EARLY WARNING SIGNALS OF DECLINING RESILIENCE AND ABRUPT TRANSITIONS IN OCEAN ECOSYSTEMS

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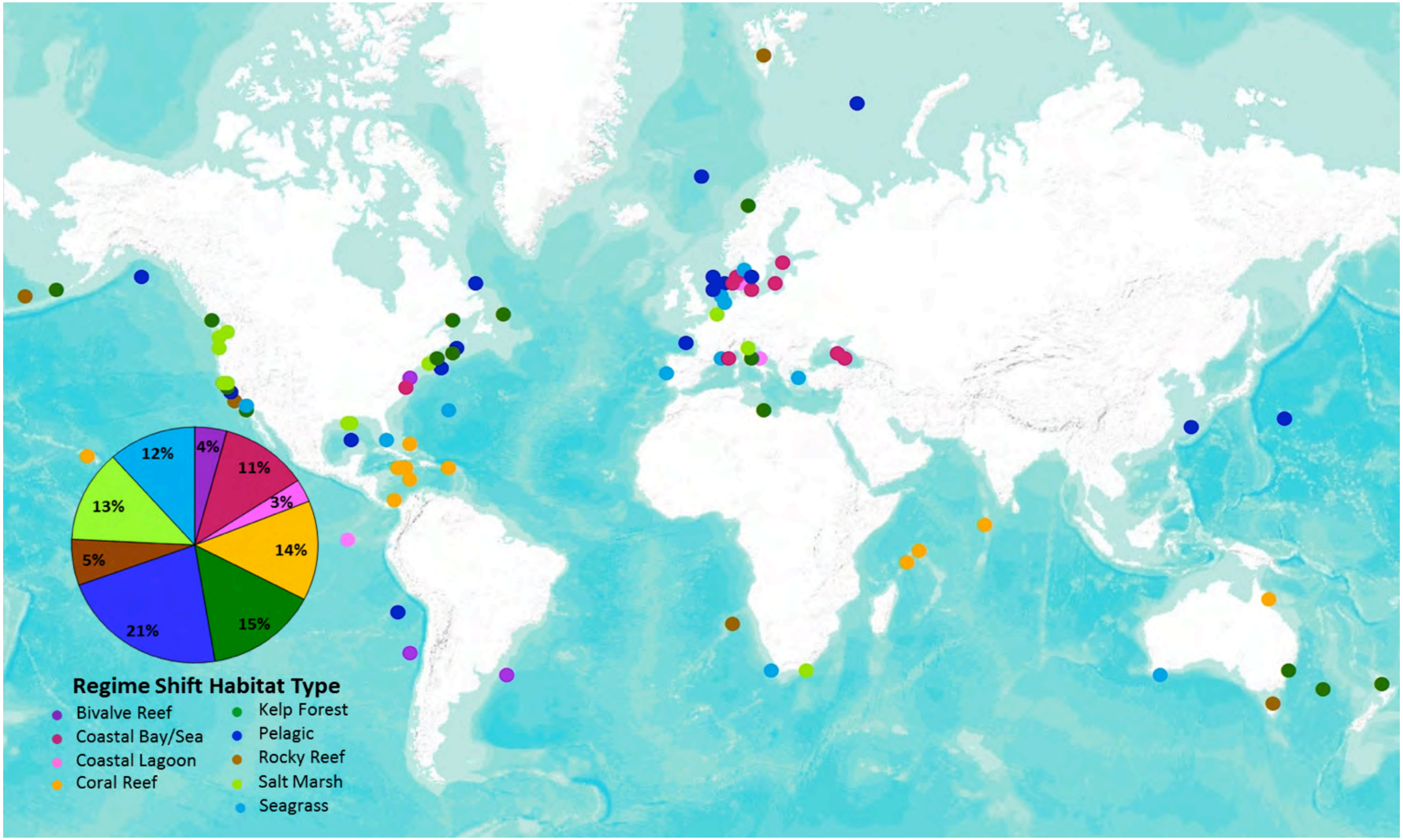
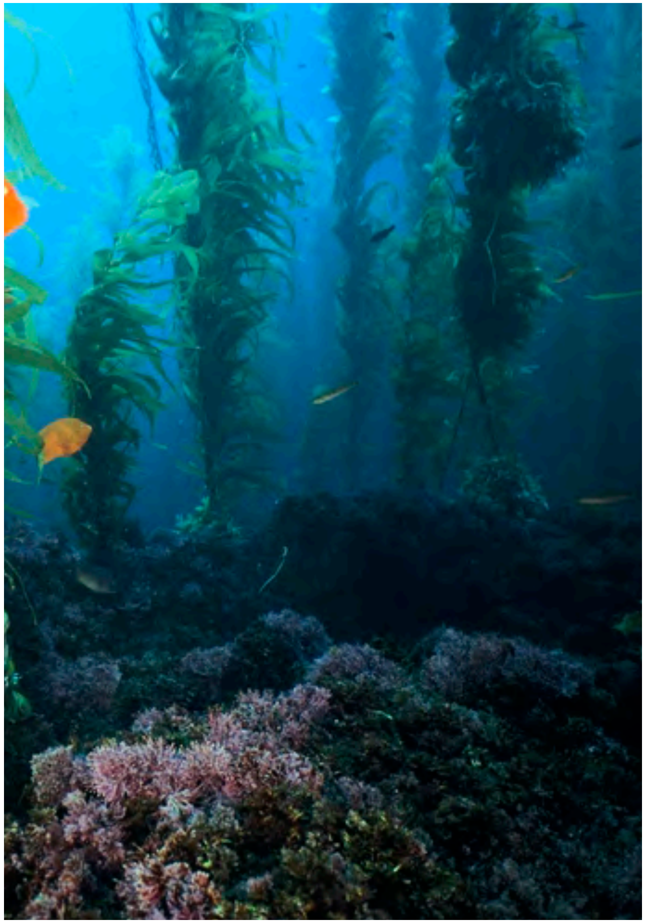
A wide range of marine habitats across the globe have experienced ecosystem shifts from the intertidal to the open ocean.



