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

UNIVERSITY OF CALIFORNIA SANTA CRUZ

Management Strategy Evaluation under shifting forage fish productivity and distributions in the California Current

CAFA Climate and Fisheries Adaptation

CPO Climate Program Office | NOAA Fisheries

Future Seas Team

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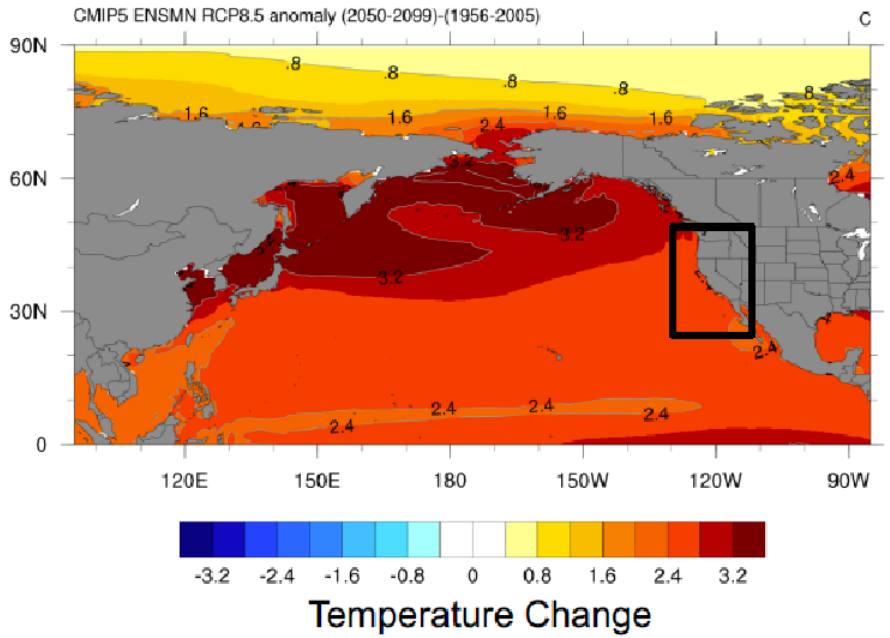
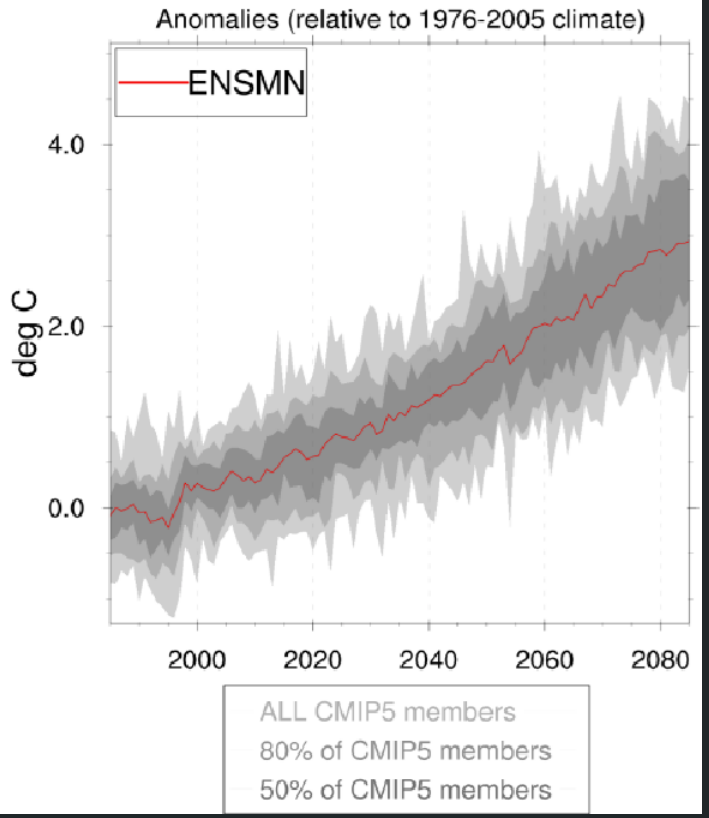
SPF Symposium, W7
May 4, 2026

