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 - **An Ecosystem Model Framework to Predict Historical and Future Ocean Conditions Impacting Juvenile Salmon off Central California**, Jerome Fietchter, Ph.D., *University of California, Santa Cruz*

Slide 26 - **Can We Use an Ocean Productivity Model to Estimate Juvenile Salmon Early Ocean Survival?,** Mark Henderson, Ph.D., *U.S. Geological Survey*

Slide 49 - **Top-down and Bottom-up Effects on Juvenile Chinook Salmon Survival off Central California from an Individual-based Model**, Kelly Vasbinder, Ph.D., *University of California, Santa Cruz*

Slide 76 – **Characterizing the Marine Distribution of California's Chinook Salmon (using tags and genetics)**, Alexander Jensen, Ph.D., *University of Washington*

Slide 103 - **Ocean Distribution of West Coast Chinook Salmon Inferred from Coded-Wire-Tags and Genetic Data**, Will Satterthwaite, Ph.D., *NOAA Fisheries, SWFSC*

An Ecosystem Model Framework to Predict Historical and Future Ocean Conditions Impacting Juvenile Salmon off California

Jerome Fiechter

Ocean Sciences Department

UC Santa Cruz

SRF Meeting, Santa Cruz, April 2022

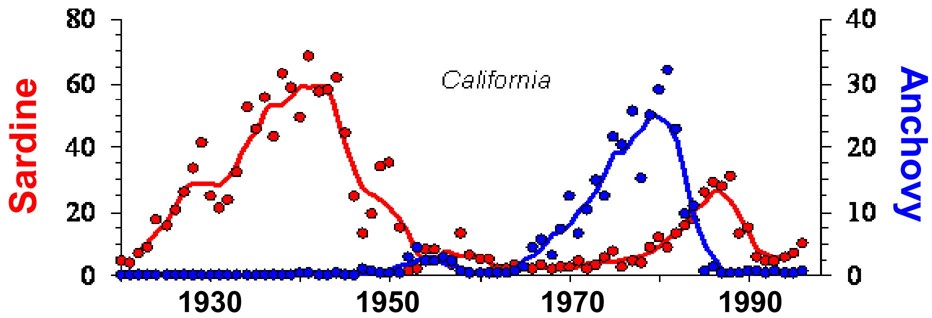
Contributors

Kenny Rose
Enrique Curchitser
Brian Wells
Jarrod Santora
Mike Jacox
Mer Pozo Buil
Chris Edwards
Andy Moore
Kate Hedstrom
Monique Messié
Dan Costa
and many more…

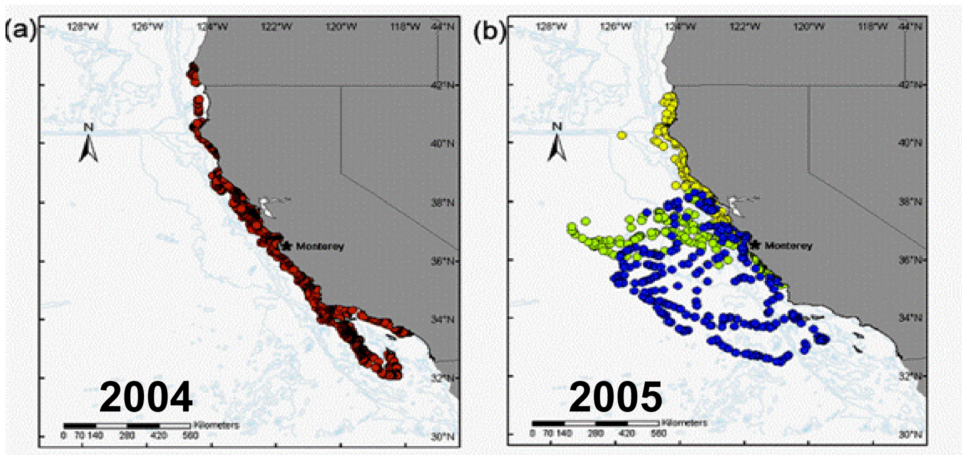
Funding

Ecosystem Variability in the California Current

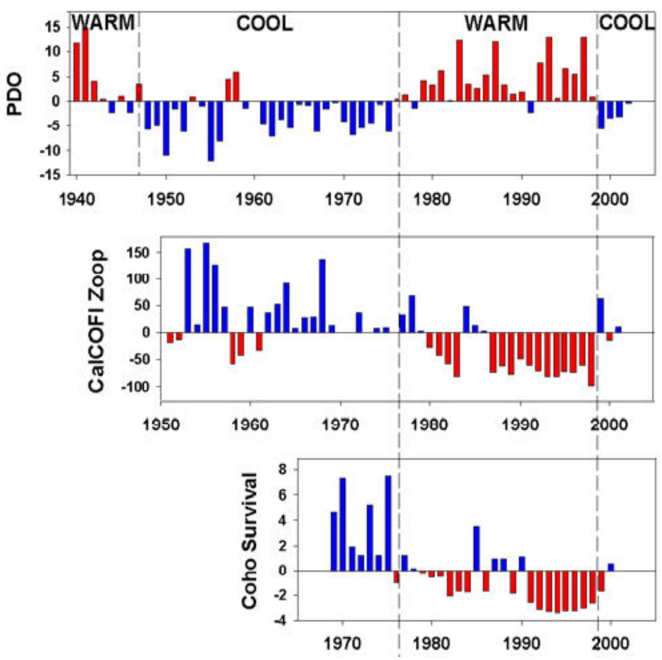
Spatial and temporal ecosystem responses integrate physical and biological processes occurring at local, regional, and basin scales



Sardine & Anchovy (Schwartzlose et al. 1999)

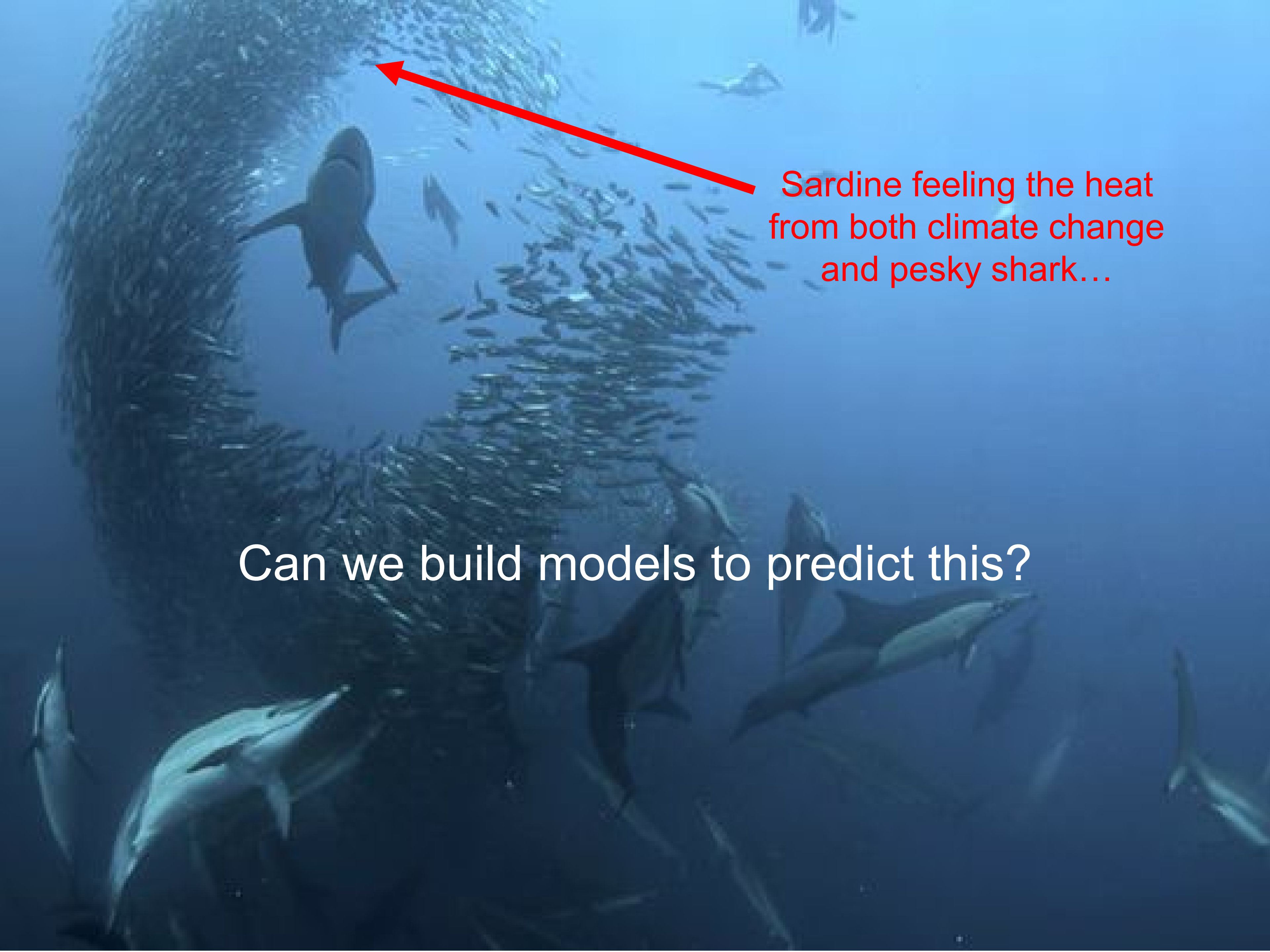


California Sea Lion (Weise et al. 2006)



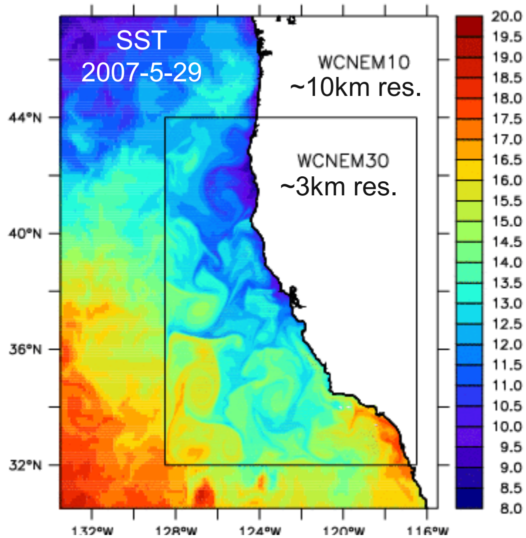
Coho Salmon Survival

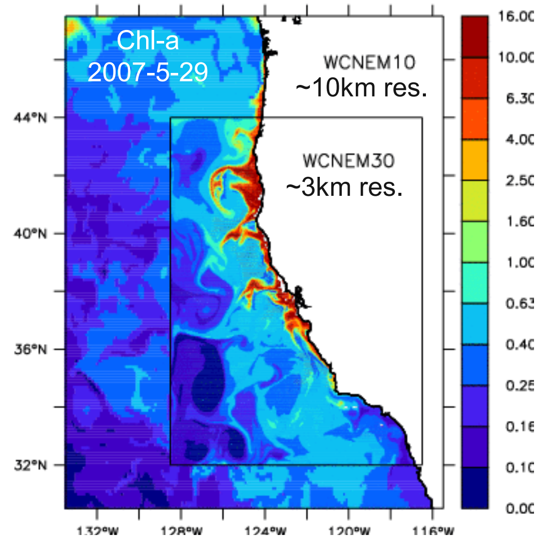
(Peterson and Schwing 2003)


Sardine feeling the heat
from both climate change
and pesky shark…
Can we build models to predict this?

Coupled Ecosystem Model using ROMS Framework

Regional Ocean Modeling System (ROMS)

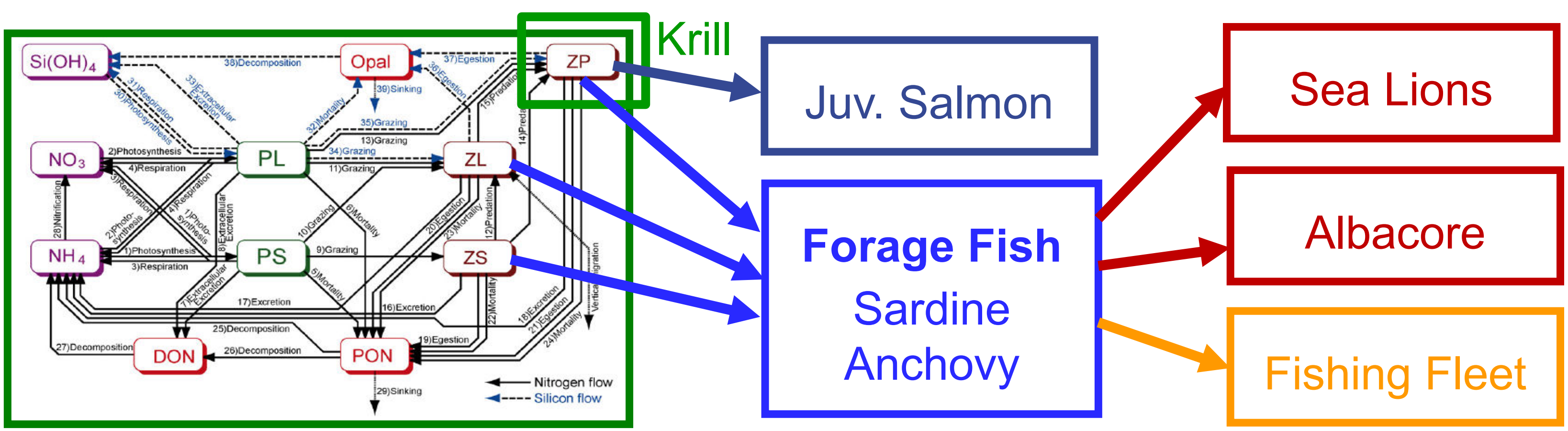




- ➢ Coastal circulation
- ➢ Multi-decadal runs
- ➢ Grid nesting
- ➢ Data assimilation
- ➢ Climate downscaling

Biogeochemistry (NEMUCSC)

Multi-species Individual-Based Model



Multi-species Individual-Based Model (IBM)

Why Individual-based Models?

- Basic unit in nature; allows for complex behavior and life history (full life cycle, growth, mortality, etc.)

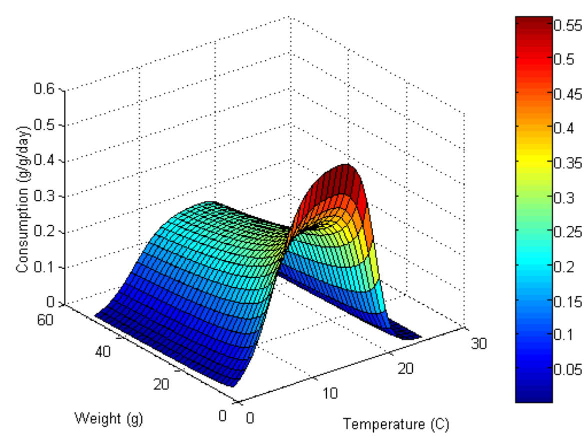
Bioenergetics

- **Wisconsin Model**

Balance between energy input and metabolic demands:

Csmp = Resp + Activ + SDA + Waste + Growth

$$C_j = \frac{C_{MAX} \cdot \dfrac{PD_{ij} \cdot v_{ij}}{K_{ij}}}{1 + \sum_{k=1}^{n} \dfrac{PD_{ik} \cdot v_{ik}}{K_{ik}}}$$



- **Dynamic Energy Budget**

Use **κ** factor to allocate assimilated energy between somatic growth and maintenance (**κ**) and maturity maintenance (**1-κ**)

Multi-species Individual-Based Model (IBM)

Why Individual-based Models?

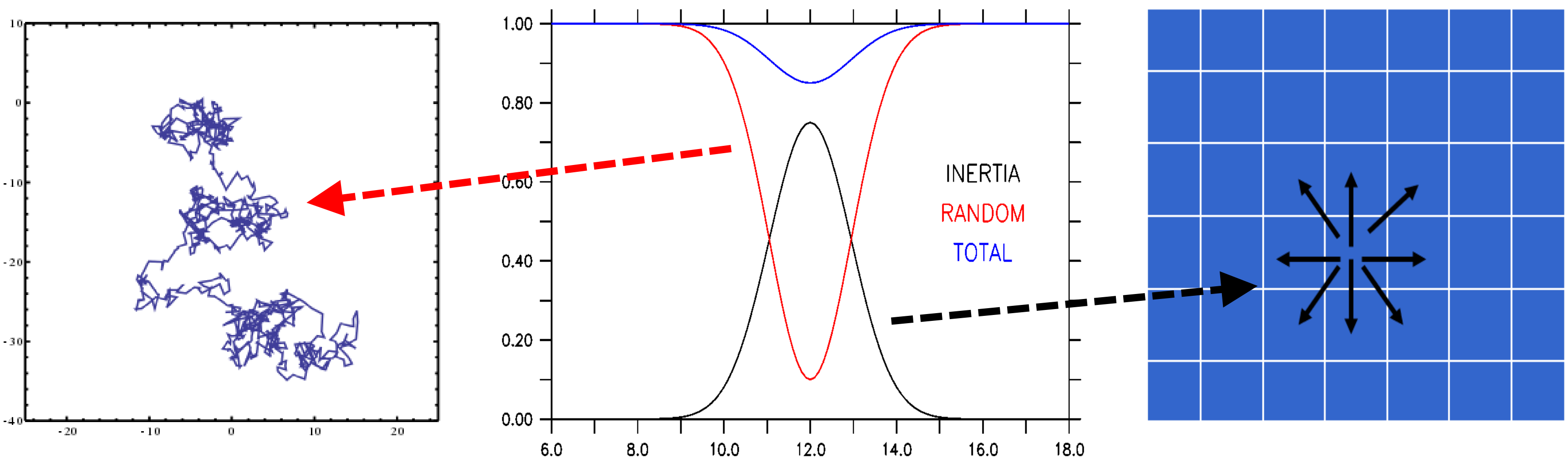
- Basic unit in nature; allows for complex life history (full life cycle, growth, mortality, etc.) and behavior.

Behavior

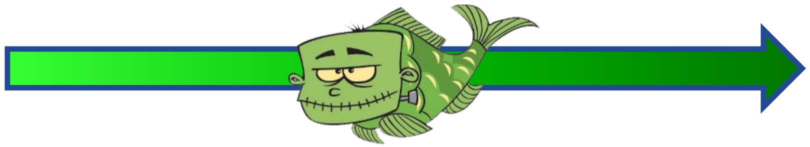
Random Walk (whatever…)

Kinesis (happiness based)

Neighborhood Search (fitness)

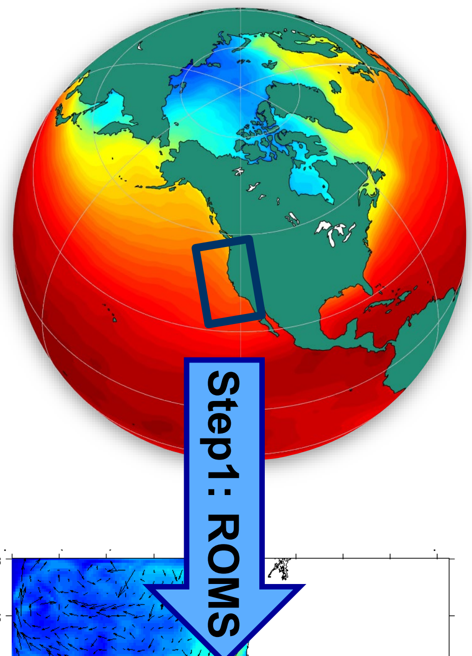


dumb fish



smart fish

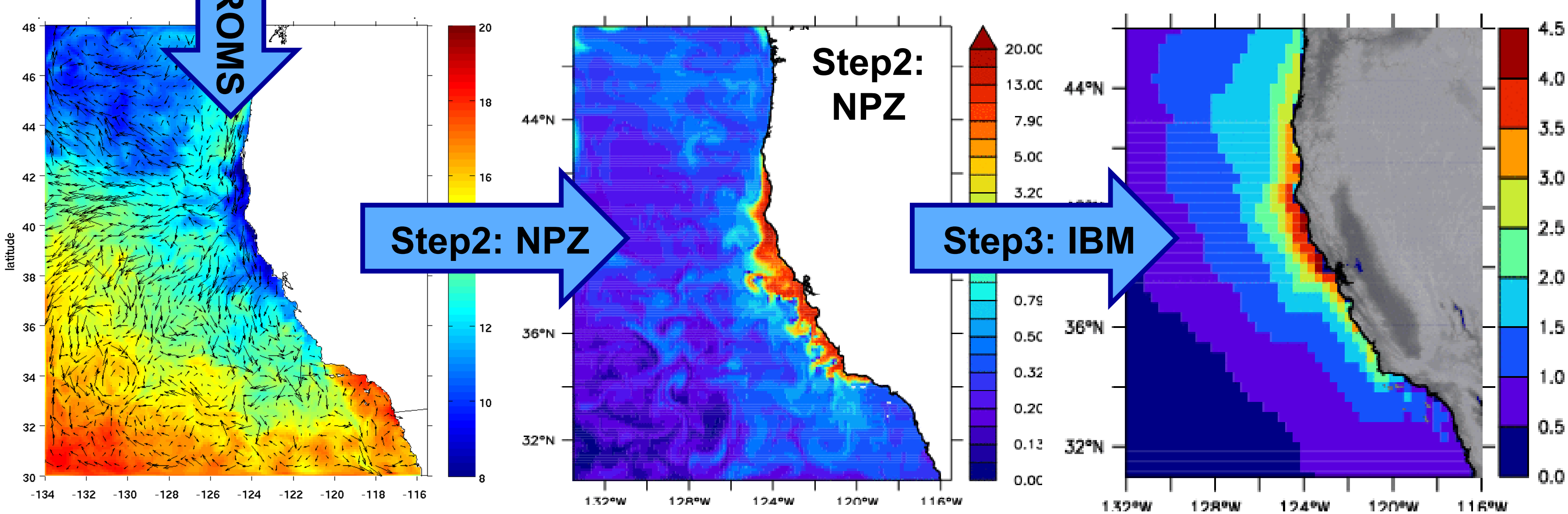
Climate to Fish: Global to Regional Downscaling



Step 1: Downscaling of global reanalysis or earth system model to regional ROMS model for the California Current (1° → 1/10° resolution)

Step 2: Offline biogeochemical (NPZ) solution forced by downscaled physical solution

Step 3: Offline fish IBM forced by downscaled physical and biogeochemical solutions



Model Evaluation is Difficult !!!

- How does uncertainty propagate from physics to biogeochemistry and higher trophic levels?
- Is behavior parameterized for present conditions applicable under future conditions?
- Scarcity of direct observations beyond physics and biogeochemistry
- Must evaluate each model component individually and in relation to the other components
- Must rely on historical simulations

What Have We Learned?

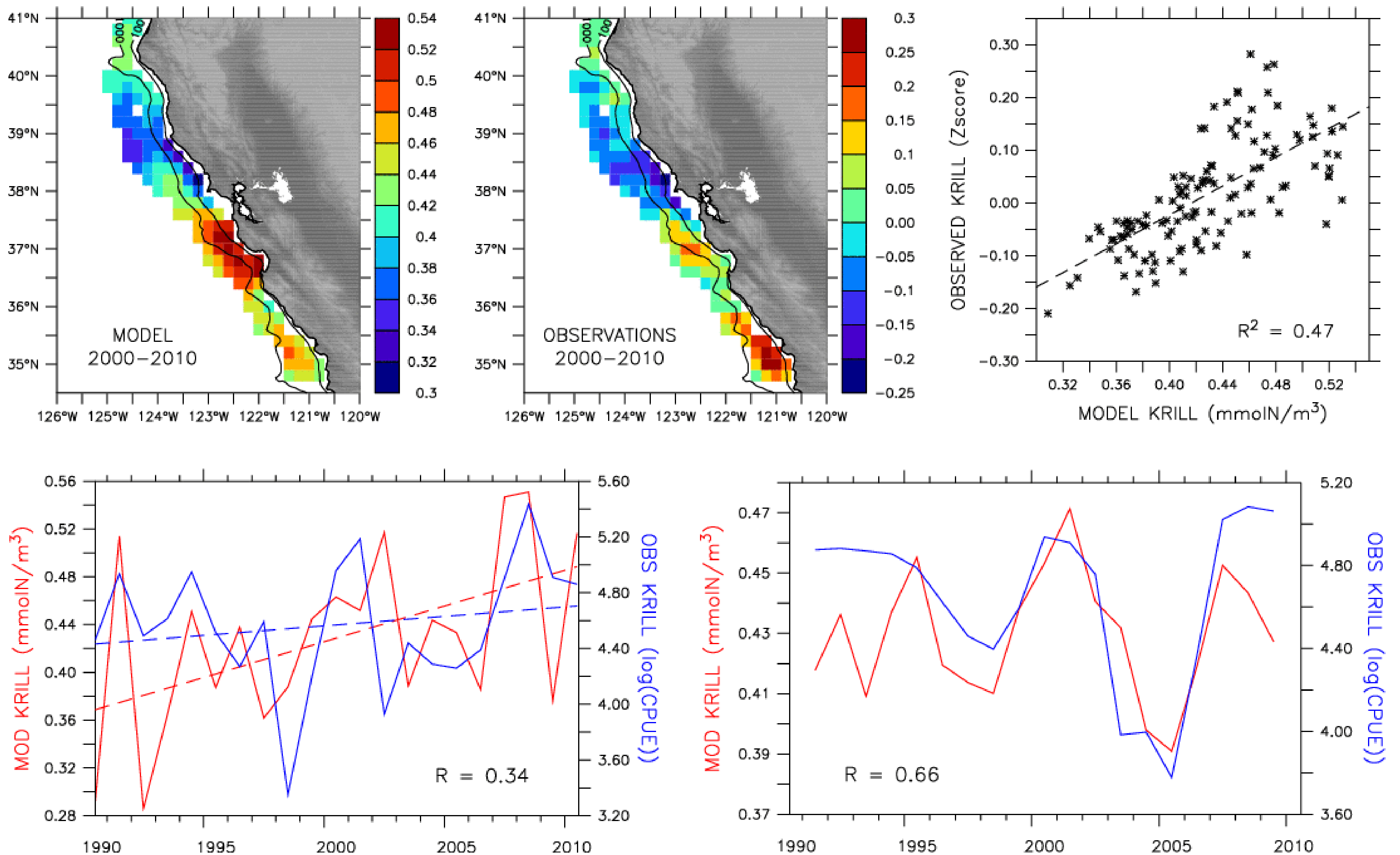
Regional Historical Simulations (1990-2010)

- Drivers of seasonal krill aggregations
- Juvenile salmon growth patterns

Regional Climate Projections (2000-2100)

- Changes in juvenile salmon growth potential
- Shifts in sardine distribution and abundance

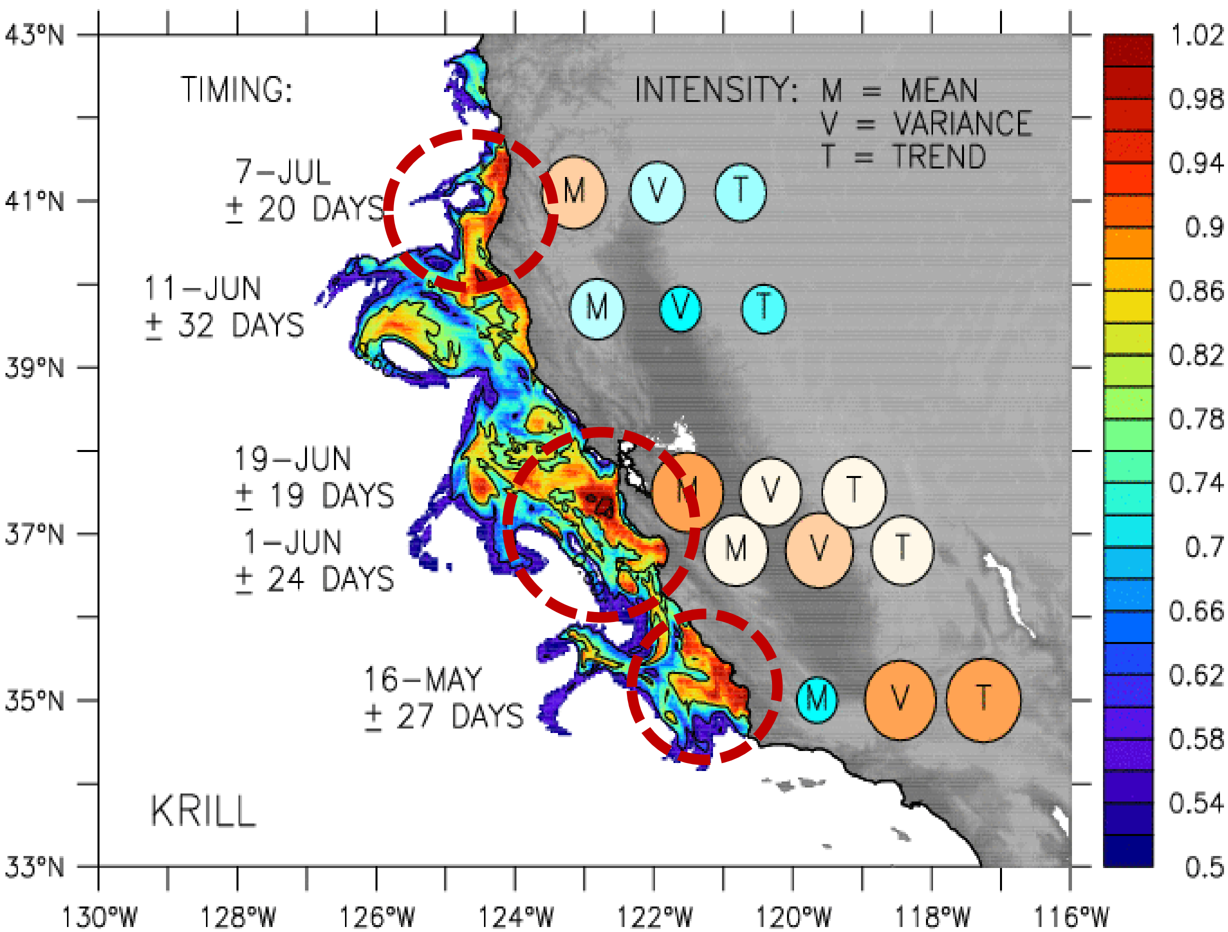
Model Evaluation: Krill Abundance and Distribution



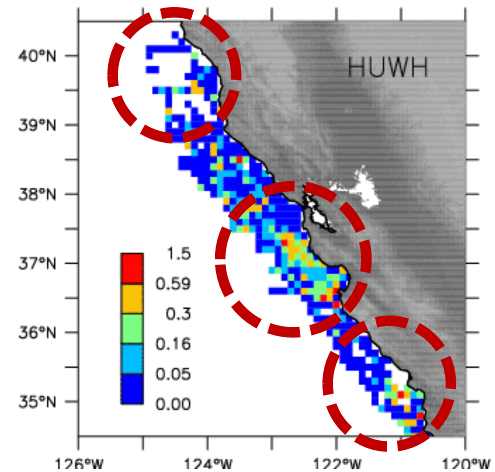
Fiechter et al., GRL, 2020

Krill Aggregations and Ecosystem Hotspots

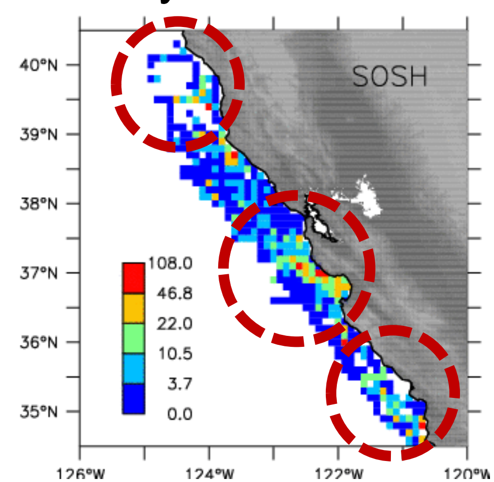
Timing and location of krill "hotspots"



Humpback Whales



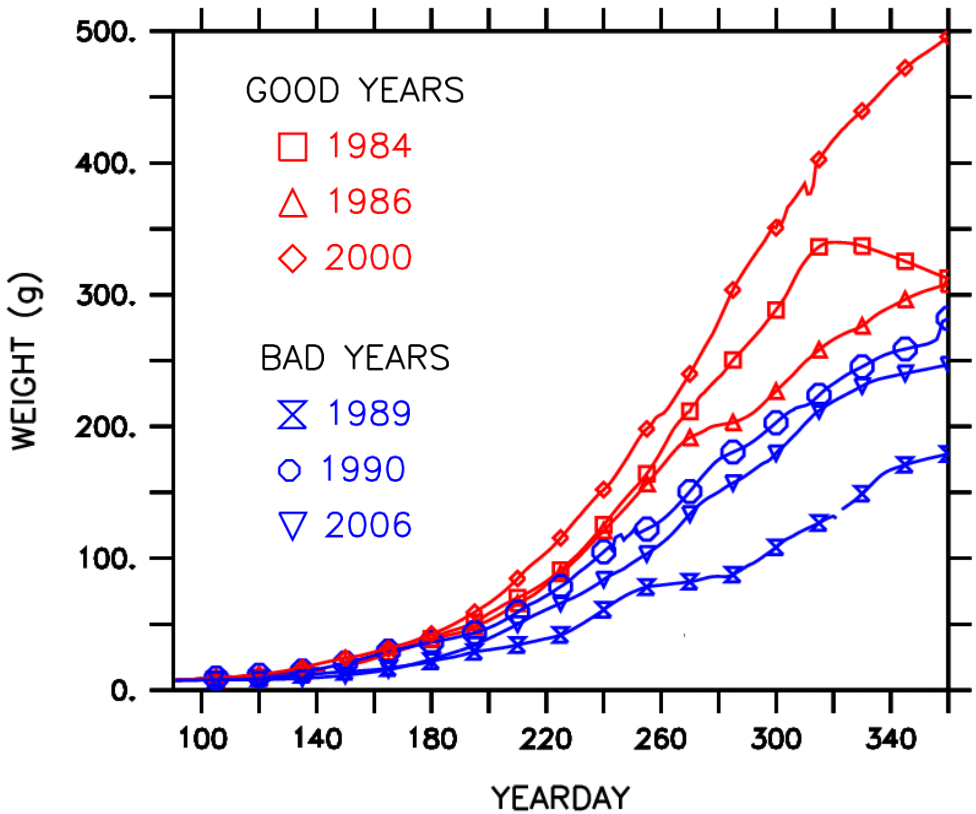
Sooty Shearwaters

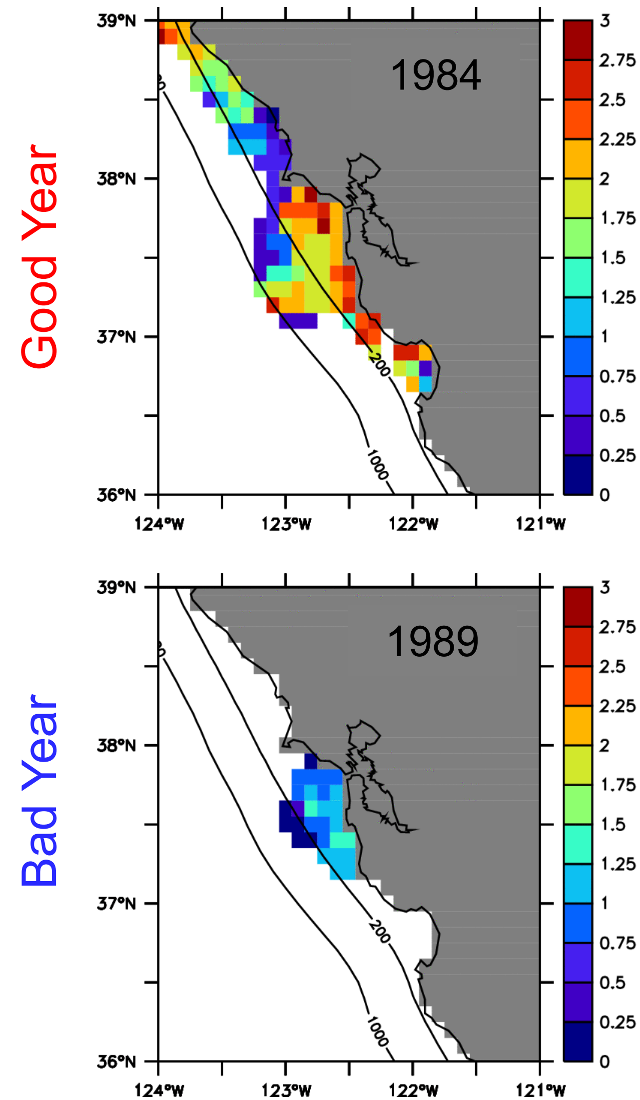


Fiechter et al., GRL, 2020

Juvenile Chinook Growth During First Year at Sea

Simulated Growth for April Ocean Entry

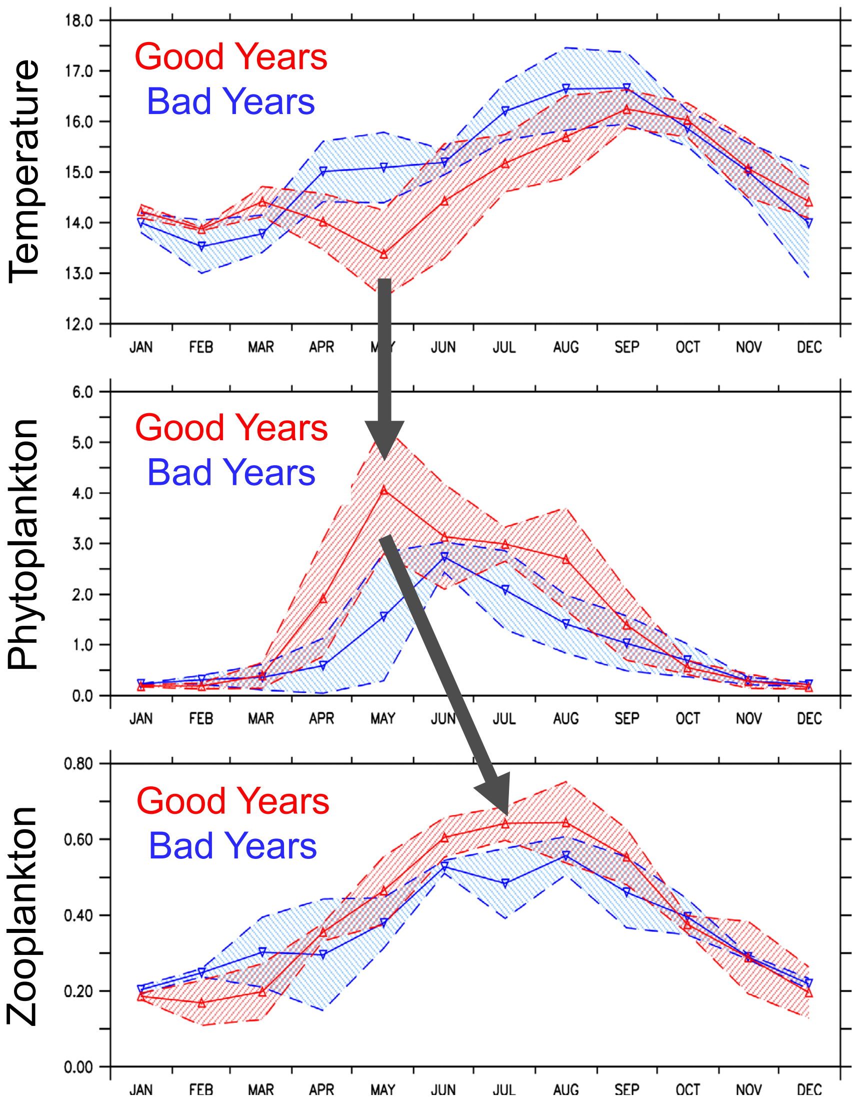




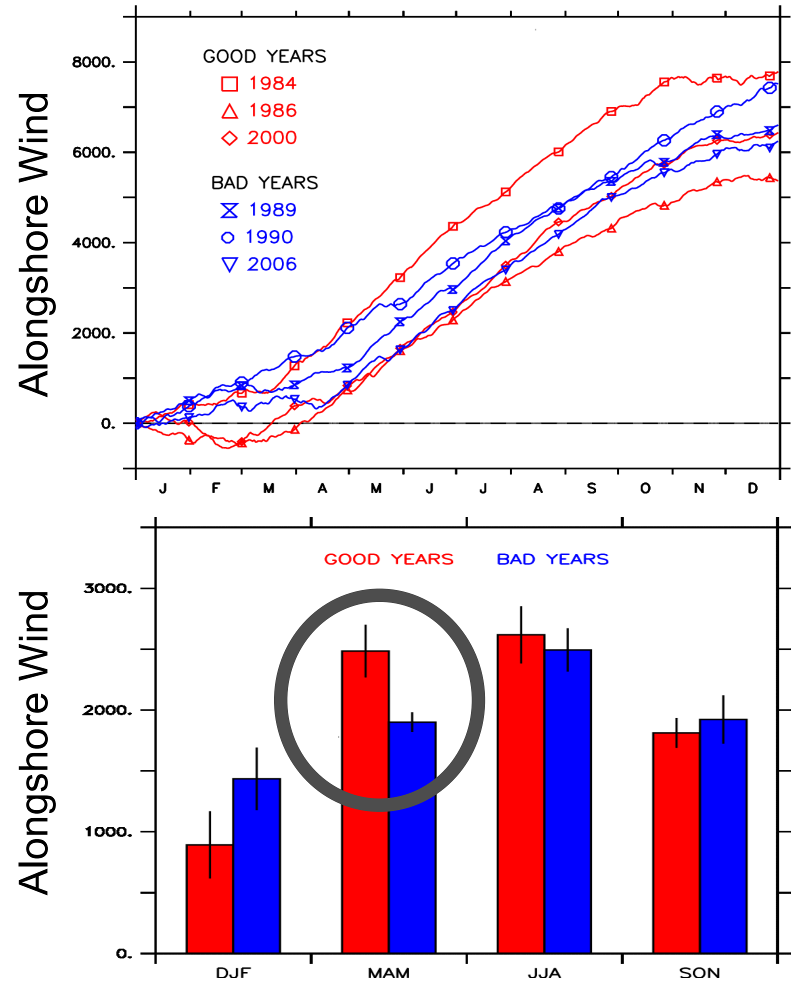
Good/bad years based on survival estimates for CA Chinook (Kilduff et al. 2014)

Juvenile Chinook Growth and Local Upwelling Intensity

Environmental Conditions



Cumulative Upwelling Intensity



Fiechter et al., GRL, 2015

What Have We Learned?

Regional Historical Simulations (1990-2010)

- Drivers of seasonal krill aggregations
- Juvenile salmon growth patterns

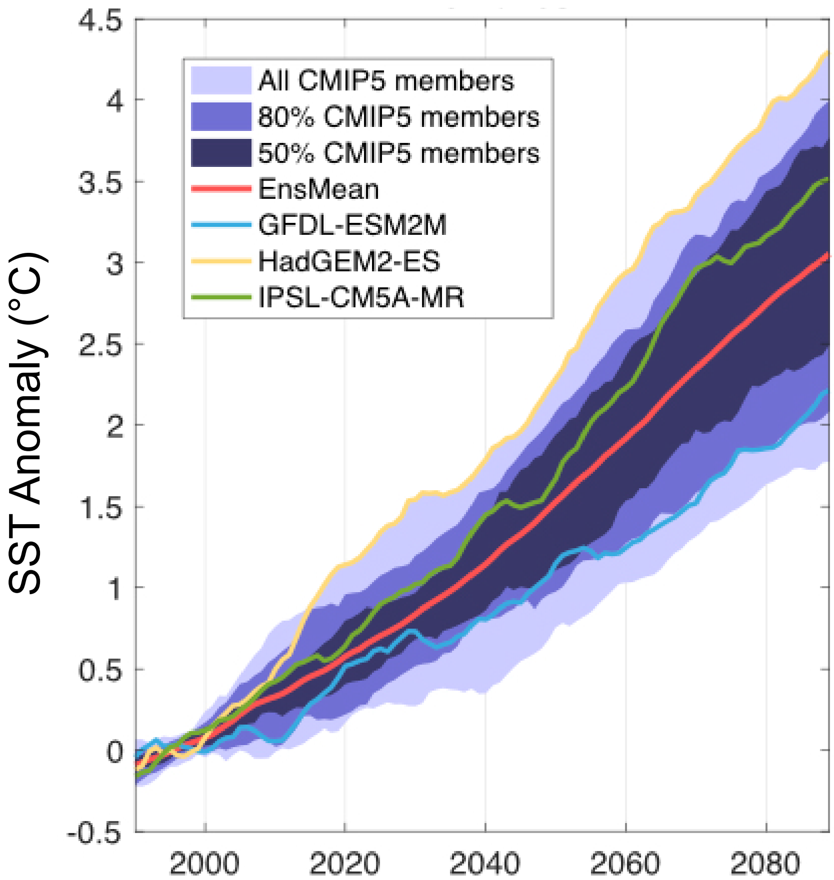
Regional Climate Projections (2000-2100)

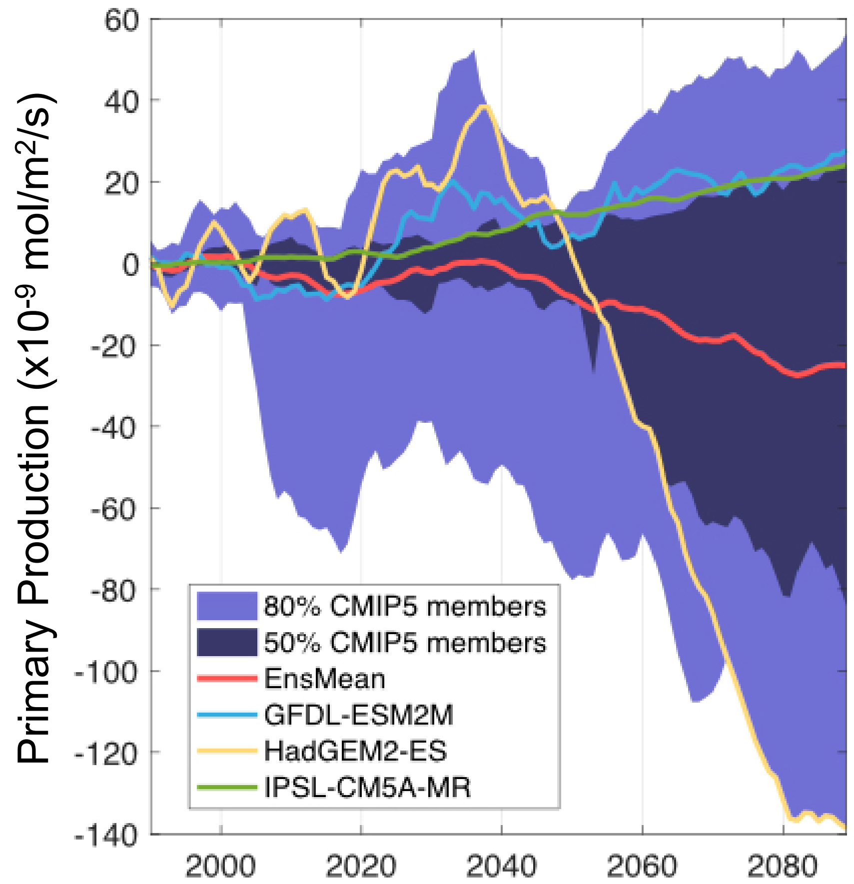
- Changes in juvenile salmon growth potential
- Shifts in sardine distribution and abundance

Regional Projections: Climate to Fish

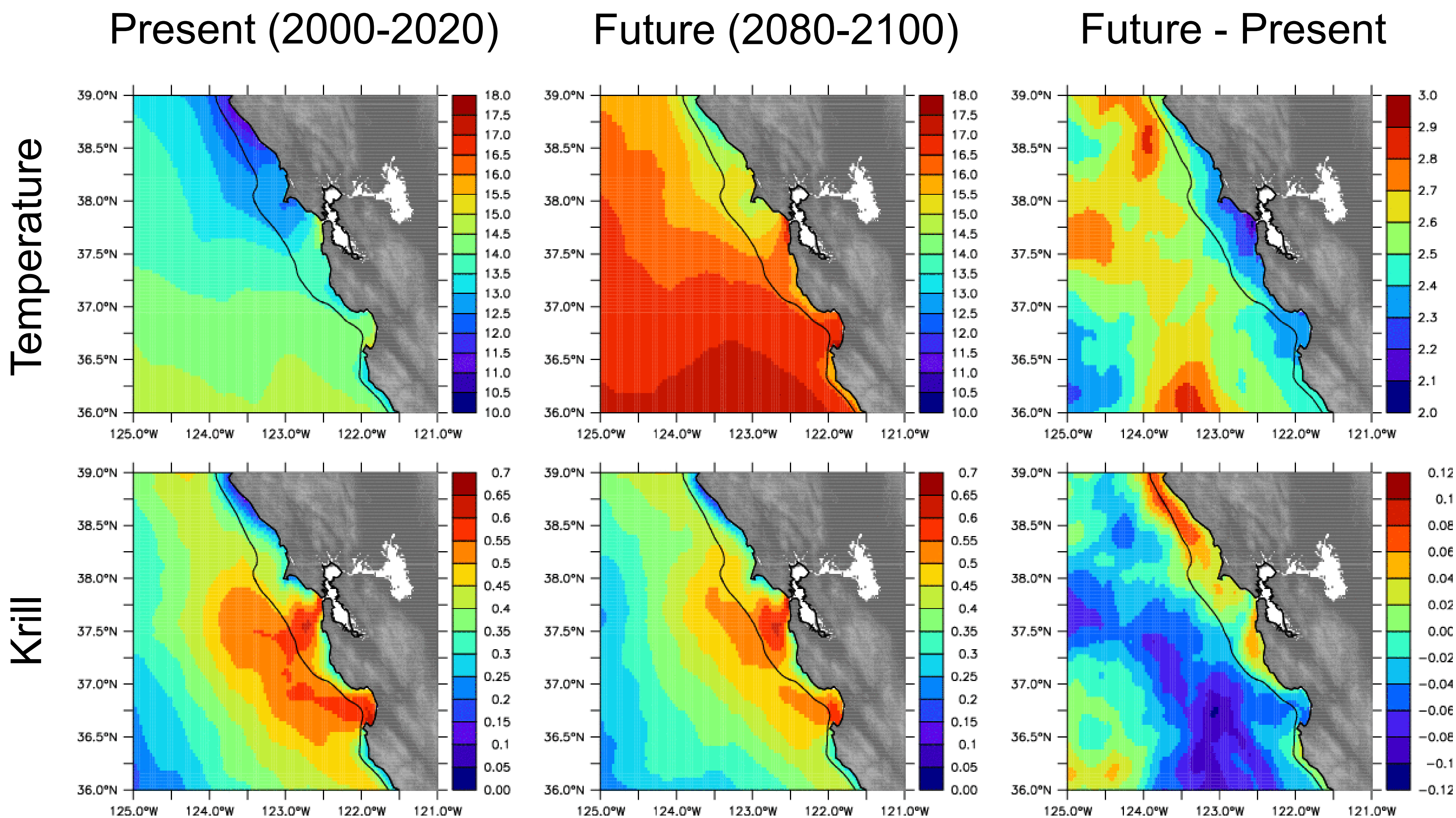
- Coupled Model Intercomparison Project (CMIP5) Ensemble

  Selected members: GFDL (1°x1°), HAD (2°x2°), IPSL (1°x1°)





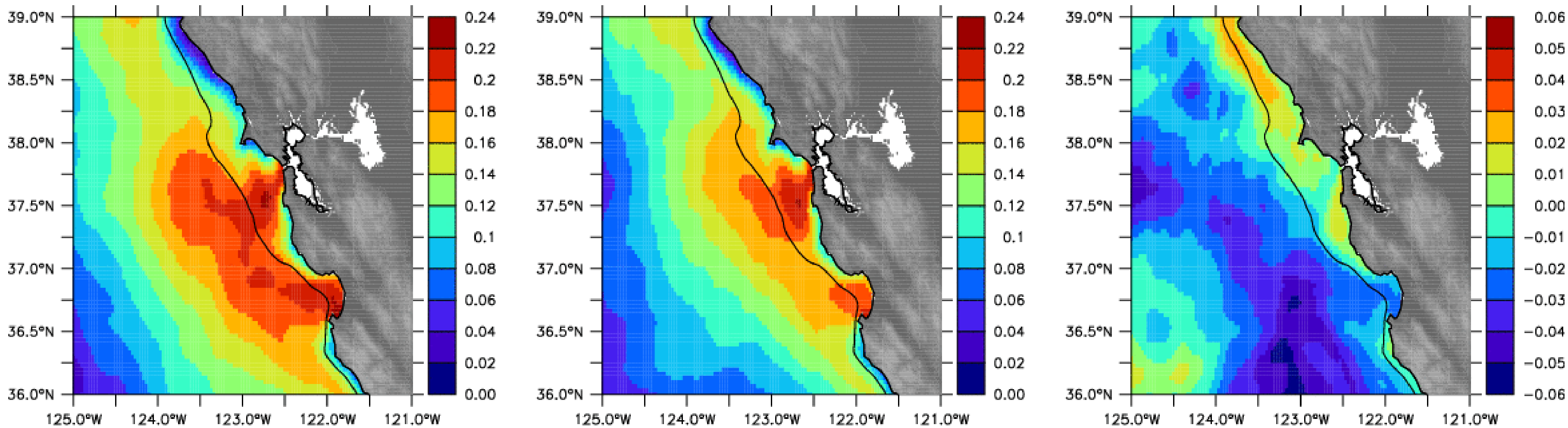
IPSL Projections: Temperature and Krill



Climate change impact much stronger on temperature than krill

IPSL Projections: Juvenile Chinook Growth

Present (2000-2020) | Future (2080-2100) | Future - Present

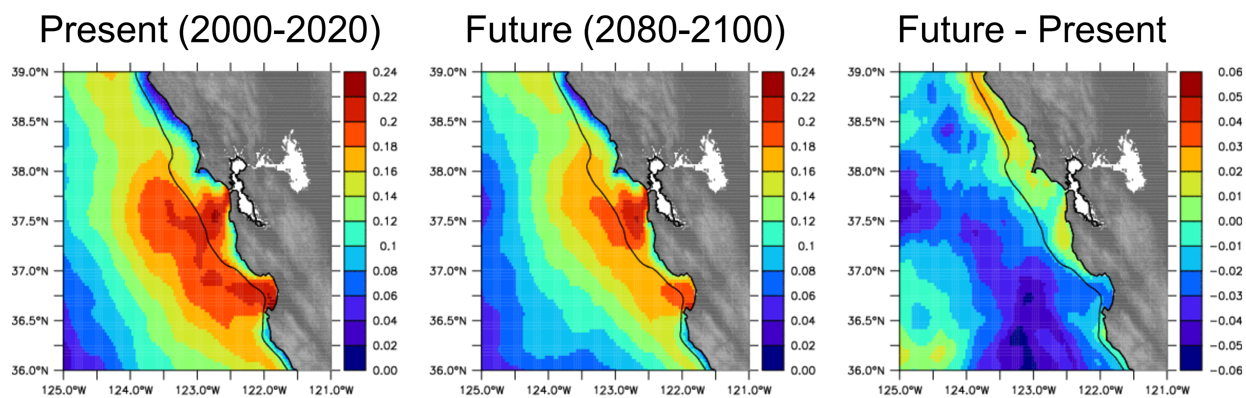


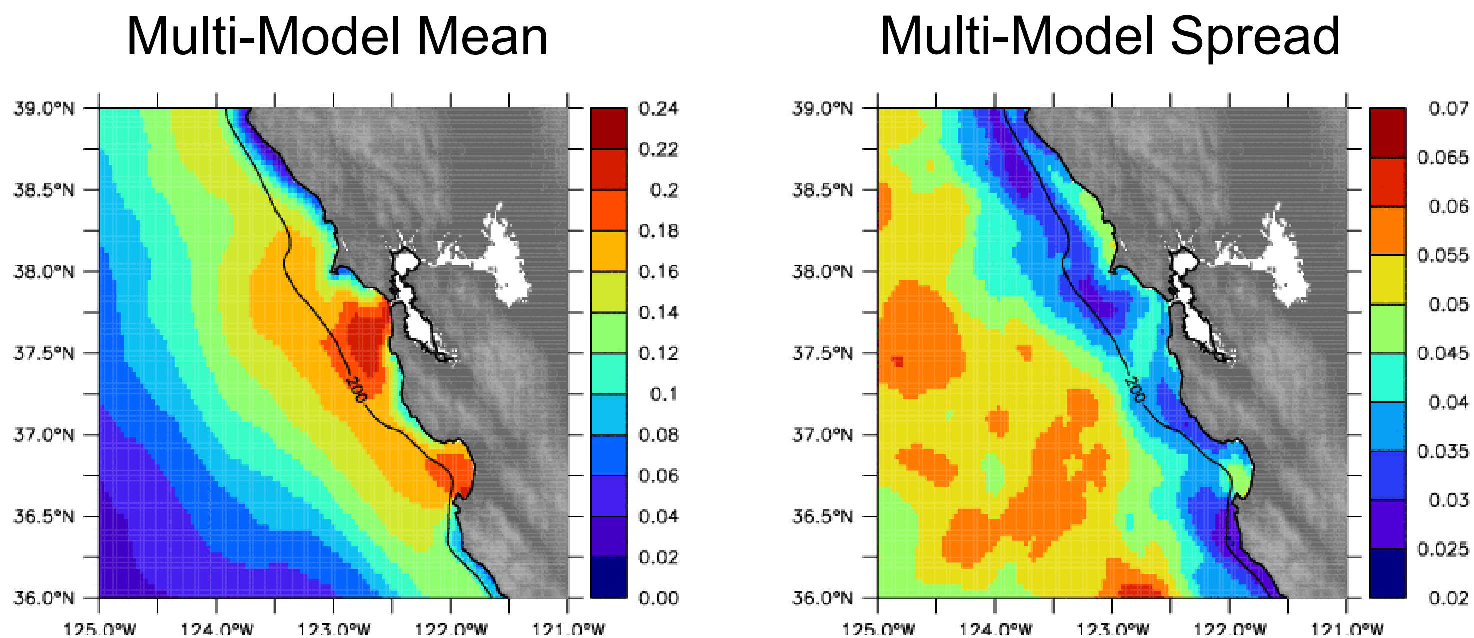
Relatively weak climate change impact on growth potential

Slight increase in growth potential in nearshore waters

How reliable are these projected patterns?

