Mechanistic population projections for sardine and anchovy in the California Current under ocean warming and changing food availability

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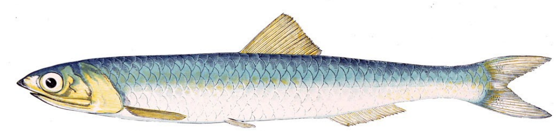

SPF Symposium Lisbon

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Southwest Fisheries Science Center
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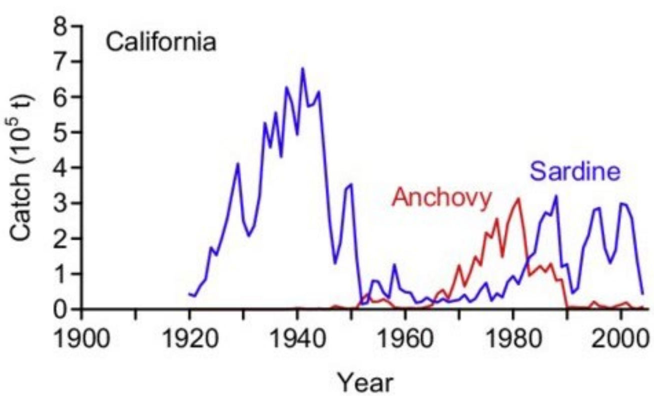
Sardine and anchovy in the California current system (CCS)

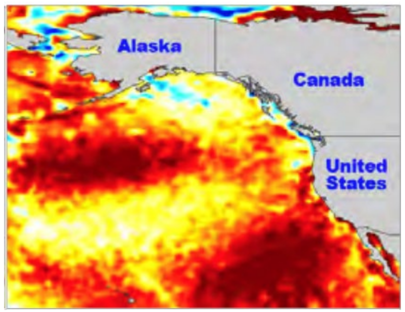
- Variability and boom-bust cycles in SPF are still not understood
  - In the CCS, links of sardine recruitment to SST have not held up
  - Correlations with PDO etc. are unlikely to hold in changing ecosystems

- Marine heat wave (+El Niño) 2014-16 in the CCS: Pacific sardine has not recovered as expected after warm years (but anchovy coming back…)

- Global & regional ocean-BGC projections & forecasts have advanced a lot… but how are marine fish population dynamics linked to environmental & ecological drivers?

Takasuka et al. 2008





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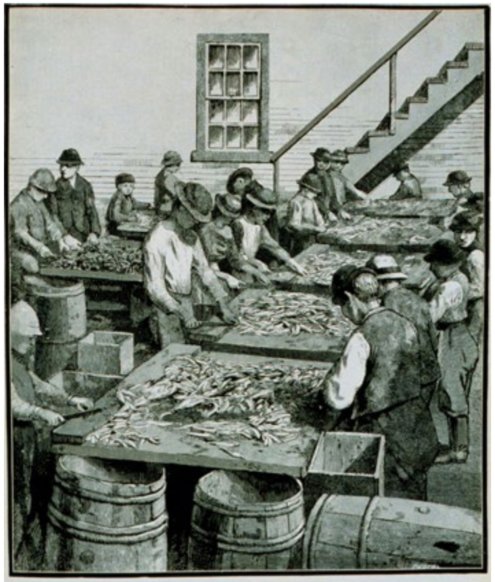


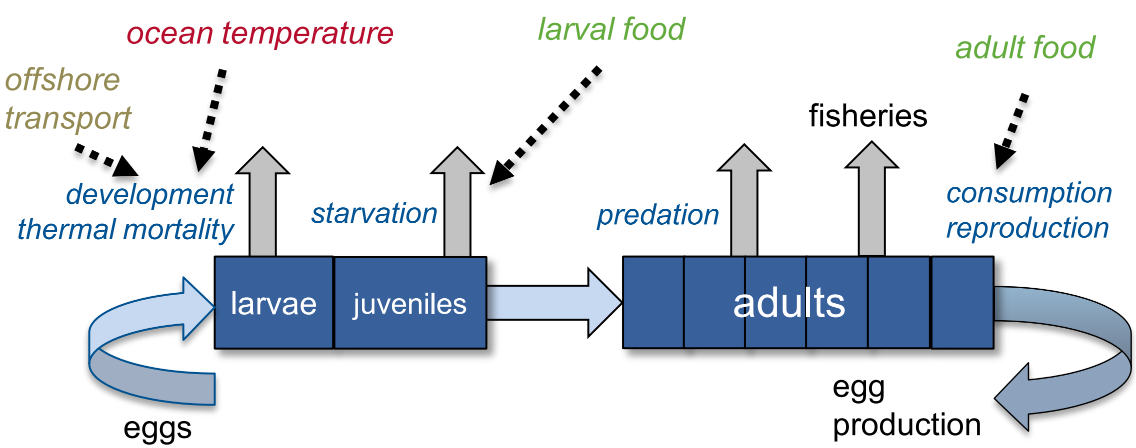
THE SARDINE INDUSTRY.