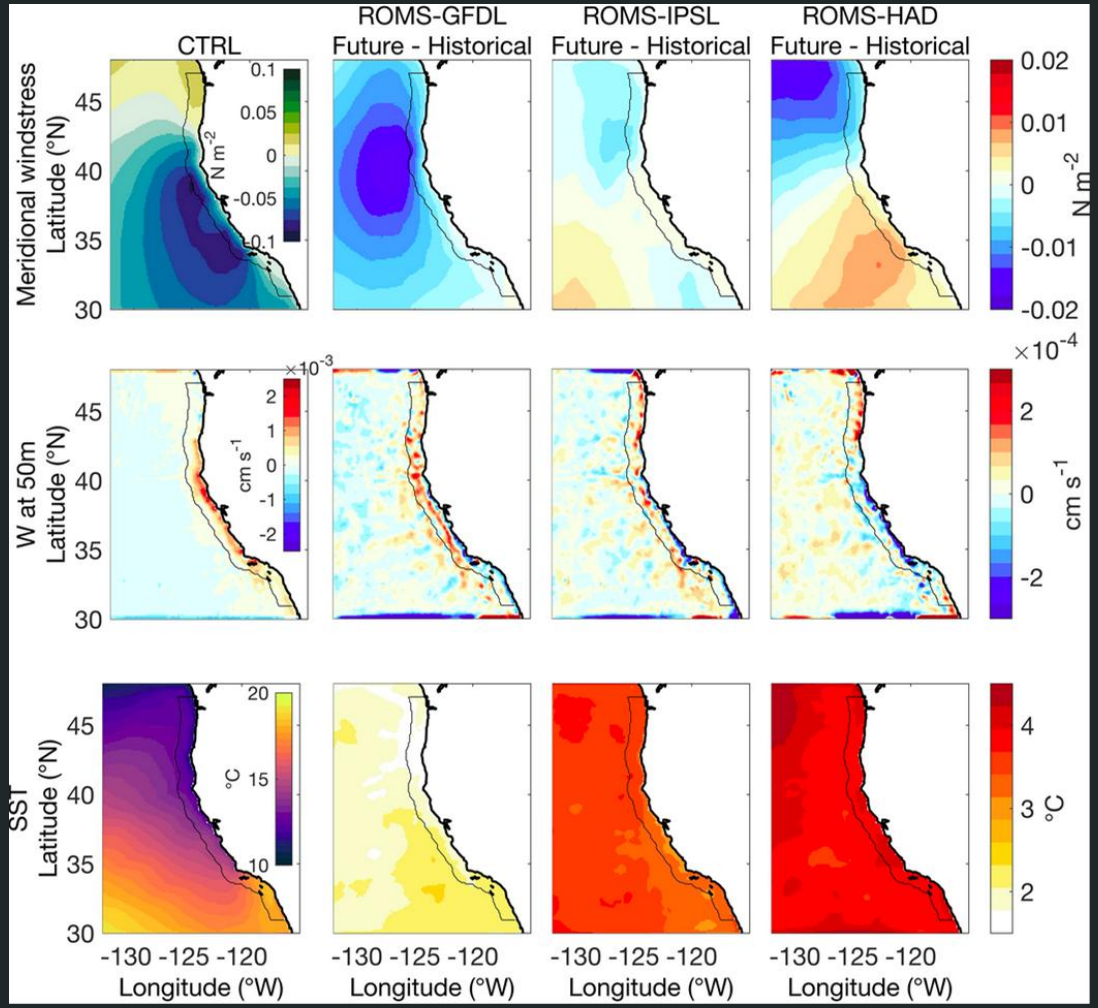
The Climate is Changing





The California Current System Will Change

Pozo-Buil et al. 2021,
https://doi.org/10.3389/fmars.2021.612874



How will these changes impact forage fish species in the California Current?

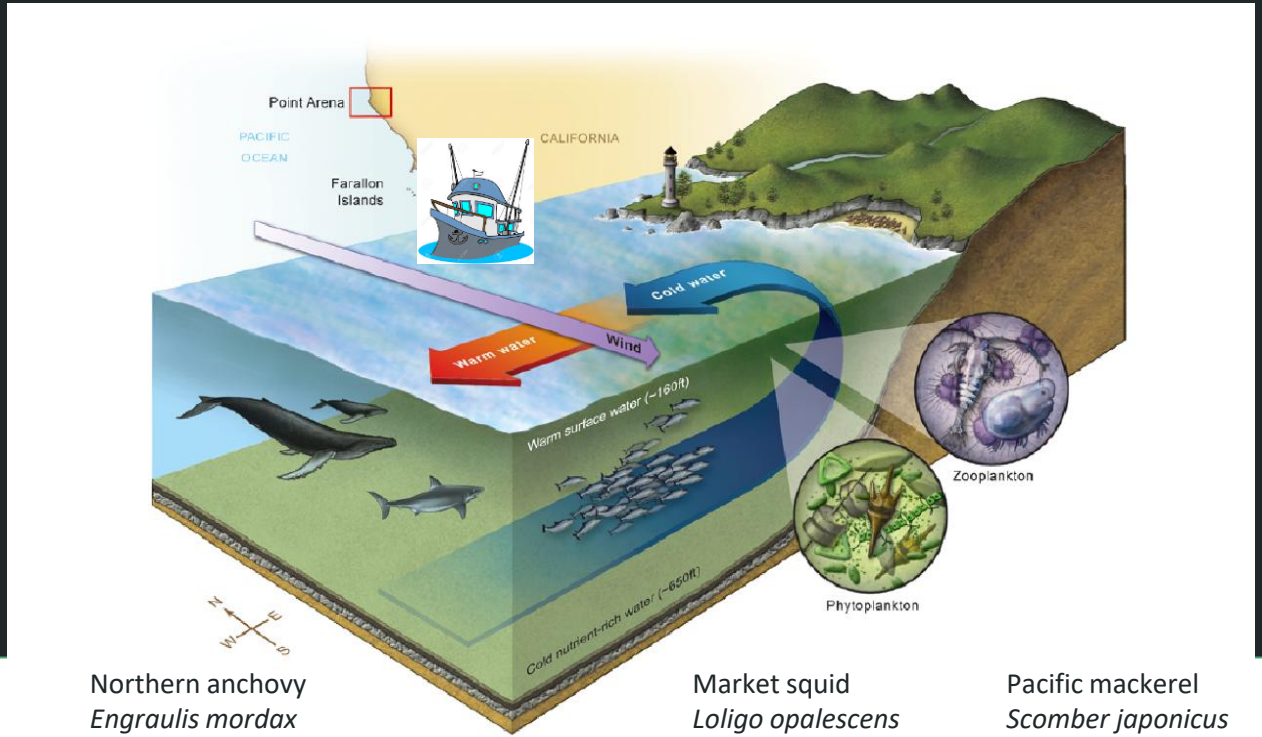


Illustration by Fiona Morris

Pacific sardine
Sardinops sagax

Northern anchovy
Engraulis mordax

Market squid
Loligo opalescens

Pacific mackerel
Scomber japonicus

Jack mackerel
Trachurus symmetricus

Are our current management systems robust to such changes?