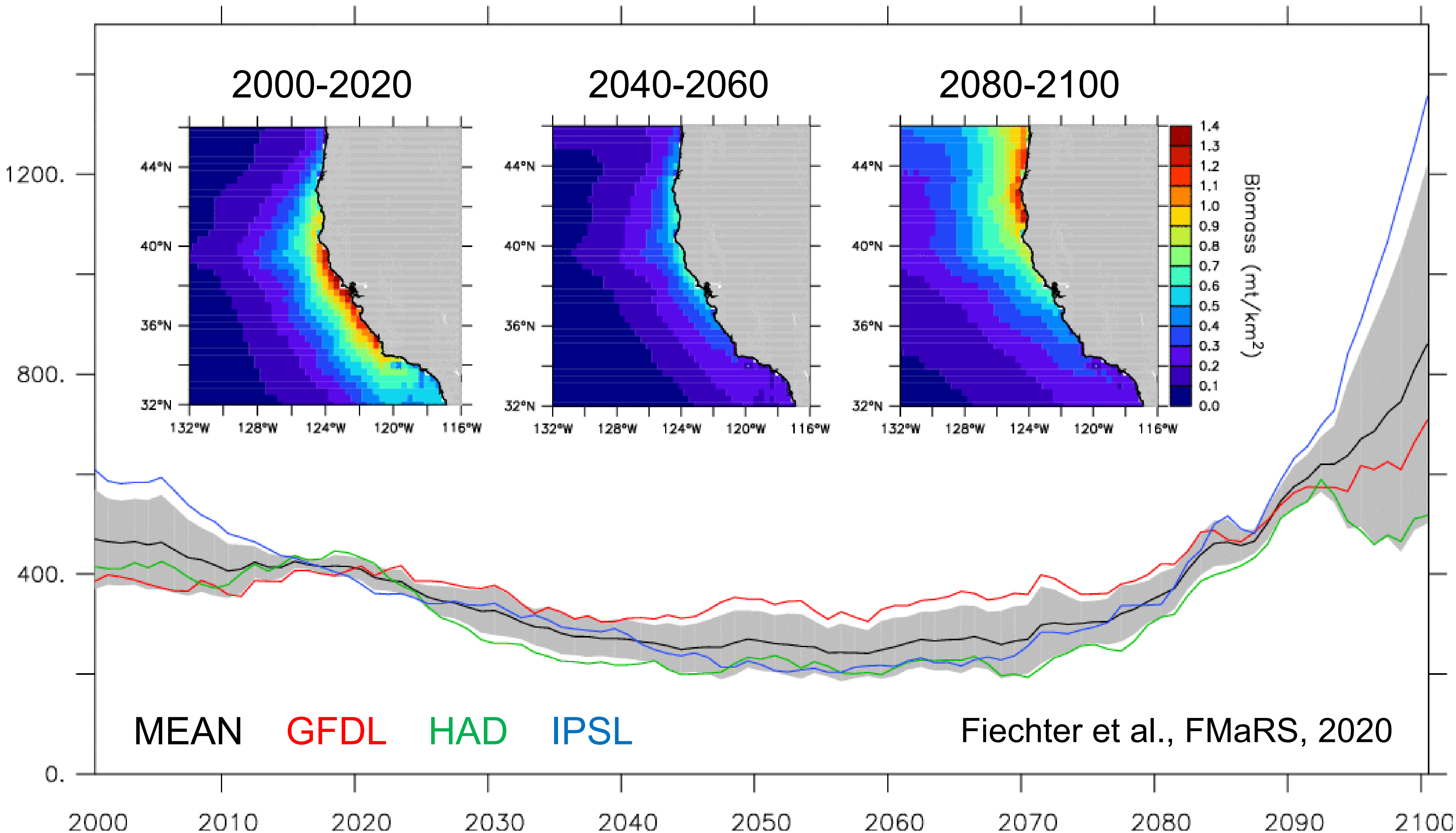
Ensemble Projections: Juvenile Chinook Growth





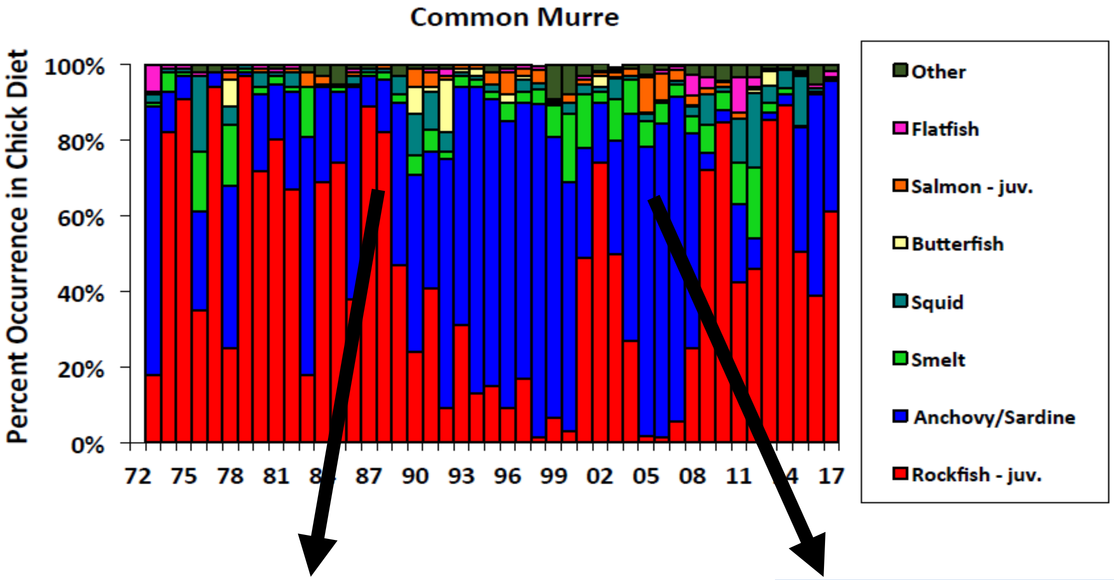
Projections are most robust (smallest spread) in coastal waters

Ensemble Projections: Sardine Population



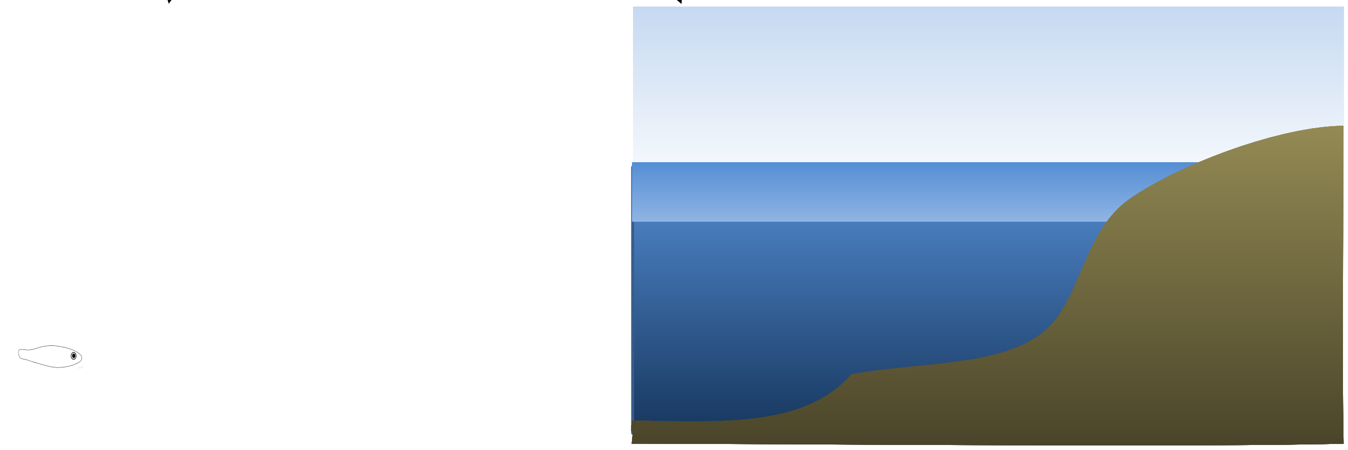
Projected change in annual sardine biomass (10^3 tons)

Importance of Predators and Alternate Forage

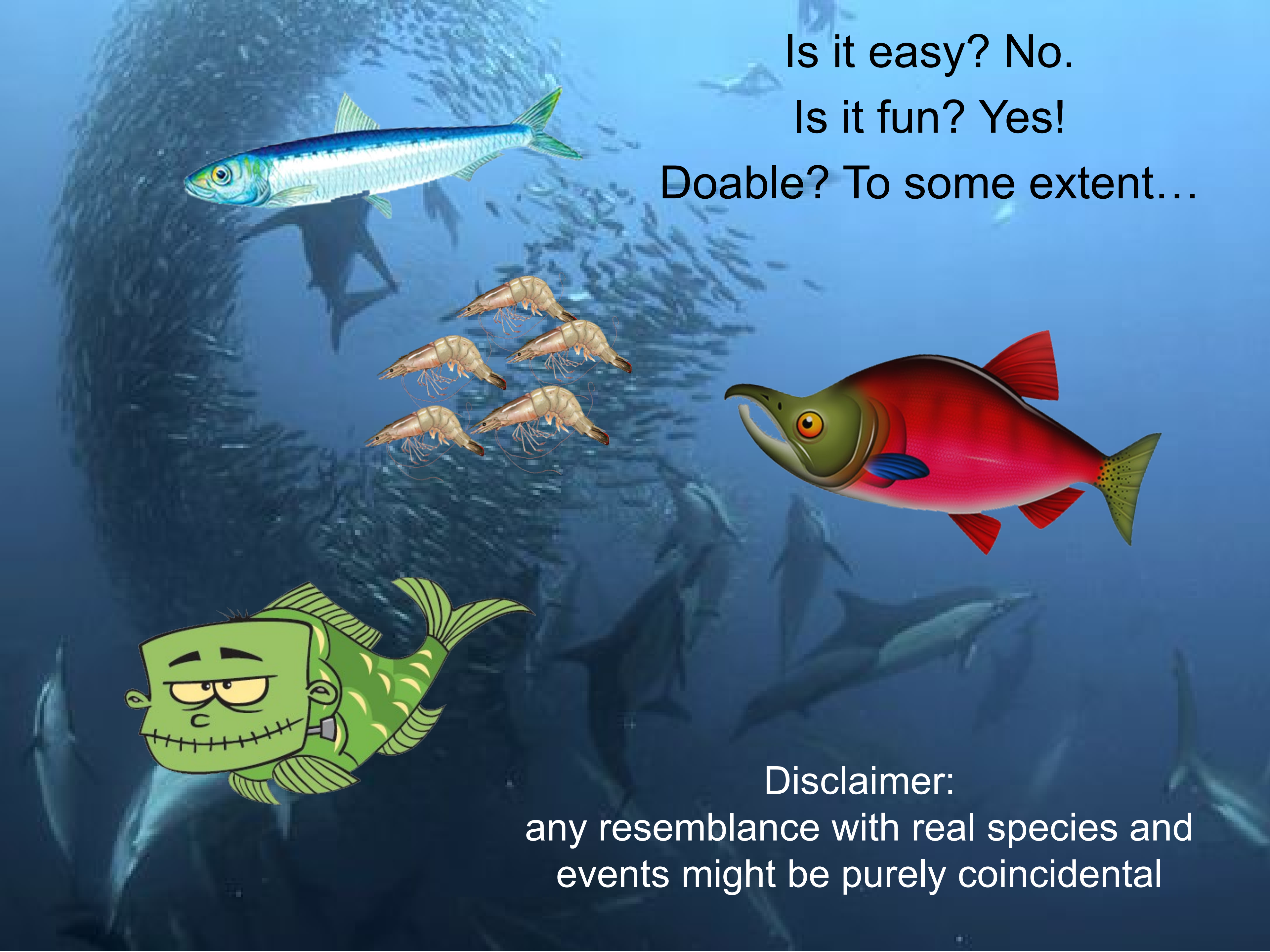


Adding explicit predation to IBM:

Stay tuned for Kelly Vasbinder's talk!



Wells et al. 2017


Is it easy? No.
Is it fun? Yes!
Doable? To some extent…
Disclaimer:
any resemblance with real species and
events might be purely coincidental

Can we use an ocean productivity model to estimate juvenile salmon early ocean survival

Mark Henderson

USGS California Cooperative Research Unit

California Cooperative Fish & Wildlife Research Unit

USGS
science for a changing world

CAL POLY HUMBOLDT
ESTABLISHED 1913

Collaborators

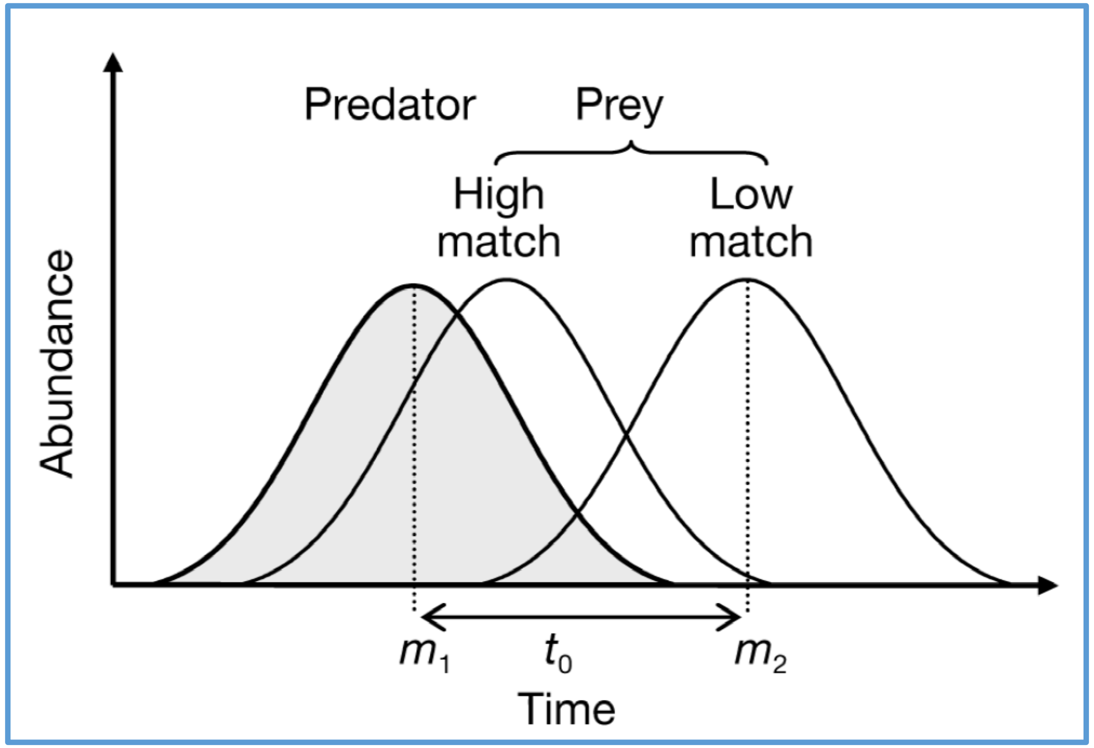
- Jerome Fiechter (UC Santa Cruz)
- Brian Wells (NOAA-SWFSC)
- David Huff (NOAA-NWFSC)



Early Ocean Survival

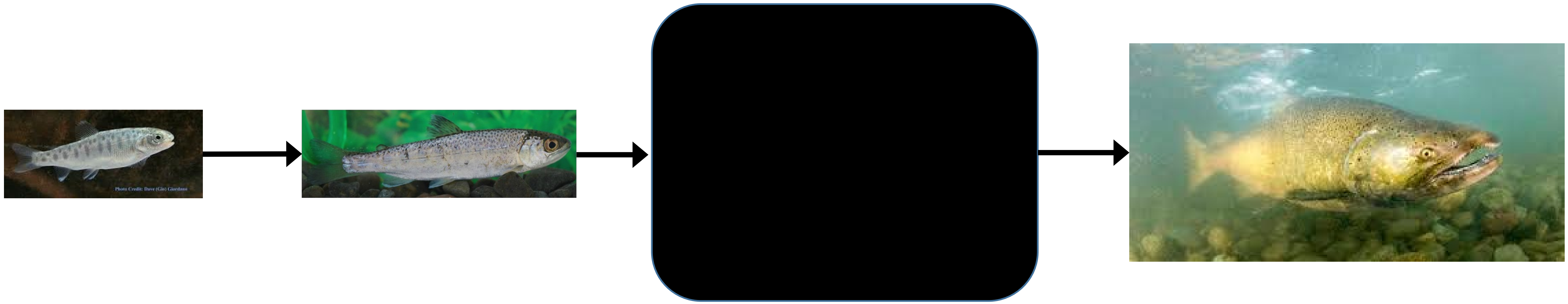
- A ‘critical’ period
- Year class strength is determined in the first ocean year
  - Immediately after smolts enter the ocean (predation)
  - During the first winter (starvation)

Cushing 1969



Salmon ocean life history - a ‘black box’

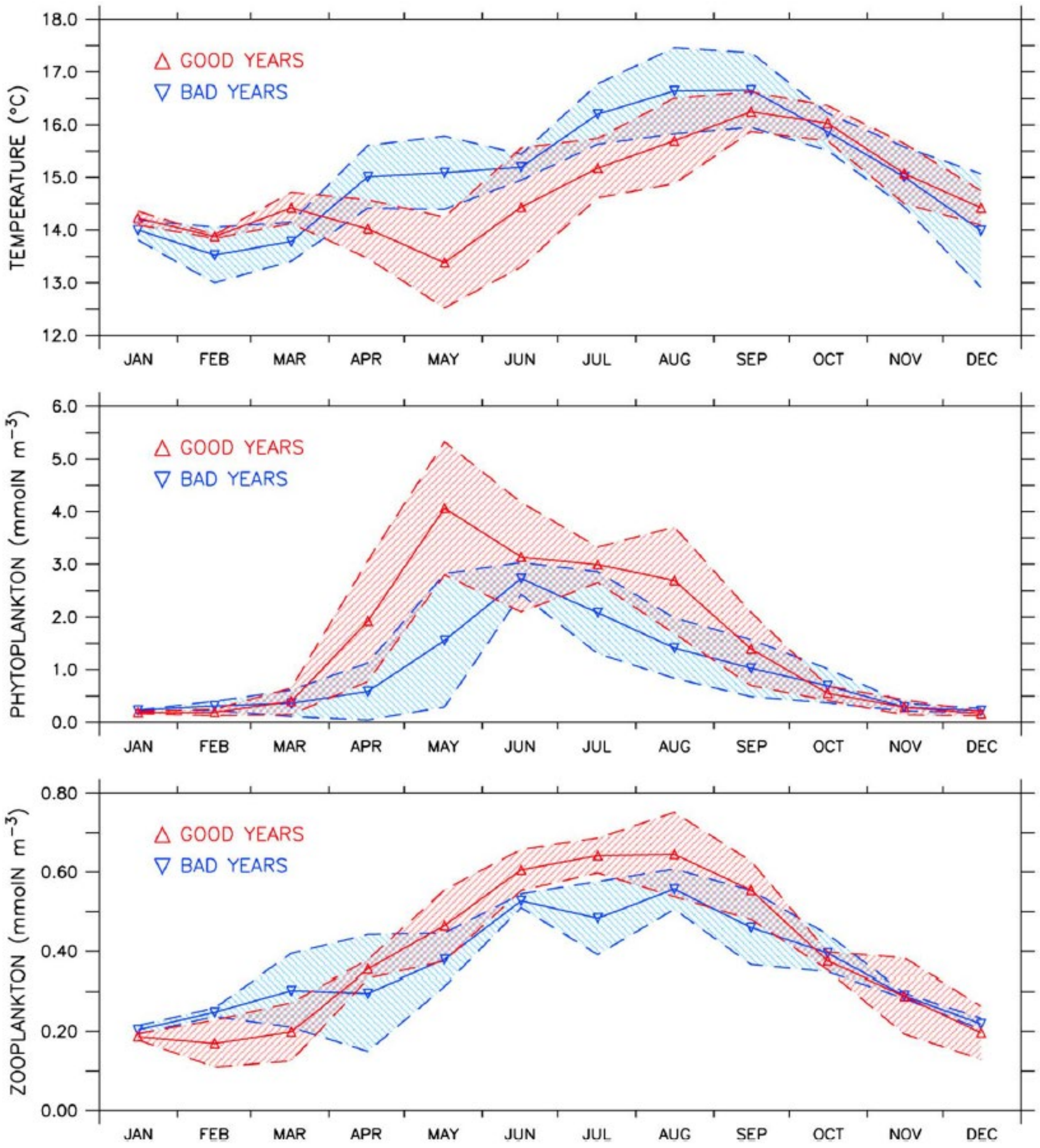
- Difficult time period to study
  - Ocean is a big place
  - Multiple complex processes interacting
    - Ocean physics
    - Climate drivers
    - Fish movements
    - Food web dynamics



Early ocean growth

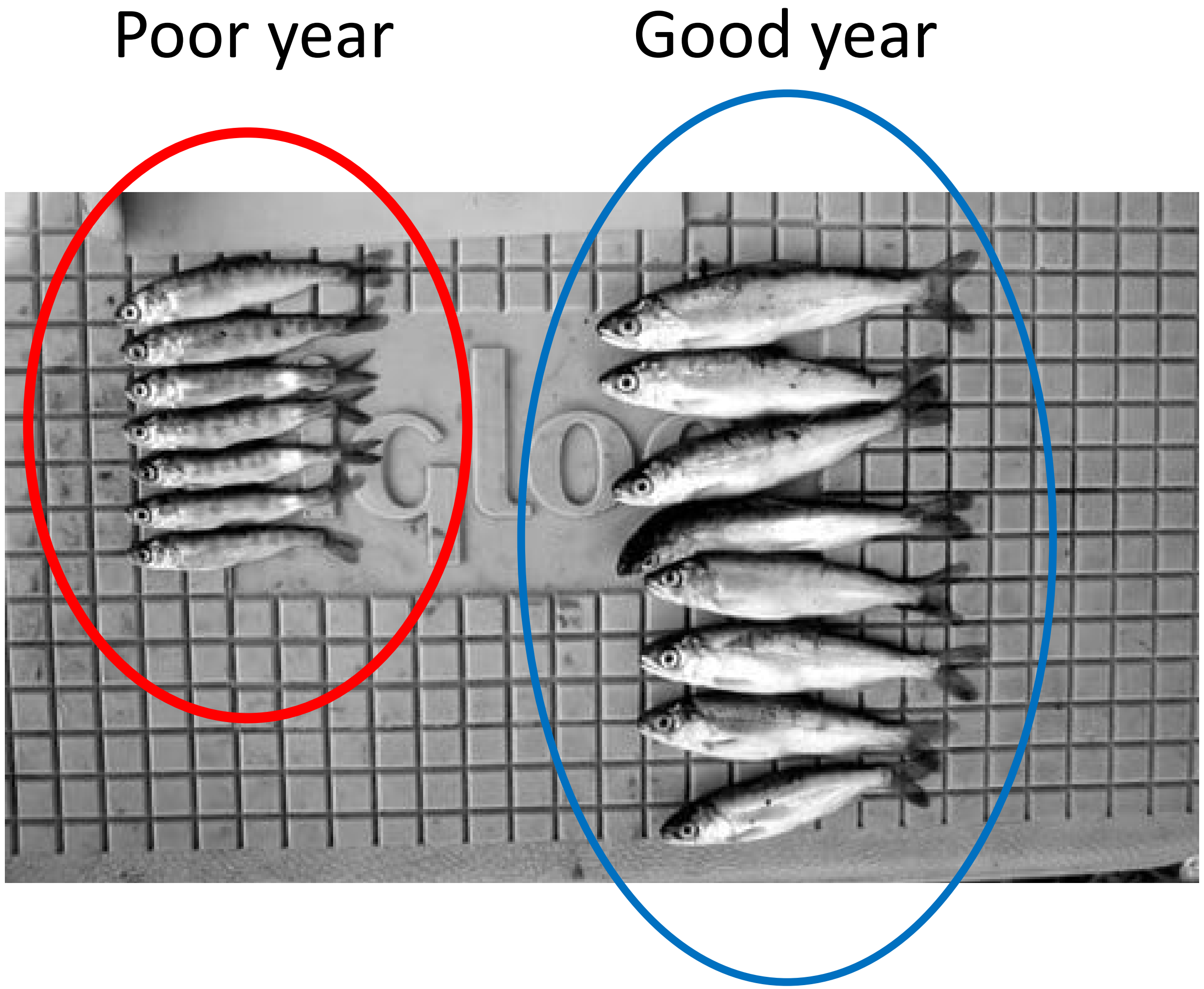
- Conditions favorable for early ocean growth
  - Early season upwelling
  - Increased zooplankton concentrations in Gulf of the Farallons

Fiechter et al 2015



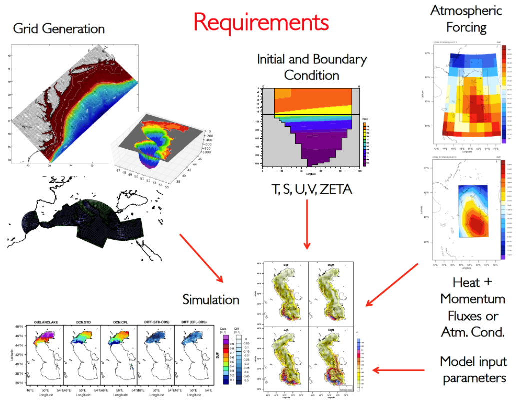
Ocean growth Potential and Juvenile salmon survival

- Main Question: Do growth conditions during ocean entry affect juvenile salmon survival?
  - What ocean conditions produce the strongest cohorts?

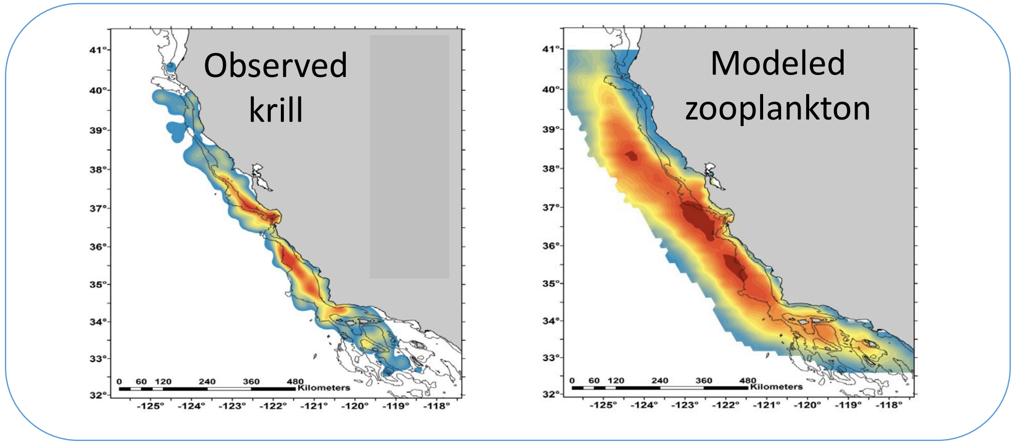


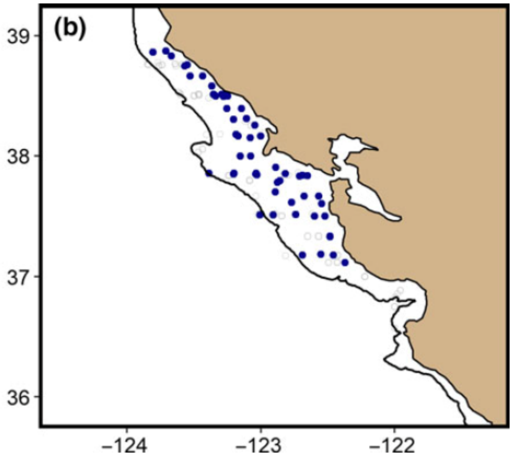
https://caltrout.org/steelhead-salmon/central-valley-floodplains-a-critical-and-missing-link-to-salmon-recovery

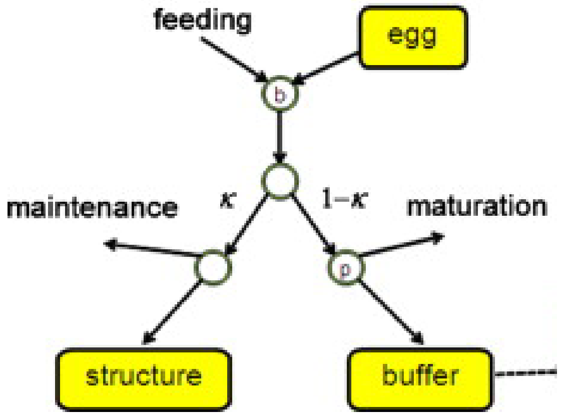
Approach Overview



- Use multiple data sources and models
  - Ocean circulation - ROMS
  - Biogeochemical model
  - Tagging data
    - Coded wire tags
  - Salmon bioenergetics model

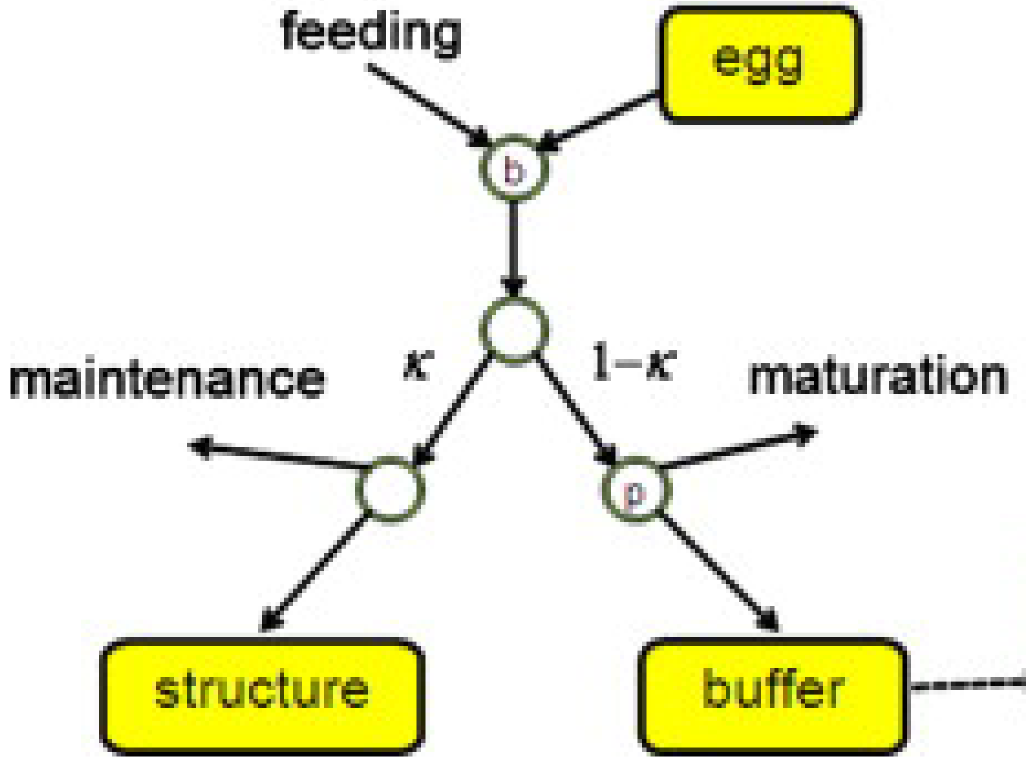






Bioenergetics model

- DEBkiss model
  - Growth = difference between assimilated biomass and maintenance metabolism

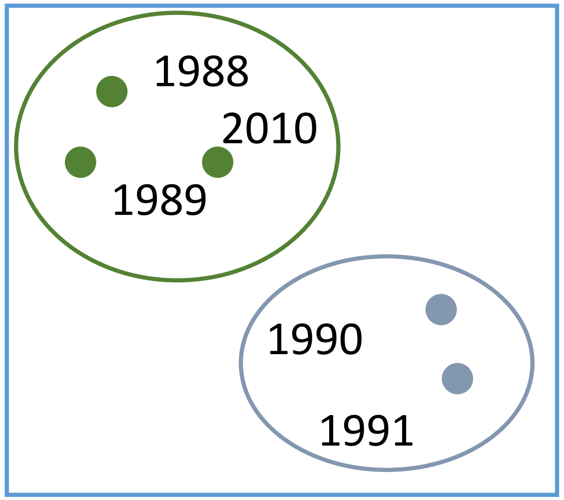


Jager, Martin, & Zimmer 2013

Non-metric Multidimensional Scaling (NMDS)

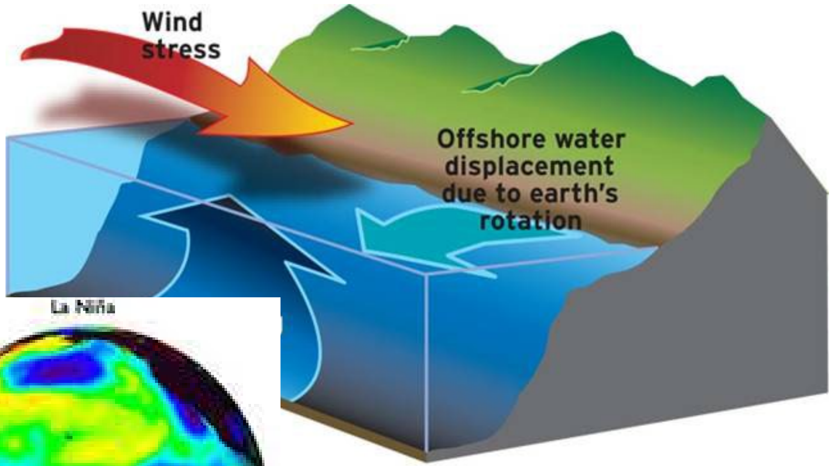
- Ordination
  - Goal: Group the most similar years together
  - Similarity based on spatial pattern in growth potential
- Sample unit: Spatial cells (n=167)

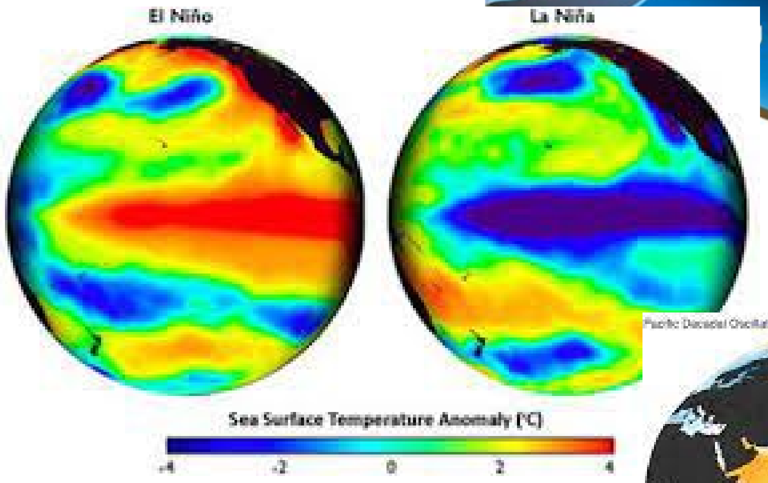
Year	Cell 1	Cell 2	Cell 3	…	Cell 167
1988	0.01	0.03	0.001	…	0.004
1989	0.01	0.025	0.002	…	0.007
1990	0.005	0.008	0.1	…	0.025
1991	0.005	0.008	0.2	…	0.04
…	…	…	…	…	
2010	0.04	0.035	0.02	…	0.025

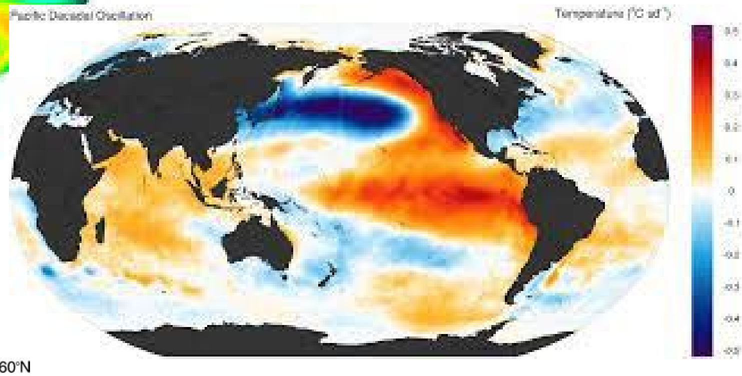


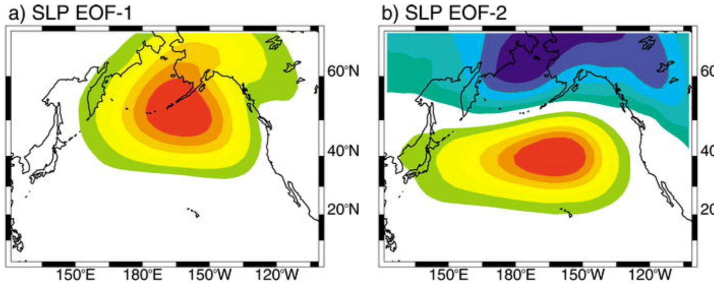
Oceanographic indices

- Upwelling index
- Oceanic Niño Index
- Pacific Decadal Oscillation
- Northern Oscillation Index
- North Pacific Gyre Oscillation
- Sea level
- ROMS currents



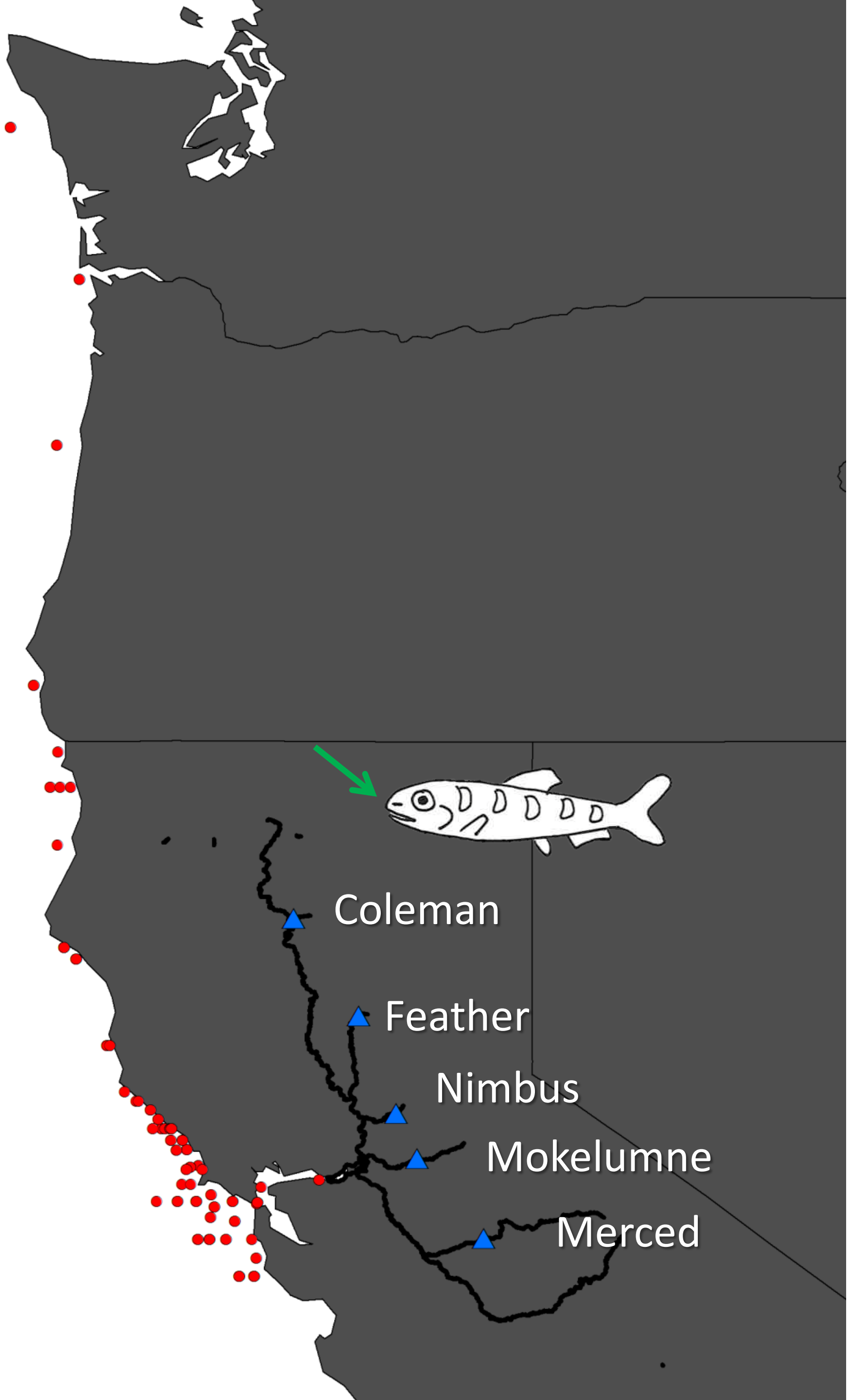






Survival Estimates

- Coded wire tags
  - Hatchery releases
  - Tag recoveries from :
    1. Juveniles (NOAA salmon surveys) n=766
    2. Adults (Fishery/Escapement)
- Survival
  - Cohort reconstruction

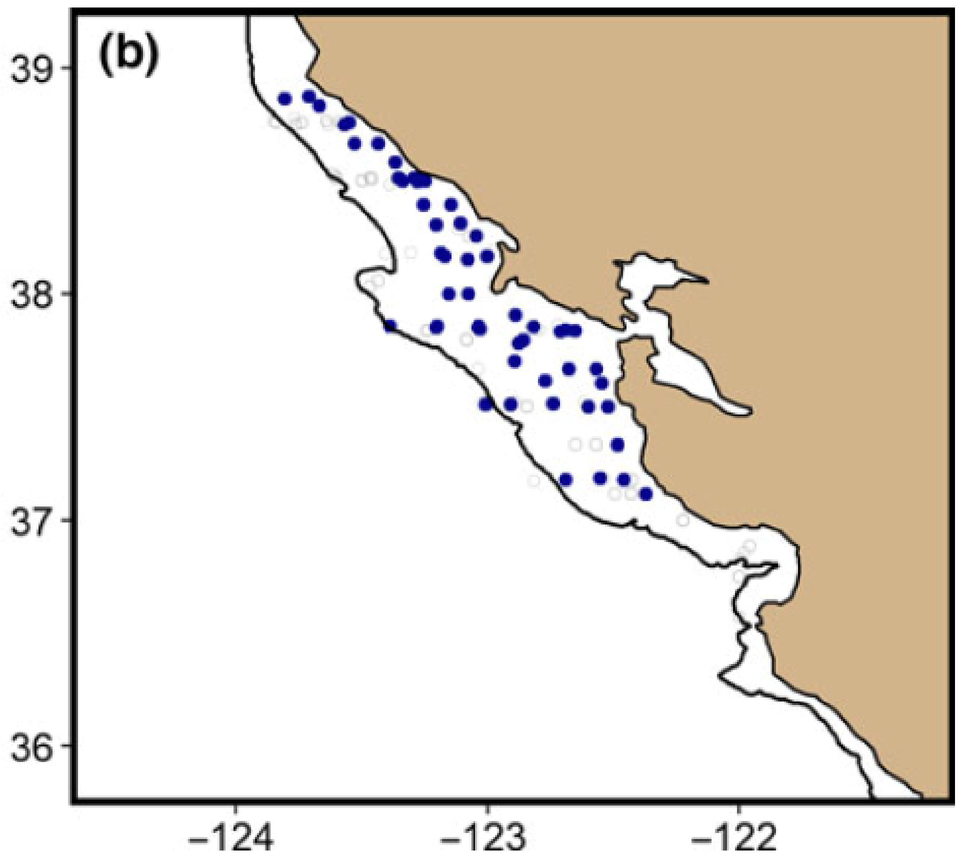


GLM

- Beta Regression
  - Survival is a proportional response
- Response: Cohort Reconstruction Survival
- Predictors:
  - NMDS axes
  - Annual growth potential
  - All two-way interactions

Growth Potential Results

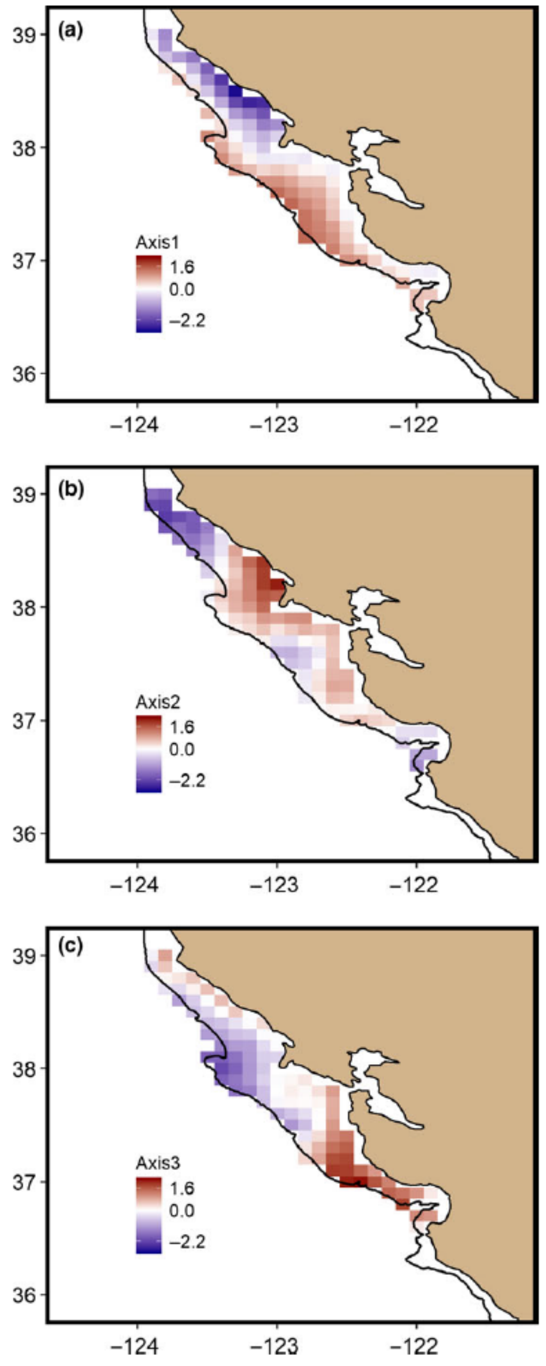
- Highest growth potential
  - Gulf of Farallons
  - Monterey Bay
- Lowest growth potential
  - Coastal waters North of Point Reyes



Henderson et al. *2019* Fisheries Oceanography

Ordination results

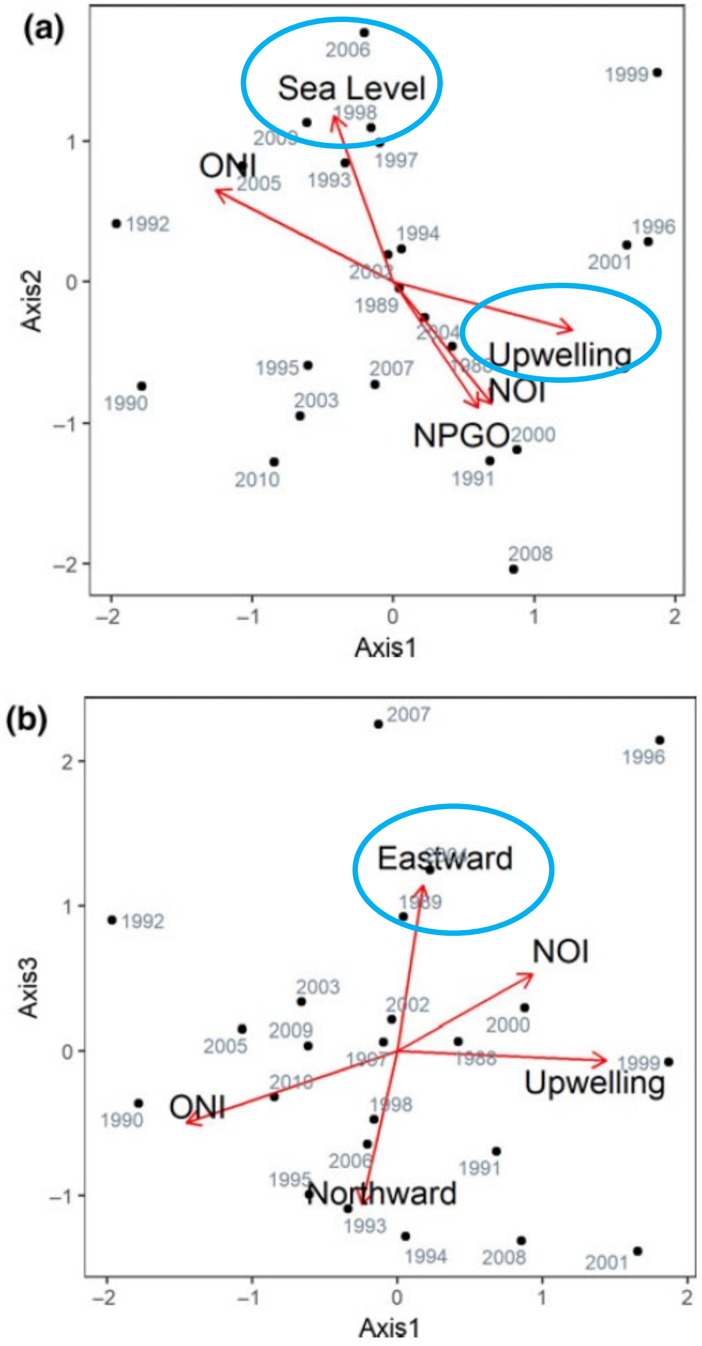
- Three axes accounted for the variability among spatial cells
- Axis 1
  - Growth variability within GoF & shelf break
- Axis 2
  - Growth variability just N. of Point Reyes
- Axis 3
  - Growth variability in most Southern region