Kappel et al. in prep.

Common Examples



Common Examples

Image: fishnavy.com

Gulf of Alaska

Image: pnw.scuba.com

Scotian shelf

Calls for more research to…

Improve knowledge and understanding of ocean tipping points, their impacts, and their relevance to management

- Identify nonlinearities in driver-response relationships
- Identify thresholds in those relationships
- Test the utility of leading indicators of abrupt change

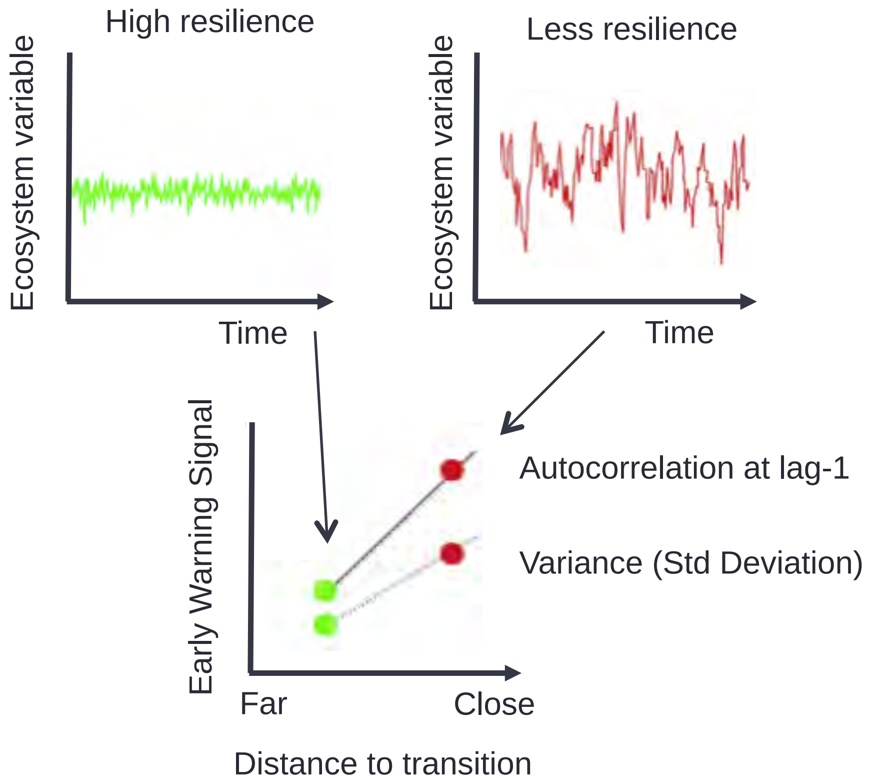
‘Generic’ early warning signals

- Metric-based indicators of ecosystem instability based on the complex systems theory of critical transitions and alternate stable states.

- ‘Critical slowing down’ in population recovery from perturbations as resilience declines and a critical transition approaches