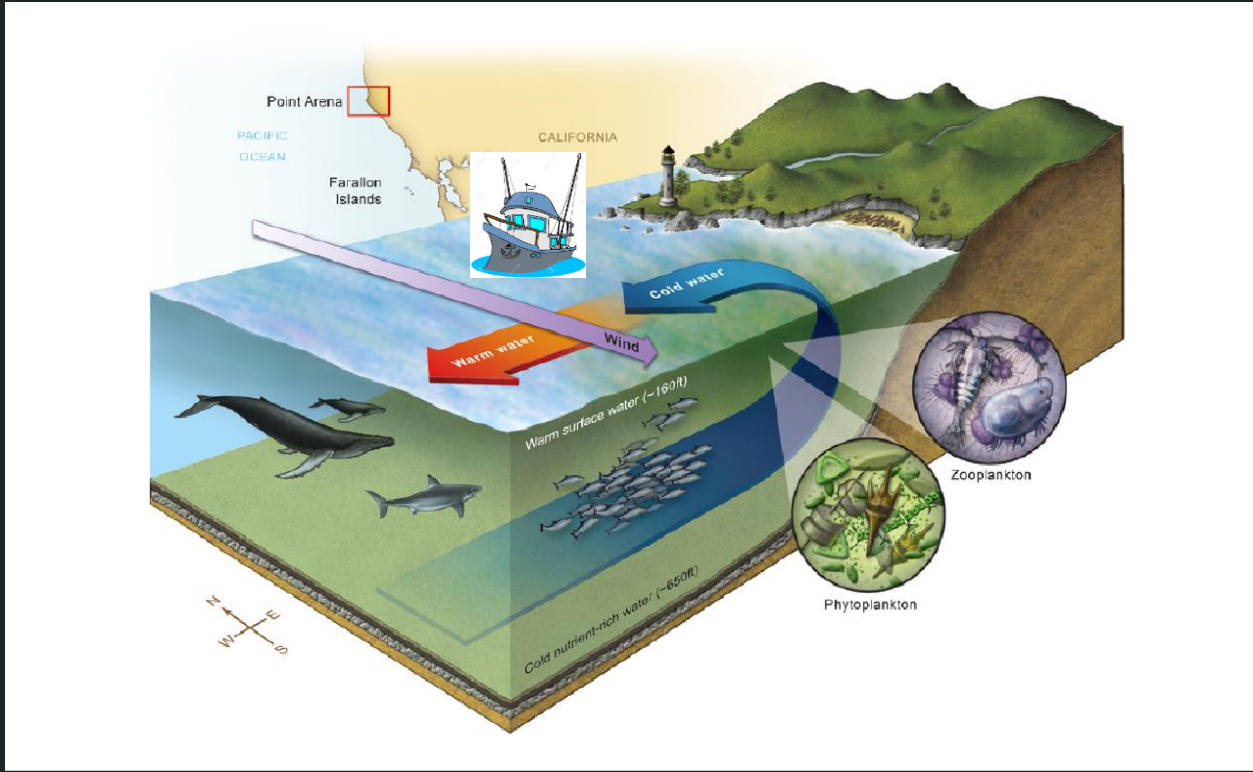


Illustration by Fiona Morris

Three examples:

1. Single-species MSE to test harvest control rules (HCR) for Pacific Sardine in the California Current
2. Multi-species HCR testing for Coastal Pelagic Species + Hake in the California Current
3. Single-species MSE for Pacific Sardine, informed by full suite of process-based ecological models

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1. Single-species MSE to test harvest control rules (HCR) for Pacific Sardine in the California Current

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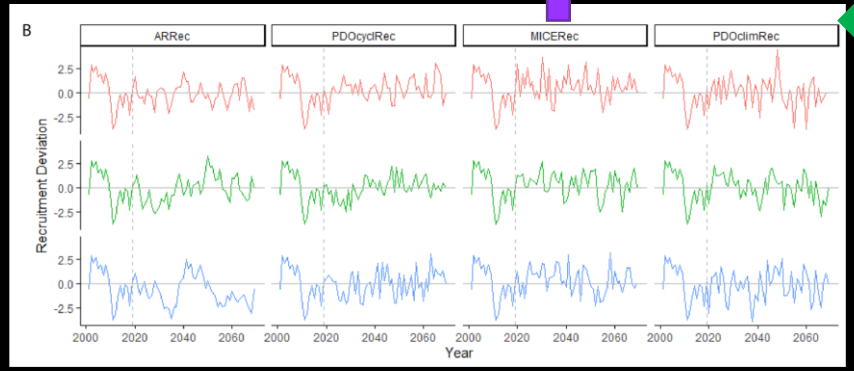
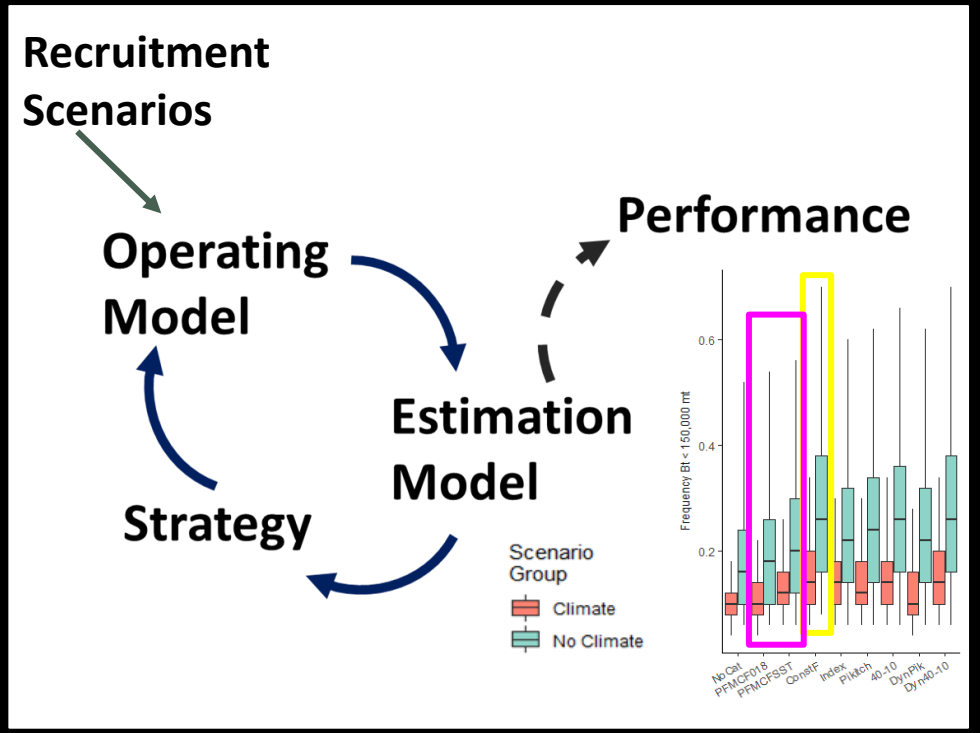
A single-species perspective (sardine)
But including ecosystem-informed HCRs