MICE for Pacific sardine: Model structure

- MICE model / age-structured population model
- *(Model of Intermediate Complexity for Ecosystem assessment; Plaganyi et al. 2012; Punt et al. 2016)*

- Goal: incorporate everything a little bit (and nothing very well)
  - ➢ Assess system behavior and feedback loops

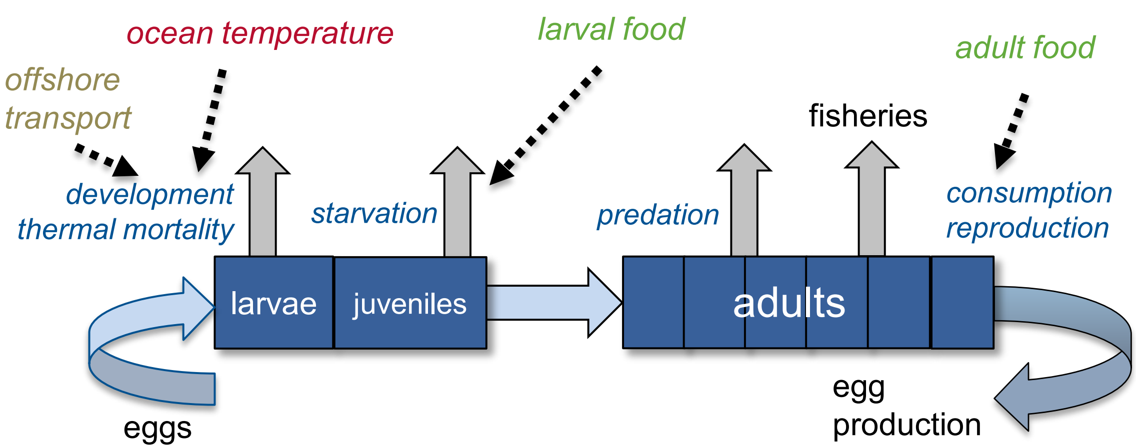
- Mechanistic model structure based on biological processes affected by environmental drivers *(Koenigstein et al. 2016)*

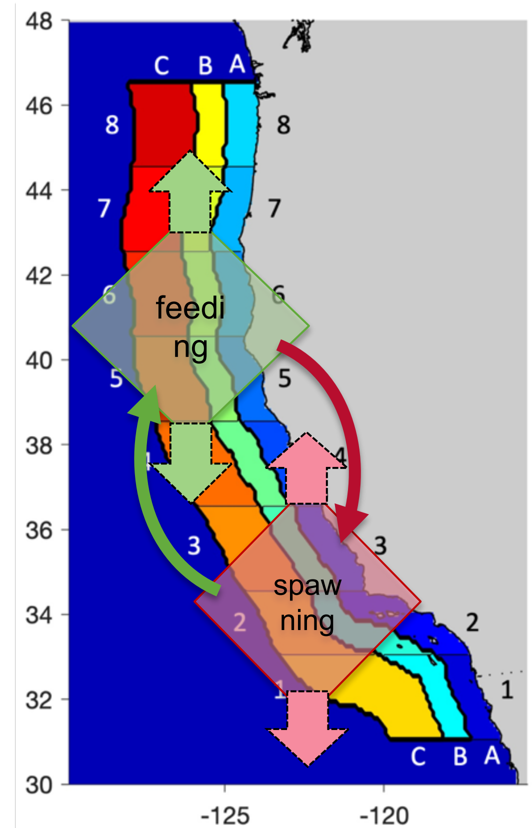


Environmental drivers and spatial migration

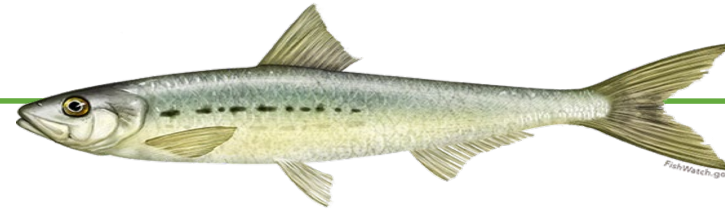
- 24 spatial cells: driven by input from ROMS-NEMUCSC hindcast and downscaled projections
  (Pozo Buil et al 2021, Fiechter et al. 2020)

- *Spatial processes:*
- Spawning latitude following optimal SST (13.5°C)
- Larval offshore transport determined by upwelling strength (CUTI)
  (Jacox et al. 2018)
- Adult feeding migration follows best food location