Henderson et al. *2019* Fisheries Oceanography

Relating Ordination axes to Oceanography

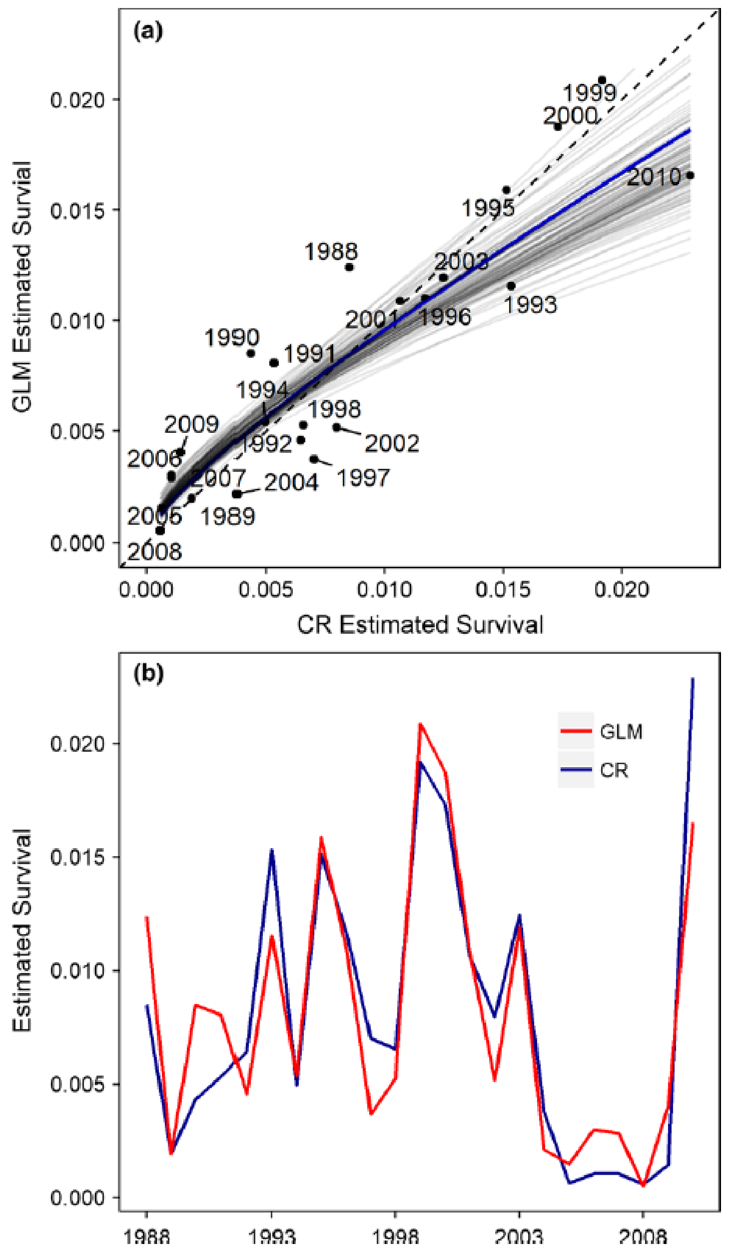
- Axis 1
  - Correlated with Upwelling index
- Axis 2
  - Correlated with Alongshore flows
- Axis 3
  - Correlated with Onshore flows



Henderson et al. *2019* Fisheries Oceanography

Ocean growth Potential and Juvenile salmon survival

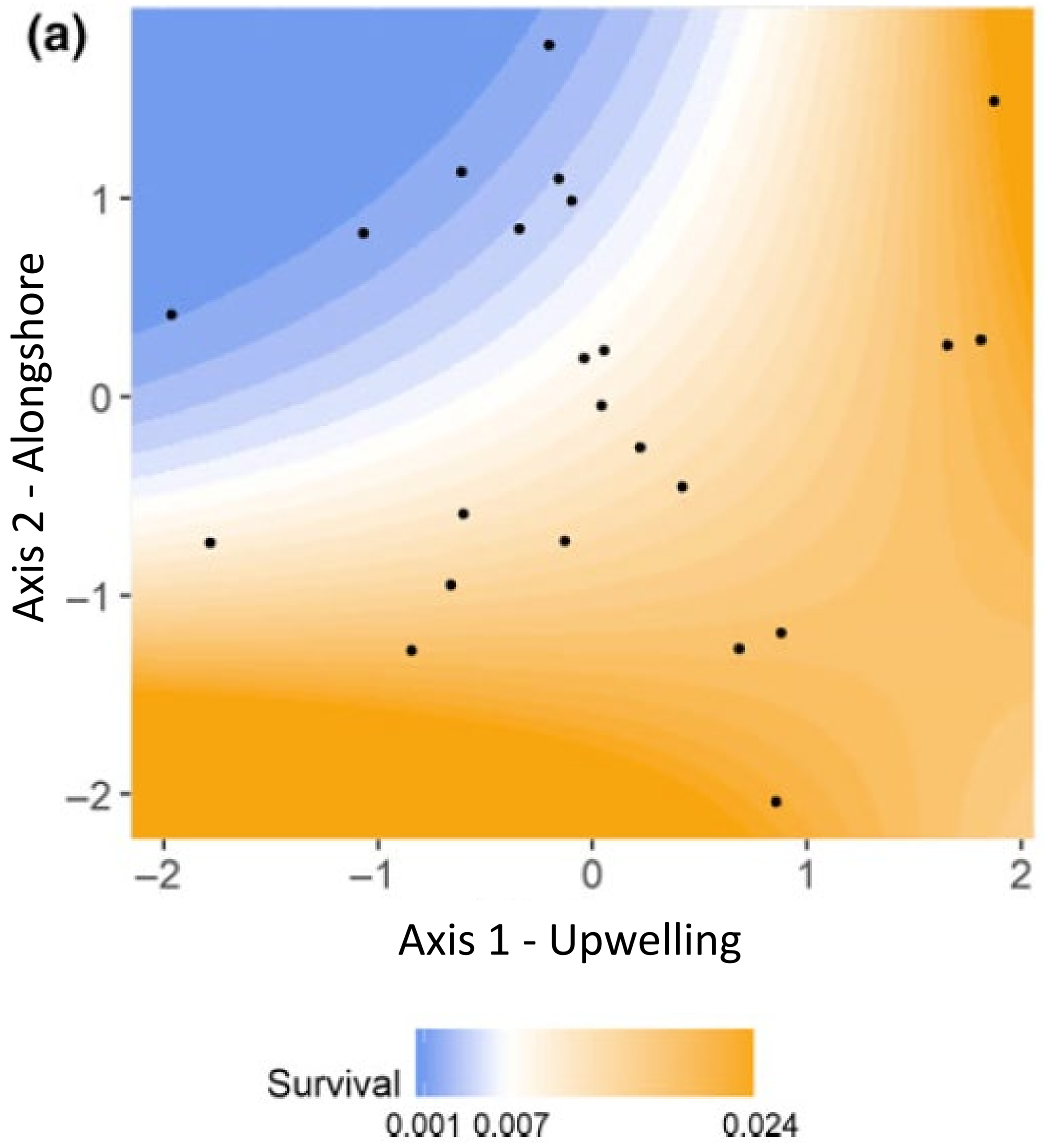
- Main conclusion: We explained 82% of the variation in juvenile salmon survival using ocean growth potential
  - These results should improve our ability to predict adult returns



Henderson et al. *2019* Fisheries Oceanography

Relating oceanography to survival

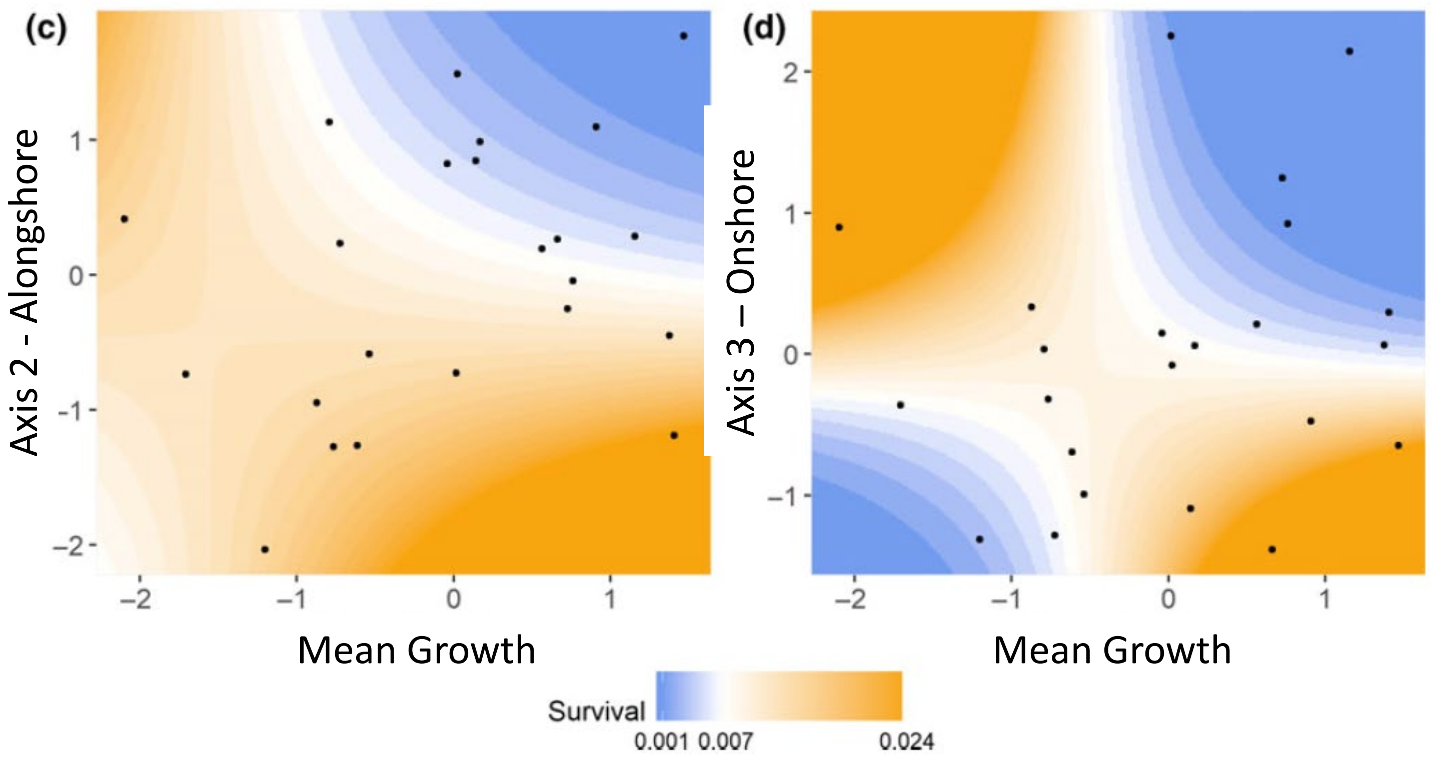
- Survival is highest when upwelling/productivity in GoF is high



Henderson et al. *2019* Fisheries Oceanography

Relating oceanography to survival

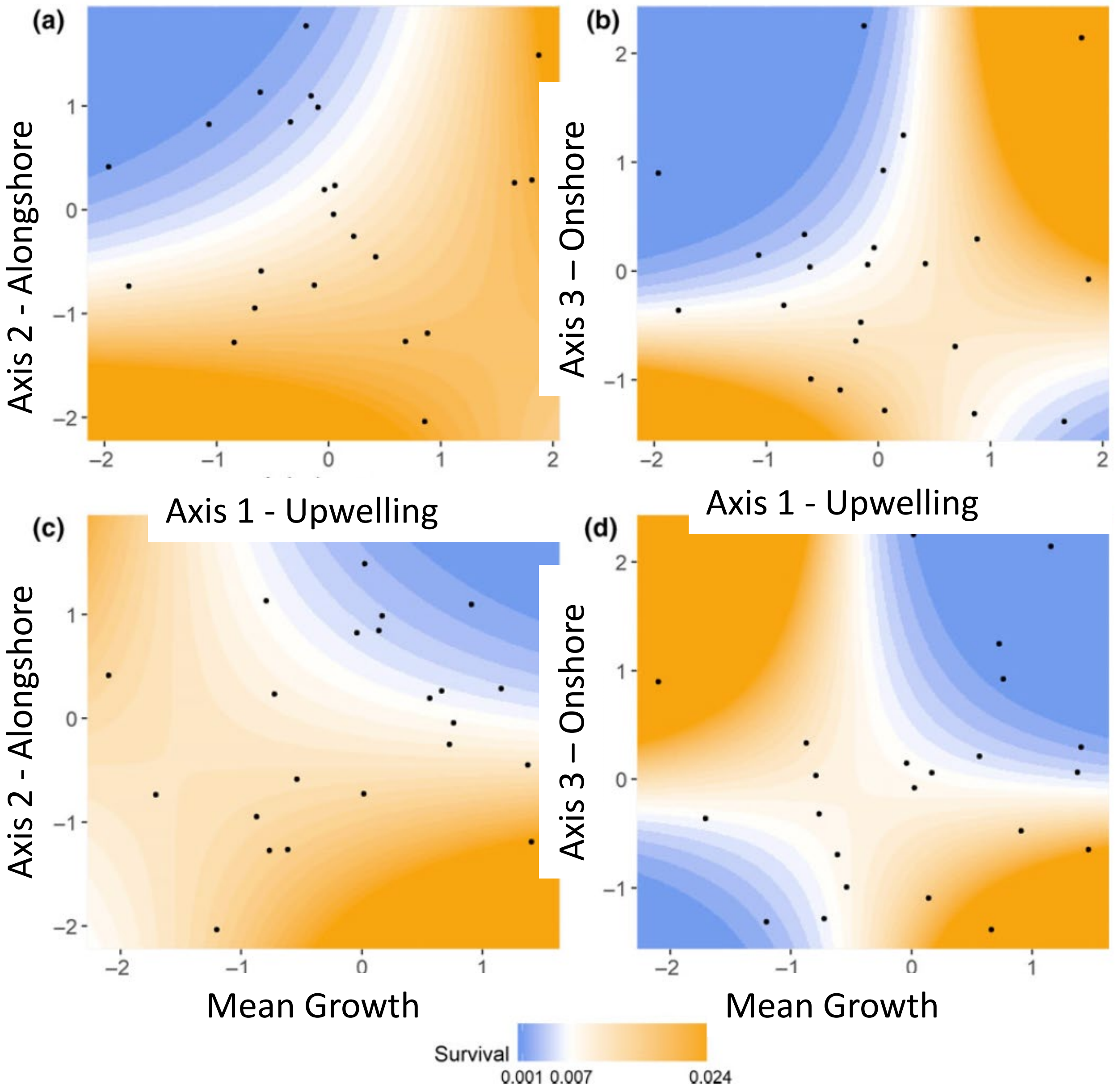
- Survival is highest when upwelling/productivity in GoF is high
- High growth potential does not always mean high survival



Henderson et al. *2019* Fisheries Oceanography

Relating oceanography to survival

- Survival is highest when upwelling/productivity in GoF is high
- High growth potential does not always mean high survival
- Interactions between oceanographic conditions are important



Henderson et al. *2019* Fisheries Oceanography

Conclusions

- We can use an ocean productivity model to estimate early ocean survival
  - Caveat 1: this is a correlative model
  - Caveat 2: we haven’t tested our model with new data to see how much we’re fooling ourselves
- There were three main patterns in growth variability along CA coast
  - Upwelling, Onshore currents, Alongshore currents
- Early ocean survival is dependent on interactions between the strength of these oceanographic conditions

Acknowledgements

- Funding
  - NSF
  - NASA
- Wisdom
  - Brian Burke
  - Kathryn Sobocinski
  - Andre Buchheister


Questions
Jonny Armstrong

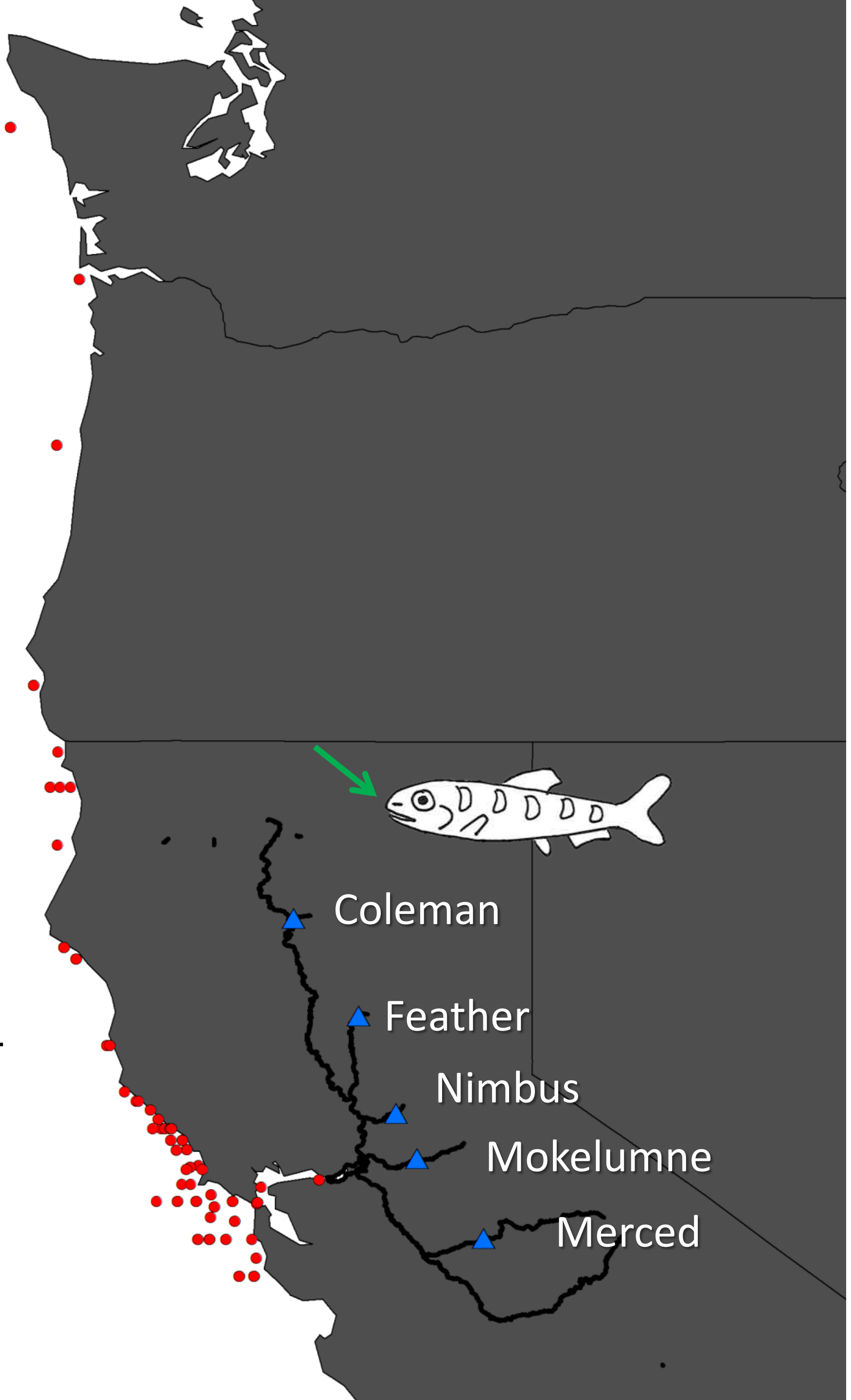
Survival Estimates

- Coded wire tags
  - Hatchery releases
  - Tag recoveries from :
    1. Juveniles (NOAA salmon surveys) n=766
    2. Adults (Fishery/Escapement)
- Survival
  - Cohort reconstruction

Tag	Year	Age	s	Catch	N
50569	2002	2	0.6	50	
50569	2003	3	0.7	594	
50569	2004	4	0.8	59	
50569	2005	5	0.9	4	
50569	2006	6	0.0	0	0

$$N_{t+1} = N_t - C_t - N_t(1 - s_t)$$

$$juvenile\ survival = \frac{N_2}{\#\ released}$$



Top-down and bottom-up effects on juvenile Chinook salmon survival off central California from an individual-based model

K. Vasbinder, J. Fiechter, J. Anderson, J. Santora, N. Mantua, S. Lindley, D. Huff, and B. Wells

UC SANTA CRUZ

NOAA

COLLEGE OF THE ENVIRONMENT
UNIVERSITY of WASHINGTON

Funding: NOAA SWFSC Santa Cruz CIMEC award 22694-443861-BICVEP (Central Valley Salmon)

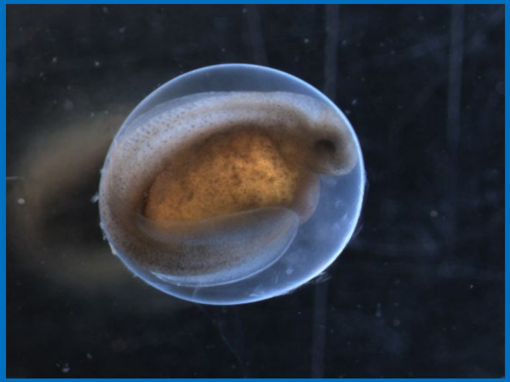
About Me

Postdoctoral researcher with the Fiechter lab

Ocean Sciences Department, UCSC

Dissertation work: University of South Florida: Larval growth and transport in the Gulf of Mexico

Research interests: population and ecosystem modeling, early life stages of fish, and how we can better represent the dynamics of larval and juvenile stages in ecosystem models



Current work: Outmigration of juvenile salmon and their predator-prey interactions off of central California

Lifecycle of Chinook Salmon

Ocean

Freshwater
and Estuaries

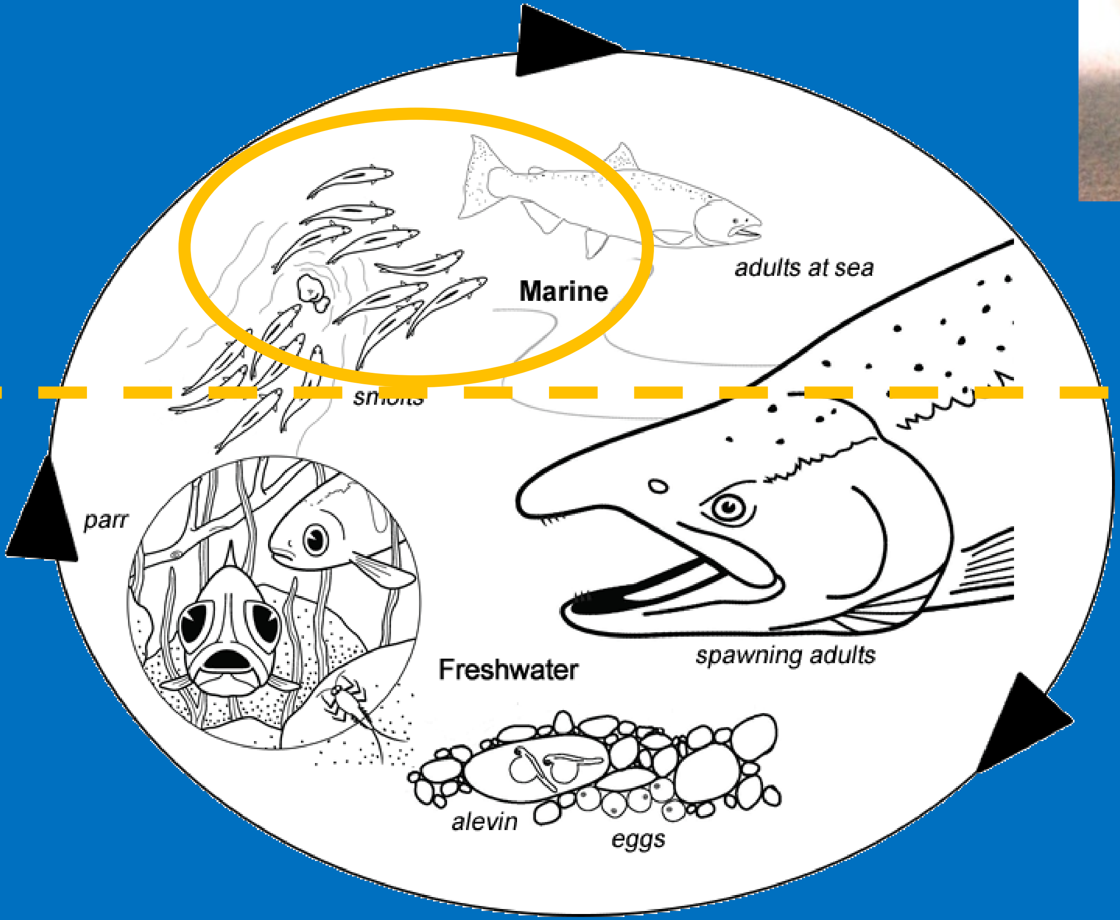
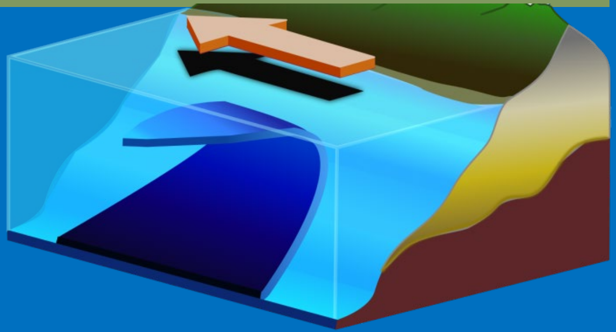


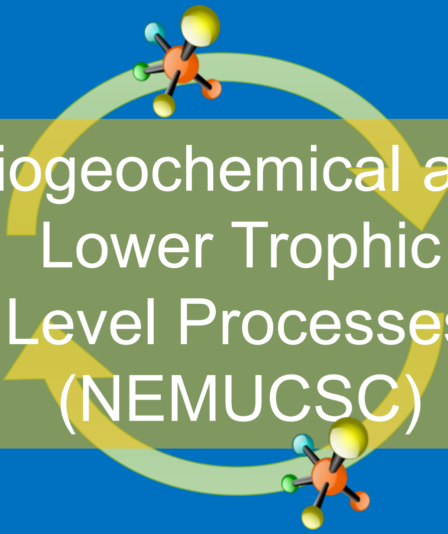
Image Credit: US Fish and Wildlife Service

Ecosystem Modeling Framework

Hydrodynamic Processes (ROMS)



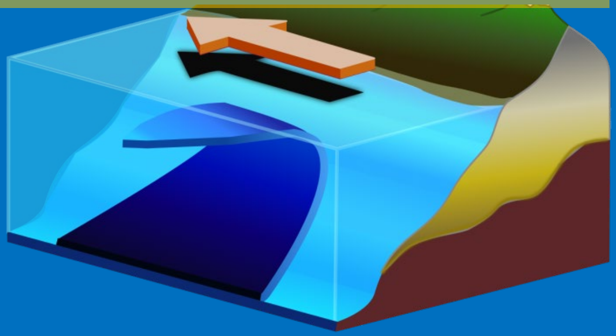
Biogeochemical and Lower Trophic Level Processes (NEMUCSC)



Salmon growth and predation (IBM)

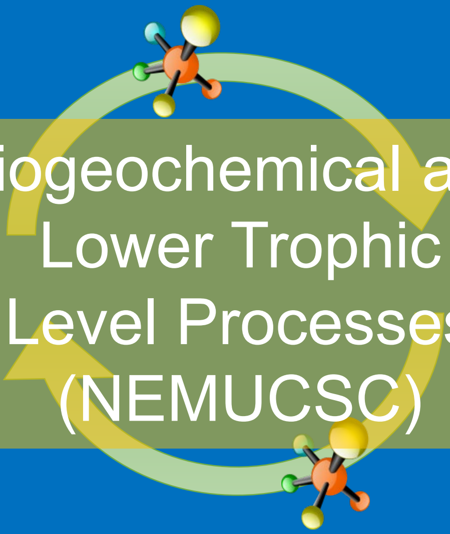
Ecosystem Modeling Framework

Hydrodynamic Processes (ROMS)



Upwelling

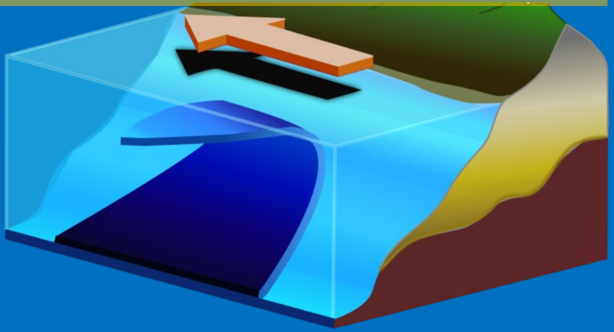
Biogeochemical and Lower Trophic Level Processes (NEMUCSC)



Salmon growth and predation (IBM)

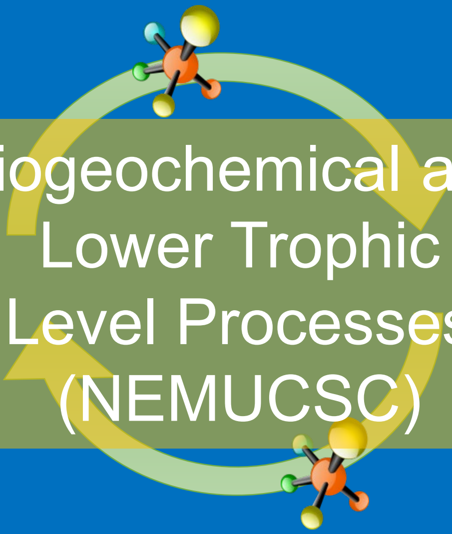
Ecosystem Modeling Framework

Hydrodynamic Processes (ROMS)



Upwelling

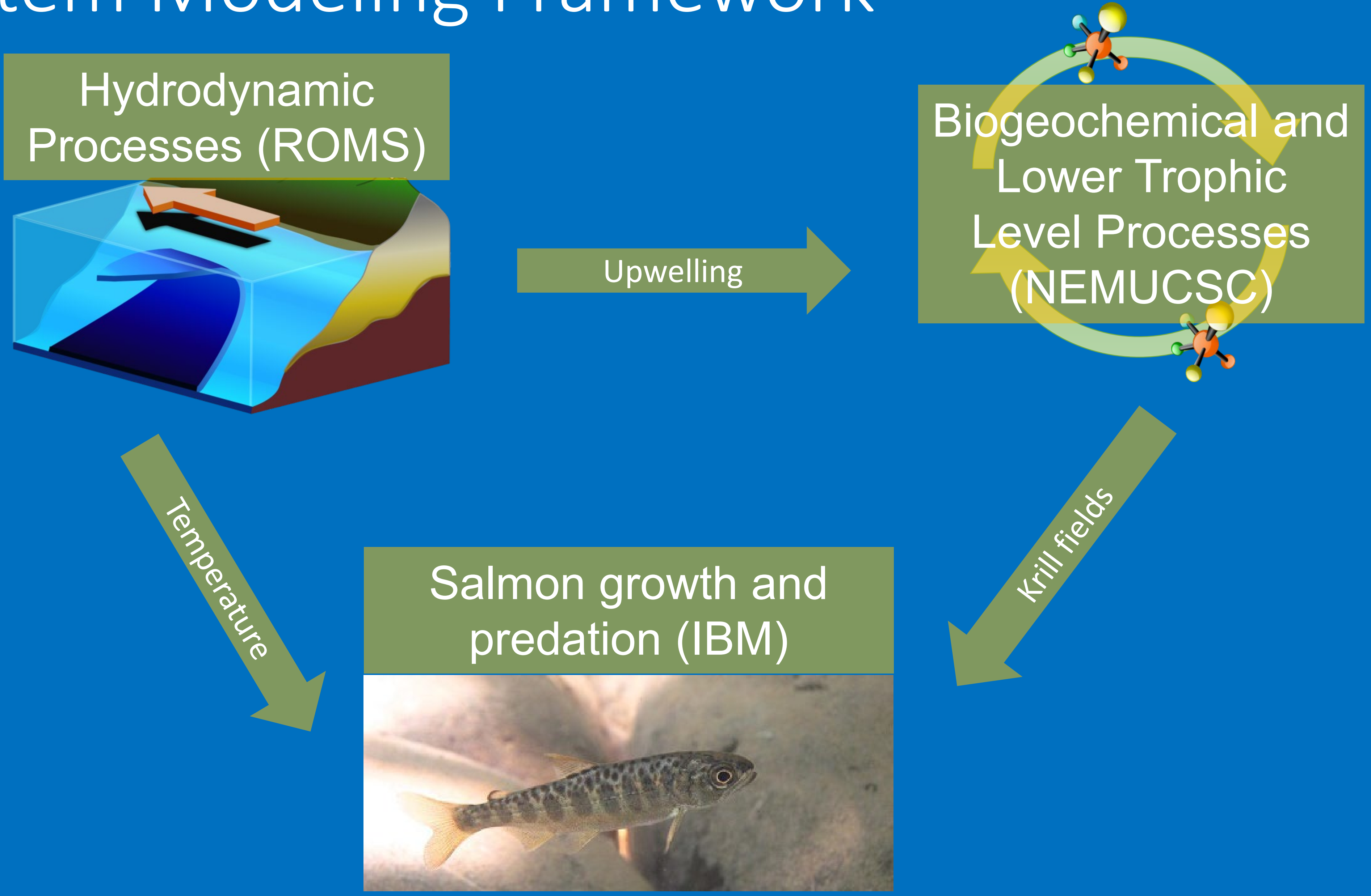
Biogeochemical and Lower Trophic Level Processes (NEMUCSC)



Temperature

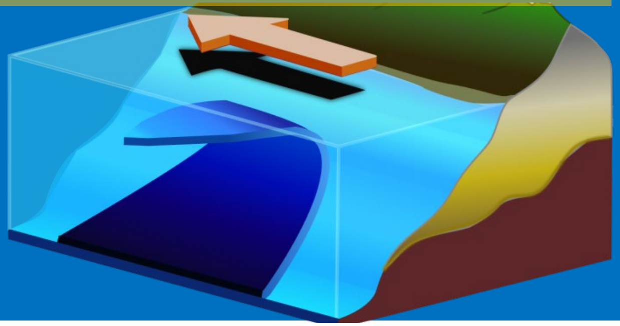
Salmon growth and predation (IBM)

Ecosystem Modeling Framework

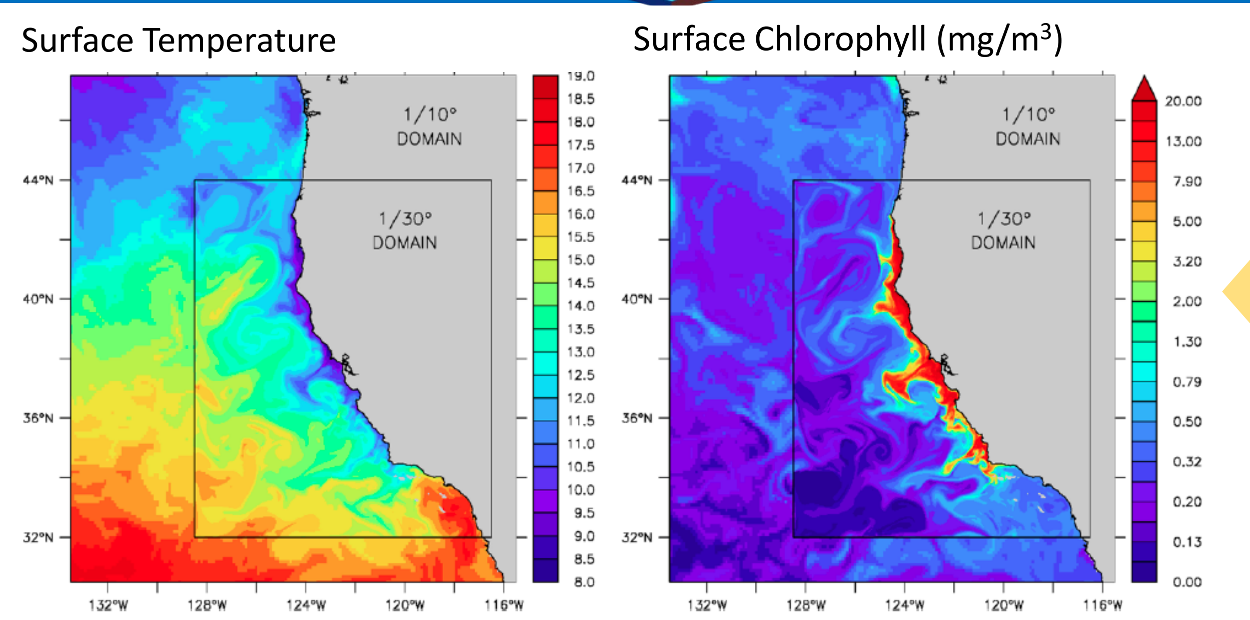


Ecosystem Modeling Framework

Hydrodynamic Processes (ROMS)



ROMS: Regional Ocean Modelling System (ROMS) in the California Current for hydrodynamics



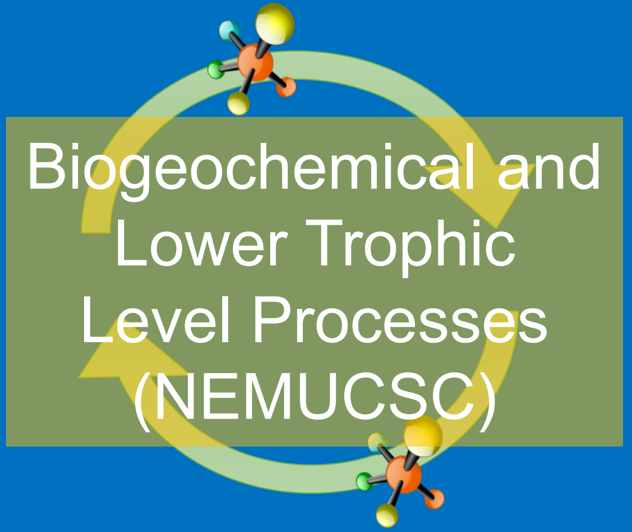
1/30° ROMS model is embedded within a reanalysis of the broader California Current System circulation at 1/10°

Nested approach allows for finer scale resolution closer to shore, resolving features that influence biogeochemical and lower trophic level processes

Fiechter et al. 2018, 2020

Ecosystem Modeling Framework

NEMUCSC: North Pacific Ecosystem Model for Understanding Regional Oceanography (NEMURO) customized for the California Current (NEMUCSC) for biogeochemical interactions and generation of the prey (krill) field



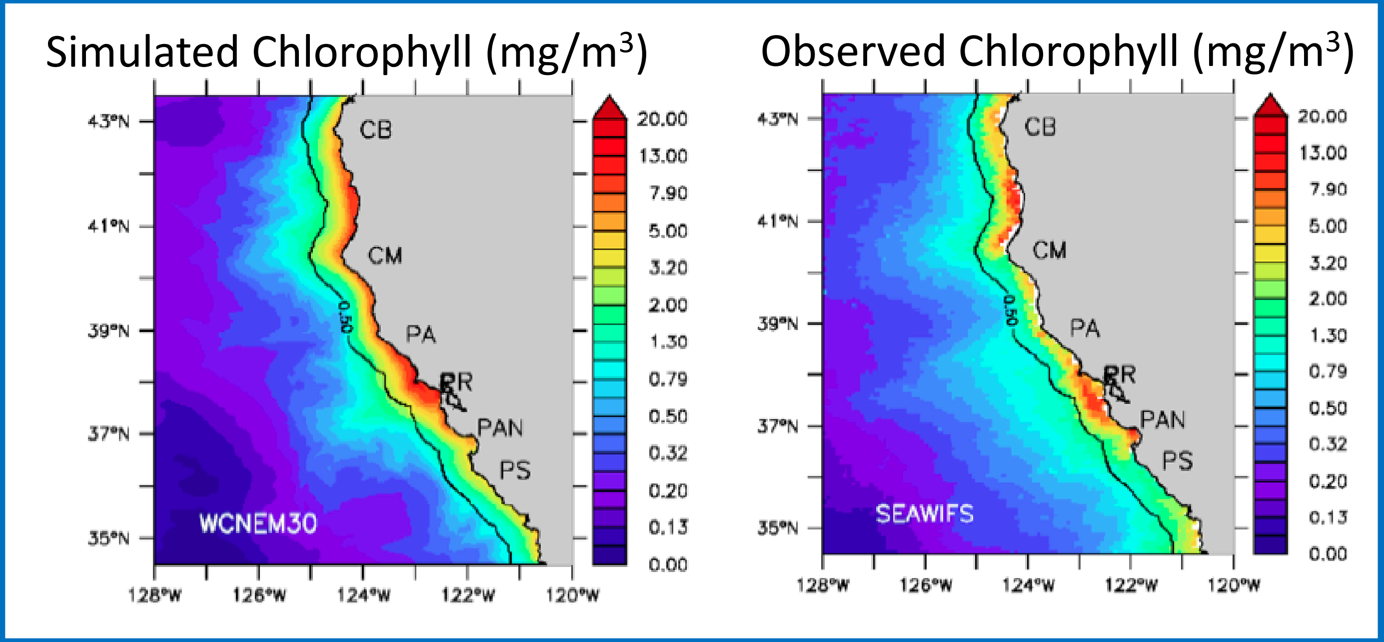
Limiting macronutrients: Nitrate, ammonium, silicic acid

Phytoplankton: nanoplankton, diatoms

Detritus pools: DON, PON, particulate silica

Zooplankton: micro, meso, predatory

- Predatory group is parameterized as krill (*Euphausia pacifica*)
- Favors diatom/copepod predation



Ecosystem Modeling Framework

Implementation of the Salmon IBM

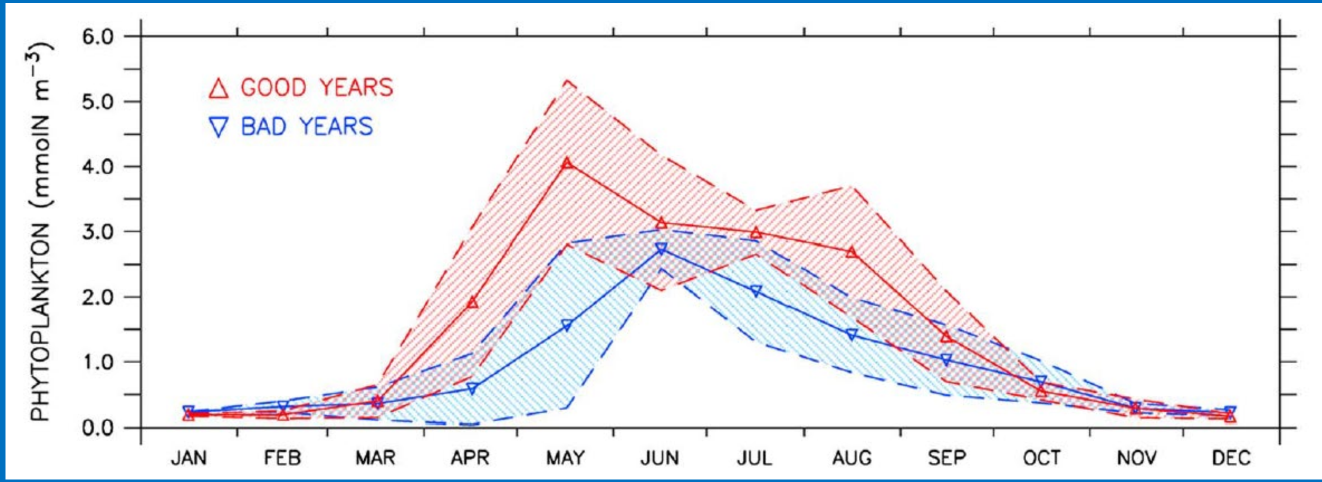
Salmon enter the model at 7.4g, and their growth is calculated in the IBM through a series of metabolic equations that rely on the **temperature and krill** from the NEMUCSC and ROMS models.

The juvenile salmon individual-based model (IBM) consists of a series of modules representing:

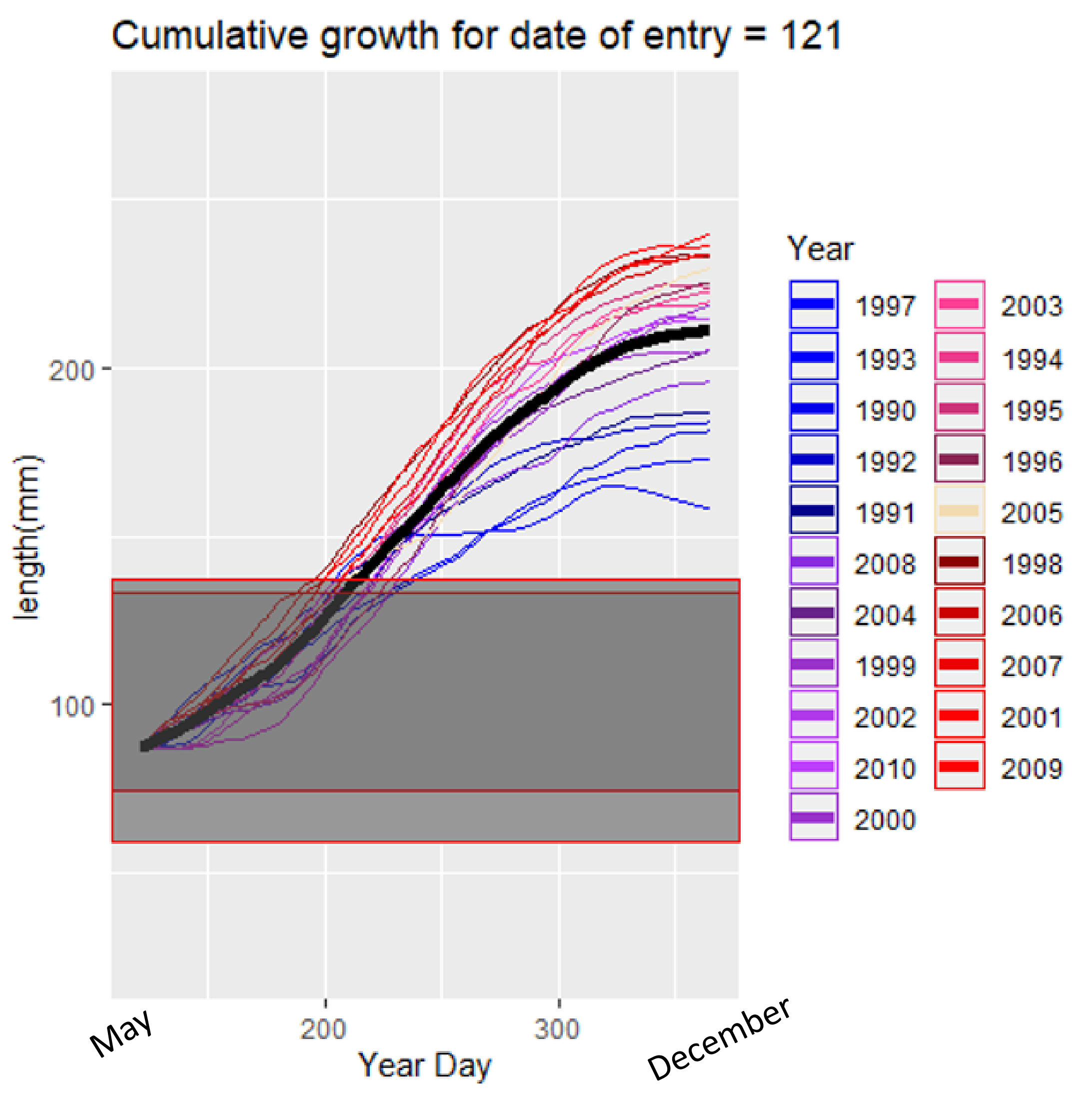
- Bioenergetics for growth
- Swimming behavior
- Mortality

Salmon growth and predation (IBM)

Model – Bottom-Up Drivers



- Good growth years are linked to stronger, early season upwelling
- Good growth years correspond well to high end of year krill anomalies, and bad growth years correspond to low end of year krill anomalies.



Wells et al. 2017, Fiechter et al. 2015

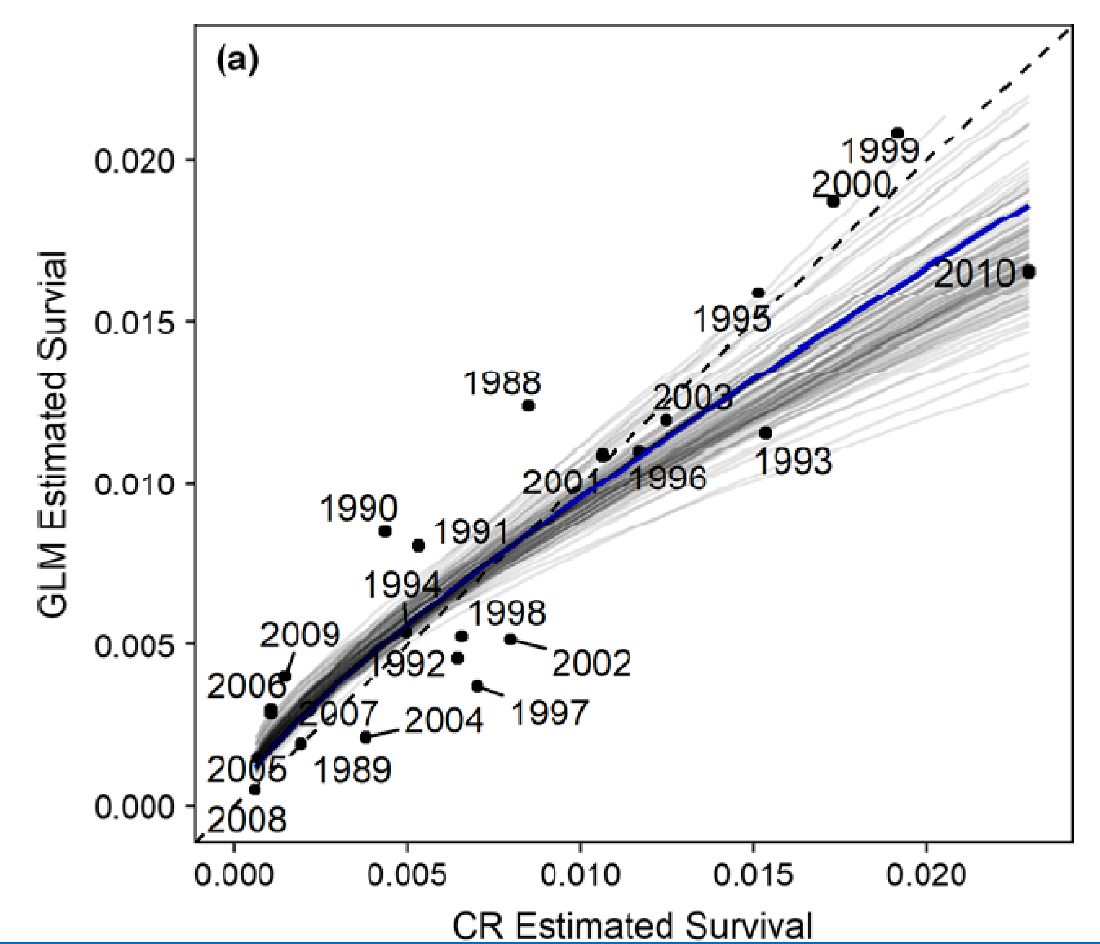
Model – Bottom-Up Drivers

Implementation of the Salmon IBM

Salmon enter the model at 7.4g, and their growth is calculated in the IBM through a series of metabolic equations that rely on the **temperature and krill** from the NEMUCSC and ROMS models.

The juvenile salmon individual-based model (IBM) consists of a series of modules representing

- Bioenergetics for growth
- Swimming behavior
- **Predation mortality**



Henderson et al. 2018. Fisheries Oceanography

When comparing coded wire tag survival and model estimated survival, the relationship is stronger for low survival years. When food is scarce it drives mortality (bottom-up), but when it is plentiful, we need an extra top-down driver to explain mortality.

