

# Mechanistic ensemble population models to evaluate environmental drivers and climate change impacts in forage fish populations

[Stefan Koenigstein & Desiree Tommasi](#)

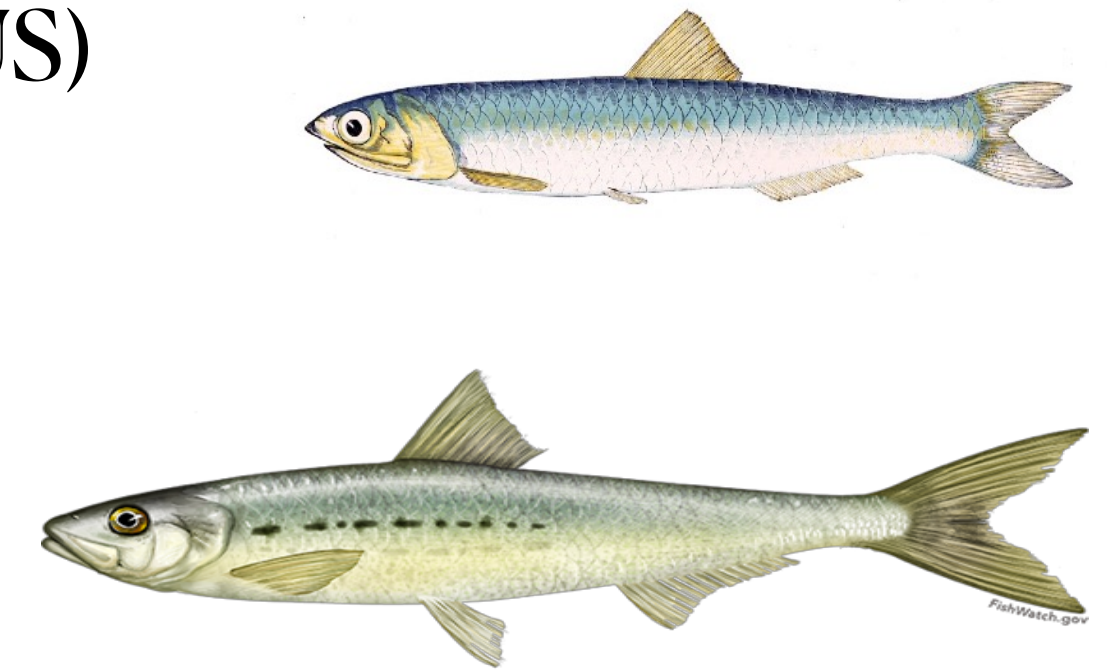
SPF Symposium, La Paz, 07.05.2026



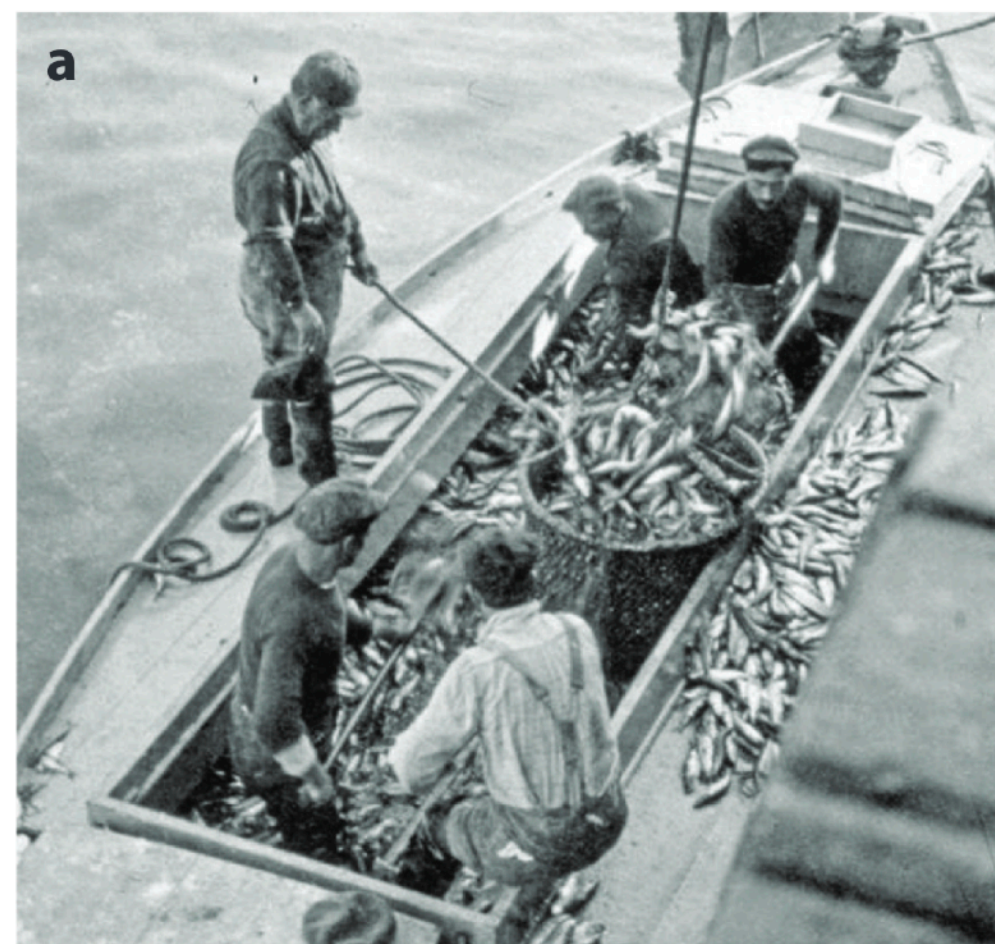
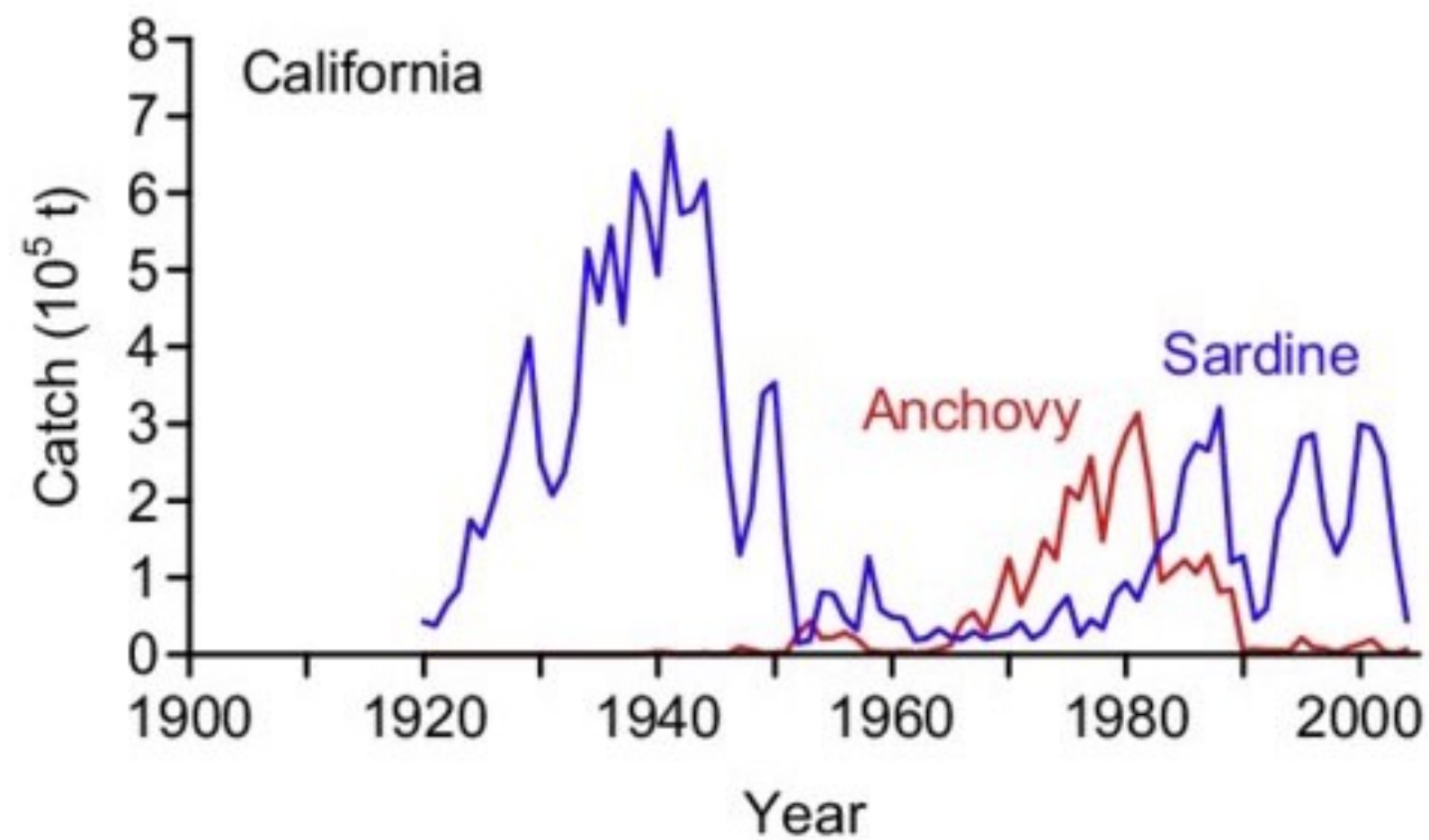
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# Sardine and anchovy in the California Current

- One of the highly dynamic and climate-driven Eastern Boundary Upwelling Systems (EBUS)
- Climate change expected to affect dynamics and productivity
  - warming! changes in upwelling? deoxygenation? ...
- Famous 'regimes' (boom-and-bust cycles) of sardine and anchovy
  - classically linked to ocean temperature and (PDO)
- Marine heat wave in 2014-15, and following warm years: Contrary to expectations, sardine still collapsed, but anchovy returned



