Seascape Ecology: Growth, Survival, and Foraging in the California Current

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

- **Session Coordinators:**
  - Cynthia Le Doux-Bloom, PhD, *Cal Poly Humboldt, Department of Fisheries Biology*
  - Nate Mantua, PhD, *NOAA, Southwest Fisheries Science Center*

Although many factors may be responsible for the declines in anadromous salmonid populations, this circumstance is commonly linked to the oceanic and estuarine conditions present during the smolt life cycle phase, which remains unstudied compared to riverine life phases. Upon saltwater entry, salmonids display a wide range of growth and survival rates and display a variety of movement and migratory behaviors, both tied to ocean and estuary productivity which influences the foraging conditions these individuals encounter across space and time.

These sessions will feature innovative and novel studies focused on understanding the ocean and estuary life cycle phase of Pacific salmonids, including: (1). An Overview of Seascape Ecology and Current Events; (2). Movement and Migration; (3). Survival and Growth; and (4). Foraging Conditions influenced by the California Current.

Presentations

Slide 4 - **Twenty-Two Years of Seascape and Salmon studies on the Pacific West Coast**, Nate Mantua, Ph.D., *NOAA Fisheries, SWFSC*

Slide 34 - **Salinity Tolerance and Smoltification Differences Between Winter, Fall and Spring-Run Chinook Salmon (Oncorhynchus tshawytscha) Brood Stocks**, Leah Mellinger, *University of California, Davis*

Slide 57 - **Climate-Driven Variability in Zooplankton in Coastal Waters off Northern California: A Potential Ecosystem Indicator for Klamath River Chinook Salmon,** Eric Bjorkstedt, Ph.D., *NOAA Fisheries, SWFSC*

Slide 83 - **California Current Seascape Influences Juvenile Salmon Foraging Ecology at Multiple Scales**, Megan Sabal, Ph.D., *Oregon State University*

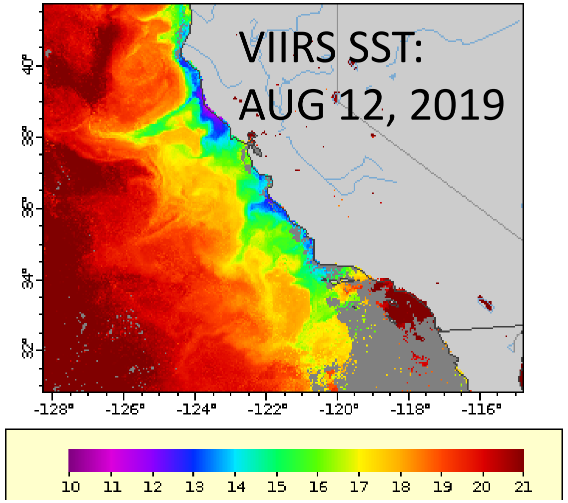
Slide 103 – **The Pelagic Juvenile Rockfish Survey in Your Backyard: Linking Forage Variability to Salmon in the California Current**, John Field and Jarrod Santora, Ph.D., *NOAA Fisheries, SWFSC*

Slide 129 - **Thiamine Deficiency in California Salmon: The Ocean is Impacting Freshwater Productivity**, Rachel Johnson, Ph.D., *NOAA Fisheries, SWFSC*

Twenty-two years of Seascape and Salmon Studies on the West Coast

NOAA FISHERIES

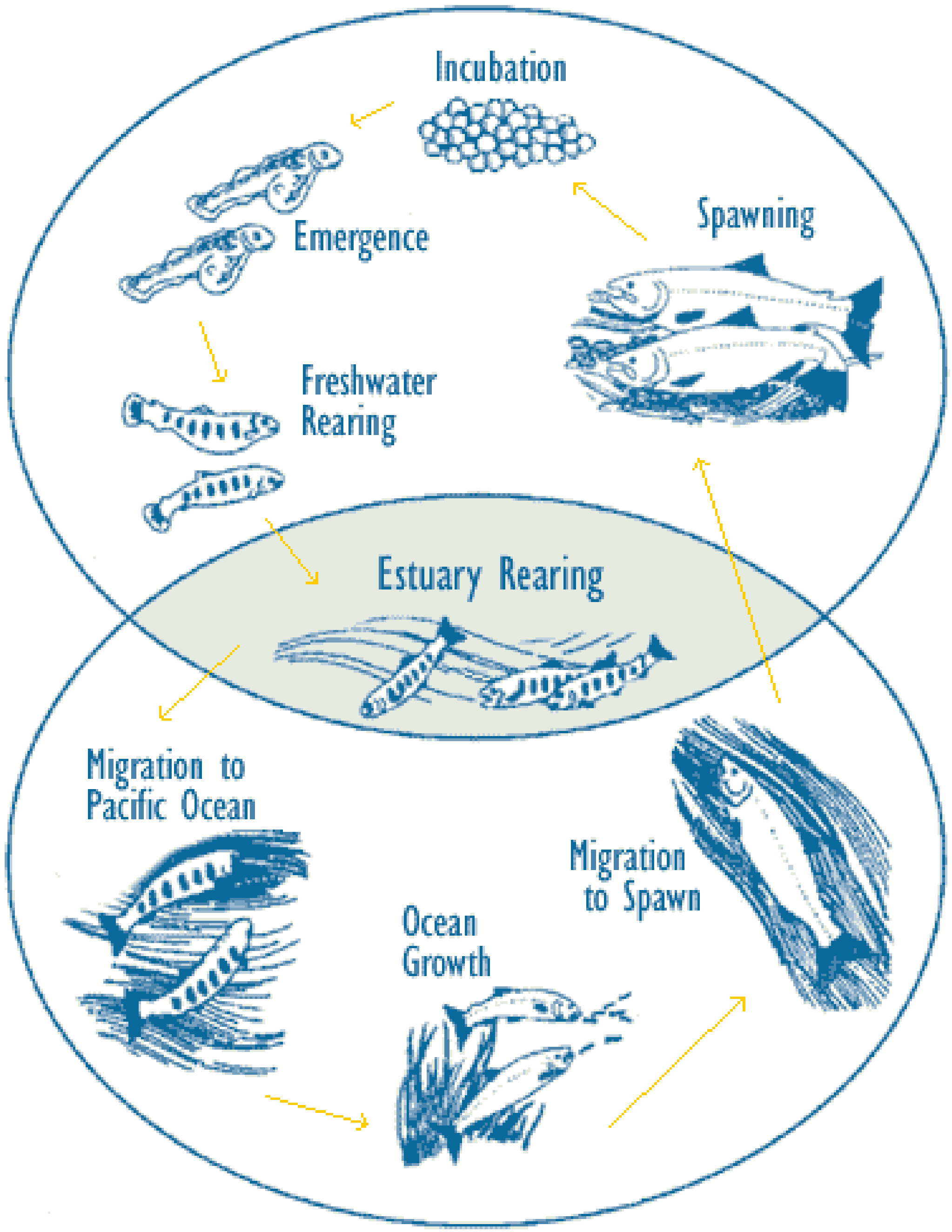
SWFSC - FED



Nate Mantua, Southwest Fisheries Science Center

Santa Cruz, CA - April 22, 2022

Co-authors: Brian Wells, Brian Burke, Steve Lindley, David Huff, Laurie Weitkamp, Joe Smith, Jeff Harding and many more…



The ocean is a key part of salmon/steelhead habitat

Chinook salmon typically spend 2-5 years in the ocean and just a few months to a year in freshwater

Coho salmon typically spend 1.5 years in freshwater, 1.5 years in the ocean

Steelhead: 1 to 3 years in streams, 1-3 years in the ocean, with lots of variation

The ocean is a high-risk but high-reward habitat option

- Ocean growth rates are typically much greater than those in freshwater
  - But juvenile salmonids enter the ocean at "forage fish" sizes!

- Smolt to adult return rates for Central Valley Chinook salmon ~.1 to 3%
  - Michel 2019 CJFAS: in-river outmigration survival 3-17%, ocean survival 4-23%

Central Valley Chinook Salmon ocean abundance

Sacramento Index: the aggregate-age index of adult Sacramento River Fall Chinook salmon ocean abundance

(O'Farrell et al. 2008, 2013)

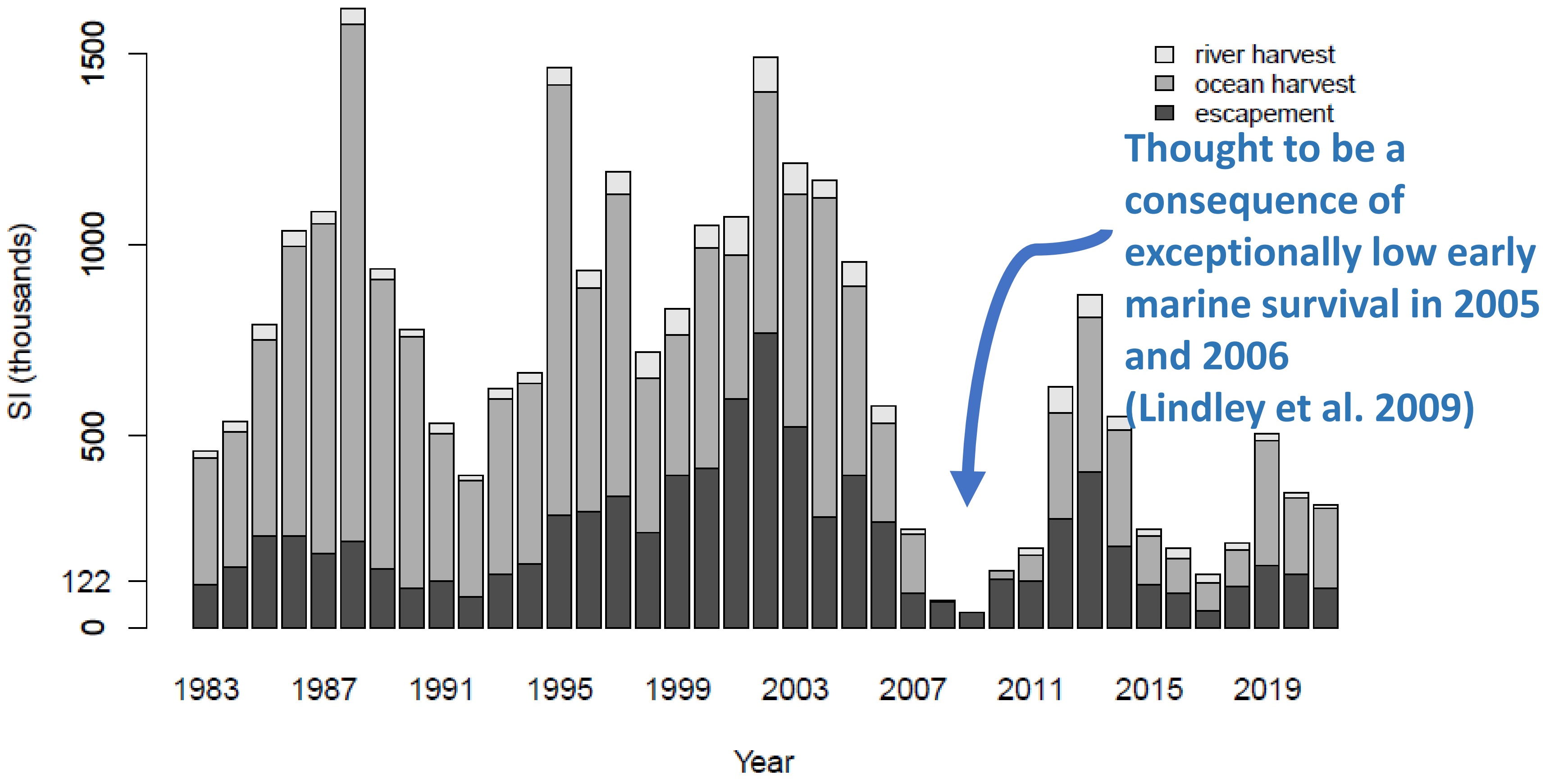


Figure from Pacific Fishery Management Council. 2022. *Preseason Report I*

Coastal Upwelling is a key process supporting exceptional productivity off the West Coast

- upwelling and related winds and ocean currents vary within and between years and decades

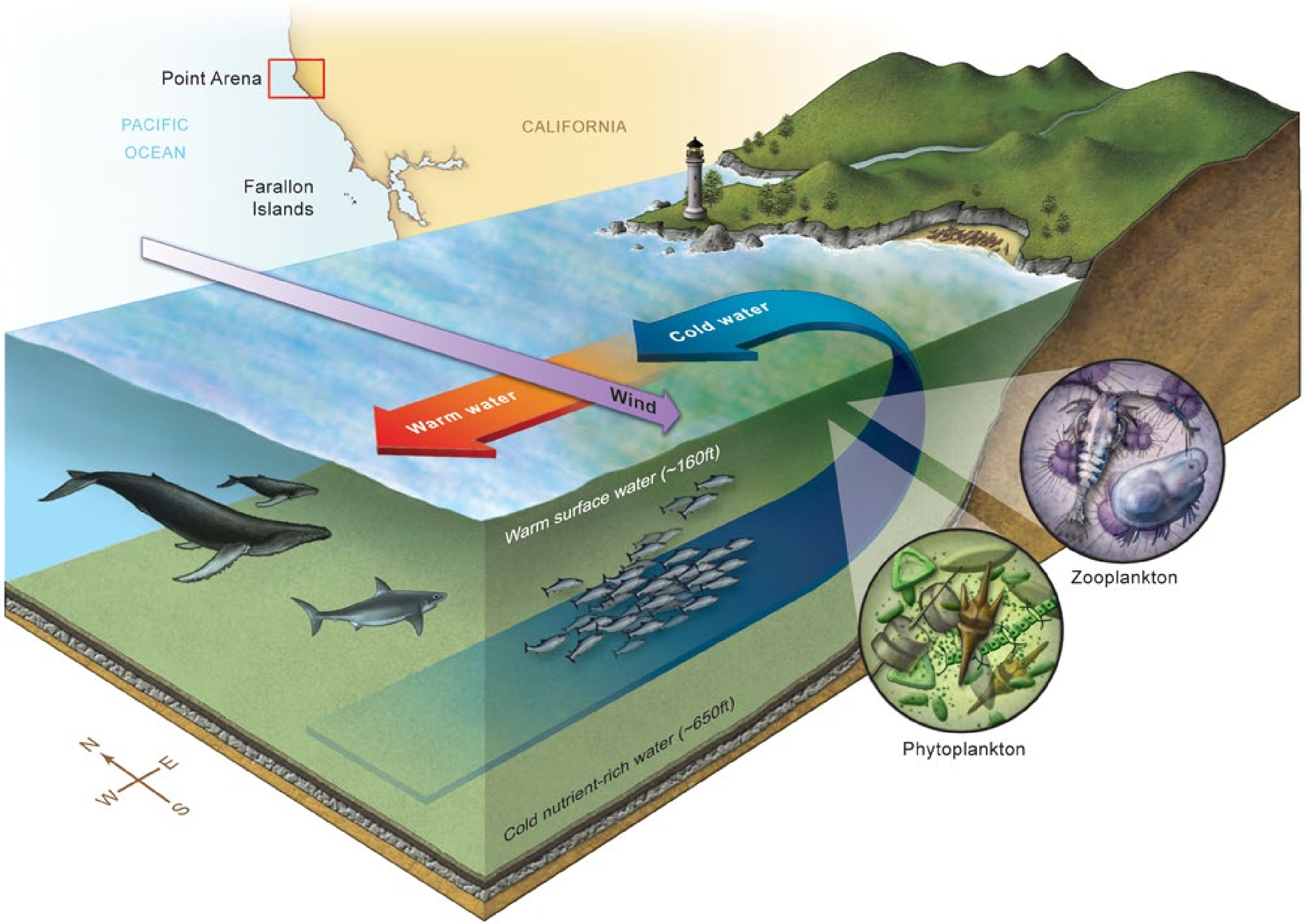
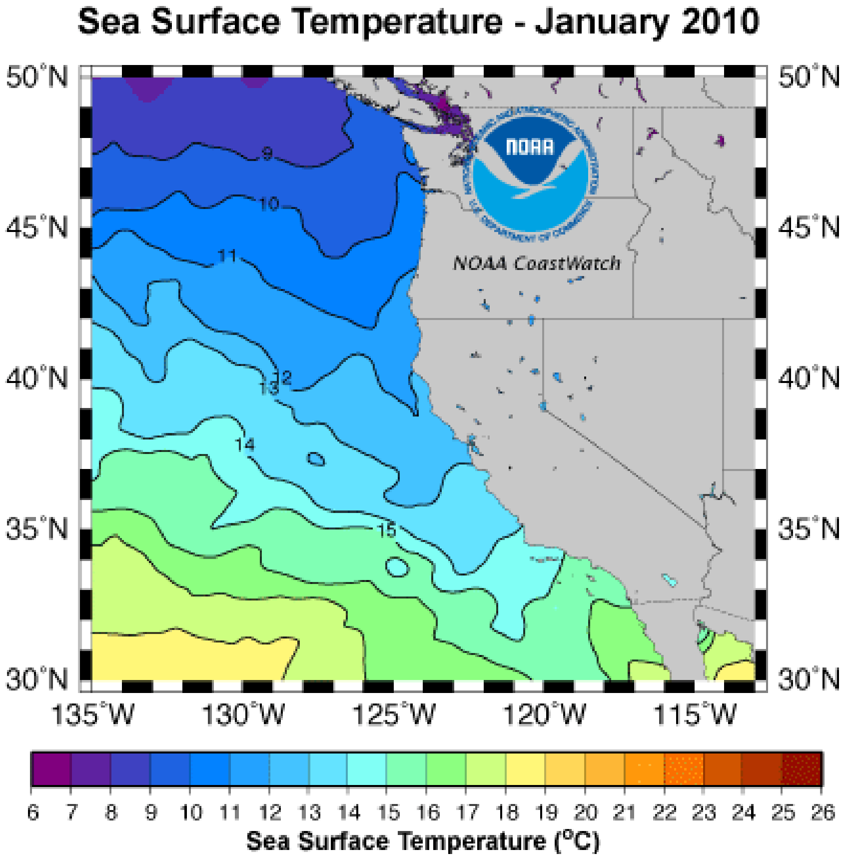
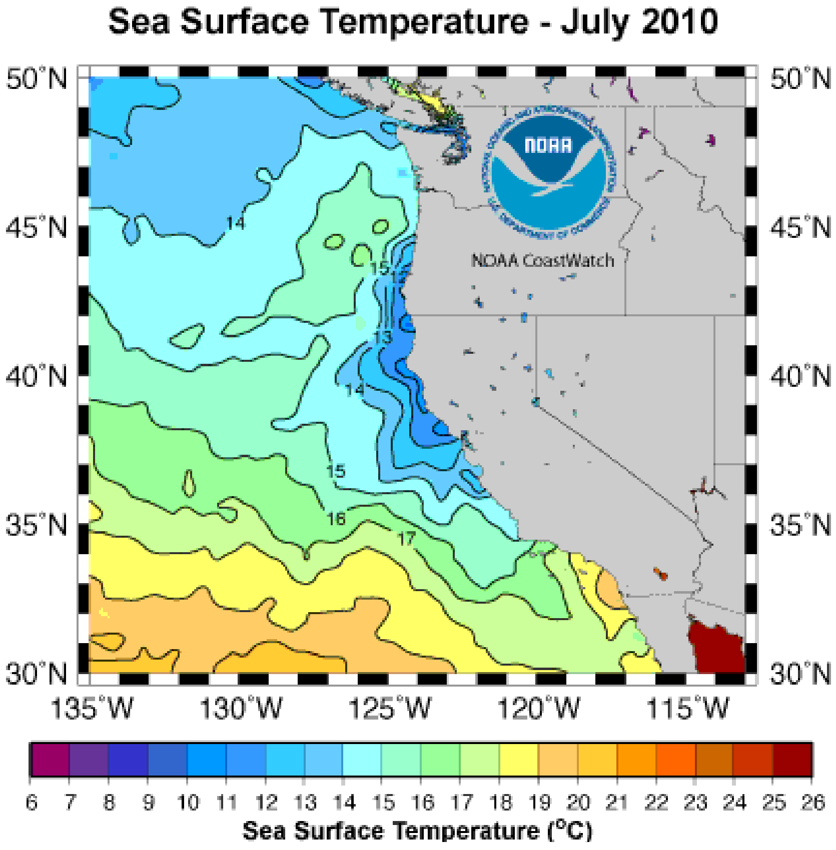


Illustration by Fiona Morris

Winter vs. Summer SSTs

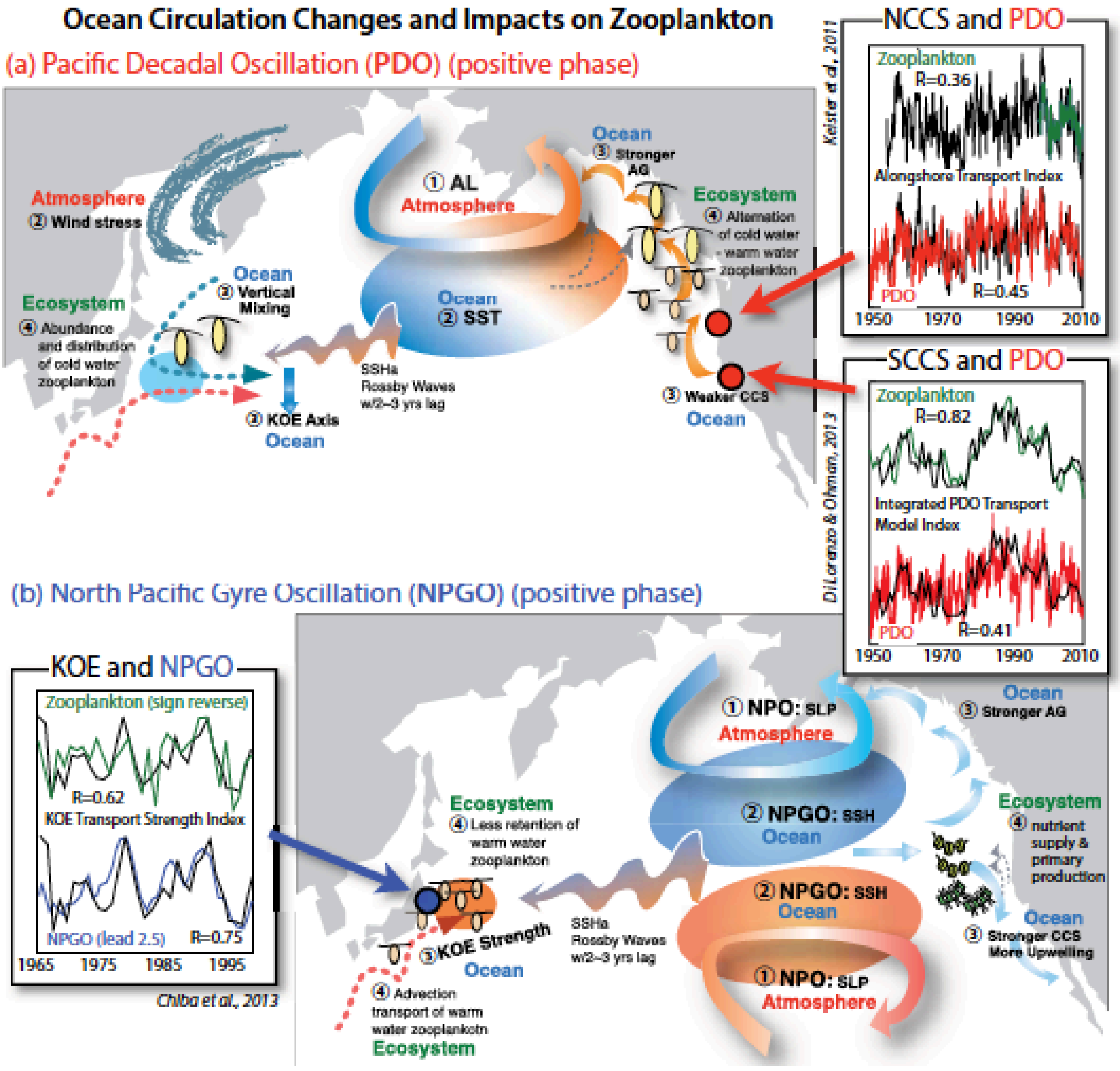




Basin-scale processes

The ocean integrates atmospheric forcing and "ocean conditions" vary more strongly at lower frequencies/longer time scales

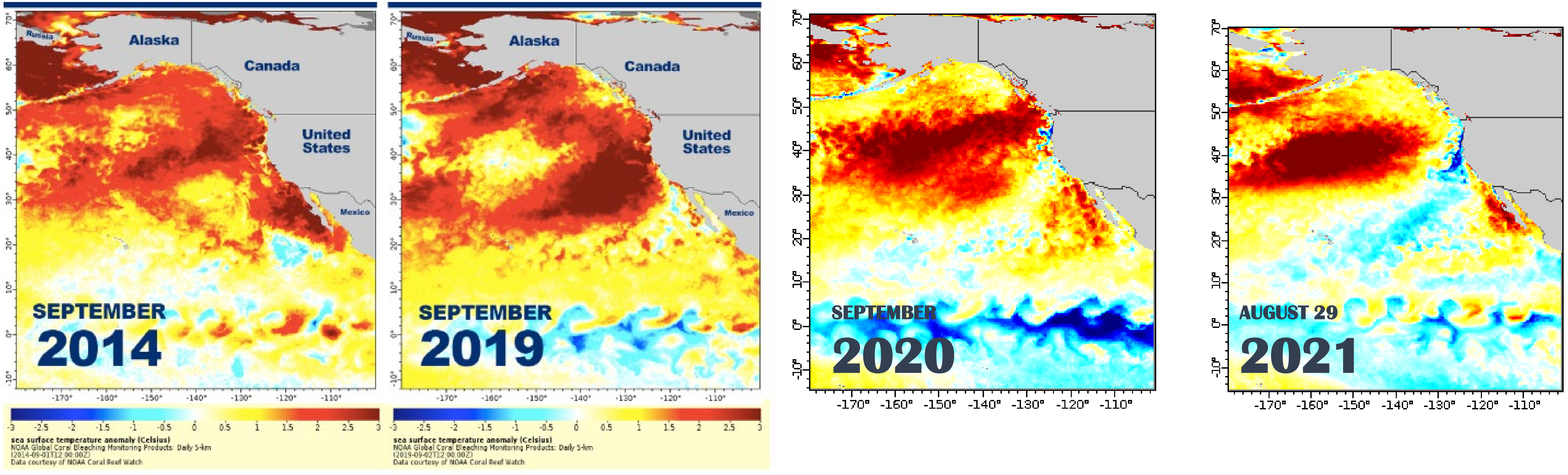
- *The Pacific Decadal Oscillation (PDO) and North Pacific Gyre Oscillation (NPGO) are particularly important patterns of variability impacting ocean temperatures, chemistry, currents, and the food-web*



Di Lorenzo et al, 2013: Oceanography
http://dx.doi.org/10.5670/oceanog.2013.76

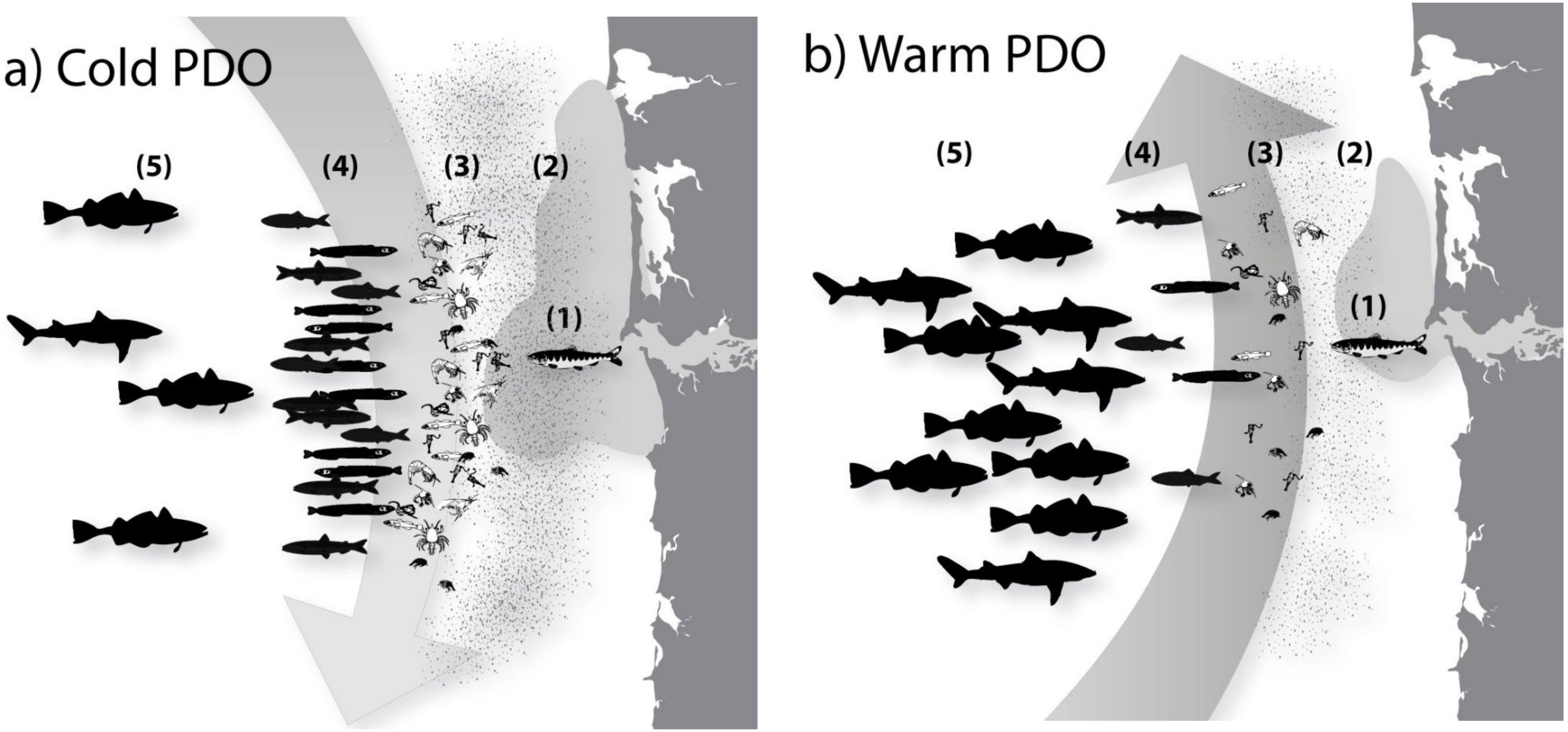
Frequent Marine Heatwaves from 2014-2021

Extreme and persistent warm periods have affected the Bering and Chukchi Seas, Gulf of Alaska, and California Current, with widespread impacts on marine life and fisheries.



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

Working hypothesis: Biological Communities significantly different under cold and warm periods

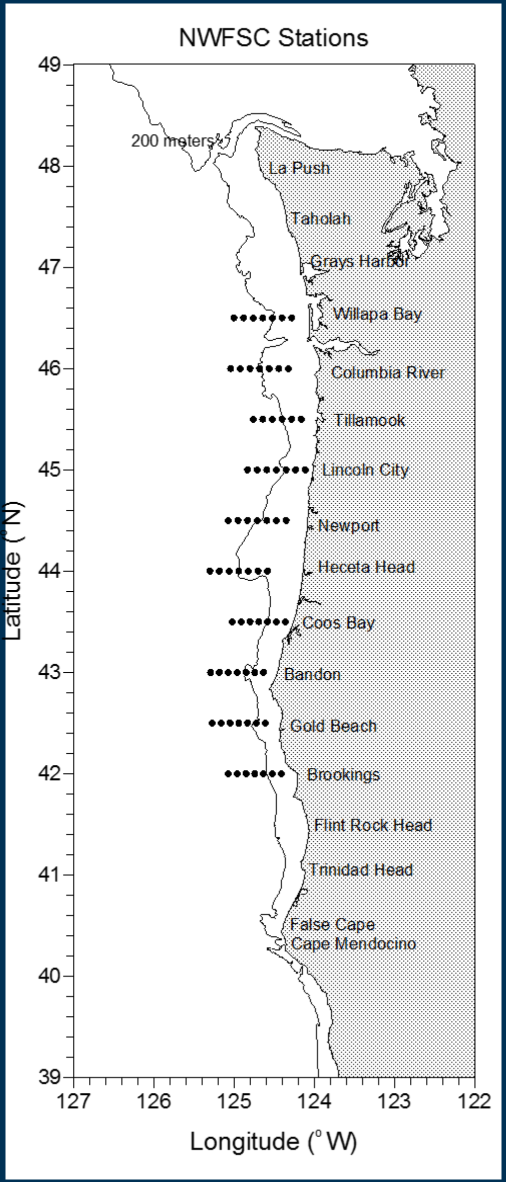


Figures courtesy of Kirstin K. Holsman, AKFSC, Seattle, WA

Juvenile Salmon and Ocean Ecosystem Survey (JSOES)

- May (2006 – 2012, 2015 - present)
- June (1998 – present)
- September (1998 – 2012)

NWFSC: Newport Hydrographic Line and Northern California Current Survey



Newport Line: Sampled biweekly for 27 years

Pre-recruit: May-June (2011, 2013-2019)

NCC Survey: Seasonal (2-4 times per year)

Slide from Brian Burke, NWFSC

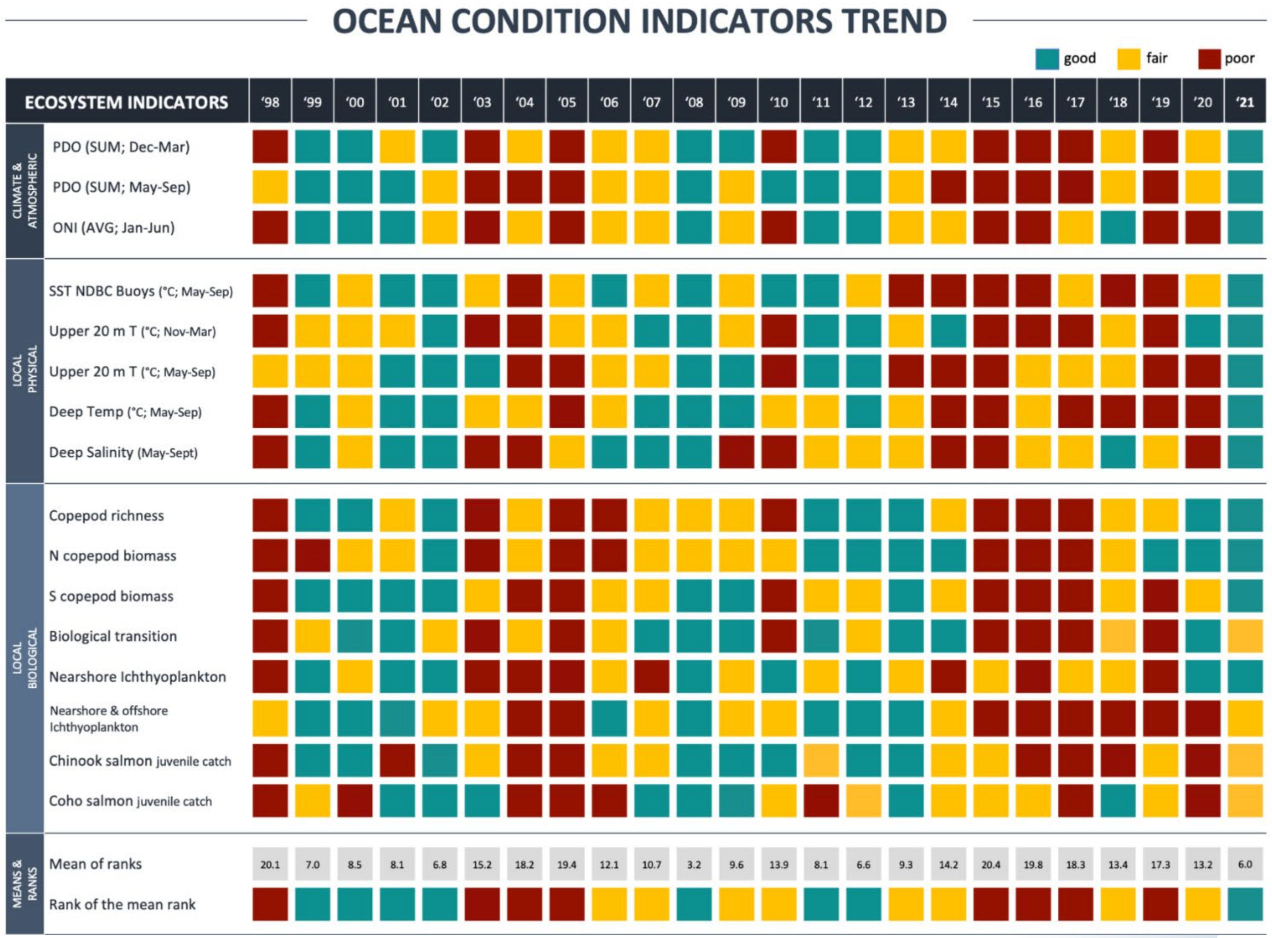
New ‘Stoplight’ Website

https://www.fisheries.noaa.gov/west-coast/science-data/ocean-ecosystem-indicators-pacific-salmon-marine-survival-northern

Stoplight Table

Ocean Conditions Summary

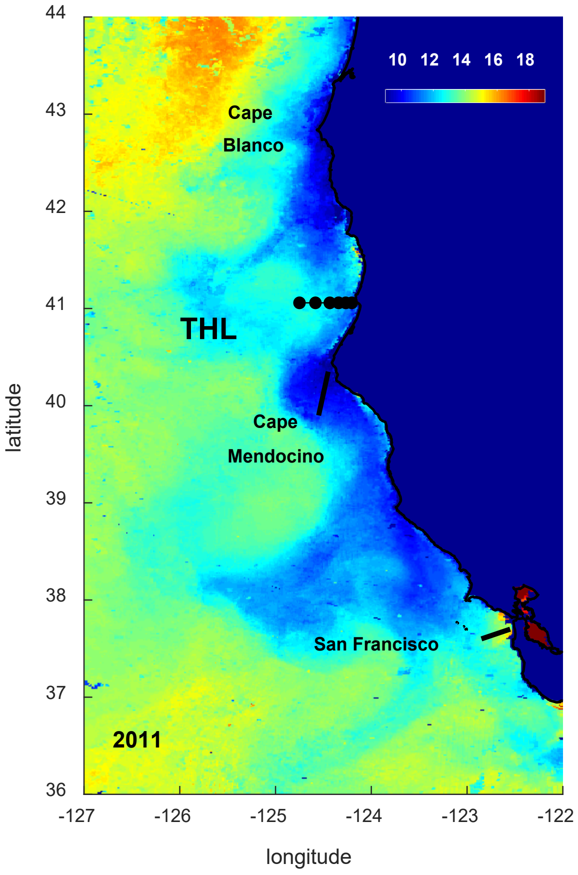
Newportal Blog



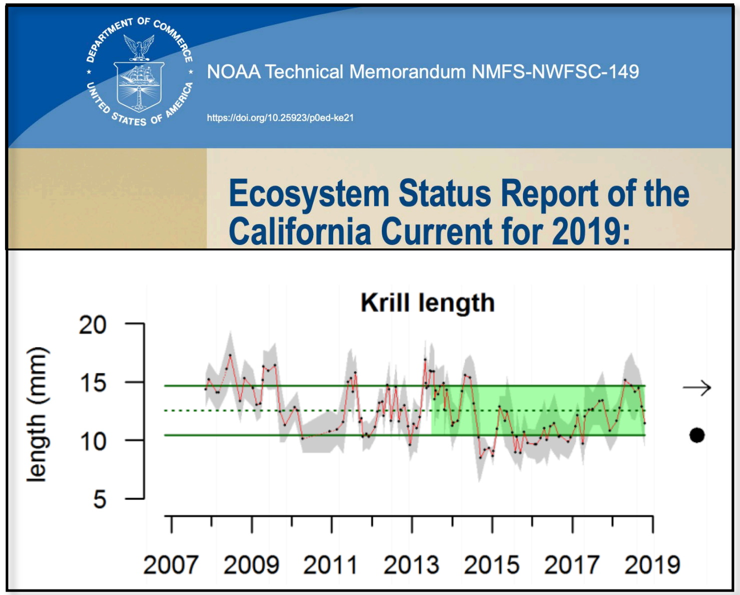
 U.S. Department of Commerce | National Oceanic and Atmospheric Administration | National Marine Fisheries Service

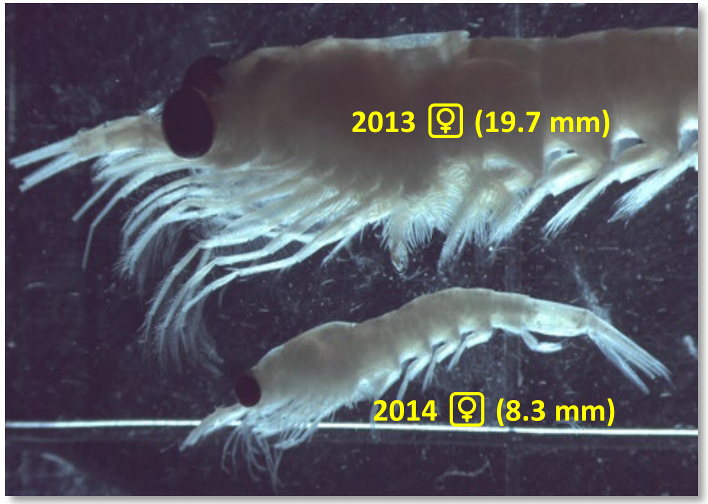
The Trinidad Head Line (THL): SWFSC and HSU

"Monthly" sampling from late 2007 to just last week.
Five stations over narrow shelf and upper slope.
Region of substantial mesoscale structure and variability.



Focus on characterizing key zooplankton in the context of environmental conditions and climate forcing.



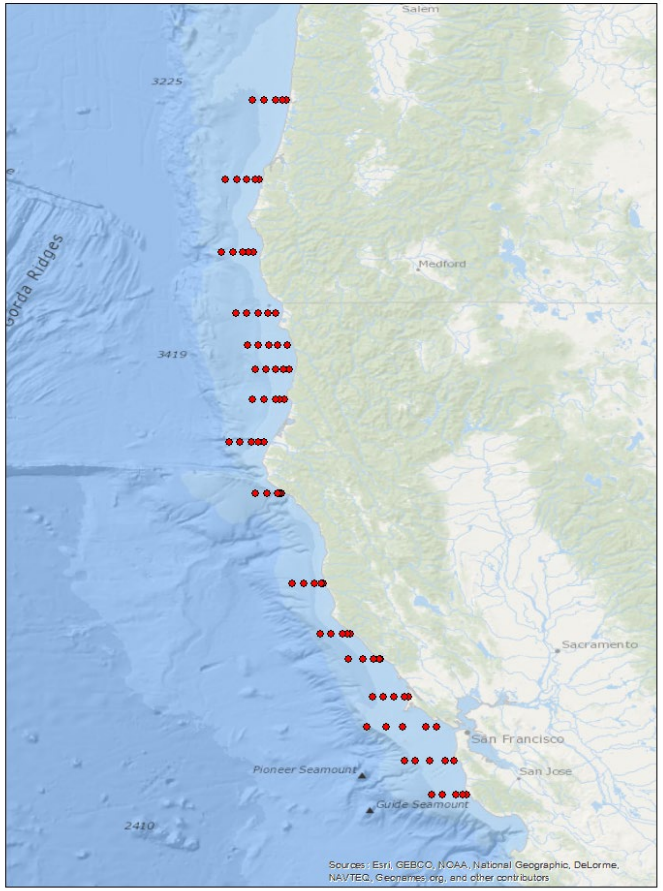


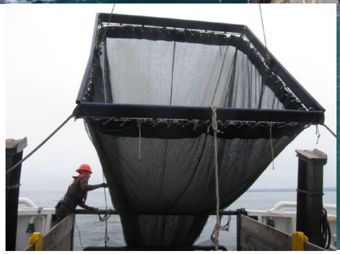
Southwest Fisheries Science Center Salmon Trawl Surveys: 1997-2016

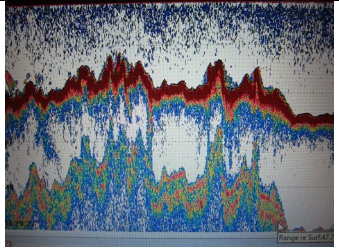
- 16 transect lines
- 80 fixed trawl stations
- Nordic Rope trawl with MME
- Sampling salmon/steelhead of multiple ages/sizes, along with many other species
- Characterizing fish physiology, diet, condition, species and stocks, taking tissue samples
- Plankton tows
- Environmental sampling (CTD casts, eDNA, acoustics)











Harding et al poster
Harding et al NMFS Tech Memo 2021

Rockfish Recruitment and Ecosystem Assessment Survey

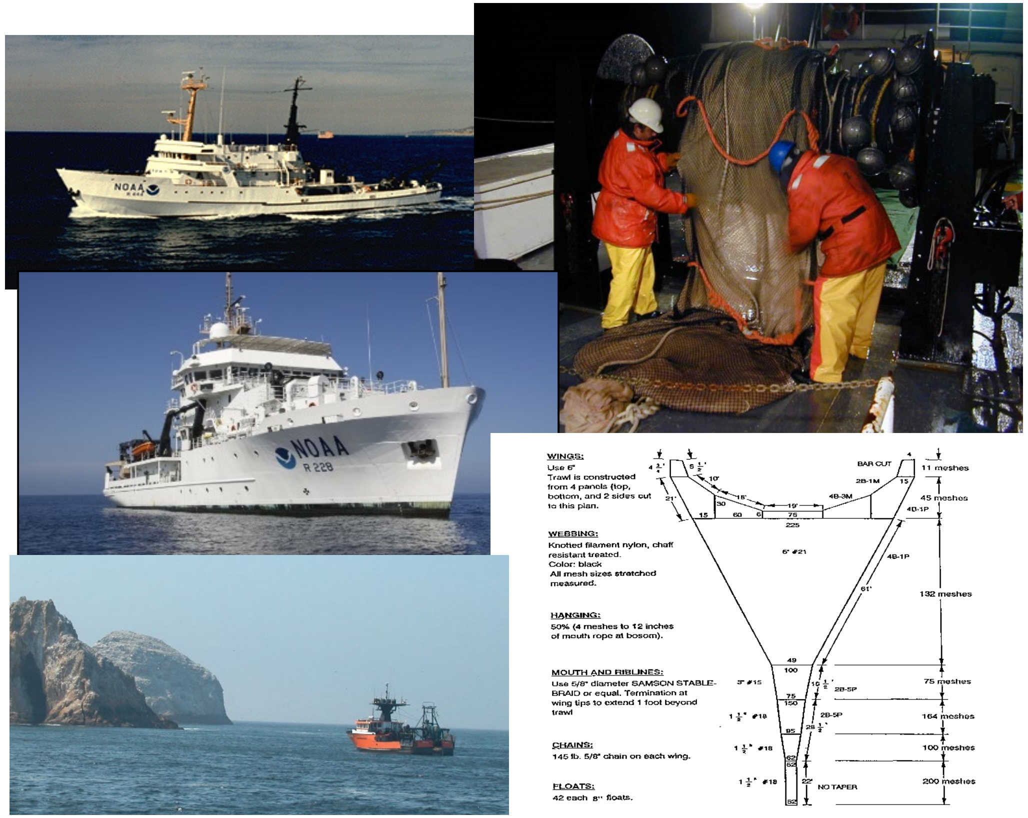
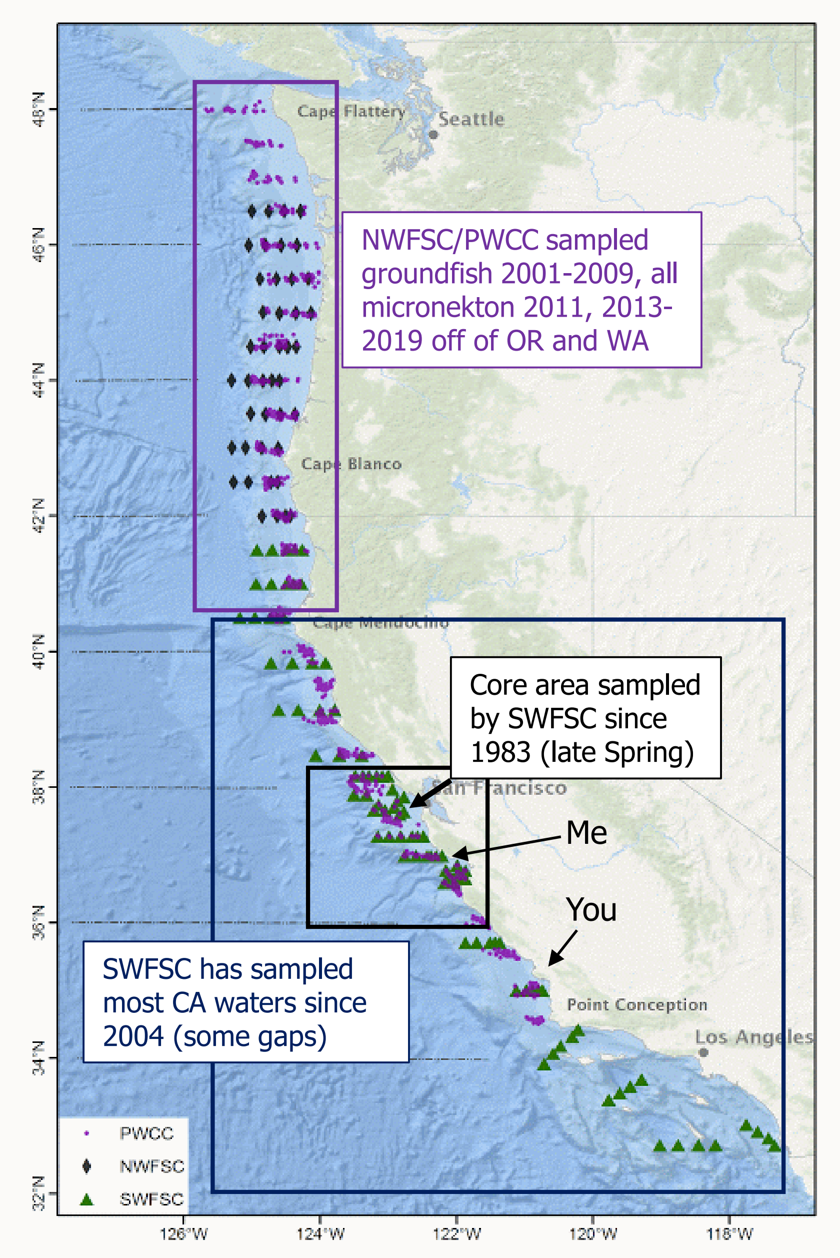


Diagram of mid-water trawl specifications.

