

Investigations into the emergence of widespread thiamine deficiency in California salmon

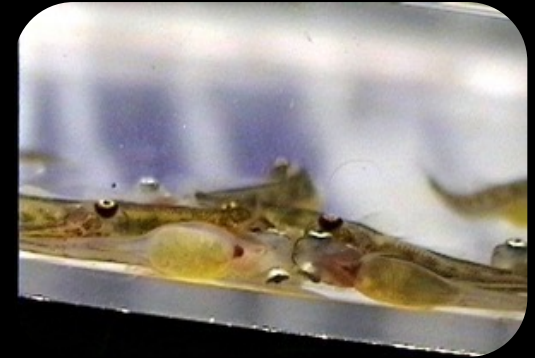
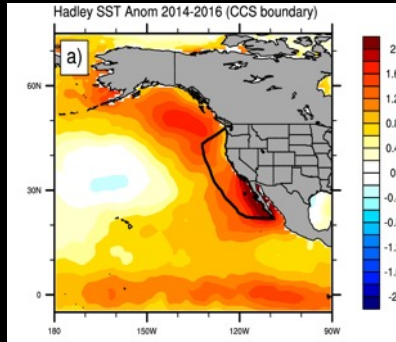


Photo courtesy Dale Honeyfield, USGS

Nate Mantua

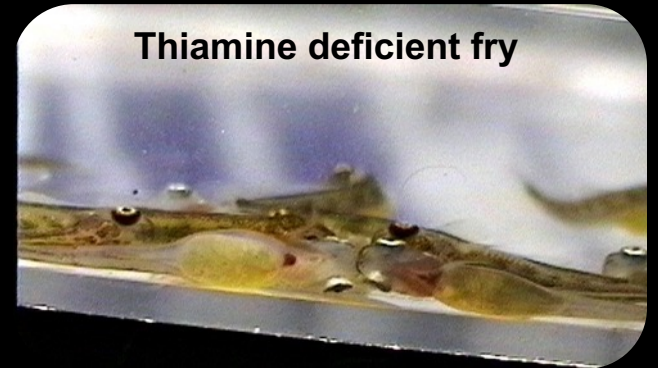
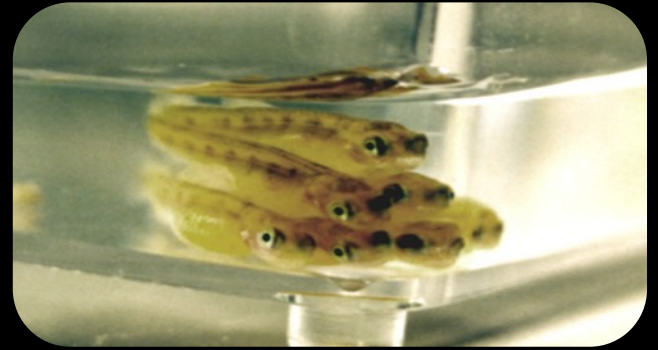
(representing many co-authors)



NOAA Fisheries, Southwest Fisheries Science Center
Santa Cruz, CA

TD detection in Central Valley Chinook salmon

- 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 early in 2020
- Scott Foott, USFWS CA-NV Fish Health Center Memo Jan 23, 2020
 - FHC, CDFW and UC Davis assays found *“fry loss not associated with infectious agent”*
 - **Thiamine bath treatments:** treated fry swimming normally and feeding soon after
- Anecdotal reports of unusually high numbers of dead fry in some Central Valley screw traps downstream of natural spawning areas in early 2020



Thiamine Research Team

NOAA: Rachel Johnson, Nate Mantua, John Field, Steve Lindley, Tommy Williams

USFWS: Taylor Lipscomb, Scott Foot, William Ardren

USGS: Donald Tillitt, Dale Honeyfield, Freya Rowland, David Walters, Catherine Richter

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SUNY: State University of New York Brockport, Jacques Rinchard

DWR: Jason Phillips

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Moss Landing Marine Laboratory and CICESE: 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

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!

