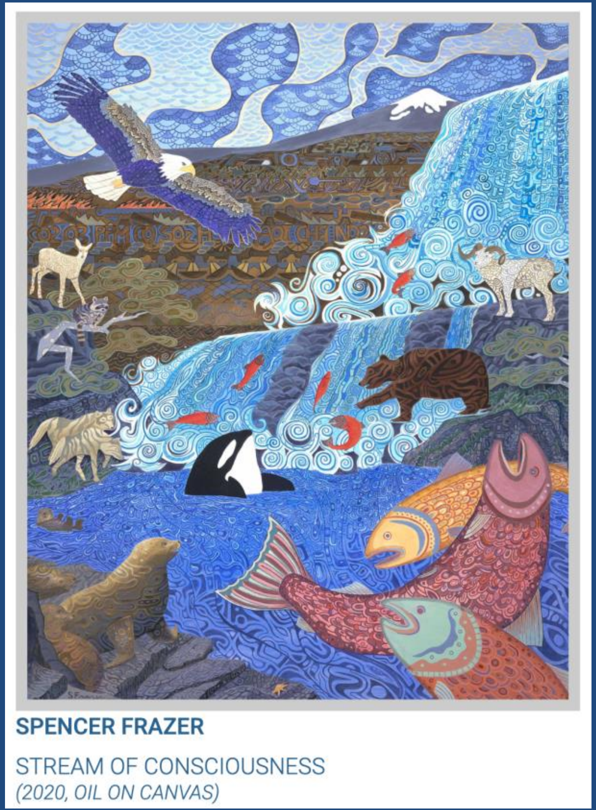
# Recent advances toward detecting ecological thresholds and ecosystem shifts to inform fisheries management

Mary Hunsicker, Raine Detmer,
Bridget Ferriss, Jameal Samhouri,
and Eric Ward

PICES Annual Science Meeting
October 28, 2024




5th National Climate Assessment
https://nca2023.globalchange.gov/art-climate/

# Climate impacts on ecosystems and people

**Sagebrush shrublands** are becoming non-native grasslands as a result of wildfire, invasive species, land use, and climate change.

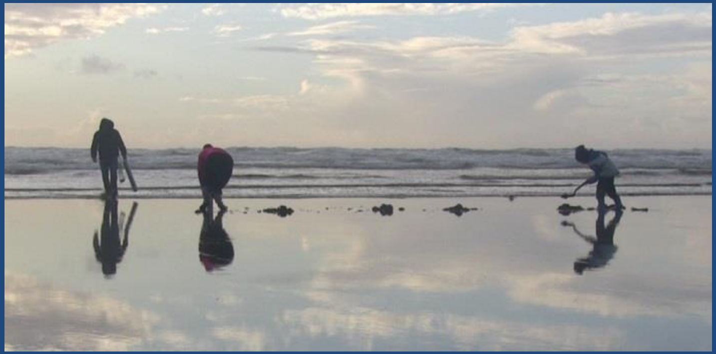
**Arctic marine ecosystems** are being altered by ocean acidification and harmful algal blooms.

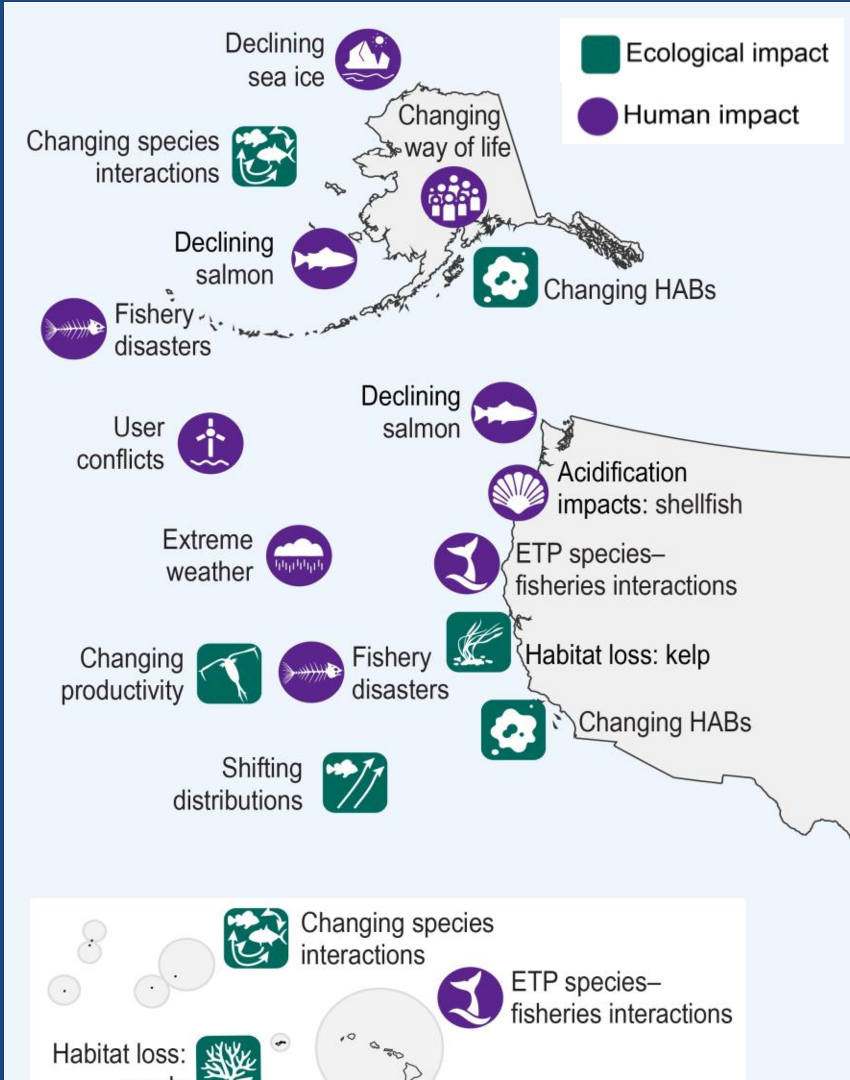
**Dry forests and woodlands** experiencing drought and wildfire are becoming grasslands and shrublands.

**Coral reefs** are being lost due to warming and ocean acidification.

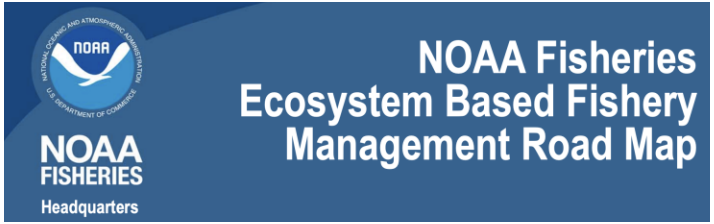
5th National Climate Assessment
https://nca2023.globalchange.gov/art-climate/