Takasuka et al. 2008



City of Monterey / Bograd et al. 2023



## A process-based, ensemble MICE model

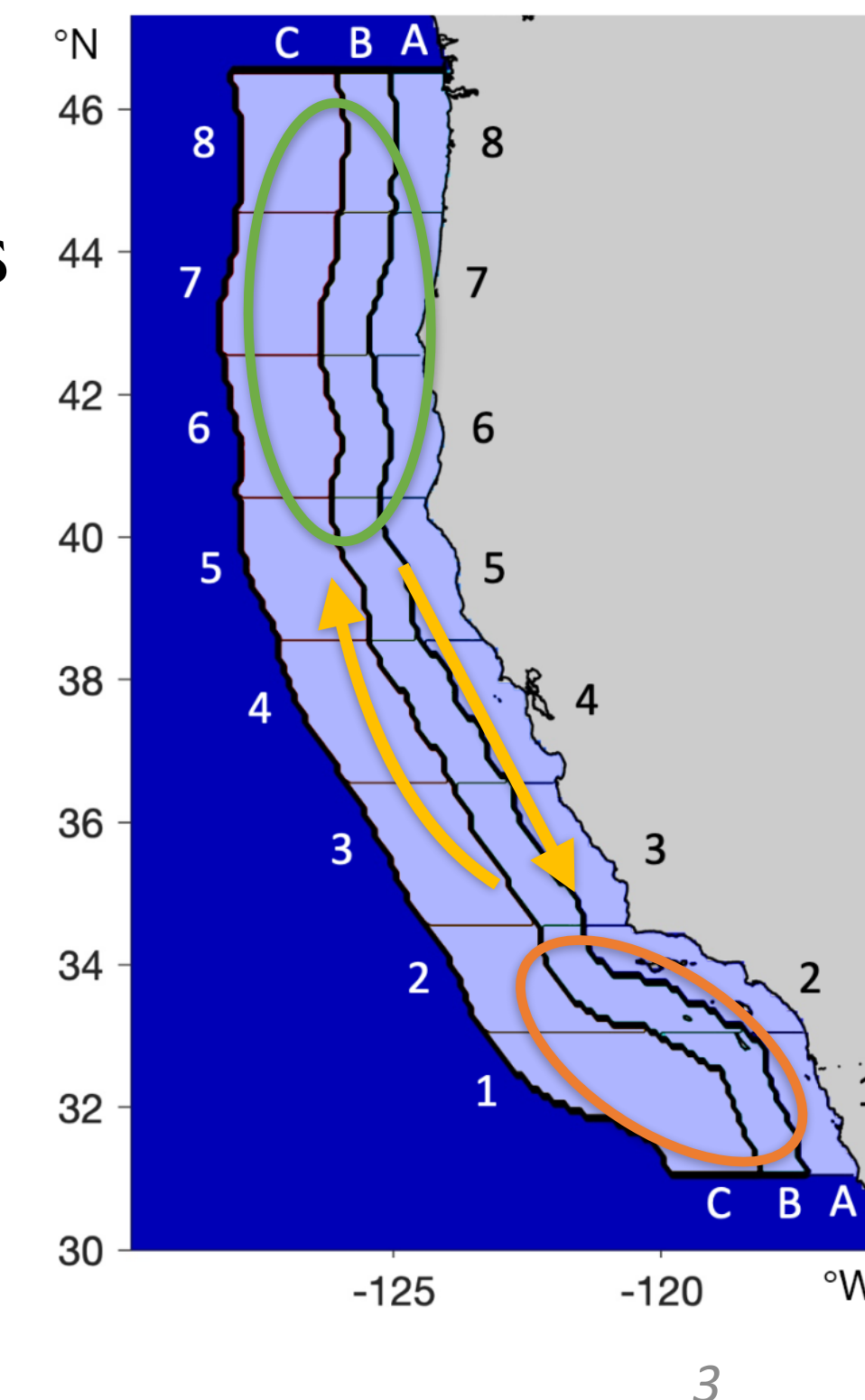
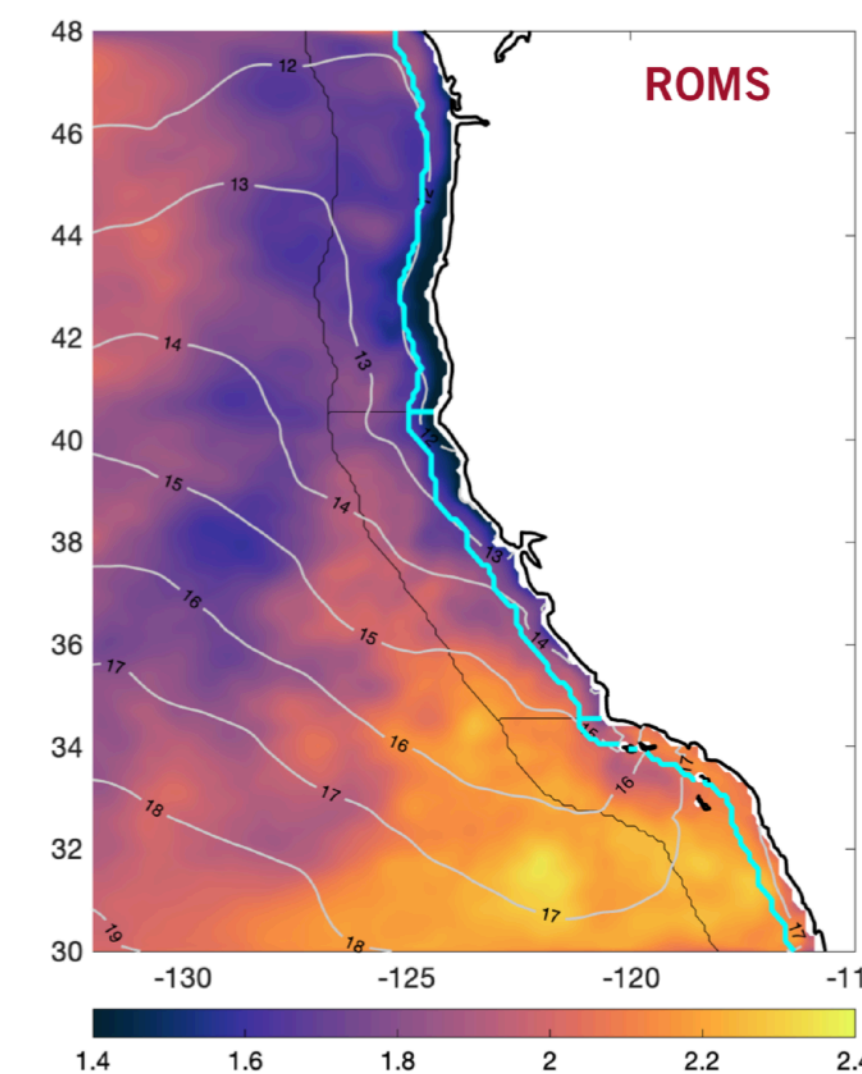
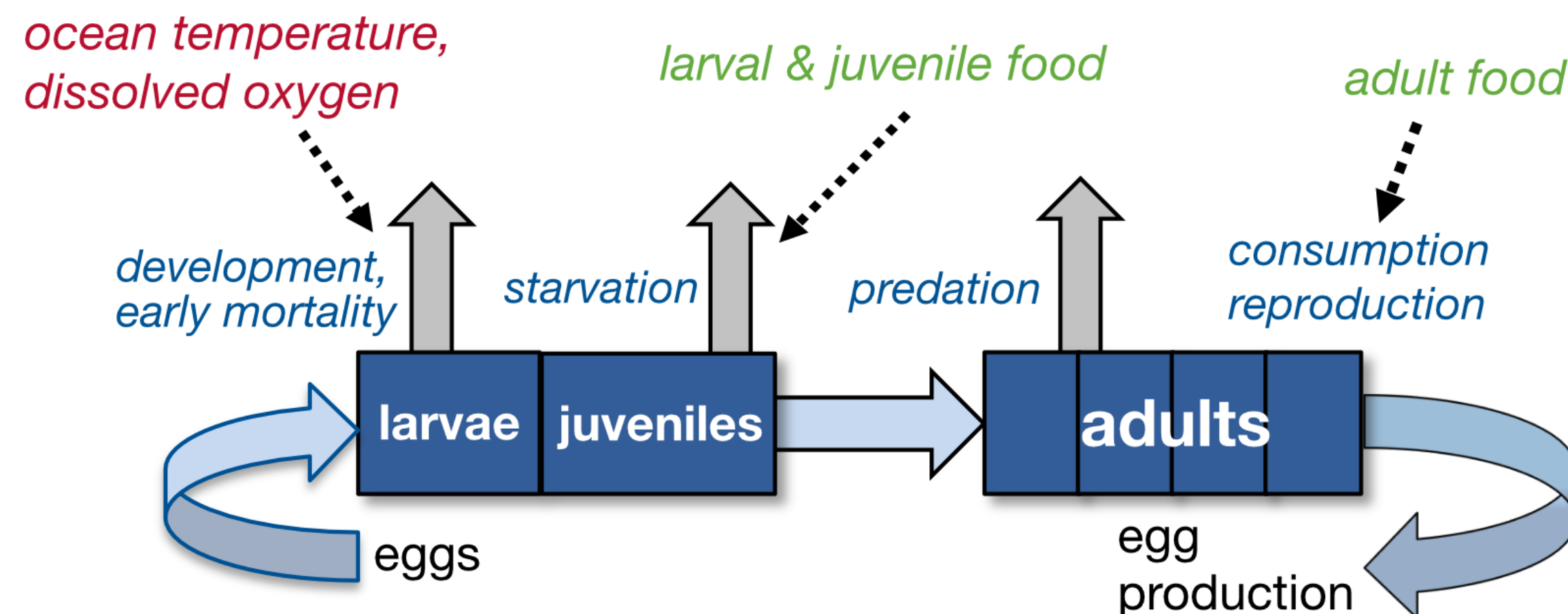
- **Model of Intermediate Complexity for assessing forage fish Dynamics (DynaMICE)**
  - mechanistic, spatial age-structured population model
  - process-based, explicit representation of early life stages (ELS) with environmental drivers
- Driven by data-assimilating hindcast of regional ocean-biogeochemical model (ROMS-NEMURO)
- Fitted to no./landings-at-age and survey data (NOAA SWFSC/CalCOFI)
- Simple migration rule for dynamic spawning (Temp cue) and feeding (food+distance) habitats



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Ecosystem Science Division  
Fisheries Resource Division

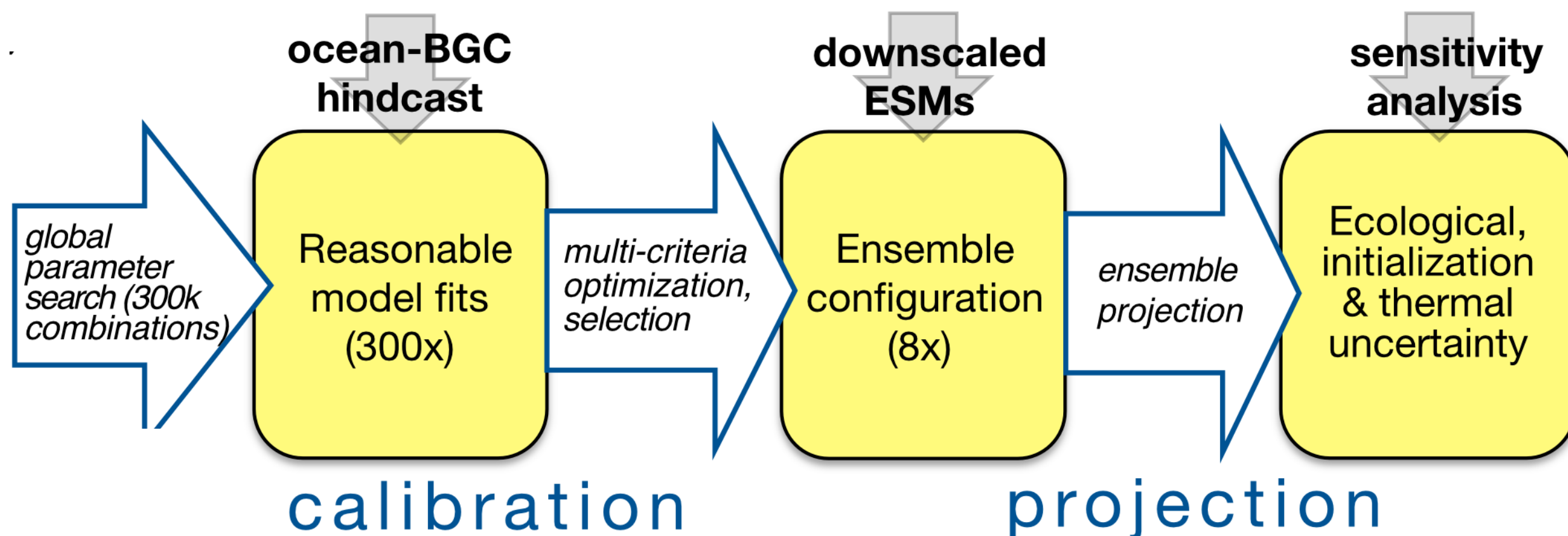
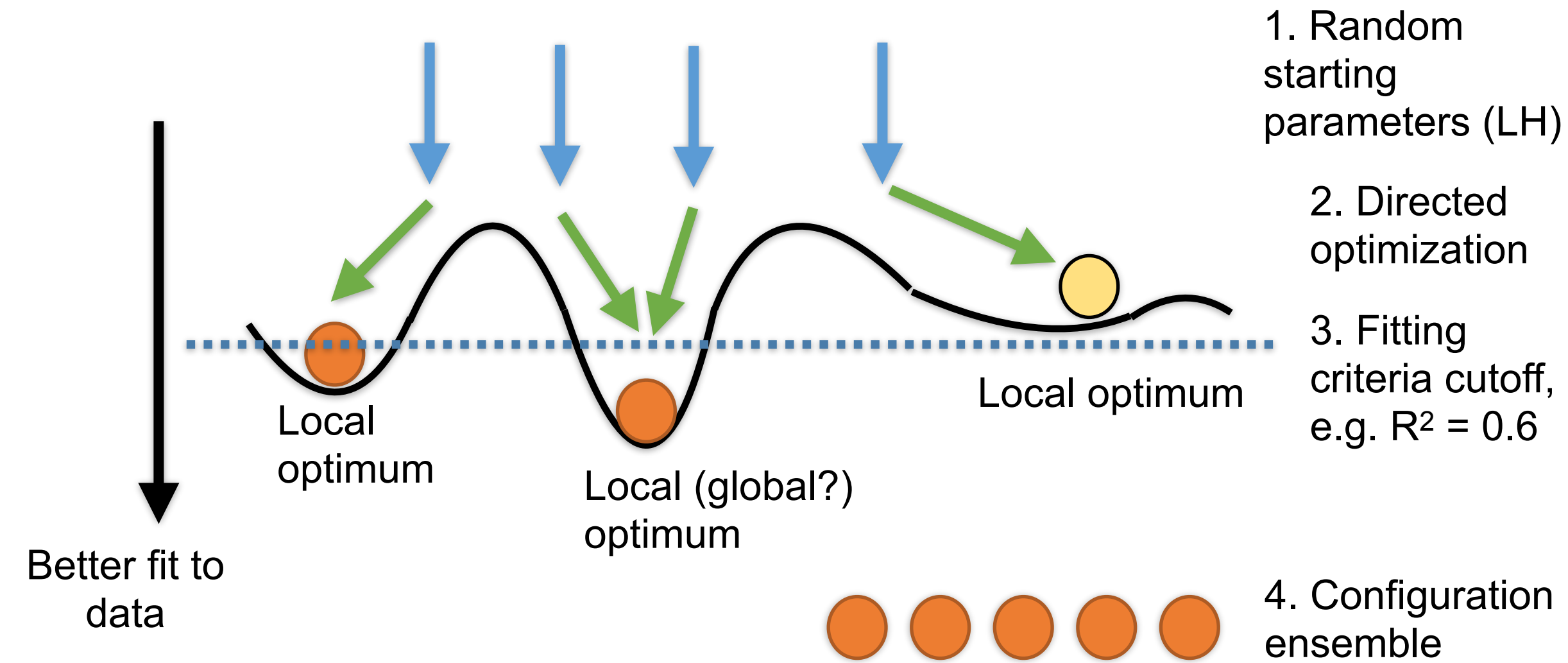