Midwater trawling conducted at night

(John Field's presentation)



Canada: CCGS Sir John Franklin

USA: NOAA Bell M. Shimada

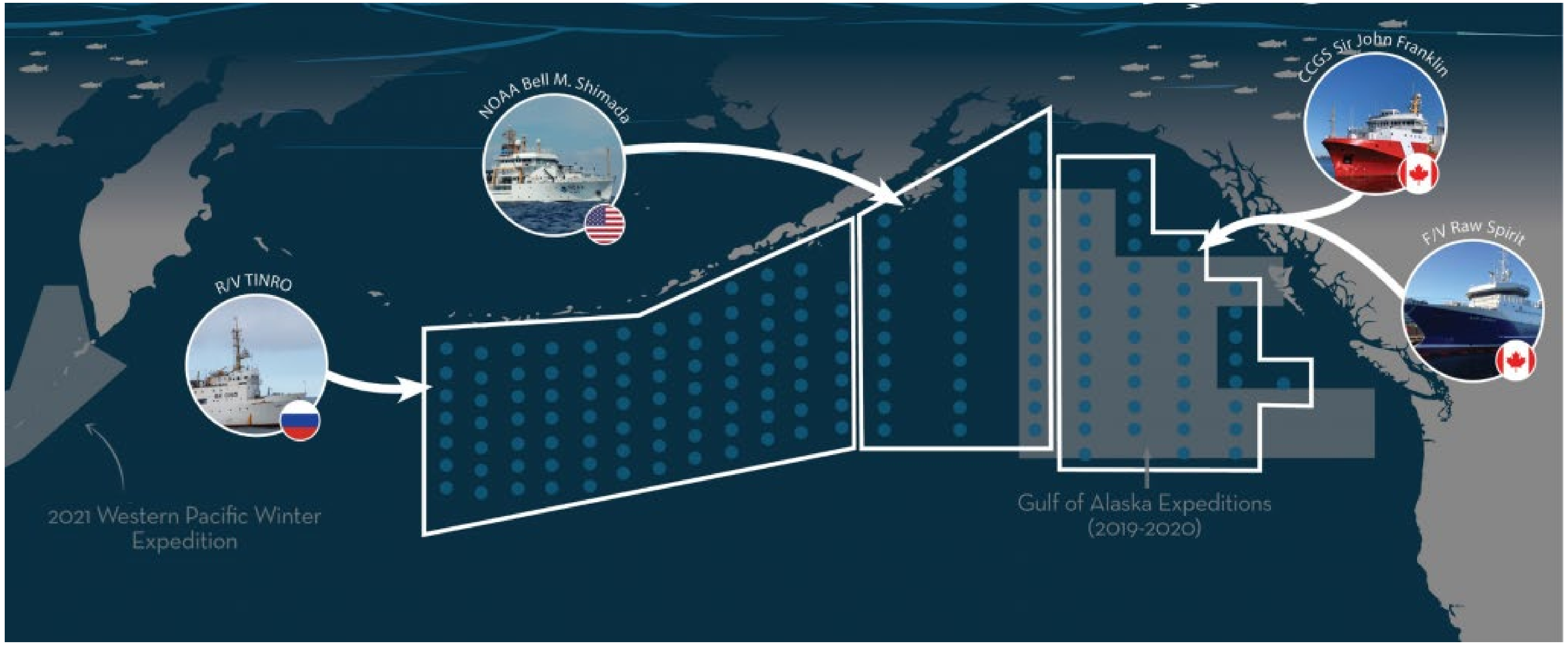
Russia: R/V TINRO

Canada: Raw Spirit

US: F/V Northwest Explorer

The 2022 International Year of the Salmon High Seas Expedition

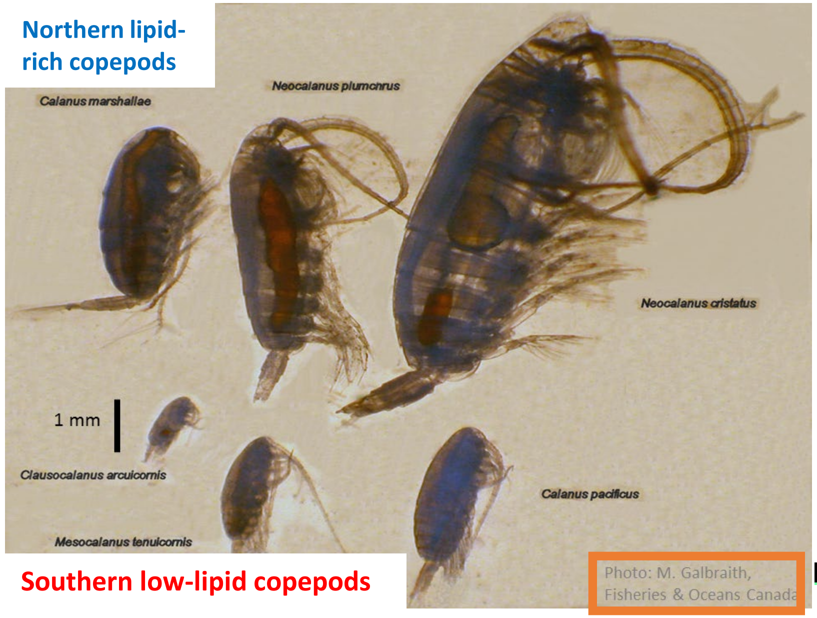
https://yearofthesalmon.org/2022expedition/



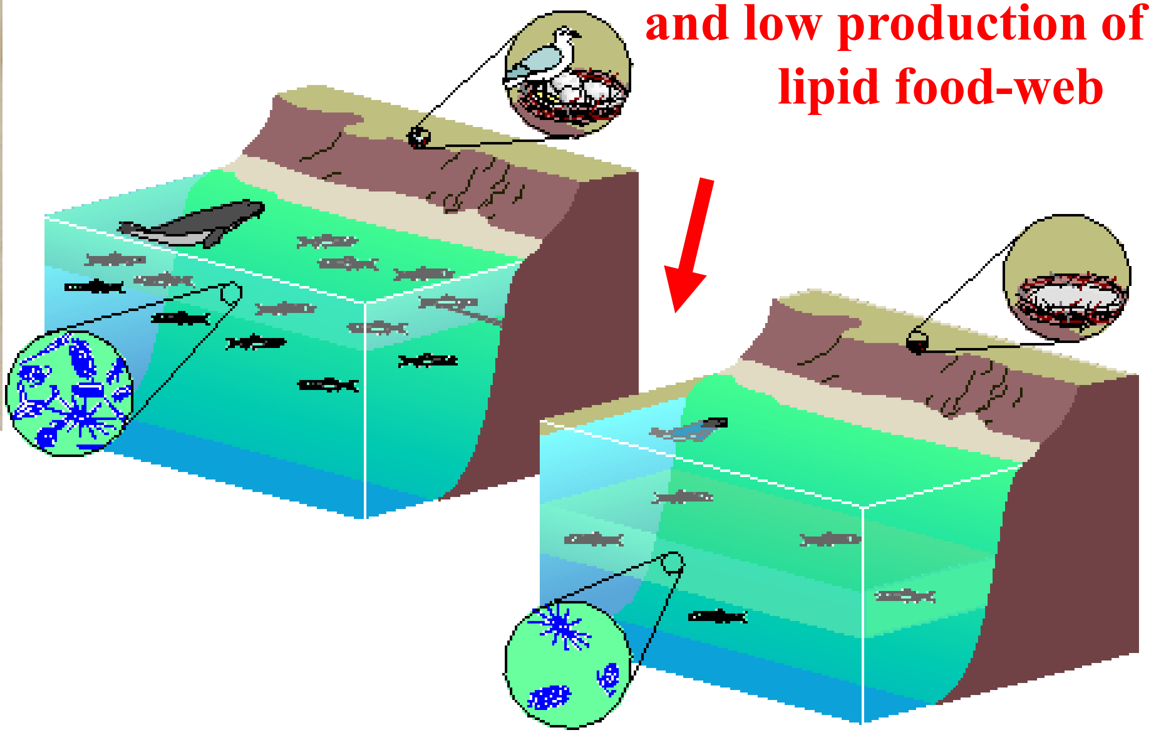
Bottom-up food-web impacts on salmon

Gyre and current strength, transport of subarctic vs. subtropical water masses, stratification and upwelling of nutrients

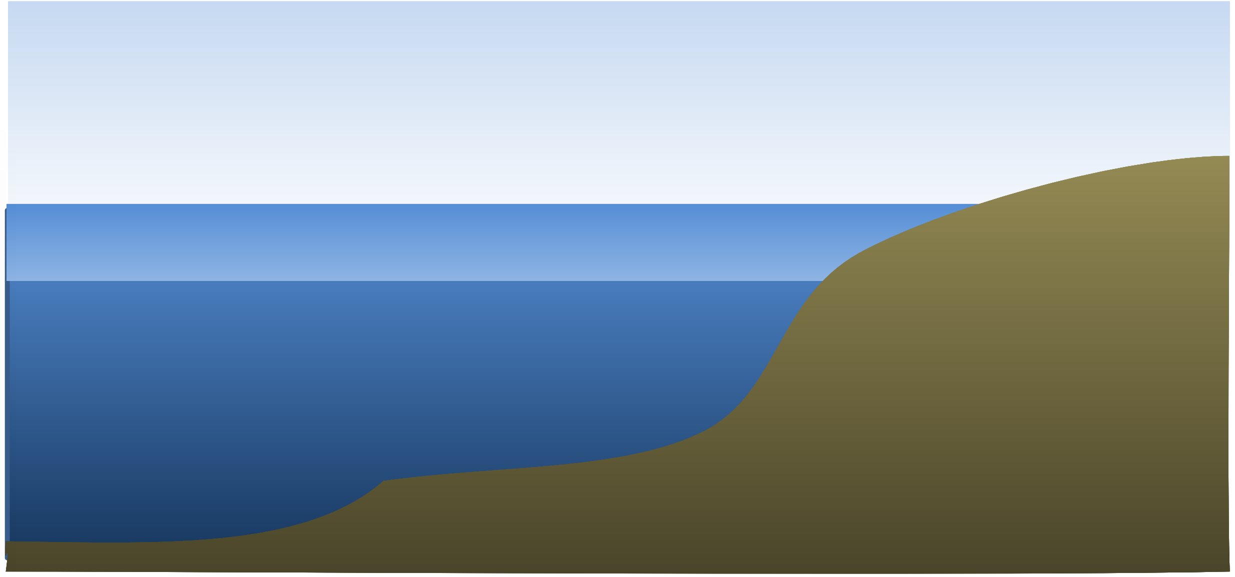
Thysanoessa spinifera



sub-tropical water, warm stratified ocean, few nutrients, weak upwelling and low production of low lipid food-web



Bottom-up driven prey-switching impacting (top-down) predation on juvenile salmon



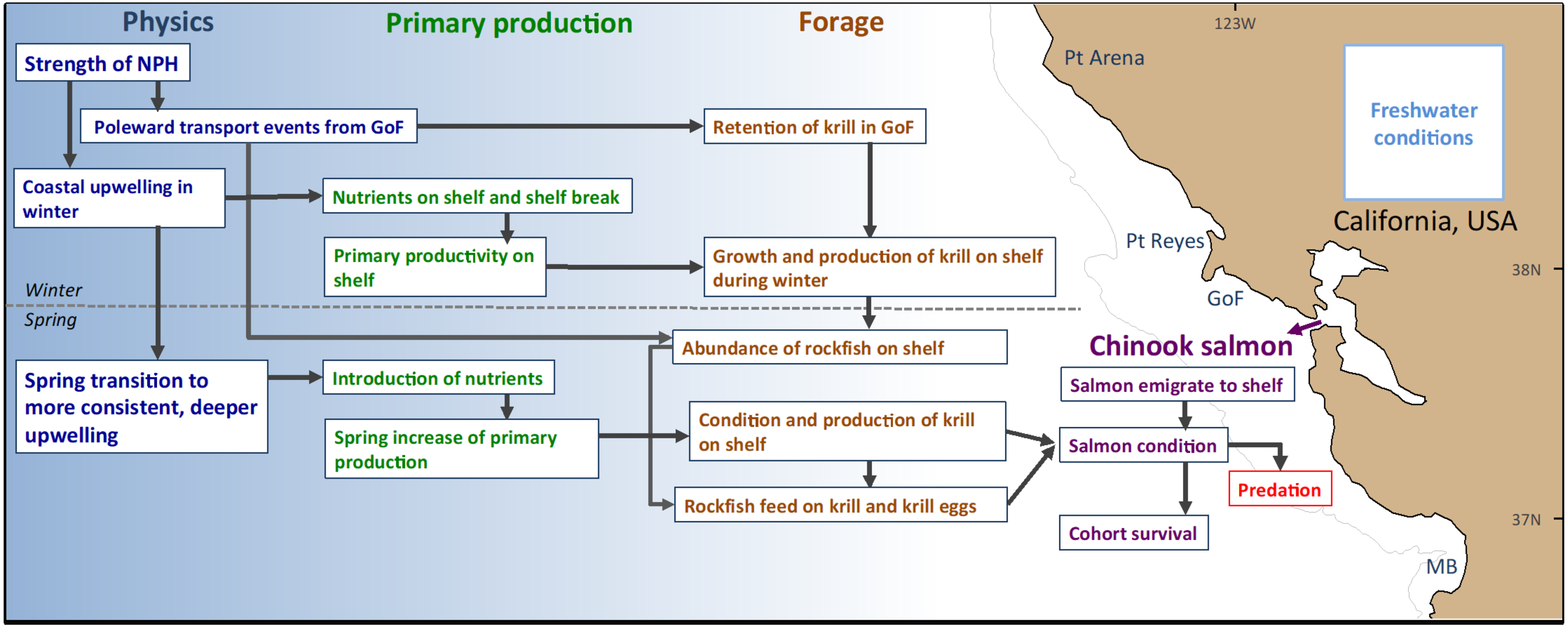
Wells, B.K, J.A. Santora, M.J. Henderson, P. Warzybok, J. Jahncke, R. W. Bradley, D. D. Huff, I.D. Schroeder, P. Nelson, J.C. Field, D.G. Ainley 2017. Environmental conditions and prey-switching by a seabird predator impacts juvenile salmon survival. *Journal of Marine Systems*

State of the California Current 2018-19

(Thompson et al. 2019, CalCOFI reports)

"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."

Our current conceptual model of salmon recruitment: homage to Cury et al 2008



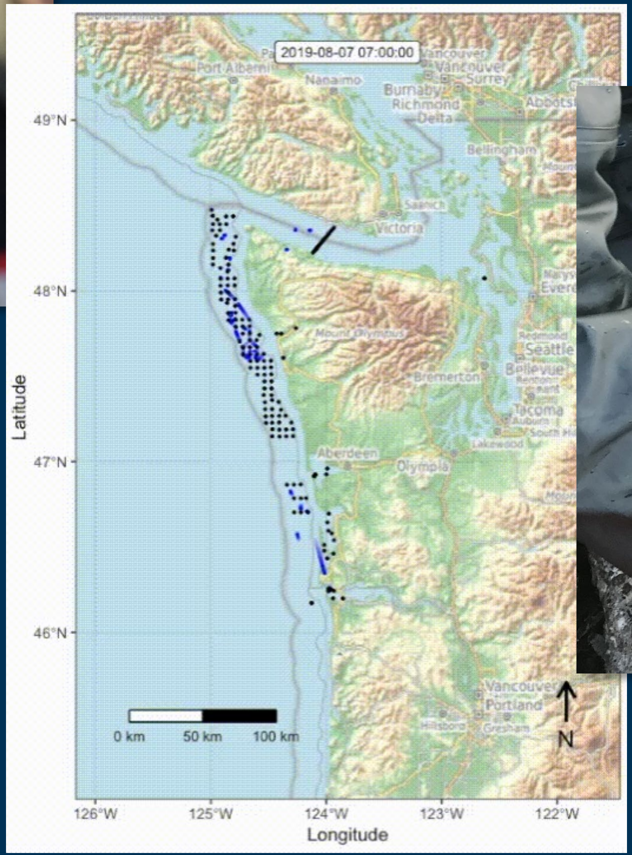
Wells, B.K., J.A Santora, I.D. Schroeder, N. Mantua, W.J. Sydeman, D.D. Huff, J.C. Field. 2016. Marine ecosystem perspectives on Chinook salmon recruitment: A synthesis of empirical and modeling studies from a California upwelling system. *Marine Ecology Progress Series*. 552:271-284

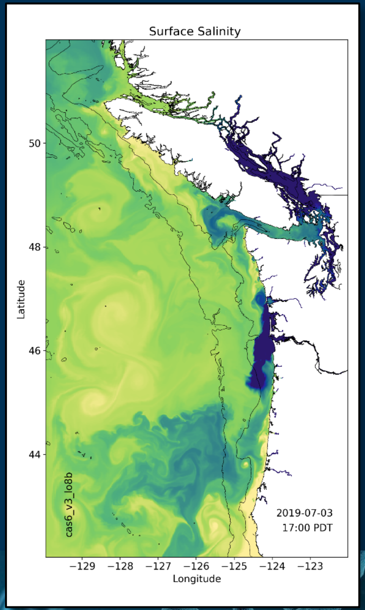
Today's Session

- The dynamic Seascape of the Northeast Pacific
- Bottom-up and top-down processes impacting salmon
- Ocean sampling/surveys/tagging and process studies that provide a foundation for ecosystem oceanography
- Modeling to synthesize data, advance our understanding, and develop decision-support tools for resource managers
- Emerging challenges with our changing ocean

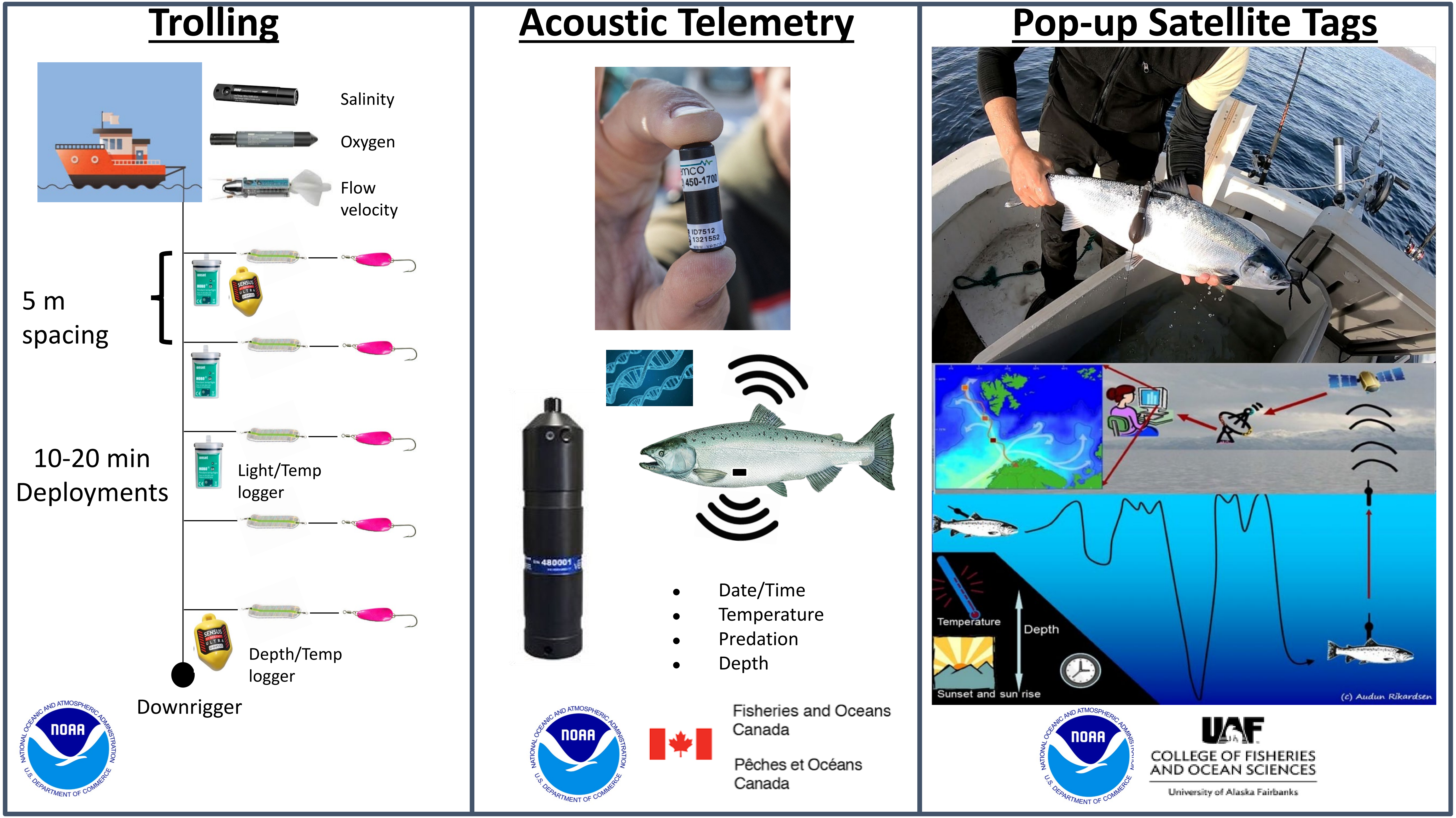

Questions?

SOBaD Advanced Technologies and Emerging Tools

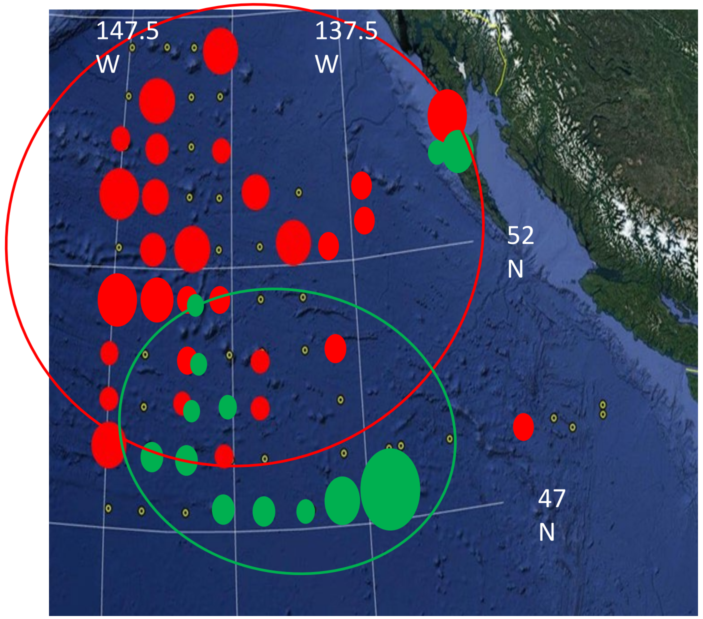




Slide from Joe Smith, NWFSC


Trolling
Salinity
Oxygen
Flow velocity
5 m spacing
10-20 min Deployments
Light/Temp logger
Depth/Temp logger
Downrigger
Acoustic Telemetry
Date/Time
Temperature
Predation
Depth
Fisheries and Oceans Canada
Pêches et Océans Canada
Pop-up Satellite Tags
Temperature
Depth
Sunset and sun rise
(c) Audun Rikardsen
COLLEGE OF FISHERIES AND OCEAN SCIENCES
University of Alaska Fairbanks

Sockeye and pink catches from the Gulf of Alaska expeditions 2019/2020

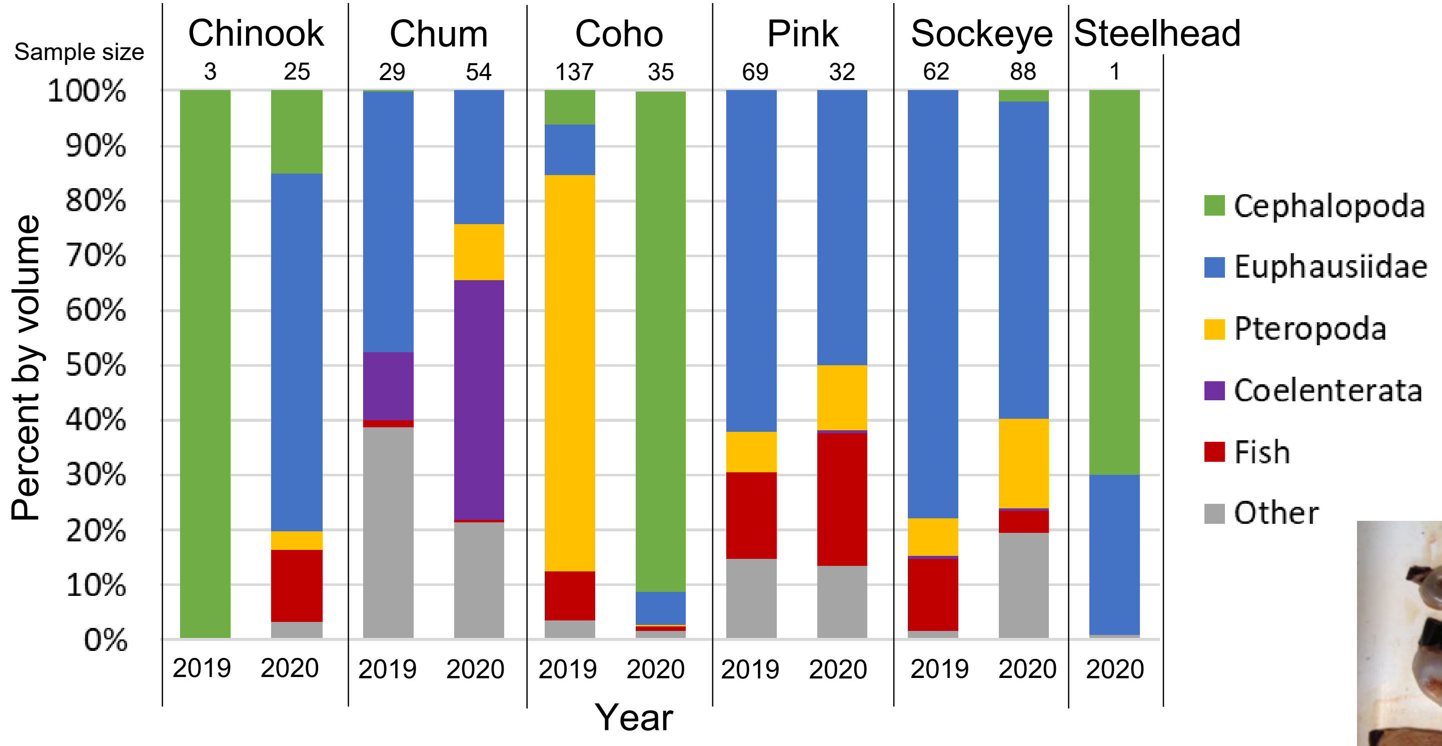


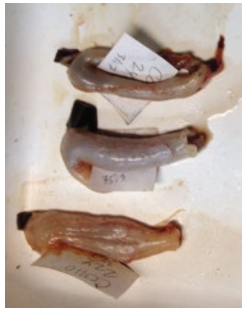
Minimal overlap of sockeye and pink salmon catch (~6%)

Diets of these species may overlap but minimal overlap in distribution during the winter.

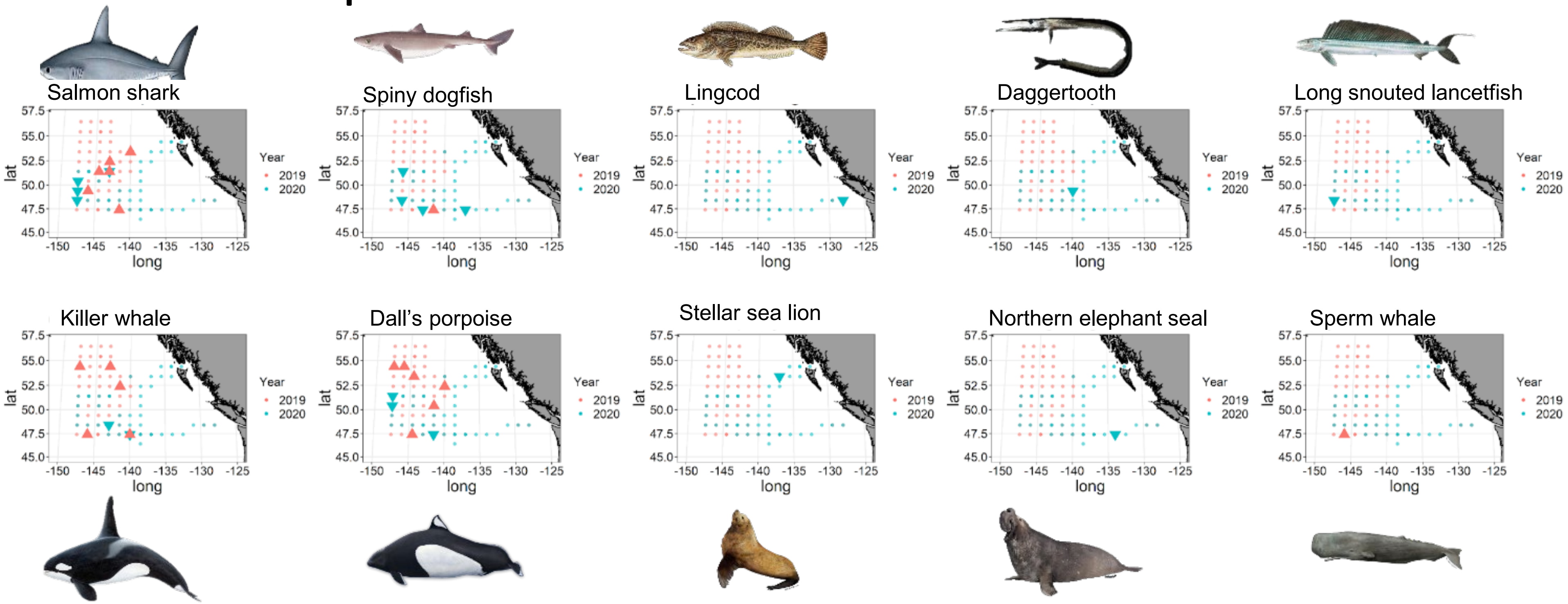

SALMON IN A RAPIDLY CHANGING WORLD
Synthesis of the International Year of the Salmon and a Roadmap to 2030
Date: October 4-6 2022
Location: The Westin Bayshore, Vancouver, Canada
INTERNATIONAL YEAR OF THE SALMON
Join us as we explore recent challenges and developments in salmon science and management from around the Northern Hemisphere and create a vision for the resilience of salmon and people
Theme Sessions
Status of Salmon | New Frontiers | Information Systems
Human Dimensions | Salmon in a Changing Salmosphere
NPAFC
www.yearofthesalmon.org/concluding_symposium
NASCO

Diets varied by species, less so by year. Euphausiids and squid (cephalopods) were important prey for most salmon

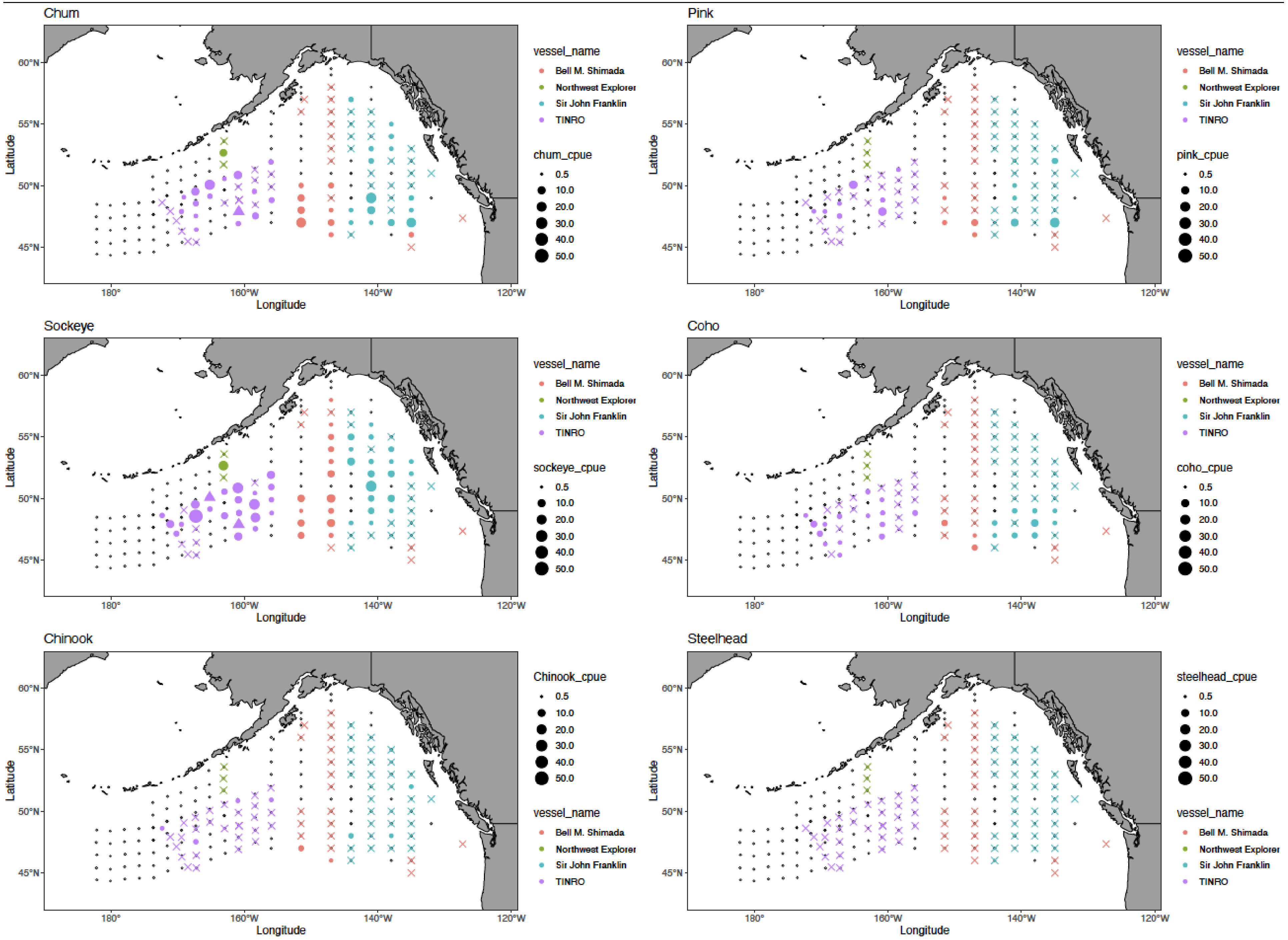


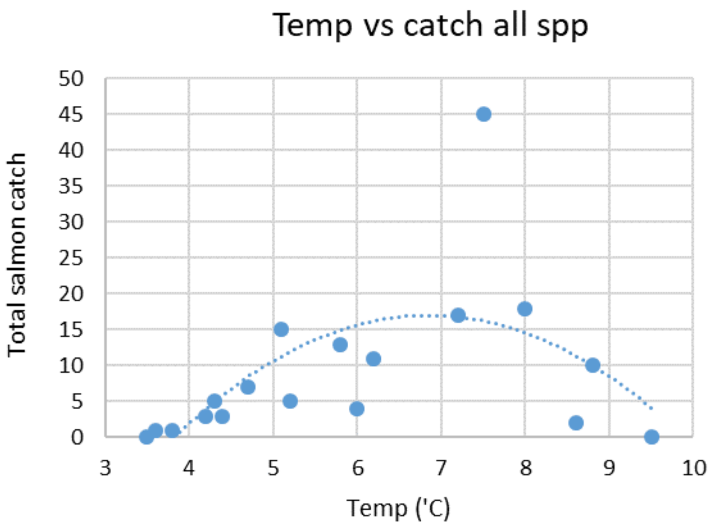


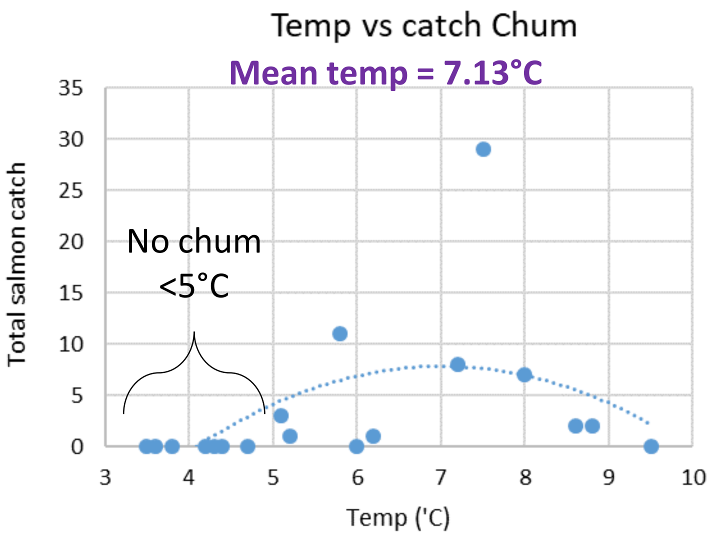
What we didn’t catch in the nets: Environmental DNA reveals potential salmon predators

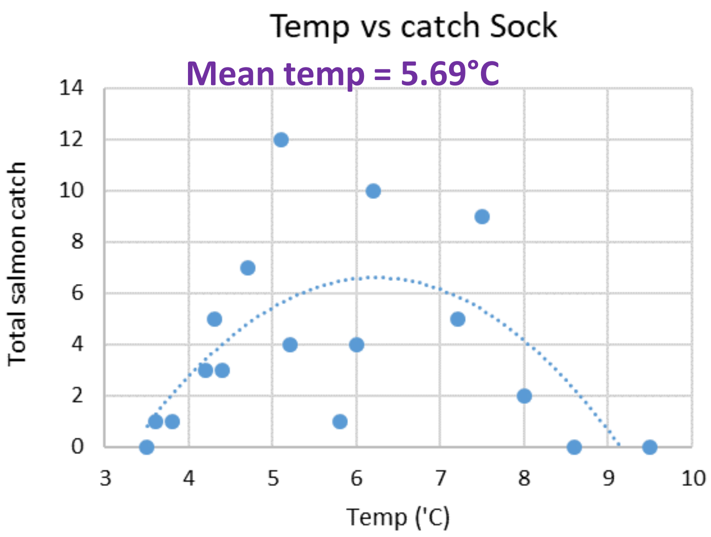


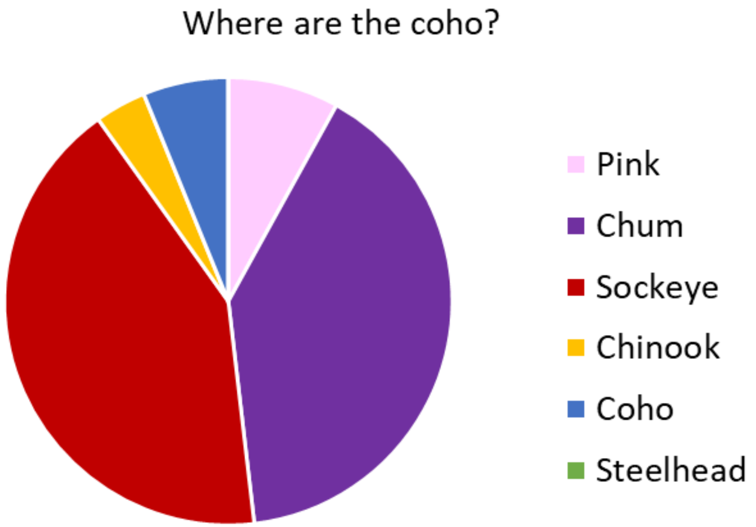
Source: Christoph Deeg (UBC/DFO)


Chum
Pink
Sockeye
Coho
Chinook
Steelhead
Latitude
Longitude
60°N
55°N
50°N
45°N
180°
160°W
140°W
120°W
vessel_name
Bell M. Shimada
Northwest Explorer
Sir John Franklin
TINRO
chum_cpue
pink_cpue
sockeye_cpue
coho_cpue
Chinook_cpue
steelhead_cpue
0.5
10.0
20.0
30.0
40.0
50.0


Temp vs catch all spp
Total salmon catch
Temp ('C)


Temp vs catch Chum
Mean temp = 7.13°C
No chum
<5°C
Total salmon catch
Temp ('C)


Temp vs catch Sock
Mean temp = 5.69°C
Total salmon catch
Temp ('C)


Where are the coho?
Pink
Chum
Sockeye
Chinook
Coho
Steelhead

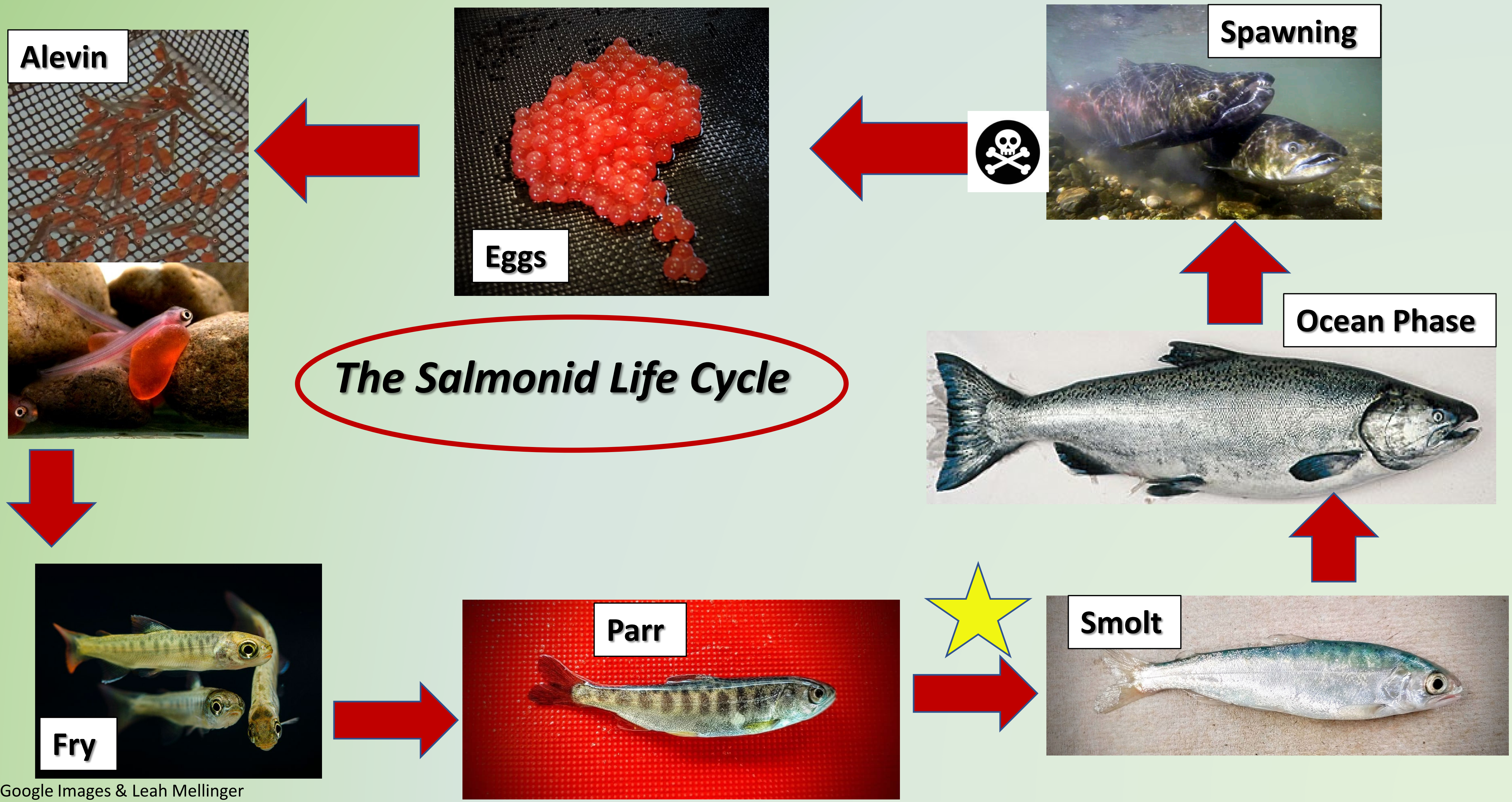
Salinity tolerance and smoltification differences between Winter, Fall and Spring-run Chinook salmon brood stocks

Leah Mellinger, Dennis Cocherell, Dr. Richard Connon, Dr. Nann Fangue, Dr. Brian Sardella

Google images

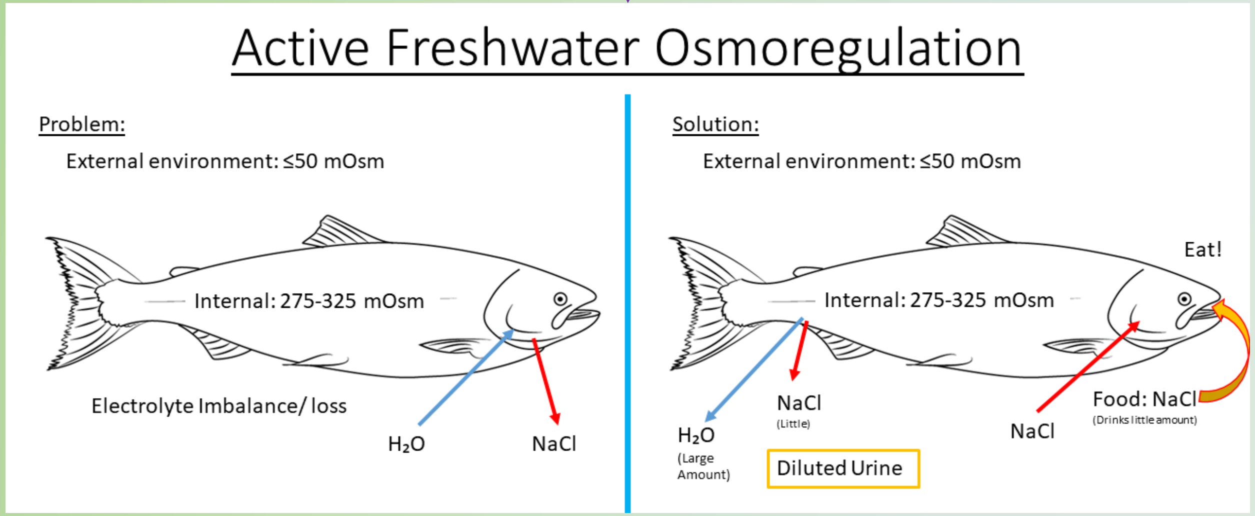
<u>Partners:</u> UC Davis Fangue Lab, UC Davis Connon Lab, CSU Stanislaus Sardella Lab, Yurok Tribe, CDFW, Trinity Hatchery, Iron Gate Hatchery, Livingston Hatchery, NSF Sustainable Oceans NRT, NOAA CA Sea Grant, Diablo Fly Fishers Club, Davis Fly Fishers Club

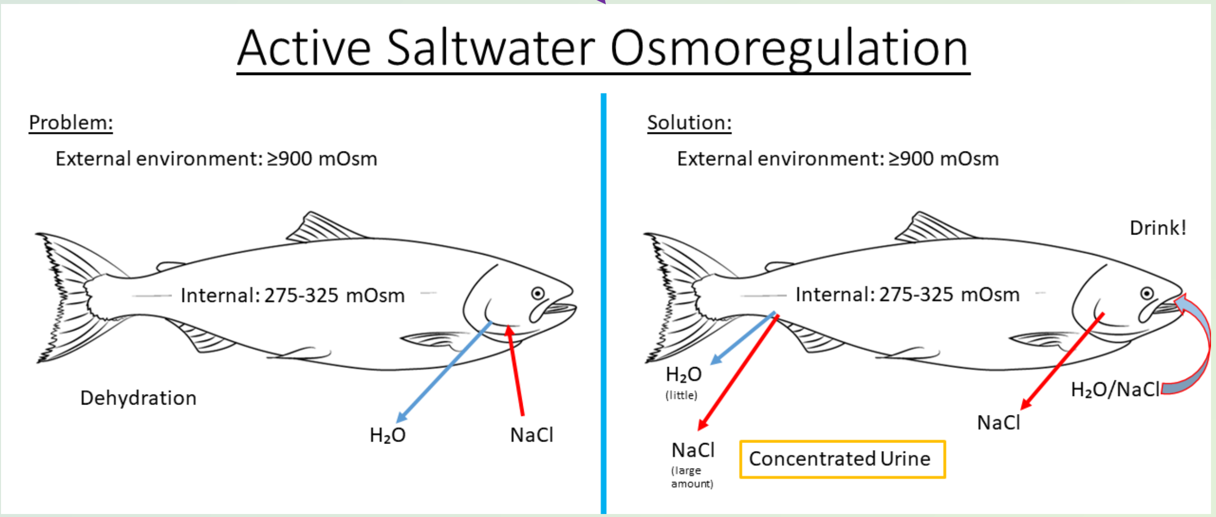
Chinook Salmon (*Oncorhynchus tshawytscha*)



Pictures: Google Images & Leah Mellinger

Critical Management: Understanding Smoltification



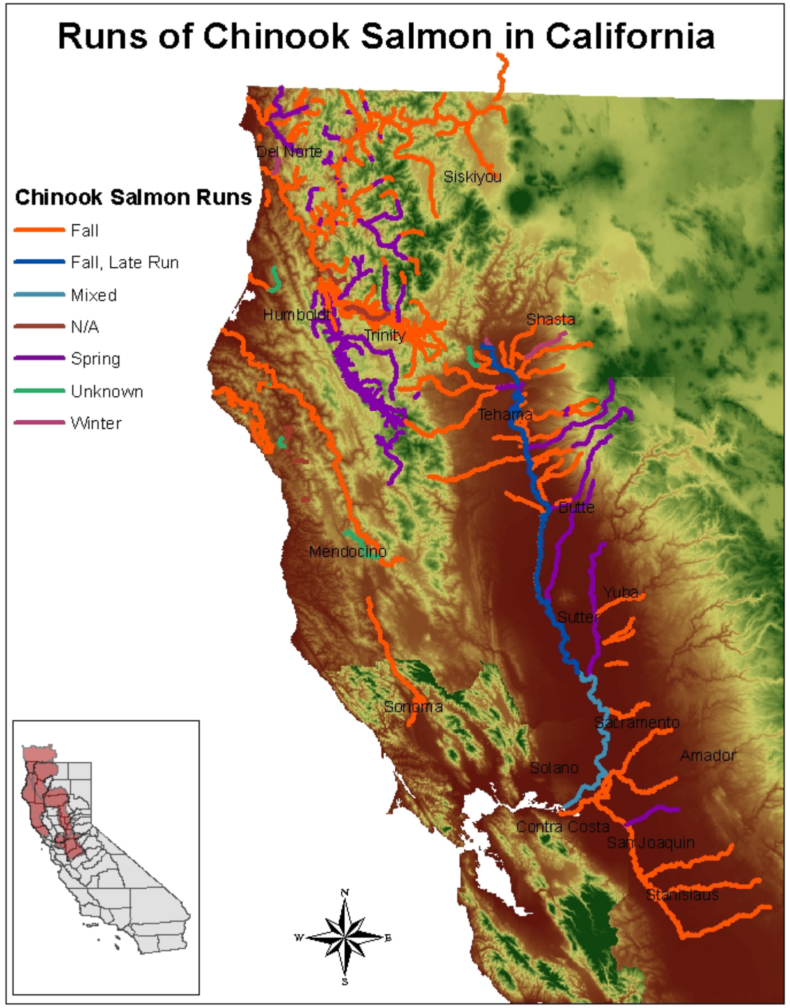


Californian Distinctive Chinook Salmon Runs

- Chinook adapted to the differing historic flow regimes and temperatures
  - **Fall run**
  - **Late Fall run**
  - **Winter run**
  - **Spring run**

- Run timing associated with divergence at three circadian clock genes
- Single genomic region is strongly associated with spring vs. fall runtime
  - Heterozygous (fall/spring), Homozygous fall and Homozygous spring

(Thraya et al. 2019; Prince et al. 2017; Miller et al. 2016)

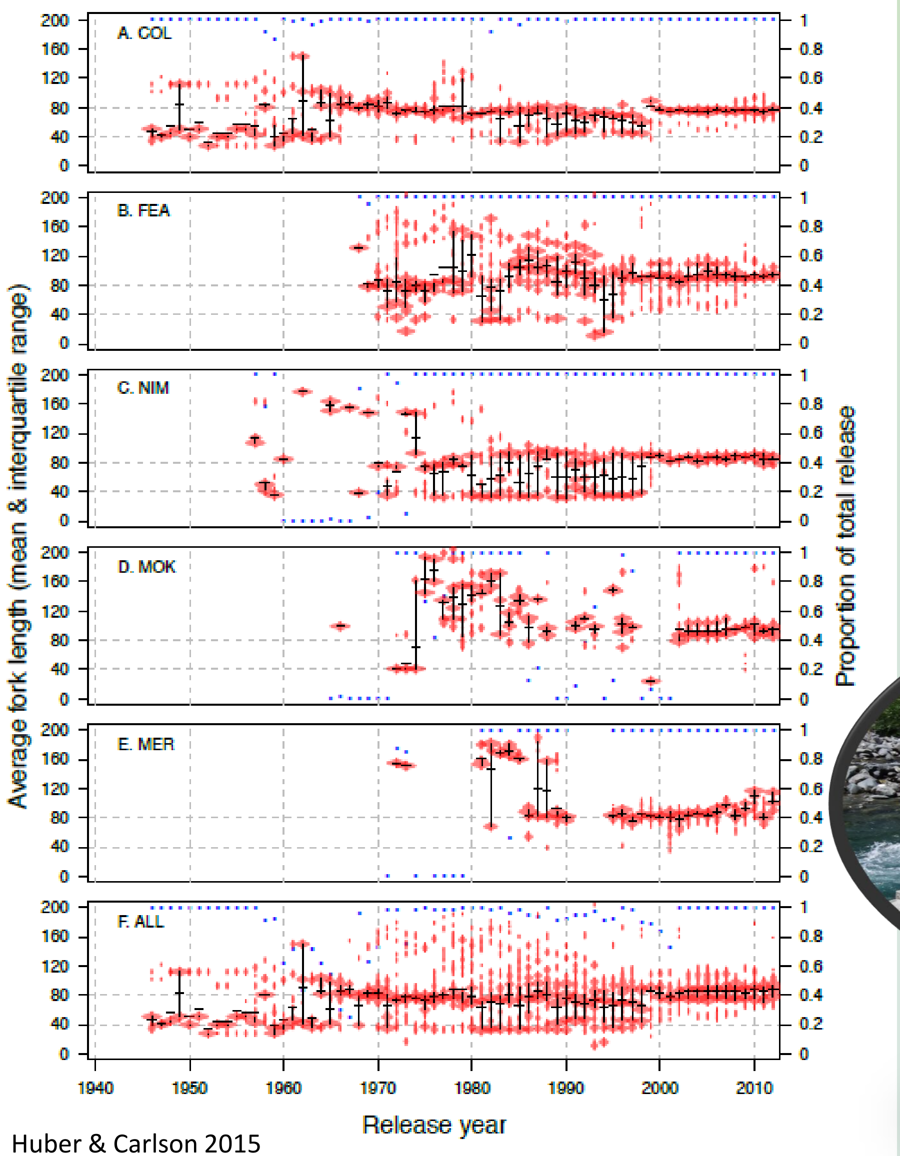


Author

Marcia Scavone-Tansey
American River College, Geography 350: Data Acquisition in GIS; Spring 2007
Contact Information: California Department of Fish and Game, (916) 327-3935

Life History: Fall-run vs. Spring-run

Juvenile Chinook Salmon Release Data



Huber & Carlson 2015

Sutter Bypass Screw Trap Data

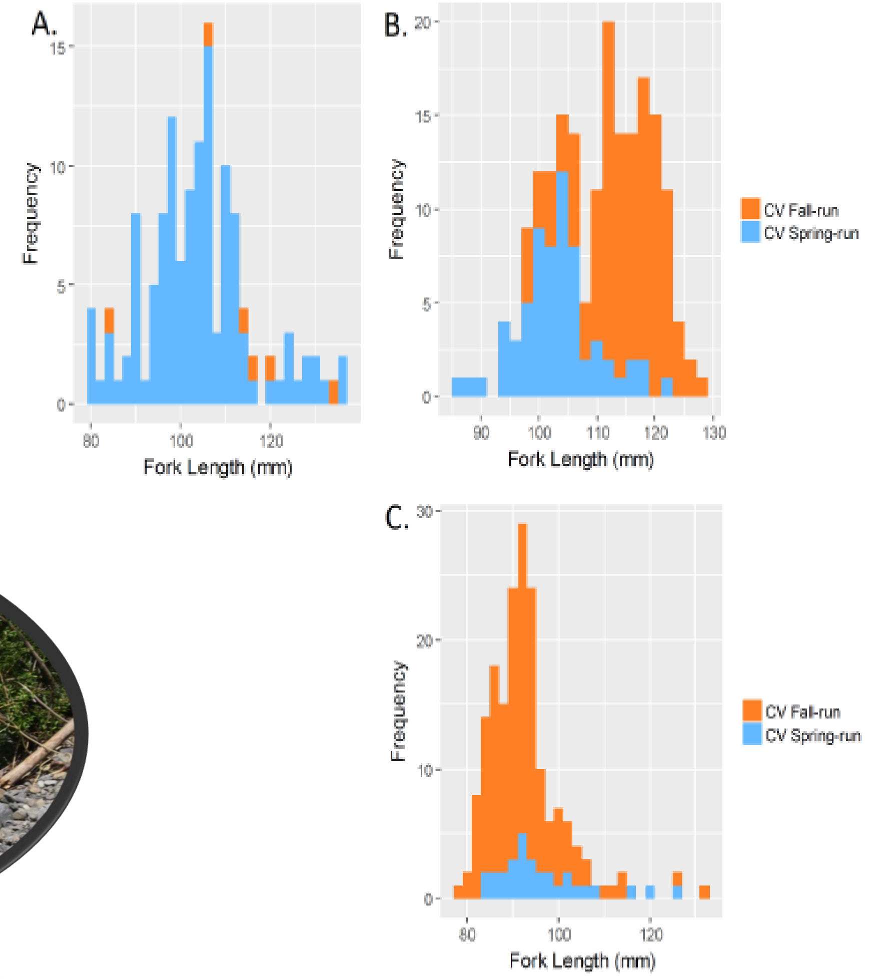


Figure 10.A. 2015, B. 2016 and C. 2017 length frequency histogram of Sutter Bypass tagged fish with genetic distinction. CV = Central Valley.

Cordoleani et al. 2017

Salinity & Smoltification Challenge

- **Questions:**
  - Do these small differences in genetics translate to measurable differences in smoltification between winter run, spring run and fall run Chinook salmon?
  - Does size/age influence saltwater tolerance and smoltification?
  - If so, does it affect Chinook salmon runs differently (i.e. Livingston Winter, Trinity Spring, Iron Gate Fall run)?

