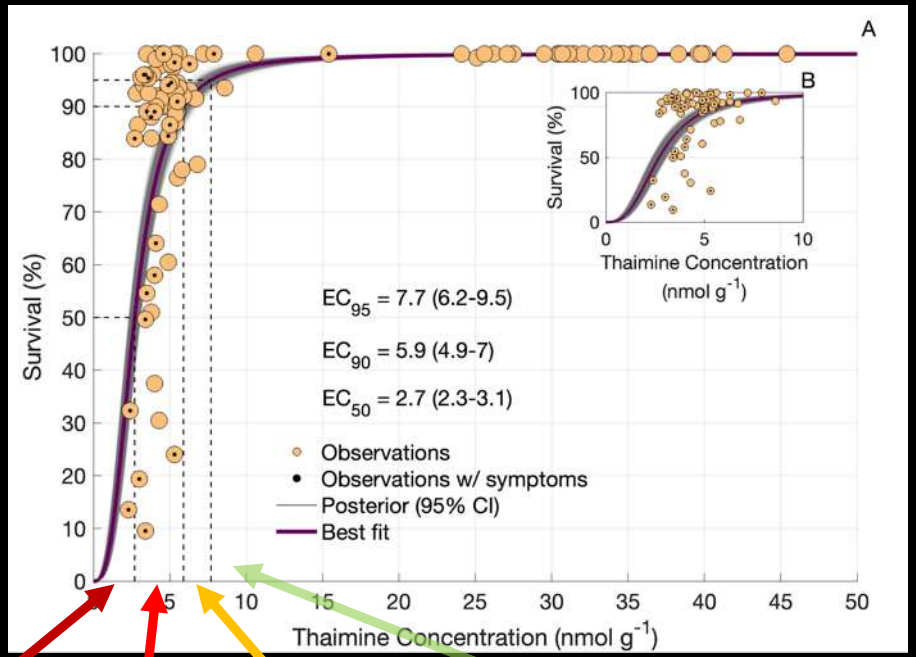
Assessing impacts

Unfed fry behavior and survival studies (to ~120 days post fertilization) using Central Valley Chinook salmon (UC Davis, Anne Todgham and Nann Fangue; Salmon in the Classroom, Carson Jeffres, Peggy Harte)

- Symptomatic fry mostly < 8 nmol/g
- Wide range of fry mortality rates at < 8 nmol/g

Data used to fit a dose-response model
- 50% fry mortality at 2.7 nmol/g
- defined ”impacts” criteria

Central Valley Chinook salmon
Thiamine Dependent Fry Survival



< 2.7 nmol/g
Severely impacted

2.7-5.9 nmol/g
Impacted

5.9-7.7 nmol/g
Likely impacted

> 7.7 nmol/g
Unlikely impacted

Provided by Miles Daniels (unpublished), UC Santa Cruz

Monitoring: Broad scale egg surveillance to identify vulnerable popn's

~70 sampling events to-date, 30 fish each time

Central Valley

- Chinook salmon (winter, spring, fall, late-fall) and steelhead

Coastal

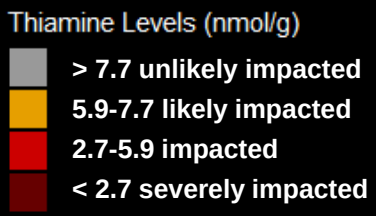
- Chinook (fall, spring) and coho salmon, steelhead

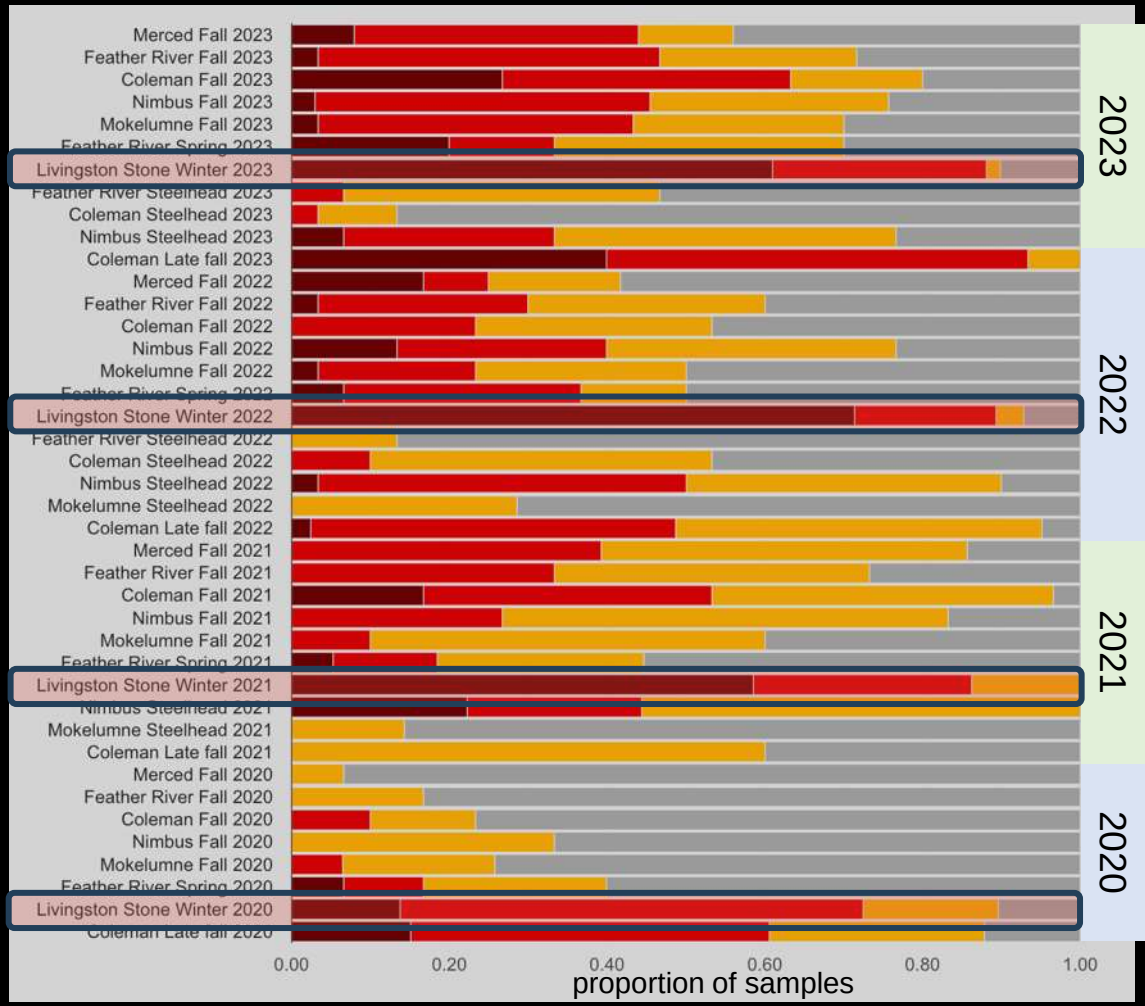
Widespread thiamine deficiency in Central Valley salmon and steelhead

winter-run Chinook salmon have had the lowest values

- WR fry mortality rates predicted to be 26, 48, 51 and 51% over 2020-2023

- Central valley steelhead and late fall-run Chinook salmon have also had low thiamine



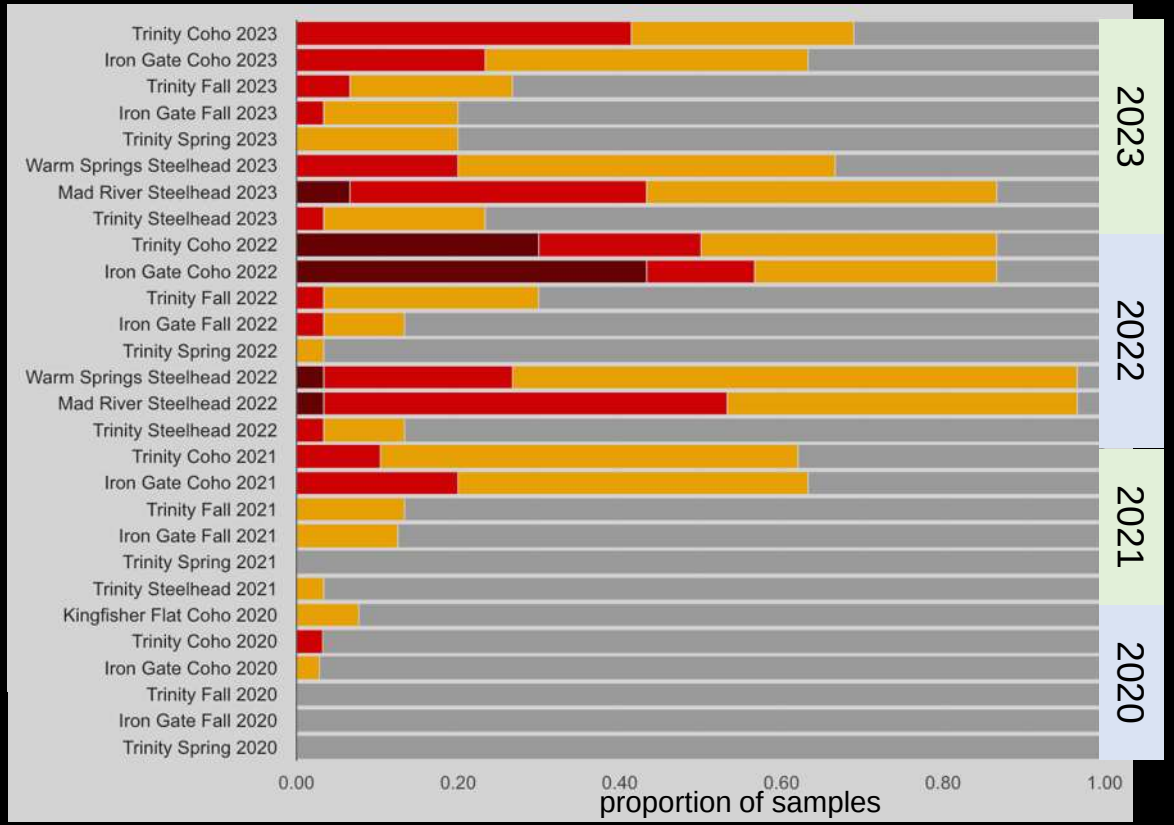


Unpublished data from Jacques Rinchard SUNY Brockport and Rachel Johnson NOAA

Increasing thiamine deficiency in coastal salmon and steelhead

Thiamine deficiency increased for coastal salmon/steelhead from 2020-2023

- coho salmon and steelhead have had the lowest egg thiamine concentrations



Thiamine Levels (nmol/g)

- **> 7.7 unlikely impacted**
- **5.9-7.7 likely impacted**
- **2.7-5.9 impacted**
- **< 2.7 severely impacted**

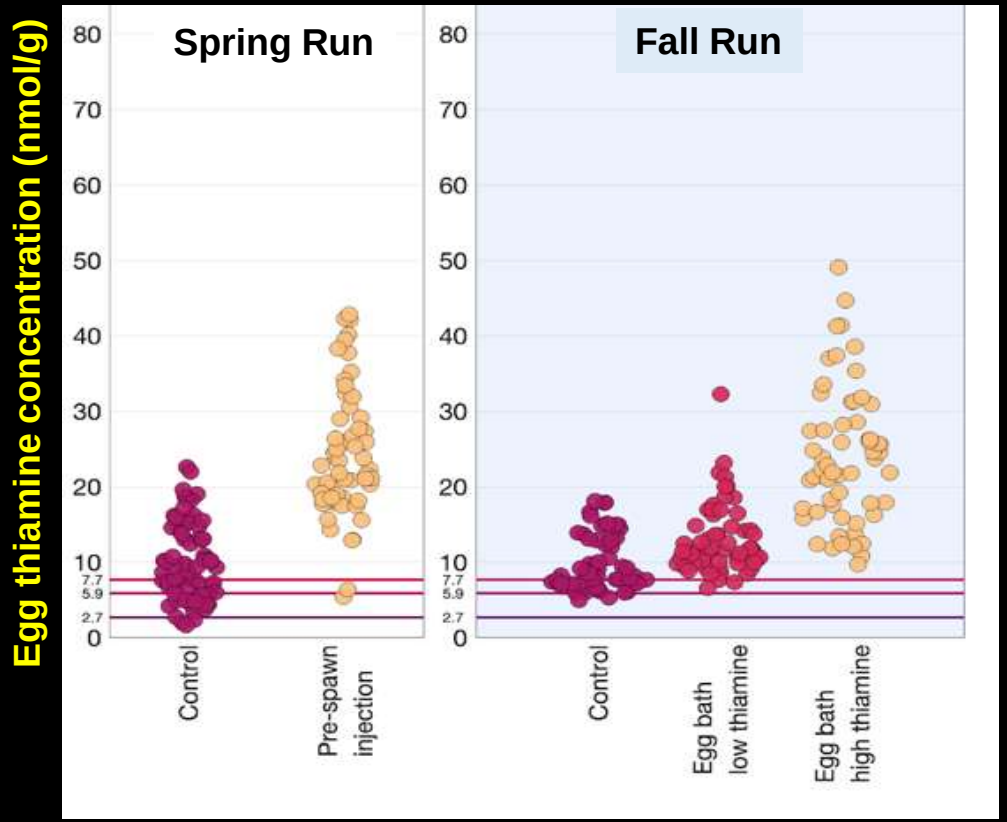
Unpublished data from Jacques Rinchard SUNY Brockport and Tommy Williams NOAA

Evaluating treatments

Two treatment options have been effective

- Pre-spawn injections for early migrating winter-run and spring-run Chinook salmon
- Egg bath at fertilization for late migrating populations that spawn soon after arrival to spawning grounds

Low dose = 1500mg/L TM
High dose = 4500mg/L TM

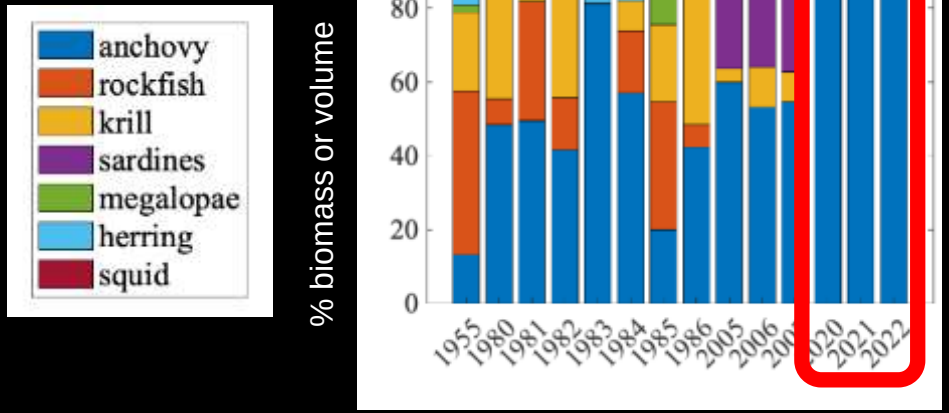


Unpublished data from Jacques Rinchard, SUNY Brockport, Kevin Kwak CDFW, and Jason Kindopp DWR

The anchovy diet hypothesis

Salmon diets dominated by Northern anchovy in 2019-22

- **97%** (2020), **86%** (2021), and **99.7%** (2022)



%volume pre-2020 from Thayer et al 2014, MEPS

2020

1980s

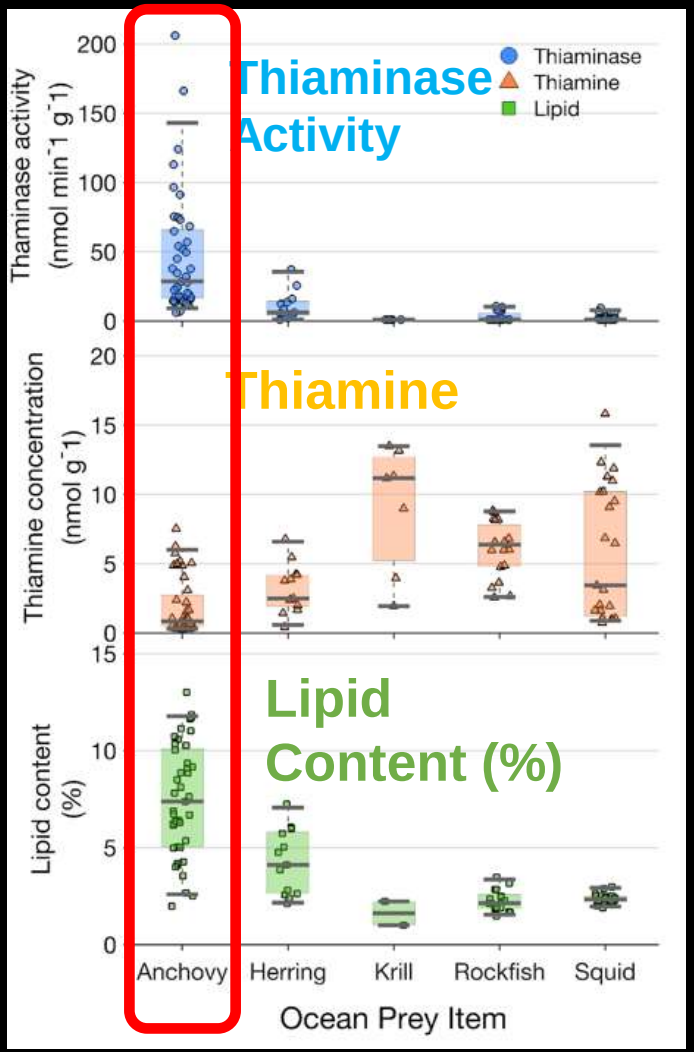
Picture from John Field, SWFSC

Prey Nutrition

Anchovies are especially high in thiaminase activity, low in thiamine, and high in lipid content

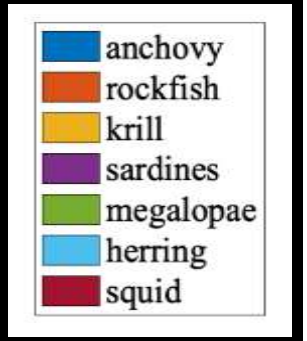
- Thiaminase is a thiamine degrading enzyme; high lipids may also cause oxidative stress that depletes thiamine

We are also looking at stable isotopes and fatty acid profiles to connect salmon egg thiamine levels to prey

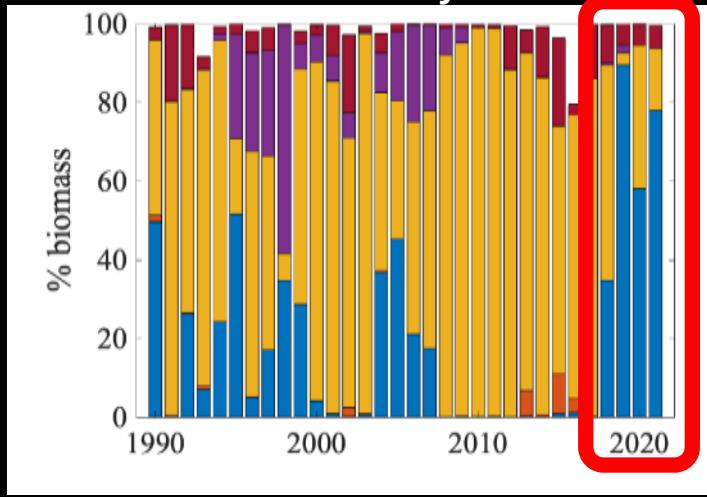


Unpublished data from J Rinchard (SUNY), F Rowland, D Walters, C Richter (USGS), J Field (NOAA)

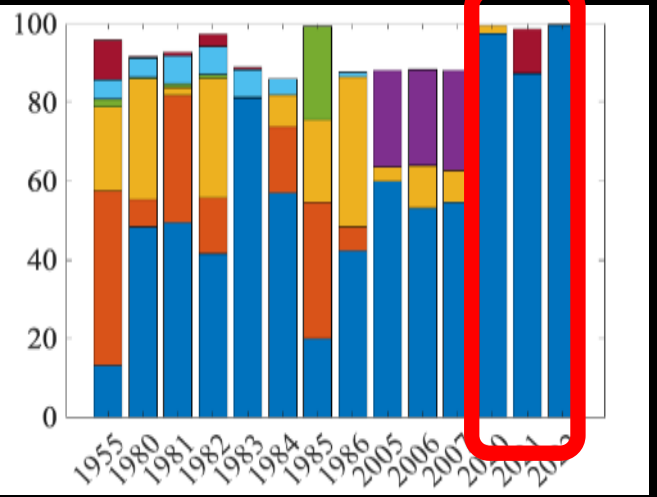
The anchovy-dominated forage base along California



RREAS springtime trawl survey catch

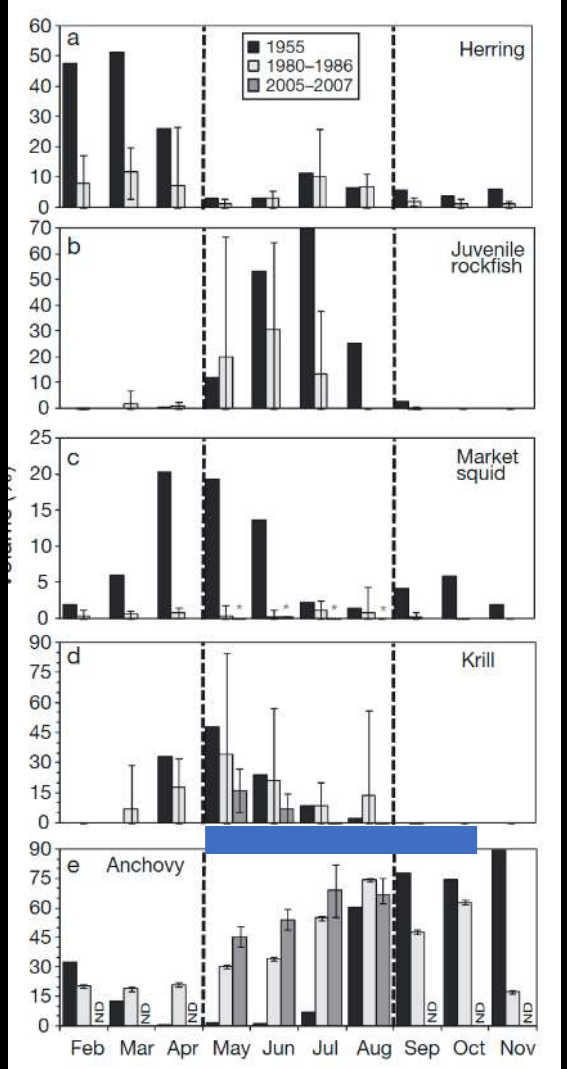


Chinook salmon gut contents



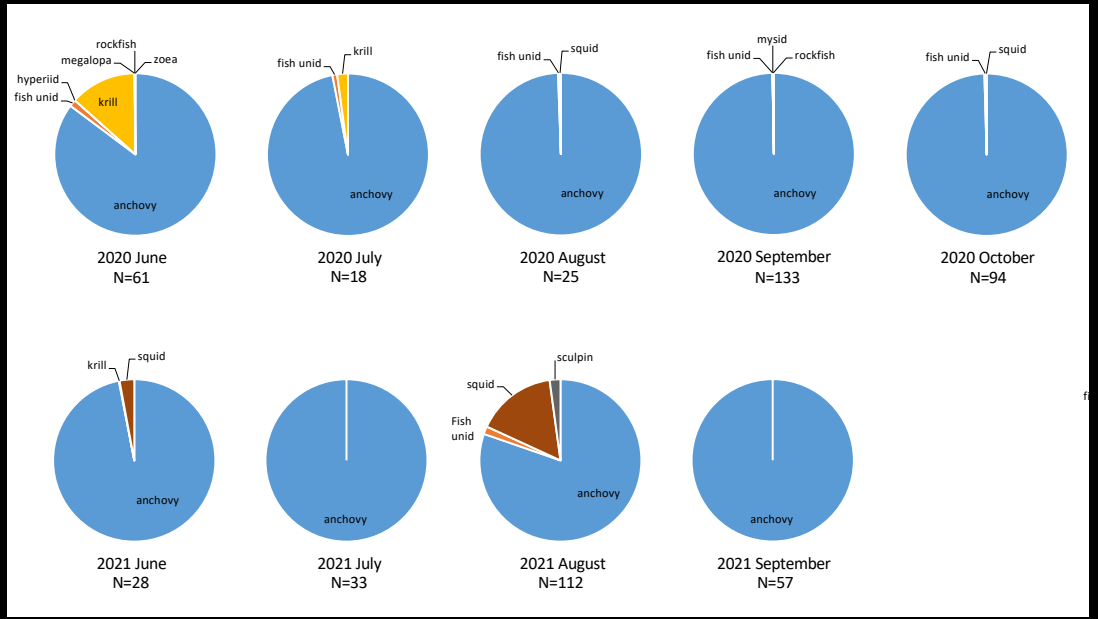
- More diversity and krill in Rockfish Recruitment trawl survey data prior to 2019

Historical %Volume



Anchovy in all seasons?

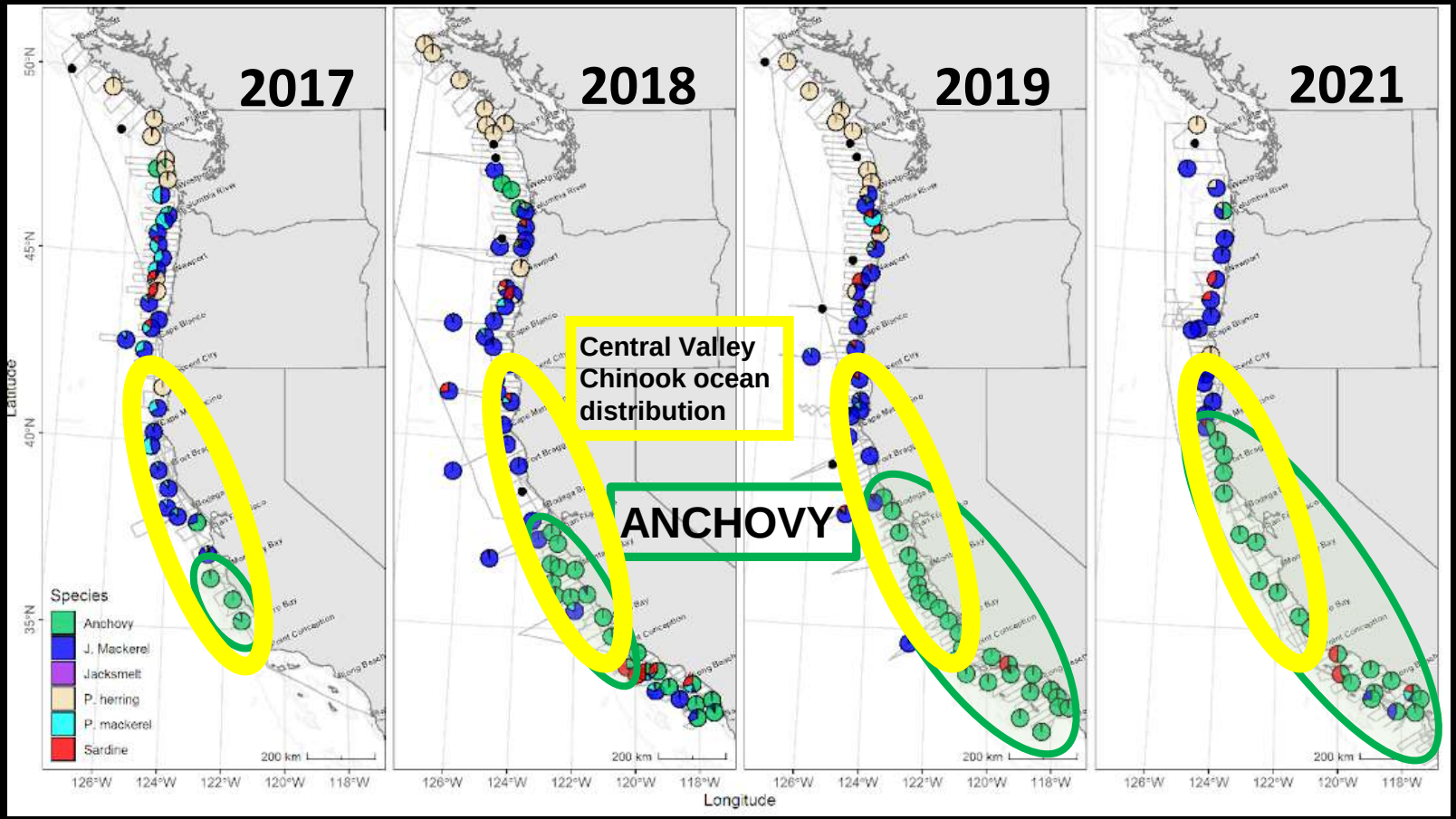
Chinook salmon gut contents in 2020-2021



Coastal Pelagic Species from NMFS Summertime acoustic-trawl surveys

Central California northern anchovy stock biomass and north end of their distribution expanded greatly from 2017-2021.

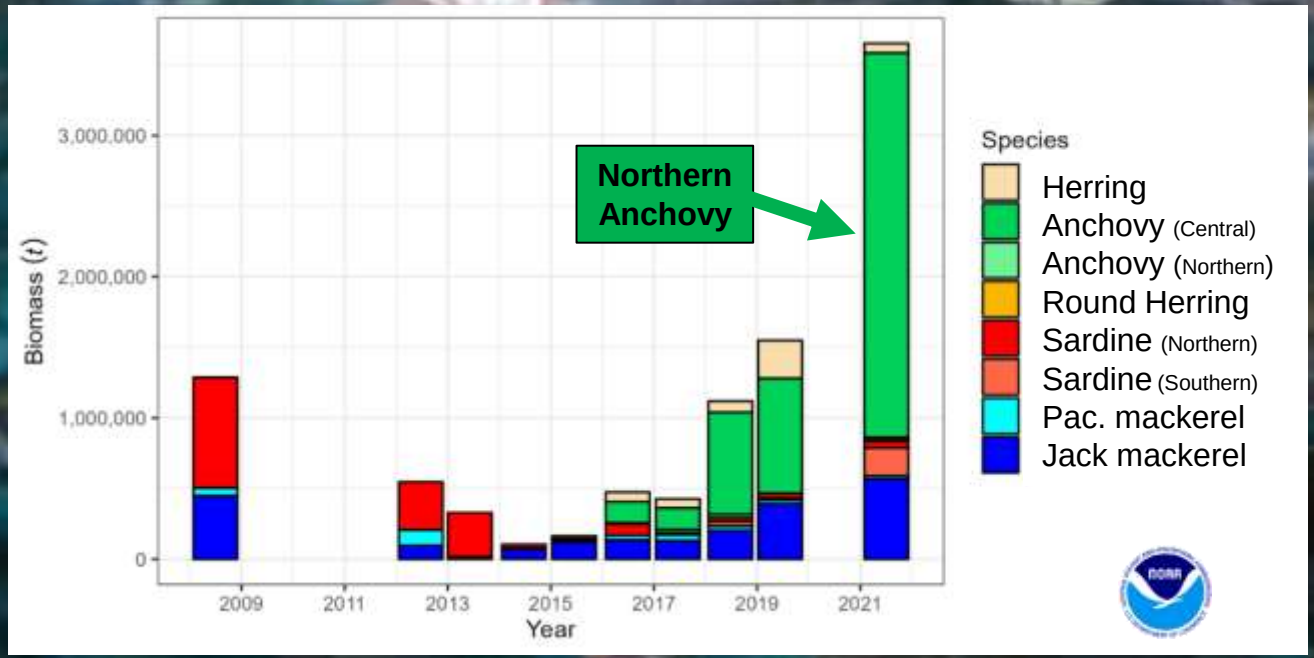
(NMFS Tech Memos; figure from K. Stierhoff, NMFS)



Forage Fish biomass in the California Current in summer

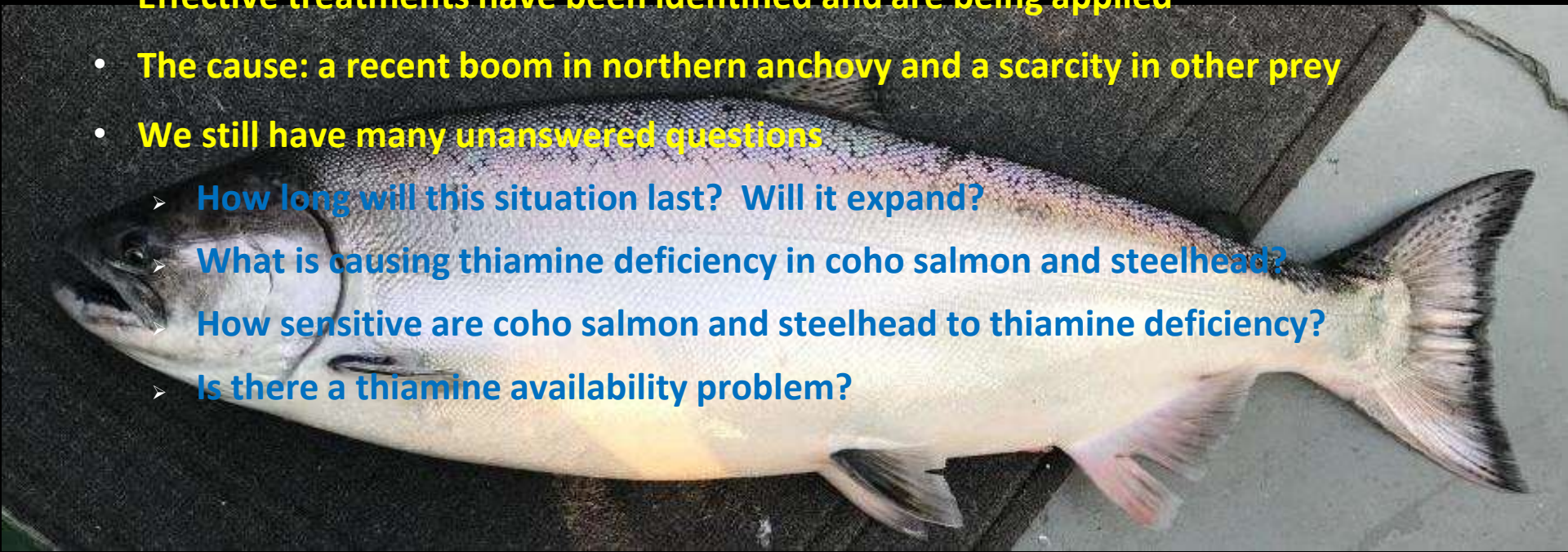
Dominated by Pacific sardine from mid-90s to 2014, central stock of Northern Anchovy after 2015

from Stieroff et al. 2022, NMFS Tech Memo



Summary

- Thiamine deficiency is a newly identified stressor on already stressed populations.
- Impacts have been severe for some years and populations
- Effective treatments have been identified and are being applied
- The cause: a recent boom in northern anchovy and a scarcity in other prey
- We still have many unanswered questions
  - How long will this situation last? Will it expand?
  - What is causing thiamine deficiency in coho salmon and steelhead?
  - How sensitive are coho salmon and steelhead to thiamine deficiency?
  - Is there a thiamine availability problem?



STEELHEAD OCEAN FORAGING ECOLOGY and THE LINK TO THIAMINE DEFICIENCY COMPLEX

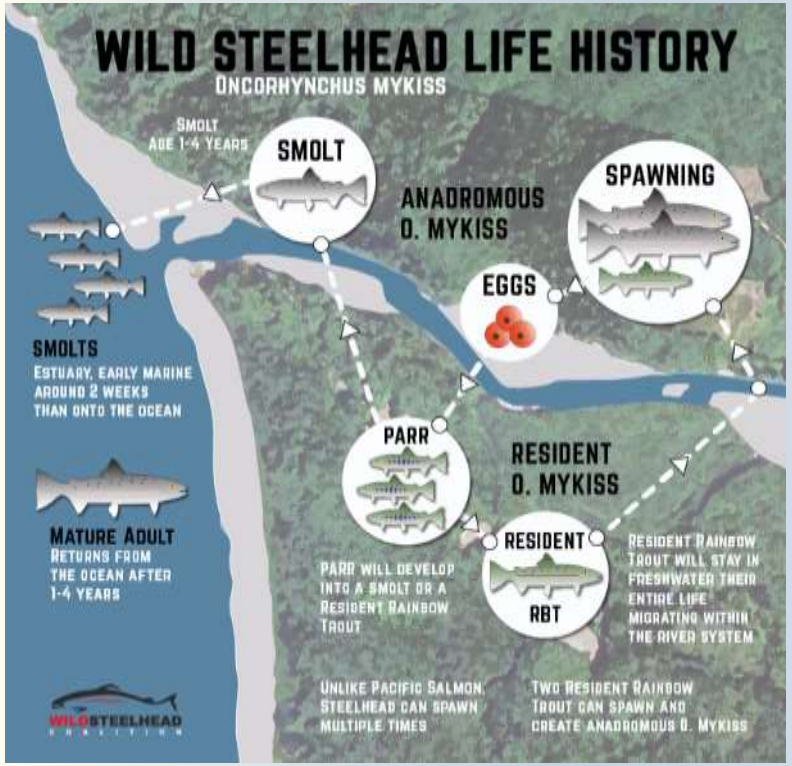
Presented by: Abigail Ward[1]

Nate Mantua[2], Carson Jeffres[1], Jacques Rinchard[3], Jarrod Ludwig[3], Bruce Finney[4], Thomas Williams[2], Miranda Bell-Tilcock[5], Rachel Johnson[2]

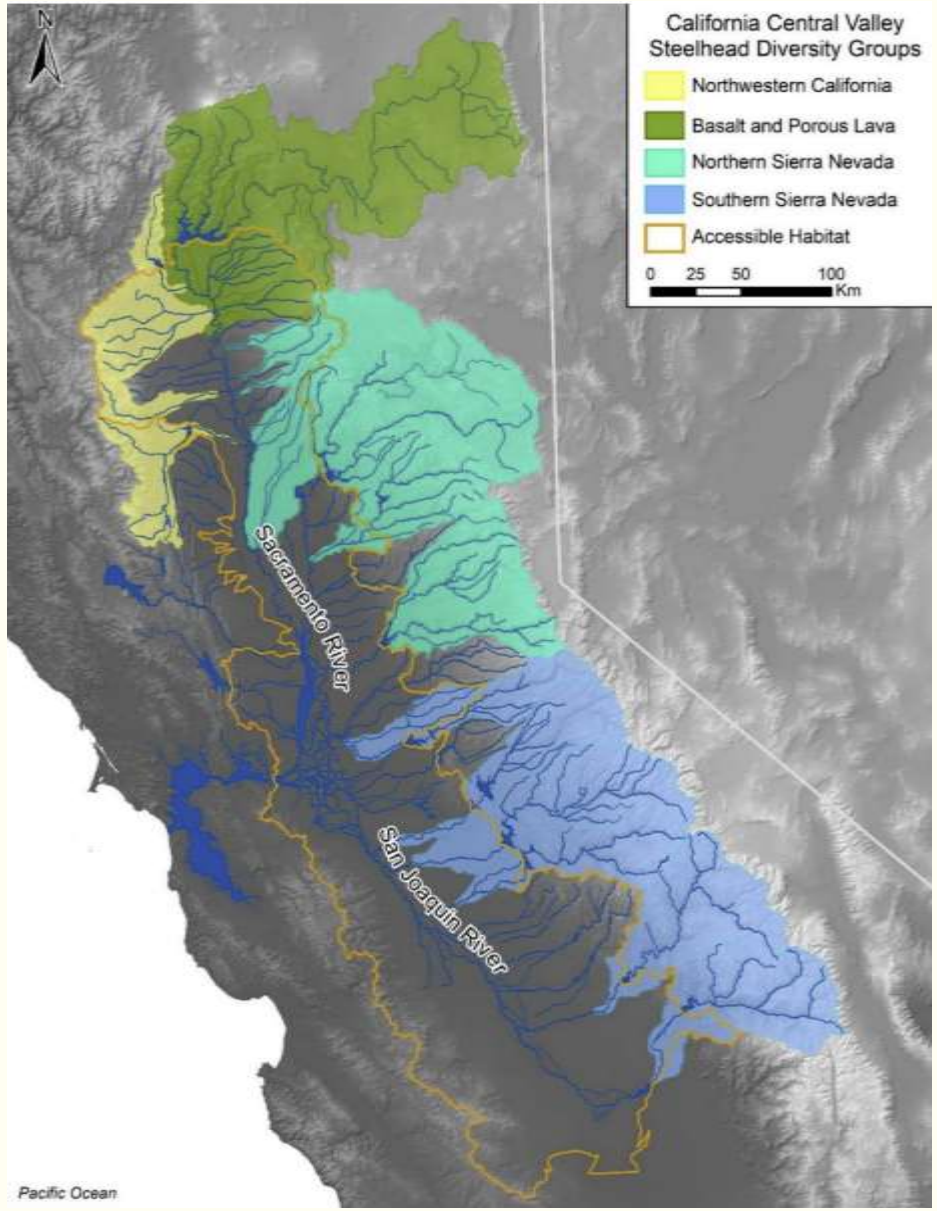
[1] Center for Watershed Sciences, University of California Davis
[2] National Marine Fisheries Service, Southwest Fisheries Science Center
[3] State University of New York, Brockport, Department of Environmental Science and Ecology
[4] Idaho State University Stable Isotope Laboratory
[5] Delta Stewardship Council

Steelhead Life History

- Steelhead are the anadromous ecotype of *Oncorhynchus mykiss*
  - Resident life histories of *O. mykiss* are called rainbow trout
- Anadromous individuals often return to freshwater for spawning larger than the ones that stay in freshwater
- *O. mykiss* can spawn multiple times during their lives, subsequently completing multiple migrations
  - This is unique compared to other Pacific salmonids



Courtesy of the Wild Steelhead Coalition and Sporting Classics



Courtesy of Ellrott et al., 2021

Population Impacts

- Damming of the Central Valley and the entirety of the California watershed severely impacted steelhead distribution and access to historical watersheds
  - An estimated 80% of historically available habitat is now blocked
  - Low returns during certain years have caused researchers to consider the possibility of extinction for particular DPS
- Steelhead trout are vulnerable to many stressors
  - Overfishing
  - Habitat loss
  - Pollution
  - Genetic Degradation? (a product of hatchery supplementation to the population)

Thiamine Deficiency in California Salmonids

DISCOVERY OF TDC

January 2020

Fry in Central Valley hatcheries began to display corkscrew swimming patterns, have high mortality rates and lethargic behaviors.