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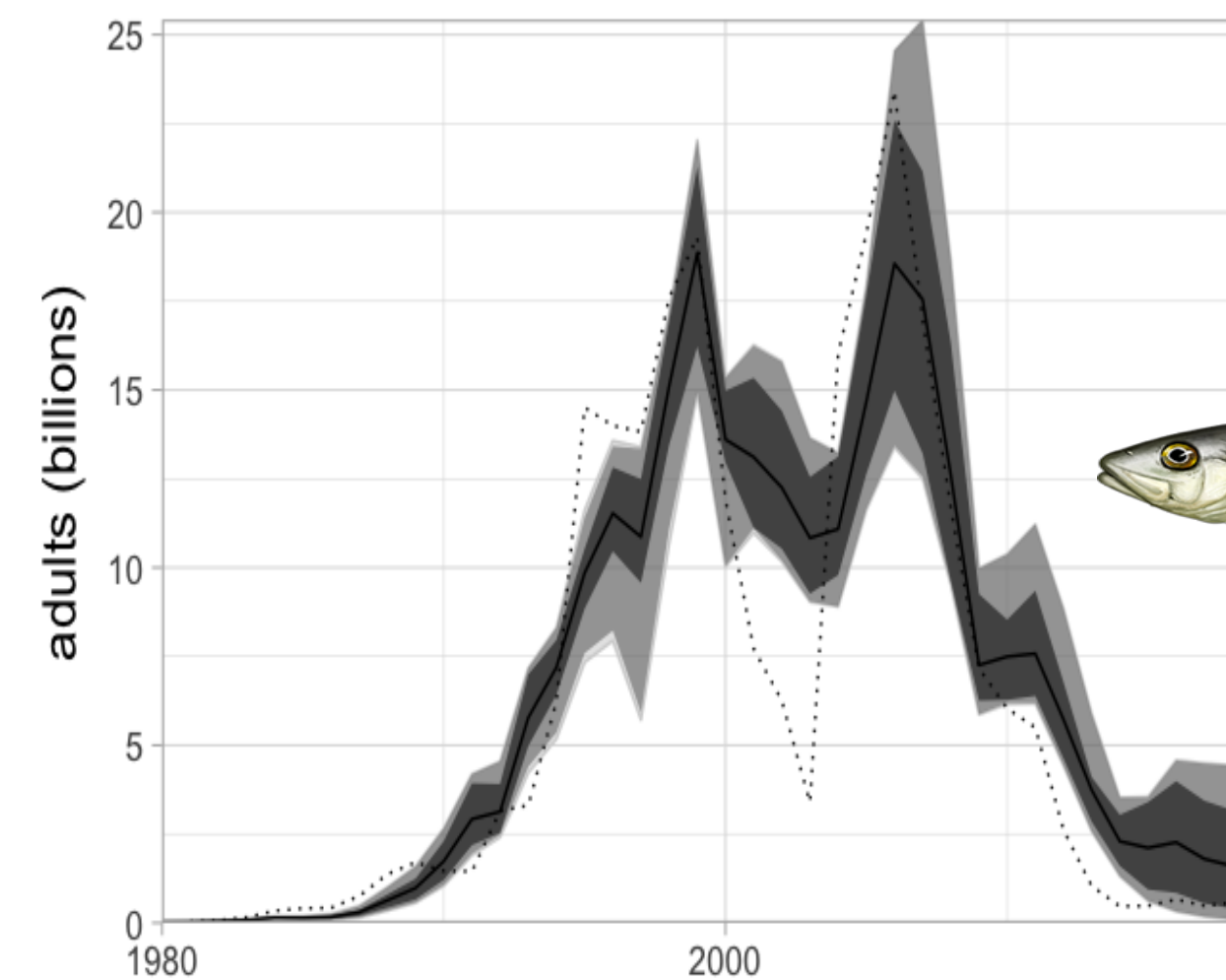
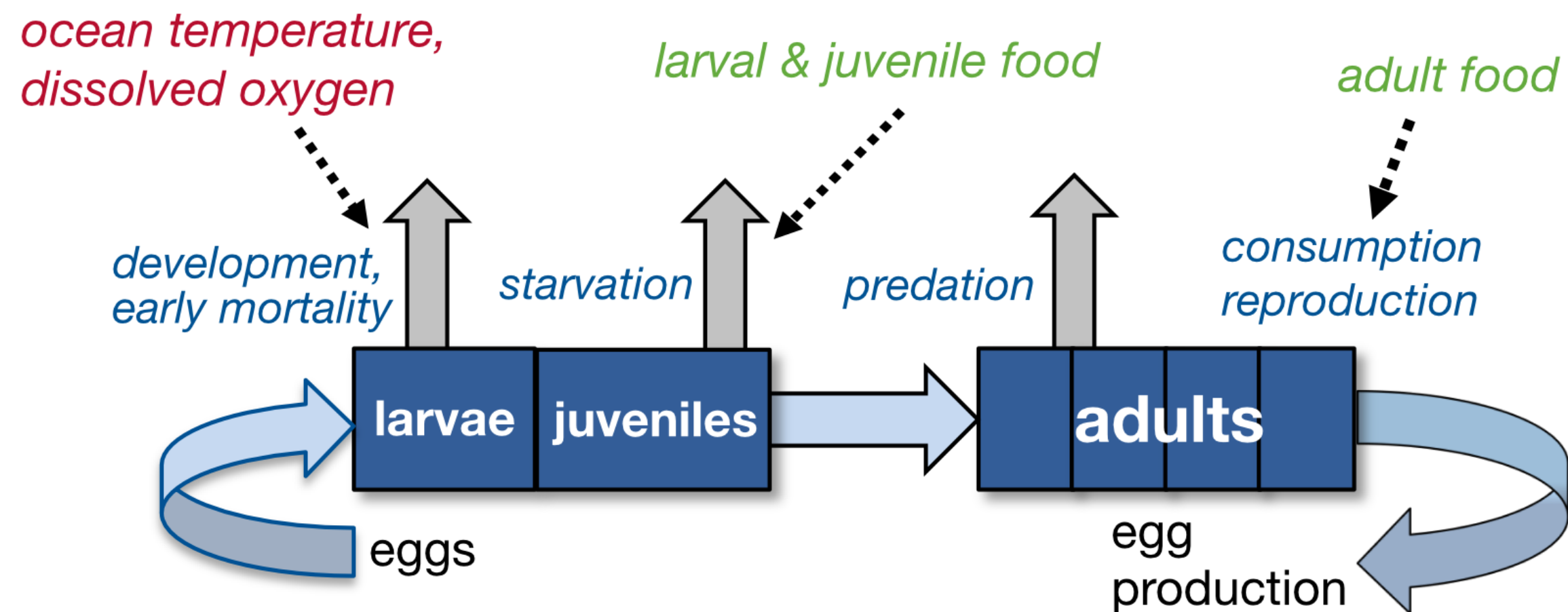
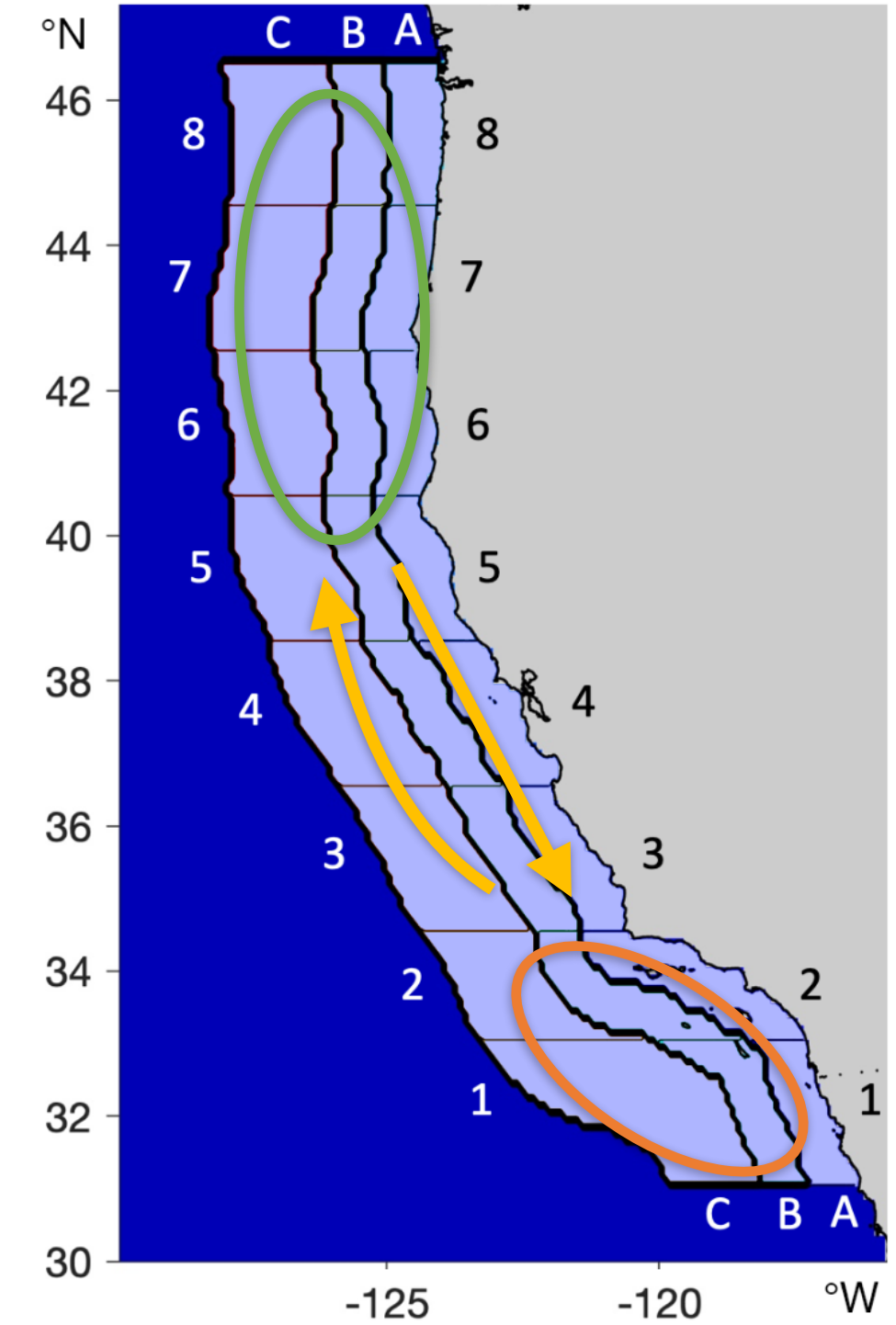
# Model configuration ensemble from global sensitivity analysis

- Comprehensive range of model configurations via
  - random parameter combination
  - directed optimization, and
  - selection of representative parameter sets (configurations)
- Brackets 'ecological uncertainty' related to env driving mechanisms



# Pacific sardine hindcast

- Last Pacific sardine boom-and-bust is reproduced (stock assessment model estimate, Kuriyama et al. 2020)
- Primary driver of sardine productivity is temperature effect on ELS
  - Limited food can explain decline (besides fisheries)



..... Stock assessment estimate  $R^2 = 0.73-0.85$

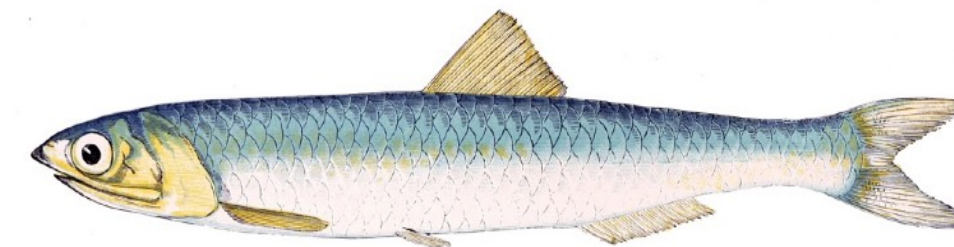
# Northern anchovy: using additional data sources



