Thresholds and early detection of abrupt change in Northeast Pacific marine ecosystems

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Acknowledgments

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WHAT'S A TIPPING POINT?
TOLES

Ocean Tipping Points

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

Classic example


Kelp forests
Coral reefs
Oyster reefs
Sand dunes
Seagrass
Pelagic systems
Mud flats
Saltmarshes
Rocky intertidal
Estuaries
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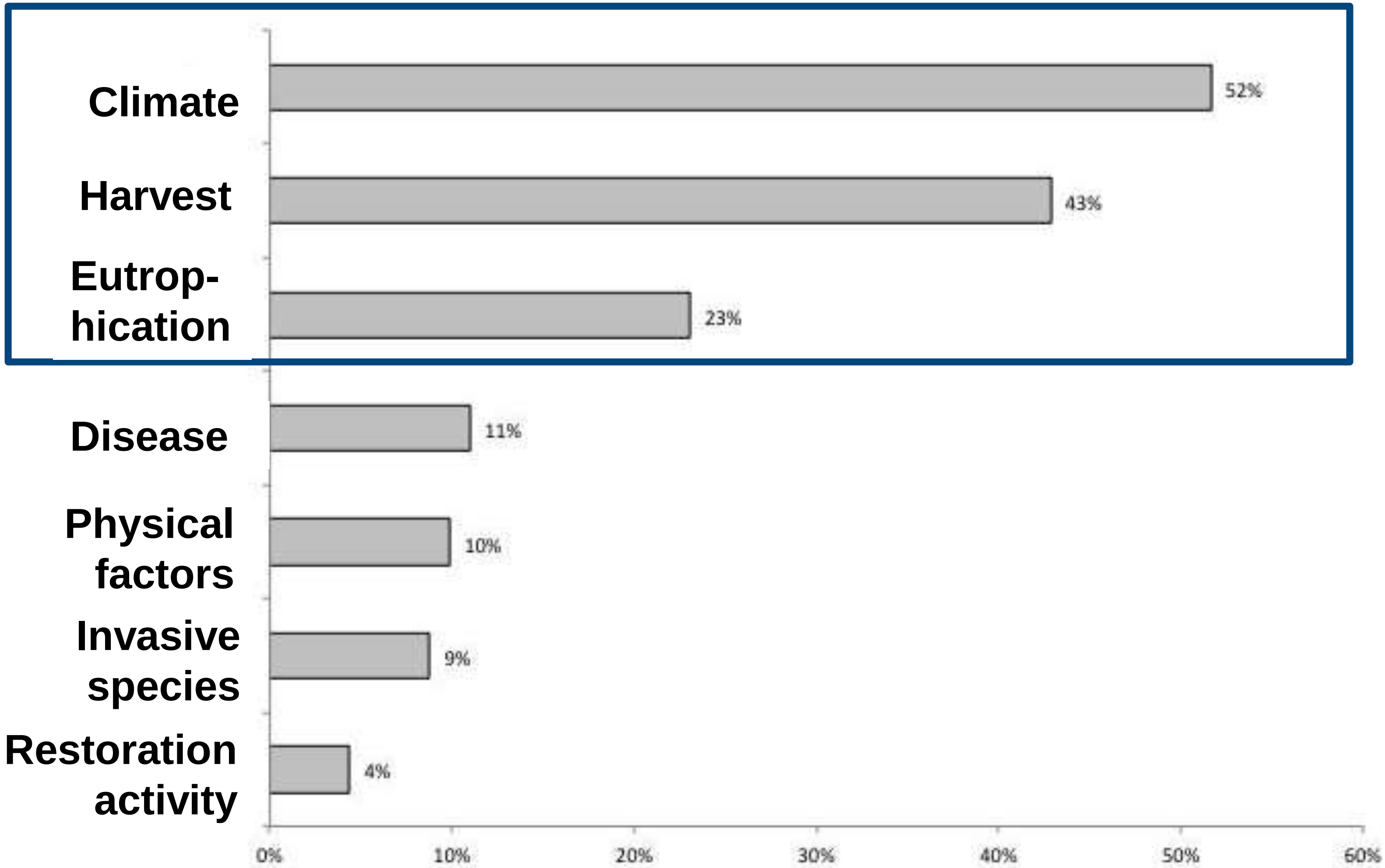
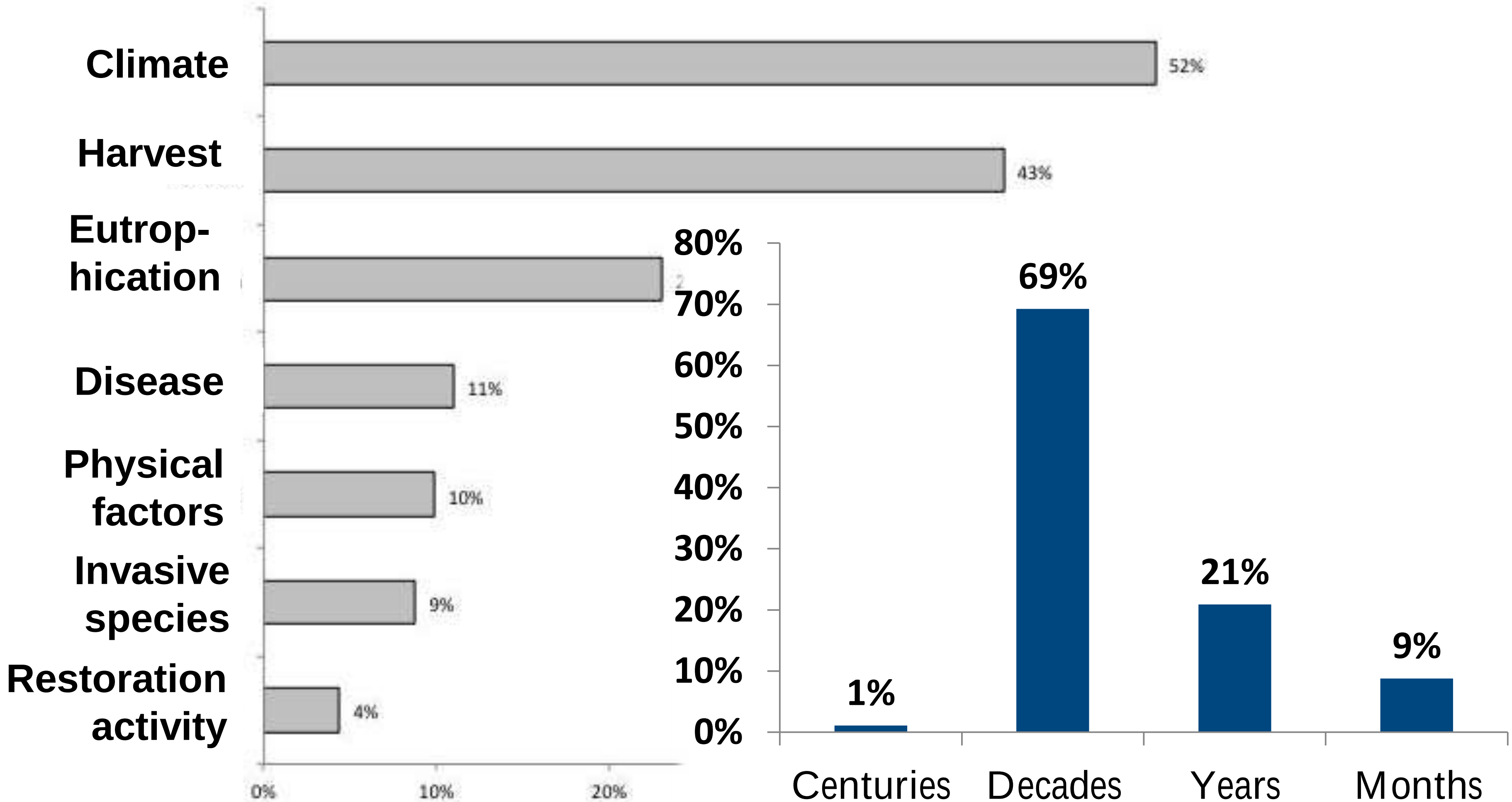
Top drivers of ecosystem shifts

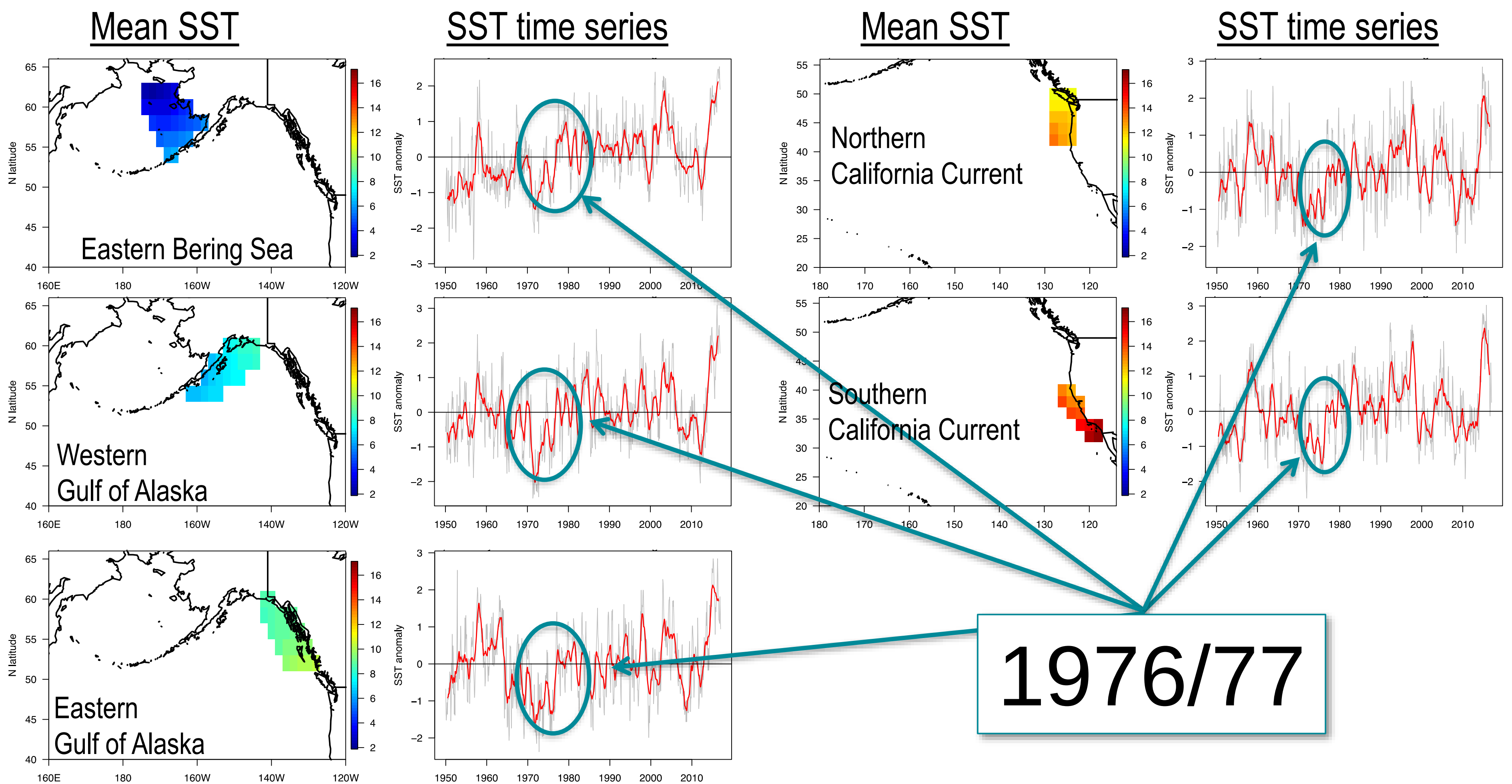


Kappel et al.

Ecosystems that have crossed a threshold tend to remain in an altered condition for decades