- **Hypotheses:**
  1. Fall run Chinook salmon will be able to handle higher salinities at smaller fork lengths than spring run Chinook salmon
  2. Spring run Chinook salmon physiologically cannot smolt as early as fall run
  3. Winter run will have the most adverse reactions to increased salinity at smaller FL's

Size/Age Classes and Salinities

Size/Age Classes: Winter, Spring & Fall run

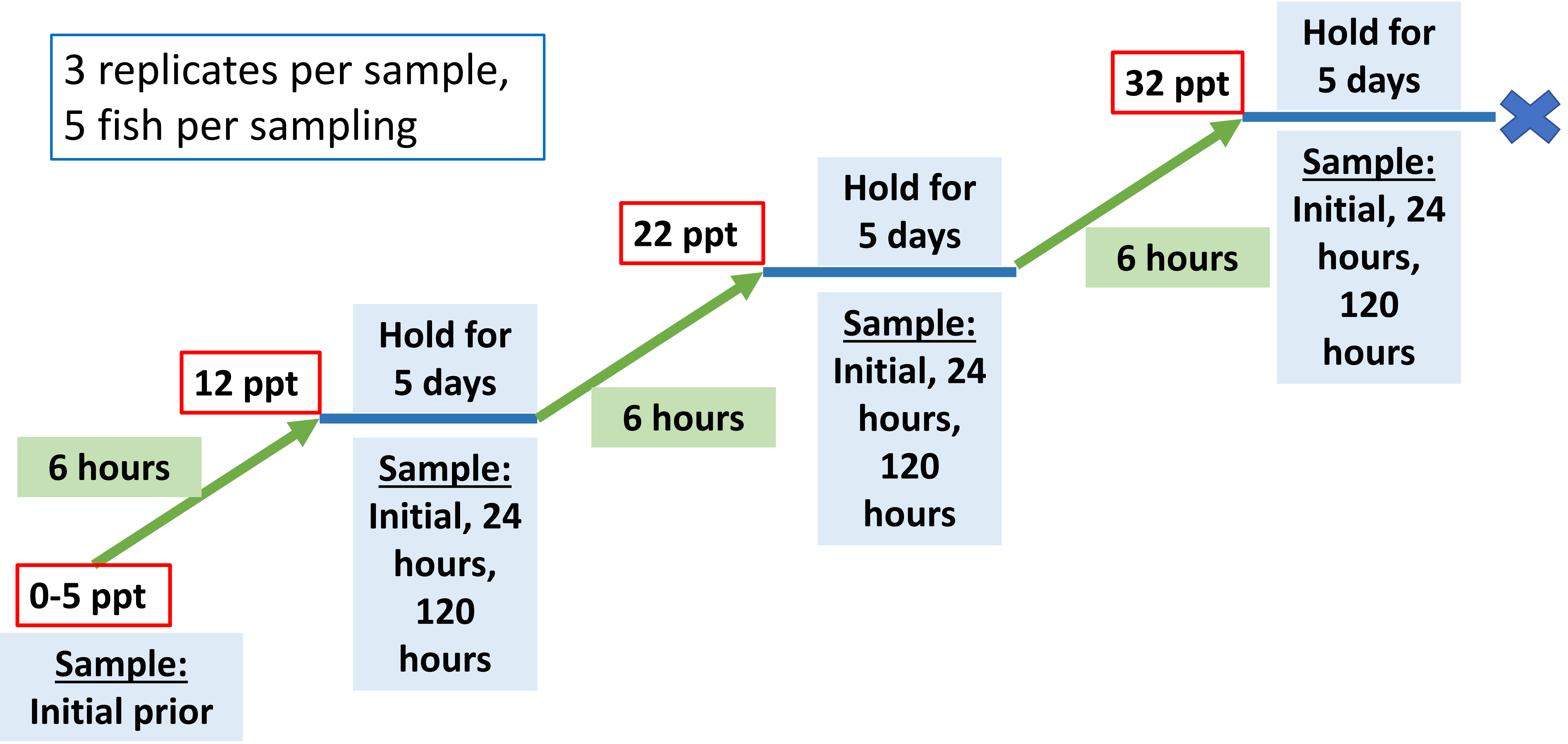
- Three replicates per size class (per brood stock)
  - 65 mm FL
  - 95 mm FL
  - 125 mm FL
- 5 fish will be sampled per replicate (individual variation)

Salinities During Stepwise Increase

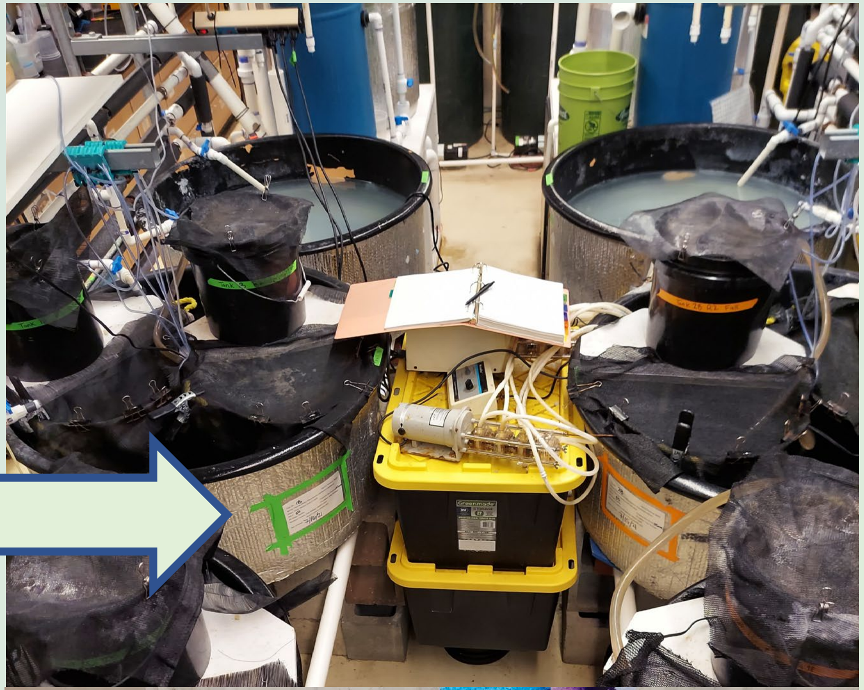
Once 150 fish reach the size class, salinity challenge will be applied

- Salinities will be increased over 6 hours and then held for a period of 120 hours
  - 0- 12 ppt
  - 12- 22 ppt
  - 22- 32 ppt

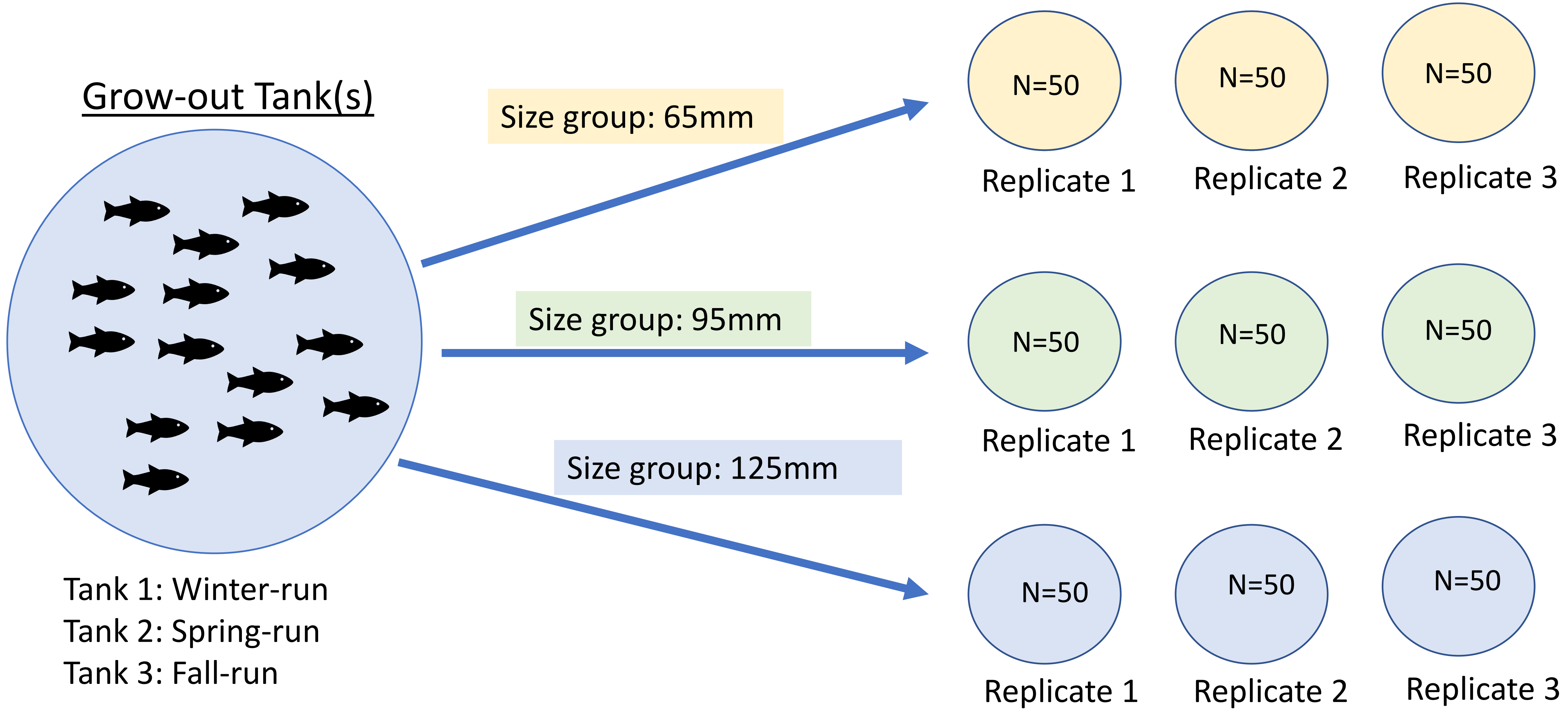
Stepwise Salinity Challenge



Salinity & Smoltification Challenge



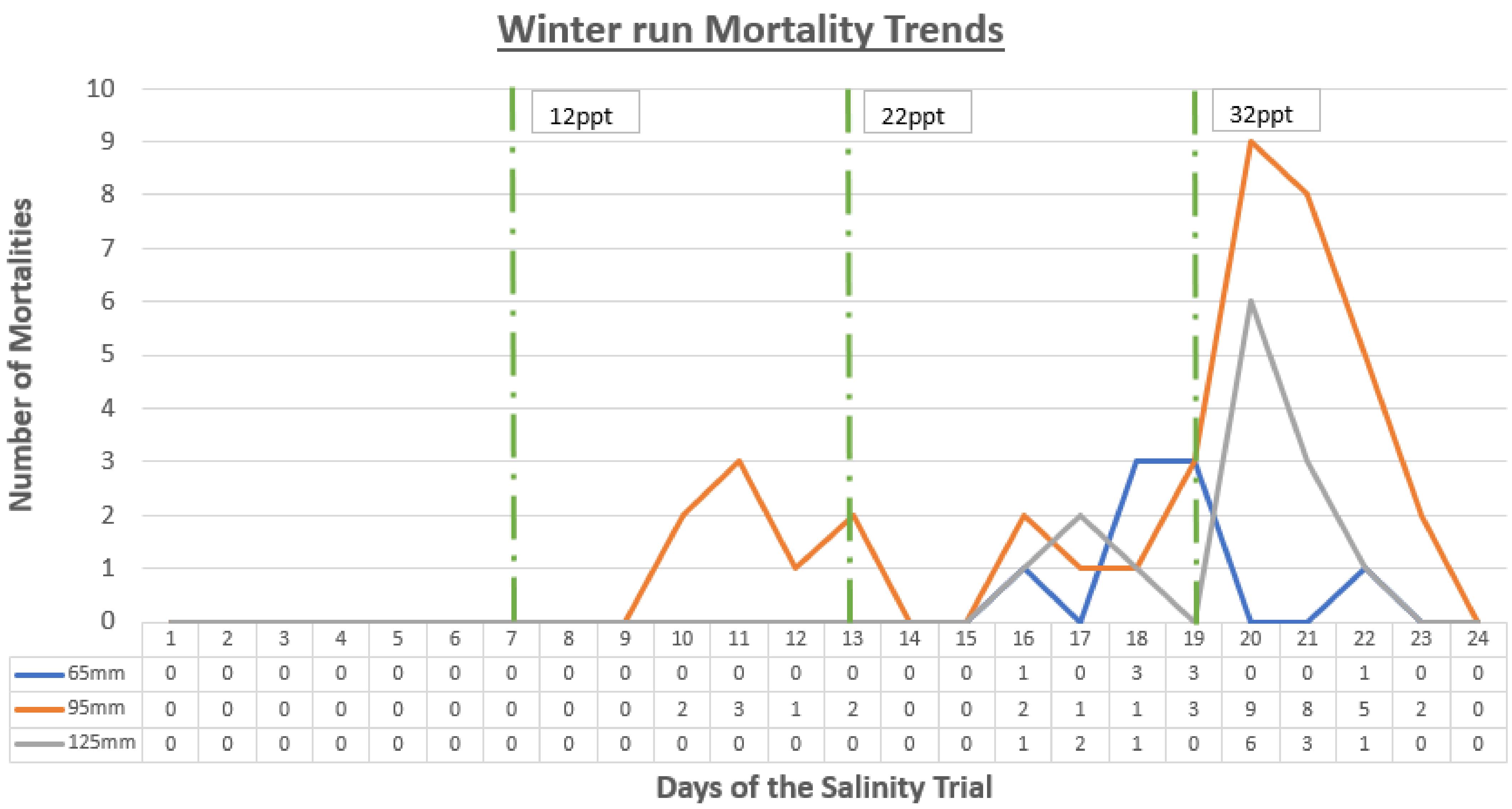
Tank Use Layout: Winter-run, Spring-run, Fall-run



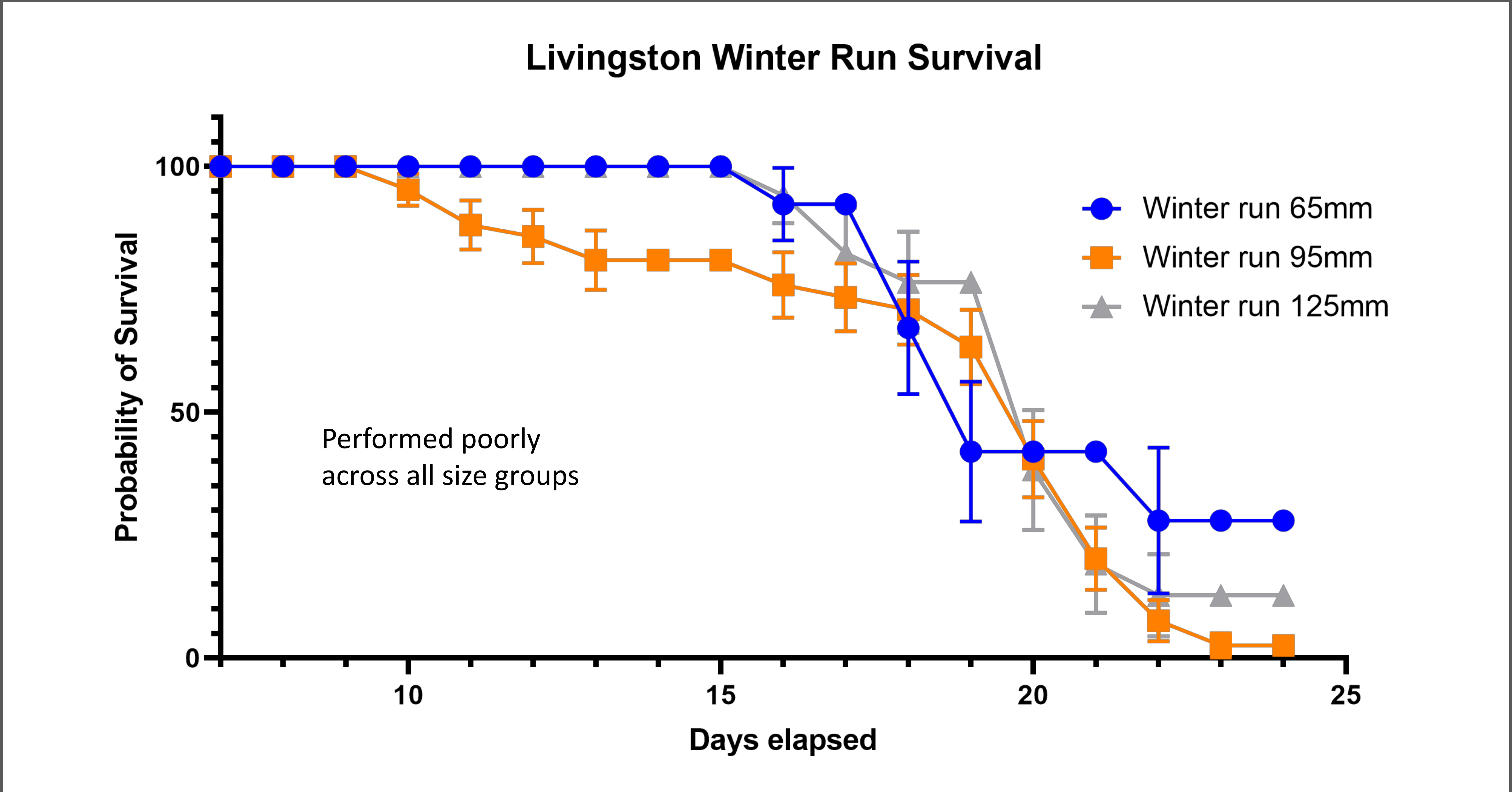
Salinity trial is 3 weeks long per size group

Fish per replicate tank: 50 fish

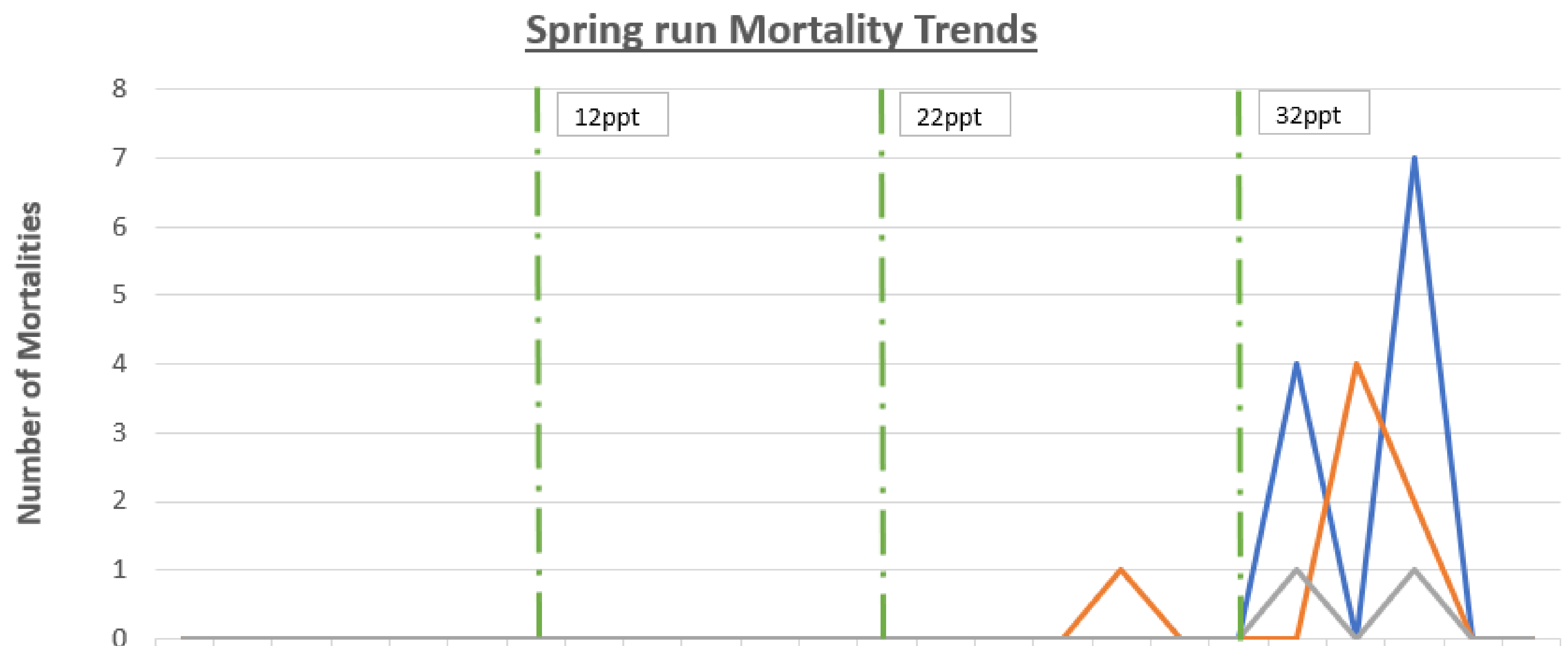
Preliminary Results



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
65mm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	3	3	0	0	1	0	0
95mm	0	0	0	0	0	0	0	0	0	2	3	1	2	0	0	2	1	1	3	9	8	5	2	0
125mm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	1	0	6	3	1	0	0



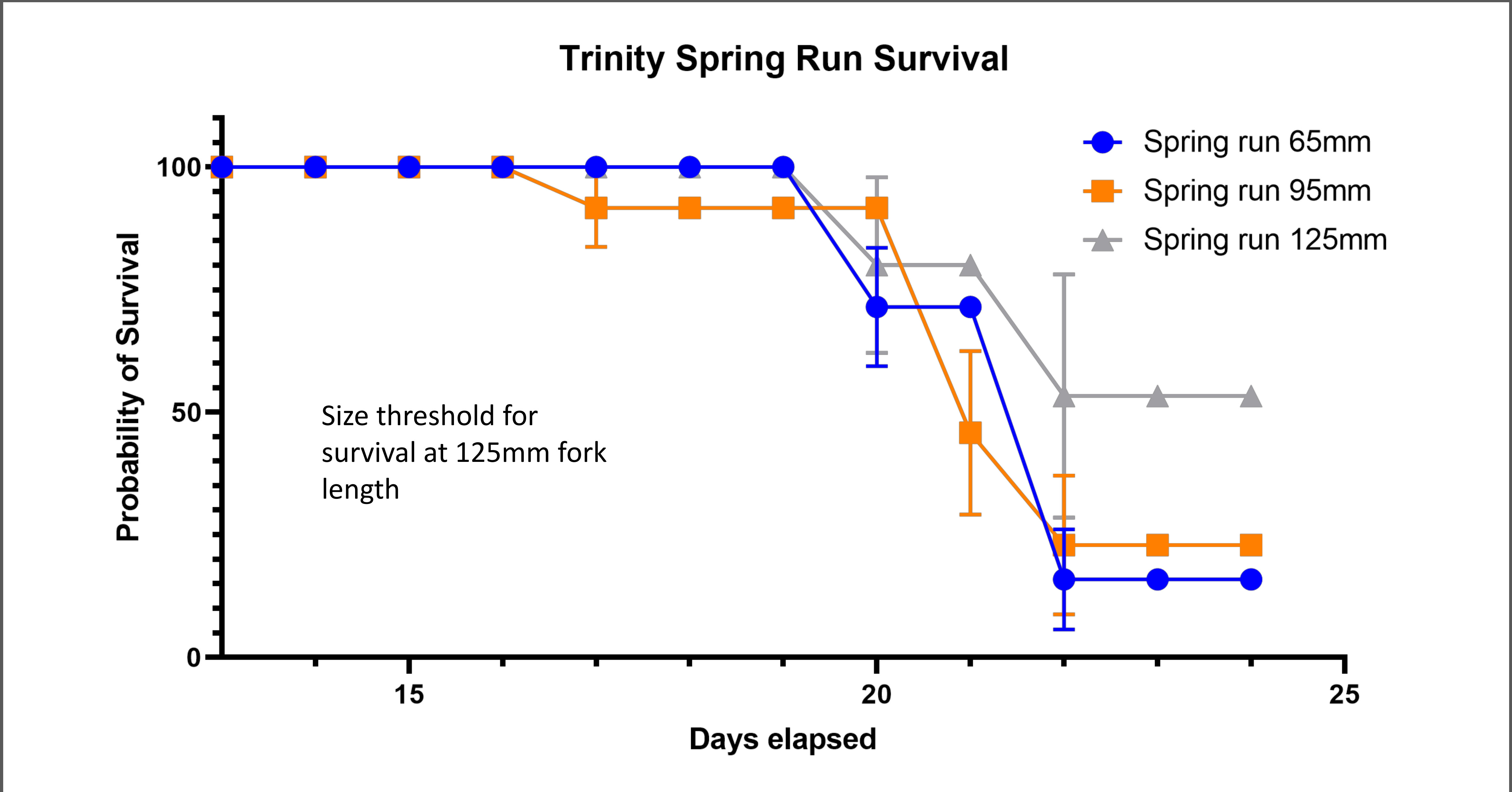
Livingston Winter Run Survival
Probability of Survival
100
50
0
10
15
20
25
Days elapsed
Winter run 65mm
Winter run 95mm
Winter run 125mm
Performed poorly
across all size groups

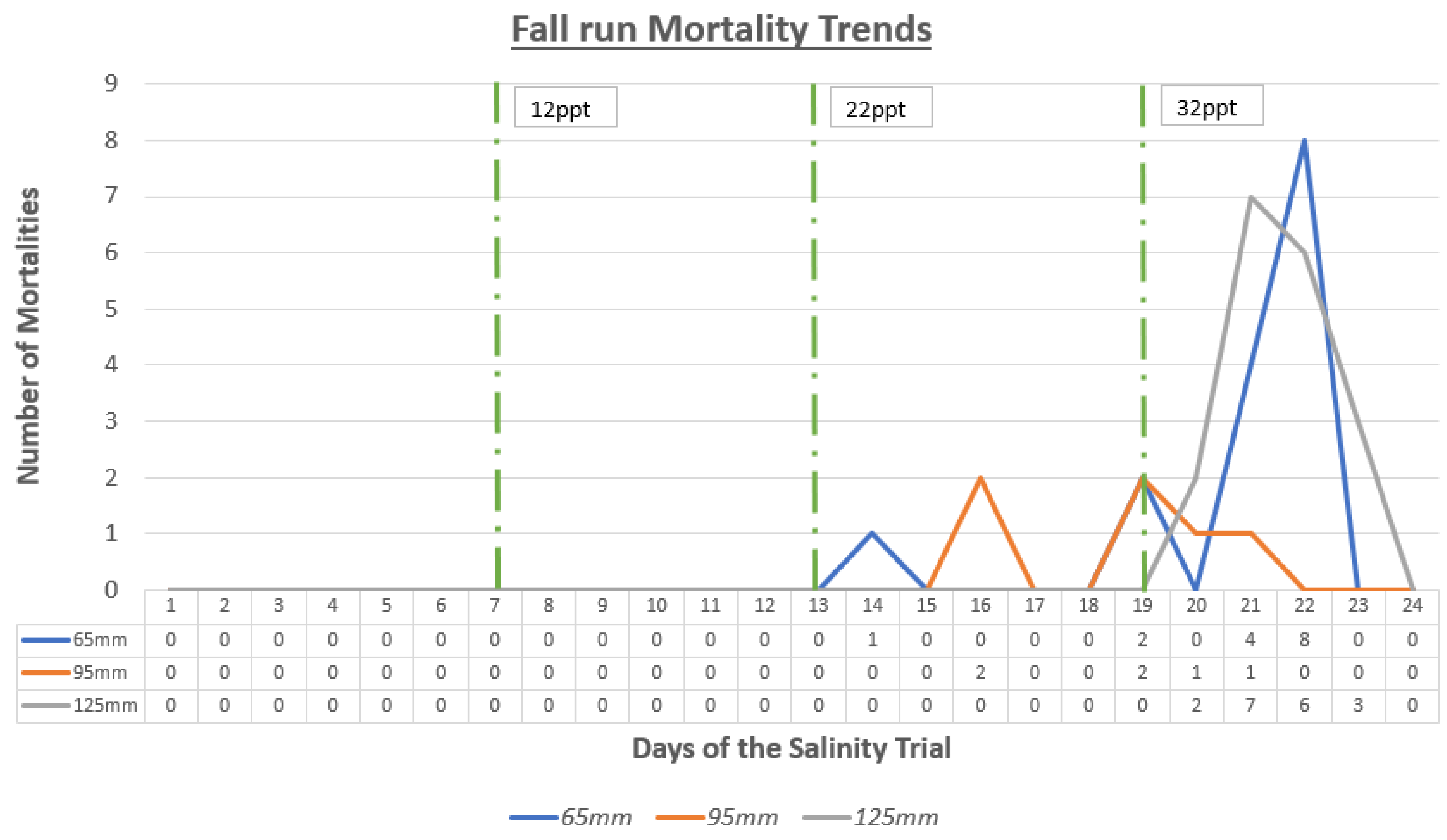


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
65mm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	7	0	0
95mm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	4	2	0	0
125mm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0

Days of the Salinity Trial

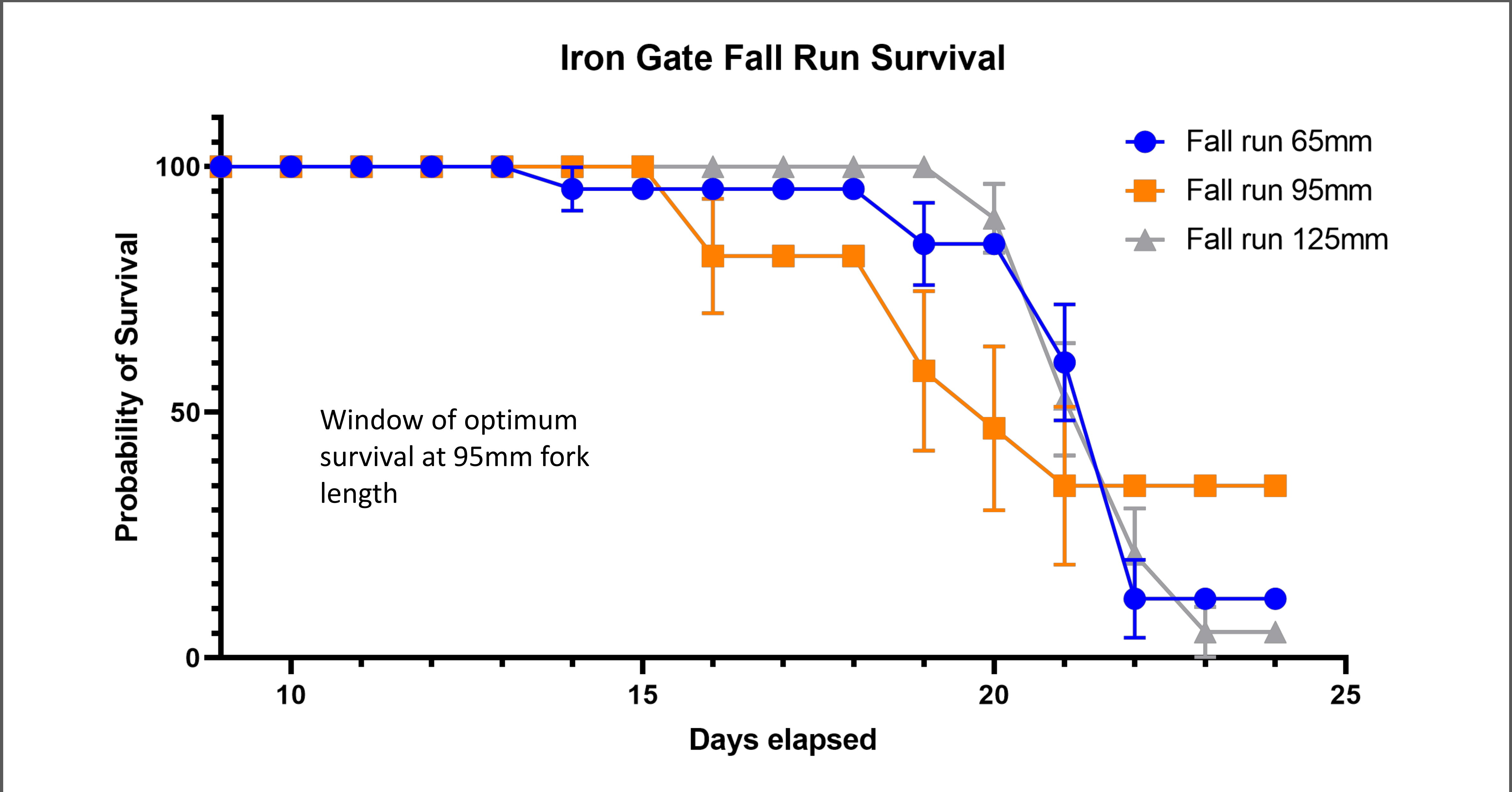
65mm *95mm* *125mm*

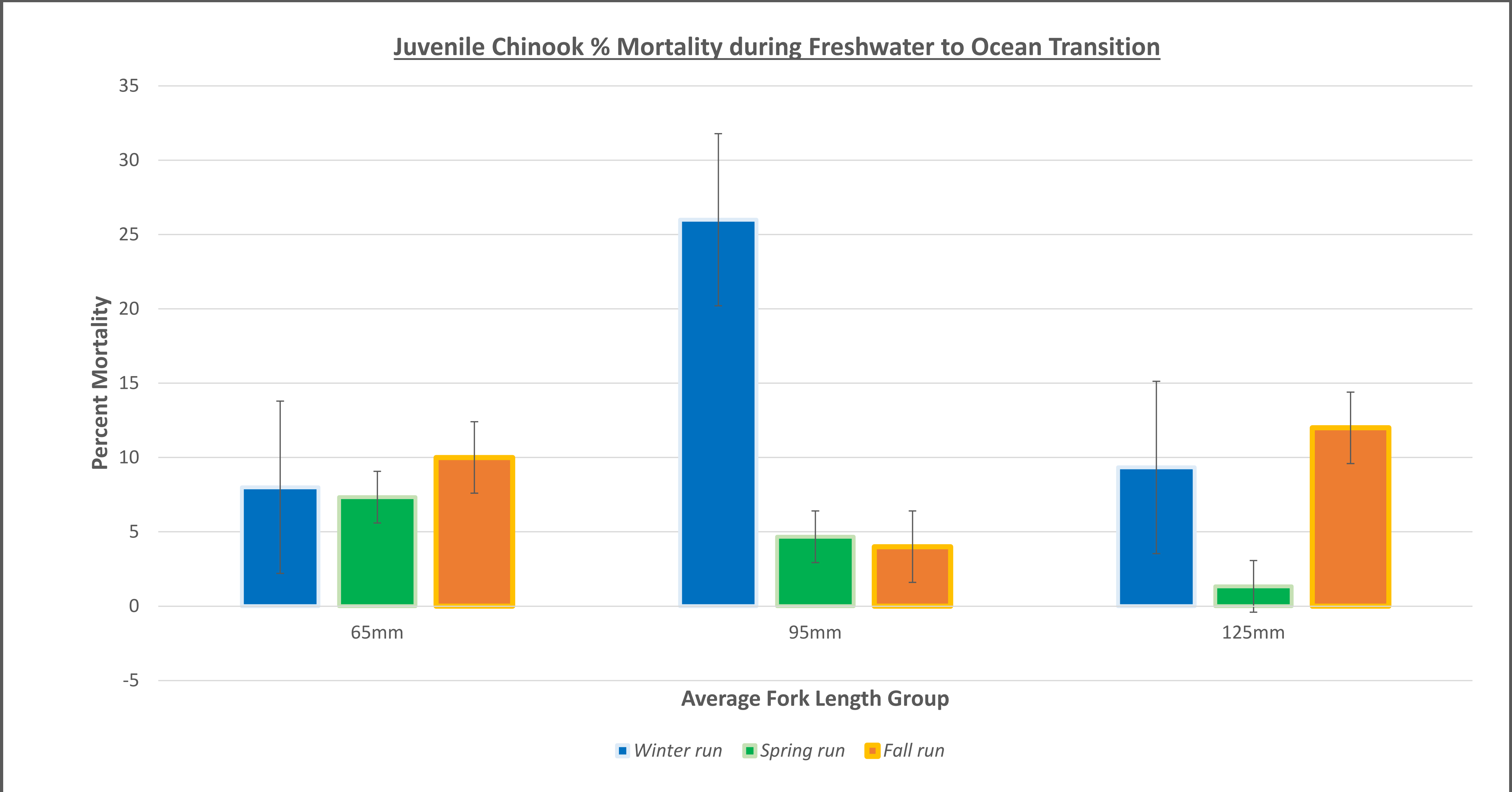

Trinity Spring Run Survival
Spring run 65mm
Spring run 95mm
Spring run 125mm
Probability of Survival
100
50
0
15
20
25
Days elapsed
Size threshold for survival at 125mm fork length



Fall run Mortality Trends
Number of Mortalities
Days of the Salinity Trial
12ppt
22ppt
32ppt
65mm
95mm
125mm

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
65mm	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2	0	4	8	0	0
95mm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	2	1	1	0	0	0
125mm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	7	6	3	0


Iron Gate Fall Run Survival
Probability of Survival
Days elapsed
100
50
0
10
15
20
25
Fall run 65mm
Fall run 95mm
Fall run 125mm
Window of optimum survival at 95mm fork length


Juvenile Chinook % Mortality during Freshwater to Ocean Transition
35
30
25
20
15
10
5
0
-5
Percent Mortality
65mm
95mm
125mm
Average Fork Length Group
Winter run
Spring run
Fall run

What does Survival tell us?

- **Livingston Winter run**
  - All groups had poor survival
  - Least tolerant of salinity increases
  - Few individuals were physiologically able to smolt
  - Possible that yearling juveniles will perform better

What does Survival tell us?

- **Trinity Spring run**
  - Highest survival: 125mm average fork length
  - Tolerant of salinity increases up to 32 ppt
  - Possible size/age threshold for smoltification around 125mm average fork length

What does Survival tell us?

- **Iron Gate Fall run**
  - Size group with the highest survival was 95mm average fork length
  - Tolerant of salinity increases up to 32 ppt
  - Possible window for smoltification rather than a size/age threshold

Additional Analyses

- Muscle Hydration Assessment
- NaK-ATPase Activity Assay
- BCA Total Protein Assay
- Plasma Osmolarity Analysis
- Quantification of Plasma Cation Concentration using Flame Spectrometry

- mRNA Expression of Salinity Stress & Smoltification Mapping

Primer Gene Abbrv.	Seq. Description	Accession #	Type	Amplicon bp#	Primer Efficiency in %
ATP6V1B2	vacuolar-type ATPase H+ transporting V1 subunit B2 (energy for NKCC transporter)	XM_042311619.1	Smoltification	169	102.2360792
SLC12a2	na-k-cl cotransporter nkcc1 (SLC12A2 gene provides instructions for NKCC1)	XM_042302639.1	Smoltification	70	103.21516
CASP3b	caspase-3 beta	XM_024428895.2	Apoptosis	195	107.2695138
ATPa1a	na k atpase alpha subunit isoform 1a	XM_042316867.1	Smoltification	168	106.7151501
ATPa1b	na k atpase alpha subunit isoform 1b	XM_042296756.1	Smoltification	152	102.0805096
GHRb	growth hormone receptor b (smolitification indicator on gill)	XM_024397386.2	Smoltification (when on gill)	150	100.2042413
GAPDH	glyceraldehyde-3-phosphate dehydrogenase	XM_024418691.2	Housekeeping	126	98.43368828
BetActin	beta actin	XM_042314795.1	Housekeeping	133	109.4640834
EF1alpha	elongation factor 1 alpha	XM_024396038.2	Housekeeping	122	102.1292999

Thank You!

Yurok Tribe
- Dave Hillemeier
- Barry McCovey

Sardella Lab
- Dr. Brian Sardella

Fangue Lab
- Dr. Nann Fangue
- Dennis Cocherell

Connon Lab
- Dr. Richard Connon
- Dr. Amelie Segarra
- Samah Abdelrazek
- Camilo Sanchez
- Celeste Valdivia
- Felix Karl Josef Biefel

CDFW
- Iron Gate Hatchery
- Trinity River Hatchery
- Livingston Stone Hatchery

UC Davis Interns
- Anne Boyd
- Mason Rogers
- Vinay Mase
- Jaquelin Arredondo
- Jason J Flores
- Cassidy Carranza
- Manny Delgado
- Nathan Tabaranza
- Sarah Harry
- Lindsey Flores
- Jocelyn Lee
- Mariel Mondragon-Becerra
- Trinity Burnham-Pohlmann
- Trevor Asbury
- Aiyanna Laws-Mcneil

Funders
- NSF Sustainable Oceans NRT
  - **Award:** 1734999
- NOAA California Sea Grant
  - **Project:** R/AQ-151F
- Davis Fly Fishers Club
- Diablo Fly Fishers Club

Climate-driven variability in zooplankton in coastal waters off northern California: a potential ecosystem indicator for Klamath River Chinook Salmon

Eric P. Bjorkstedt[1,3]

Roxanne R. Robertson[2,3]

Blair Winnacott[2,3]

CAL POLY
HUMBOLDT

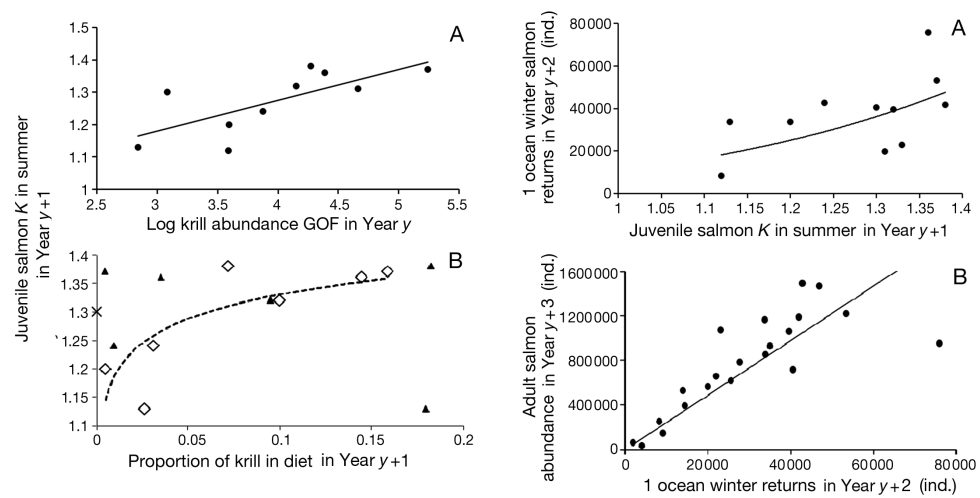
[1]FED, NOAA Fisheries SWFSC
[2]CIMEAS at Cal Poly Humboldt
[3]Department of Fisheries Biology, CPH

Zooplankton and Salmon

Cold-water, lipid-rich copepods off Oregon →

… stronger returns to Oregon stocks

Peterson et al. 2006, 2014



Cool-water, lipid-rich krill →

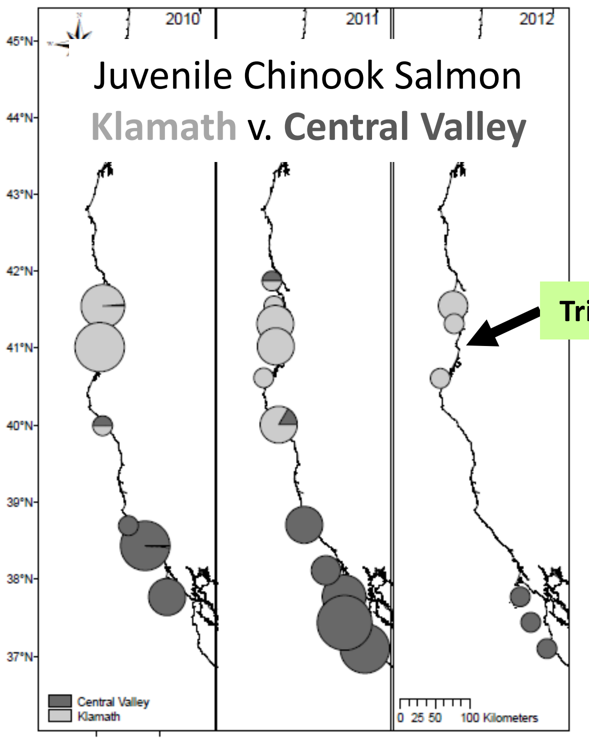
… fatter juvenile salmon →

… stronger returns to Central Valley stocks

Wells et al. 2012

Coastal waters off Northern California

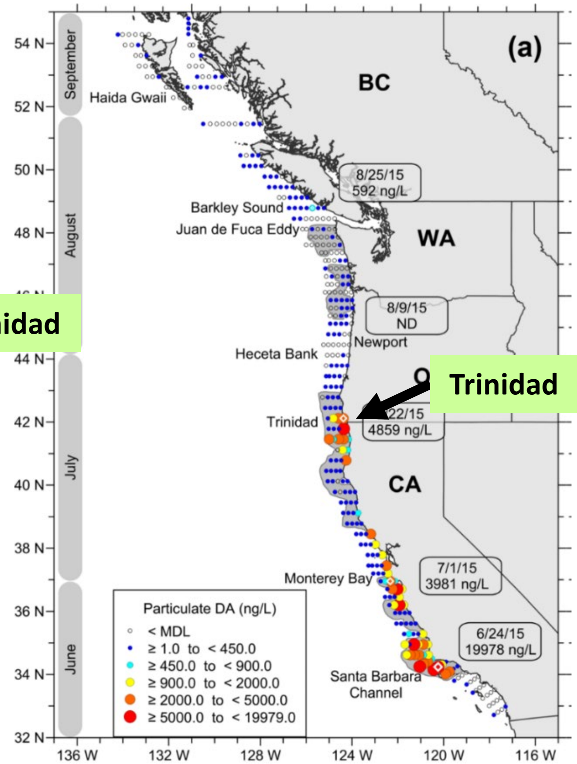
Early (and late) marine habitat for Klamath River salmon



Hassrick et al. 2016

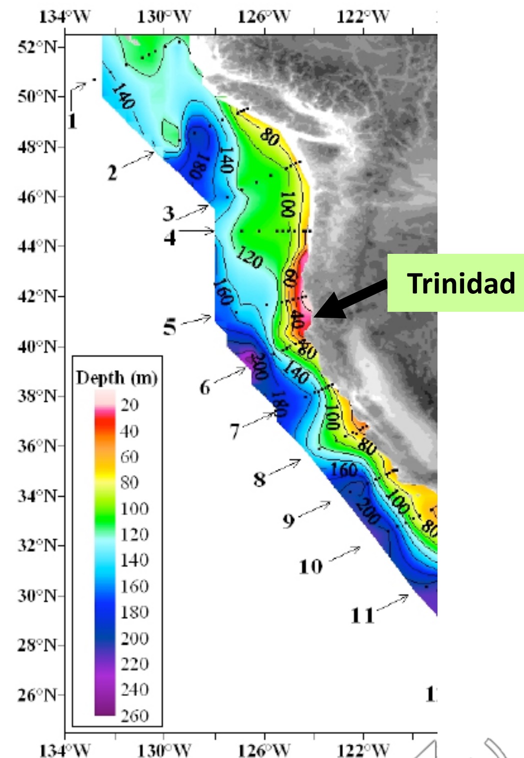
Hotspot for

Harmful Algal Blooms (HABs)



McCabe et al. 2016

OAH exposures



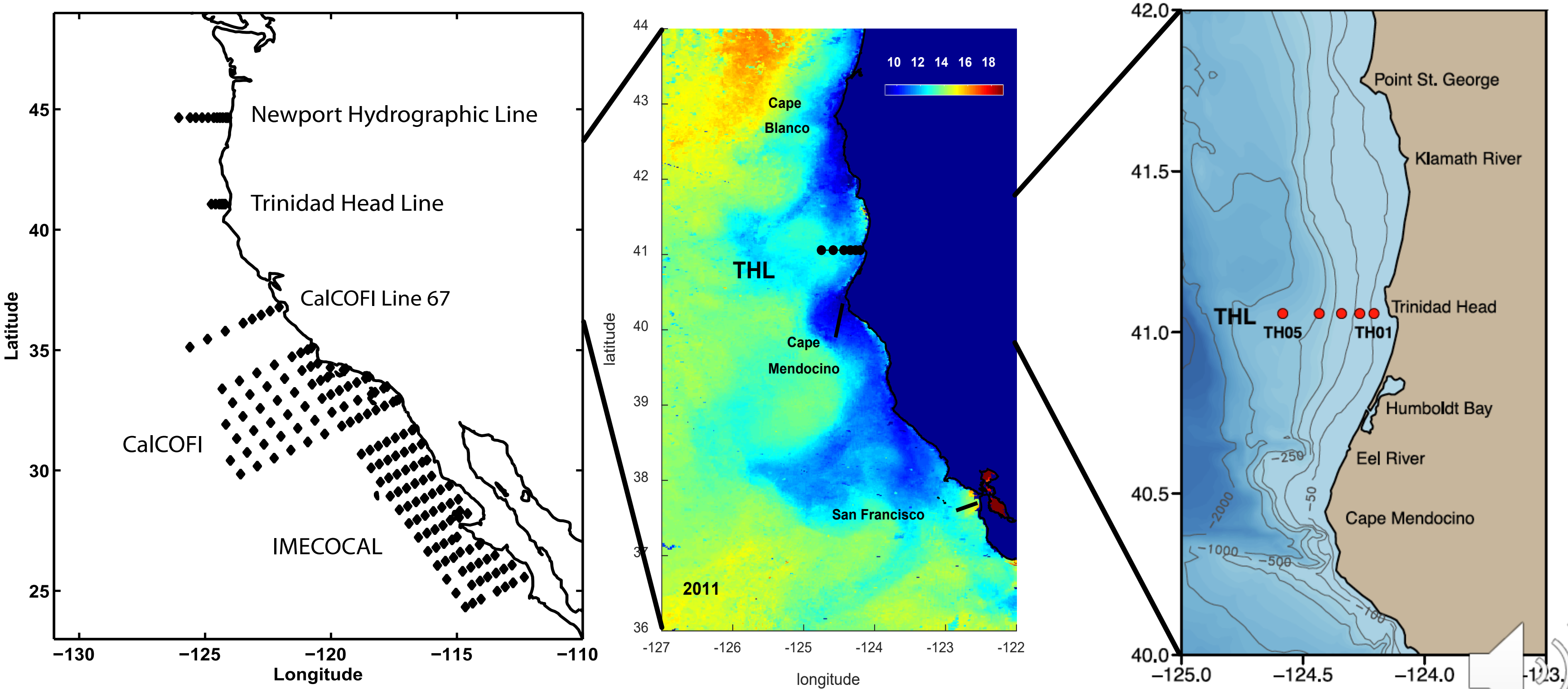
Feely et al 2008

The Trinidad Head Line (THL)

Situated in an extensive gap in year-round ship observations.

In a transitional region marked by substantial mesoscale structure.

Five stations (3 over narrow shelf; 2 over upper slope) ~4-36 km offshore



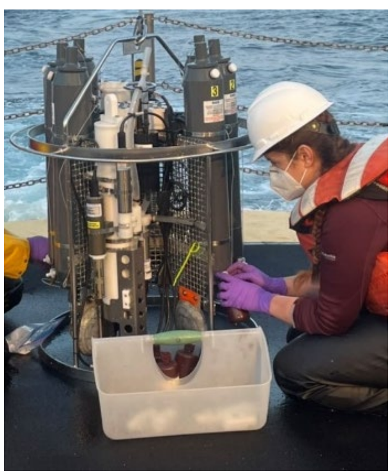
Thanks to **ALL** who have contributed to the THL project!

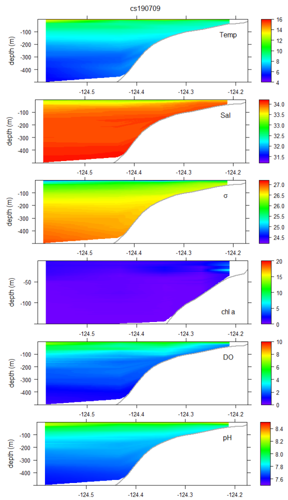
Technicians: Phil White, Kat Crane, Caymin Ackerman, Winn McEnery, Spencer Hitzeroth, Erin Damm; *R/V Coral Sea* Captain and Crew; **130+ undergrad and grad students**.

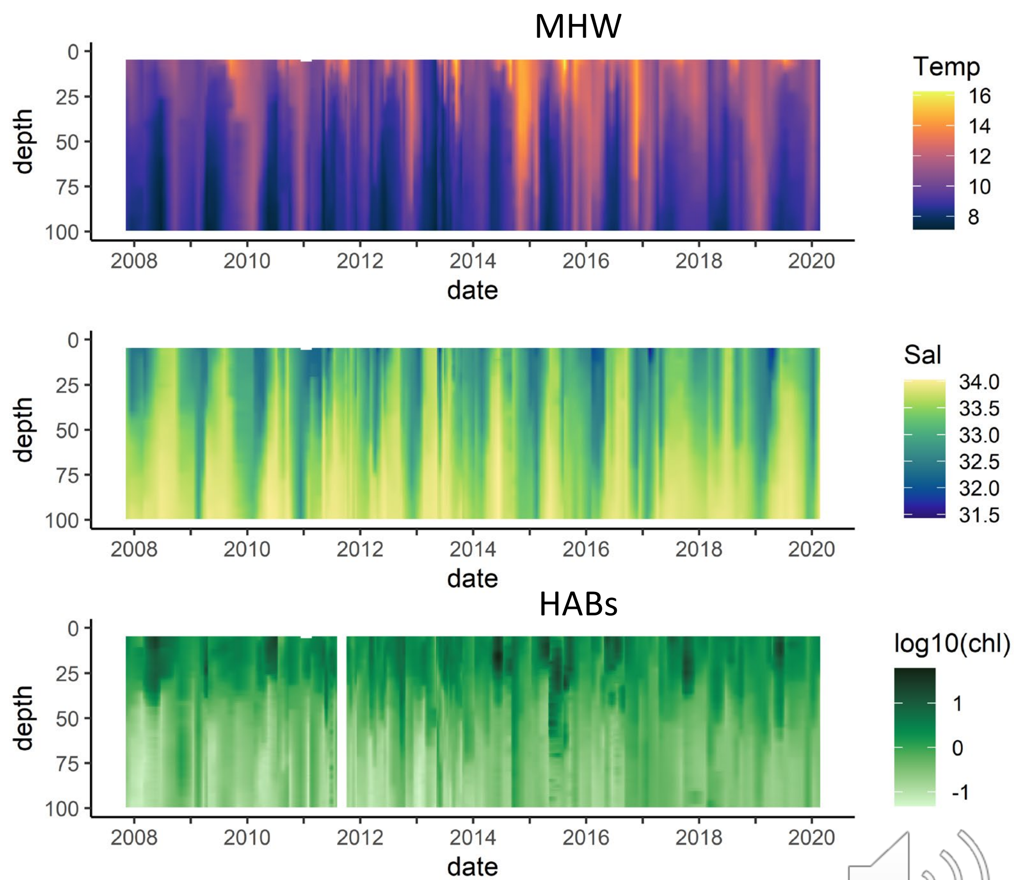
Supported by NOAA's SWFSC via CIMEC/CIMEAS

Oceanographic observations

- CTD Profiles/Sections
  - T, S, fluorescence, DO, pH, etc.
- Water sampling
  - nutrients, chl a, domoic acid*, pCO_2*, eDNA*

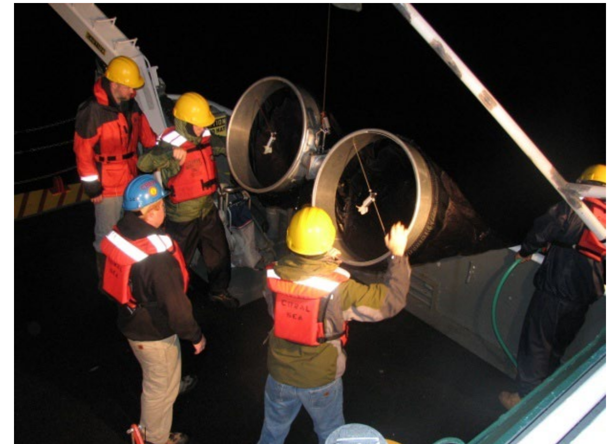






Zooplankton sampling

- Oblique Bongo net (0.7 m, 505/335 µm, dyed mesh).
  - 505 µm net → 5% buff. formalin in seawater
  - 335µm net → 95% ethanol (replaced in 24 h)
  - ***Krill, larval fish, etc.***
- Vertical ring net (0.5 m; 202 µm white mesh)
  - 5% buff. formalin in seawater
  - ***Copepods***
- Upper 100 m of water column
- Cruises are centered on sunset
  - shelf stations (TH01-TH03) are sampled in afternoon to evening
  - slope stations (TH04 & TH05) are sampled in darkness (vertical migrators!)

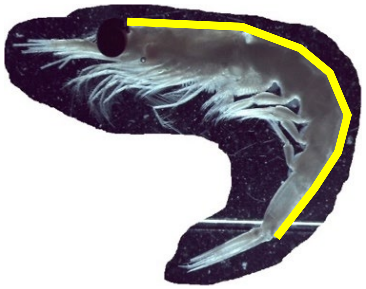


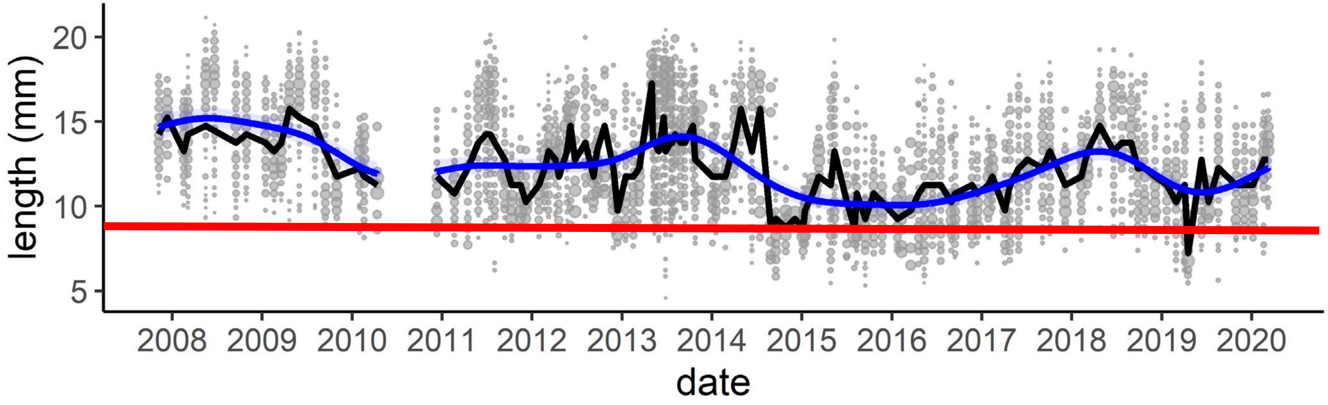
TH01	4.1 km	35 m
TH02	9.2 km	75 m
TH03	15.2 km	140 m
TH04	22.6 km	410 m
TH05	34.7 km	700 m

Krill analysis

- Euphausiids are identified to species and life history stage*
- Up to 25 individuals of each species-stage are measured using imaging software
- Adults are identified on basis of 2° sexual characteristics, not a size threshold.