**NOAA**  
**FISHERIES**

Alexandra Curtis  
Charles Hinchliffe  
Barbara Muhling

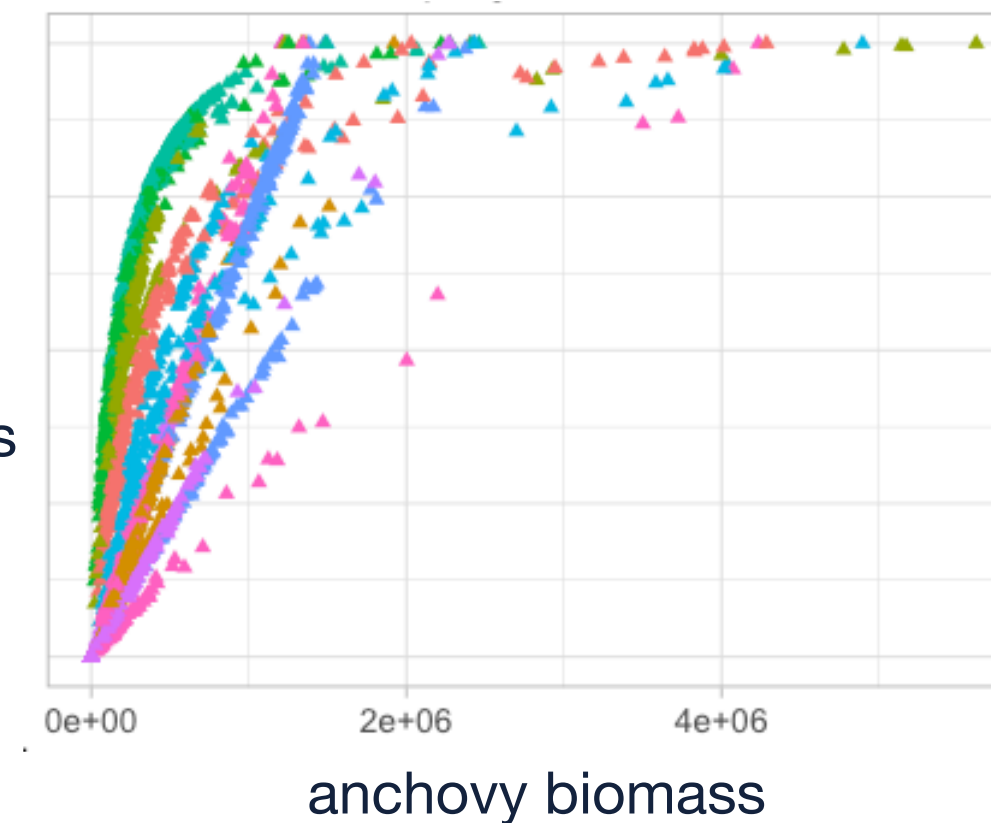
- Northern anchovy: Lower data availability, different survey indices sometimes contradictory
- Multi-criteria fitting using
  - a long-term predation index from California sealion scats
  - Different surveys and stock assessments
- Reproduces recent anchovy increase



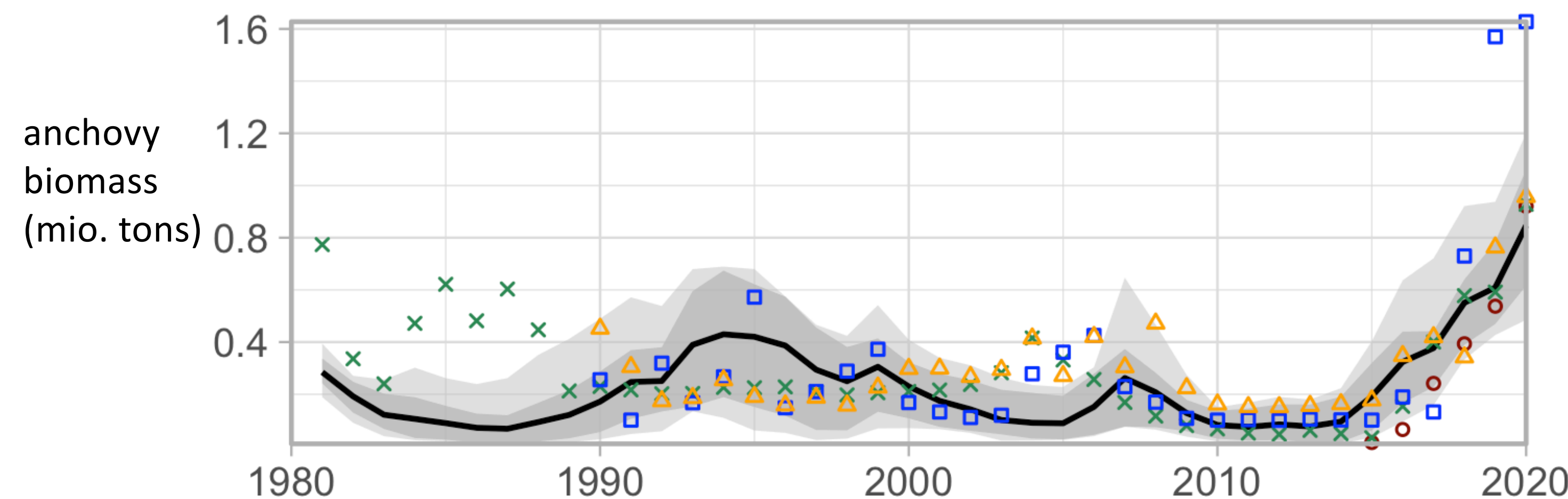
anchovy  
consumed  
by sea lions

survey (RREAS)  
sealion consumption index  
stock assessments

(Koenigstein et al. in prep.)

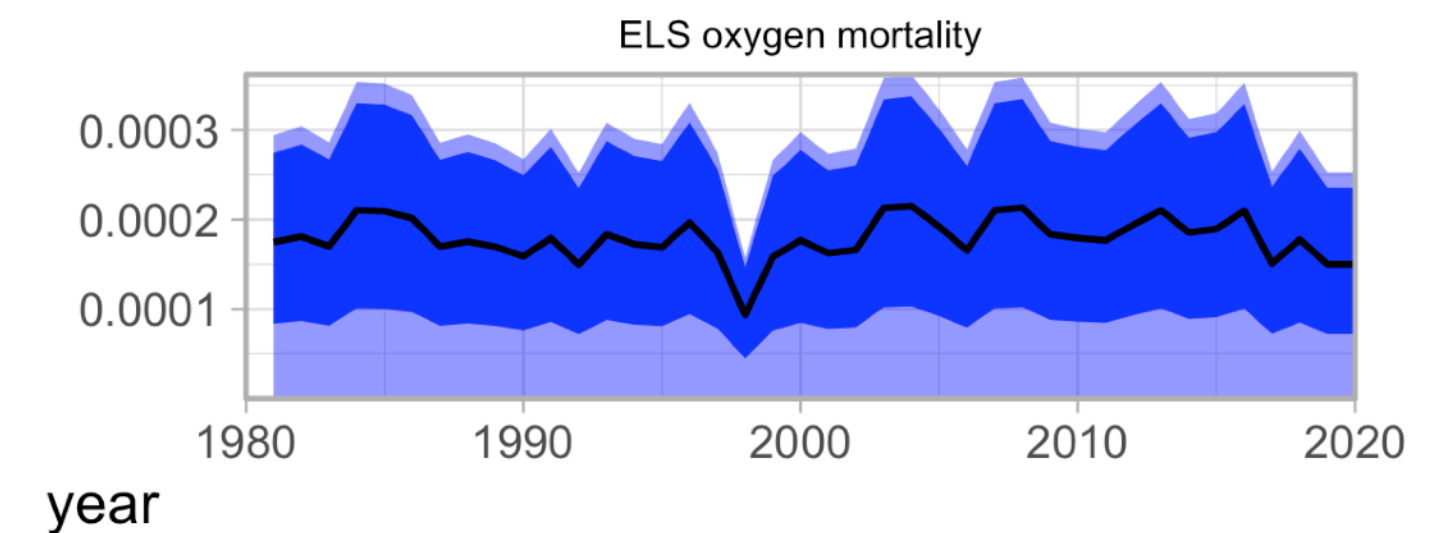
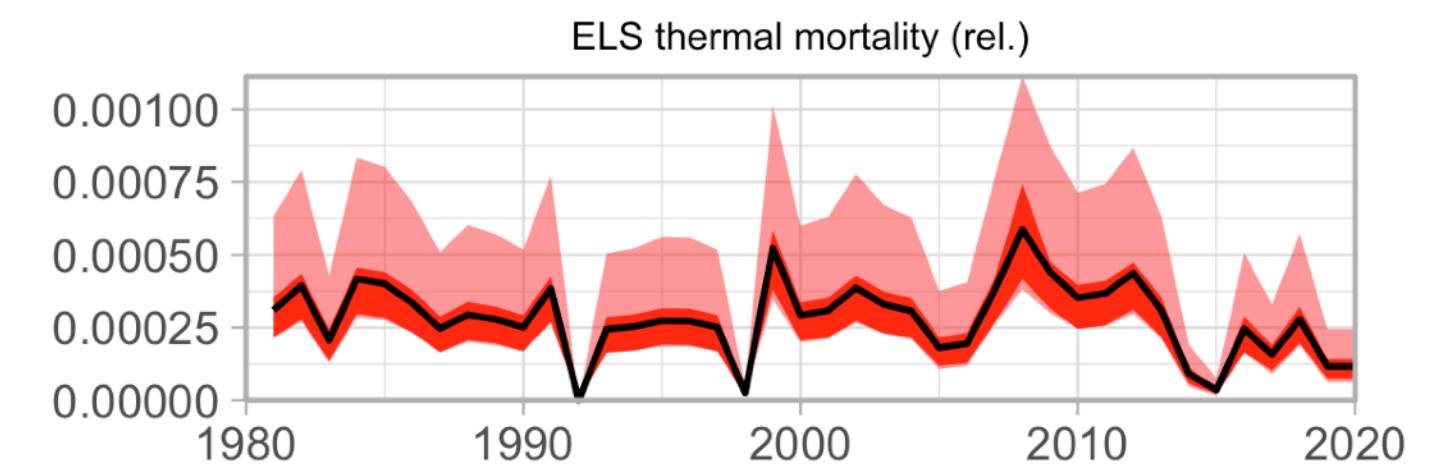
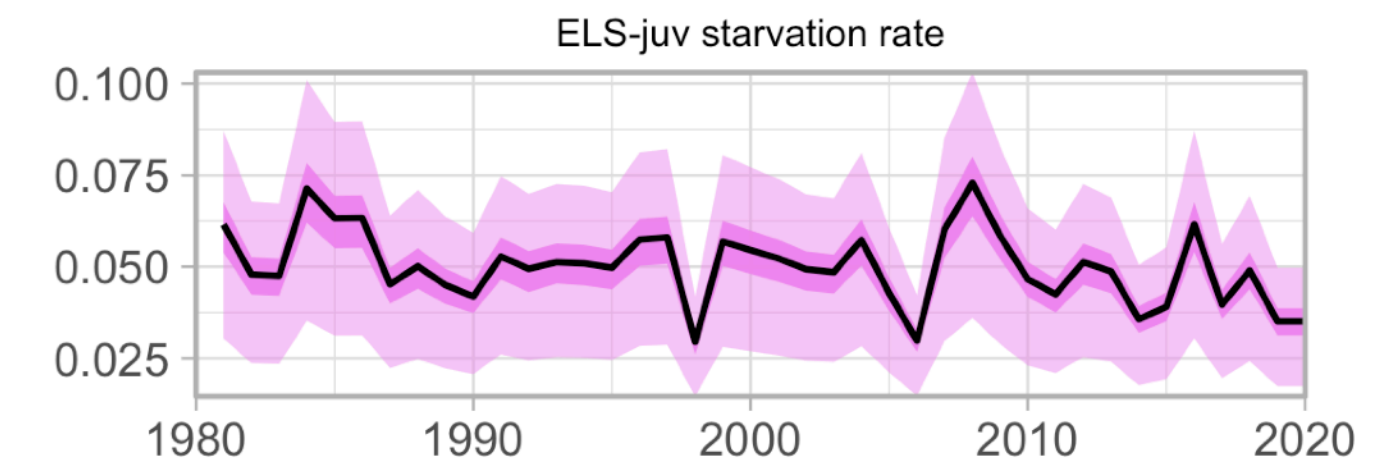