HCR Robustness to Recruitment Changes

From DynaMICE includes impact of temperature, food, advection Koenigstein et al. 2022



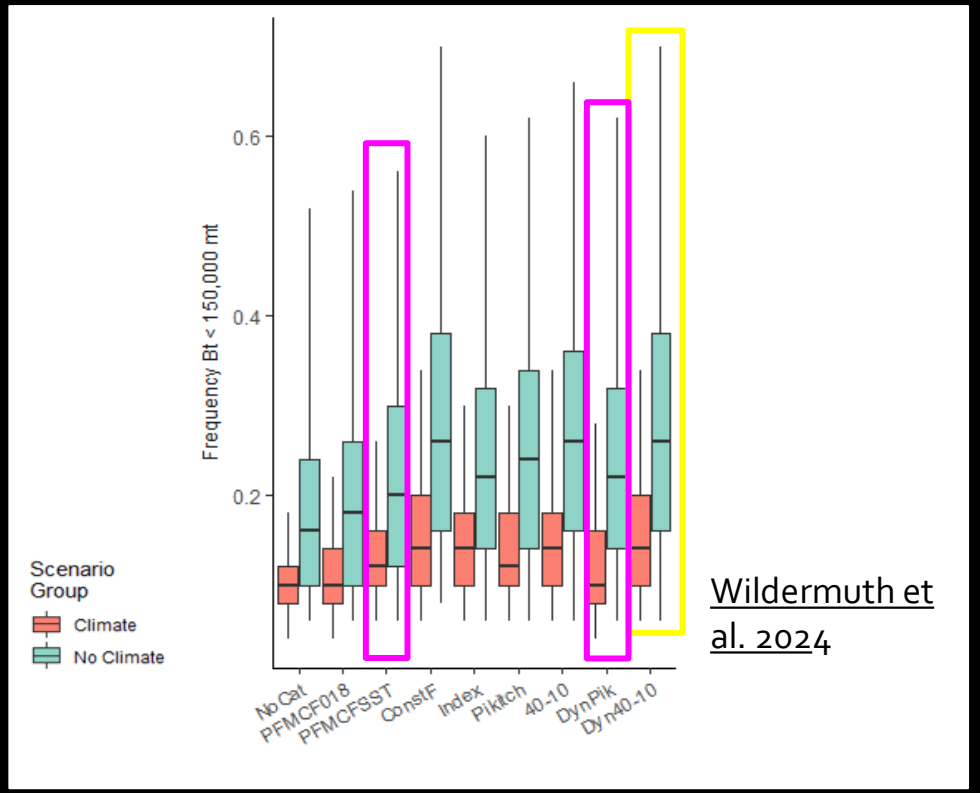


☑ The current survey and assessment process and frequency can track changes in the population status of sardine, making current management rule robust to changes in sardine recruitment as compared to more static approaches or a lagged index-based rule

Wildermuth et al. Can. J. Fish. Aquat. Sci. 81: 1029–1051 (2024)

HCR Robustness to Recruitment Changes

- ☑ Harvest control rules that are responsive to environmentally driven changes can improve outcomes compared to static management