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TREATING CHINOOK

March 2020

By spring 2020, hatcheries were treating their eggs with vitamin B1 and endangered winter run adult females were receiving thiamine injections prior to spawning.

Thiamine Deficiency in California Salmonids

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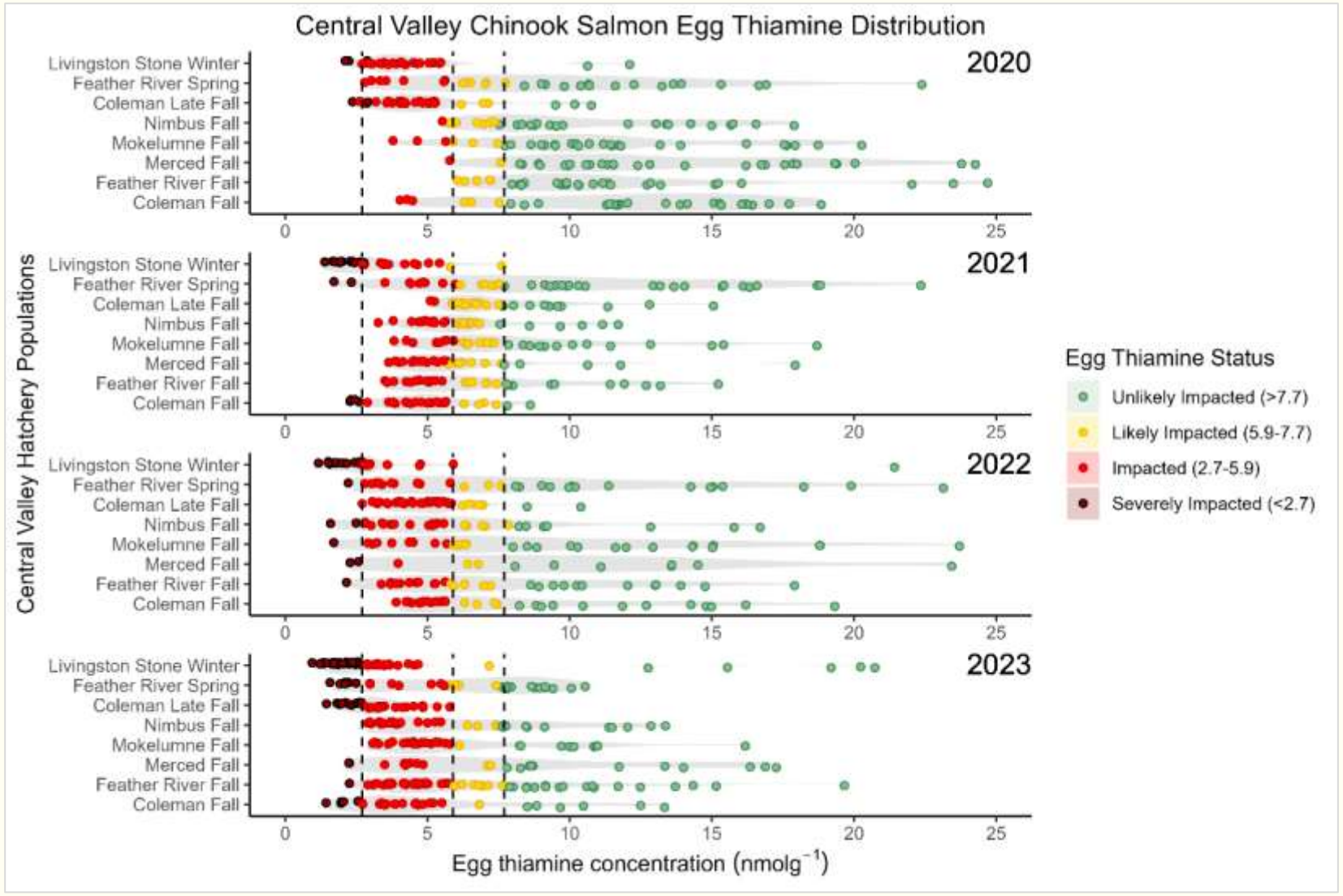
AGENCY COLLABOARTION

April 2020

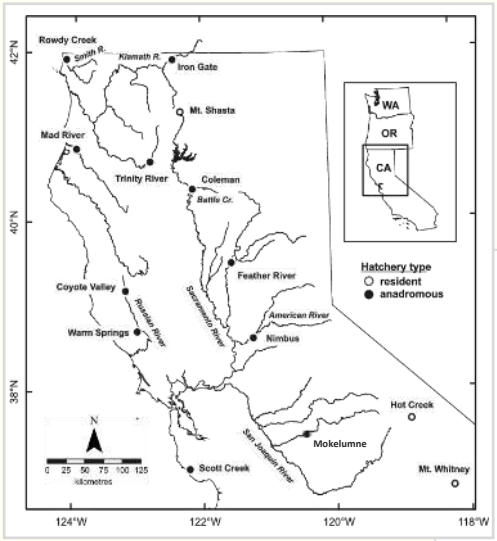
Researchers across California and beyond came together to begin to explore the causes and mitigate against TDC in out salmon populations.

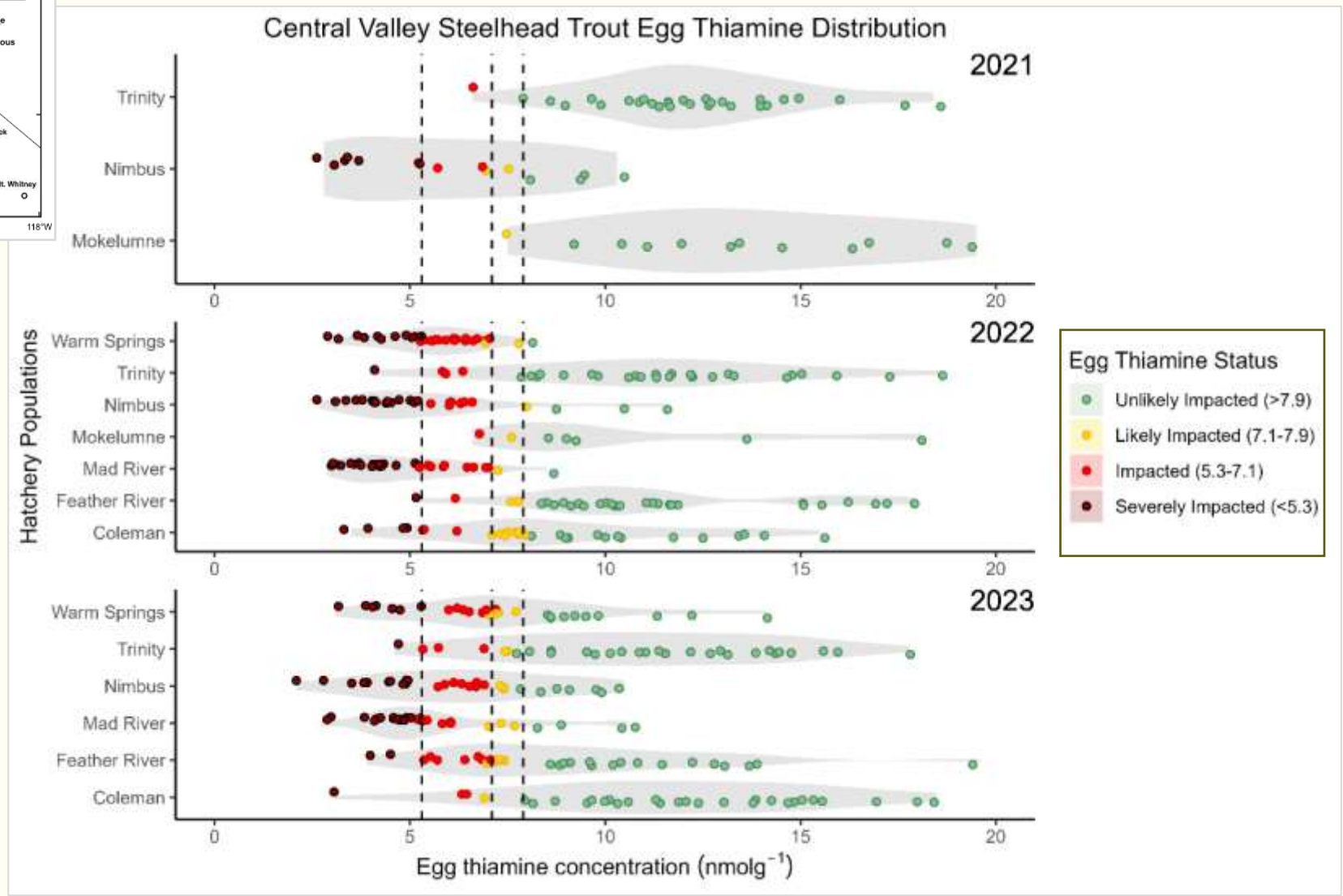
Egg Thiamine Monitoring



Unpublished data from Jacques Rinchard (SUNY Brockport)

Steelhead Monitoring

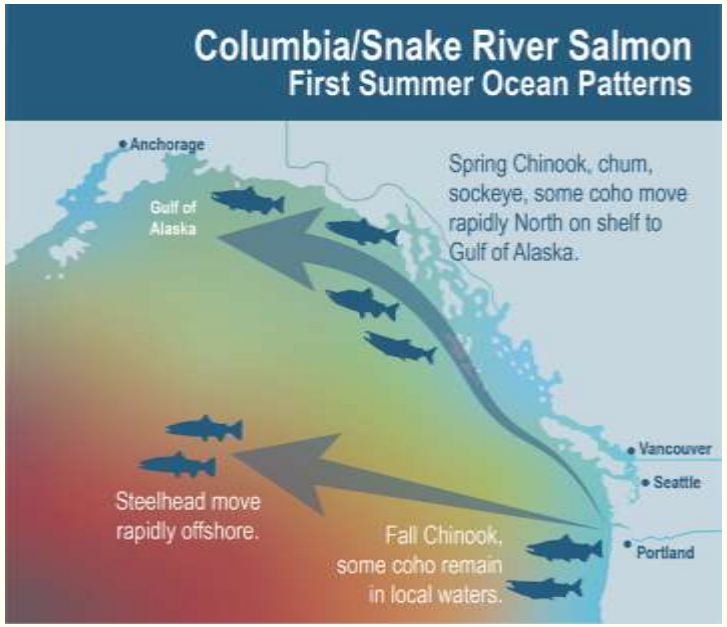




Unpublished data from Miles Daniels (NOAA Southwest Fisheries)

Unpublished data from Jacques Rinchard (SUNY Brockport)

Marine Heatwaves and Ocean Migrations



Credit: Su Kim, NOAA Fisheries

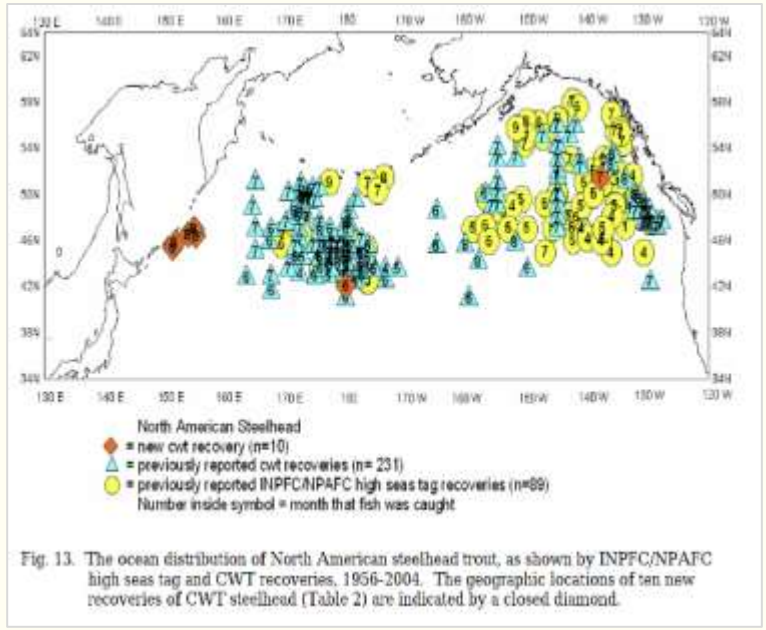
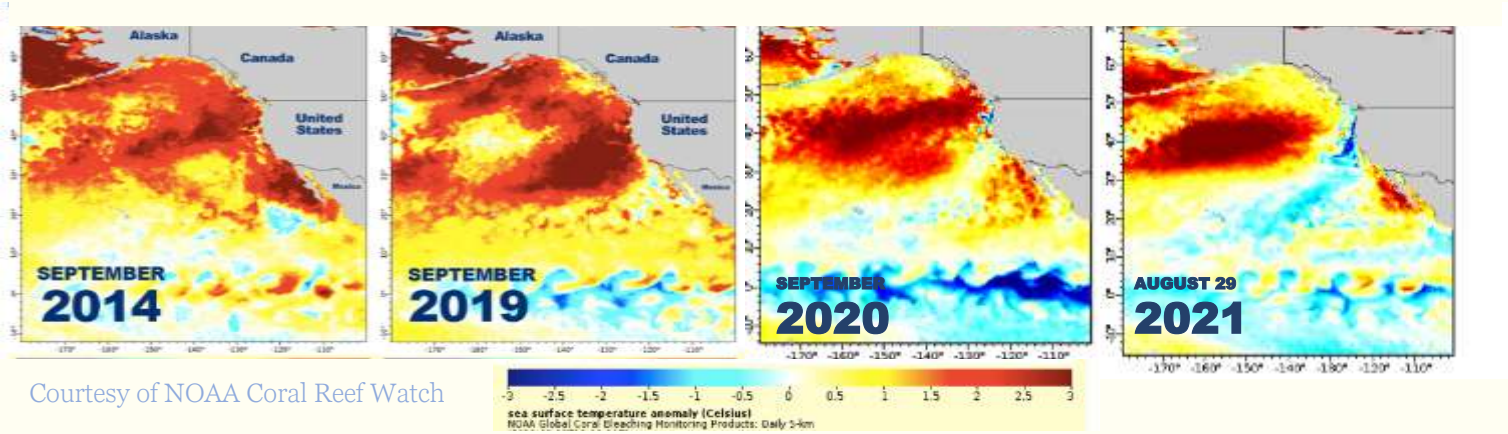


Fig. 13. The ocean distribution of North American steelhead trout, as shown by INPFC/NPAFC high seas tag and CWT recoveries, 1956-2004. The geographic locations of ten new recoveries of CWT steelhead (Table 2) are indicated by a closed diamond.

Myers and Davis, 2005

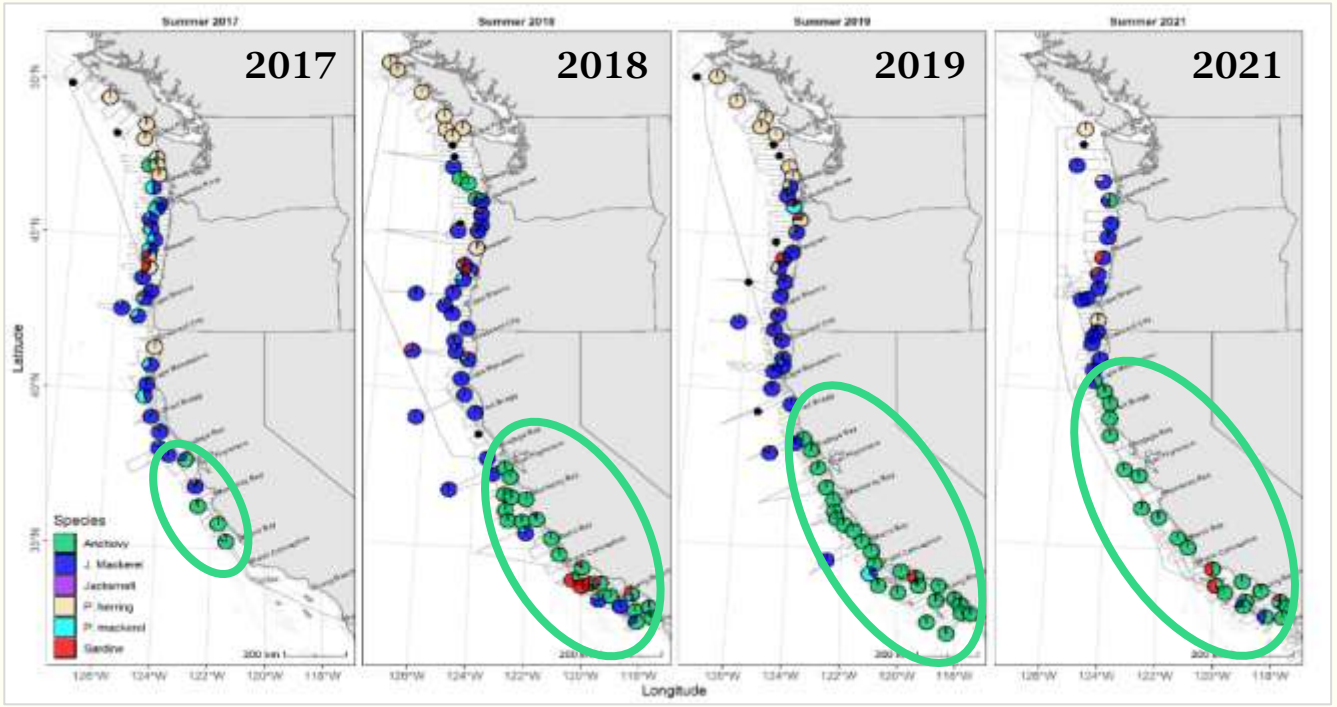
Frequent Marine Heatwaves from 2014-2021?

Extreme and persistent warm periods have affected the northeast Pacific, bringing widespread impacts on marine life and fisheries.



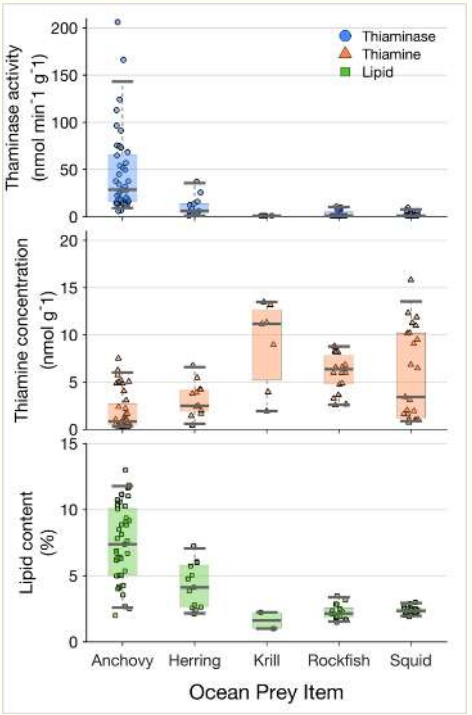
Courtesy of NOAA Coral Reef Watch

Anchovy abundance in the ocean



National Marine Fisheries Service Tech Memos, CPS summer trawl

Courtesy of John Field



Unpublished data from Freya Rowland and David Walters

Anchovy biomass and the northern end of their distribution has been changing over time, allowing them to be more readily available in salmon marine foraging habitat

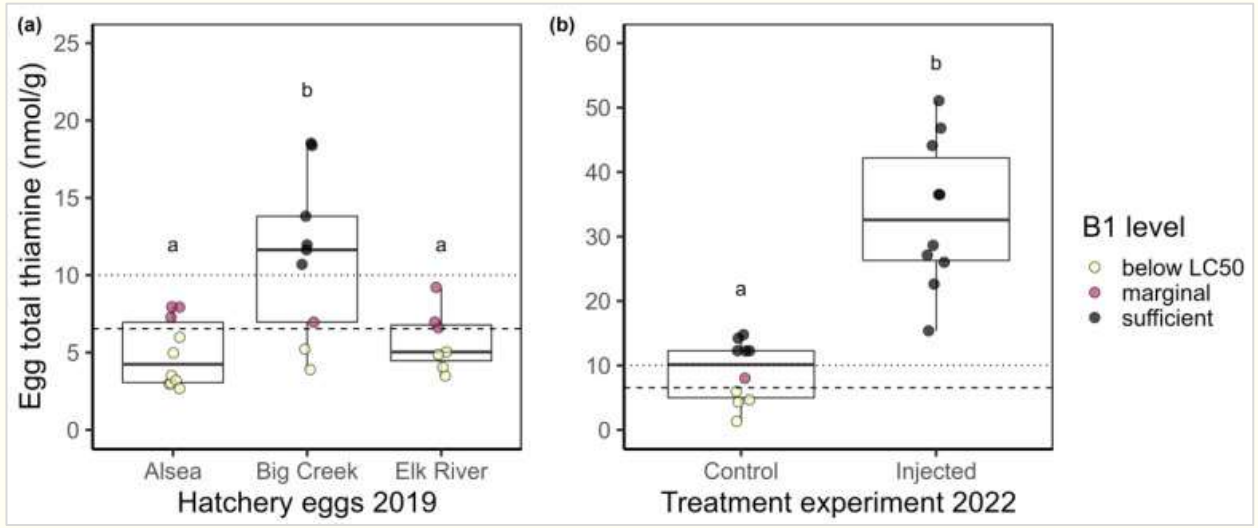
- Anchovies produce thiaminase– a thiamine-degrading enzyme

The lipid content of anchovies is high compared to other species of prey

Limited Steelhead TDC Research

- Thiamine deficiency in steelhead is severely under researched, specifically in our Pacific populations
  - Within the Great Lakes, steelhead have exhibited signs of TDC since 2014 with treatments beginning shortly thereafter (Futia et al., 2017)

- TDC was identified in Oregon steelhead in Reed et al., 2023 revealing the importance of treatment within hatchery populations



Reed et al., 2023

Investigating prevalence, causes and impacts

Ocean Migration

Marine Food Web

Evolutionary Impacts

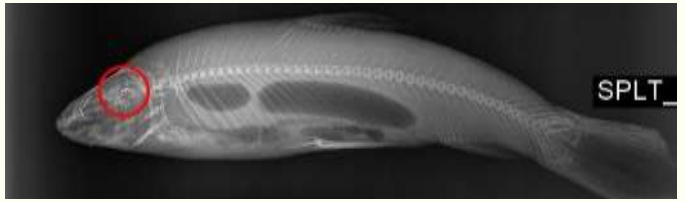
Investigating prevalence, causes and impacts

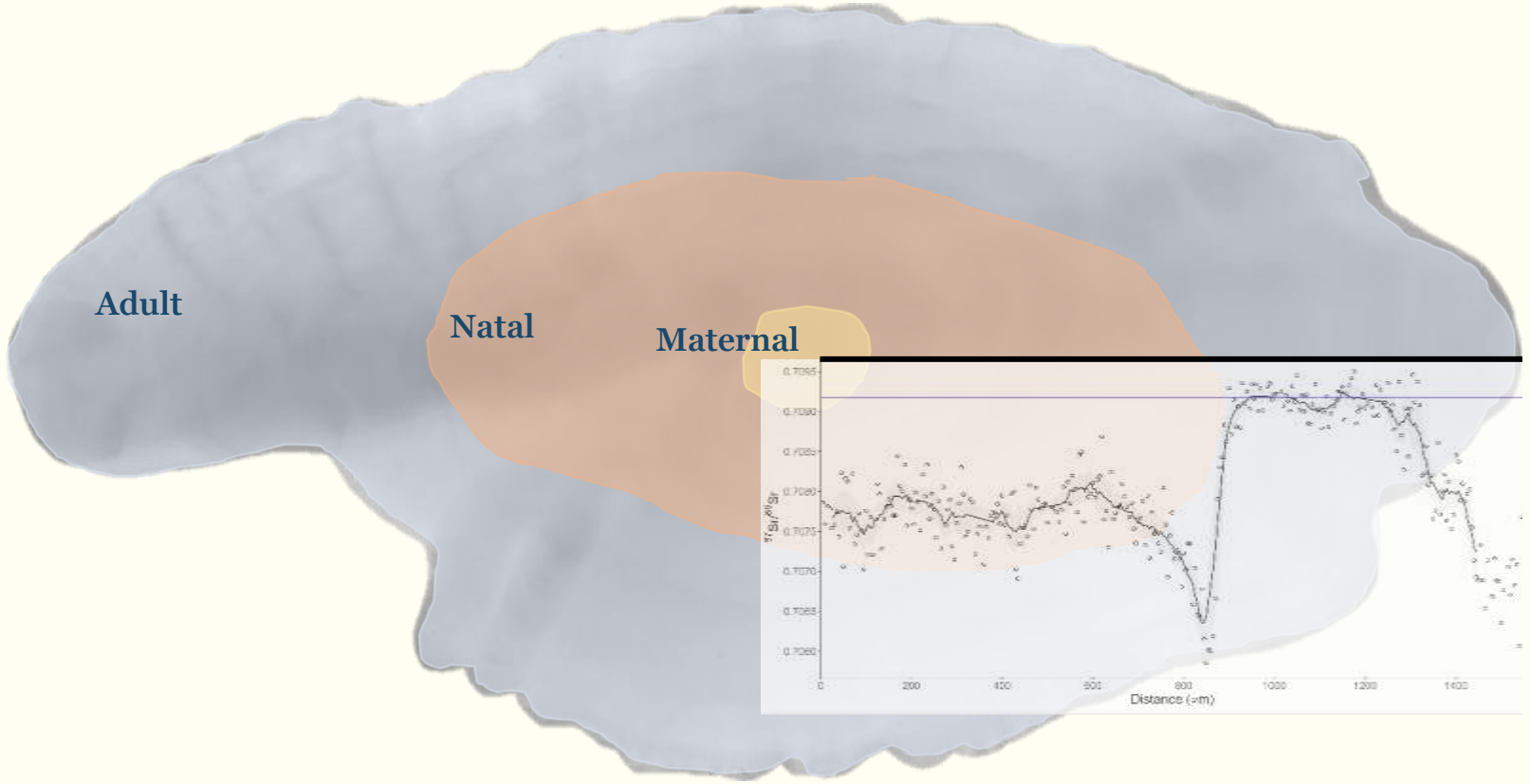
Objectives and Hypotheses:

- To understand the importance and the influence of ocean migration on thiamine deficiency
  - H1: Migratory behavior will have an influence on egg thiamine concentrations
  - H2: Length of freshwater migration time at spawning will have an influence on egg thiamine concentrations

Ocean Migration

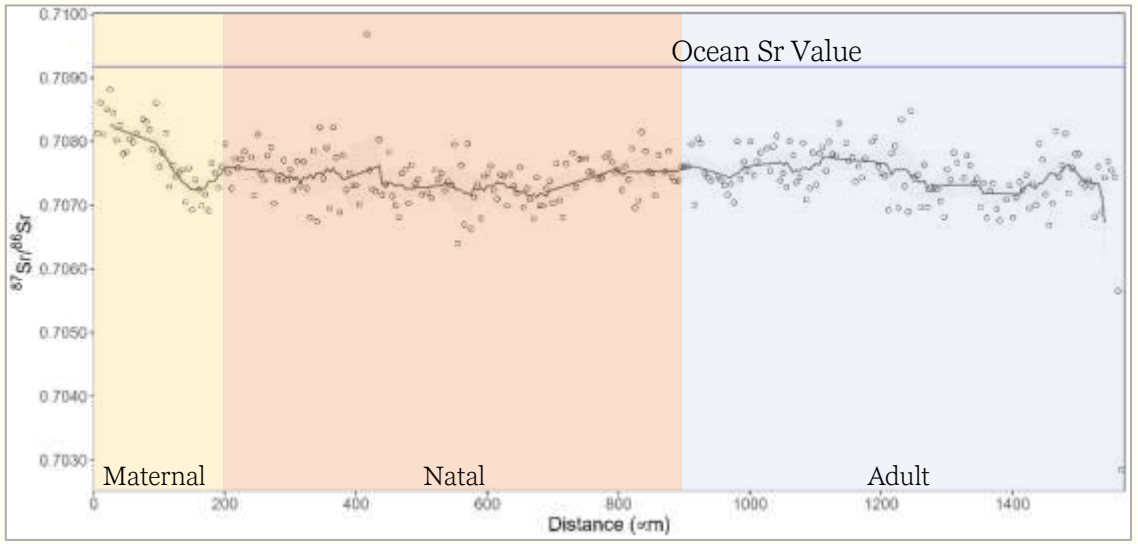
Using Otoliths to Understand Migratory Behavior