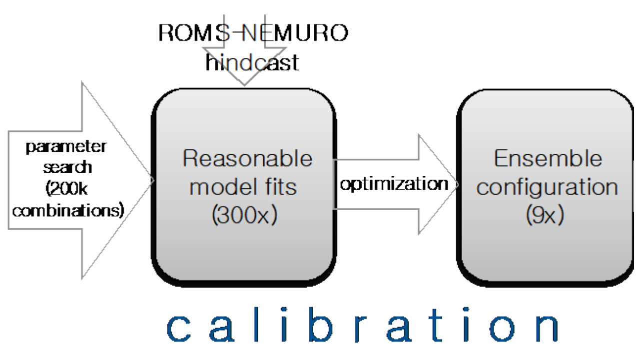
Pacific sardine: model calibration

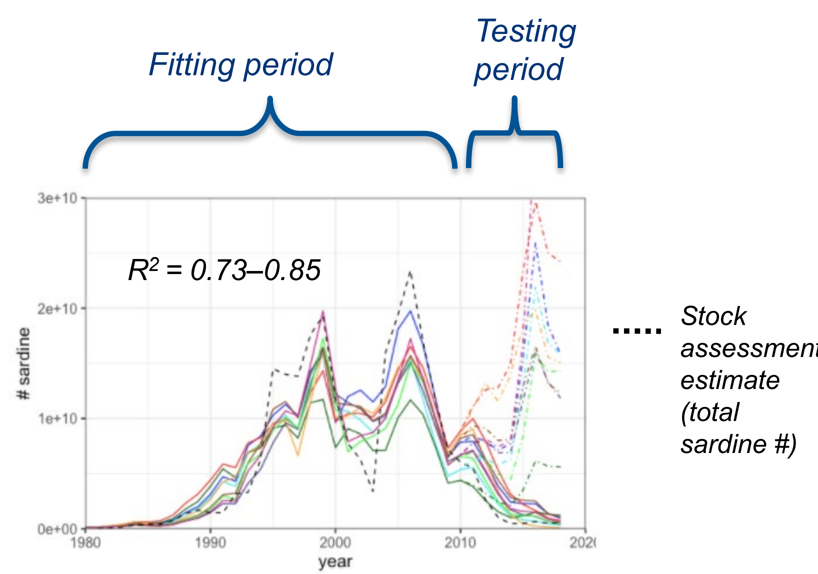


- Fitting period: 1980-2010
  - stock assessment no. & landings at age *(Kuriyama et al. subm.)*
  - CalCOFI egg+larvae data for annual spawning habitat *(Auth et al. 2018, Muhling et al. 2020)*

- 9 ensemble model configurations represent wide parameter range
  - ➢ *"Ecological uncertainty"*

- Testing period 2011-18 (low plankton): Recent lack of recovery explained by low food

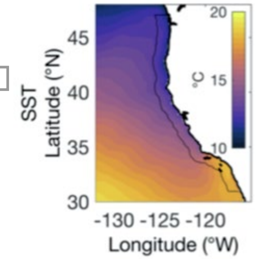




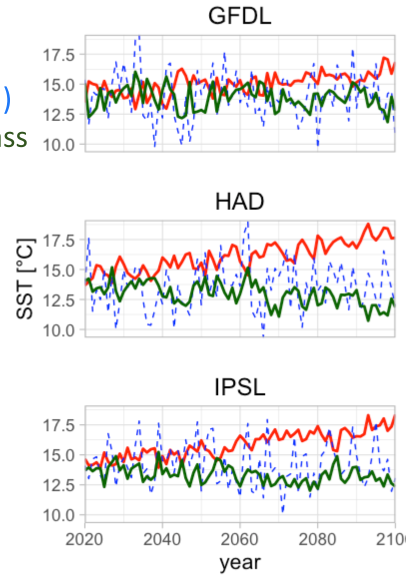
Model projections

- Projections under 3 downscaled earth system models (CMIP5) under business-as-usual emissions (RCP 8.5)

(Pozo Buil et al. 2021)

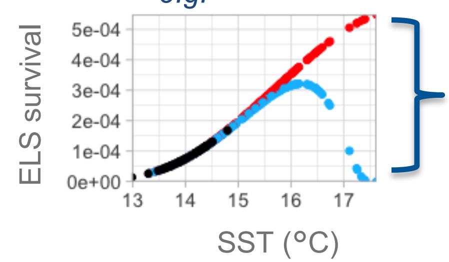


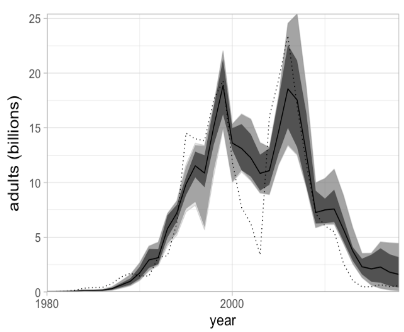
SST
upwelling (CUTI)
plankton biomass
(total shown)



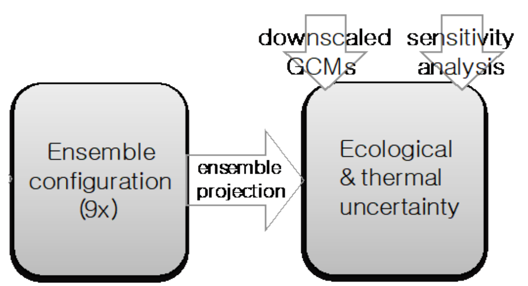
- "Thermal uncertainty": sensitivity to T_{opt} of ELS thermal window

e.g.





