Detecting and forecasting community-level shifts in marine ecosystems

Mary Hunsicker[1], Eric Ward[1], Mike Litzow[1], Sean Anderson[2], Chris Harvey[1], Jin Gao[3], John Field[1], Michael Jacox[1,4], Sharon Melin[1], Andrew Thompson[1], Megan Wilson[5]

[1] NOAA, National Marine Fisheries Service, USA
[2] Department of Fisheries and Oceans, British Columbia, Canada
[3] Memorial University of Newfoundland, Newfoundland, Canada
[4] NOAA, Physical Sciences Laboratory, USA
[5] Oregon State University, USA

ICES-PICES Small Pelagic Fish Symposium
November 2022

Outline

Session 3 Understanding Population- and Ecosystem-level Shifts: From Seasonal Timing to Tipping Points

- Overview of tipping points
- Ecological thresholds
- Ecosystem state indicators
- Future directions

What is a tipping point?

'When incremental changes in human use or environmental conditions result in large, and sometimes abrupt, changes in ecosystem structure, function, and often, benefits to people'

Ocean Tipping Points project | oceantippingpoints.org

Increasing attention on tipping points

The quiet crossing of ocean tipping points

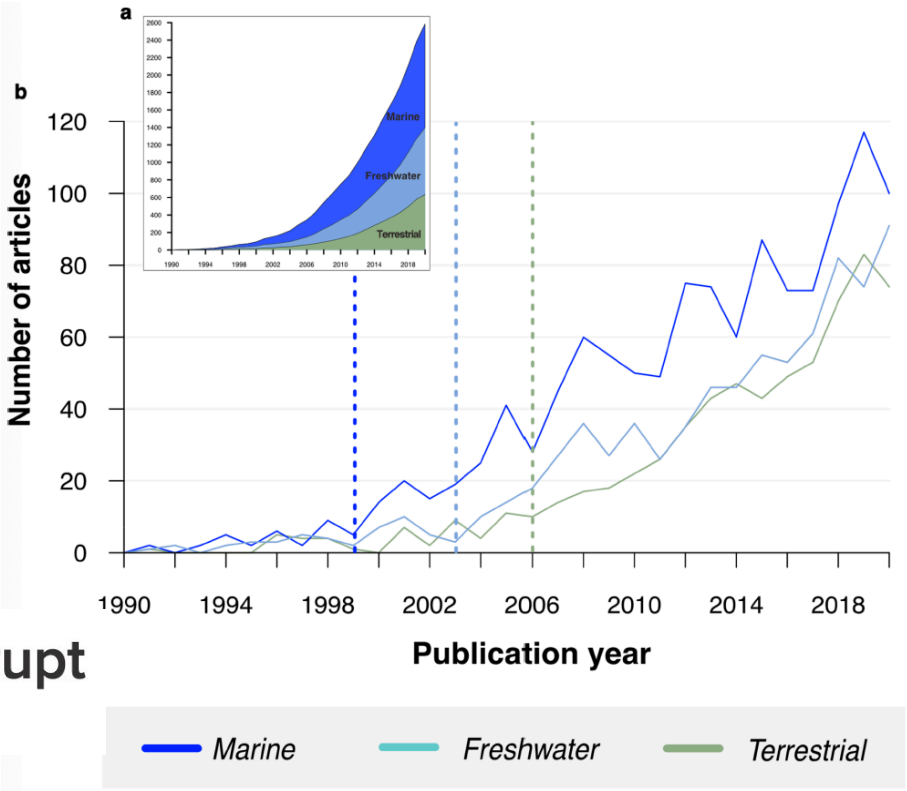
Heinze et al. PNAS 2021

Climate tipping points – too risky to bet against

Lenton et al. Nature 2019

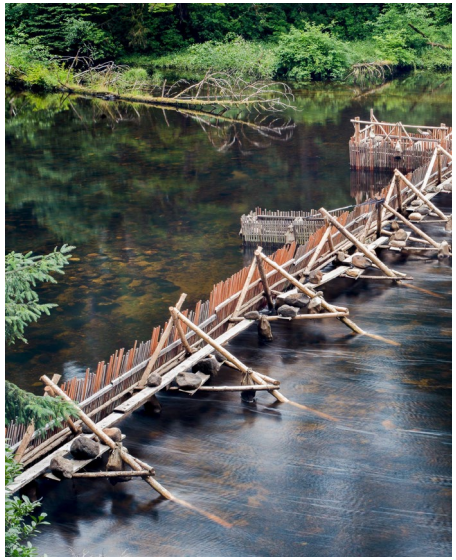
Climate change, ecosystems and abrupt change: science priorities

Turner et al. Phil. Trans. R. Soc. B 2020



Carrier-Belleau et al. Limn. and Ocean. 2022

Increasing attention on tipping points



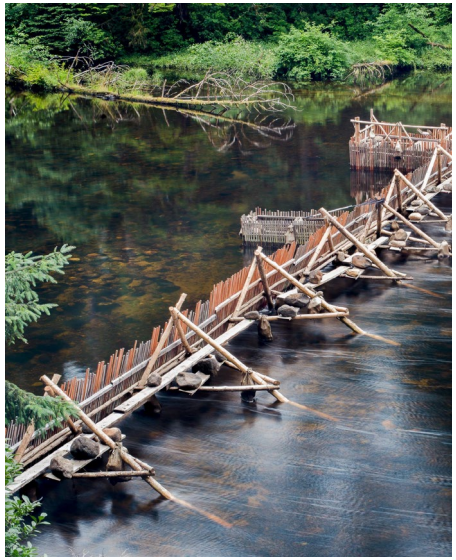
BBC

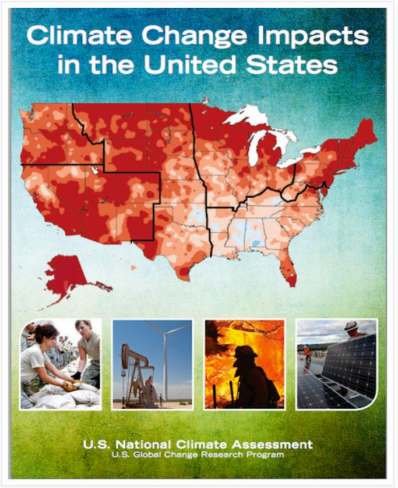
Climate change: Six tipping points 'likely' to be crossed

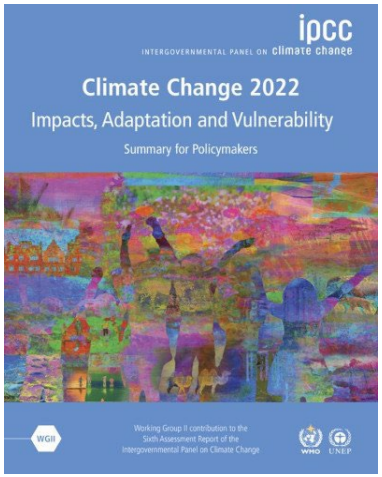
The New York Times

Failure to Slow Warming Will Set Off Climate 'Tipping Points,' Scientists Say

Increasing attention on tipping points








Kelp forests
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Coral reefs
Oyster reefs
SCDNR
Sand dunes
© Dave Ingram
Seagrass
© Orthia Marine
Pelagic systems
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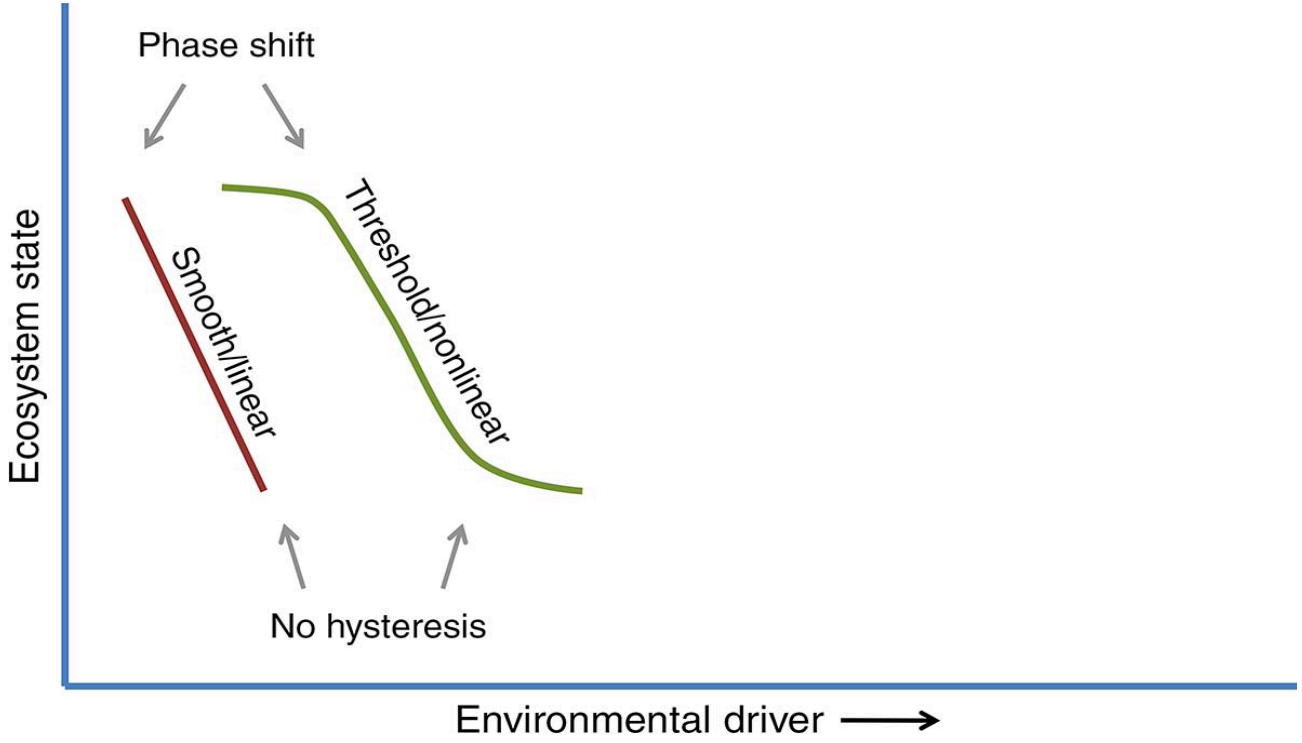
Mud flats
Saltmarshes
Rocky intertidal
Estuaries