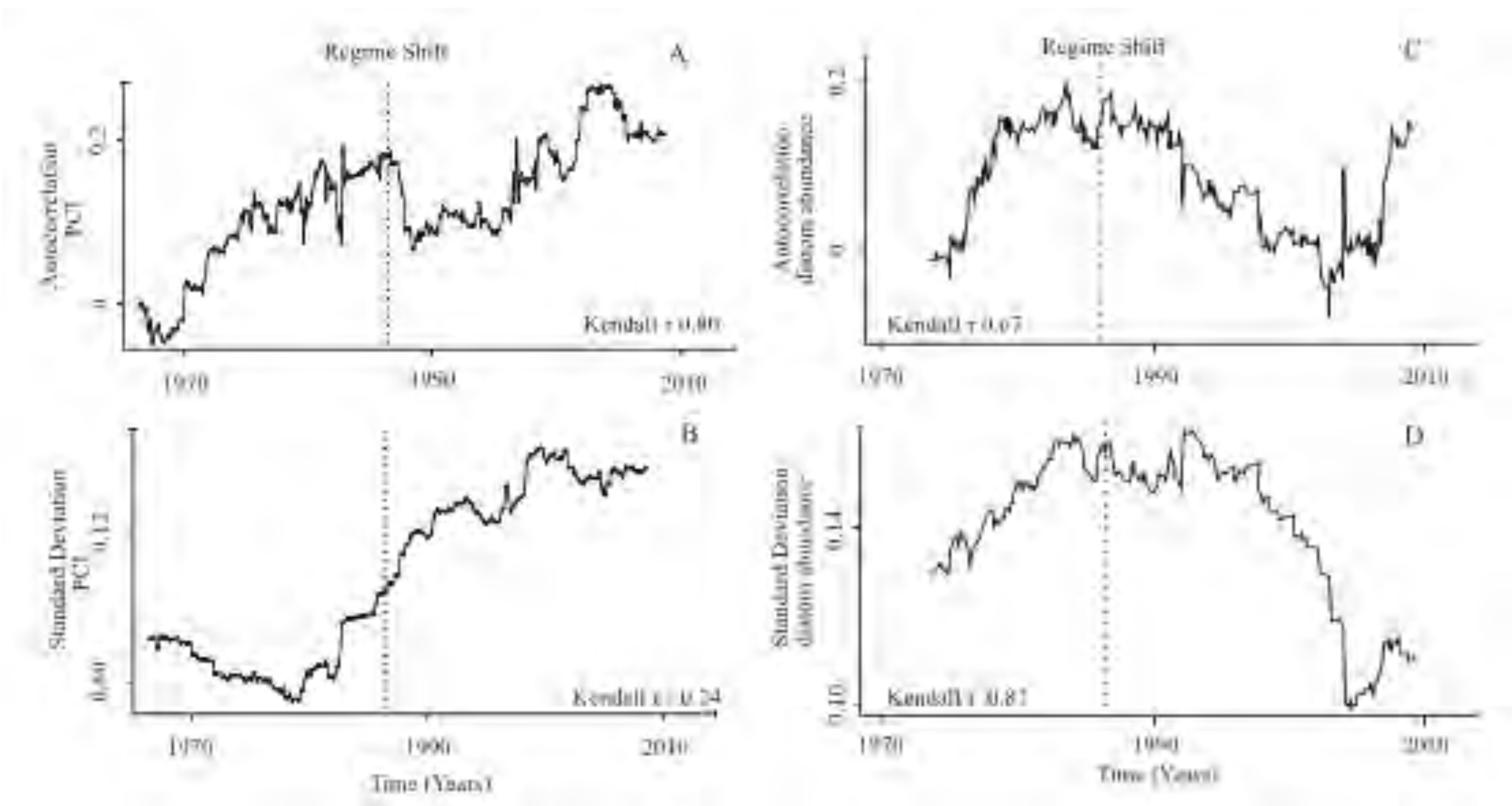
- Can apply to many systems even if the underlying system dynamics are poorly understood

Rising variance and rising autocorrelation are potentially a signal of an approaching shift



From Wouters et al. 2015

Rise in temporal variability (SD and autocorrelation) prior to regime shift in the North Sea



From Wouters et al. 2015

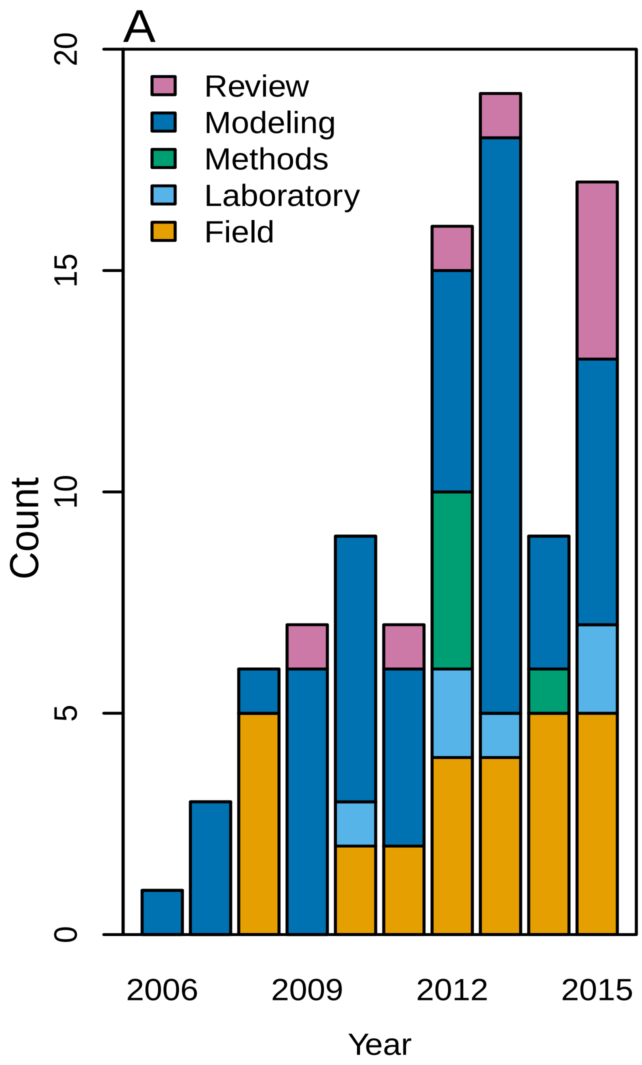
What factors distinguish successful and unsuccessful applications of EWS?

