



Model-derived scenarios of forage fish productivity and distribution for management strategy evaluation

FUTURE SEAS
A Physics-to-Fisheries Management Strategy
Evaluation for the California Current System



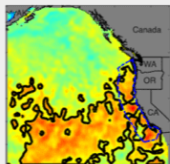
Desiree Tommasi - detommas@ucsc.edu,
Fisheries Collaborative Program, University of California Santa Cruz, Working
collaboratively with NOAA SWFSC

Robert Wildermuth, Barbara Muhling, Isaac Kaplan, Jerome Fiechter,
Pierre-Yves Hervann, Stefan Koenigstein, Mercedes Pozo Buil,
Caitlin Allen Askelrud, Steven Bograd, Ana Guerra, Elliott L. Hazen,
Stephanie Hopkins, Michael Jacox, Alexander Jensen, Peter
Kuriyama, Nerea Lezama-Ochoa, Owen Liu, Felipe Quezada
Escalona, and Stephen Stohs

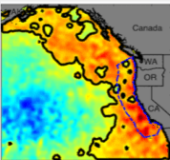
The Climate is Changing



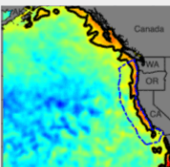
Marine Heat Waves off the West Coast



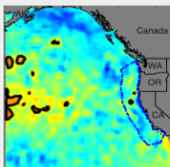
December 2025
Only the third time West Coast waters have grown so warm over so much area at this time of year.



December 2014
The last time waters warmed so much was a large heatwave known as "The Blob," which disrupted the marine ecosystem.



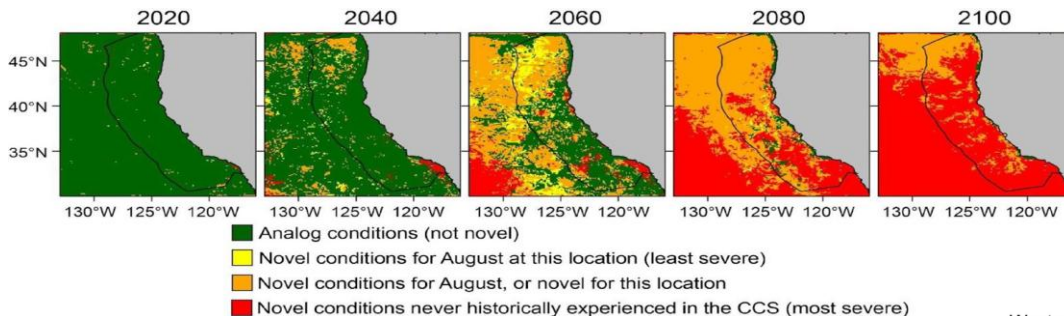
December 1997
Strong El Niño conditions pushed temperatures so high for the first time, prompting shifts in marine species.



December 1990
Historically "normal" conditions in the North Pacific that are cooler at this time of year.



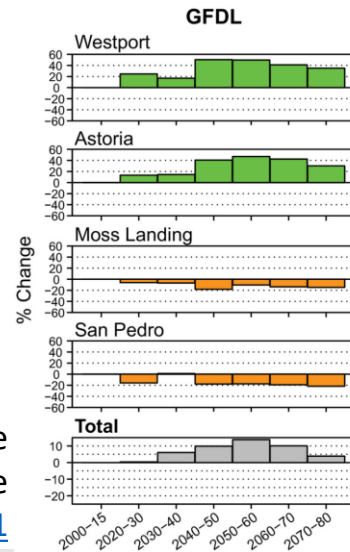
Shifts in habitat conditions off U.S. West Coast Smith et al. 2023



Potential Impacts on Small Pelagic Species and Fisheries

[NOAA Feature Story, March 3, 2026](#)

% change in mean landings of northern sardine subpopulation relative to 2000-2015 average
[Smith et al. 2021](#)