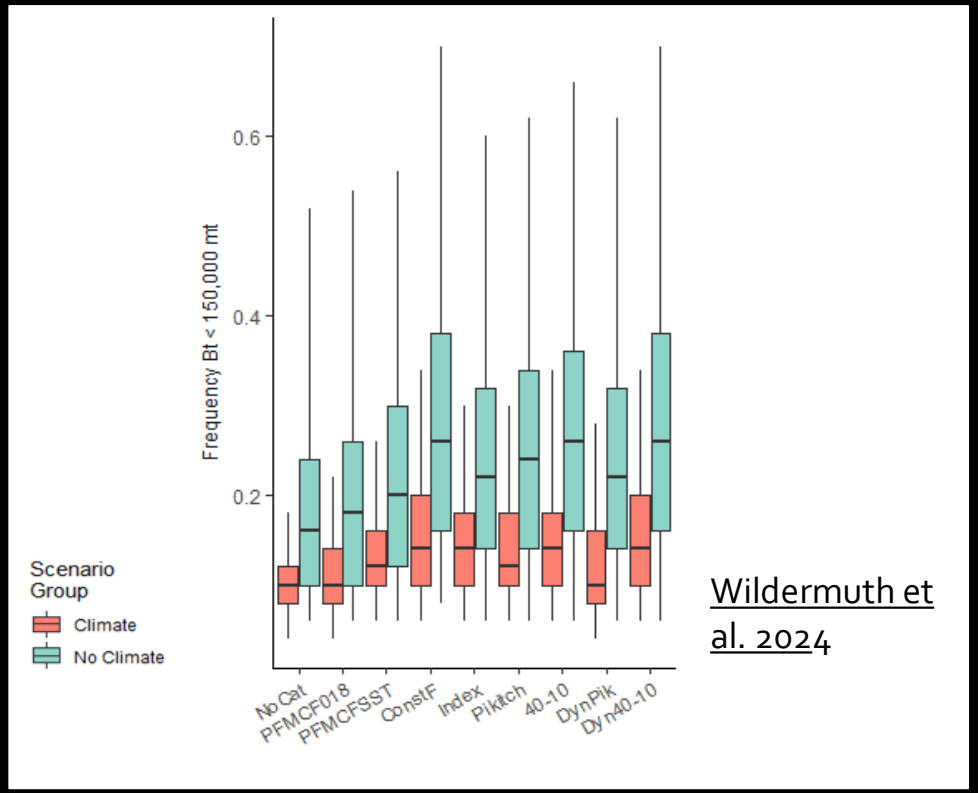


Wildermuth et al. 2024

Wildermuth et al. Can. J. Fish. Aquat. Sci. 81: 1029–1051 (2024)

HCR Robustness to Recruitment Changes

- ☑ Performance varied more among recruitment scenarios than among HCRs, thus management performance may depend more on understanding and modeling drivers of climate-driven changes in recruitment dynamics than on refining shape of harvest control rule



Wildermuth et al. 2024

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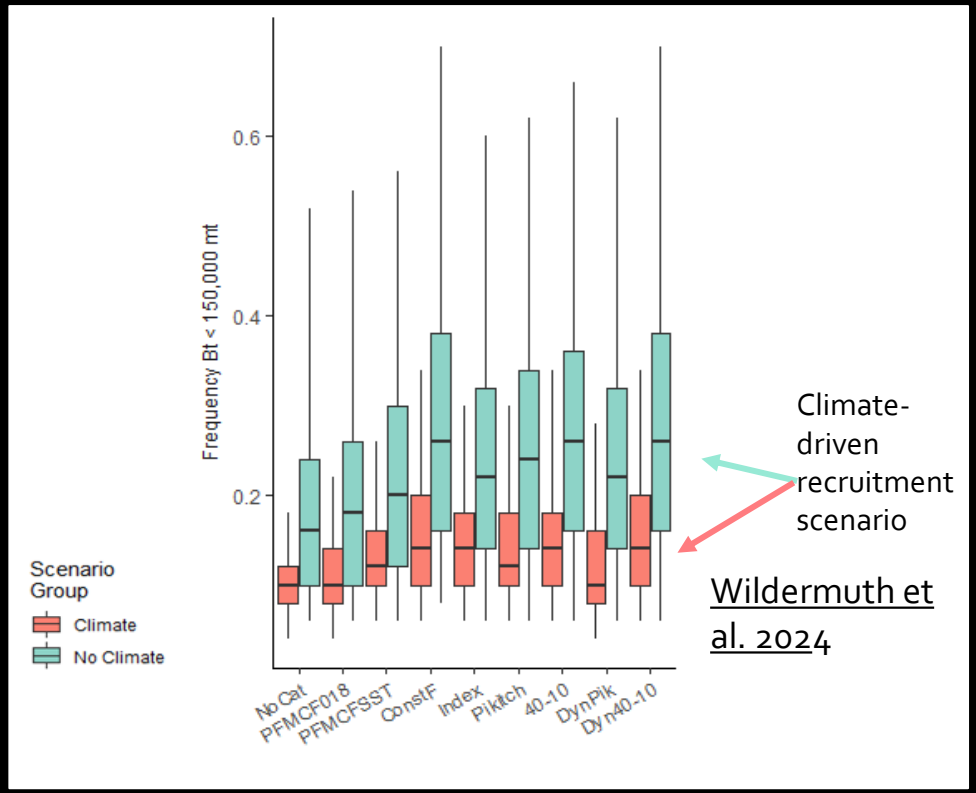
Wildermuth et al. Marine Ecology Progress Series (2026). **Revealing climate impacts on recruitment drivers of small pelagic fish through Dynamic Factor Analysis**



Wildermuth et al. Can. J. Fish. Aquat. Sci. 81: 1029–1051 (2024)

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2. Multi-species HCR testing for Coastal Pelagic Species + Hake in the California Current

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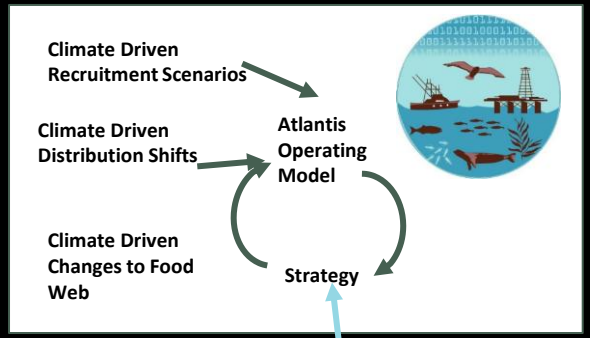
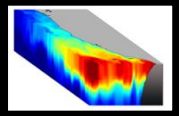
An ecosystem perspective (Atlantis)
Including both single-species and ecosystem-informed HCRs

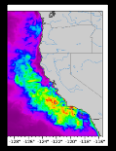
Atlantis MSE
HCR Robustness to Ecosystem Change