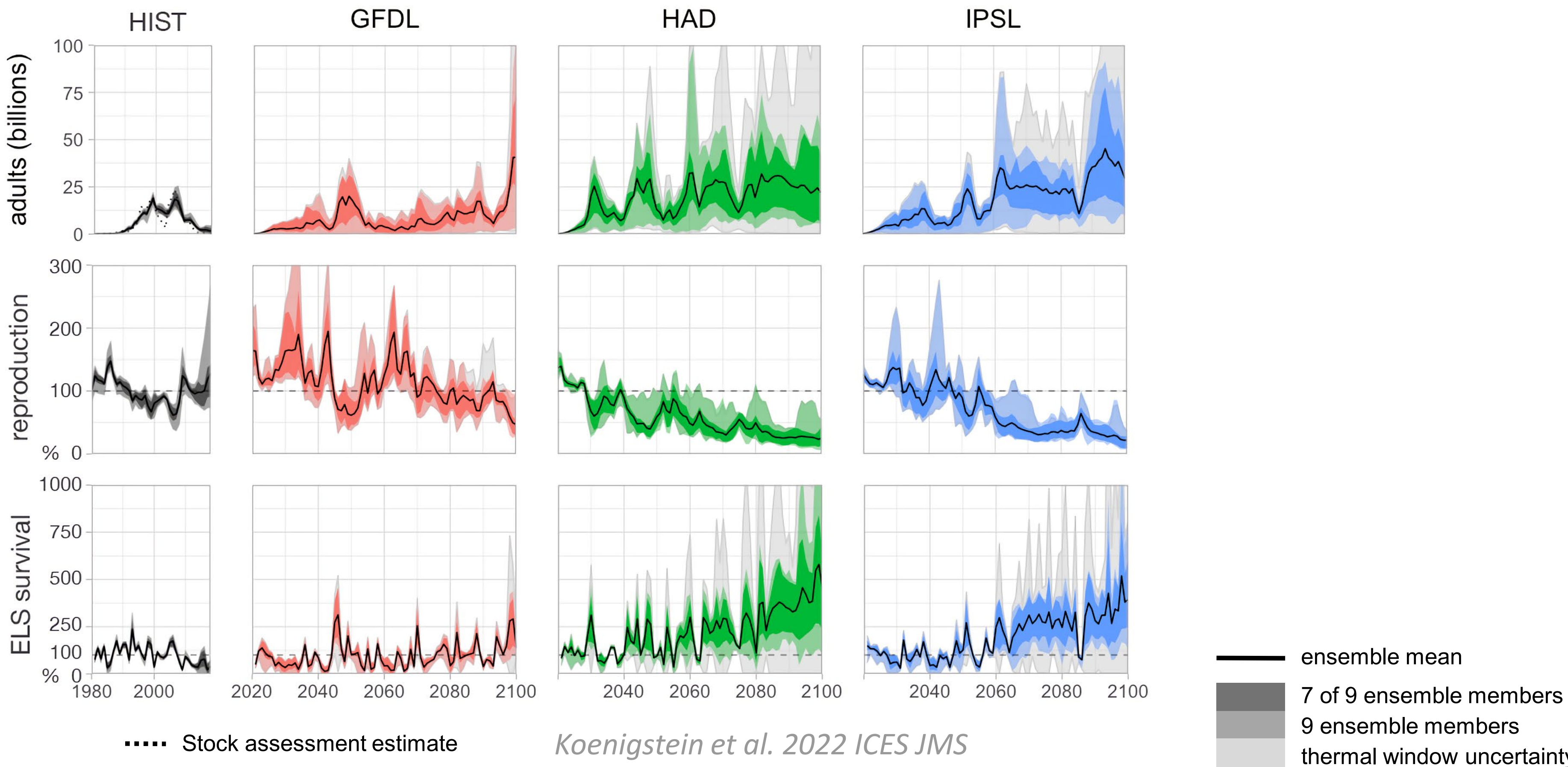
Ensemble configuration range



projection

Sardine projections, ecological + thermal uncertainty

- GFDL: recovery, limited by ELS food availability and slower warming
- HAD+IPSL: increasing stock through high ELS survival, later adult food-limited
  - ELS thermal uncertainty dominates after ~2070
- Decadal-scale fluctuations produced from modulated process fluctuations