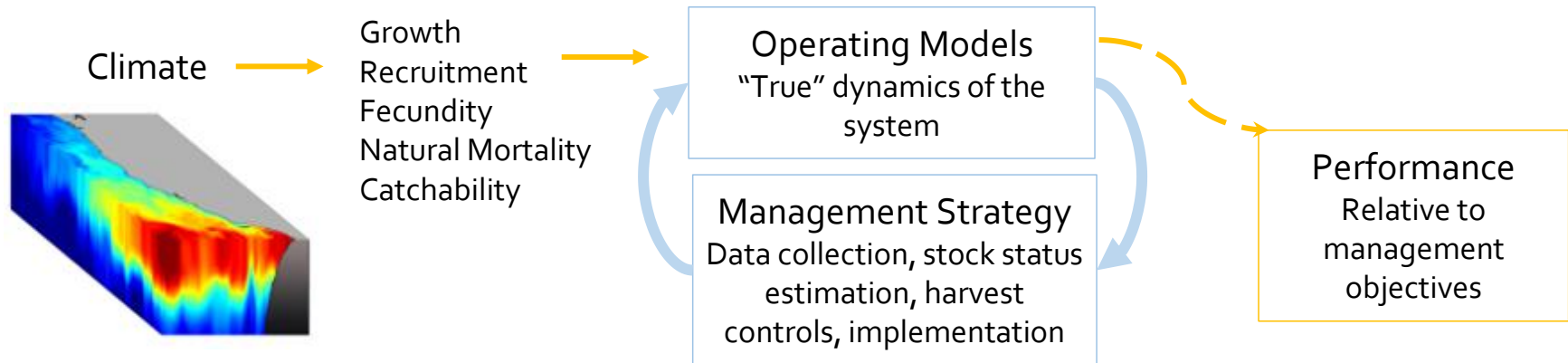
Are our Management Systems Resilient to Such Changes?

- **Monitoring Systems** - Will scientific surveys still cover main habitat of assessed stocks?
- **Transboundary Issues** - Will availability change across management boundaries?
- **Stock Assessments** - Will stock assessment performance be maintained under climate change?
- **Catch Advice** - Will current management strategies remain effective under climate change? Do alternative rules perform better?



Management Strategy Evaluation as a Tool to Test Robustness of Management System to Climate Variability and Change

- MSE is a process to evaluate the trade offs and performance of candidate management strategies under a range of uncertainties using computer simulations
- Uncertainties can include climate driven uncertainty



How to integrate climate uncertainty into MSE

- Defining future state of nature by generating range of operating models (OMs)
- Approach depends on understanding of climate and biology/fisheries relationship and availability of oceanographic projections
- **EMPIRICAL APPROACH** (*sensu* [Punt et al. 2014](#)) - Consult experts to define potential scenarios, **no direct climate-biology/fisheries link** identified. Easily implementable but hard to assign plausibility

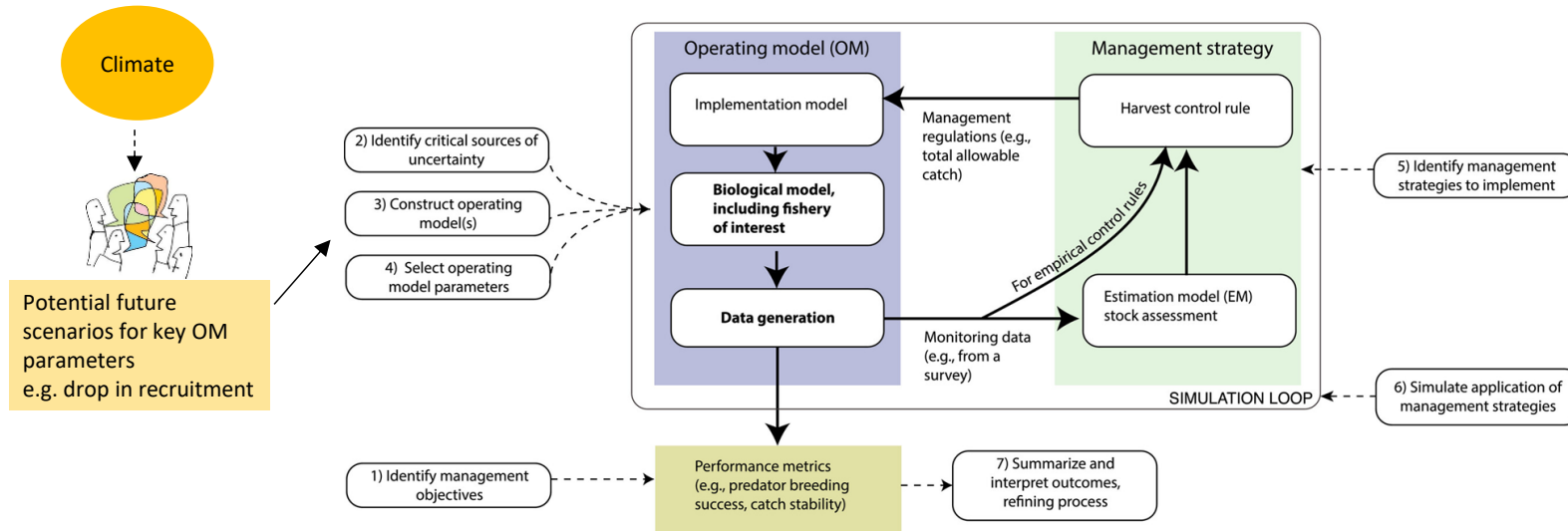


Figure from [Siple et al. 2021](#)