Tipping points can occur in multiple forms

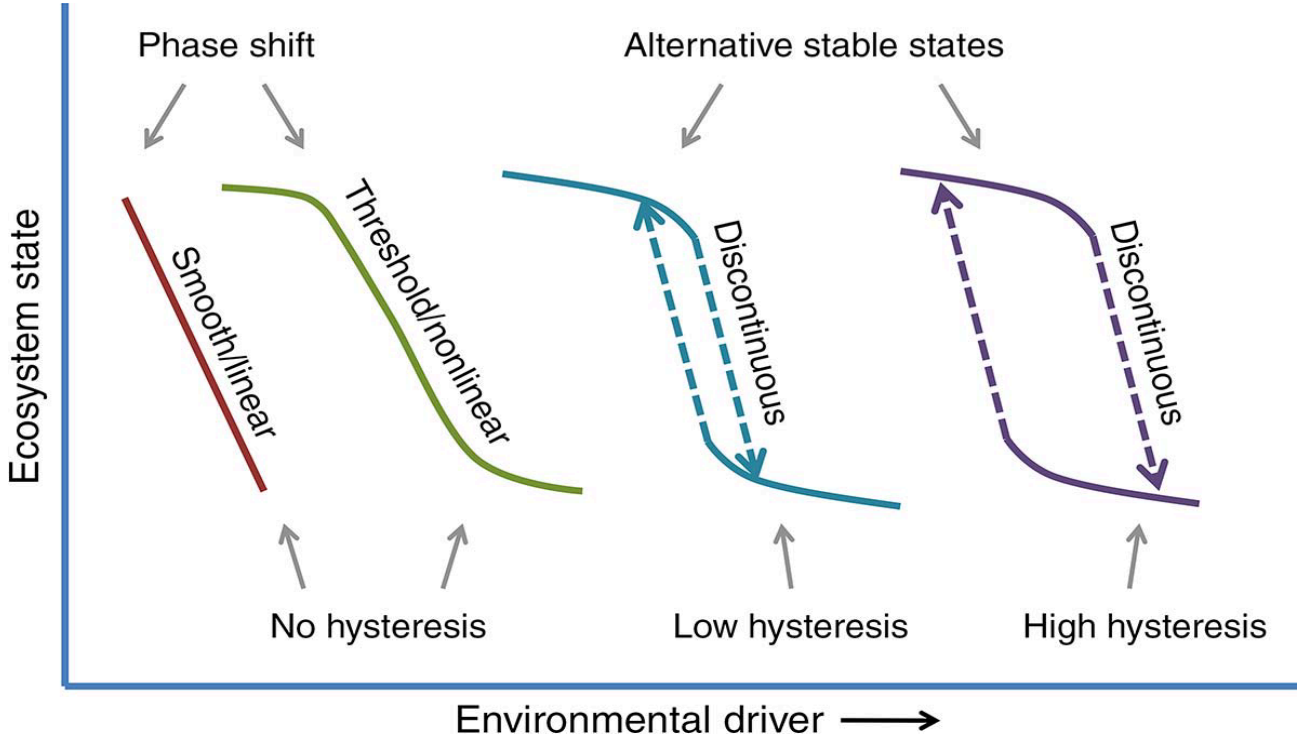


Driver exhibits threshold behavior that is tracked by the ecosystem response

Relationship is nonlinear

Selkoe et al. Eco. Health and Sustain. 2015

Tipping points can occur in multiple forms



Driver exhibits threshold behavior that is tracked by the ecosystem response

Relationship is nonlinear

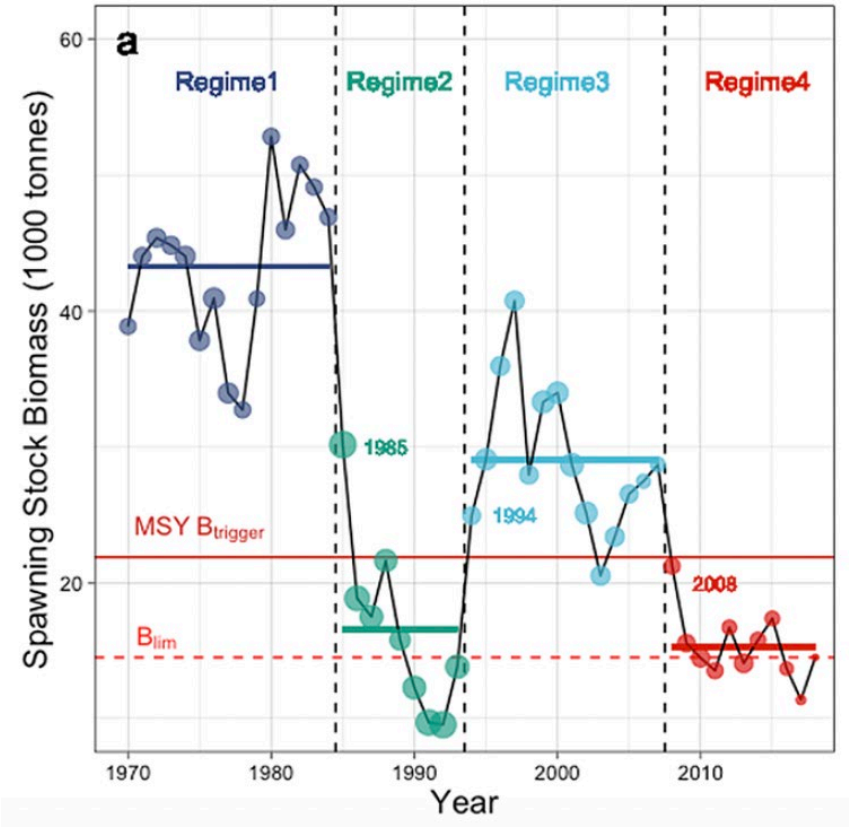
Relationship is different after shift. Pathway to recovery is different.

Selkoe et al. Eco. Health and Sustain. 2015

scientific reports

Tipping point realized in cod fishery

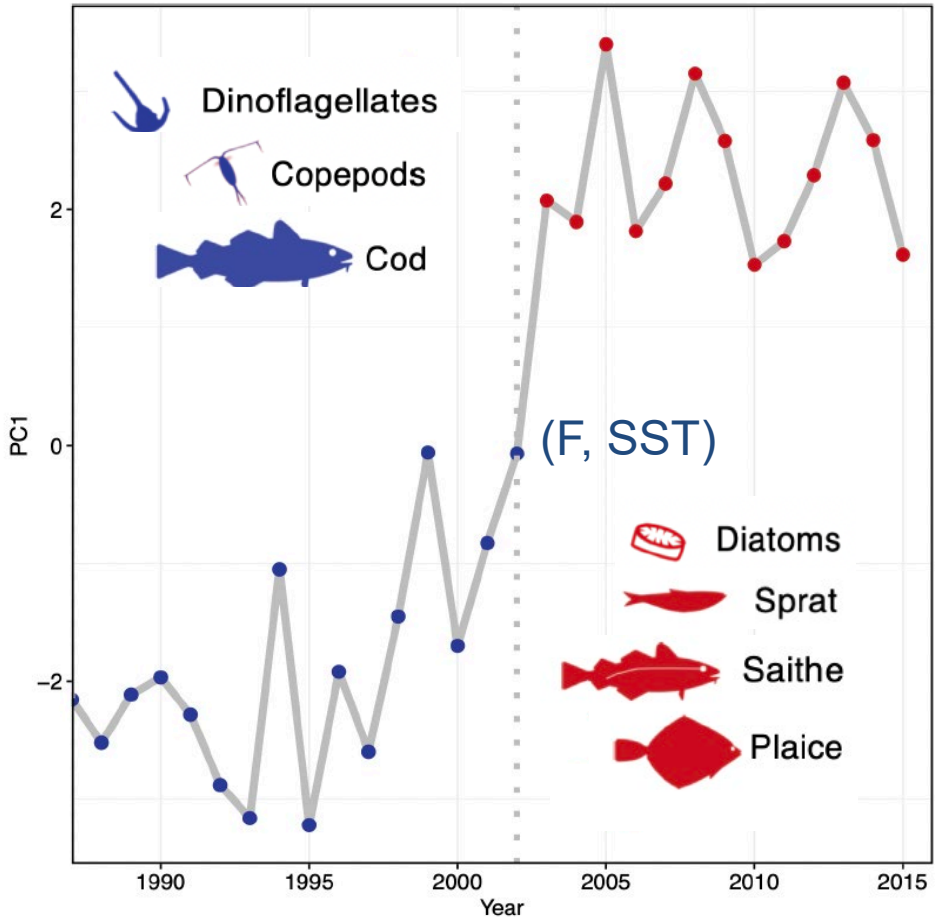
- Abrupt change in population variables (SSB, R, R/SSB)
- Nonstationary relationships among variables and external drivers (F, SST)
- Recently developed alternative stable of low cod productivity (F, SST)
- Beyond a tipping point and unlikely to recover



Mollmann et al. Scientific Reports 2021

frontiers | Frontiers in Marine Science

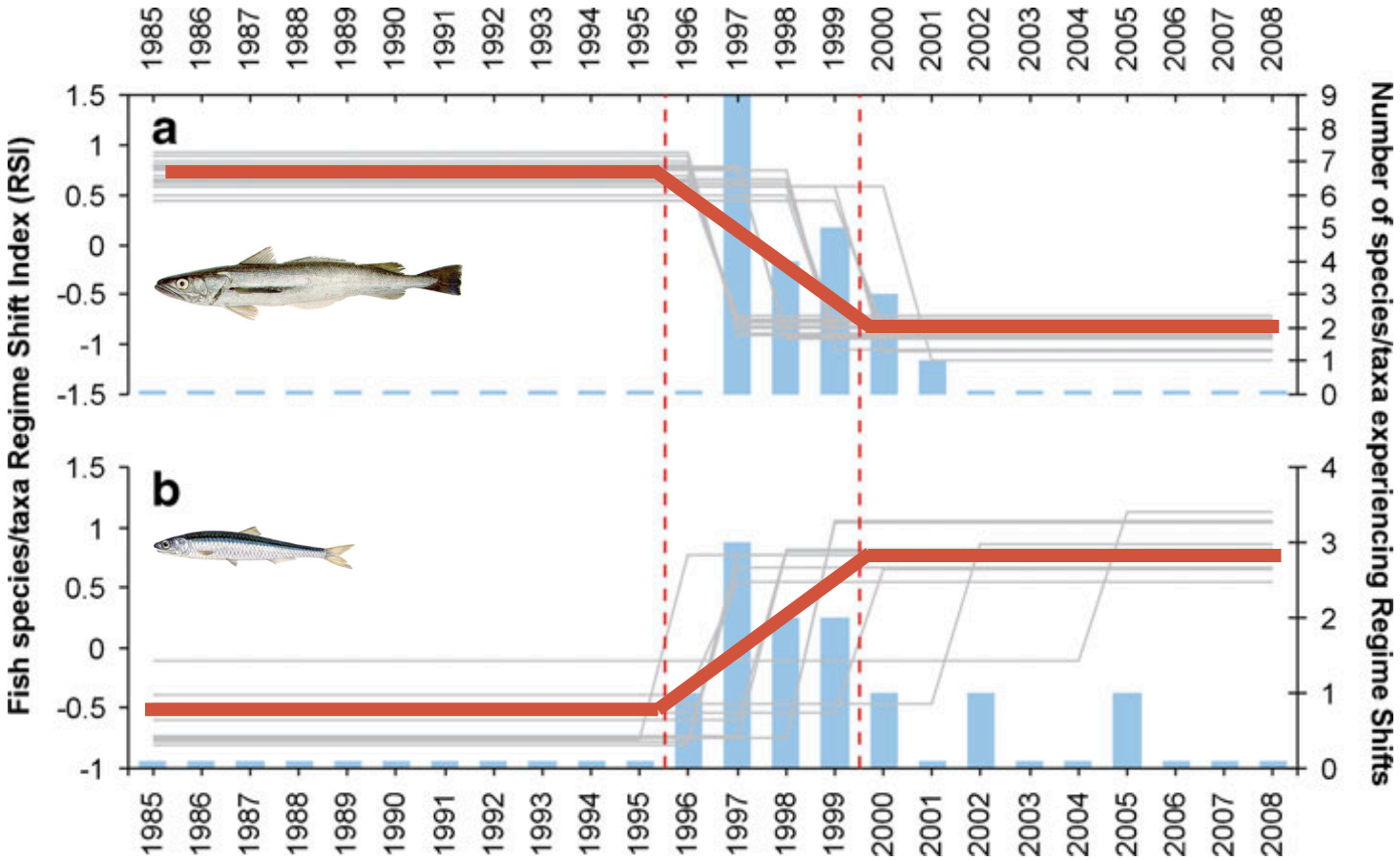
Irreversibility of regime shifts in the North Sea



Sguotti et al. Front. Mar. Sci. 2022

Climatic Change

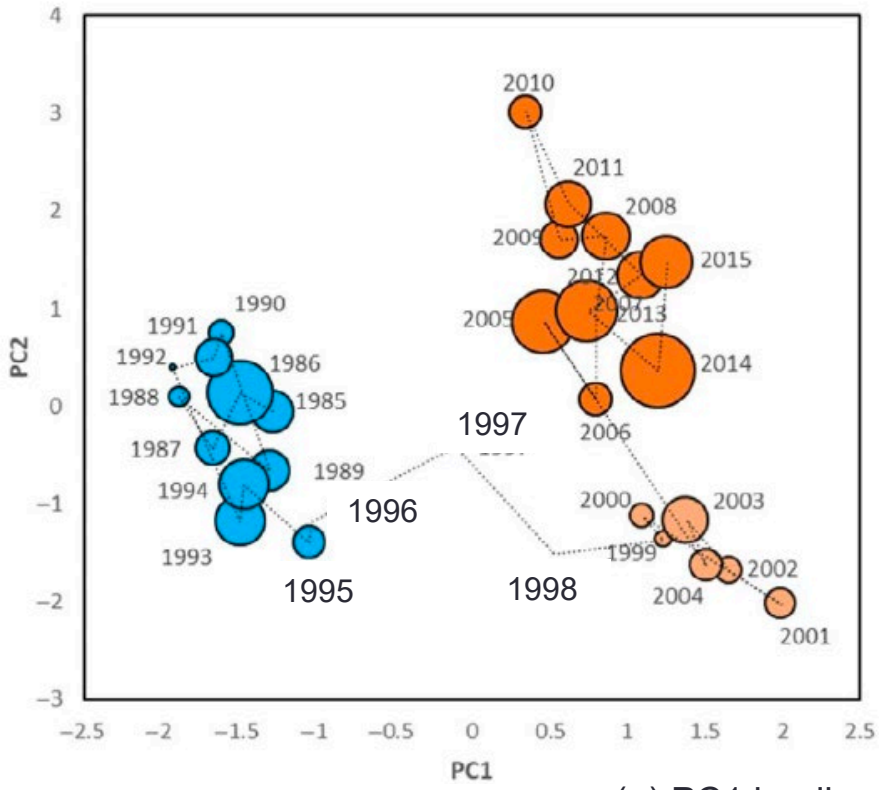
Indications of a climate effect on Mediterranean fisheries



Tzanatos et al. 2014 Clim. Change

An Integrated Traits Resilience Assessment of Mediterranean fisheries landings

Journal of Animal Ecology
BRITISH ECOLOGICAL SOCIETY



(-) PC1 loadings
Opt. temperature 15-20ºC
Spawning period winter
Longevity > 20 years
Max. length > 1m
Diet piscivore
Opt. depth > 200 m

(+) PC1 loadings
Opt. temperature 25-30ºC
Spawning period summer
Longevity 5-9 years
Max. length 20-50 cm
Diet planktivore
Opt. depth 50 - 200 m

Tsimara et al. 2021 J. Anim. Ecol.