DELTA
STEWARDSHIP
COUNCIL



UC DAVIS
UNIVERSITY OF CALIFORNIA

NOAA West Coast Region: Amanda Cranford, Charlotte Ambrose



Coordinated investigations: 2020-2022

1. **Testing:** Broad scale egg surveillance to identify vulnerable popn's
2. **Identify the cause:** Marine food web and freshwater response
3. **Develop Treatments:** Different salmon runs have different needs
4. **Assess impacts:** Thiamine-dependent mortality estimates
5. **Engagement:** Informing stakeholders, salmon in the classroom, and cooperative research with fishers

1. Testing: Broad scale hatchery egg surveillance 2020-2022

42 hatchery sampling events so far: 30 untreated females per group, 10g eggs per female

Central Valley

- 6 Chinook: 5 fall-run, 1 late fall-run, 1 spring run, and 1 winter-run
- 2 Steelhead: 1 winter-run, 1 fall-run

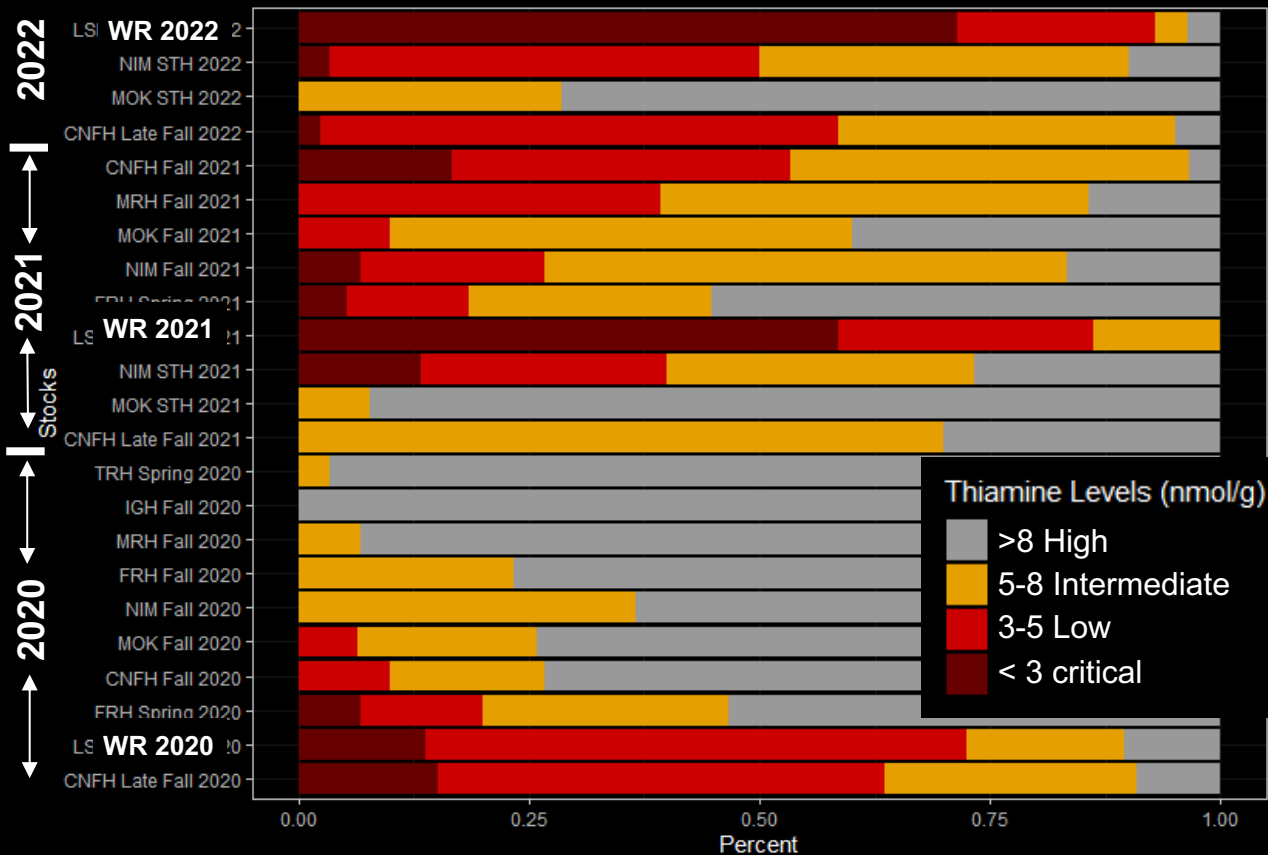
Coastal

- 3 Chinook: 2 fall-run, 1 spring-run
- 2 Coho