Behind eye to base of telson



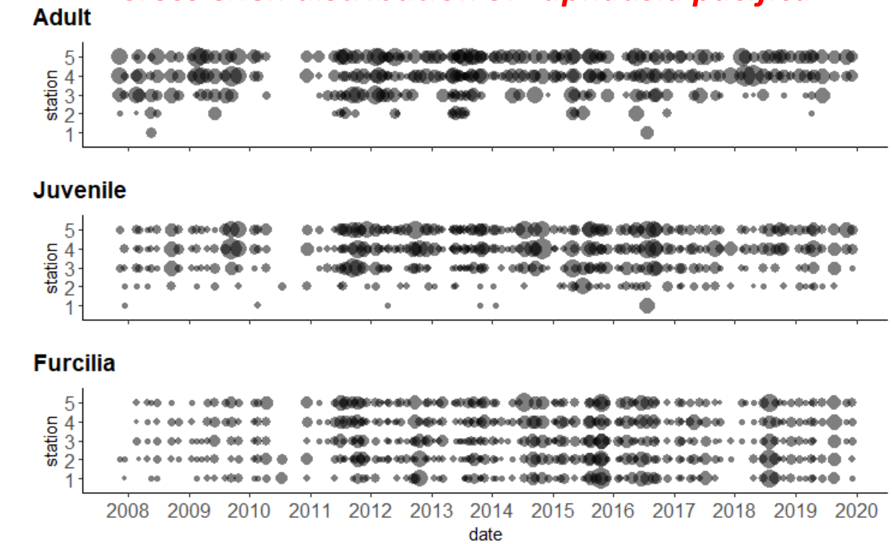


Size thresholds yield substantial (asymmetric) misclassification of adults and juveniles during warm periods.

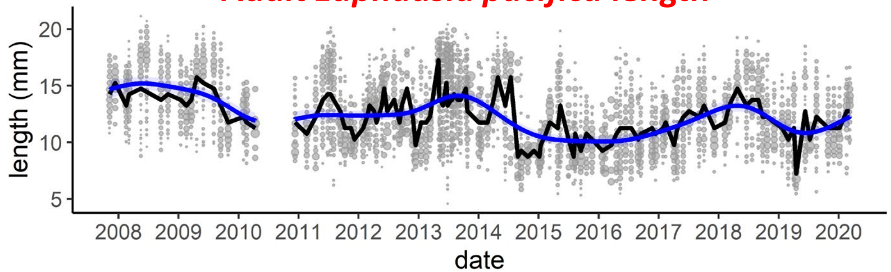
*(Brinton et al. (2000) and expert consultations)

Krill data sets

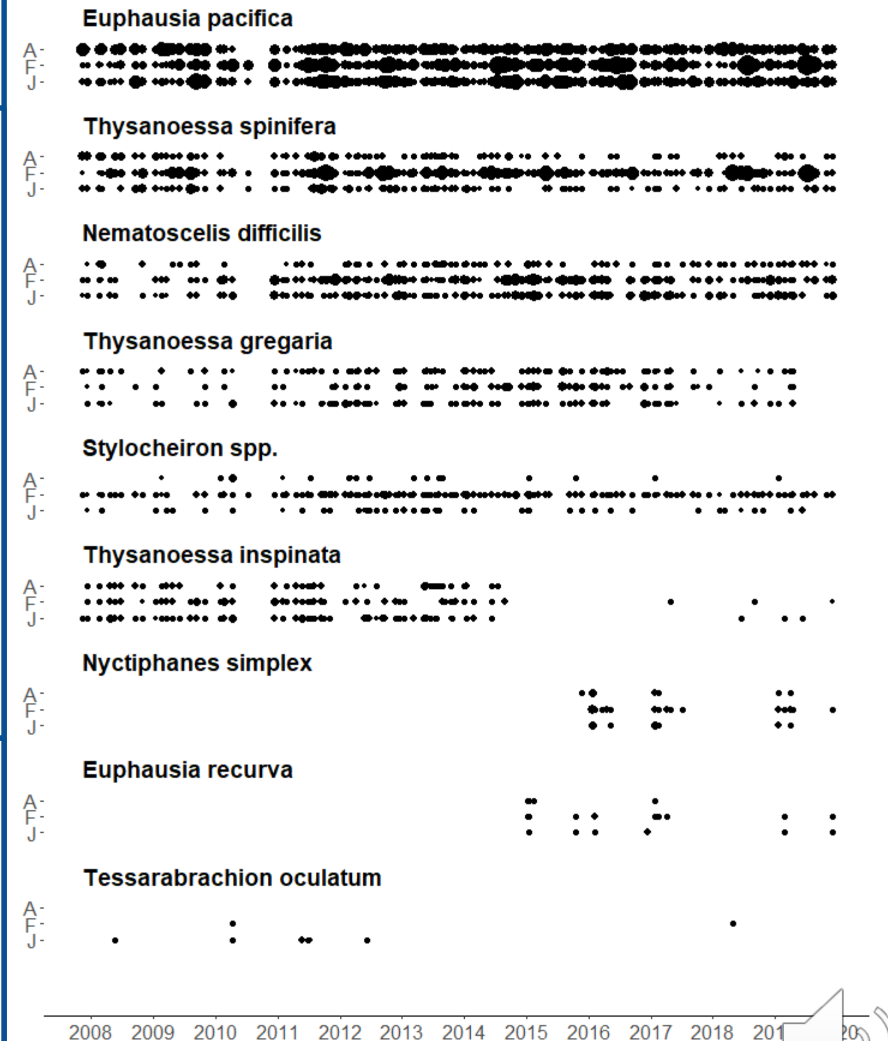
Cross-shelf distribution of *Euphausia pacifica*



Adult *Euphausia pacifica* length

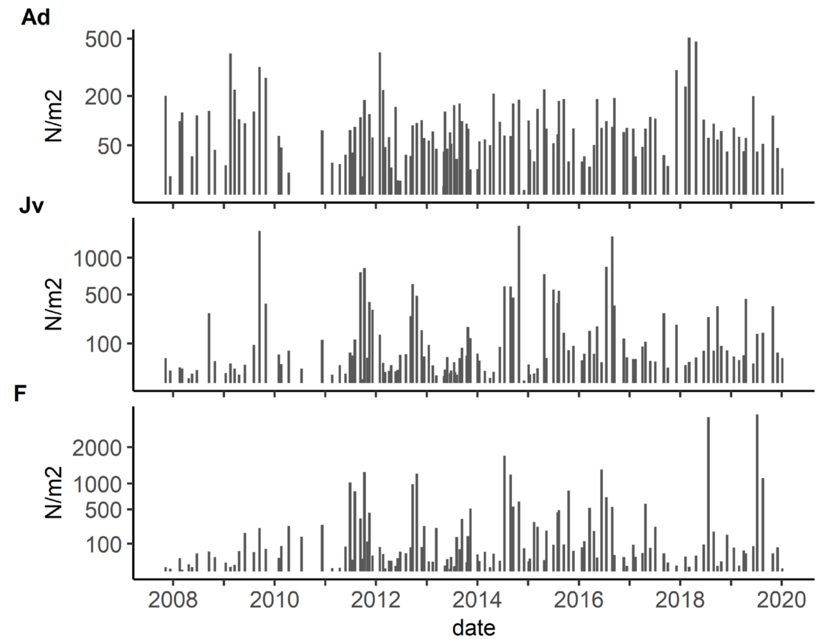


Euphausiid Assemblage (excl. 4 very rare spp.)

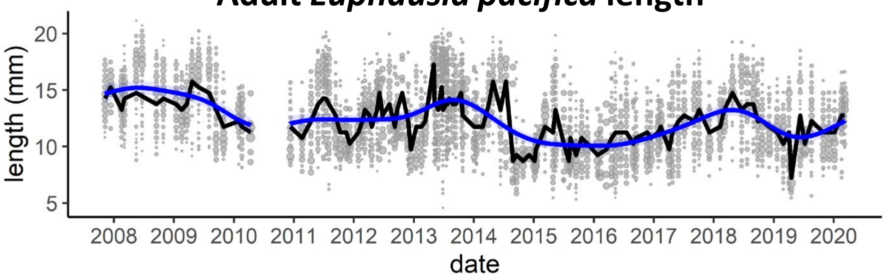


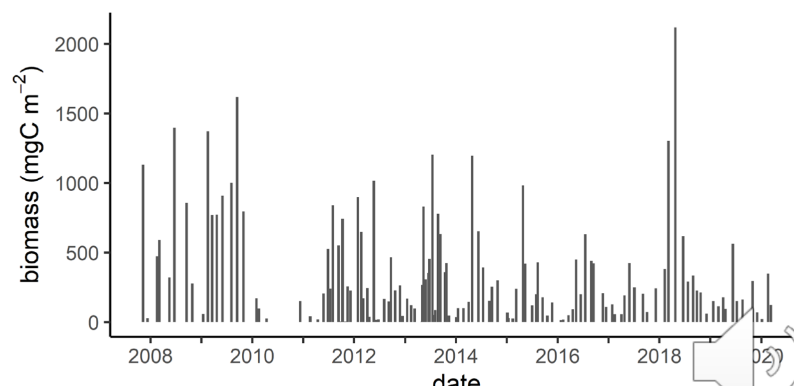
Biomass index

- Abundance & Length → Biomass
  - Feinberg et al 2007
  - Shaw and Peterson 2010
- Mean mg C m^{-2} by cruise

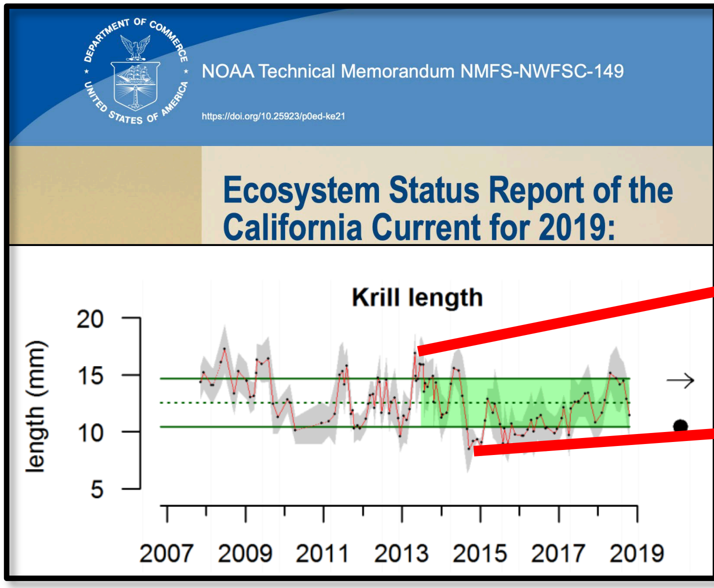


Adult *Euphausia pacifica* length



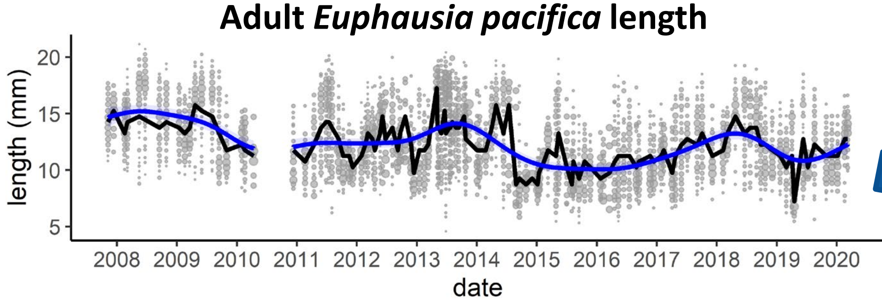


Adult size as an indicator



2013 ♀
(19.7 mm)

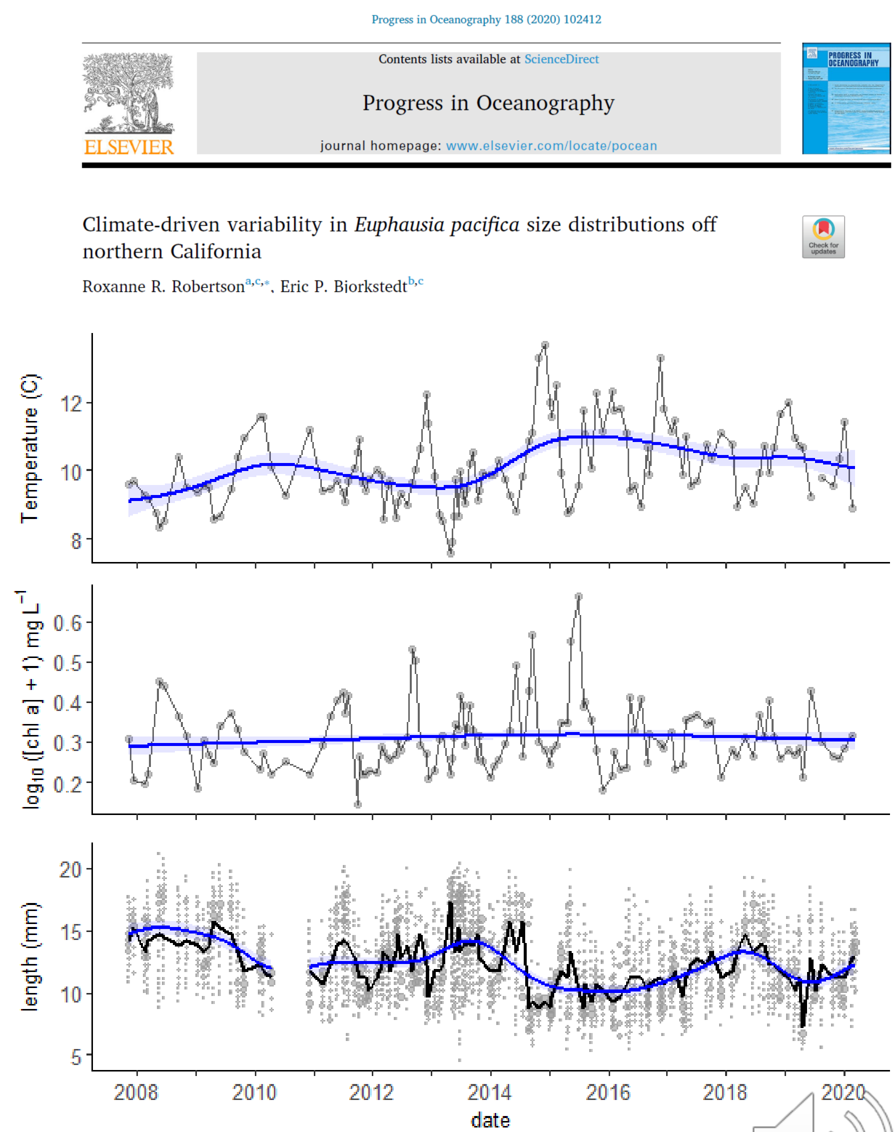
2014 ♀
(8.3 mm)



Nm^{-2} weighted mean & SD across transect

Climate response

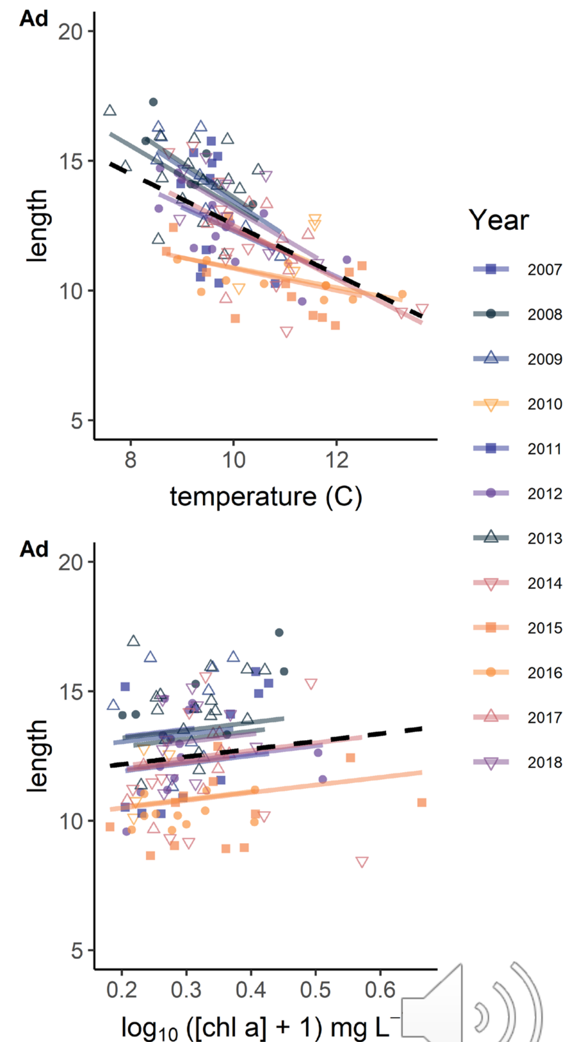
- Variability in size distributions mirrors pattern in temperature.



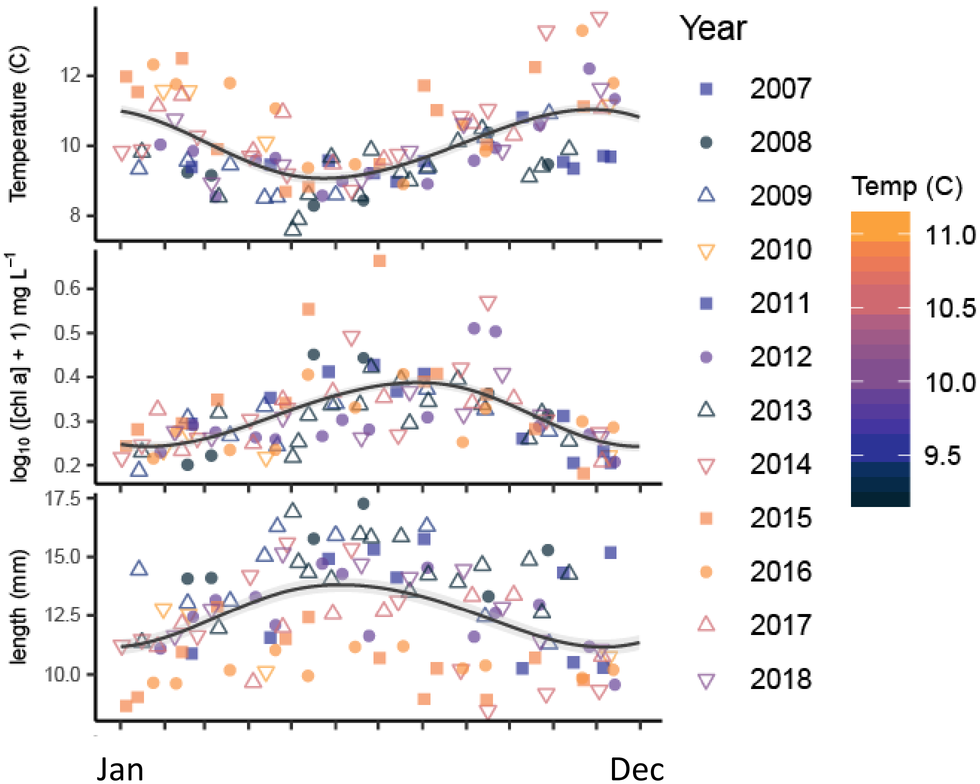
Length ~ Environment

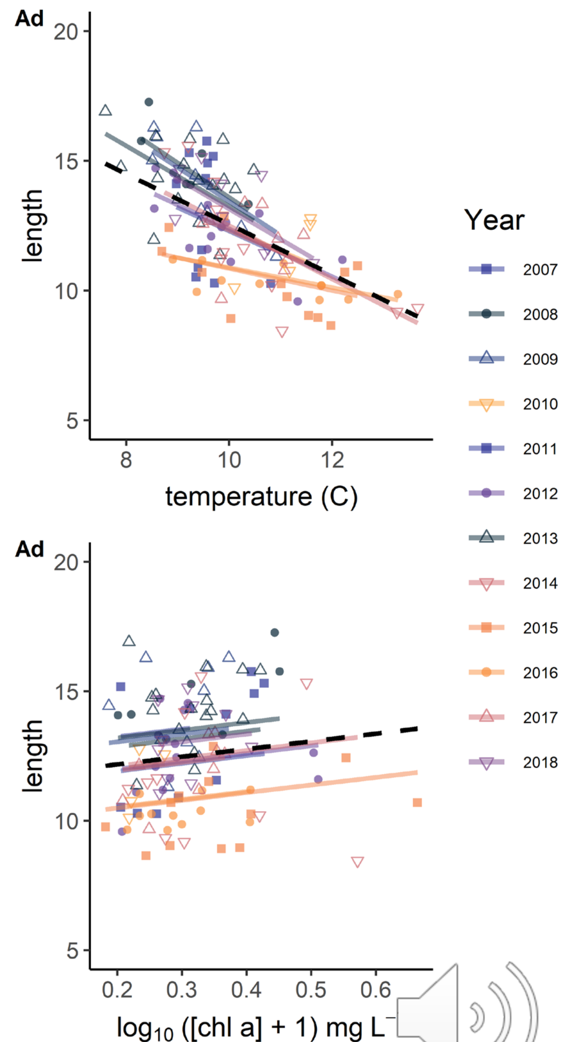
- Convergence towards common minimum median adult size at warm temperatures.

- Scope for seasonal increase in mean size reduced under warm conditions.
  - size-at-maturity: negative relation to T
  - max size: positive relation to CHL

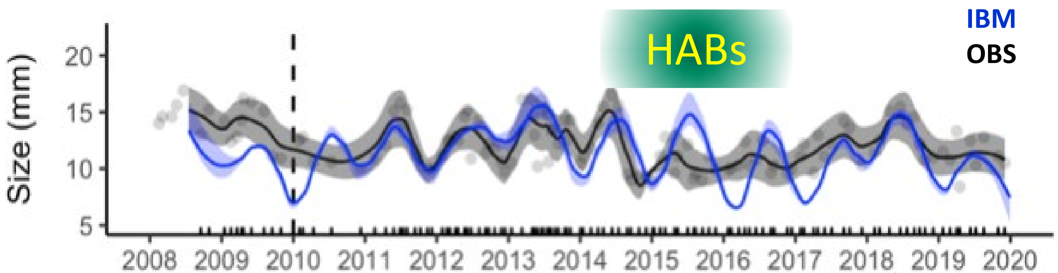


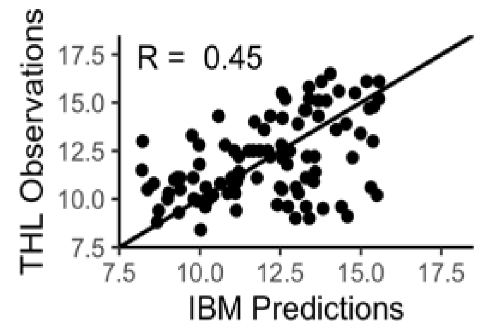
Each year set up early?





Individual Based Model





Robertson (2020)

Temperature

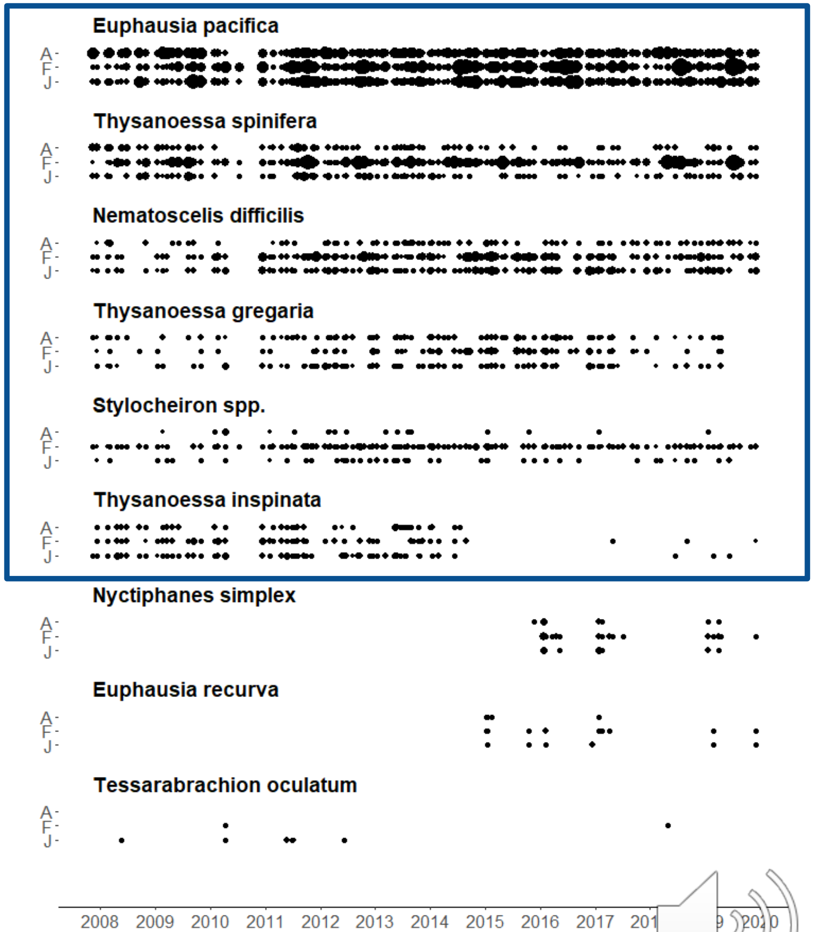
- Controls metabolism
- Controls development

Seasonal patterns

- Seasonal variability in activity/energetics
- Seasonal variability in food quality

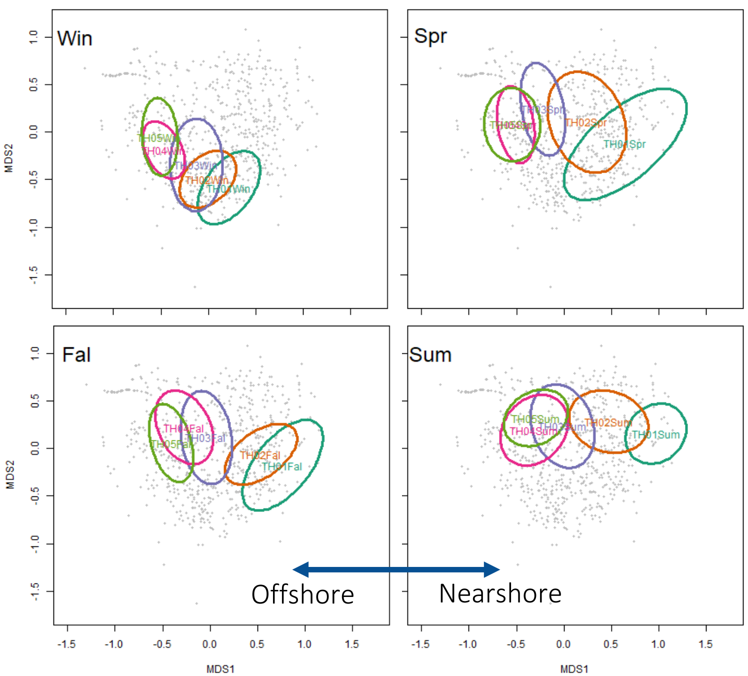
Krill Assemblage

Core assemblage:
Occur in >8% of samples
and >30% of cruises



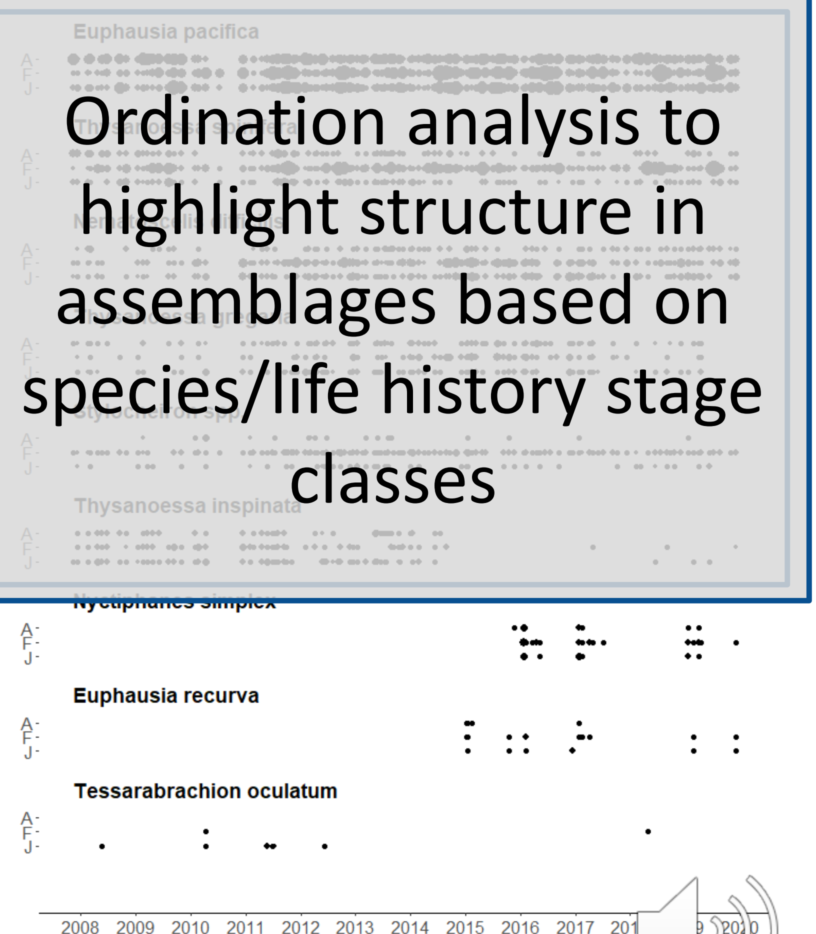
Krill Assemblage

Core assemblage:
Occur in >8% of samples
and >30% of cruises



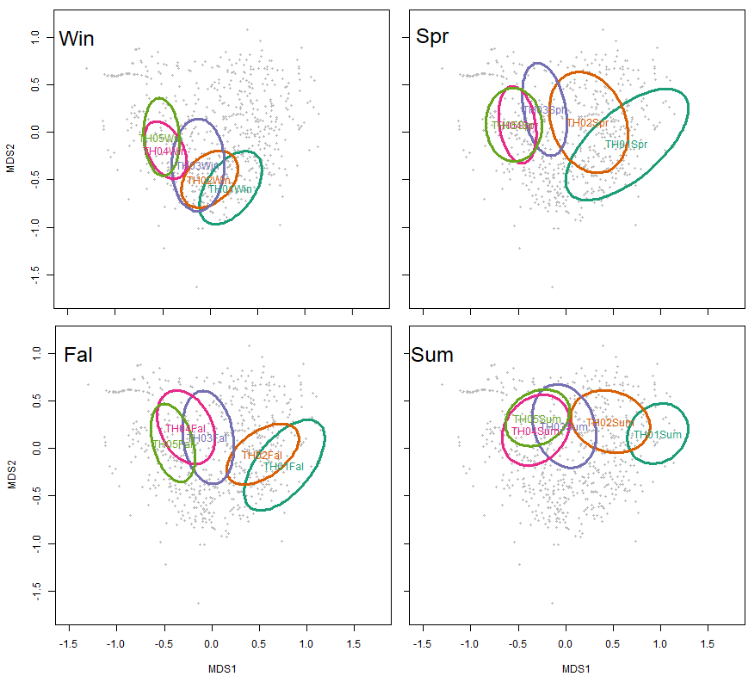
Assemblage differentiates across shelf during spring-fall, converges during winter.

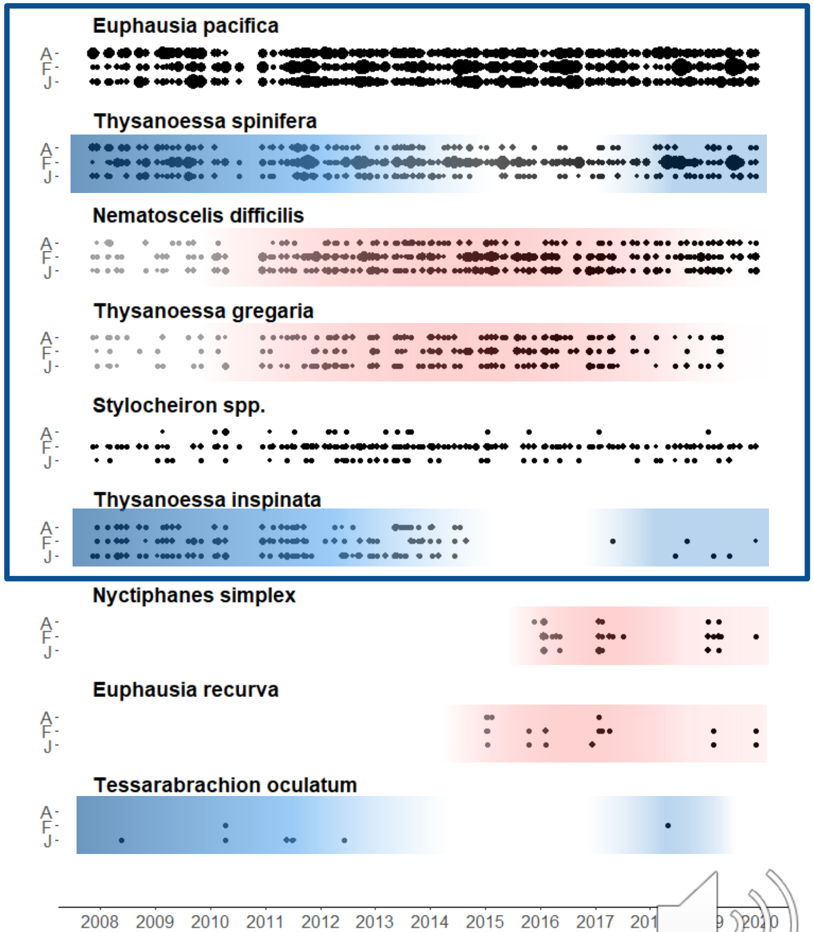
Ordination analysis to highlight structure in assemblages based on species/life history stage classes



Krill Assemblage

Core assemblage:
Occur in >8% of samples
and >30% of cruises

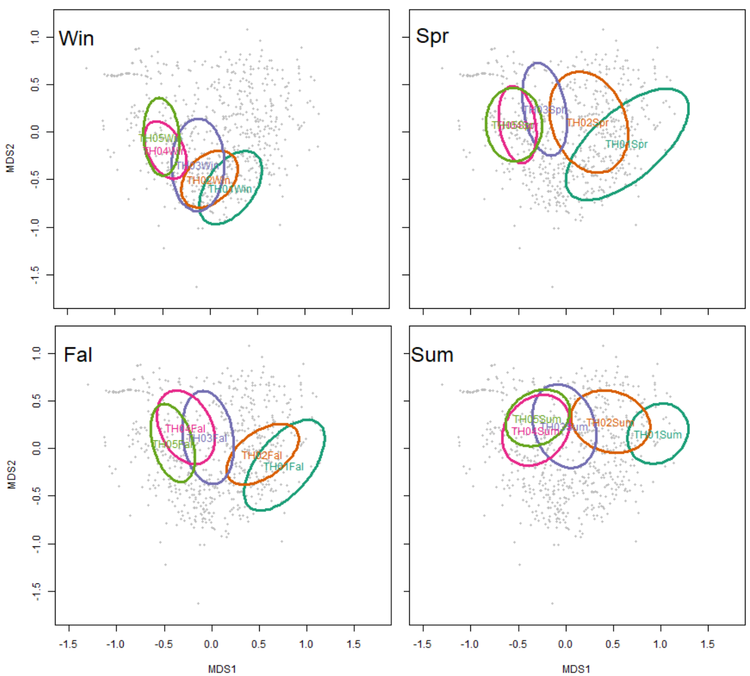


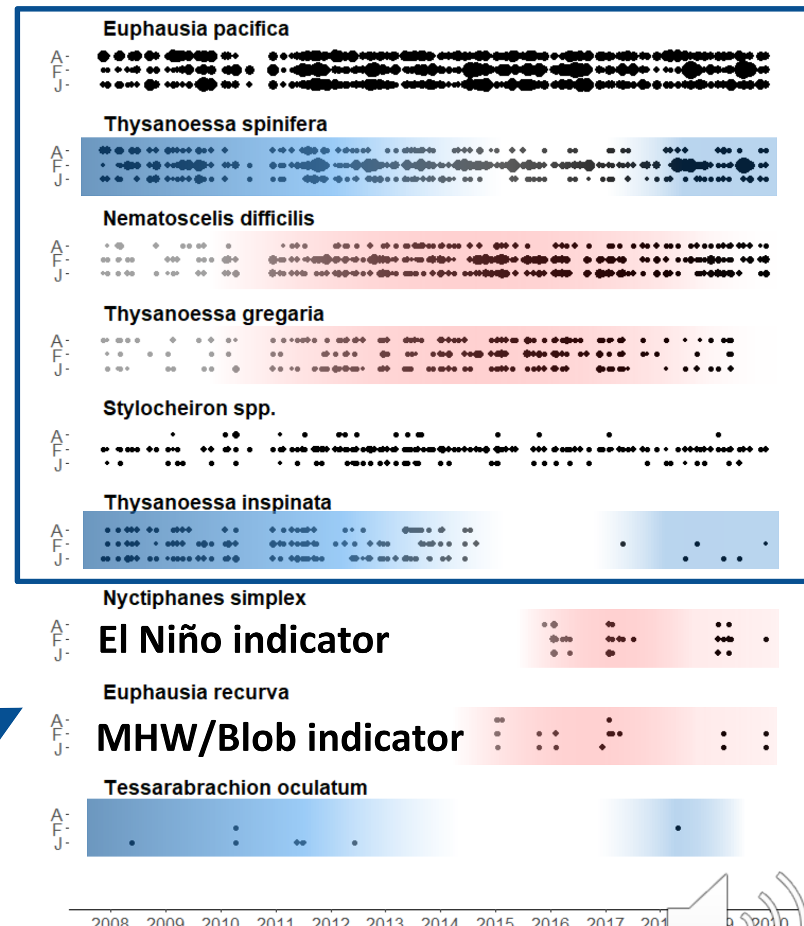


Also captures climate-driven transitions between cool- and warm- water species.

Krill Assemblage

Core assemblage:
Occur in >8% of samples
and >30% of cruises



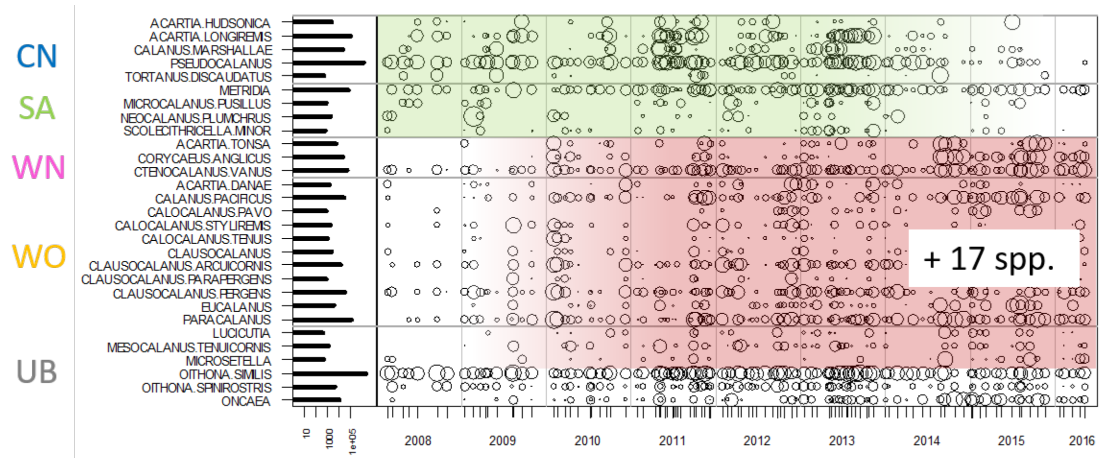


Rare species are important indicators of change.

Other Plankton Assemblages

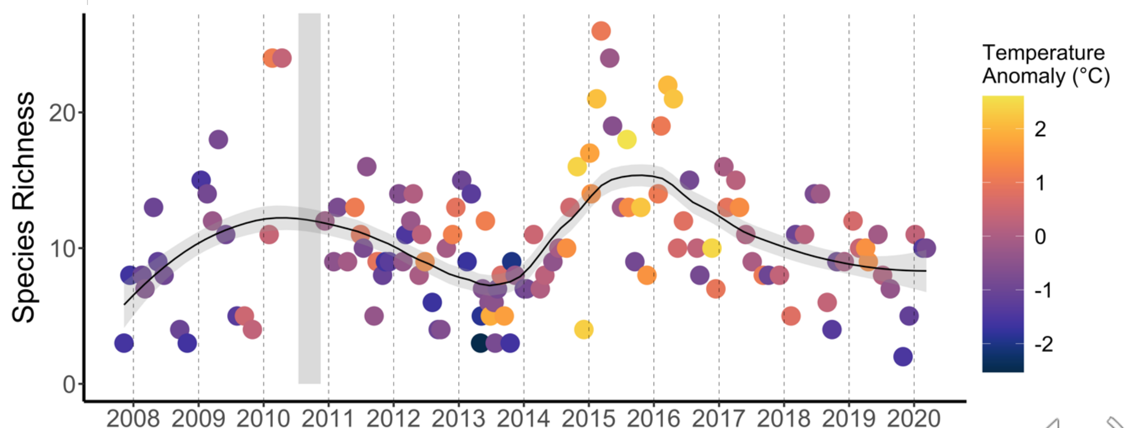
Copepods 2008-2016*

Similar phased transition from cold- to warm-water assemblages



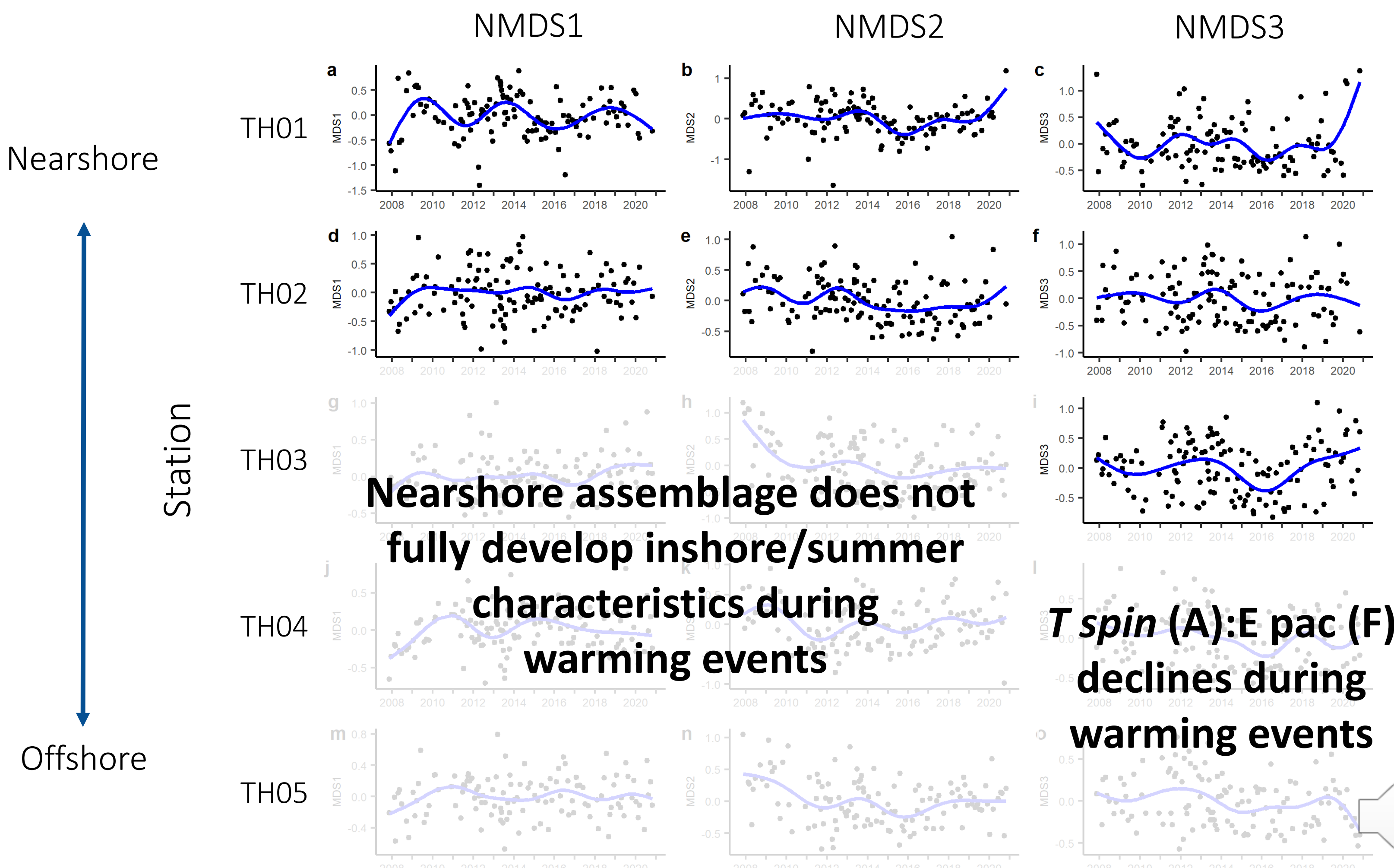
Larval Fishes, etc.

Similar influx of southern and offshore species during warming events



Winnacot 020)

Krill Assemblage



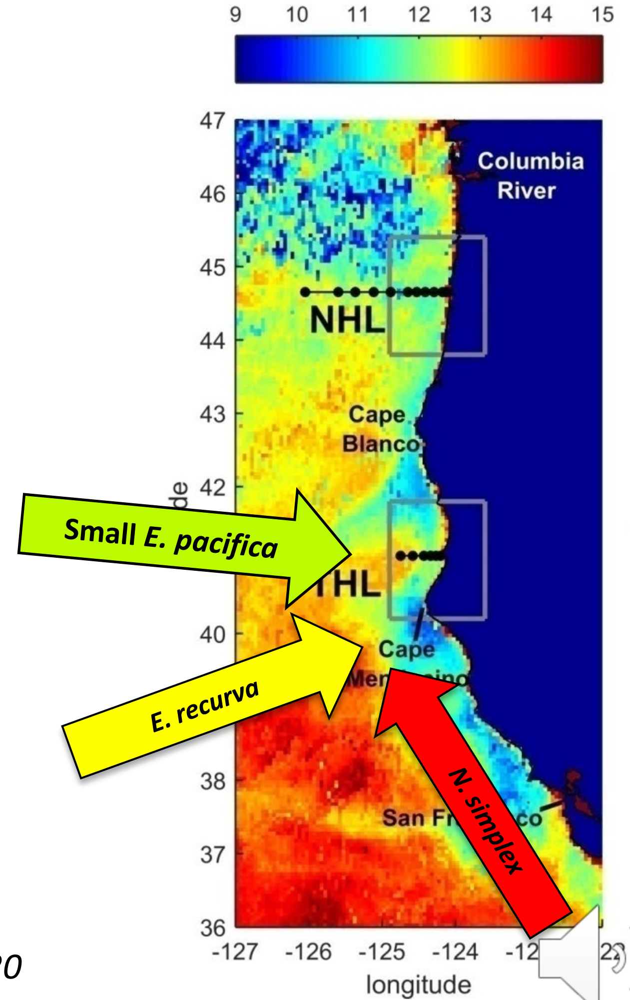
Nearshore assemblage does not fully develop inshore/summer characteristics during warming events

T spin **(A):E pac (F) declines during warming events**

Physical drivers

Sharp shifts in size structure & assemblage corroborate advection of offshore waters to the coast (Blob) and poleward advection during El Niño.

In the case of fish, there is evidence that stocks shifted north as well.



Chao et al 2017; Nielsen et al. 2020; Winnacott 2020

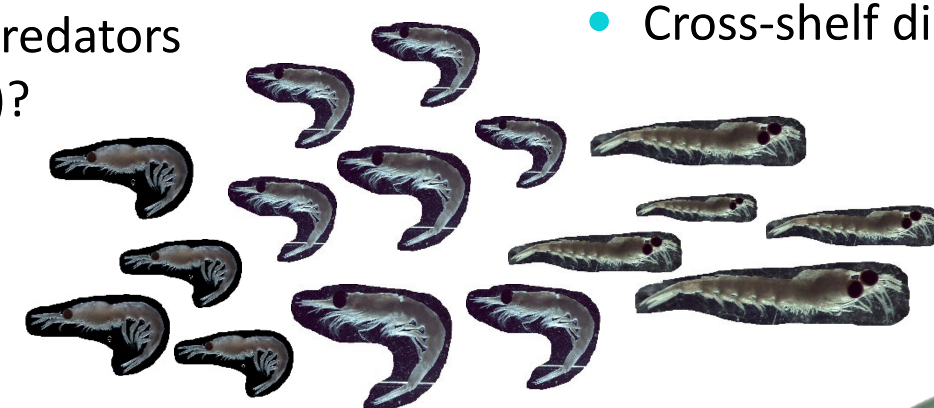
Plankton-based indicators

Biomass

- How much energy is available to predators (e.g., salmon)?

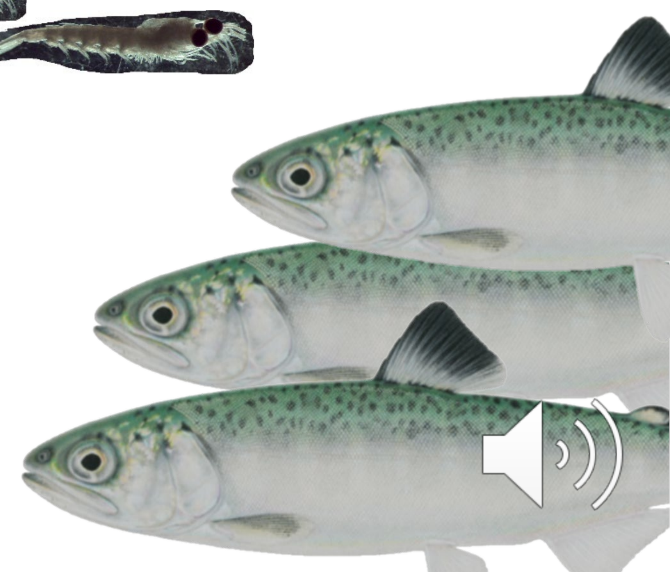
Assemblage

- Energy content of prey
- Cross-shelf distribution



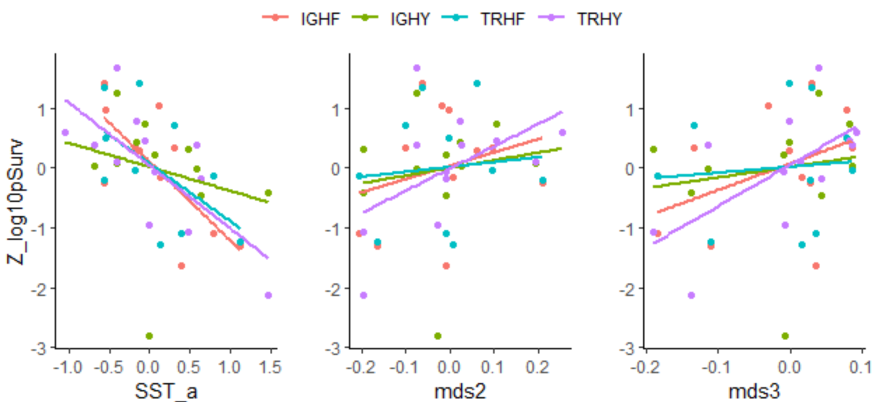
Length

- Energy per bite
- Foraging efficiency



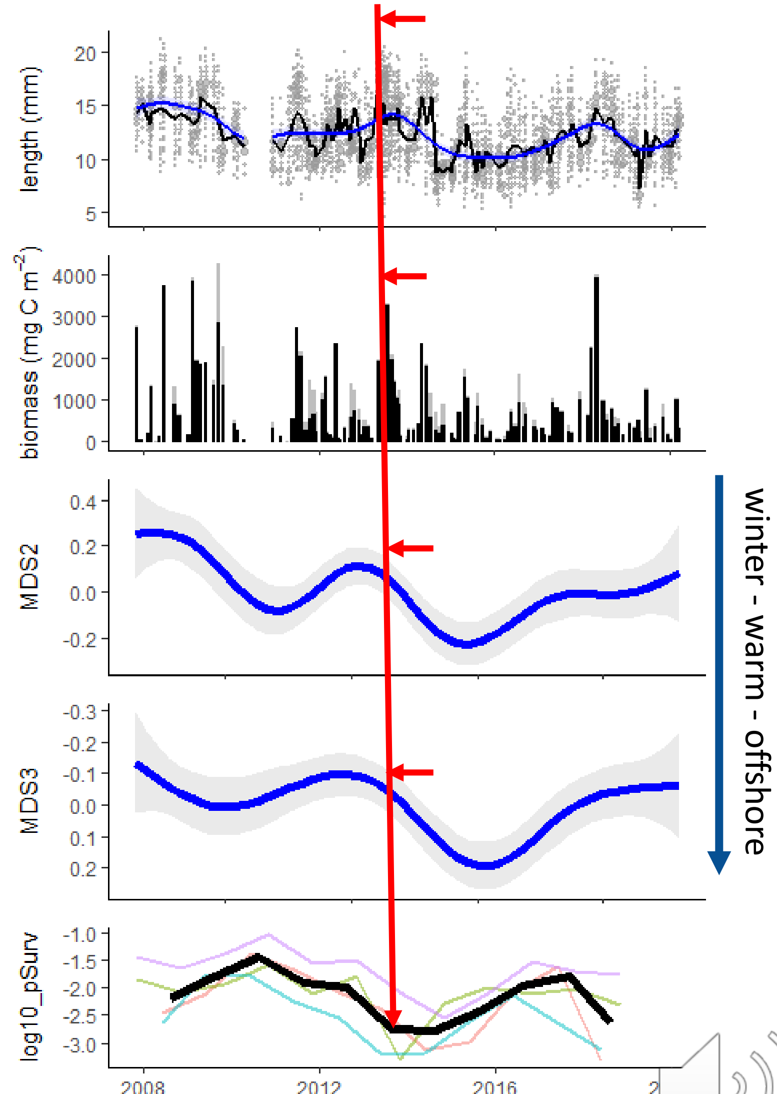
Link to salmon?

- Matching estimates of ocean survival* to concurrent ocean observations indicates potential.



- SSTa: subsumes direct effects and ecological proxies
- Need to account for river effects, too.

*based on CWT; Ken Lindke CDFW (*pers. comm.*)



Final thoughts

- Warm climate events shift several characteristics of krill and the broader plankton ecosystem – intermediate links between physics and fisheries.
- Krill indicators are part of the CCIEA; ongoing work to inform early estimates of marine survival for salmon.
- Value of high-frequency coastal surveys → rich data sets to support analysis and model development.

Questions → Nate

California Current seascape influences juvenile salmon foraging ecology at multiple scales

Megan Sabal

Postdoctoral Scholar, Oregon State University

Sabal et al. (2020) Marine Ecology Progress Series.