An Integrated Traits Resilience Assessment of Mediterranean fisheries landings

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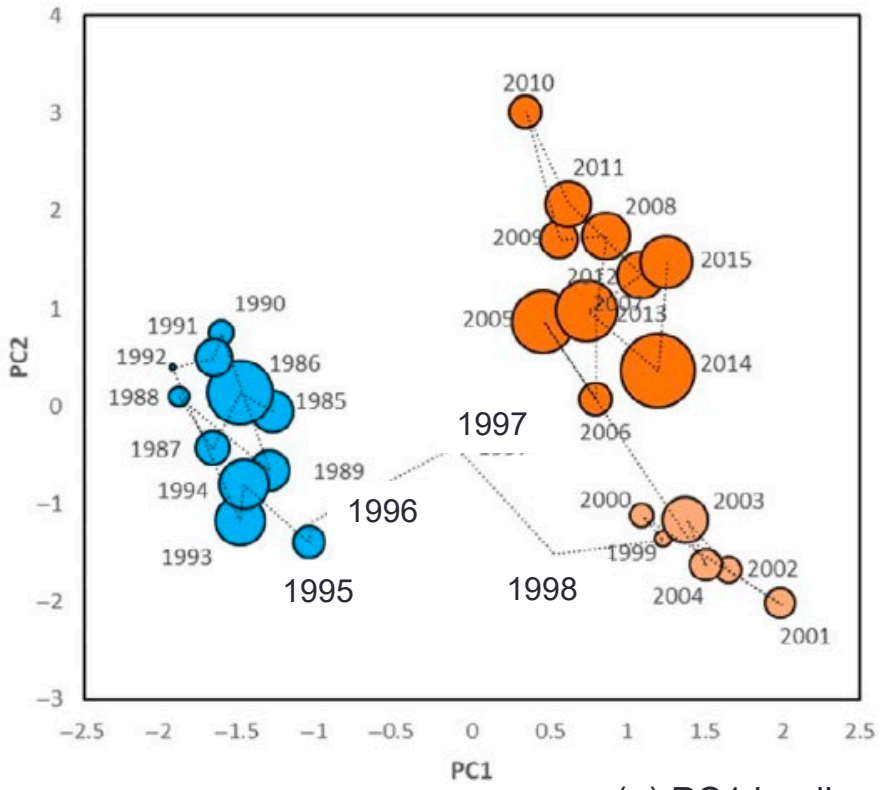

- Lagged nonstationary response to warming
- Shift did not interchange species with similar traits
- Implications for ecosystem functioning

(-) PC1 loadings
Opt. temperature 15-20ºC
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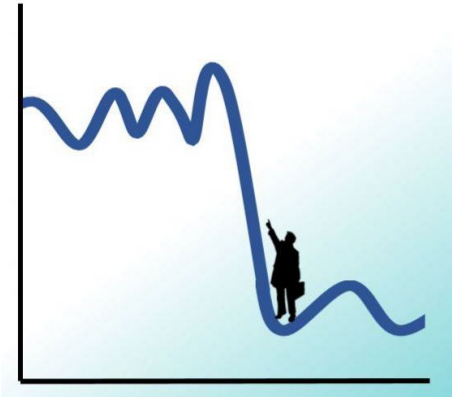
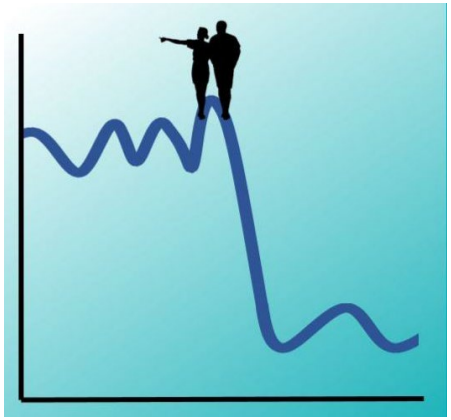
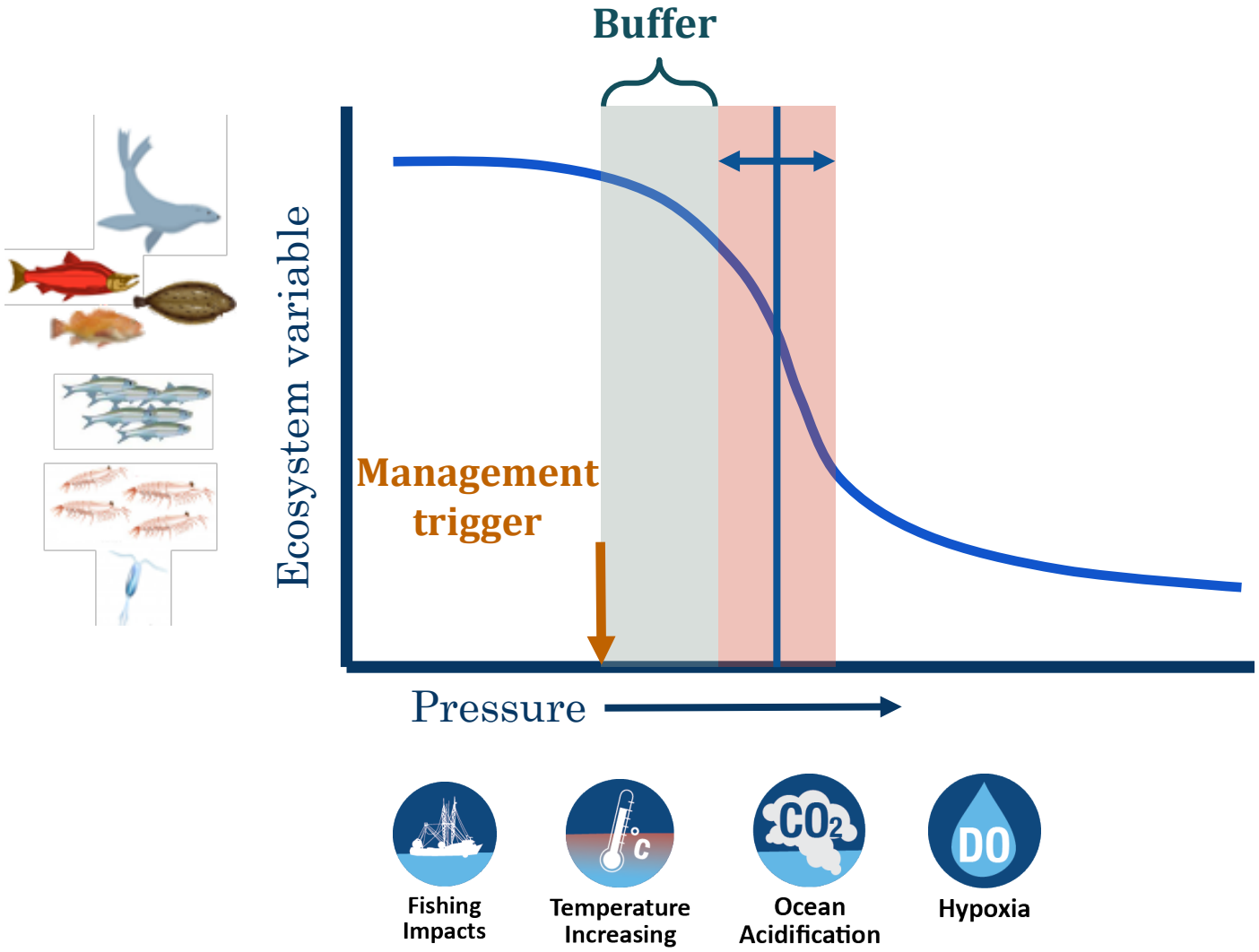
- Future directions



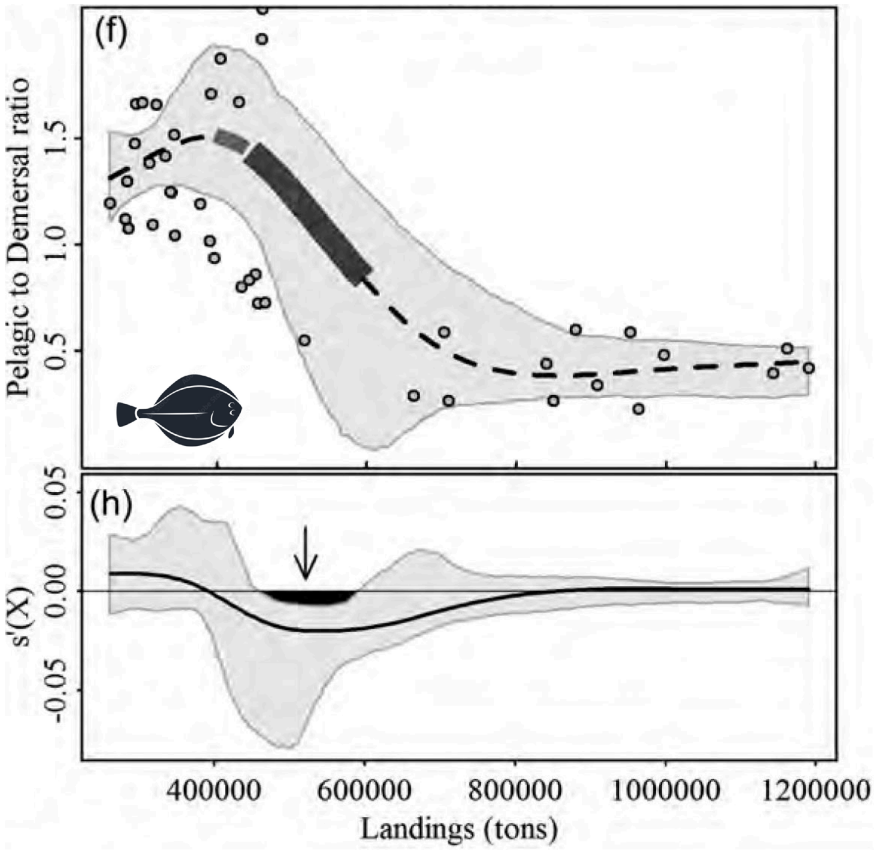


Learnz.org | Tipping points

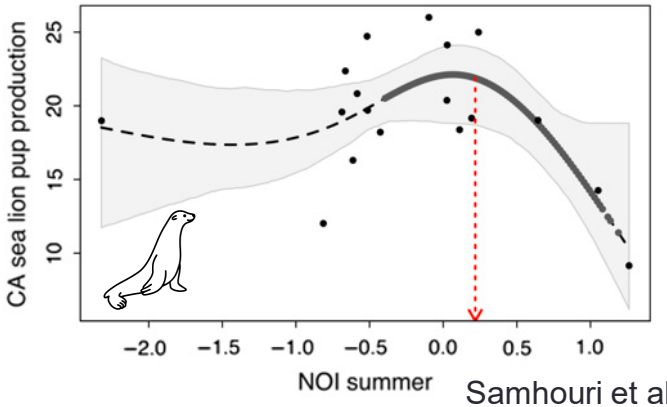
Thresholds to help inform management strategies