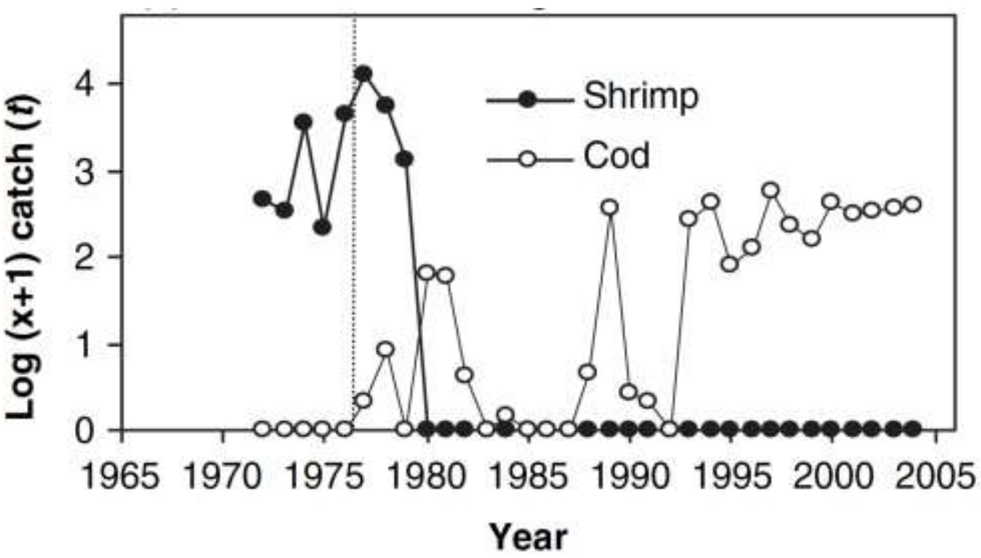
Ecosystem perturbations in NE Pacific



Abrupt, persistent ecosystem changes

Gulf of Alaska (Pavlof Bay) example

Commercial catches



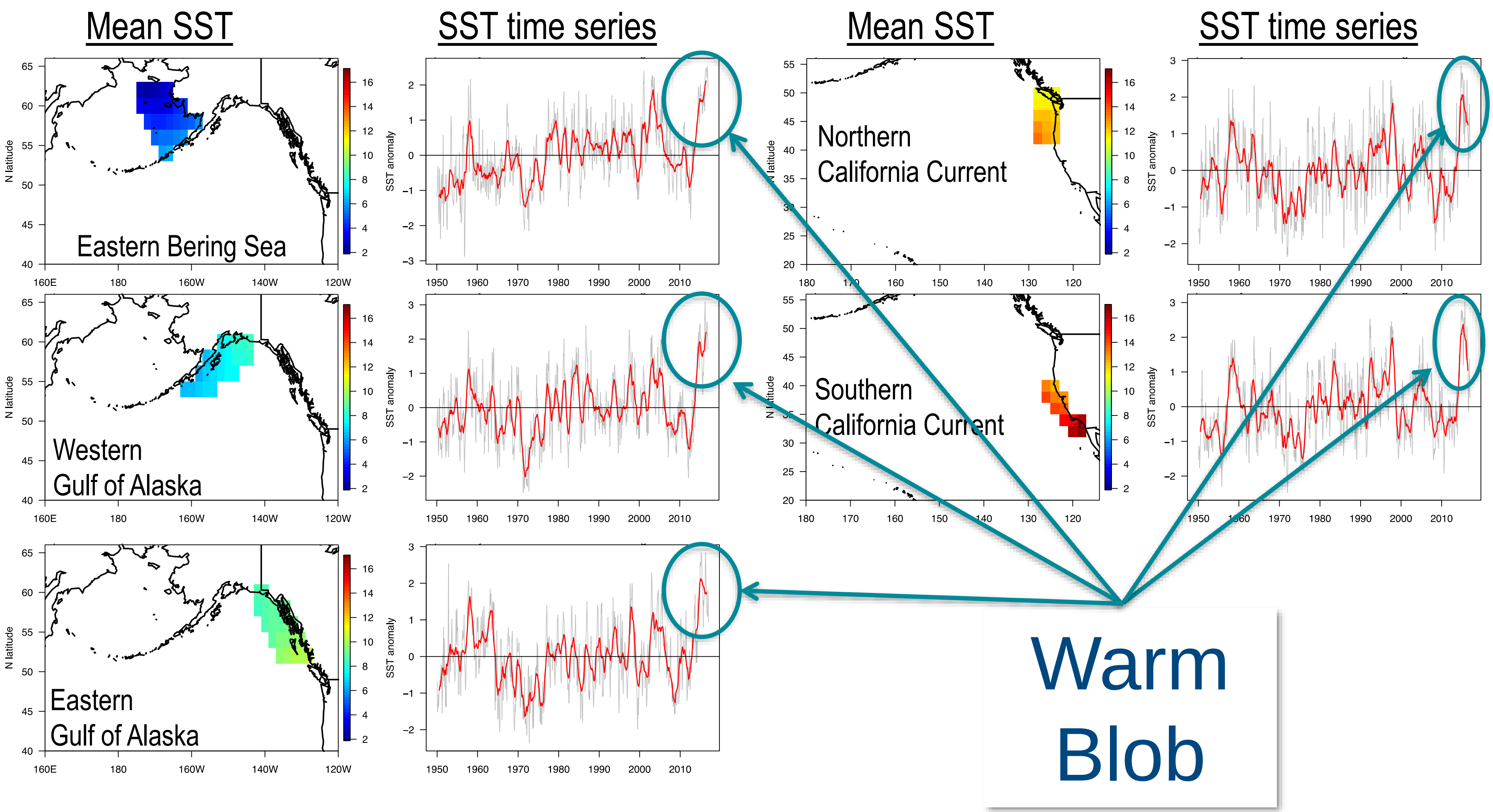
Nearshore survey catches

1970s

Late 1970s

1980s

Ecosystem perturbations in NE Pacific



Biological responses to warm ocean

Crab and clam fisheries closures due to domoic acid

Red pelagic crabs in Oregon

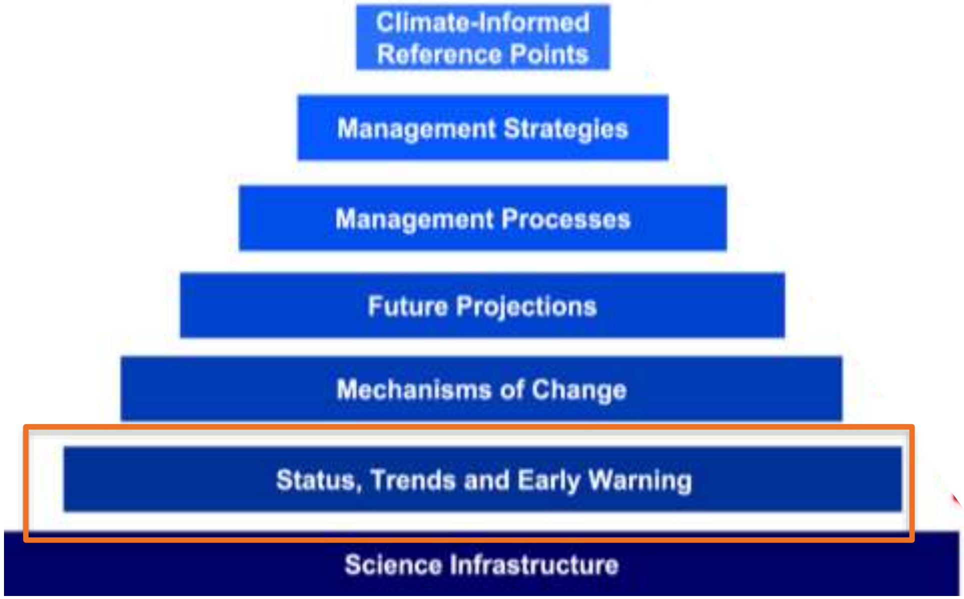
Record low spring Chinook & steelhead returns to Columbia

Caspian terns abandon East Sand Island colony in mid-season

- ➢ Stay tuned for Laurie Weitkamp's presentation on ocean conditions and biological responses

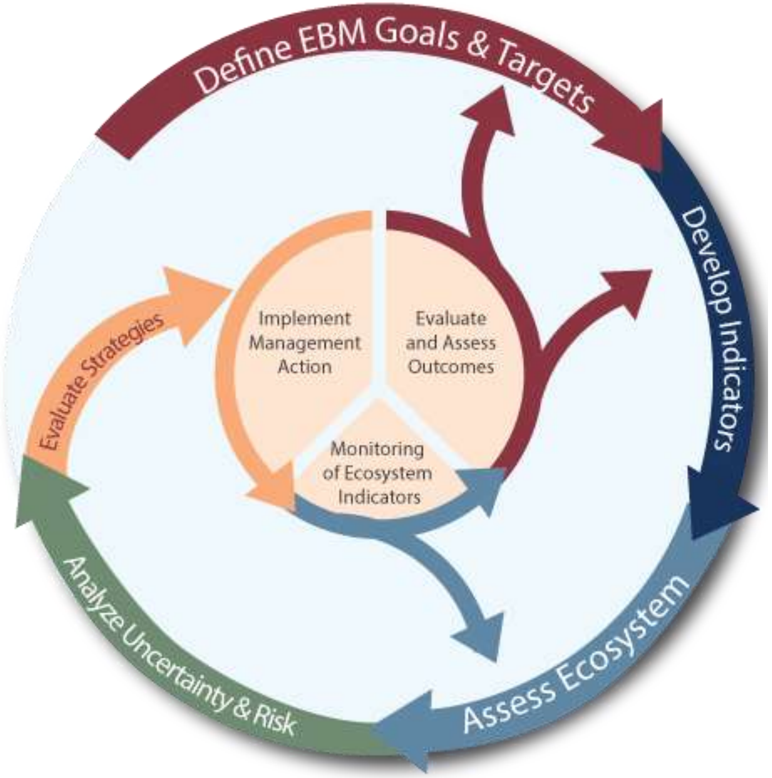
Tracking and providing early warning of changes in ecosystem state is a leading goal of ecosystem-based management

NOAA Fisheries Climate Science Strategy



Busch et al. 2016 Marine Policy

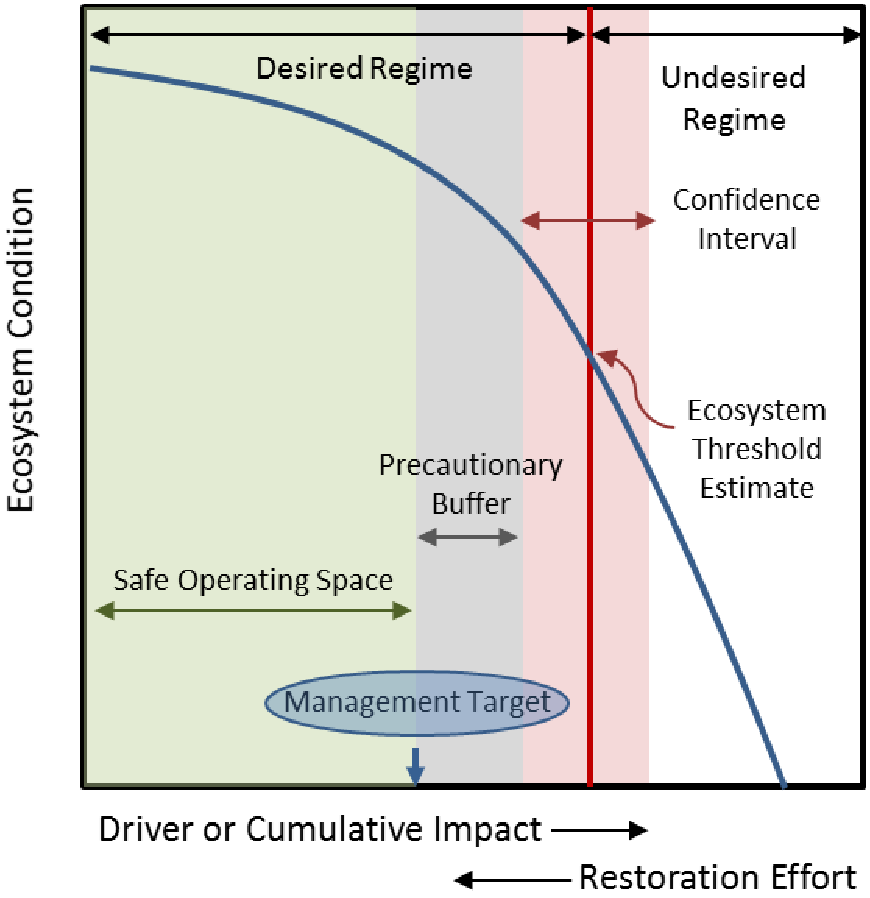
NOAA Integrated Ecosystem Assessment



Define thresholds of indicators and early detection of shifts

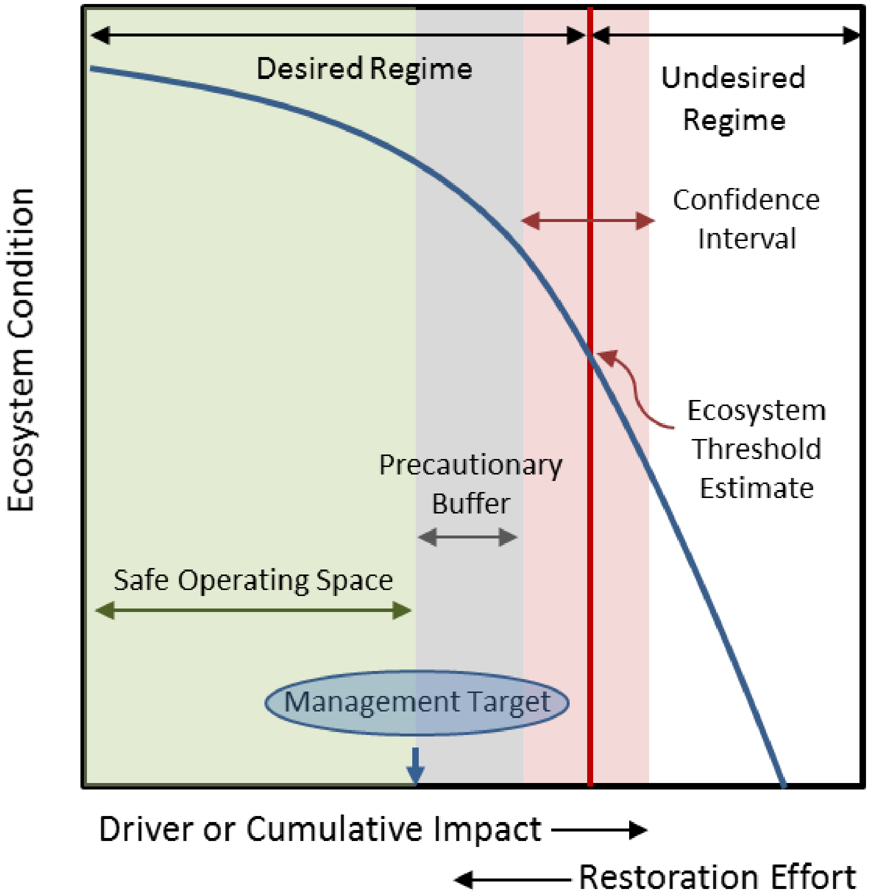
Levin and Mollmann (2015)

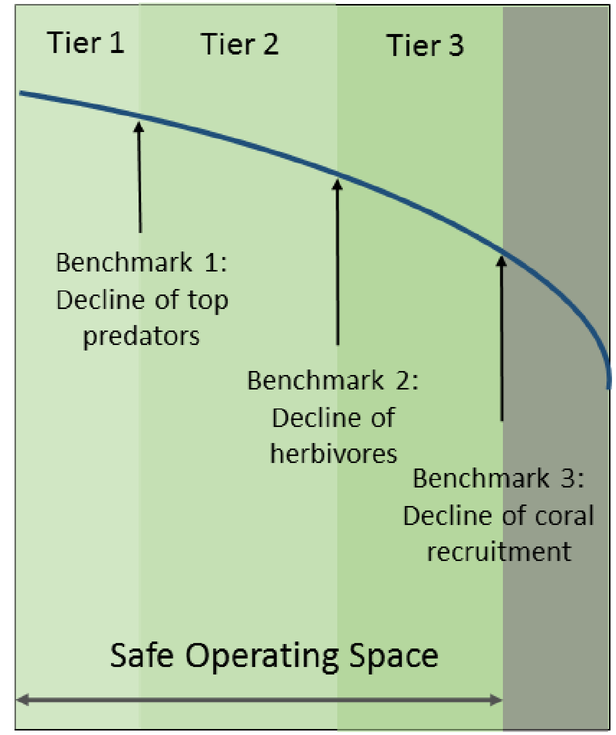
Information on thresholds can be used to identify reference points or safe zones for management



Selkoe et al. 2015 Eco Health & Sustainability

Increase monitoring and management action as risks of tipping points rise





Tier	Risk of Tipping Point	Threat reduction	Monitoring Intensity
1	Low	None	Low
2	Moderate	Light	Moderate
3	High	Aggressive	High

Selkoe et al. 2015 Eco Health & Sustainability

Calls for more research to…

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

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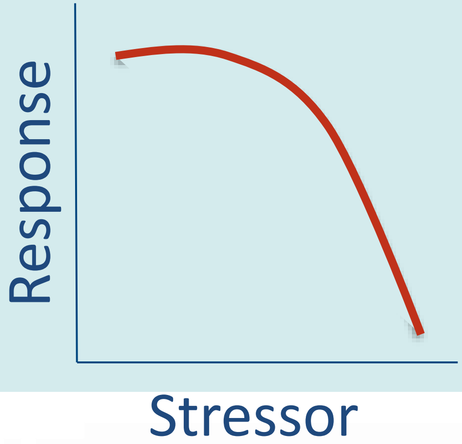
Improve knowledge and understanding of ocean tipping points, their impacts, and their relevance to management

How do we do it?