- Review the state of empirical EWS research to date
- Meta-analysis of published studies
- Comparative analysis of 8 NE Pacific Ocean time series

➢ Meta-analysis of published studies

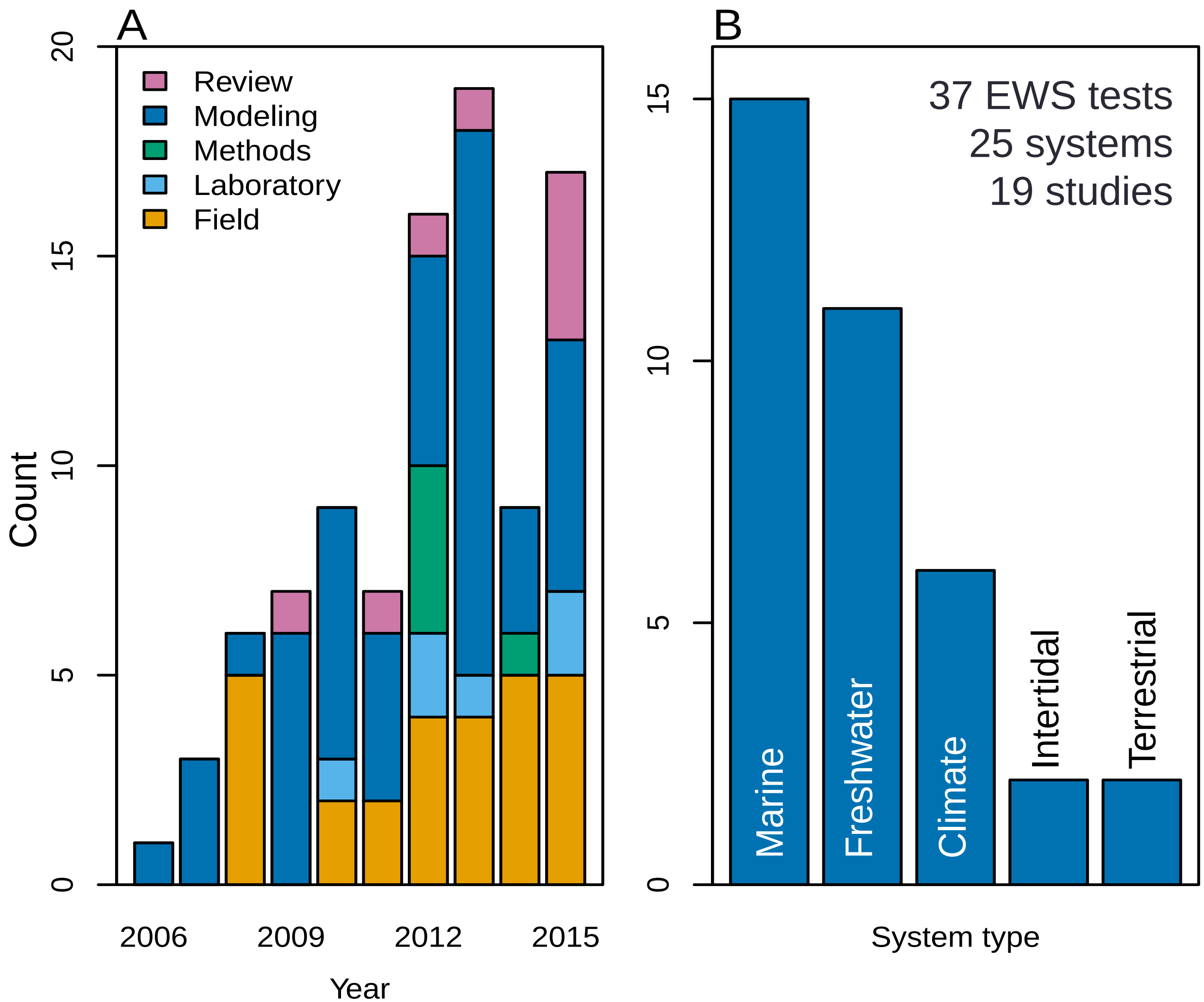
- Searched Web of Science and references cited to identify examples of empirical EWS studies 2006 - 2015
- Included only non-laboratory examples that presented a quantitative test of EWS predictions
- Categorized system as nonlinear / linear and supporting / not supporting EWS theory (ac, variance, skewness)
- Compared proportion of positive and negative results between systems deemed nonlinear and linear