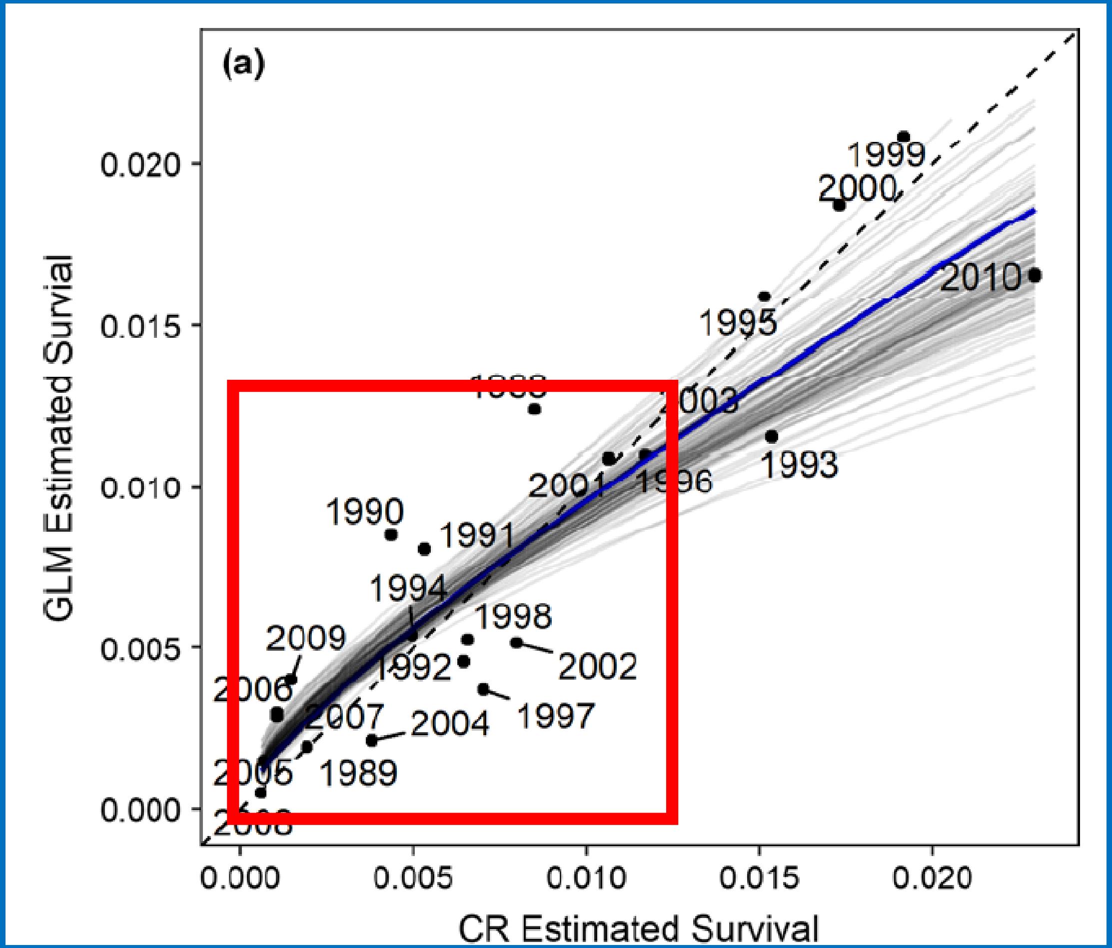
Model – Bottom-Up Drivers

Implementation of the Salmon IBM

Salmon enter the model at 7.4g, and their growth is calculated in the IBM through a series of metabolic equations that rely on the **temperature and krill** from the NEMUCSC and ROMS models.

The juvenile salmon individual-based model (IBM) consists of a series of modules representing

- Bioenergetics for growth
- Swimming behavior
- **Predation mortality**



Henderson et al. 2018. Fisheries Oceanography

When comparing coded wire tag survival and model estimated survival, the relationship is stronger for low survival years. When food is scarce it drives mortality (bottom-up), but when it is plentiful, we need an extra top-down driver to explain mortality.

Model – Bottom-Up Drivers

Implementation of the Salmon IBM

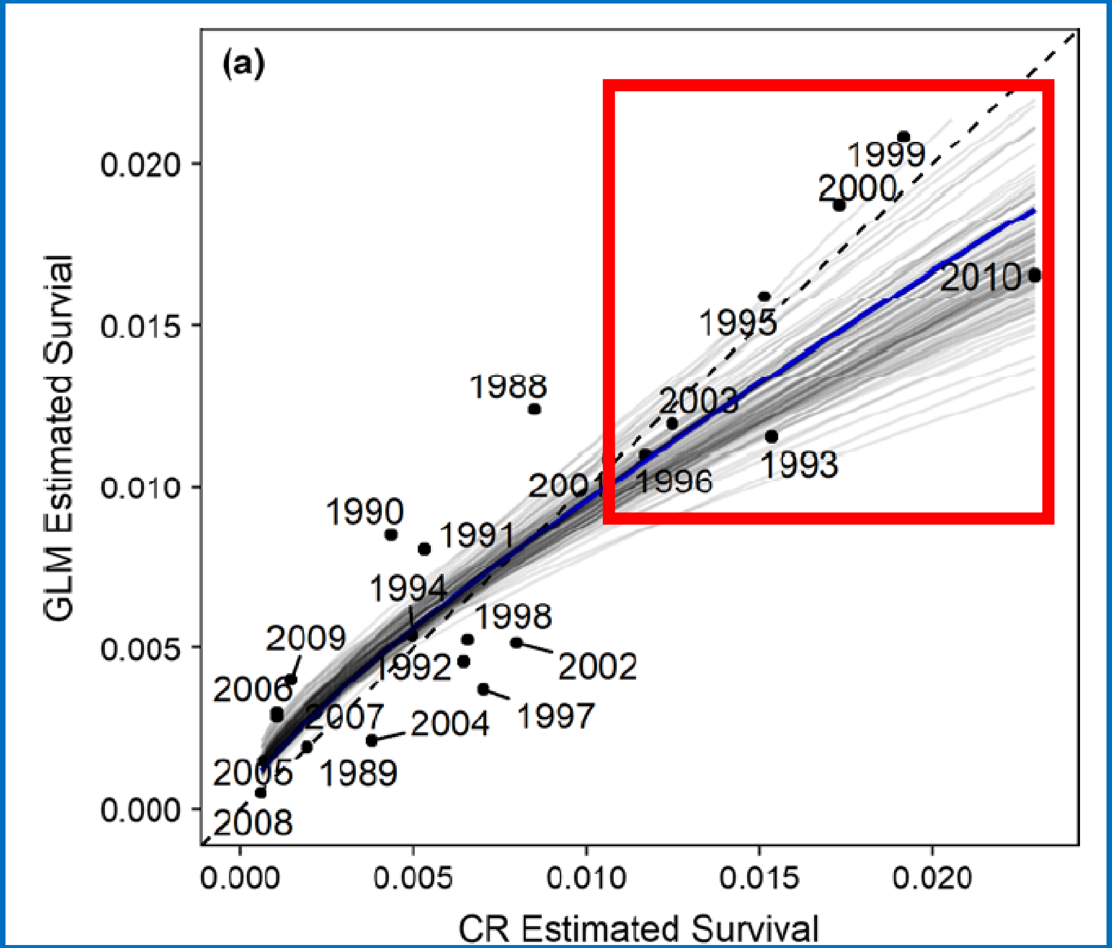
Salmon enter the model at 7.4g, and their growth is calculated in the IBM through a series of metabolic equations that rely on the **temperature and krill** from the NEMUCSC and ROMS models.

The juvenile salmon individual-based model (IBM) consists of a series of modules representing

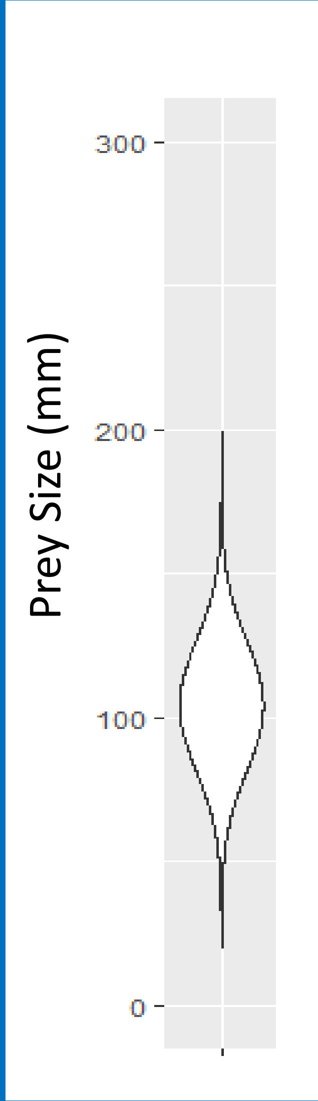
- Bioenergetics for growth
- Swimming behavior
- **Predation mortality**

Henderson et al. 2018. Fisheries Oceanography

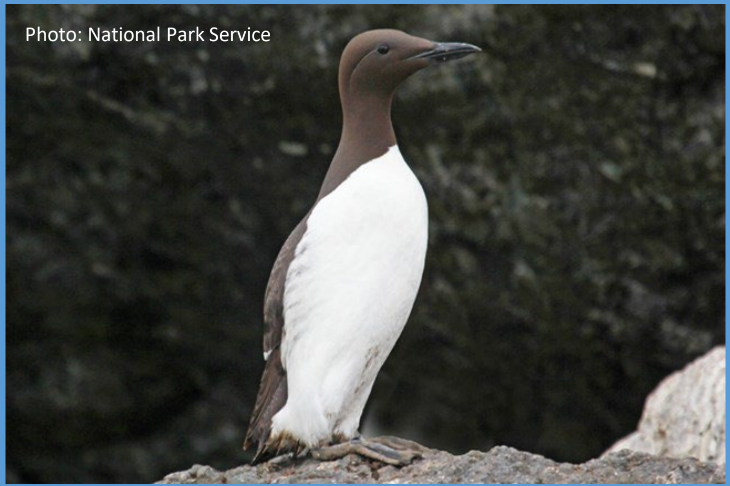
When comparing coded wire tag survival and model estimated survival, the relationship is stronger for low survival years. When food is scarce it drives mortality (bottom-up), but when it is plentiful, we need an extra top-down driver to explain mortality.

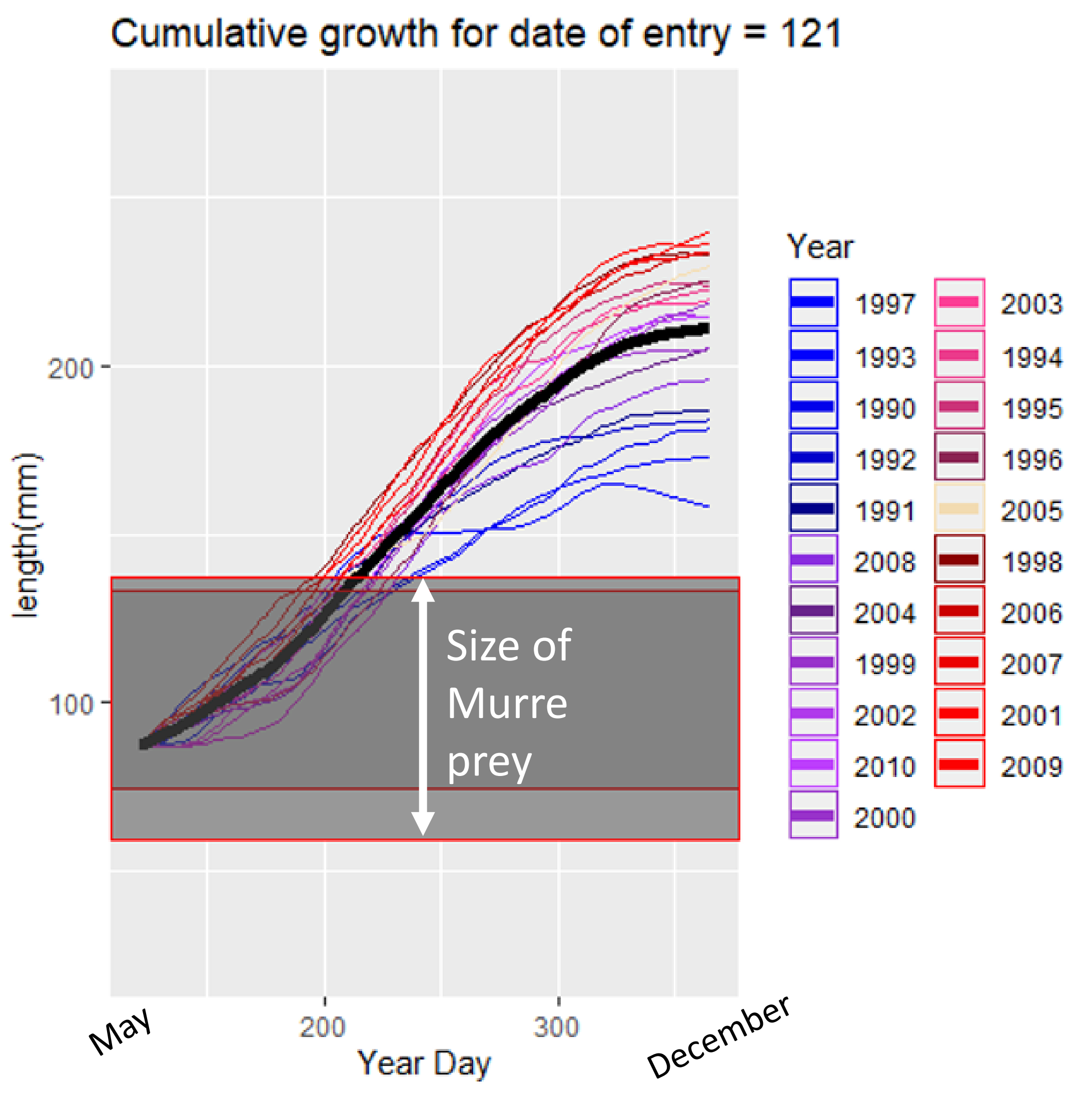


Model - Top-Down Drivers



Size-Based Mortality =
(interaction probability between predation and prey)
x
(relationship between predator's prey distribution and prey size)

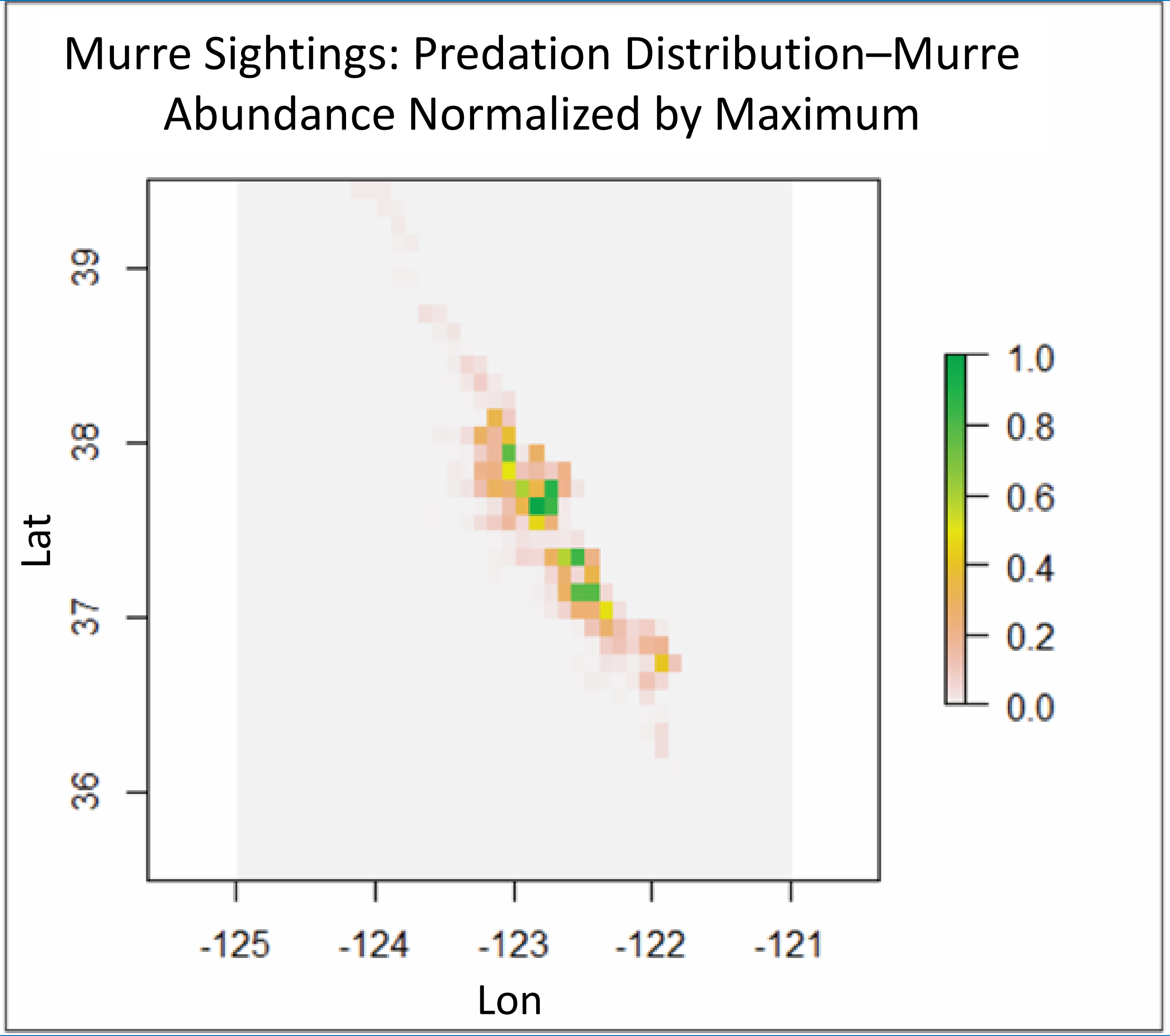




Interaction equation in: J. Anderson, 2019 (in prep). Survival of prey growing through gape-limited and apex predators
Predation tuning value from: Friedman, W. R. et. al. 2019. Ecosphere.

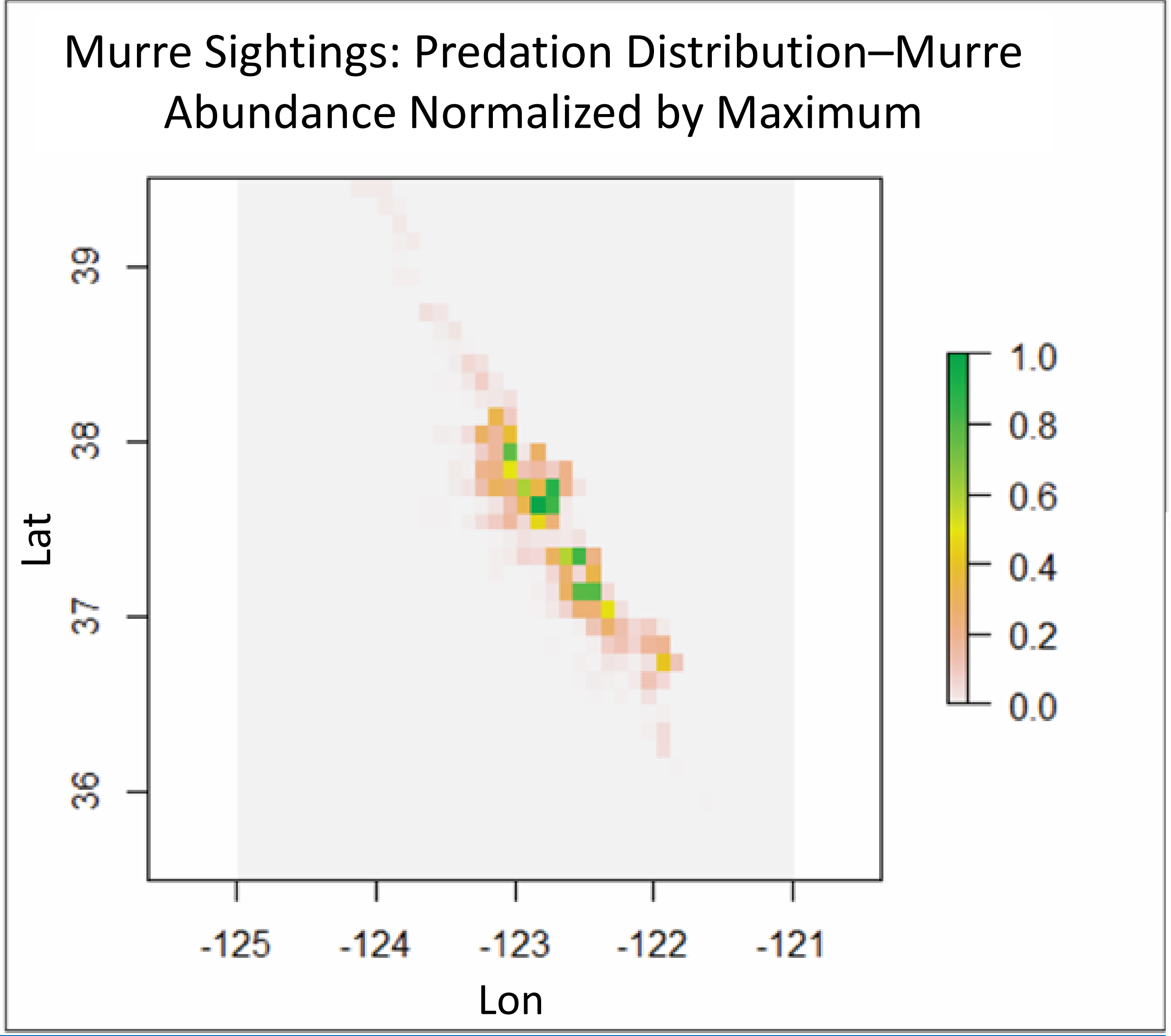
Model - Top-Down Drivers

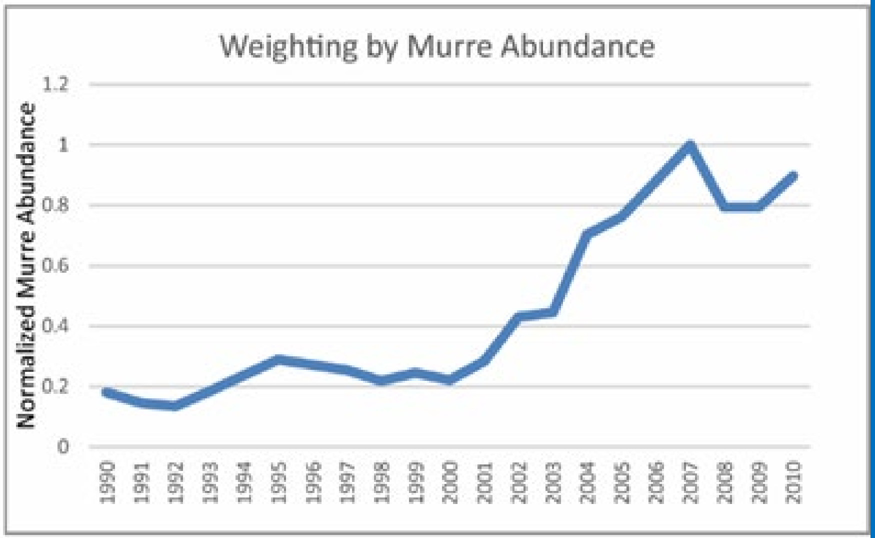
Predation Mortality = Size-Based Mortality x Sightings



Model - Top-Down Drivers

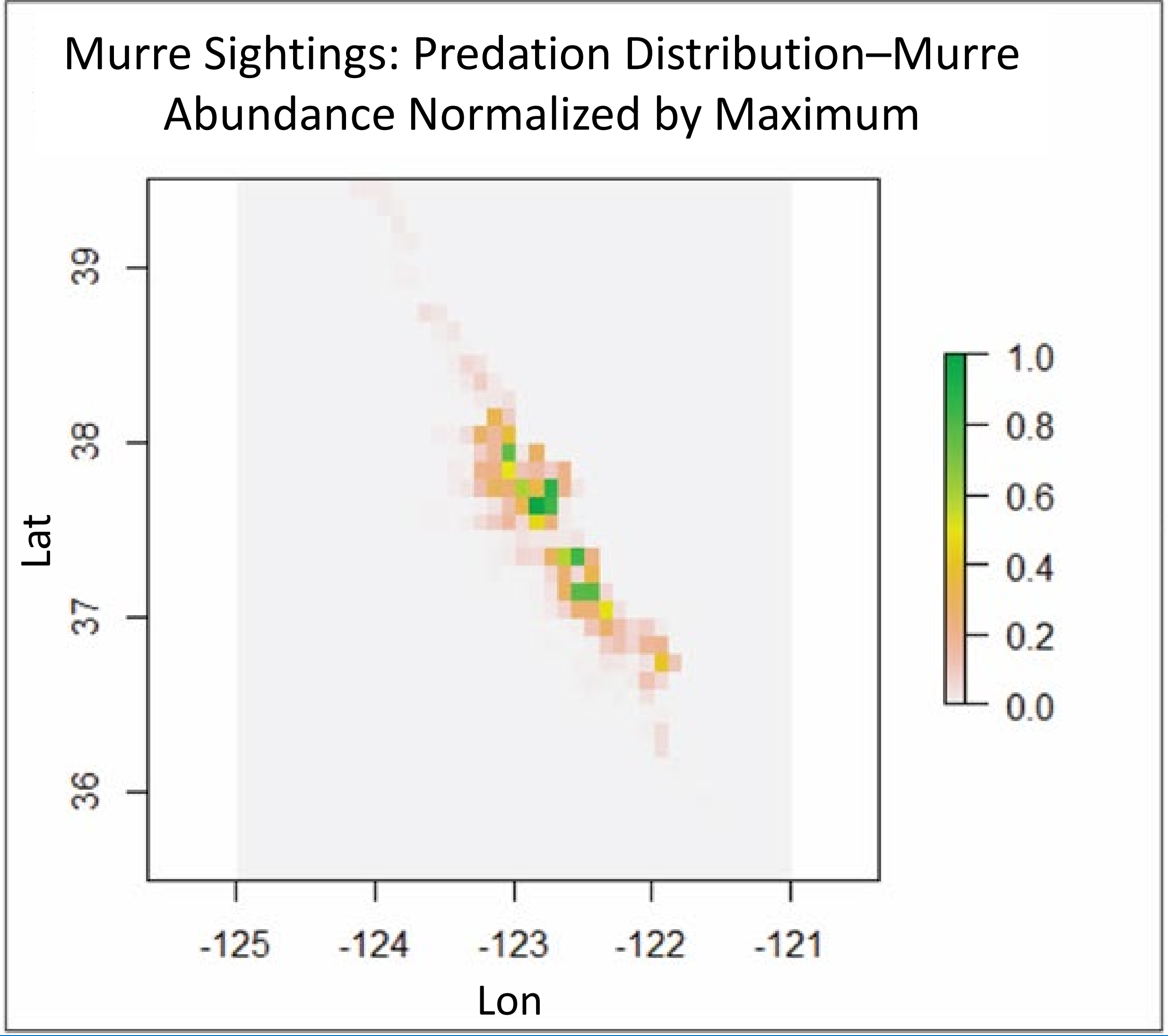
Predation Mortality = Size-Based Mortality x Sightings x Abundance

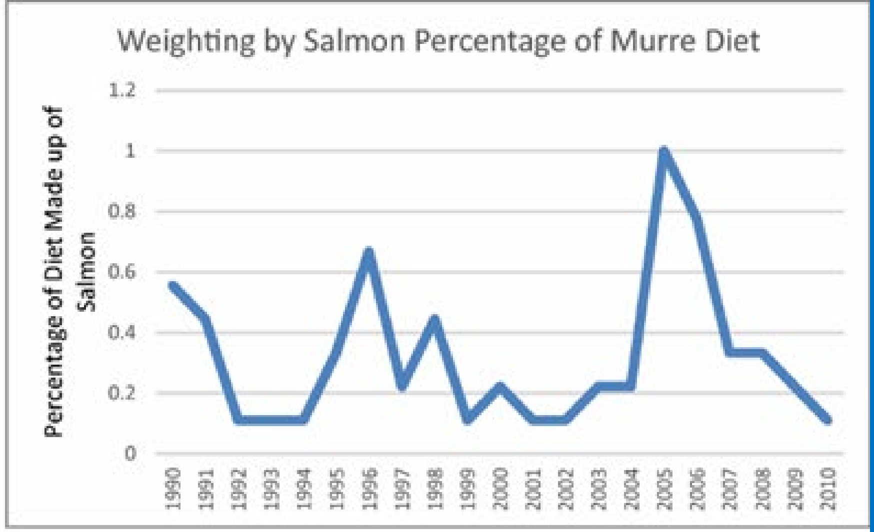


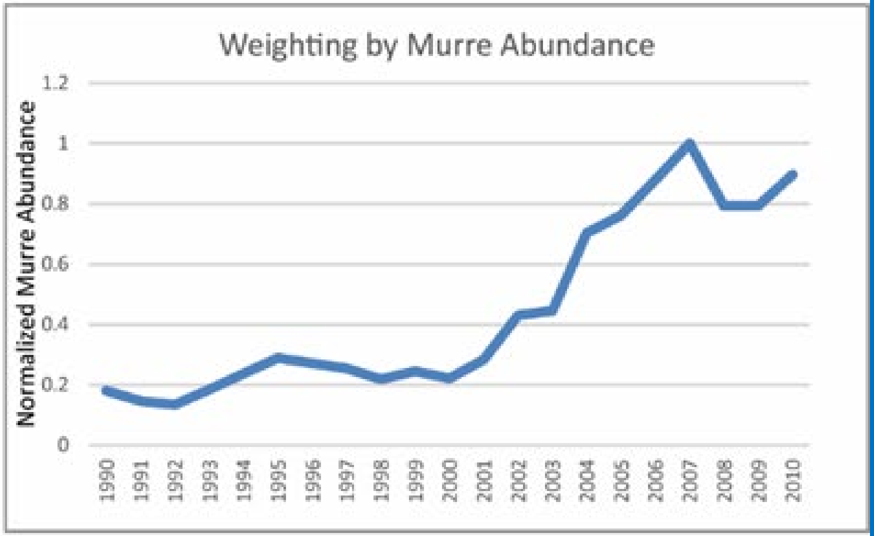


Model - Top-Down Drivers

Predation Mortality = Size-Based Mortality x Sightings x Abundance x Diet



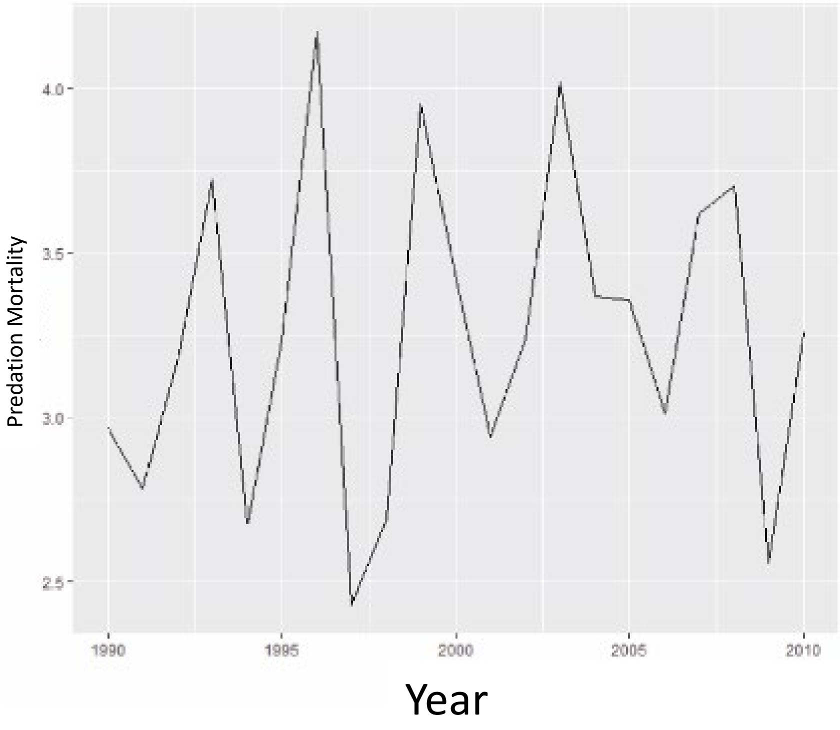




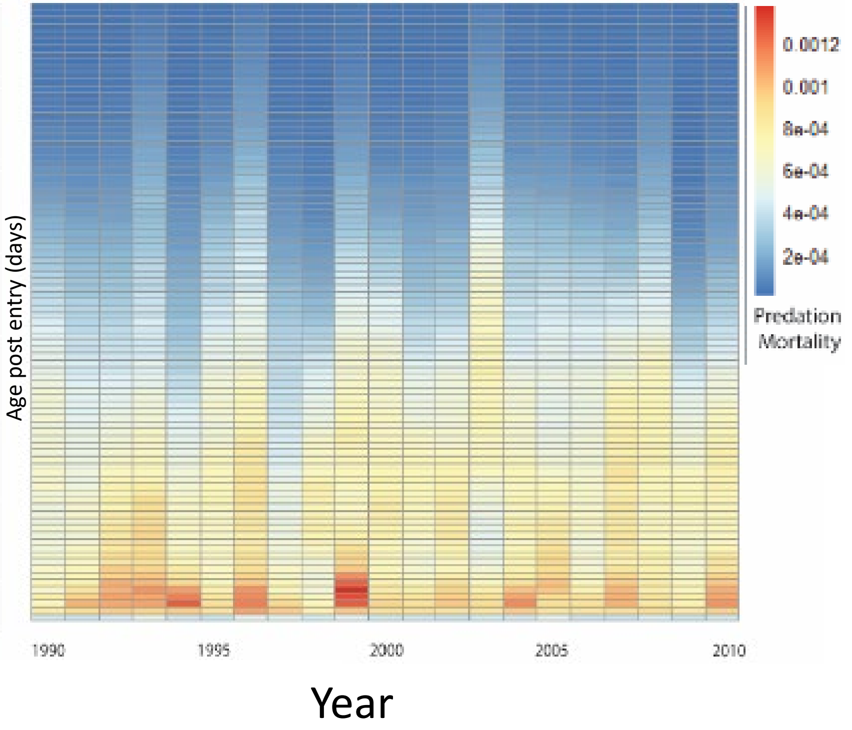
Scenario 1: Environmentally driven mortality modulated by predator distribution, but not abundance or diet

Predation Mortality = Size-Based Mortality x Sightings

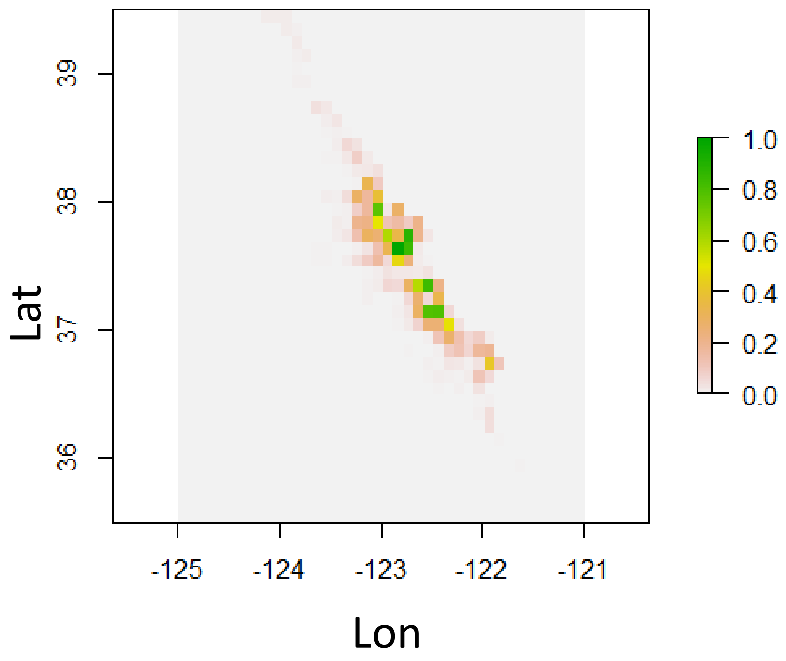
Predation Mortality by Year



Predation Mortality by Year and Age



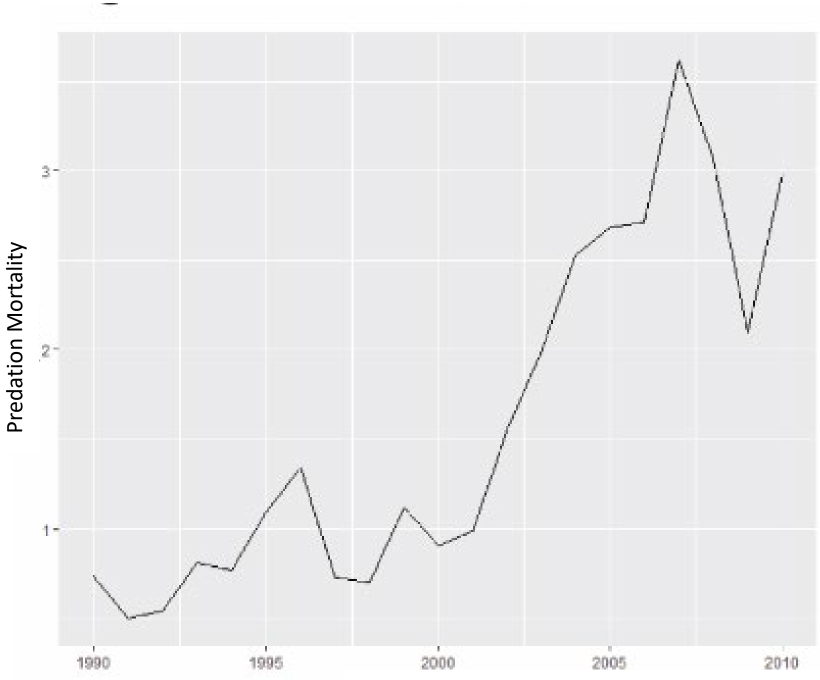
Murre Sightings: Predation Distribution–Murre Abundance Normalized by Maximum



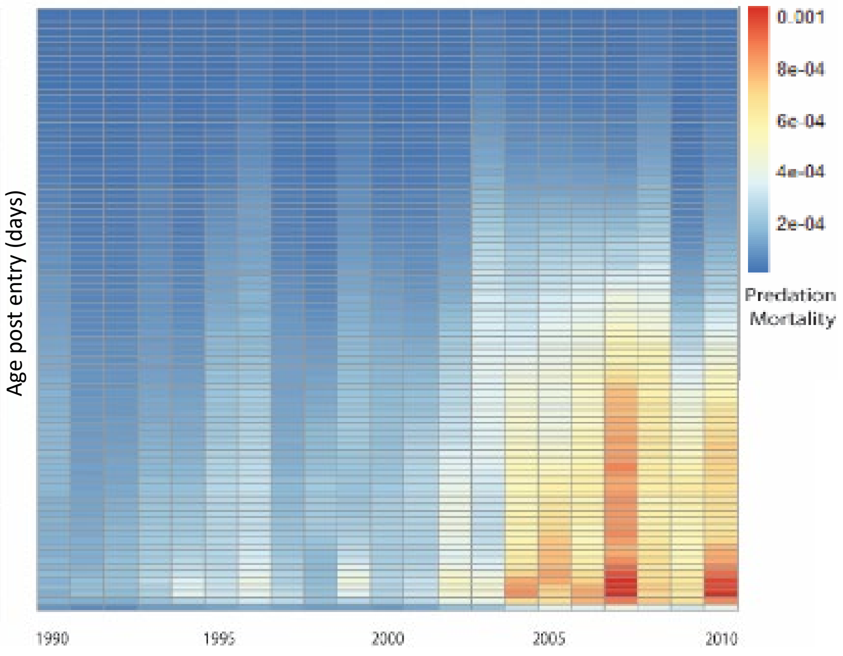
Scenario 2: Environmentally driven mortality modulated by predator distribution and abundance, but not diet

Predation Mortality = Size-Based Mortality x Sightings x Abundance

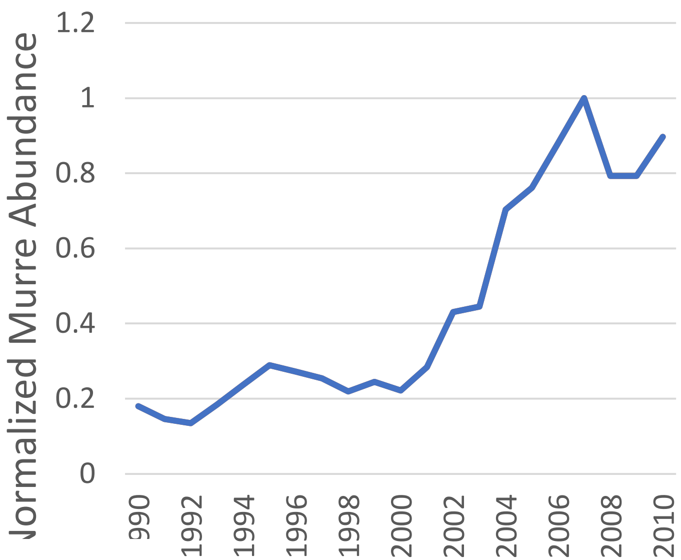
Predation Mortality by Year



Predation Mortality by Year and Age



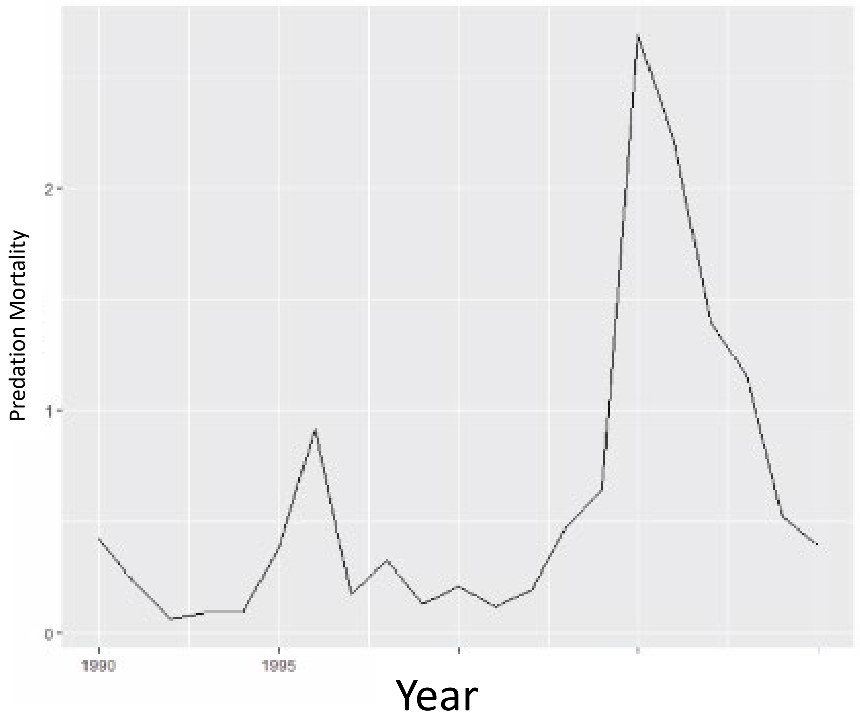
Weighting by Murre Abundance



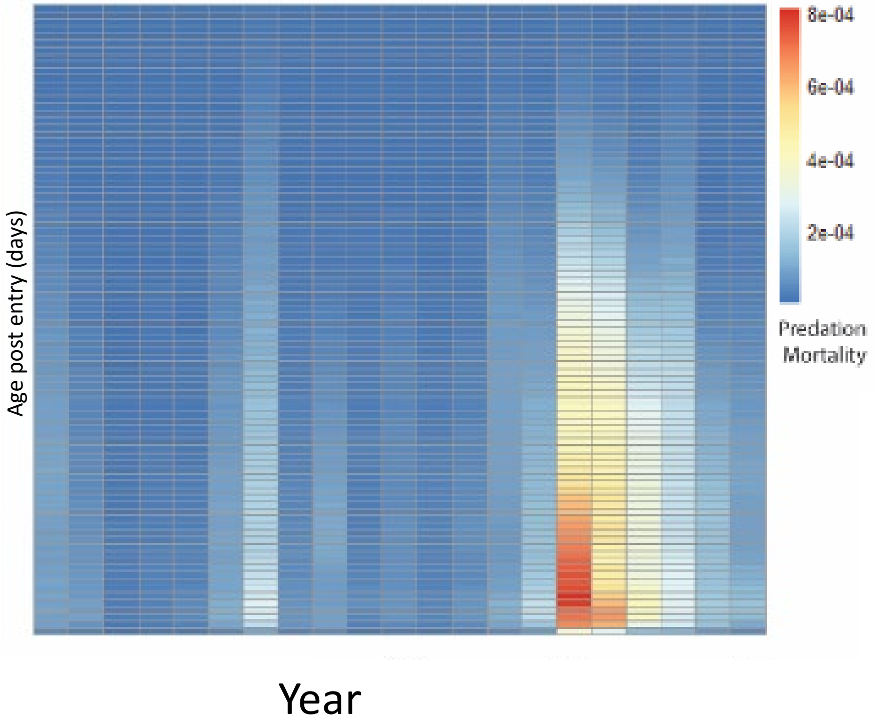
Scenario 3: Environmentally driven mortality modulated by predator distribution, abundance and diet

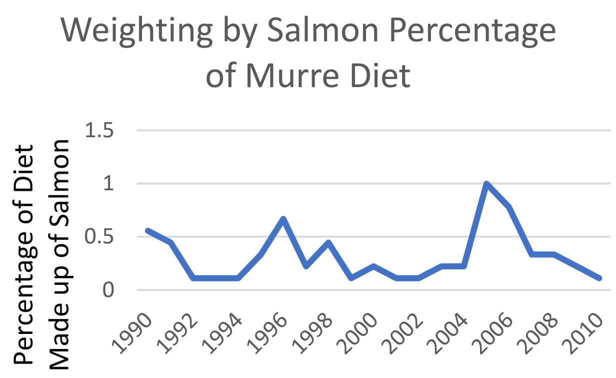
Predation Mortality = Size-Based Mortality x Sightings x Abundance x Diet

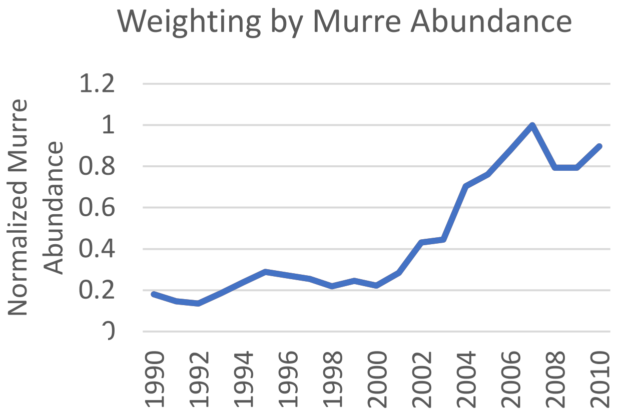
Predation Mortality by Year



Predation Mortality by Year and Age

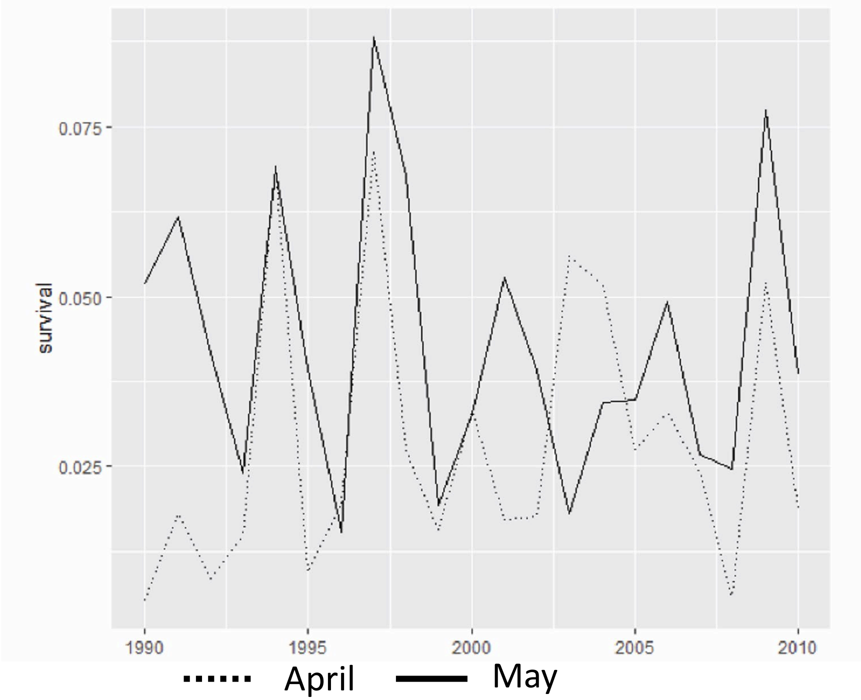




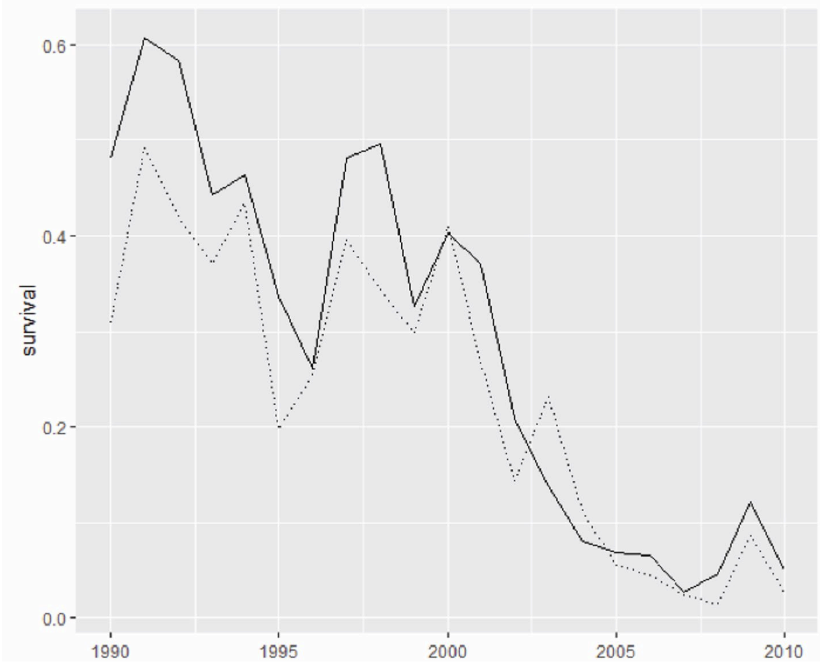


What does this mean for survival?

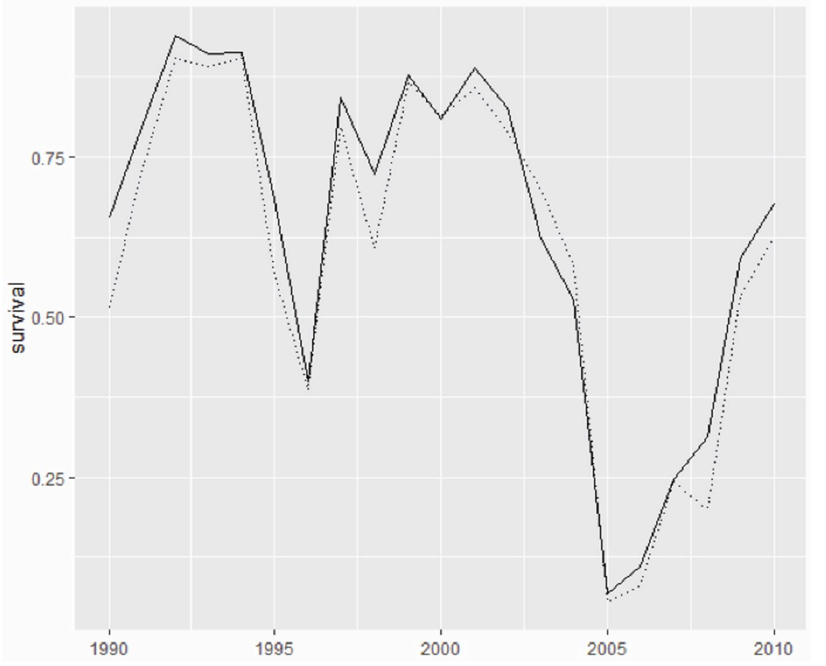
Scenario 1: Environment and Predator Distribution



Scenario 2: Environment, Predator Distribution, and Abundance



Scenario 3: Environment, Predator Distribution, Abundance and Diet



Environment only:

- Variability between years driven by environment
- Timing of outmigration matters

Including Abundance:

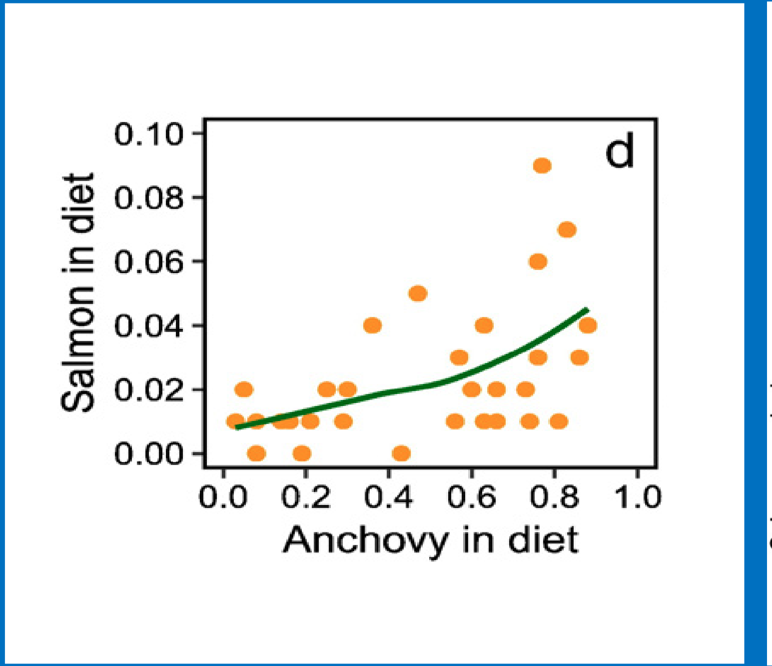
- Signal from Murre abundance swamps environmental signals, especially after 2000

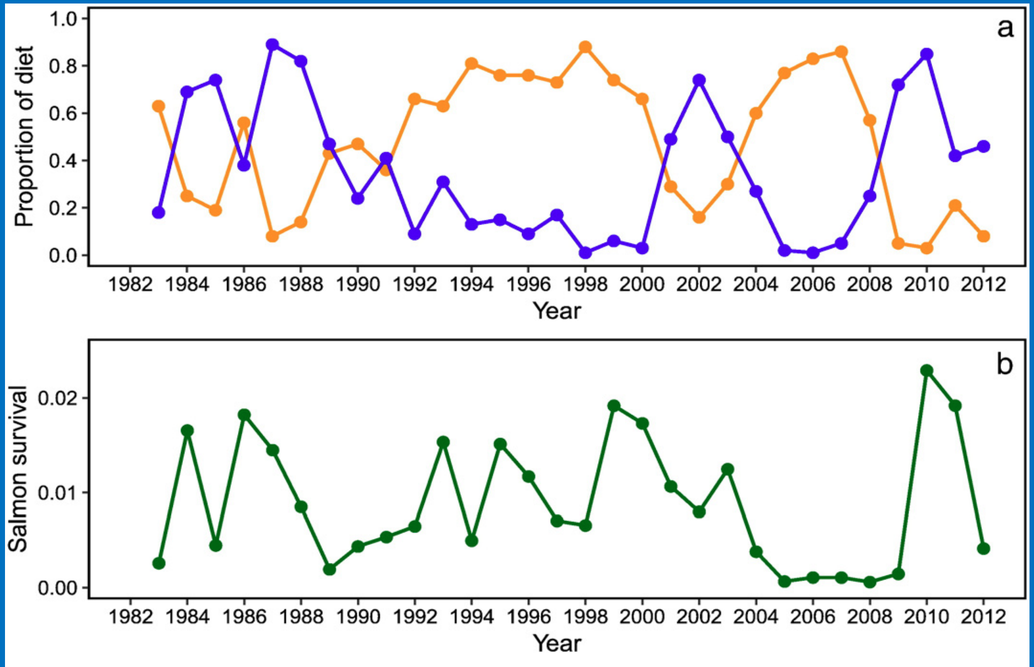
Abundance and Diet:

- Including diet mitigates some of the drop in survival due to abundance
- Diet as a driver seems effective, but is self-imposed…what if information on diet could come from the IBM?