How common are nonlinearities?



How common are nonlinearities?

Ecosystem thresholds?

How common are nonlinearities?

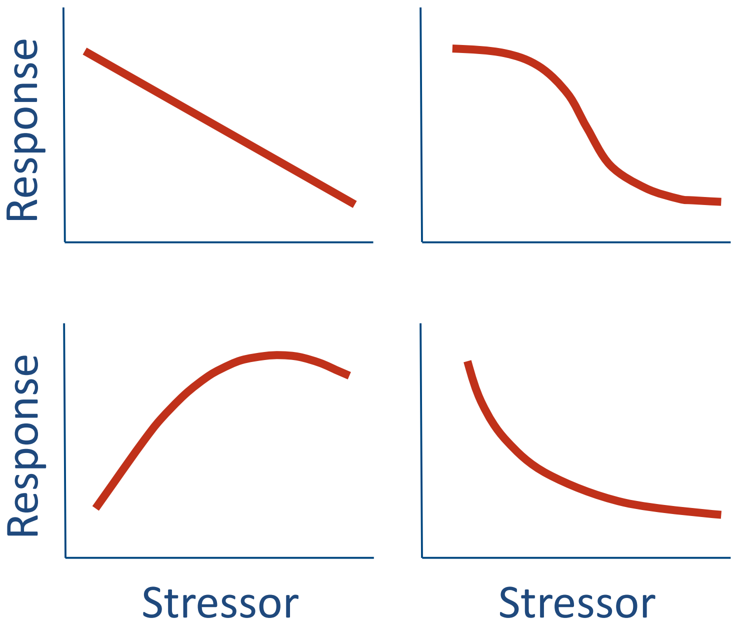
Ecosystem thresholds?

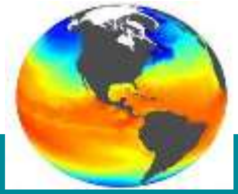
Early detection?

How common are nonlinear relationships?

To better understand the relationships between single stressors and ecosystem components in pelagic systems

To identify when nonlinearities and threshold responses are likely to exist





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Approach

1) Literature search

Meta-analysis approach

1) Literature search

2) Selection criteria

- Field study in pelagic marine ecosystem
- Statistical analysis (regression, correlation) used to identify the relationship between stressor and response
- Sign. relationships identified by p-value and model selection

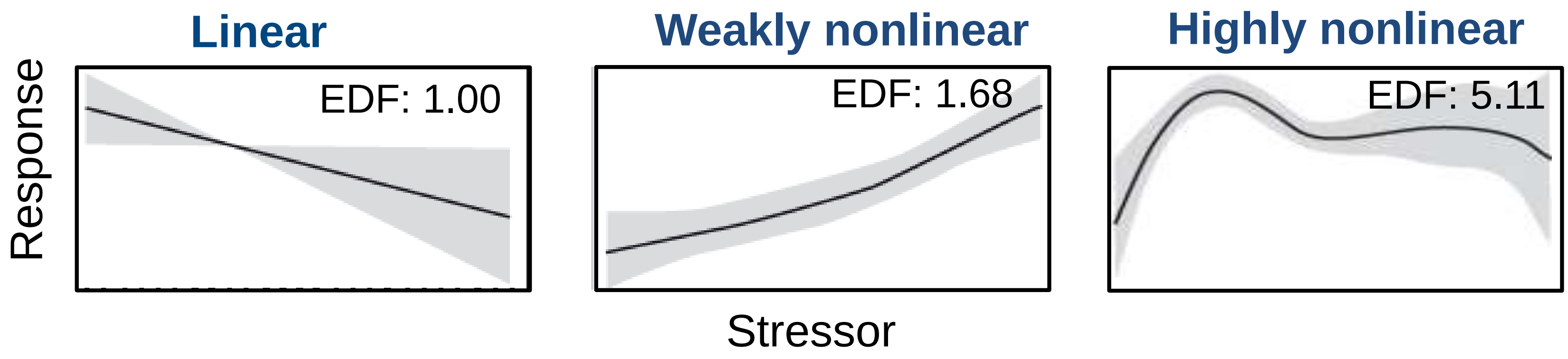
➢ 75 papers; 736 relationships

Approach

1) Literature search

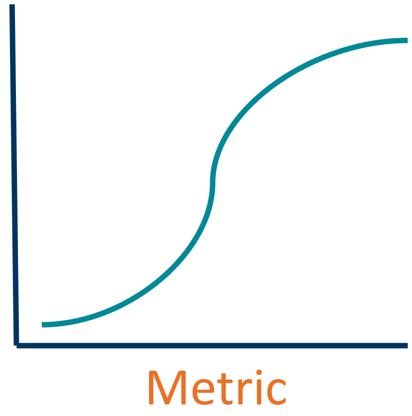
2) Selection criteria

3) Published or derived effective degrees of freedom from GAMs are a measure of degree of nonlinearity



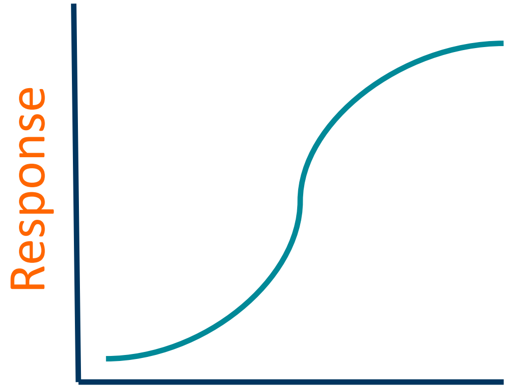
Outcome of meta-analysis

Driver / Stressor	Examples of metrics
Climate	- Temperature - Large-scale climate pattern - Salinity
Exploitation	- Fishing effort - Catch/landings - Fishing mortality
Pollution	- Nutrient loading - Oxygen - Water clarity
Trophodynamics	- Predator/prey biomass, abundance - Primary production, nutrients - Density dependence

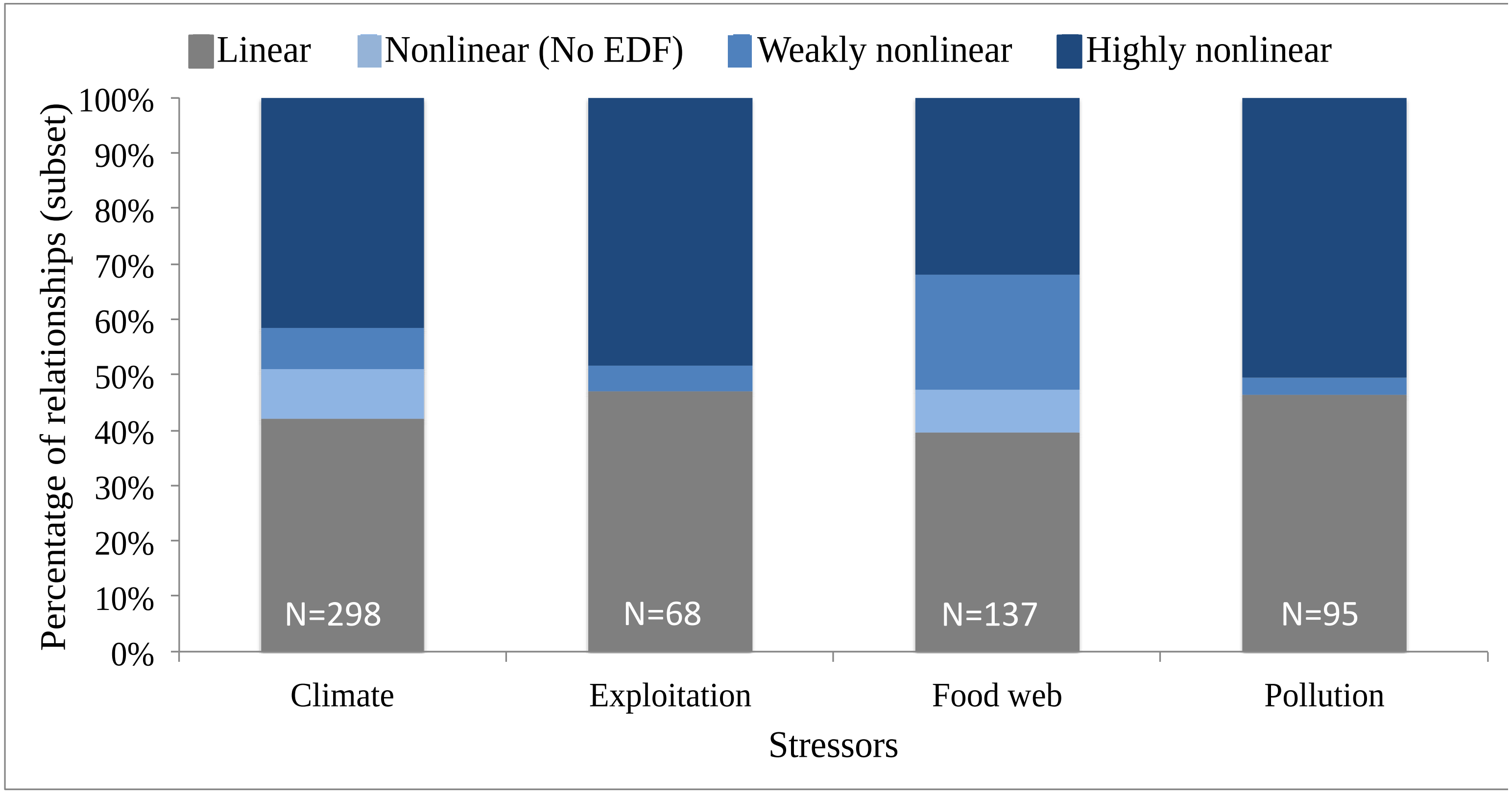


Outcome of meta-analysis

Ecological Responses
Growth
Survival
Reproductive success
Recruitment
Species occurrence
Species biomass and abundance
Species richness
Community composition and diversity



Highly nonlinear relationships are common



And thus may have detectable thresholds that could inform target-setting

Hunsicker et al. 2016

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How common are nonlinearities?

Ecosystem thresholds?

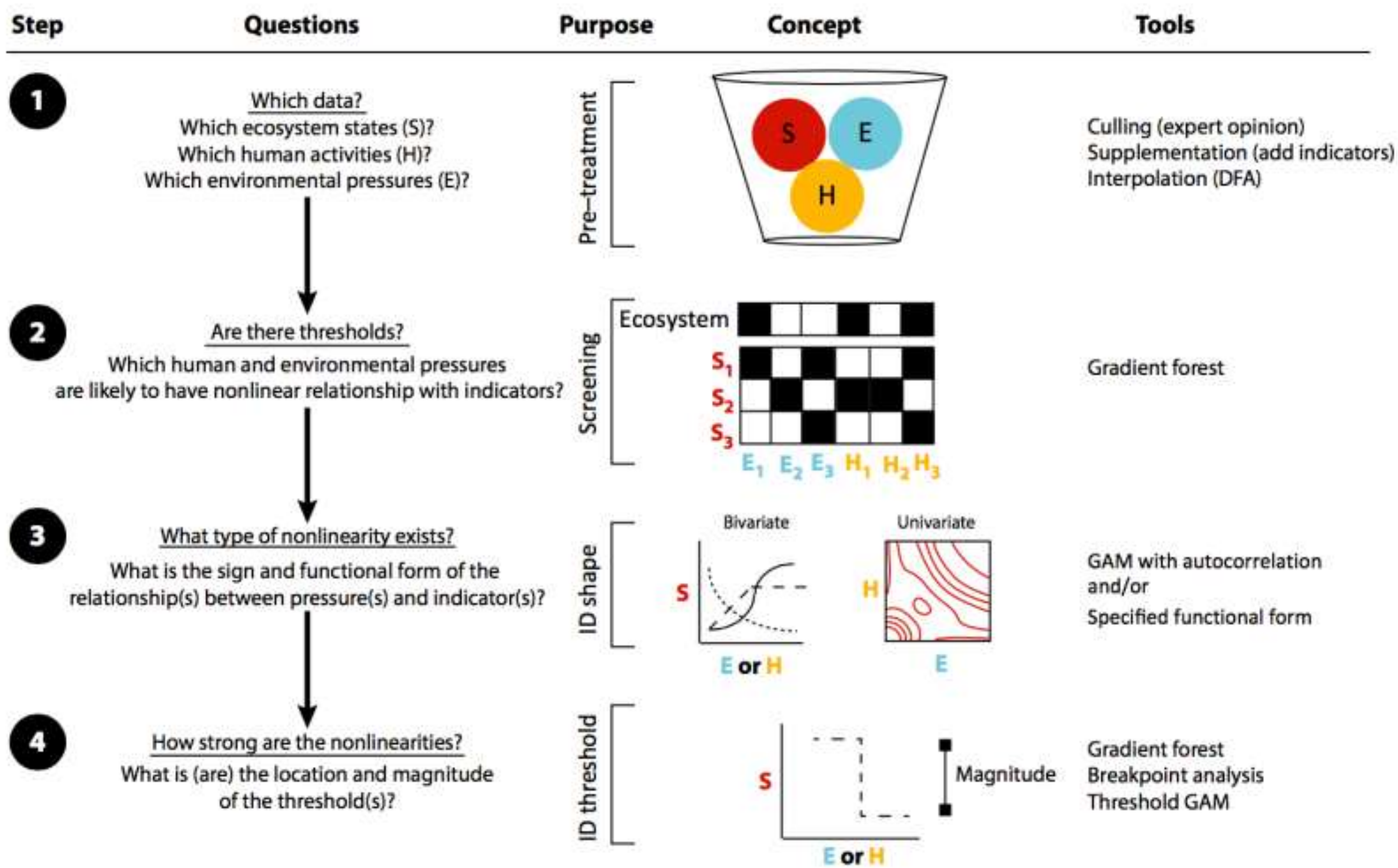
esa

ECOSPHERE

Defining ecosystem thresholds for human activities and environmental pressures in the California Current