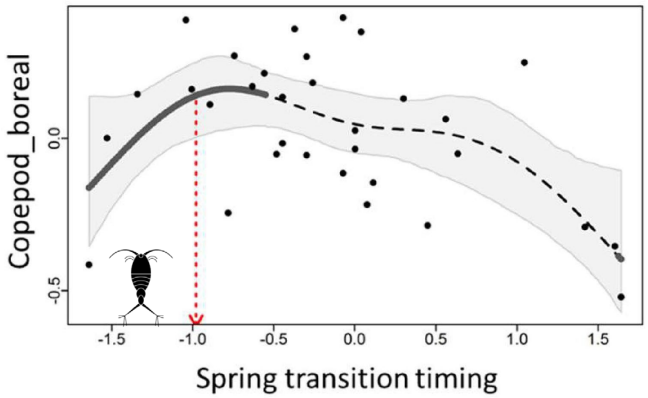
Evidence of ecological thresholds



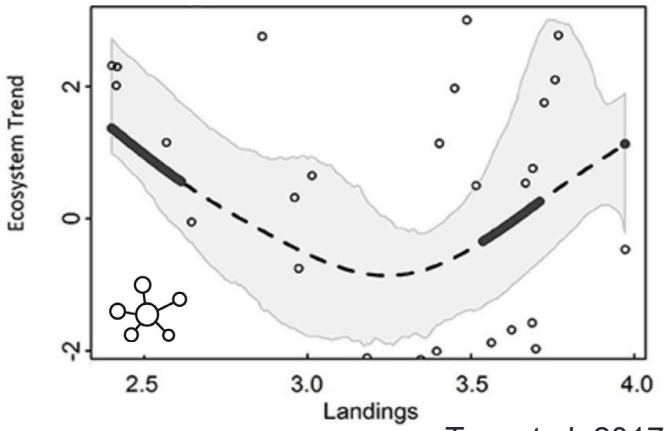
Large et al. 2013 ICES JMS



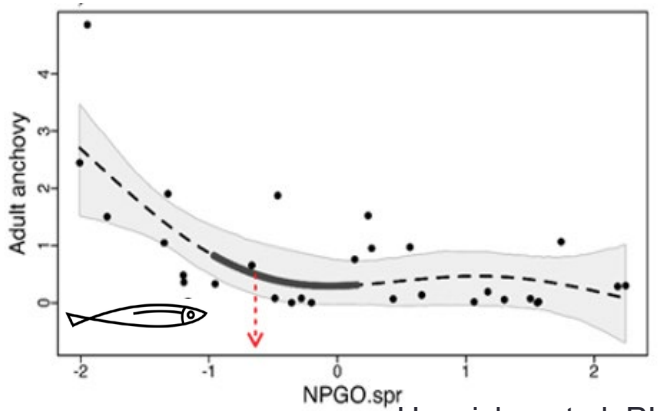
Samhouri et al. 2015



Boldt et al. 2021; PICES WG36 Report



Tam et al. 2017



Hunsicker et al. PICES WG36 Report

Threshold management works. More explicit use of thresholds in management is strongly associated with better environmental outcomes

Kelly et al. 2014 Phil. Trans. Roy. Soc. B

How to increase uptake of thresholds in management?

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Simulation studies to demonstrate how incorporating thresholds in management applications could improve knowledge of risk and uncertainty

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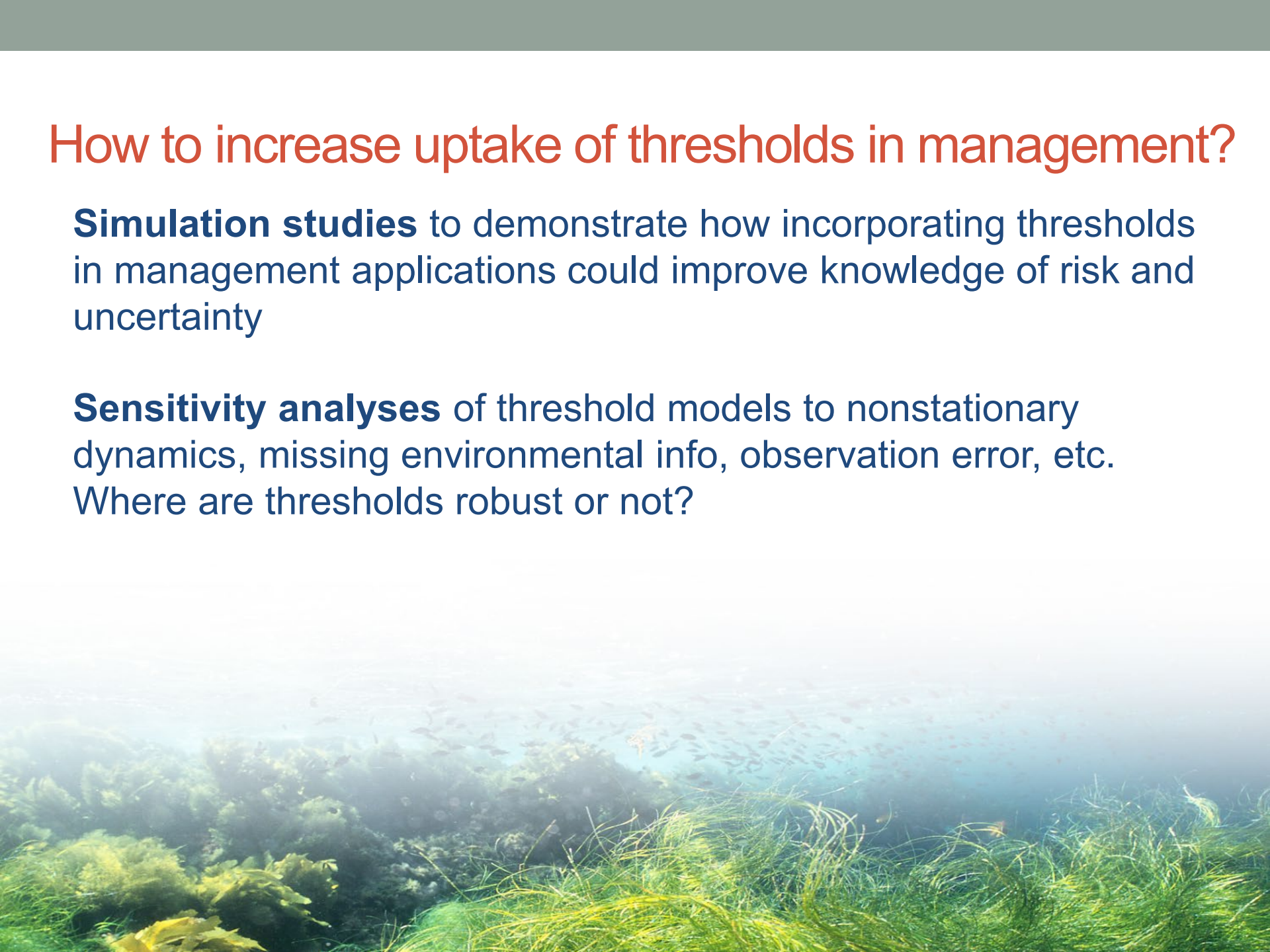
Sensitivity analyses of threshold models to nonstationary dynamics, missing environmental info, observation error, etc. Where are thresholds robust or not?



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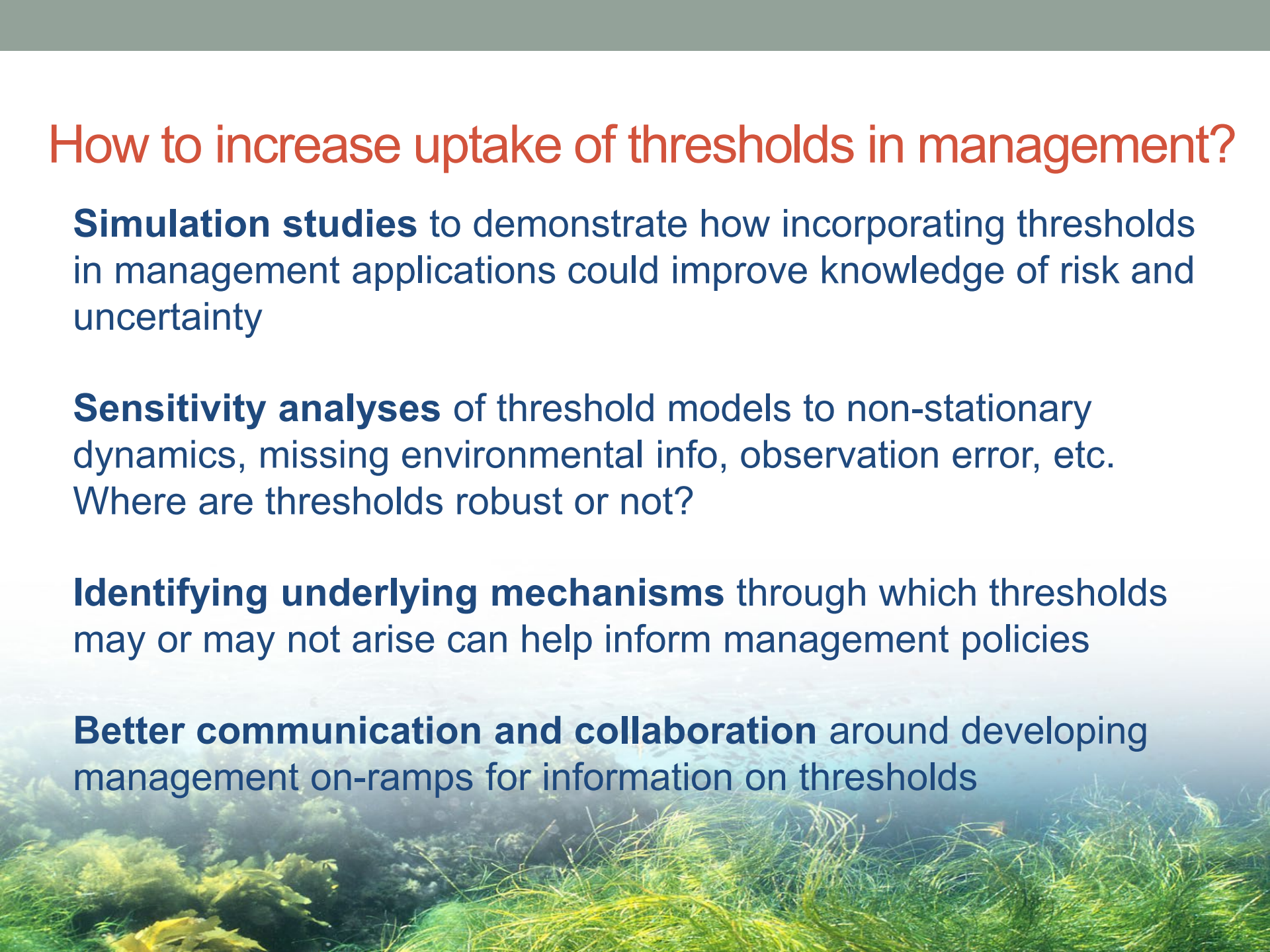
Better communication and collaboration around developing management on-ramps for information on thresholds