Elliott Hazen, Steven Bograd, Bruce MacFarlane,

Isaac Schroeder, Sean Hayes, Jeffrey Harding,

Kylie Scales, Peter Miller, Arnold Ammann, Brian Wells

SRF 4/22/2022

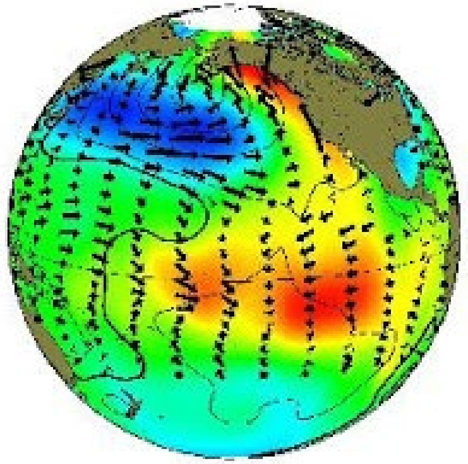
Salmon are vulnerable during early ocean entry

- Juvenile Chinook salmon enter coastal ocean in early summer
- Many salmon die during early ocean entry (3 mo)
    - High RISK
- **Early growth** is very important to survival and adult returns
    - High REWARD

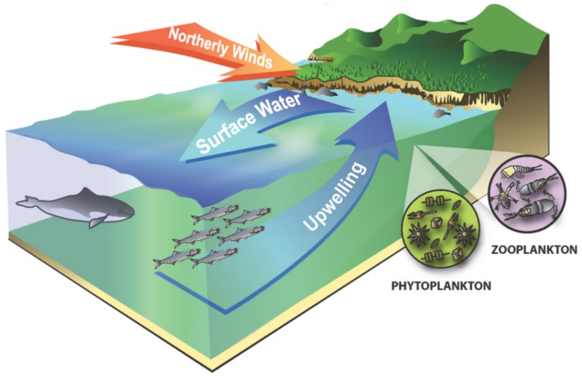
Seascape: Physical to Biological Links

- Growth is influenced by **physical environment & foraging ecology**
- Seascape processes can be complex and occur over multiple scales

Broad scales



Local scales



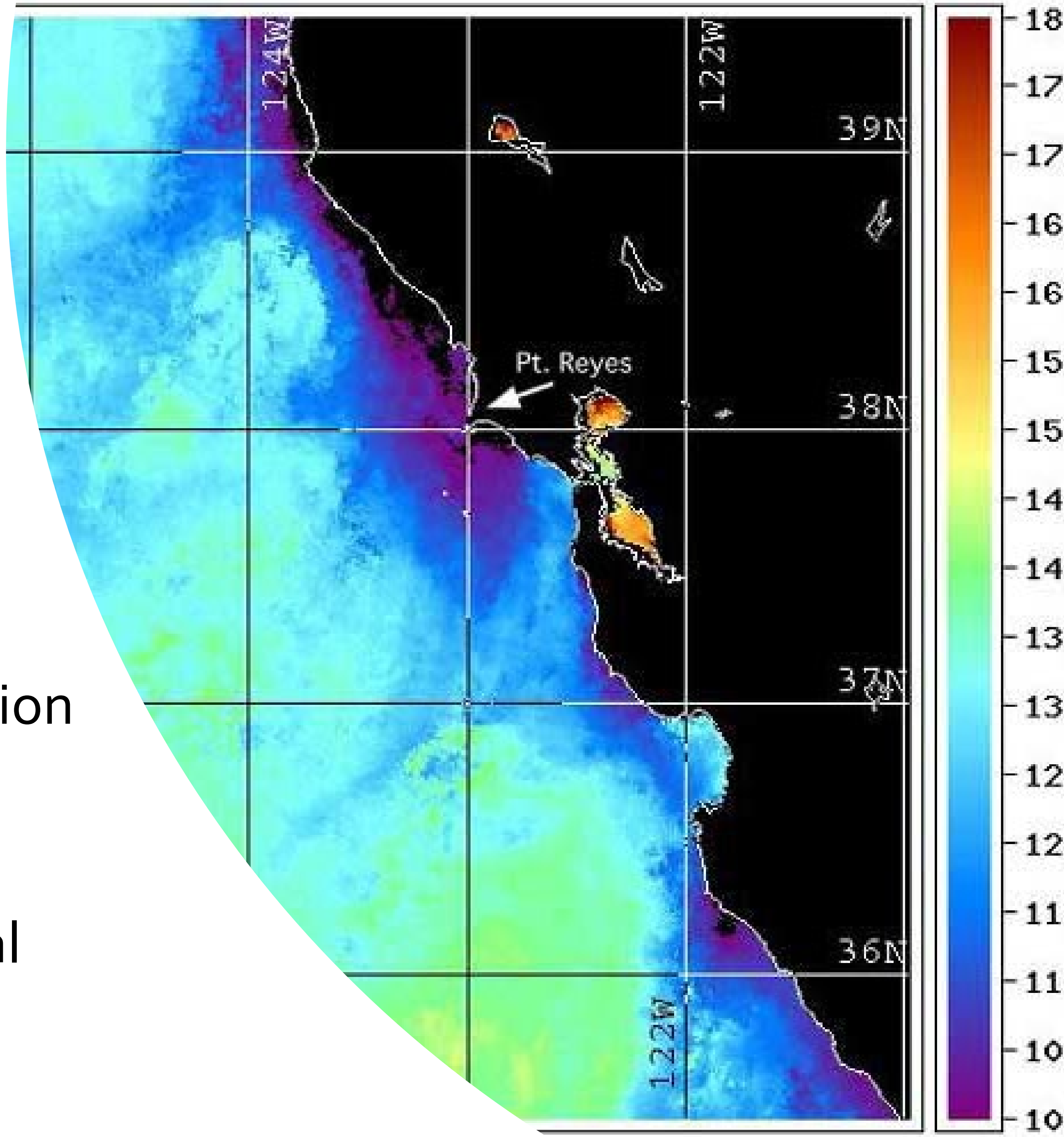
Broad (annual) processes affecting salmon

- Coastal upwelling
  - How much? (intensity)
  - When? (timing)

- Affects spatial/temporal distribution of salmon prey

Foraging ecology

- Affect salmon growth and survival
(Fiechter et al. 2015; Henderson et al. 2019)



Local (event) processes affecting salmon

<u>Local prey distribution</u>
unique habitat associations

- Temperature, depth

<u>Salmon foraging behavior</u>
concentrate prey

- Local upwelling, relaxation, fronts, stratification

Questions

(1) How does salmon stomach fullness relate to seascape conditions at broad spatial (e.g. regional) and temporal (e.g. annual) scales?

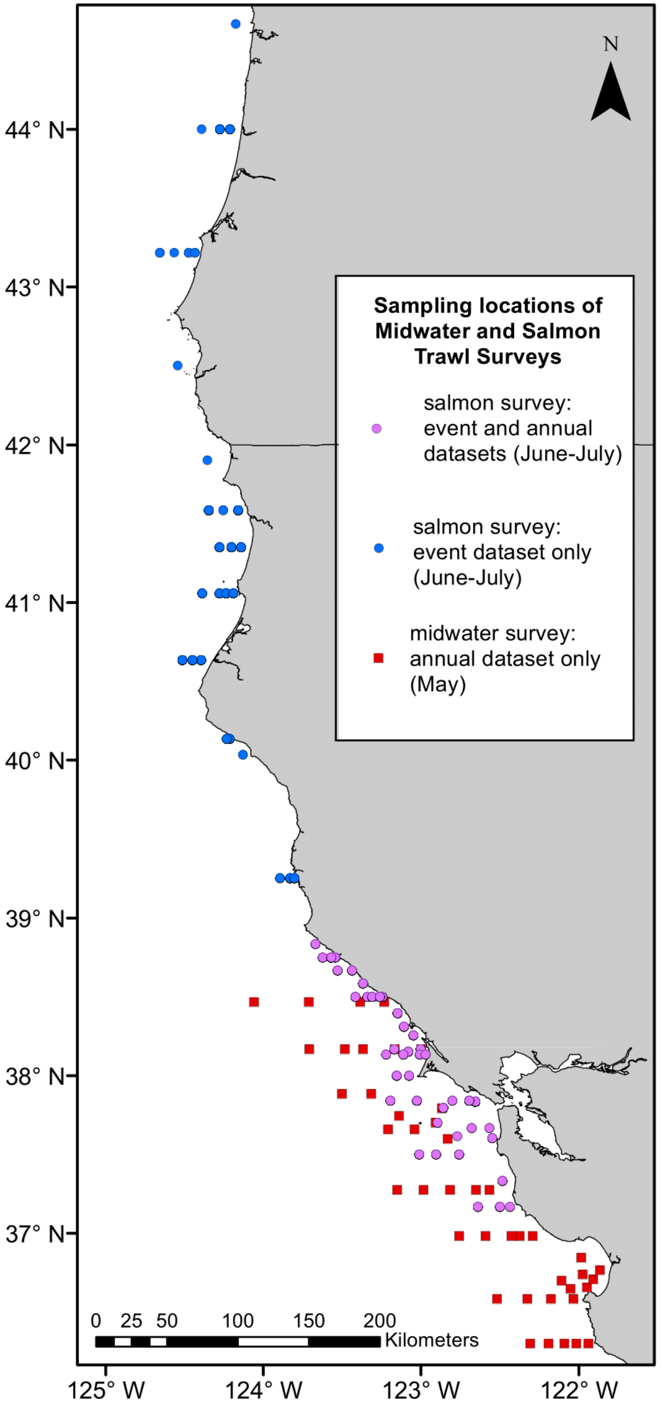
Hypothesis: stronger and early season upwelling will relate to higher salmon stomach fullness via increased preconditioning and abundant prey.

(2) How do salmon stomach fullness and diet composition relate to local seascape features at fine spatial (e.g. 1-10 km) and temporal (e.g. days) scales?

Hypothesis: local features that drive productivity and concentrate prey will increase salmon fullness. Also, local features will influence diet composition via habitat associations of prey.

Methods: salmon & diets

- Salmon ocean survey
  - June-July
  - 1999-2005, 2010-2016
- Chinook salmon < 250 mm FL
- Diets
  - **Stomach fullness index:**
    - Fullness = (stomach weight / salmon weight – stomach weight)*100
    - Fullness index are residuals from Fullness by salmon FL
  - **Presence/absence of prey groups**
    - Fish, krill, non-krill invertebrates (amphipods, copepods, decapods)



Methods: model covariates (annual)

PCUI *Preconditioning upwelling index*

- Sum of positive daily mean upwelling indices through Jan and Feb at 39˚ N (Schroeder et al. 2013)

Amount of productivity

STDATE *Spring transition date*

- The day where the cumulative coastal upwelling index at 39˚ N first starts increasing (Bograd et al. 2009)

Timing of productivity

FORAGE *Salmon prey abundance index*

- Summed relative abundances from May Midwater trawl cruise

Amount of salmon food

MEI *Multivariate El Niño Southern Oscillation Index*

- Winter (Jan-Mar) monthly average

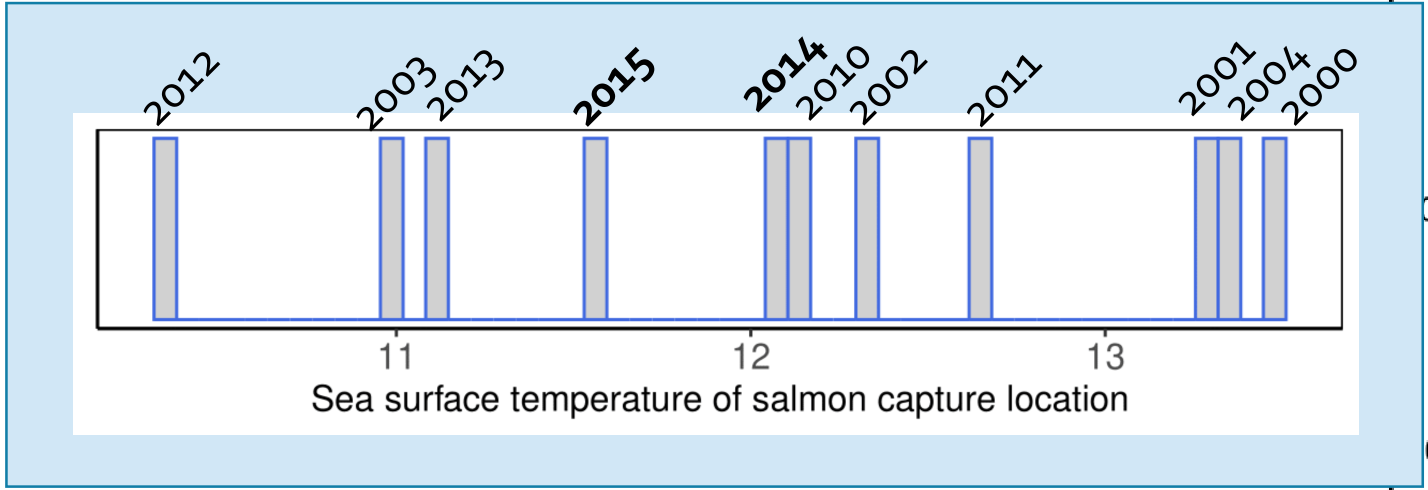
El Niño vs. La Niña

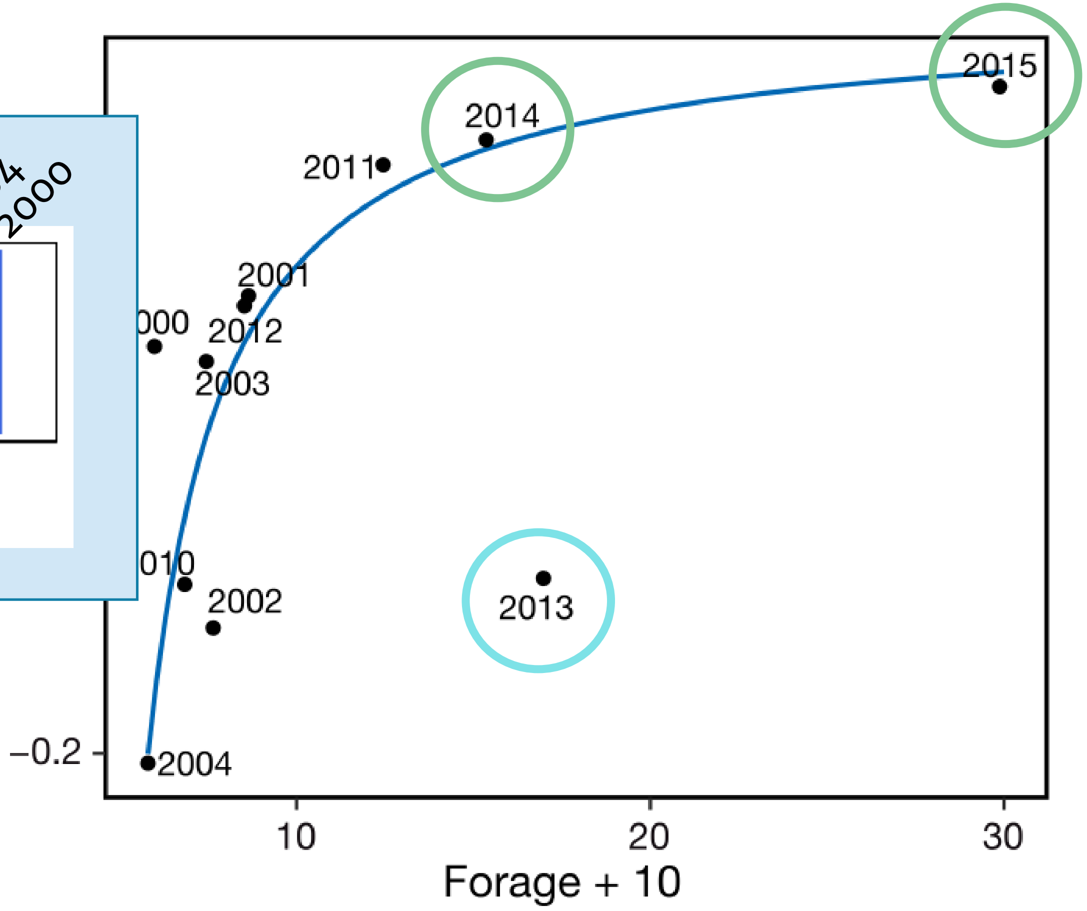
Methods: model covariates (event)

Covariate	Description	Association
DEP	*Bottom depth (m)*	
FRONT	*Distance to nearest thermal front (km)*	***Concentrate prey***
TURB	*Turbulence ([m/s]^3)*	
THERM	*Thermocline depth (m)*	
UP	*10 days prior cumulative upwelling index (m^3/s per 100 km coastline)*	
CHL	*Chlorophyll at surface (mg/m^3)*	***Upwelling associations***
TEMP	*Sea surface temperature at surface (˚C)*	
FL	*Fork length (mm)*	***Ontogeny***
DEN	*Number of salmon in tow*	***Competition***

Results: annual

Salmon had fuller stomachs in the summer in years with more forage in the spring



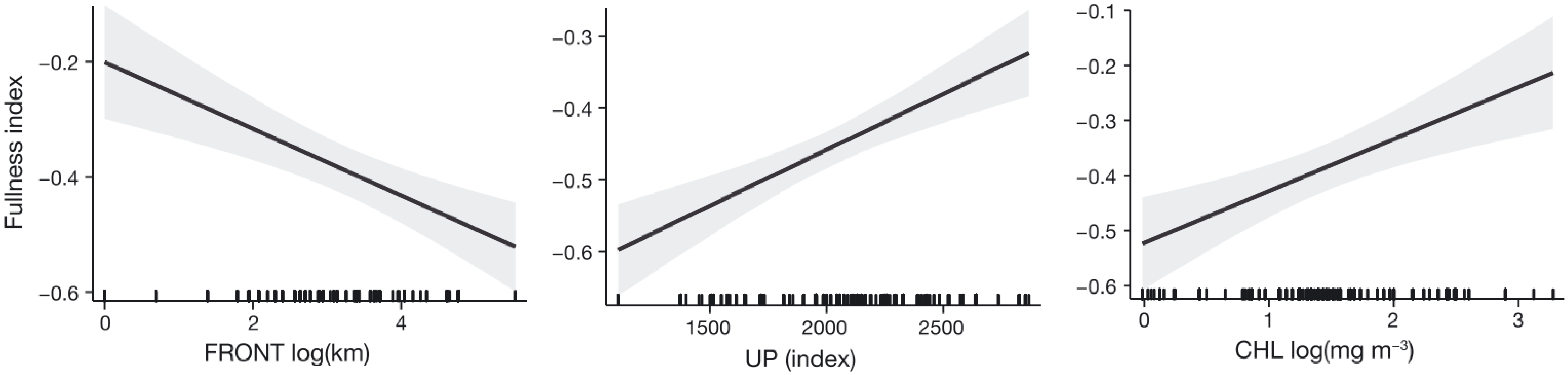


- What happened in 2014 & 2015?! (Warm Blob)
  - Prey base changed → opportunistic salmon
  - Need to eat more when warm
  - Locations of salmon capture were NOT warm
  - Upwelling provides cool refugia?

Results: event

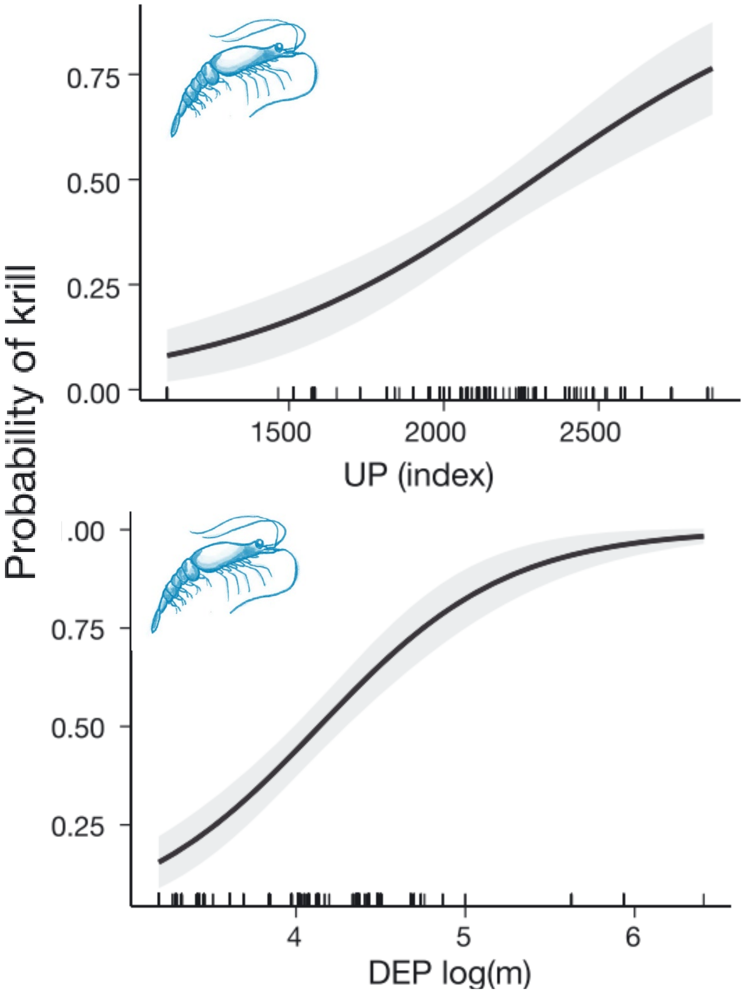
Salmon had fuller stomachs after recent upwelling, with high chlorophyll, and closer to thermal fronts

- Increased **productivity** noted by recent upwelling and chlorophyll
- Increased **retention** of recently upwelled water and near thermal fronts

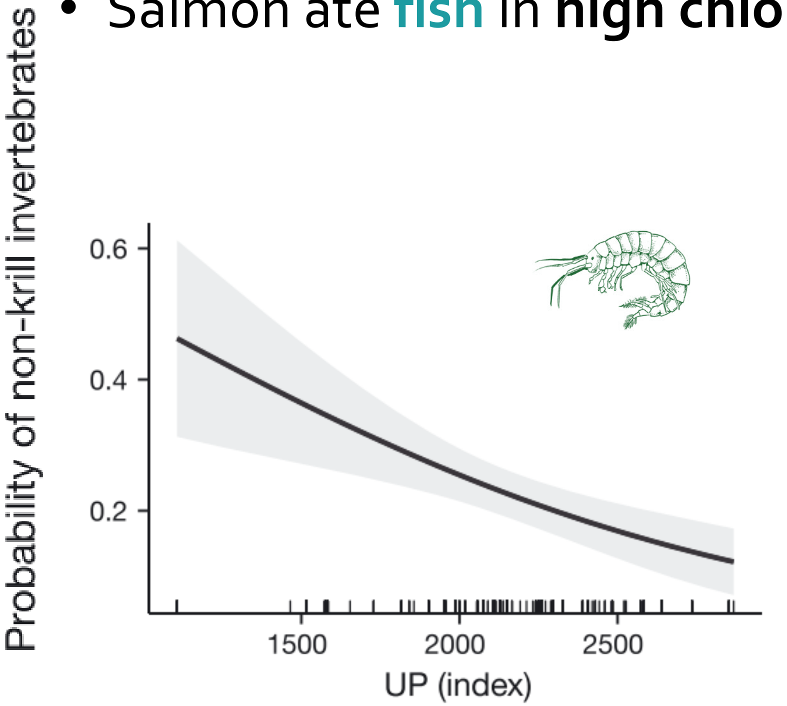


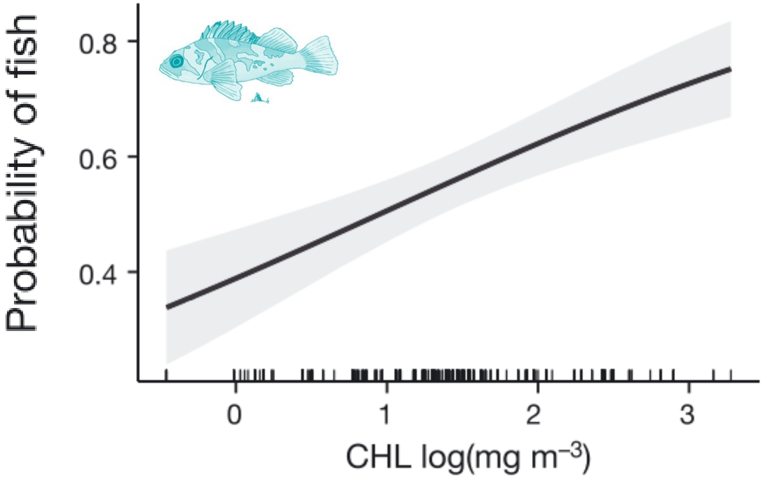
Results: event

Salmon diet composition fit known habitat associations of prey



- Salmon ate **krill** after **recent upwelling** in **deep water**
- Salmon ate **non-krill invertebrates** after **low recent upwelling**
- Salmon ate **fish** in **high chlorophyll** water

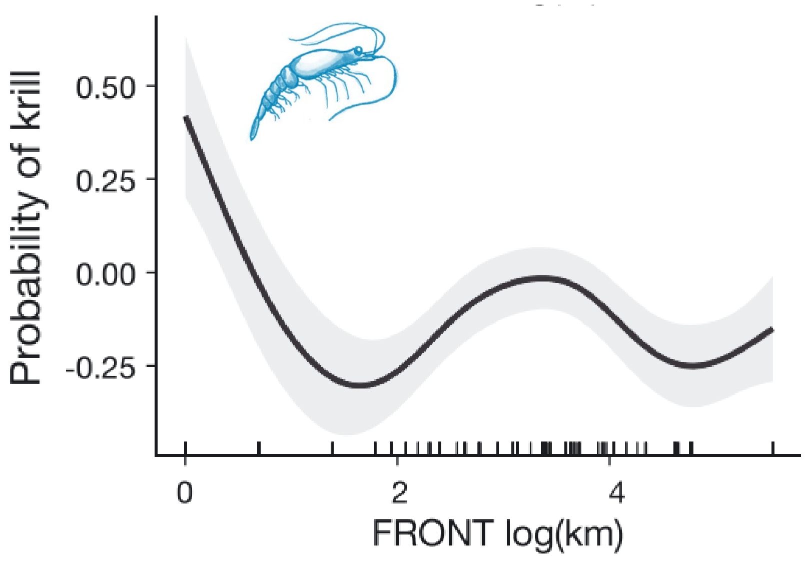




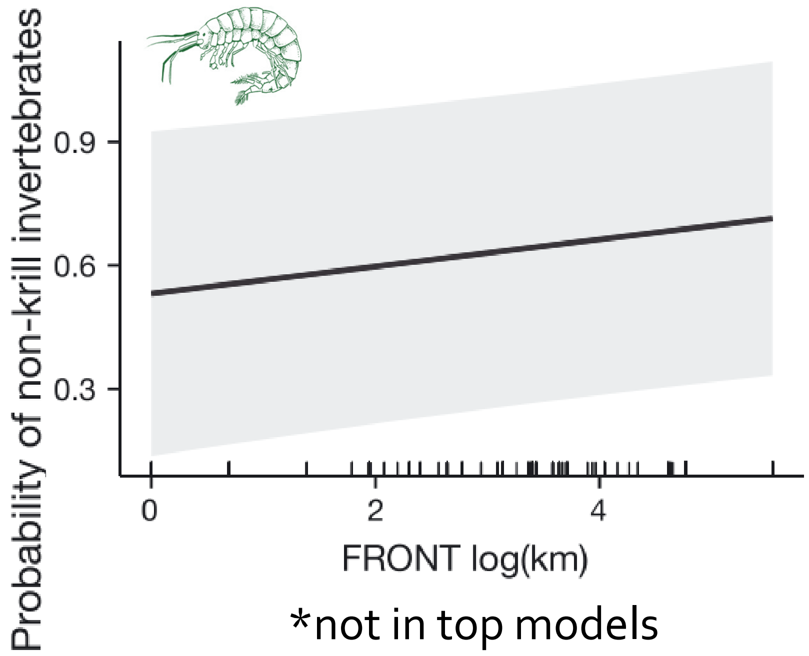
Results: event

Salmon ate less fish and more krill near thermal fronts

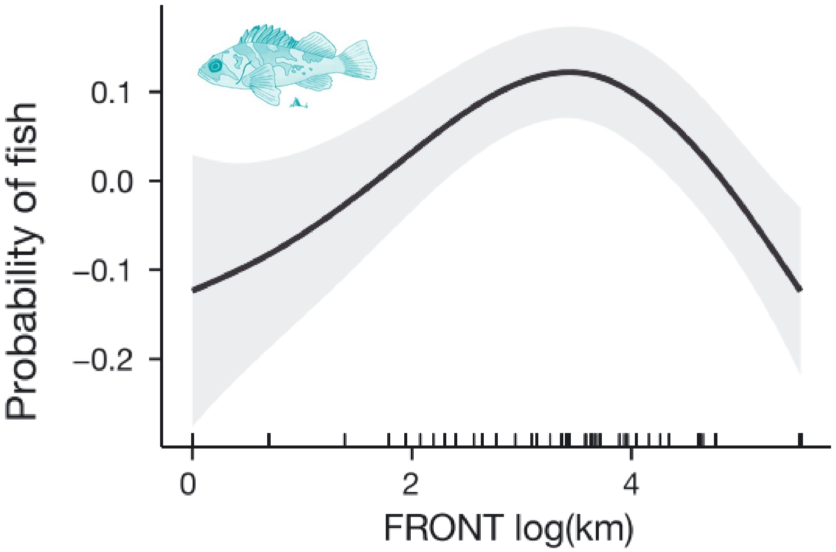
- Evidence that all prey can be concentrated near fronts
- Perhaps salmon prefer krill when concentrated?



*not in top models



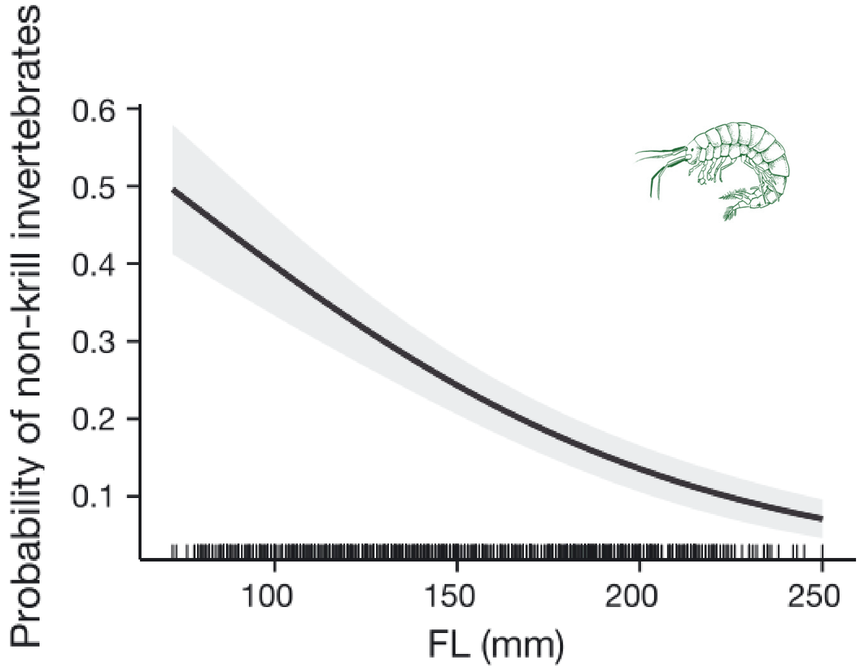
*not in top models

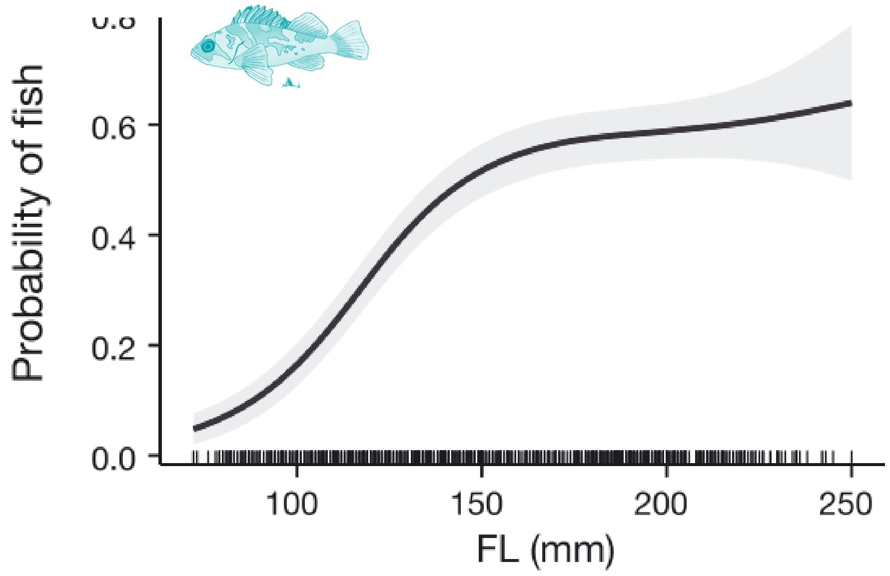


*YES in top models

Results: event

Salmon ate more fish, less non-krill invertebrates, and equal amounts of krill with ontogeny





Conclusions

- **Broad** and **local** seascape processes influence salmon foraging
- **Annual** processes affect overall **productivity (how much food)**
- **Local** processes affect **distribution of prey (accessibility of food)**

Seascape *→* ***Salmon foraging*** *→ Growth → Survival → Adult returns*

Implications: salmon in a changing world

- Flexible foragers = costs? resilience?
- Upwelling as thermal refugia
  - Variable patterns across latitude (CA vs. OR)
- Consequences difficult to predict?
  - Broad x local processes

Current postdoctoral research

- Michael Banks (OSU), Taal Levi (OSU), Kate Richerson (NOAA)

- **How does the environment modify Chinook bycatch in the hake fishery?**

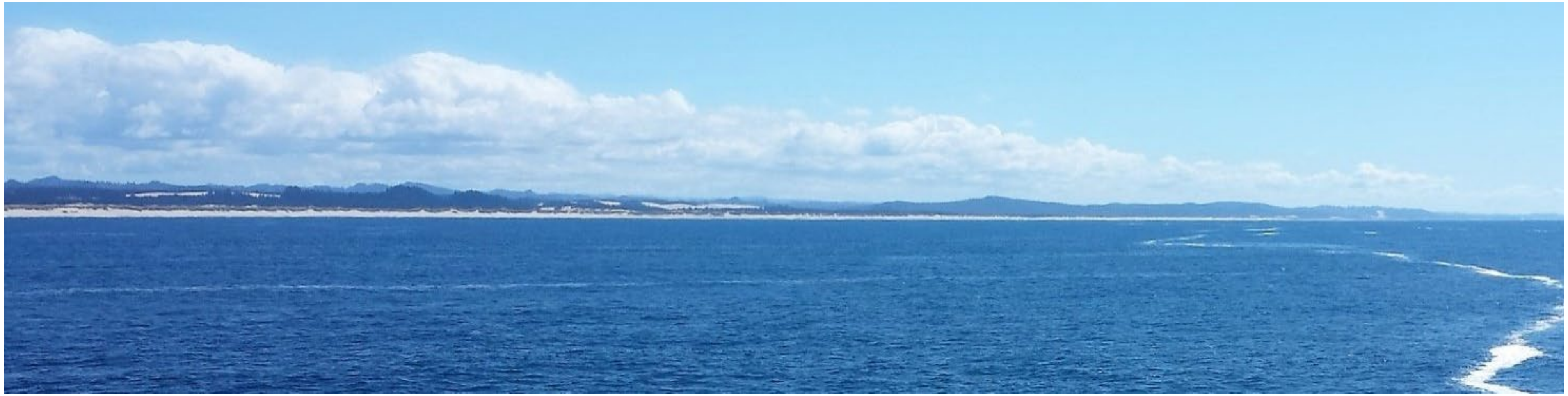
- Warm water → Chinook & hake distributions → exacerbate bycatch?

- Are Chinook stocks differentially affected? Does this present tradeoffs to managers?

megan.sabal@oregonstate.edu

Thank you! Questions?

Sabal et al. (2020) Marine Ecology Progress Series.
California Current seascape influences juvenile salmon foraging ecology at multiple scales



Acknowledgements

All past crews of Salmon Ocean Surveys and Rockfish Recruitment and Ecosystem Assessment Surveys

Funding by CDFW and Delta Science Fellowship (via the State Water Control Board)

megan.sabal@oregonstate.edu

Methods: generalized additive models (GAMs) & AICc model selection

	Model response variable	Data subset	Full model covariates	Random effect	Offset
annual	Mean fullness index	n = 923	FORAGE + PCUI + MEI + STDATE		
event					

Methods: model covariates (annual)

PCUI *Preconditioning upwelling index*

- Sum of positive daily mean upwelling indices through Jan and Feb at 39˚ N (Schroeder et al. 2013)

STDATE *Spring transition date*

- The day where the cumulative coastal upwelling index at 39˚ N first starts increasing (Bograd et al. 2009)

FORAGE *Salmon prey abundance index*

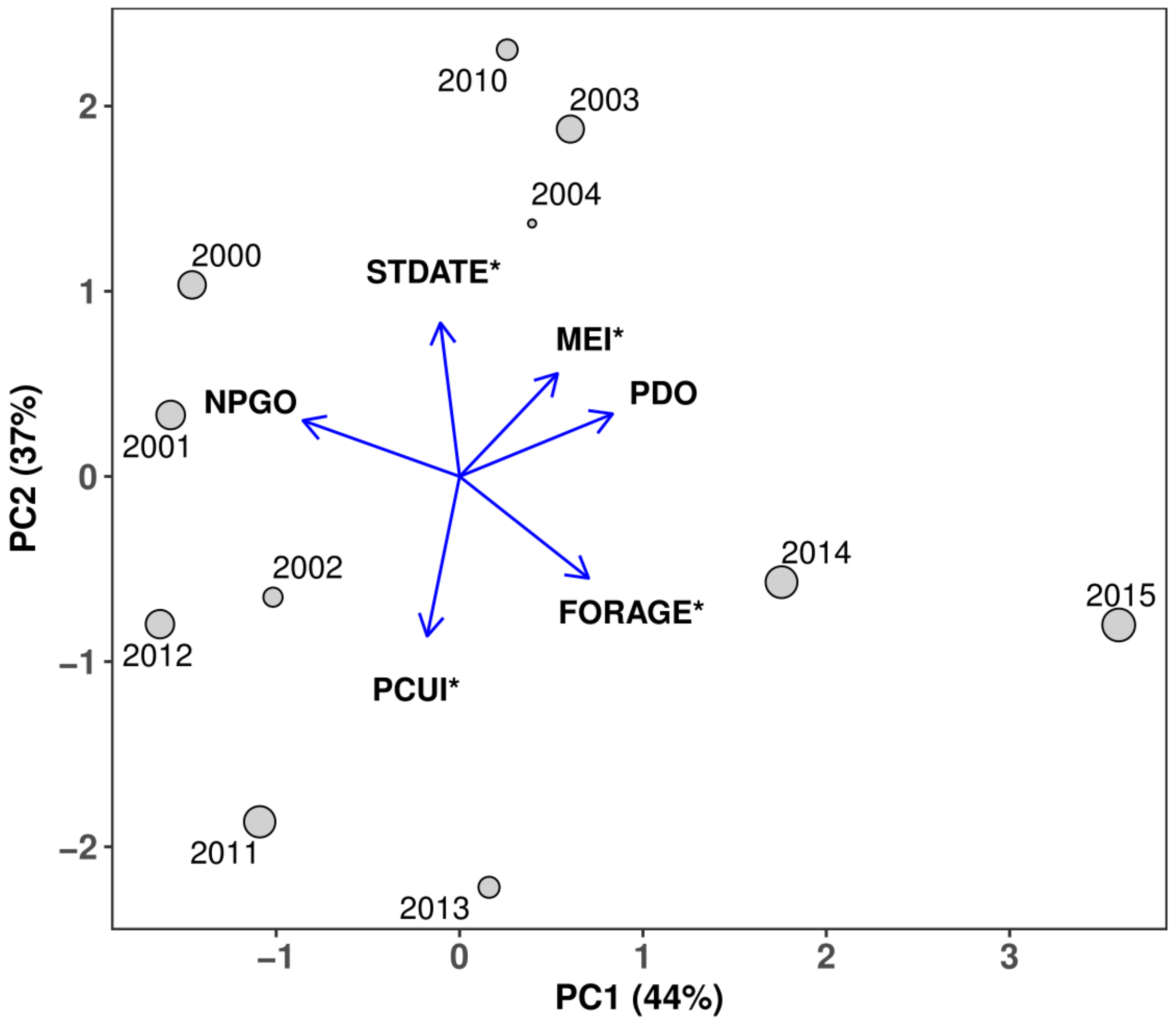
- Summed relative abundances from May Midwater trawl cruise

MEI *Multivariate El Niño Southern Oscillation Index*

- Winter (Jan-Mar) monthly average

PDO *Pacific Decadal Oscillation*

NPGO *North Pacific Gyre Oscillation*



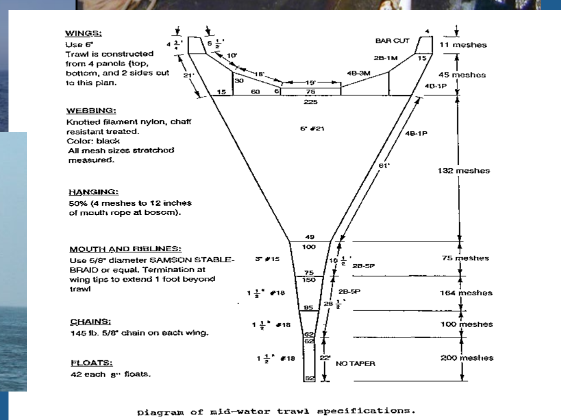
The pelagic juvenile rockfish survey in your backyard: linking forage variability to salmon in the California Current

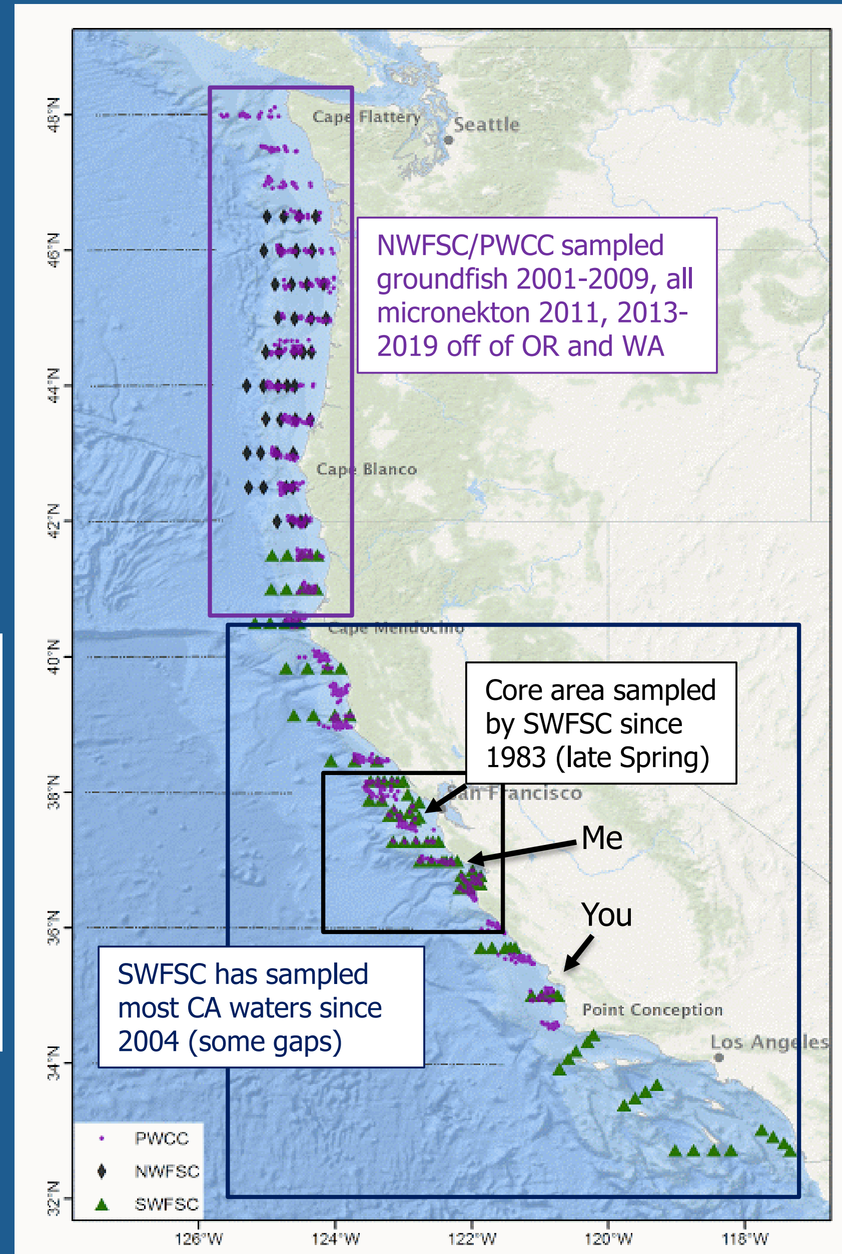
John Field, Jarrod Santora, Tanya Rogers, Keith Sakuma, Rebecca Miller, Brian Wells and many others!!

Fisheries Ecology Division
Southwest Fisheries Science Center
NMFS/NOAA

NOAA FISHERIES

Rockfish Recruitment and Ecosystem Assessment Survey

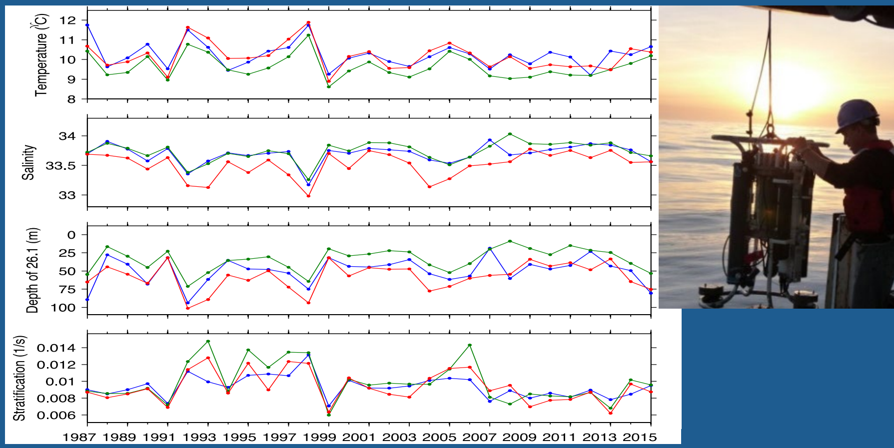




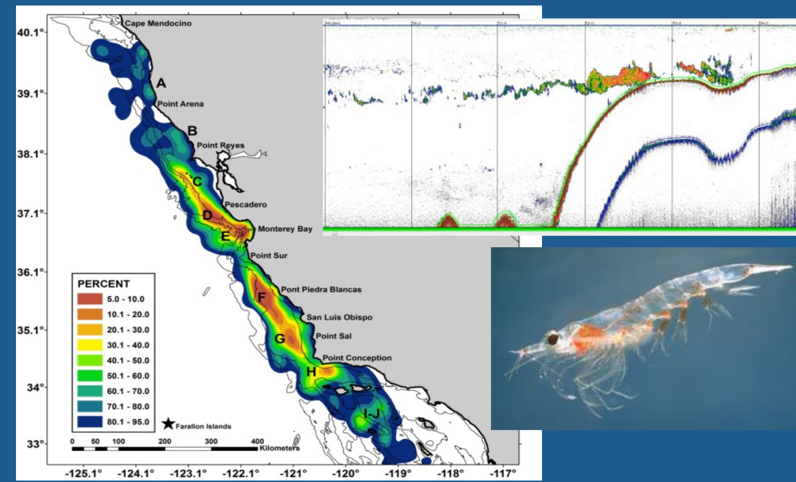
Midwater trawling conducted at night, at 30 meters headrope depth, using a modified Cobb trawl with 3/8” codend liner, towed at 2 knots (smaller, slower than Nordic rope trawl)

NOAA FISHERIES

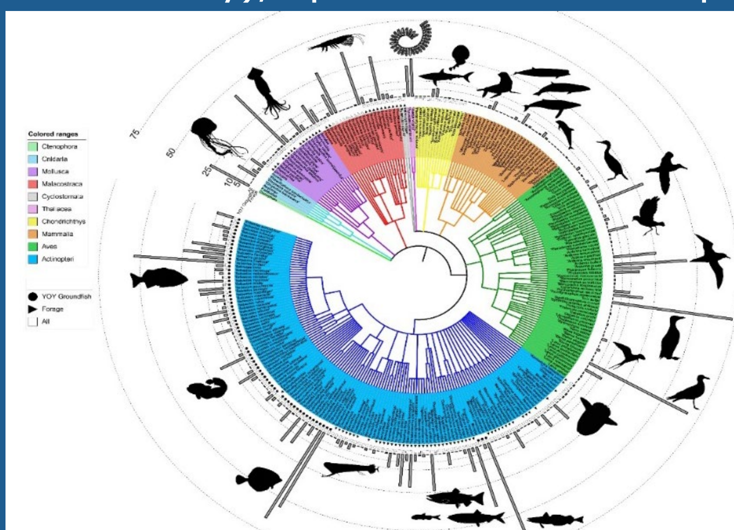
In addition, survey collects a suite of physical and biological observations



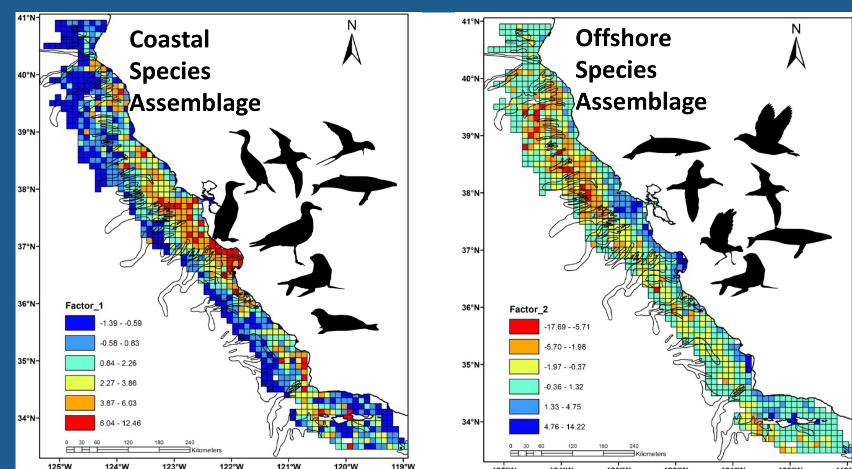
Physical and biological oceanography (CTD and Fluorometry), upwards of 300 casts per year



Acoustic estimates of abundance and distribution of krill and other micronekton



Environmental DNA and biodiversity studies



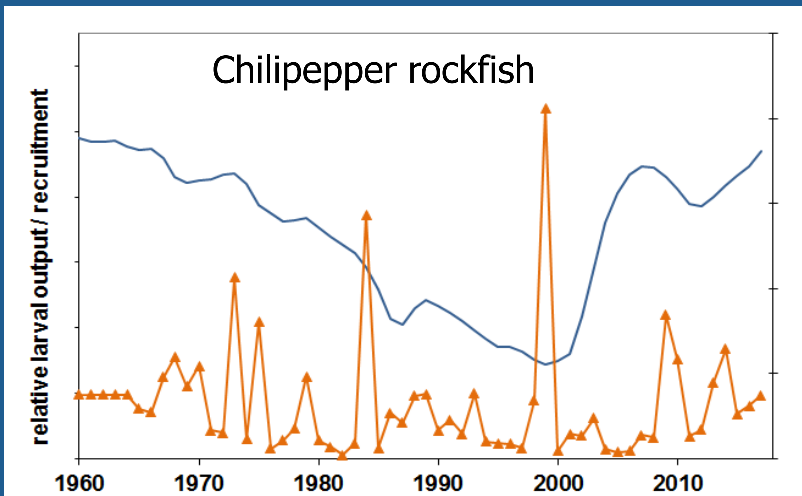
Daytime seabird and marine mammal observations (data back to 1983)

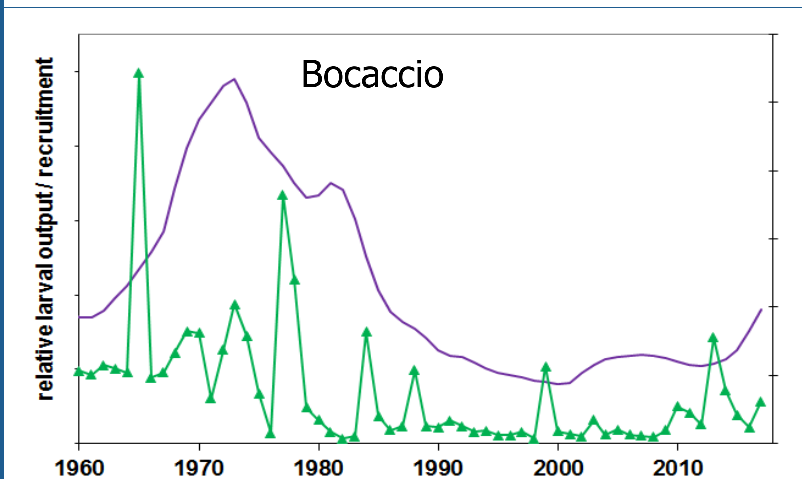
Rockfish recruitment survey and studies- multiple objectives

- Develop estimates of abundance for Young-of-the-Year (YOY) rockfish and other species as pre-recruit indices in stock assessments (Assessment survey)
- Improve our understand of the physical and biological factors that lead to strong or weak year classes (Fisheries Oceanography, Process Studies)
- Improve our understanding of the spatial and temporal variability in the micronekton (forage) assemblage, and impacts to predators (such as salmon!), as related to climate and ocean conditions (Ecosystem Oceanography)

Why does rockfish recruitment matter?