Identified 94 EWS studies, 1/3 included empirical test



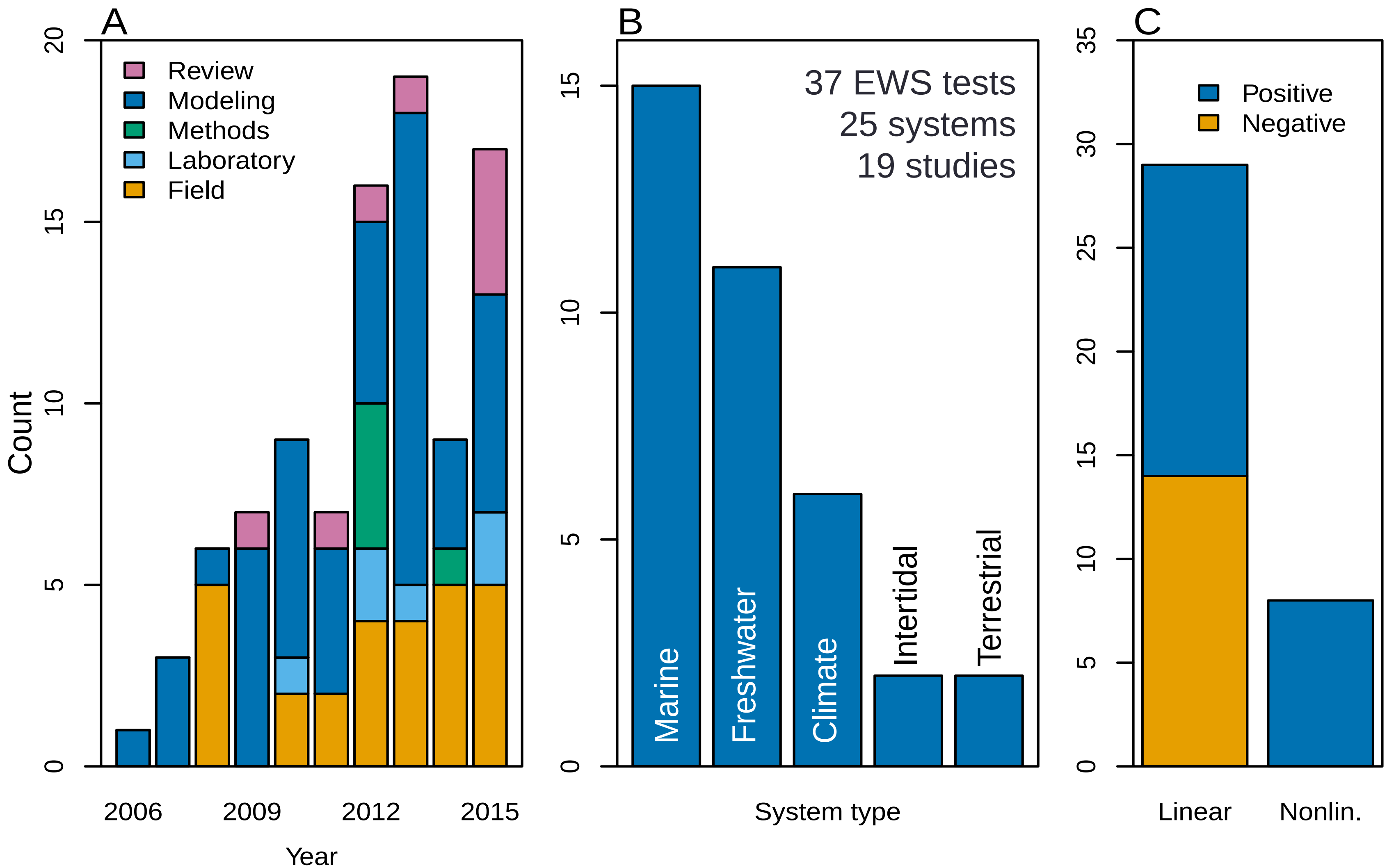
Litzow and Hunsicker Ecosphere *In press*

Trophic cascades, desertification, and shifts in species abundance, community composition and climate patterns



Litzow and Hunsicker Ecosphere *In press*

Nonlinearity was demonstrated in only six of the 25 systems.
These systems produced eight positive EWS tests and no negative tests