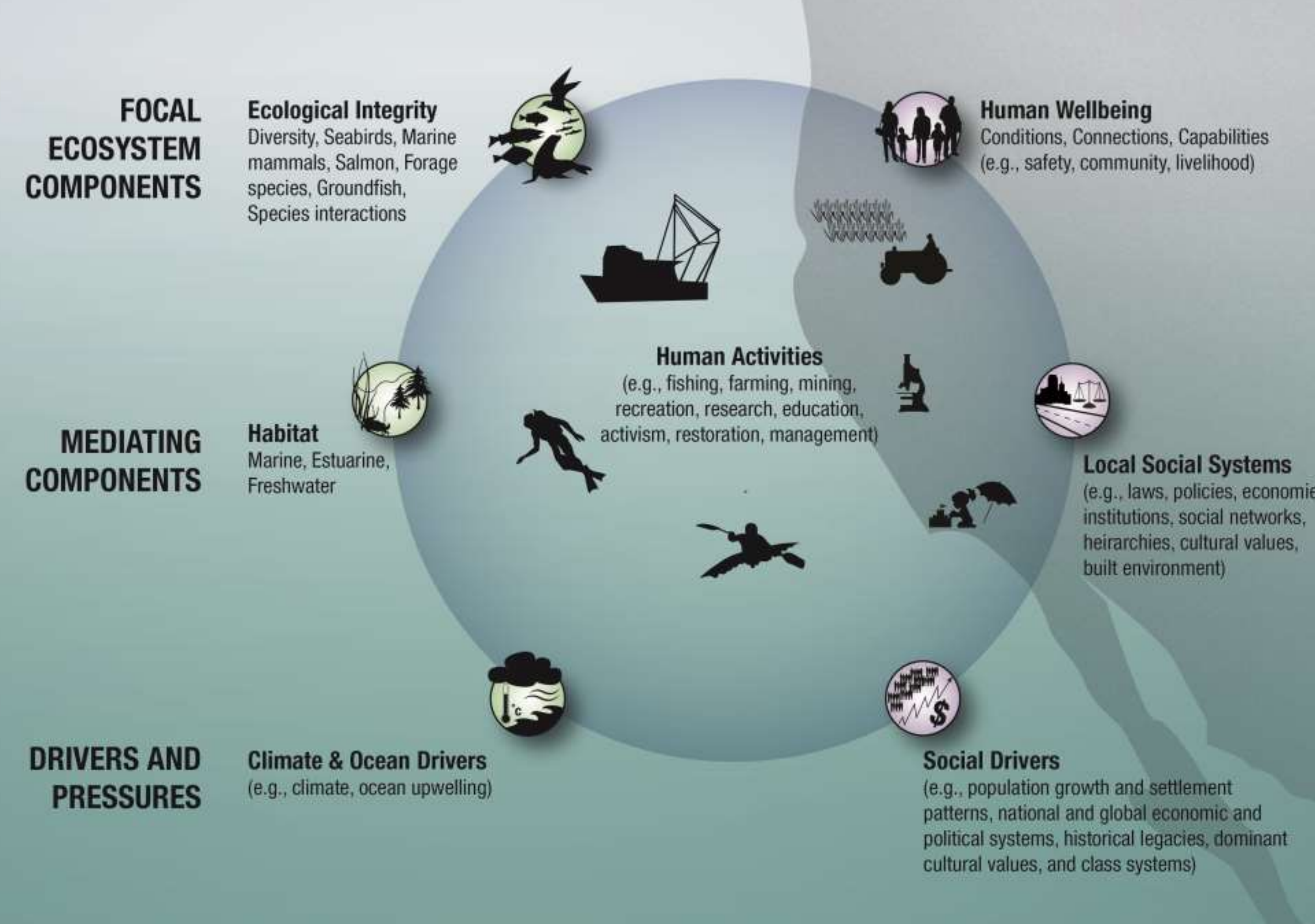
Jameal F. Samhouri,[1,†] Kelly S. Andrews,[1] Gavin Fay,[2] Chris J. Harvey,[1] Elliott L. Hazen,[3] Shannon M. Hennessey,[4] Kirstin Holsman,[5] Mary E. Hunsicker,[6] Scott I. Large,[7] Kristin N. Marshall,[1] Adrian C. Stier,[8,9] Jamie C. Tam,[10] and Stephani G. Zador[5]

Ecosystem-based thresholds for environmental drivers and human activities in the California Current



Samhouri et al. 2017

INTEGRATED SOCIO-ECOLOGICAL SYSTEM OF THE CALIFORNIA CURRENT



INTEGRATED SOCIO-ECOLOGICAL SYSTEM OF THE CALIFORNIA CURRENT

Ecological Integrity

Scavengers

Sea lion pup production and growth

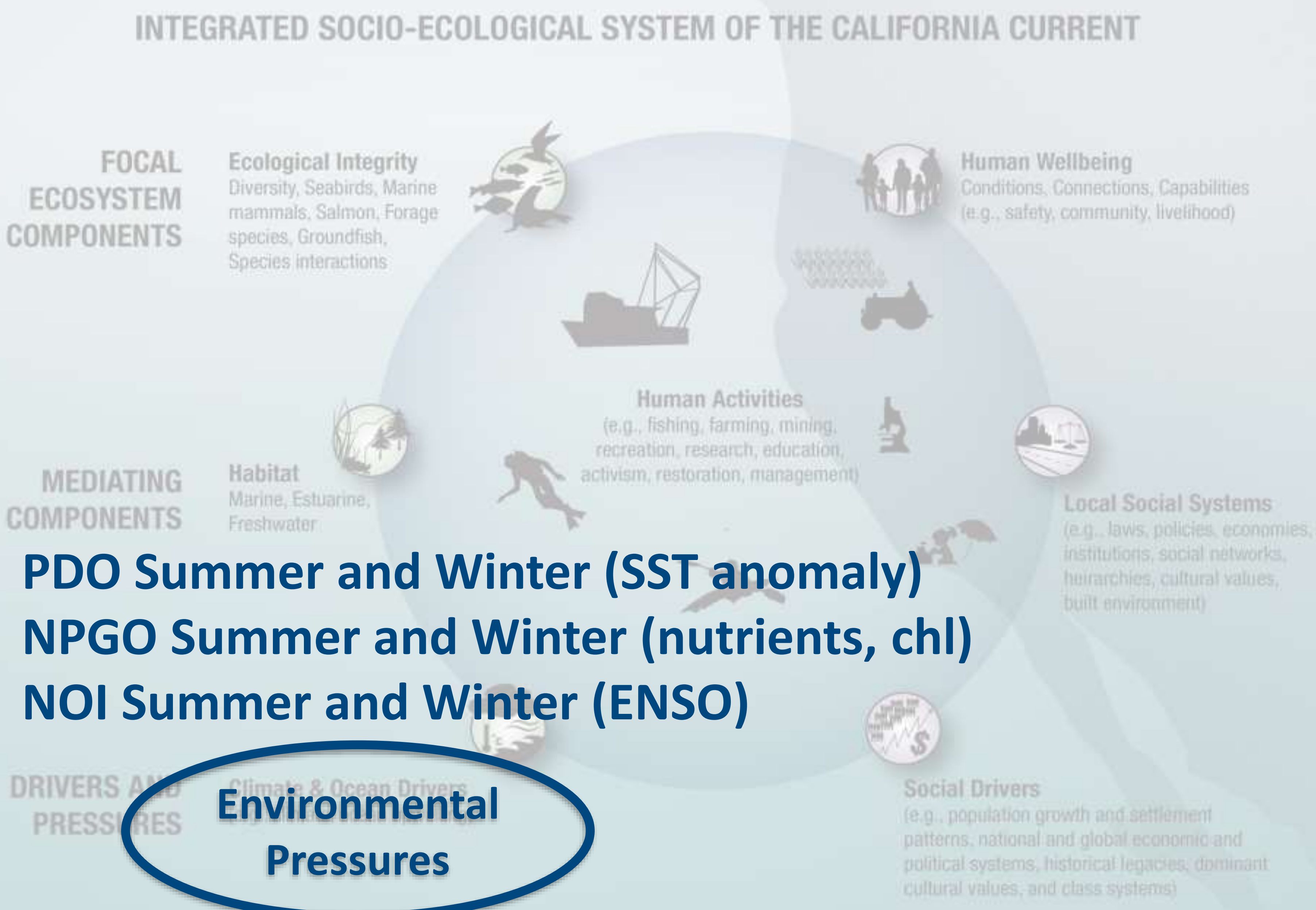
Groundfish mean trophic level and diversity

Northern copepod anomaly

Human Activities

- **Atmospheric Pollution**
- **Commercial Shipping Activity**
- **Dredging**
- **Fishery Removals**
- **Habitat Modification**
- **Inorganic Pollution**
- **Nutrient Inputs**
- **Organic Pollution**

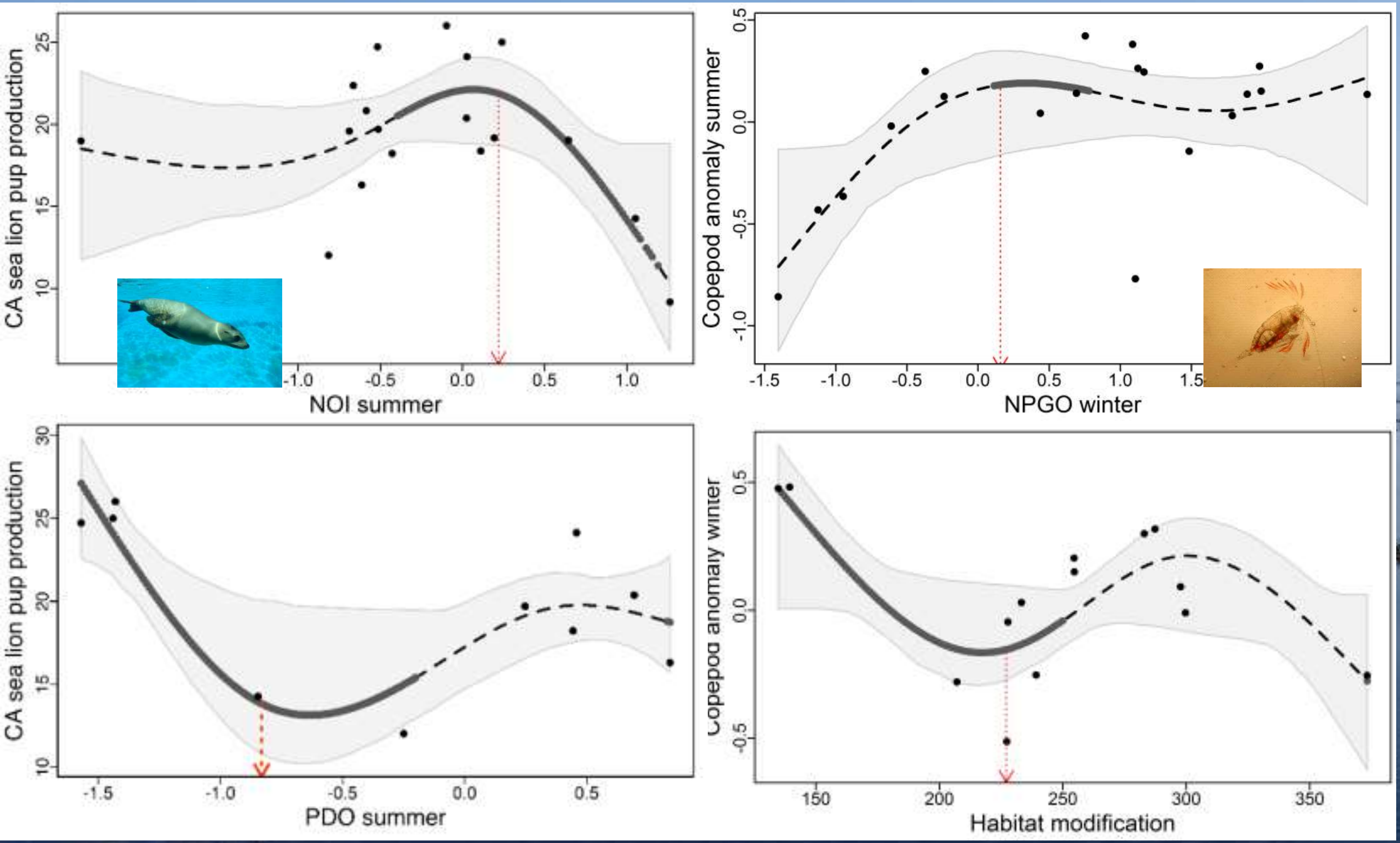
(see Andrews et al. 2015 *EnvCons)*



- **PDO Summer and Winter (SST anomaly)**
- **NPGO Summer and Winter (nutrients, chl)**
- **NOI Summer and Winter (ENSO)**