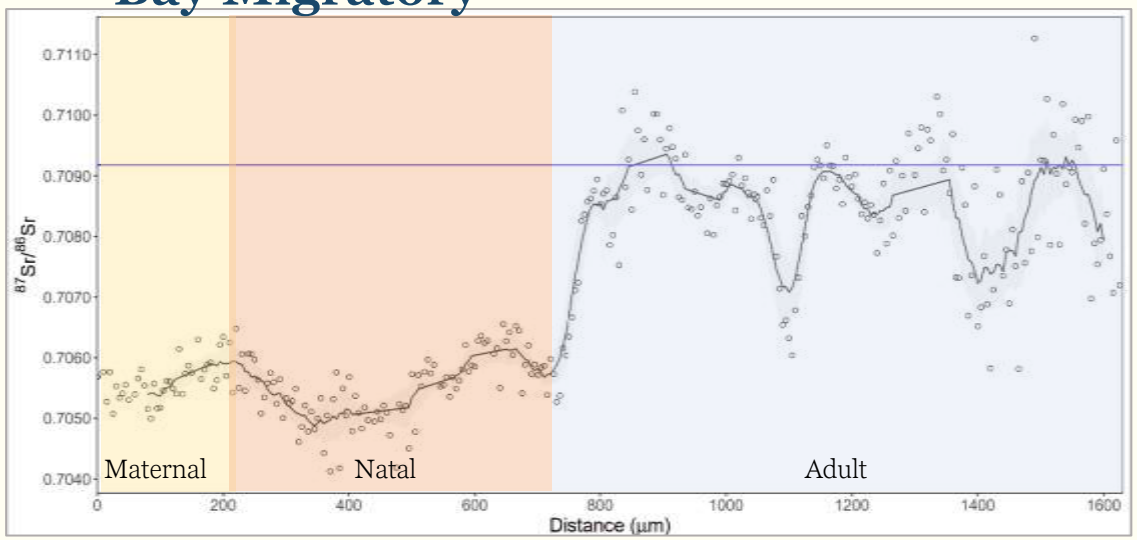


$^{87}Sr/^{86}Sr$ otolith profiles

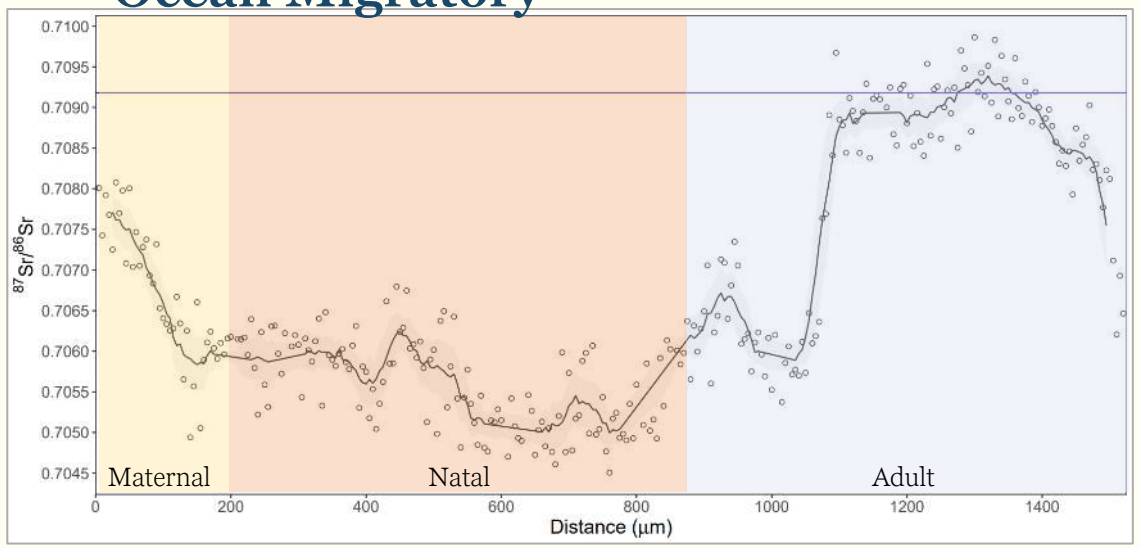
Resident



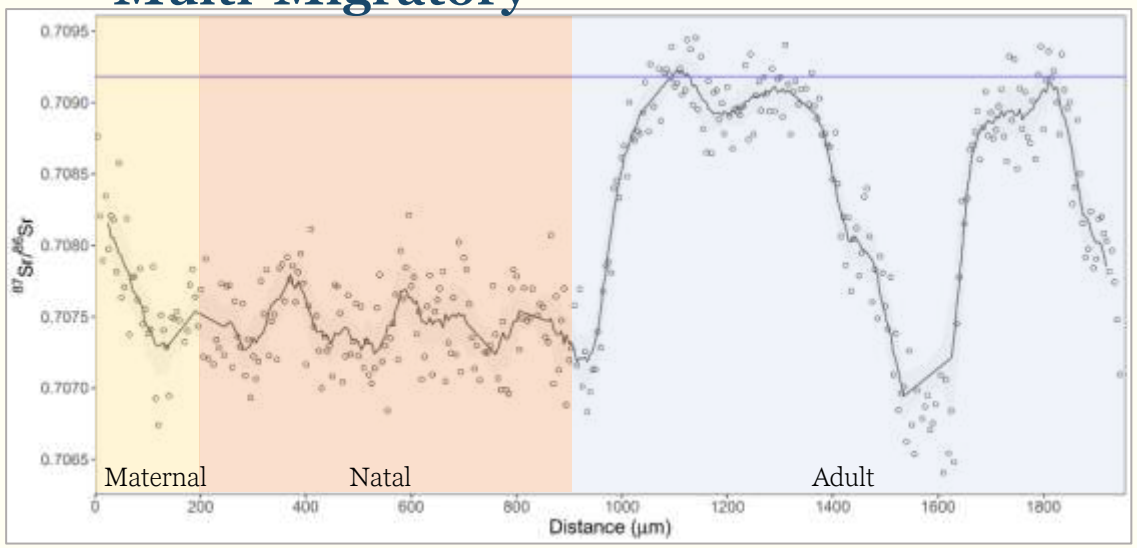
Bay Migratory



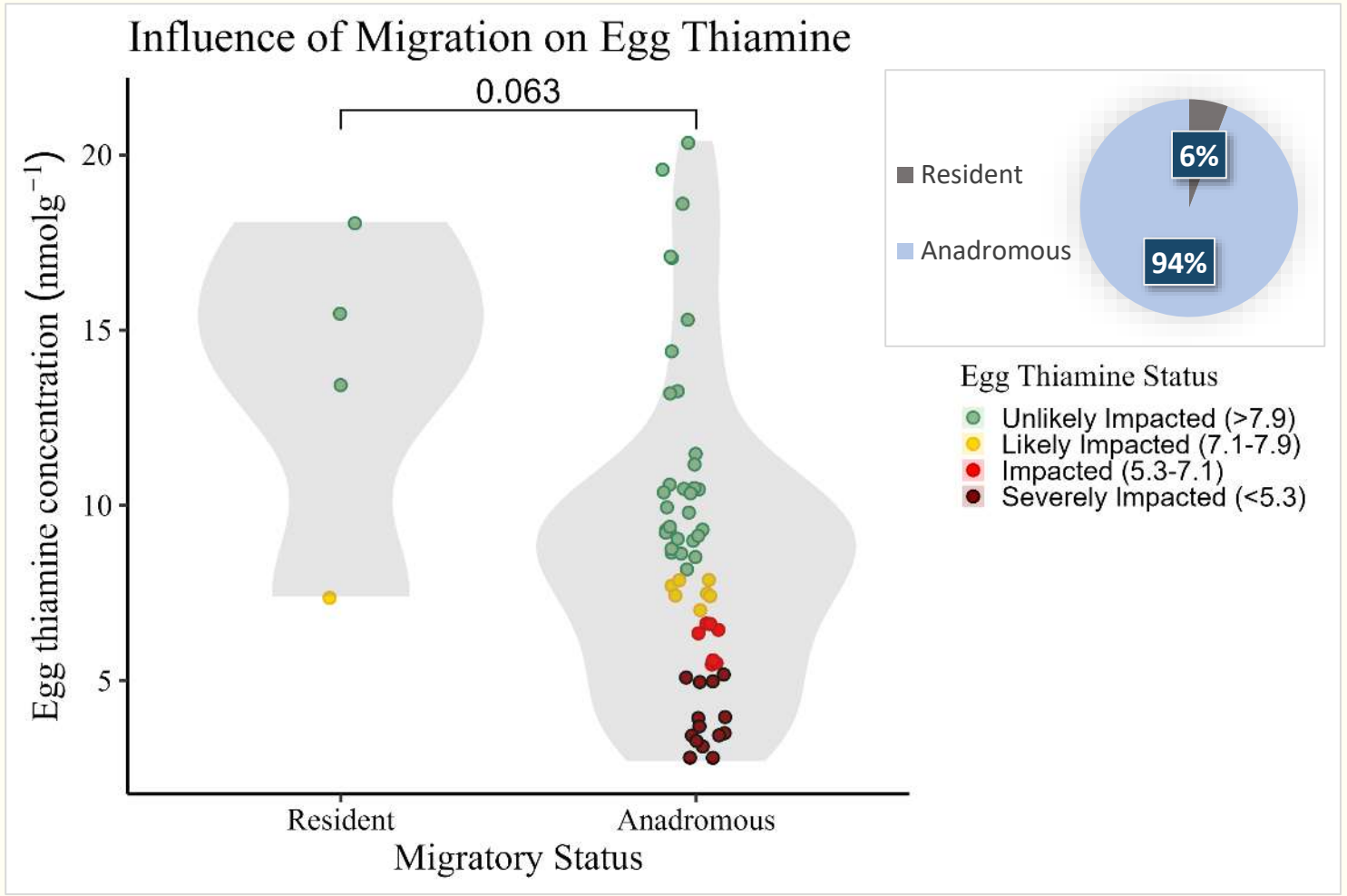
Ocean Migratory

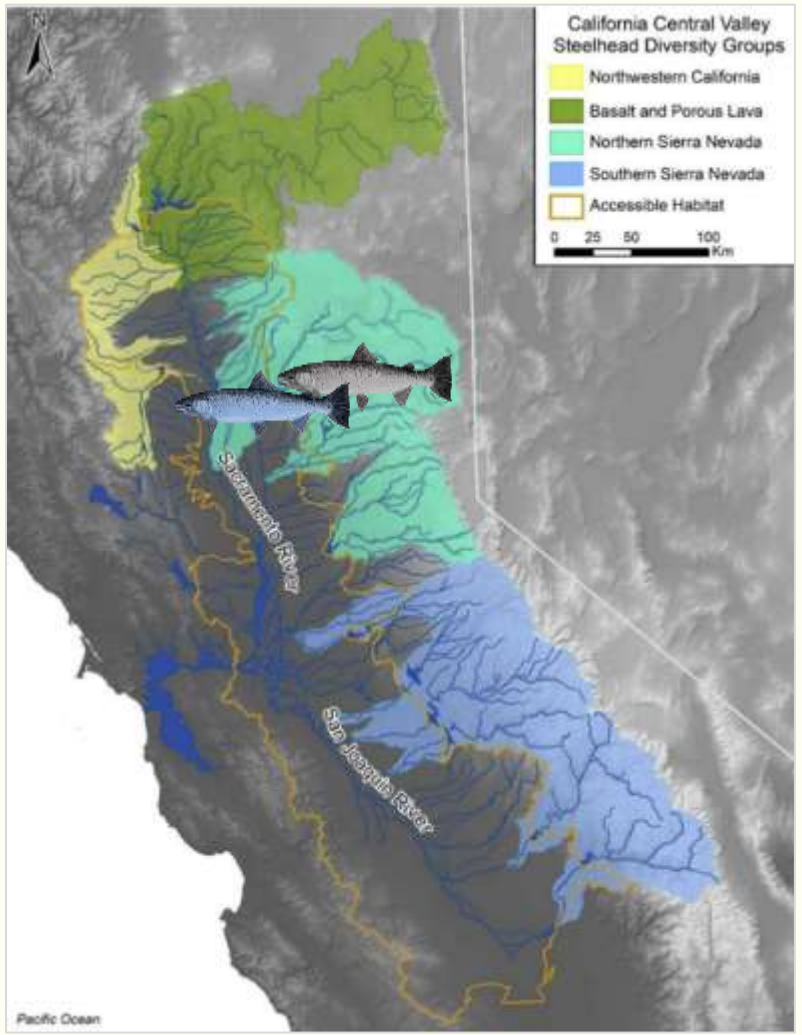


Multi-Migratory

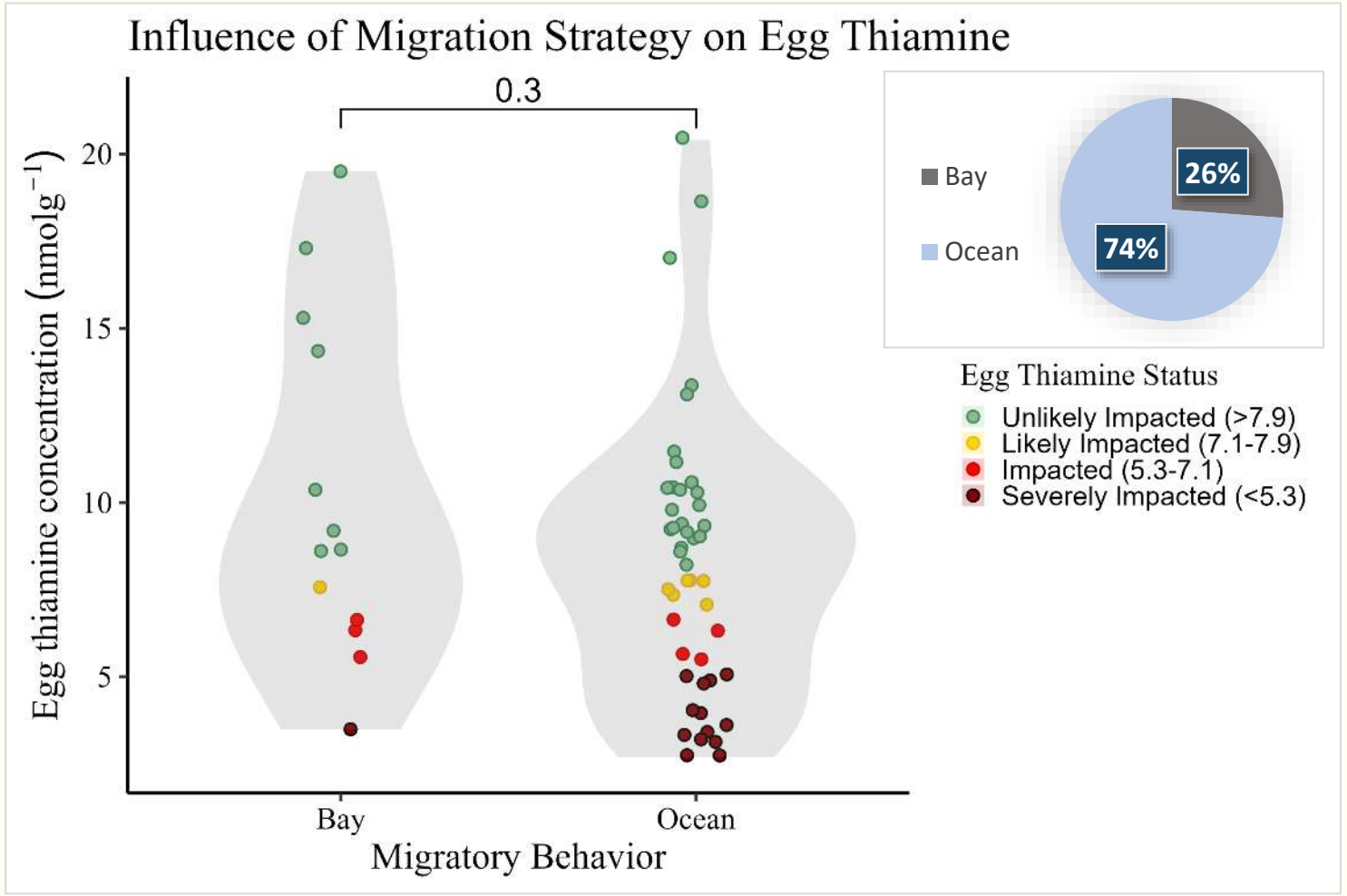


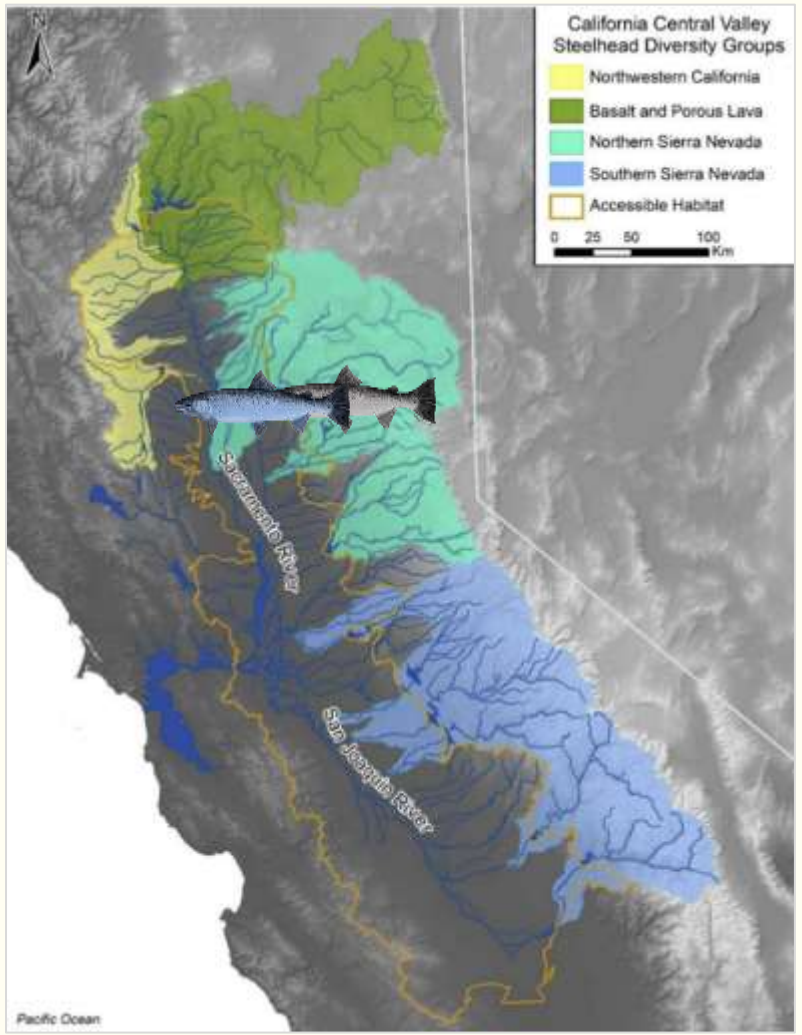
Influence of Ocean Migration on TDC



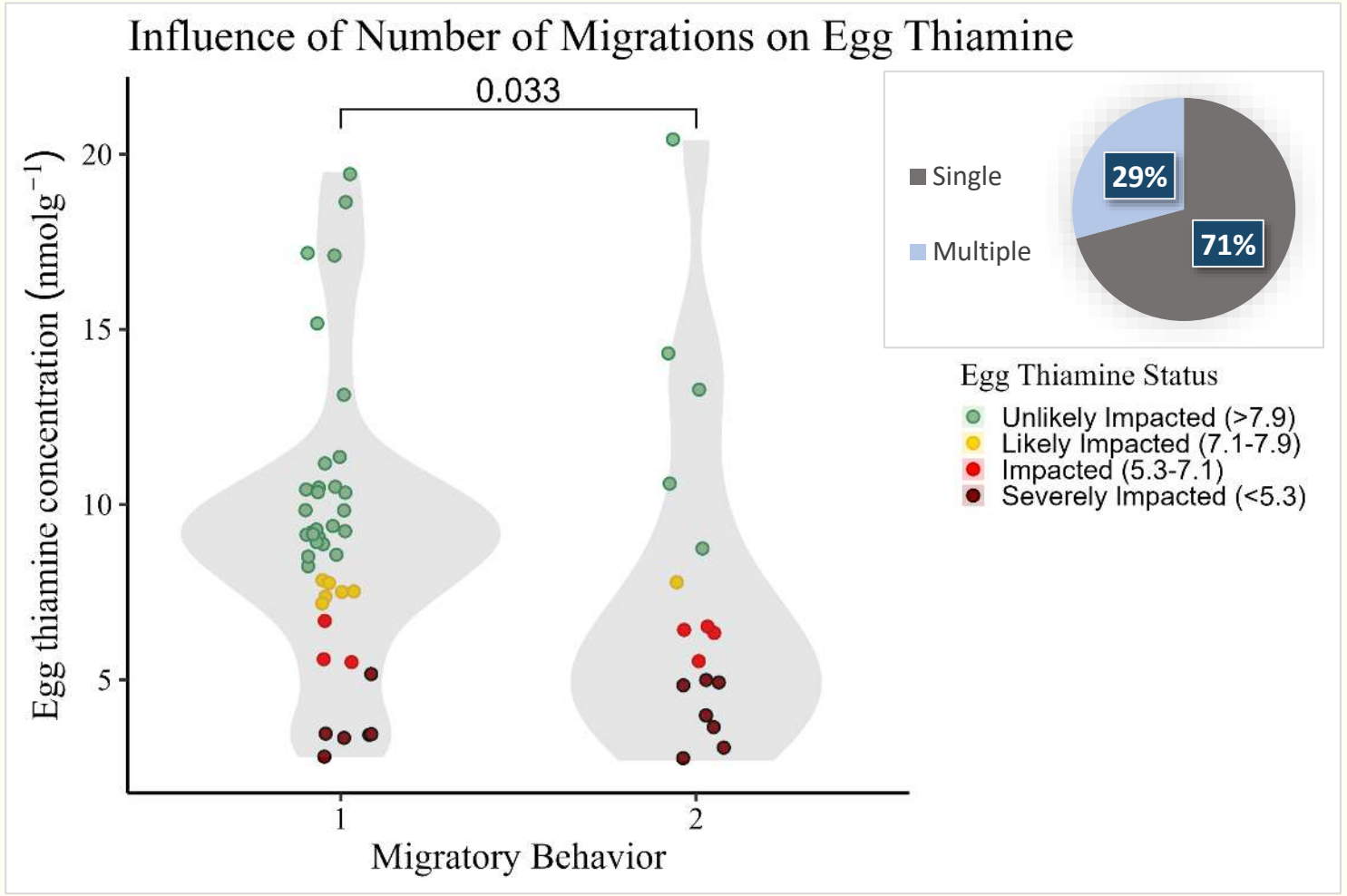


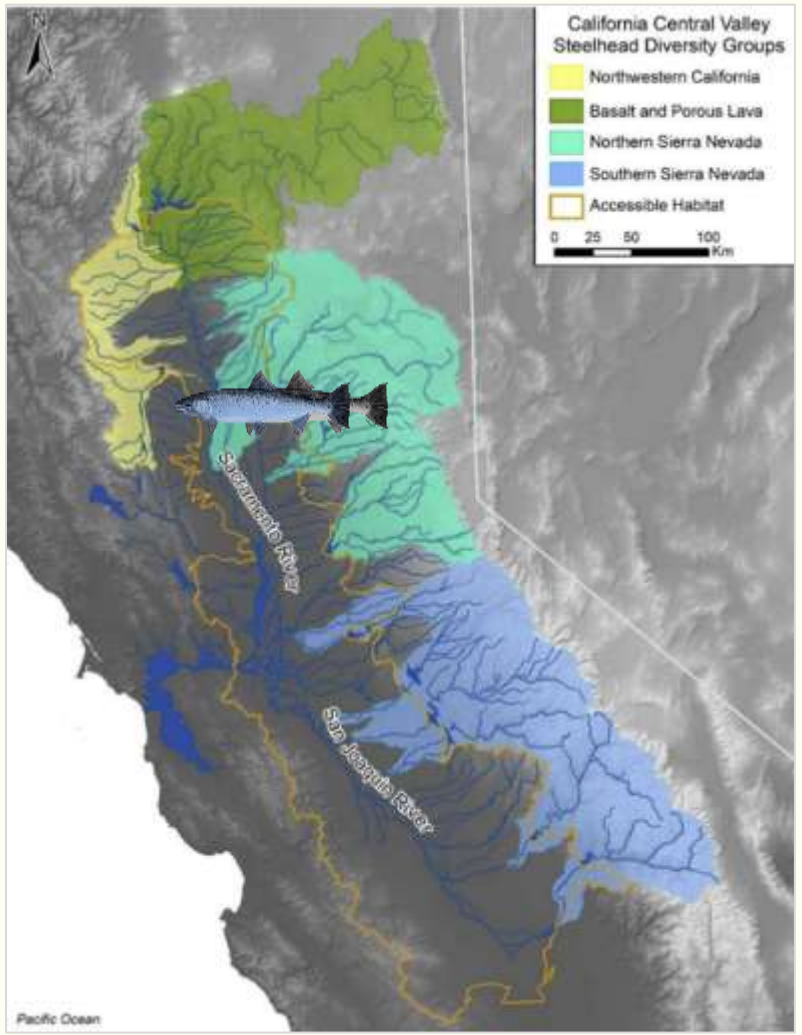
Influence of Migration Strategy on TDC



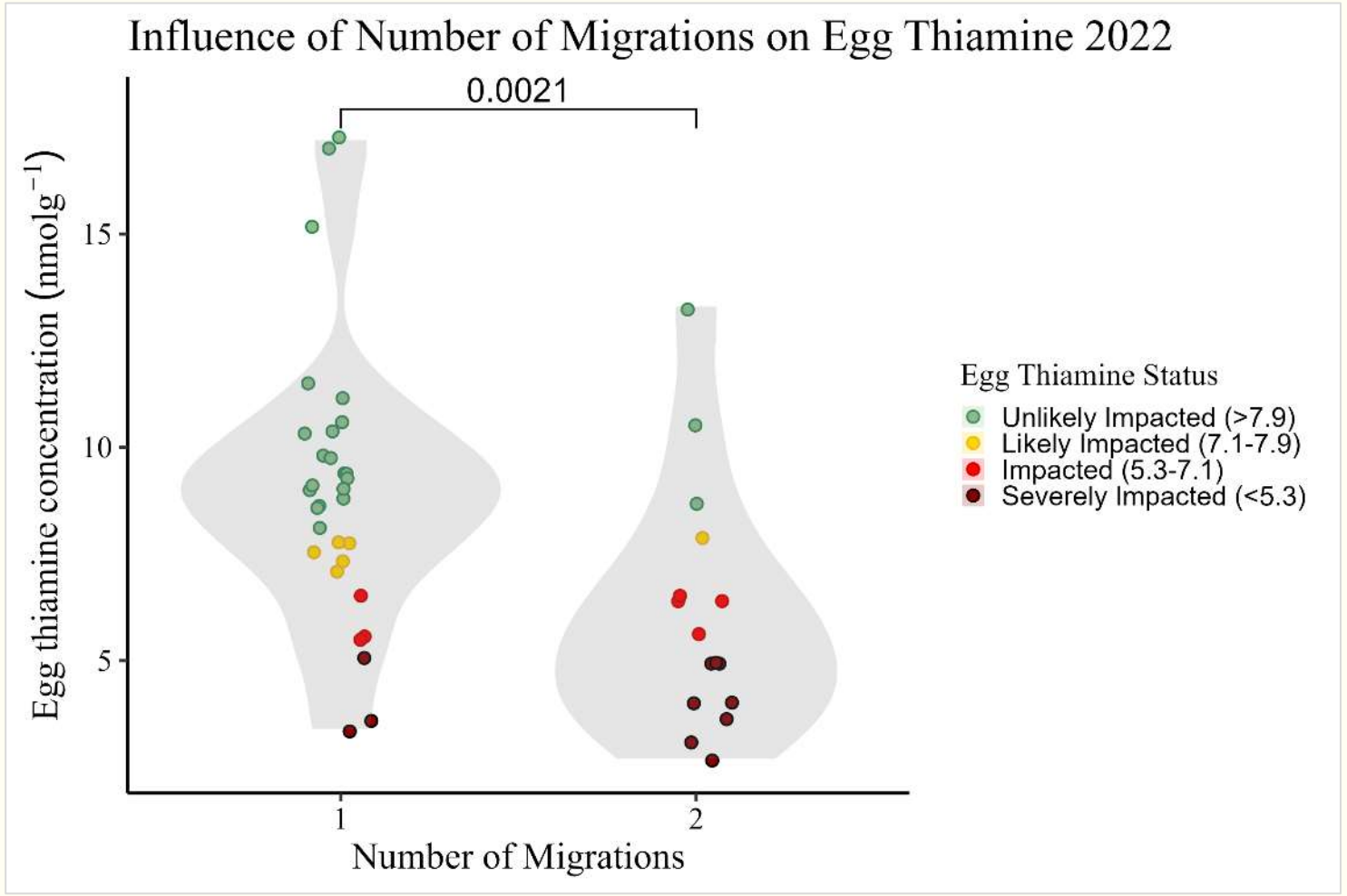


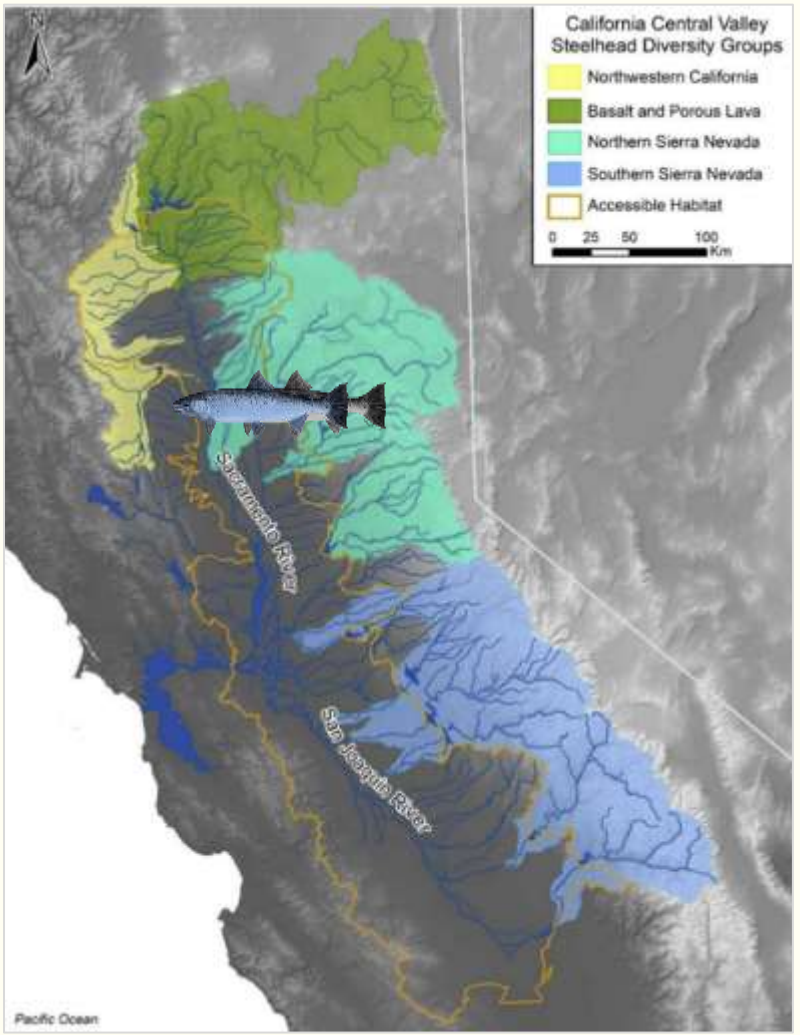
Influence of Number of Migrations on TDC



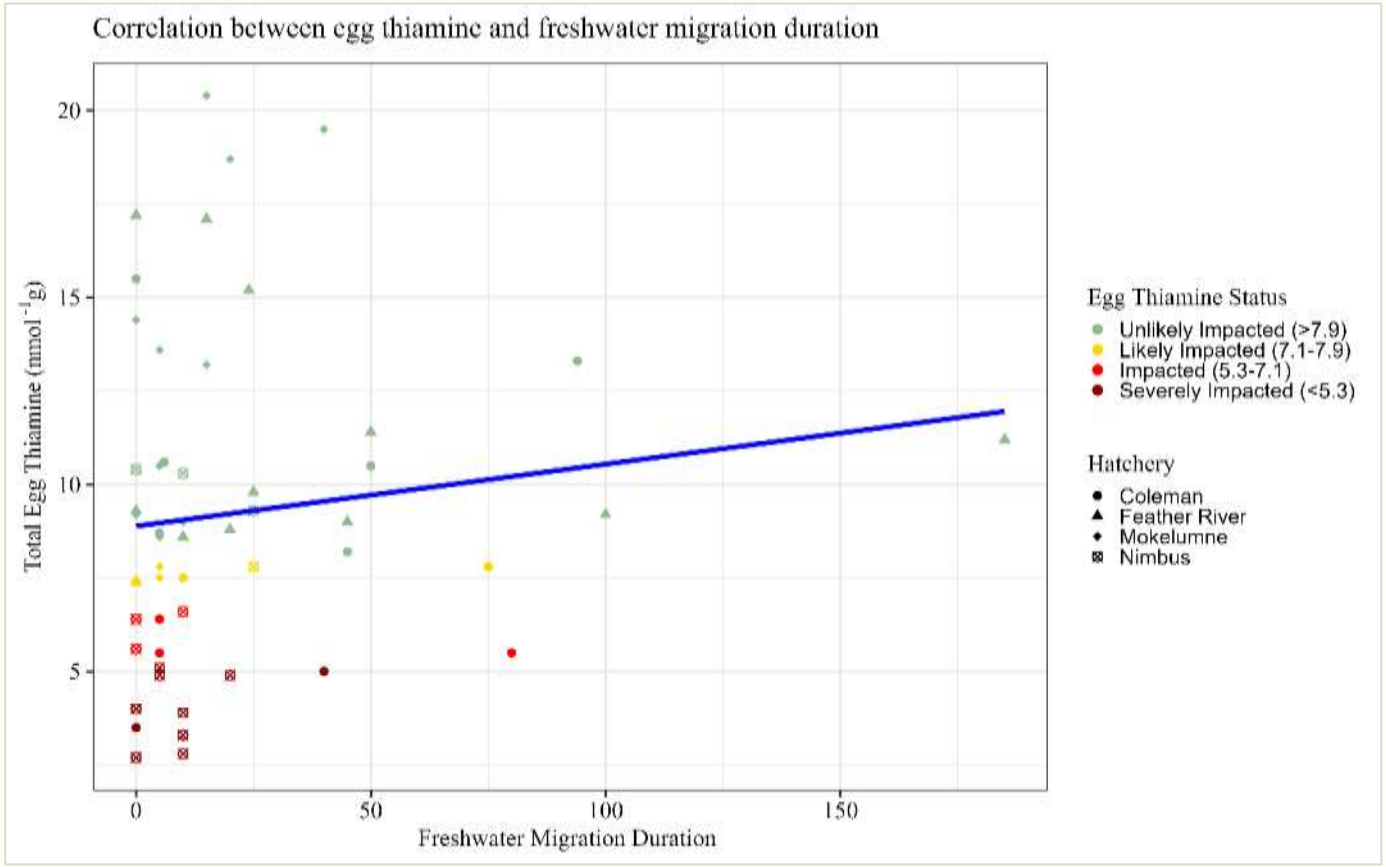


Influence of Number of Migrations on TDC



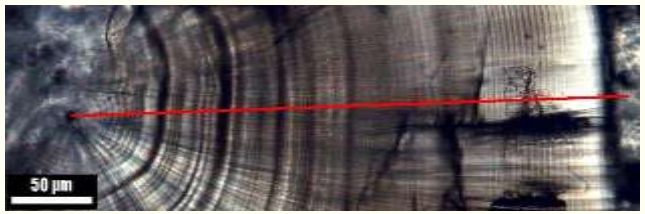


Influence of Freshwater Migration on TDC



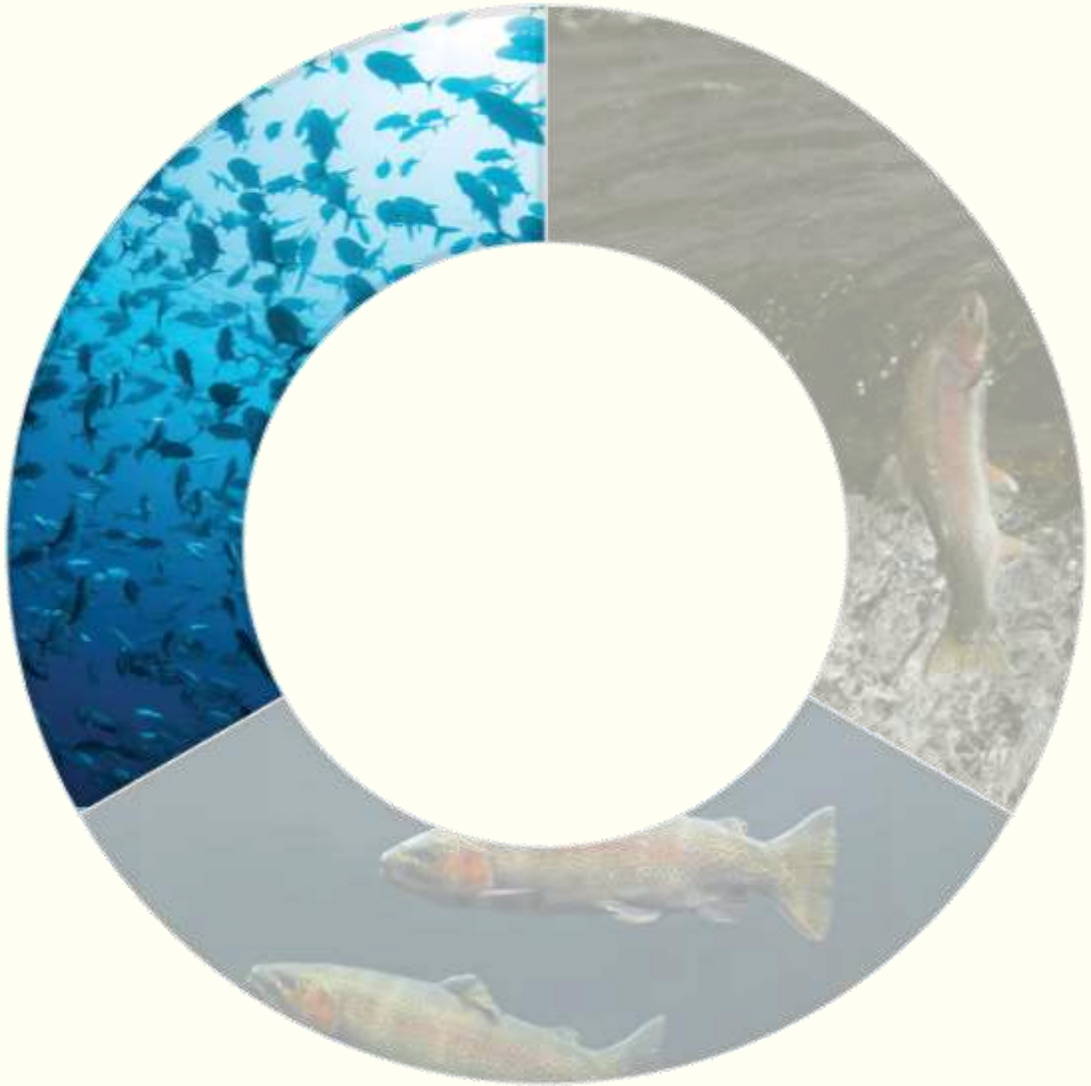
Understanding the influence of freshwater migration time during spawning on egg thiamine concentration could give us insight into freshwater thiamine uptake and how migration influences TDC.

This is being researched in other regions as well where correlations have been clearer.



Investigating prevalence, causes and impacts

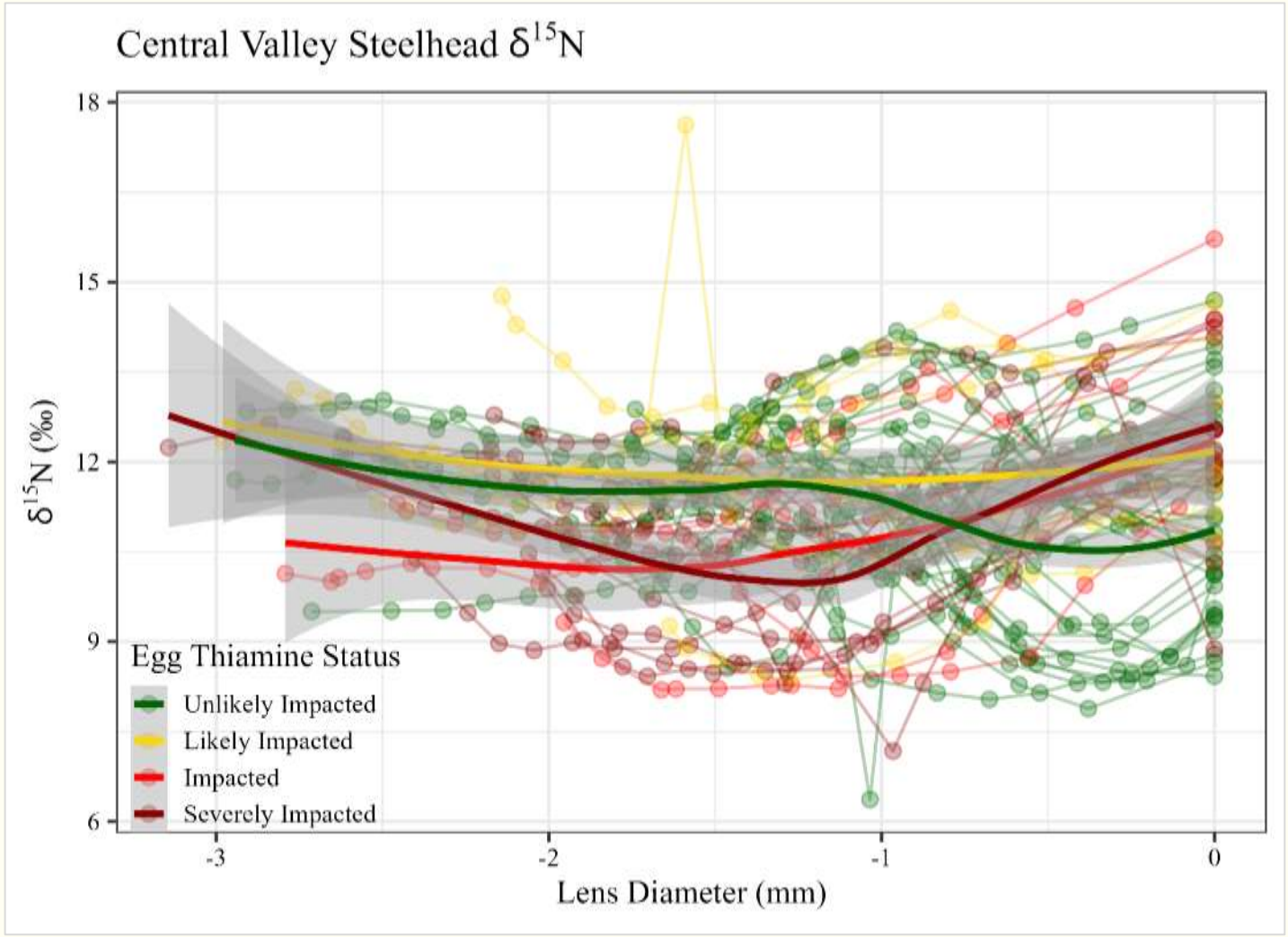
Marine Food Web

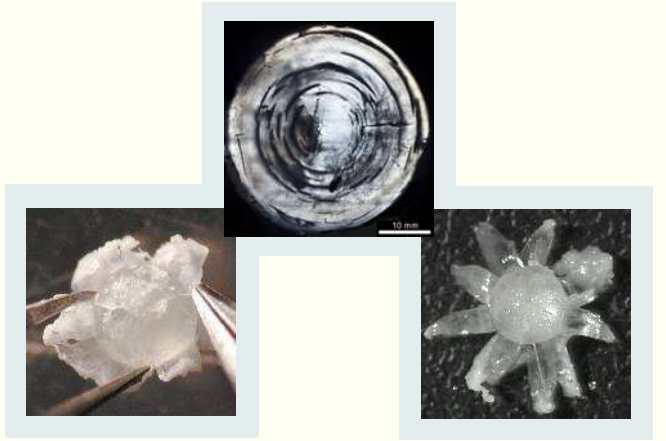


Objectives and Hypotheses:

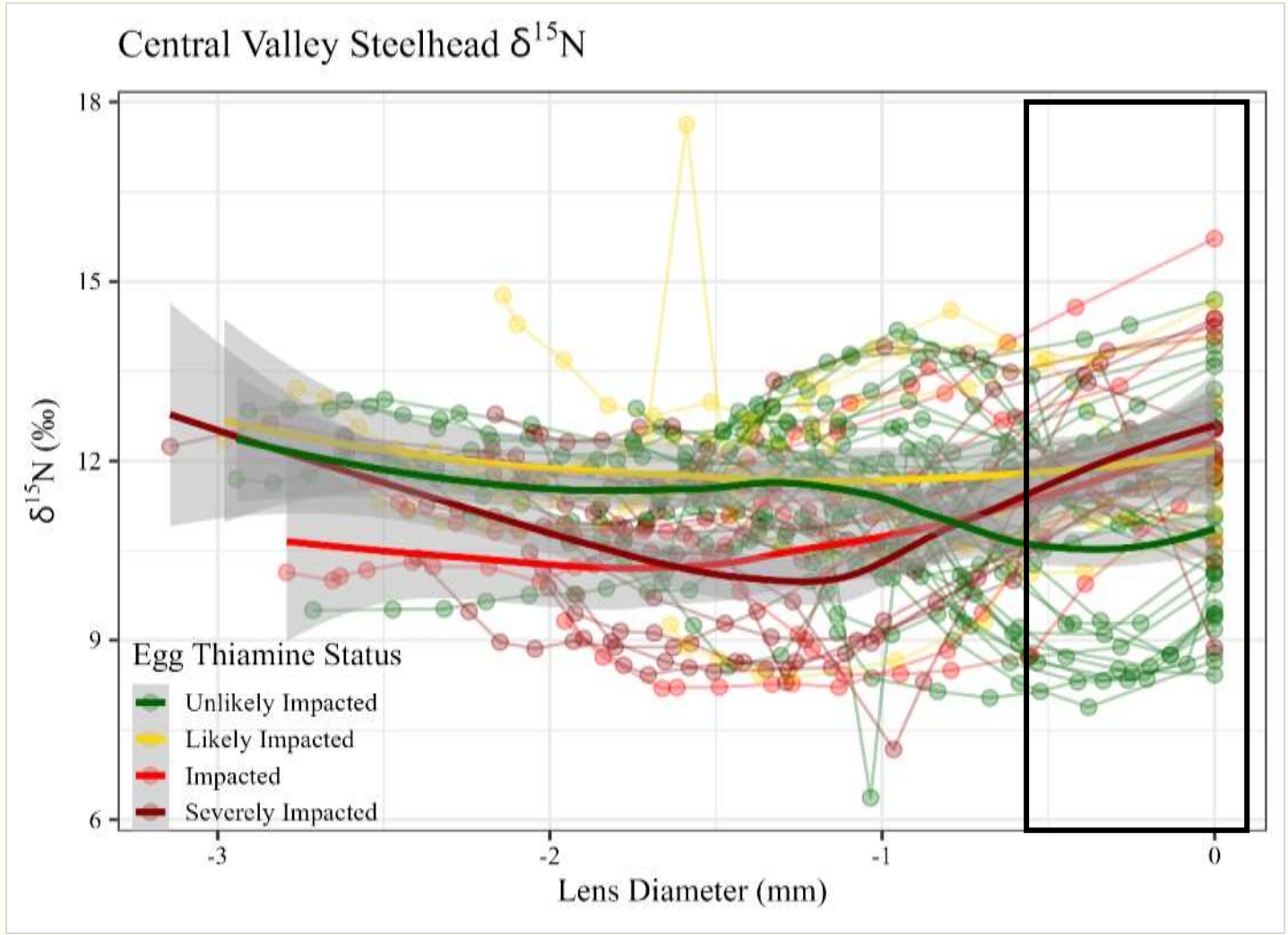
- To understand the diets of steelhead populations in the Central Valley and how their diets may be influencing thiamine concentrations
  - H1: Differences among Central Valley hatchery populations, specifically the population coming out of Nimbus
  - H2: Individuals more impacted with thiamine deficiency will show a distinctly higher $\delta^{15}N$ during their late stages of life due to influences of anchovies