Litzow and Hunsicker Ecosphere *In press*

Linear

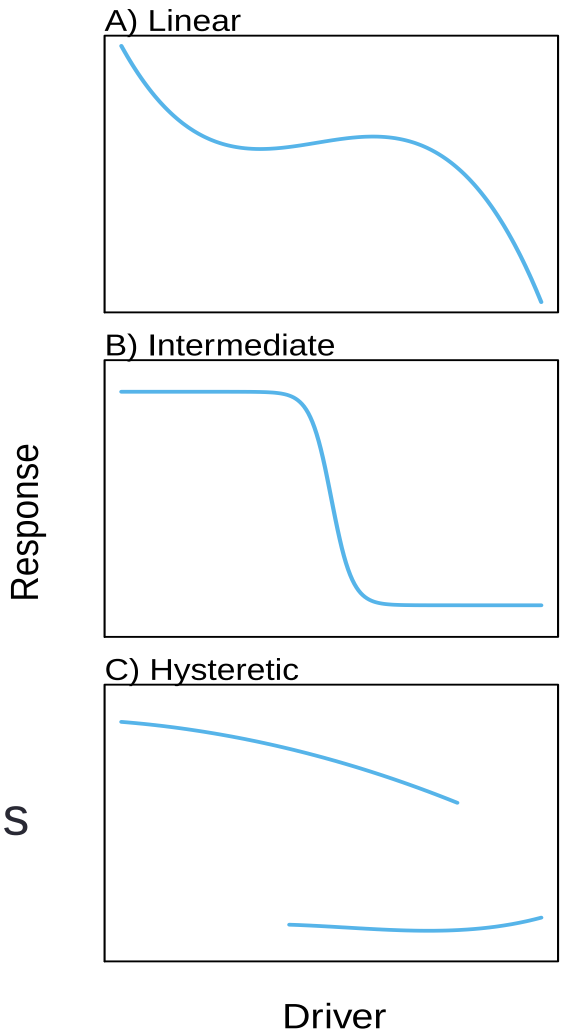
Underlying driver exhibits threshold behavior that is tracked by the ecosystem response

Nonlinear

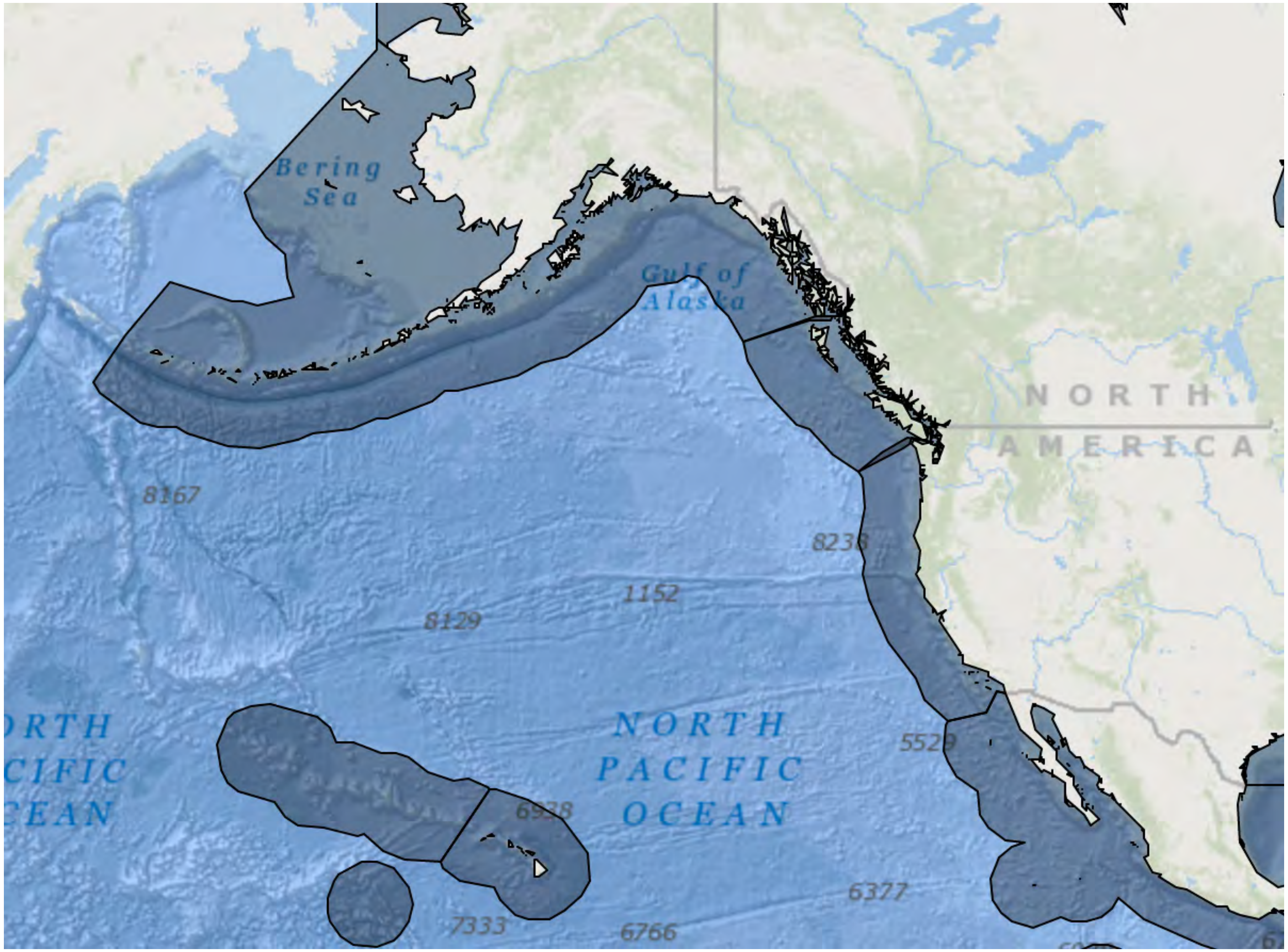
Relationship between driver and response variable is nonlinear