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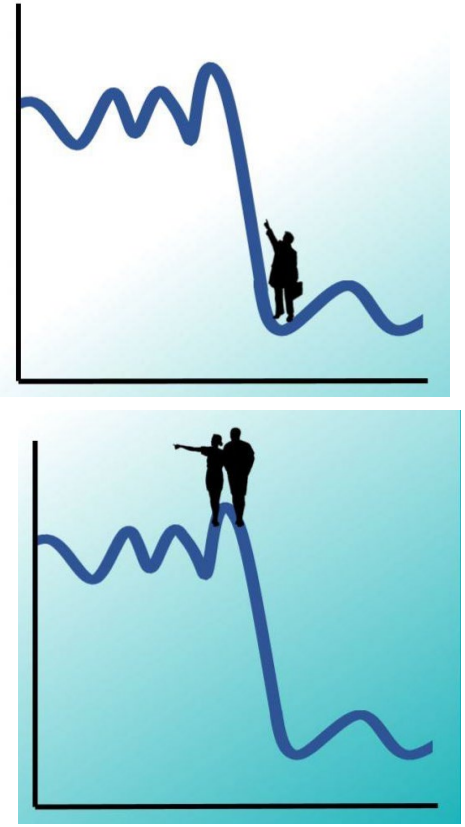
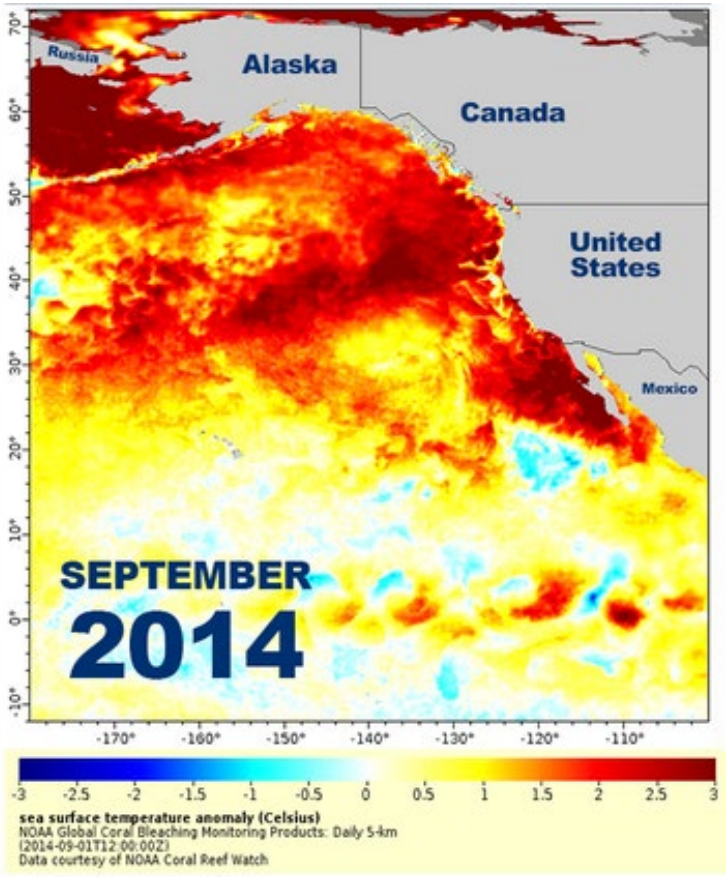
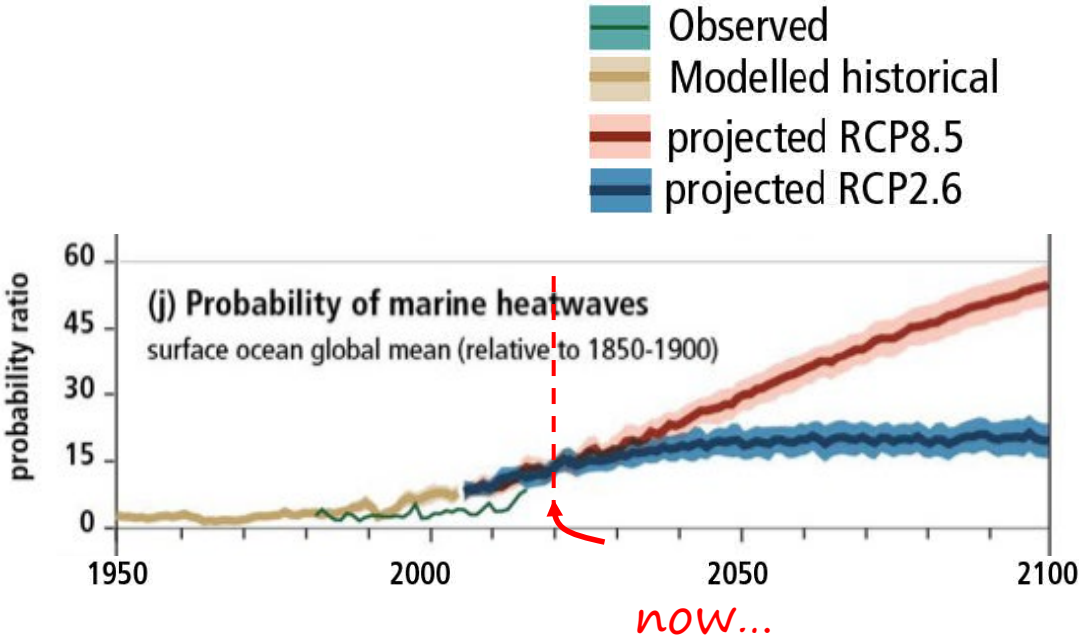


Learnz.org | Tipping points

Marine heatwaves in northeast Pacific

Sea surface temperature anomaly





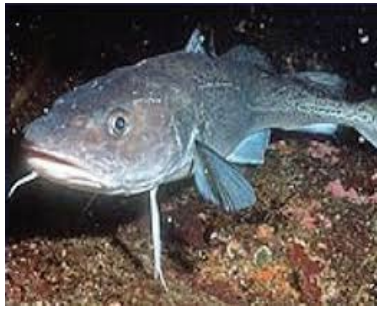
IPCC 2019. The Ocean and Cryosphere in a Changing Climate, Fig SPM.1

Will biological responses to warm ocean conditions result in ecosystem shift?

Crab and clam fisheries closures due to domoic acid

Species range extensions / invasions

Record low returns / abundance / poor condition



Caspian terns abandon colony in mid-season

Ecosystem state index

- Evaluate changes in mean community state in response to climate perturbations
- Distinguish normal variability from changes signaling a major shift (i.e. reference points)
- Early detection of abrupt ecosystem-level changes

Bayesian Dynamic Factor Analysis

Can we identify latent 'trends' that are useful as indices?

- Large changes in trends values indicate large changes in the underlying community of shared trends
- Handles missing values in time series
- Identify states/regimes in estimated shared trends
- Create one year ahead forecasts

'bayesDFA' R package on CRAN / Github

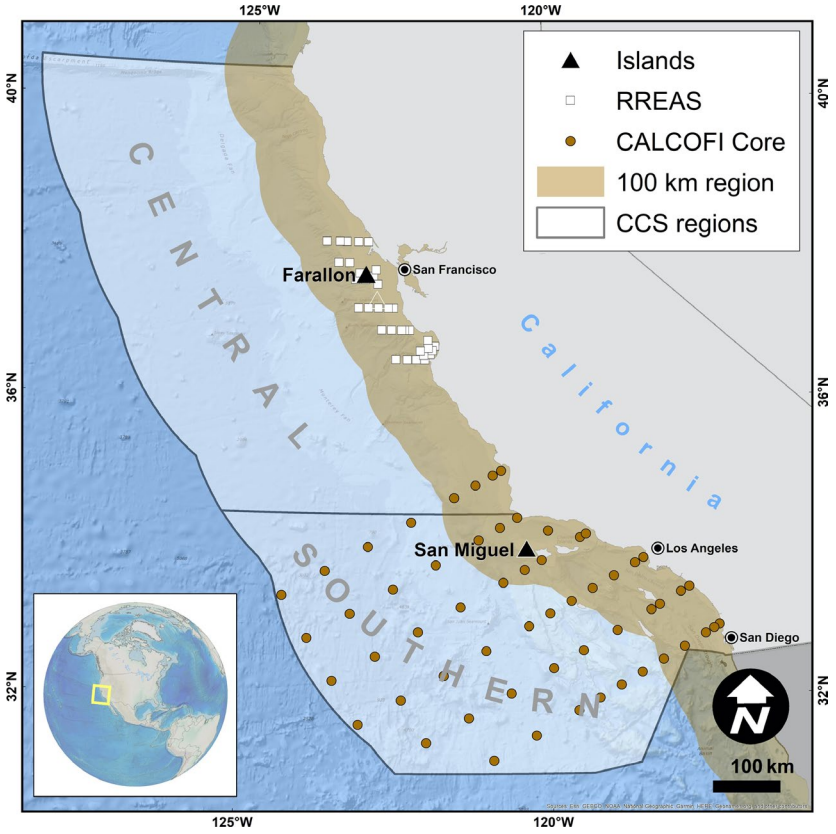
Ward et al. 2019, 2022

Objectives

- Summarize environmental and biological variability in the southern and central regions of the CCE, evidence of regime shift?
- Identify relationships between community variability and climate variables
- Test our ability to create one-year ahead forecasts



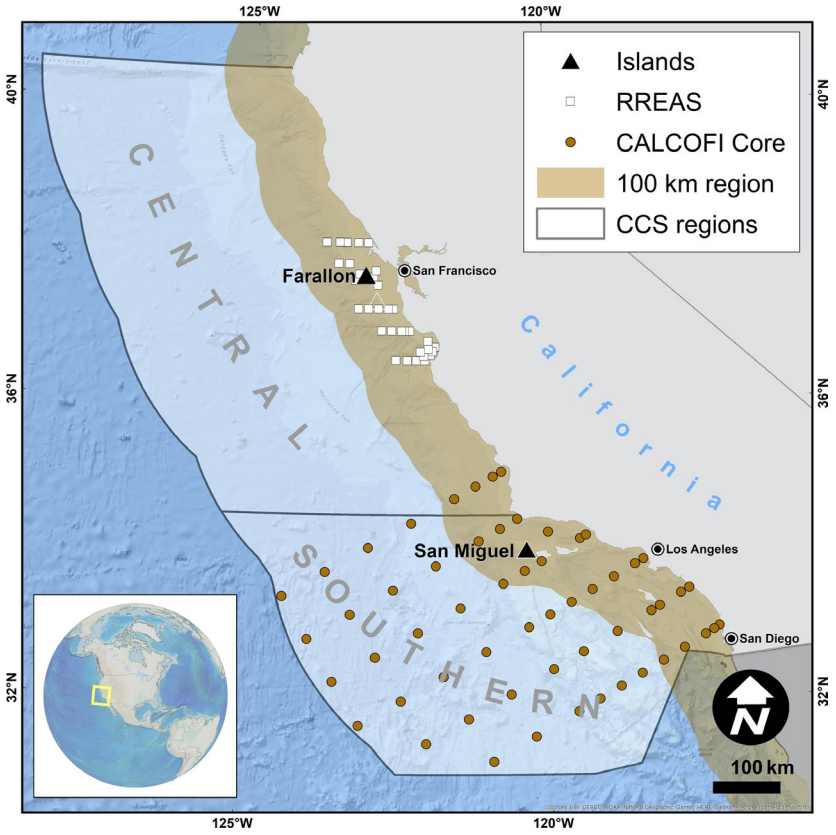

South/Central California Current Ecosystem



Data

- Short lag in response (0-1 years)
- 15+ year time series
- Sampled at least annually
- Short processing time

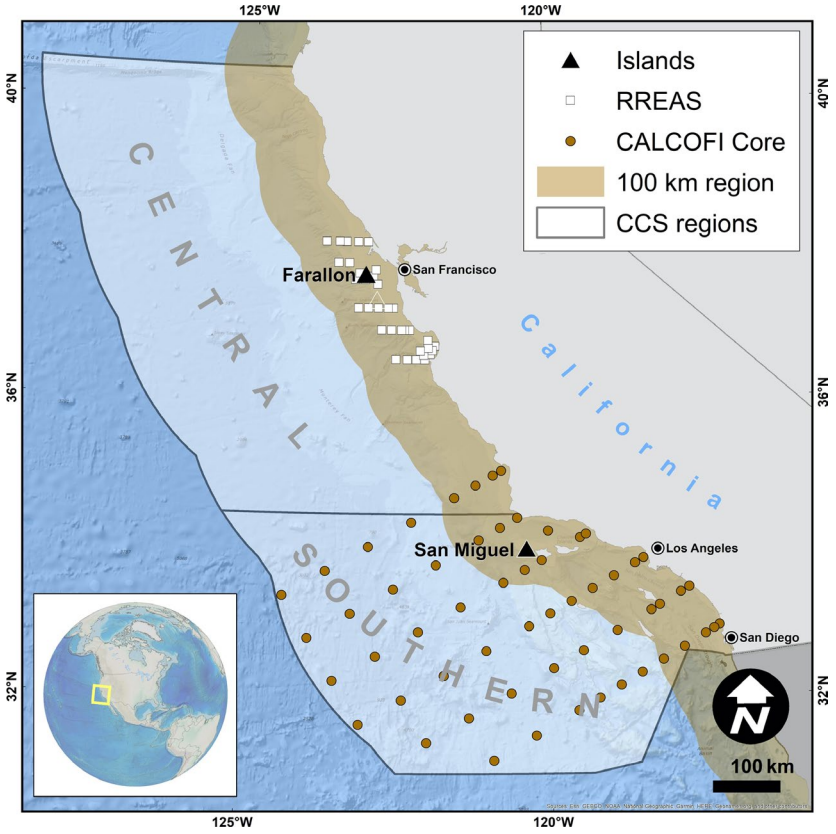
South/Central California Current Ecosystem



Climate data (1980-2018)

- SST
- Sea surface height
- Isothermal layer depth
- Brunt-Vaisala frequency (stratification)
- CUTI (Upwelling)
- BEUTI (Nitrate flux)

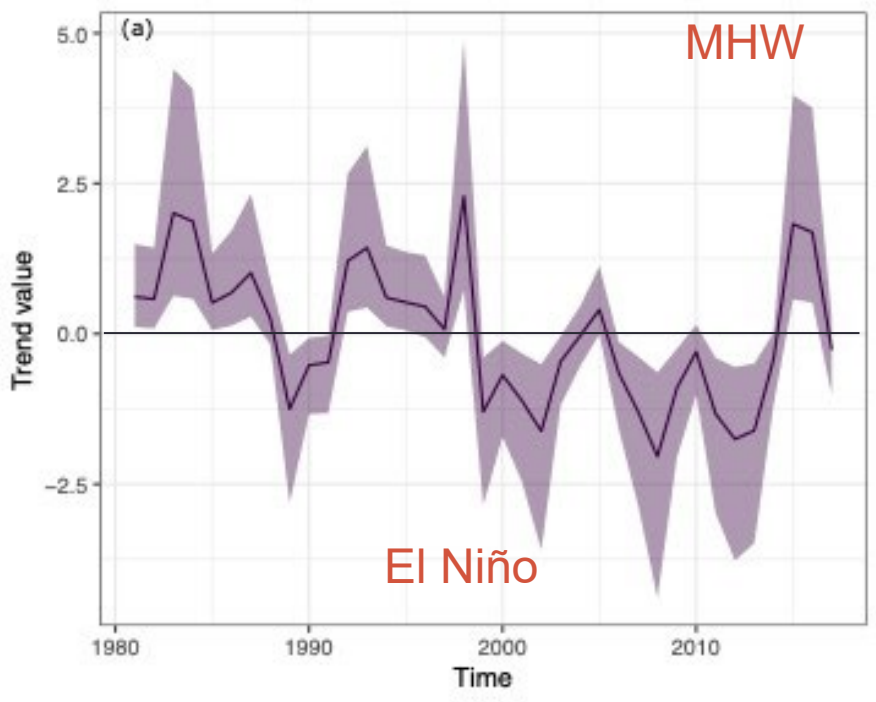
South/Central California Current Ecosystem