- 3 Steelhead: winter-run



Proportion of Eggs with Different Levels of Thiamine

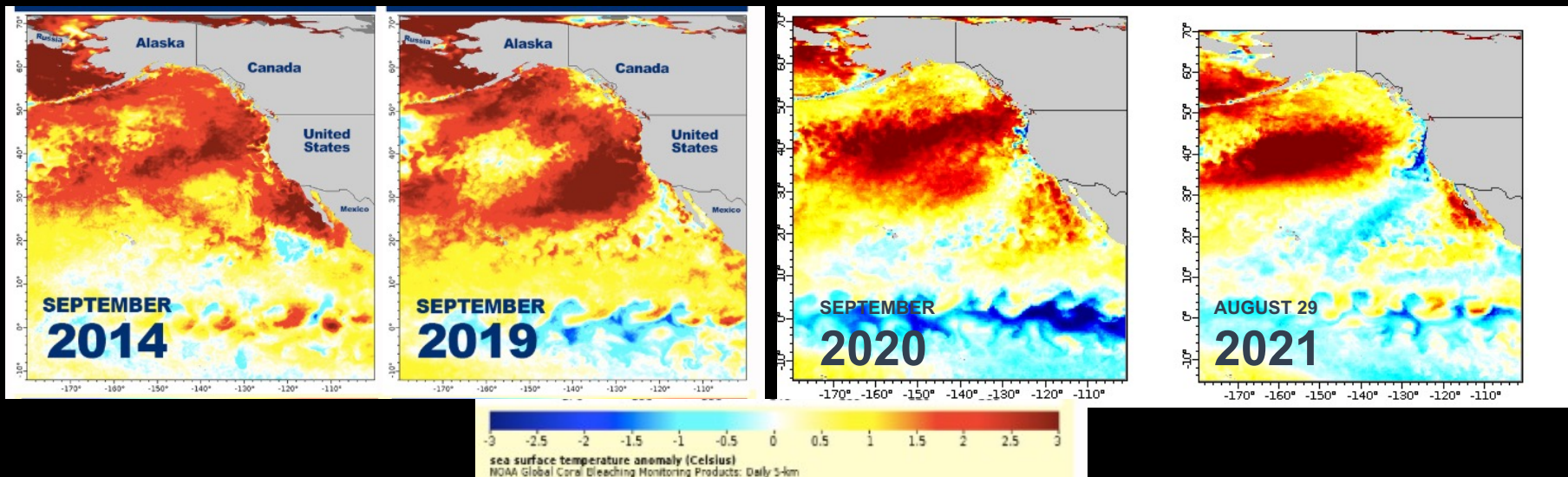
- CV winter run and late fall Chinook salmon: lowest!
- Winter run steelhead from the American River (CV), Mad River (coastal), and Russian River also notably low
- 2021 Klamath/Trinity Chinook and Coho: substantial declines from 2020 to 21



Unpublished data from Jacques Rinchar (SUNY)

2. The Cause? Frequent Marine Heatwaves from 2014-2021?

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



<https://www.fisheries.noaa.gov/feature-story/new-marine-heatwave-emerges-west-coast-resembles-blob>

2. The Cause?

“In California, 2019 northern anchovy abundance from both larval and midwater surveys was the highest in recorded history while many common forage fish (e.g., juvenile rockfishes, sanddabs) and krill were very low. This unique forage base had clear and predictable effects on predators.”