How to integrate climate uncertainty into MSE

- **MECHANISTIC APPROACH** (*sensu* [Punt et al. 2014](#)) - Use **climate-informed OM**. If complex ecosystem model, high computational needs. If climate-enhanced single species model, statistical relationship between environment and vital rates may break down

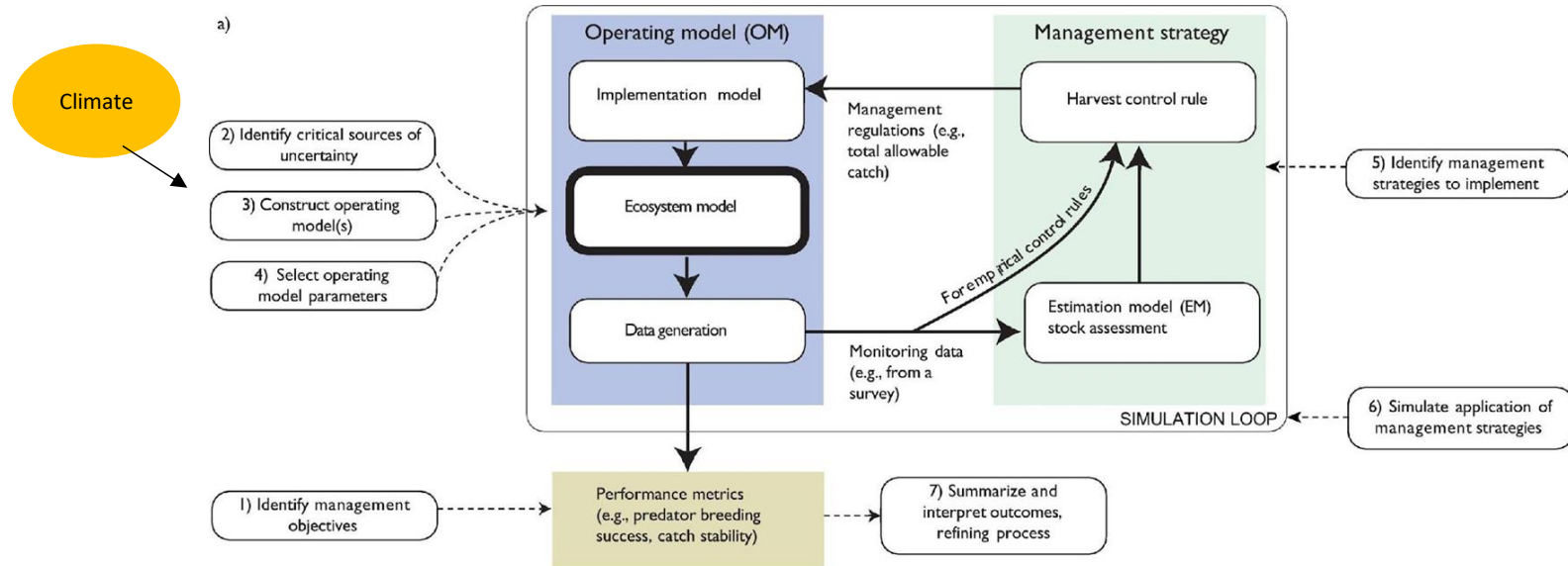


Figure from [de Moor et al. 2023](#)

How to integrate climate uncertainty into MSE

- **HYBRID APPROACH** (*this study*) - Use existing climate-informed ecosystem models to develop **climate-informed uncertainty scenarios for OM parameters**. Less computationally intensive to run than mechanistic approach, but still process-based