# Climate impacts on NE Pacific

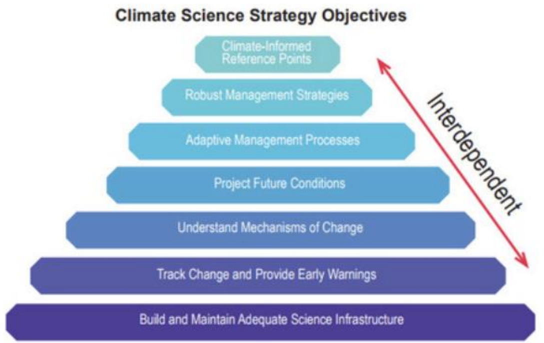




# How to advance ecosystem-based fisheries management under a changing climate?



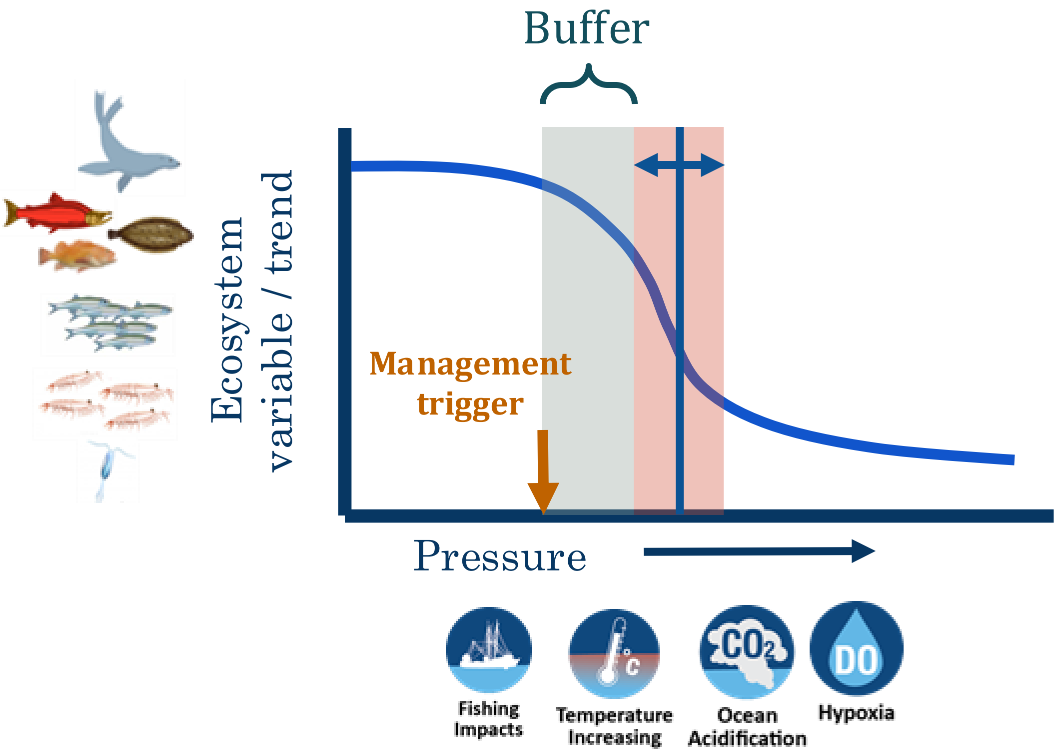

deReynier, Harvey, Link, Morrison et al. 2024



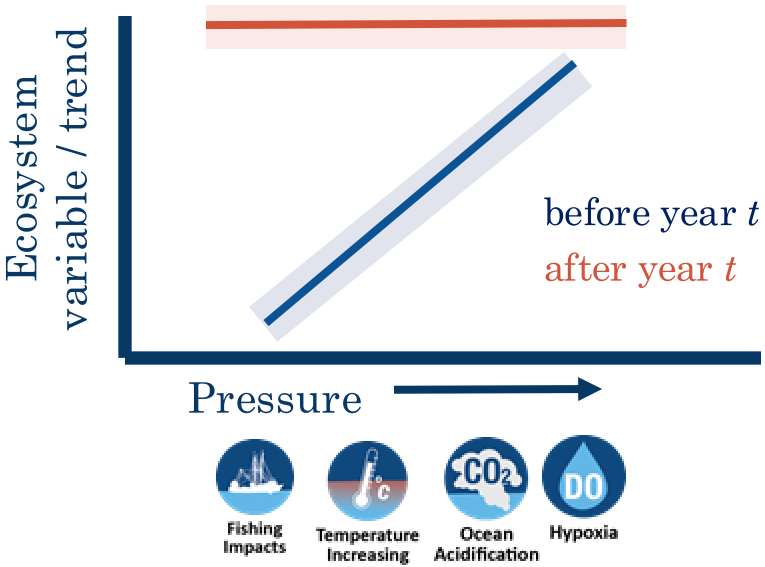

Link, Griffis, Busch et al. 2015

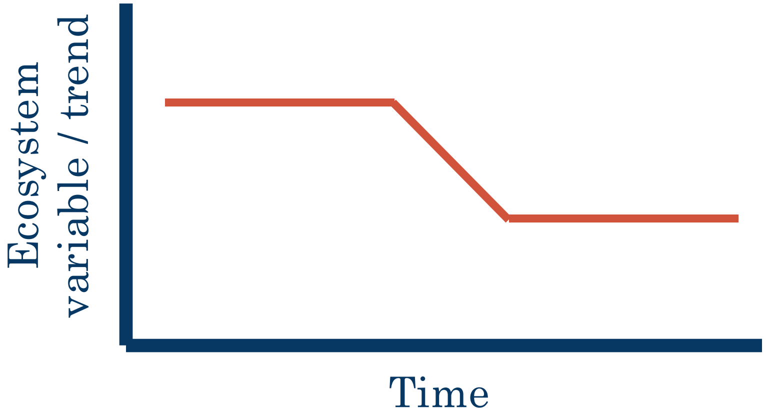
- Develop/monitor ecosystem reference points
- Identify nonlinear and nonstationary pressures and ecological surprises
- Provide early warning
- Minimize risk to resources, communities

# Ecosystem thresholds



# Nonstationary change



# Management pathways for ecosystem and climate information

**2023-2024 CALIFORNIA CURRENT ECOSYSTEM STATUS REPORT**

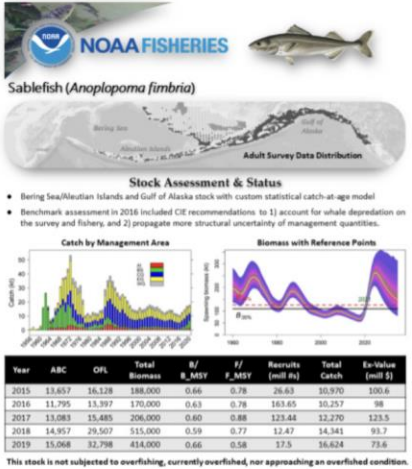
**A report of the NOAA California Current Integrated Ecosystem Assessment Team (CCIEA) to the Pacific Fishery Management Council**

*Andrew Leising, Mary Hunsicker, Nick Tolimieri, Greg Williams, Abigail Harley*

Ecosystem Status Report 2023

GULF OF ALASKA

## Ecosystem and Socioeconomic Profile




Sablefish (*Anoplopoma fimbria*)

**Stock Assessment & Status**

- Bering Sea/Aleutian Islands and Gulf of Alaska stock with custom statistical catch-at-age model
- Benchmark assessment in 2016 included CIE recommendations to 1) account for whale depredation on the survey and fishery, and 2) propagate more structural uncertainty of management quantities.

| Year | ABC | OFL | Total Biomass | B/ B_MSY | F/ F_MSY | Recruits (mill #s) | Total Catch | Ex-Value (mill $) |
|---|---|---|---|---|---|---|---|---|
| 2015 | 13,657 | 16,128 | 188,000 | 0.66 | 0.78 | 26.63 | 10,970 | 100.6 |
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| 2019 | 15,068 | 32,798 | 414,000 | 0.66 | 0.58 | 17.5 | 16,624 | 73.6 |

**This stock is not subjected to overfishing, currently overfished, nor approaching an overfished condition.**

## Risk Tables

| | Assessment-related considerations | Pop dynamics considerations | Ecosystem considerations | Fishery considerations |
|---|---|---|---|---|
| Level 1: Normal | | | | |
| Level 2: Increased concern | | | | |
| Level 3: Extreme concern | | | | |

A risk table to address concerns external to stock assessments when developing fisheries harvest recommendations

Martin W. Dorn and Stephani G. Zador

# Outline

## Ecosystem thresholds

- Simulation-based evaluation of a threshold detection tool

## Nonstationary change

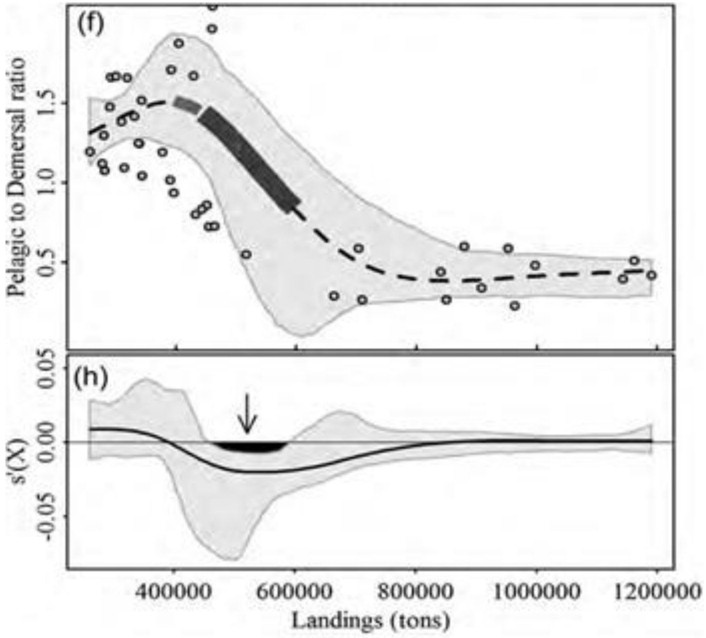
- Tracking ecosystem-level trends and shifts

SCARLETT W.
YOUTH ENTRY, GRADE 12

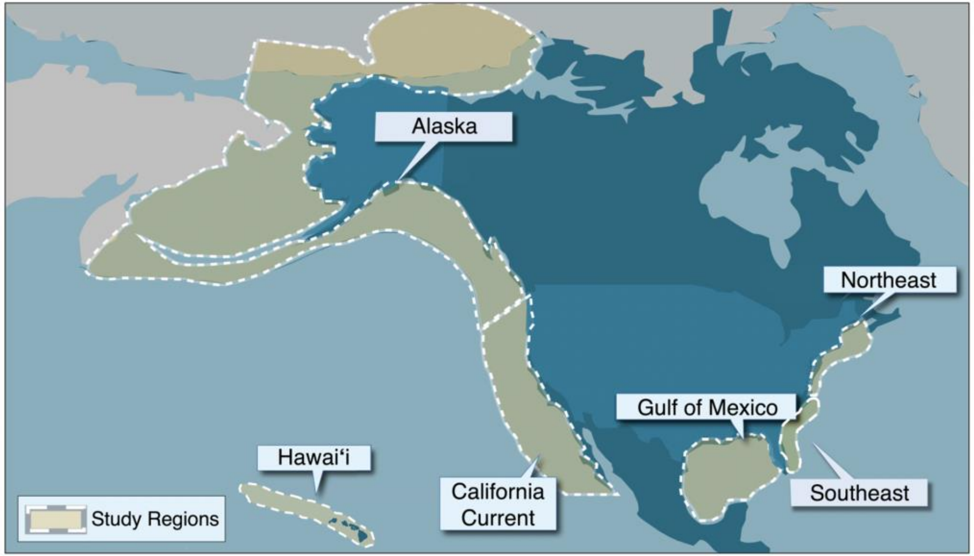
POLYCHROMATIC CAST
*(2023, WATERCOLOR)*

5th National Climate Assessment
https://nca2023.globalchange.gov/art-climate/

# Evidence of ecological thresholds




Large et al. 2013 ICES JMS




Identifying social thresholds and measuring social achievement in social-ecological systems: A cross-regional comparison of fisheries in the United States