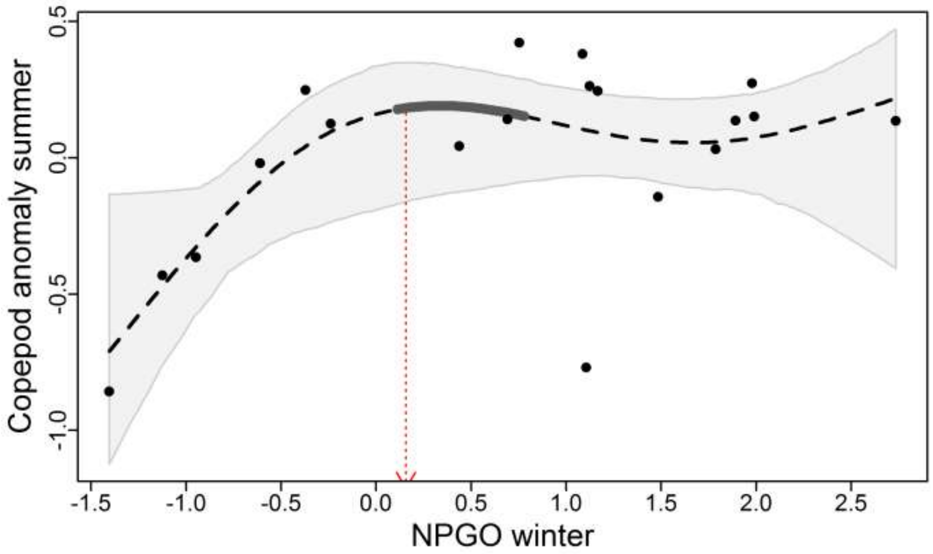
Environmental Pressures

Some relationships were strongly nonlinear with distinct thresholds



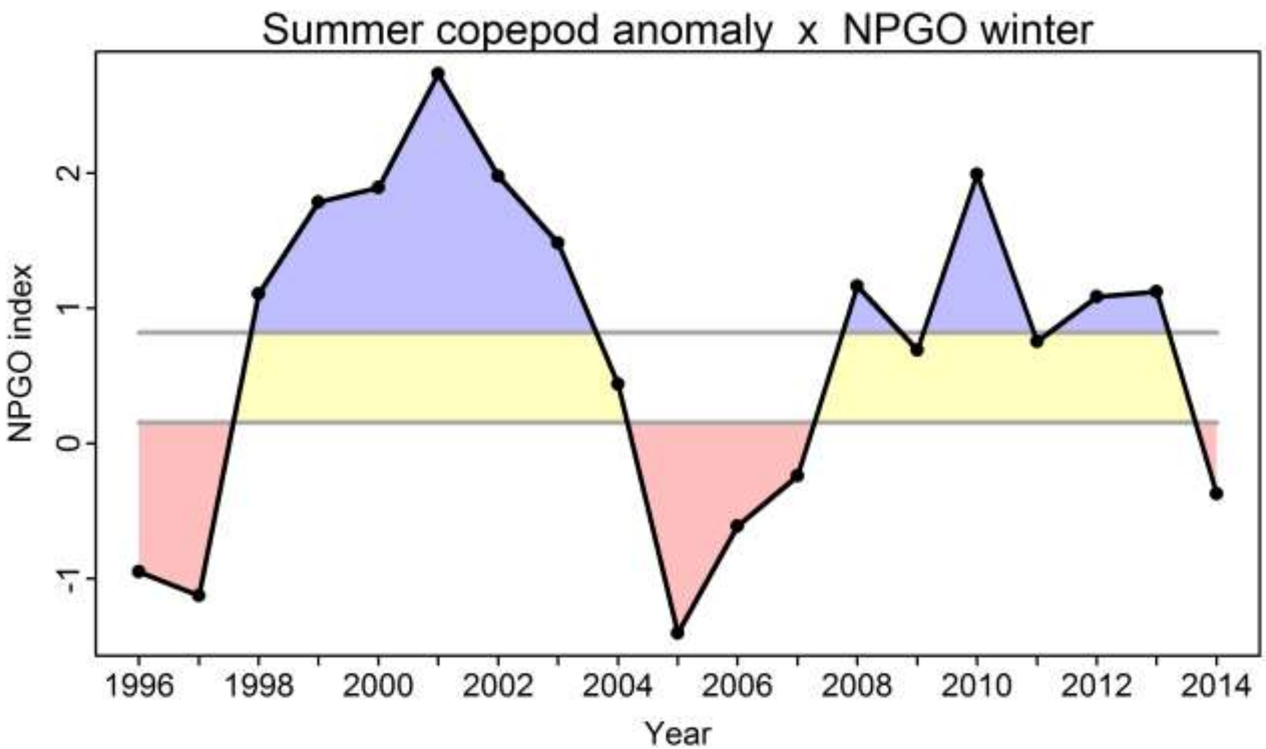
Samhouri et al. 2017

How do temporal changes in the California Current pressures relate to ecosystem states?



Good conditions for northern copepod anomalies in 10 of 19 years (blue)

Poor conditions in 6 years (red)



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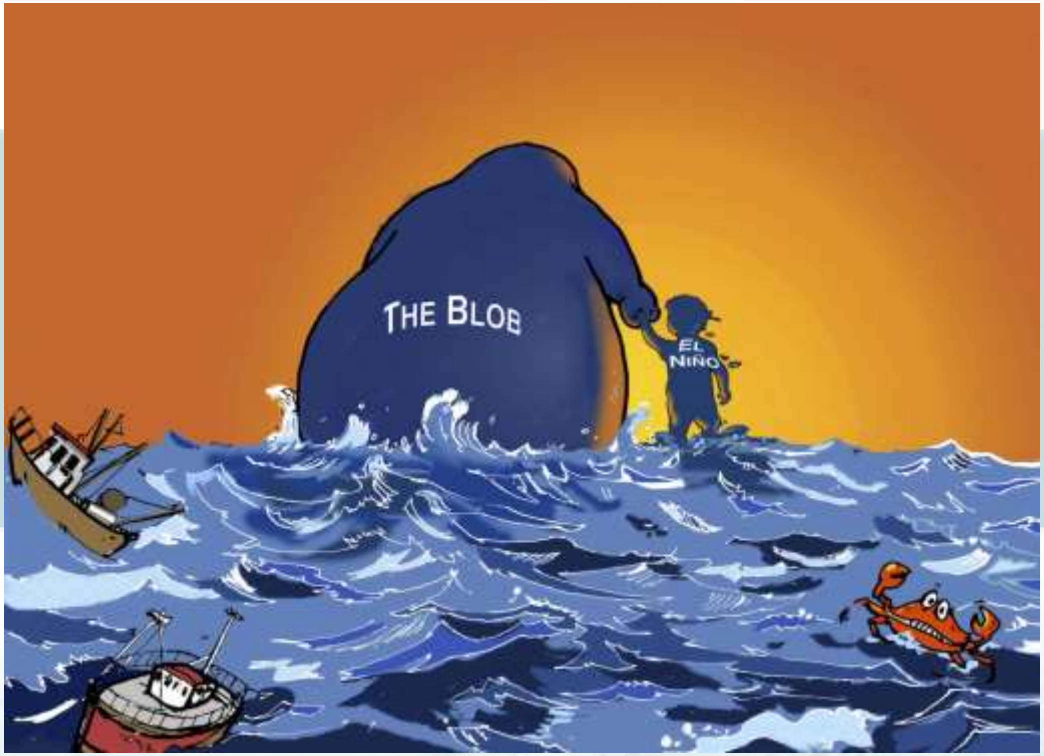
How common are nonlinearities?

Ecosystem thresholds?

Early detection?



Early detection?

Early detection of abrupt change in NE Pacific Ecosystems

Develop a *state index* for early detection of abrupt community-level changes

- Document range of variability to distinguish normal variability from changes signaling a major shift (i.e. reference points)

- Provide tools to update information for ecosystem assessments in future years

Approach

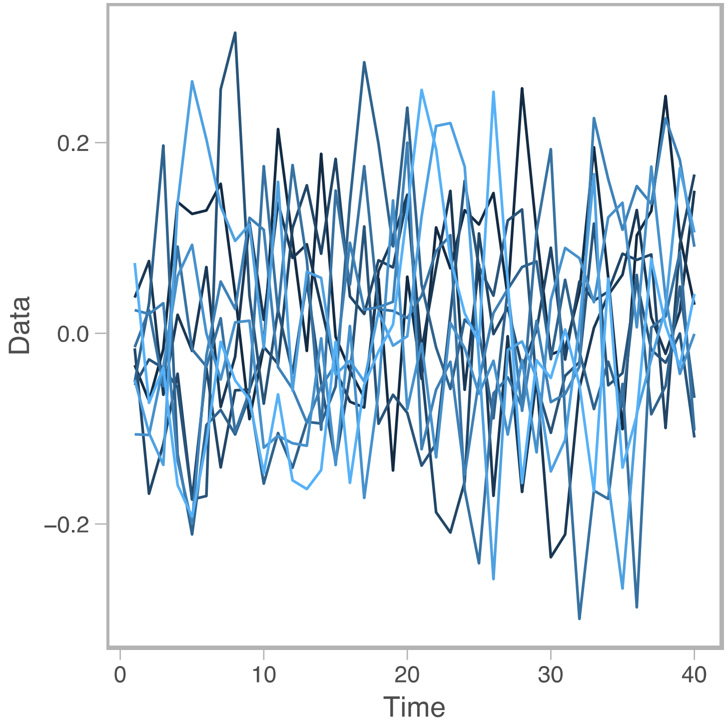
- Evaluate changes in mean community state, as measured with ordination of time series, using Dynamic Factor Analysis (Bayesian)

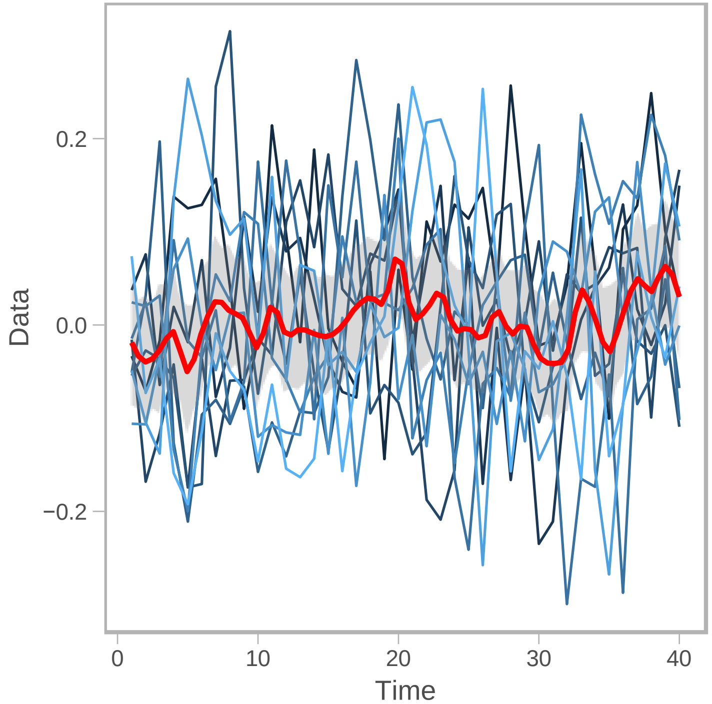
- Viewed as 'dimension reduction tool' for time series (similar to PCA): used in finance, economics, psych.

- Large changes in ordination axes will indicate large changes in the underlying community or shift away from current ecosystem state

- Incorporate methods for detecting rare or extreme events as well as regime shift like behavior

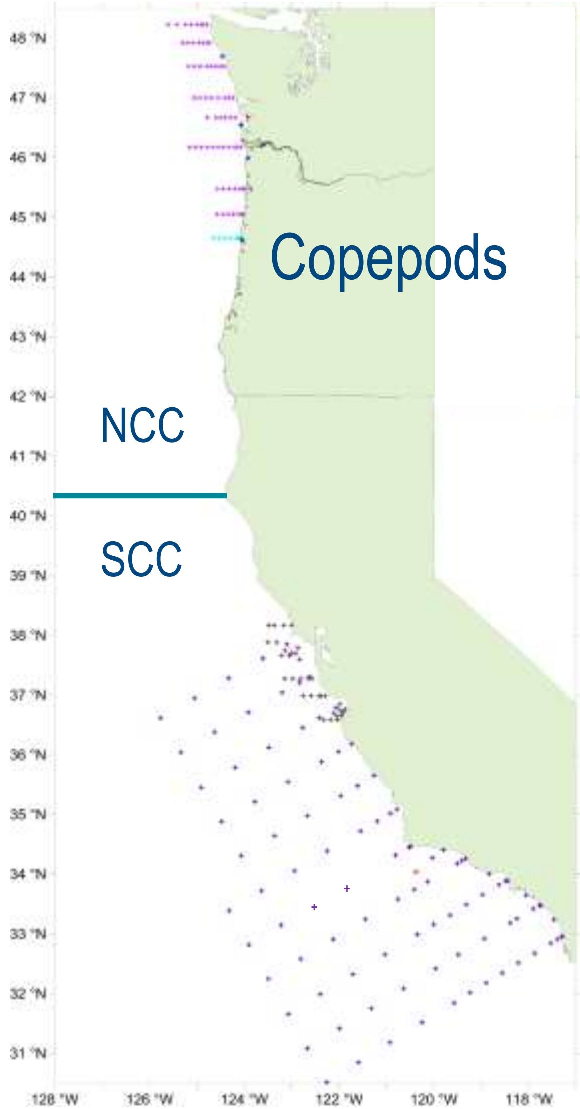
A lot of time series – can we identify latent (hidden) 'trends' that are useful as indices?





Info shared by a set of response variables that cannot be explained by the measured explanatory variables

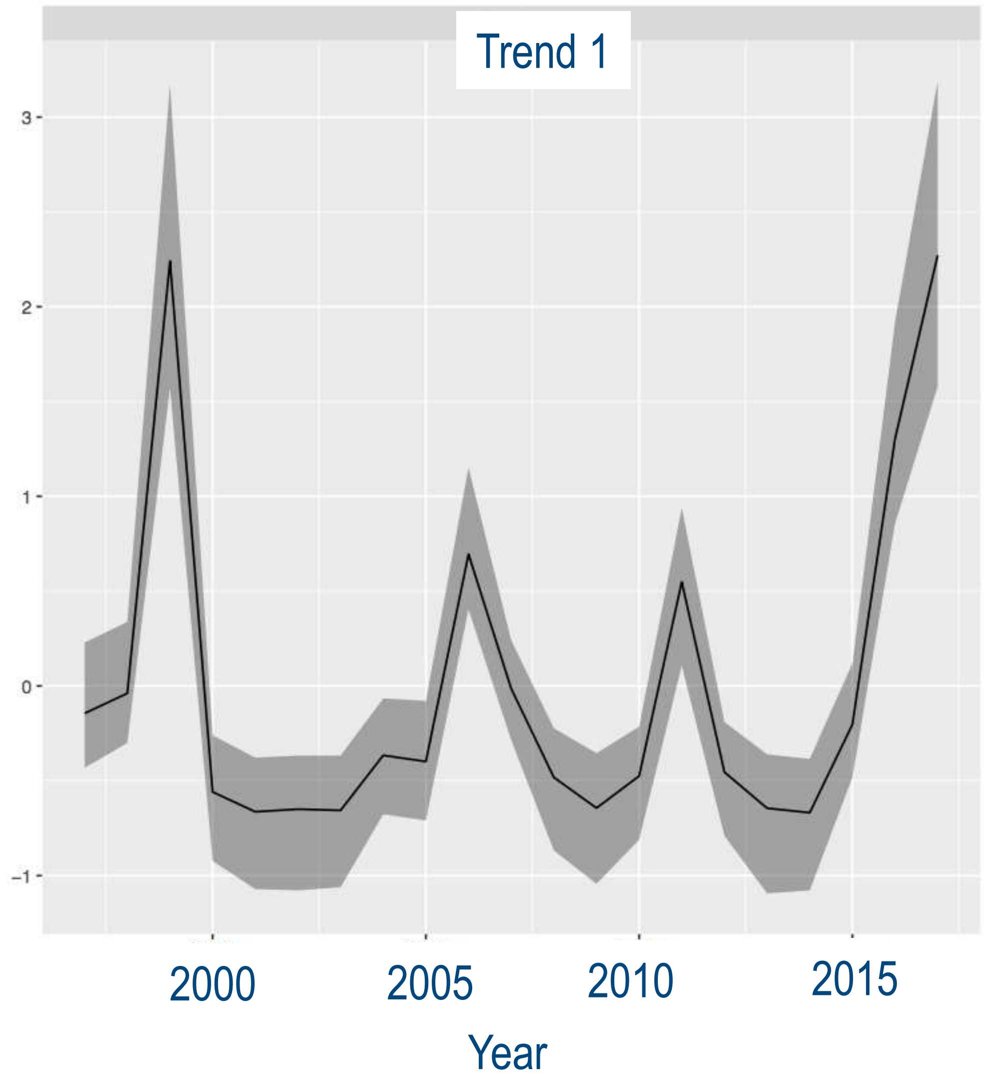
California Current Ecosystem Time Series