functional response  
Cal. sea lion – anchovy

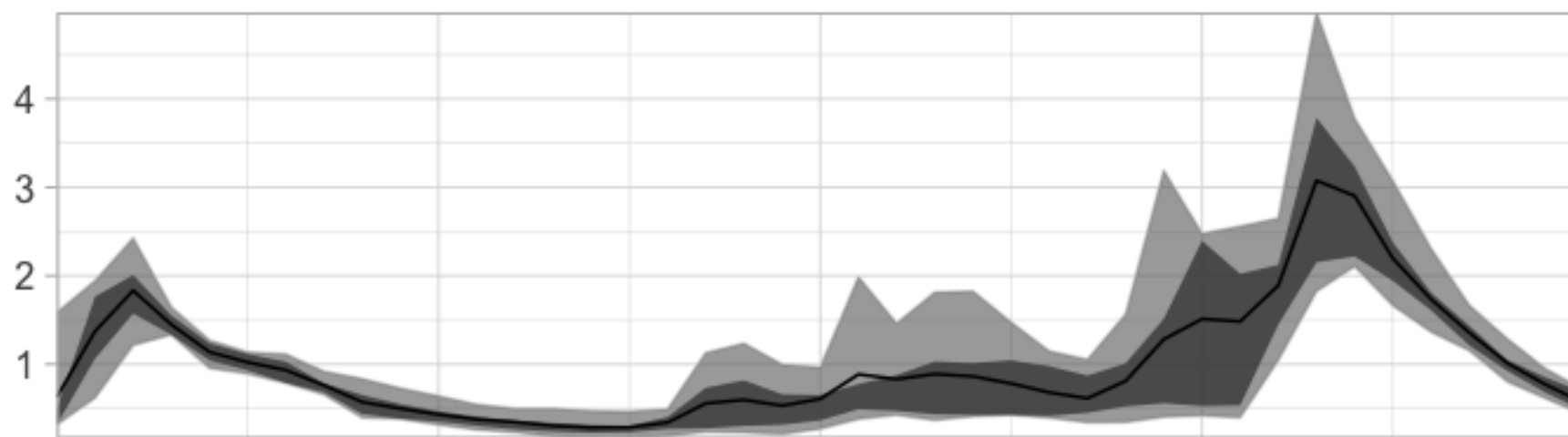


# Understanding driving mechanisms

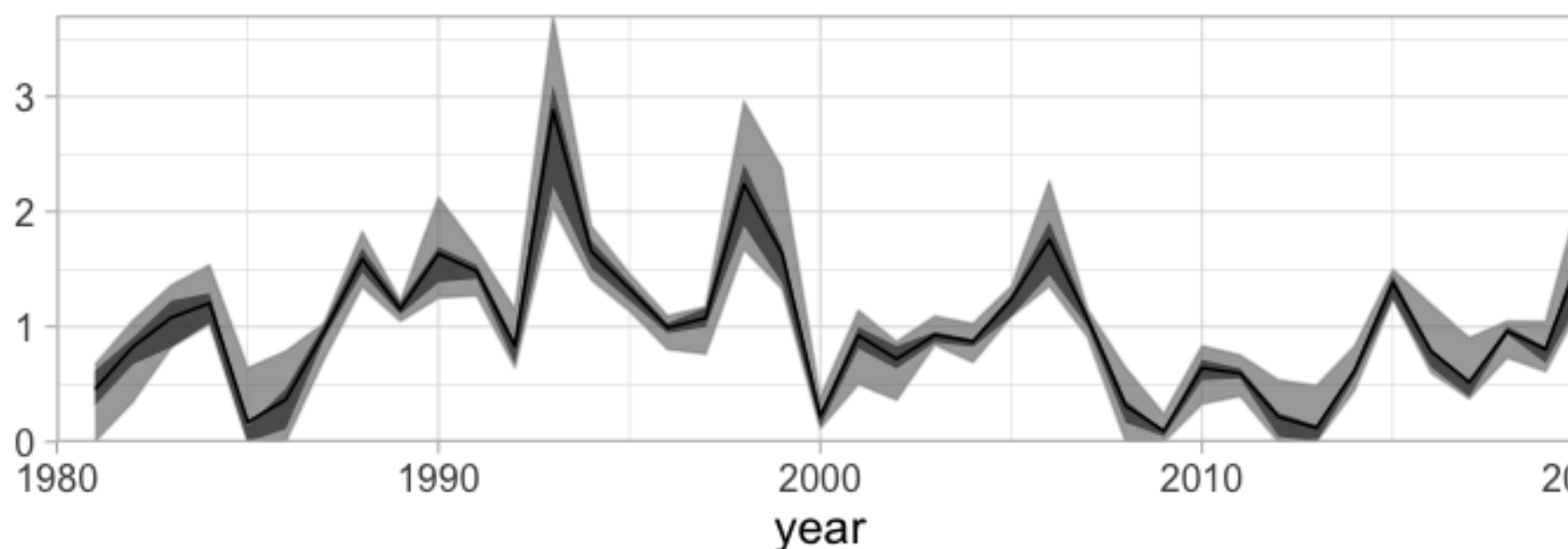
- Biol. processes with uncertainty range can be tested and further constrained with external data
- It's never one environmental factor alone driving a population response...
- Timing & biological lag (cohort resonance) matter
  - Recent anchovy increase primarily caused by high egg production (& solid recruitment in subsequent years)



eggs / biomass  
(consumption-dependent  
egg production)