4 different harvest control rules, some informed by an ecosystem indicator

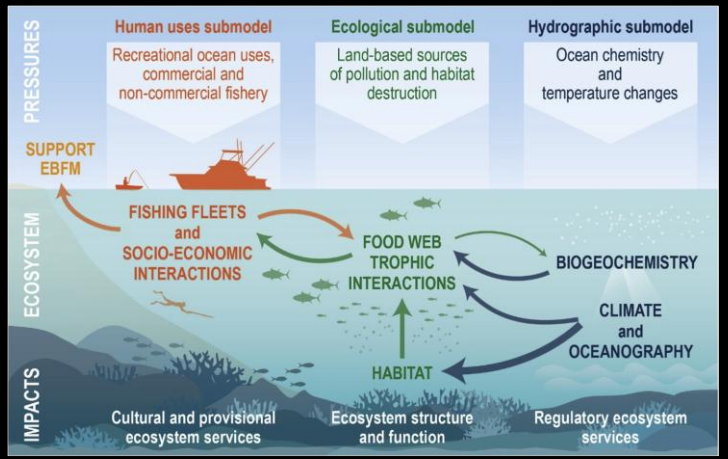


Oceanography (warming)



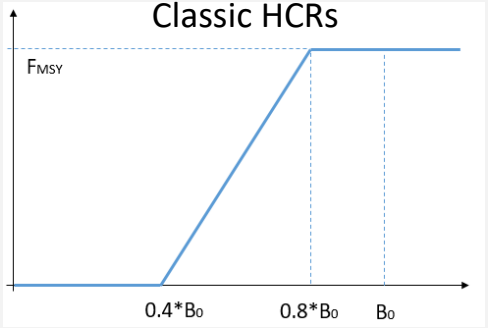
SDMs (Species Distribution Models)

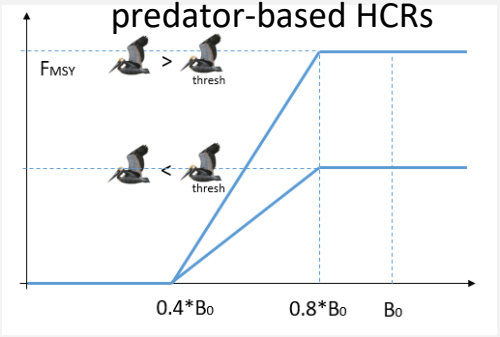
Fishing grounds per port



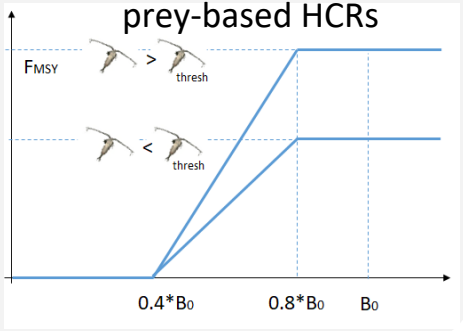
Atlantis model captures shifting forage fish productivity and distributions

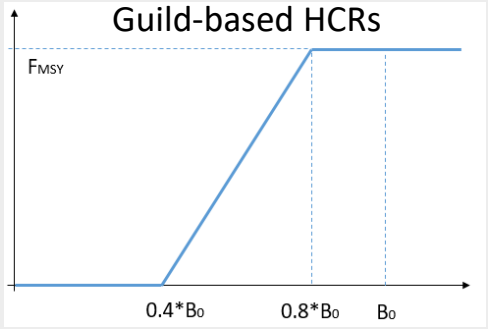
HCR Robustness to Ecosystem Change - Atlantis MSE





Individual species HCRs

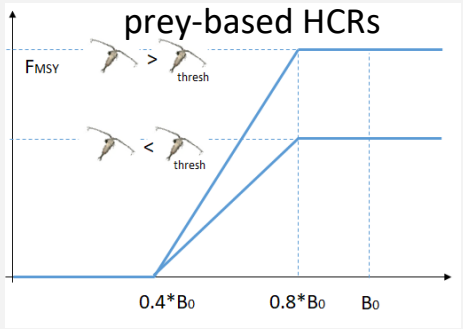




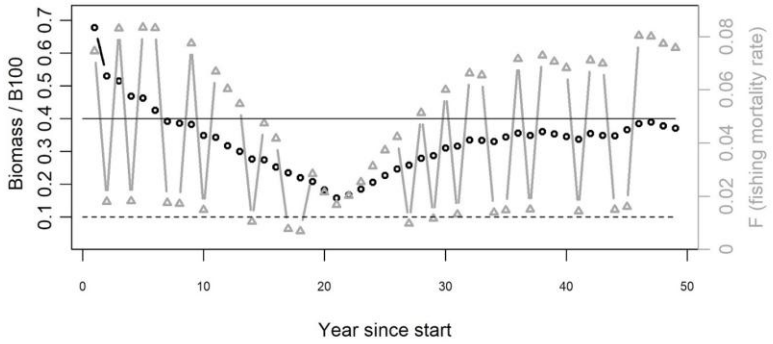
Multispecies HCRs

Hernvann et al., in prep

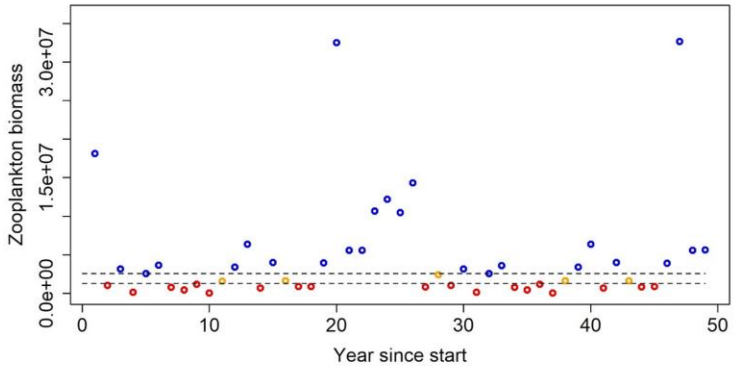
HCR Robustness to Ecosystem Change - Atlantis MSE