Nonlinear
with hysteresis

Relationship between driver and response variable is different before and after shift



- Comparative analysis of multiple time series



Comparative analysis of multiple time series

Alaska:

- Community composition (Pavlof Bay)
- Community distribution from trawl surveys (EBS)
- Mean length for juvenile Pacific cod, walleye pollock (EBS)

Northern California Current:

- Population abundance for three copepods
- Naturally-produced population of coho salmon

All respond to climate variability on monthly, annual, or decadel time scales

Comparative analysis of multiple time series

- Test for nonlinearity in biological responses to a climate driver between different climate states (linear and sigmoidal regressions, GAMs)

- Test for rise in EWS, included *ad hoc* randomization approach to conduct valid hypothesis tests for EWS in the presence of autocorrelation

i. Shifts in mean values are preceded by rising EWS
ii. Persistent perturbation (i.e. cold anomaly) should be accompanied by rising EWS

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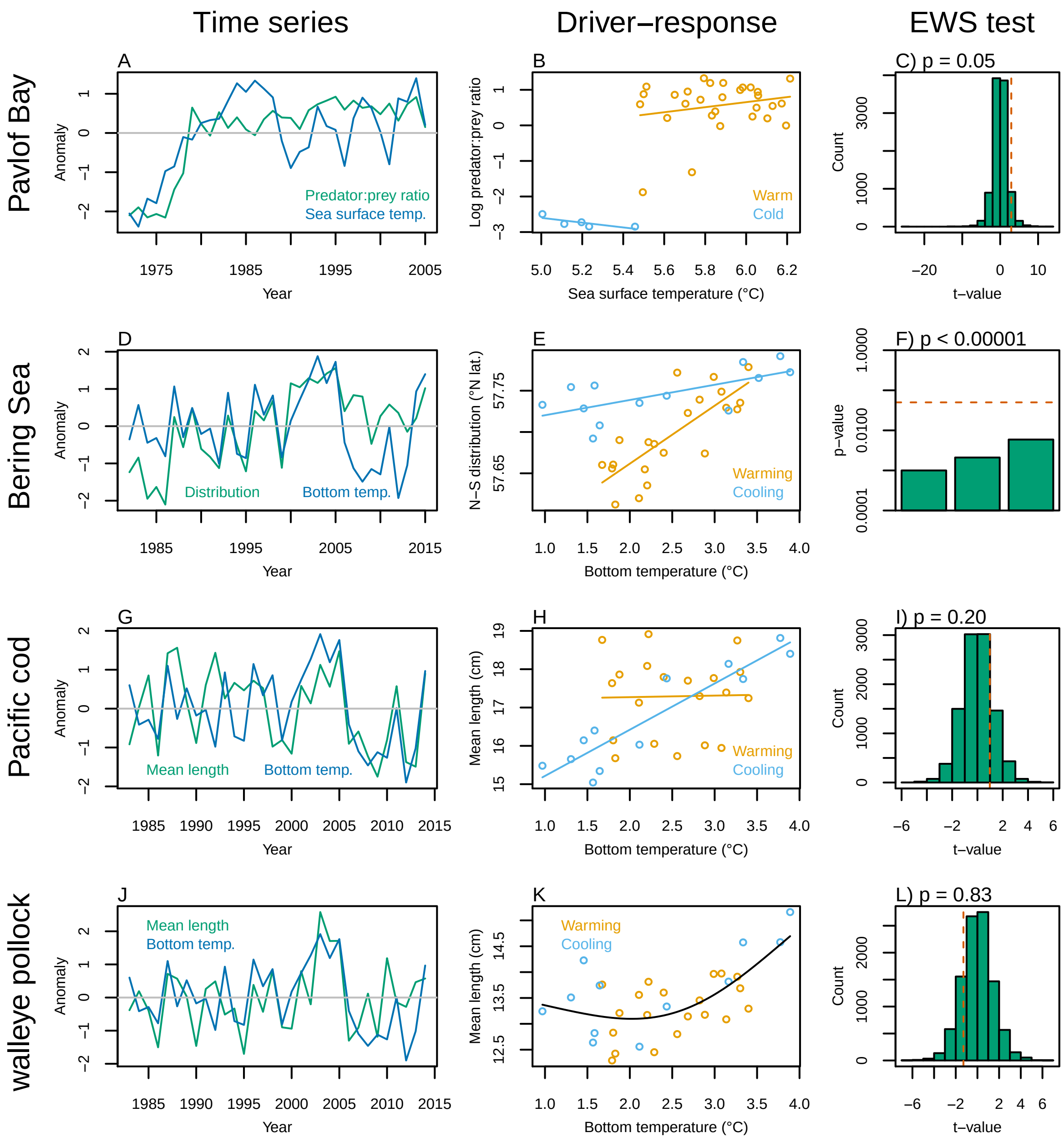
- Calculate combined probability of observed EWS behavior from multiple EWS tests within and across time series with Fisher’s combined probability test spatial variance