Perng et al. 2023

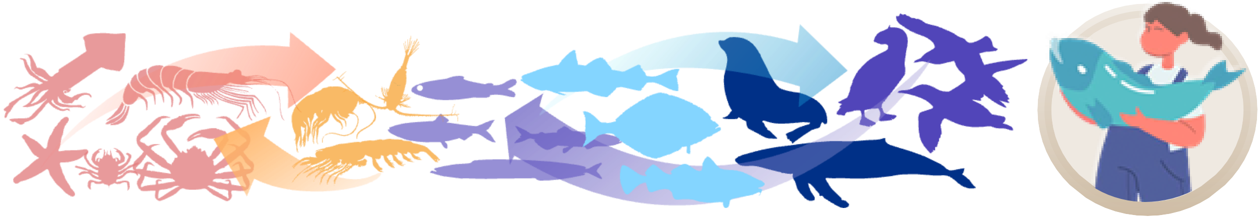
*E.g. Samhouri et al. 2015, Tam et al. 2017, Boldt et al. 2021, Hunsicker et al. 2022 PICES WG36 Report*

# How to increase uptake of thresholds in management?

**Sensitivity analyses** of threshold models to time series length, missing environmental info, observation error, etc. -> improve confidence

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

**Identifying underlying mechanisms** through which thresholds may or may not arise can help inform management policies

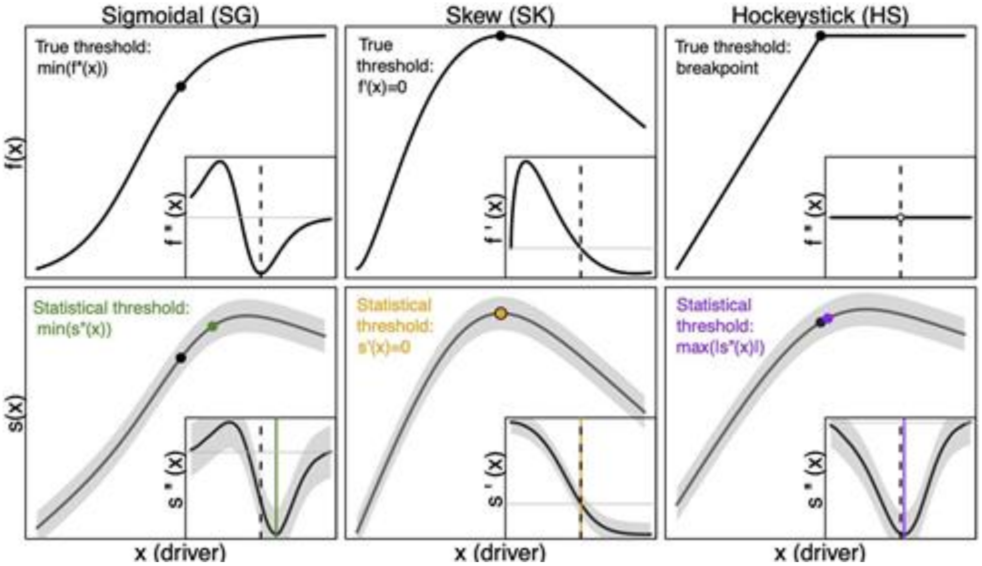


Raine Detmer, UCSB
NSF INTERN program

# Are threshold detection tools robust or not?

## Generalized Additive Models (GAM)

- Simulations to explore how method performs under various scenarios
- Several functional forms that differ in the definition of threshold locations
- Definition of 'threshold' that managers want to avoid may depend on the shape of relationship




*Where slope of s(x) is decreasing most rapidly*

*Local optimum of s(x)*

*Where slope of s(x) is changing most rapidly*

Detmer et al. Ecosphere In revision

Raine Detmer, UCSB
NSF INTERN program

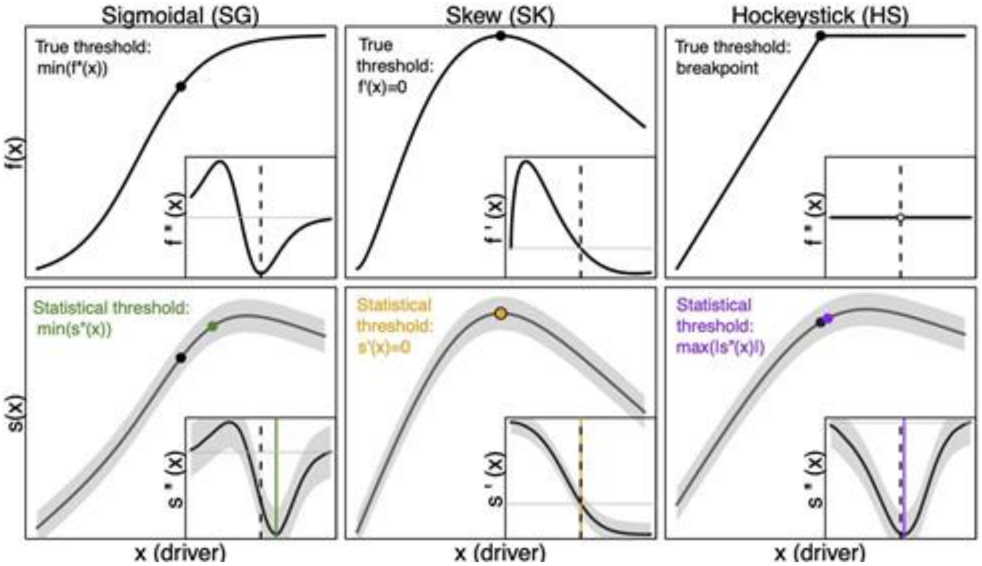
# Are threshold detection tools robust or not?

## Scenarios

(1) Number of data points (time series length)

(2) Observation error of response

(3) Effect of a missing covariate




*Where slope of s(x) is decreasing most rapidly*

*Local optimum of s(x)*

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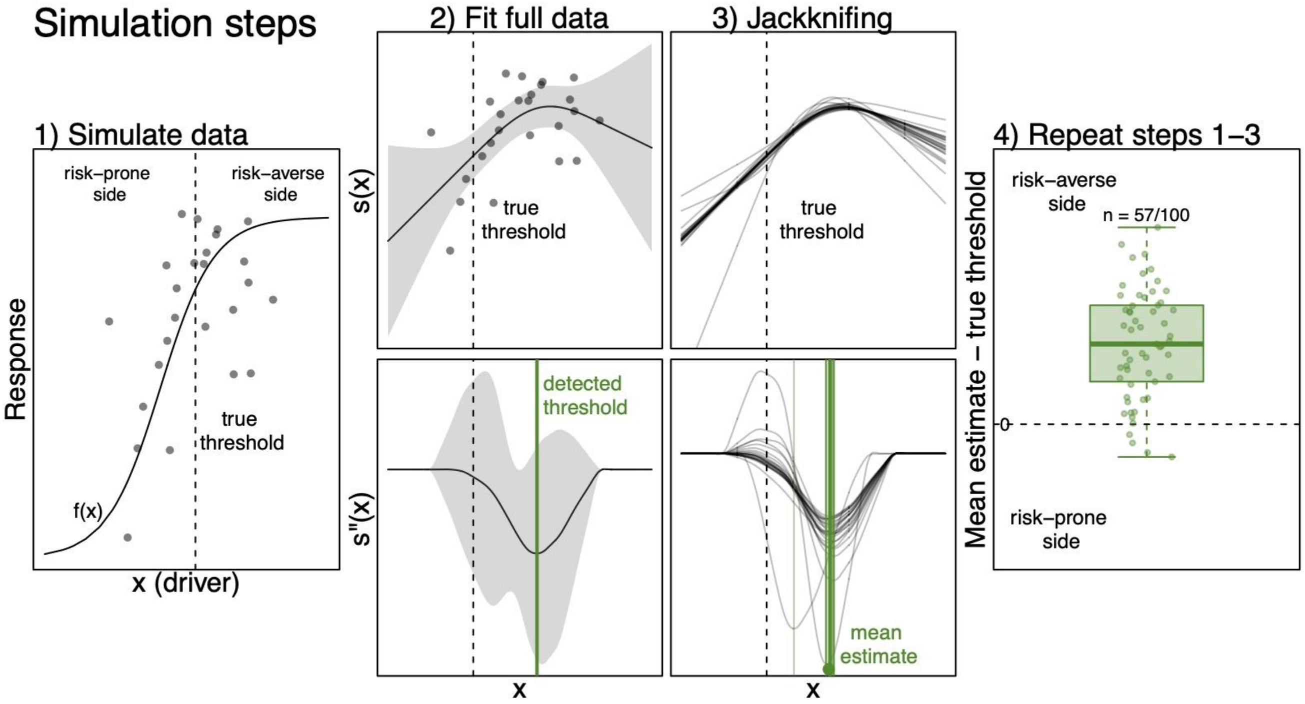
Detmer et al. Ecosphere In revision