Pacific hake*

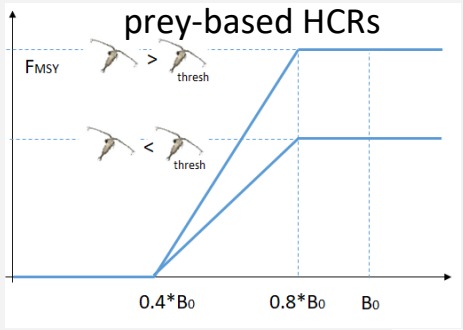


Prey (Zooplankton)



Kaplan, I. C., Hansen, C., Morzaria-Luna, H. N., Girardin, R., & Marshall, K. N. (2020). Ecosystem-based harvest control rules for Norwegian and US ecosystems. *Frontiers in Marine Science*, *7*, 652.

HCR Robustness to Ecosystem Change - Atlantis MSE

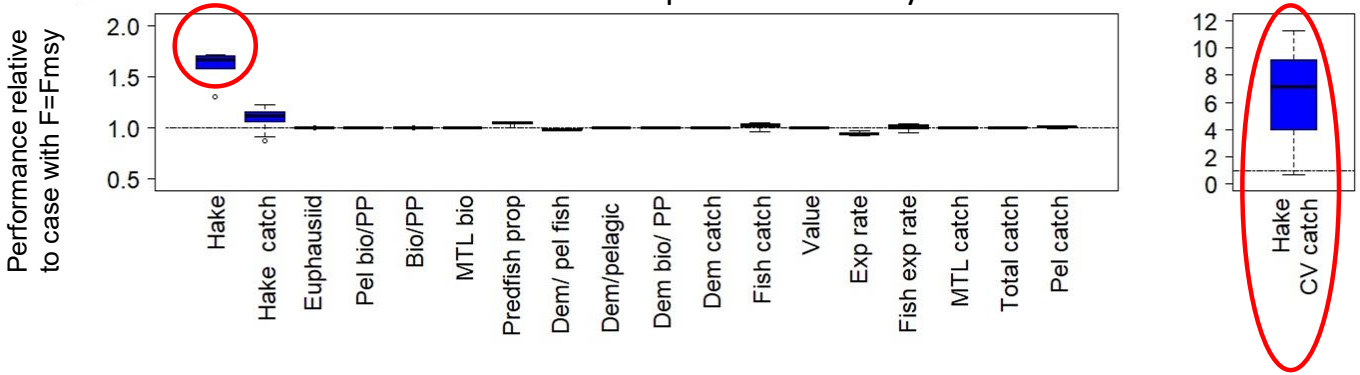


Pacific hake

Threshold rule for target fish that decreases F when zooplankton low (<25%):

Stronger increases in target fish biomass but at a cost of very high variation in catch. Minimal effects on other ecosystem metrics. Catches similar to simpler threshold rule.

An ecosystem model to investigate performance of both single-species and ecosystem-informed HCRs



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3. Single-species MSE for Pacific Sardine, informed by full suite of process-based ecological models