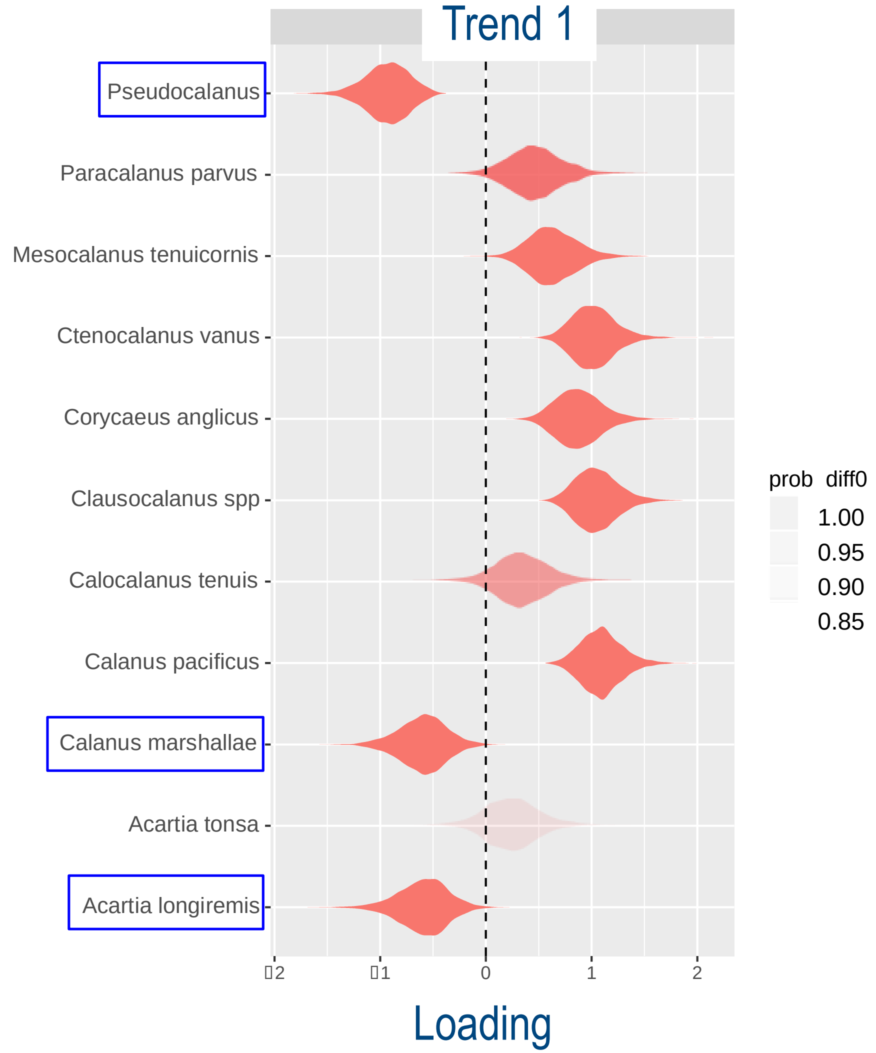


Data

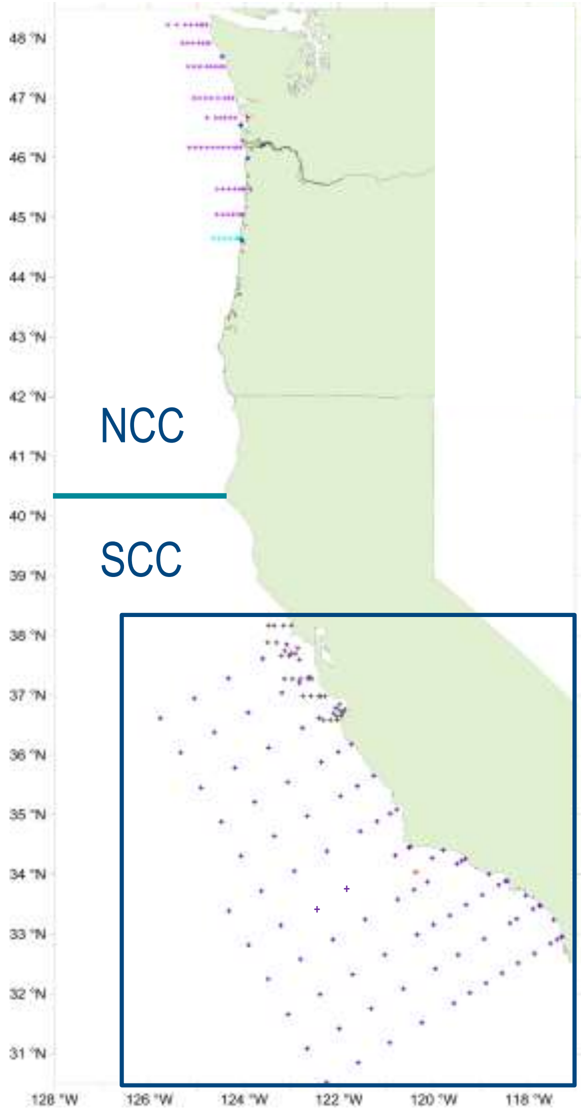
- short lag in response (0-1 yrs)
- sampled at least annually
- short processing time
- 15+ year time series

Single dataset: copepods

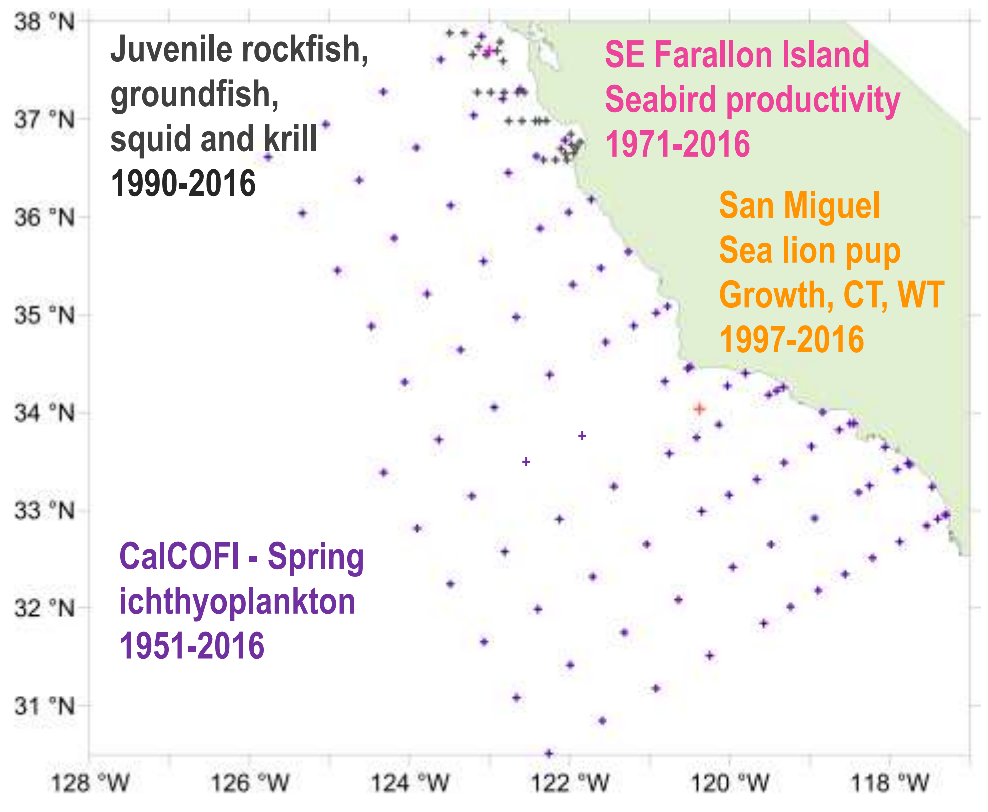




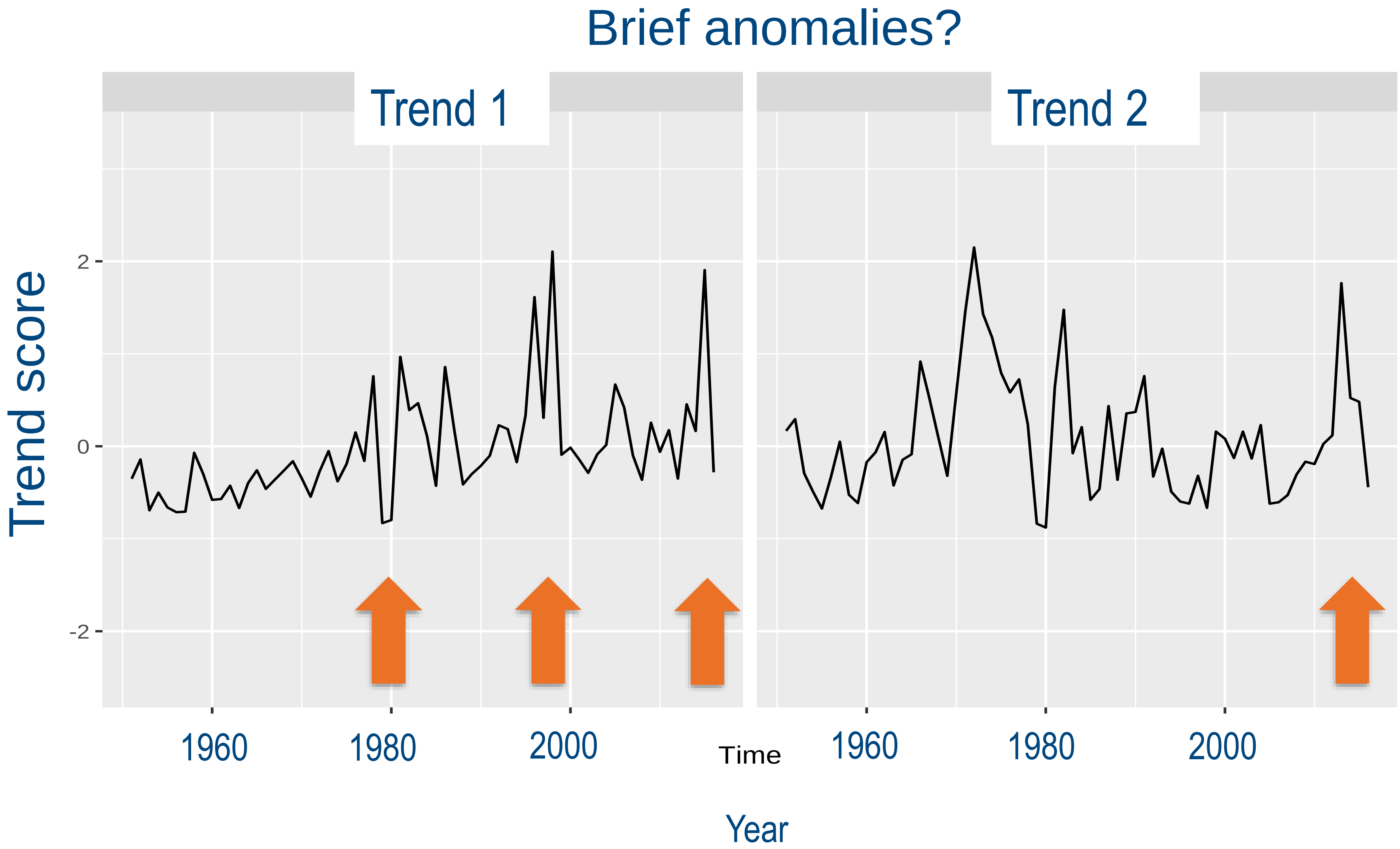
California Current Ecosystem Time Series