State of the California Current 2018-19

(Thompson et al. 2019, CalCOFI reports)



<http://swfsc.nmfs.noaa.gov/PRD/>

Comelia Oedekoven

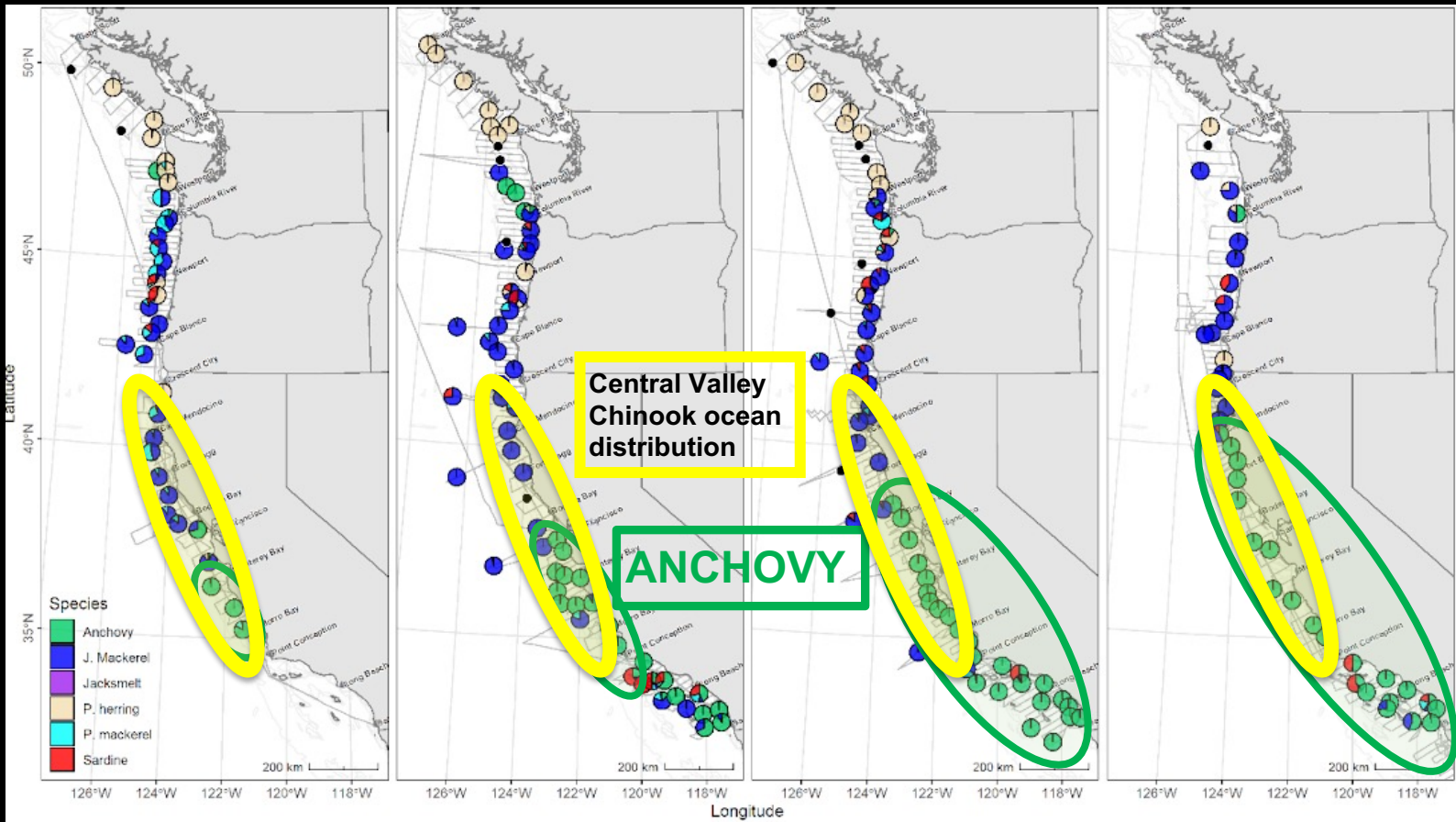
Coastal Pelagic Species from NMFS Summertime acoustic-trawl surveys