## For each simulation scenario:

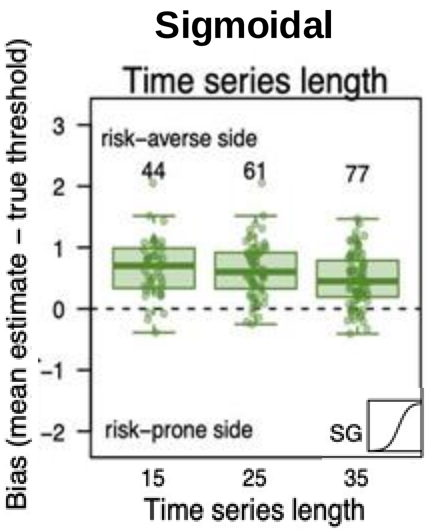



Jackknife resampling to evaluate robustness of each detected threshold existence and location

True and false positive rates were also calculated

Detmer et al. Ecosphere In revision

# GAMs generally performed best when time series were long



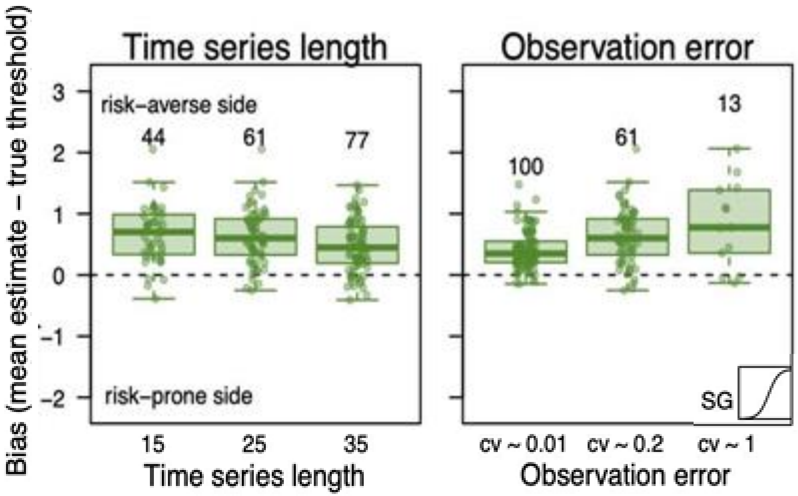

Estimated threshold preceded abrupt change to undesired levels of the response

Estimated threshold was on the “risk-prone” side with undesired response values

Sample sizes represent the number of simulations that detected a threshold, out of a total of 100 replicates

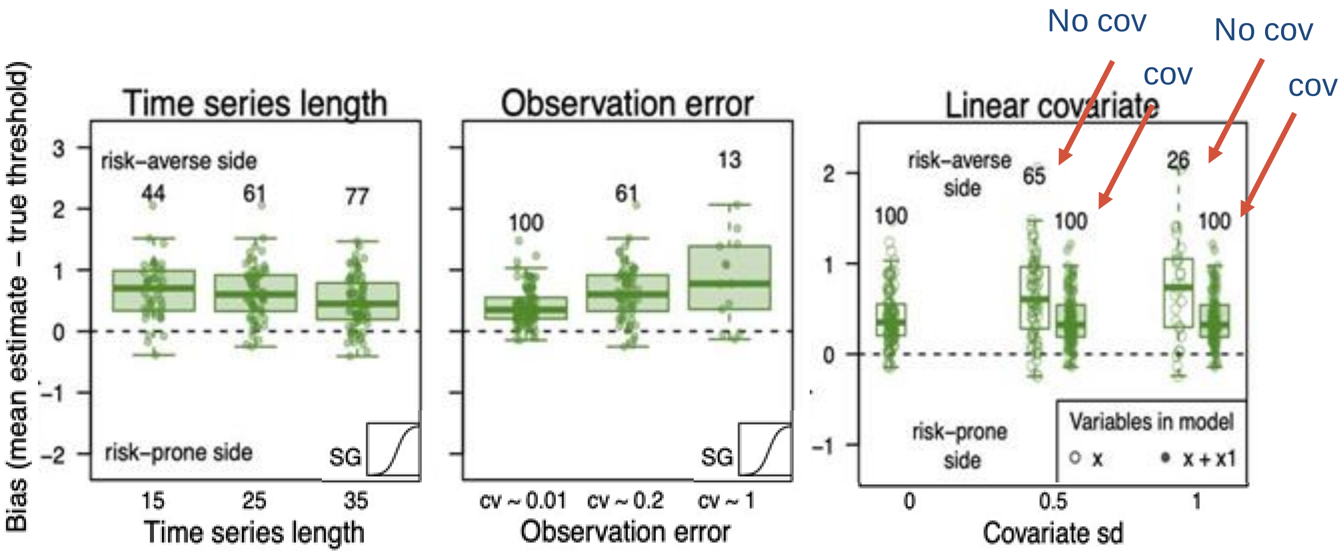
Detmer et al. Ecosphere In revision

# GAMs generally performed best when observation error was low




Detmer et al. Ecosphere In revision

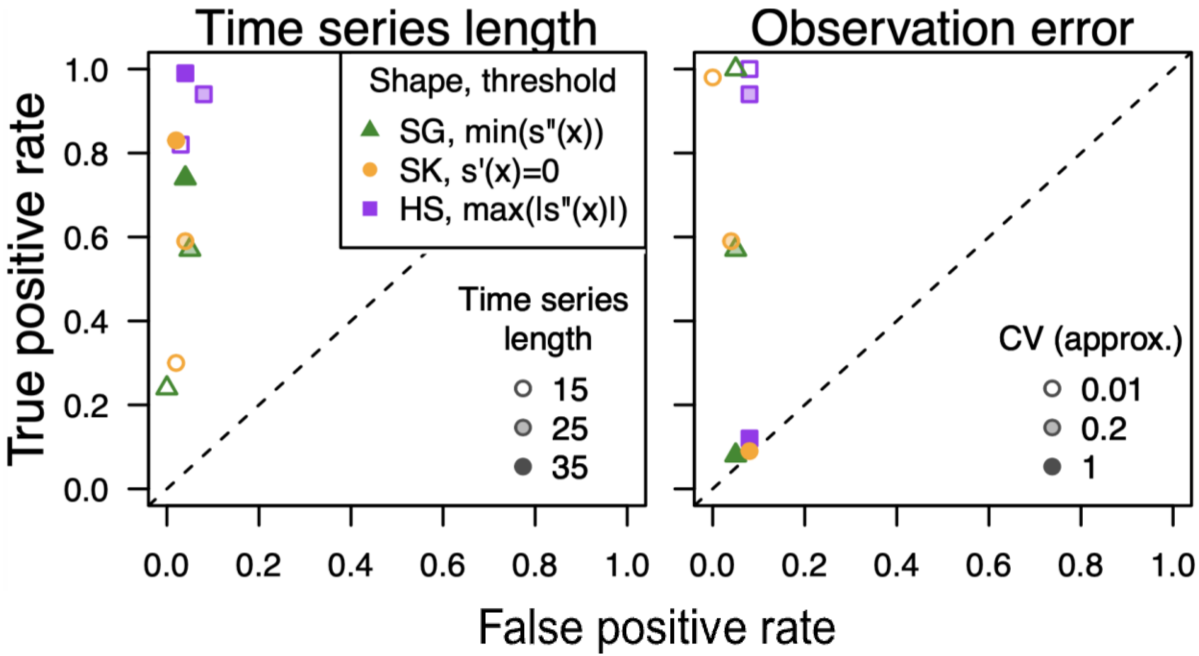
# GAMs generally performed best when covariates were accounted for




- Effects of factors held up across the functional forms
- Bias toward risk adverse side indicates low risk of mistakenly concluding a threshold lies far on the undesirable side of its true value