Southern California Current

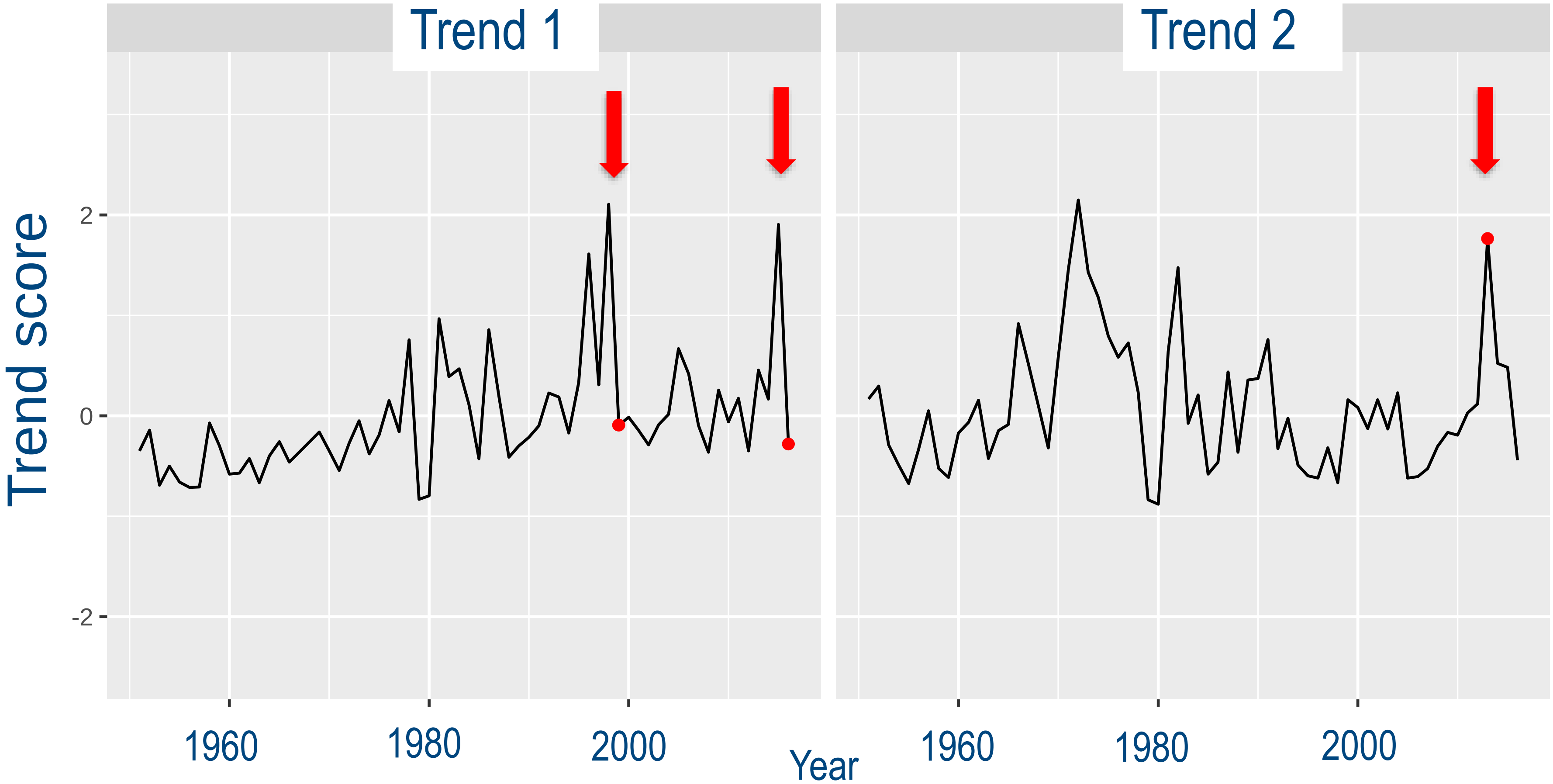


Southern California Current biology

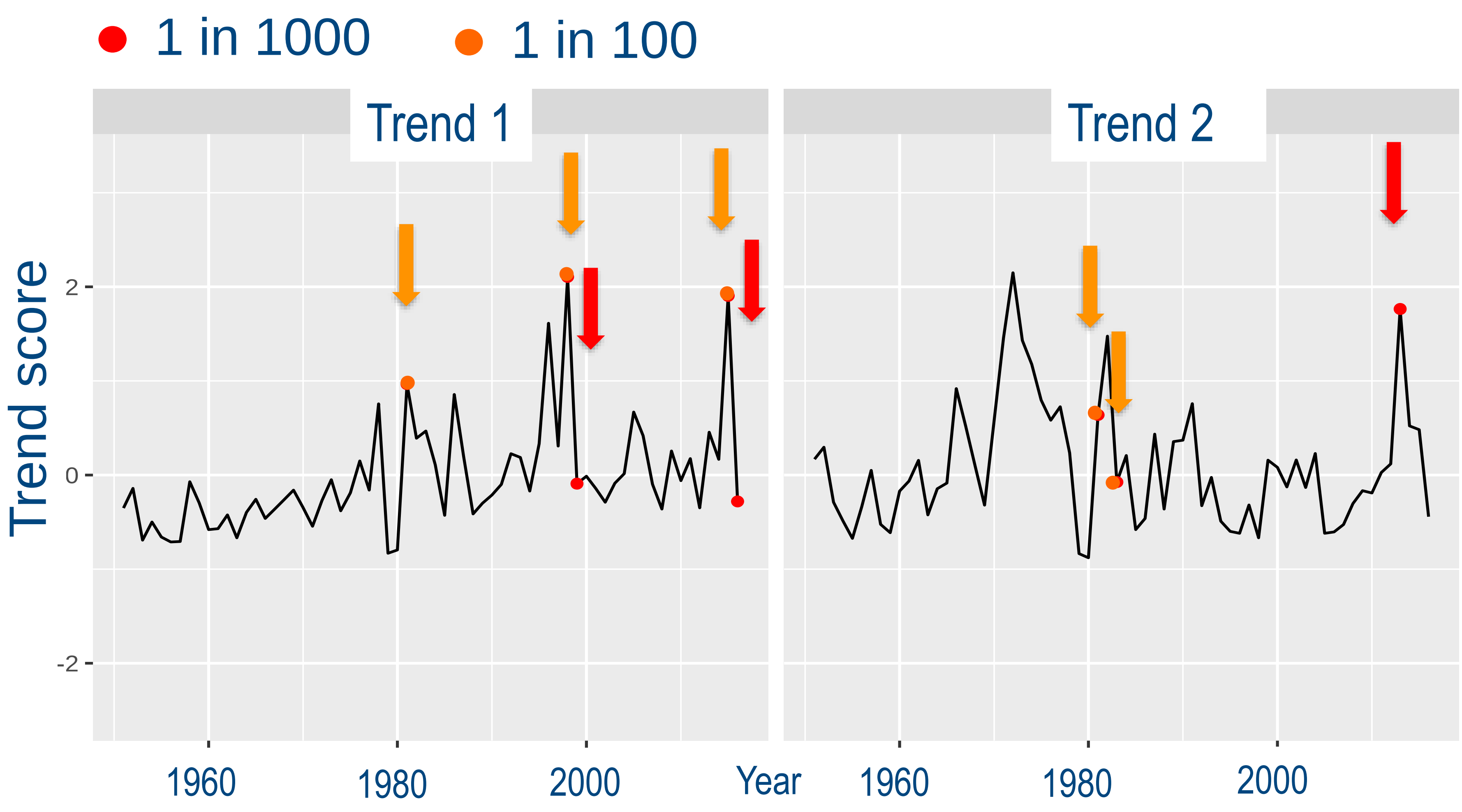


Evaluate probability of abrupt change

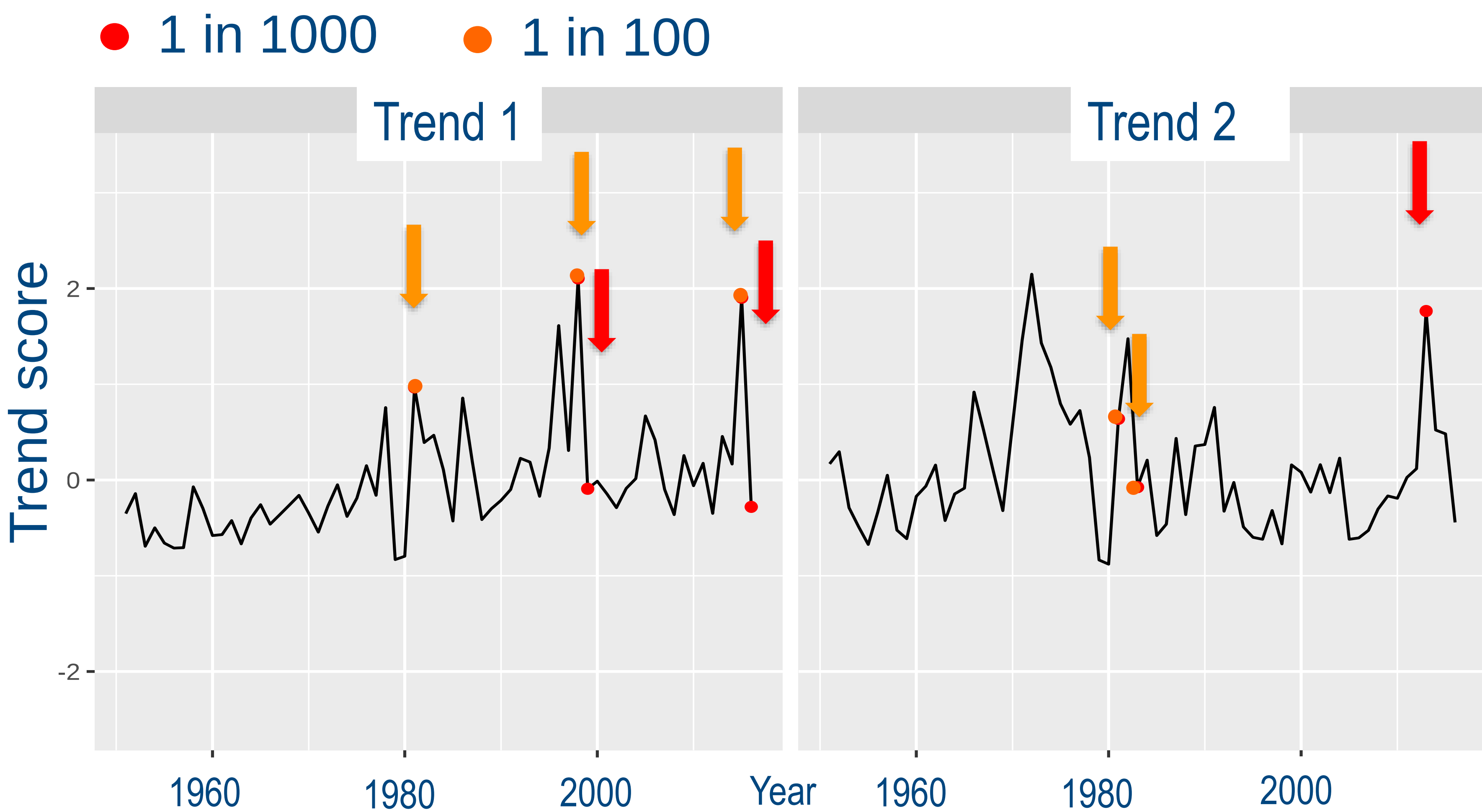
- 1 in 1000



Evaluate probability of abrupt change



Evaluate probability of abrupt change



**** Evaluate evidence for *regime shifts***

Next steps

- Publish R package (Ward, Anderson)
- Update with new data over next 5 years
- Biology – climate interactions and forecasts

How do we do OTP science?

How common are nonlinearities?

Safer to assume driver-response relationships are nonlinear

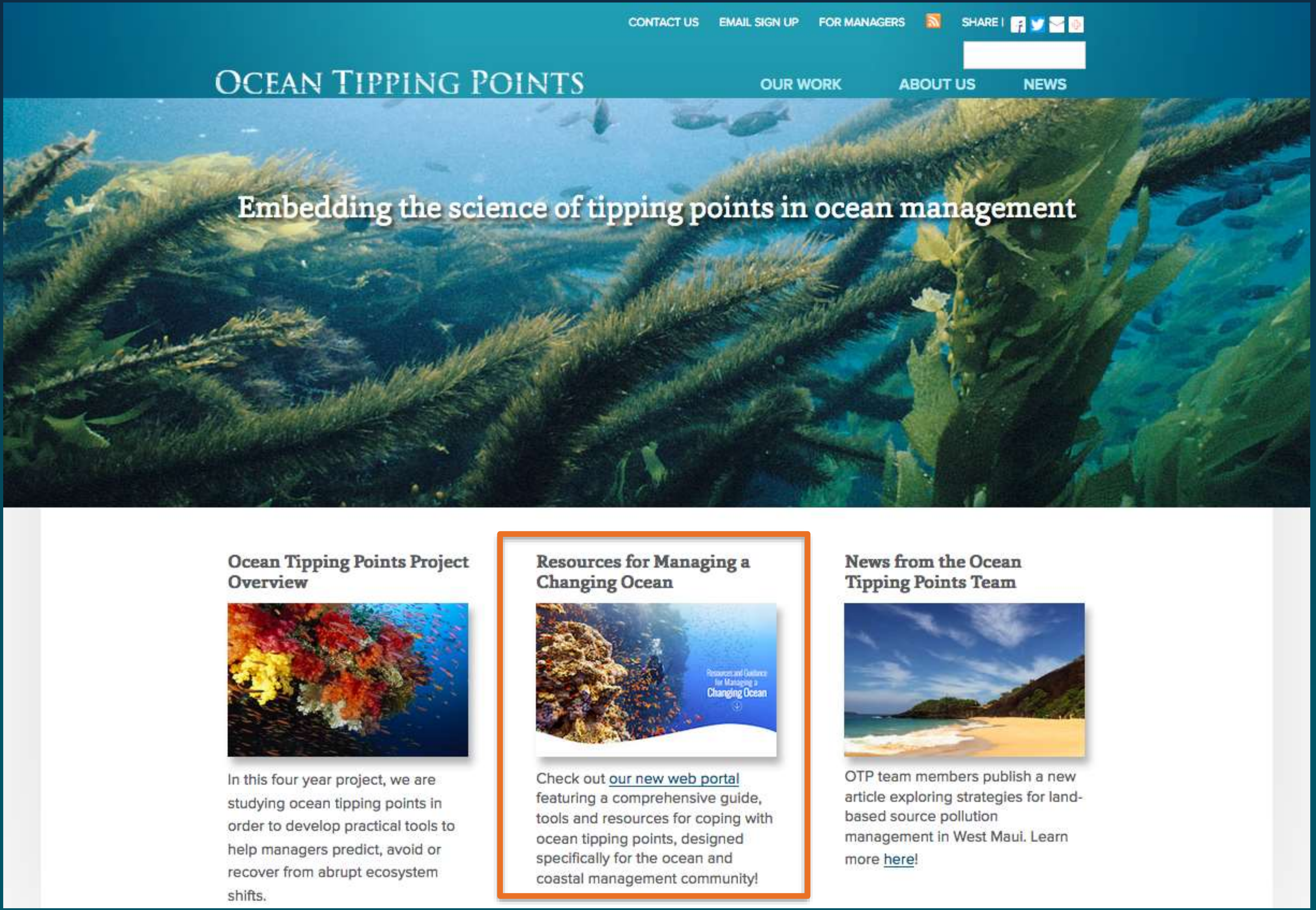
Ecosystem thresholds?

Framework for screening threshold relationships. Multiple threshold responses in CCE

Early detection?

Framework for evaluating community-level changes in coming years, including extreme events and regime-like shifts

www.oceantippingpoints.org



www.oceantippingpoints.org/portal/otp

Outlines strategies and tools for putting OTP science into practice

Thank you!