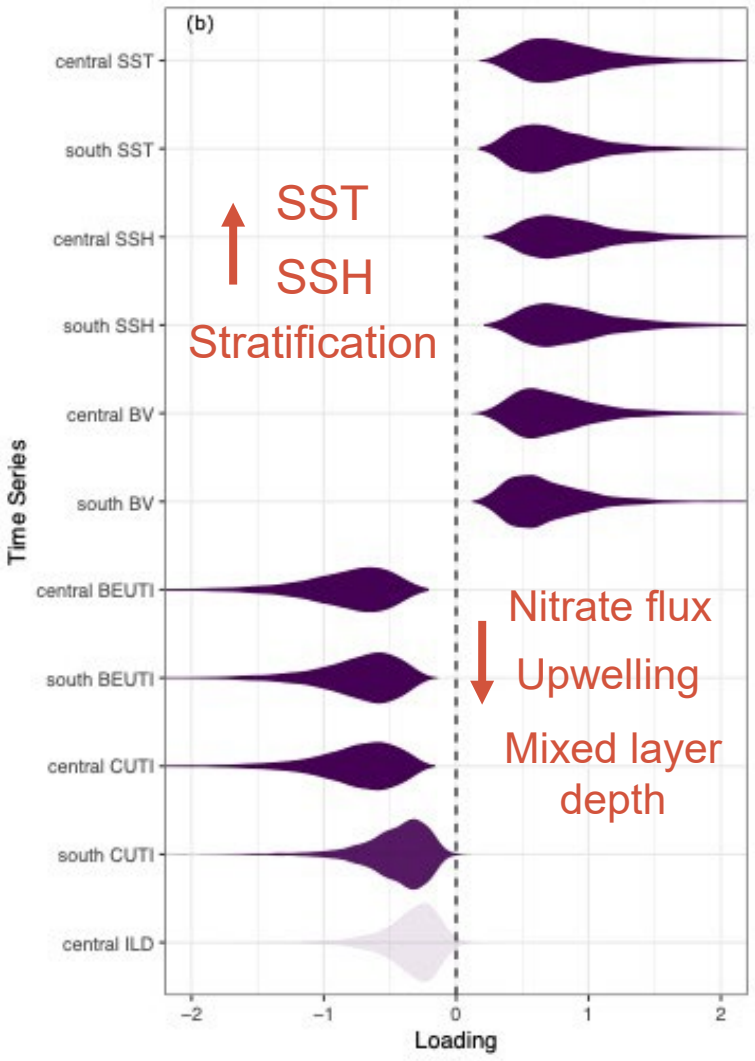
Biology data

- Ichthyoplankton (1951-2016)
- Juvenile rockfish, groundfish, squid and krill (1990-2016)
- Seabird productivity (1971-2016)
- Sea lion pup growth, count, weight (1997-2016)

Climate trend captured cooling period, El Niño events, and MHW

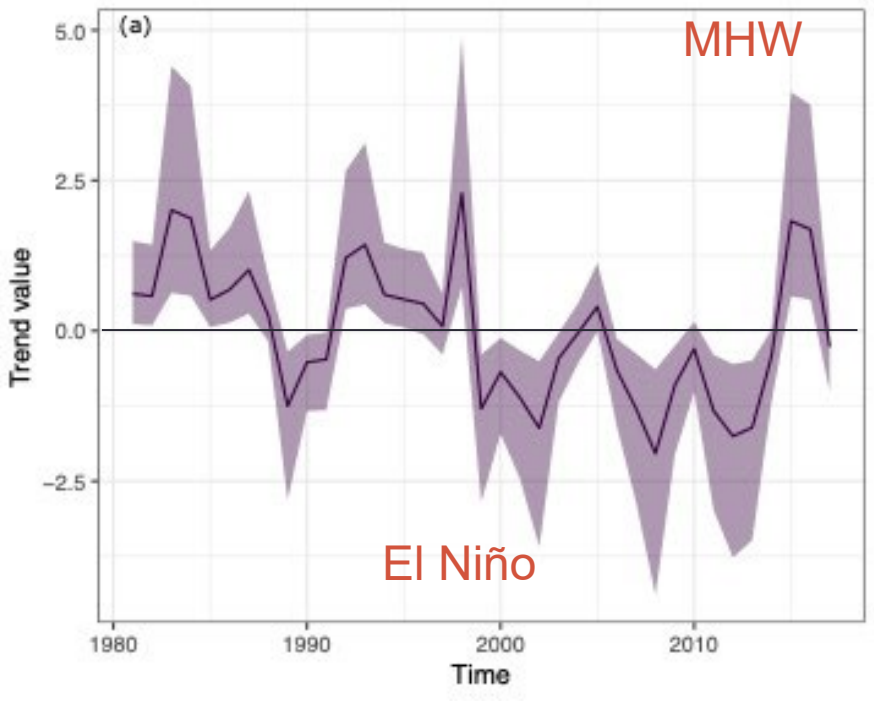


Shared trend with 95% credible intervals



Hunsicker et al. 2022 PLOS Climate

Presence of two states, warmer versus cooler conditions



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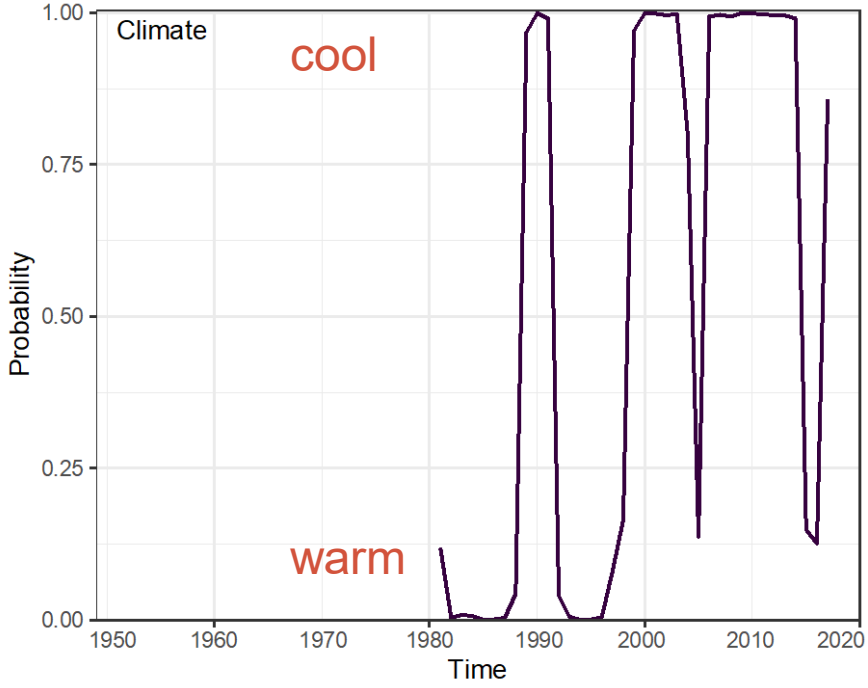
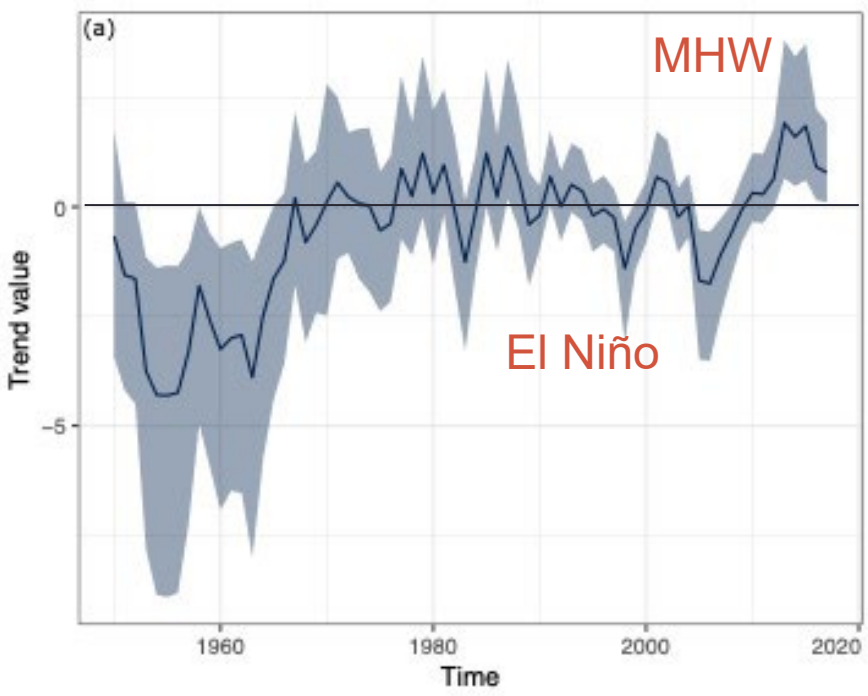


Assigns a probability of shared trends being in a particular state (median, 95% CI)