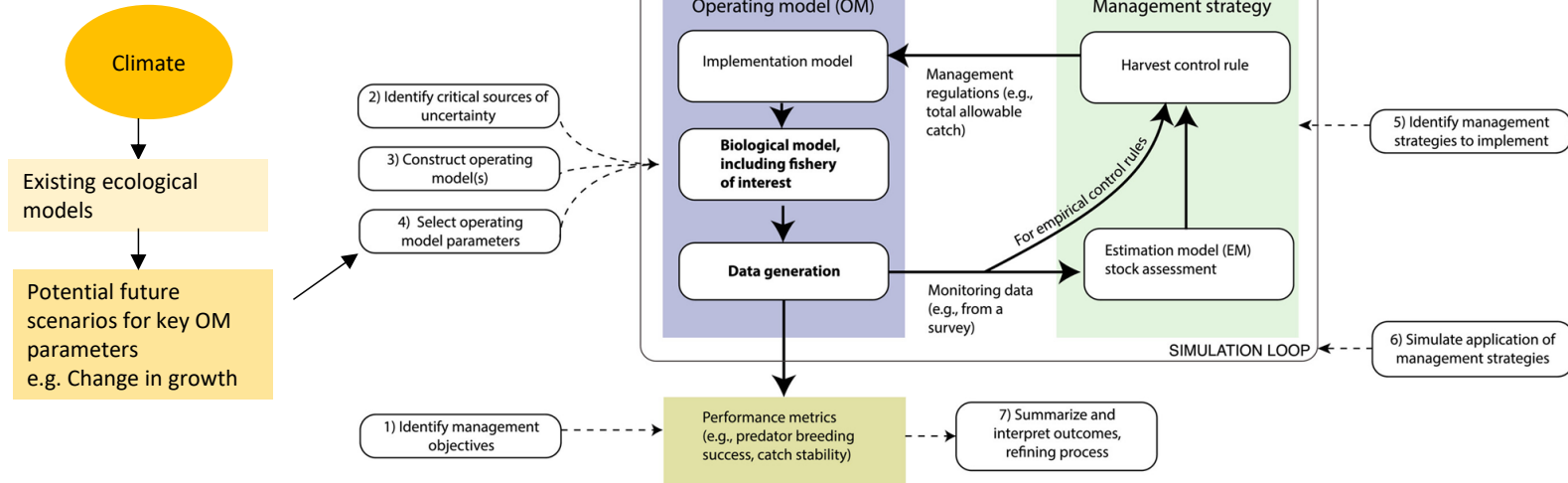
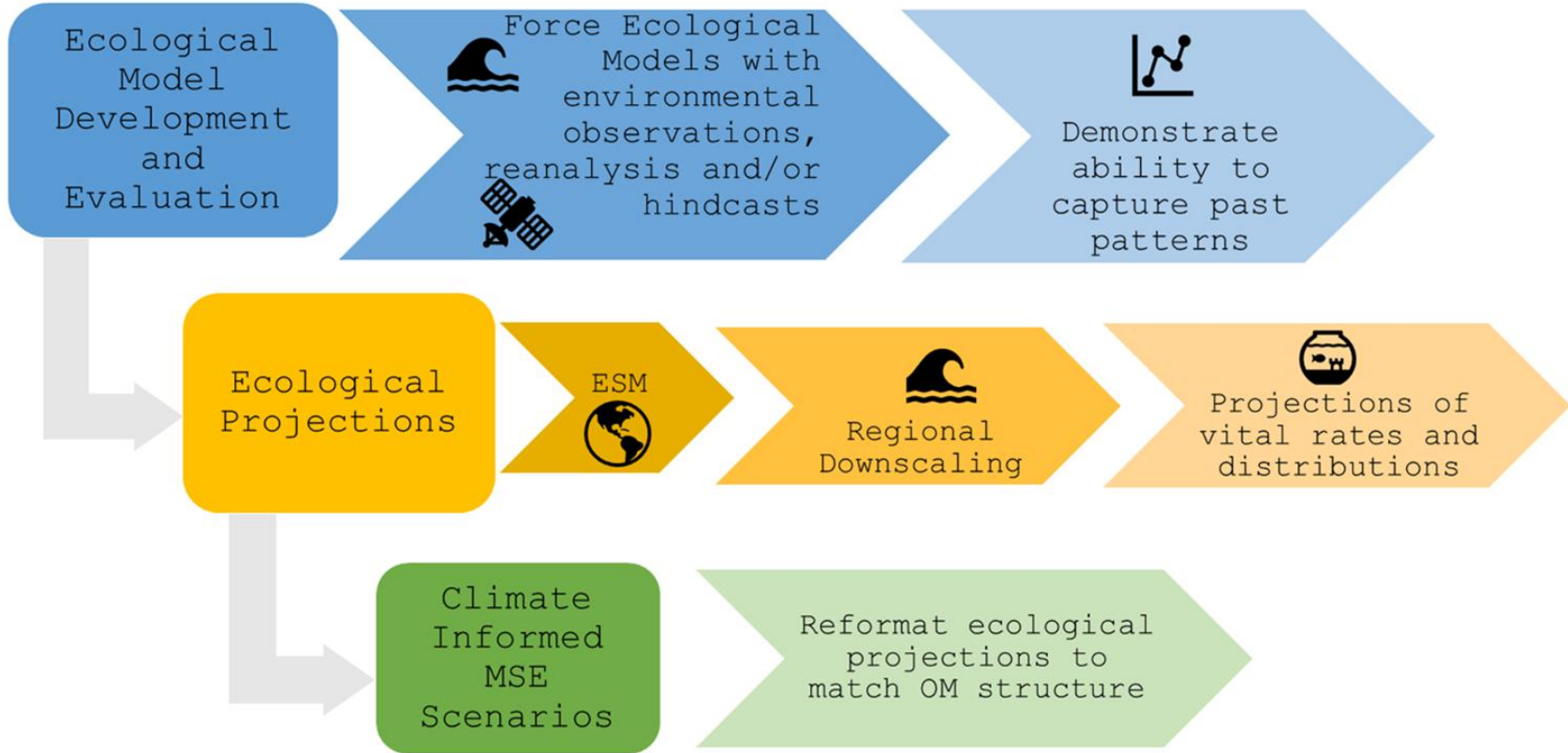