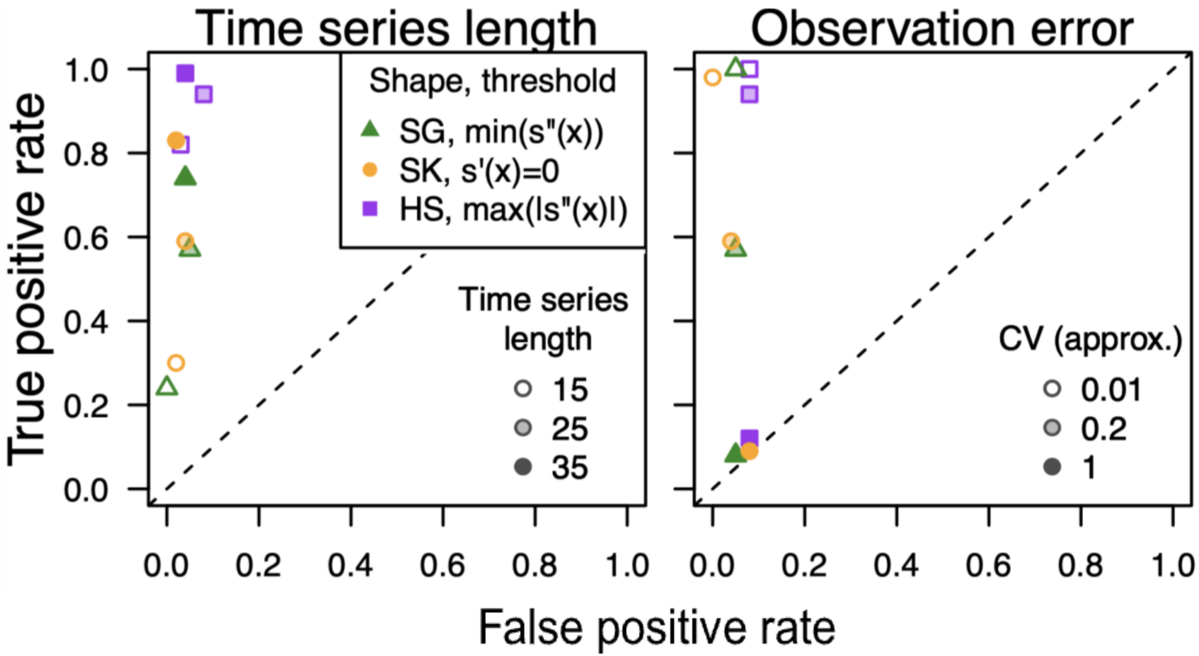
Detmer et al. Ecosphere In revision

# True positive rates were highest for long time series and low observation error




TPRs = fraction of simulation replicates that detected a threshold when one existed

# False positive rates were generally low across parameter combinations




FPRs = fraction of simulation replicates that detected a threshold
when true relationship was linear

# Are threshold detection tools robust or not?

- GAMs generally performed best with long time series, low observation error, and covariates accounted for
- Direction of bias was generally towards risk-averse side of threshold -> low risk of mistakenly concluding a threshold lies far on the undesirable side of its true value
- Detectability depended on shape of relationship and definition of the threshold location
- Other factors to consider: temporal and/or spatial autocorrelation, nonstationarity, more complex driver-response-covariate relationships

# Outline

## Ecosystem thresholds

- Simulation-based evaluation of a threshold detection tool (GAM)

## Nonstationary change

- Tracking ecosystem-level trends and shifts

**ANANYA A.**
**YOUTH ENTRY, GRADE 9**

A DESPERATE OCEAN
*(2023, ACRYLIC)*

5th National Climate Assessment
https://nca2023.globalchange.gov/art-climate/

# Developing ecosystem state indicators: Gulf of Alaska

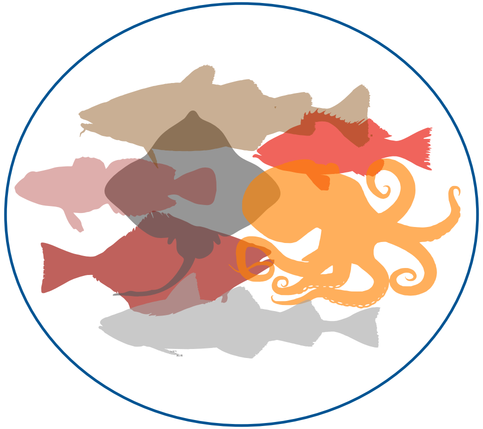
Bridget Ferriss
NOAA AFSC

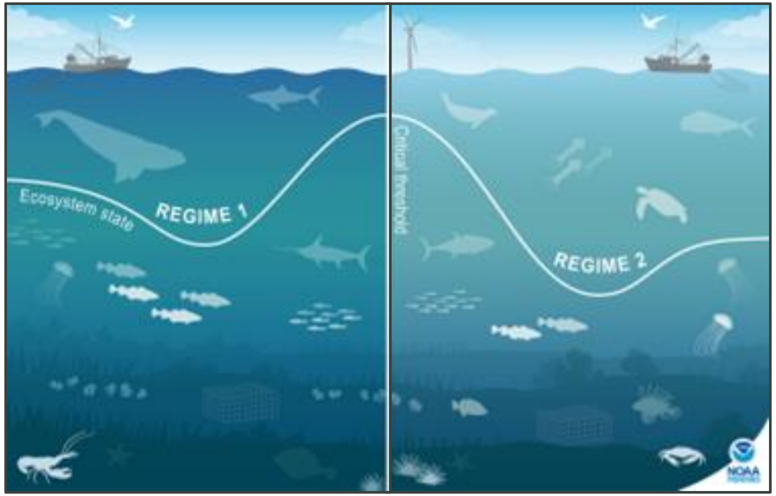


Annual synthesis of marine ecosystem conditions to inform fisheries management

Bridget Ferriss
NOAA AFSC

# Developing ecosystem state indicators: Gulf of Alaska




May provide early detection of ecosystem-level changes

# Ecosystem state indicators for NE Pacific ecosystems

- Identify shared trends among time series that are useful as indices
- Detect changes in mean ecosystem state
- Distinguish normal variability from changes signaling a major shift

ELSEVIER

Progress in Oceanography

Volume 186, July 2020, 102393

Evaluating ecosystem change as Gulf of Alaska temperature exceeds the limits of preindustrial variability

Litzow et al. 2020

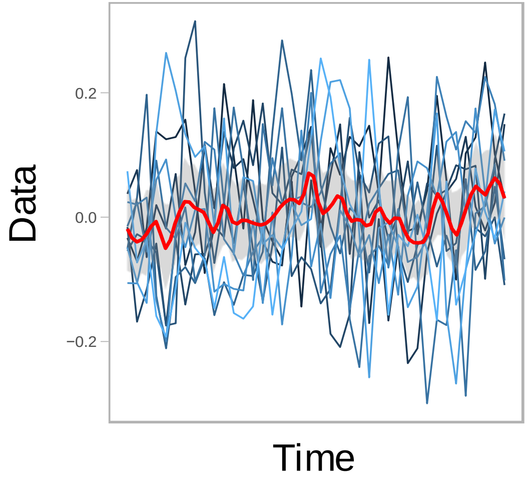
PLOS CLIMATE

Tracking and forecasting community responses to climate perturbations in the California Current Ecosystem

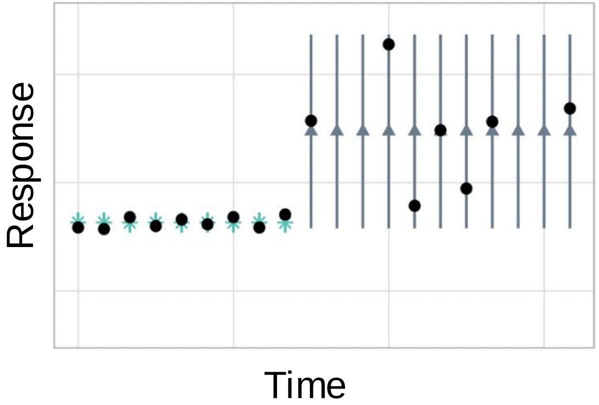
Hunsicker et al. 2022

# Methods

- Dynamic Factor Analysis (MARSS R package, Holmes et al. 2012)
  - Identify latent ’trends’ that may be useful as environmental indices




- Hidden Markov Models (hmmTMB R package, Michelot and Glennie 2023)
  - Estimate underlying state at any point in time
  - Estimate means and variances in the response in each state
  - Estimate probability of state transitions



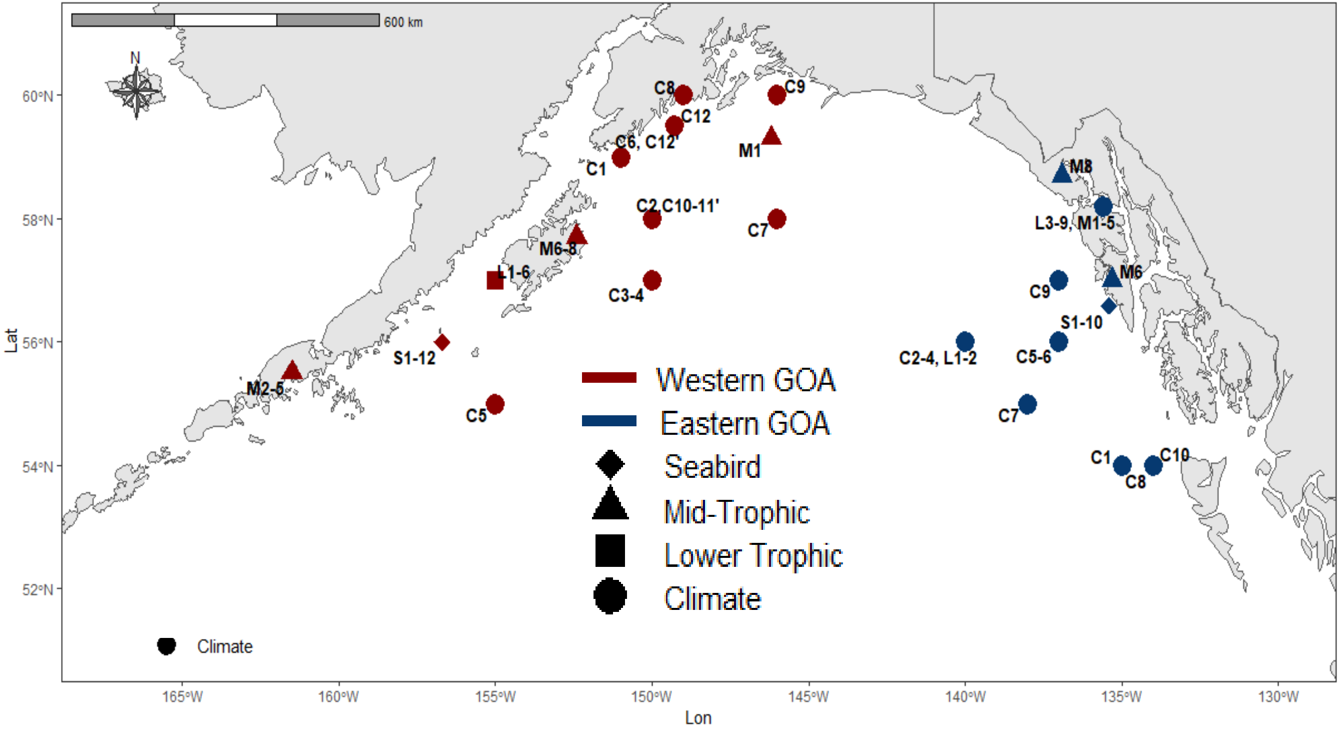
**Seabird (13,10)**
Reproductive success
Hatch date