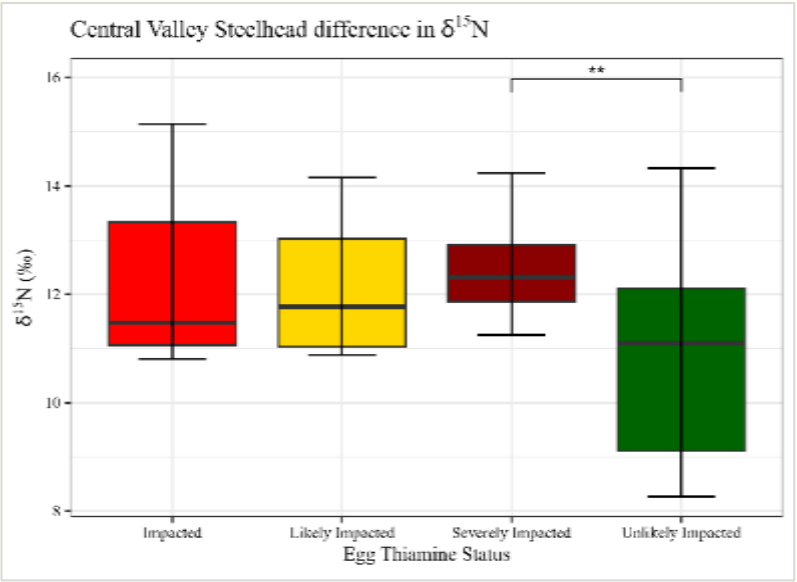
Eye Lens $\delta^{15}N$





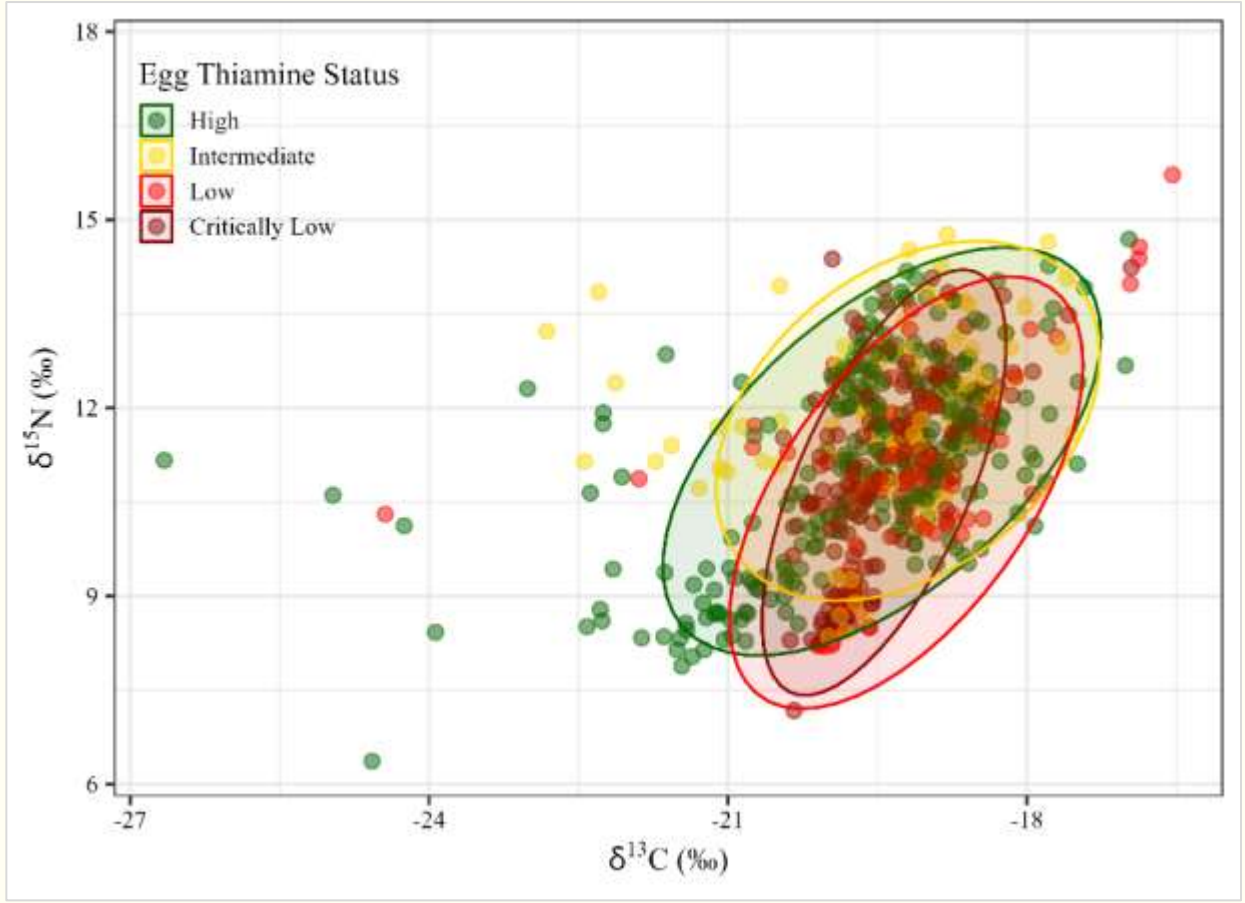
Eye Lens $\delta^{15}N$

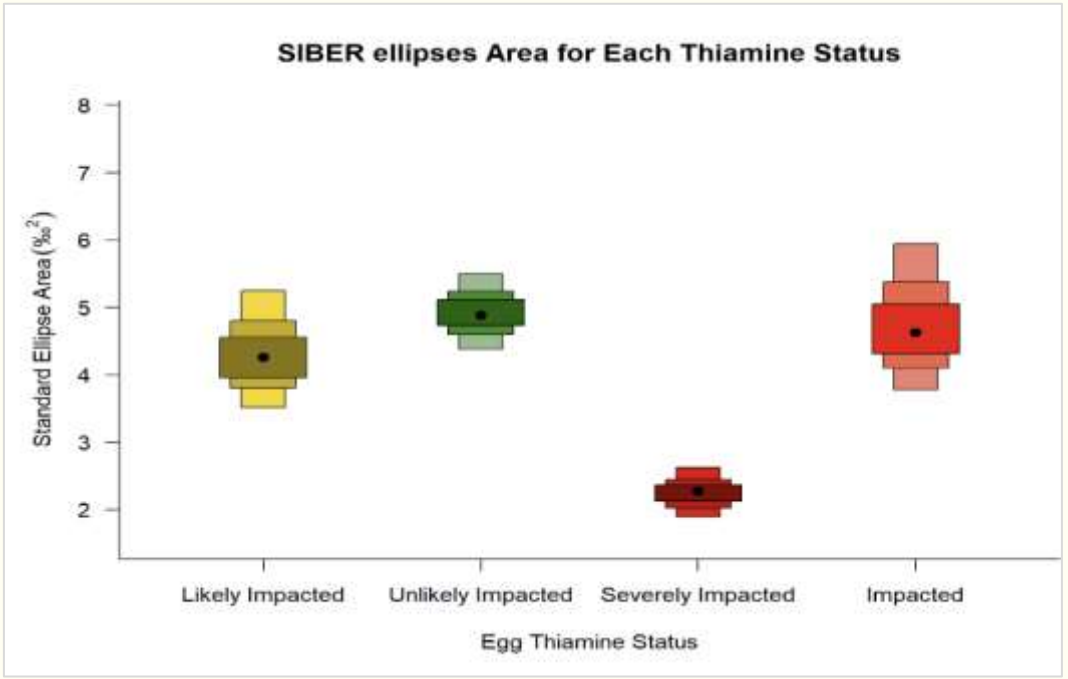




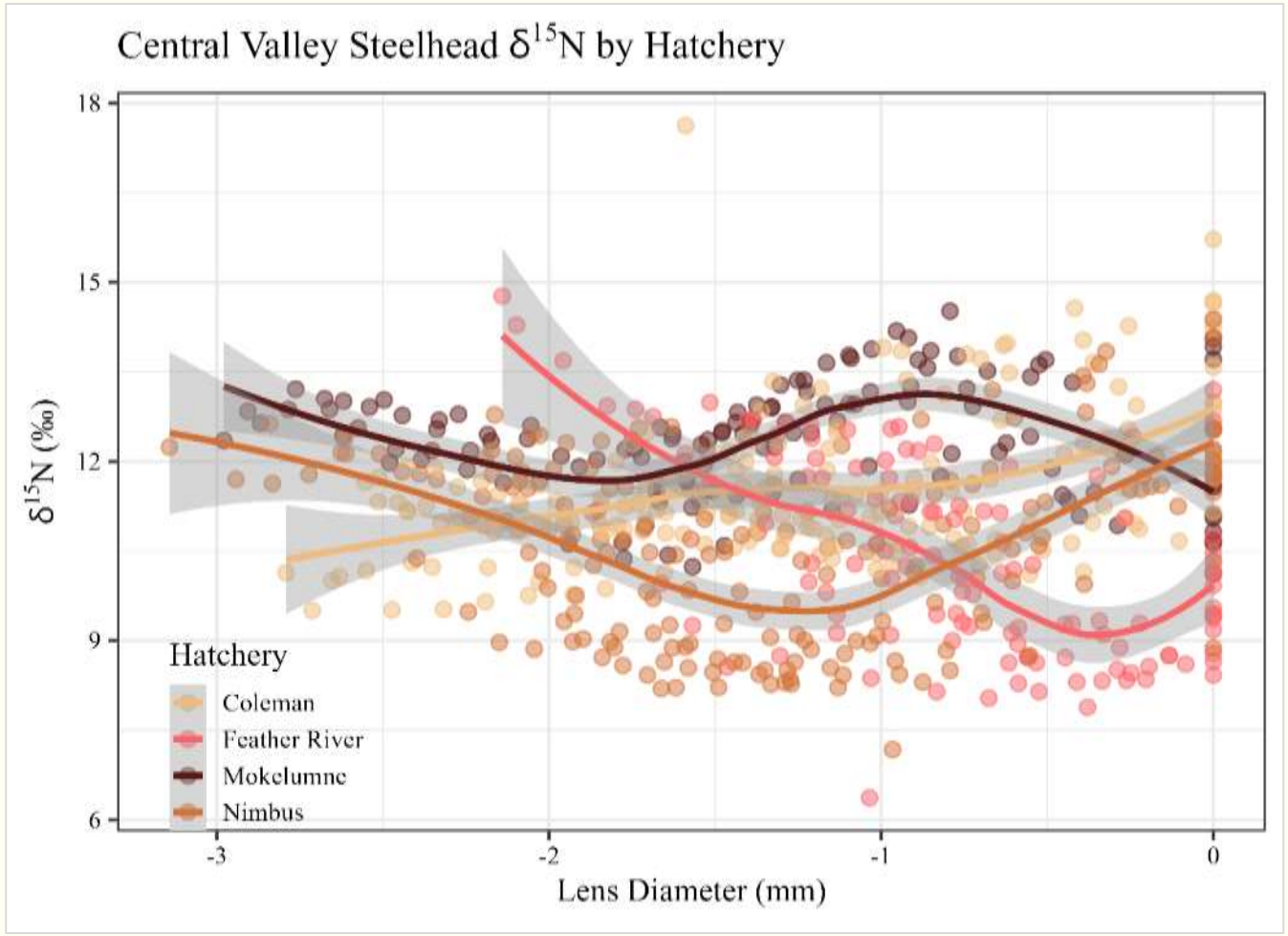
Eye Lens $\delta^{15}N$

The steelhead with the lowest thiamine resources (critically low), fill a much smaller isotopic niche space than other egg thiamine concentrations

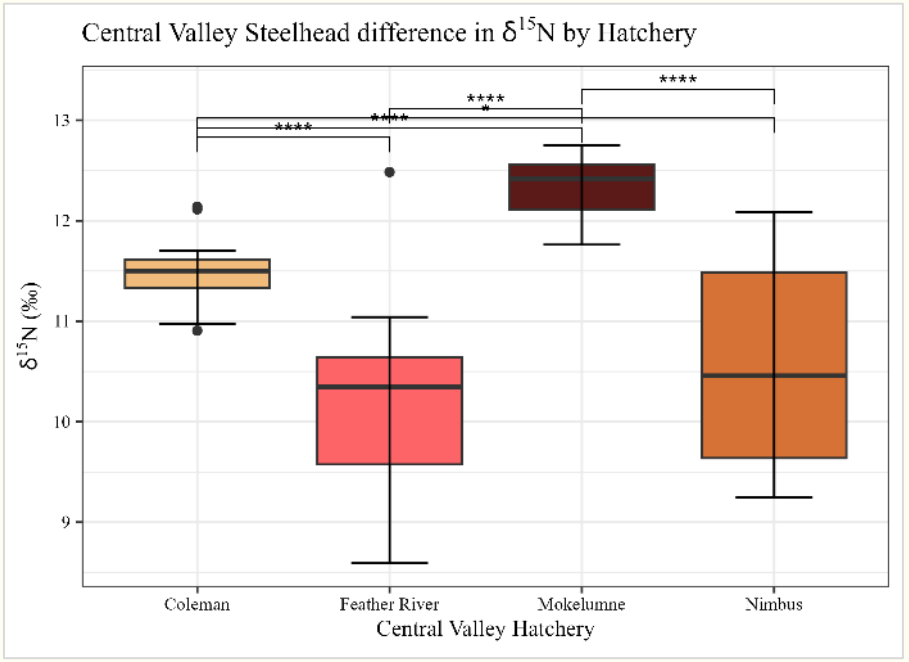




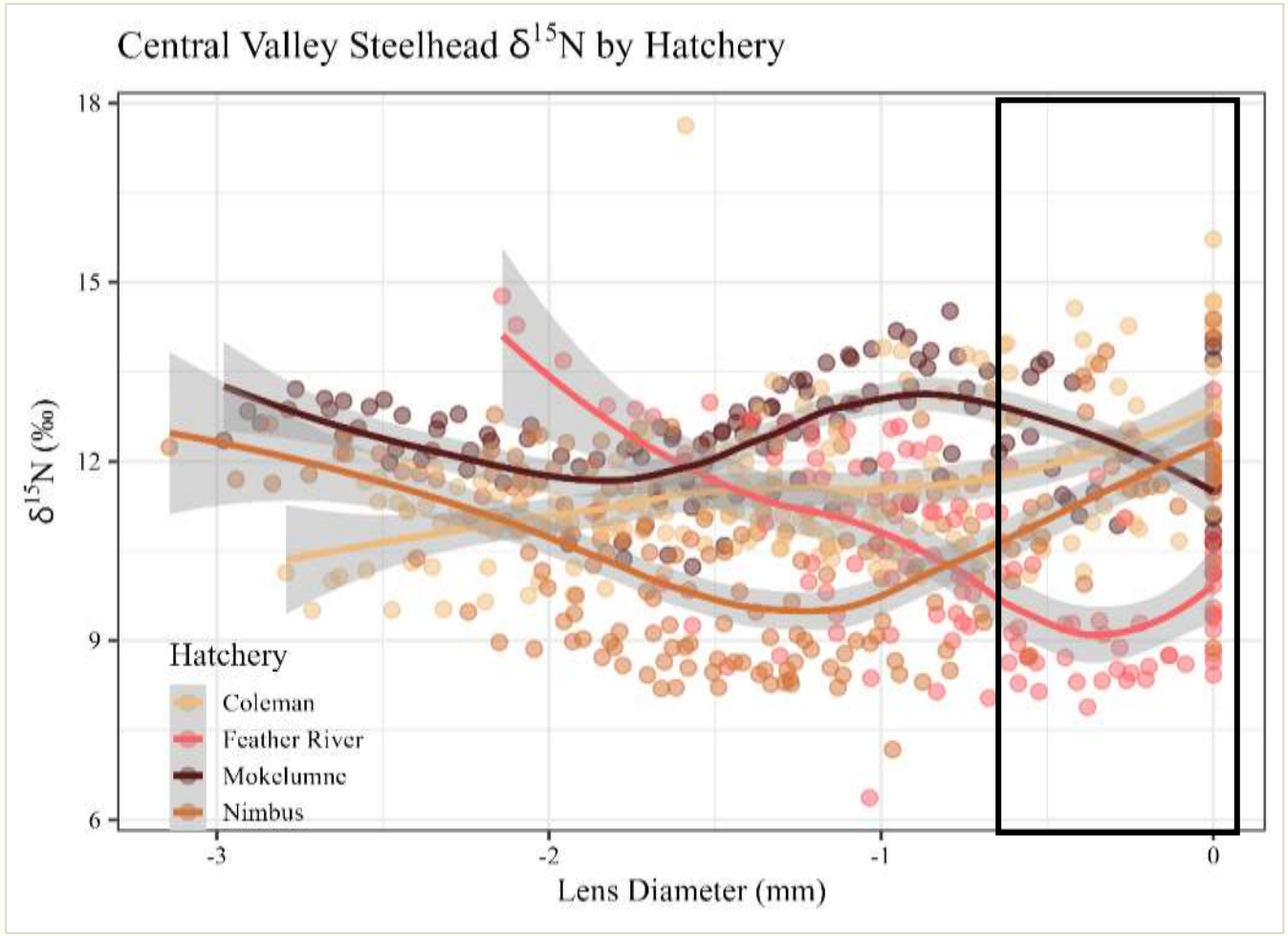
Eye Lens $\delta^{15}N$



The most significant difference in $\delta^{15}N$ was seen between hatchery populations.



Eye Lens $\delta^{15}N$



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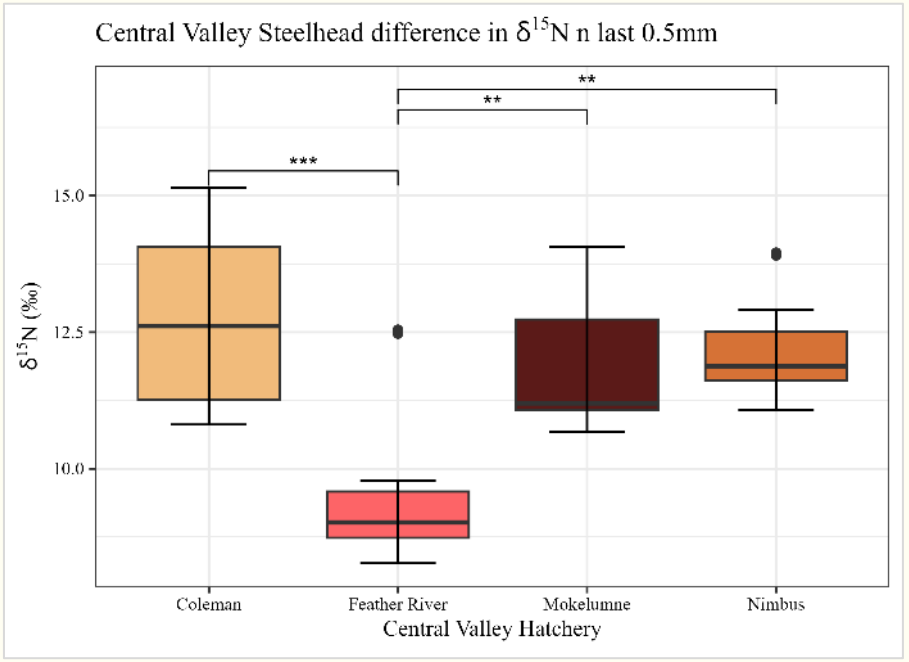
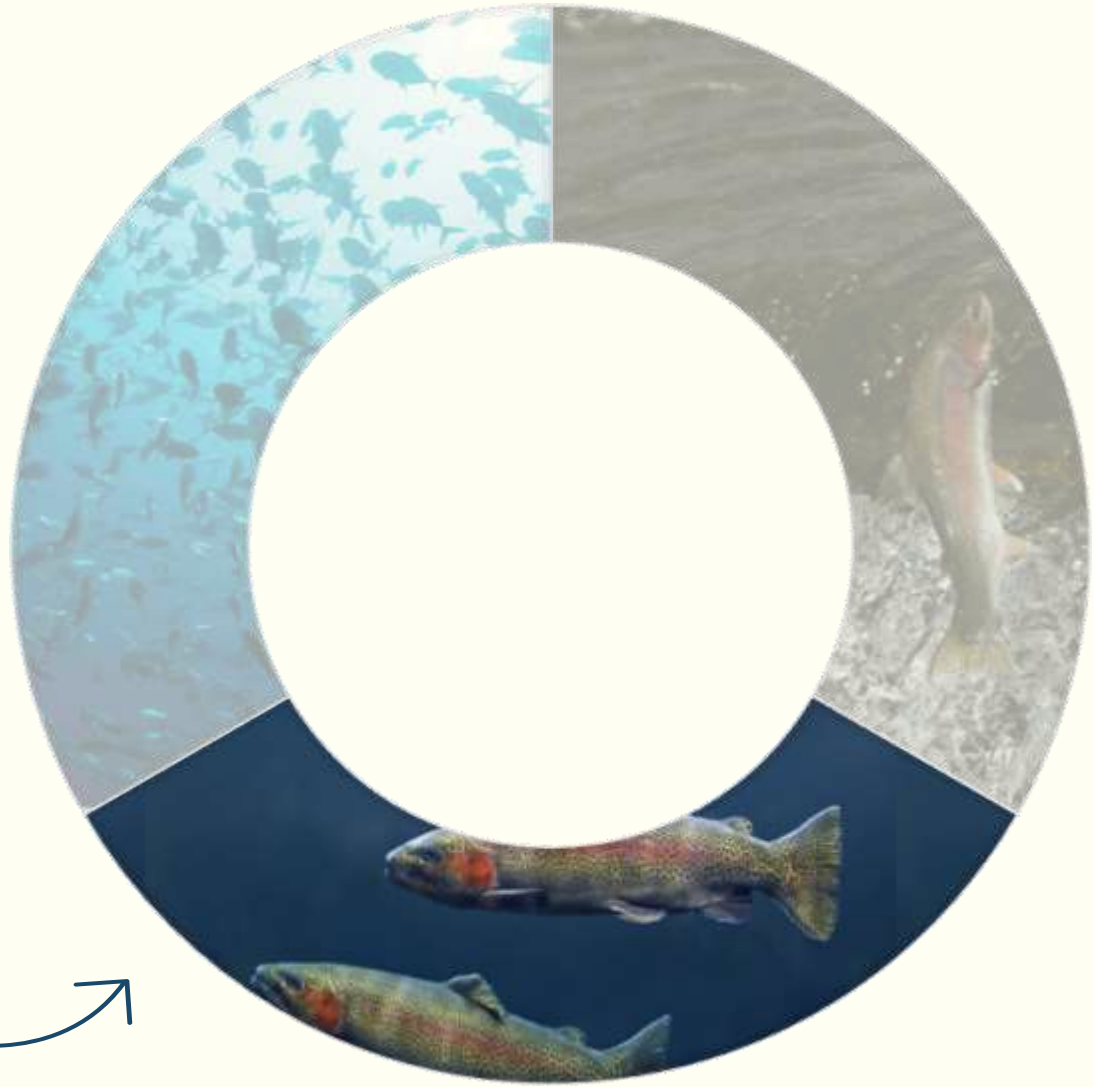


Investigating prevalence, causes and impacts



Evolutionary Impacts

Objectives and Hypotheses:

- Explore the potential impacts of TDC on the anadromous life history strategy of steelhead, investigating the selection for a resident life history strategy
  - H1: If the current state of the ocean is depleting steelhead of their essential resources and lowering survival and reproductive success, TDC could be selecting for a freshwater residency strategy over ocean migration

In Summary

- There is little known about steelhead ocean distribution and foraging ecology in connection to thiamine deficiency
  - This work suggests that while various life history strategies could be advantageous, there is still a lot to learn

- Potential risk for TDC in both the marine and freshwater environment?
  - What does steelhead foraging look like when they are migrating to spawn?

- Ocean foraging steelhead are occupying a smaller isotopic niche space, suggesting a limited diet while in the ocean could lead to a higher chance of TDC
  - More research needs to be done in order to understand the diets of both anadromous and resident *O. mykiss*

Next steps…

- Continuing broadscale monitoring of steelhead populations in the Central Valley and beyond
  - https://oceanview.pfeg.noaa.gov/projects/salmon_thiamine/intro
- Collecting paired tissues alongside eggs and continuing with other analyses to better understand foraging ecology and migration
  - Egg stable isotope analysis
  - Fatty acids
- Beginning to investigate offshore prey items and include them in analyses for diet
- Starting to explore natural selection pieces

Thiamine Research Team and Partners

NOAA Fisheries: Rachel Johnson, Nate Mantua, John Field, Steve Lindley, Tommy Williams, Lynn Dewitt, Cody Pinger, Miles Daniels, Drew Porter

NOAA West Coast Region: Amanda Cranford, Charlotte Ambrose, Michael Milstein

USFWS: Taylor Lipscomb, Scott Foot, William Ardren, Christie Nicols, Christine Parker-Gram, Alison Deary, Ronald Twibell

USGS: Donald Tillitt, Freya Rowland, David Walters, Cathy Richter, and Dale Honeyfield (retired)

CDFW: Kevin Kwak, Mark Adkison, Brett Kormos, Mitsuko Grube, Michael Stuhldreher, Jeff Rodzen

SUNY Brockport: Jacques Rinchard, Jarrod Ludwig

OSU: Frederick Colwell, Chris Suffridge, Kelly Shannon, Aimee Reed

Department of Water Resources: Jason Kindopp, Ryon Kurth, Kyle Hartwigsen

Idaho State University: Bruce Finney

Moss Landing Marine Laboratory: Iliana Ruiz-Cooley

Monterey Bay Aquarium Institute: Steve Litvin

UC Davis: Carson Jeffres, Anne Todgham, Nann Fangue, Esteban Soto, Heather Bell, Dennis Cocherell, Sage Lee, Peggy Harte, Ryan Meyer, Abigail Ward, Ryan Peek, Alexandra Chu, Miranda Bell-Tilcock, Miranda Lowe-Webb

Binghamton University: Katie Edwards

Cornell University: Cliff Kraft

University of British Colombia: Brian Hunt, Anna McLaskey, Jacob Lerner

Anglers and charter boats: New Sea Angler, New Rayann, Erick Owens

#Spinning Salmon in the Classroom: Teachers and Students!

Hatchery Managers: Brett Galyean, Anna Kastner, Penny Crawshaw, Gary Novak, Paula Hoover, Jason Julienne, William Smith, Mary Serr, Steve Tsao, Amy Knabe, Pat Brock, Shad Overton, Alan Pariani

Yurok Tribe: Keith Parker

Acknowledgements

Bruce Finney and his lab at Idaho State University as well as the Stable Isotope Facility at UC David for their aid in our stable isotope analyses

Jacques Rinchard and his lab at SUNY Brockport for their continued support analyzing our samples for total thiamine

California Department of Fish and Wildlife and American Fisheries Society for funding this research

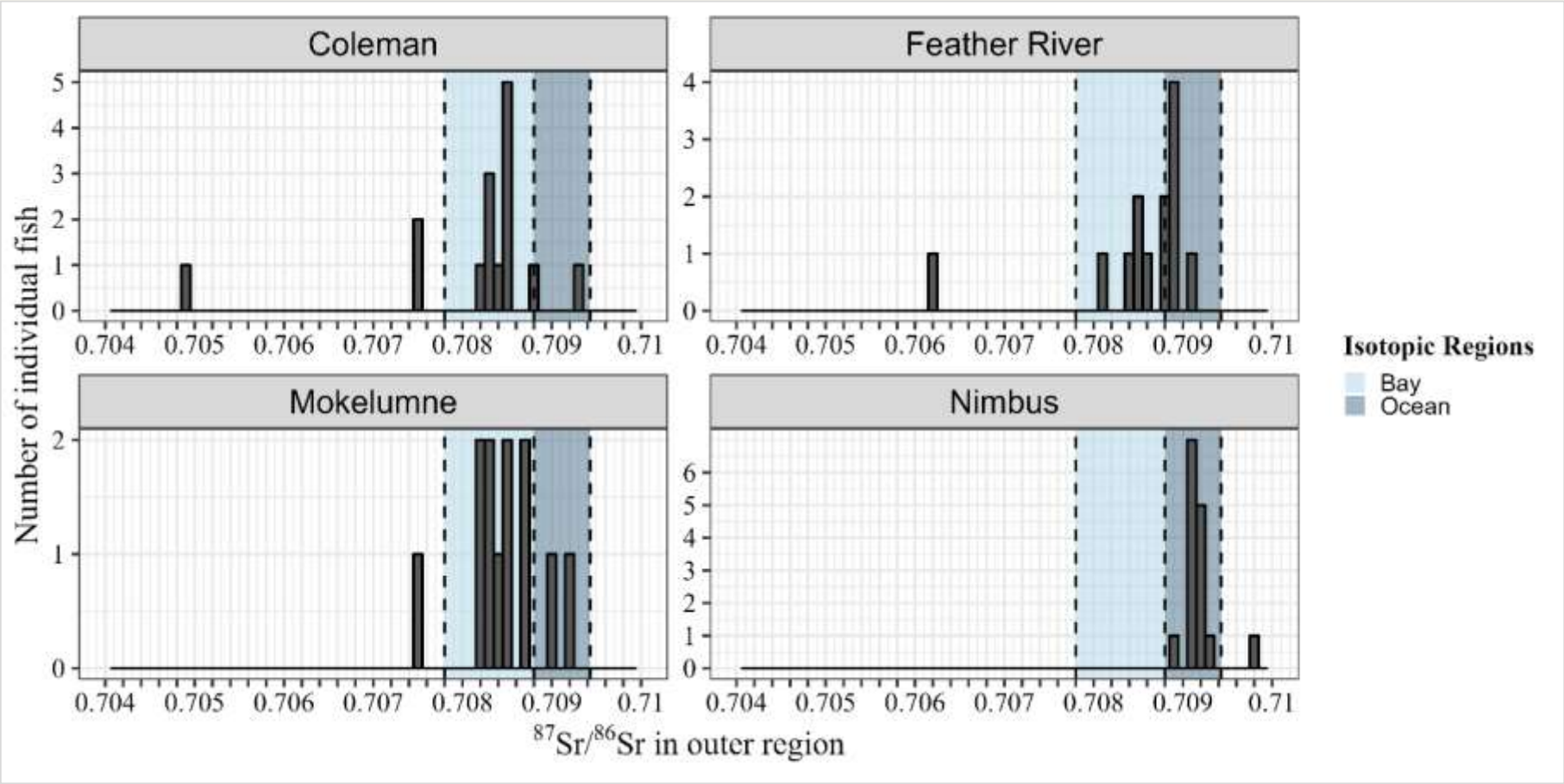
Contact: abbward@ucdavis.edu

Questions?

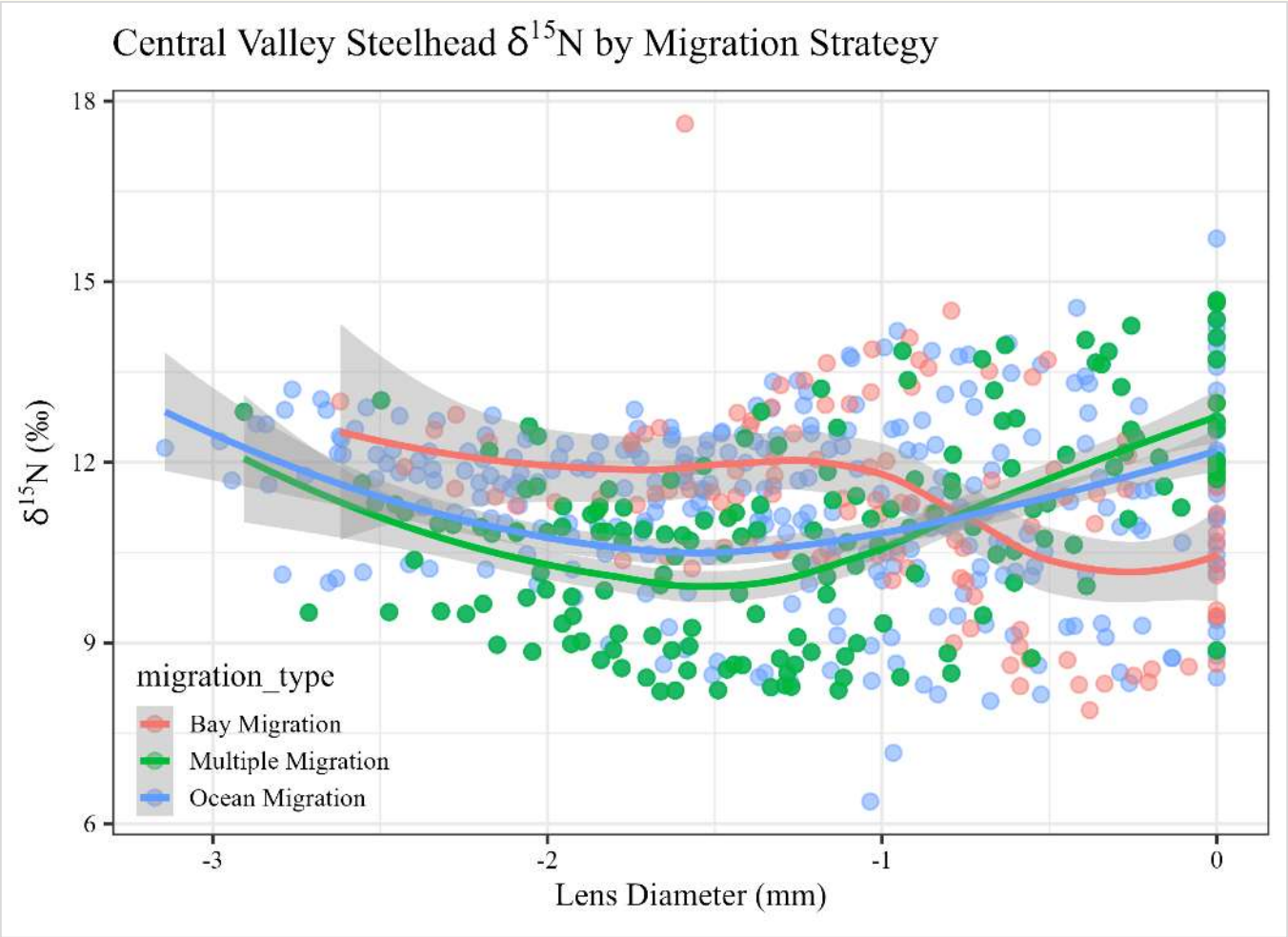




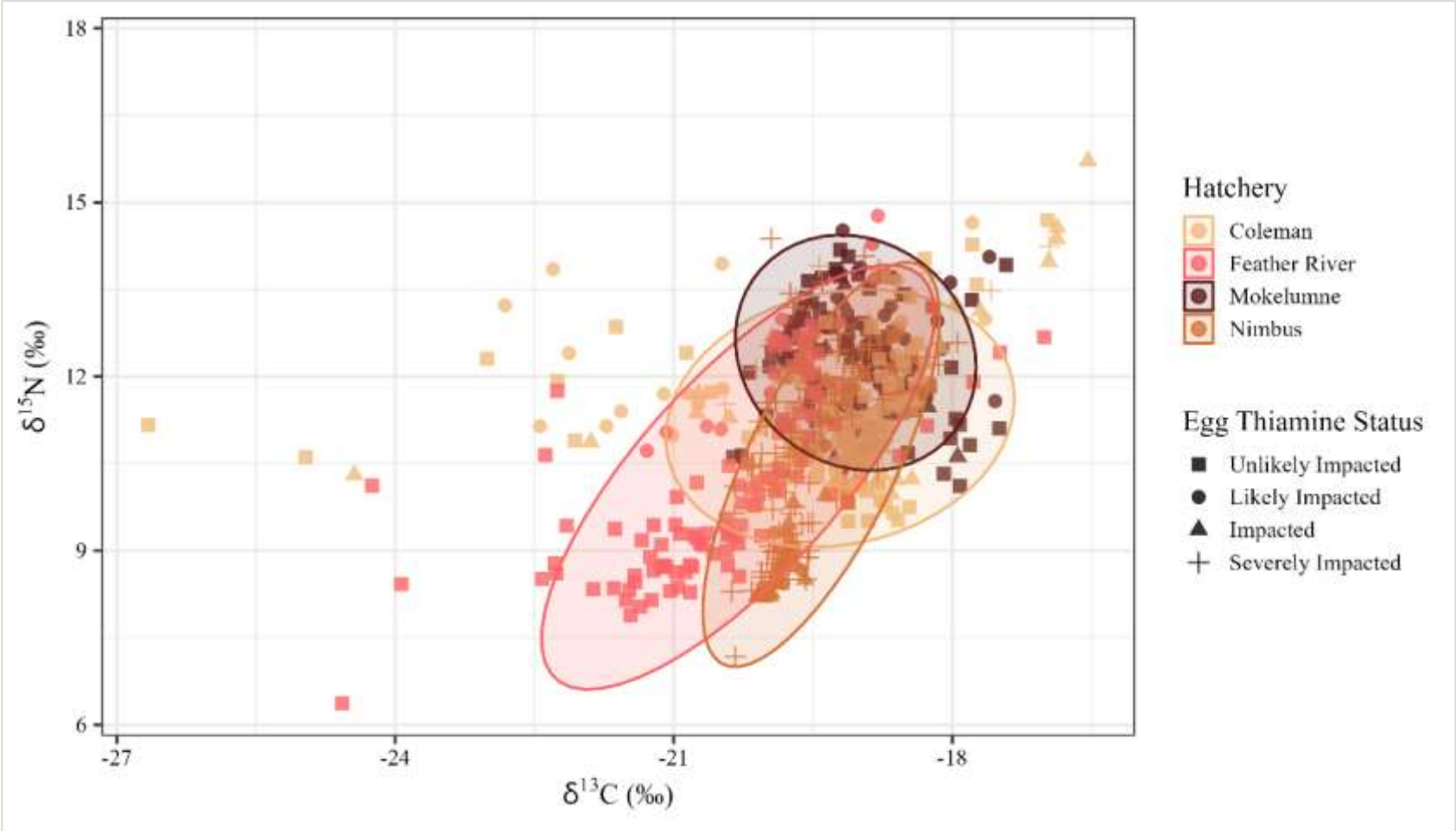
Extra Data


Coleman
Feather River
Mokelumne
Nimbus
Number of individual fish
$^{87}Sr/^{86}Sr$ in outer region
Isotopic Regions
Bay
Ocean