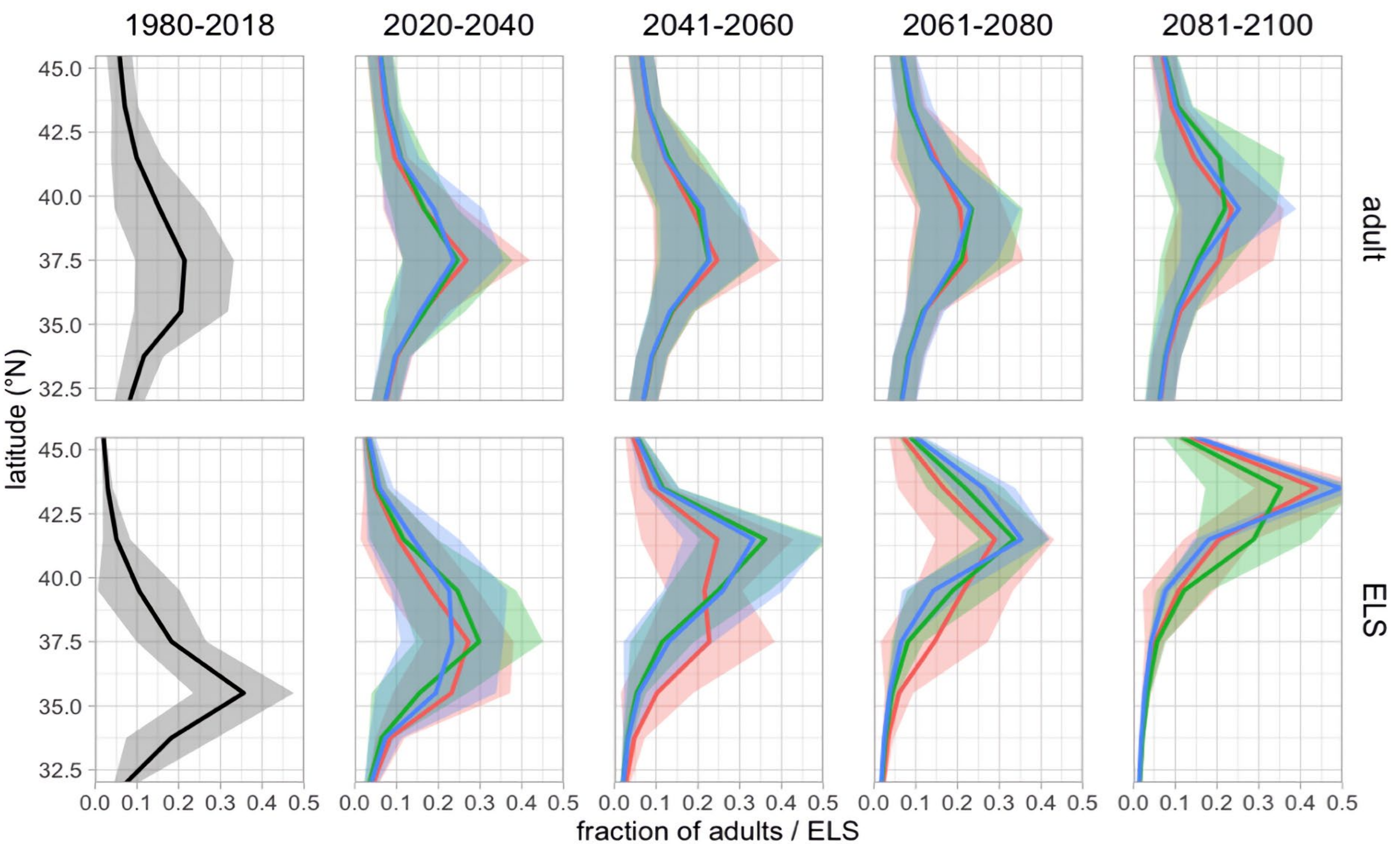


Koenigstein et al. 2022 ICES JMS

Sardine distribution

- Spawning habitat shifts northward faster than feeding habitat

➢ Total latitudinal shift (center of gravity) is less than when only looking at physical parameters



Mean and SD among ensemble configurations

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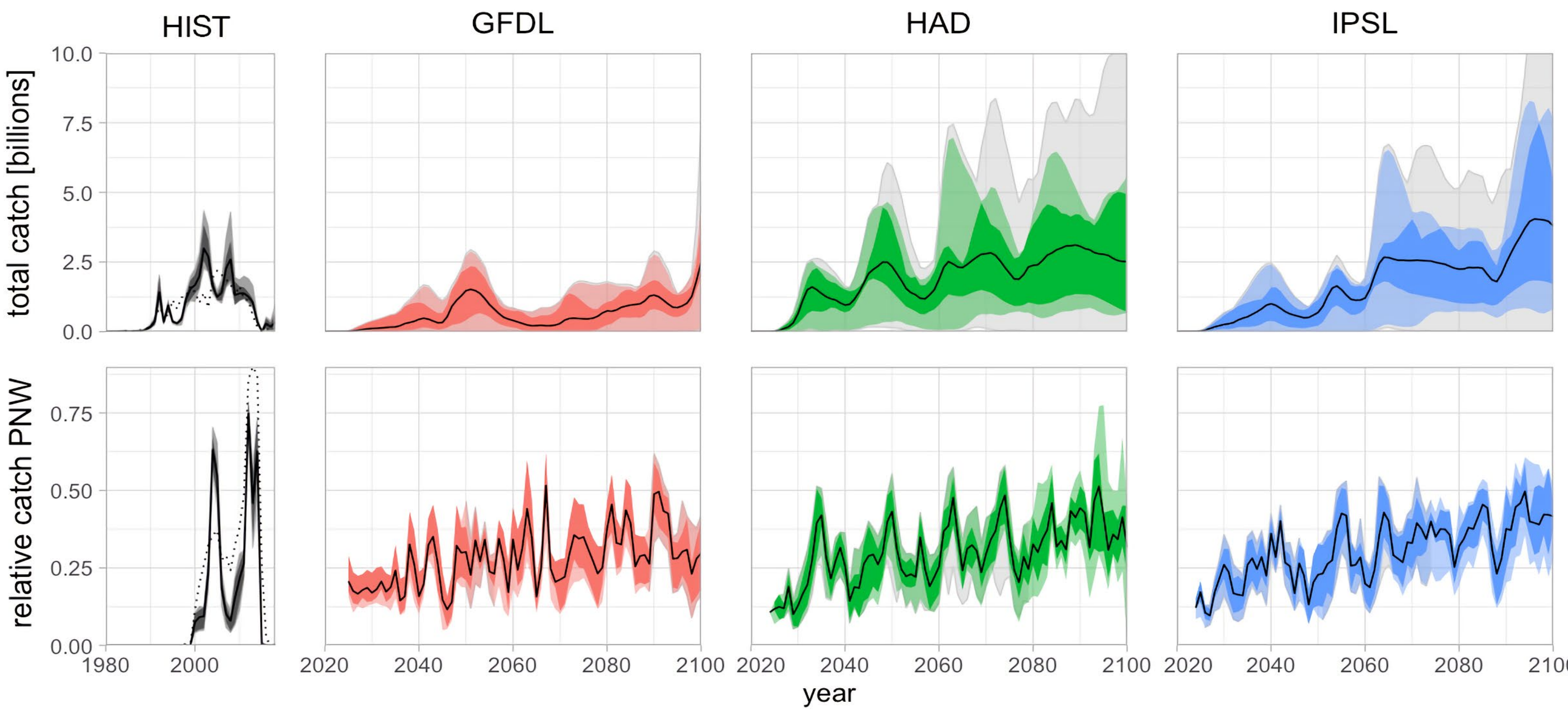
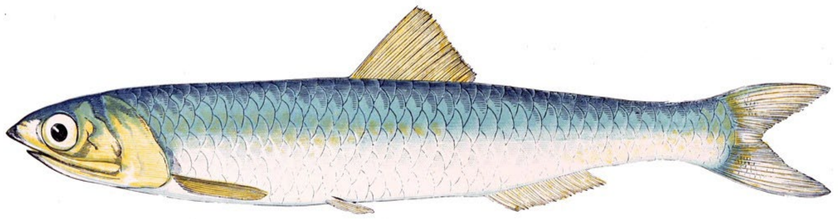
Landings and shift among fleets