**Mid-trophic (8,8)**
Forage fish abundance
Shrimp abundance
Jellyfish abundance
Juvenile salmon

**Lower trophic (10,9)**
Chl-a
Zooplankton
Ichthyoplankton

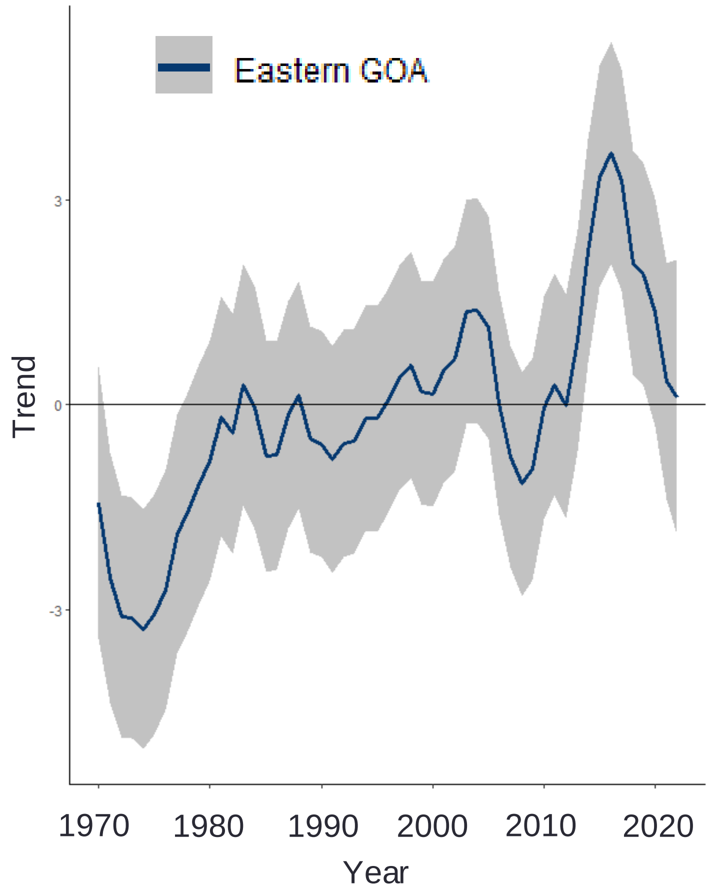
**Climate (12,10)**
SST (seasonal)
Temperature at depth
Salinity
Wind direction
Upwelling

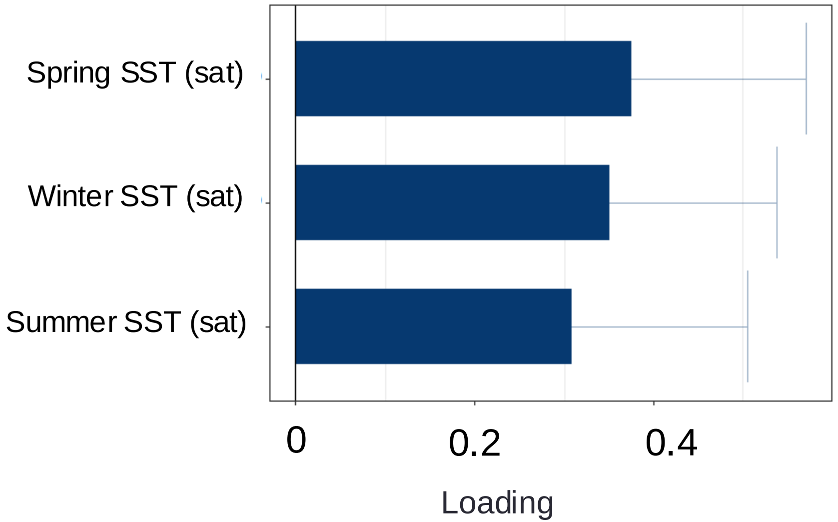
# Gulf of Alaska time series



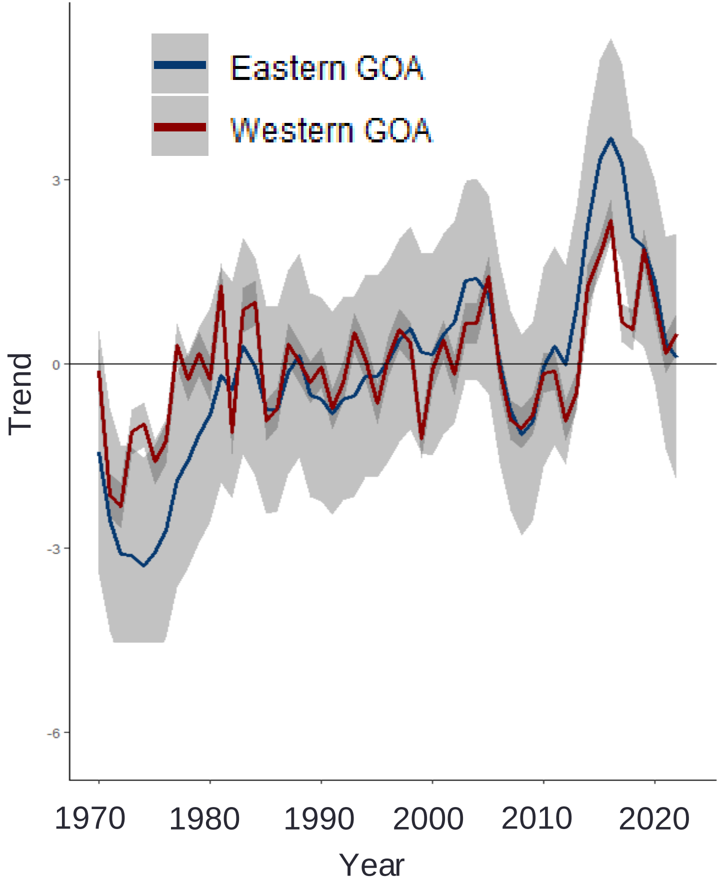

Time series ranged from 25 to 52 year in length, all ending in 2022

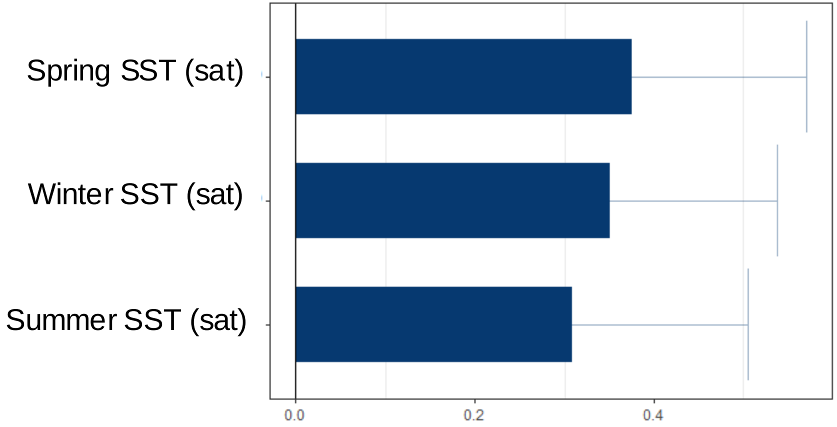
# One common trend identified in EGOA climate variables