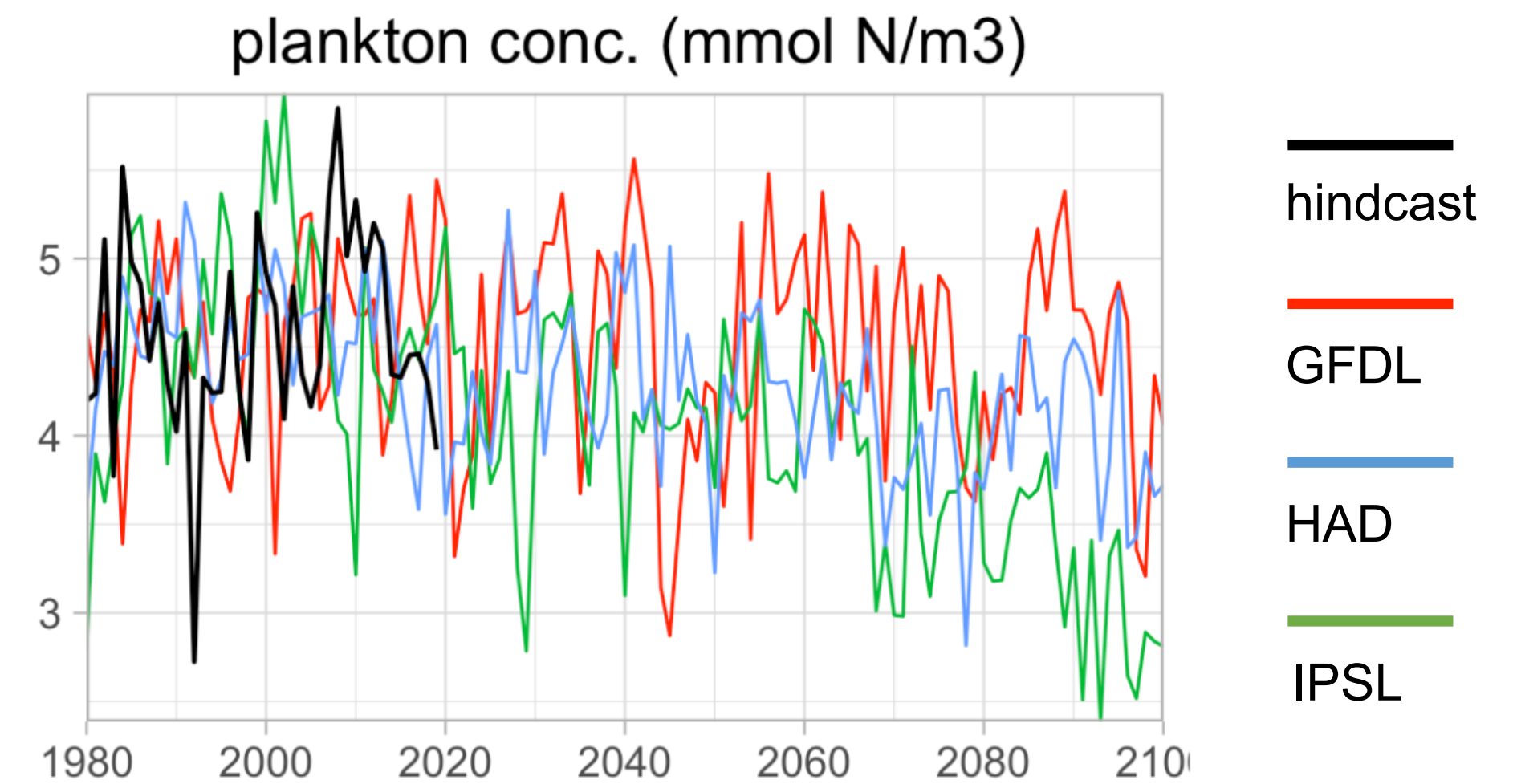
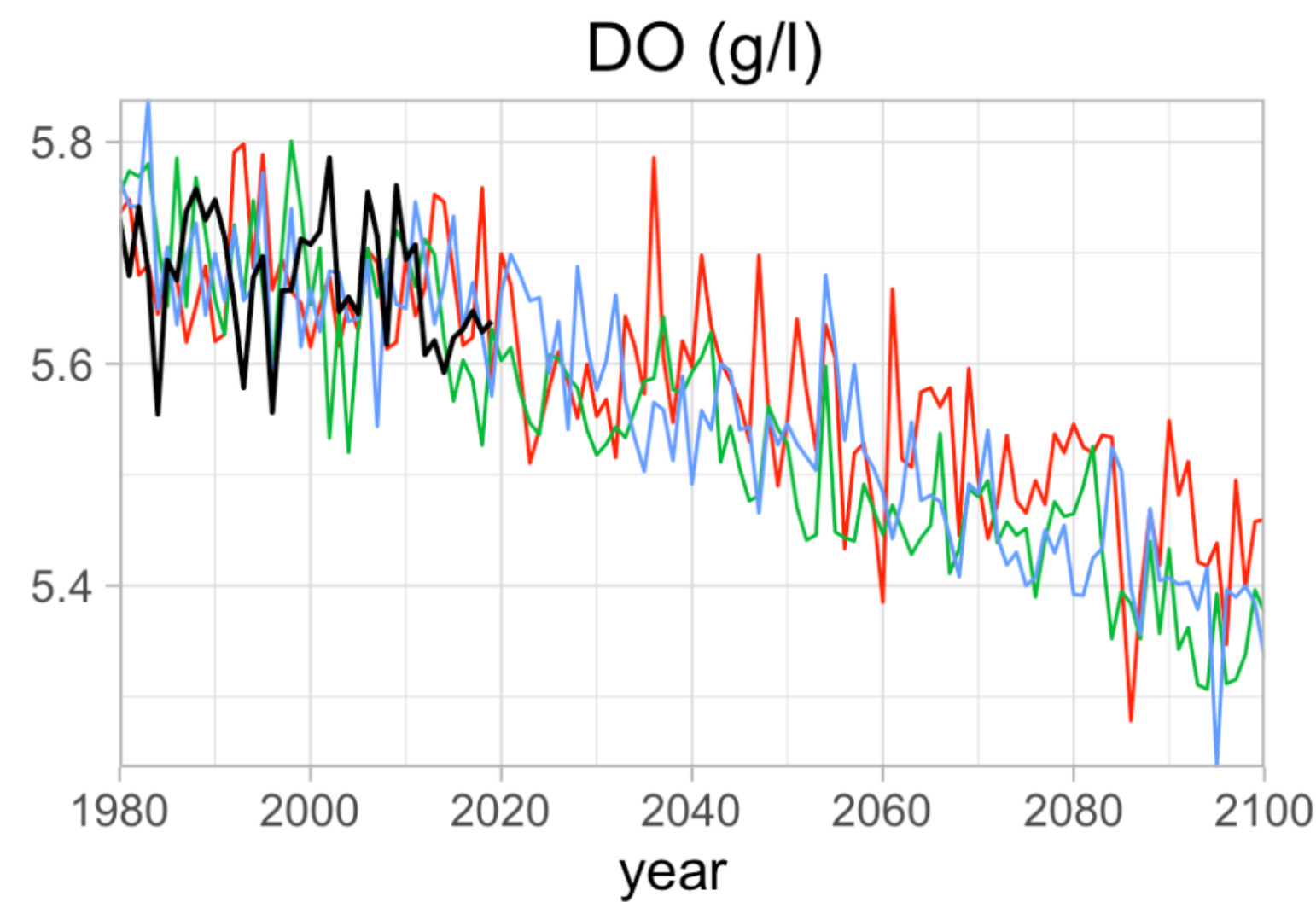
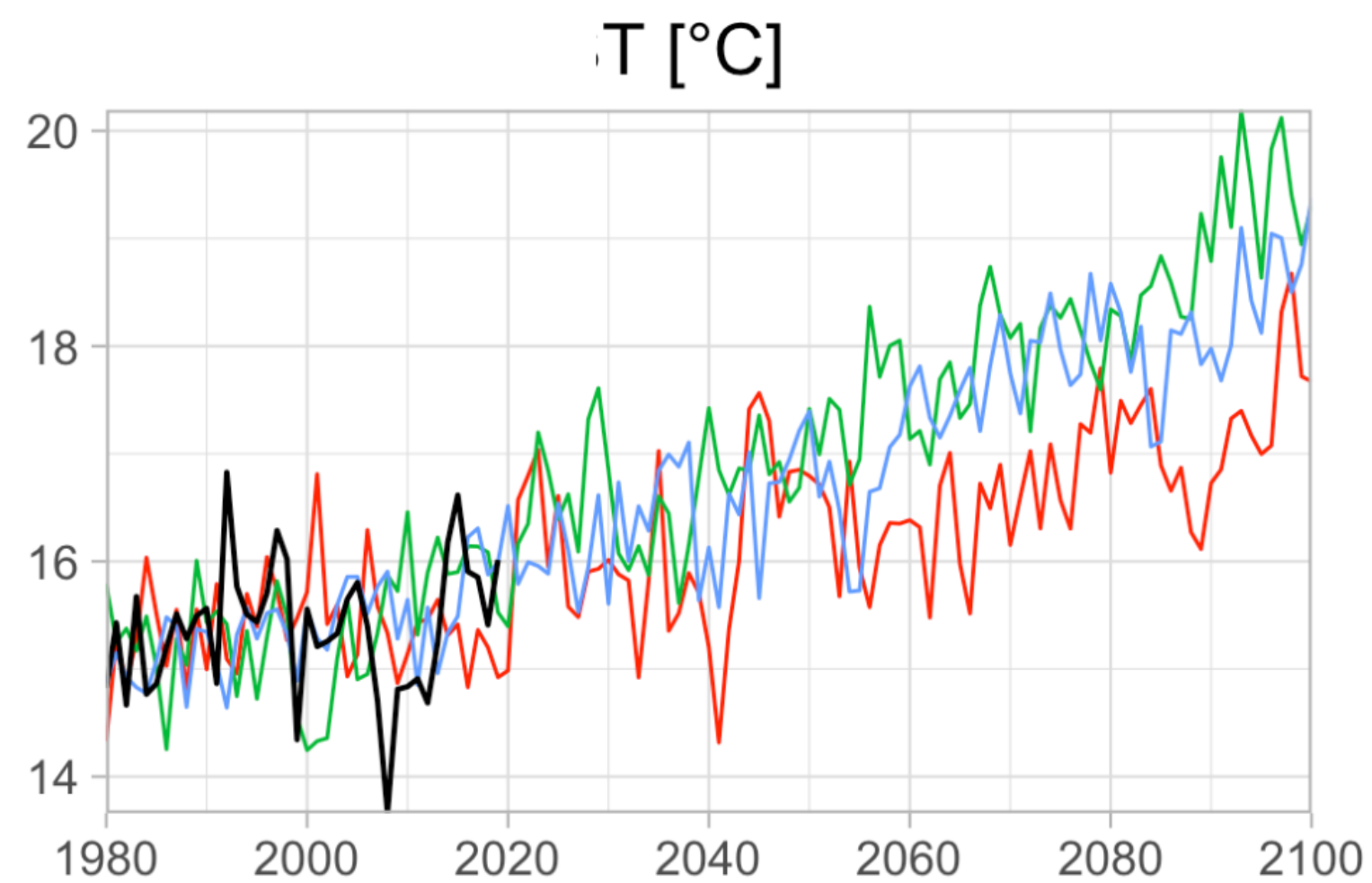
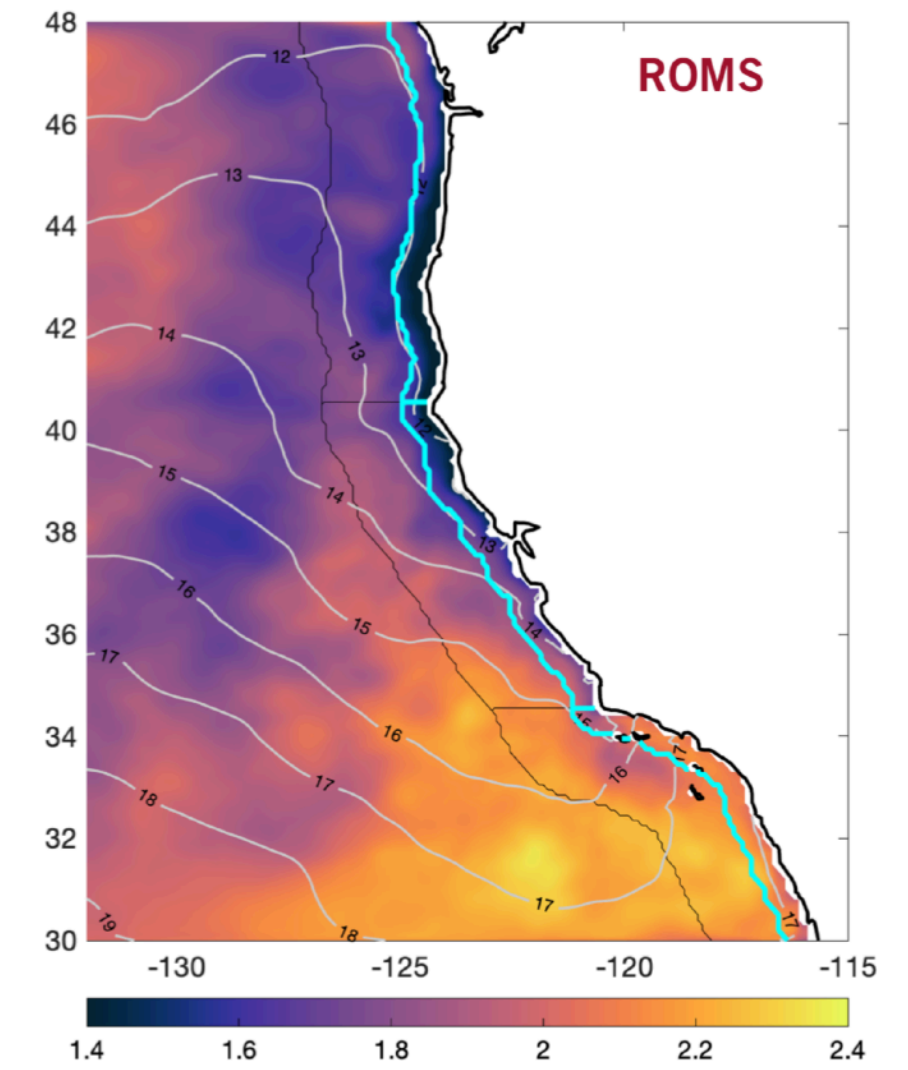
recruits / egg  
(early life stage survival)



(Koenigstein et al. in prep.)

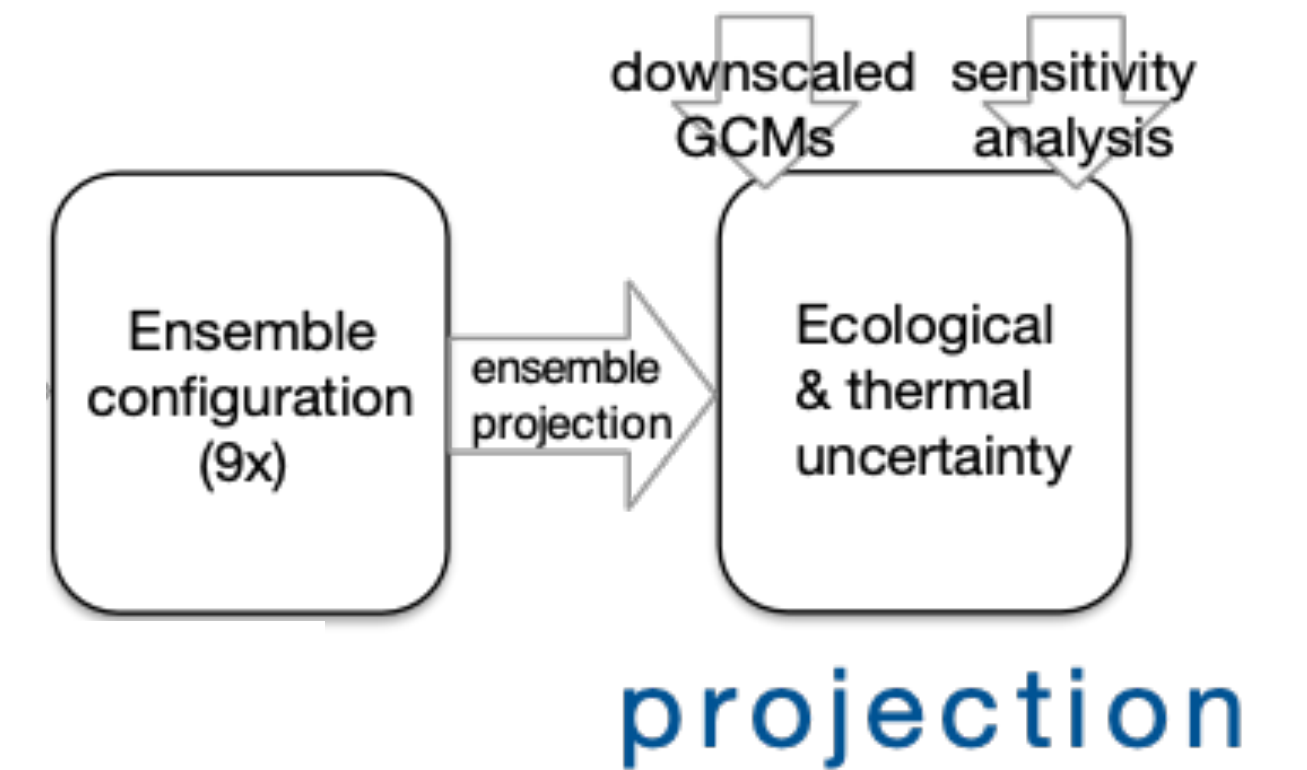
# Future ocean-biogeochemical projections for the California Current

- Driven by three ROMS-NEMUCSC downscaled earth system model projections to 2100 (RCP8.5)

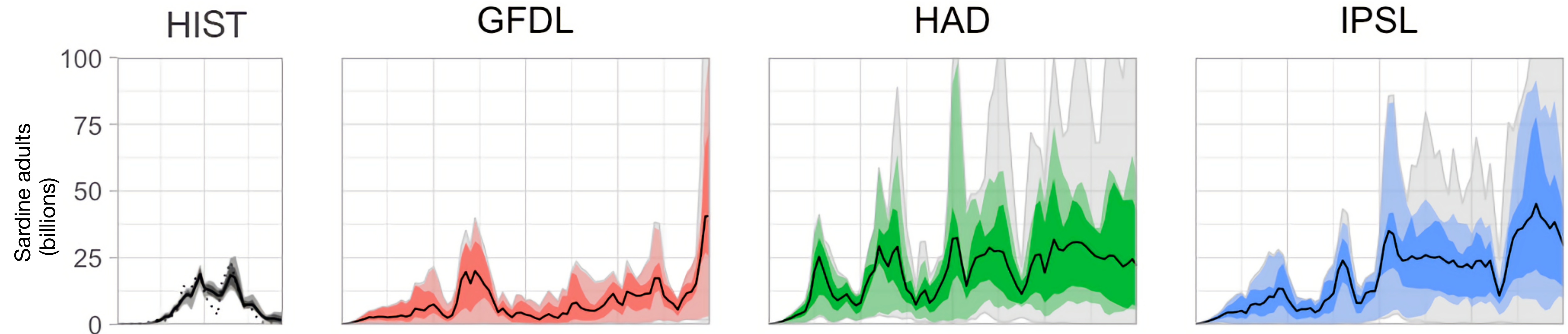
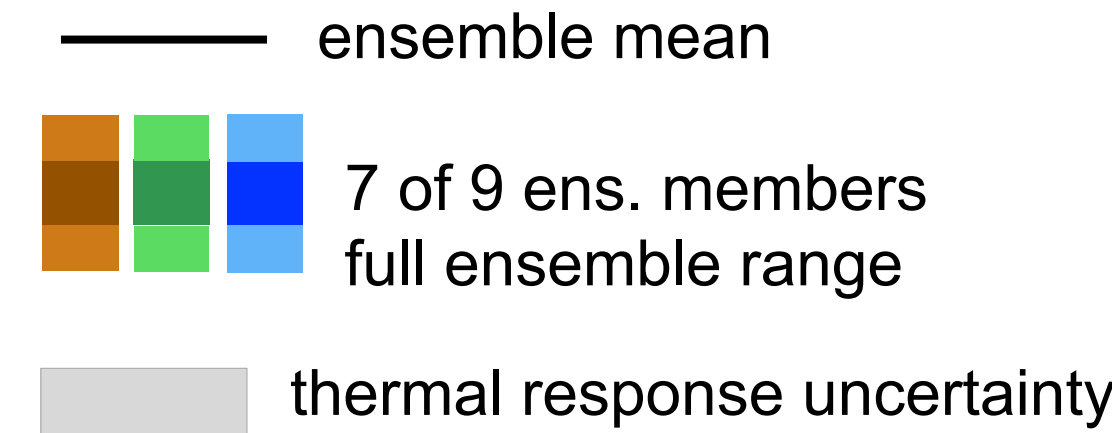