Image: www.marineresearch.oregonstate.edu

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Collaborators

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Estimation and Model Selection

These constraints have been adopted using Maximum Likelihood methods, widely used

Model selection criteria have been used to evaluate

- support for number of trends
- structure for variance matrix R

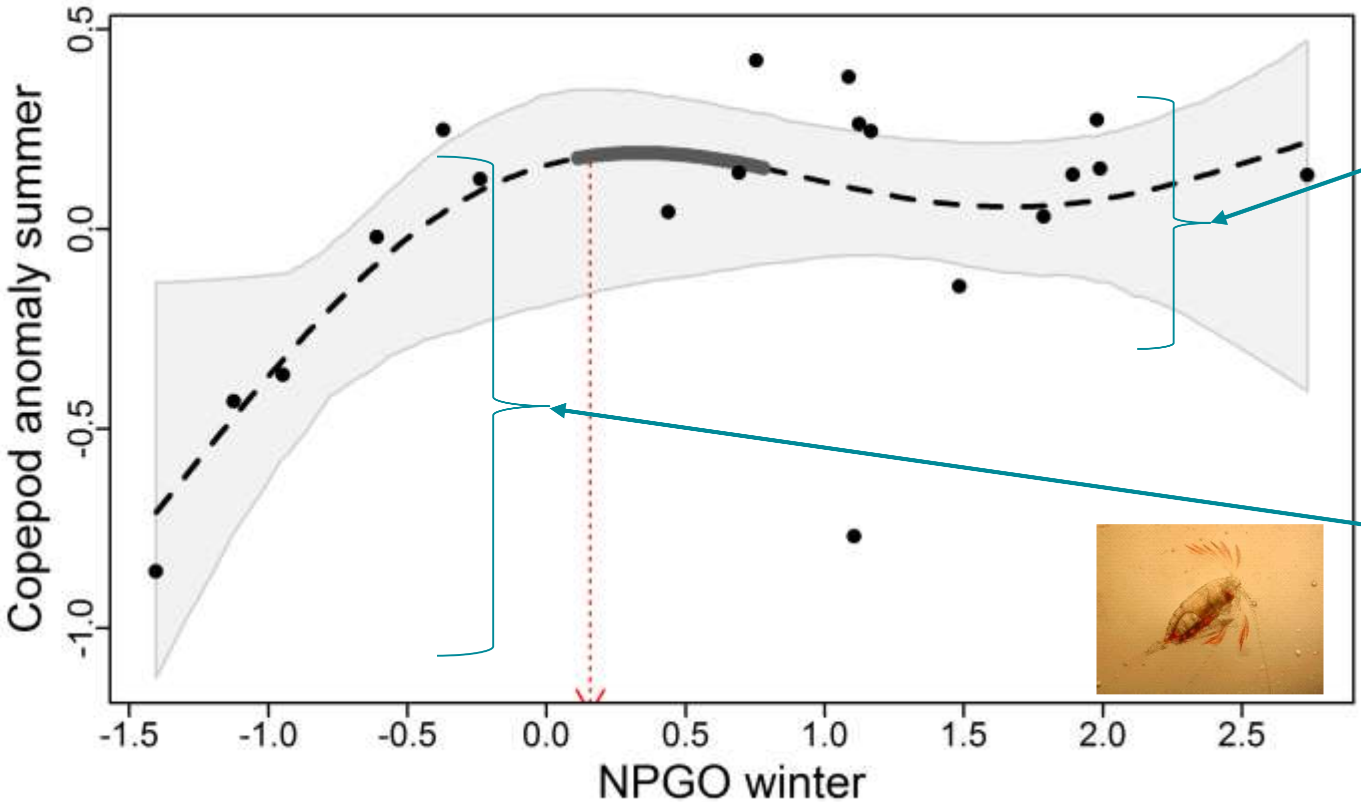
Tools developed by NOAA include **MARSS**

(R package on CRAN)

- commonly used in fisheries / ecology

What is the magnitude of the response?

Summer copepods were 130% more abundant on right side of NPGO winter threshold



Mean to the right of threshold

Magnitude of response

Mean to the left of threshold

Copepod threshold ~0.1-0.8

11 threshold responses of ecosystem states to pressures

Ecosystem state	Driver/Pressure	Analysis	Functional form(s)	Location of threshold(s)	Best estimate of threshold location(s)	Magnitude of response(s) (%)
Copepod anomaly winter	PDO winter	GF	–	−0.5 to −0.2	–	–
Copepod anomaly winter	Habitat modification	Truncated GAM	Parabolic	143–234	208	70
		Full GAM	Sinusoidal	138–252	227	30
Copepod anomaly summer	NPGO winter	GAM	Hockey stick	0.2–0.8	0.2	180
Copepod anomaly summer	PDO summer	GF	–	−1.2 to 0.5	–	–
Copepod anomaly summer	PDO winter	GF	–	0.7–0.8	–	–
Scavenger ratio	Commercial shipping activity	GF	–	14.7–15.2	–	–
Scavenger ratio	PDO summer	GF	–	−0.6 to 0.1	–	–
Groundfish mean trophic index	PDO summer	GF	–	−0.3 to 0	–	–
CA sea lion pup production	NOI summer	GAM	Hockey stick	−0.4 to 1.2	0.2	10
CA sea lion pup production	PDO summer	Truncated GAM	Sigmoidal	−1.5 to −0.2	−0.8	10
		Full GAM	Hockey stick	NTI	NTI	NTI
CA sea lion pup production	PDO winter	Truncated GAM	Sigmoidal	0.7–1.5	0.9	30
		Truncated GAM		−1.4 to 0.2	−0.8	0

Note: NTI, no threshold identified by CI of the second derivative; –, information not determined from the model.

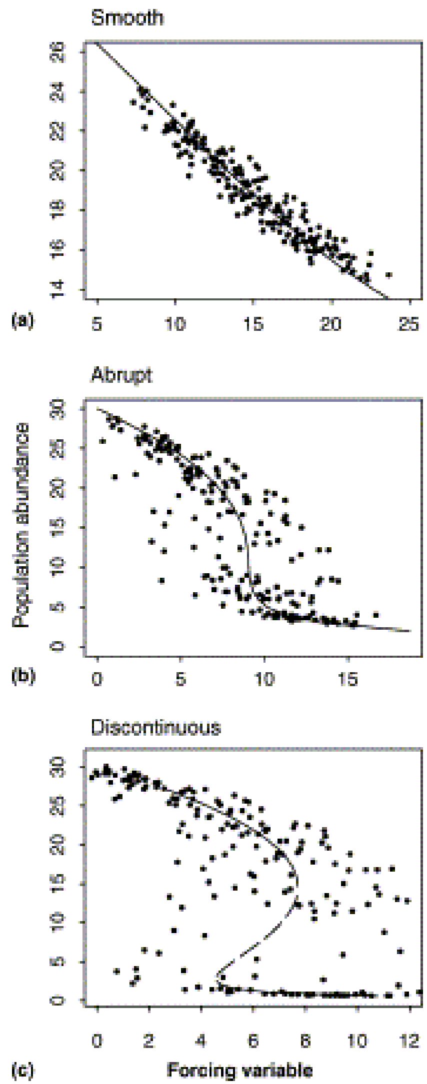
Linear

<1%

Nonlinear 29%

Nonlinear with hysteresis 31%

Uncertain = 28%



Underlying driver exhibits thresholds

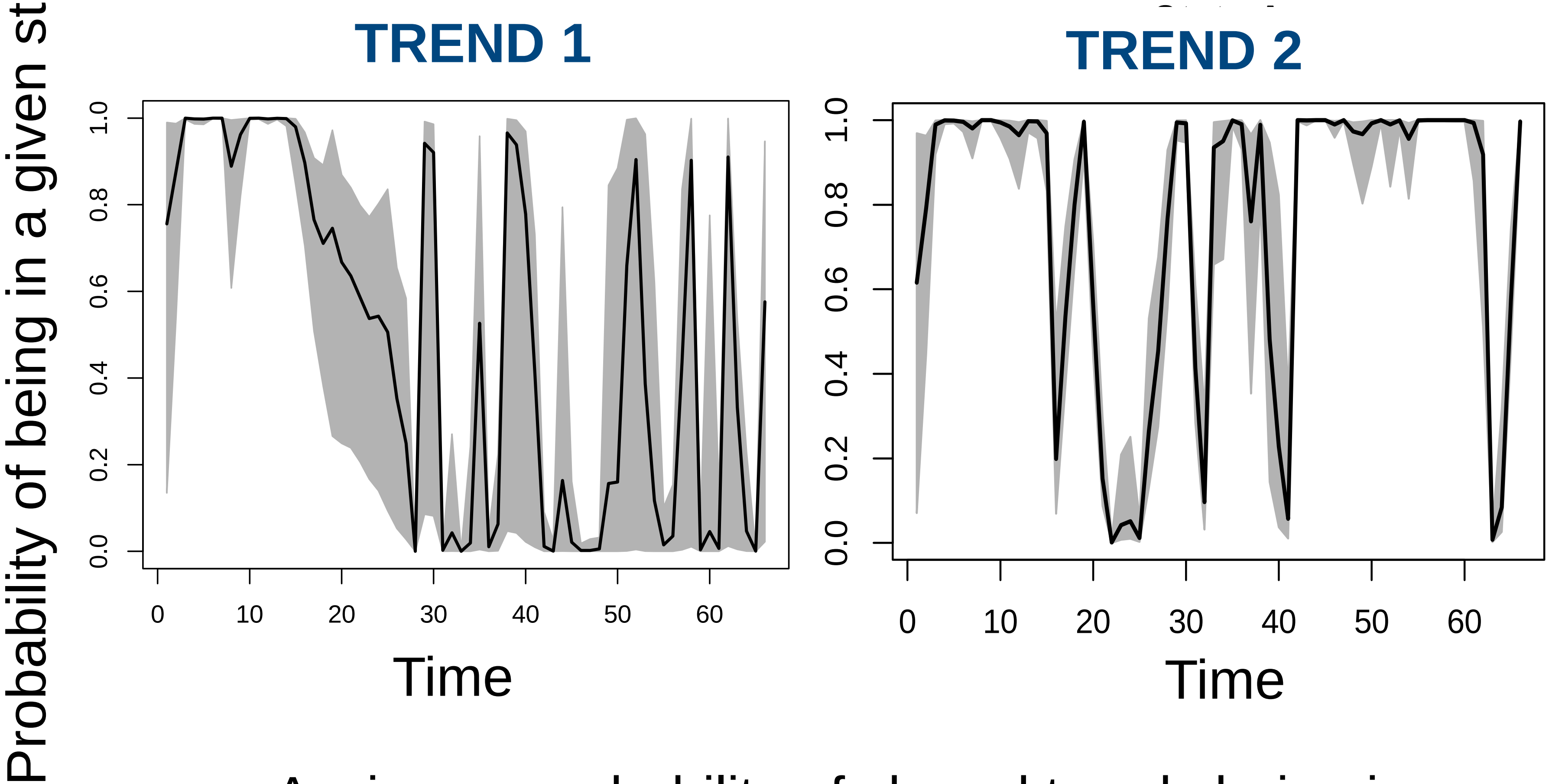
Relationship between driver and response variable is nonlinear

Relationship between driver and response variable is different after shift

Collie et al. 2004 Progress in Oceanography

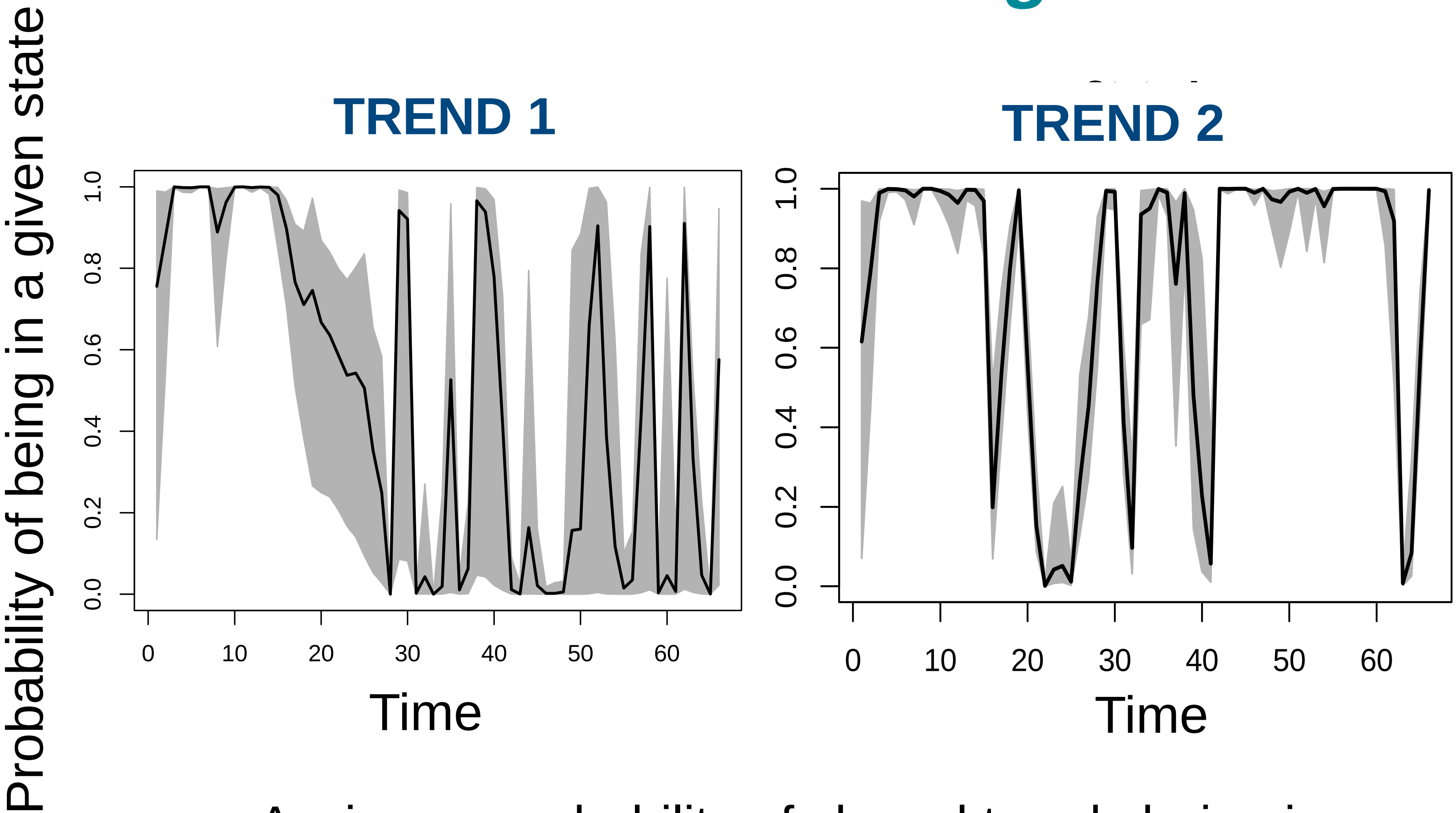
Other common examples

Evaluate evidence for *regime shifts*



Assigns a probability of shared trends being in a particular quasi-stable state

Evaluate evidence for *regime shifts*



Assigns a probability of shared trends being in a particular quasi-stable state