- Landings per age class fitted to data for PNW/MexCal fleets
- Base HCR for projections: mean historical E_{MSY} = 0.096 (1980-2014 stock-landings correlation, current range: E_{MSY} = 0.05-0.2)
- Catchability depends on annual position (latitude COG) –> increasing share for PNW fleet



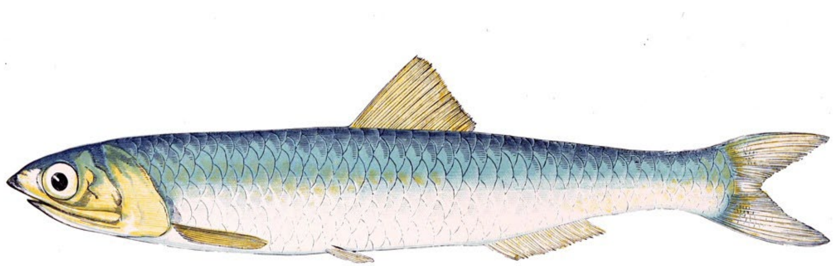
Koenigstein et al. 2022 ICES JMS

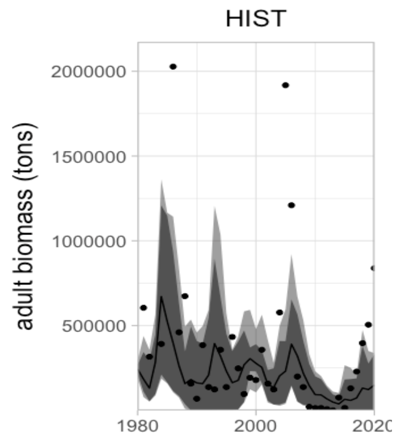


2. anchovy

II. Northern Anchovy

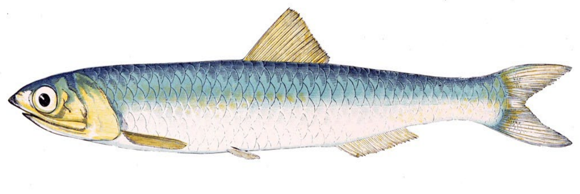
- Adaptation of model for Northern anchovy stock:
  - Less (reliable) data available (no stock assessment)
    - Alternatives: Egg production based population estimate, sealion diet timeseries
  - Life history characteristics adjusted, spawning and feeding lcoation re-fitted
- New extended ROMS-NEMUCSC to 2019
- Preliminary model configuration set reproduces CalCOFI-based estimate and fluctuations roughly, low stock 2009-15 and increase 2016-18