Figure from Siple et al. 2021

Application to Pacific Sardine Northern Subpopulation

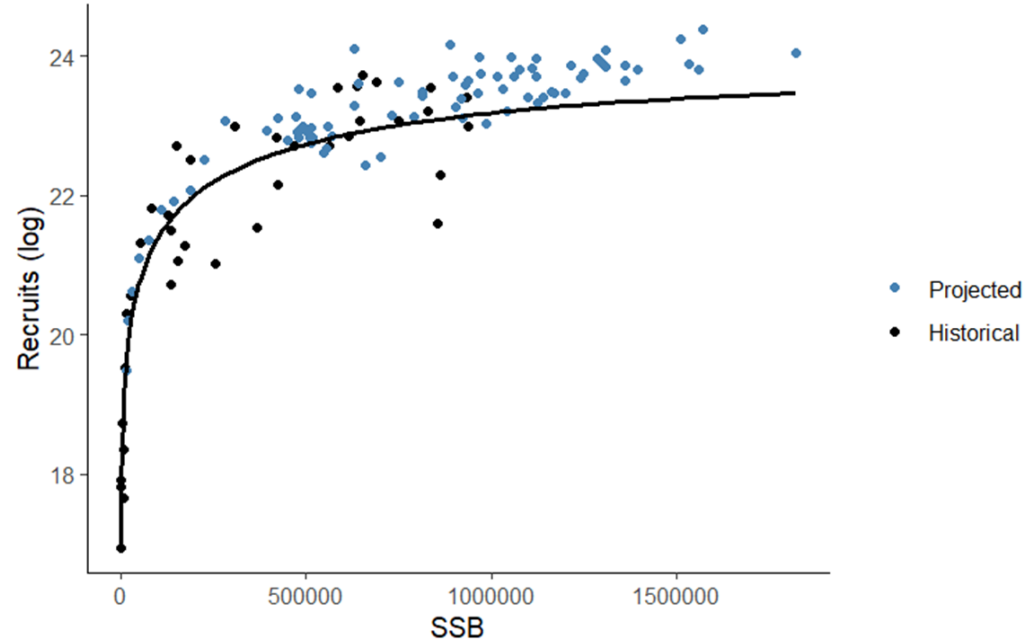
- Leverages existing projections of vital rates and distribution for the northern subpopulation of Pacific sardine from regional ecological models
- Ecological model output informs recruitment, growth, natural mortality, or catchability parameters in MSE OMs
- OMs based on single species OM similar to stock assessment ([Wildermuth et al. 2024](#))
- Ecological models used are DynaMICE ([Koenigstein et al. 2022](#)), the end-to-end Atlantis ecosystem model ([Liu et al. 2025](#)), an Individual Based Model (IBM, [Fiechter et al. 2021](#)), and Species Distribution Models (SDMs, [Muhling et al. 2025](#))
- Climate projections from three global Earth System Models (ESMs) and emission scenario RCP 8.5, downscaled for U.S. West Coast using a regional ocean model ([Pozo-Buil et al. 2021](#)), were integrated into the ecological models

Scenario Development Workflow



Recruitment Projections from DynaMICE

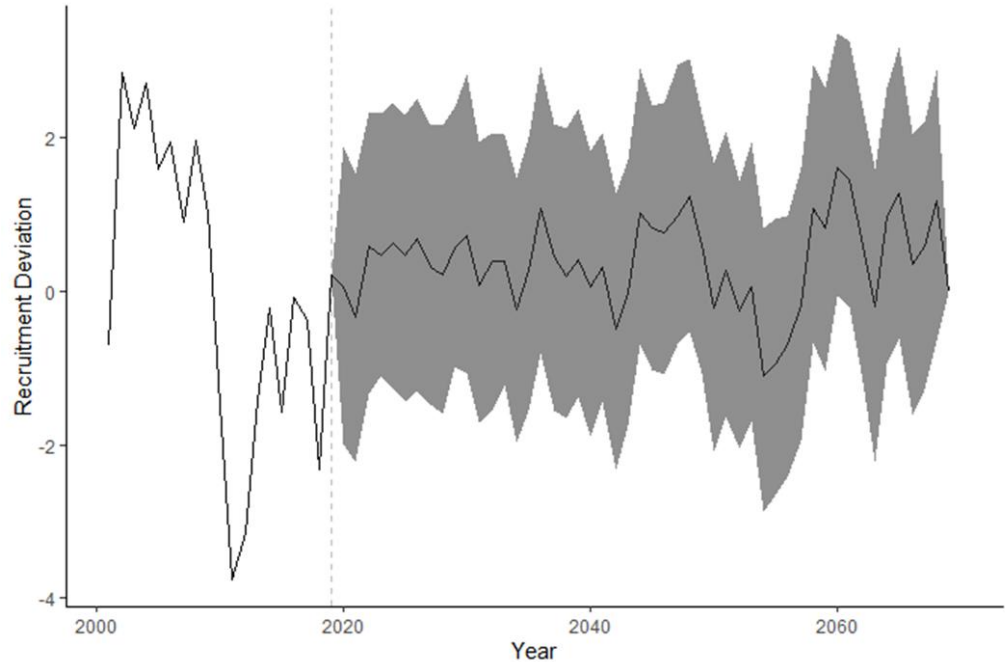
- Explicitly models egg production and early life stage survival
- Stock-Recruitment relationship fit to DynaMICE output
- Resulting recruitment projections integrate effects of temperature, food, and offshore transport