What if the amount of salmon eaten by Murre could be emergent?

We can do this by looking at alternative forage, prey switching, and co-occurrence of juvenile salmon and anchovy





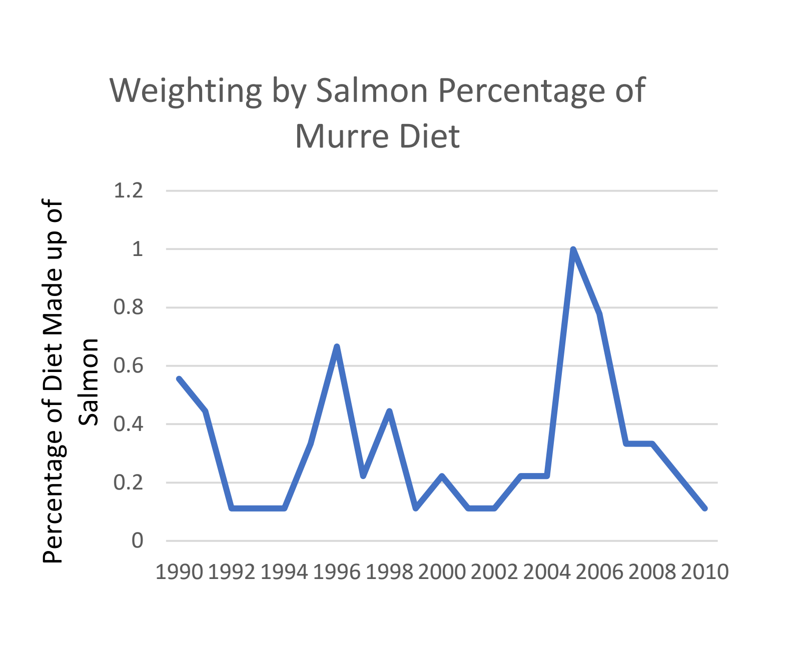
- Murre forage on YOY rockfish
- When rockfish are low, Murre switch to foraging on anchovies, bringing them closer to shore and increasing consumption of juvenile salmon due to spatial overlap between anchovy and juvenile salmon

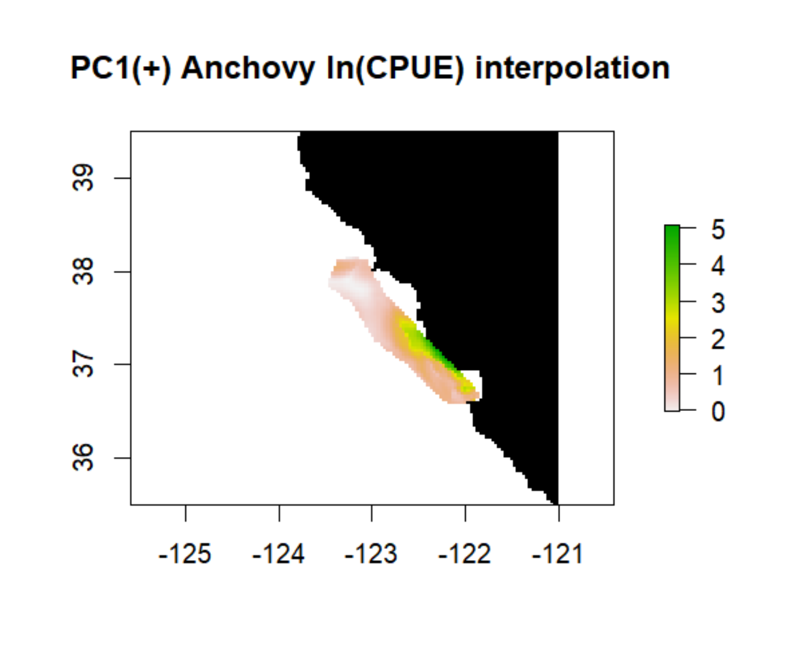
Figures from Wells et al. 2017

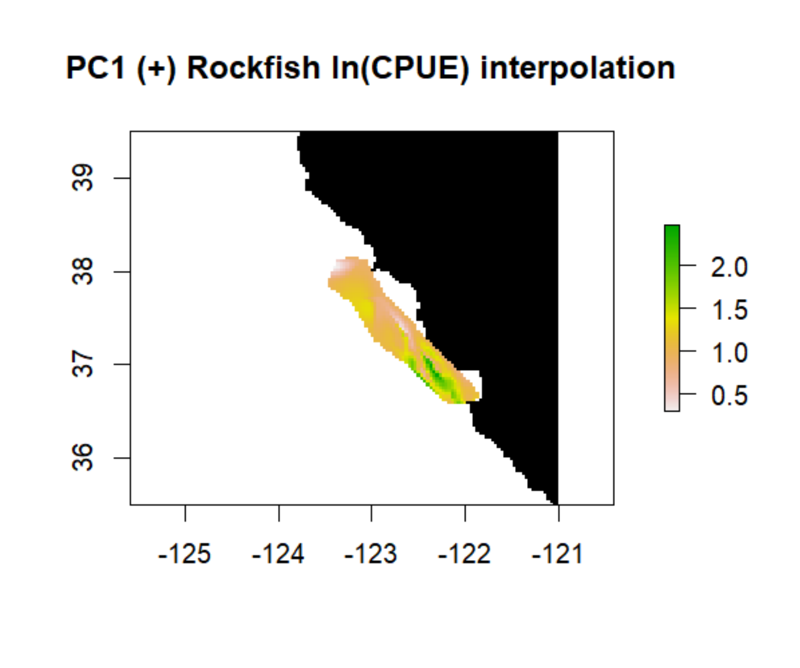
What if the amount of salmon eaten by Murre could be emergent?

Predation Mortality = Size-Based Mortality x Sightings x Abundance x Diet

New approach: Drive diet with alternative forage instead of percentage of murre diet made up of salmon



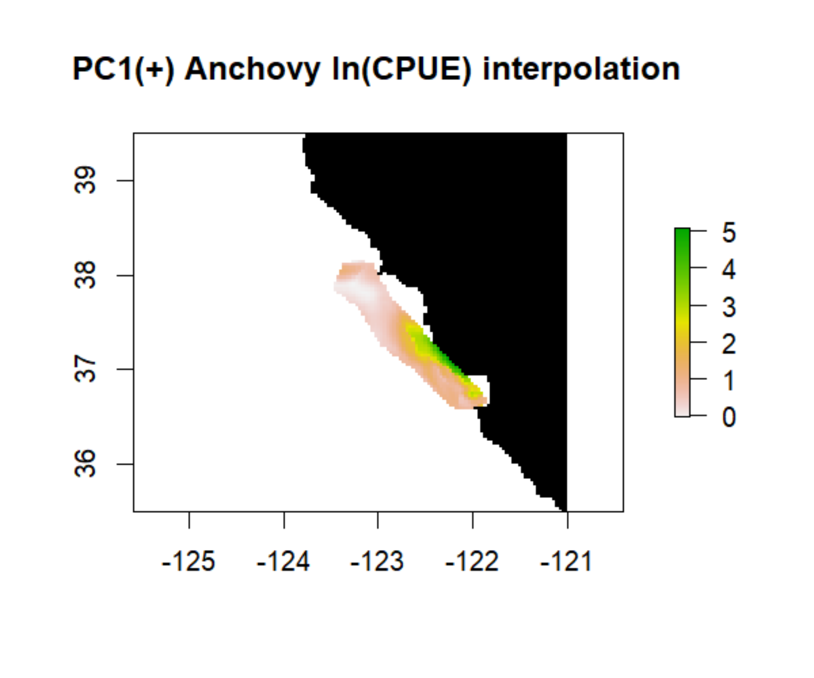


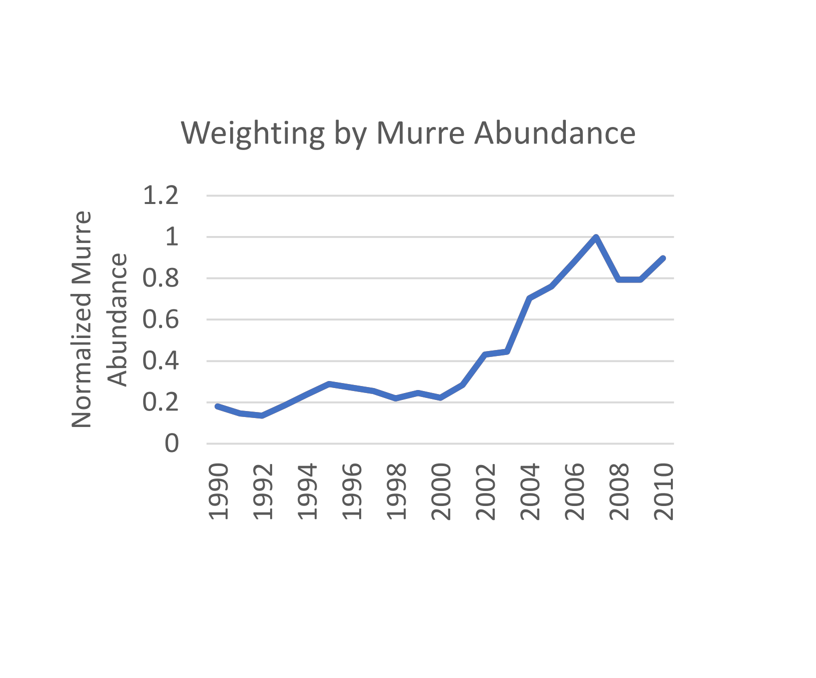


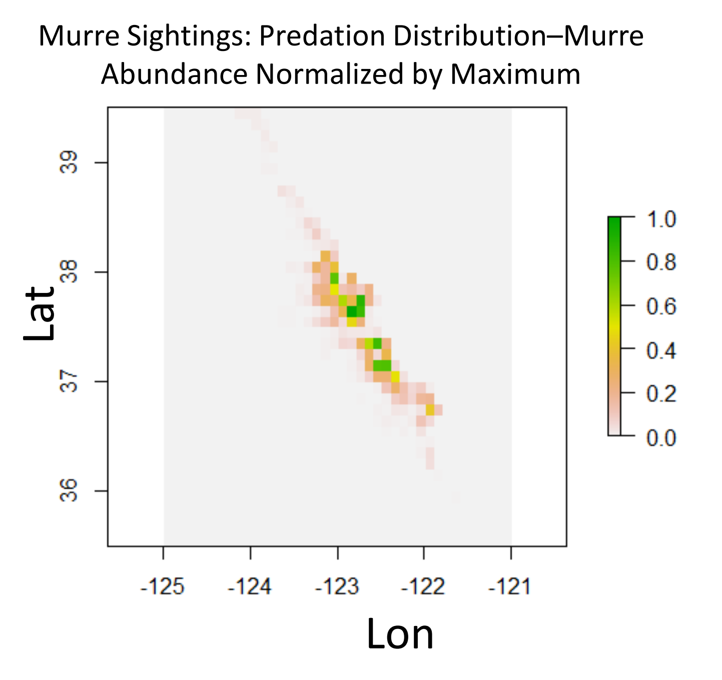
PCA method in Santora et al. 2014

What if the amount of salmon eaten by Murre could be emergent?

Predation Mortality = Size-Based Mortality x Sightings x Abundance x Alternate Forage







Scenario 1: Predation Mortality = Size-Based Mortality x Sightings

Scenario 2: Predation Mortality = Size-Based Mortality x Sightings x Abundance

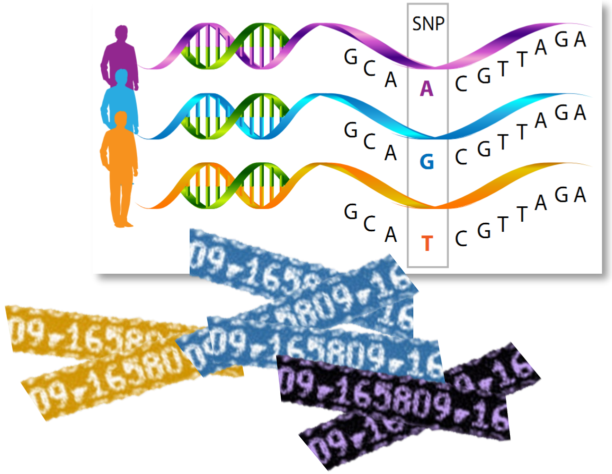
Scenario 3: Predation Mortality = Size-Based Mortality x Sightings x Abundance x Diet

New Scenario: Predation Mortality = Size-Based Mortality x Sightings x Abundance x Alternate Forage

Thank you! Questions?

Contact me at:
kvasbind@ucsc.edu

Characterizing the marine distributions of California's Chinook salmon (using tags and genetics)



Alexander Jensen
Postdoctoral Scholar
School of Marine and Environmental Affairs
University of Washington

39th Annual Salmonid Restoration Conference
Seascape Ecology
April 22, 2022

UNIVERSITY of WASHINGTON

NOAA FISHERIES

Acknowledgment of research collaborators

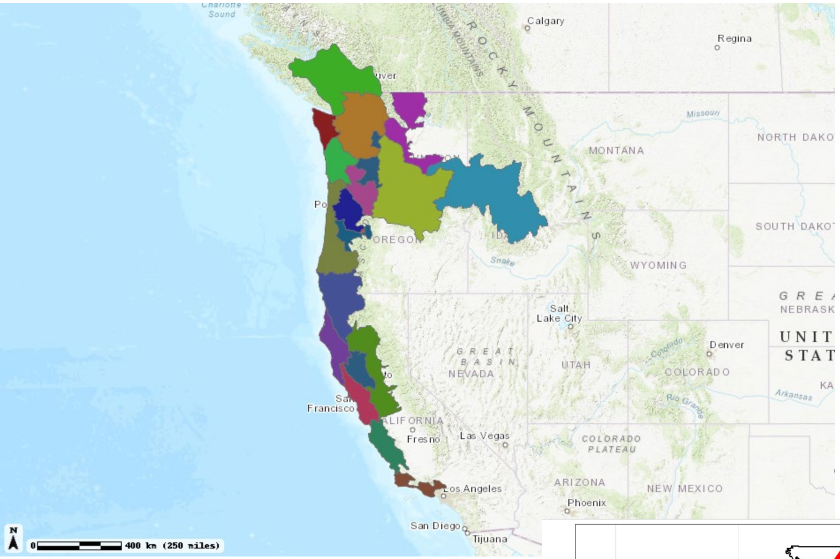
- University of Washington:
  - Ryan Kelly
  - Kelly lab members
- Southwest Fisheries Science Center:
  - Will Satterthwaite, Eric Anderson
- Northwest Fisheries Science Center:
  - Ole Shelton, Eric Ward, Paul Moran, Stephanie Moore

NOAA FISHERIES

UNIVERSITY of WASHINGTON

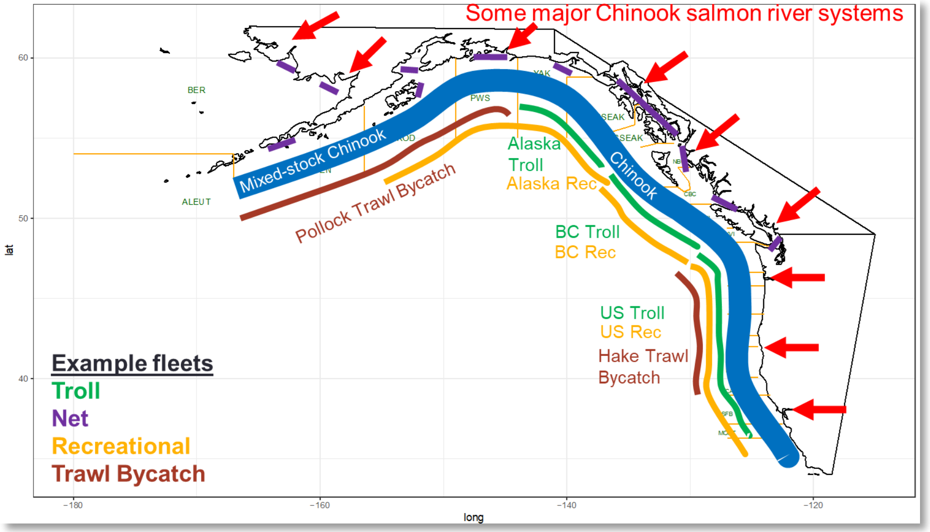
Research context

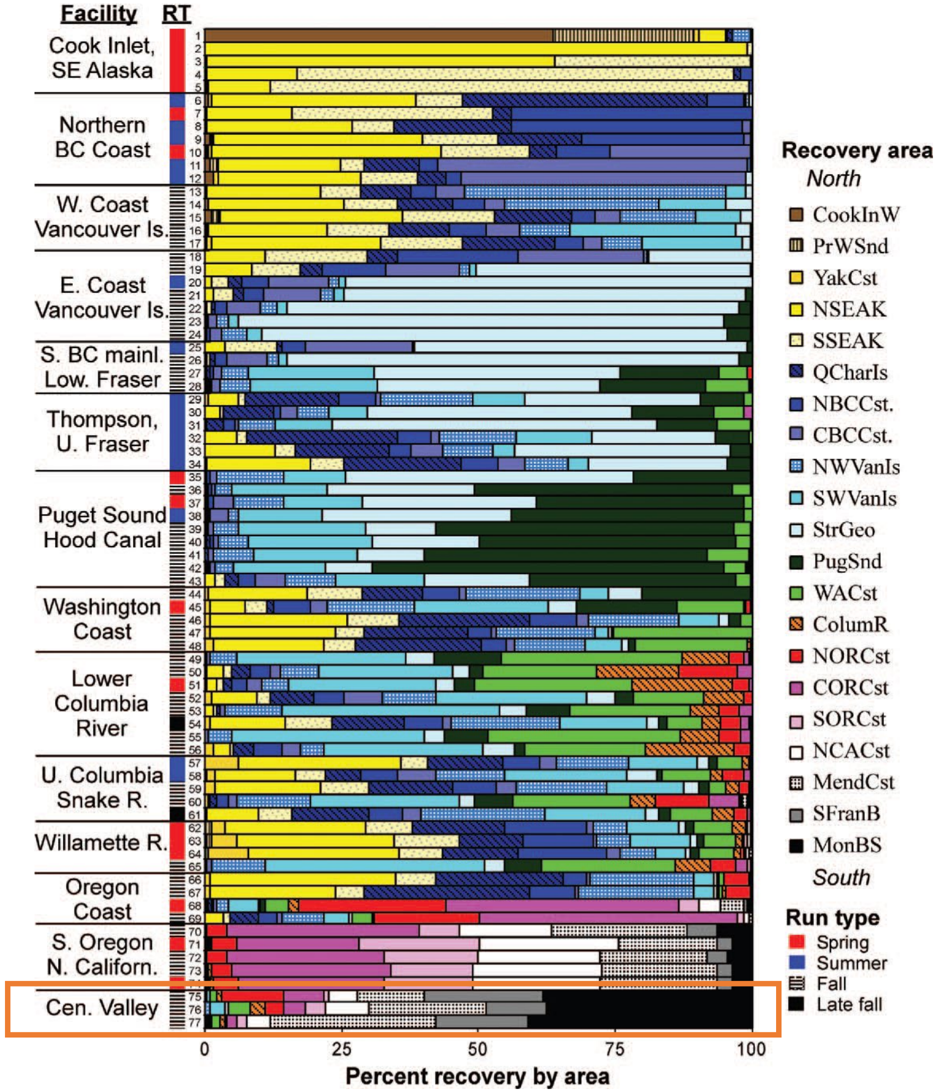
Understanding Chinook salmon distributions



Complex evolutionary structure with varying life histories

Mixed-stock groupings with varying vulnerability in the marine environment

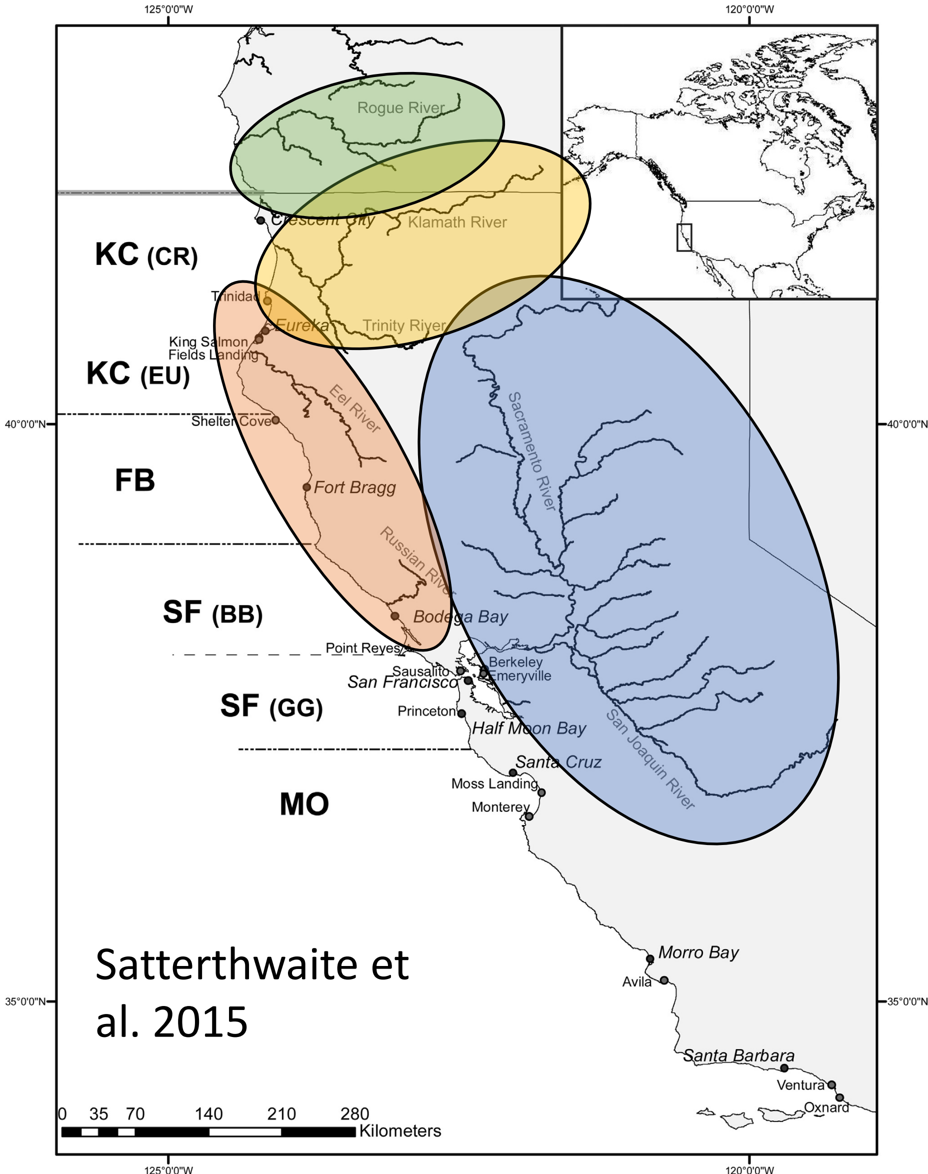




Weitkamp 2010

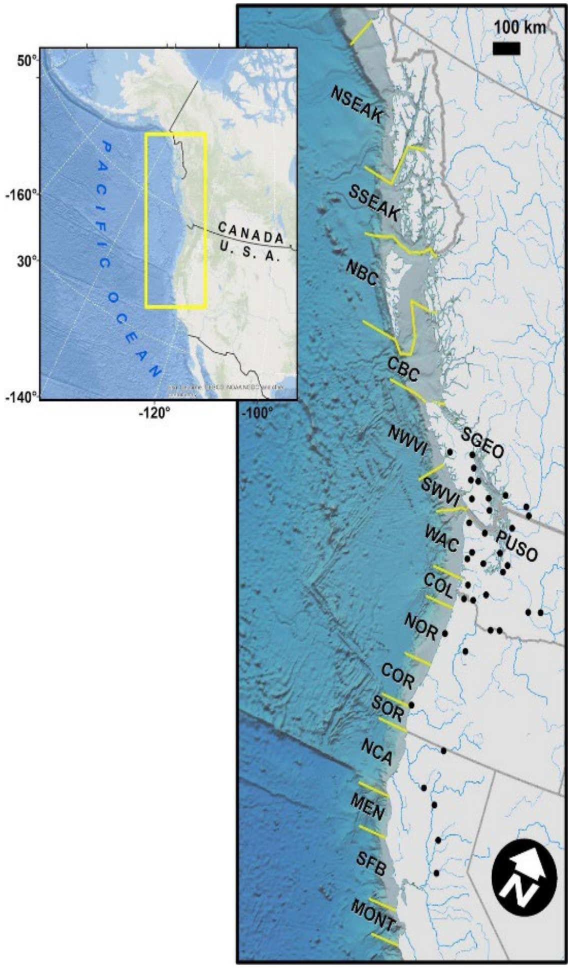
Relevance to California's salmon stocks

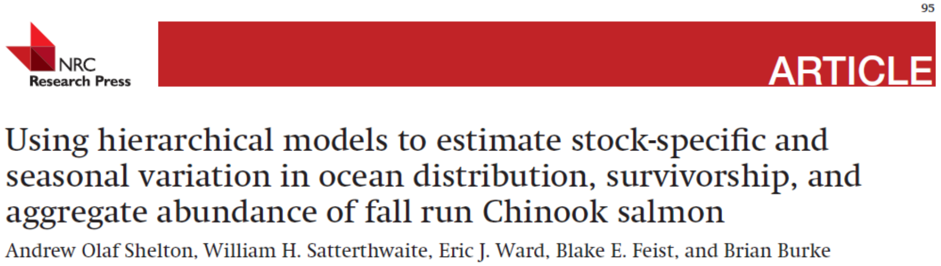
- Central Valley fall-run
- Central Valley spring-run (Threatened)
- Sacramento River winter-run (Endangered)
- California Coast (Threatened)
- Upper Klamath and Trinity Rivers
- Southern Oregon and Northern California Coast



Satterthwaite et al. 2015

Shelton et al. 2019





NRC Research Press

ARTICLE

Using hierarchical models to estimate stock-specific and seasonal variation in ocean distribution, survivorship, and aggregate abundance of fall run Chinook salmon

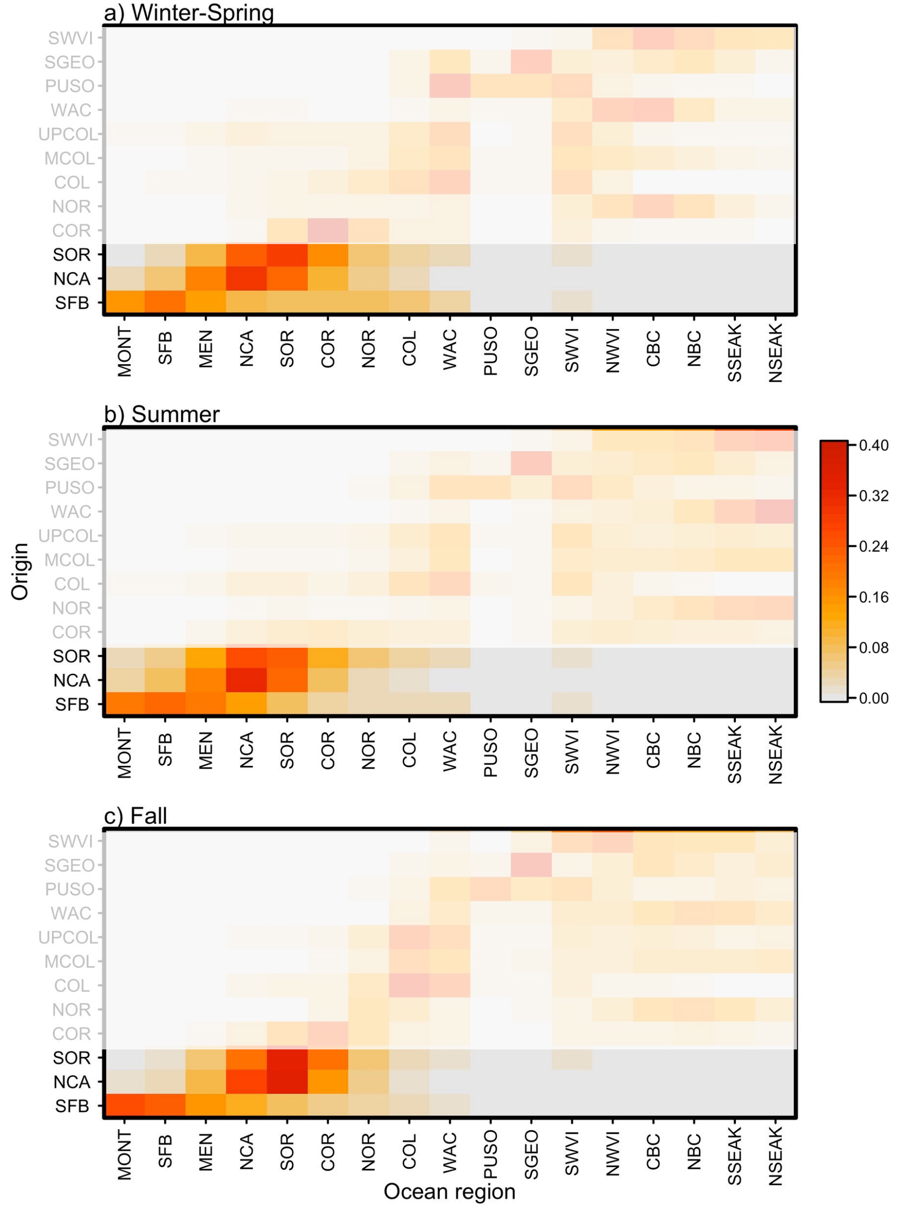
Andrew Olaf Shelton, William H. Satterthwaite, Eric J. Ward, Blake E. Feist, and Brian Burke

Integrated coast-wide modeling framework

Modeled life history of fall-run Chinook salmon stocks

Relied on CWT recoveries

Observed spatial segregation among stocks and seasons



Shelton et al. 2021

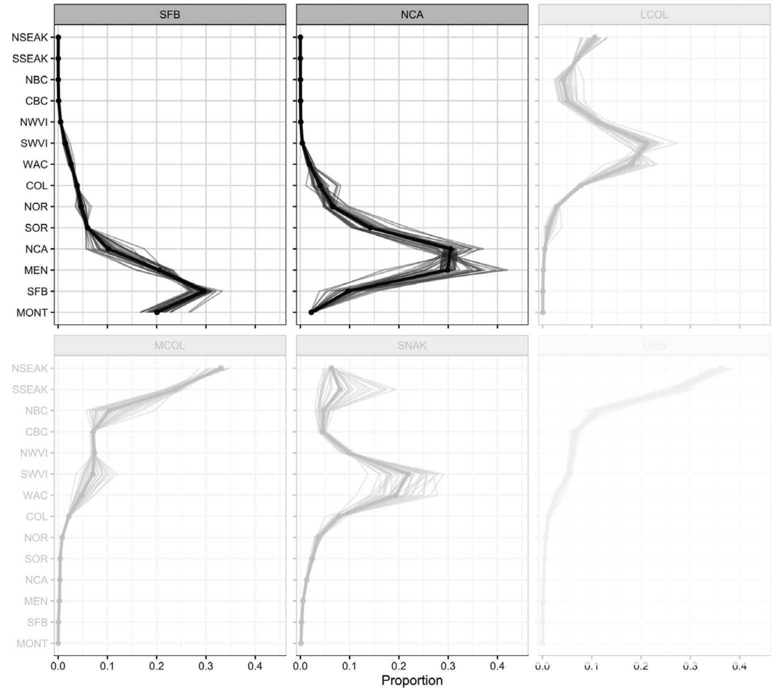
Received: 12 August 2020 | Revised: 5 November 2020 | Accepted: 11 November 2020
DOI: 10.1111/faf.12530

ORIGINAL ARTICLE

FISH and FISHERIES WILEY

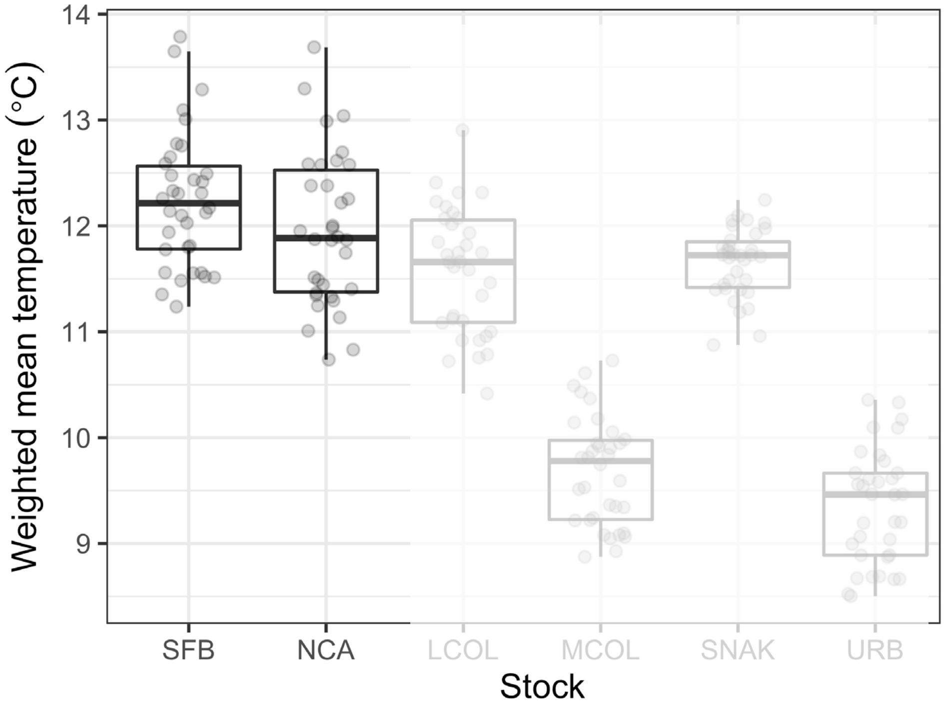
Redistribution of salmon populations in the northeast Pacific ocean in response to climate

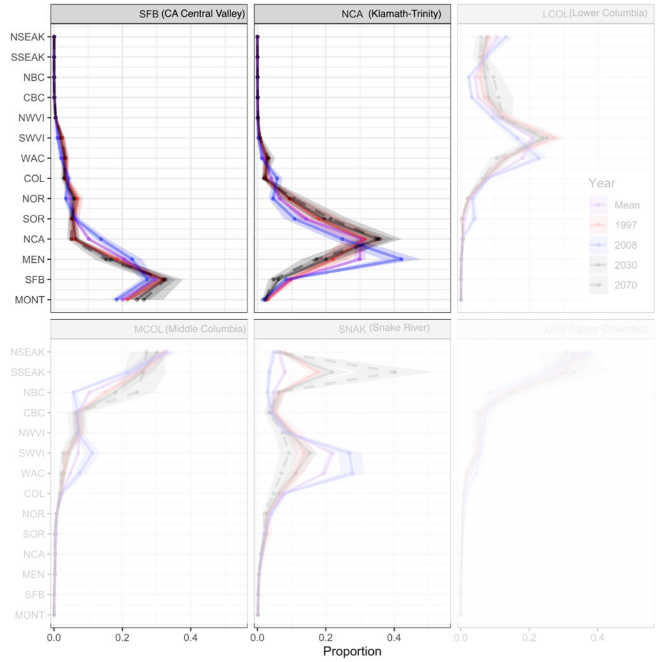
Andrew Olaf Shelton[1] | Genoa H. Sullaway[2] | Eric J. Ward[1] | Blake E. Feist[1] | Kayleigh A. Somers[3] | Vanessa J. Tuttle[3] | Jordan T. Watson[4] | William H. Satterthwaite[5]



Added more years of data

Modeled stock-specific temperature associations

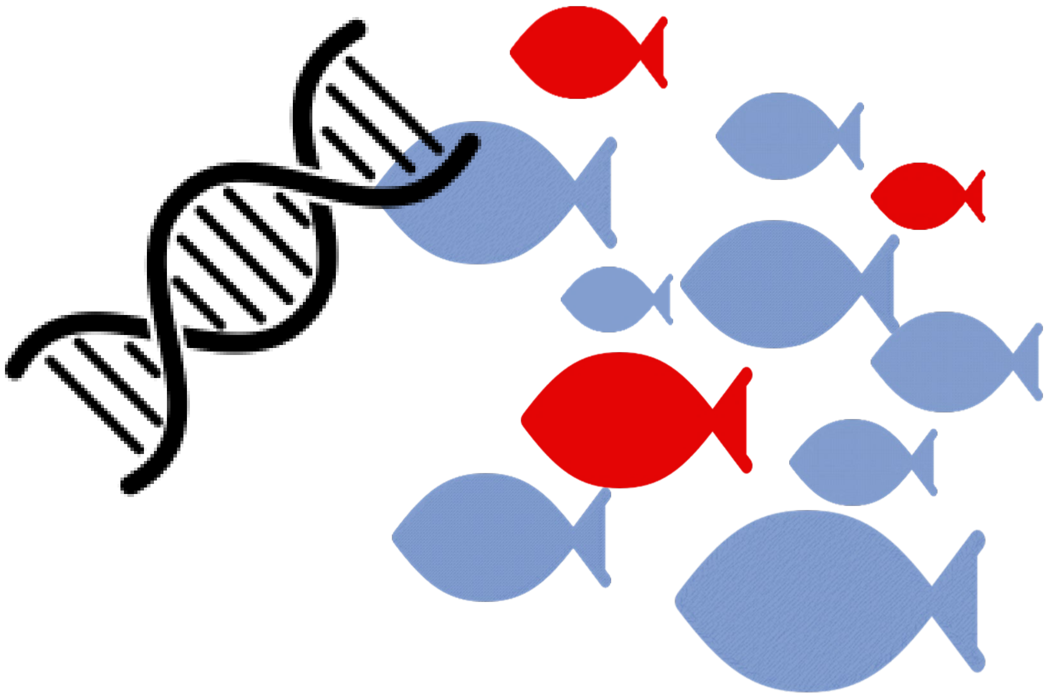




Next steps

- Increase resolution of stock groupings
  - E.g., NCA / SOR -> California Coast / Klamath / North California South Oregon Coast
- Obtain inference on untagged portion of stocks
- How do we do this?
  - *Add new sources of data!*

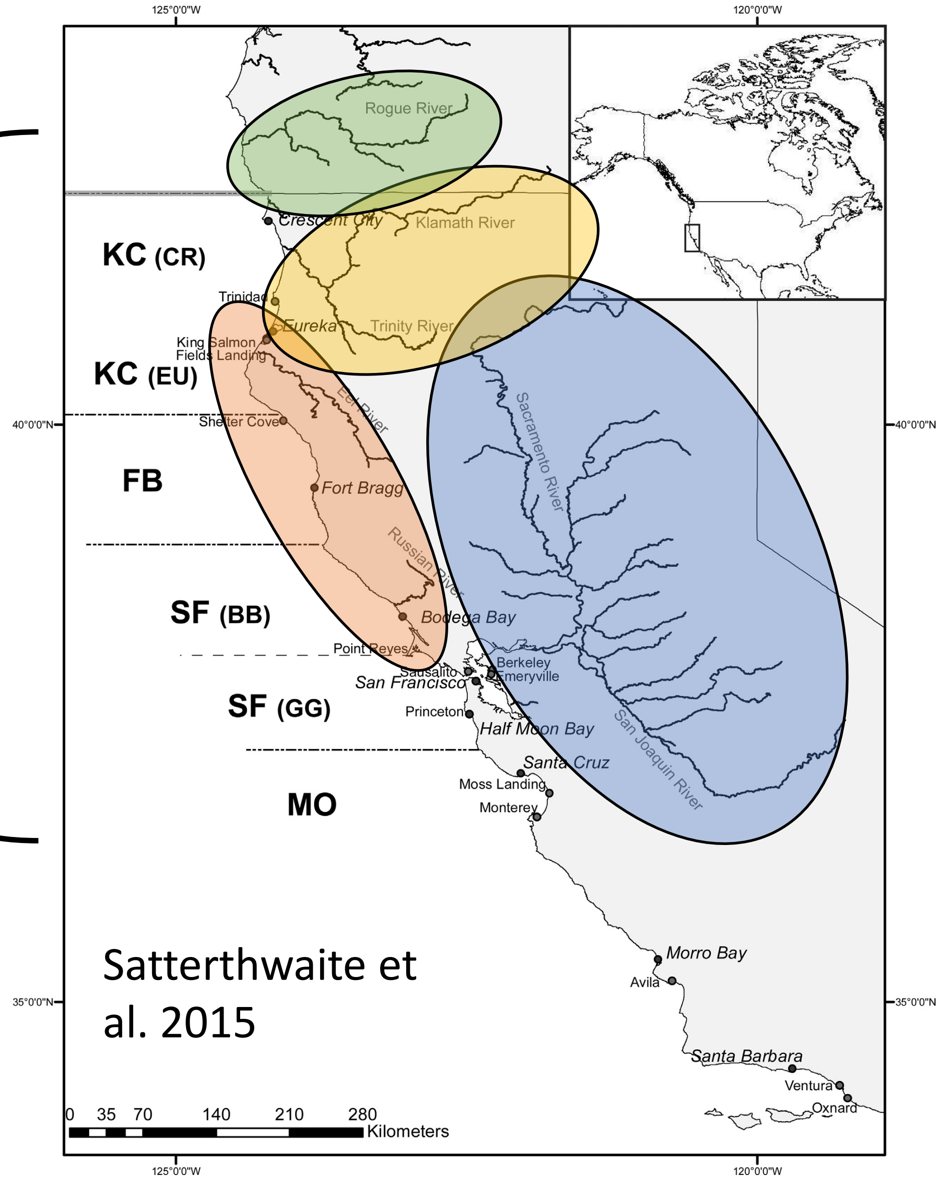
New Sources of Fishery Data: Genetic Stock Identification (GSI)



- Using genetics to:
  - Assign assemblage to stock proportions, or individuals to stock probabilities, using genetic markers
  - Seeb et al. 2007; Clemento et al. 2014
- Advantages:
  - Assign every sampled fish to group
    - Hatchery- and natural-origin both assigned
- Disadvantages:
  - Imprecision in assignments
    - Lose information on release year, age
    - Assignments may be uncertain

New research objective

1. Integrate CWT and GSI information to estimate Chinook salmon stock distribution and abundance in the ocean
   - Start with a case study of CA and S. OR stocks
     - Central Valley fall
     - California Coast
     - Klamath River
     - North California/South Oregon Coast
   - Leverage CWT and GSI data to improve understanding of low abundance stocks and natural-origin stock components

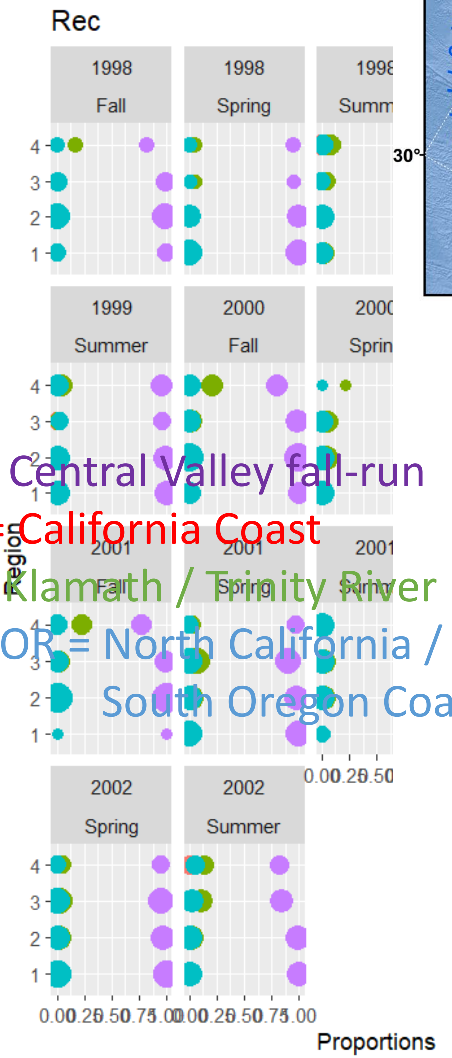


Satterthwaite et al. 2015

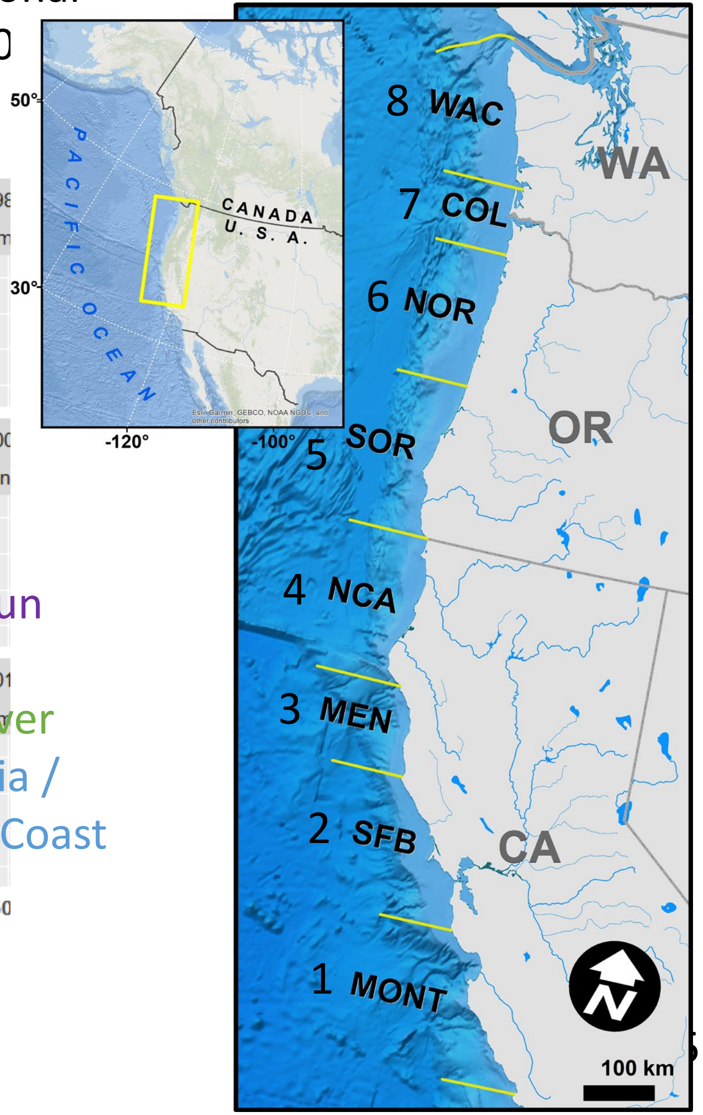
Research methods

Overview of GSI data

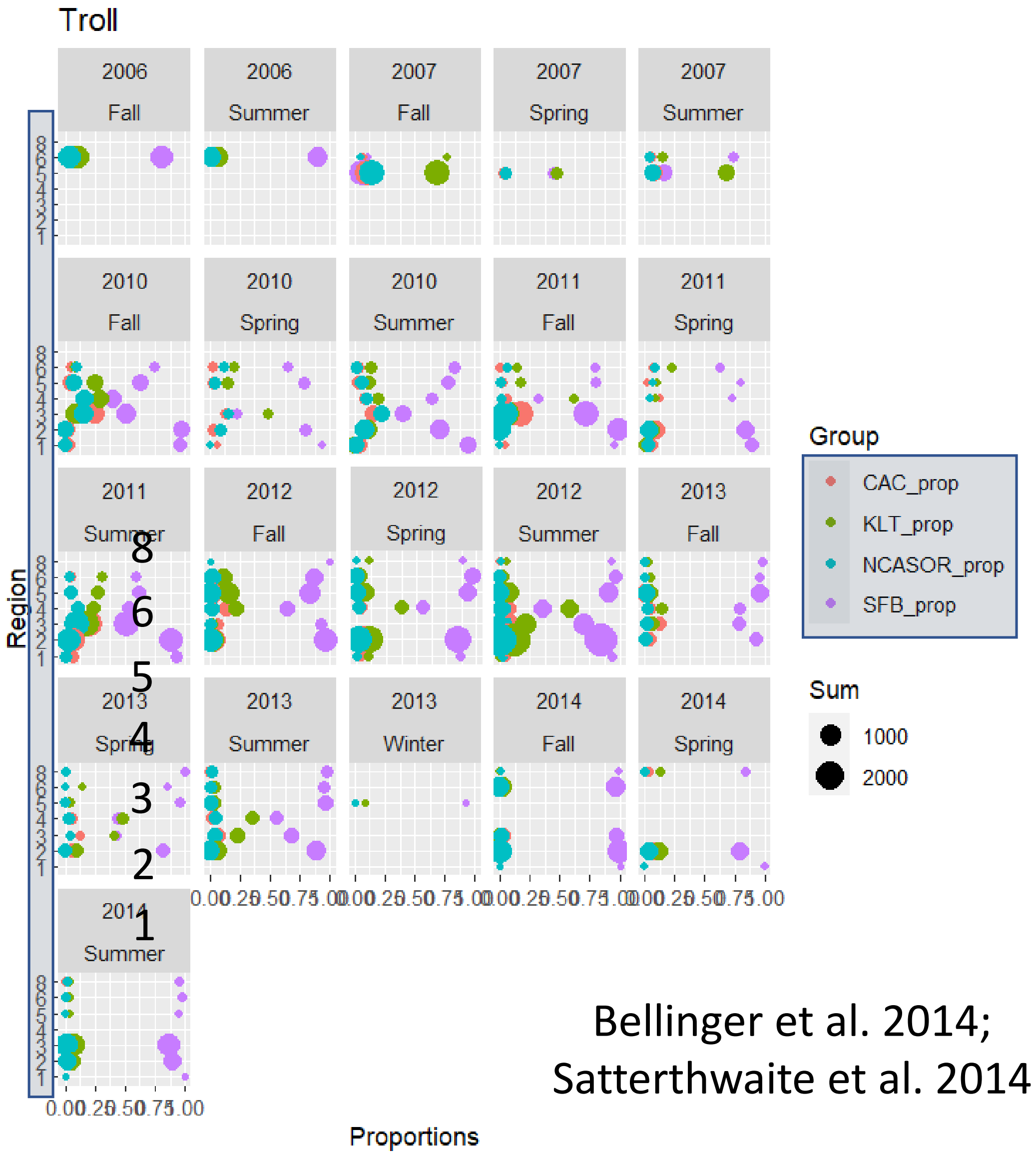
Recreational
1998-20
CA



SFB = Central Valley fall-run
CAC = California Coast
KLT = Klamath / Trinity River
NCASOR = North California / South Oregon Coast