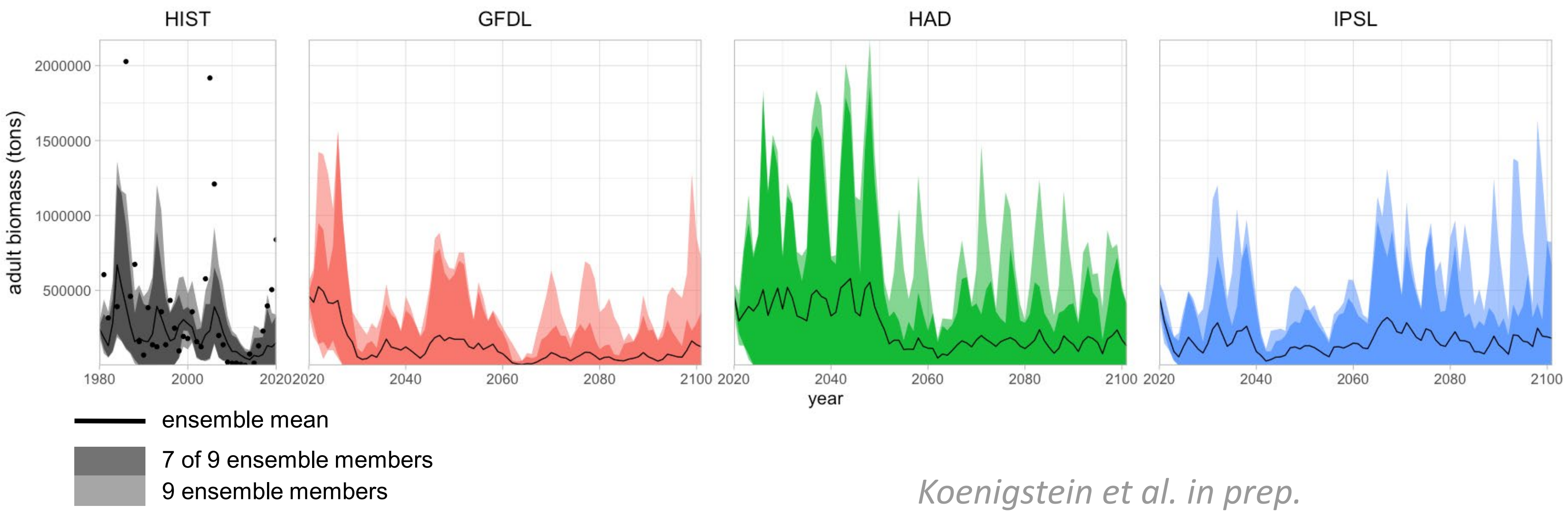


Anchovy model projections

- *Preliminary results:*
- No catch (during 1980-1990 and future)
- Detailed thermal sensi upcoming: Not inhibited by T_{opt}



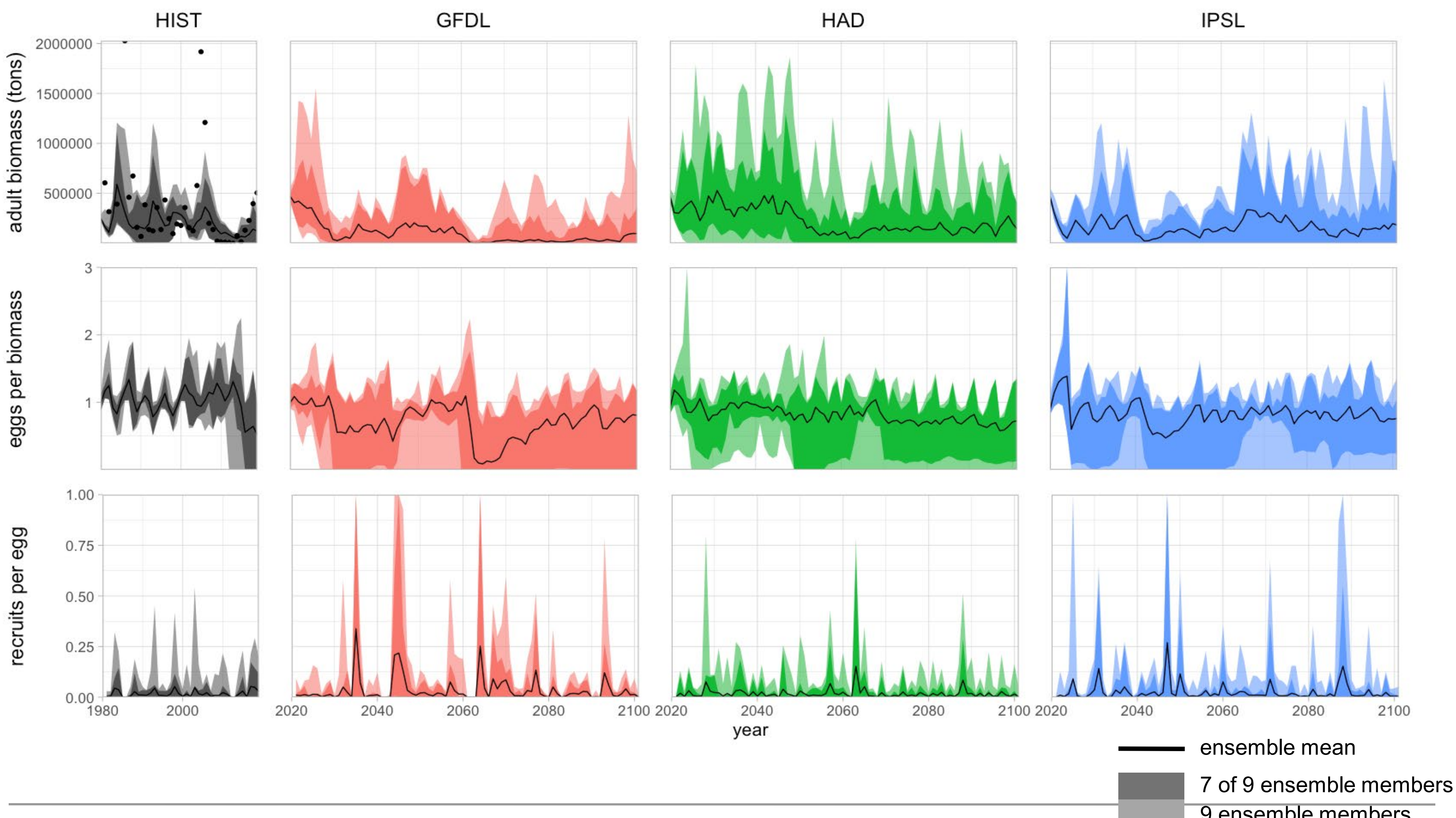
➢ Periods of solid biomass, but no long-term recovery



Koenigstein et al. in prep.