Population dynamics, productivity



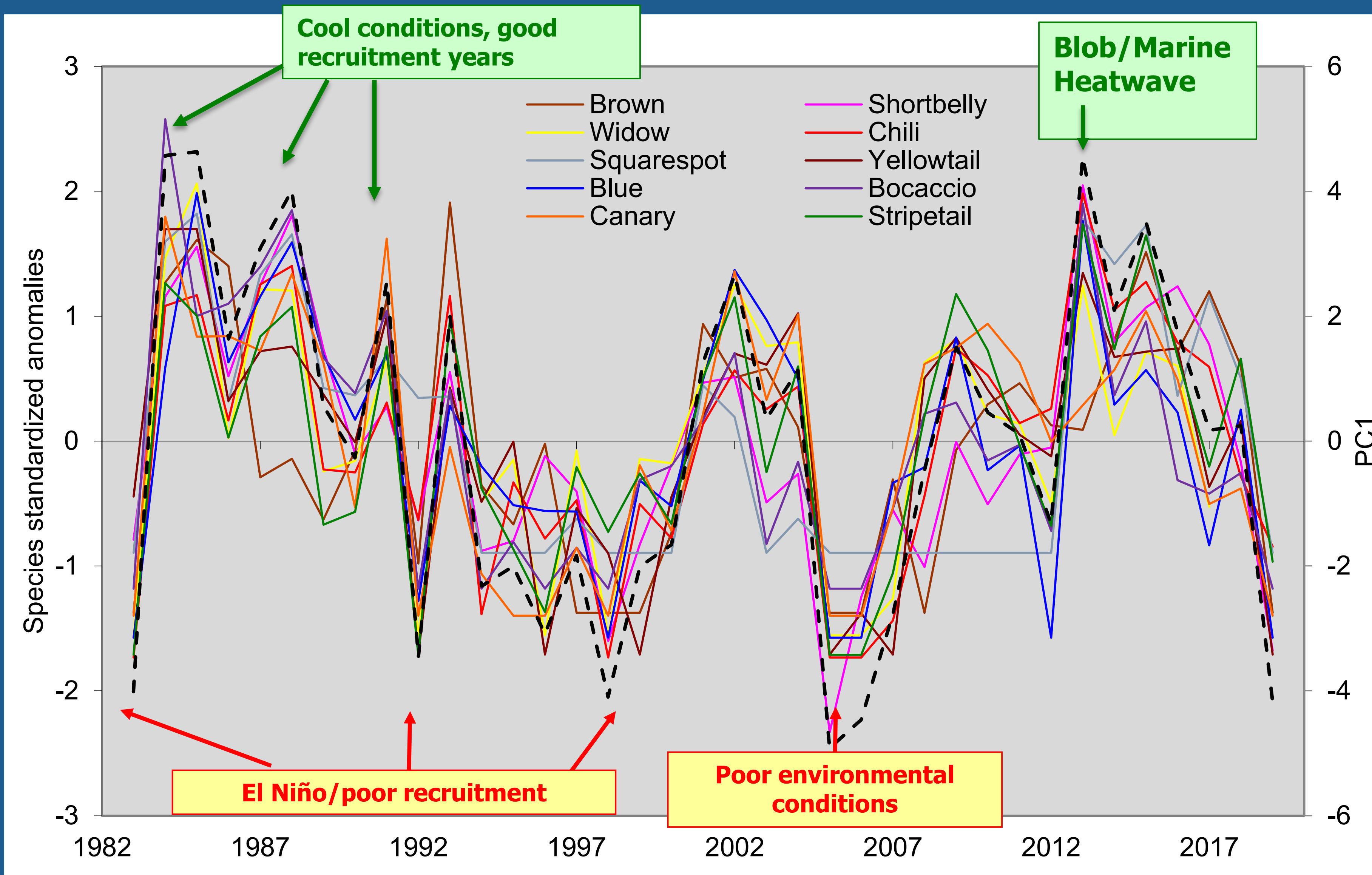


Key forage for predators

Table 2
Forage categories and summaries of their occurrence in the databas
percentage for number of predators eating different prey taxa (highe

Prey Category Scientific Name	Prey Common Name	Number of Predators
Sebastes spp.	rockfishes	61
Engraulis mordax[a]	northern anchovy	57
Euphausiacea	krill	56
Clupea pallasii[a]	Pacific herring	52
Loligo opalescens	market squid	51
Pleuronectidae[a]	righteye flounders	41
Myctophidae	lanternfishes	40
Cottidae	sculpins	40
Citharichthys spp.[a]	sanddabs (lefteye flounder)	39
Gonatidae[b]	gonatid squid	38
Embiotocidae	surfperches	37
Merluccius productus	Pacific hake	35
Cololabis saira	Pacific saury	34
Osmeridae	smelts	33
Sardinops sagax[a,c]	Pacific sardine	32

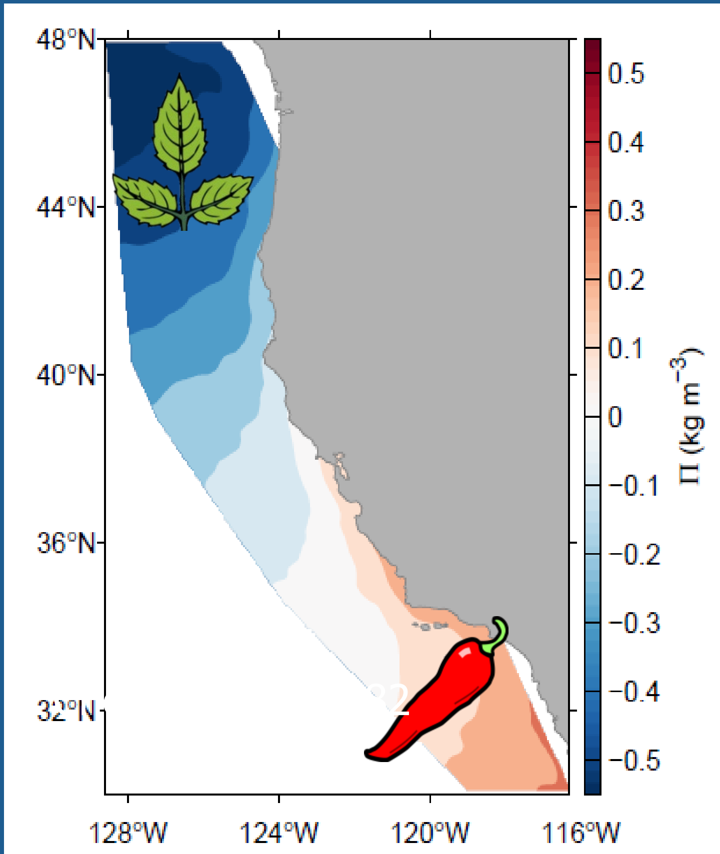
(Chilipepper stock assessment, Field et al. 2015, Bocaccio stock assessment, He et al. 2017, forage, Szoboszlai et al. 2015)

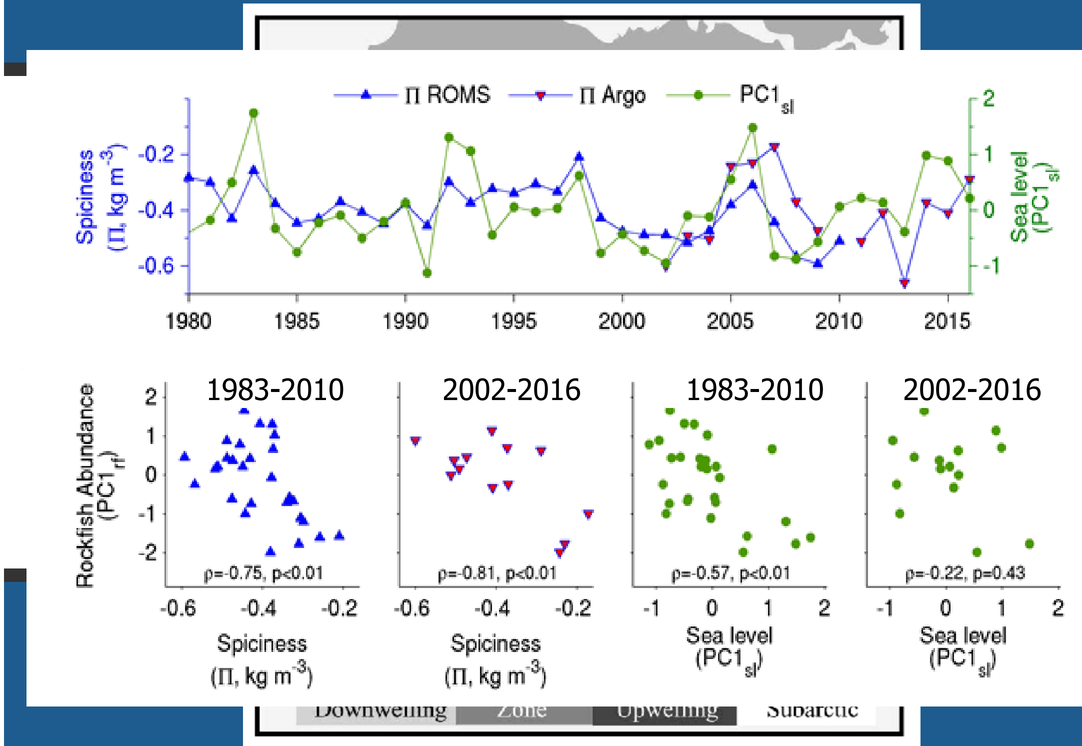


Covariation in abundance of 10 most frequently occurring YOY rockfish

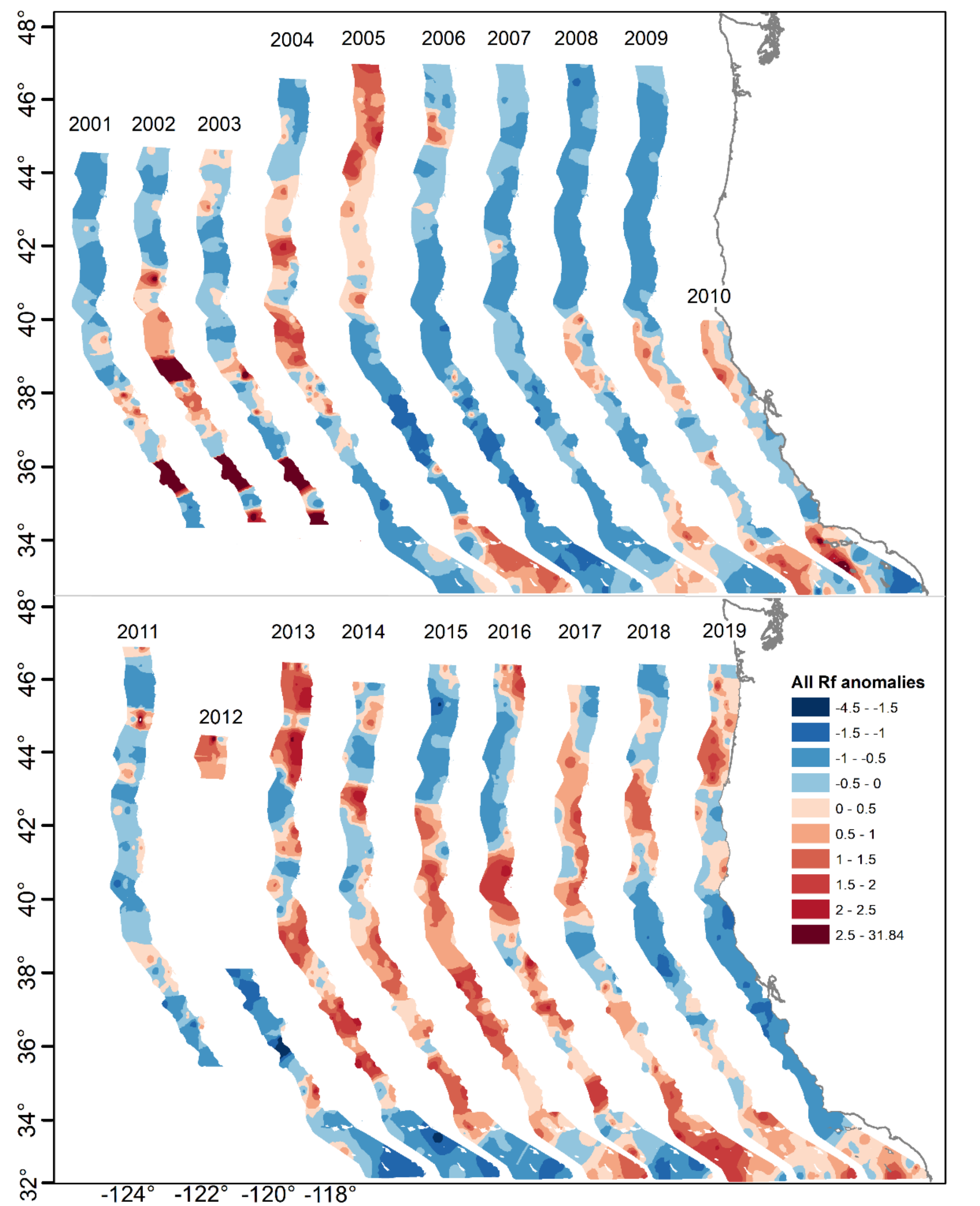
NOAA FISHERIES

(Updated from Ralston et al. 2013)





Changes in relative sea level have long been known to track geostrophic flow, an indicator of the transport and productivity in the California Current. Ralston et al. (2013) found that relative sea level had the strongest relationship to common trend of juvenile rockfish. More recently Schroeder et al. (2019) provided the basis for linking recruitment to “subarctic” versus “equatorial” source waters (at depth).



With the coastwide survey data, we have also worked to quantify and understand interannual shifts in the distribution of YOY rockfish (shown) and other forage taxa.

In general, results suggest that there is a fair amount of coastwide coherence in relative abundance trends, but also a fair amount of variability, with regions north and south of the major promontories (Cape Mendocino, Cape Blanco, Point Conception) showing the greatest regional variability (Field et al. 2021).

Unfortunately, only the YOY groundfish data are available prior to 2011…

Rockfish recruitment survey and studies- multiple objectives

- Improve our understand of the physical and biological ecosystem factors that lead to strong or weak year classes (Fisheries Oceanography)
- Develop estimates of abundance for Young-of-the-Year (YOY) rockfish and other species as pre-recruit indices in stock assessments (Assessment survey)
- **To improve our understanding of the spatial and temporal variability in the micronekton (forage) assemblage, and impacts to predators (such as salmon!), as related to climate and ocean conditions (Ecosystem Oceanography)**

The Epipelagic Micronekton community: Forage!

Contents lists available at ScienceDirect

Ecological Informatics

journal homepage: www.elsevier.com/locate/ecolinf

ELSEVIER

Forage species in predator diets: Synthesis of data from the California Current

Amber I. Szoboszlai [a,*], Julie A. Thayer [a], Spencer A. Wood [b,c], William J. Sydeman [a], Laura E. Koehn [d]

[a] Farallon Institute for Advanced Ecosystem Research, 101 H Street Suite Q, Petaluma, CA 94952, USA
[b] School of Environment and Forest Sciences, University of Washington, Box 352100, Seattle, WA 98195, USA
[c] Woods Institute for the Environment, Stanford University, Stanford, CA 94305, USA
[d] School of Aquatic and Fishery Sciences, University of Washington, Box 355020, Seattle, WA 98195, USA

ARTICLE INFO

Article history:
Received 15 April 2015

ABSTRACT

Characterization of the diets of upper-tro[p]
in the development of ecosystem-based

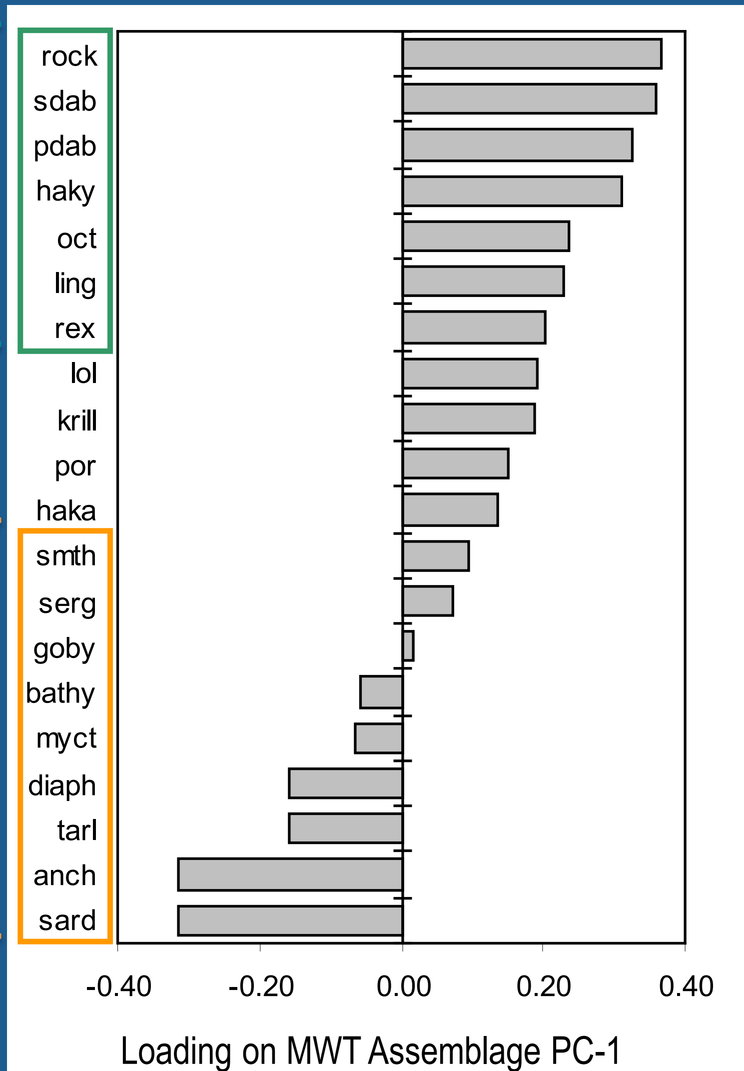
Table 2
Forage categories and summaries of their occurrence in the database, arranged by descending number of predators and percentage for number of predators eating different prey taxa (highest (51–61 predators), high (32–41), intermediate (2

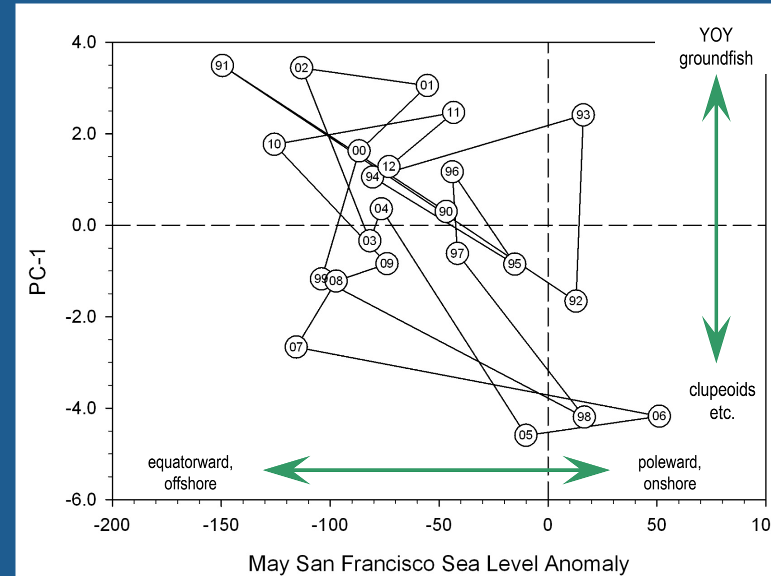
Prey Category Scientific Name	Prey Common Name	Number of Predators	Number of Predator Samples[d]	Number of Citations w/ Prey in Diet
Sebastes spp.	rockfishes	61	-	97
Engraulis mordax[a]	northern anchovy	57	92,479	91
Euphausiacea	krill	56	-	66
Clupea pallasii[a]	Pacific herring	52	103,019	85
Loligo opalescens	market squid	51	59,821	69
Pleuronectidae[a]	righteye flounders	41	-	58
Myctophidae	lanternfishes	40	-	39
Cottidae	sculpins	40	-	60
Citharichthys spp.[a]	sanddabs (lefteye flounder)	39	-	46
Gonatidae[b]	gonatid squid	38	-	43
Embiotocidae	surfperches	37	-	63
Merluccius productus	Pacific hake	35	46,471	64
Cololabis saira	Pacific saury	34	22,751	39
Osmeridae	smelts	33	-	62
Sardinops sagax[a,c]	Pacific sardine	32	22,936	43
Ammodytes hexapterus	Pacific sandlance	32	102,399	56
Cancridae	rock crabs	30	-	20
Gadidae	codfishes	29	-	42
Octopodidae	octopods	27	-	42
Pandalidae[b]	pandalid shrimp	27	-	24

Survey collects pretty good data on 11 of the top 20 forage components in the California Current, including 8 of the top 10 (Szoboszlai et al. 2015)

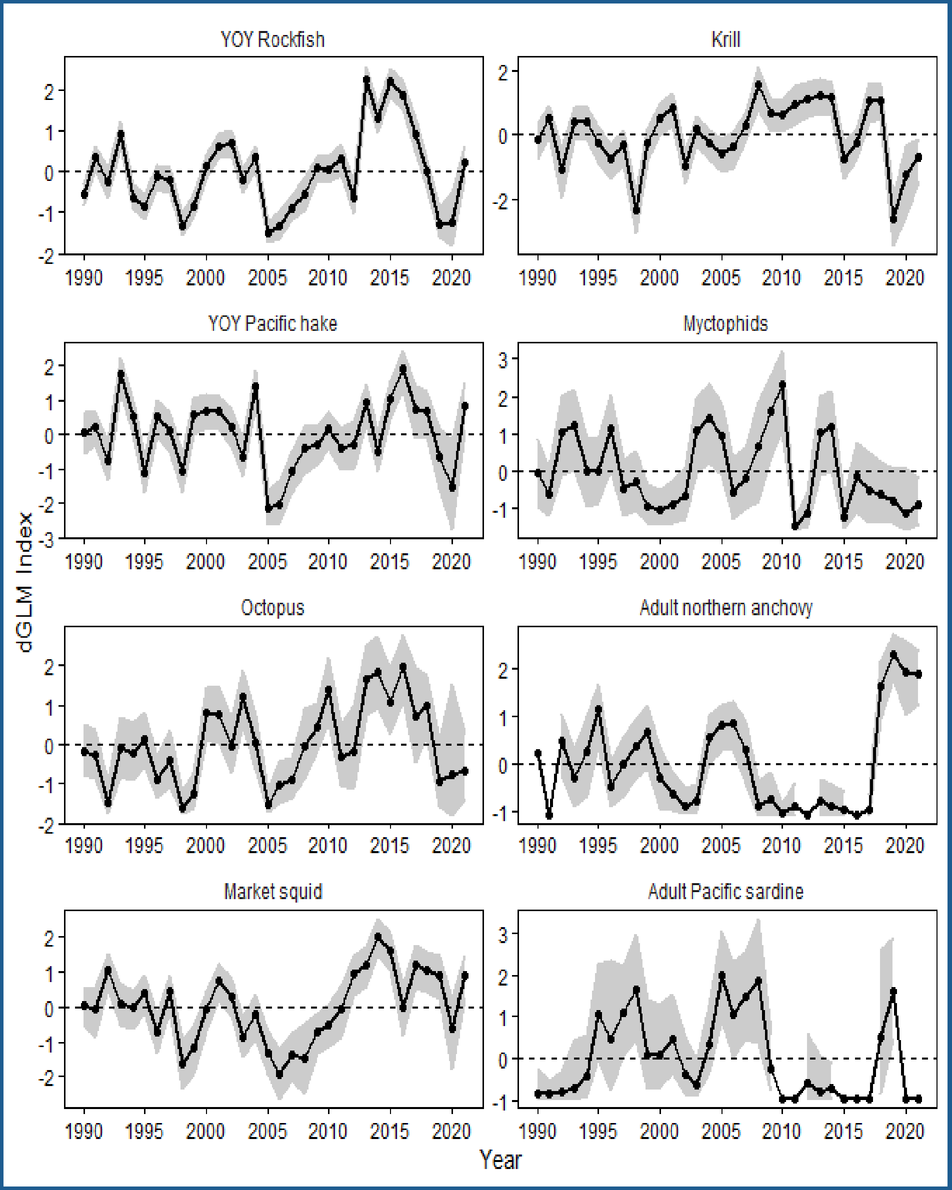
Young-of-year ground fish

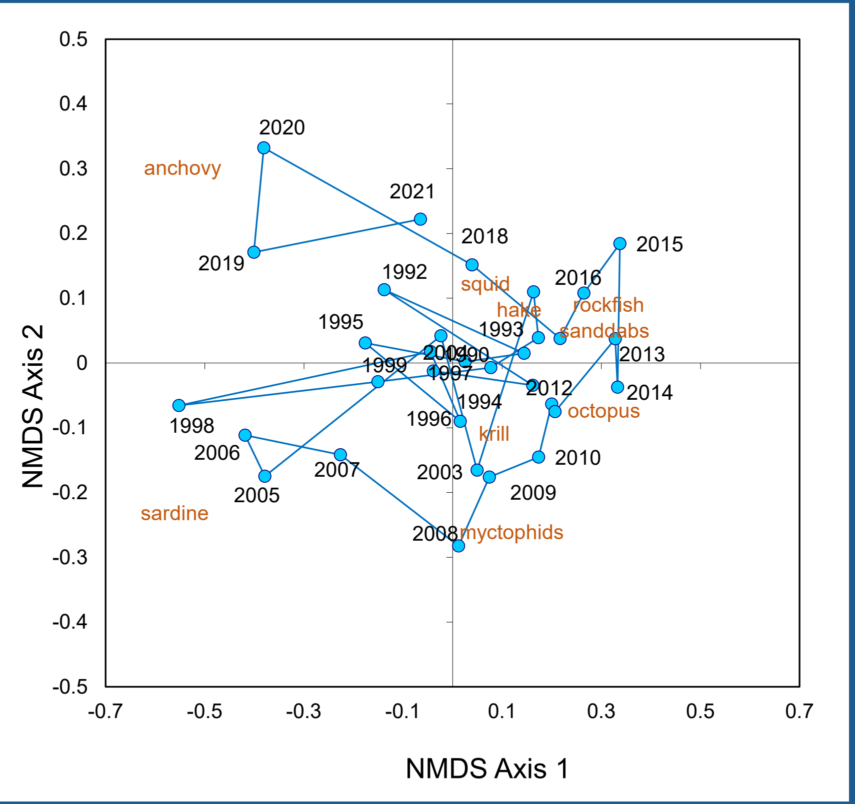
Coastal pelagics and deep scattering layer



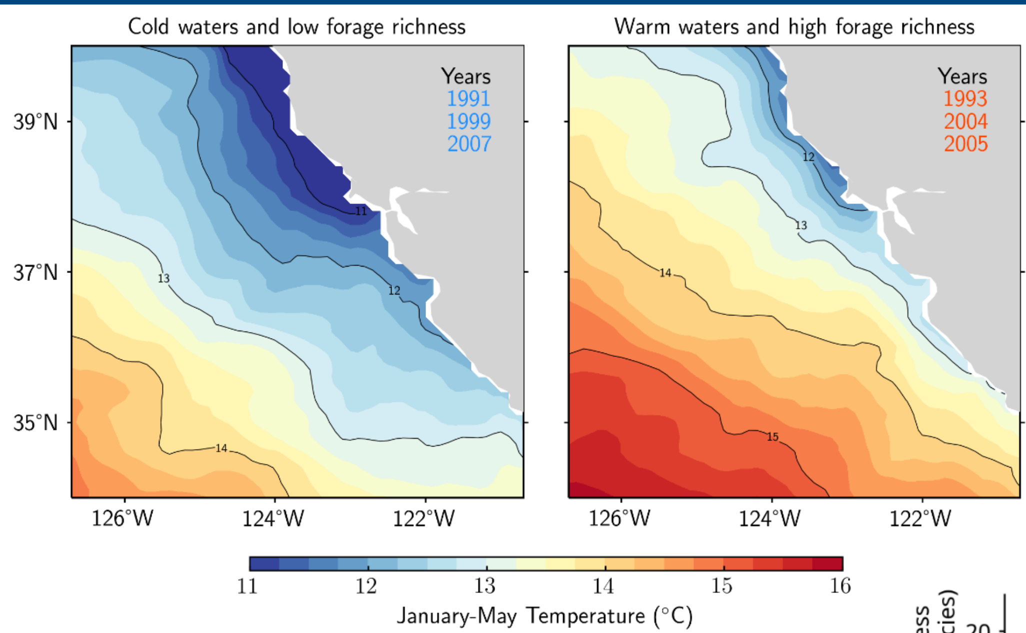


Ralston et al. (2015) showed that, similar to rockfish, much of the forage assemblage in the core (Central California) region also varies in response to sea level.

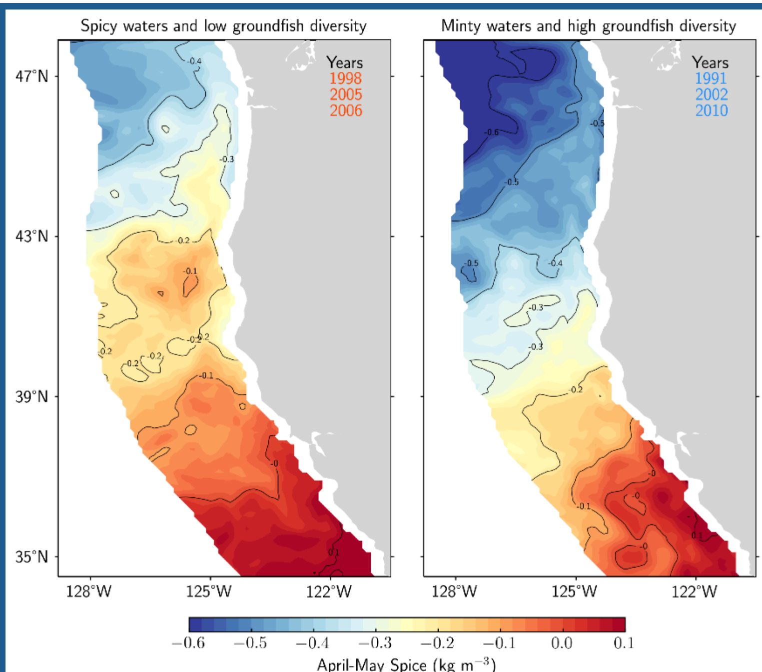


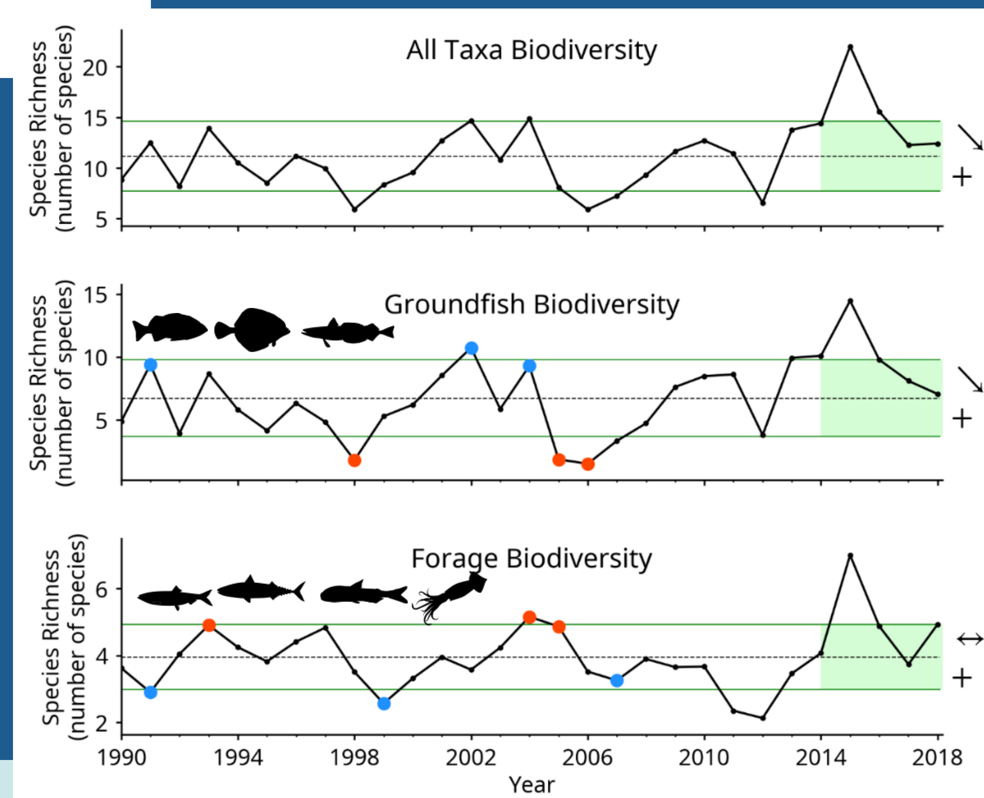


Non-metric multidimensional scaling analysis of forage time series show shift between forage species assemblages



We have also developed indices of forage community diversity. These indices also relate to large scale patterns of temperature and source waters (Santora et al. 2017).





Friedman et al. (2018) took a closer look at a larger number of forage taxa that are known juvenile chinook salmon prey. Using coastwide data from more taxa (~30) at a finer spatial scale is consistent with these results, but suggests more complexity in the structure of forage communities, a more complex suite of oceanographic drivers (Friedman et al. 2018).

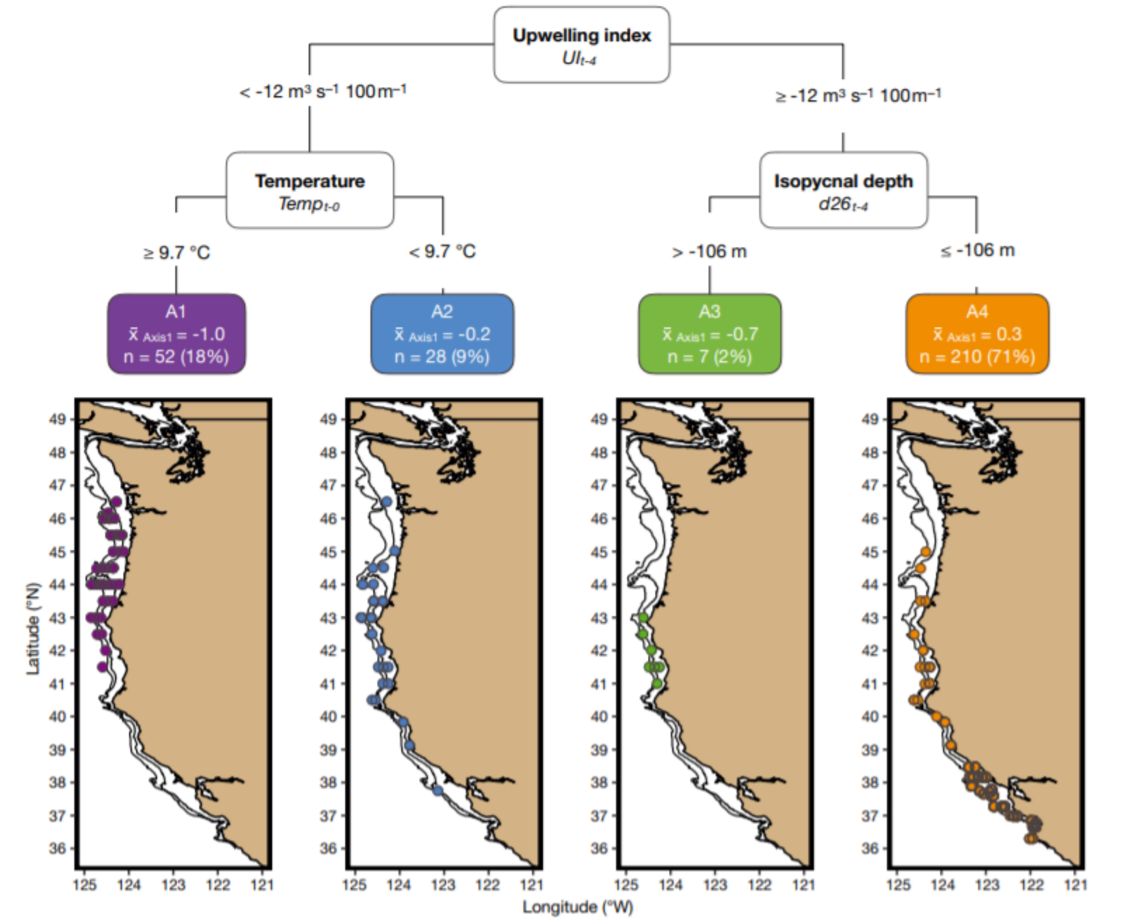
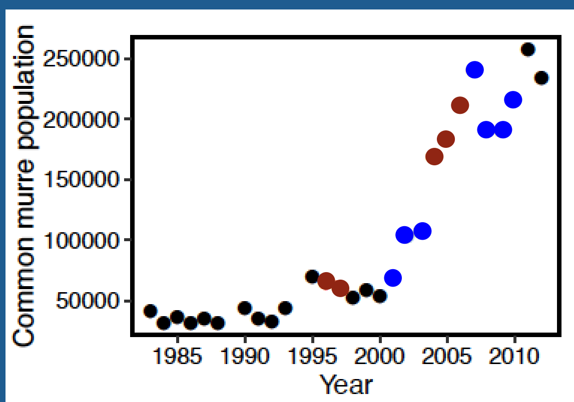
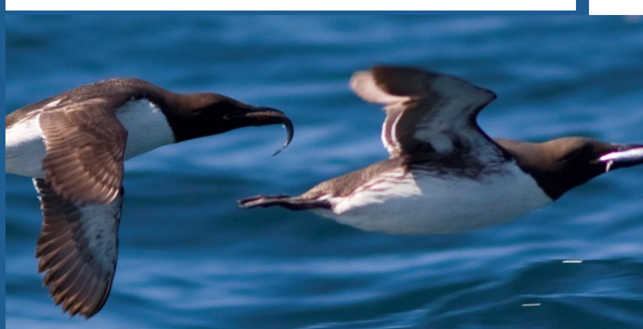


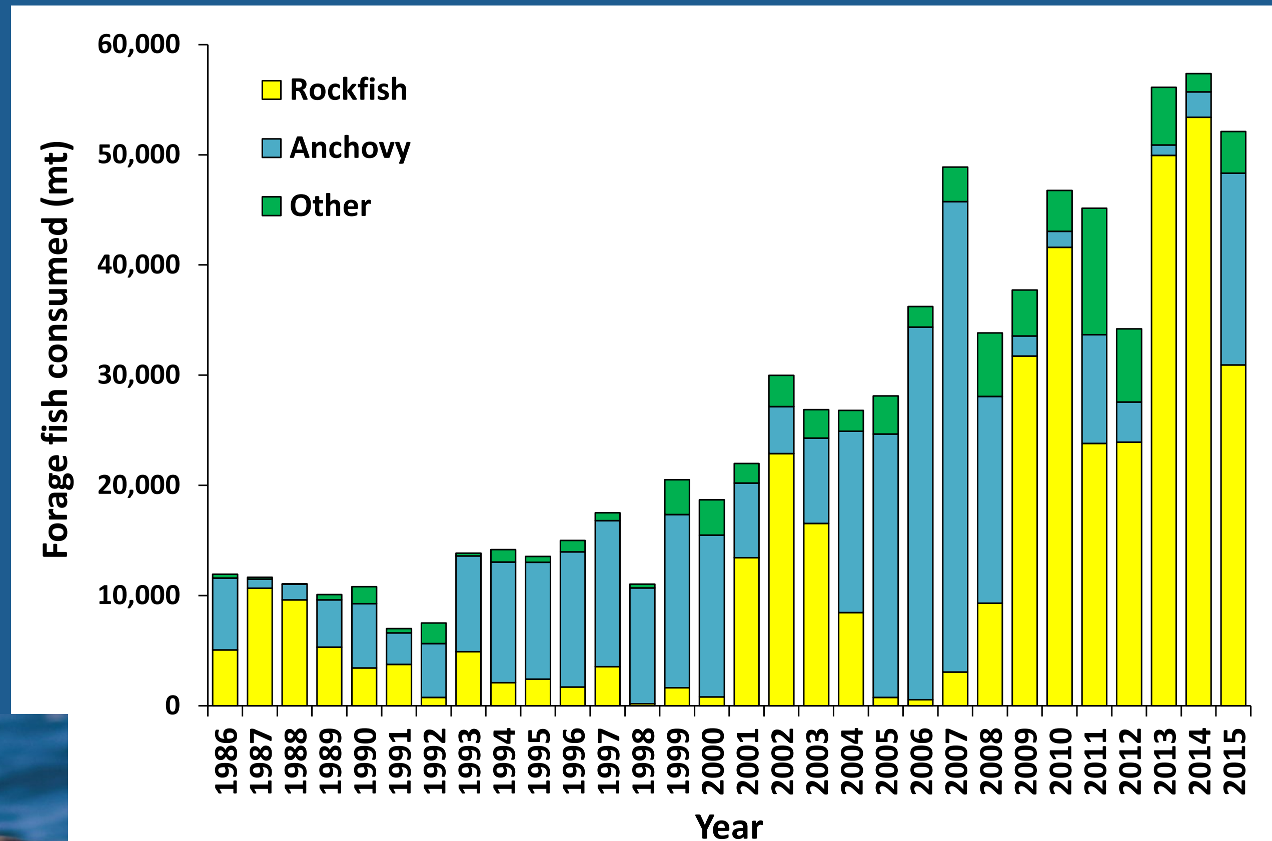
Fig. 3. Four assemblage types (A1–A4) based on regression tree analysis of non-metric multidimensional scaling axis 1 scores. Values in the colored boxes represent mean axis scores and number and percentage of samples allocated to each assemblage type. Maps show individual trawls for each assemblage type. Further detail on these assemblages can be found in Tables 1 & 3

NOAA FISHERIES

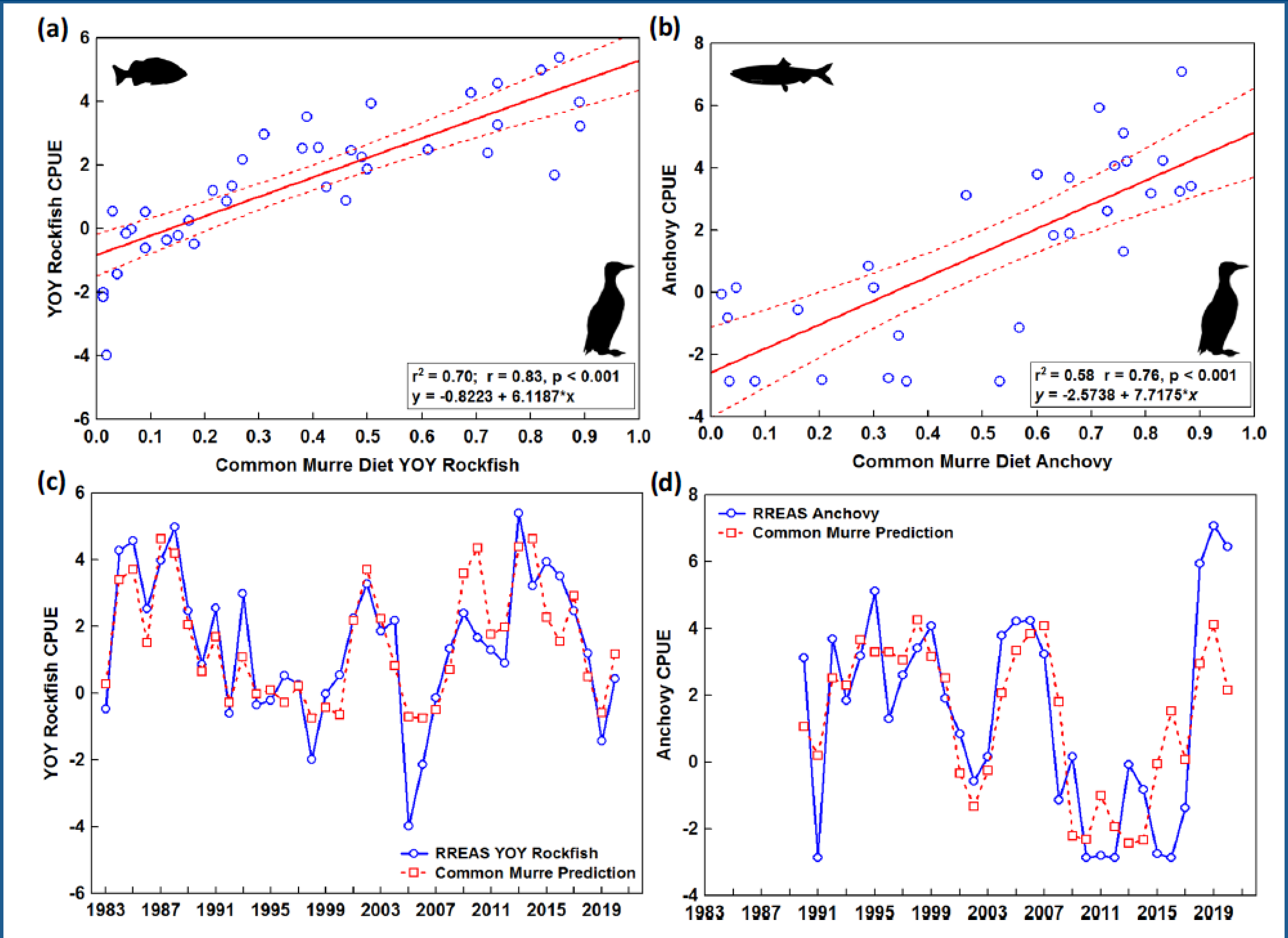
What we see in the survey also relates very strongly to what predators in this ecosystem are eating!



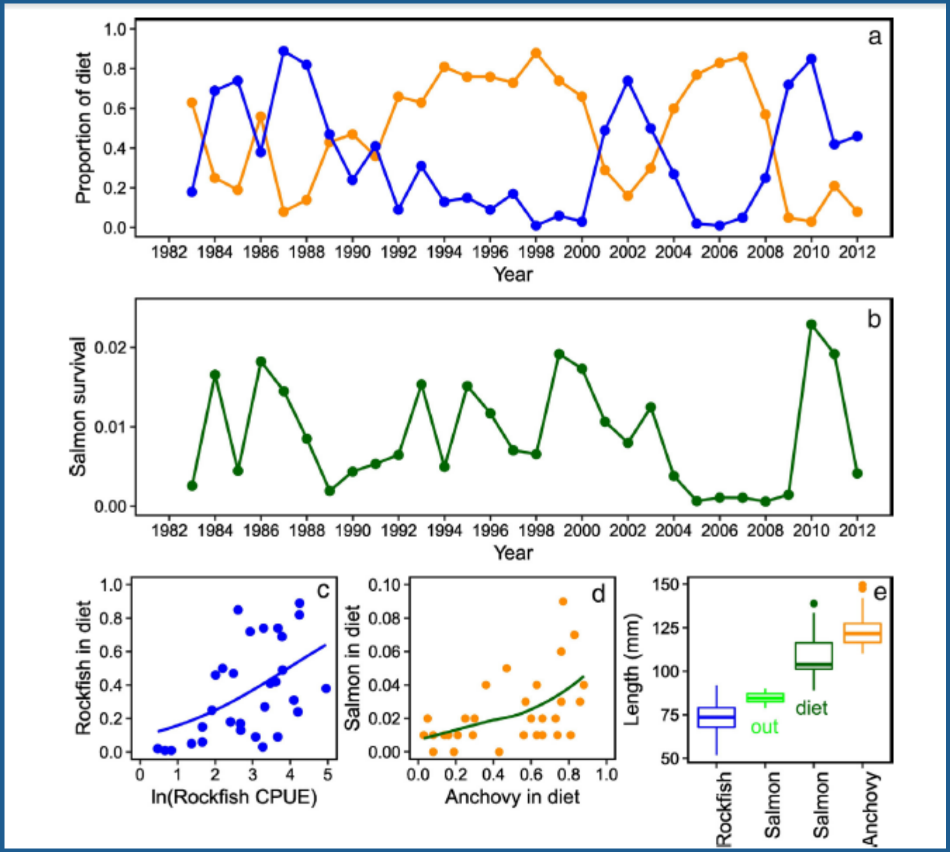


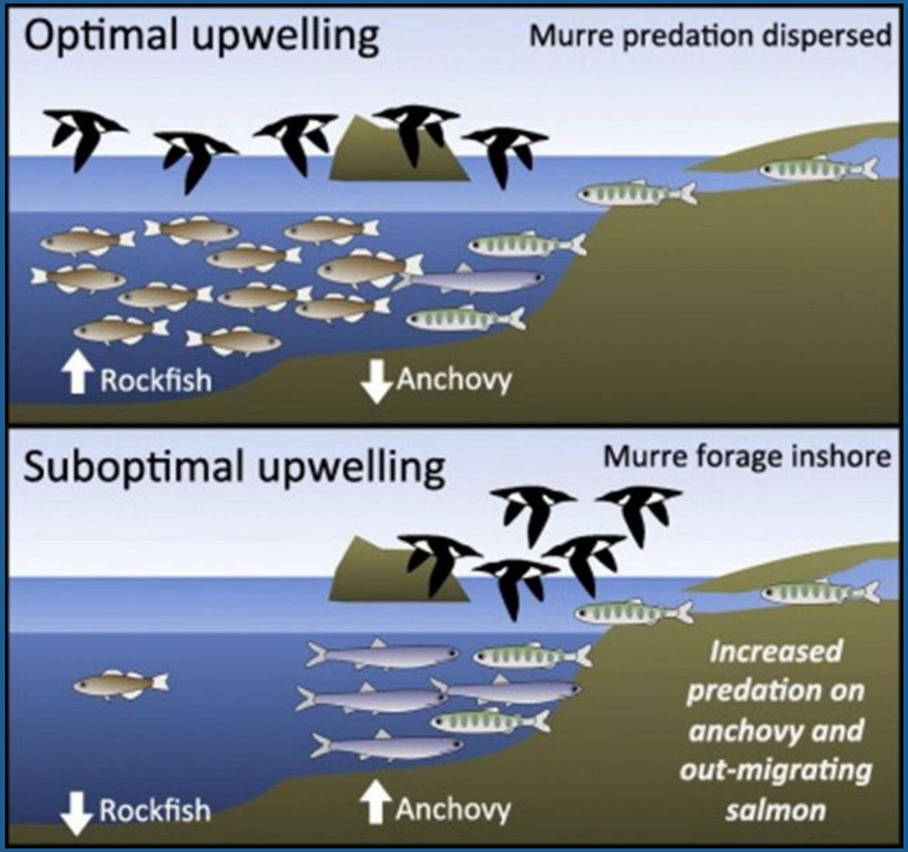


Warzybok et al. JMS 2018

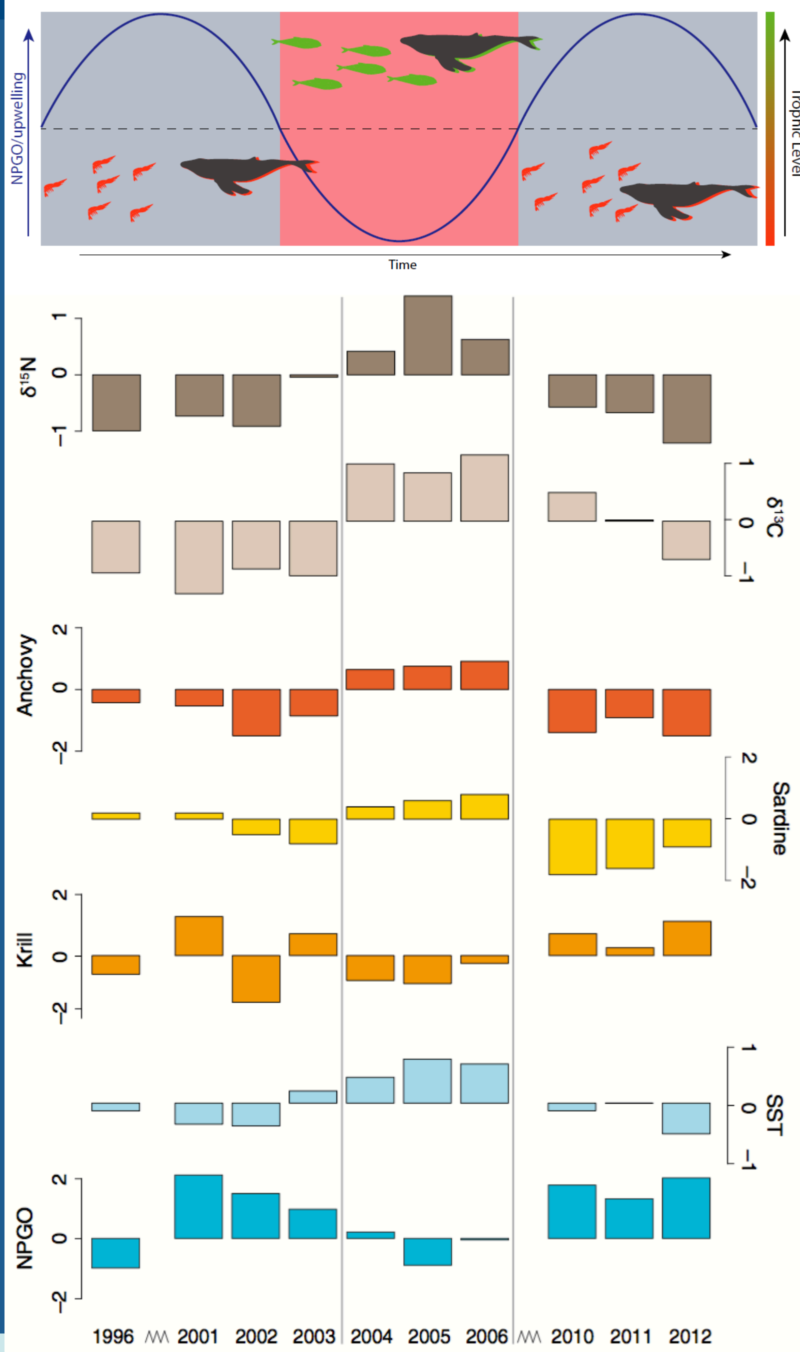


A closer look at the relationship between Common Murre diet and survey relative abundance indices (Santora et al. 2021)





Seabird prey switching between rockfish and anchovy can lead to complex ecosystem interactions. During years of low rockfish abundance, Common Murres will fly further from their colonies to forage on anchovy, where they encounter more juvenile salmon. Years of higher predation on anchovy are associated with lower salmon survival (Wells et al. 2017).



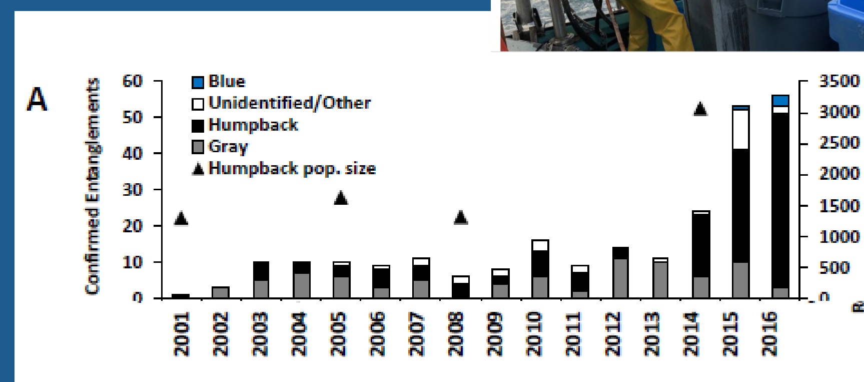
Humpback whales also exhibit prey switching between krill and anchovies, associated with habitat compression and distributional shifts in forage. This contributed to an increase in whale entanglements in crab fishing gear during the 2015-16 large marine heatwave, when krill abundance was low.