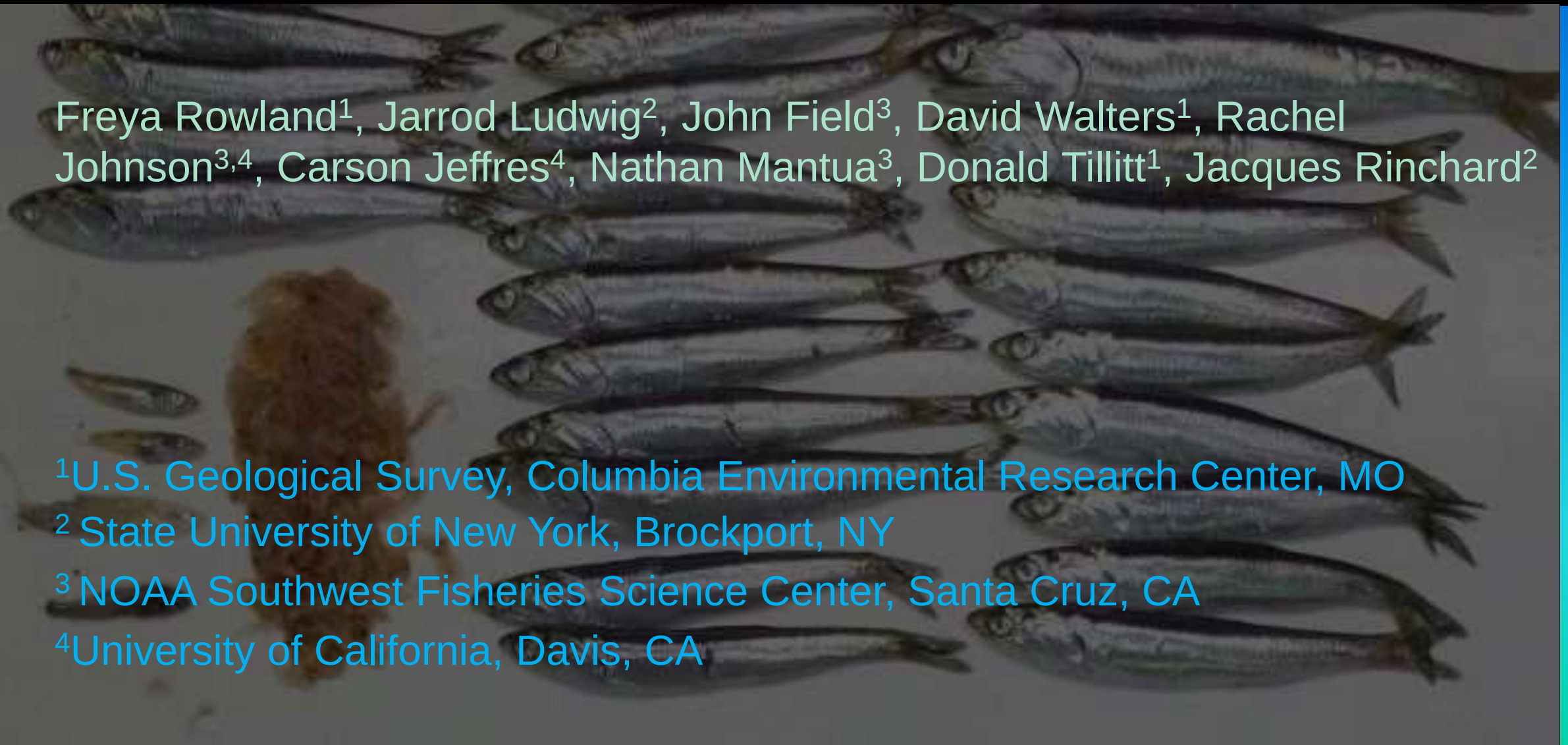
Extra Data


Central Valley Steelhead δ15N by Migration Strategy
δ15N (‰)
18
15
12
9
6
-3
-2
-1
0
Lens Diameter (mm)
migration_type
Bay Migration
Multiple Migration
Ocean Migration

Extra Data


18
15
12
9
6
δ15N (‰)
-27
-24
-21
-18
δ13C (‰)
Hatchery
Coleman
Feather River
Mokelumne
Nimbus
Egg Thiamine Status
Unlikely Impacted
Likely Impacted
Impacted
Severely Impacted

Baseline Forage Fish Nutritional Quality in the California Current Ecosystem



Freya Rowland[1], Jarrod Ludwig[2], John Field[3], David Walters[1], Rachel Johnson[3,4], Carson Jeffres[4], Nathan Mantua[3], Donald Tillitt[1], Jacques Rinchard[2]

[1]U.S. Geological Survey, Columbia Environmental Research Center, MO
[2] State University of New York, Brockport, NY
[3] NOAA Southwest Fisheries Science Center, Santa Cruz, CA
[4]University of California, Davis, CA

Thiamine Deficiency Complex (TDC) – An emerging global issue

Trends in Ecology & Evolution

CellPress REVIEWS

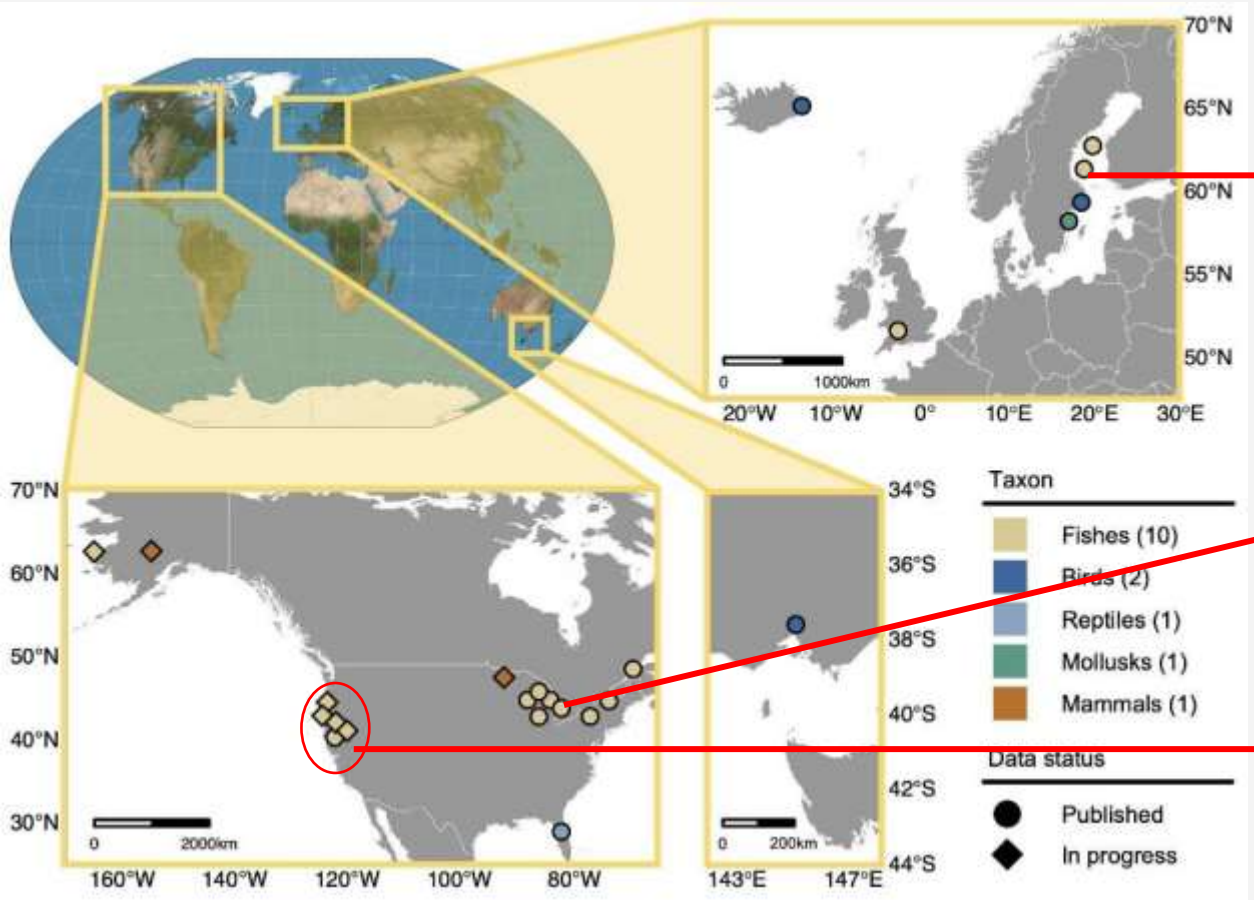
Review

A 2018 Horizon Scan of Emerging Issues for Global Conservation and Biological Diversity

Emerging Issues

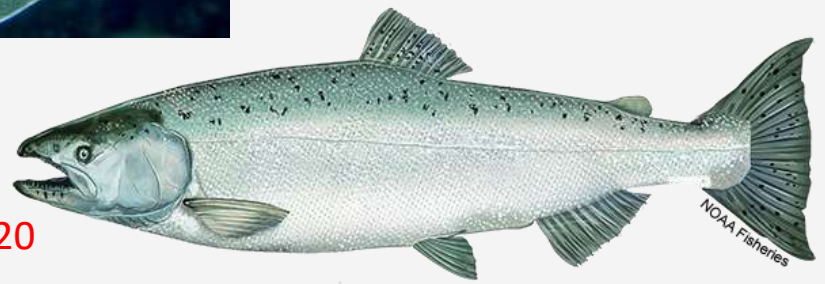
Thiamine Deficiency as a Possible Driver of Wildlife Population Declines

Evidence is increasing that a range of taxonomic groups, including bivalve molluscs, ray-finned fish, and birds across the Northern Hemisphere, are deficient in thiamine (vitamin B1)



1970s

1960s



2020

Images: Creative commons – public domain

Thiamine deficiency more common in humans than we previously believed

Open Access Review

Hiding in Plain Sight: Modern Thiamine Deficiency

by **Chandler Marrs** [1,*] and **Derrick Lonsdale** [2]

[1] Independent Researcher, Henderson, NV 89074, USA

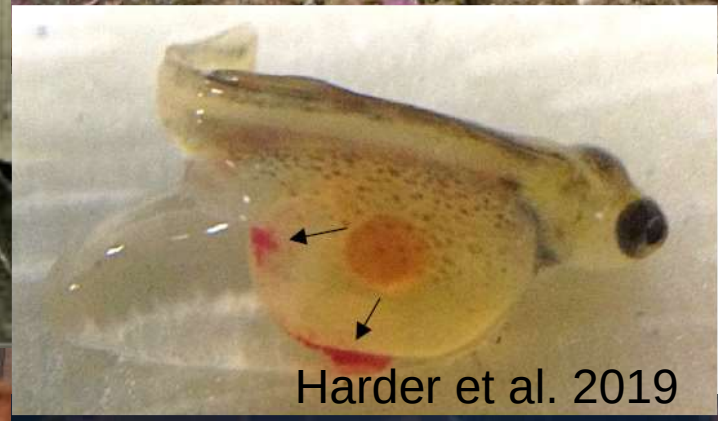
[2] Emeritus, Cleveland Clinic, Cleveland, OH 44195, USA

[*] Author to whom correspondence should be addressed.

Cells **2021**, *10*(10), 2595; **https://doi.org/10.3390/cells10102595**

Submission received: 27 August 2021 / Revised: 22 September 2021 / Accepted: 23 September 2021 / Published: 29 September 2021

Thiamine (B_1) deficiency has been documented worldwide in humans, alligators, mussels, birds, mammals, and fishes

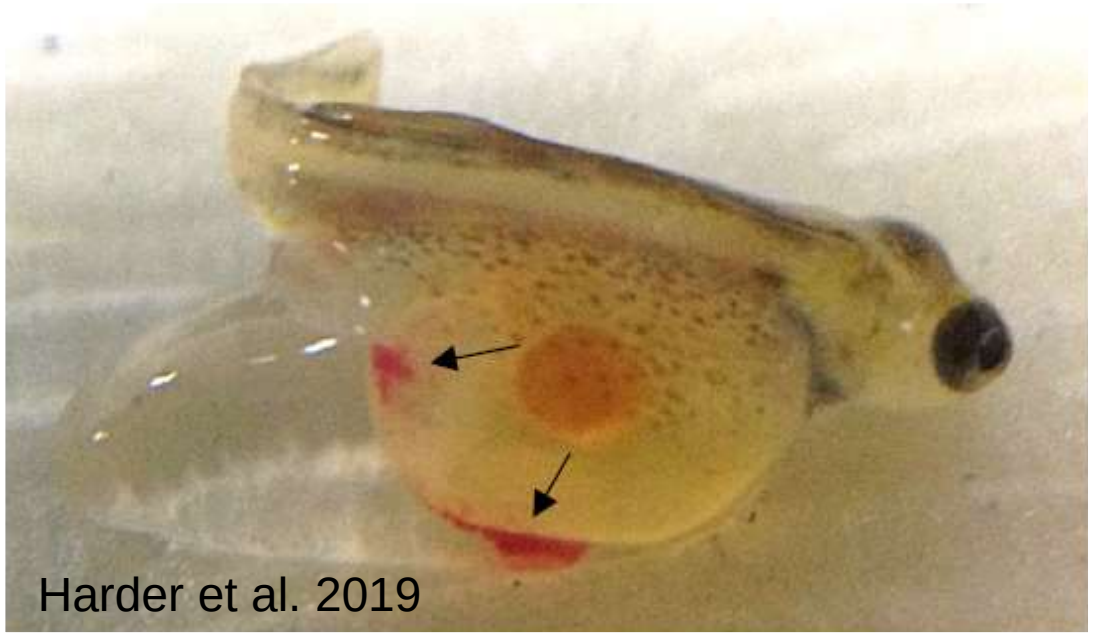


Harder et al. 2019

Insufficiency can cause:

- Neurological problems
  - Confusion
  - Abnormal eye movements
  - Loss of control over body movements
- Altered metabolism
- Immunosuppression
- Death

Animals are especially prone to thiamine deficiency early in development


Harder et al. 2019

- The main source of thiamine early in development is the egg yolk
- Egg yolk thiamine stores are maternally derived
- Thiamine deficiency can cause recruitment failure

TDC: A ‘new’ bottleneck on salmon recruitment?

Los Angeles Times

CLIMATE & ENVIRONMENT

Something was killing baby salmon. Scientists traced it to a food-web mystery

JAN. 26, 2021

The Ocean’s Mysterious Vitamin Deficiency

A puzzling lack of thiamine is disrupting some marine ecosystems.

Hakai magazine Coastal science and societies

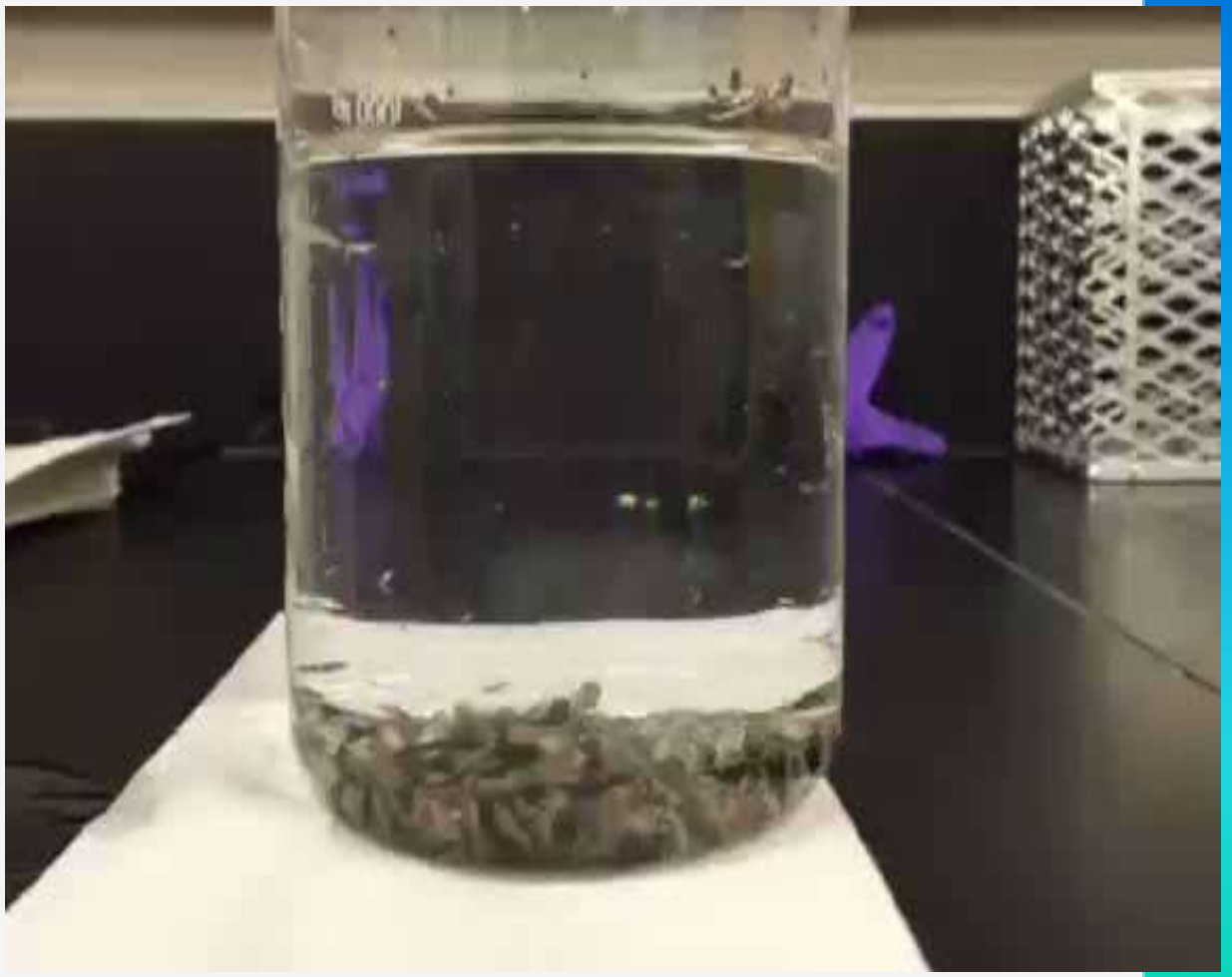
by Alastair Bland

January 28, 2021 | 2,700 words, about 14 minutes

APRIL 7, 2023

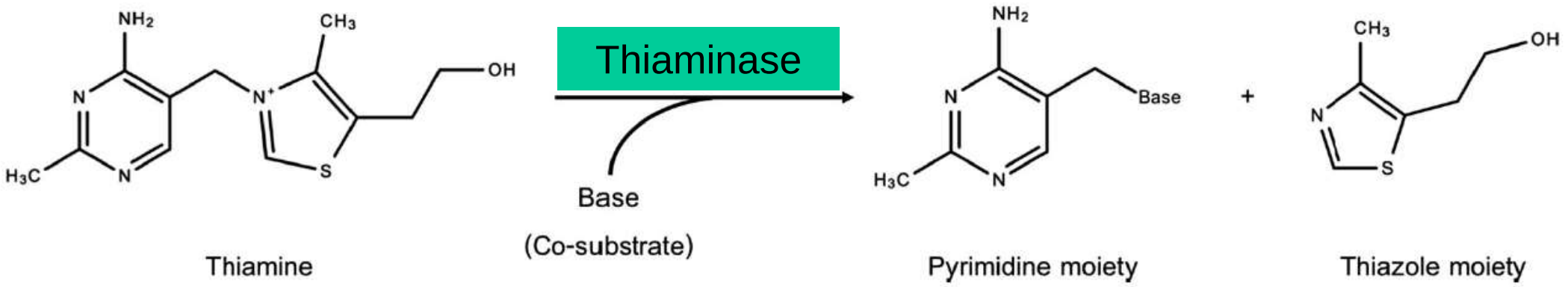
Wild salmon crisis hits US West Coast with closure of California, Oregon chinook fisheries

SeafoodSource



Video from J. Rinchard

Two ways to become deficient: not enough in diet or eating something that destroys thiamine in the body



Harder et al. 2018

Evolutionary and ecological correlates of thiaminase in fishes

Freya E. Rowland, Catherine A. Richter, Donald E. Tillitt & David M. Walters

Gizzard shad

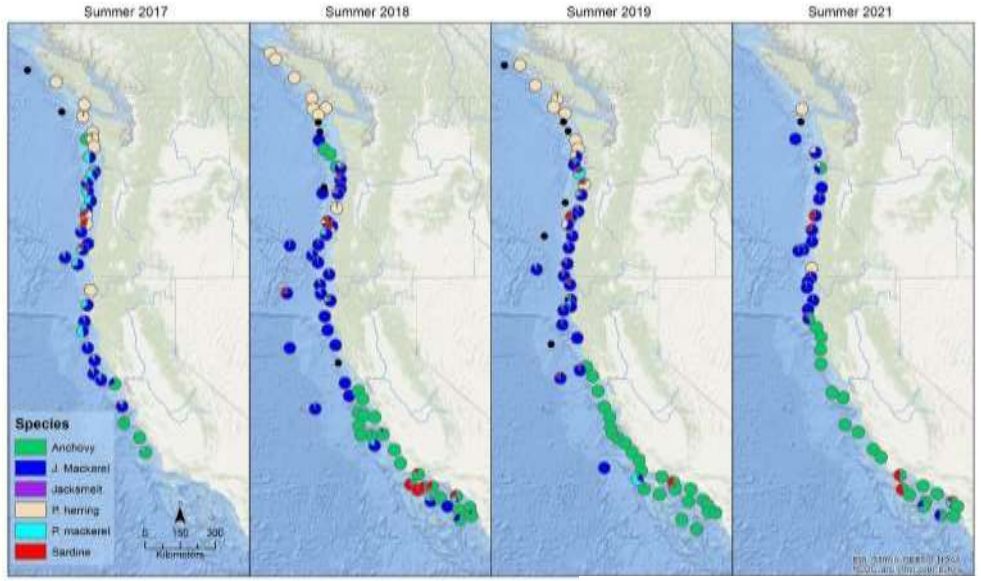
Anchovy

Atlantic herring

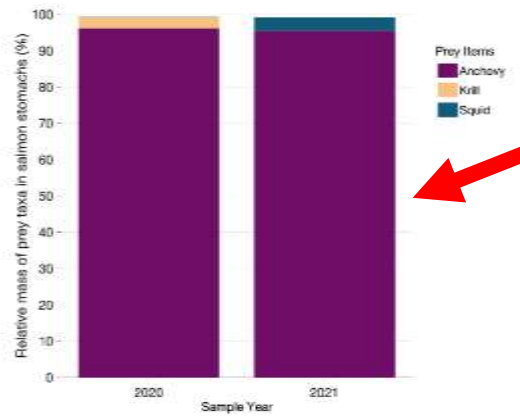
Alewife

Hypothesis: Shifts in forage base is contributing to TDC in Pacific salmon

Range Expansion

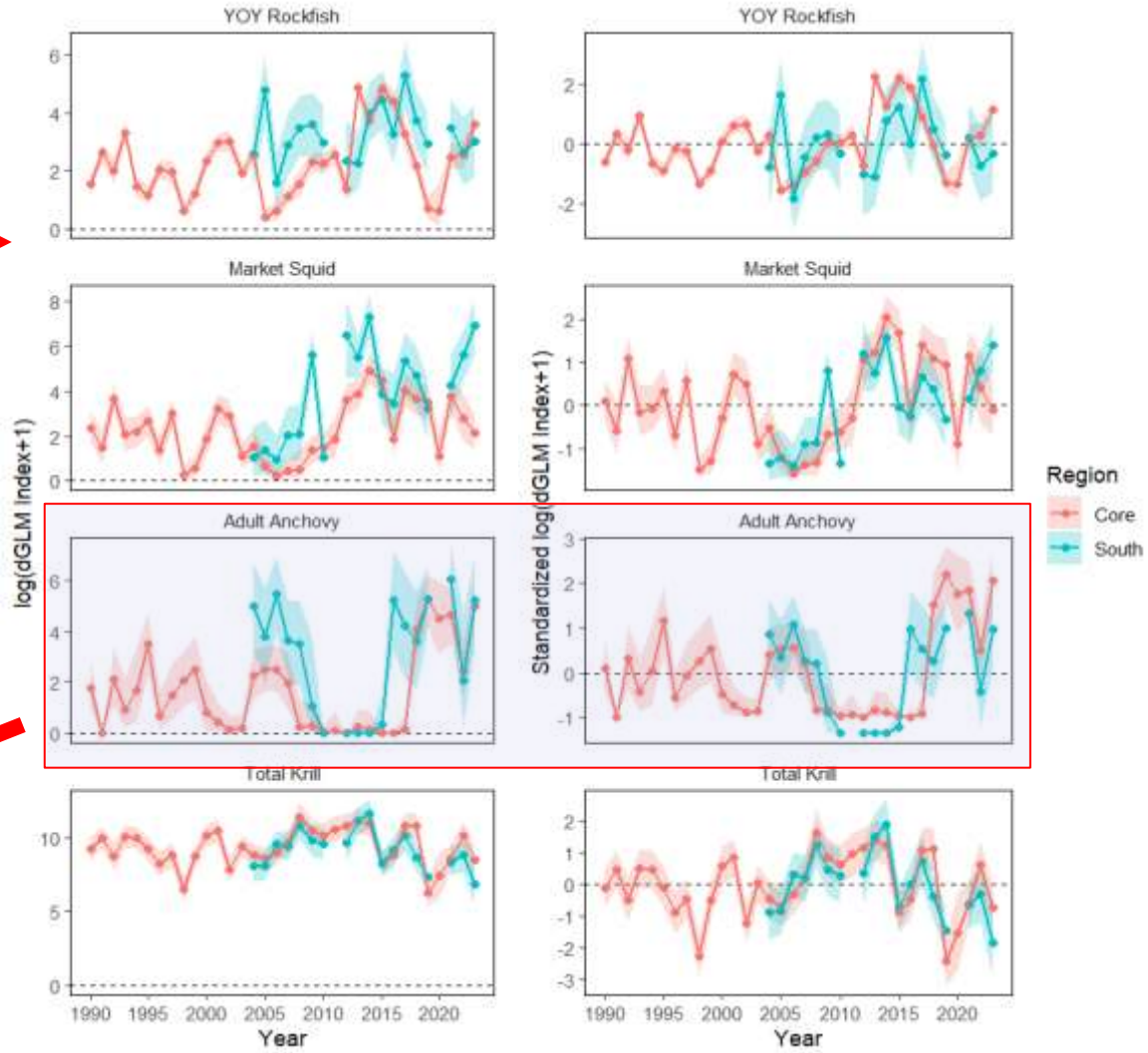


Northern Anchovy

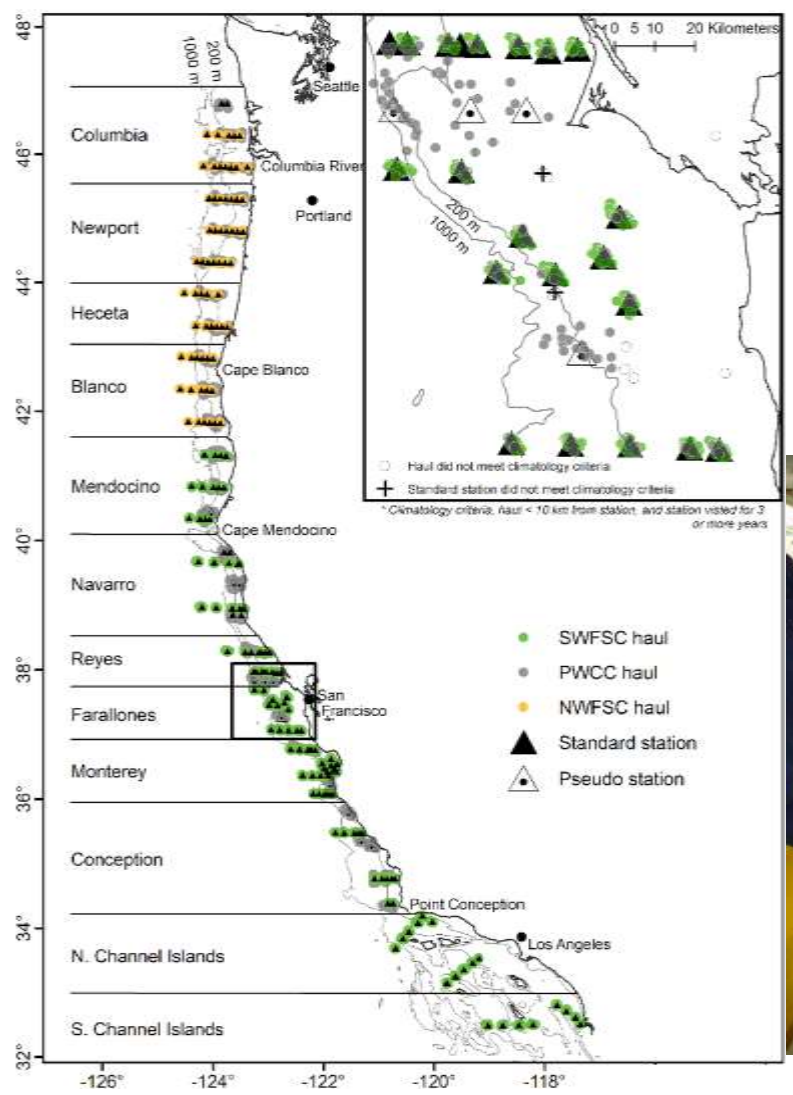


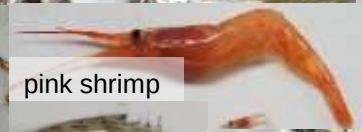
Dominant salmon prey

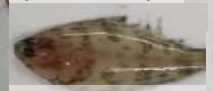
Booming anchovy biomass since ~2015

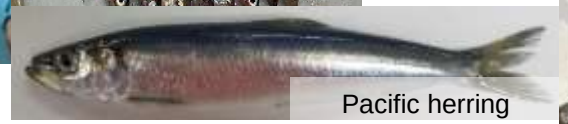


What is nutritional quality of prey in the CCE? (surveys 2020-2023)





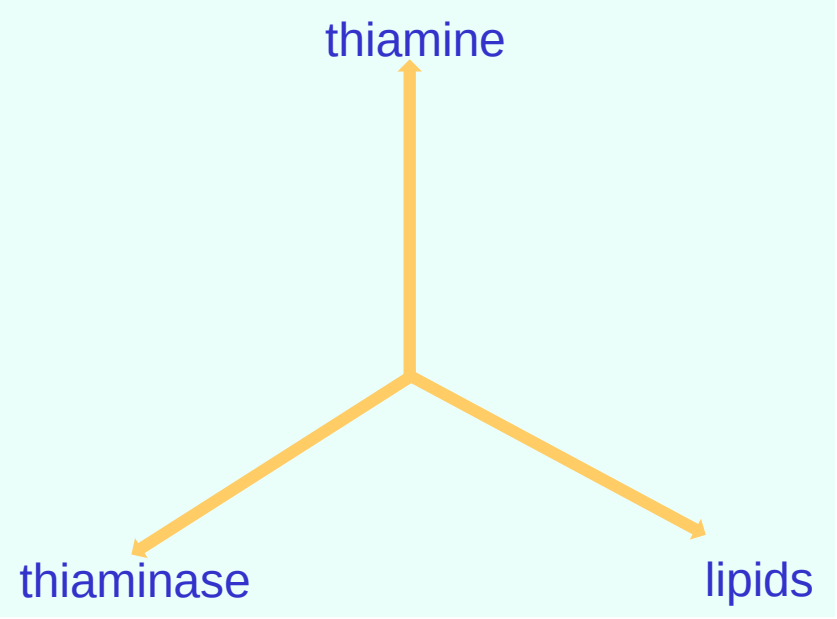




Three aspects of prey nutritional quality

Thiamine (vitamin B1) → more = good

- water soluble
- needed for metabolism



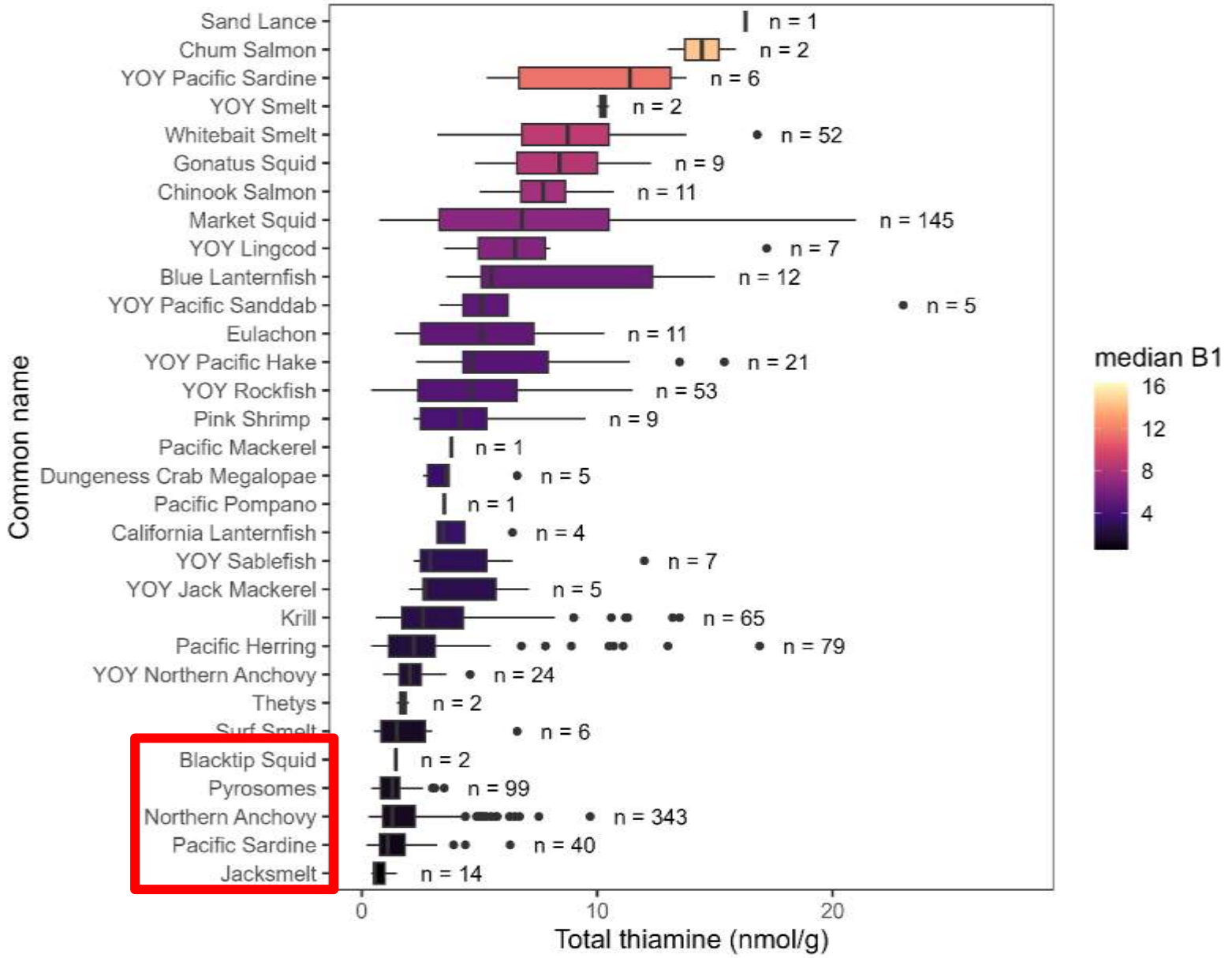
Thiaminase I activity → more = bad if in food

- thiaminolytic enzyme
- more thiaminase in prey = bad for predator
- produced by some fishes
- high thiaminase activity in prey linked to TDC

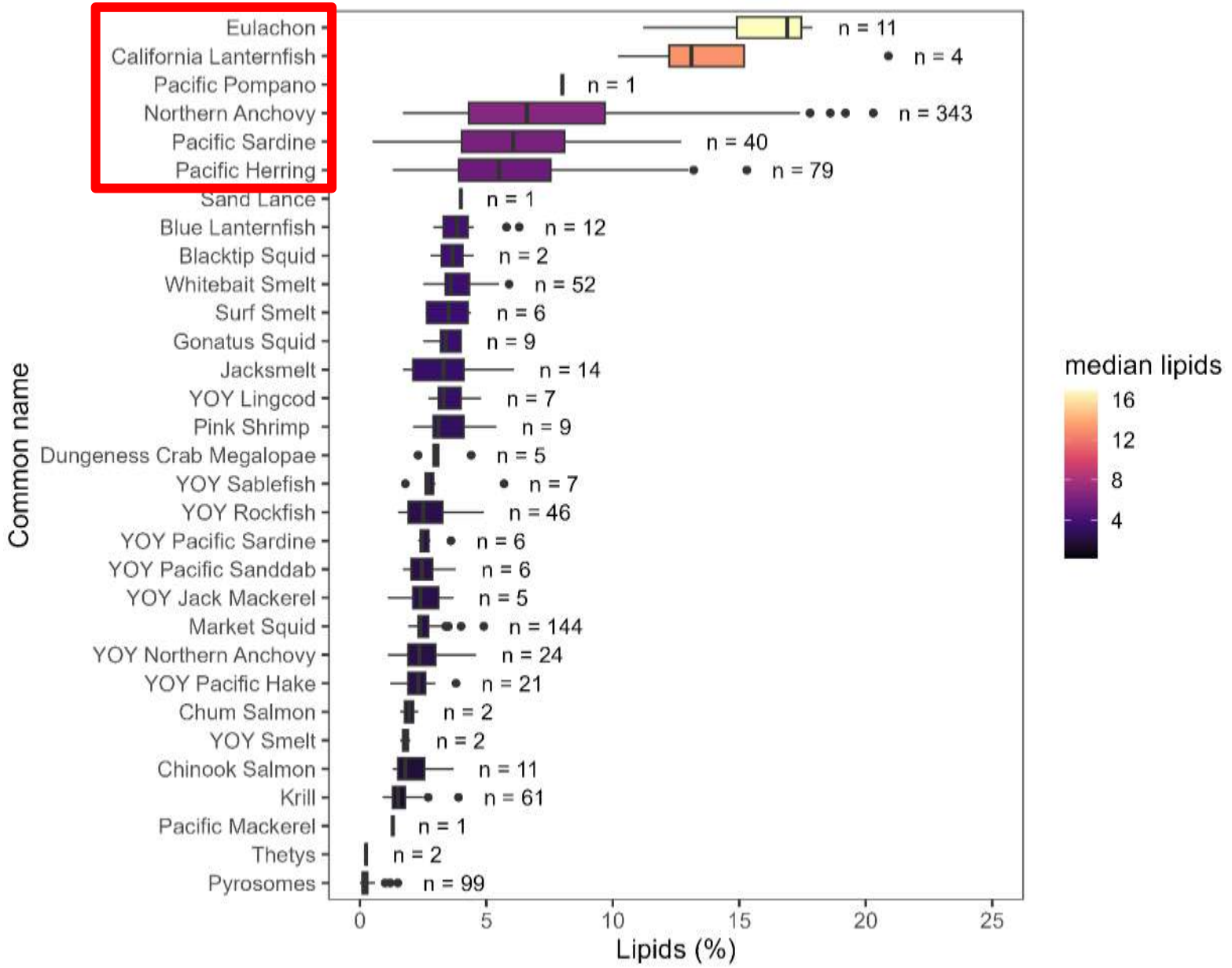
Lipids (%) → more = good/bad

- high energy density per g
- could cause oxidative stress or reduce the ability of predators to absorb thiamine (high C:thiamine)
- many contaminants hitch a ride in fats