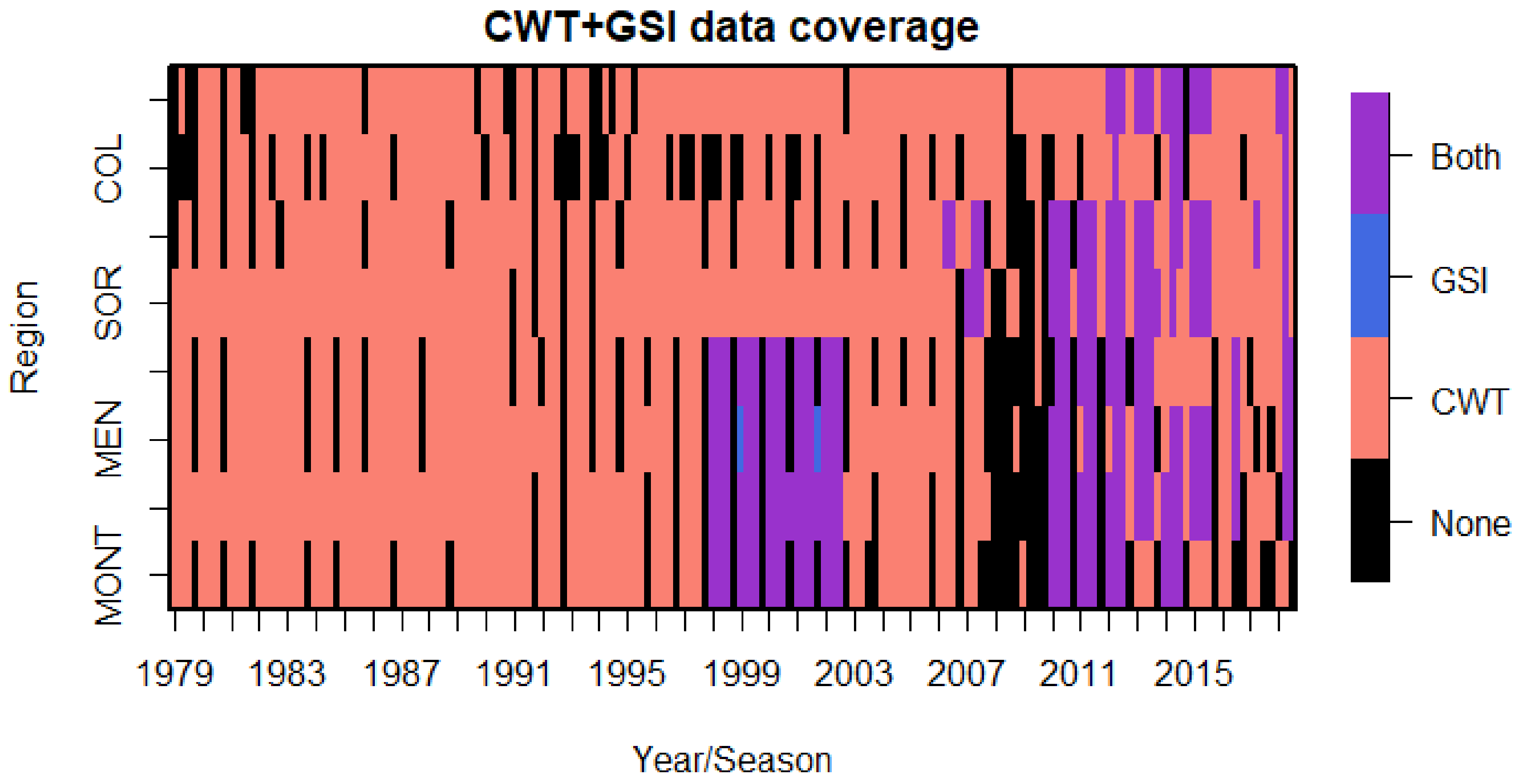


Commercial troll
2006-2019
CA, OR, WA

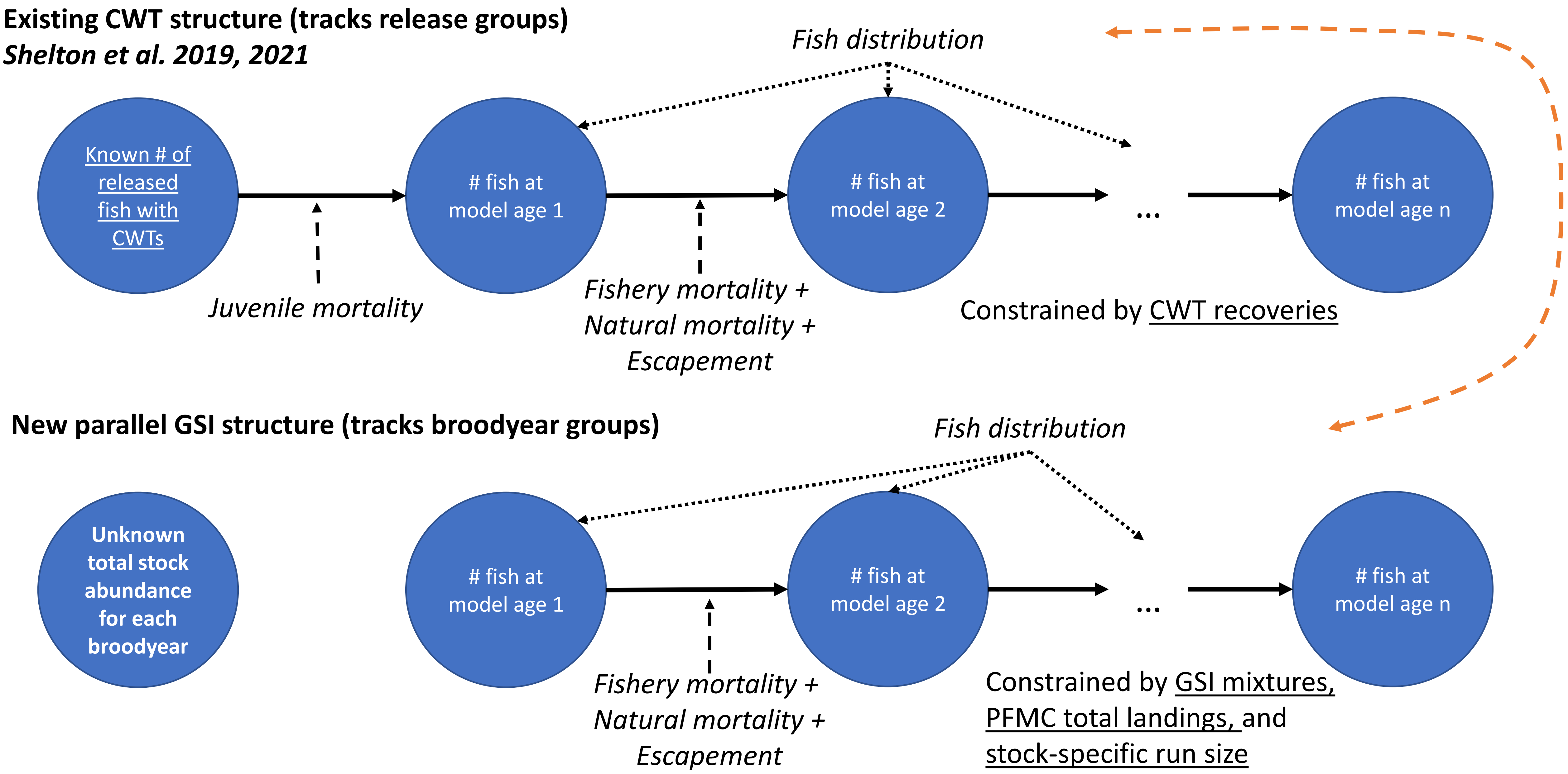


Bellinger et al. 2014;
Satterthwaite et al. 2014

Data coverage: CWT vs GSI

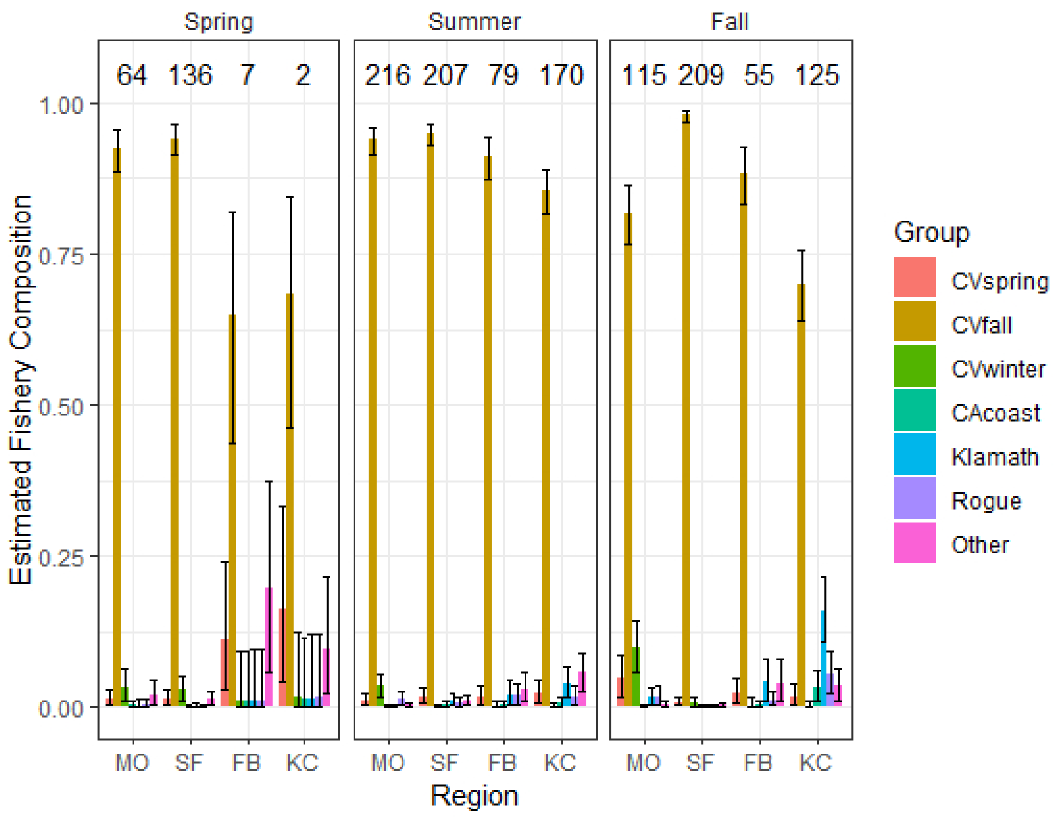


Overview of model structure



zoid: A mixture model (and R package) for modeling proportional data with 0s and 1s in ecology

- We developed a new method for analyzing complex proportional data
- Models are available as R projects on GitHub and CRAN
  - https://nwfsc-cb. github.io/zoid/
  - https://cran.r-project.org/web/packages/zoid/index.html
- In revision at *Ecology*



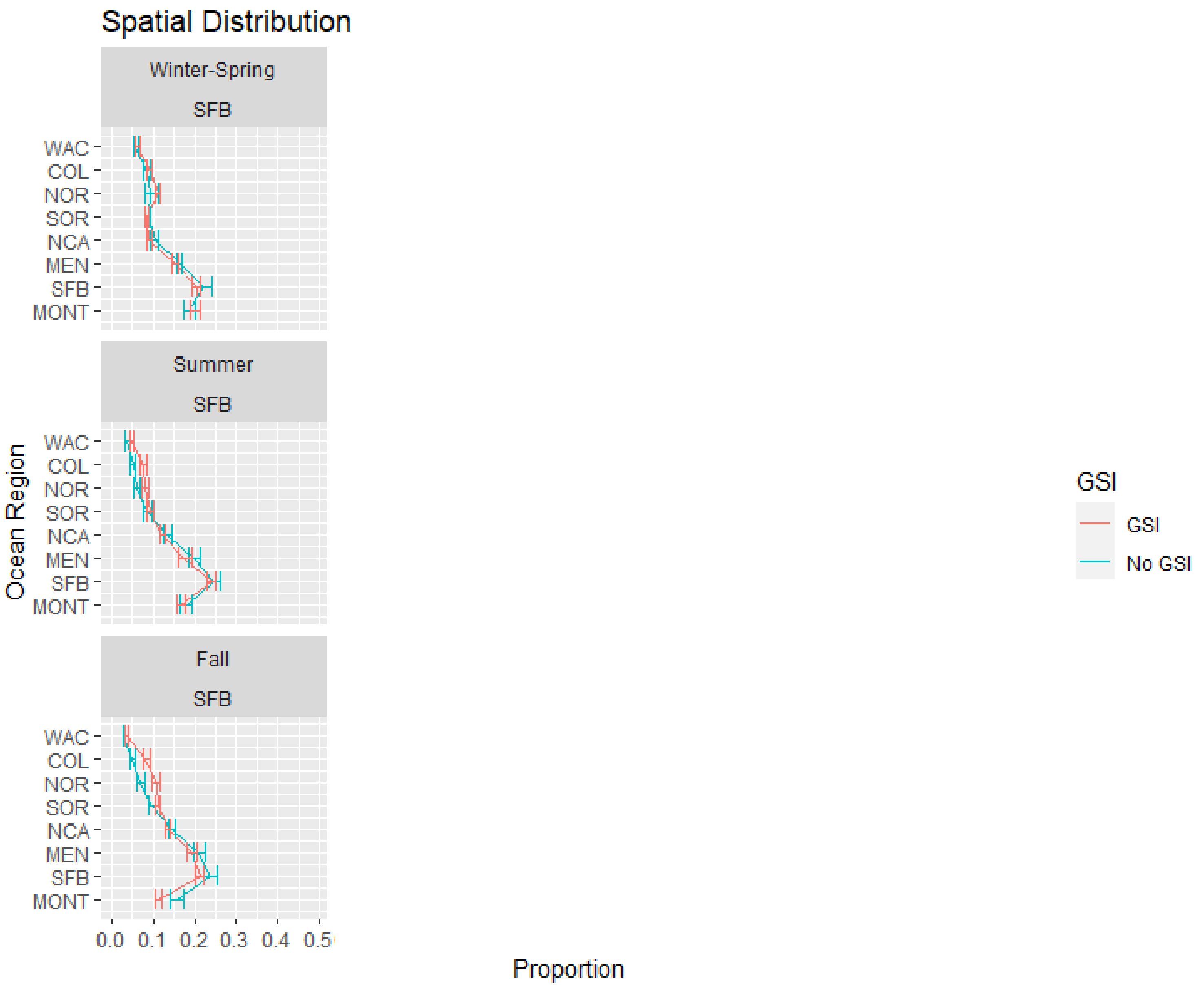
Jensen et al. 2022,
data from Satterthwaite et al. 2015

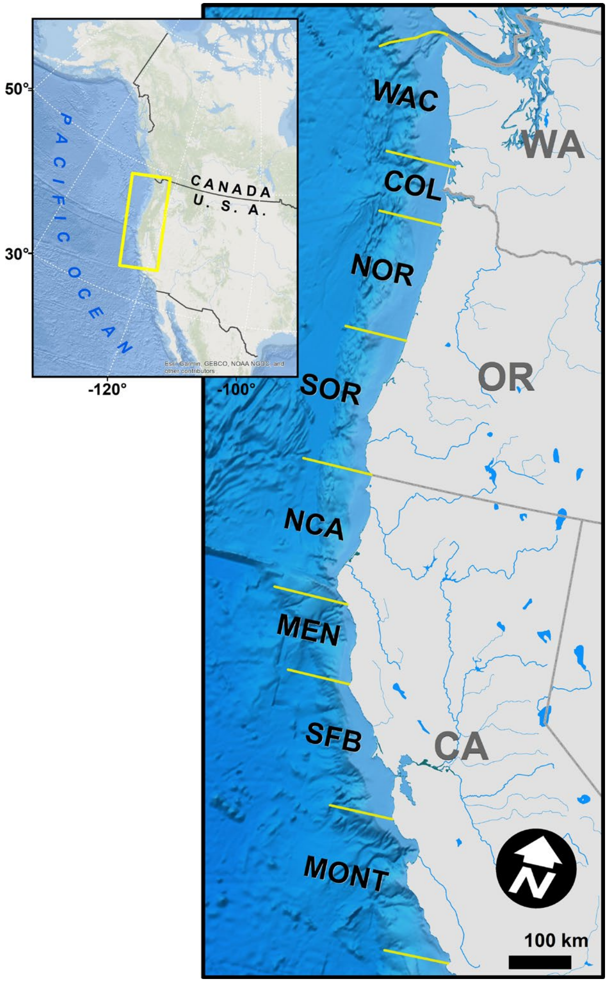
Research results

*Results to date are preliminary

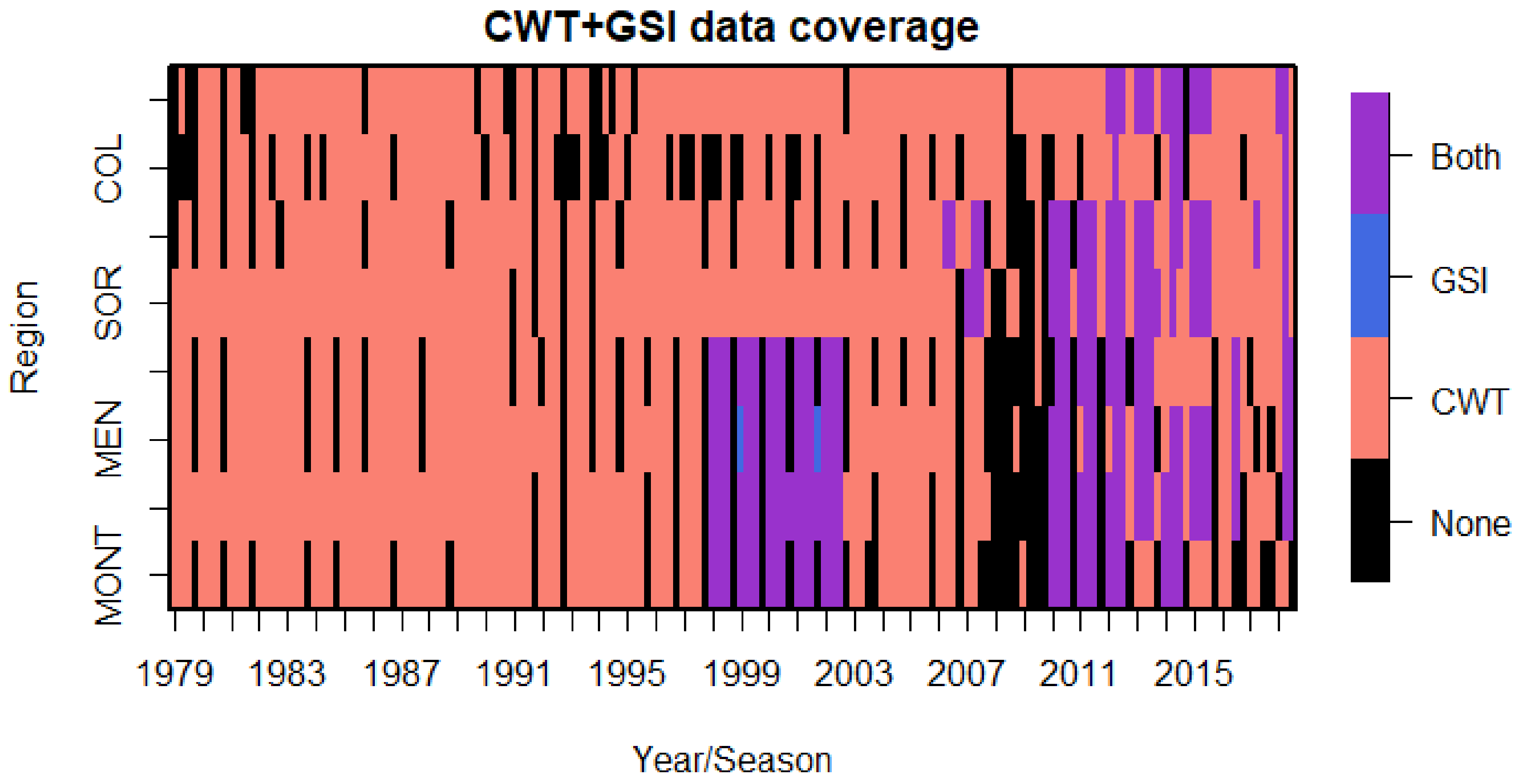
Estimated spatial distribution

SFB = Central valley fall
CAC = California Coast
KLT = Klamath
NCASOR = North California/ South Oregon Coast



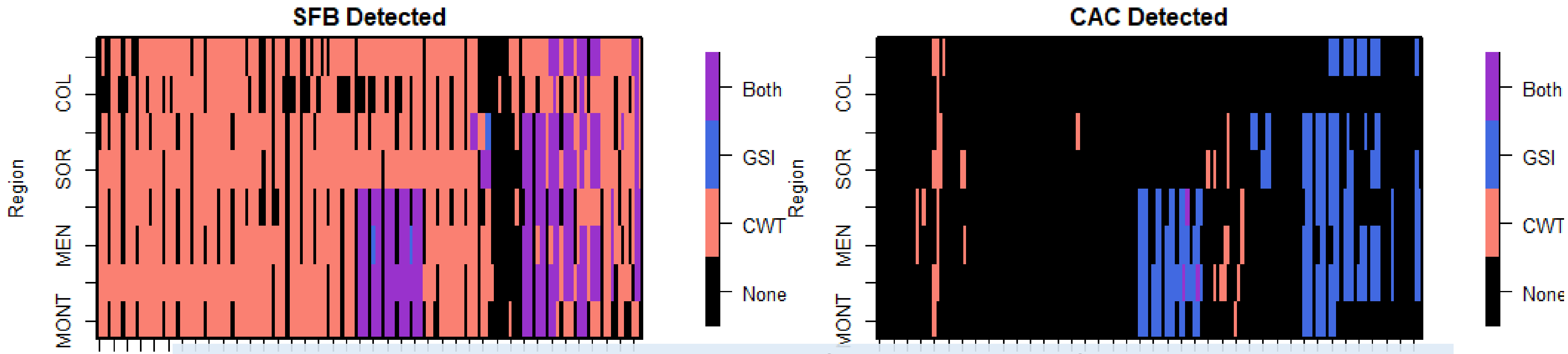


Data coverage: CWT vs GSI

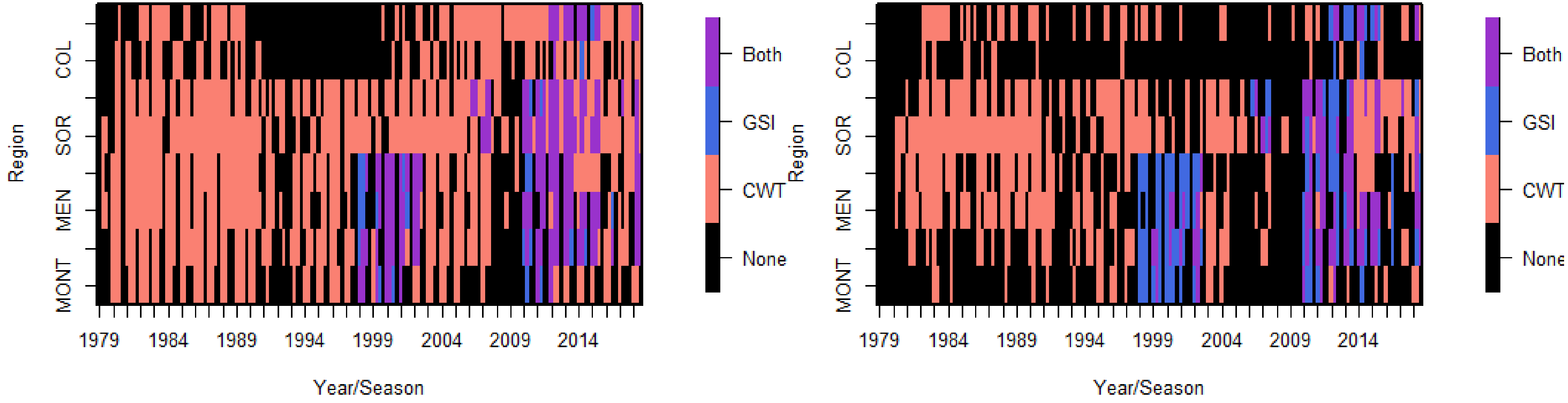


SFB = Central valley fall
CAC = California Coast
KLT = Klamath
NCASOR = North California/ South Oregon Coast

Data coverage: CWT vs GSI

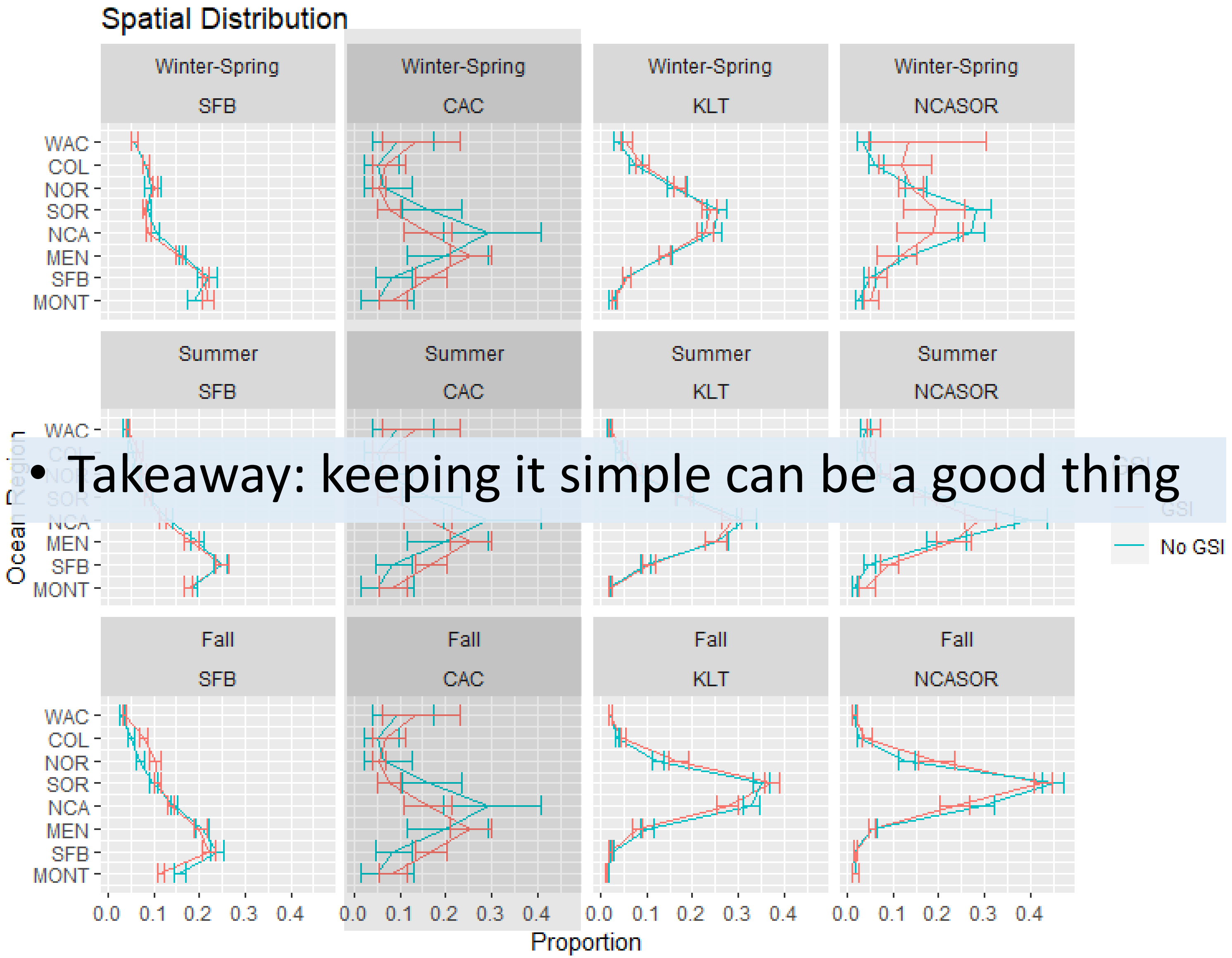


- Takeaway: not enough information for reliable modeling of rare stocks

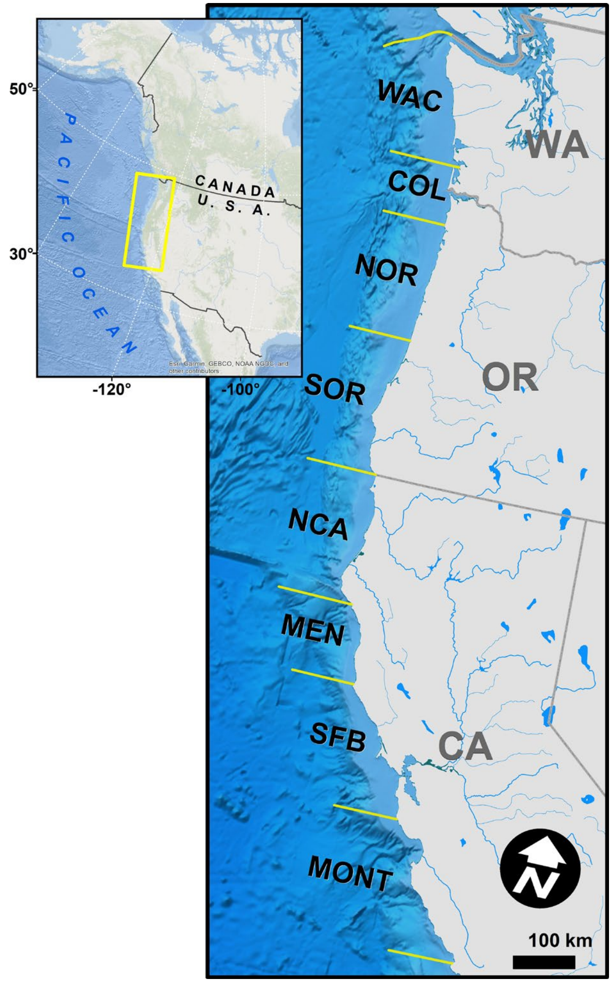


Simplified CAC distribution

SFB = Central valley fall
CAC = California Coast
KLT = Klamath
NCASOR = North California/
South Oregon Coast



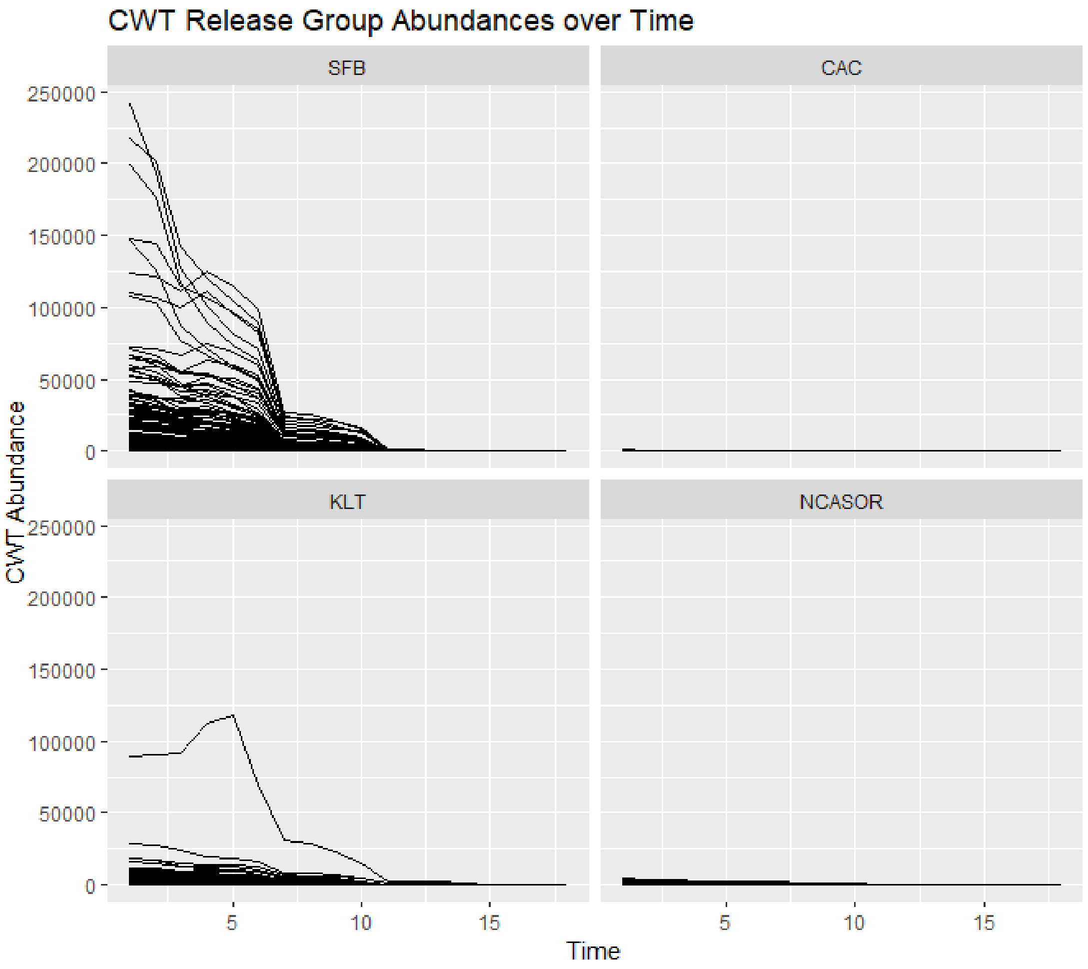
- Takeaway: keeping it simple can be a good thing



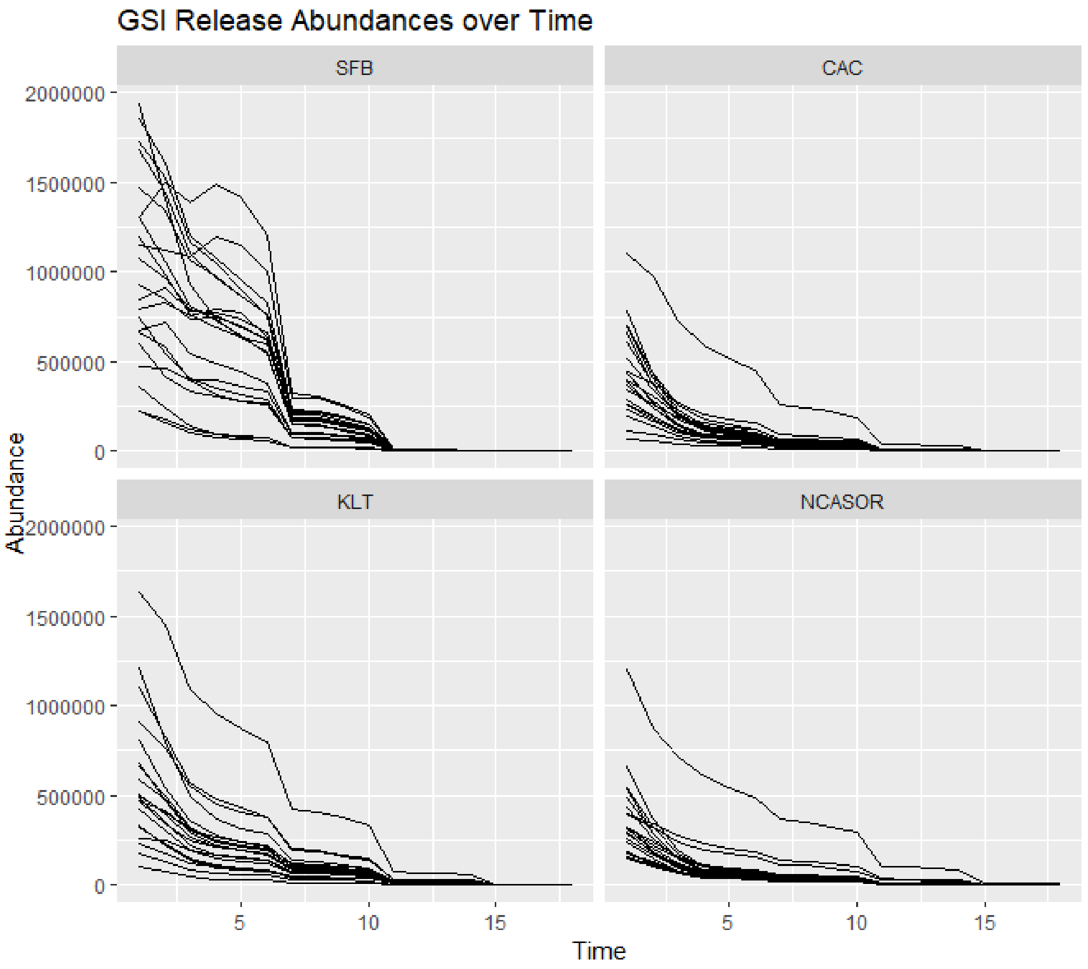
Release group abundances

SFB = Central valley fall
CAC = California Coast
KLT = Klamath
NCASOR = North California/ South Oregon Coast

CWT groups

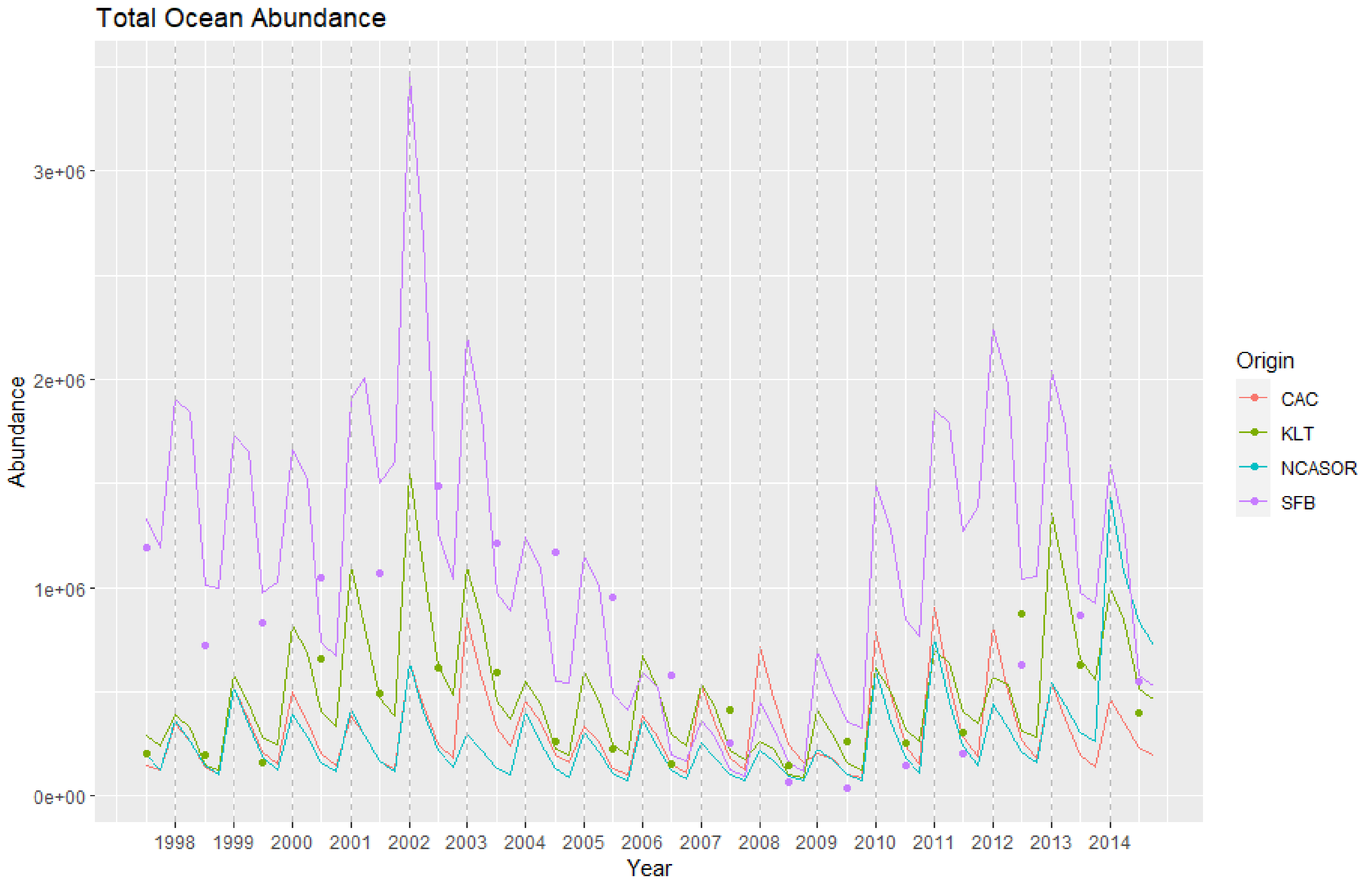


GSI groups



Abundances of GSI groups

SFB = Central Valley fall-run
CAC = California Coast
KLT = Klamath / Trinity River
NCASOR = North California / South Oregon Coast



Discussion + next steps

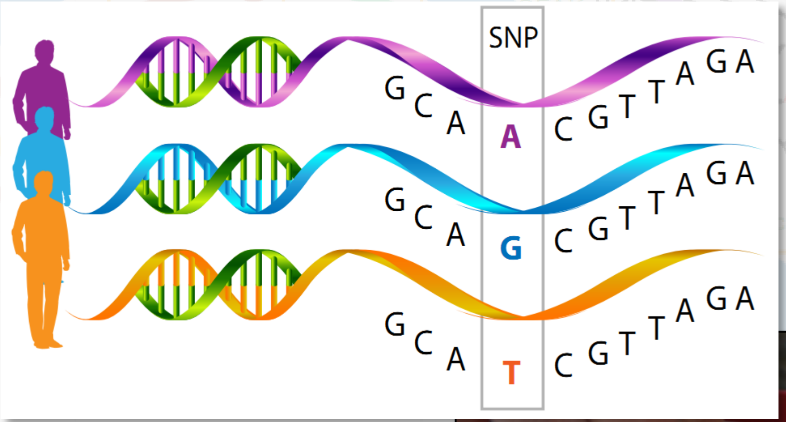
What have we learned?

- Novel estimates of ocean distribution for rare stocks
  - Estimates correspond to naïve expectations
- First use of combined CWT and GSI data to inform the life history of Chinook salmon at spatial scales relevant to management
- GSI data expands breadth of inference but doesn’t necessarily improve estimates of distribution for rare stocks
  - Gain inference on hatchery- and natural-origin fish, plus overall abundance
  - Available data can limit our scale of inference, regardless of GSI
    - GSI data are less information rich than CWT recoveries

Future work

- Add model functionality for spring- and winter-run life histories
- Expand the number of modeled stocks
- Incorporate new data sources
  - Expand GSI to include datasets from British Columbia and Alaska
  - Obtain outmigrant estimates by stock, release year to better scale stock abundances over time
- Expand modeling of life history parameters as a function of habitat

Questions?



Questions? → jensena1@uw.edu

Cited resources

- Bellinger, M. R., M. A. Banks, S. J. Bates, E. D. Crandall, J. C. Garza, G. Sylvia, and P. W. Lawson. 2015. Geo-referenced, abundance calibrated ocean distribution of Chinook salmon (Oncorhynchus tshawytscha) stocks across the west coast of North America. PLoS ONE 10(7): e0131276.
- Clemento, A.J., Crandall, E.D., Garza, J.C., and Anderson, E.C. 2014. Evaluation of a single nucleotide polymorphism baseline for genetic stock identification of Chinook salmon (Oncorhynchus tshawytscha) in the California Current large marine ecosystem. Fishery Bulletin 112: 112-130.
- Moran, P., J. Dazey, L. LaVoy, and S. Young. 2018. Genetic mixture analysis supports recalibration of the fishery regulation assessment model. Fisheries, 43: 83-97. doi:10.1002/fsh.10017
- Satterthwaite, W. H., J. Ciancio, E. Crandall, M. L. Palmer-Zwahlen, A. M. Grover, M. R. O'Farrell, E. C. Anderson, M. S. Mohr, and J. C. Garza. 2015. Stock composition and ocean spatial distribution inference from California recreational Chinook salmon fisheries using genetic stock identification. Fisheries Research 170: 166-178.
- Seeb, L.W., Antonovich, A., Banks, M.A., Beacham, T.D., Bellinger, M.R., Blankenship, S.M., Campbell, M.R., Decovich, N.A., Garza, J.C., Guthrie III, C.M., Lundrigan, T.A., Moran, P., Narum, S.R., Stephenson, J.J., Supernault, K.J., Teel, D.J., Templin, W.D., Wenburg, J.K., Young, S.F., and Smith, C.T. 2007. Development of a standardized DNA database for Chinook salmon. Fisheries 32(11): 540-552.
- Shelton, A. O., W. Satterthwaite, E. Ward, B. Burke, and B. E. Feist. 2019. Using hierarchical models to estimate stock-specific and seasonal variation in ocean distribution, survivorship, and aggregate abundance of fall run Chinook salmon. Canadian Journal of Fisheries and Aquatic Sciences. 76:95-108.
- Shelton, A. O., G. H. Sullaway, E. J. Ward, B. E. Feist, K.A. Somers, V. J. Tuttle, J. T. Watson, and W. H. Satterthwaite. 2021. Redistribution of salmon populations in the Northeast Pacific Ocean in response to climate. Fish and Fisheries 22(3): 503-517. DOI: 10.1111/faf.12530
- Weitkamp, L. A. 2010. Marine distributions of Chinook salmon from the west coast of North America determined by coded wire tag recoveries. Transactions of the American Fisheries Society 139.1:147-170.

Ocean distribution of West Coast Chinook salmon inferred from coded-wire-tags and genetic data

Will Satterthwaite
NOAA Fisheries, SWFSC
will.satterthwaite@noaa.gov
Alex Jensen
University of Washington
Ole Shelton
NOAA Fisheries, NWFS

Data sources on subadult Chinook salmon ocean distribution

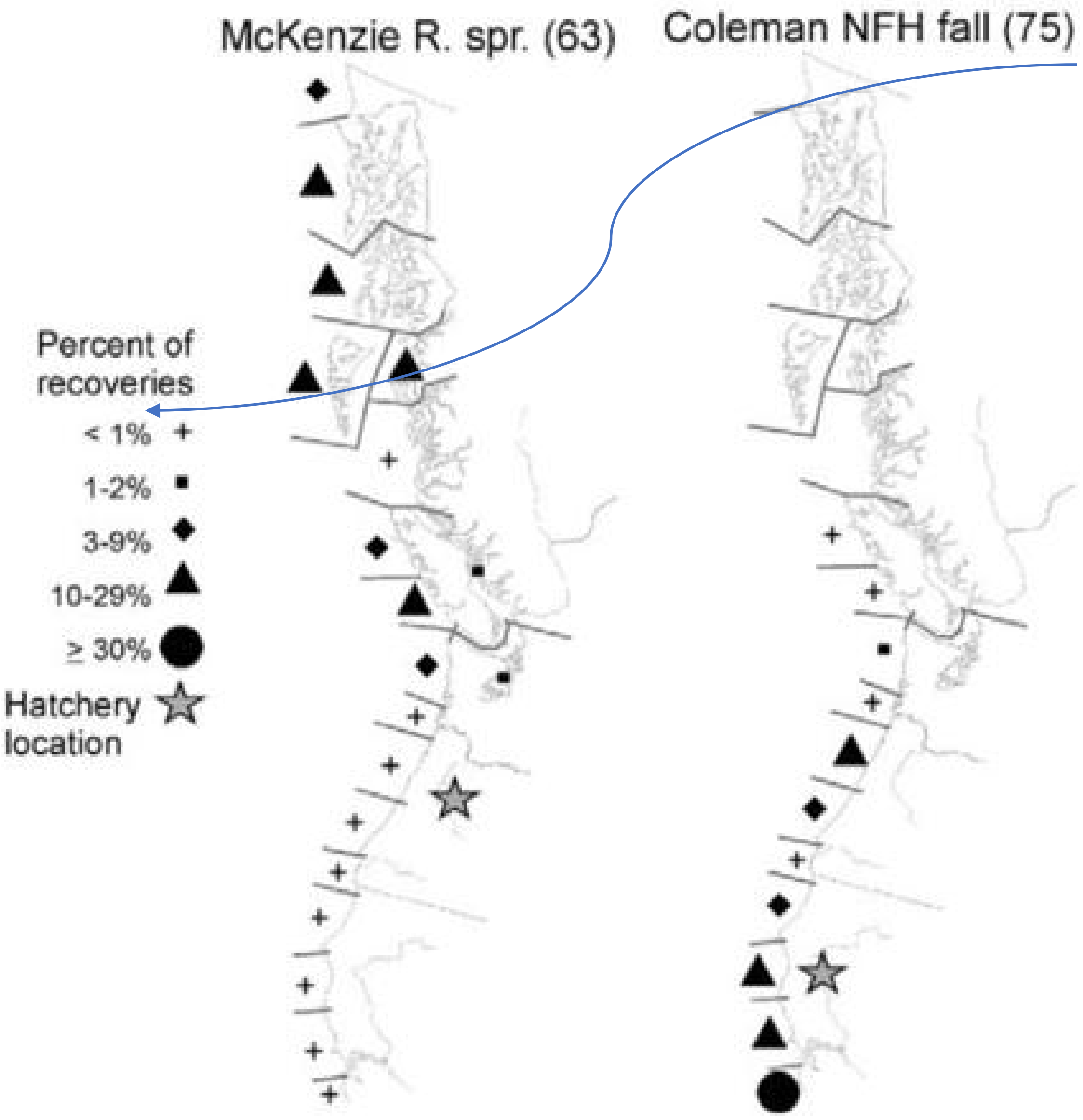
- Primarily fishery-dependent data
- Long history of coded-wire tag program
  - Coast-wide coordination in sampling required by Pacific Salmon Treaty
  - Largely but not exclusively deployed in hatchery setting
- Increasing use of genetic techniques
  - GSI – genetic stock identification
  - PBT – parent-based tagging
- Often pursued independently, different modeling/analysis paradigms

What have we learned and what are the next steps?

- Coastwide patterns in tag recoveries for select stocks along the coast
- CPUE-based, seasonal patterns for California stocks
  - Suitability of proxies, hatchery- versus natural-origin
  - Challenges making inference for rare stocks
- State-space population models: area-specific abundance
  - Applications to rare stocks and alternative run timings
  - Future work- changes in distribution across years
  - Drivers?
  - Predictions for a future climate?

What have we learned and what are the next steps?

- Coastwide patterns in tag recoveries for select stocks along the coast
- CPUE-based, seasonal patterns for California stocks
  - Suitability of proxies, hatchery- versus natural-origin
  - Challenges making inference for rare stocks
- State-space population models: area-specific abundance
  - Applications to rare stocks and alternative run timings
  - Changes in distribution across years
  - Drivers?
  - Predictions for a future climate?

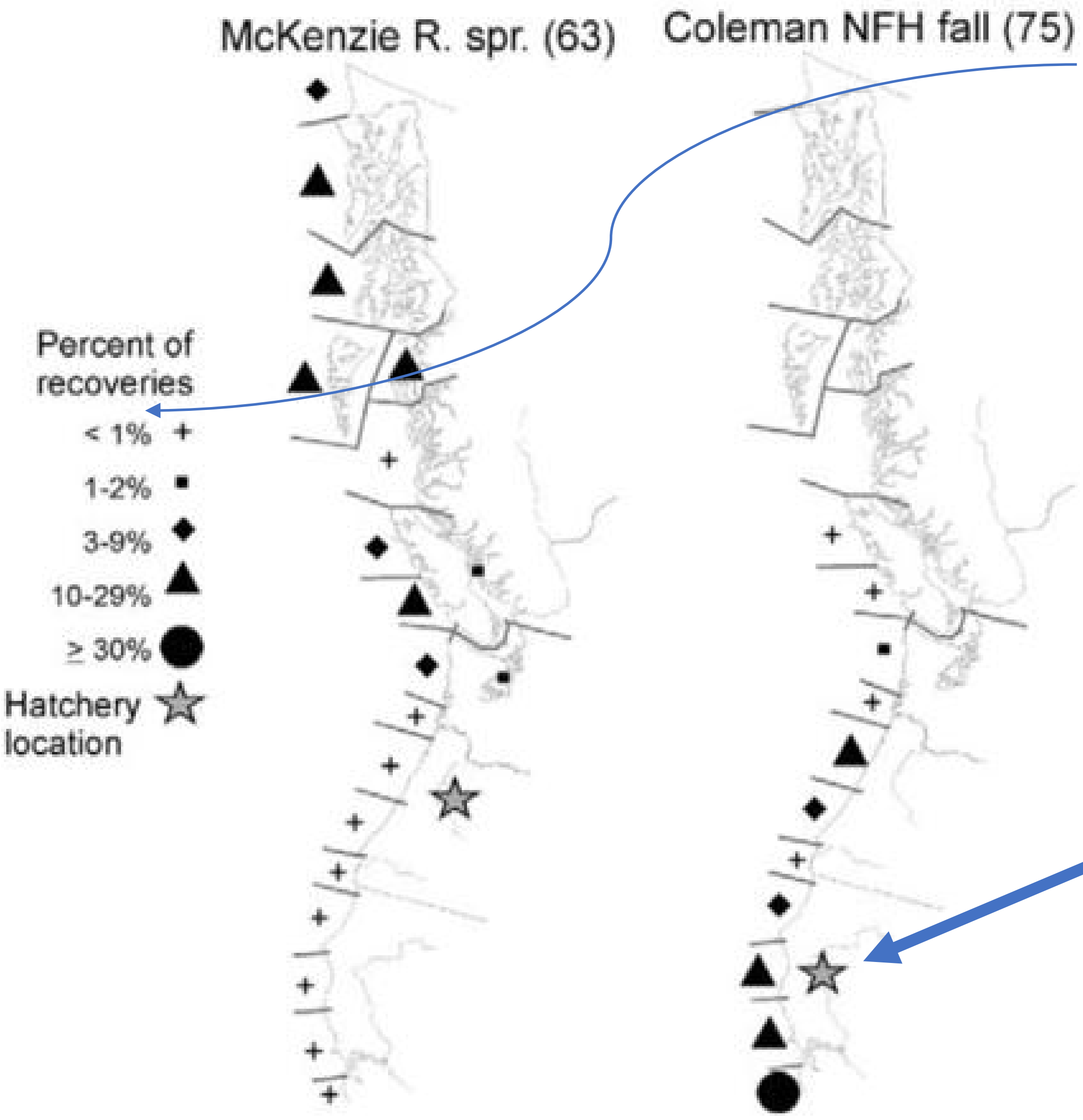


Distribution metric:

Proportion of all ocean fishery tag recoveries by area

Pools across seasons, ages; no accounting for effort

- Weitkamp 2010 Trans. Am. Fish. Soc. 139:147-170



<u>Distribution metric:</u>

Proportion of all ocean fishery tag recoveries by area

Pools across seasons, ages; no accounting for effort

Central Valley Fall Run

- Weitkamp 2010 Trans. Am. Fish. Soc. 139:147-170

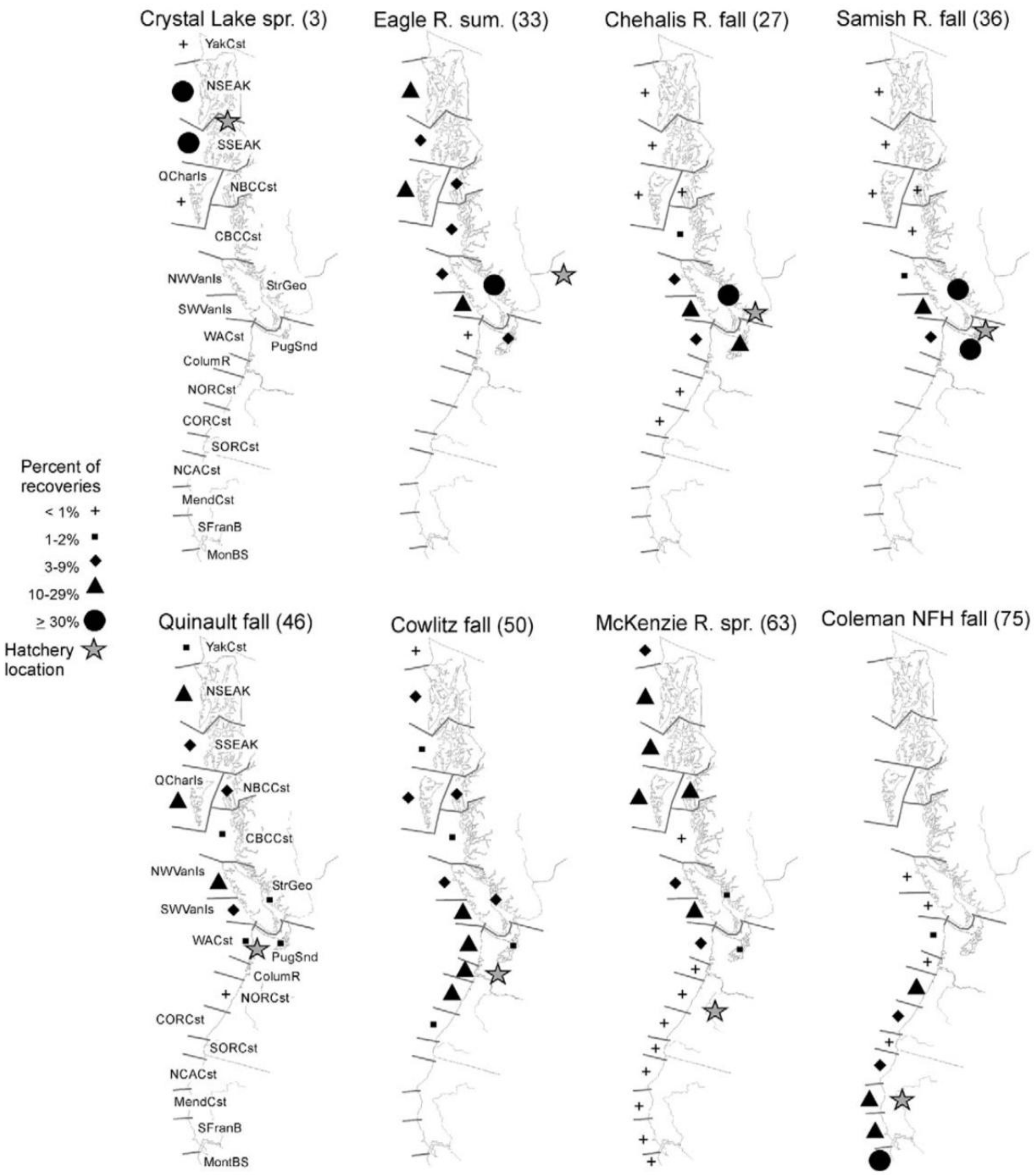


FIGURE 3.—Maps illustrating the percentages of recoveries by marine recovery area from the Yakutat coast to Monterey Bay south for select HRGs. Recoveries in recovery areas with less than 0.1% are not shown; recoveries in the Cook Inlet West and Prince William Sound recovery areas are included with Yakutat recoveries. The stars indicate the approximate locations of the different hatcheries.