THE CALIFORNIA REPORT

California Dungeness Crab Fishery to Close 3 Months Early to Protect Whales

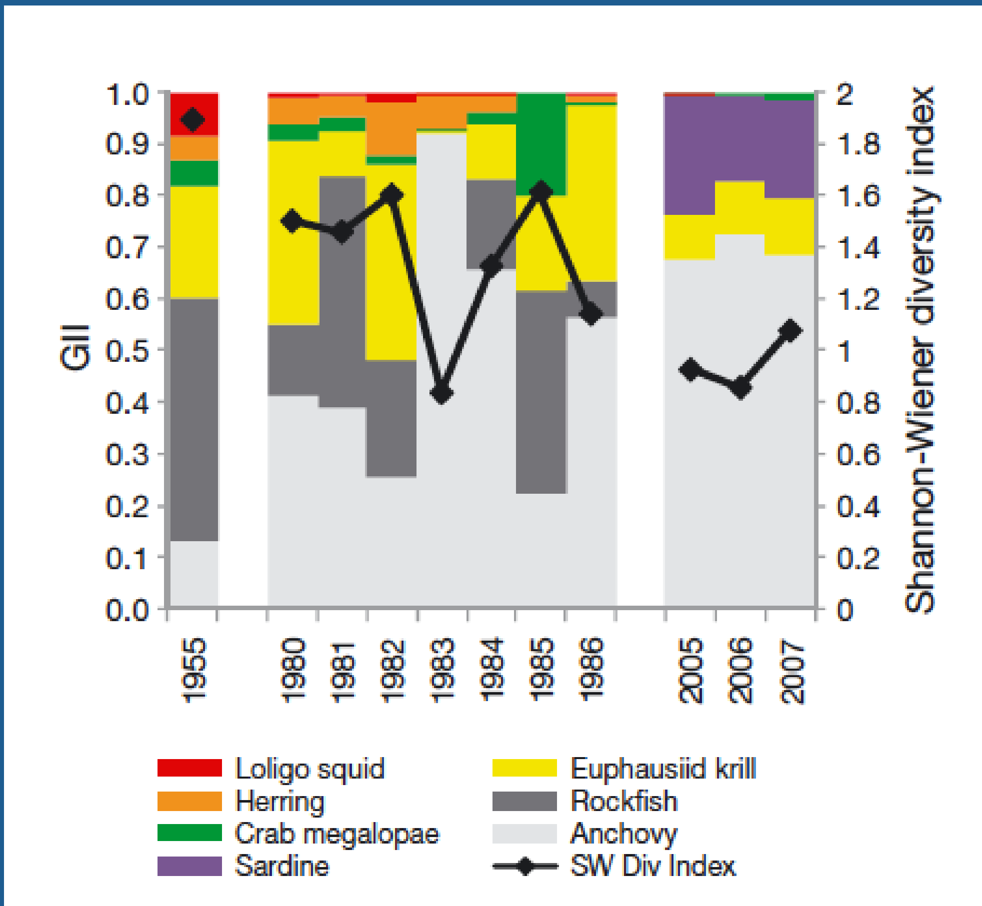
LISTEN 2 min

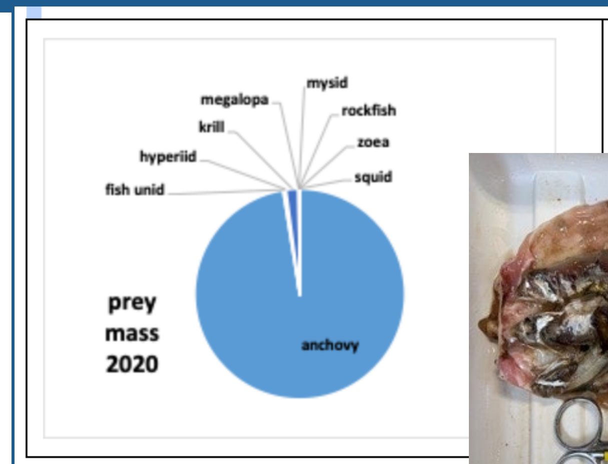
By Amy Westervelt Mar 27

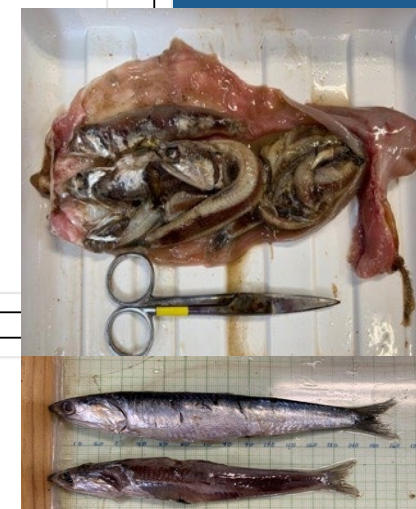


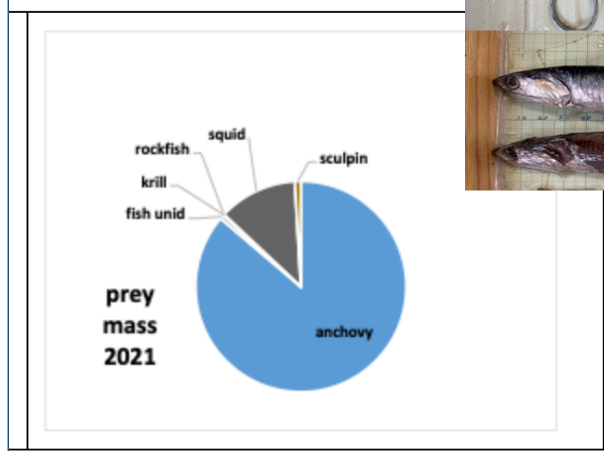
Left, Fleming et al. GCB 2016; right, Santora et al. Nature Communications 2020, data online at https://oceanview.pfeg.noaa.gov/whale_indices/

We have less data on adult salmon diet, with less overlap with survey data, but there is consistency between diets and survey data, as well as a general trend towards decreasing diet diversity



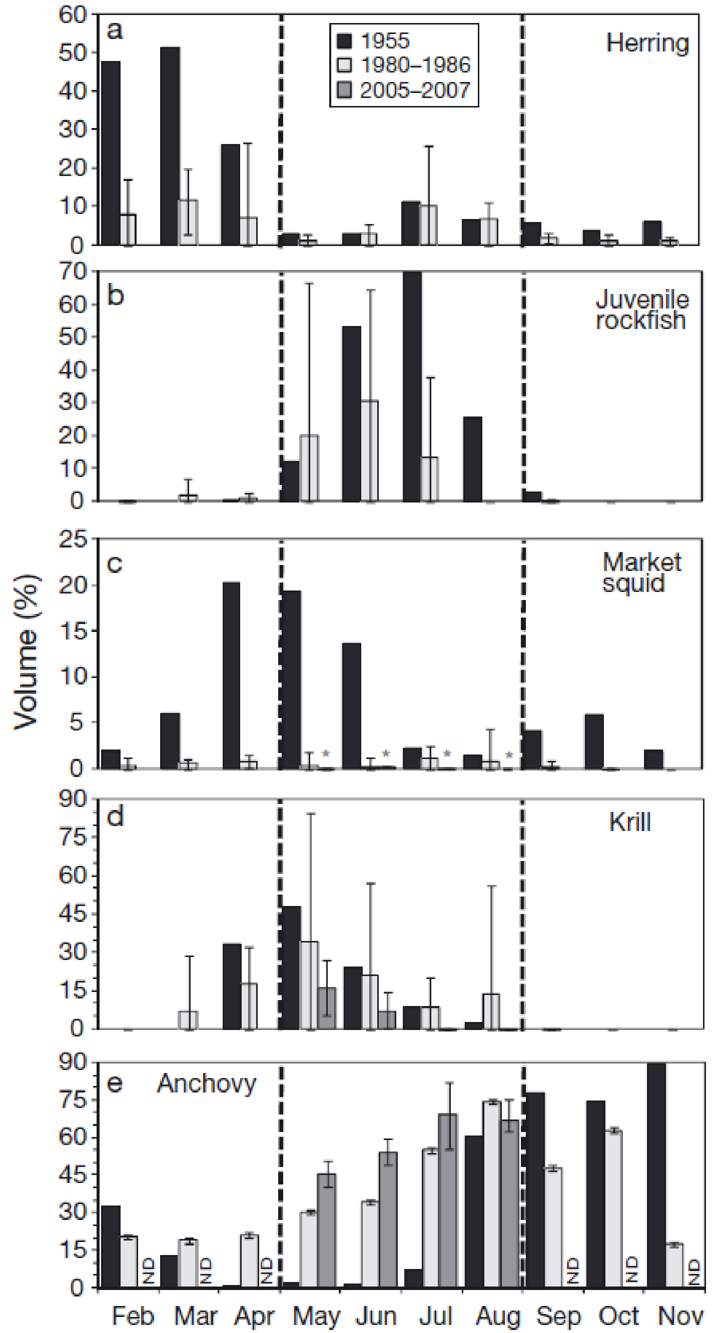


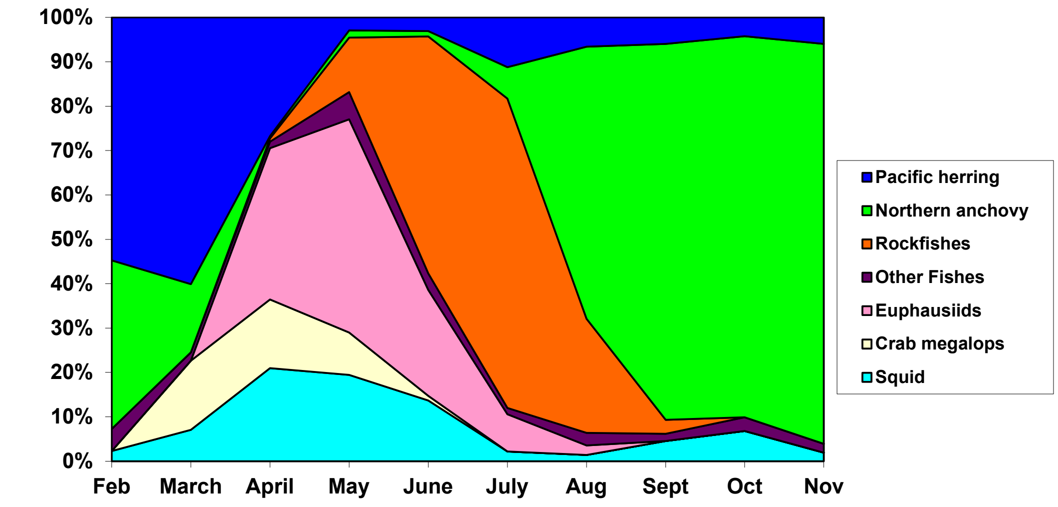




Left, from Thayer et al. 2014; Right, J. Harding, unpublished data

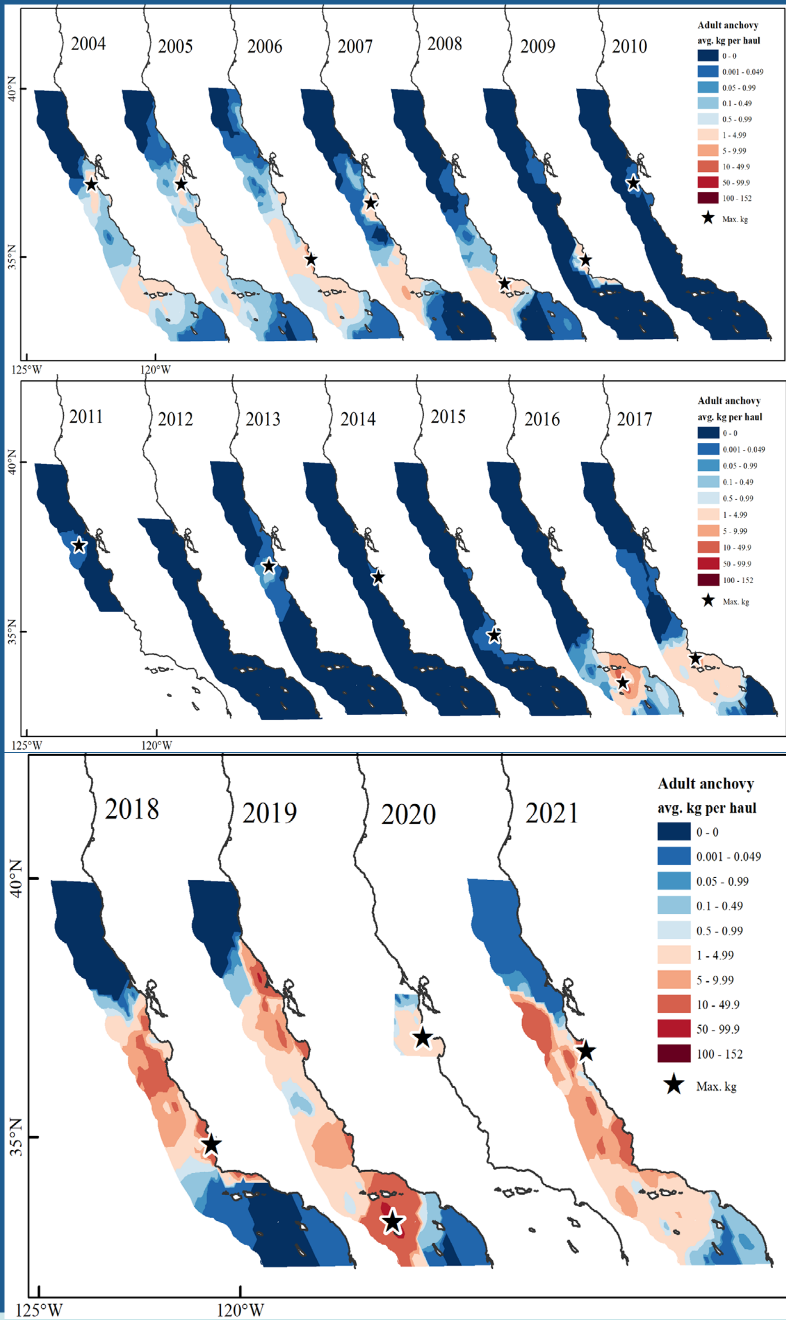
NOAA FISHERIES

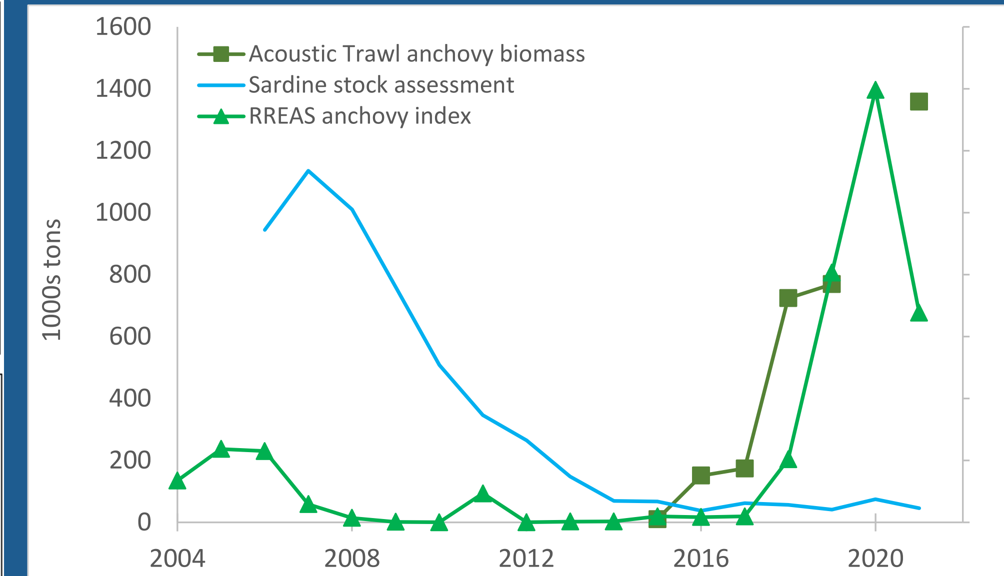




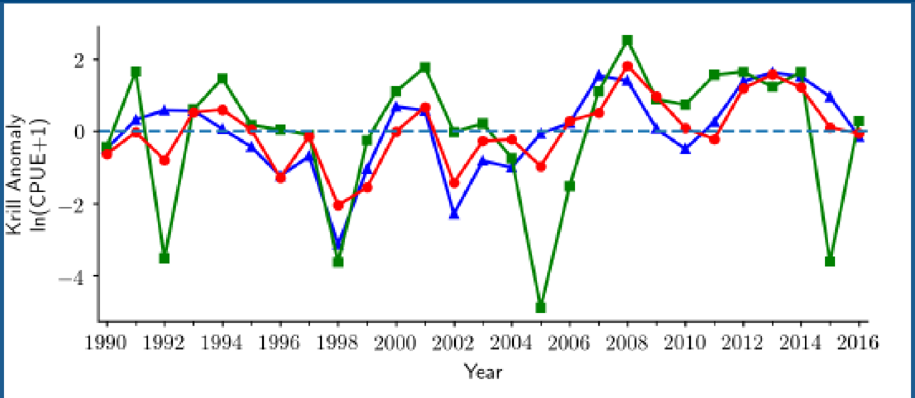
Strong seasonality in adult Chinook diets had long been apparent, with greater diversity in late spring and summer diets in earlier years (recent years limited to late spring/summer sampling). Prey include a combination of exploited and unexploited species.

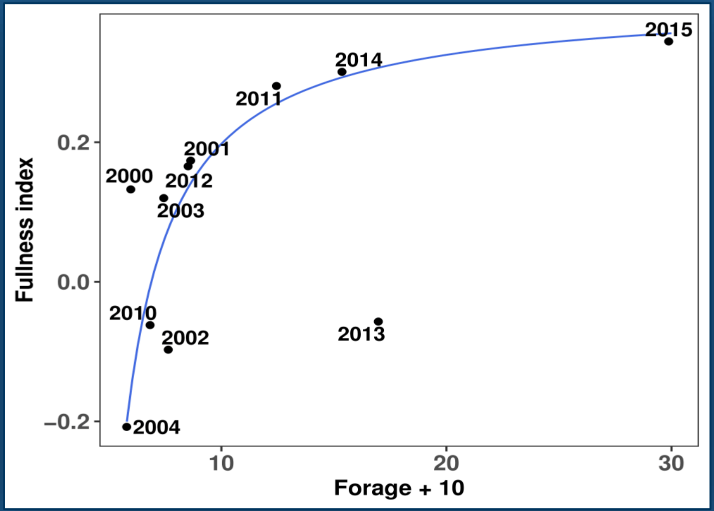
Left: Thayer et al. 2014; Top: data from Merkel 1955





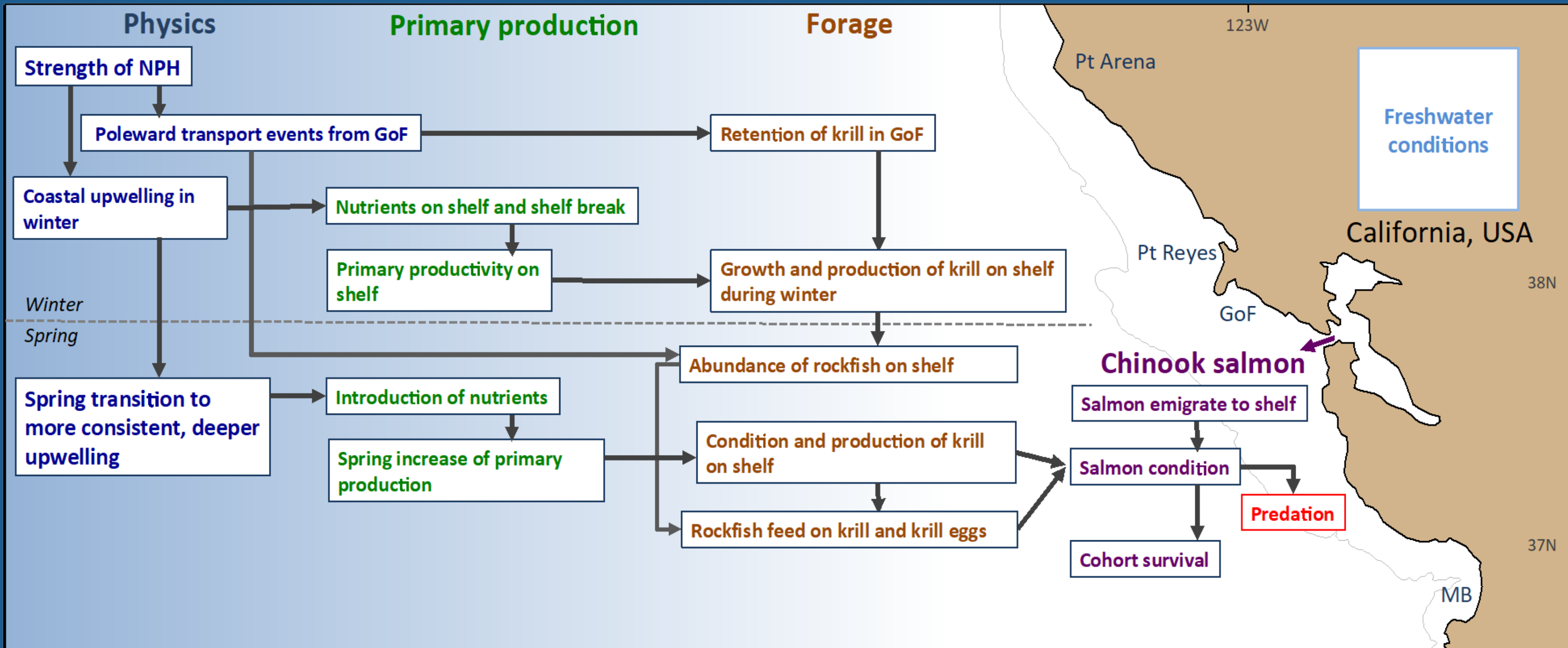
Anchovy are clearly undergoing a strong resurgence after several decades of low abundance - concurrent with sardine decline. Anchovies were also low in 1950s, high in 1970s-1980s. Increased abundance often associated with expansion in range (MacCall's 1990 Basin Model).



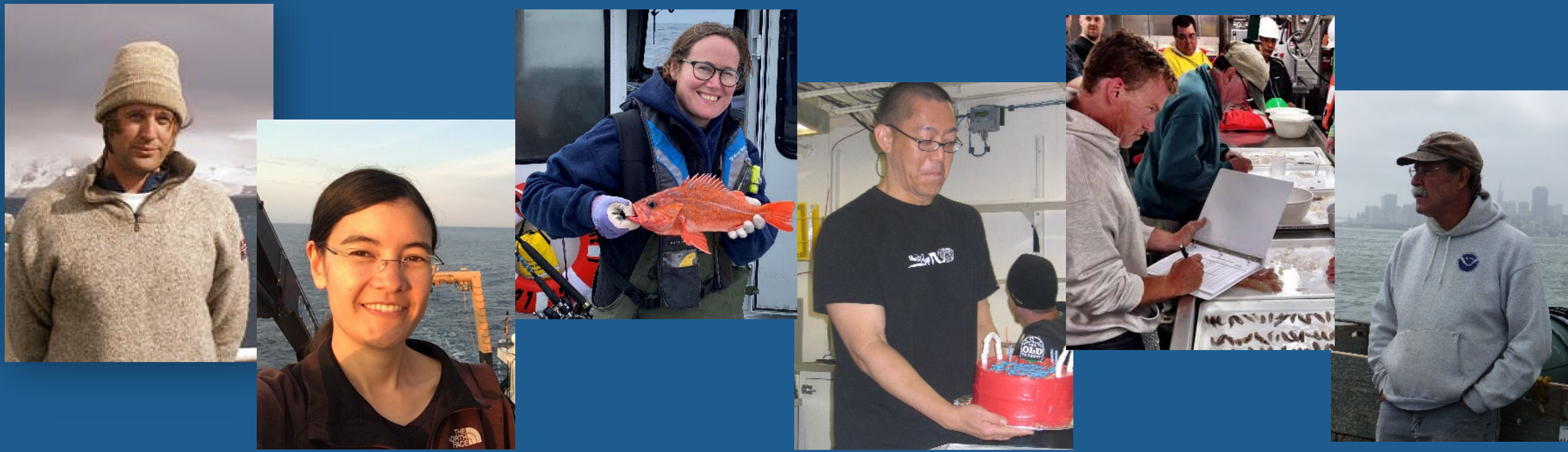


In addition to influencing predation mortality and diet, ocean forage conditions, particularly the abundance of krill on the shelf, also factor into condition of outmigrating smolts in central CA (Wells et al. 2012), and forage indices relate well to gut fullness in juveniles (Sabal et al. 2020).

An ecosystem perspective on the "ocean side" of factors influencing salmon recruitment and productivity (Wells et al. 2016)



These studies have demonstrated how oceanographic conditions influence the abundance, timing and location of forage, which in turn are critical to seabird breeding success, salmon survival and productivity, and the dynamics of many other higher trophic level species

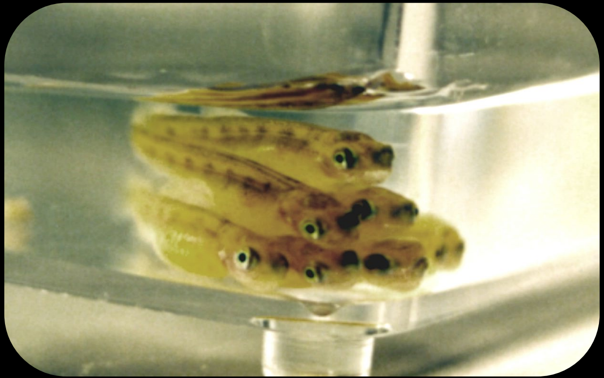


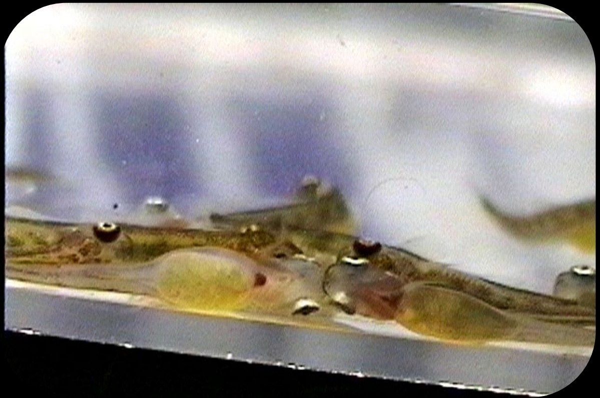
Acknowledgements: Many collaborators, NOAA Corps officers, ships crew, scientists, research partners and volunteers who have made these surveys and analyses possible. And taxpayers.

CIMEC


Questions?

Thiamine Deficiency in California Salmon: the ocean is impacting freshwater productivity





Photos courtesy Dale Honeyfield, USGS

Rachel C. Johnson[1,2], Carson Jeffres[2], Miranda Bell-Tilcock[2], Alexandra Chu[2], John Field[1], Bruce Finney[3], Dale Honeyfield[4], Brett Kormos[5], Danhong Ally Li[2], Steve Lindley[1], Steve Litvin[6], Jacques Rinchard[7], Iliana Ruiz-Cooley[8], Donald Tillitt[4], Abigail Ward[2], and Nate Mantua[1]

1 NOAA 2 UC Davis, University of California 3 Idaho State University 4 USGS 5 California Department of Fish & Wildlife 6 MBARI, Monterey Bay Aquarium Research Institute 7 SUNY Brockport 8 Moss Landing Marine Laboratories

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

Insufficiency can cause:

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

SCIENTIFIC REPORTS

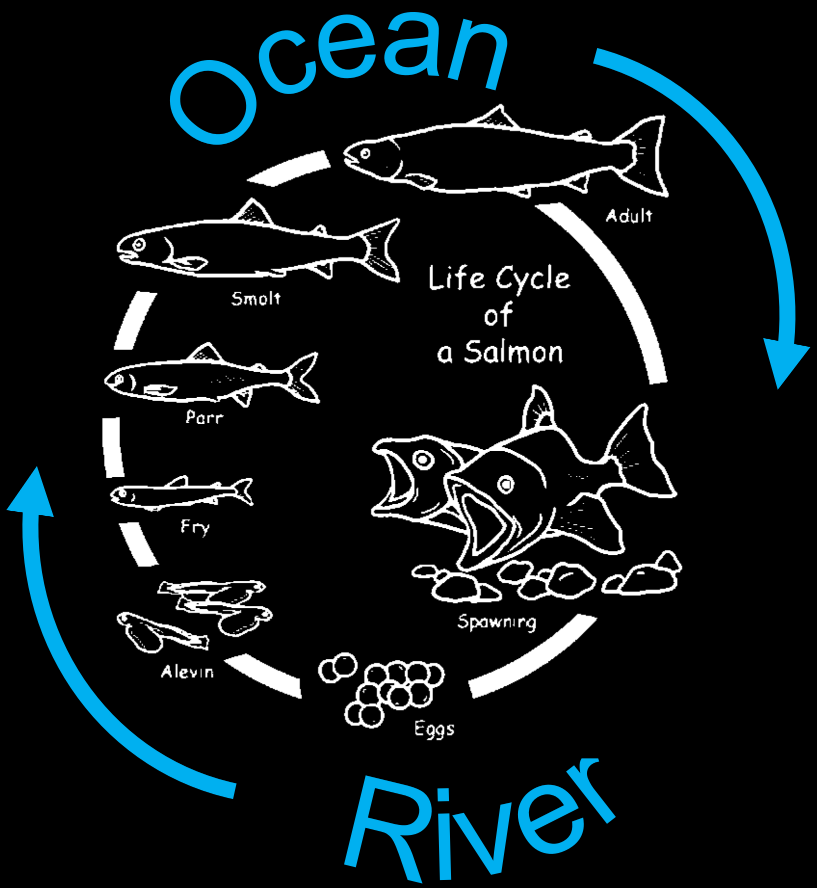
OPEN

Widespread episodic thiamine deficiency in Northern Hemisphere wildlife

Received: 19 September 2016
Accepted: 14 November 2016
Published: 13 December 2016

Lennart Balk[1], Per-Åke Hägerroth[1], Hanna Gustavsson[1], Lisa Sigg[1], Gun Åkerman[1], Yolanda Ruiz Muñoz[2], Dale C. Honeyfield[3], Ulla Tjärnlund[1], Kenneth Oliveira[4], Karin Ström[1], Stephen D. McCormick[5], Simon Karlsson[6,7], Marika Ström[1,8], Mathijs van Manen[1,9], Anna-Lena Berg[10], Halldór P. Halldórsson[11], Jennie Strömquist[7], Tracy K. Collier[12], Hans Börjeson[13], Torsten Mörner[14] & Tomas Hansson[1]

Salmon linkages among aquatic ecosystems



Rapid Response to 2020 Salmon Thiamine "Pandemic"

* 1. Testing: Broad scale surveillance to identify vulnerable popn's

* 2. Identify the cause: Marine food web and freshwater response

* 3. Assessing impacts: Thiamine-dependent mortality estimates

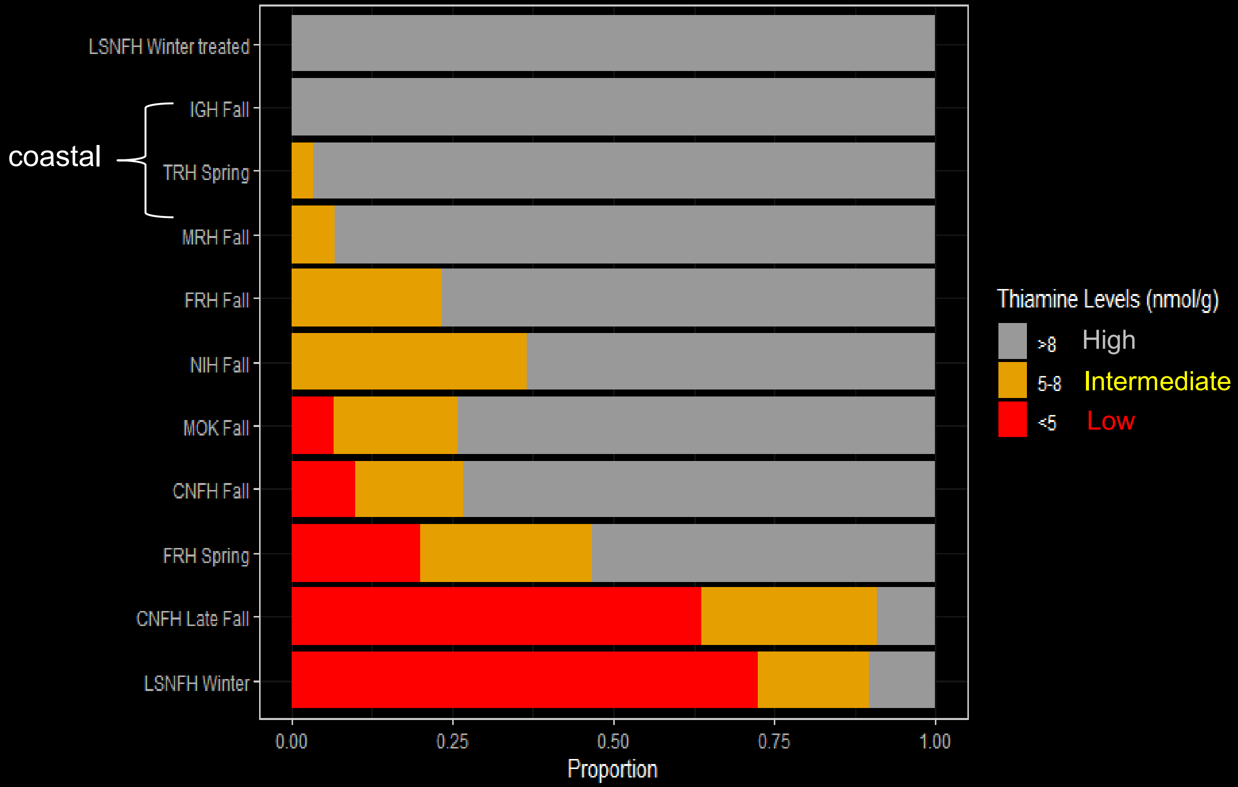
4. Freshwater microbial thiamine: Estimates of aqueous thiamine

* 5. Develop Treatments: Different salmon runs have different needs

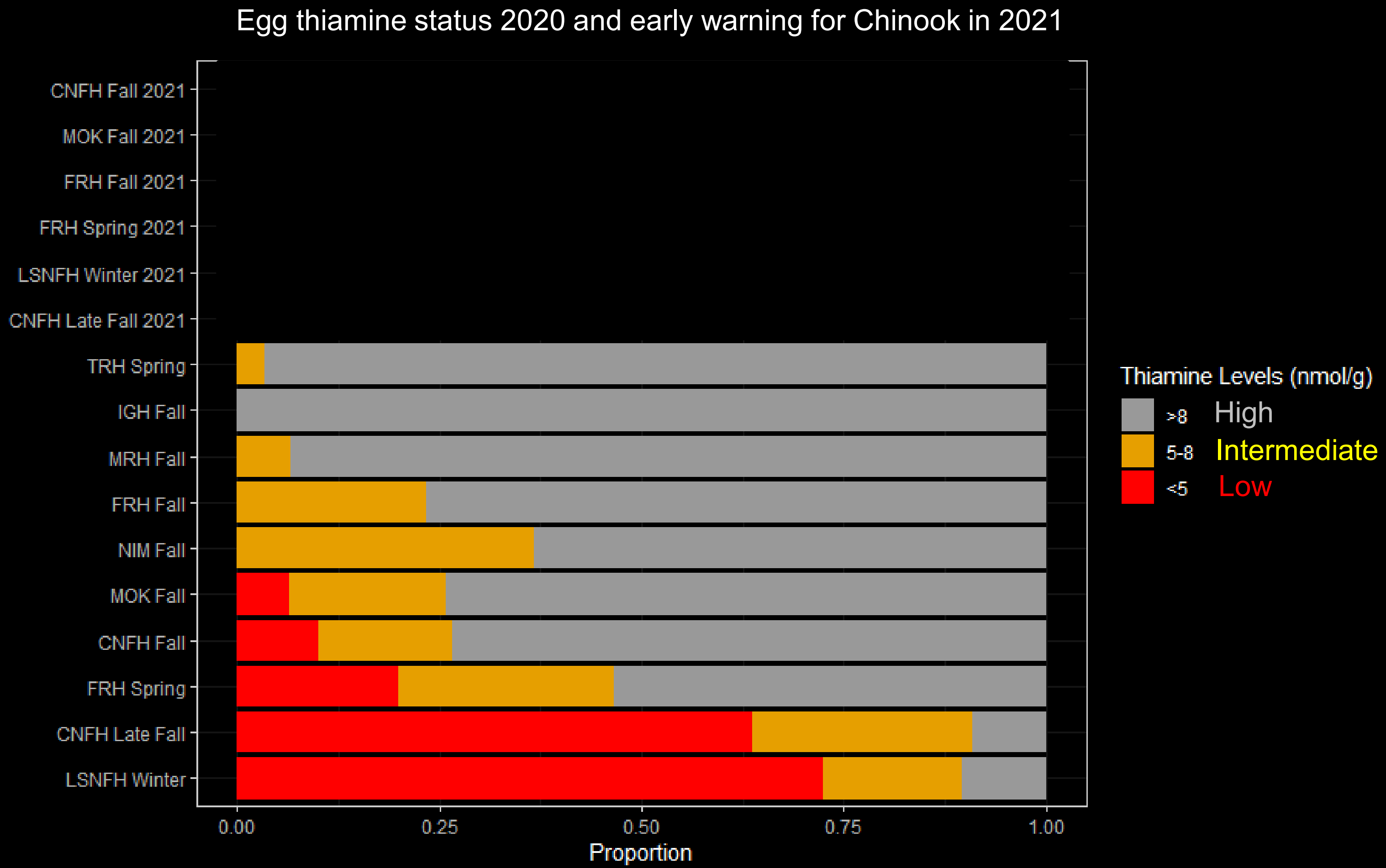
6. Citizen science: Spinning salmon in the classroom

1. Testing: Broad scale egg surveillance 2020 to identify vulnerable popn's

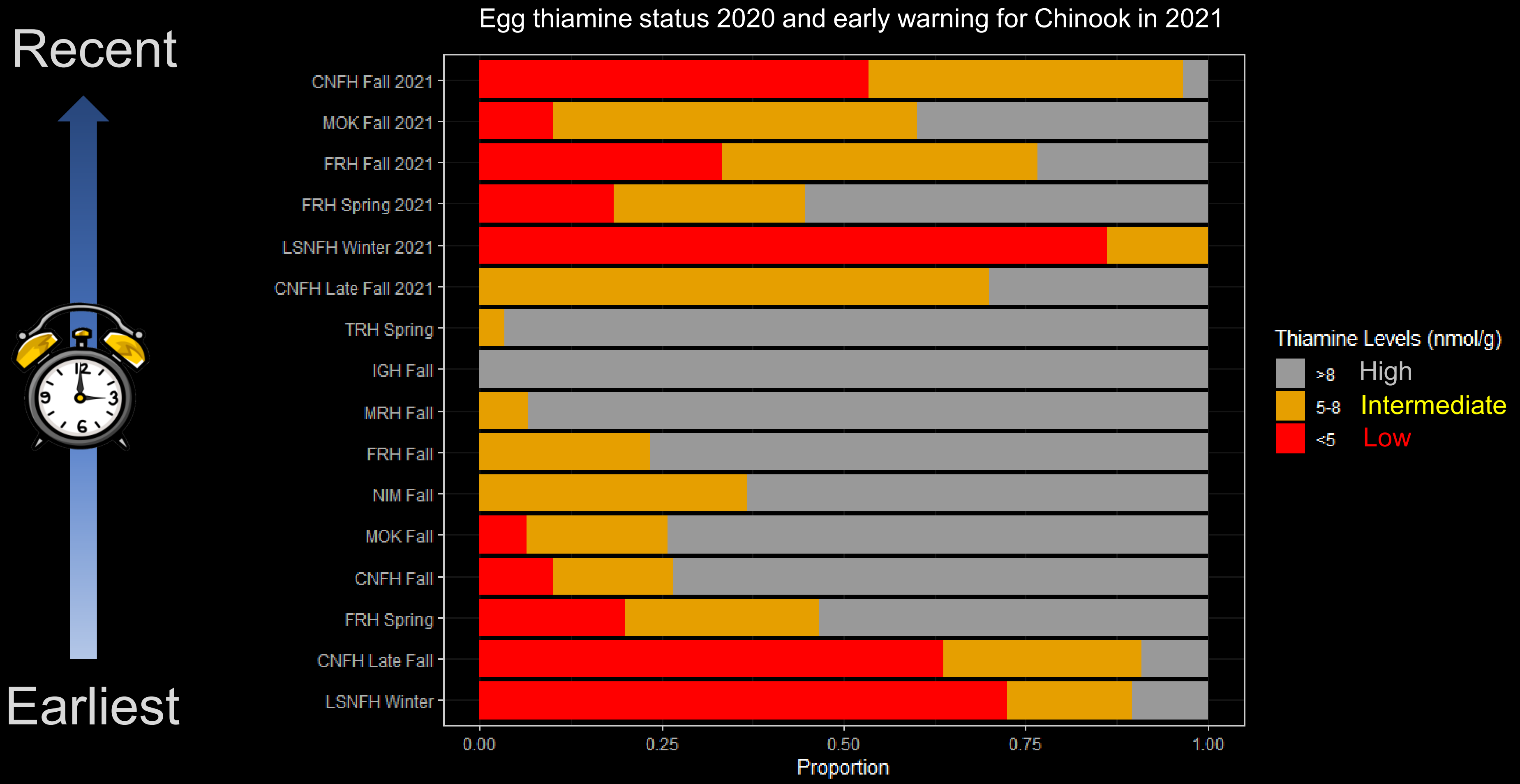
Proportion of Chinook Salmon Eggs with Different Levels of Thiamine



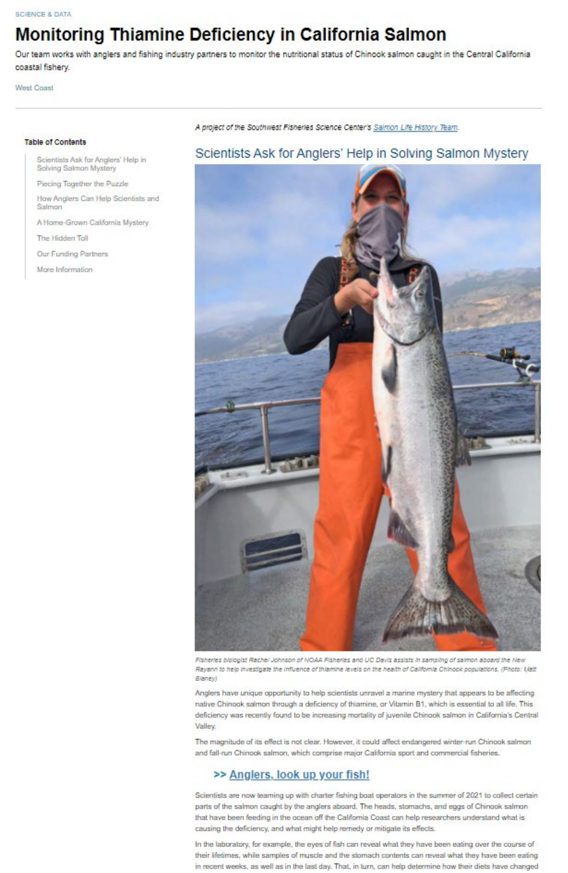
Flattening the curve or surge in 2021: Evidence for end of deficiency?

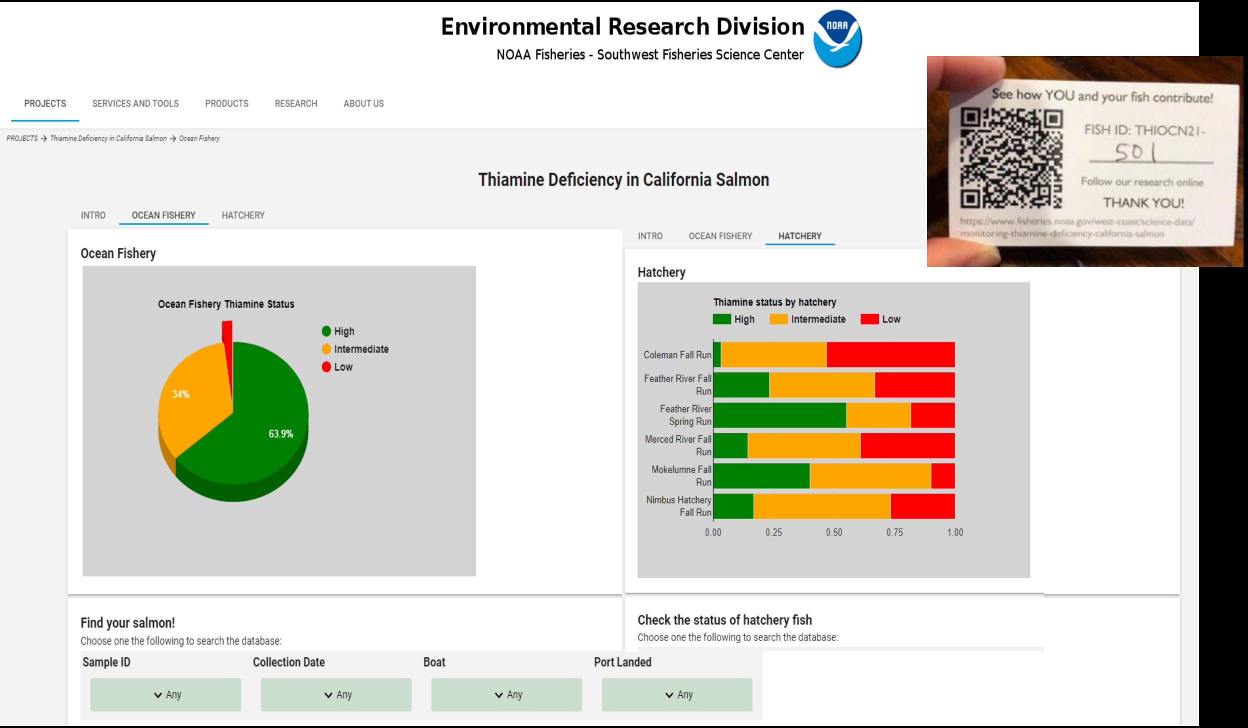


Flattening the curve or surge in 2021: Evidence for end of deficiency?



1. Testing: Broad scale egg surveillance and early warning to identify vulnerable popn's





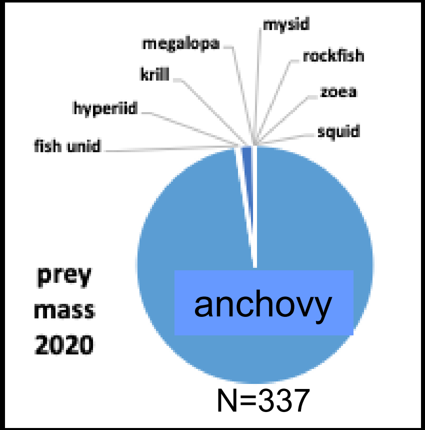
Updated when new data available. Stored on NOAA's ERDDAP database publicly available

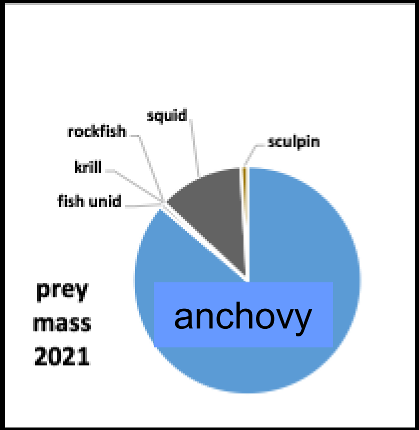
https://oceanview.pfeg.noaa.gov/projects/salmon_thiamine/ocean_fishery

2. Identify the cause: Are anchovies the villain?

Anchovies produce an enzyme, thiaminase, that breaks down B1

Current salmon diets



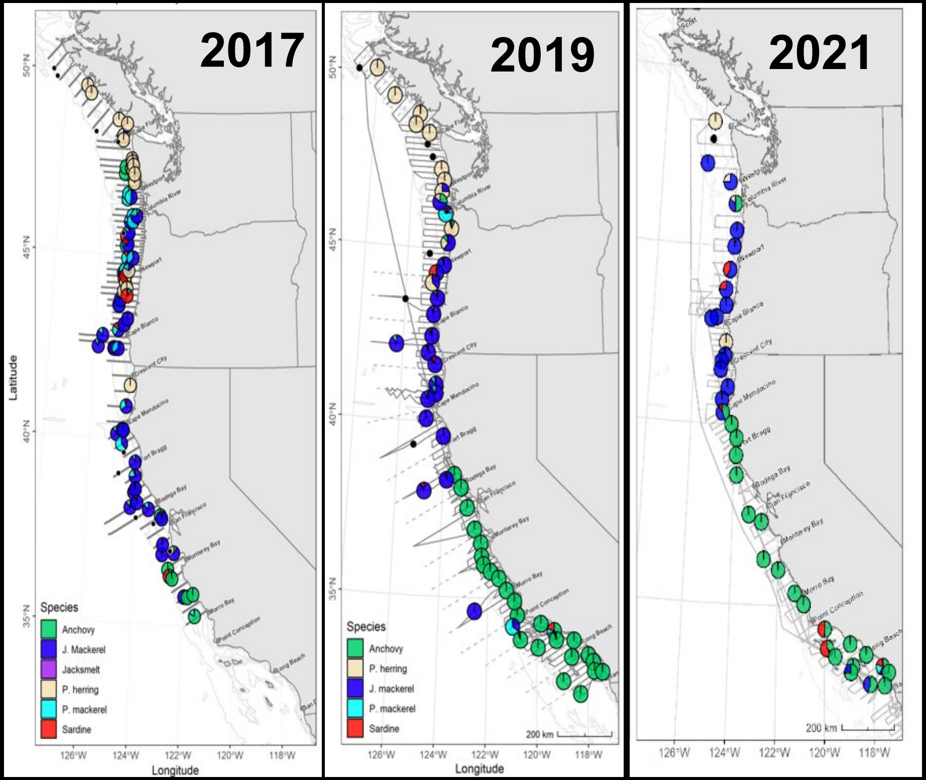


Representation of shift in salmon diet

Historical data source: Thayer et al. 2014; courtesy of John Field

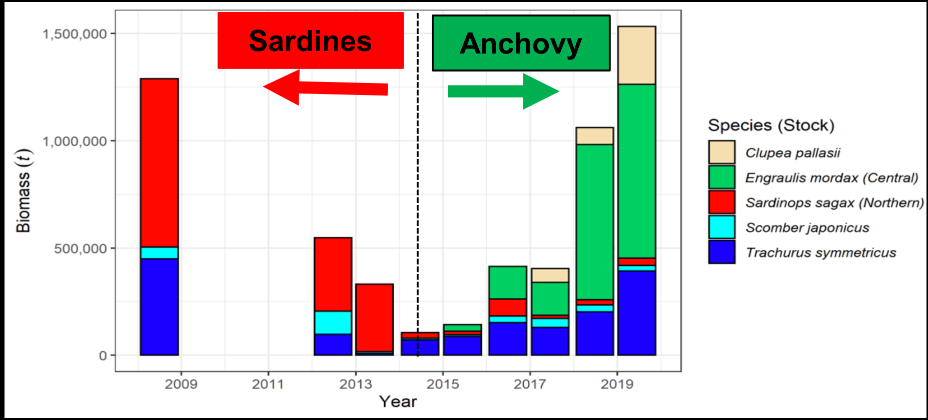
2. Identify the cause: Anchovy expansion

Central anchovy distribution



(NMFS tech memos)

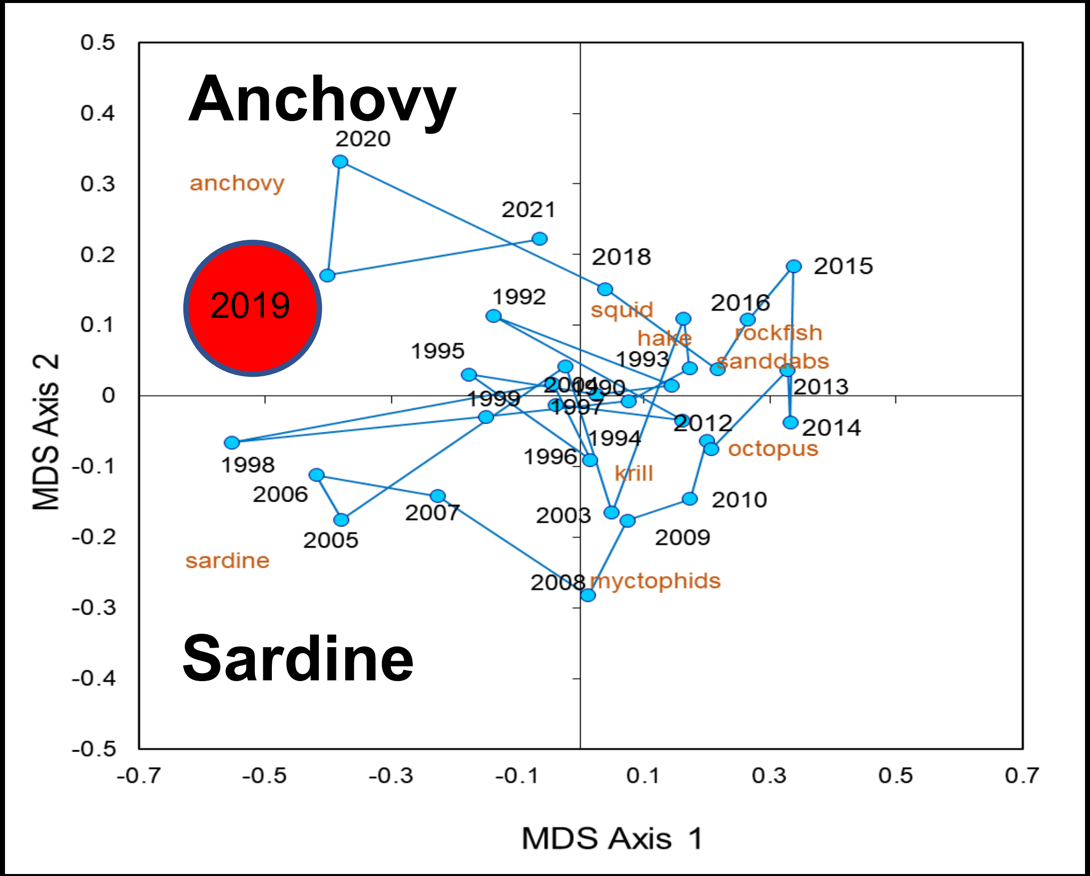
Coastal Pelagic Species biomass



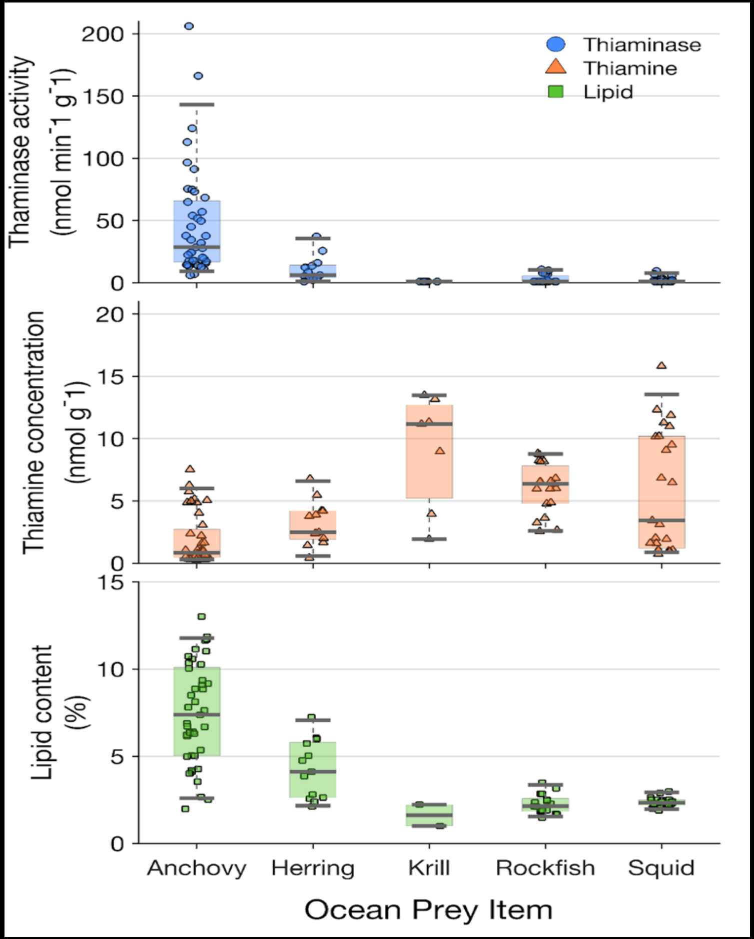
Stieroff et al. 2020

2. Identify the cause: Central CA forage fish composition 1990-2019

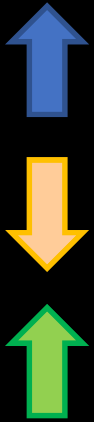
The 2019 “Anchovy Regime”



2. Identify the cause: Thiamine, thiaminase, and lipids in salmon prey



Anchovies

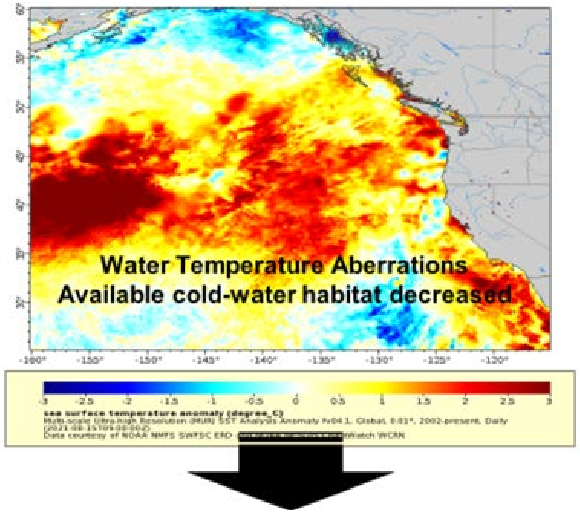


Thiaminase

Thiamine

Lipids

2. Identify the cause: Marine food web and freshwater response



Central Valley Chinook Salmon

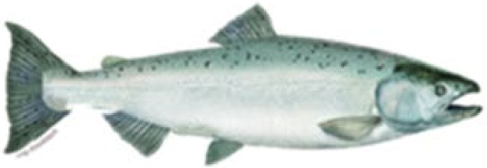
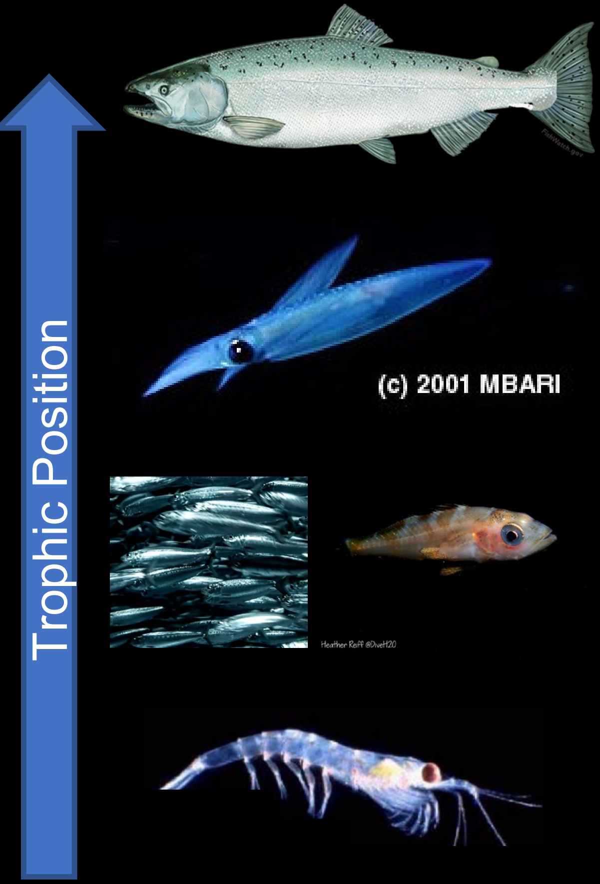