Strong deviations in community trend around the time of El Niño events, and MHW



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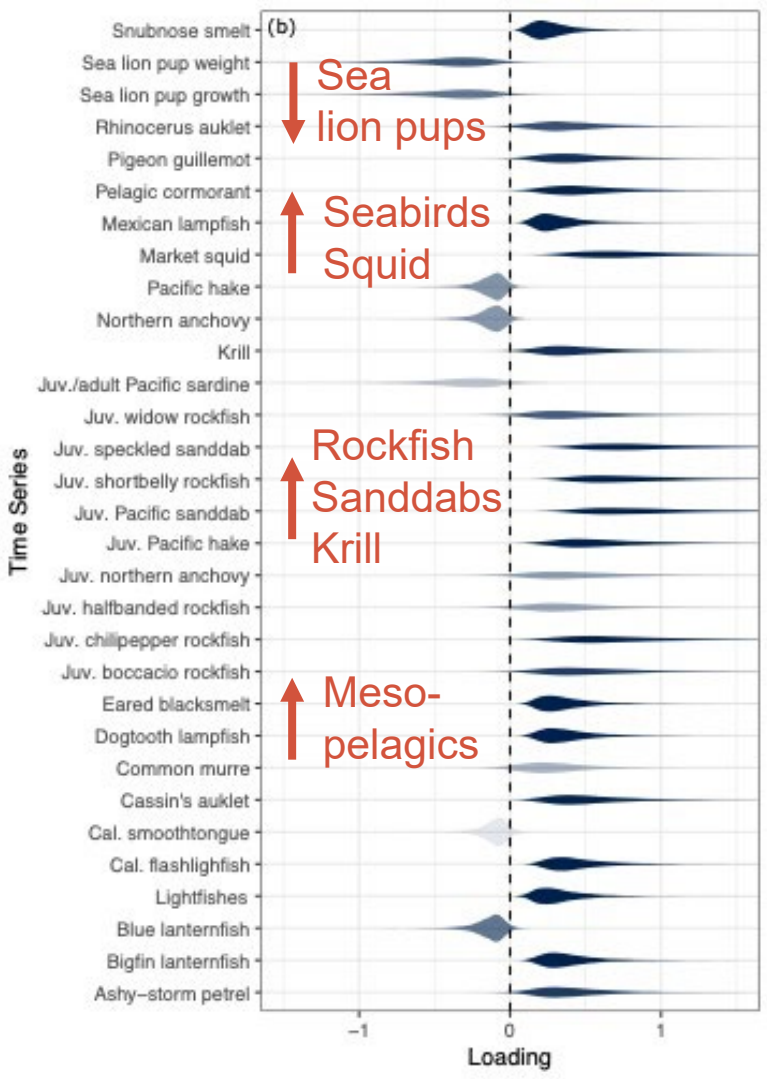
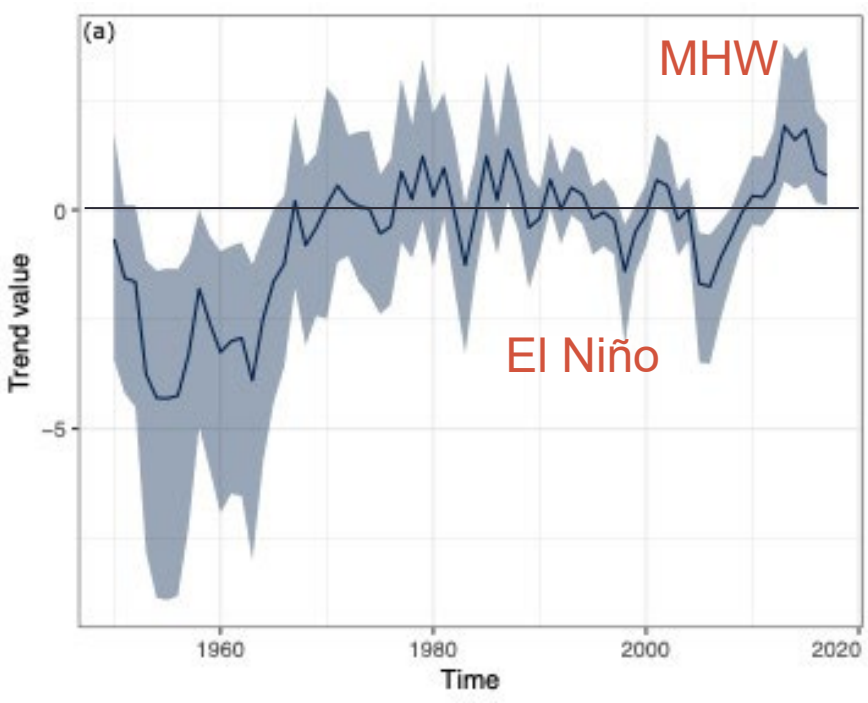
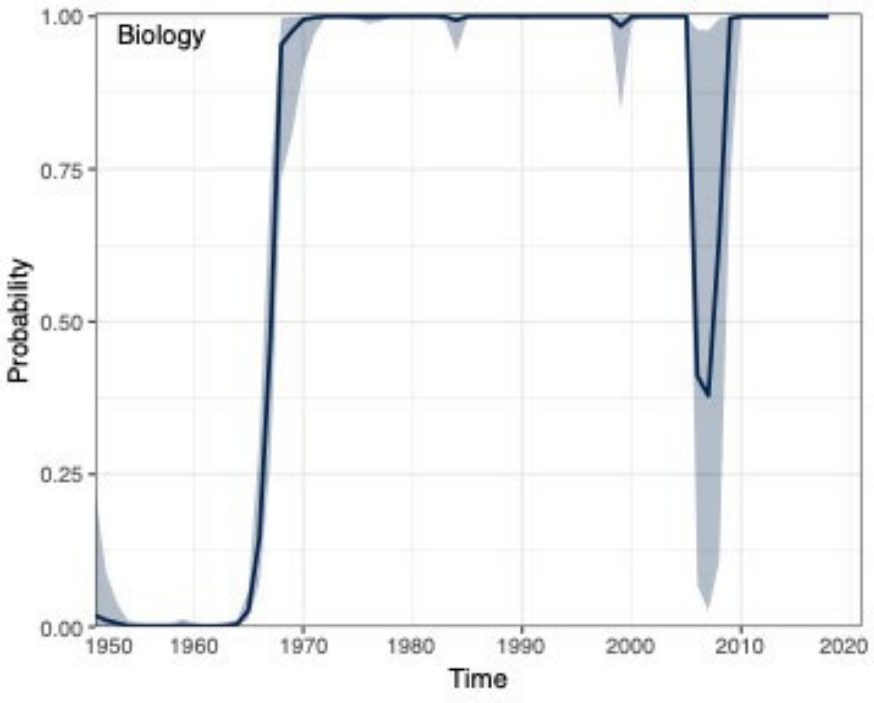


Evidence for regime shift in 1960s, not after MHW





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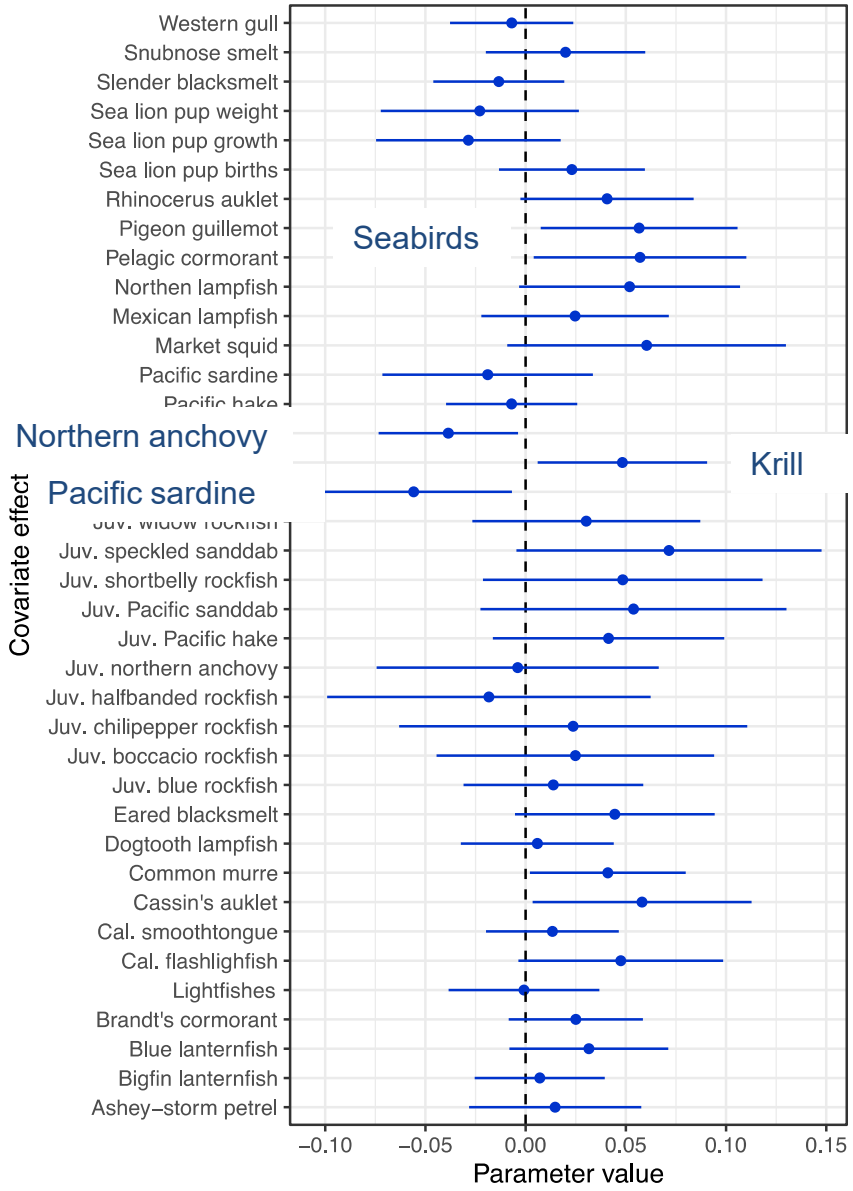
Assigns a probability of shared trends being in a particular state (median, 95% CI)

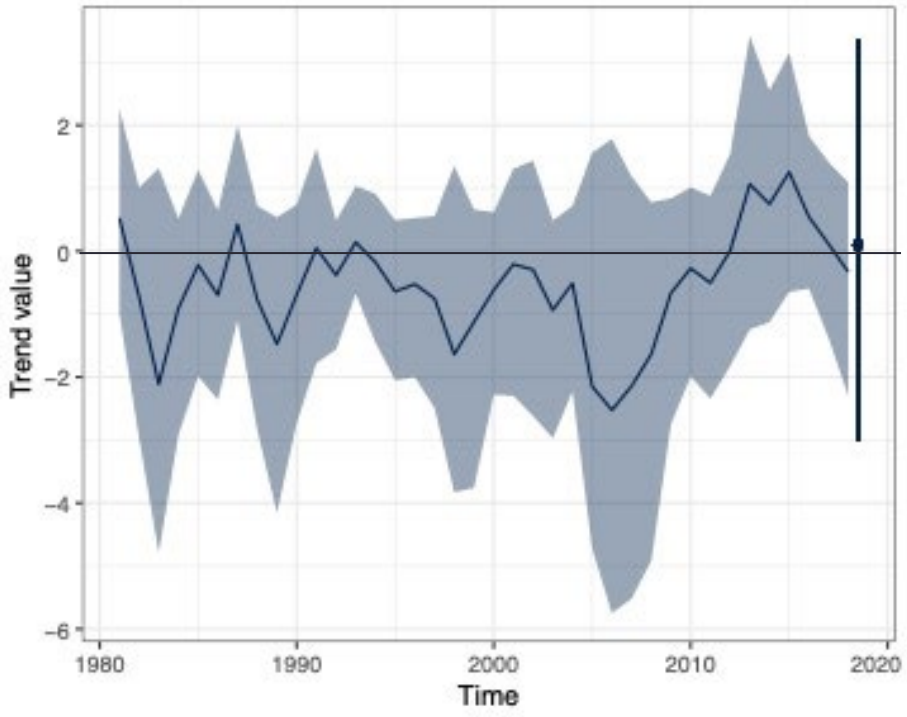
One year ahead forecasts of ecosystem state

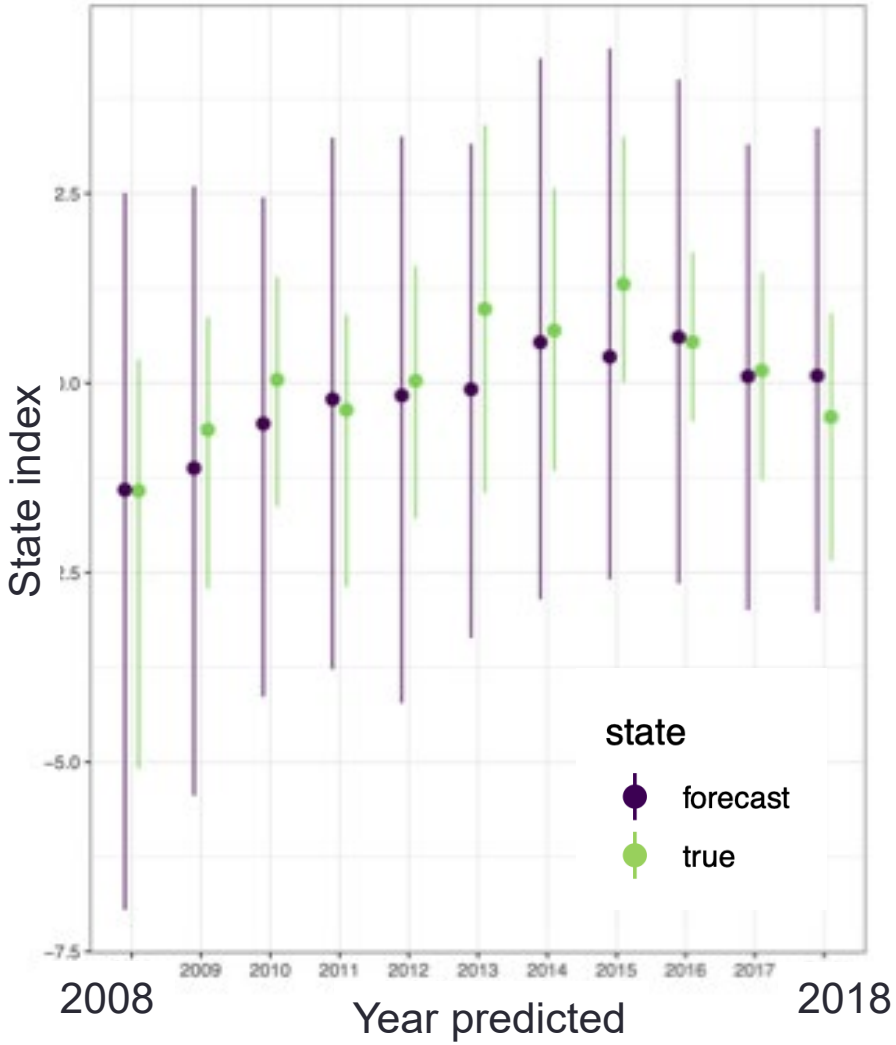
Nitrate flux exhibited strongest relationship with species and community-level responses

Model	Process sigma	Trends	ELPD	SE ELPD	Covariate	Region
1	**No**	**1**	**-1878.71**	**71.52**	**BEUTI**	**central**
2	No	1	-1905.27	81.98	CUTI	central
3	No	1	-1914.62	83.22	ILD	south
4	No	1	-1927.33	88.26	SST	south
5	No	1	-1928.03	88.39	BV	south
6	No	1	-1946.75	86.33	SSH	south
7	No	1	-1951.44	73.59	None	-
8	Yes	1	-2038.71	91.44	None	-