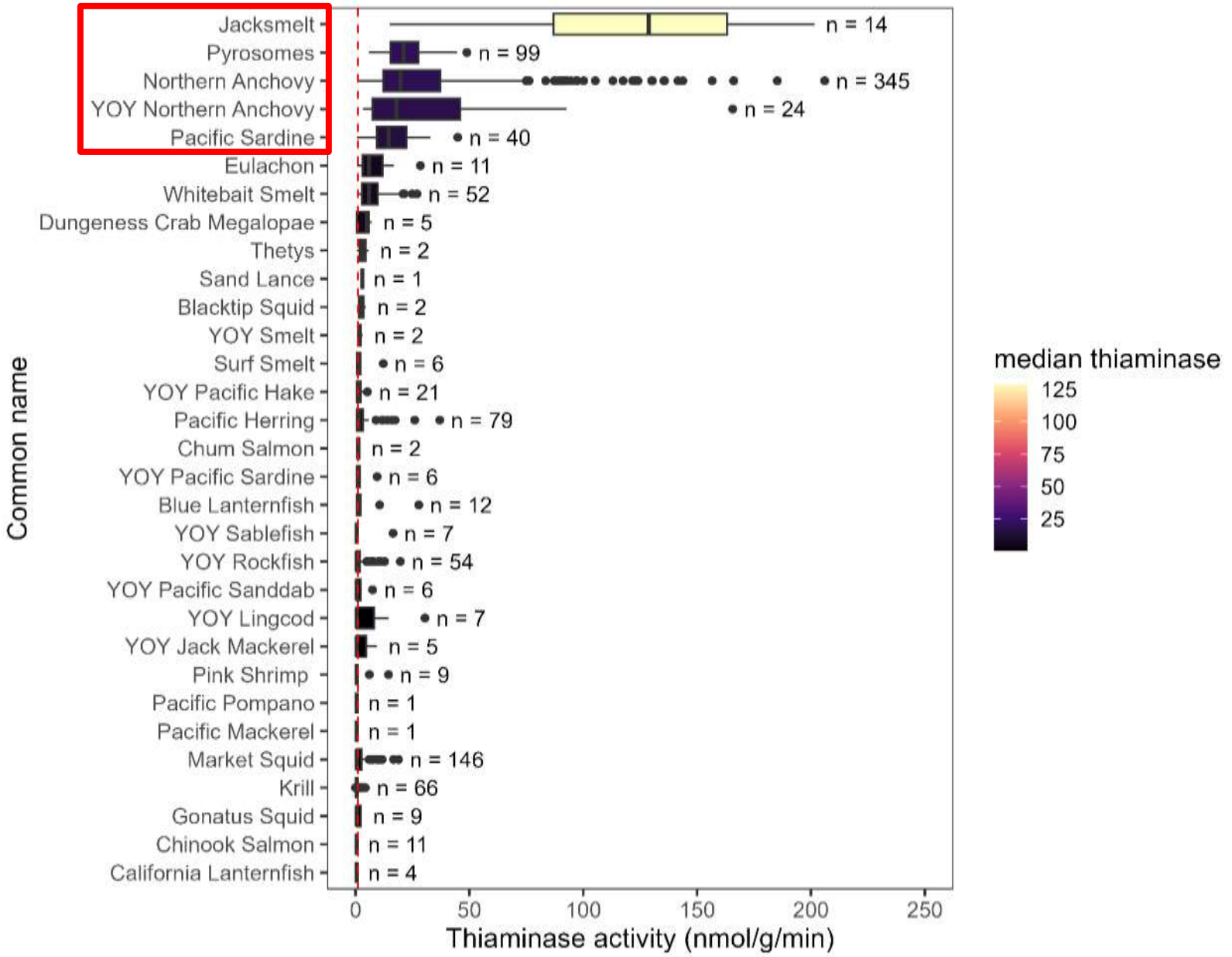
Thiamine (vitamin B_1) in prey → more = better



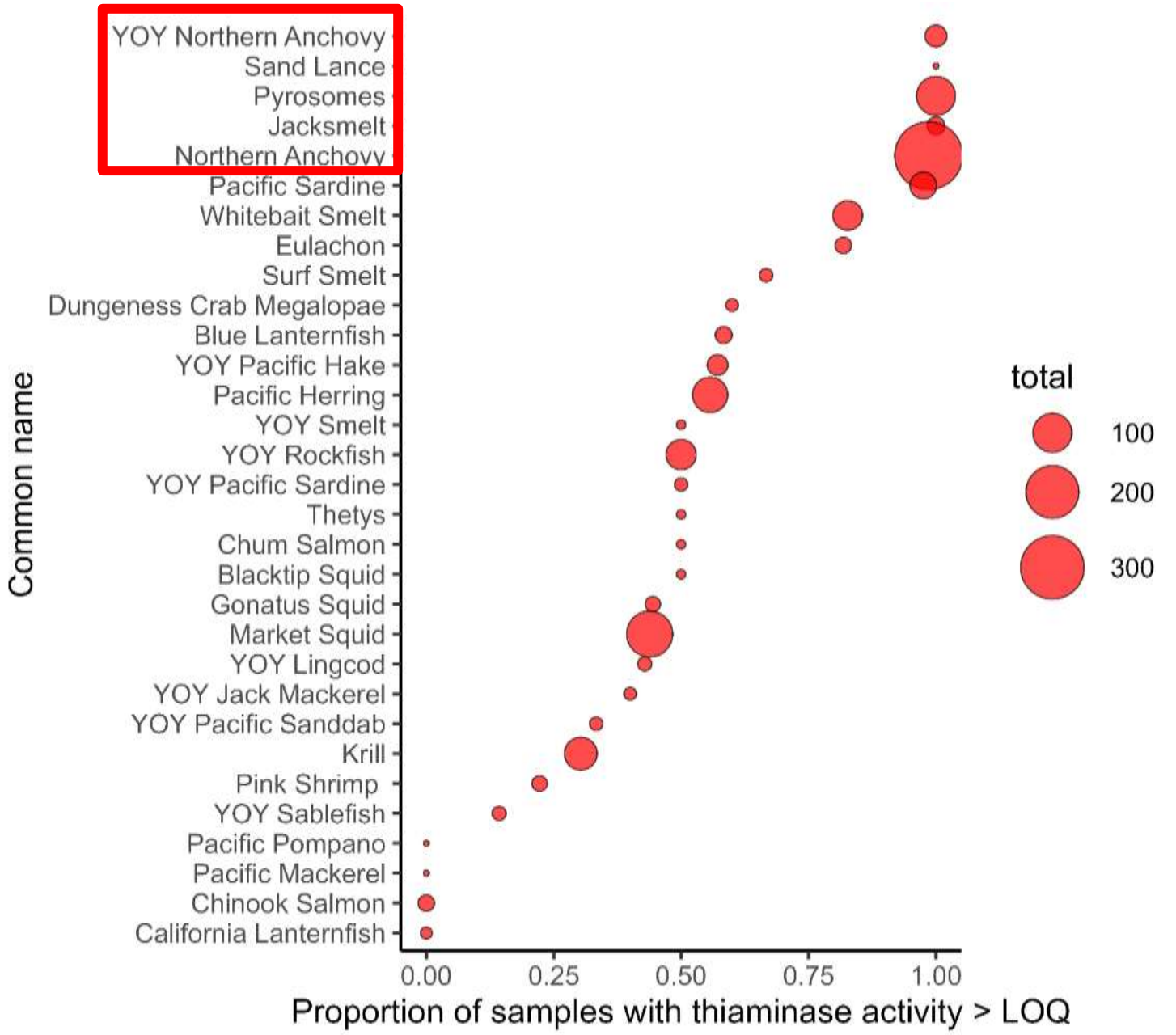
Lipids (%) in prey → more = good/bad



Thiaminase activity in prey

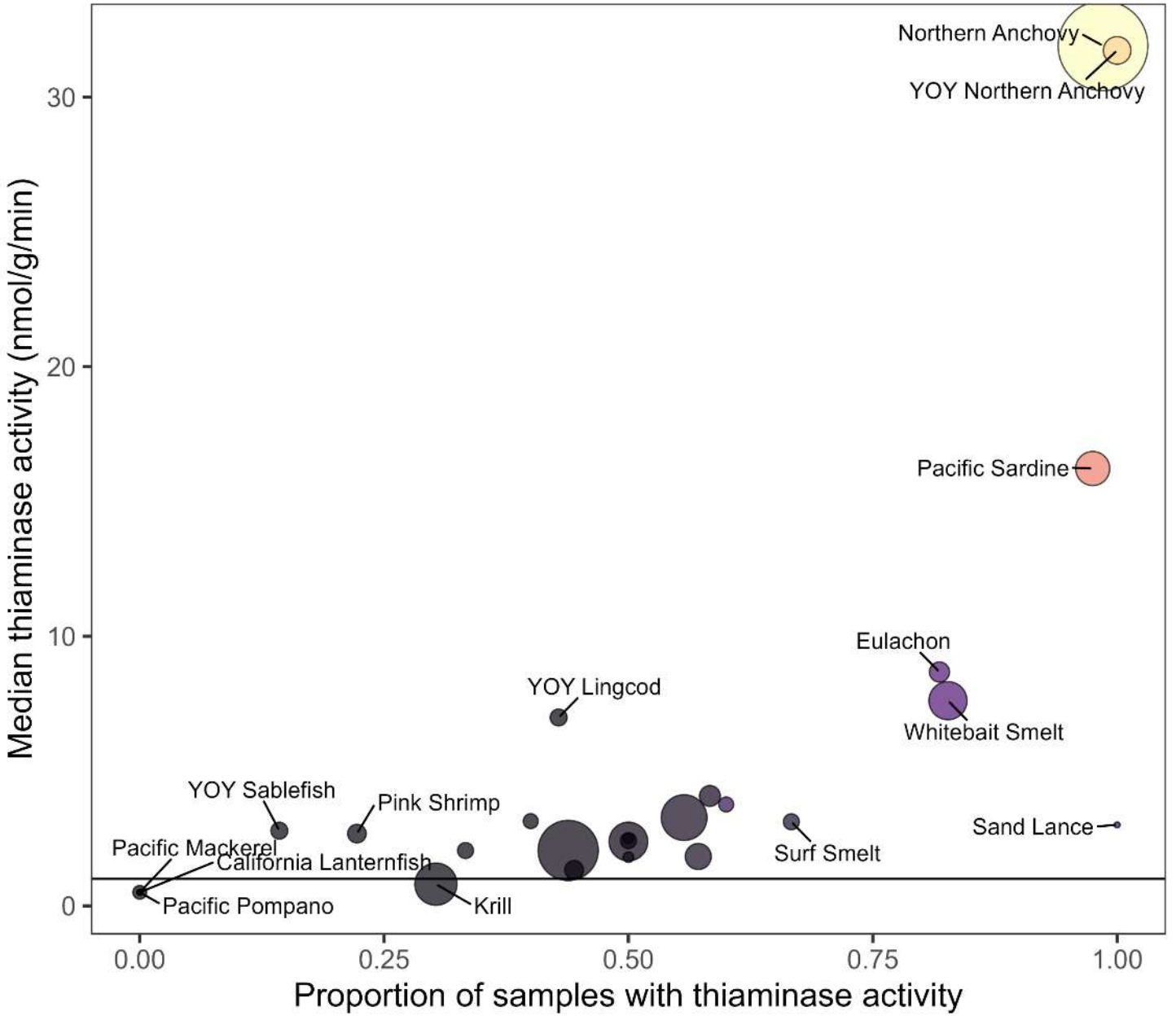


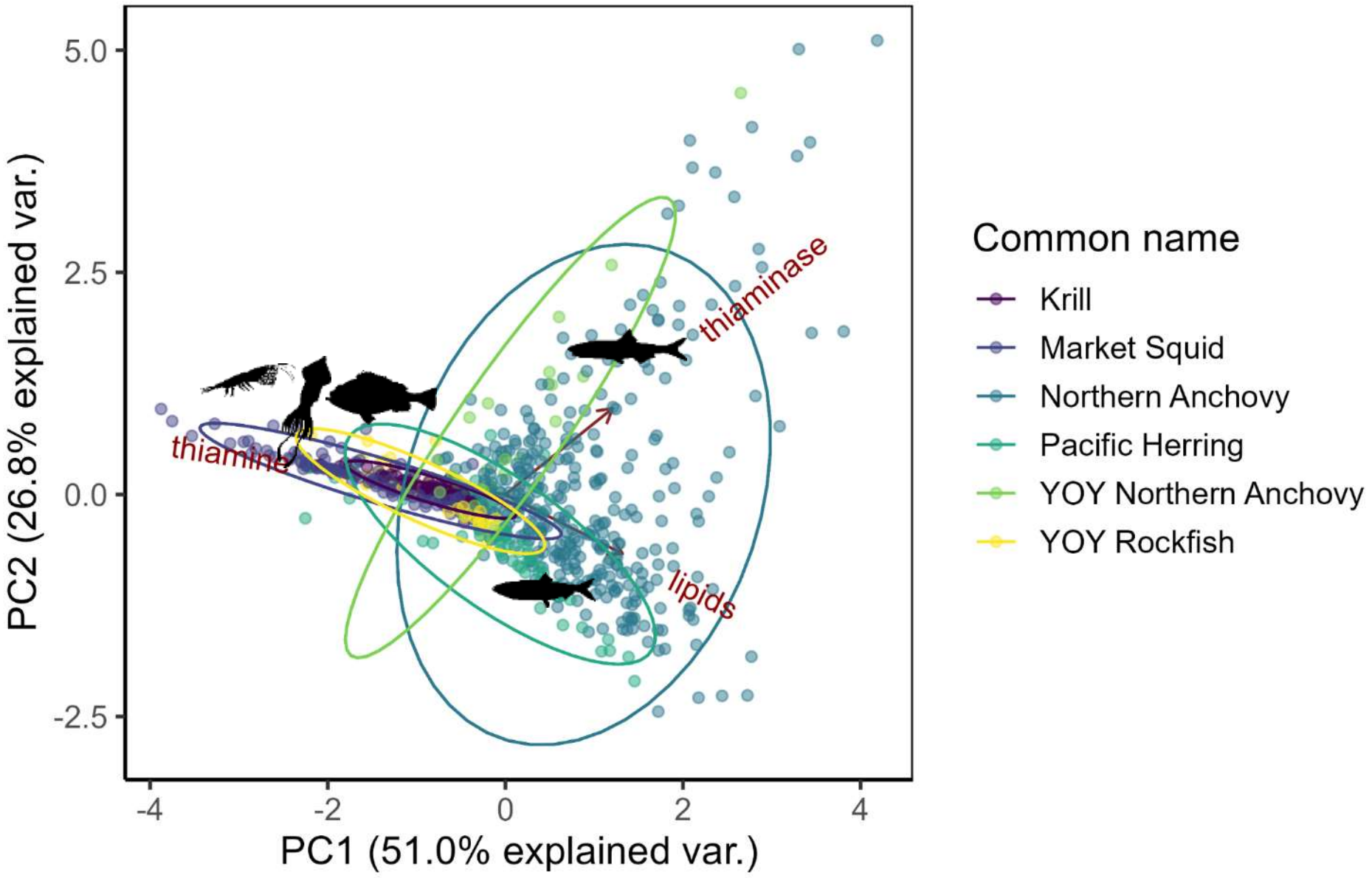
Proportion of samples with thiaminase activity > limit of quantification (LOQ)



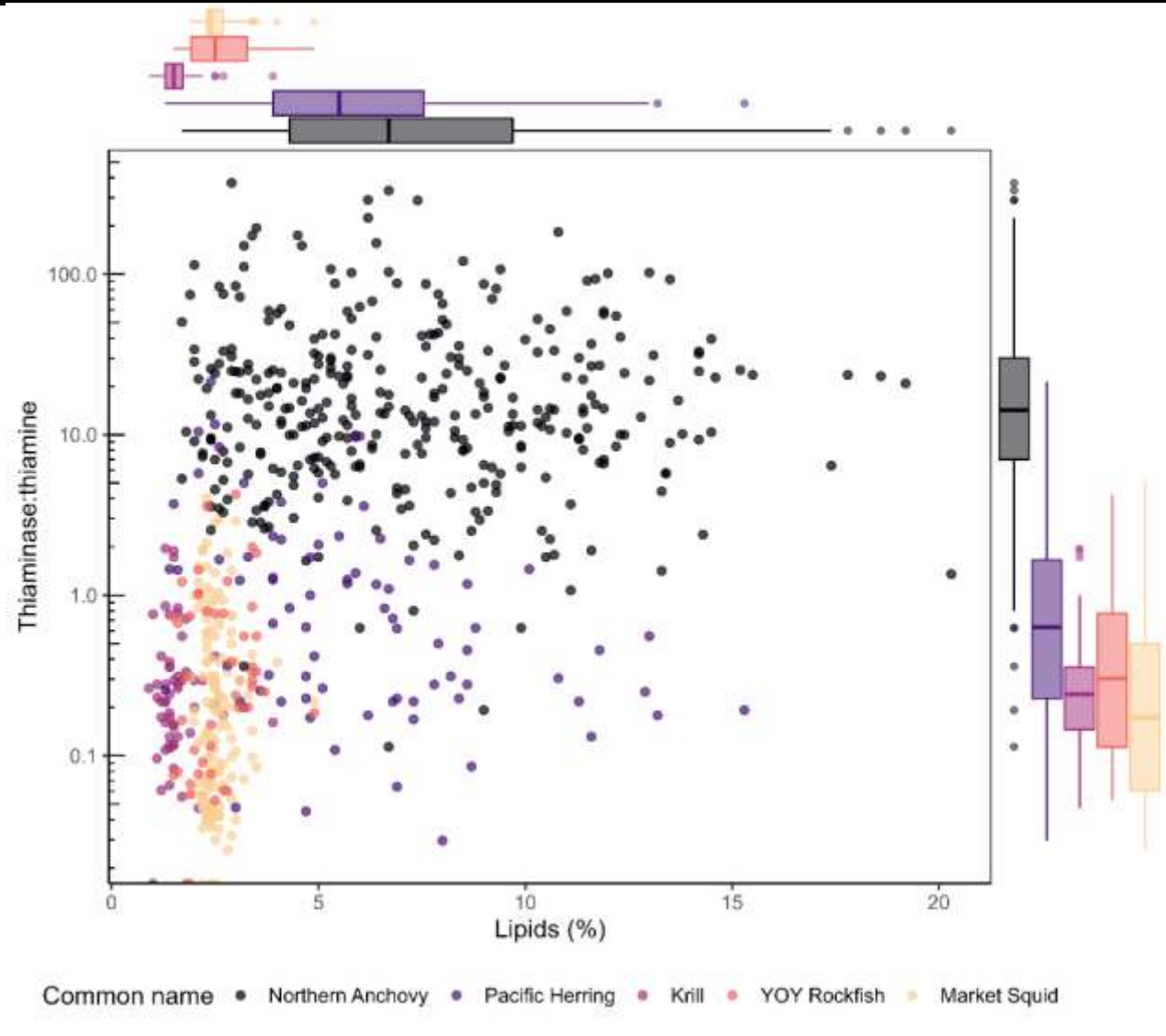
$$Risk = prob\ of\ T1\ activity\ \times median\ T1\ activity$$

Anchovy (both YOY and adult) are the “riskiest” prey that salmon are seeing in the ocean




5.0
2.5
0.0
-2.5
PC2 (26.8% explained var.)
-4
-2
0
2
4
PC1 (51.0% explained var.)
thiamine
thiaminase
lipids
Common name
Krill
Market Squid
Northern Anchovy
Pacific Herring
YOY Northern Anchovy
YOY Rockfish

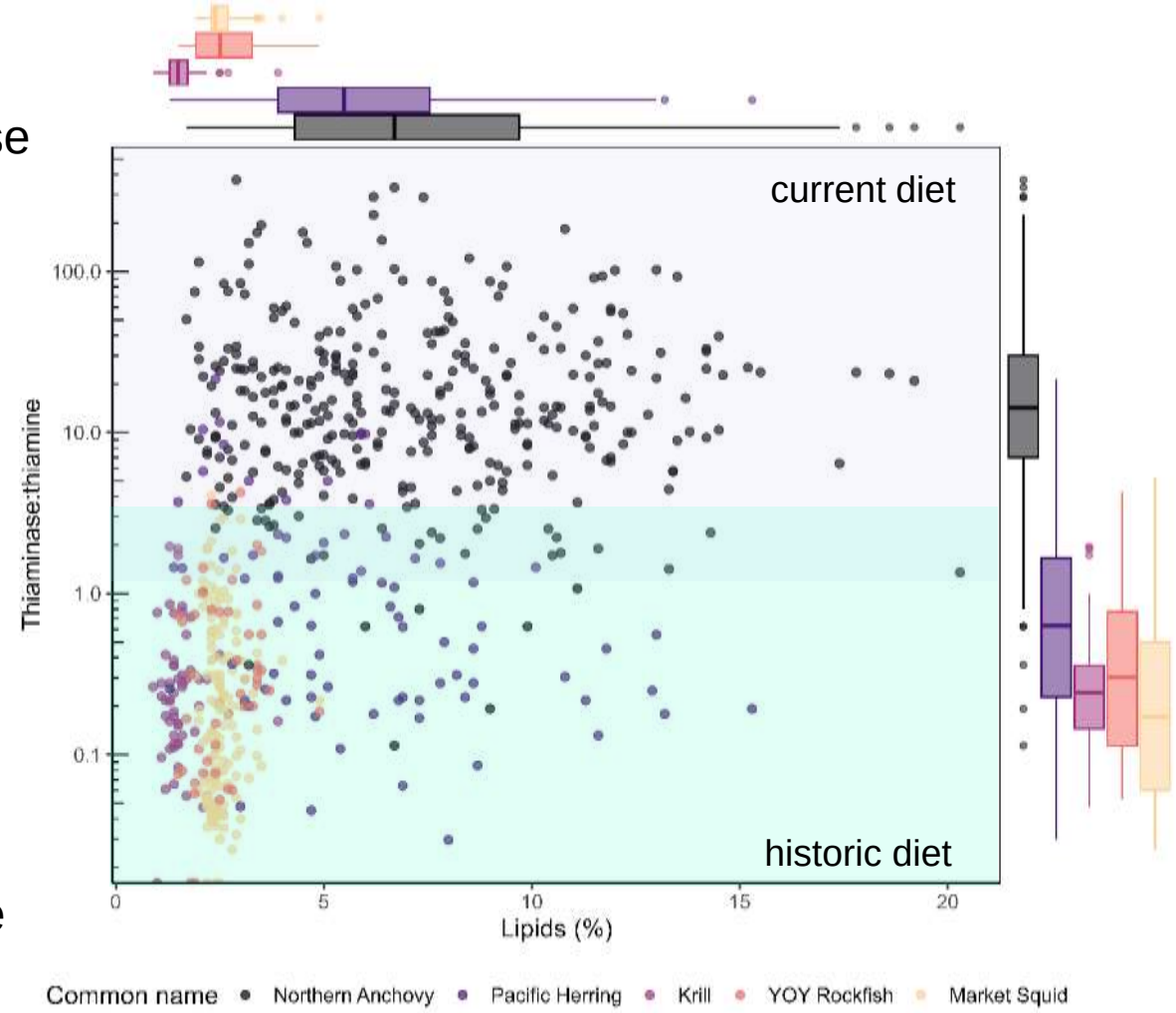
Anchovy are nutritionally unique – low thiamine, high thiaminase, and high lipid



Shifting Chinook diet favors prey linked with thiamine deficiency

Thiaminase

Thiamine



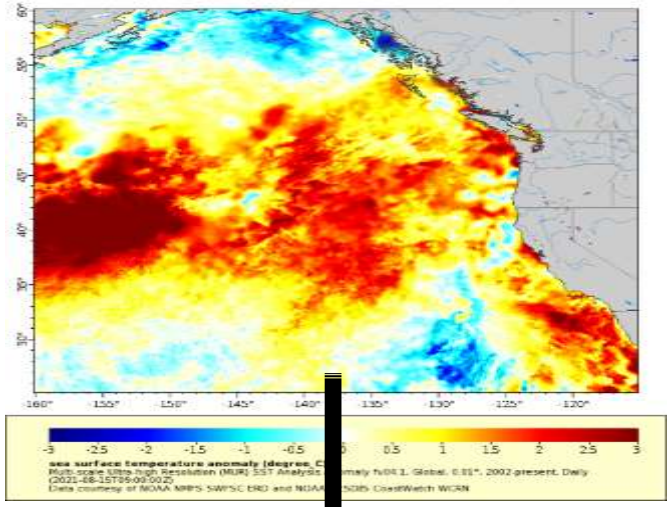
Chinook diet

Current

Historic

Photo credit: John Field

Altered ocean regimes favor anchovy which contributes to TDC in salmon



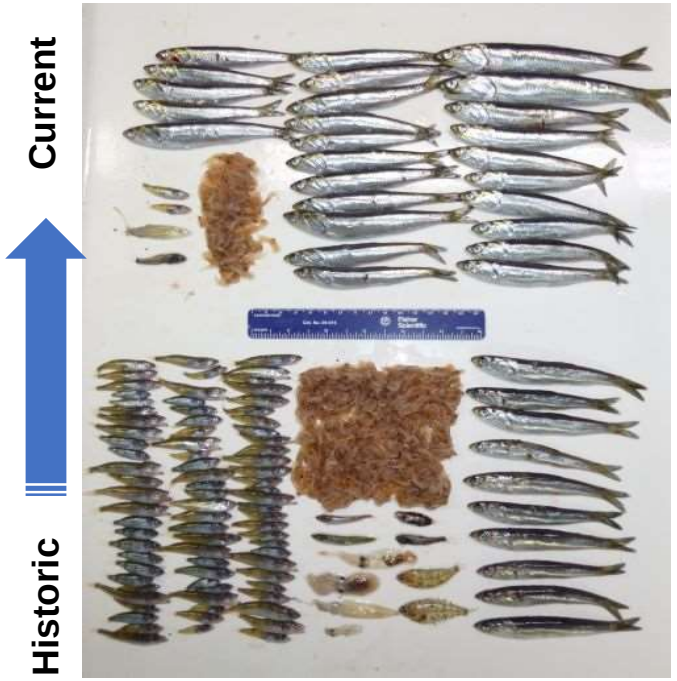
Altered forage abundance

- Krill ↓
- Rockfish ↓
- Squid ↓
- Anchovy ↑

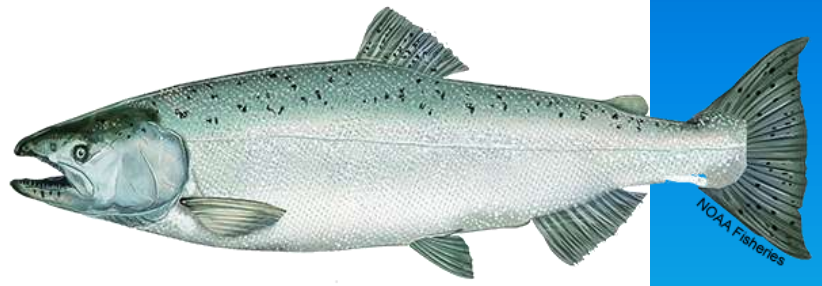
Climate-related changes in Pacific Ocean

- Water temperature – increased
- Habitat - compressed
- Forage– reduced diversity
- Salmon Diets – homogeneous
- Thiamine (vitamin B_1) Deficiency

Altered Salmon Diet

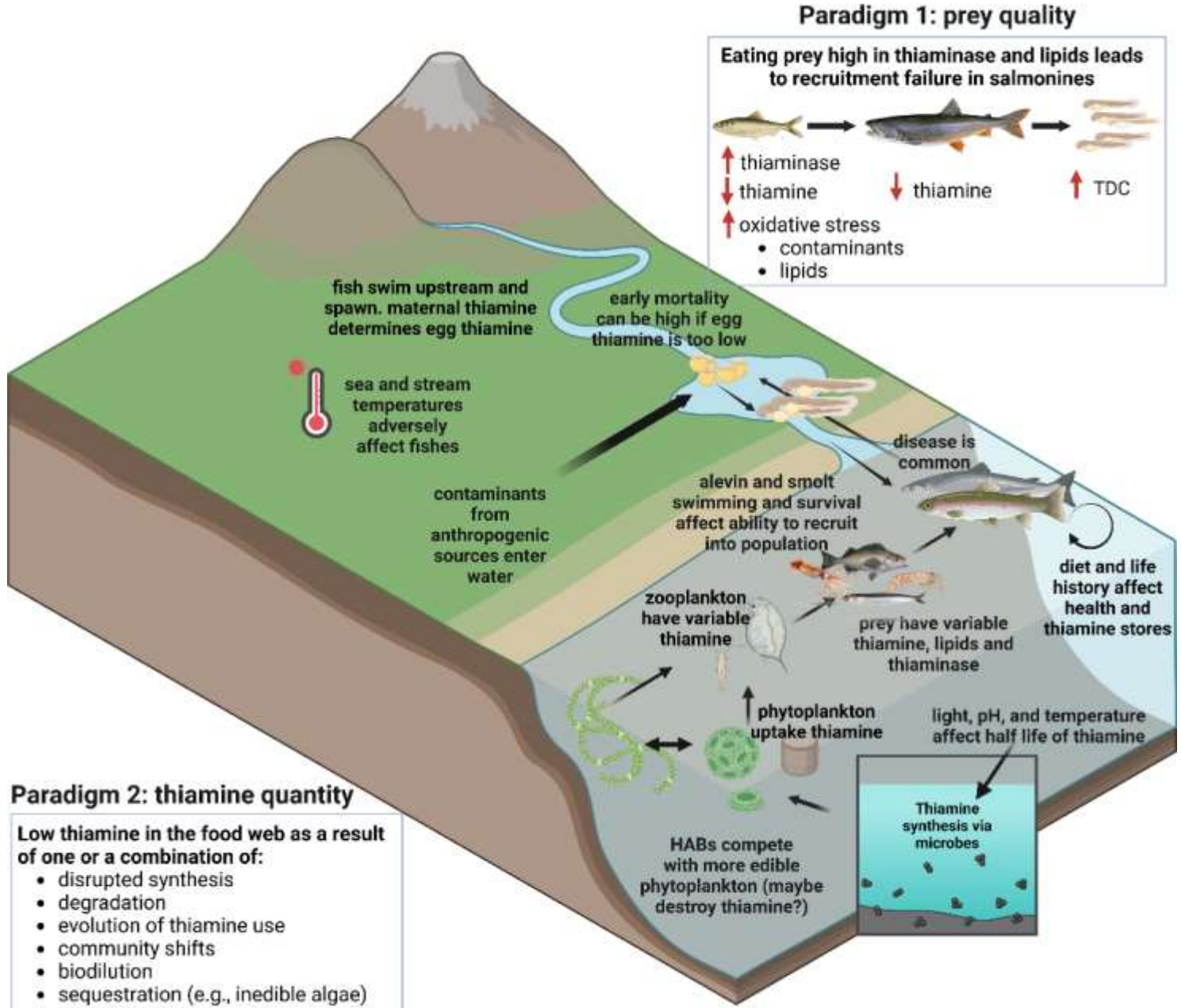


Central Valley Chinook

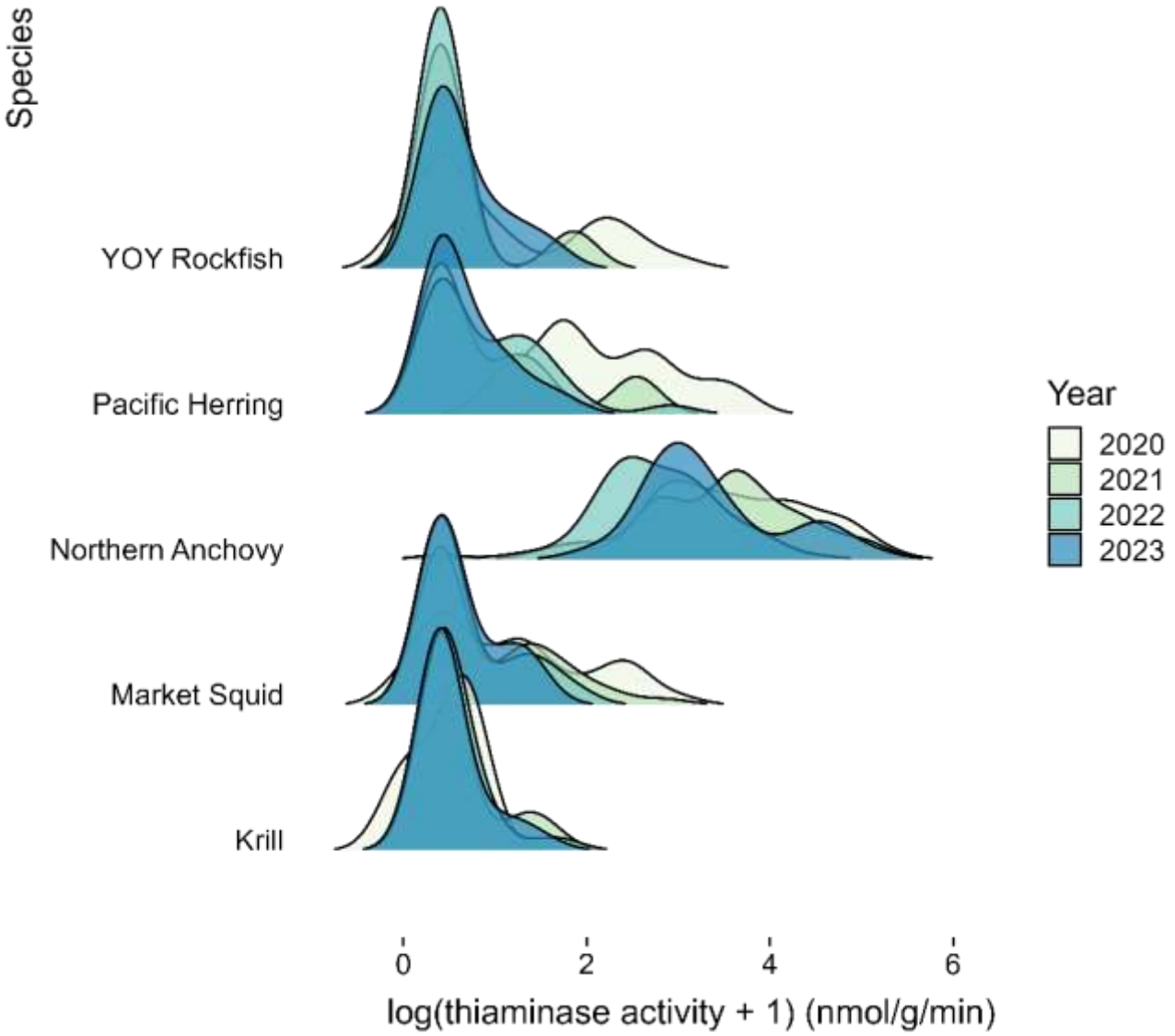


Nutritional Stress
Thiamine deficiency complex (TDC)

- Migration ↓
- Spawning ↓
- Fry Survival ↓
- Recruitment ↓
- Populations ↓

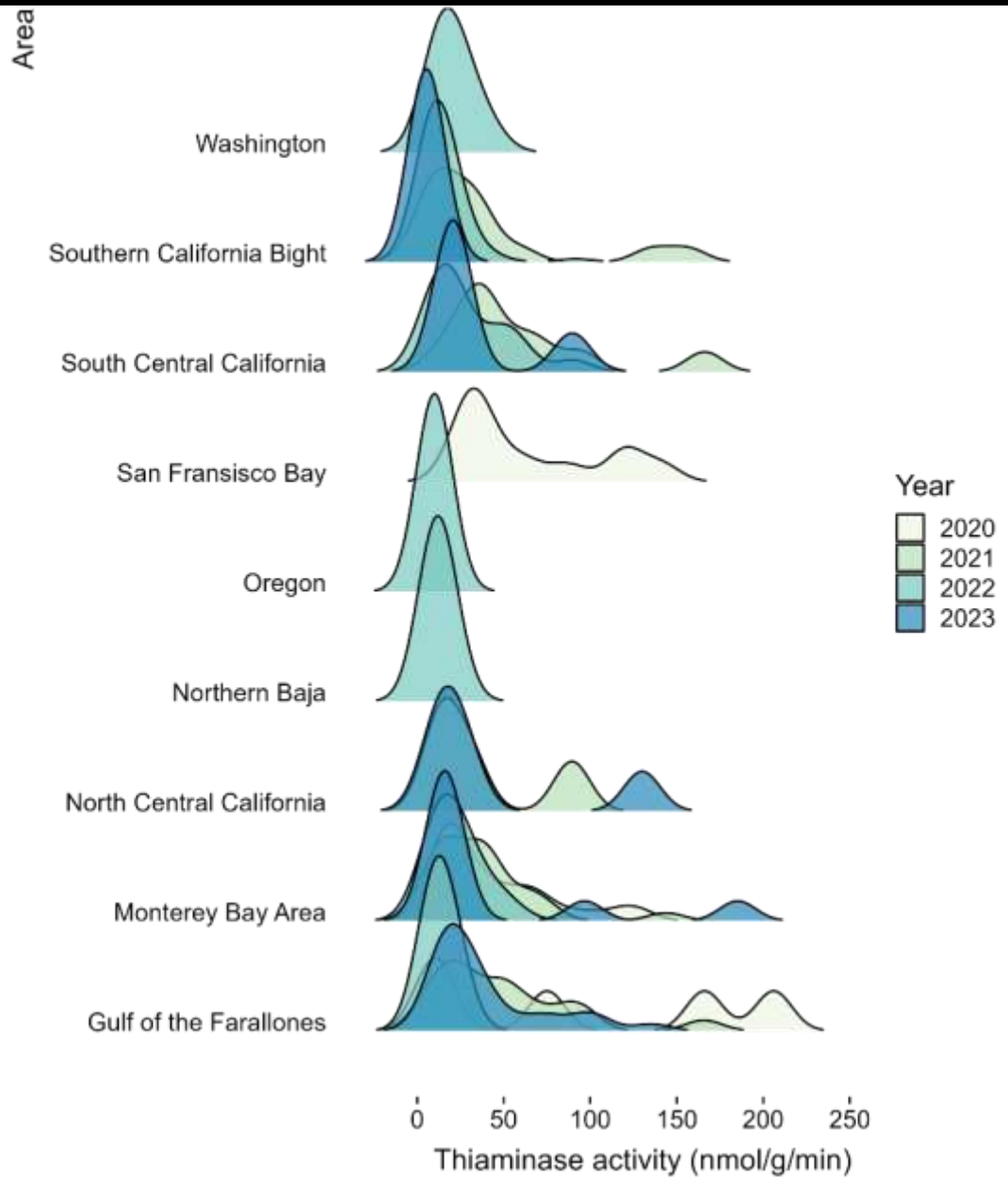

Paradigm 1: prey quality
Eating prey high in thiaminase and lipids leads to recruitment failure in salmonines
thiaminase
thiamine
thiamine
TDC
oxidative stress
contaminants
lipids
fish swim upstream and spawn. maternal thiamine determines egg thiamine
early mortality can be high if egg thiamine is too low
sea and stream temperatures adversely affect fishes
contaminants from anthropogenic sources enter water
disease is common
alevin and smolt swimming and survival affect ability to recruit into population
diet and life history affect health and thiamine stores
zooplankton have variable thiamine
prey have variable thiamine, lipids and thiaminase
phytoplankton uptake thiamine
light, pH, and temperature affect half life of thiamine
Thiamine synthesis via microbes
HABs compete with more edible phytoplankton (maybe destroy thiamine?)
Paradigm 2: thiamine quantity
Low thiamine in the food web as a result of one or a combination of:
disrupted synthesis
degradation
evolution of thiamine use
community shifts
biodilution
sequestration (e.g., inedible algae)
heat-stable anti-thiamine compounds

Future questions: can we predict thiaminase?