spatial ac, variance, and temporal ac

spatial variability

spatial variability



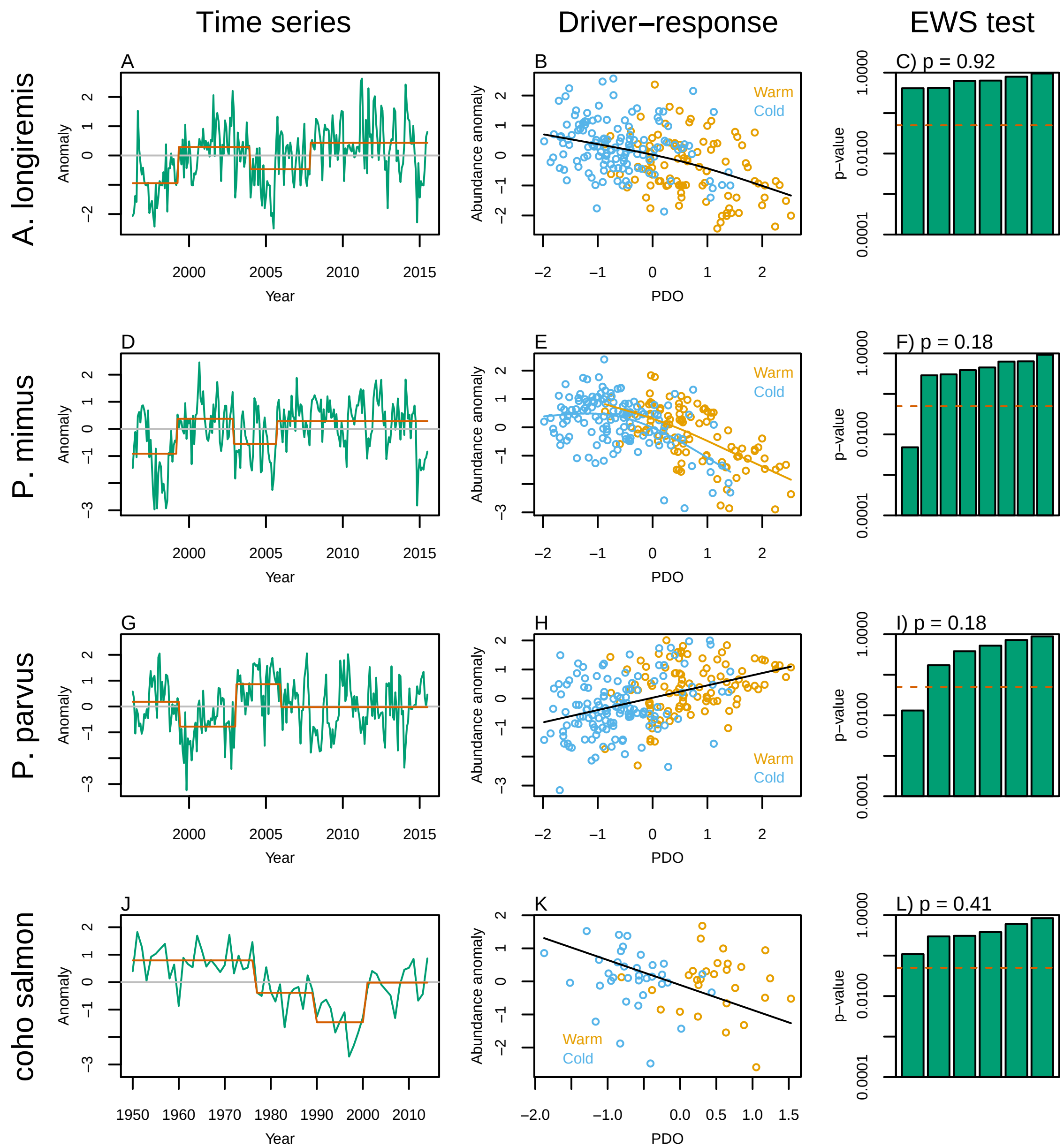
Litzow submitted, Litzow et al 2008, Litzow and Hunsicker Ecosphere *In press*

temporal
variance, ac

temporal
variance, ac

temporal
variance, ac

temporal
variance, ac



Litzow and Hunsicker Ecosphere In press

Combined probability across linear and hysteretic groups

- EWS tests for time series showing hysteretic driver-response relationships led to rejection of the null hypothesis of no EWS behavior prior to shifts ($p < 0.00001$).

- EWS tests for for time series with linear driver-response relationships failed to reject the null hypothesis ($p = 0.67$).

Summary

- Our analyses demonstrate that nonlinearity in system dynamics are more likely to support theoretical EWS predictions
- EWS have been described as ‘generic’, but theoretical support for EWS is largely generated from nonlinear models
- Tests are needed for either nonlinear dynamics or hysteresis are needed before employing EWS

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Thank you!

Google images