Applied in MSE of [Wildermuth et al. 2024](#)

Recruitment Scenario for MSE

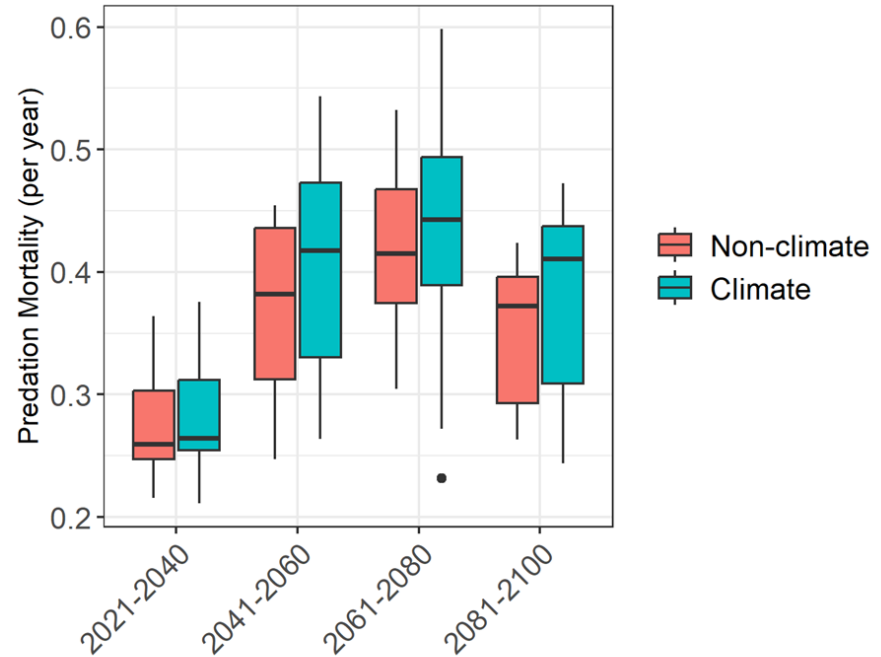
- Assumed that the DynaMICE recruitment deviations explained 70% of the variability in recruitment deviations, with the rest being random process error.
- The standard deviation of the resulting total recruitment deviations were scaled to match that of the stock-recruitment relationship defined in the conditioning period.



Applied in MSE of [Wildermuth et al. 2024](#)

Predation Mortality Projections from Atlantis

- Predation mortality dependent on overlap of sardine with predator, abundance of sardine and other prey, metabolic effects of temperature on growth of sardine and predators
- 2.5% to 8.6% increase in predation mortality under climate change
- Temporal variability higher than climate induced change
- Due to changes in sardine abundance - lower M in boom years due to predation satiation



Preliminary Results

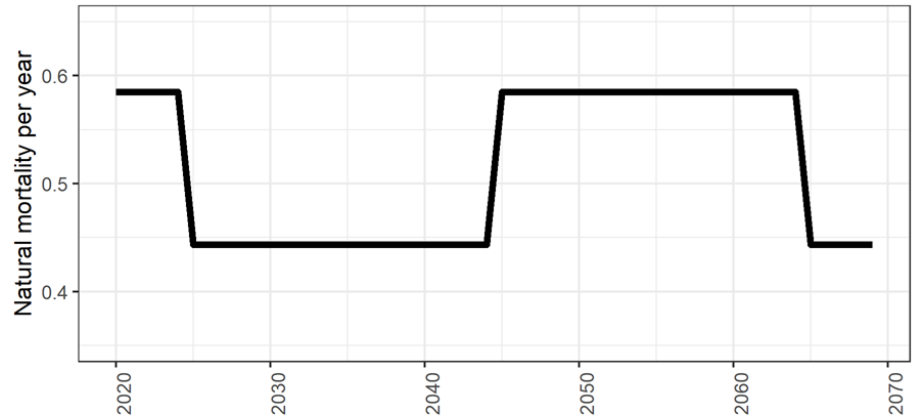
Natural Mortality Scenarios for MSE

Climate Driven M Scenario:

- Natural mortality (M) in base OM scaled by the proportional climate driven change in predation mortality from Atlantis
- Climate-driven M scenarios of 0.6 to 0.635 yr⁻¹ depending on 20-yr block

Density Dependent M Scenario:

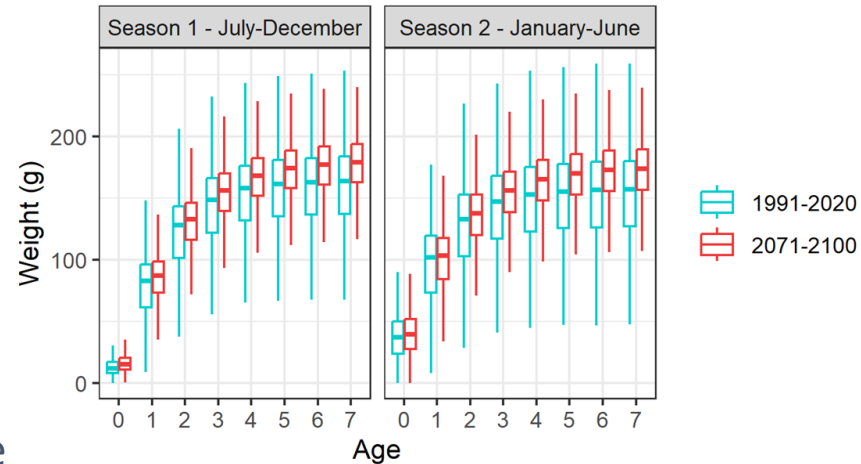
- Uses time-variability in predation mortality from Atlantis non-climate run to derive a time-varying M scenario
- As density dependent, shift in M has to be accompanied by shift in recruitment



Preliminary Results

Weight-at-age Projections from IBM

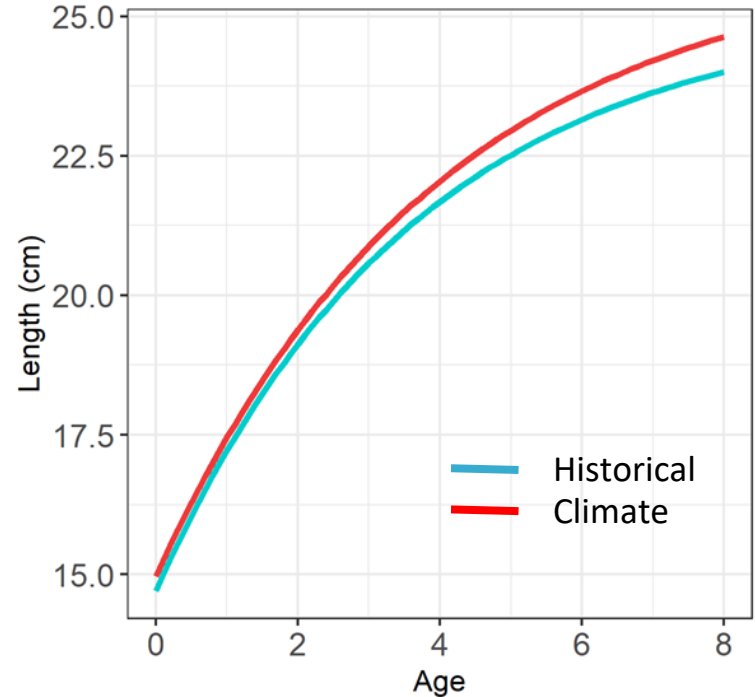
- Spatial model; eggs and larvae advected based on water velocity; movement of other stages based on a kinesis approach that uses temperature and food cues.
- Temperature and zooplankton impact growth based on bioenergetics
- Small, but statistically significant increase in weight at age under climate change despite large individual variability
- Lower variability under climate change may be due to northward movement and concentration of subpopulation into smaller region