Figure courtesy of Freya Rowland

2. Identify the cause: Reconstructing diet with stable isotopes



Isoscape of Marine Food Web of California Current

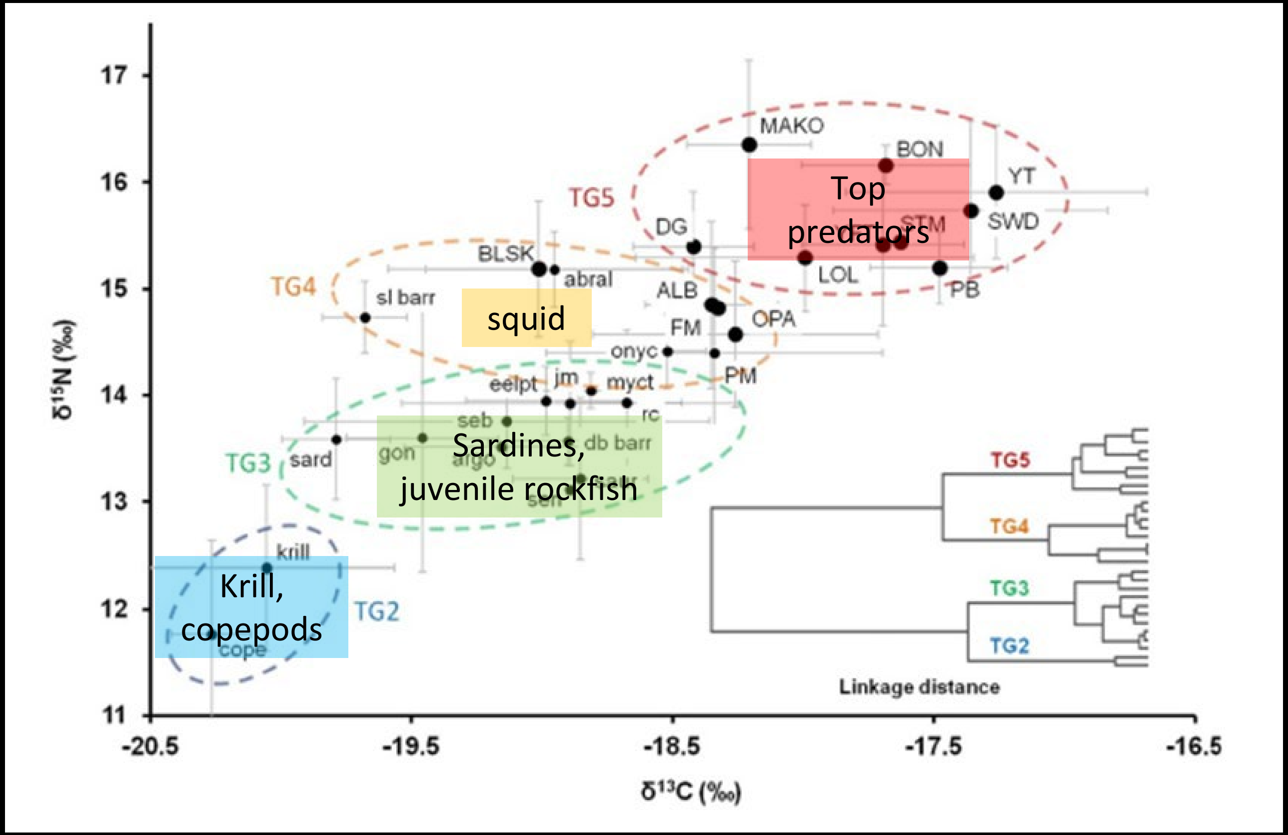


Figure from Madigan et al. 2012

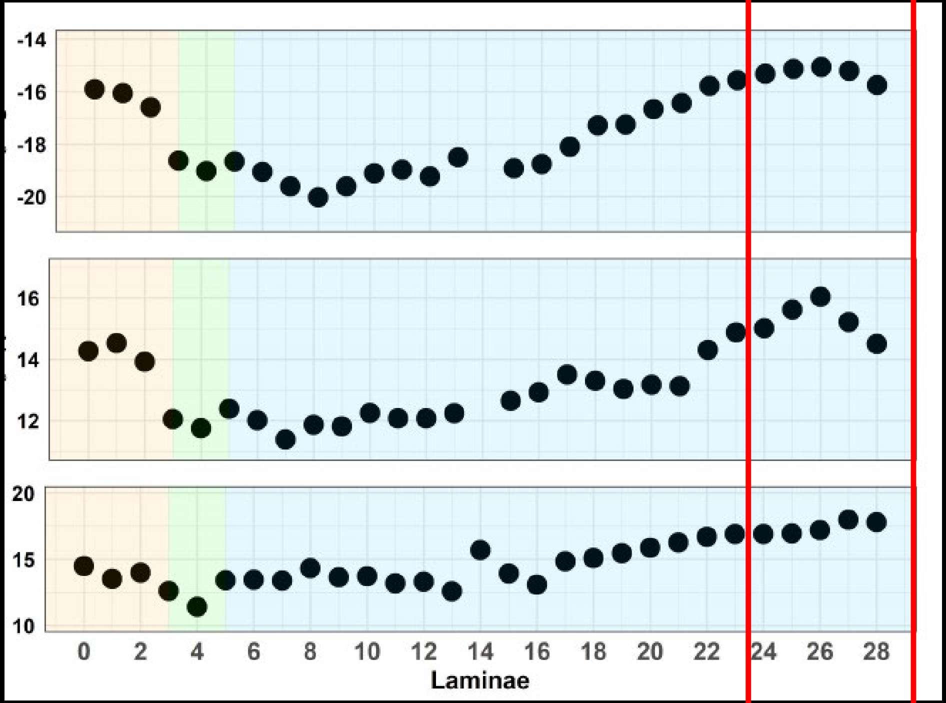
3. Identify the cause: Reconstructing diet history using eye lenses

Adult salmon lifetime diet reconstruction

$\delta^{13}C$

$\delta^{15}N$

$\delta^{34}S$



Freshwater → Marine

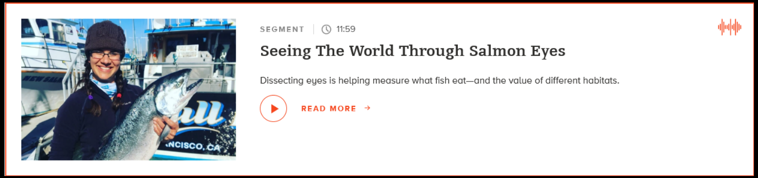


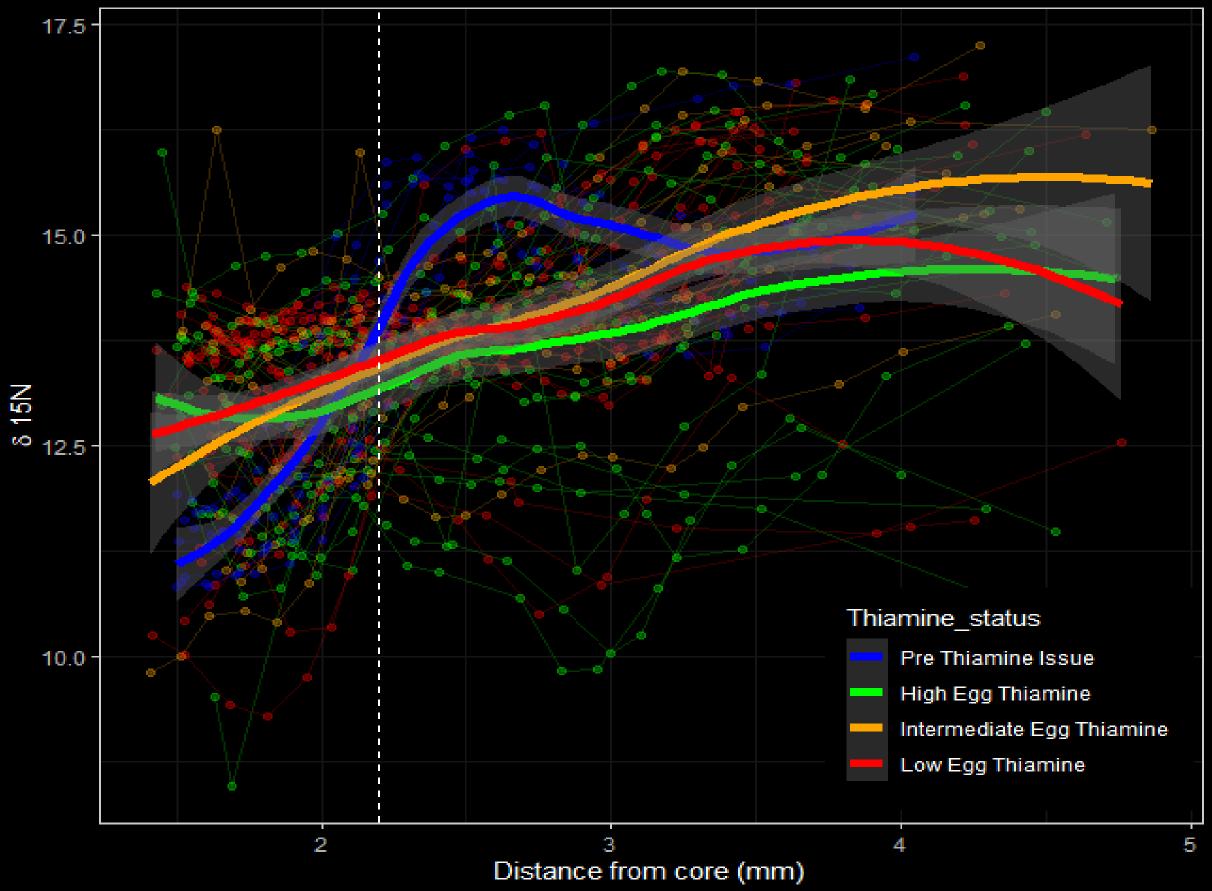
Photo: Jim McKinney

Bell-Tilcok et al. 2021

NOAA

UC DAVIS
UNIVERSITY OF CALIFORNIA

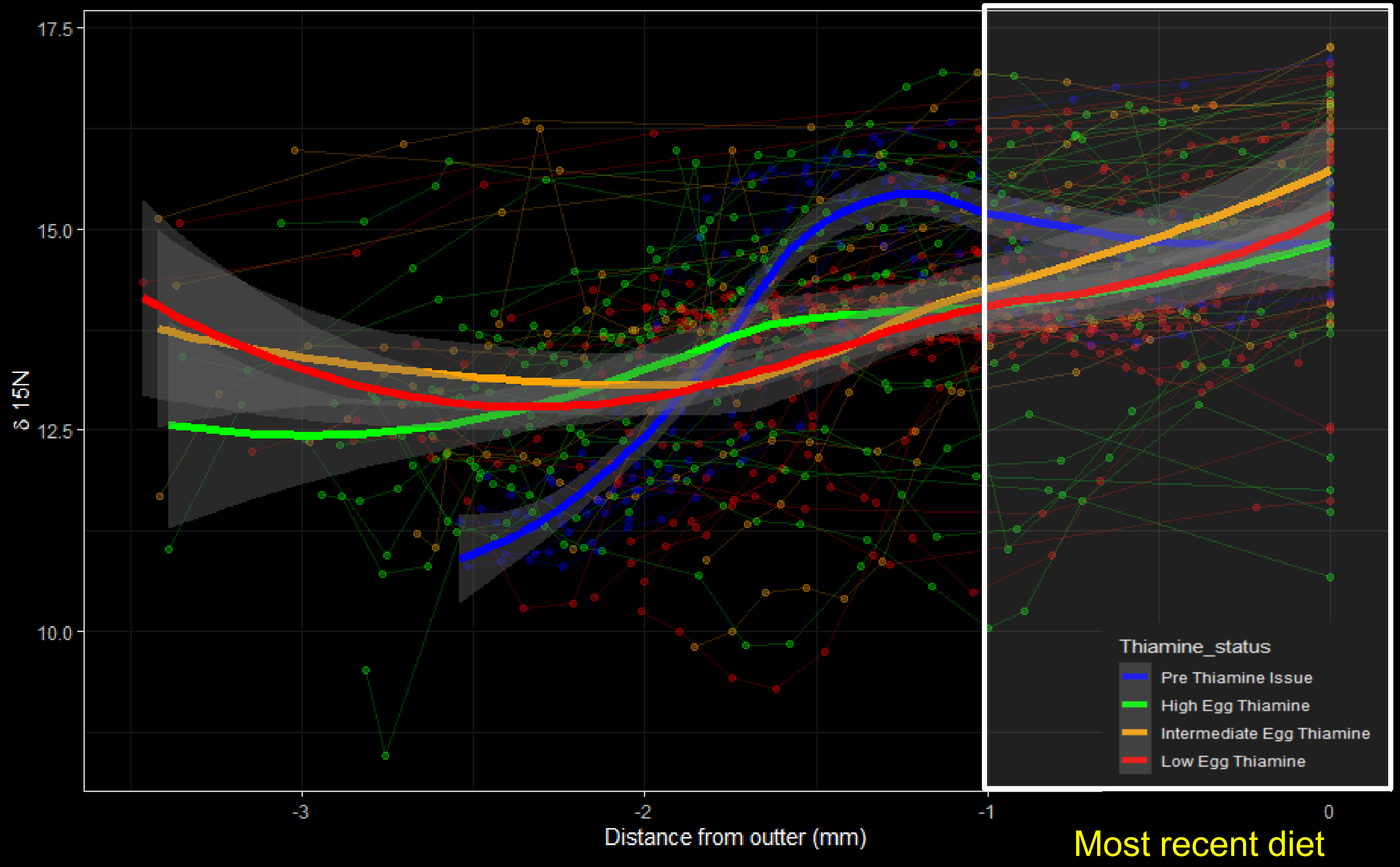
Chinook salmon N diet chronology pre (2018) and post (2020) thiamine deficiency



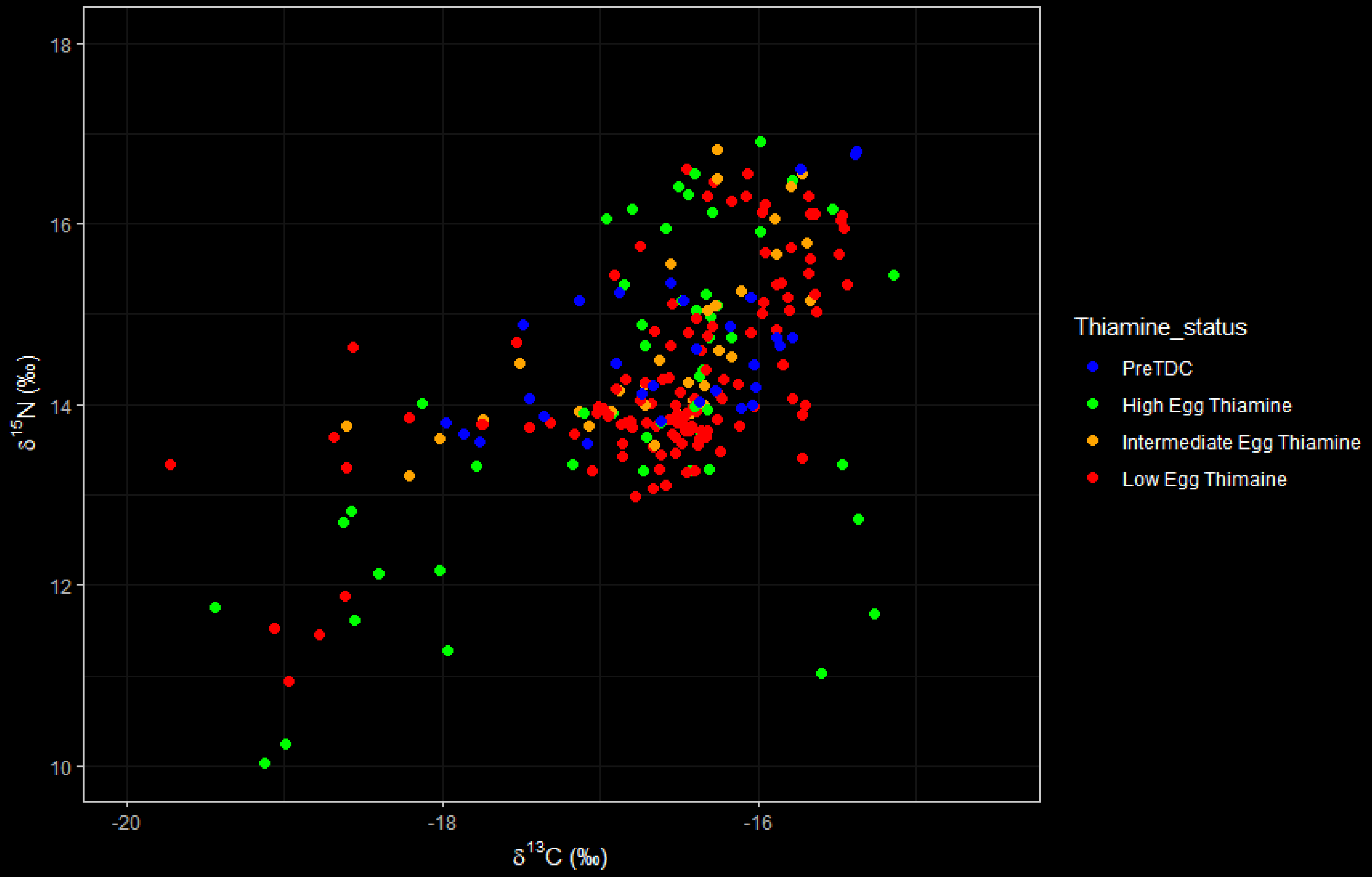
Conceptual model of marine food web isotopes and thiamine deficiency

Egg Thiamine Status	Recent Diet	Isotope niche area
 Historical [pre thiamine issue]	Diversity in prey items Diets high in thiamine/low in thiaminase	Wide area
 High Thiamine	Diversity in prey items Diets high in thiamine/ low in thiaminase	Wide area
 Low Thiamine	Narrowing of prey items Diets low in thiamine/ high in thiaminase	Narrow area

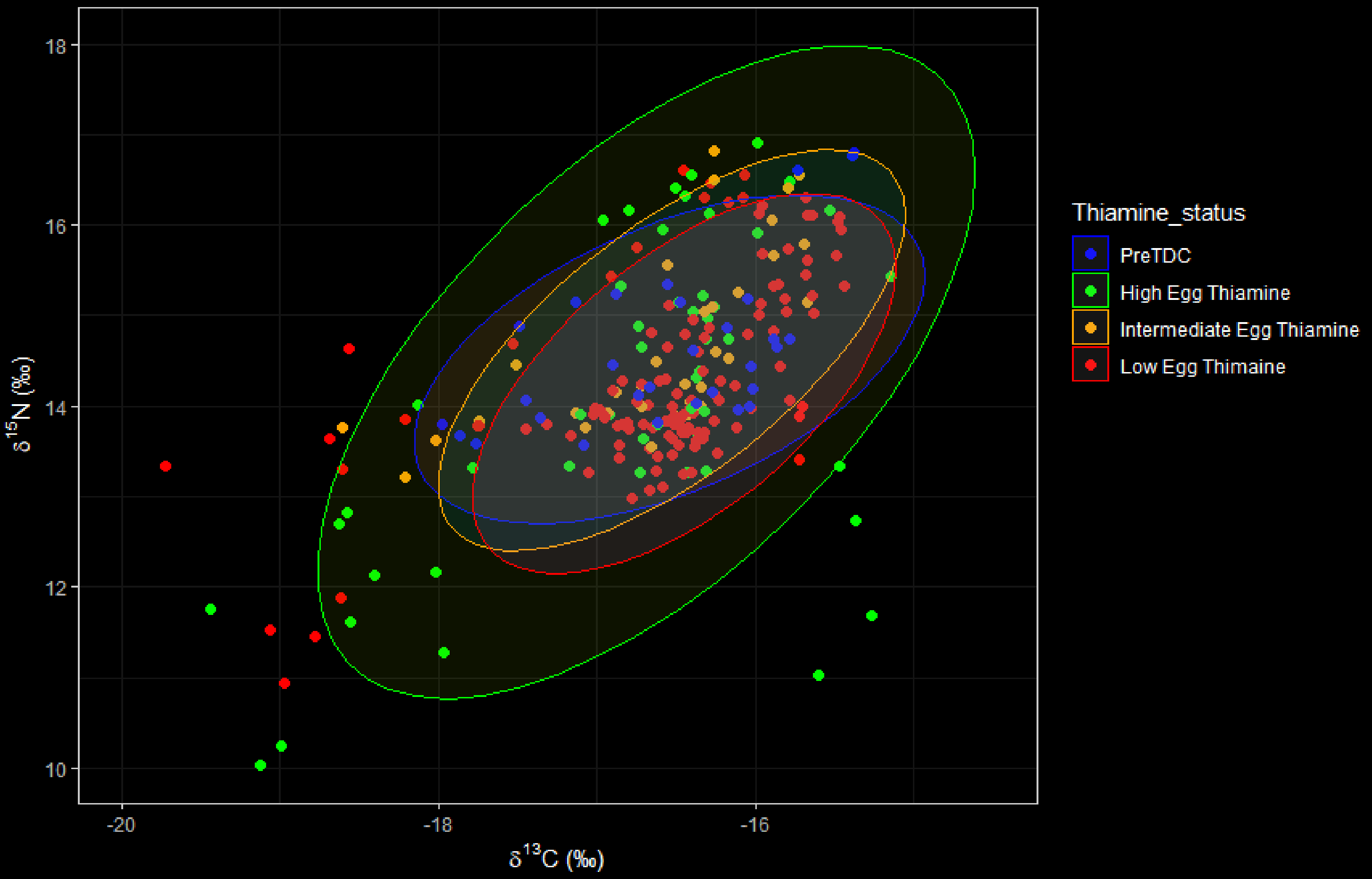
Chinook salmon N diet normalized back in time from most recent diet



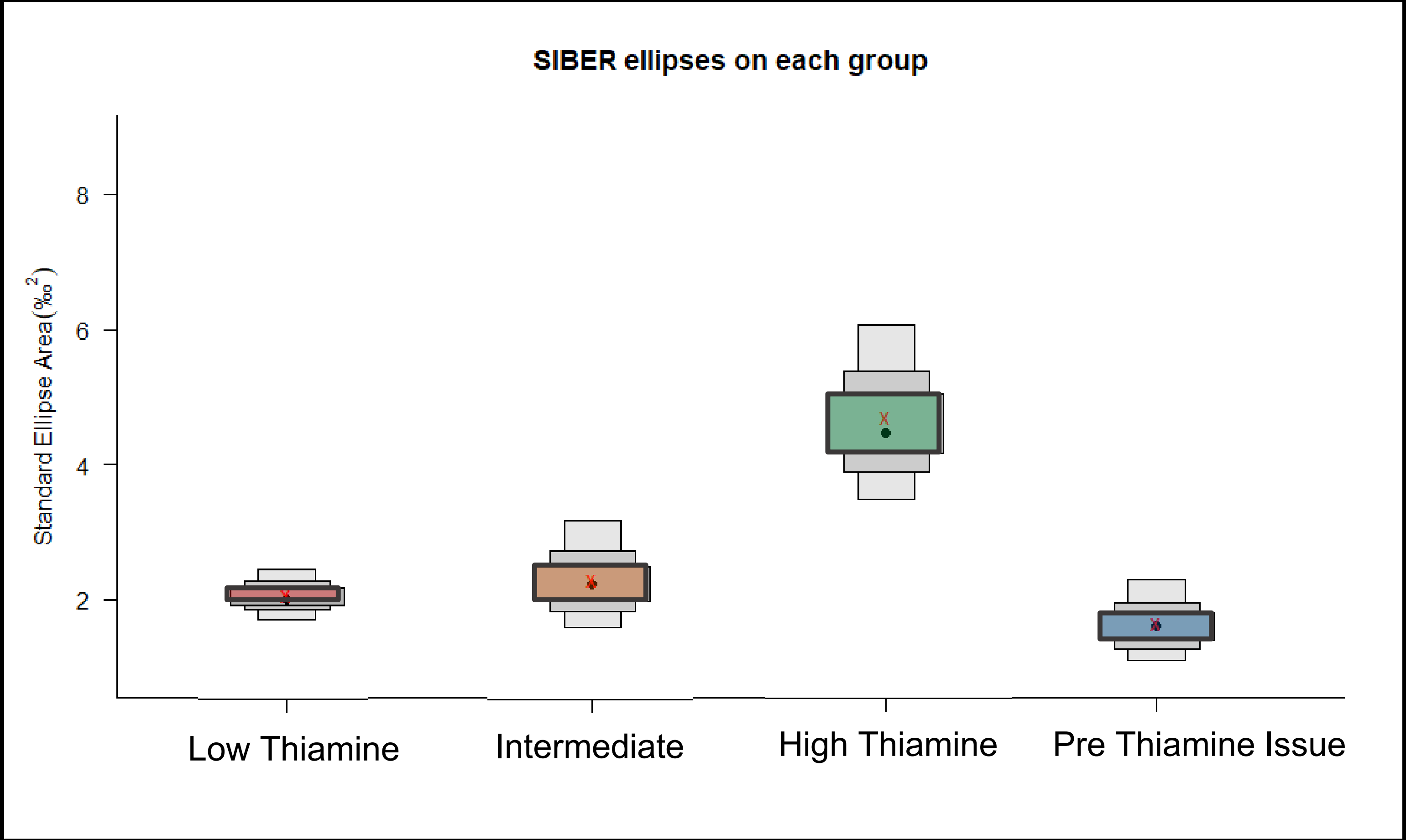
Chinook salmon C and N in recent ocean diet (1mm eye lens)



Chinook salmon C and N in recent ocean diet (1mm eye lens)

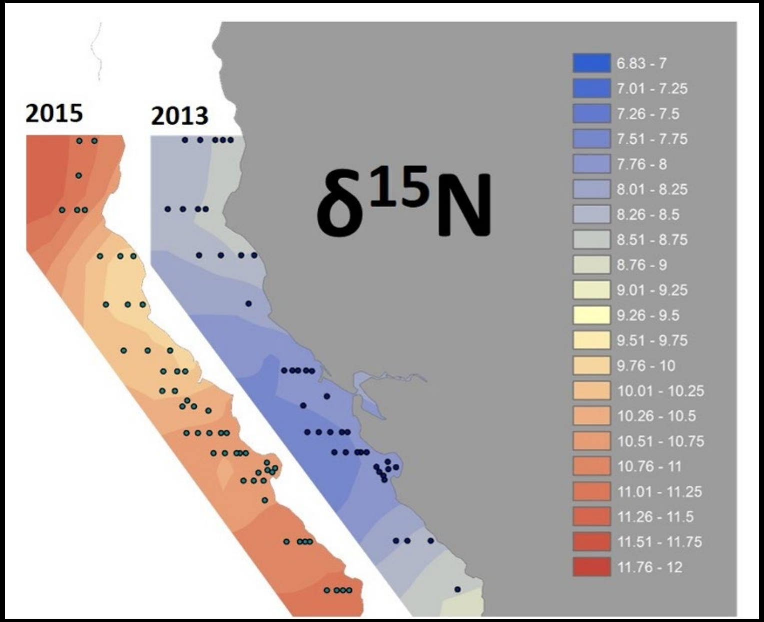


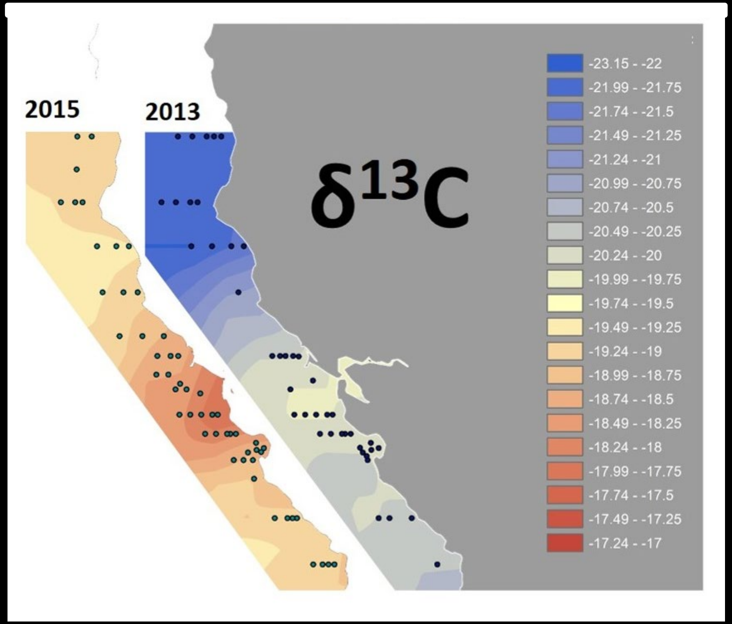
Bayesian ellipse model showing breadth of diet by thiamine status



2. Identify the cause: Dynamic marine isoscapes

Krill "Isoscape"





Courtesy of B. Finney and S. Litvin

Rapid Response to 2020 Salmon Thiamine "Pandemic"

* 1. Testing: Broad scale surveillance to identify vulnerable popn's

* 2. Identify the cause: Marine food web and freshwater response

* 3. Assessing impacts: Thiamine-dependent mortality estimates

4. Freshwater microbial thiamine: Estimates of aqueous thiamine

* 5. Develop Treatments: Different salmon runs have different needs

6. Citizen science: Spinning salmon in the classroom

4. Assessing impacts: Thiamine-dependent mortality estimates

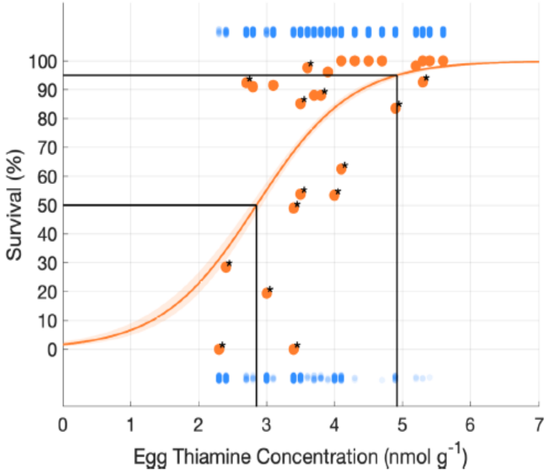
UCDAVIS
UNIVERSITY OF CALIFORNIA

Photo: Sarah Baird, UCD

Thiamine Studies at UCD

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

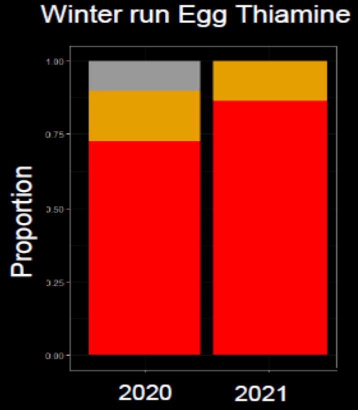
$$\pi(TC) = \frac{e^{-4.097+1.432*x_1}}{1+e^{-4.097+1.432*x_1}}$$



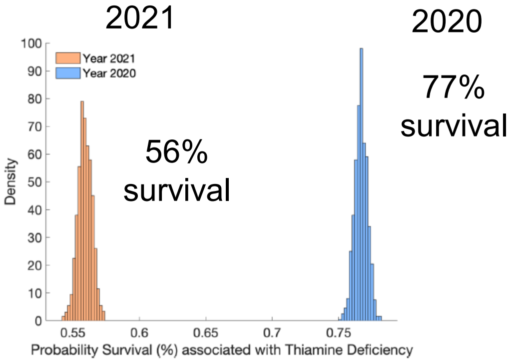
EC_{50} = 2.9 nmol g^{-1}

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

*Same estimate as from H. Bell



Population level effects



23% Egg mortality due to Thiamine Deficiency 2020

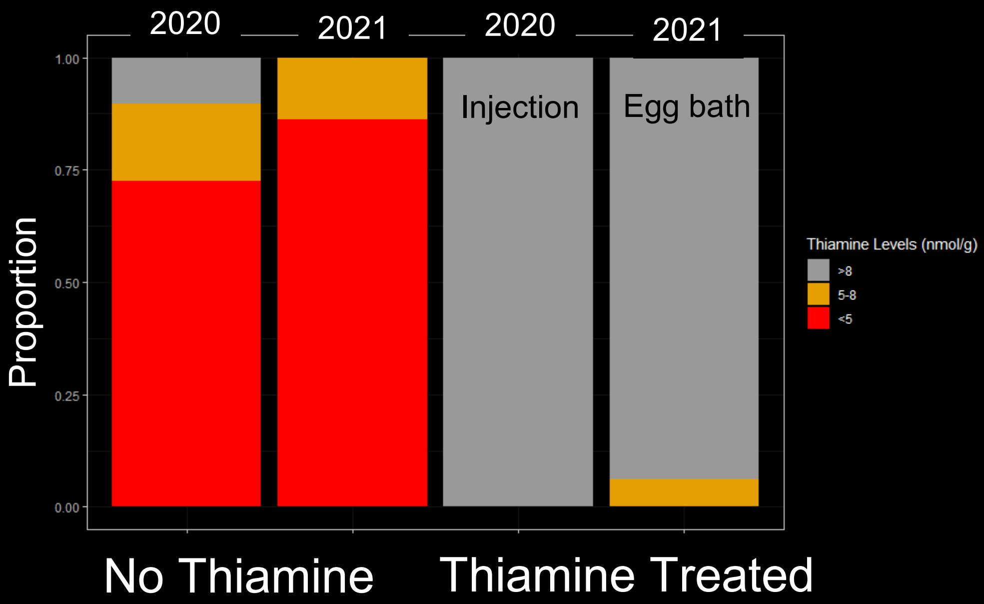
44% Egg mortality due to Thiamine Deficiency 2021

M. Daniels, unpublished

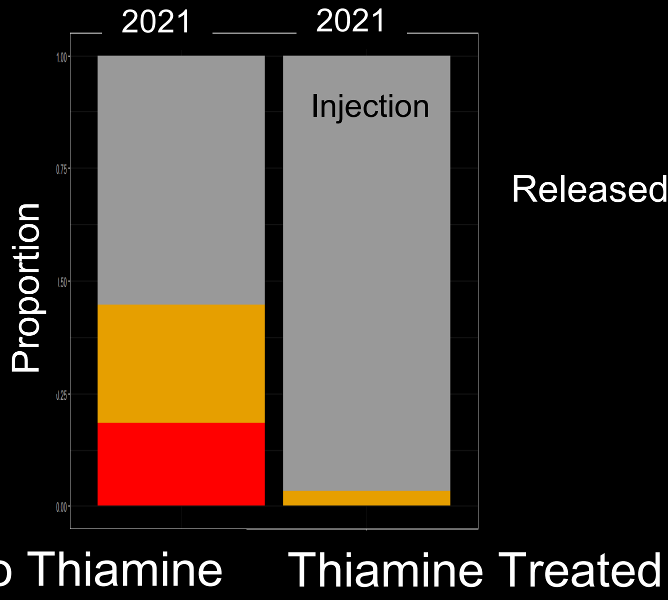
5. Develop Treatments: Different salmon runs have different needs

Thiamine Treatments Winter & Spring run

Winter run Egg Thiamine



Spring run Egg Thiamine



Released in river

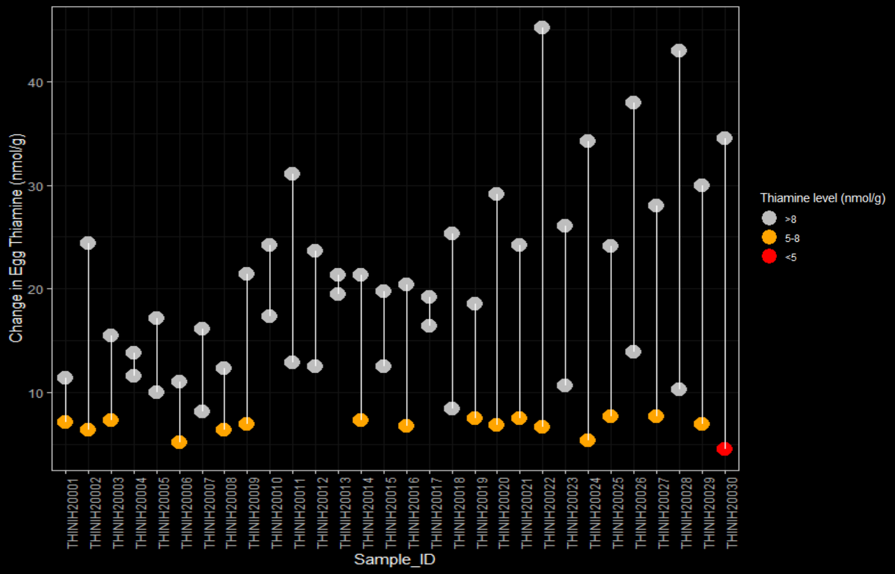
5. Develop Treatments: Different salmon runs have different needs

Injections work for winter run but not fall run……

Kevin Kwak, CDFW

Thiamine at Egg Fertilization

Influence of high dose (4500ppm) treatment on egg thiamine



Key Summaries

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

- Central Valley hardest hit
- Stocks most vulnerable in 2020/2021 (late-fall, winter, spring)
- Value to operationalize egg thiamine monitoring

Identify the cause: Marine food web

- Anchovies most dominant prey in salmon diets
- Eye lens isotope diet chronologies show low thiamine females narrowest diet
- No evidence the marine food web is back to pre-2020 normal

Assessing impacts: Thiamine-dependent mortality estimates

- Thiamine dependent mortality was 44% in 2021 contributing to lowest egg-to-fry observed on record
- Identified mortality thresholds (EC_{95}= 5 nmol/g)

Develop Treatments: Different salmon runs have different needs

- Injections and egg treatments at fertilization two options that are wildly successful

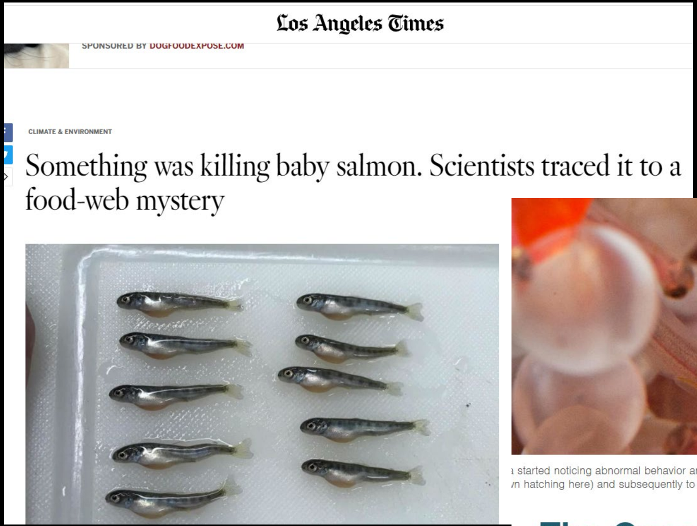
Thiamine Research Team & Partners

Delta Stewardship Council

NOAA Fisheries: Rachel Johnson, Nate Mantua, John Field, Steve Lindley, Tommy Williams
USFWS: Taylor Lipscomb, Scott Foot, William Ardren
USGS: Donald Tillitt, Freya Rowland, David Walters, Cathy Richter, and Dale Honeyfield, retired
CDFW: Kevin Kwak, Mark Adkison, Brett Kormos
SUNY: State University of New York Brockport, Jacques Rinchard
Department of Water Resources: Jason Kindopp
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

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

To learn more:



Los Angeles Times

SPONSORED BY DOGFOODEXPOSE.COM

CLIMATE & ENVIRONMENT

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

Hakai Magazine

...started noticing abnormal behavior and high mortality in their salmon fry, leading to concerns that a disruption in the marine ecosystem may be affecting the trans... ...n hatching here) and subsequently to juvenile fish. Photo by Randall Benton/Sacramento Bee/Zuma Press/Alamy Stock Photo

The Ocean's Mysterious Vitamin Deficiency

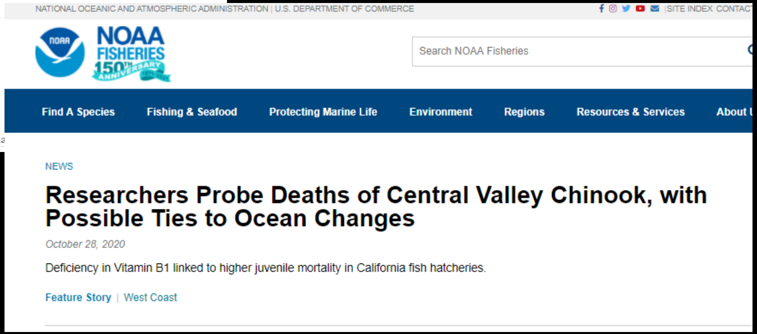
A puzzling lack of thiamine is disrupting some marine ecosystems.

by Alastair Bland

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

Share this:

Disoriented little fish caught the attention of staff members at the Colema...



NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION | U.S. DEPARTMENT OF COMMERCE | SITE INDEX CONTAC...

NOAA FISHERIES 150th ANNIVERSARY

Search NOAA Fisheries

Find A Species | Fishing & Seafood | Protecting Marine Life | Environment | Regions | Resources & Services | About U...

NEWS

Researchers Probe Deaths of Central Valley Chinook, with Possible Ties to Ocean Changes

October 28, 2020

Deficiency in Vitamin B1 linked to higher juvenile mortality in California fish hatcheries.

Feature Story | West Coast

Questions: Rachel.Johnson@noaa.gov

2. Identify the cause: Marine food web and freshwater response

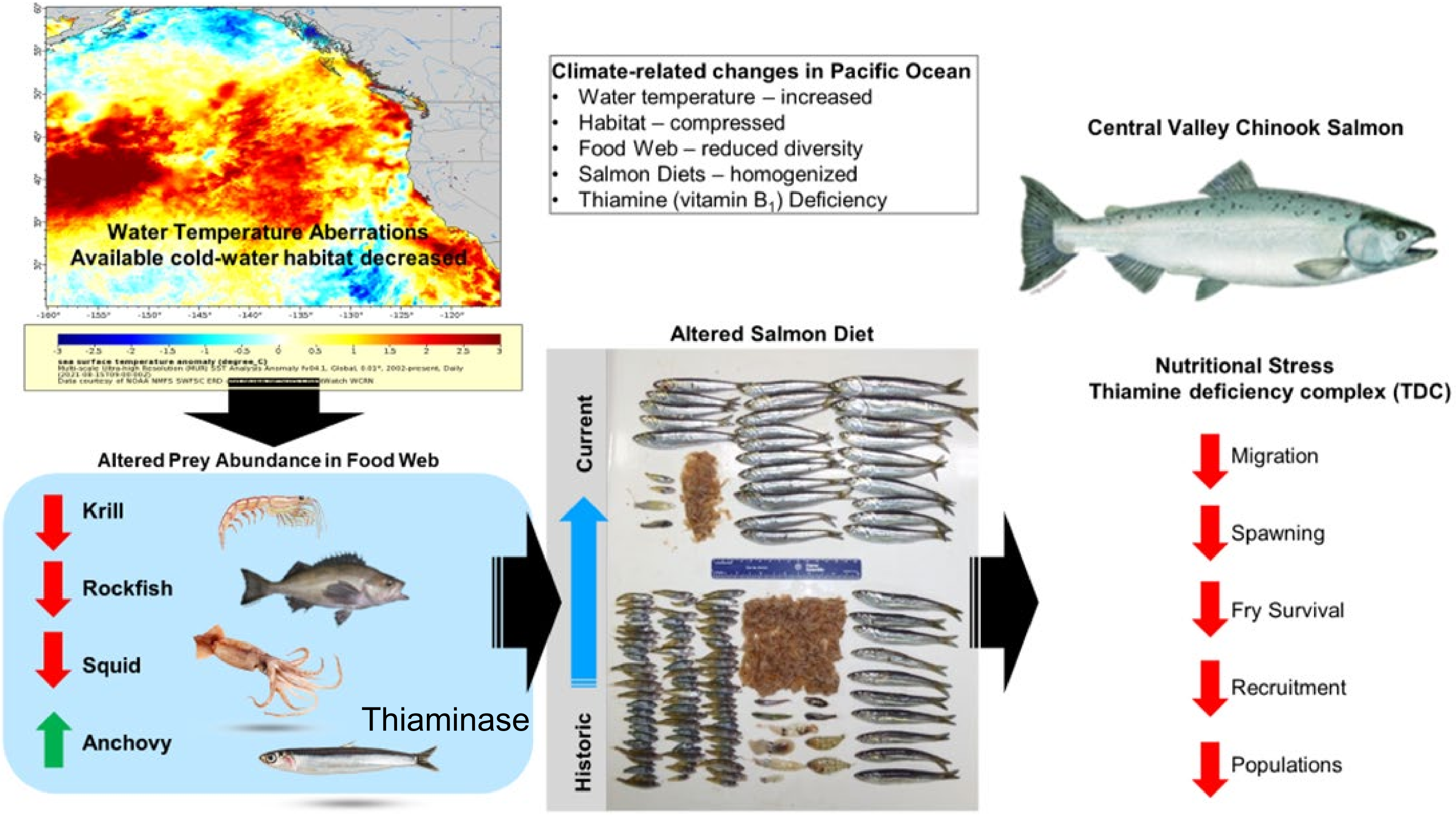
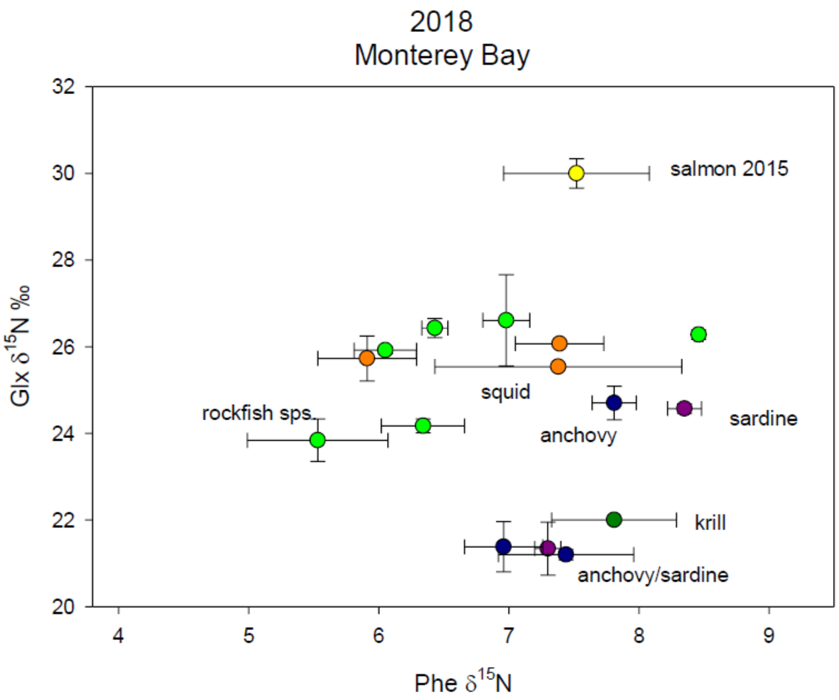
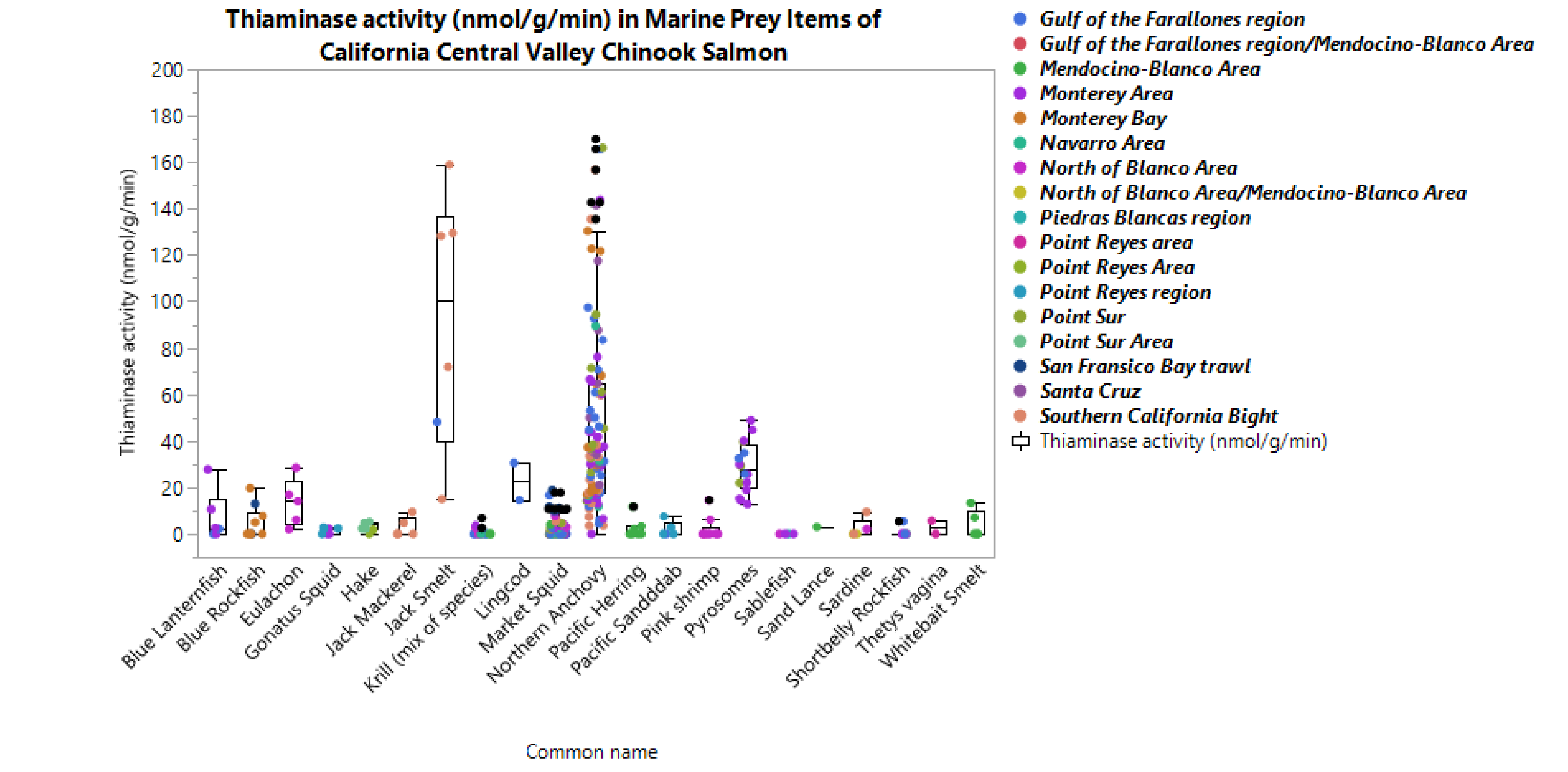


Figure courtesy of Freya Rowland

CSIA-AA d15N data.
Glx =glutamic acid (indicator of diet),
Phe = phenyalanine (baseline indicador = habitat)

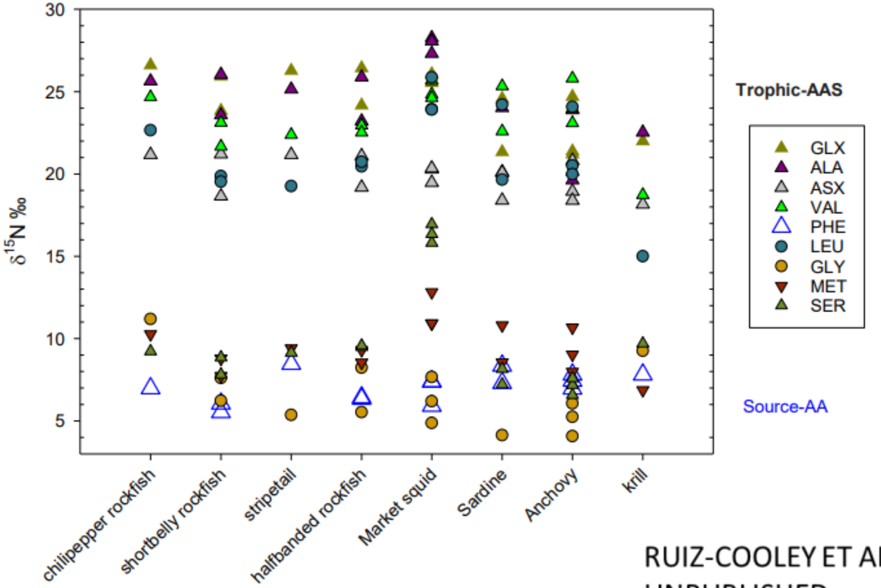


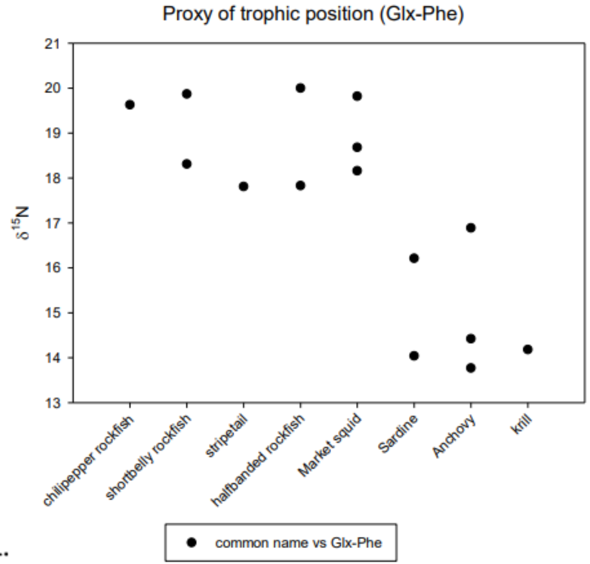
RUIZ-COOLEY ET AL.
UNPUBLISHED



Thiaminase activity (nmol/g/min) in Marine Prey Items of California Central Valley Chinook Salmon
Thiaminase activity (nmol/g/min)
200
180
160
140
120
100
80
60
40
20
0
Blue Lanternfish
Blue Rockfish
Eulachon
Gonatus Squid
Hake
Jack Mackerel
Jack Smelt
Krill (mix of species)
Lingcod
Market Squid
Northern Anchovy
Pacific Herring
Pacific Sandddab
Pink shrimp
Pyrosomes
Sablefish
Sand Lance
Sardine
Shortbelly Rockfish
Thetys vagina
Whitebait Smelt
Common name
Gulf of the Farallones region
Gulf of the Farallones region/Mendocino-Blanco Area
Mendocino-Blanco Area
Monterey Area
Monterey Bay
Navarro Area
North of Blanco Area
North of Blanco Area/Mendocino-Blanco Area
Piedras Blancas region
Point Reyes area
Point Reyes Area
Point Reyes region
Point Sur
Point Sur Area
San Fransico Bay trawl
Santa Cruz
Southern California Bight
Thiaminase activity (nmol/g/min)

Amino acid d15N variability and proxies of trophic position. Squid show high variability in trophic AA 15N values suggesting a wider range in dietary protein and perhaps diverse diet.





RUIZ-COOLEY ET AL.
UNPUBLISHED

Chinook salmon C diet chronology pre (2018) and post (2020) thiamine deficiency