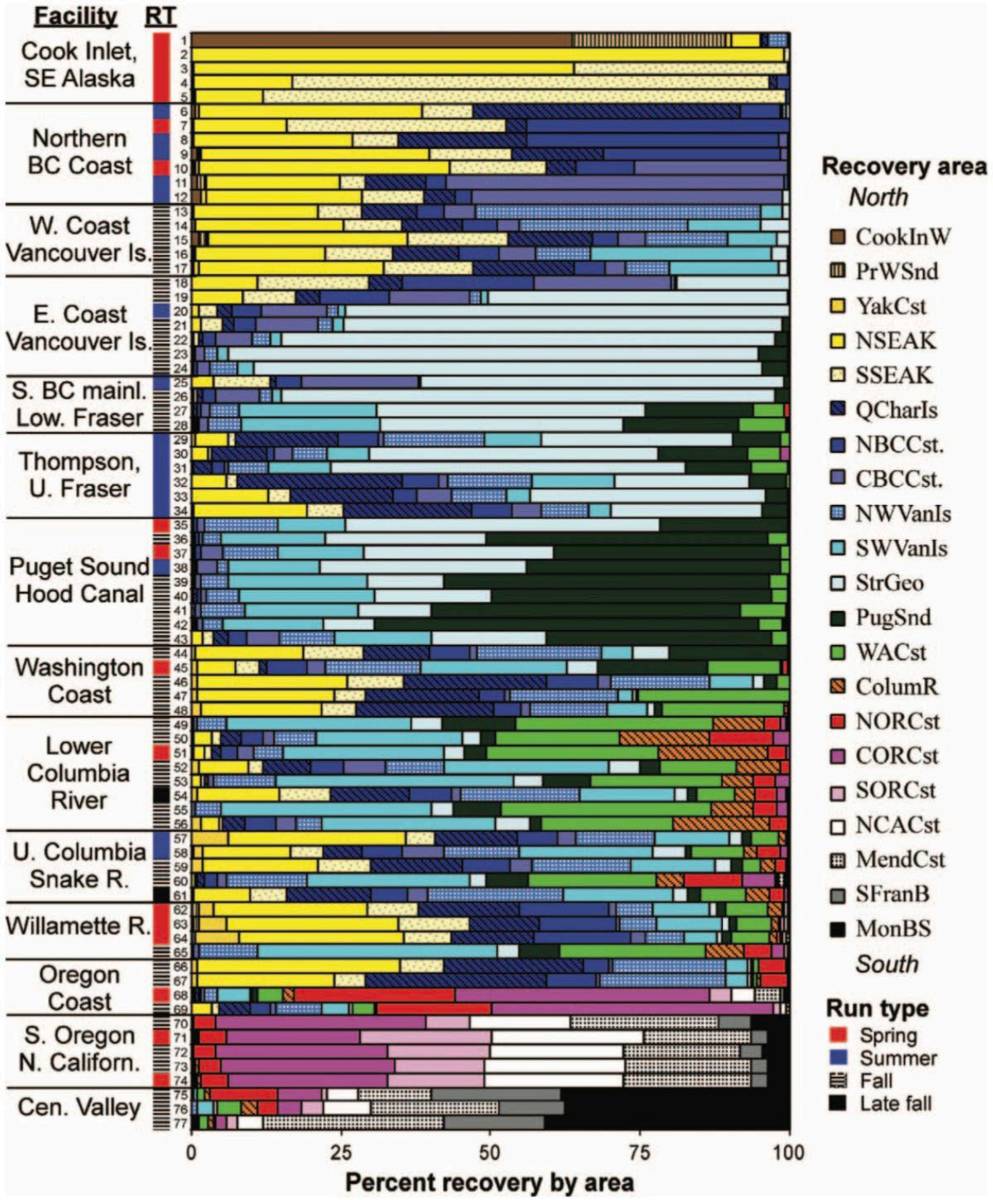
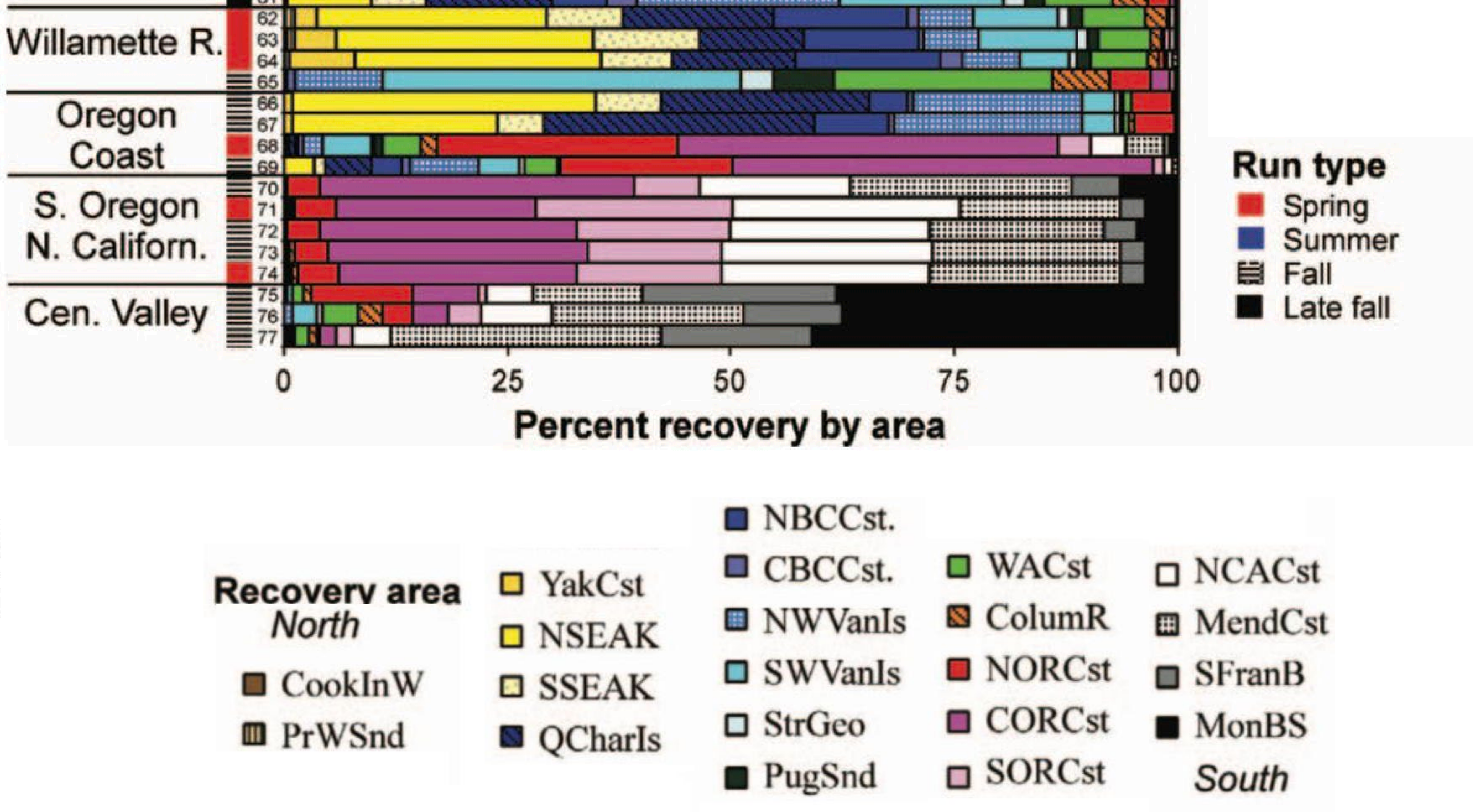
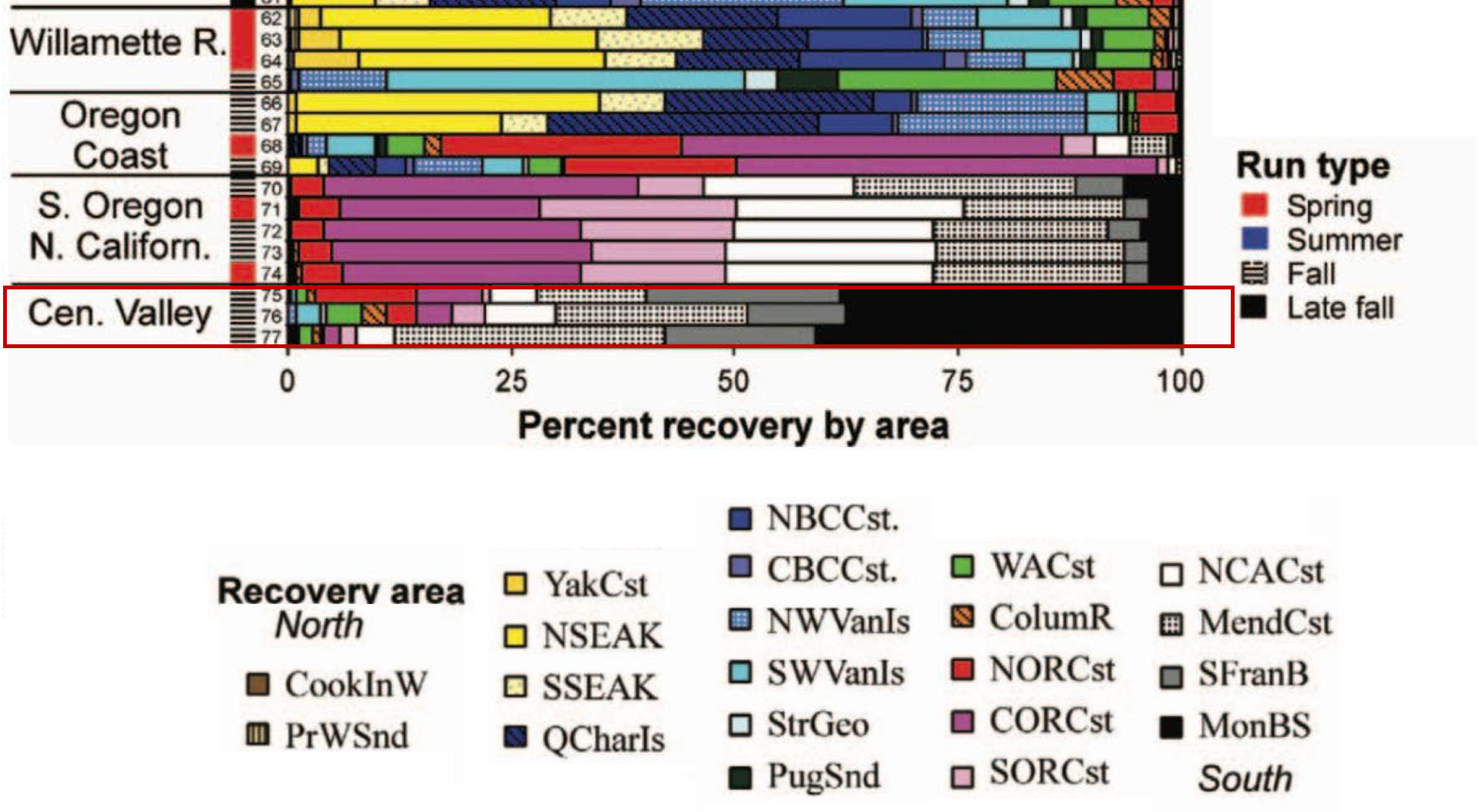


FIGURE 2.—Recovery patterns for coded-wire-tagged Chinook salmon by HRG, arranged by geographic region from north (top) to south (bottom). Each horizontal bar represents the percentages of recoveries in the 21 marine recovery areas for a single HRG; recovery area abbreviations and boundaries are provided in Figure 1. Run timing (RT) and HRG numbers are indicated to the left of the bar chart. See Figure 1 for HRG locations and Table A.1 for HRG names and recovery statistics.

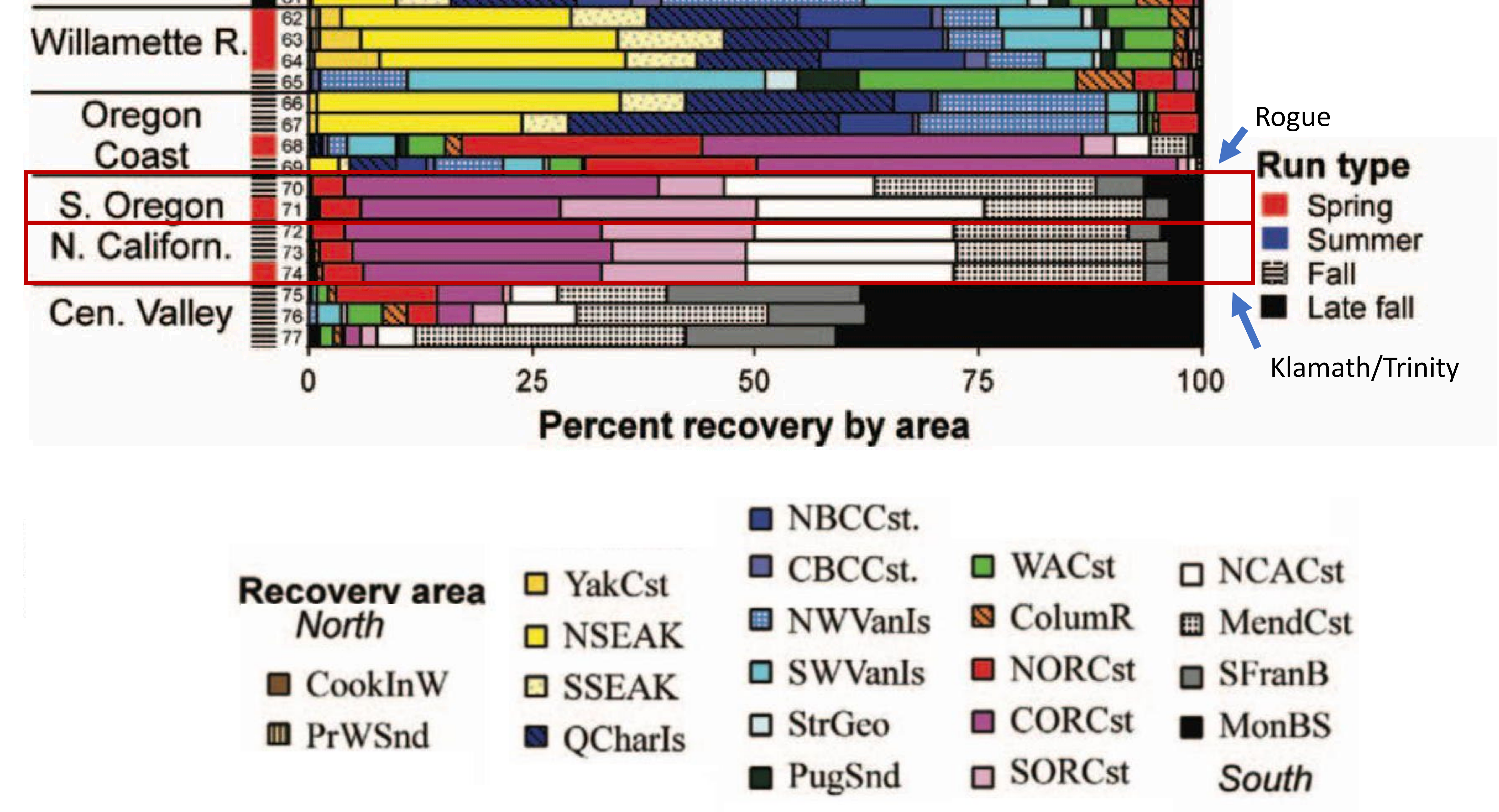
Weitkamp 2010 Trans. Am. Fish. Soc. 139:147-170



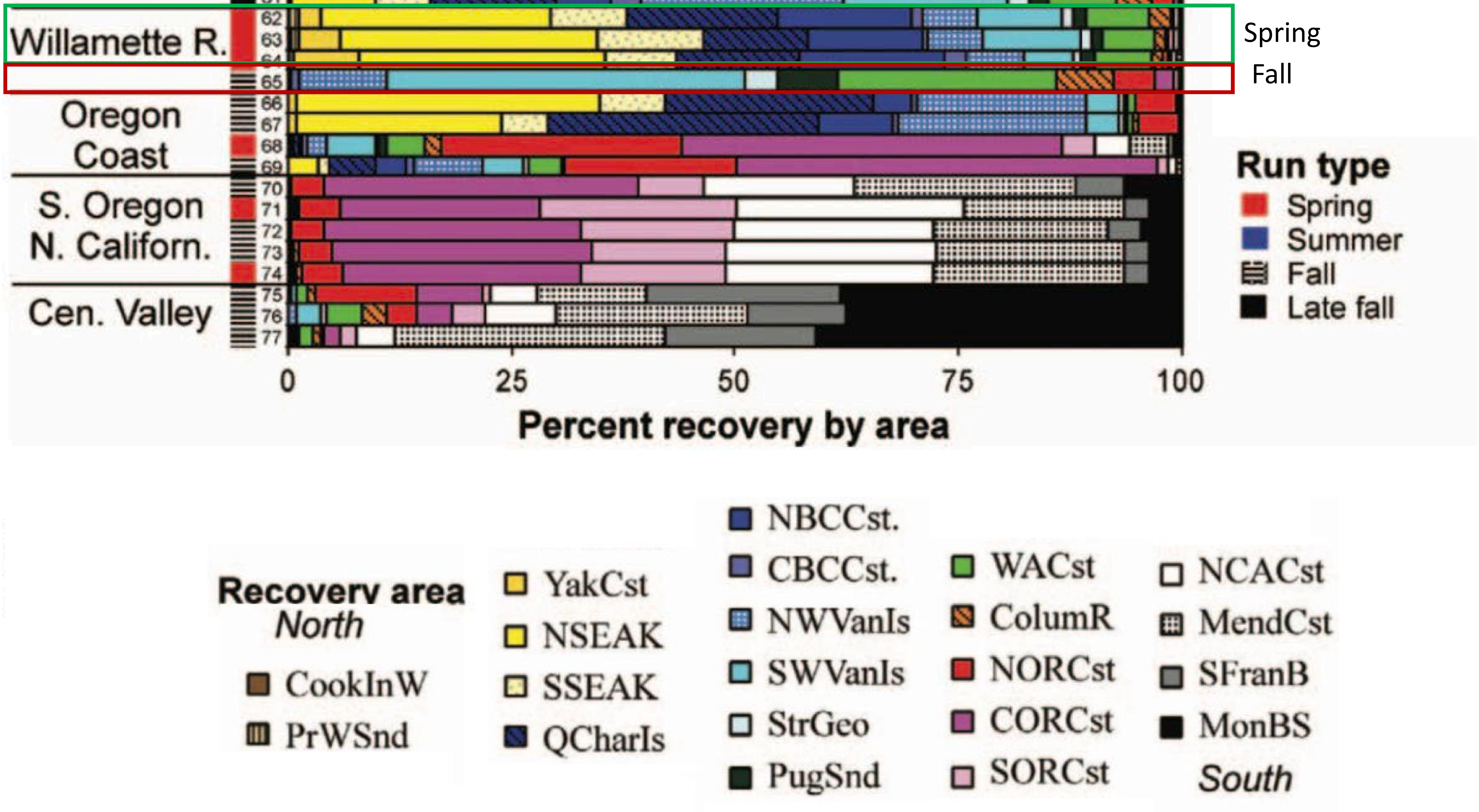
- Weitkamp 2010 Trans. Am. Fish. Soc. 139:147-170



- Weitkamp 2010 Trans. Am. Fish. Soc. 139:147-170



• Weitkamp 2010 Trans. Am. Fish. Soc. 139:147-170



• Weitkamp 2010 Trans. Am. Fish. Soc. 139:147-170

What have we learned and what are the next steps?

- Coastwide patterns in tag recoveries for select stocks along the coast
- CPUE-based, seasonal patterns for California stocks
  - Suitability of proxies, hatchery- versus natural-origin
  - Challenges making inference for rare stocks
- State-space population models: area-specific abundance
  - Applications to rare stocks and alternative run timings
  - Changes in distribution across years
  - Drivers?
  - Predictions for a future climate?

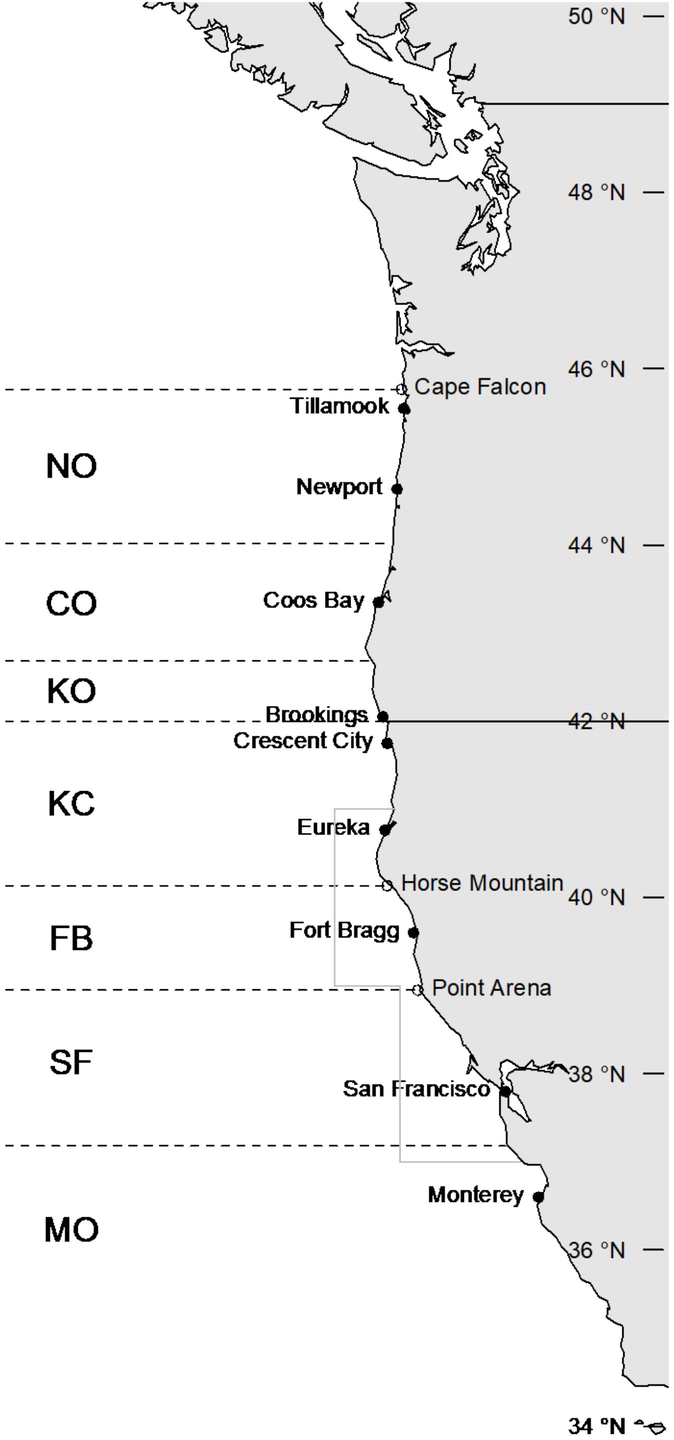
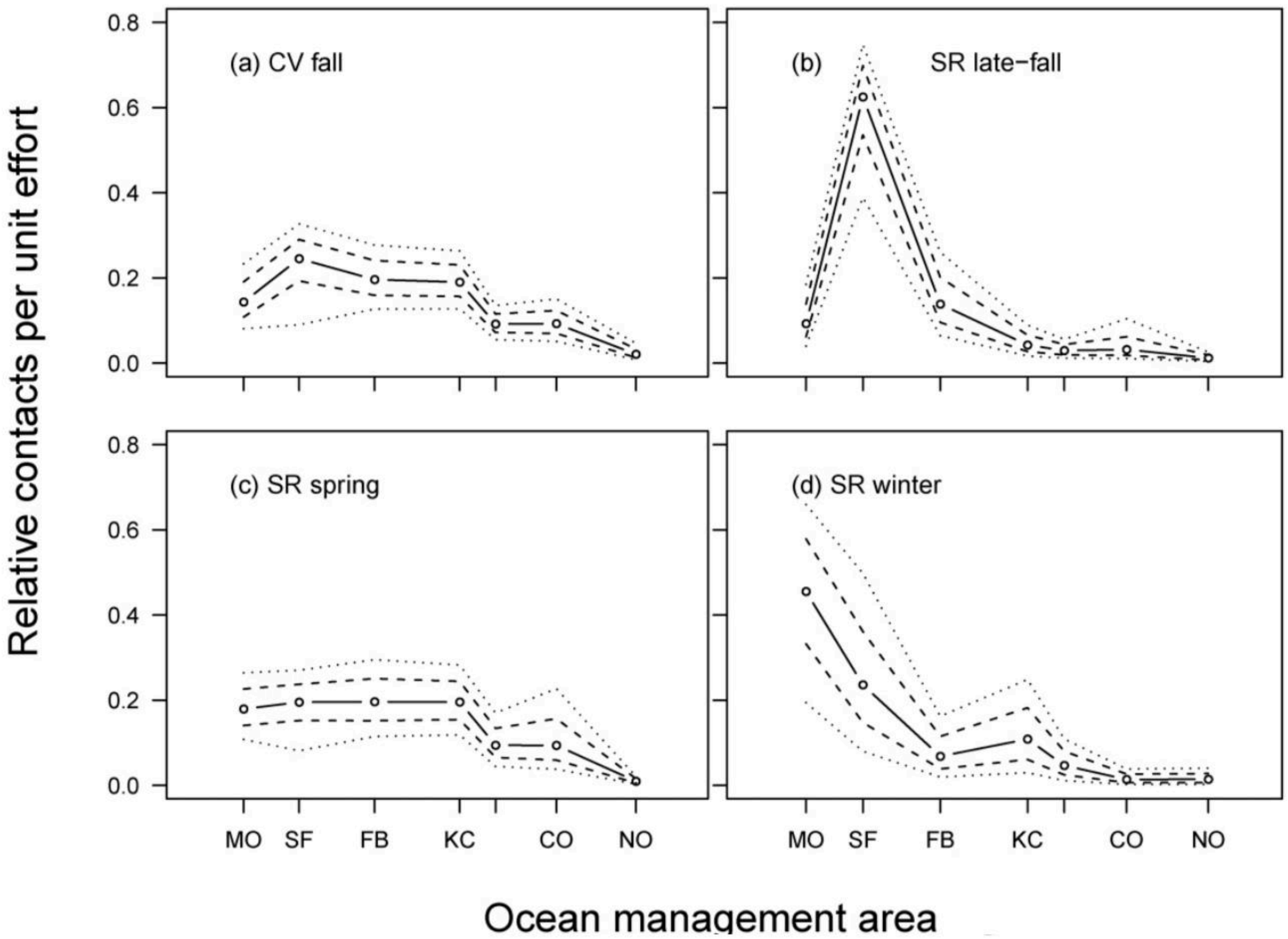


Fig. 2. Relative contacts per unit effort estimated for each management area (see Fig. 1), for age-3 fish in June (ag
advance in age on 1 May). Management areas are arranged along the *x* axis in order of increasing latitude of their
posterior medians; broken lines represent 68% and 95% credible intervals. CV, California Central Valley; SR, Sacra
River.



- Satterthwaite et al. 2013 CJFAS 70:574-584

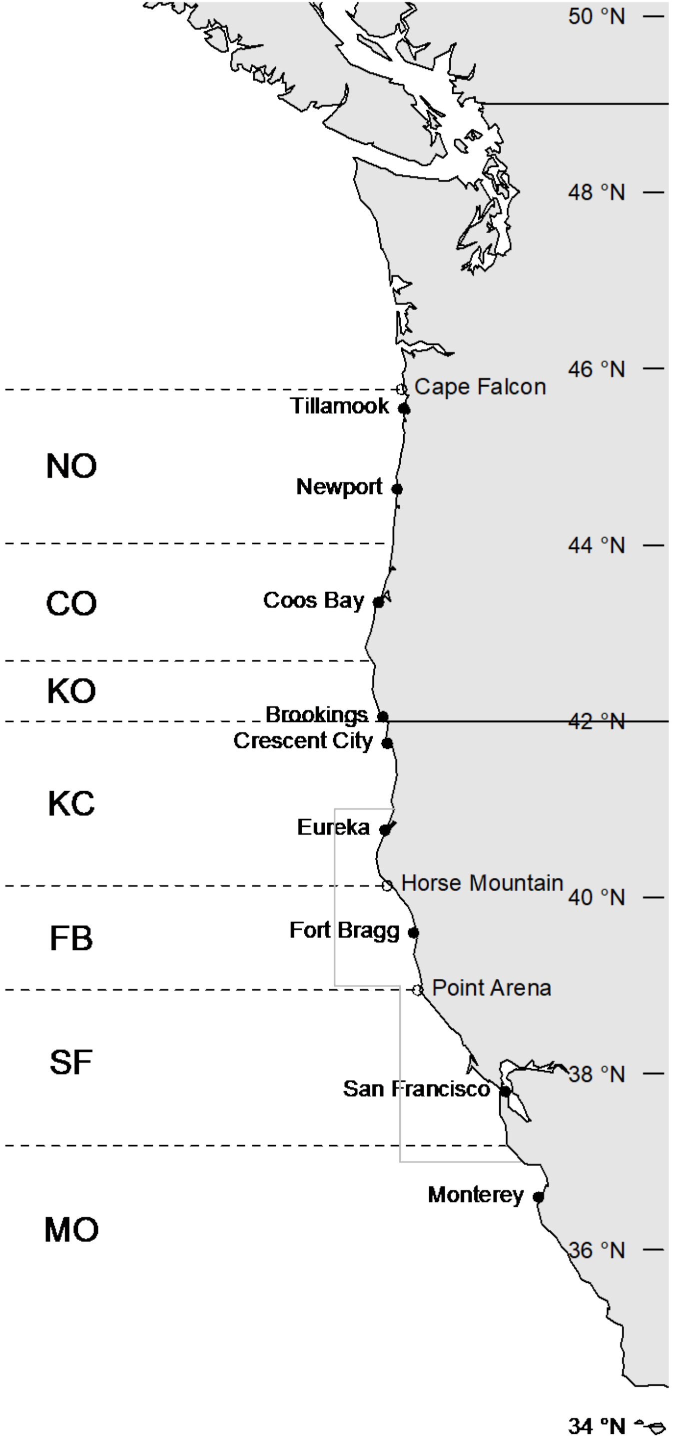
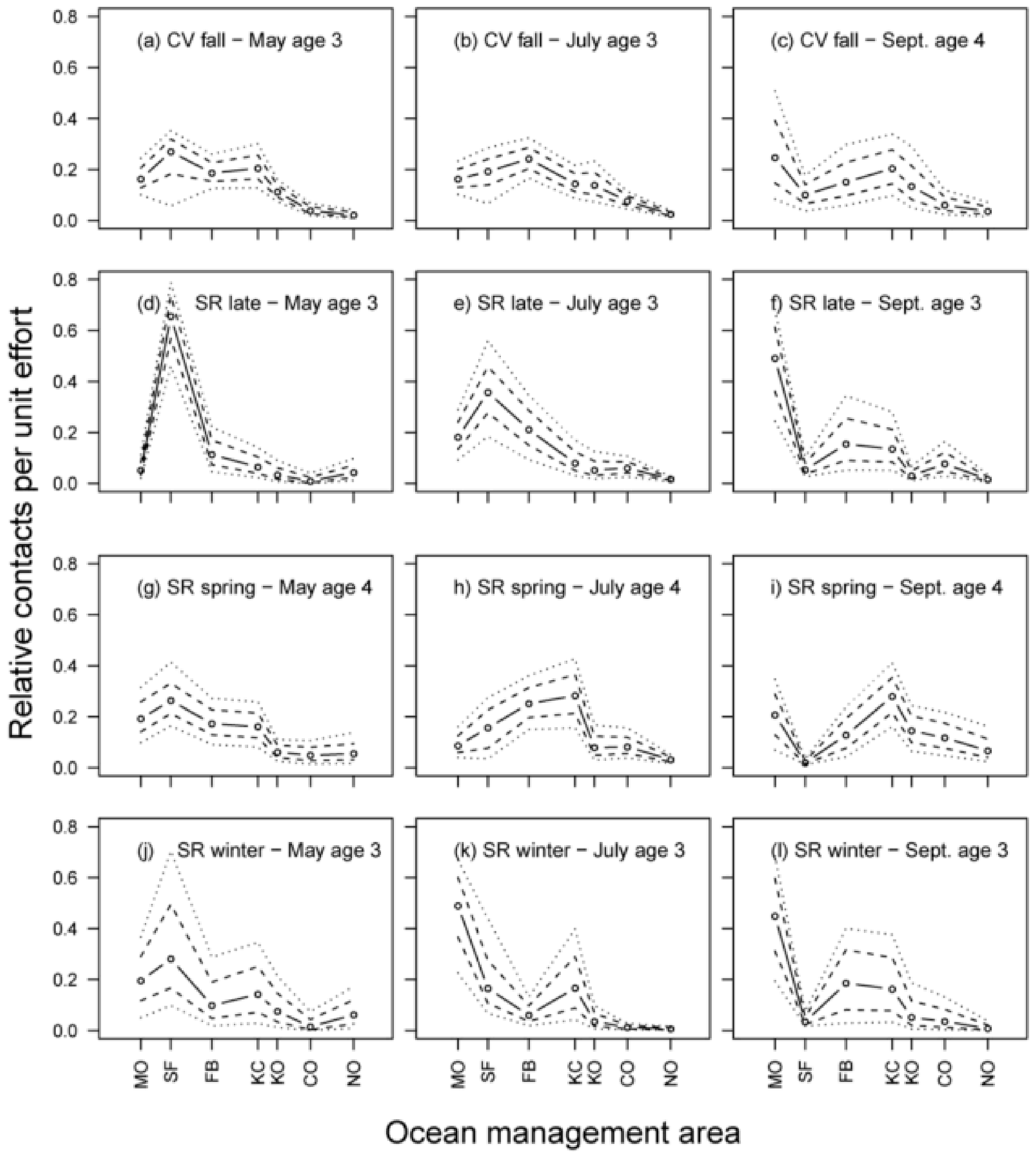
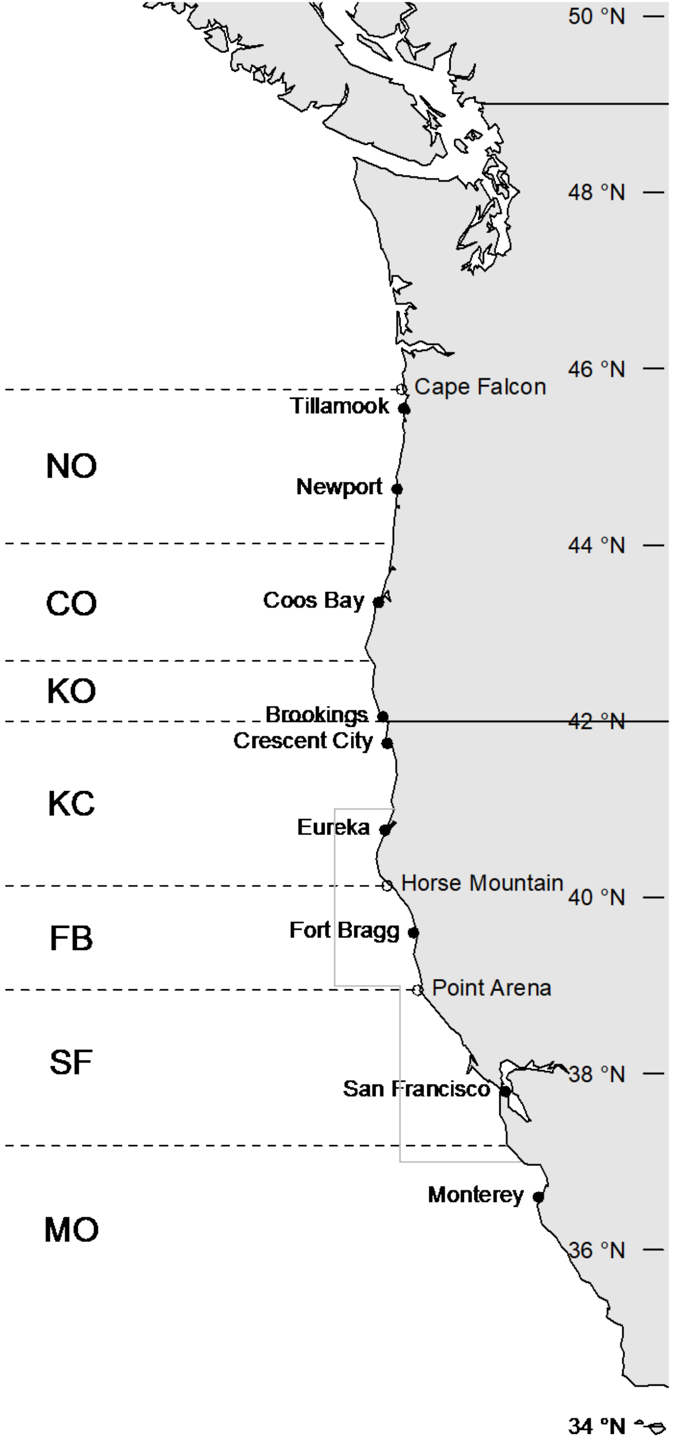
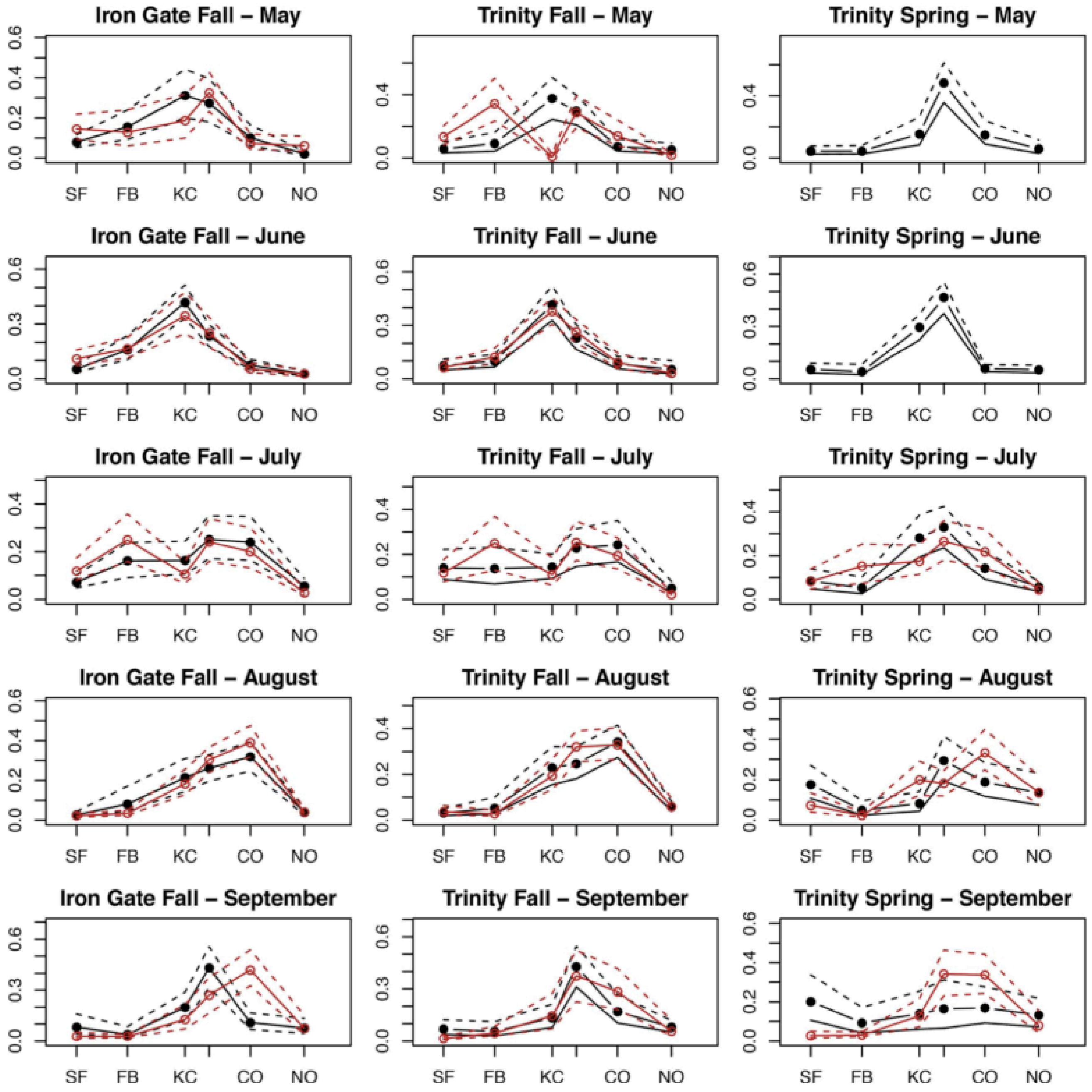


Fig. 3. Relative contacts per unit effort estimated for each management area, for fish starting the year at age-3 from CV fall and SR late-fall, spring, and winter runs in May, July, and September. Points are posterior medians; broken lines represent 68% and 95% credible intervals.



- Satterthwaite et al. 2013 CJFAS 70:574-584



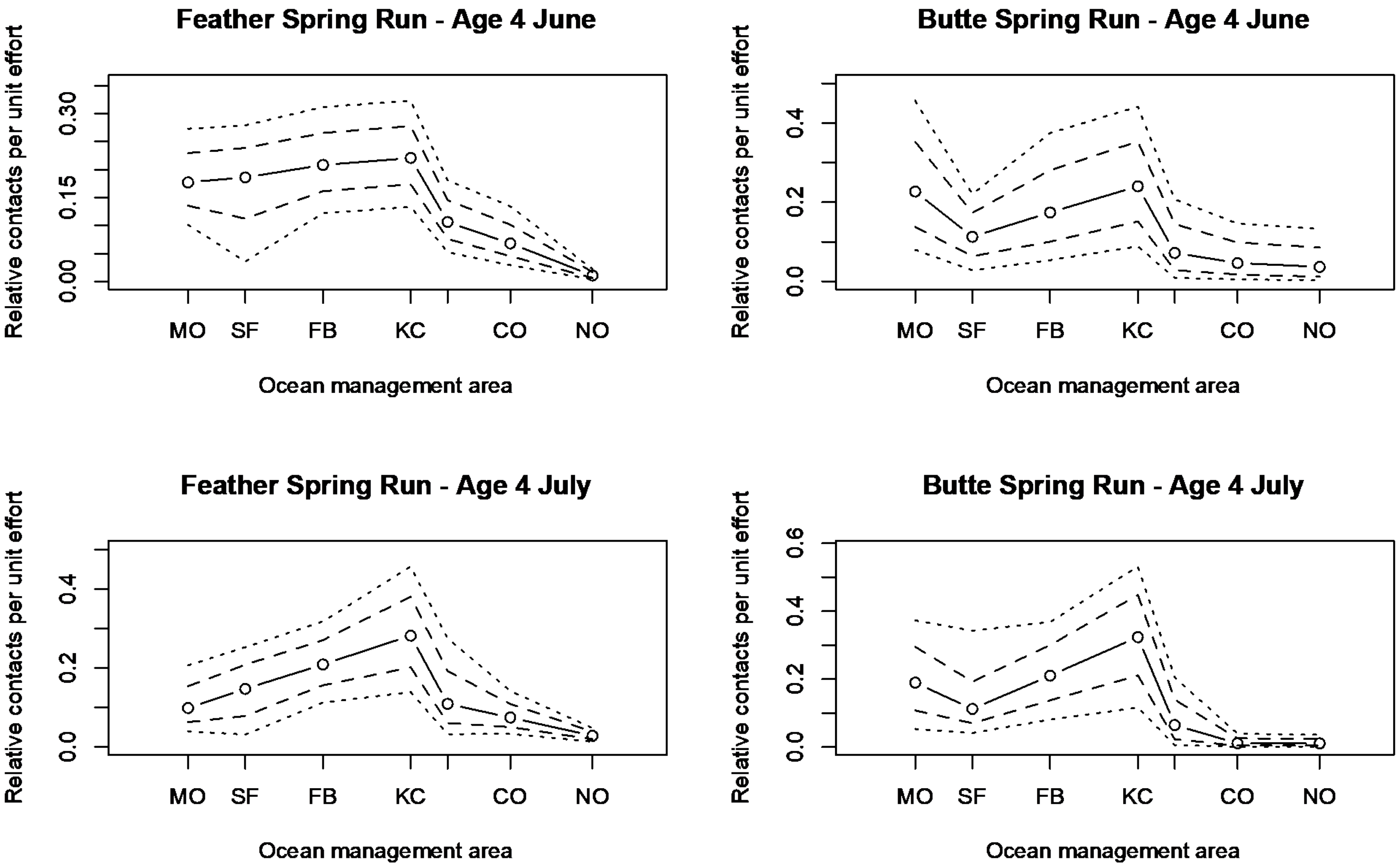


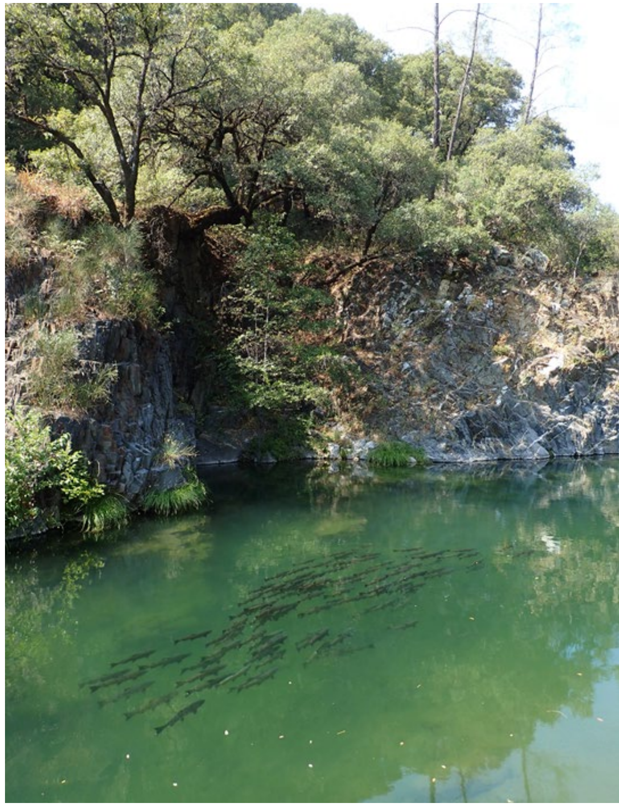
- Satterthwaite and O’Farrell 2015 Fish. Res. 199:171-176

What have we learned and what are the next steps?

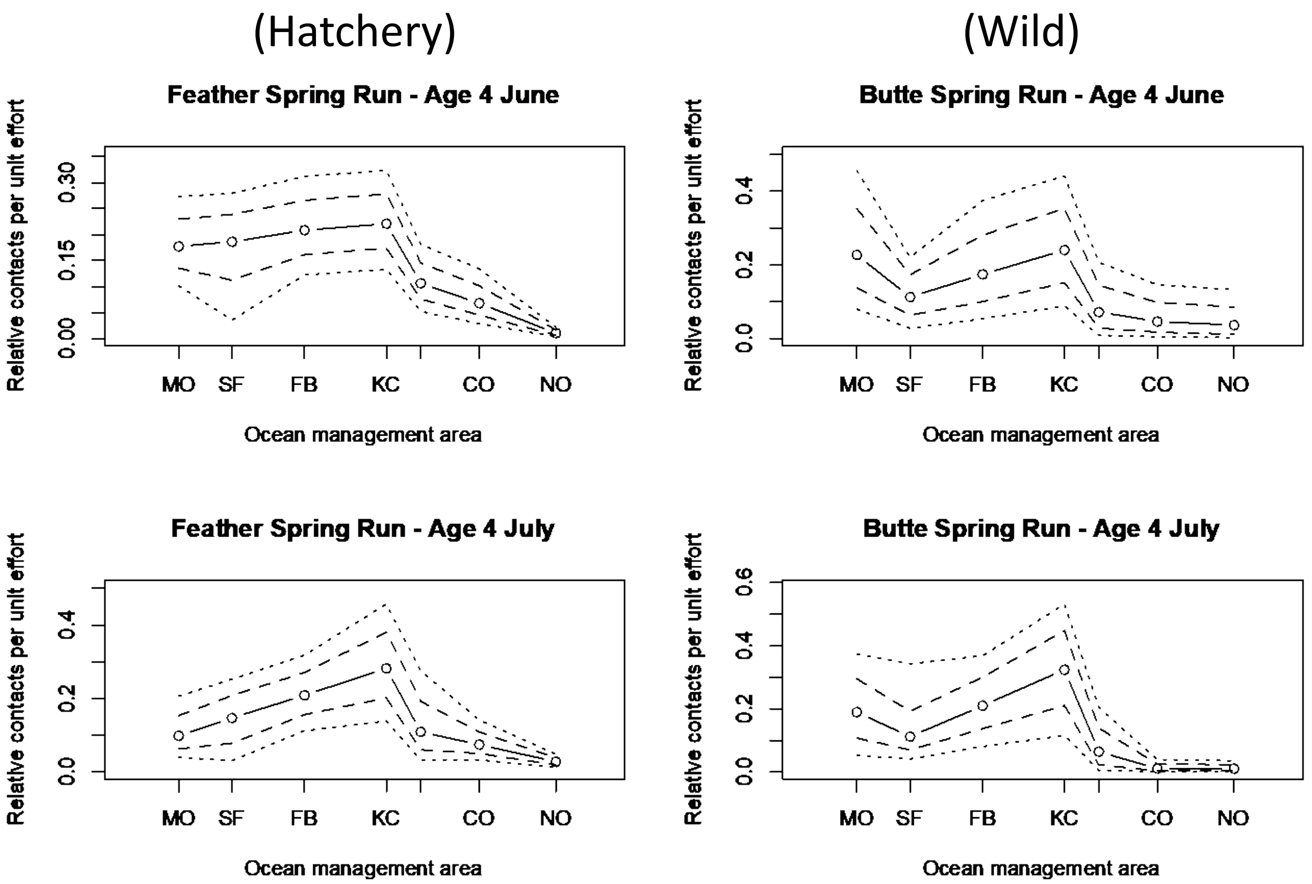
- Coastwide patterns in tag recoveries for select stocks along the coast
- CPUE-based, seasonal patterns for California stocks
  - Suitability of proxies, hatchery- versus natural-origin
  - Challenges making inference for rare stocks
- State-space population models: area-specific abundance
  - Applications to rare stocks and alternative run timings
  - Changes in distribution across years
  - Drivers?
  - Predictions for a future climate?