2017

2018

2019

2021



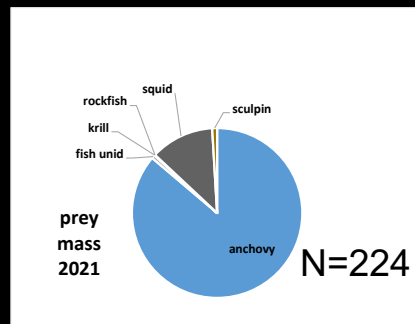
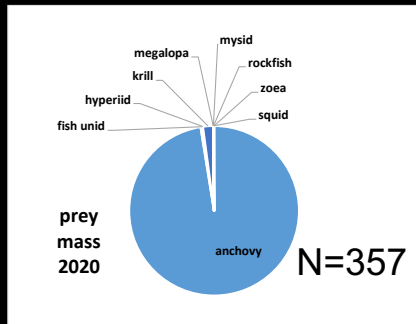
Central California northern anchovy stock biomass and north end of their distribution expanded greatly from 2017-2021.

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

The anchovy diet hypothesis

Salmon diets dominated by Northern anchovy in 2019-20-21

- Anchovies carry thiaminase, an enzyme that degrades or destroys thiamine in consumers
- Chinook gut contents: 97% (2020) and 86% (2021) anchovies by biomass!
- much more diversity in diets from 1950s to 2010 (Thayer et al. 2014, MEPS)