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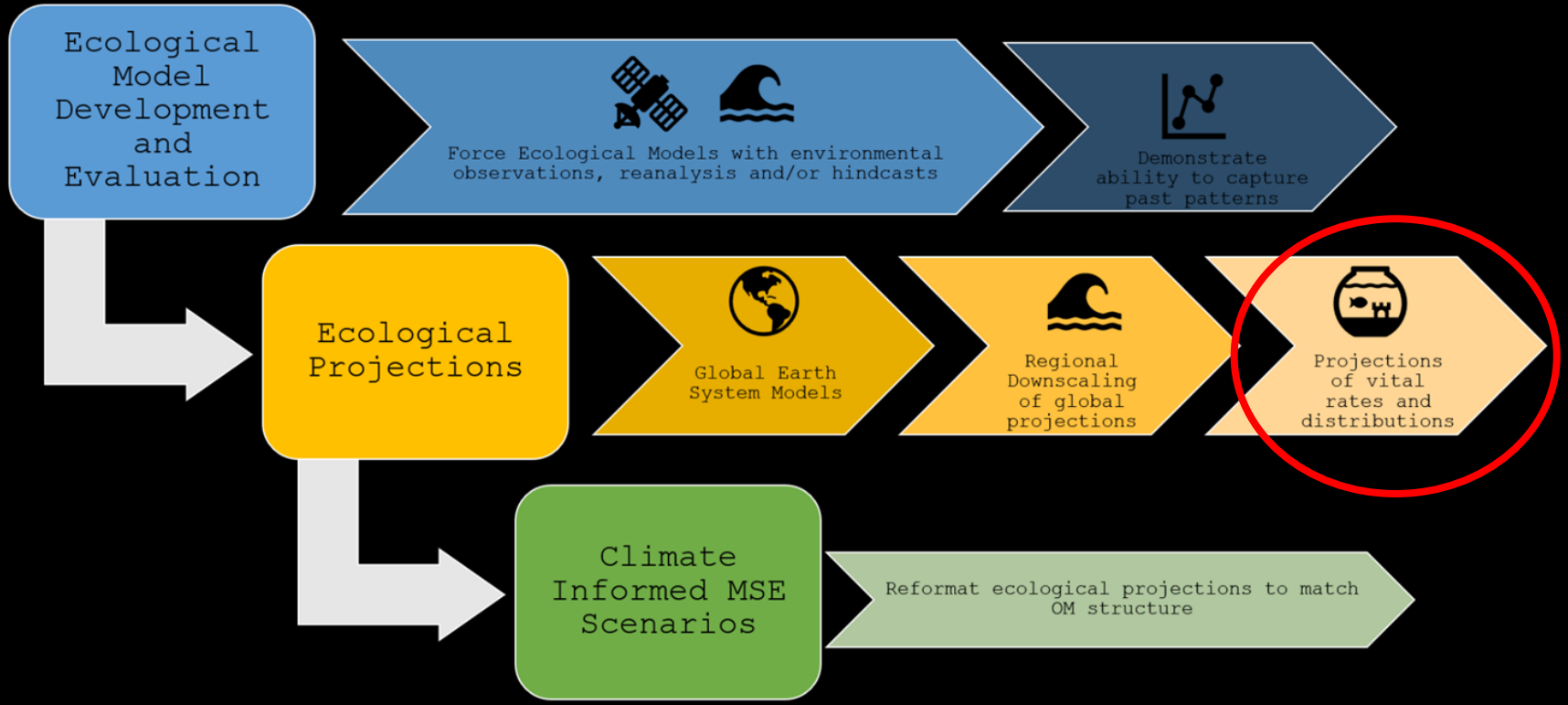
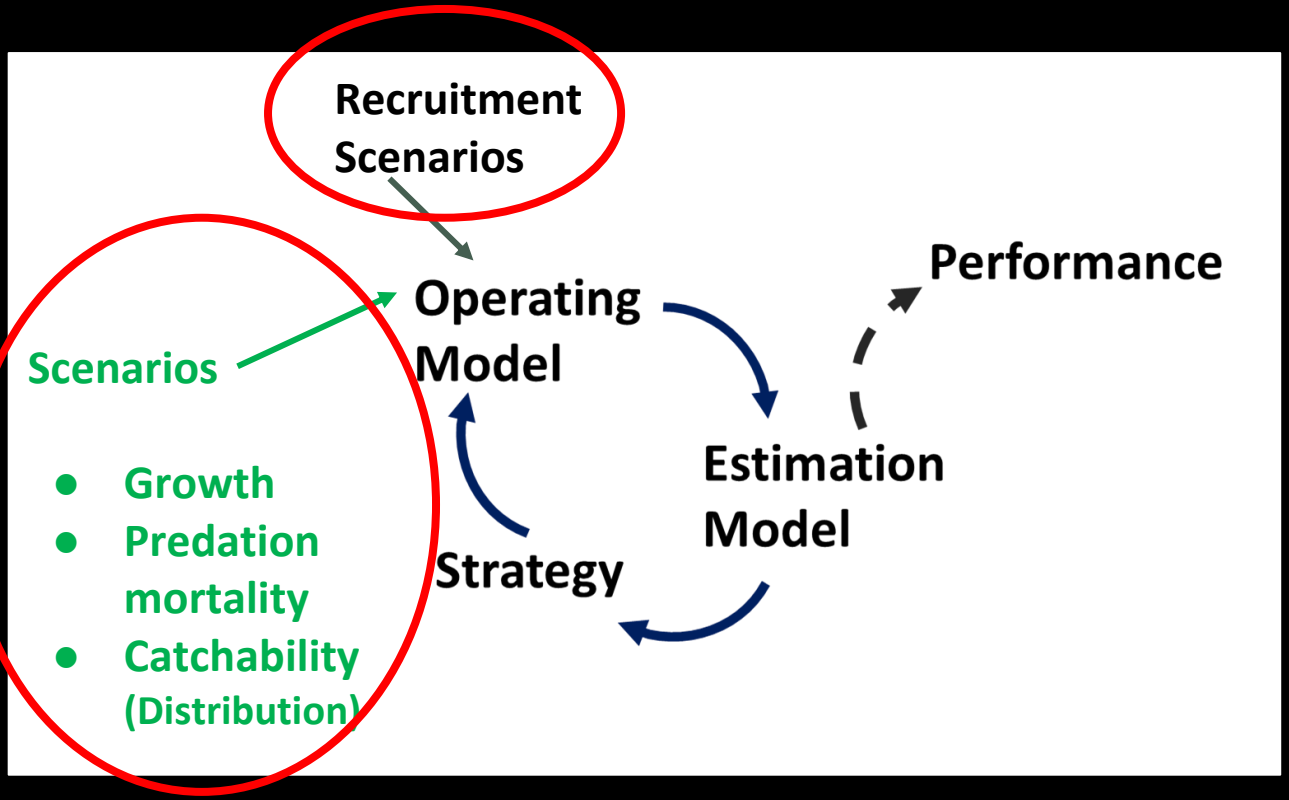
Utilizing process-based models of distribution, recruitment, and predation mortality to inform MSE Operating Models

Integrating Ecological Climate Projections into Uncertainty Scenarios for Fisheries Management Strategy Evaluation



Tommasi et al. *in prep*, and Session 1 presentation

Integrating Ecological Climate Projections into Uncertainty Scenarios for Fisheries Management Strategy Evaluation



- ☑ Outputs from a suite of regional ecological models to develop → alternative operating models (OMs) for MSE
- ☑ Projected changes in recruitment, growth, natural mortality, and survey index catchability, w/uncertainty

Tommasi et al. *in prep*, and Session 1 presentation

Summary

- Empirical and modeling evidence suggest past and future shifts in productivity and spatial distribution of California Current small pelagic fish
- These patterns and climate uncertainty can be included within MSE, to identify robust harvest rules and assessment options
- Future Seas
  - applies research models ranging from single species to full ecosystem
  - explores single-species and ecosystem-based harvest rules and approaches

Future Seas MSE Team

Isaac Kaplan, Stephanie Hopkins, Robert Wildermuth, Caitlin Allen Akselrud, Alexander Jensen, Peter Kuriyama, Desiree Tommasi, Charlie Hinchliffe

Lead PIs: Mercedes Pozo Buil, Isaac Kaplan, Desiree Tommasi