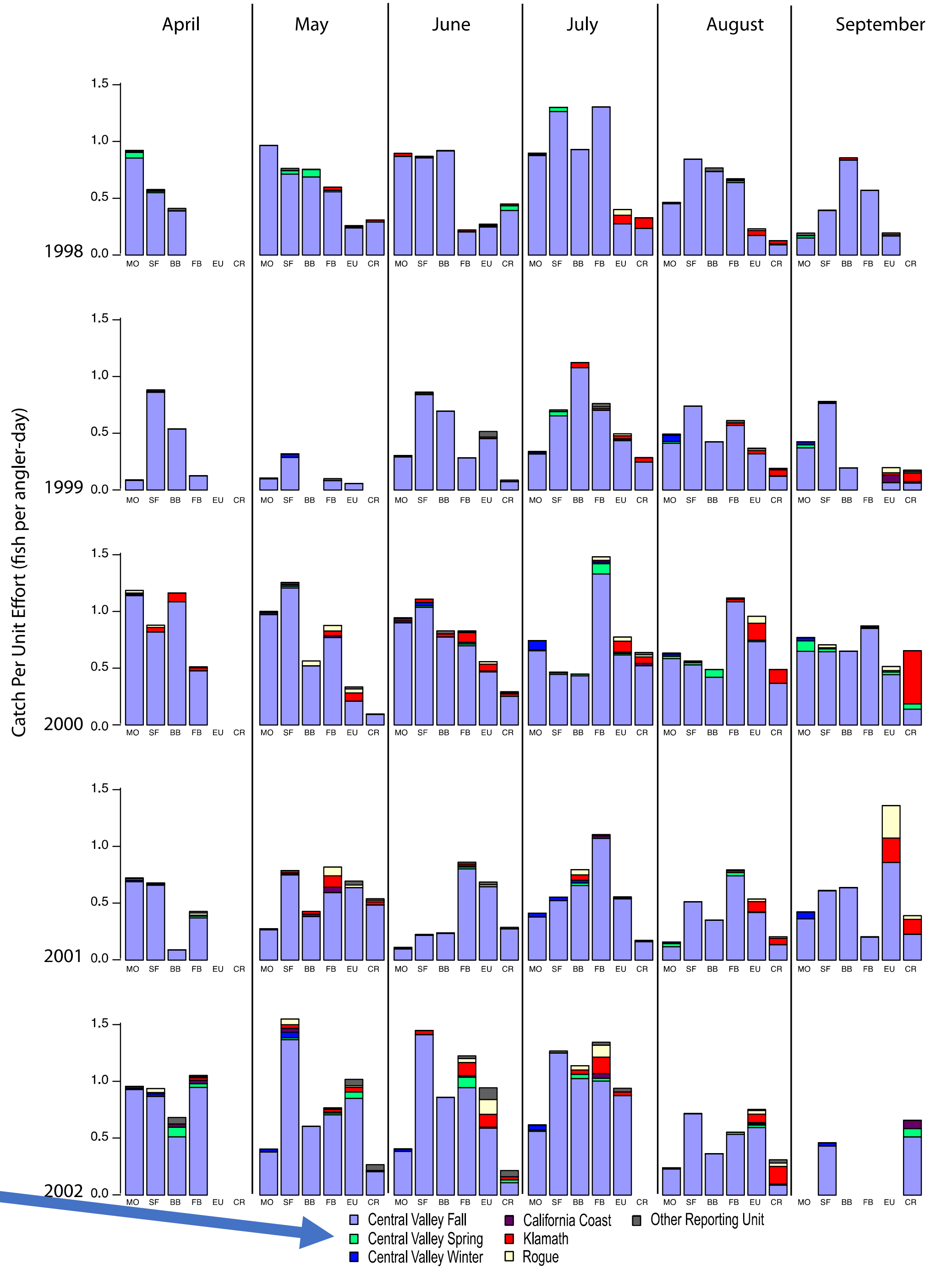
(Hatchery) (Wild)





• Satterthwaite et al. 2018 SFEWS 16(1):4

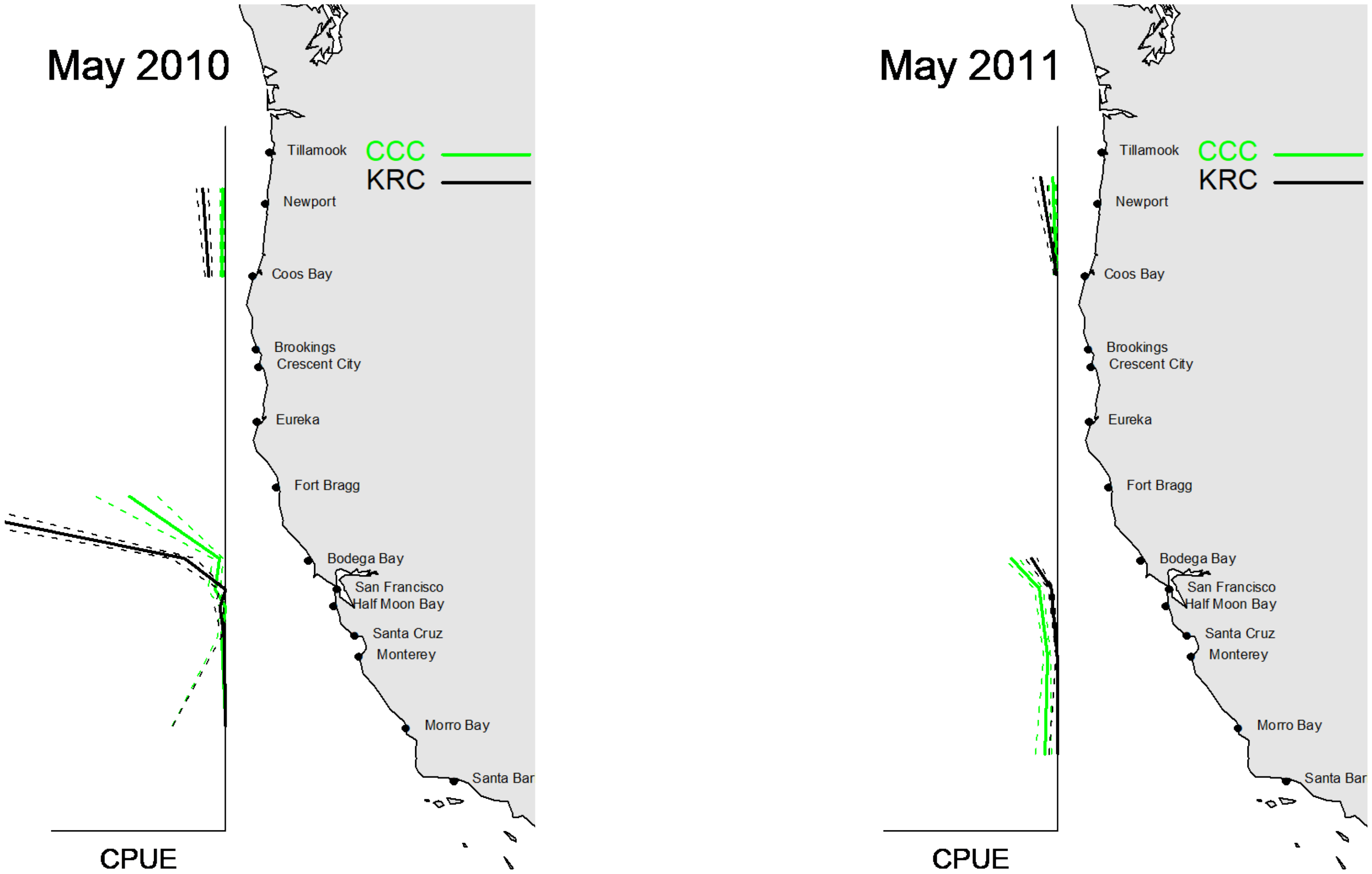




GSI on wild Central Valley spring run: look for the green
wild+hatchery winter run: dark blue

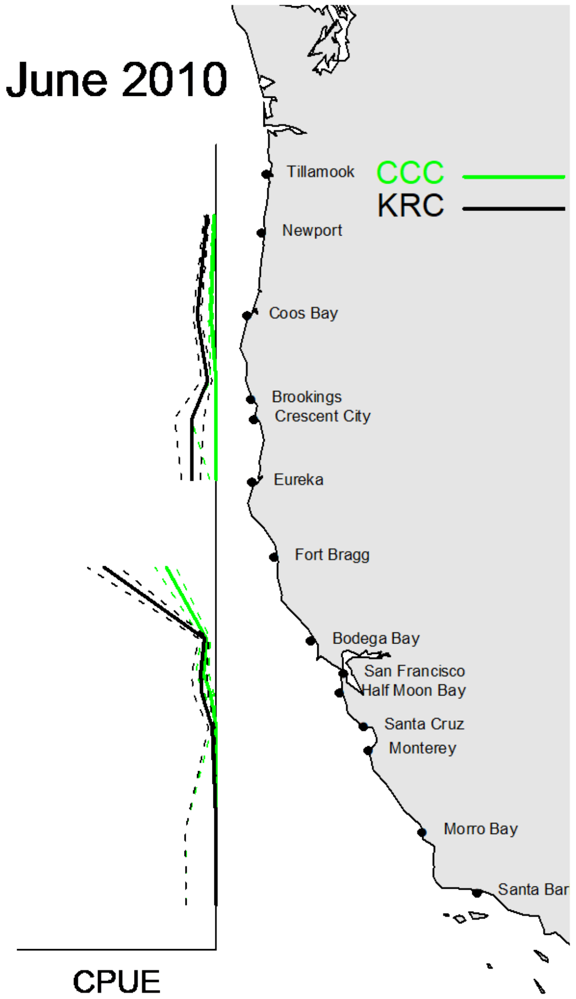
- Satterthwaite et al. 2018 SFEWS 16(1):4
- Satterthwaite et al. 2015 Fish Res 170:166-178

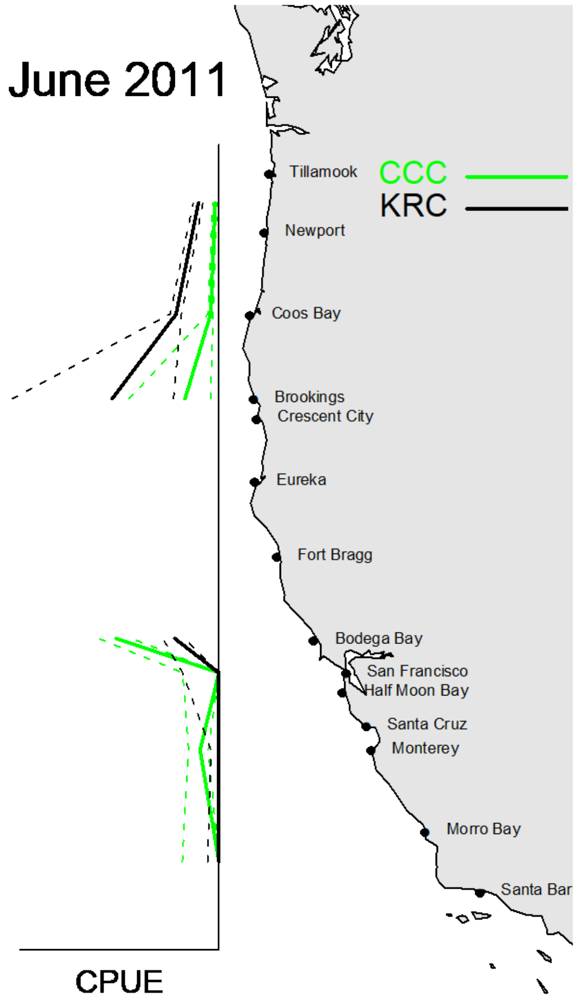
Klamath compared to California Coastal Chinook



- Satterthwaite et al. 2014 Trans. Am. Fish. Soc. 143:117-133

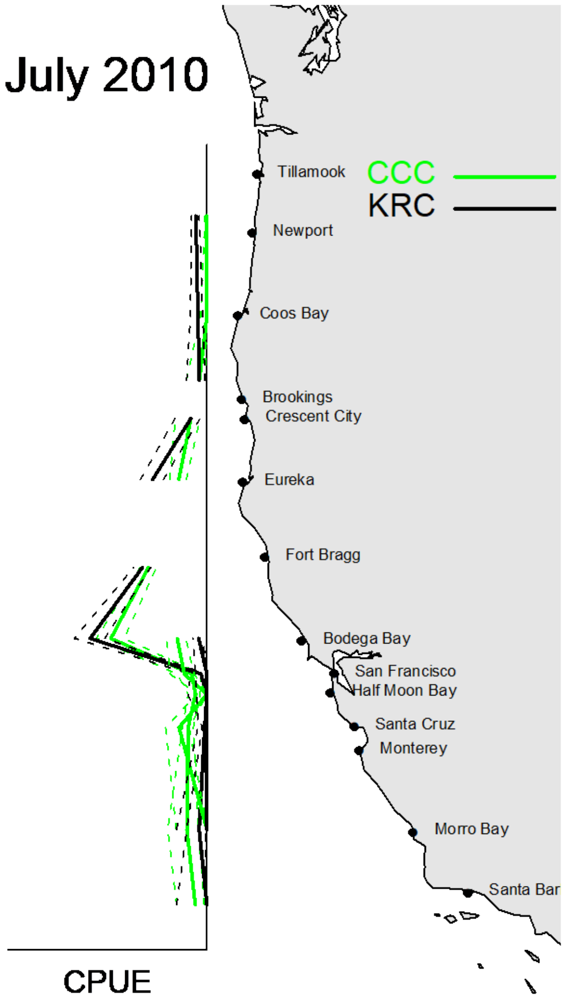
Klamath compared to California Coastal Chinook

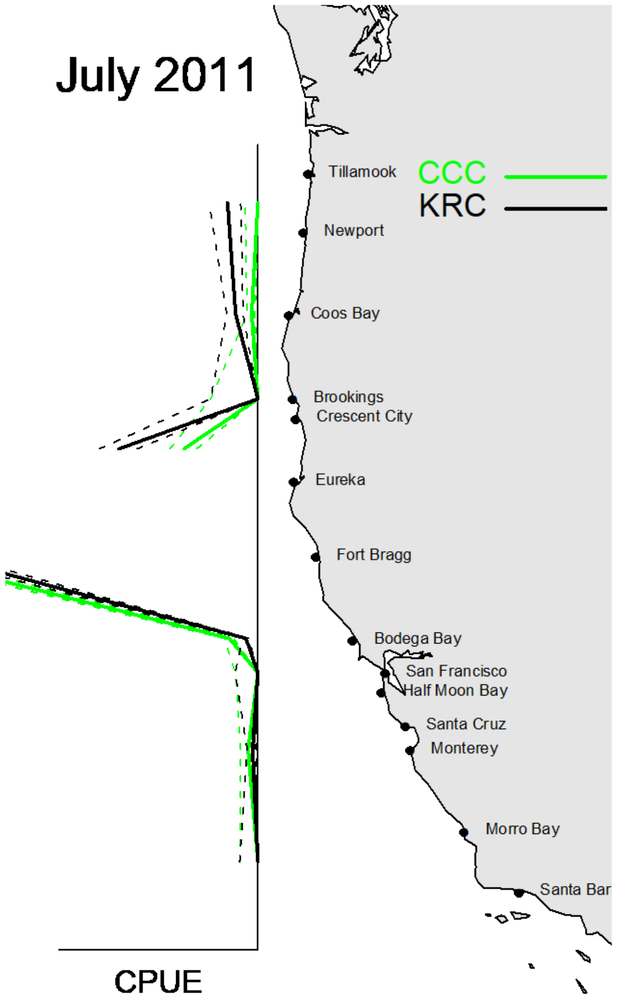




- Satterthwaite et al. 2014 Trans. Am. Fish. Soc. 143:117-133

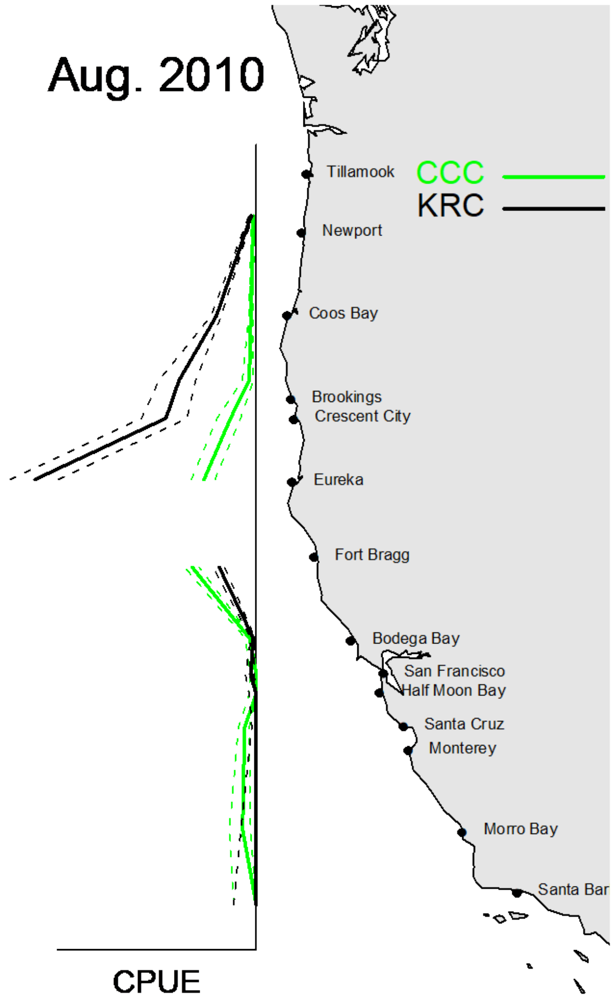
Klamath compared to California Coastal Chinook

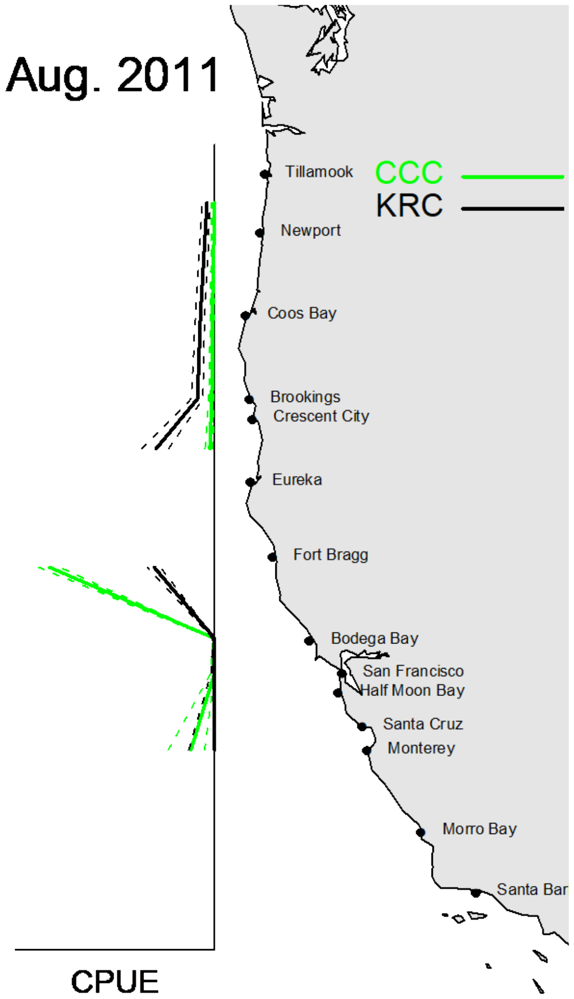




- Satterthwaite et al. 2014 Trans. Am. Fish. Soc. 143:117-133

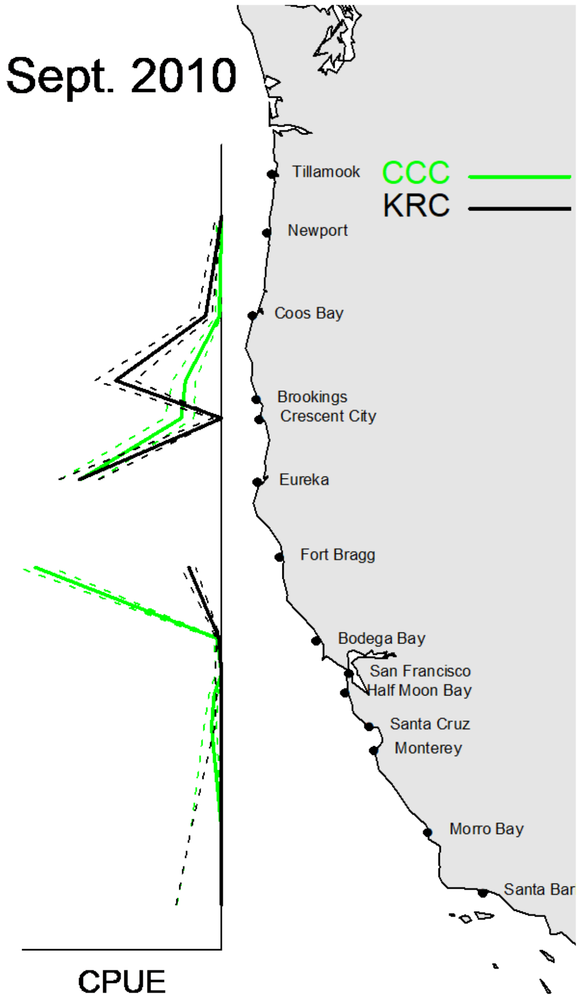
Klamath compared to California Coastal Chinook

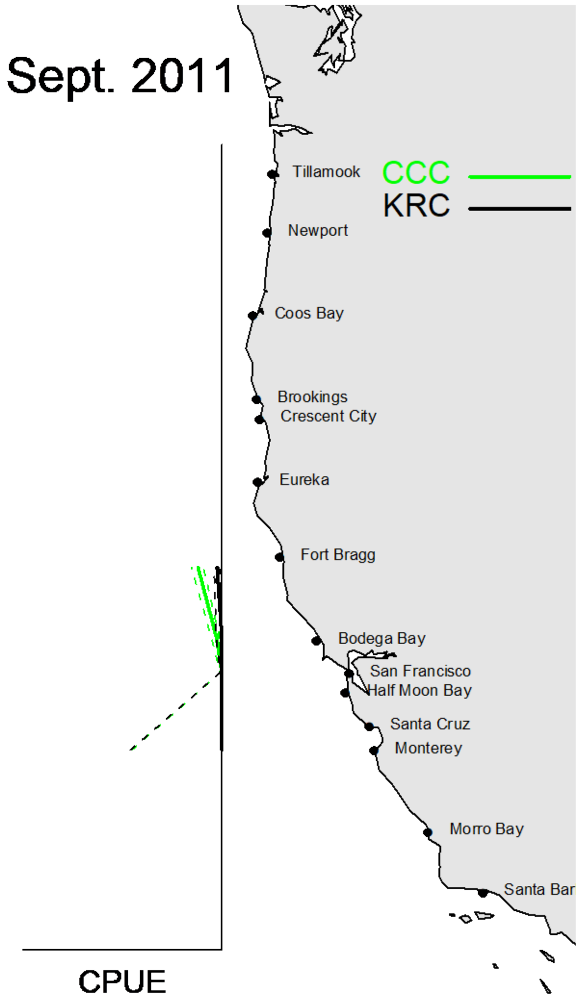




- Satterthwaite et al. 2014 Trans. Am. Fish. Soc. 143:117-133

Klamath compared to California Coastal Chinook





- Satterthwaite et al. 2014 Trans. Am. Fish. Soc. 143:117-133

Take-home on CA spring & winter run distributions

- Winter run fishery recoveries highly concentrated south of Point Arena
- Central Valley Fall versus Spring recoveries differ much less
  - Spring possibly more spread out to the north later in the year
- Klamath-Trinity Spring do seem concentrated to the north relative to Fall
  - Especially early in the year
  - But distributions don’t seem radically different
- No obvious hatchery-wild differences within runs in their distributions
  - But, sample sizes are often limited

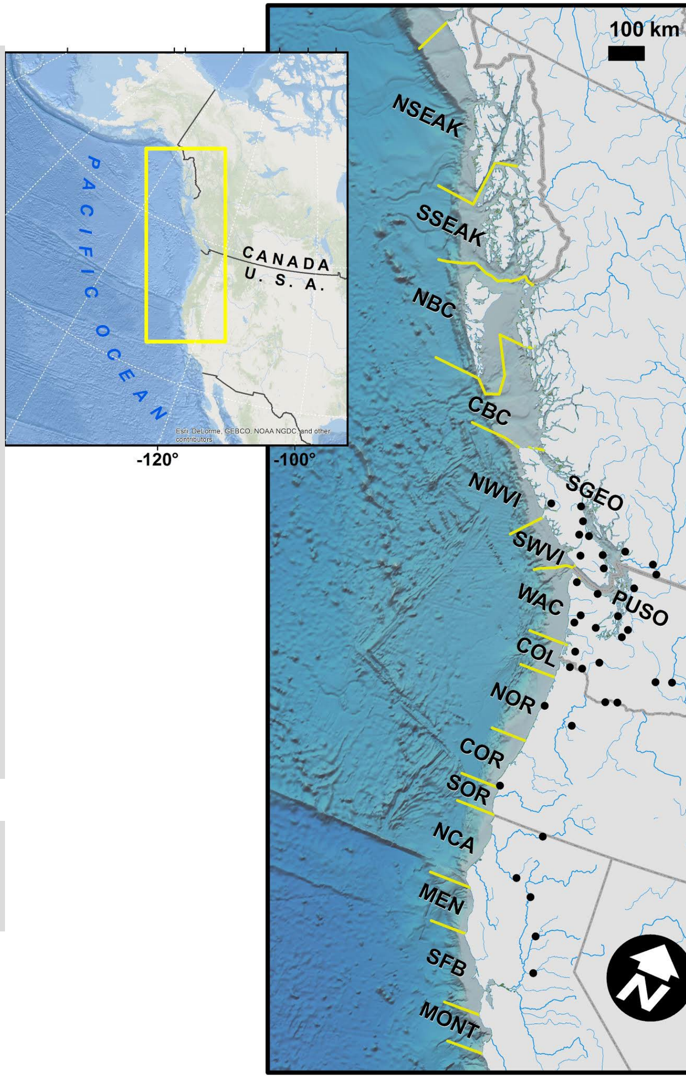
What have we learned and what are the next steps?

- Coastwide patterns in tag recoveries for select stocks along the coast
- CPUE-based, seasonal patterns for California stocks
  - Suitability of proxies, hatchery- versus natural-origin
  - Challenges making inference for rare stocks
- State-space population models: area-specific abundance
  - Applications to rare stocks and alternative run timings
  - Changes in distribution across years
  - Drivers?
  - Predictions for a future climate?

Bayesian state-space model

Coastwide integrated model for fall Chinook

- **Spatial distribution of fish in ocean** (by season and origin region)
- **Juvenile mortality** (by release and year)
    - River and early ocean mortality
- **Adult mortality** (by release and year)
- **Maturation schedule** (by age and origin region)
- **Spatio-temporal variation in fishing** (by season, area, year) and **vulnerability** (by age, area, and gear type)



Simultaneously considering all major stocks of fall Chinook

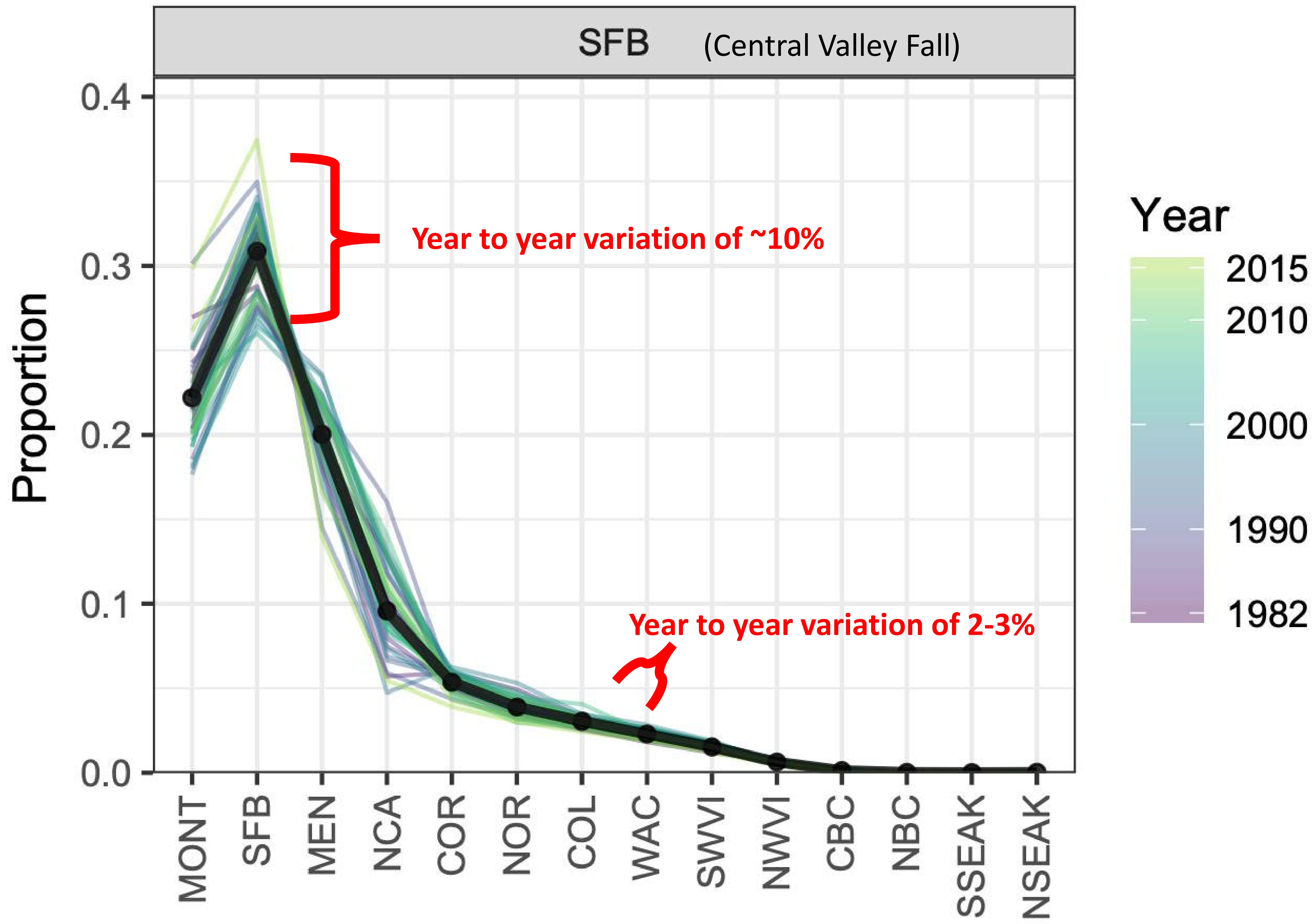
- Shelton et al. 2019 CJFAS 76:95-108

What have we learned and what are the next steps?

- Coastwide patterns in tag recoveries for select stocks along the coast
- CPUE-based, seasonal patterns for California stocks
  - Suitability of proxies, hatchery- versus natural-origin
  - Challenges making inference for rare stocks
- State-space population models: area-specific abundance
  - Applications to rare stocks and alternative run timings
  - Changes in distribution across years
  - Drivers?
  - Predictions for a future climate?

What have we learned and what are the next steps?

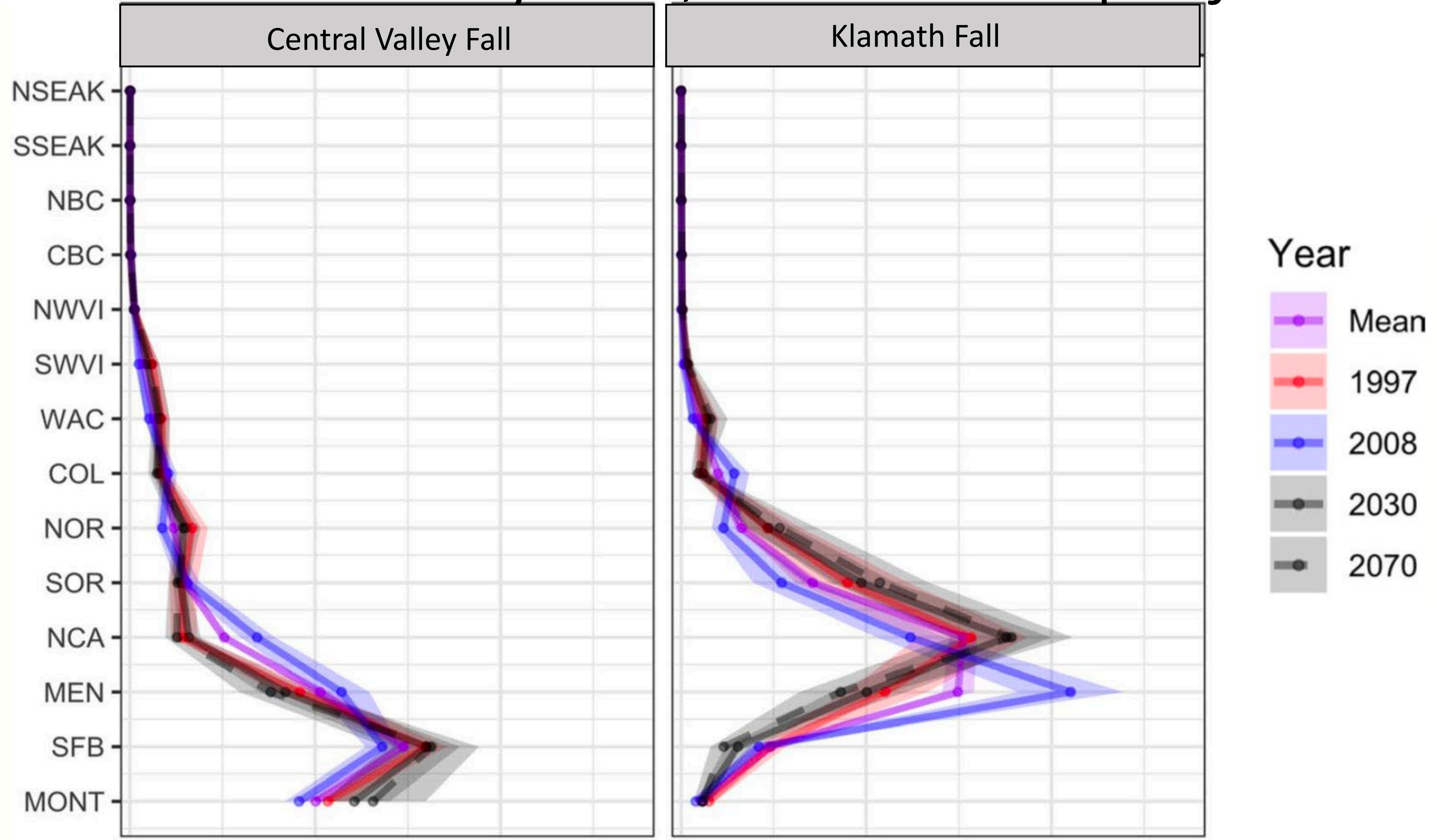
- Coastwide patterns in tag recoveries for select stocks along the coast
- CPUE-based, seasonal patterns for California stocks
  - Suitability of proxies, hatchery- versus natural-origin
  - Challenges making inference for rare stocks
- State-space population models: area-specific abundance
  - Applications to rare stocks and alternative run timings
  - Changes in distribution across years
  - Drivers?
  - Predictions for a future climate?


SFB (Central Valley Fall)
Year to year variation of ~10%
Year to year variation of 2-3%
Proportion
0.4
0.3
0.2
0.1
0.0
MONT
SFB
MEN
NCA
COR
NOR
COL
WAC
SWVI
NWVI
CBC
NBC
SSEAK
NSEAK
Year
2015
2010
2000
1990
1982

What have we learned and what are the next steps?

- Coastwide patterns in tag recoveries for select stocks along the coast
- CPUE-based, seasonal patterns for California stocks
  - Suitability of proxies, hatchery- versus natural-origin
  - Challenges making inference for rare stocks
- State-space population models: area-specific abundance
  - Applications to rare stocks and alternative run timings
  - Changes in distribution across years
  - Drivers?
  - Predictions for a future climate?

Warm versus cool years, and future projections



- Shelton et al. 2021 Fish & Fisheries 22:503-517

Thanks. Questions?

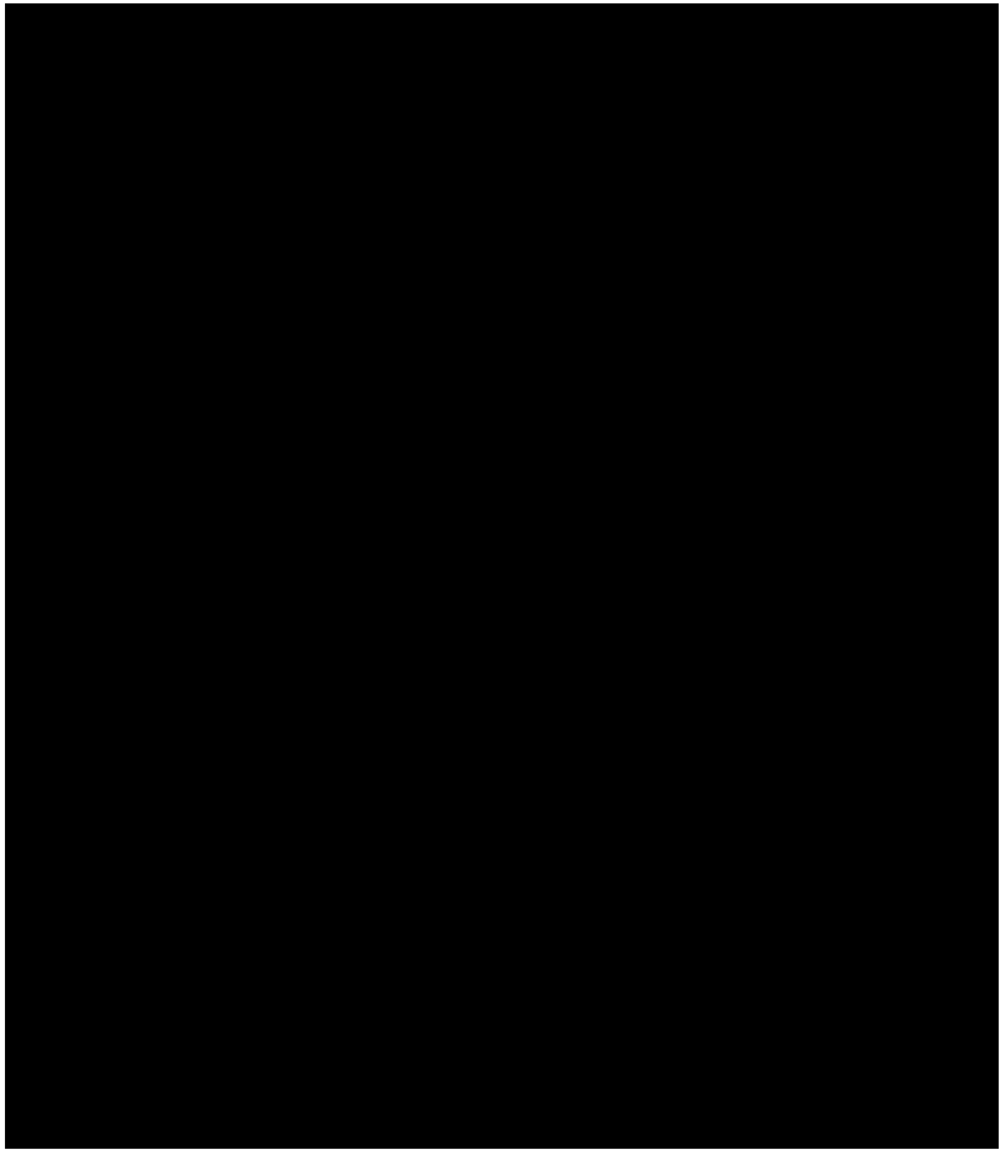
will.satterthwaite@noaa.gov

Photo credit: Zeke Lunder

Distribution from CPUE and Sampling

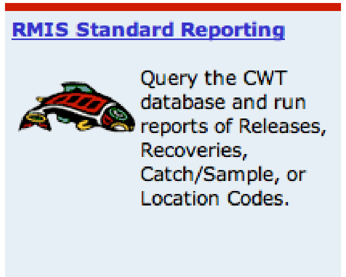
Sampled
CWT fish
of interest

S



"Abundance" of
fish of interest
in ocean area

λ



RMIS

Wiki Images

Distribution from CPUE and Sampling

Sampled CWT fish of interest	Retained CWT fish of interest	Contacted CWT fish of interest	Contact with all fish (tagged+untagged) of interest	Unitless relative abundance of tagged fish of interest in ocean area
S	C	H	χ	λ

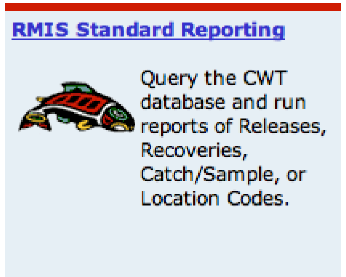
ρ - proportion legal size
(binomial)

f - fishing effort, q – catchability
(Poisson or Neg. Binomial)

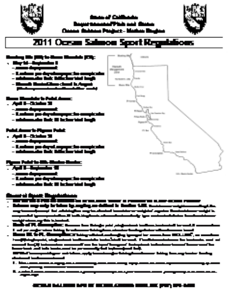
x – sampling fraction
(binomial)

z-tagging fraction (and potentially proportion hatchery-origin)
(binomial)

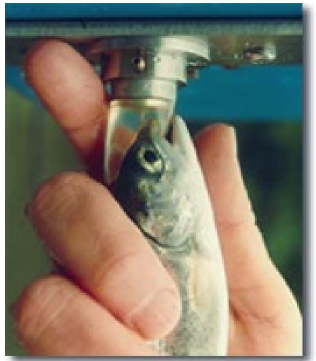
Satterthwaite et al. 2013 CJFAS 70:574–584



RMIS



CDFG



CDFO

AP

Wiki Images

Combining information across years

Contacts per unit effort for particular stock, age, & month:

- Fitting a long-term mean (fixed effects model)

$$\lambda_{py}=\beta Y_y \pi_p$$

annual cohort strength (ocean-wide)

proportion found in each management area

Satterthwaite et al. 2013 CJFAS 70:574–584

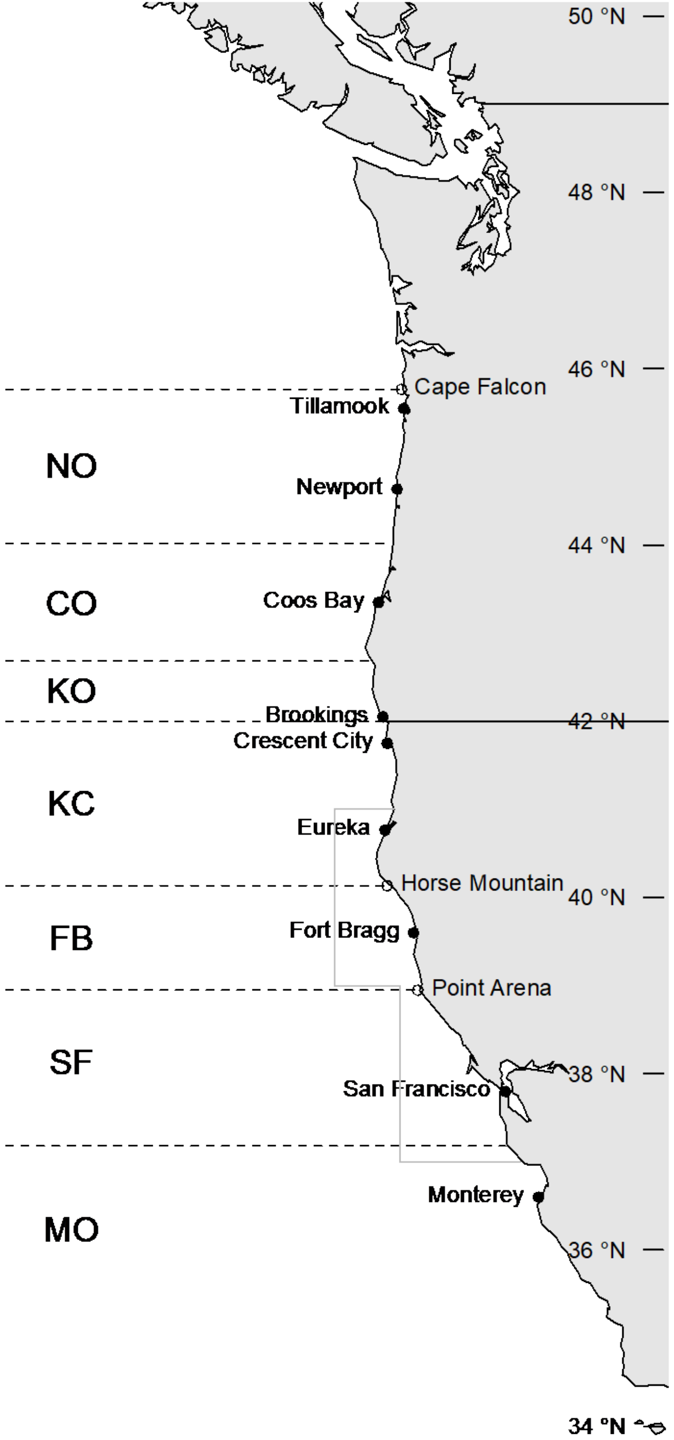
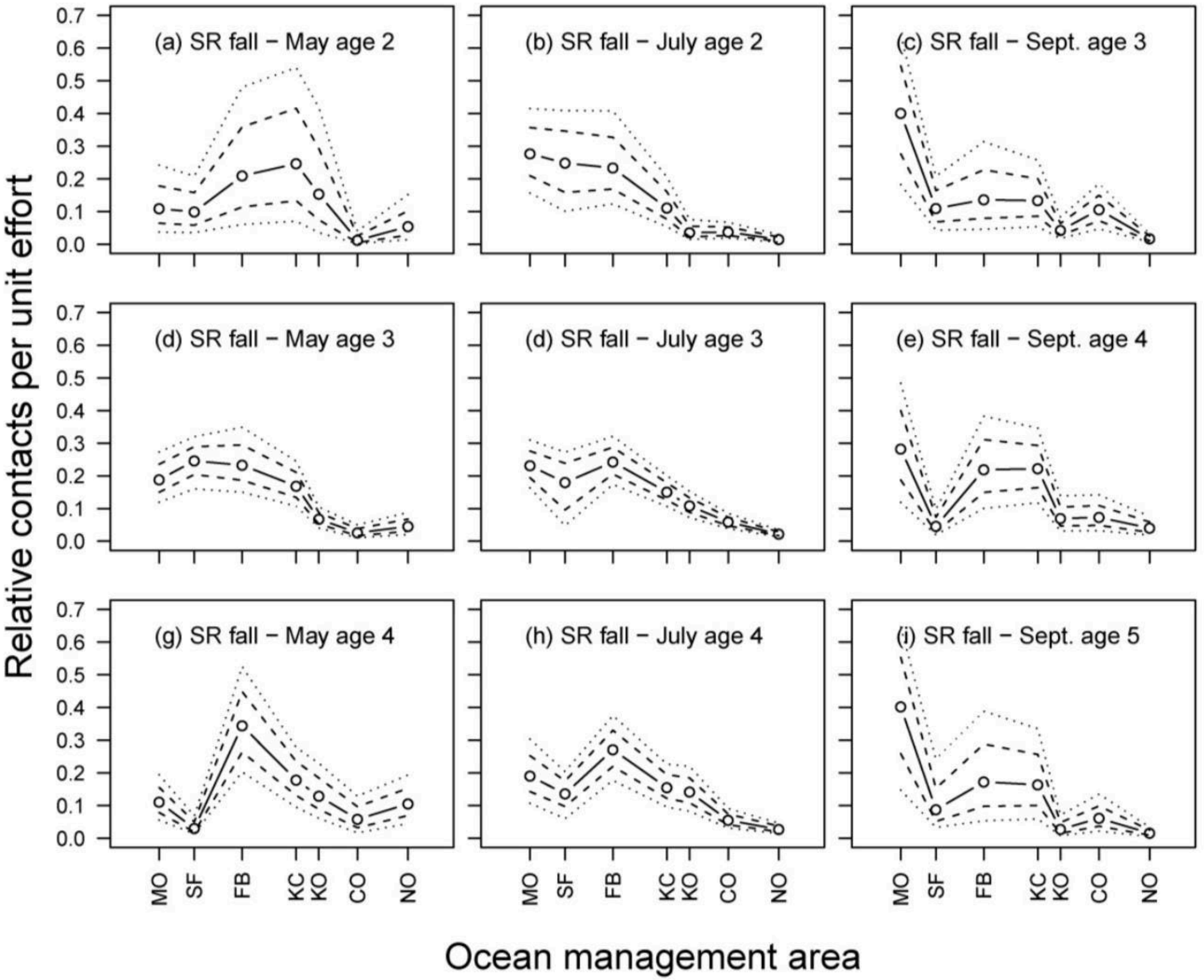
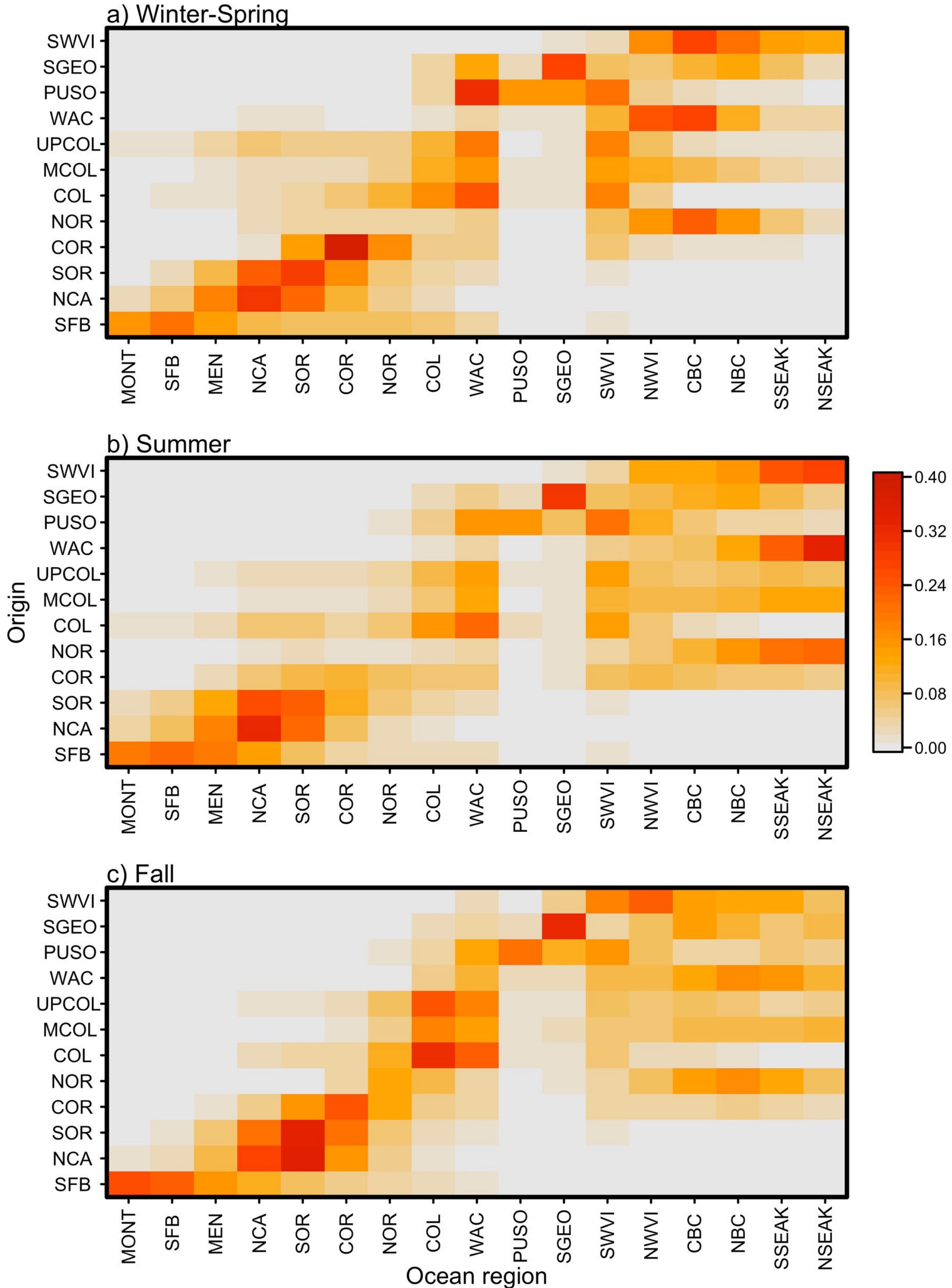


Fig. 4. Relative contacts per unit effort estimated for each management area, for SR fall run fish of September. Note that age advances in September. Points are posterior medians; broken lines represe



- Satterthwaite et al. 2013 CJFAS 70:574-584

Fall Run Ocean Distribution



Strong spatial segregation

Regions don’t differ much by season.

Shift slightly north in the Summer
Shift to river mouths in Fall
Shift south in Winter-Spring