2020

1980s

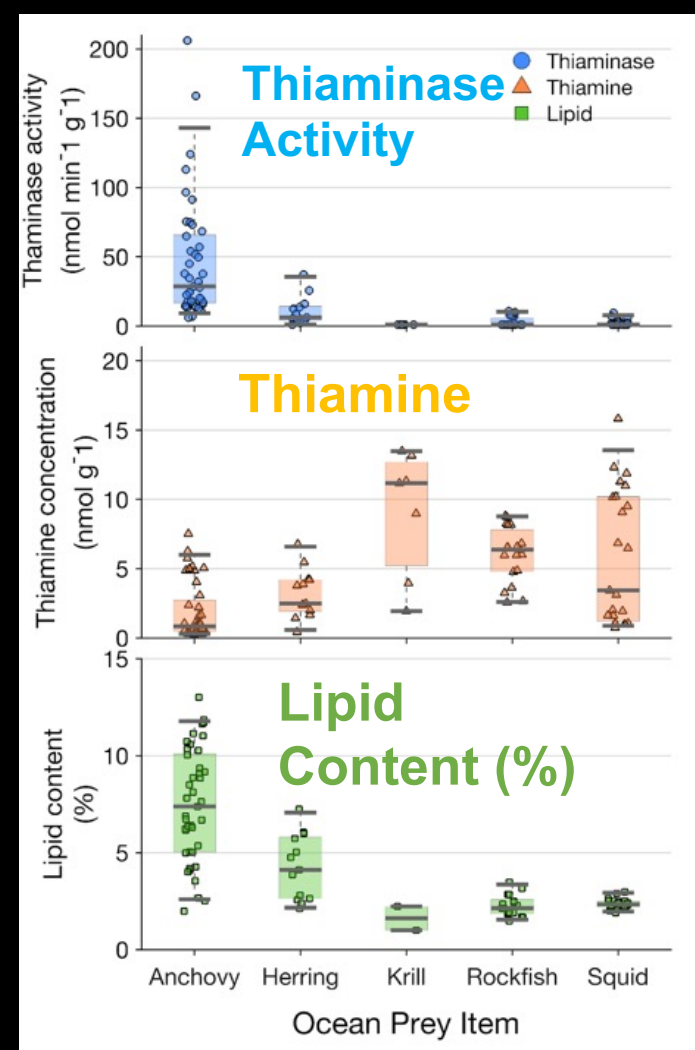


Picture from John Field, SWFSC

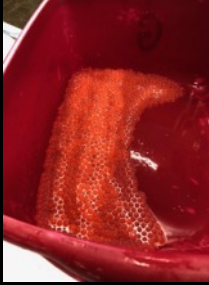
Prey Nutrition

- Anchovies are especially high in thiaminase activity, low in thiamine, and high in lipid content
- We are also looking at Fatty Acid profiles in salmon eggs and prey items, and stable isotopes in salmon tissues and prey

Unpublished data from J Rinchard (SUNY) and D Tillitt (USGS)



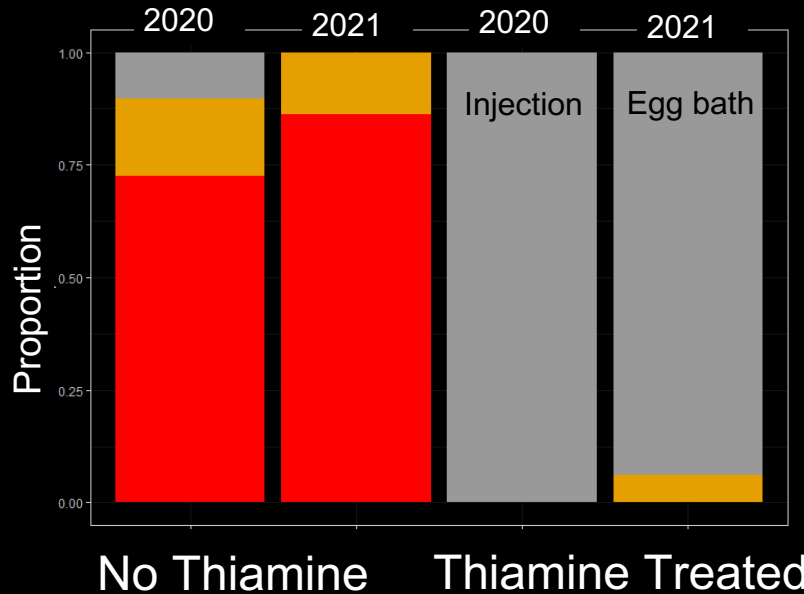
3. Develop Treatments: Different salmon runs have different needs



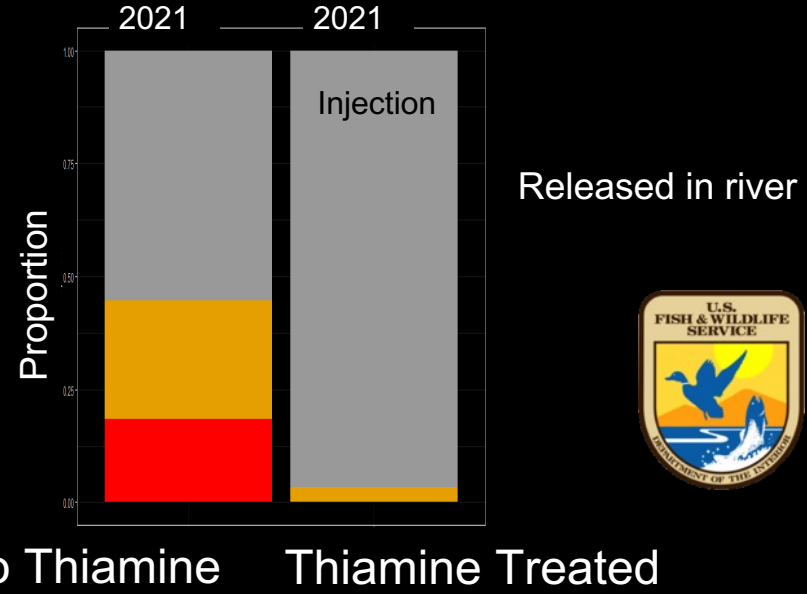
Thiamine Treatments: injecting pre-spawn females and egg-baths at fertilization