Preliminary Results

Growth Scenario for MSE

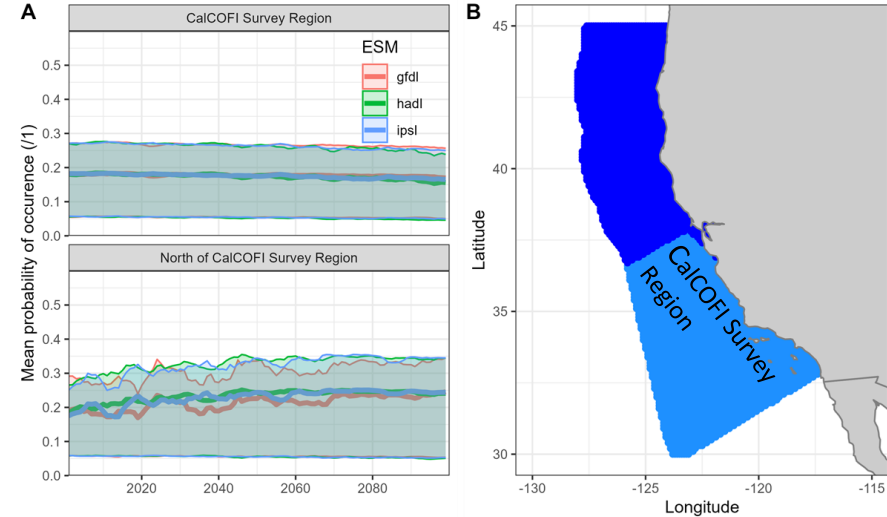
- Von Bertalanffy growth curves fit to the IBM output for the historical (1991-2020) and projection period (2071-2100)
- OM Von Bertalanffy growth parameters scaled by proportional change in growth from IBM climate projection



Preliminary Results

Distribution Projections from SDMs

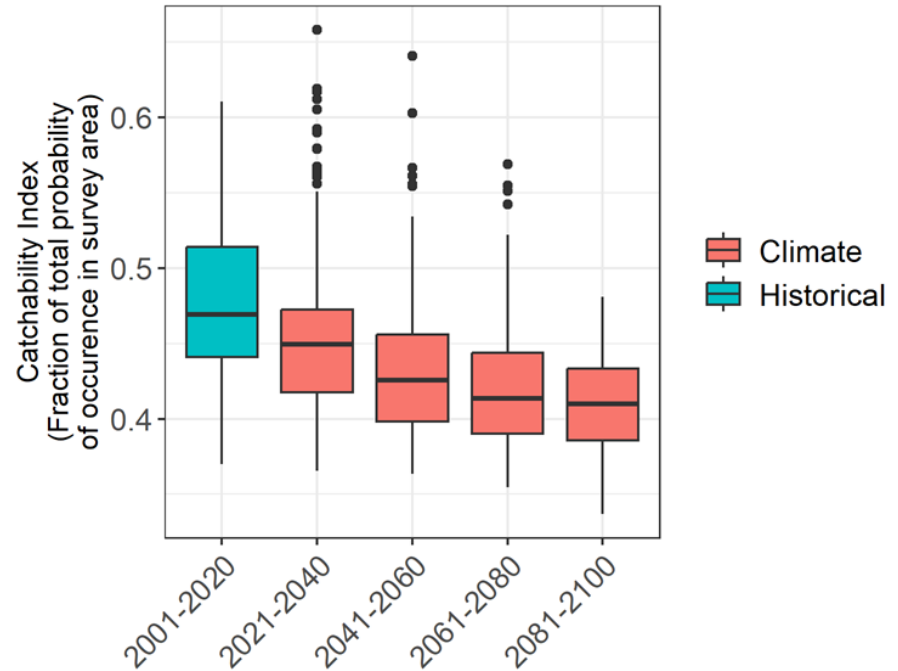
- Statistical model
- Probabilities of occurrence will increase north of the CalCOFI survey area
- For illustration purposes only as the sardine assessment does not use a CalCOFI survey index



Preliminary Results

Catchability Scenario for MSE

- Catchability index is the proportion of the total probability of occurrence that is in the survey region
- 5.48% to 13.4% decrease in future catchability relative to historical (2001-2020) depending on the time block



Preliminary Results

Conclusions: Hybrid approach of Using Ecological Models to Drive Climate-informed MSE scenarios

- Enhanced ecological realism as compared to empirical MSE scenarios approaches
- Less computing intensive than using a process-based model as OM, enabling larger exploration of uncertainty space
- Integration of output of ecological models into simpler single-species OM necessitates a rescaling process to address the mismatch in ecological resolution
- Pacific sardine vital rates highly variable, climate driven change in parameter small relative to interannual variability
- Ecological model output is useful for generating MSE scenarios beyond changes directly driven by climate (e.g. density dependent predation mortality from Atlantis ecosystem model)

Next Steps: Incorporate scenarios into OMs

Thank you

- Future Seas Team
- All the folks collecting and processing oceanographic data and biological data for Pacific sardine in the California Current
- The Climate and Fisheries Adaptation Program of the NOAA's Climate Program Office for funding
- Questions? detommas@ucsc.edu

FUTURE SEAS
A Physics-to-Fisheries Management Strategy
Evaluation for the California Current System

https://joshcullen.github.io/Future_Seas_Website/

<https://github.com/futureseas>



UC SANTA CRUZ