# Sardine population projections

- Decadal-scale biomass fluctuations reproduced from environmental drivers
- Long-term biomass increase driven by warming
- Uncertainty from different sources quantified (model vs. data vs. ESMs)

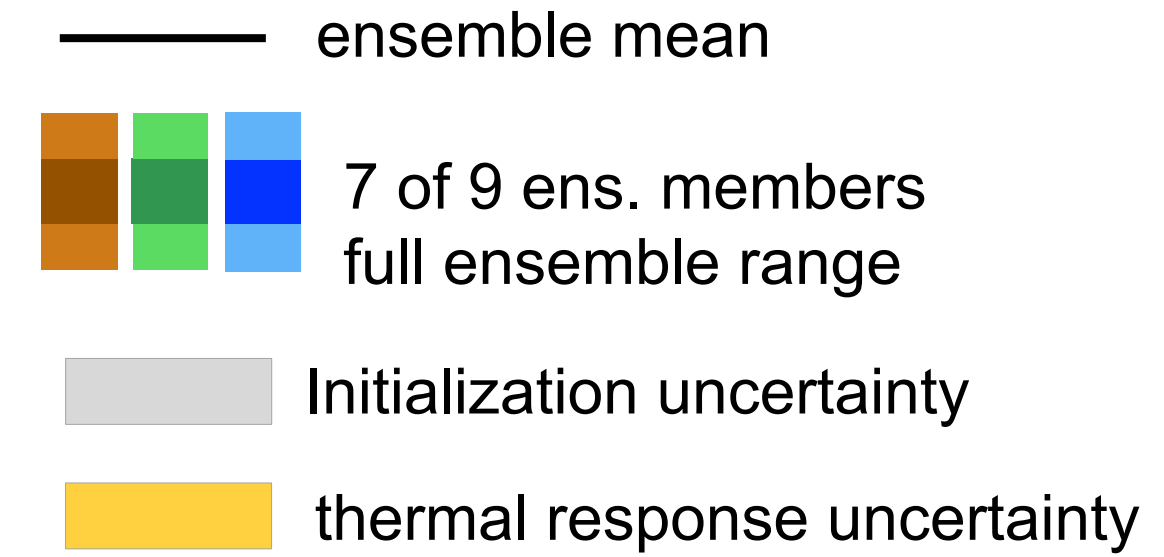


Pacific sardine  
(Koenigstein et al. 2022)

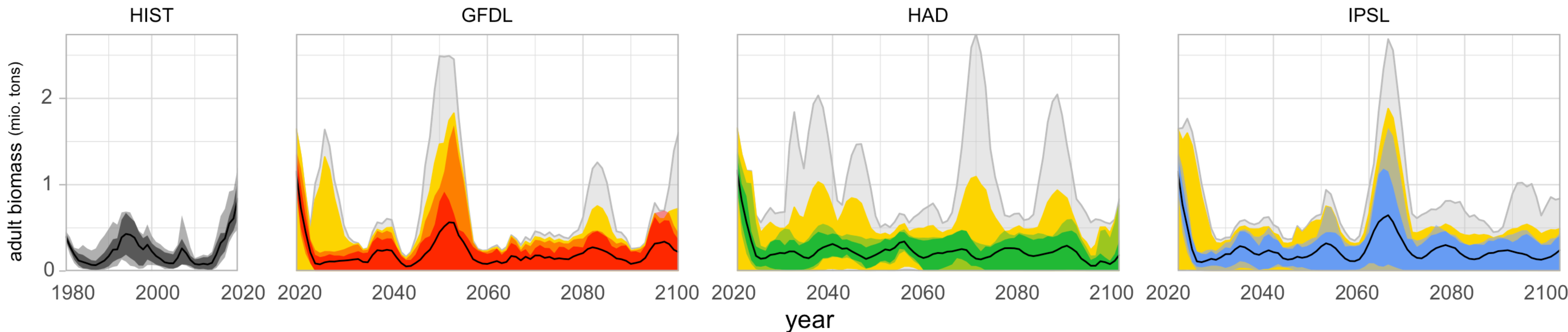


# Northern anchovy population projections

- Short, temporary 'booms' projected, no new 'anchovy regime'
- Anchovy more strongly driven by food impact on adult consumption & egg production (Temp 2nd)



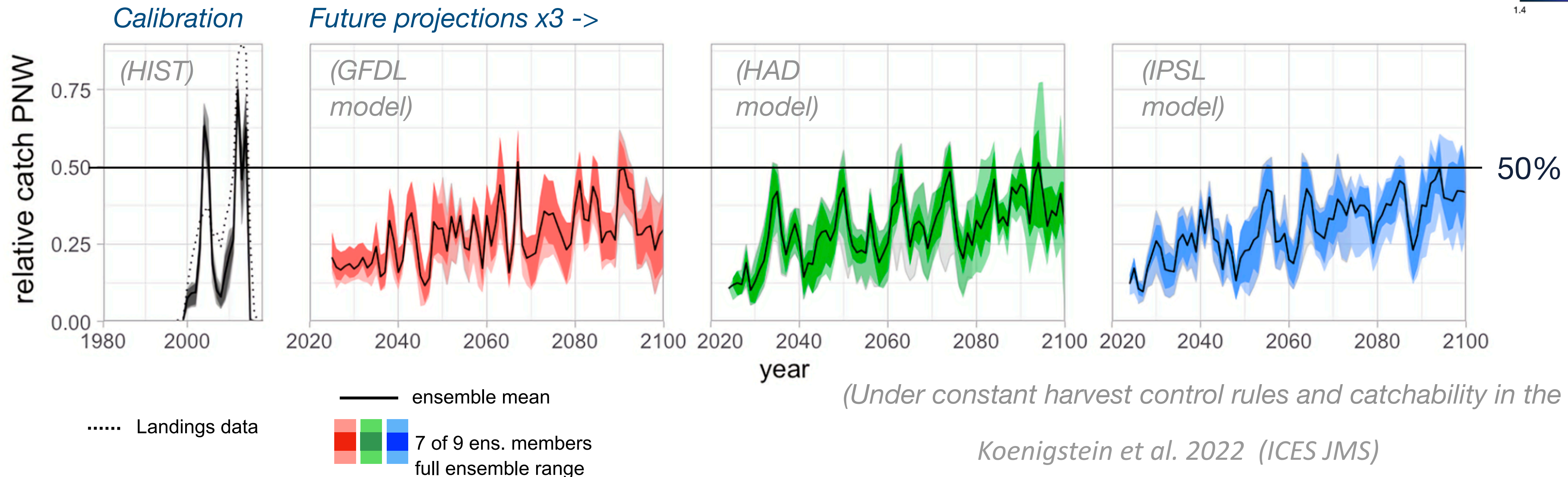
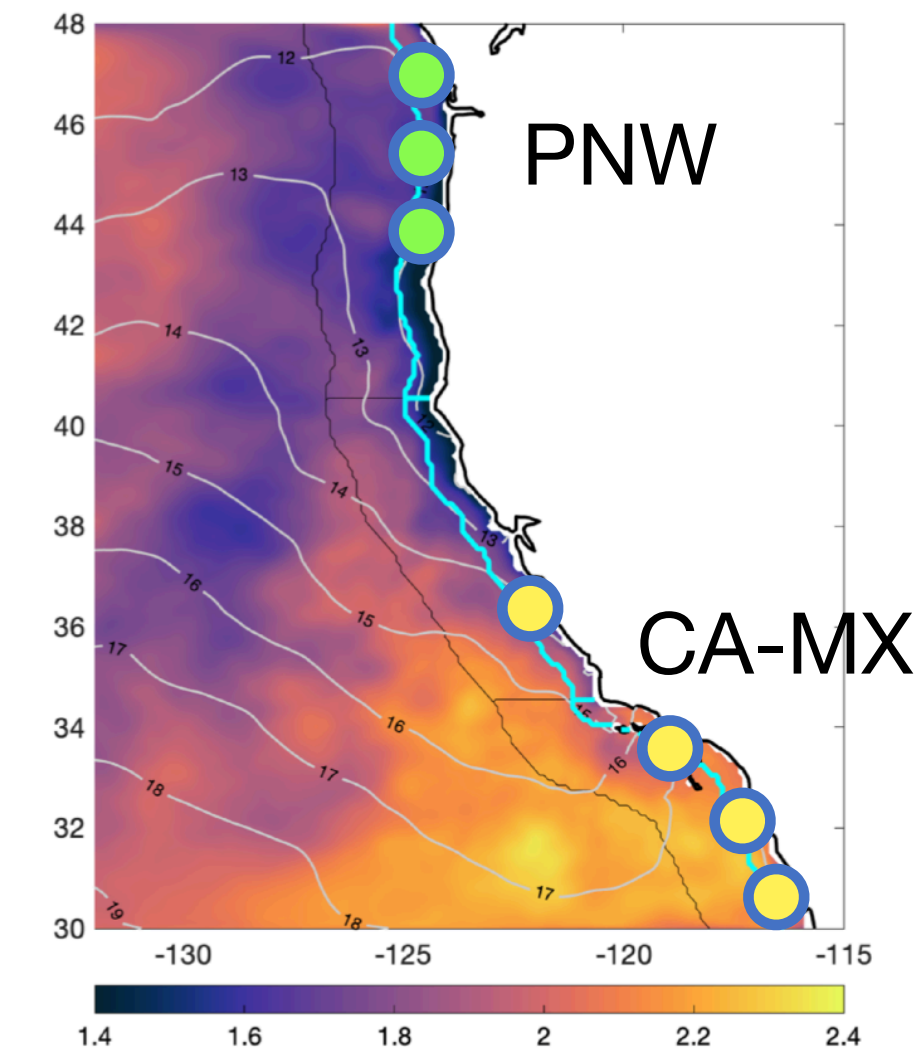
Northern anchovy  
(Koenigstein et al. in prep.)