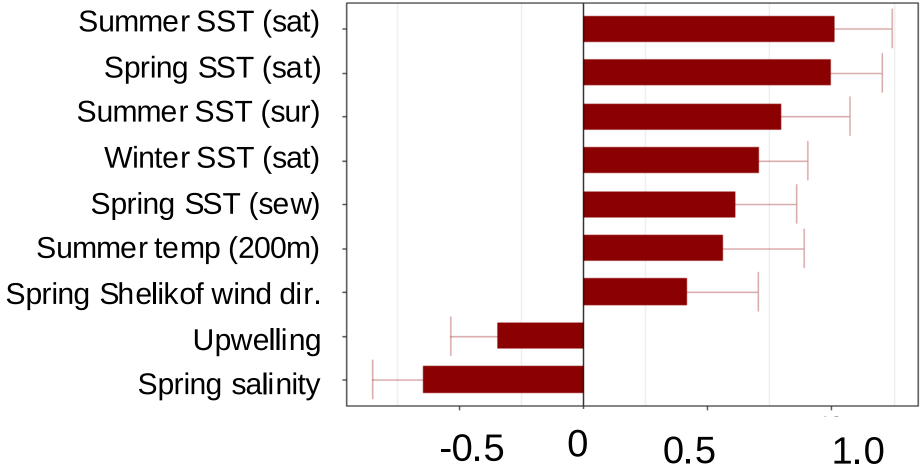


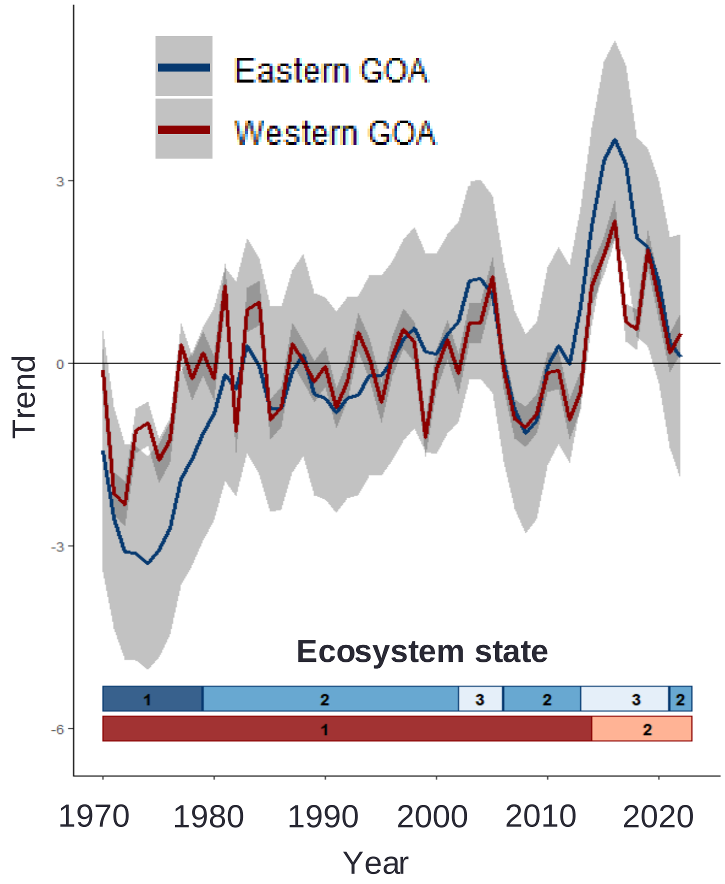
# One common trend identified in WGOA climate variables

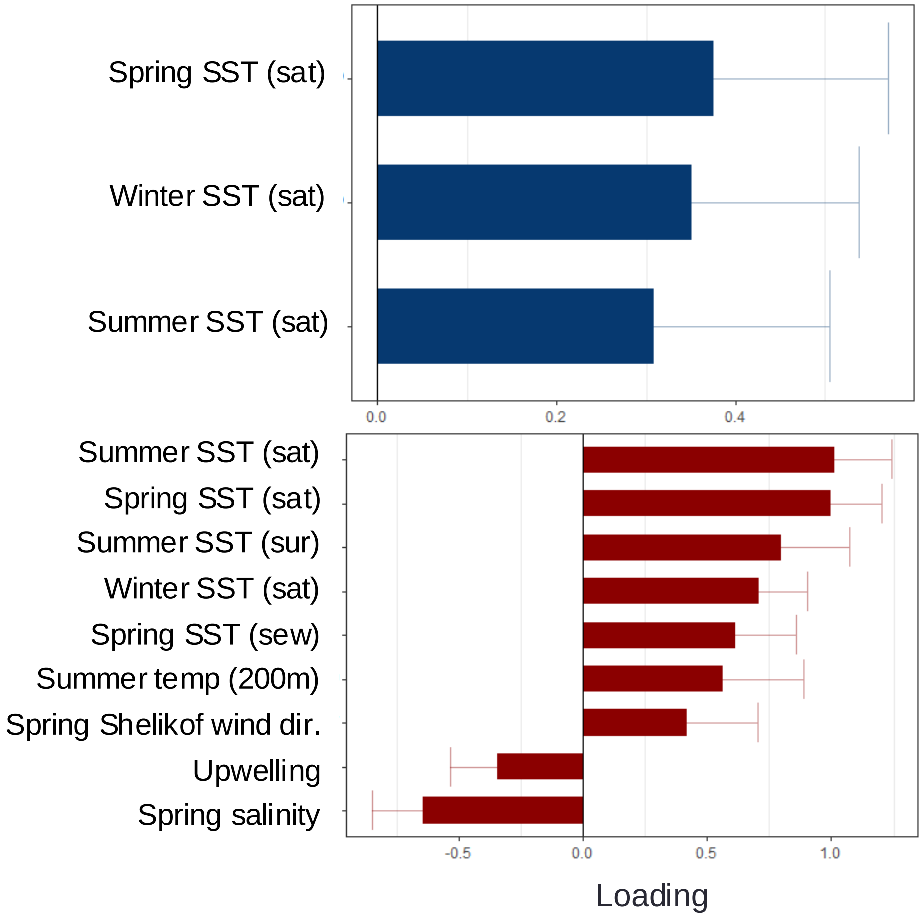


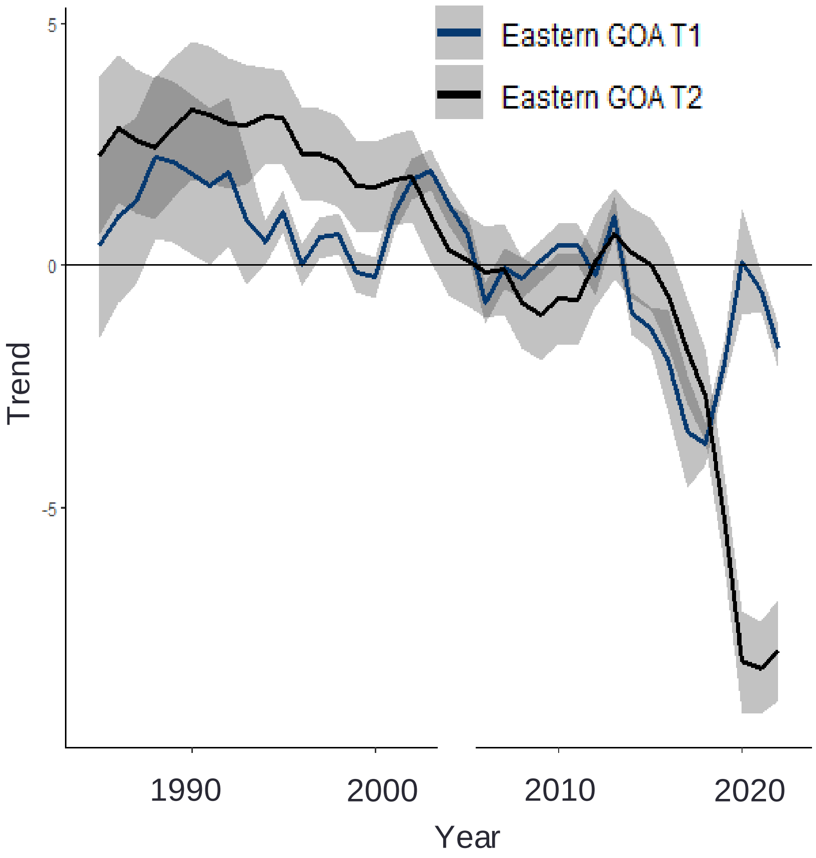



# State transitions largely aligned with previous observations (1977,1988,2014)



# Two common trends identified in EGOA biology variables




## Eastern GOA T1

**+**
- Humpback whale birth rate
- Herring biomass (Craig)
- Herring biomass (Sitka)
- Juv chum salmon cpue
- Chla biomass