Winter run Egg Thiamine



Spring run Egg Thiamine



Released in river



4. Assessing impacts: Thiamine-dependent fry mortality (TDM) estimates

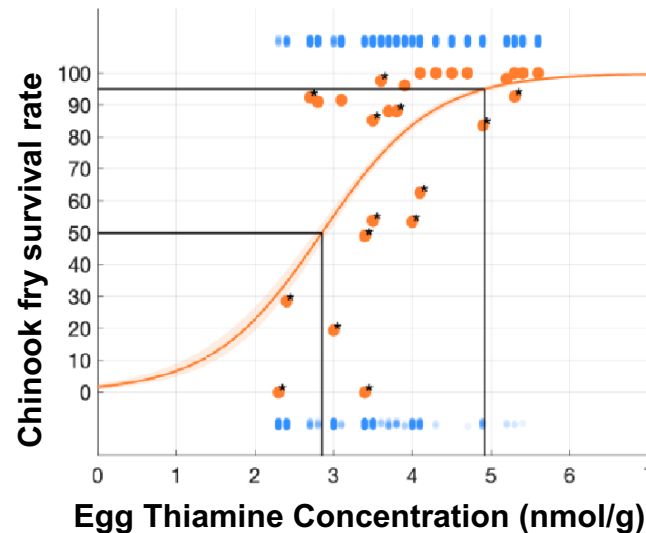
**untreated winter run
Chinook fry TDM**
2020: 23%
2021: 44%
2022: 45%

Estimates from Miles Daniels and
Heather Bell based on the survival
curve at right

Thiamine Studies at UCD

- Analysis Method: A logistic regression model fit to the data to predict survival probability given thiamine concentration.

$$\pi(TC) = \frac{e^{-4.097+1.432*x_1}}{1 + e^{-4.097+1.432*x_1}}$$



$$EC_{50} = 2.9 \text{ nmol g}^{-1}$$

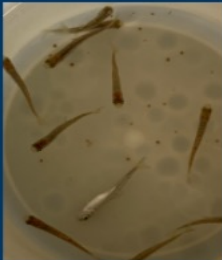
$$^*EC_{95} = 4.9 \text{ nmol g}^{-1}$$

*Same estimate as from H. Bell

Unpublished data from Heather Bell
and Anne Todgham

5. Engagement

- Frequent meetings/briefings with salmon management community
- Cooperative sampling with the fishing industry
- Salmon in the Classroom through the UC Davis Center for Community and Citizen Science



Some outstanding questions

- Are some naturally-spawning populations buffered by thiamine-rich spawning grounds?
- What is causing the diversity of egg thiamine concentrations in different population groups and individuals?
- Why do some families exhibit more/less mortality than others for a given egg thiamine concentration?
- What is going on with steelhead?

Significance

Our research indicates that thiamine deficiency is a new stressor on California's already stressed salmon, linked with a recent and surprising dominance of northern anchovy in their ocean food-web.

Thiamine deficiency will likely persist and expand to impact other West Coast salmon populations if recent trends in the abundance and distribution of marine forage species continue.

Unlike many stressors on salmon, thiamine deficiency effects are at least partly observable and can be managed in fish hatcheries and possibly in early-migrating naturally-spawning populations.

Summary

1. **Testing:** Central Valley hardest hit in 2020-21; we documented the emergence of low thiamine in Coho salmon and coastal CA steelhead eggs in 2021
2. **Identify the Cause:** shift in the ocean food web came with anchovy dominated salmon diets from 2019-2021
3. **Develop Treatments:** pre-spawn injections and egg baths at fertilization are effective; different runs require different treatments
4. **Assessing impacts:** population level impacts have been substantial for endangered winter run Chinook salmon 2020-2022
5. **Engagement:** has been critical for our progress, for effective decision-support, and for keeping stakeholders informed, interested, and critically helpful in sampling