Forecasts of community trend for ten additional years indicate some skill for many of the years tested





Future Directions

- Evaluate multiple covariates at the same time
- Apply analysis to other NE Pacific ecosystems
- Tailor to particular species, improve predictions of recruitment /survival?
- Evidence of nonstationary relationships in California Current

Image: marineresearch.oregonstate.edu

Concluding remarks

- Tipping points science to mitigate and adapt to impacts, especially in the face of climate change

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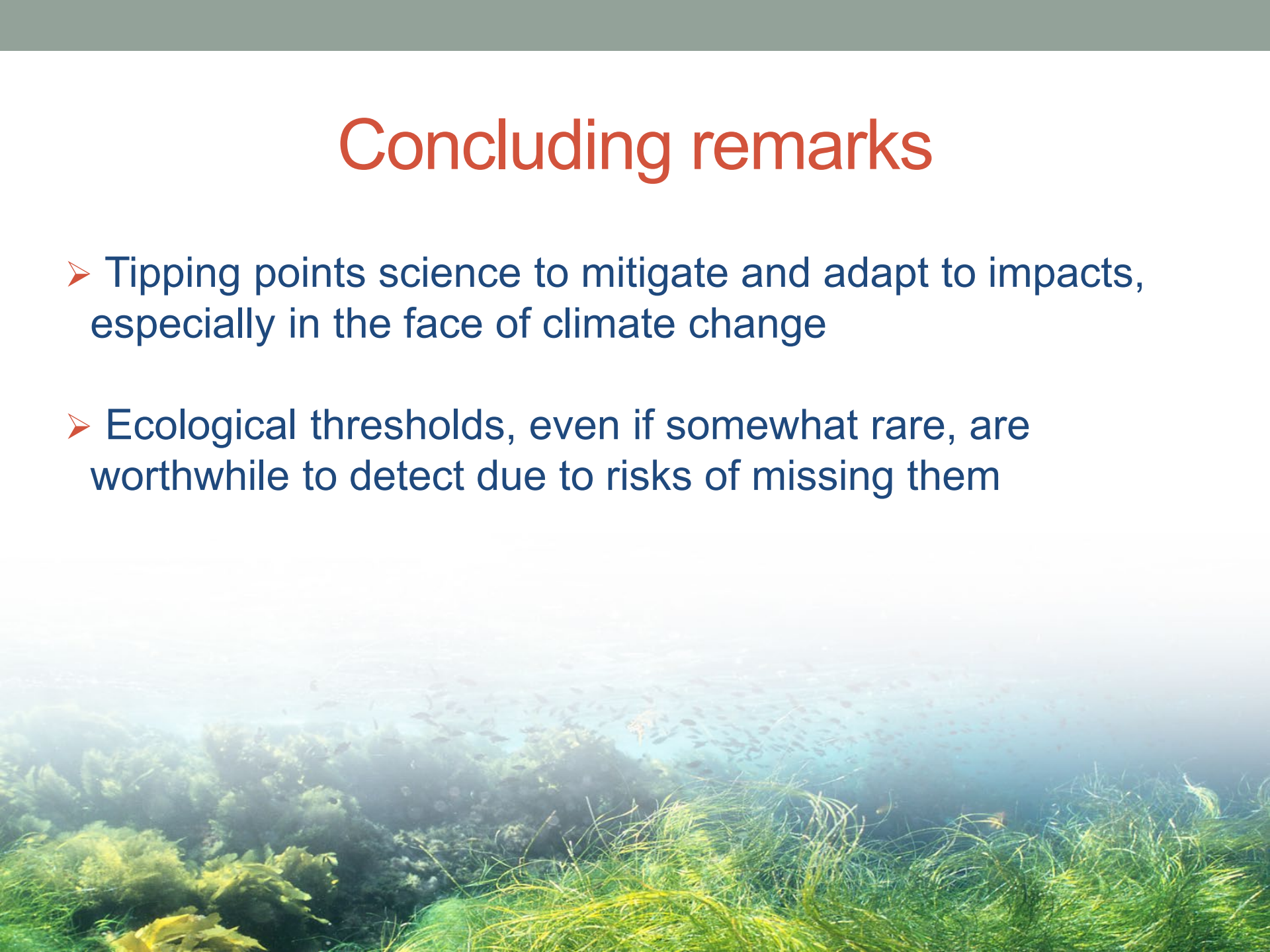
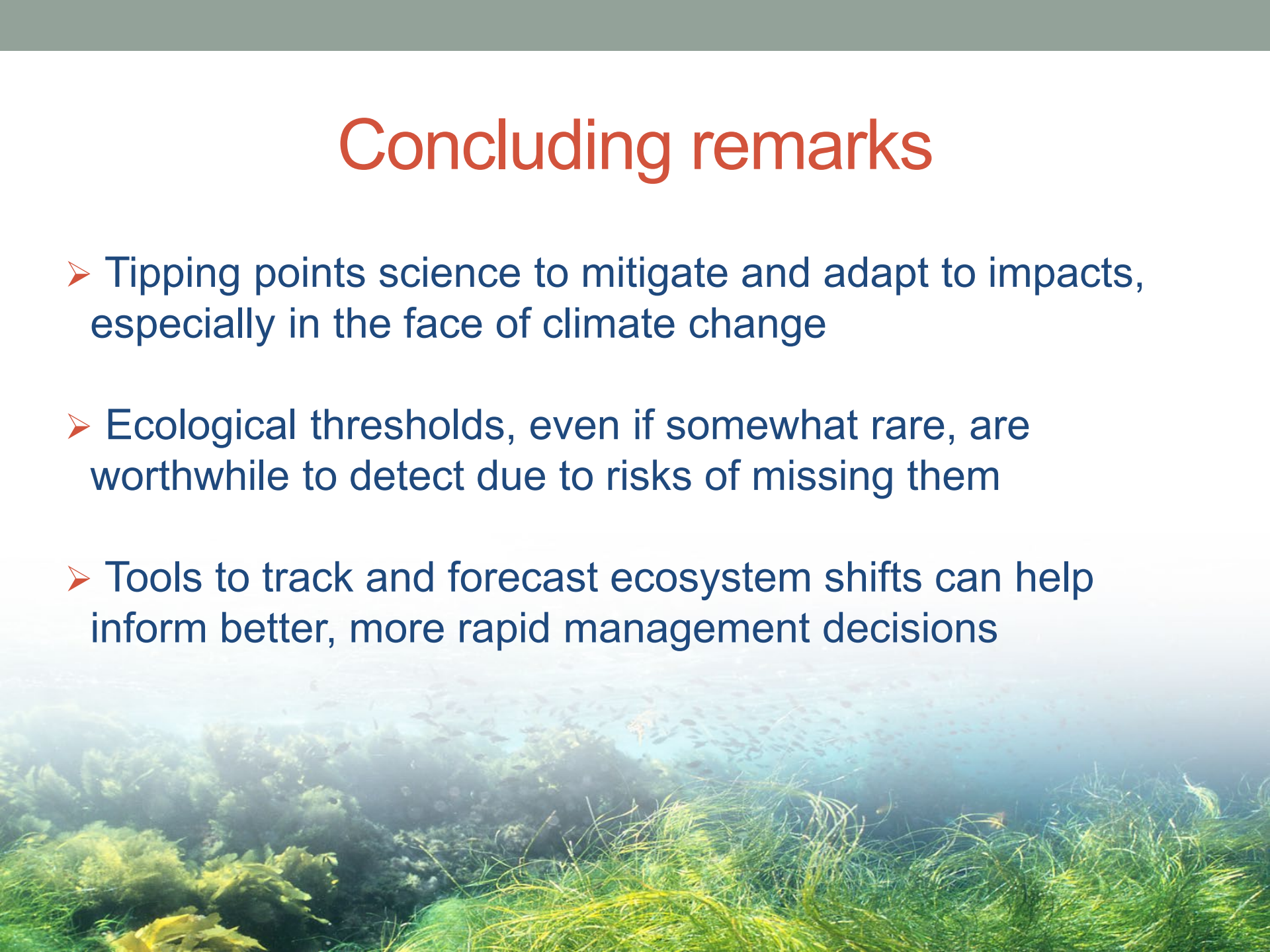


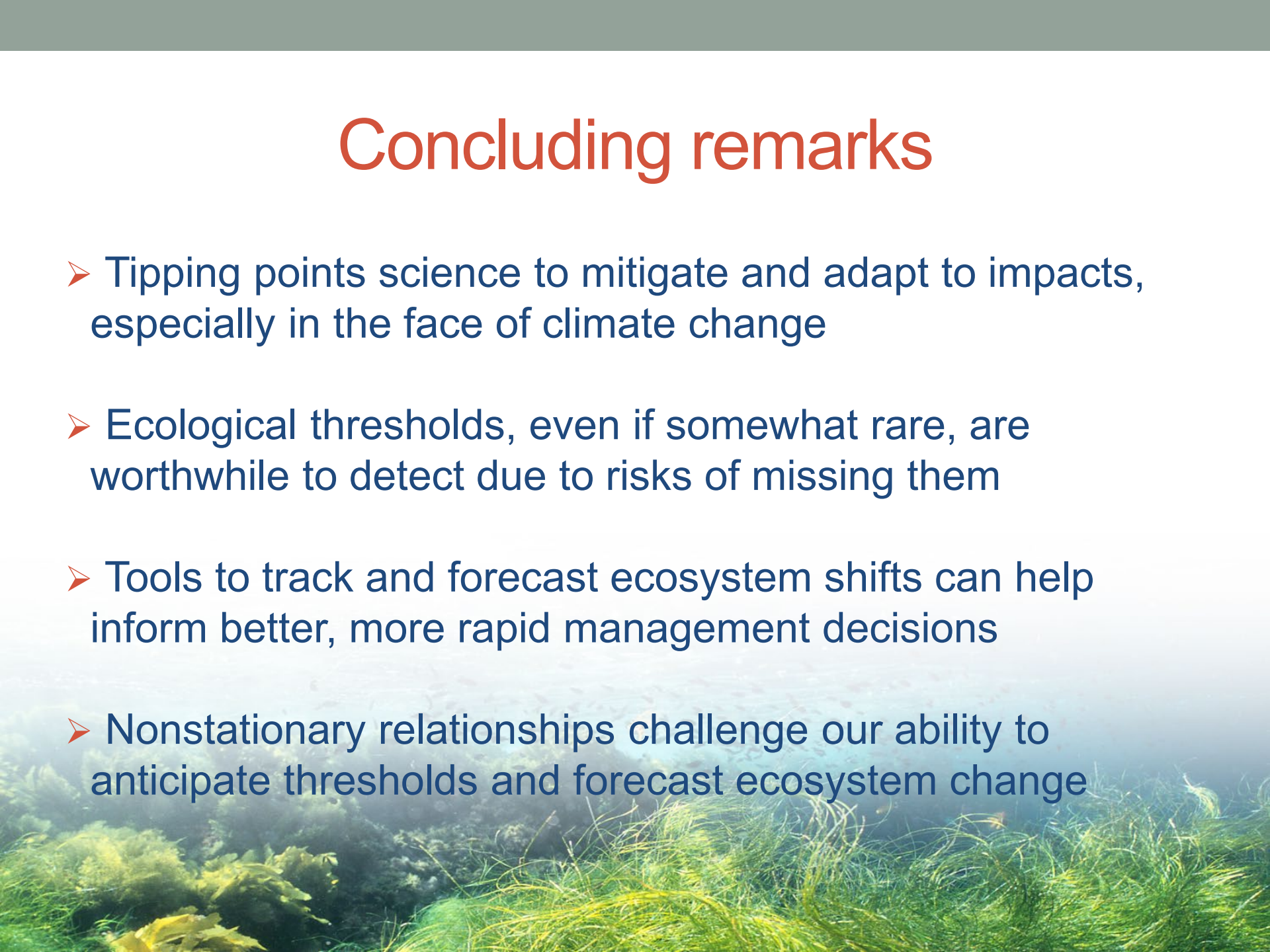
Concluding remarks

- Tipping points science to mitigate and adapt to impacts, especially in the face of climate change
- Ecological thresholds, even if somewhat rare, are worthwhile to detect due to risks of missing them
- Tools to track and forecast ecosystem shifts can help inform better, more rapid management decisions



Concluding remarks

- Tipping points science to mitigate and adapt to impacts, especially in the face of climate change
- Ecological thresholds, even if somewhat rare, are worthwhile to detect due to risks of missing them
- Tools to track and forecast ecosystem shifts can help inform better, more rapid management decisions
- Nonstationary relationships challenge our ability to anticipate thresholds and forecast ecosystem change



Thank you!

mary.hunsicker@noaa.gov
Newport, Oregon