No real differences between years in thiaminase activity

Future questions: can we predict thiaminase?

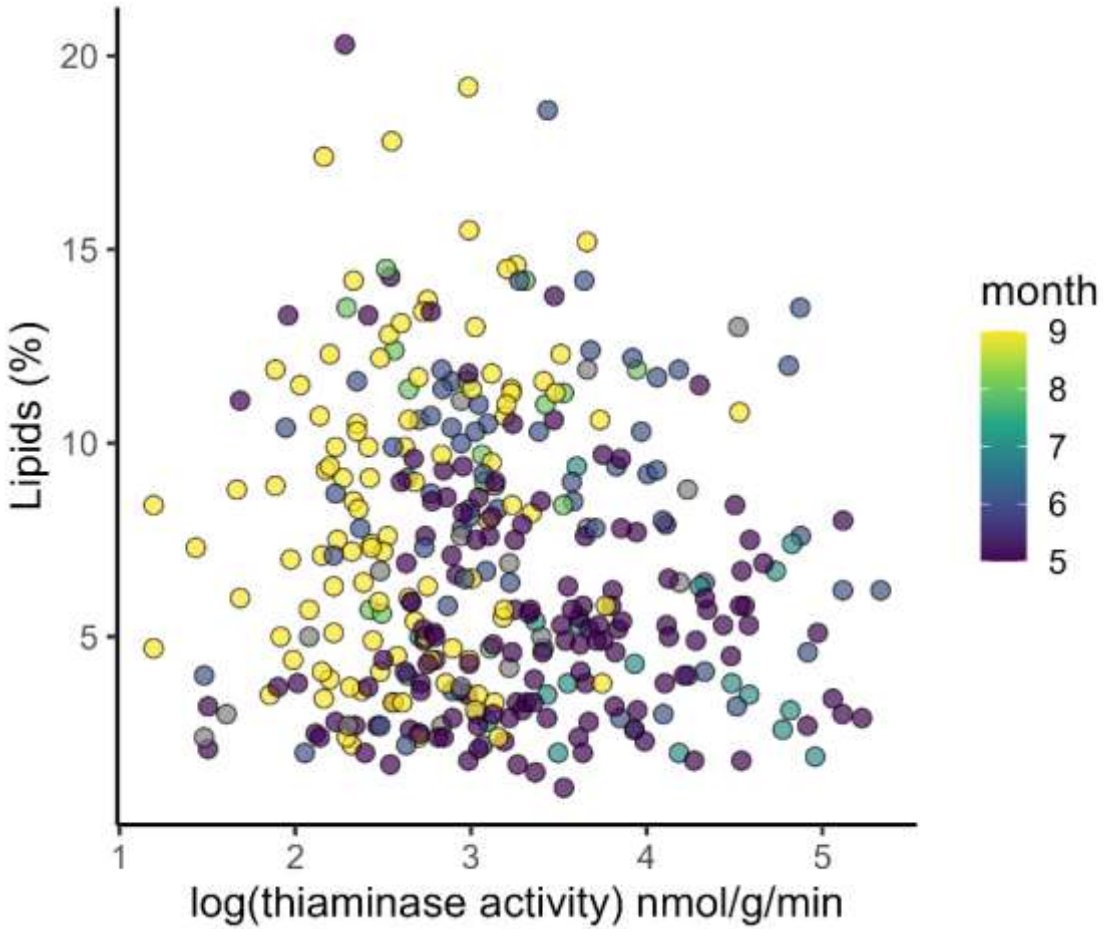


Anchovy didn’t show any remarkable regional differences

Future questions: can we predict thiaminase?

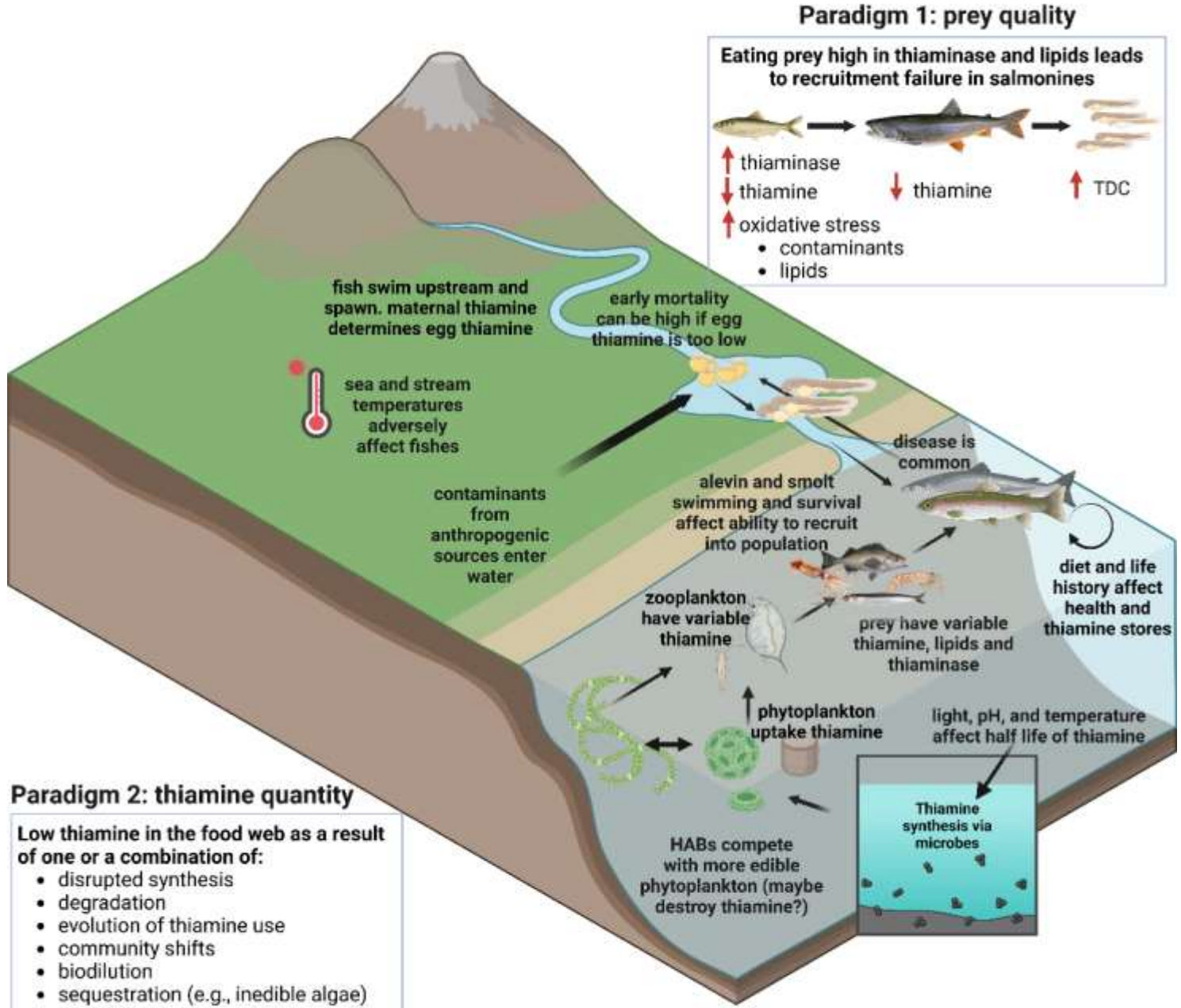
Anchovy from August and September are very risky prey

- Is thiaminase involved in lipid allocation?
  - Is this related to spawning? Or migrations?
  - Is it just a transition of the ecosystem during fall?
- Does a last meal of September anchovy make winter-run Chinook even more deficient in thiamine?



Future directions

- Convert thiamine to C:thiamine (molar)
- What are the sublethal effects of thiamine deficiency?
- Why do some fishes make thiaminase?
- How does the microbiome relate to thiamine deficiency?
- Can we predict years where thiamine deficiency is likely?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sequestration (e.g., inedible algae)
heat-stable anti-thiamine compounds

Thiamine Research Team and Partners

NOAA Fisheries: Rachel Johnson, Nate Mantua, John Field, Steve Lindley, Tommy Williams, Lynn Dewitt, Cody Pinger, Miles Daniels, Drew Porter
NOAA West Coast Region: Amanda Cranford, Charlotte Ambrose, Michael Milstein
USFWS: Taylor Lipscomb, Scott Foot, William Ardren, Christie Nichols, Christine Parker-Gram, Alison Deary, Ronald Twibell, Theresa Thom
USGS: Donald Tillitt, Freya Rowland, David Walters, Cathy Richter, and Dale Honeyfield, retired
CDFW: Kevin Kwak, Mark Adkison, Brett Kormos, Mitsuko Grube, Michael Stuhldreher
SUNY: State University of New York Brockport, Jacques Rinchard, Jarrod Ludwig
OSU: Frederick Colwell, Chris Suffridge, Kelly Shannon, Aimee Reed
Department of Water Resources: Jason Kindopp, Ryon Kurth, Kyle Hartwigsen
Idaho State University: Bruce Finney
Moss Landing Marine Laboratory: Iliana Ruiz-Cooley
Monterey Bay Aquarium Institute: Steve Litvin
UC Davis: Anne Todgham, Carson Jeffres, Nann Fangue, Esteban Soto, Heather Bell, Dennis Cocherell, Sage Lee, Peggy Harte, Ryan Meyer, Abigail Ward, Ryan Peek
Binghamton University: Katie Edwards
Cornell University: Clifford Kraft
University of British Columbia: Brian Hunt, Anna McLaskey, Jacob Lerner
Anglers and charter boats: New Sea Angler, New Rayann, Erick Owens
#Spinning Salmon in the Classroom: Teachers and Students!
Hatchery Managers: Brett Galyean, Anna Kastner, Penny Crawshaw, Gary Novak, Paula Hoover, Jason Julienne, William Smith, Mary Serr, Steve Tsao

Developing a dose-response model for thiamine deficiency in Central Valley Chinook

Miles Daniels (miedanie@ucsc.edu)

Heather Bell, Steve Lindley, Nate Mantua, Nann Fangue, and Anne Todgham

Thiamine Deficiency Complex (TDC)
Background

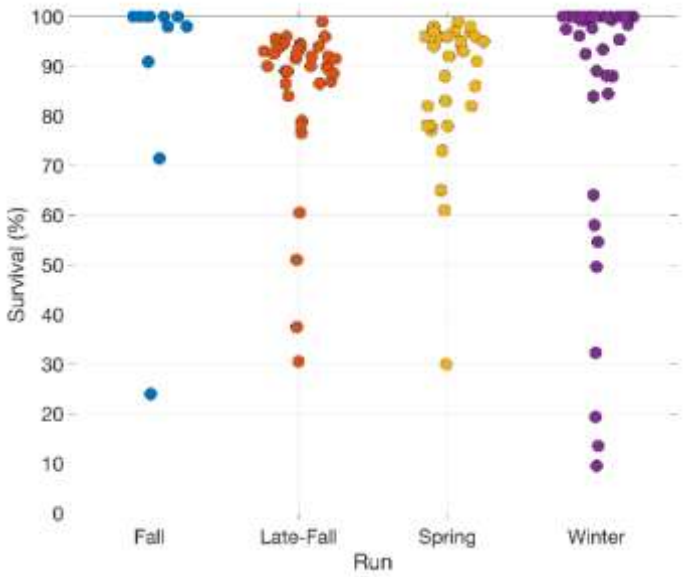
- Thiamine (vitamin B1) is an essential vitamin required by almost all living organisms.
- Adult salmon that develop TDC may produce eggs that are low in thiamine resulting in subsequent mortality at fry stage.
- Morbidities associated with low thiamine include impacts on fry growth, predator avoidance, prey capture ability, visual development, swimming ability and immune function.
- The causal factor of TDC is still being investigated, but evidence points to marine diet.

Given that TDC has been observed in the Central Valley, it would be valuable to have a model able to predict impacts to hatchery and wild populations

Thiamine Concentration
laboratory studies

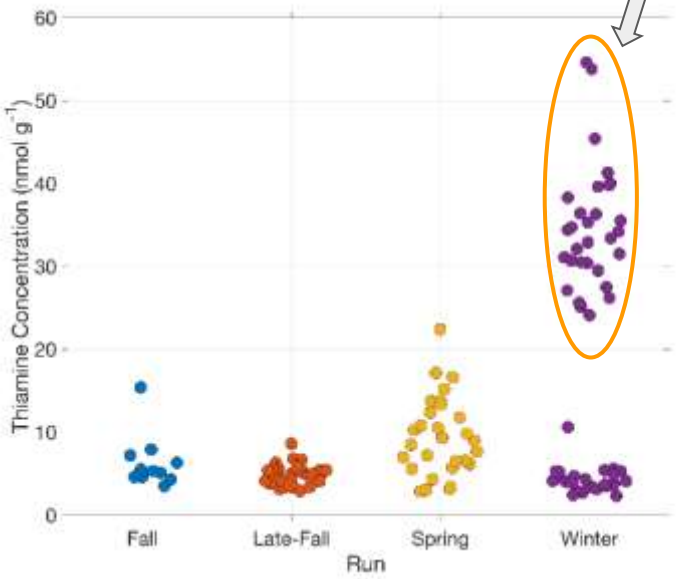
- Embryos from hatcheries from 4 runs
  - Fall, Late-Fall, Spring, Winter
- Thiamine concentration estimated for each run
    - units = nmol g^{-1}
- Batches of embryos (*n = 35-200*) held without feed at UC Davis & salmon in the classrooms
- Observed for 120 days post-hatching
- Endpoint of study is proportion survival

Thiamine Concentration
laboratory studies (DATA)



Raw survival data

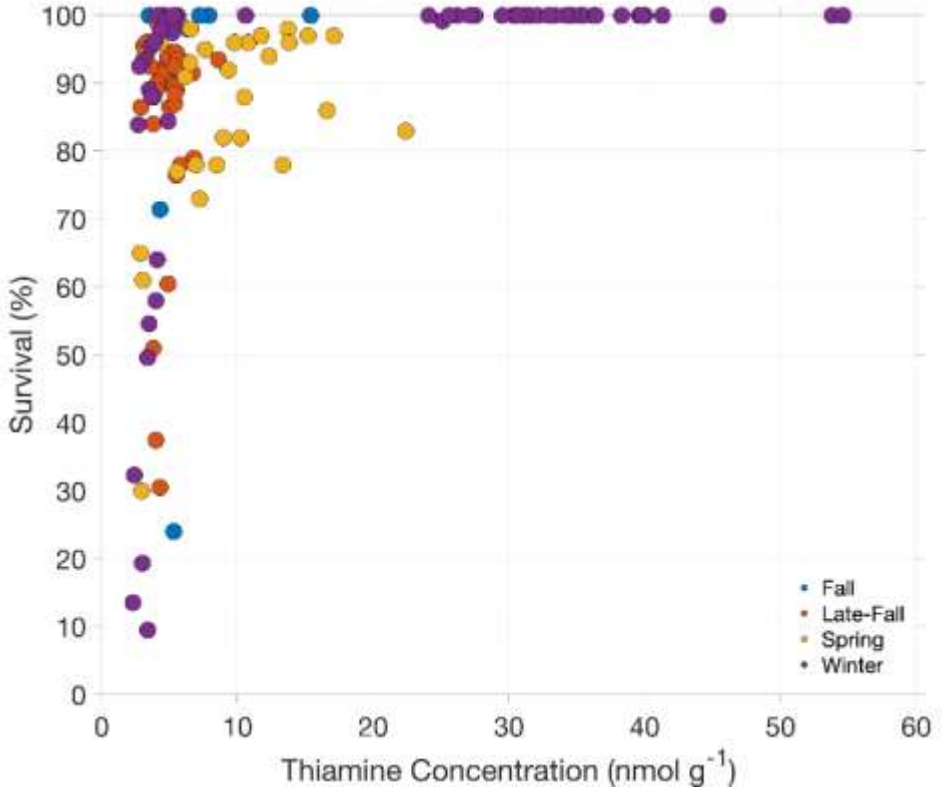
Treated for TDC



Raw concentration data

Thiamine Concentration
laboratory studies (DATA)

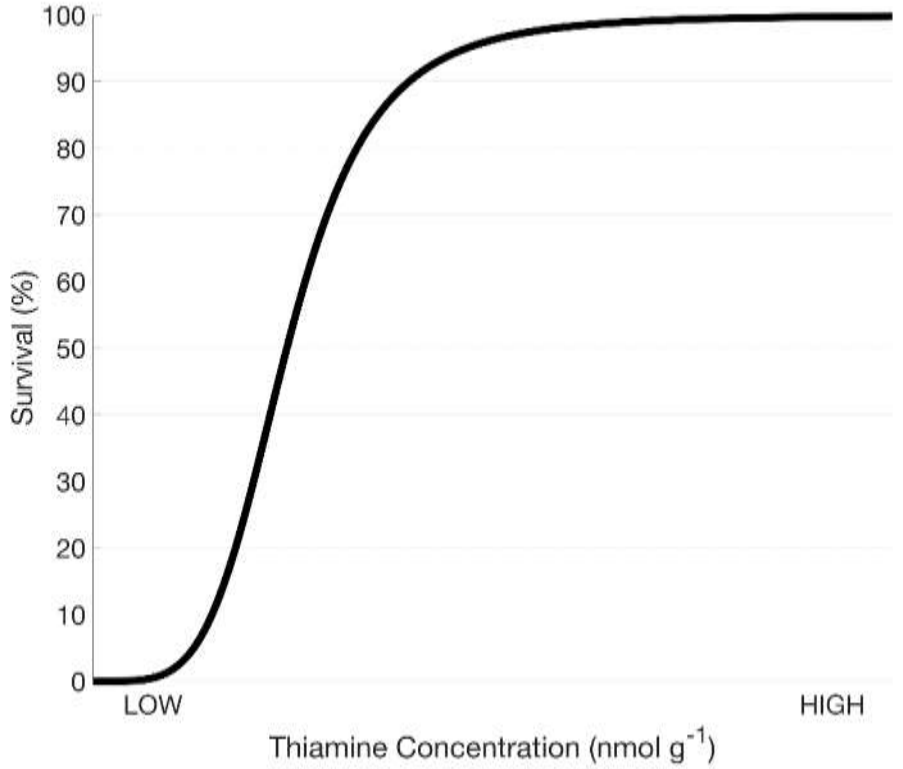
- Plotting survival as a functions of thiamine concentration indicates a relationship



Dose-response model

$$Survial = U + \frac{L - U}{1 + \left(\frac{C}{E}\right)^{S}}$$

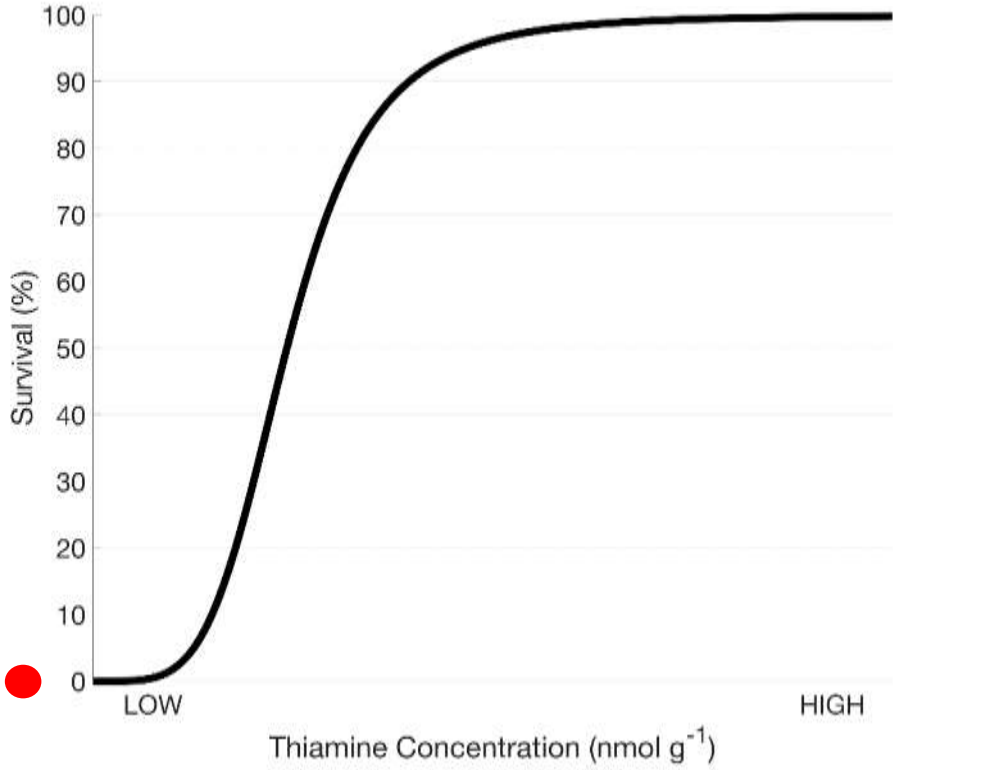
- Use a 4-parameter sigmoid dose-response model to describe relationship, where:



Dose-response model

$$Survial = U + \frac{L - U}{1 + \left(\frac{C}{E}\right)^{S}}$$

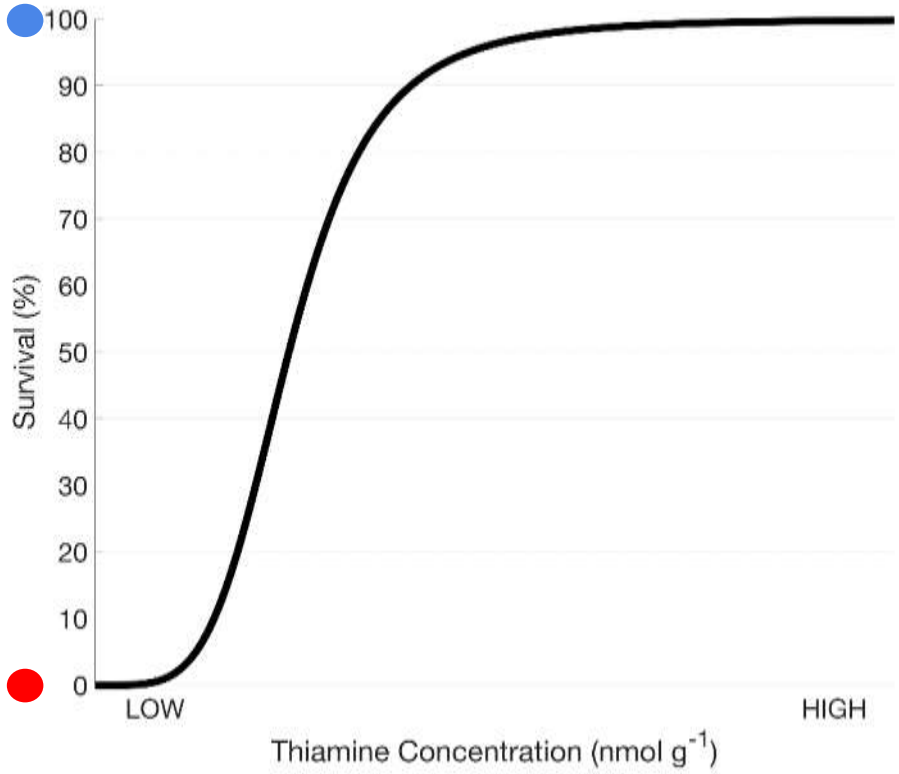
- Use a 4-parameter sigmoid dose-response model to describe relationship, where:
  - *L* = lower limit



Dose-response model

$$Survial = U + \frac{L - U}{1 + \left(\frac{C}{E}\right)^{S}}$$

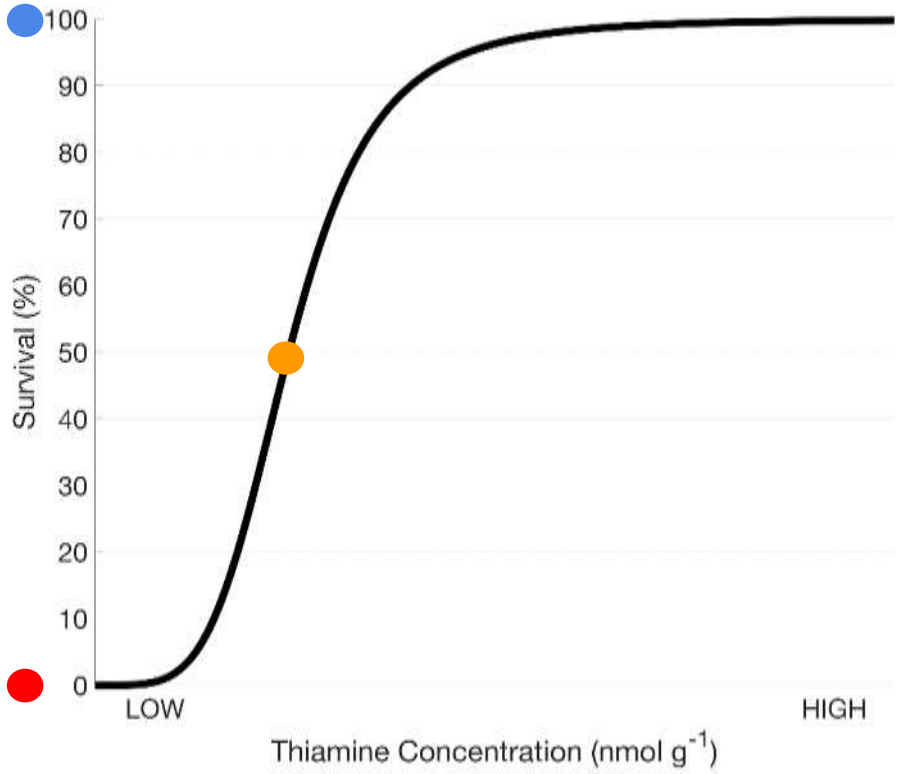
- Use a 4-parameter sigmoid dose-response model to describe relationship, where:
  - *L* = lower limit
  - *U* = upper limit



Dose-response model

$$Survial = U + \frac{L - U}{1 + \left(\frac{C}{E}\right)^{S}}$$

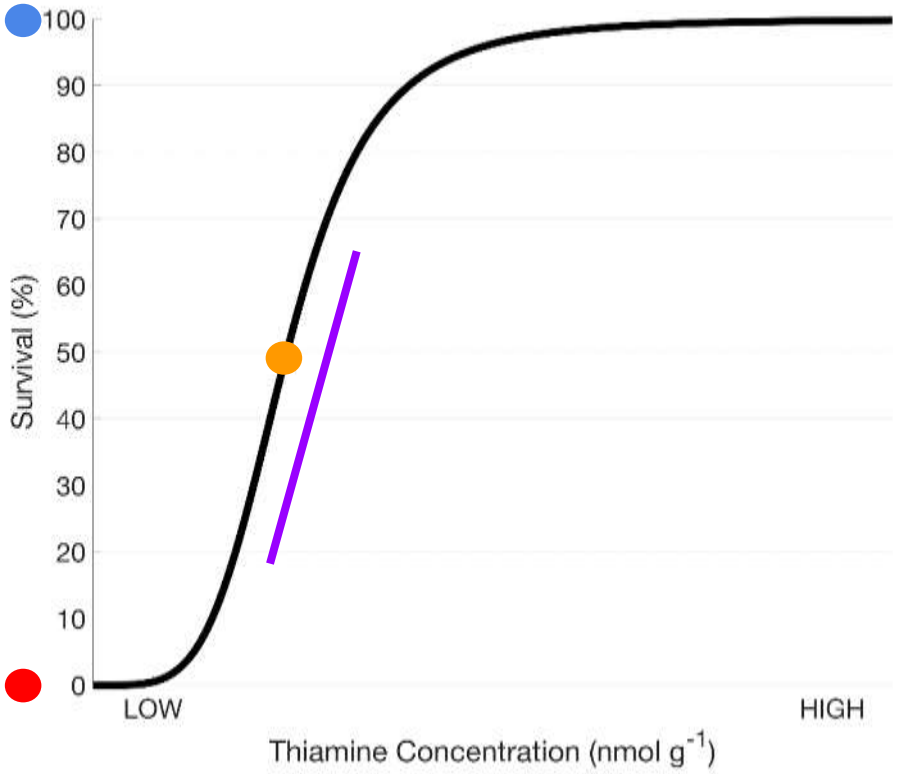
- Use a 4-parameter sigmoid dose-response model to describe relationship, where:
  - *L* = lower limit
  - *U* = upper limit
  - *E* = EC50



Dose-response model

$$Survial = U + \frac{L - U}{1 + \left(\frac{C}{E}\right)^{S}}$$

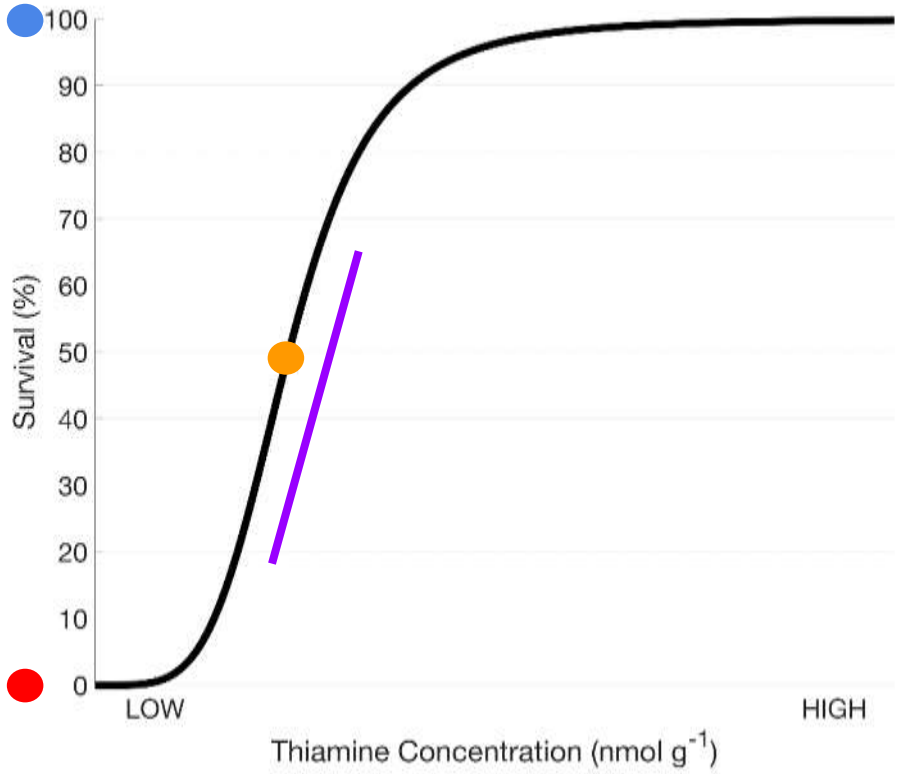
- Use a 4-parameter sigmoid dose-response model to describe relationship, where:
  - *L* = lower limit
  - *U* = upper limit
  - *E* = EC50
  - *S* = slope



Dose-response model

$$Survial = U + \frac{L - U}{1 + \left(\frac{C}{E}\right)^{S}}$$

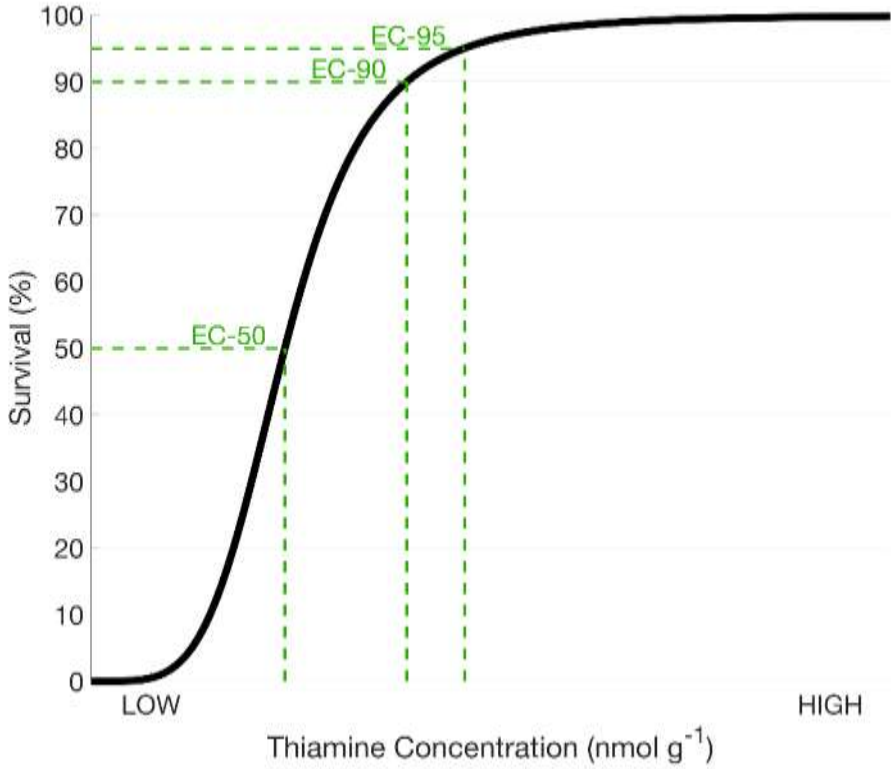
- Use a 4-parameter sigmoid dose-response model to describe relationship, where:
  - *L* = lower limit
  - *U* = upper limit
  - *E* = EC50
  - *S* = slope
  - C = thiamine concentration



Dose-response model

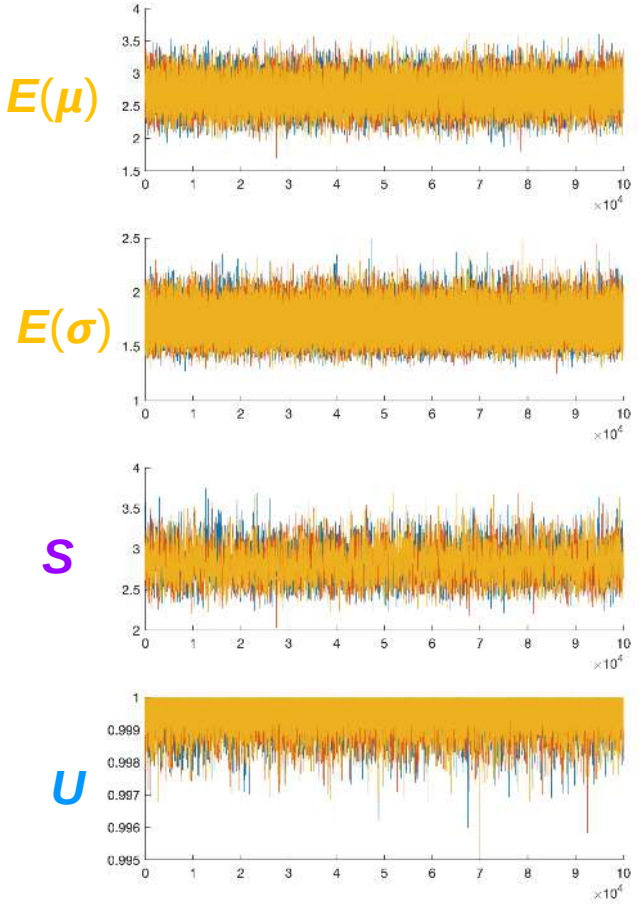
$$Survial = U + \frac{L - U}{1 + \left(\frac{C}{E}\right)^{S}}$$

- From this model, we can infer effective concentrations (EC) such that:
  - *EC-X is the concentration where survival is X%*

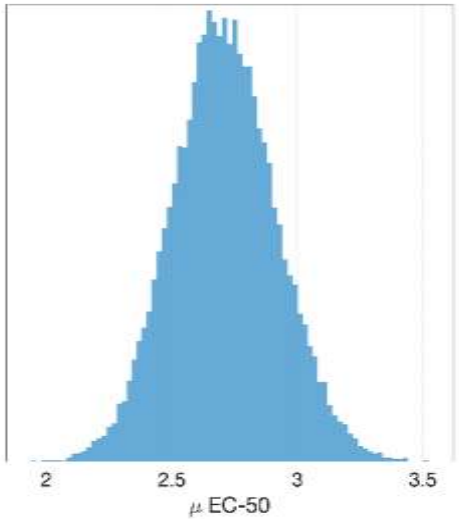


Fitting routine

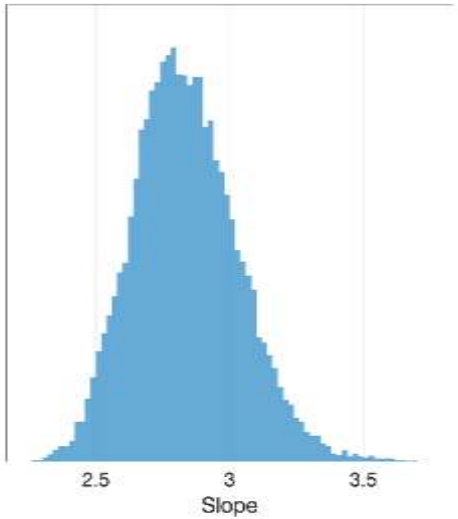
- Survival ~ Thiamine fit in Bayesian framework
- Parameters ***E*(*μ*,*σ*)**, ***S***, *and* ***U*** were fit with hierarchical model
- 3 chains of 100K converged



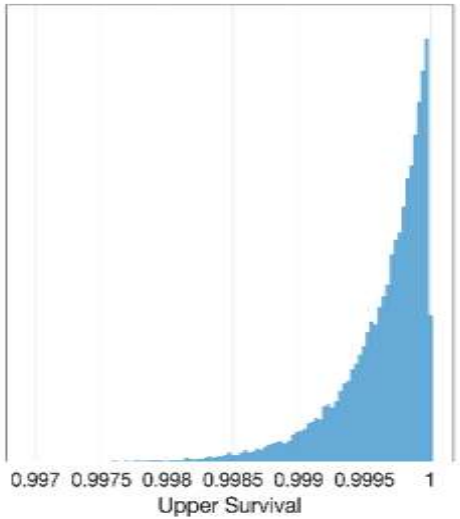
Dose-response model
parameter estimates (posteriors)