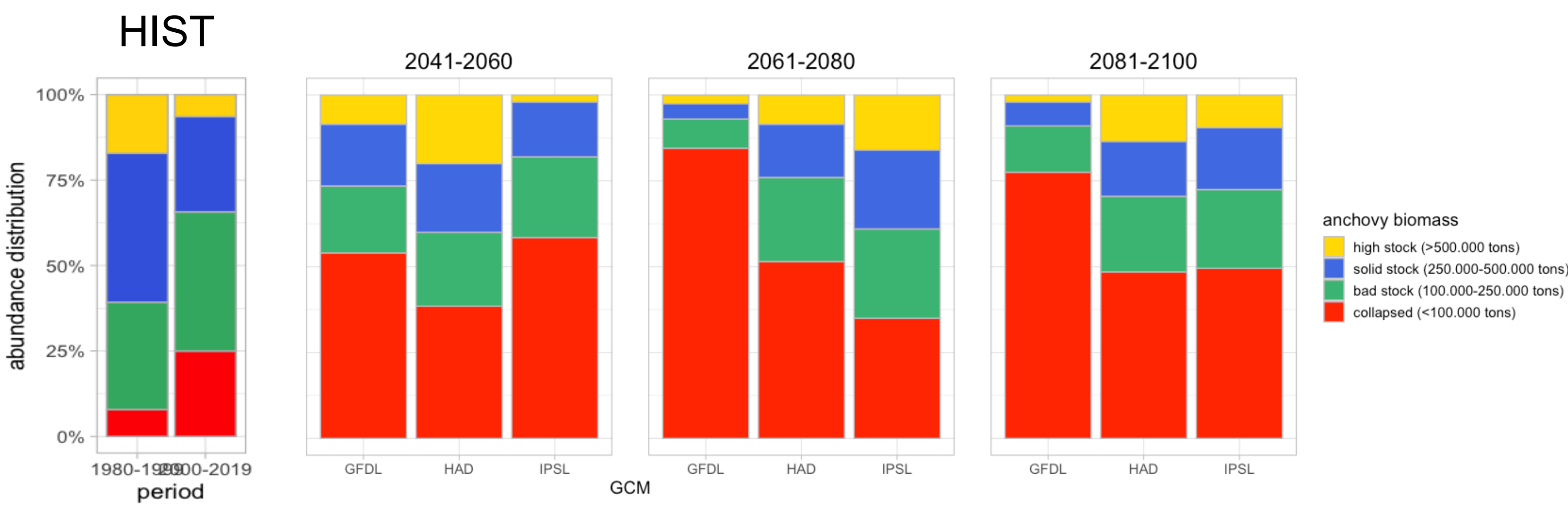
Anchovy processes

- Decreasing adult food availability inhibits egg production
- Regularly good recruitment success

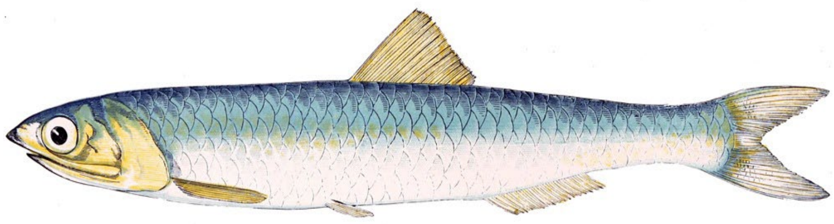


Cumulative risk for anchovy

- Stock collapse risk for anchovy increasing (w/o thermal sensitivity)



upcoming work



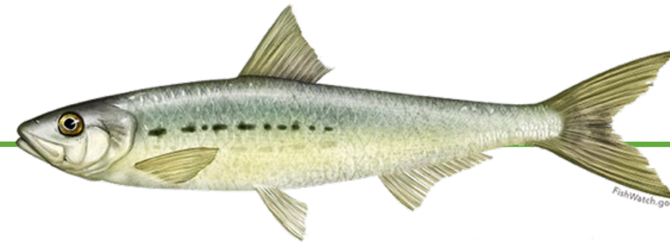
- Anchovy: calibration to sealion diet timeseries and no-at-age assessment estimates for recent years
- More highly resolved spawning timing / ELS module
- Test feeding interactions

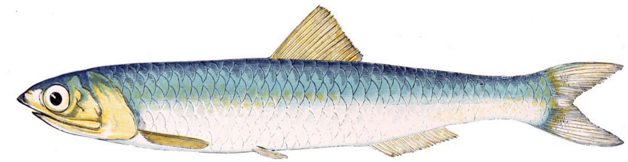
Summary / conclusions

- Using ESM-ROMS-BGC models, we can explain sardine boom-bust in the 1990-2000s and decadal-scale fluctuations:
  - driven by ELS temperature, ELS food, adult food
  - modulated by population feedbacks (age structure, density-dependent consumption, migration, and fisheries)
- ➢ Anticipating SPF booms and busts seems possible
- Sardine will likely recover by mid-century, while there are no indications for a long-lasting anchovy resurgence

- ➢ Projections will have:
- **Environmental uncertainty** *(diverging earth system models*)
  - limiting factors and boom/bust timing differs among ESMs
- **Ecological uncertainty** *(contribution of population processes and feedbacks):*
  - dominant in mid-term (20–50y)
  - can be further constrained by biological data on vital rates
- **Thermal window uncertainty** *(physiological optima/limits for ELS):*
  - dominates long-term uncertainty (>60y) in fast-warming models

Contributors / Reference





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***Future Seas* 1 and 2 projects: www.futures-seas.com**

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