# Applications? Variability vs. long-term trends



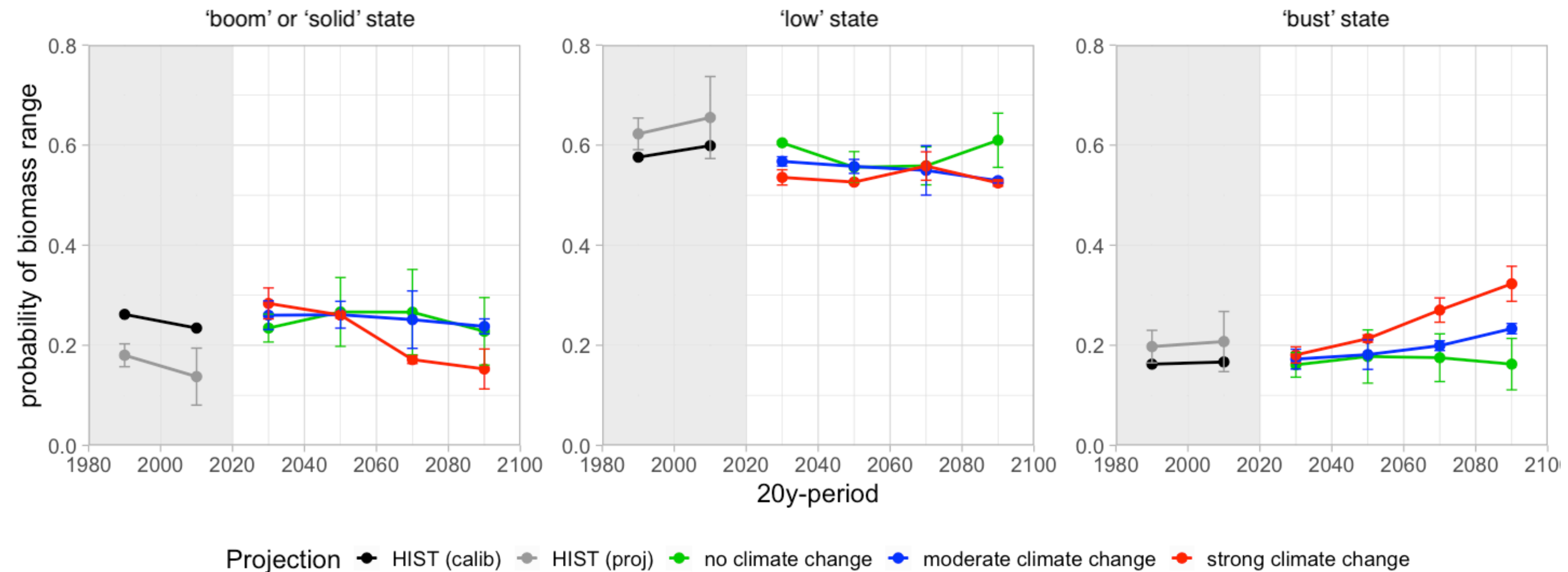
- Shift in Pacific sardine landings from Southern to Northern ports projected
  - Considers distribution shift, pop age structure, adaptive migration, fleet catchability...
- Looking at relative catch 'evens out' some uncertainties
- Can be used to assess harvest control rules under climate change (MSE)



(Under constant harvest control rules and catchability in the future)

# Application: Risk assessment / long-term planning

- Probability for anchovy biomass states (bust – low – solid – boom ) within 20y-periods, over complete uncertainty/sensitivity range of projections
- Risk of an anchovy biomass in ‘bust’ state significantly increases in the second half of 21st century under strong climate change (RCP 8.5)



## Summary/conclusions

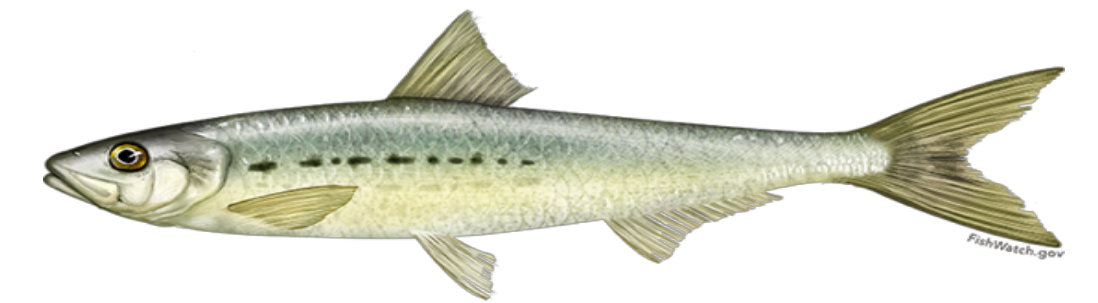
- Combining a process-based model of intermediate complexity, (lots of) empirical data, and sensitivity analyses, we can
  - identify likely driving mechanisms of fish productivity,
  - produce future projections that represent both variability and long-term trends, and
  - quantify uncertainty
- The interplay of multiple drivers, plus population modulation can produce booms, busts and decadal-scale fluctuations in SPF
  - Don't expect to find "the one driver" of SPF productivity!
- Applications are in...



Thank you!

## Contributors

Michael G. Jacox, Mer Pozo Buil, Jerome Fiechter, Barbara Muhling, Peter Kuriyama, Robert Wildermuth, Pierre-Yves Hervann, Isaac Kaplan, K. Alexandra Curtis, Steven Bograd... et al.



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**FISHERIES**

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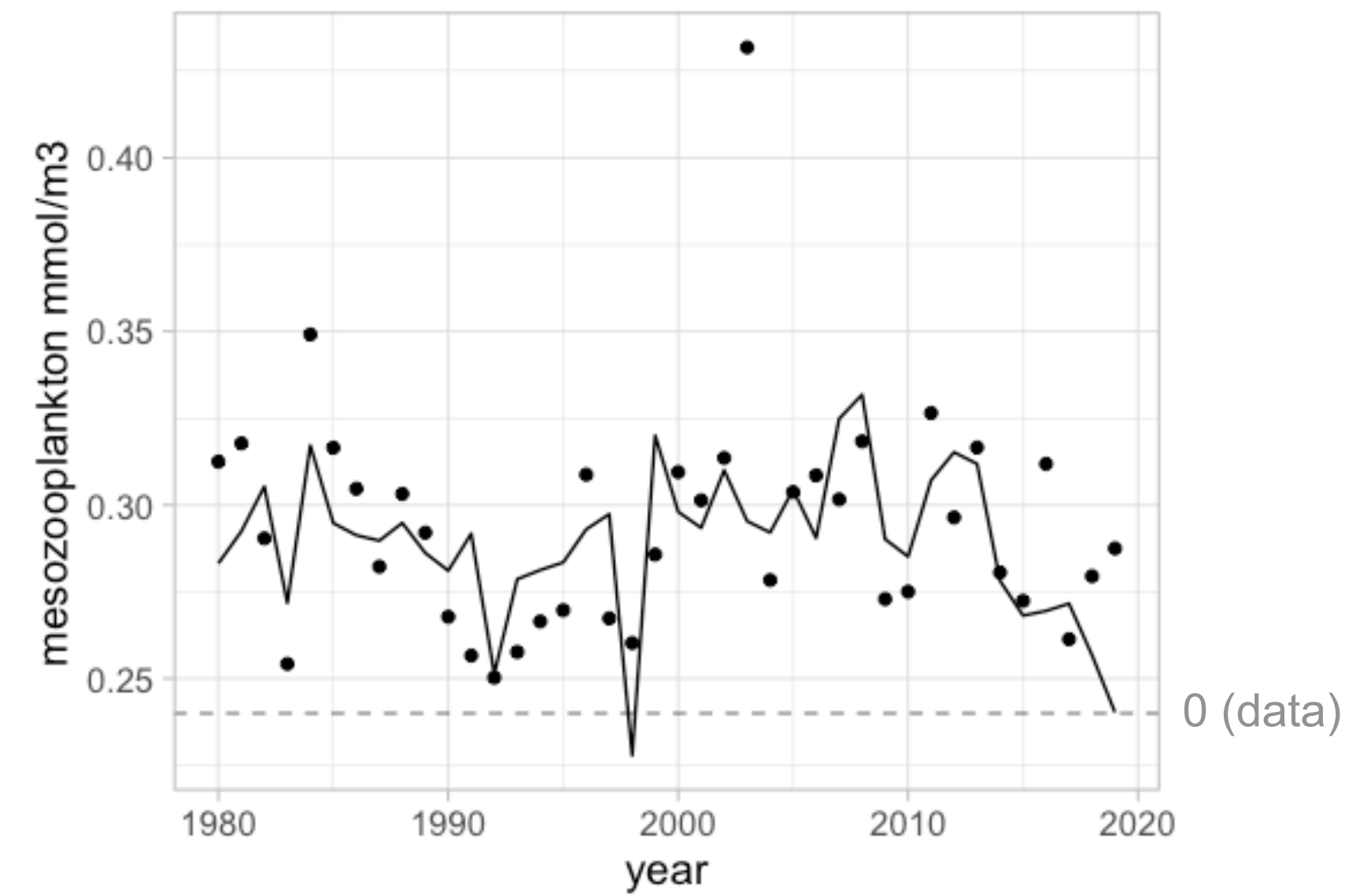
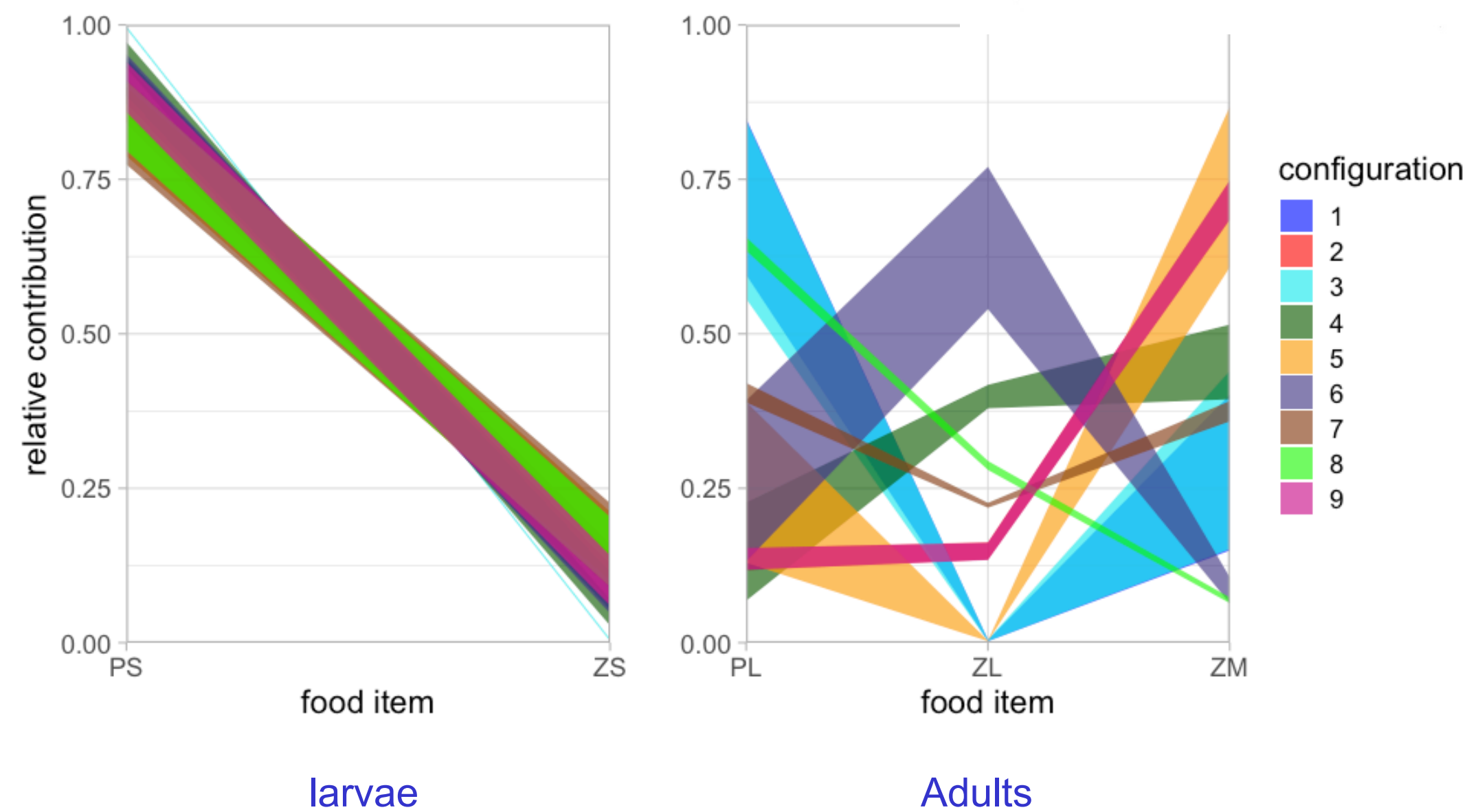
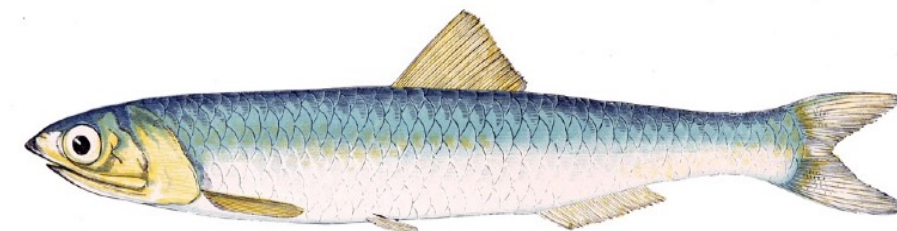
# Extra slides

# Planktonic food availability

- NEMURO hindcast shows some fit with zooplankton groups that are important for anchovy feeding
- Adults have a wide diet range with mesozooplankton as most common food item (diets not constrained by data)
- ELS starvation mostly depends on small phytoplankton, not small zooplankton

*(Koenigstein et al. in prep.)  
w/ Andrew Thompson*

Northern anchovy diet  
(emerged from model fitting)



- NEMURO mesozooplankton 0-40m, SoCal bight
- Small copepods abundance/m<sup>2</sup>, re-scaled)