E

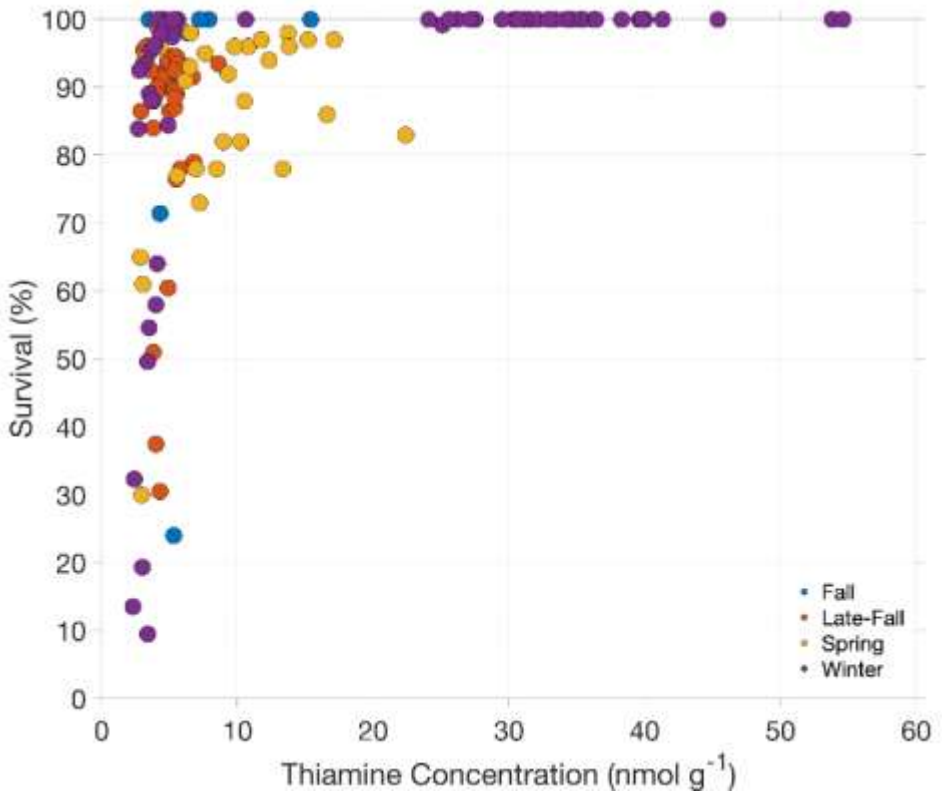


S



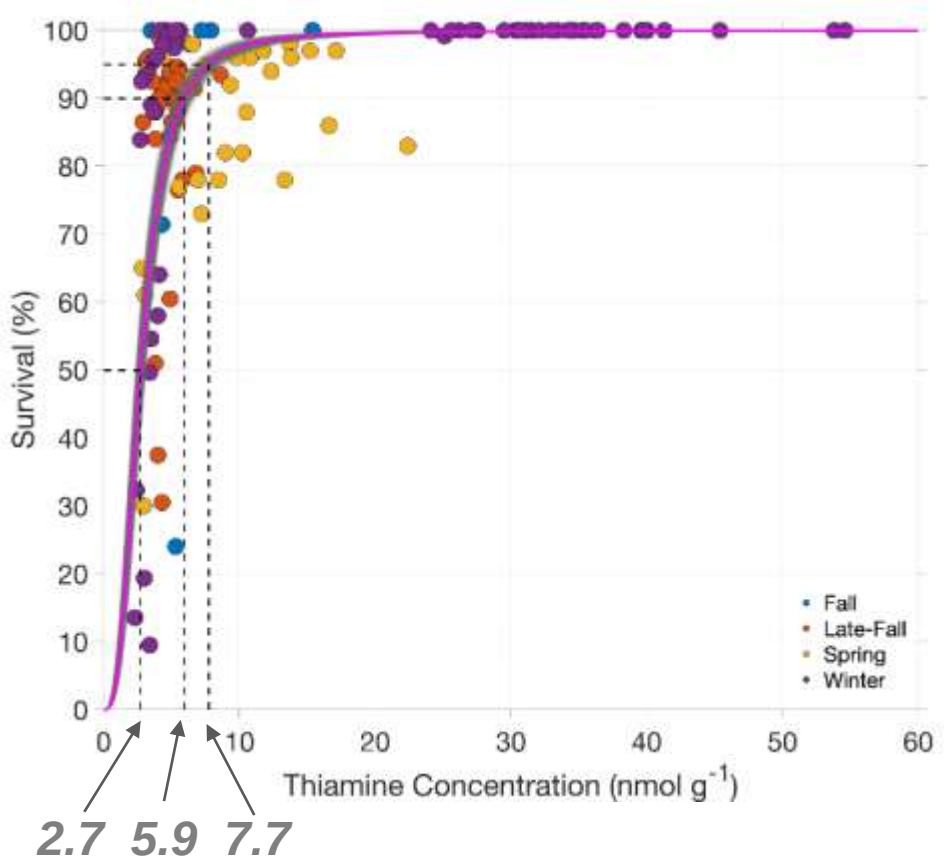
U

Dose-response model

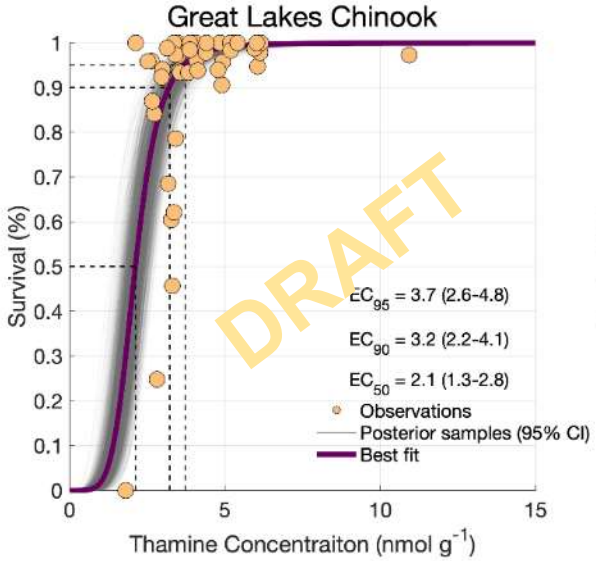


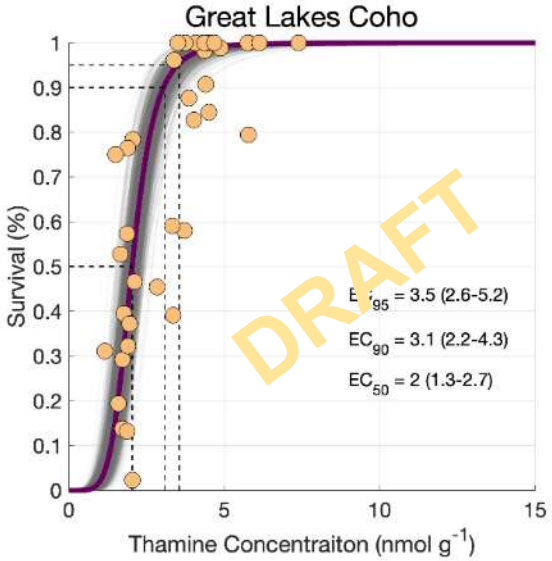
Dose-response model

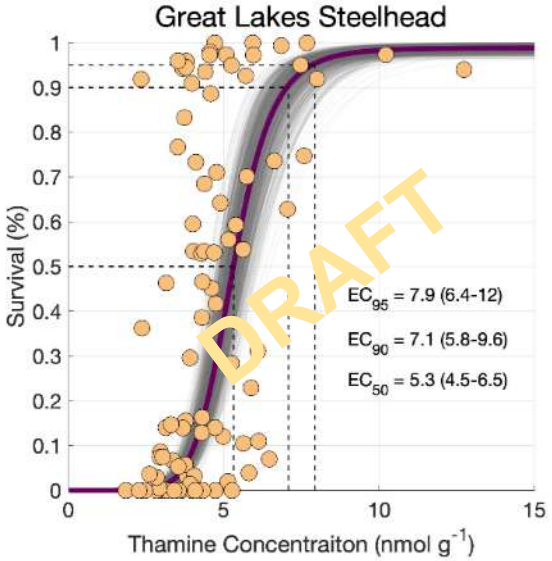
- Fitted model (-) shown with 95% credible intervals
- Model indicates very steep survival relationship between 2-8 nmol g^{-1}
- EC-50 = 2.7 nmol g^{-1}
- EC-90 = 5.9 nmol g^{-1}
- EC-95 = 7.7 nmol g^{-1}



How does this compare to other work?







Evaluation of adult and offspring thiamine deficiency in salmonine species from Lake Ontario

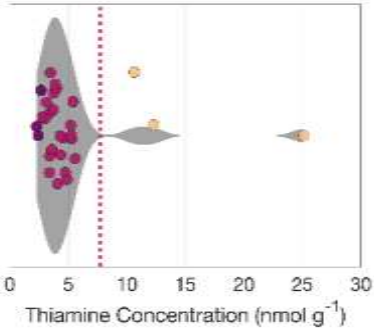
Matthew H. Futia *, Jacques Rinchard

Department of Environmental Science and Ecology, The College at Brockport – State University of New York, 350 New Campus Drive, Brockport, NY, USA

Translating model predictions to population impacts

Population level impacts

Winter-run 2020



Population level impacts

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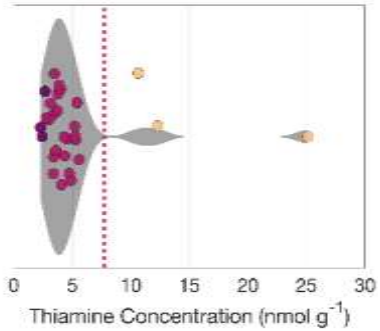
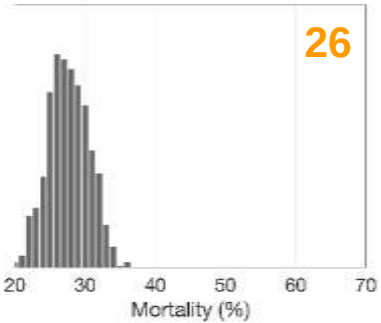
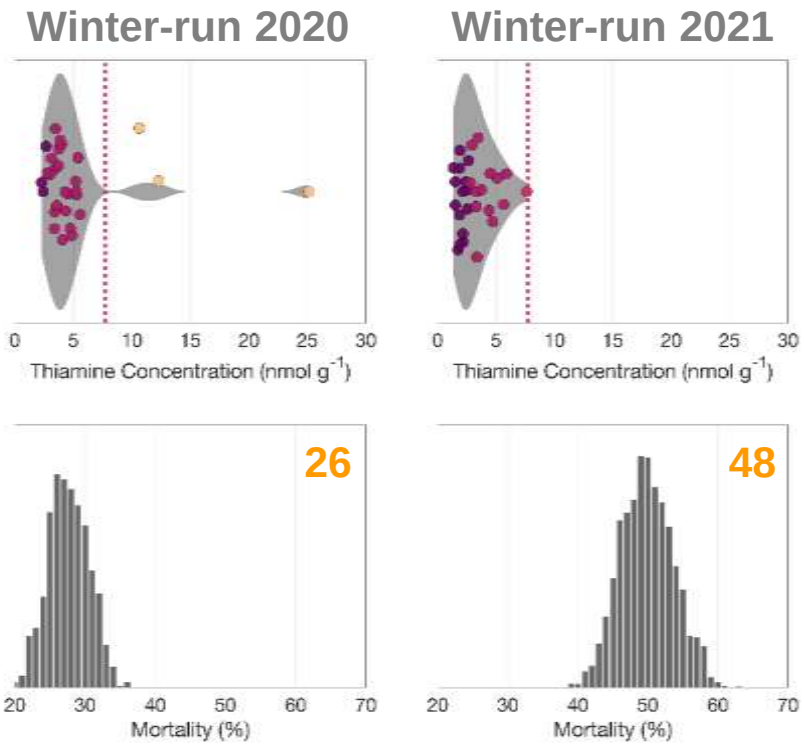




Mean thiamine-dependent fry mortality (%) estimate

Population level impacts



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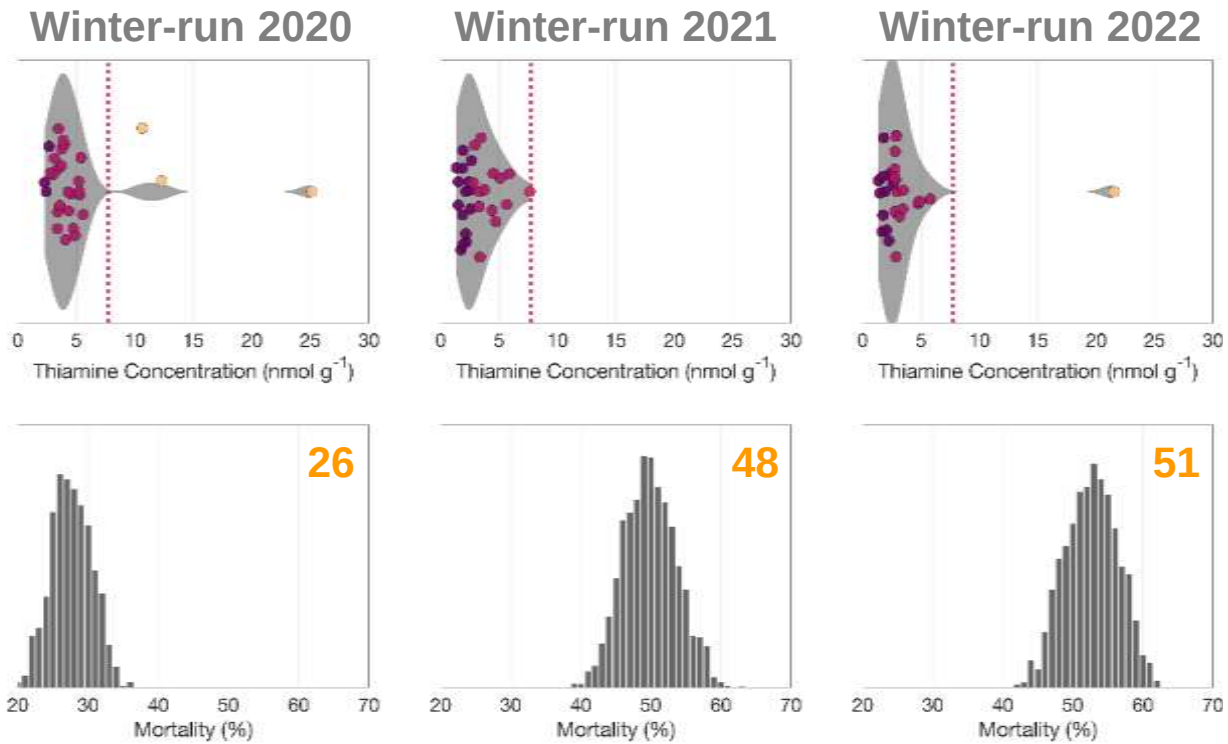

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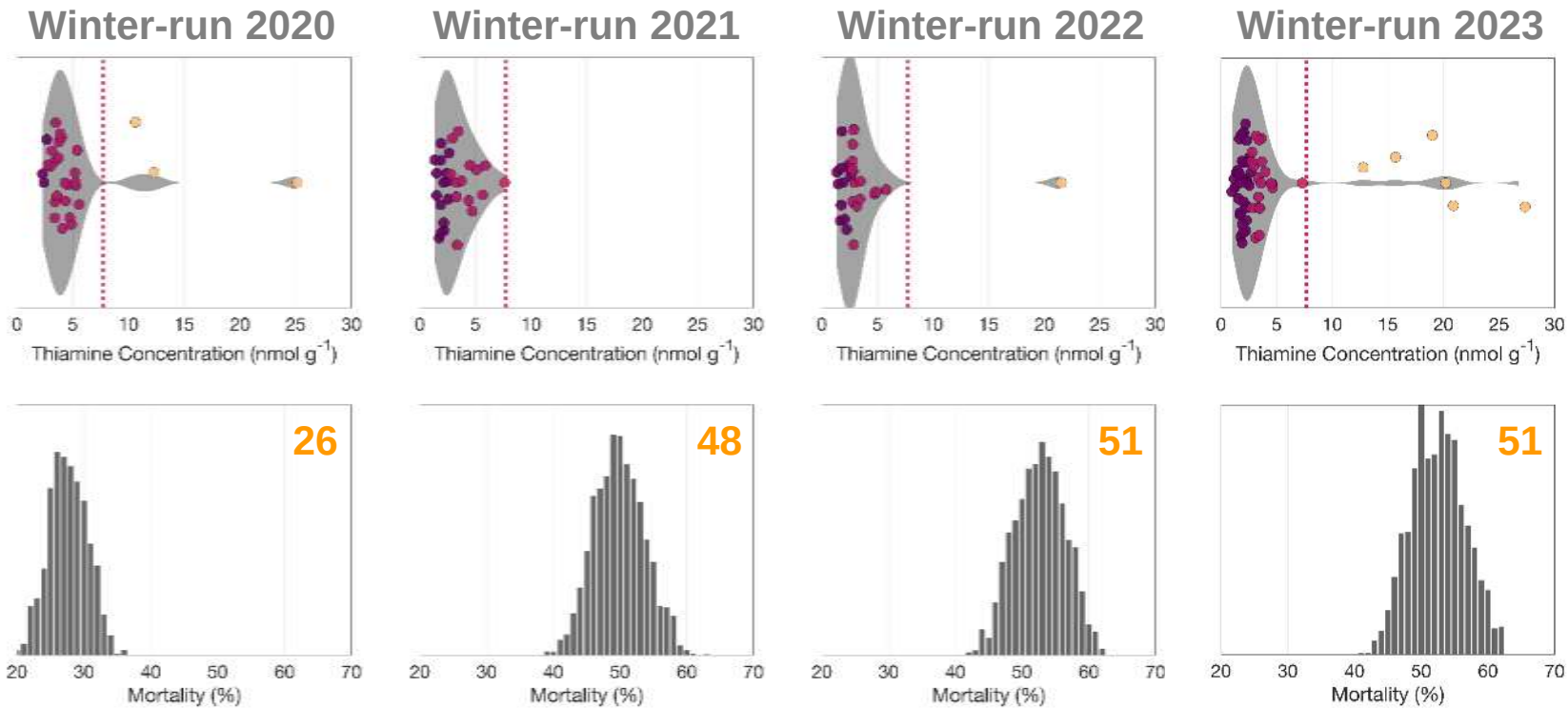


Mean thiamine-dependent fry mortality (%) estimate

Conclusions

- We have a model that can predict TDFM to all runs of Chinook in Central Valley given thiamine concentration
- TDFM for winter-run has increased since first observed in 2020, with conservative estimates indicating that ~40% of untreated population in 2023 suffered mortality
- Other runs (*data not shown*) have been observed to have TDFM > 10%
- Model could be refined with additional data/studies and other potential explanatory variables
    - *e.g. more samples in the lower range of thiamine*

Thanks for listening!

Miles Daniels (miedanie@ucsc.edu)

Developing Interdisciplinary Participatory Science for Youth Alongside Watershed Researchers

Engaging High School Students in Scientific Research

Partnering with Youth

Fisheries and Aquariums in the Classroom Programs

UC Davis Center for Community and Citizen Science At the School of Education

UC Davis Research Team- Leading Broader Collaborative

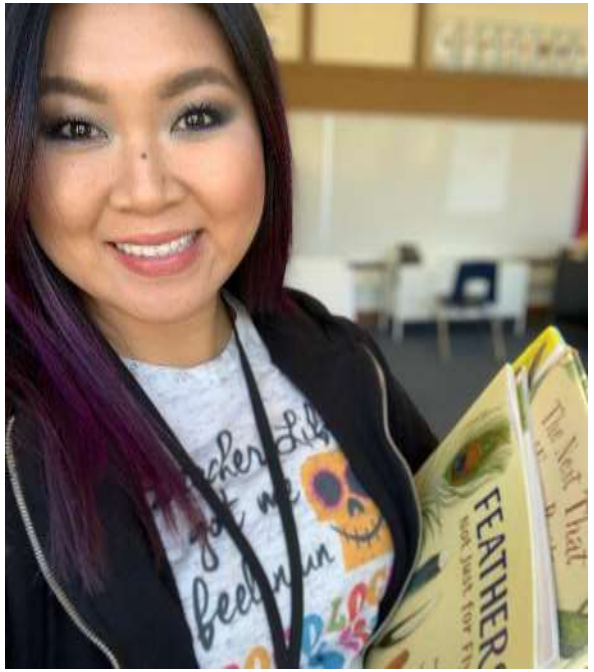
Lead Research team and funders (B-WET Program)

UC DAVIS GEAR UP A Program of the School of Education

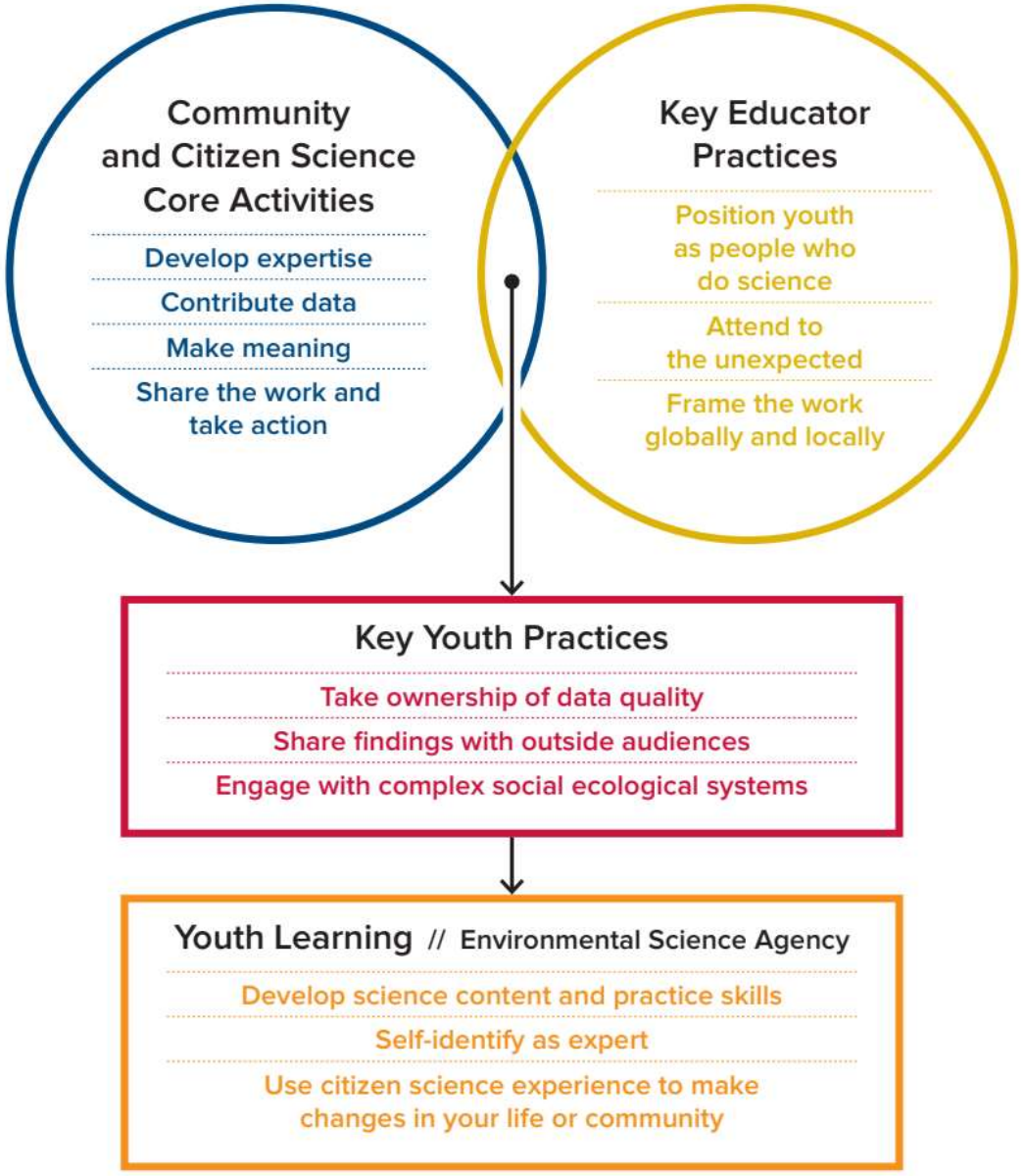
High School College Opportunity Program

County Office of Education- NOAA B-WET Grant Recipient

A story about a teacher and some fish



Our Role: Developing a program for youth engagement that delivered high quality data, supported student learning and connected researchers with classrooms.



Goals

- Develop protocols that would support **high quality data** (data collection skill building WHILE supporting content instruction in a variety of settings)
- Design **lessons and resources** that would support student engagement, background knowledge and connections across disciplines & content areas. Key: teacher training and ongoing mentoring*
- **Expanding access** by taking an interdisciplinary approach with a universal design
- **Connect** students directly with the research team

Connect students directly with the research team and local partners focusing on watershed health and restoration.

Goal #1- High Quality Data

Developing protocols and skill building resources

Salmon in the Classroom Data Sheet

Tank Location:			Tank Number:			Delivery Date: ____/____/2023				
Date	Time	Temp (F)	Water Clarity	Eye'd Up (unhatched)	Hatched	Mortalities today / total	Curling Up	Swimming Up	TDC Behavior(s)	Notes/Deformities/Questions

Protocols that produce data that are:

- Reliable
- High Quality
- Timely
- Meeting researcher needs

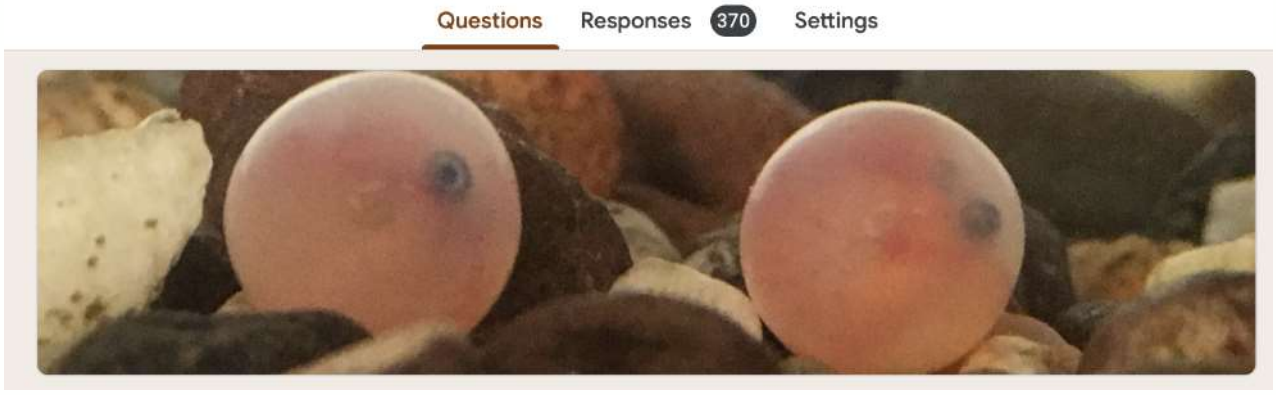
TDC Research Data: Spinning Salmon 2023/2024

*NOTE- When submitting data, please use **Google Chrome** as the calendar selection option does not show with Safari/Firefox.

Thiamine Deficiency Complex (TDC) was first documented in California's salmon in 2020. Hatchery staff noticed offspring swimming in circles and dying at elevated rates. They traced the condition to a deficiency of thiamine, or vitamin B1, passed on from the returning adults to their offspring. Impacts to naturally spawning populations remain the greatest unknown and could be an unrecognized factor affecting harvest opportunities and impede salmon recovery.

Researchers at the UC Davis Center for Watershed Sciences and the National Oceanic and Atmospheric Administration (NOAA) together with the Department of Fish and Wildlife are developing an Observation Protocol as part of the Salmon in the Classroom Program to help gather observation data of salmon during these critical stages of the salmon life cycle. These data will support the efforts of the broad coalition of scientists working on figuring out the TDC puzzle. By submitting data and participating in this project, you are supporting not only the data gathering for these programs, but also the development of further research protocols.

370 responses!

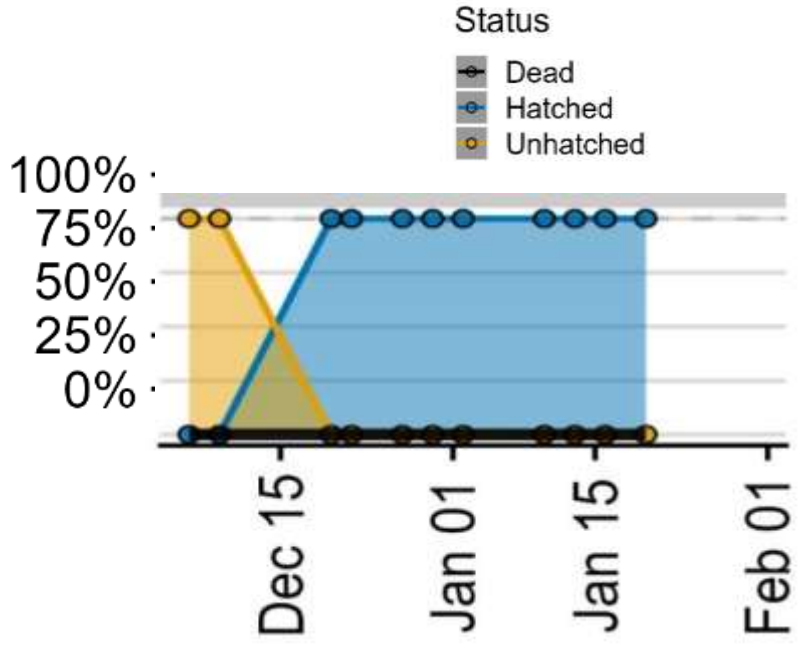


Protocol:

- Students observed fish for 5 min. recording signs of TDC, mortalities and tank conditions
- Submitted data 2x/week for 8 weeks
- Quality control, questions and additional observations

Key Learning: Lessons on how we turn the data into information that we can understand

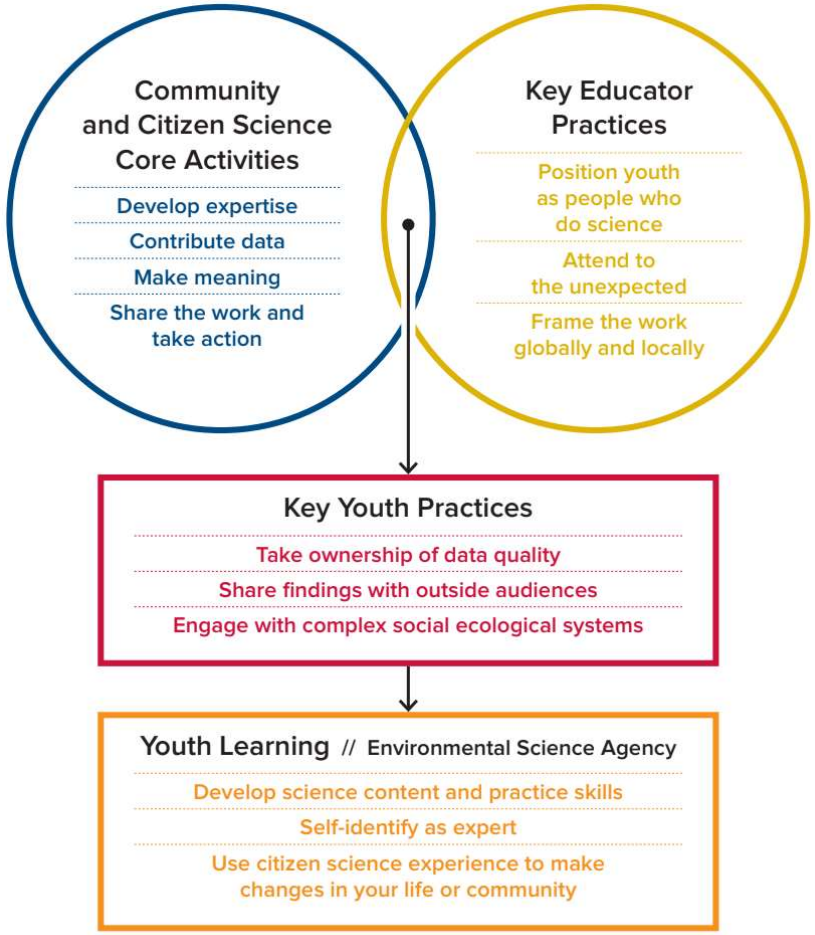
?



Goal #2- Program Development: Lessons and Resources

Supporting both student content learning and teacher professional development

YCCS Framework



Community and Citizen Science Core Activities

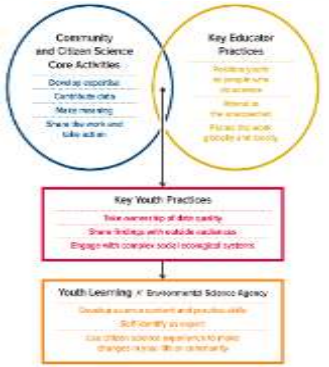
ACTIVITY	EXAMPLES
Develop expertise Develop youth interest and gain proficiency in the monitoring protocol	> Introduce the project > Learn from field guides > Observe and sketch specimens > Practice collecting or identifying organisms > Work with a local expert
Contribute data Do the monitoring protocol with youth and upload the data	> Small group practice > Develop specific roles > Develop peer leaders > Review and compare data > Investigate monitoring site
Make meaning Reason and reflect about the data and experience	> Analyze data by identifying species, describing patterns, and making graphs > Further investigate based on youth questions > Reflect on experiences
Share the work and take action Apply understandings and extend the work beyond the classroom	> Present to other classes > Talk to local citizen scientists > Share findings with stakeholders such as local organizations, school leaders, city council, and parents

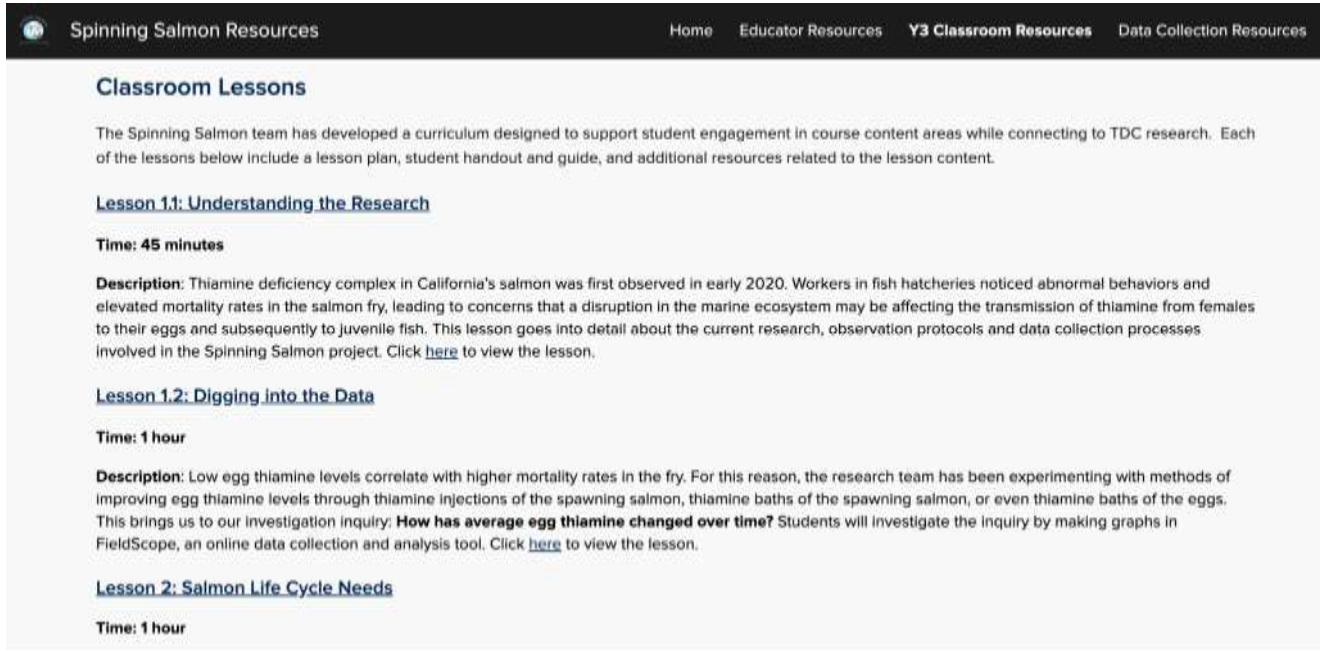
Participatory Science Lessons:

Development of teacher and student resources:

- **Professional development** and teacher mentoring
- Lessons developed in collaboration with the Center for Watershed Sciences that can be used by **multiple disciplines**. Focus on **developing student agency** using research-based framework for youth engagement in citizen science projects.
- Teacher and student resources compiled for each lesson tied to TDC research focusing on **student skill-building and understanding of their connection** to the watershed.

Lesson Development





- Background resources for both students and teachers
- Focus on skill-building around analyzing and interpreting data over time
- Multiple means of engagement across disciplines

Resource Development

- Supplemental materials for every lesson, blend of articles, videos, interactive data analysis
- Lessons (English/ Spanish) focusing on framing of the program supports for teachers and student reflections.

Youth Voice

Video of Experience

Scientific Poster

Advocacy with community partners

In the News

Engagement with the Research Team

Professional Development and Ongoing Mentoring

Professional Development-

- All teachers and advisors given a 1- or 2-day training that included an introduction to both the program as well as pedagogical shifts associated with participatory science/solutions-oriented inquiry programs
- Permitting -- CDFW Central Region CAEP: Salmonids in the Classroom
- Connections to Current Research (member of the research team)

Ongoing Mentoring and Professional Learning Opportunities-

- Training on participatory science skill-building and protocols
- Understanding connections to the ongoing research (FAQ, videos)

Goal #3- Expanding Access

Supporting student content learning, designing for multiple settings

Recruitment: High School Classroom Research Teams Recruited from TDC Impacted Areas

Five counties across California's Central Valley:

Tehama

Glenn

Colusa

Sacramento

Solano

Teams from Across the Central Valley

GEAR UP:

Tehama

Glenn

Colusa

CDFW:

Sacramento

NOAA B-WET:

Solano

Years 1-3: Expanding Access Focused on Equity

- 35 teachers
- 1,800 students
- 5 counties

Content:

Environmental Science

Biology

Math

English

Agricultural Science

Chemistry

Programs:

Traditional High Schools

Continuation Schools

Court and Community Schools

Advanced Placement Courses

Deaf-Hard of Hearing Program

County Juvenile Hall

Goal #4- Connect classrooms directly with the research team

From learning about to learning alongside.

Of the fish attempting to swim, are any exhibiting signs of TDC? (Video example of signs of TDC) *

- ○ Yes
- ○ No

If yes, how many are exhibiting signs of TDC? (Video example of signs of TDC)

Your answer

Of those exhibiting signs of TDC, which symptoms are they exhibiting? Check all that apply.

Observe the tank for five minutes. Record observations of fish that you see laying on their side, showing signs of lethargy, erratic swimming or spinning.

- ☐ laying on side
- ☐ signs of lethargy
- ☐ erratic swimming
- ☐ spinning

Working and learning alongside the research team.

The importance of asking questions and documenting observations.

What makes this different?

Connecting Directly With Researchers: Teacher Support & Student Engagement

- real-world, local and timely
- authentic engagement with the scientific community
- 1:1 mentoring for teachers and classroom connections with research team
- Need for data and feedback during the process

Connecting to the Broader Research Team

- Response to student questions (122 of them!) submitted as part of the observation submission process (FAQs)
- Sharing of resources and presentations connected to lessons
- Direct connections to the current research findings

Connections across a wide variety of career paths, research topics and backgrounds.

Release

Students #1 take away: feeling excited about being connected to the scientific community working on a local real world problem!

Next Steps

With a focus on equity and access throughout the county:

- **Mentoring**, development of additional micro PD, facilitated connections to researchers
- Build out **additional data analysis lessons** based on new FieldScopes data visualization platform (supporting NGSS and Math Frameworks)
- Develop additional supports for the county **DHH program**.
- Develop additional connections to **community partners** through Meaningful Watershed Educational Experiences (MWEE)
- **Educational Research of program outcomes, focusing on shifts in environmental science agency and identity.**

Learn More

- University of California, Davis:

  Center for Community and Citizen Science
  - Project Page includes Program Resource

For additional questions, feel free to reach out to Peggy Harte

Youth Education Program Manager **mharte@ucdavis.edu**