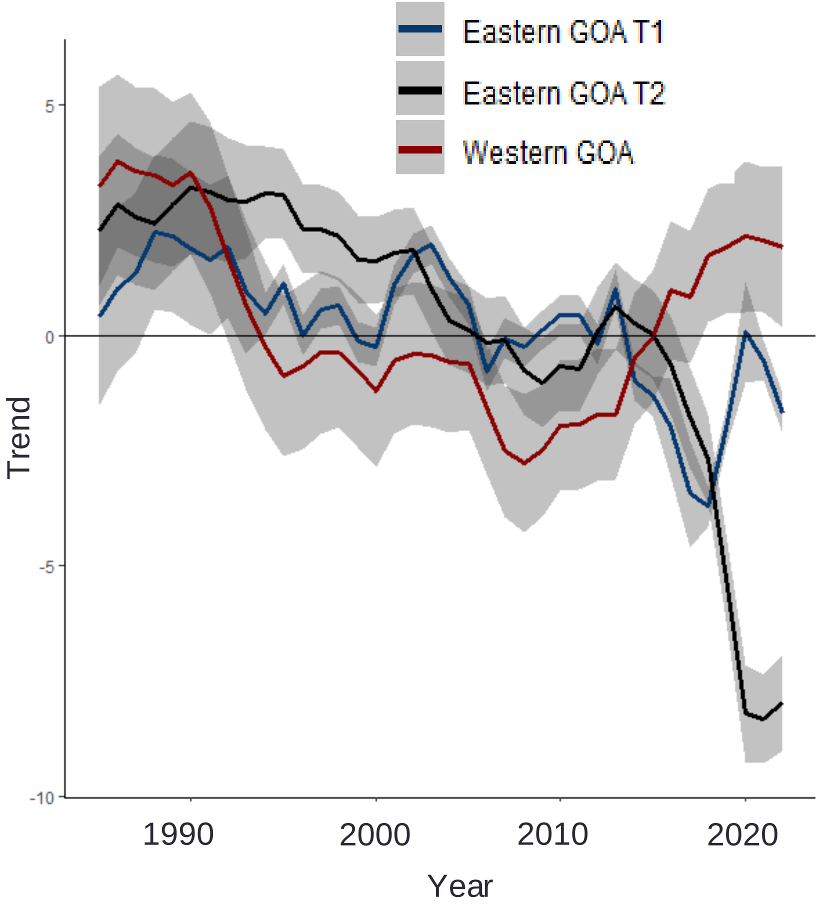
**-**
- Glaucous wing gull hatch
- Thick billed murre hatch
- Common murre hatch

## Eastern GOA T2

**+**
- Chla biomass
- Juv coho salmon cpue

**-**
- Herring biomass (Craig)
- Herring biomass (Sitka)

# One common trend identified in WGOA biology variables

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Humpback whale birth rate
Herring biomass (Craig)
Herring biomass (Sitka)
Juv chum salmon cpue
Chla biomass

\+

Glaucous wing gull hatch
Thick billed murre hatch
Common murre hatch

\-

## Eastern GOA T2

Chla biomass
Juv coho salmon cpue

\+

Herring biomass (Craig)
Herring biomass (Sitka)

\-

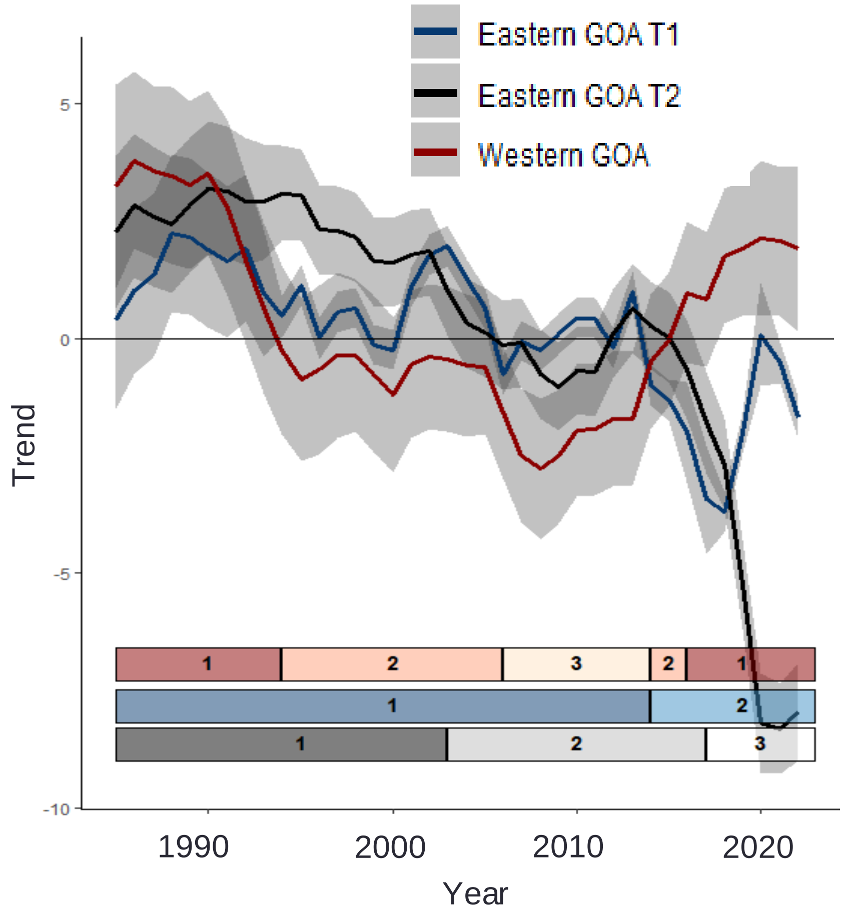
## Western GOA

Tufted puffin prod
Chiniak pink shrimp
Pavlof shrimp
Pavlof capelin

\+

Chiniak jellyfish
Chla biomass
Prop. capelin in diet
Tufted puffin hatch

\-

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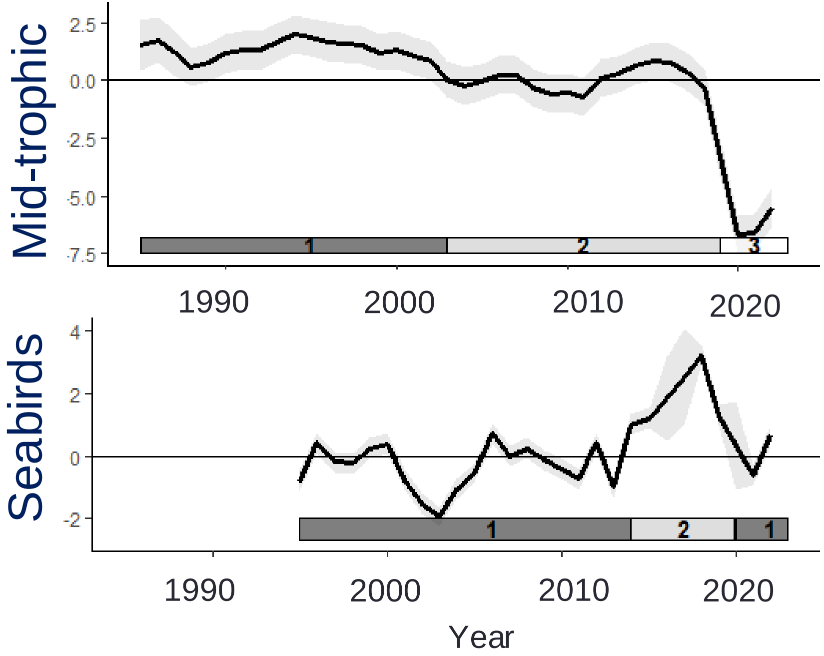
# Common trends within trophic levels




## Mid-trophic

Juvenile coho salmon cpue
Juvenile pink salmon cpue
Juvenile chinook salmon cpue
Herring biomass (Craig)
Herring biomass (Sitka)

+

-

## Seabirds

Thick-billed murre hatch
Common murre hatch
Glaucous-winged gull hatch

+

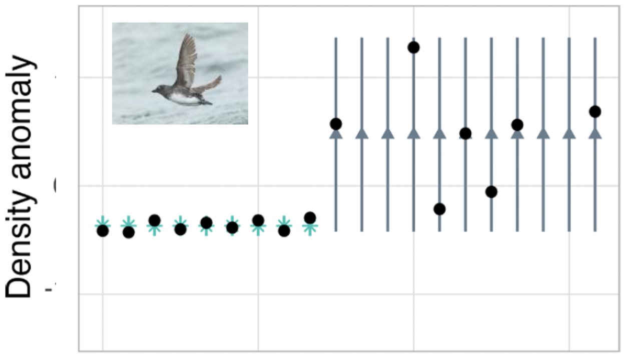
Useful for communication and identifying redundant indicators

Using Hidden Markov Models to develop ecosystem indicators from non-stationary time series

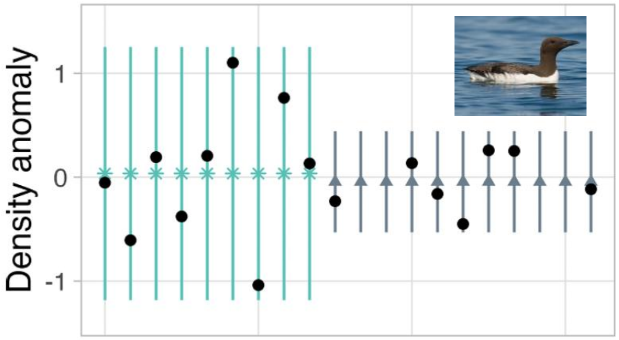
Zoe R. Rand [a,*], Eric J. Ward [b], Jeanette E. Zamon [c], Thomas P. Good [b], Chris J. Harvey [b]

- Joint HMMs – multiple time series vs trend
- Estimate mean *and* variances in the response
- Identify timing of underlying shift
- Identify redundant indicators

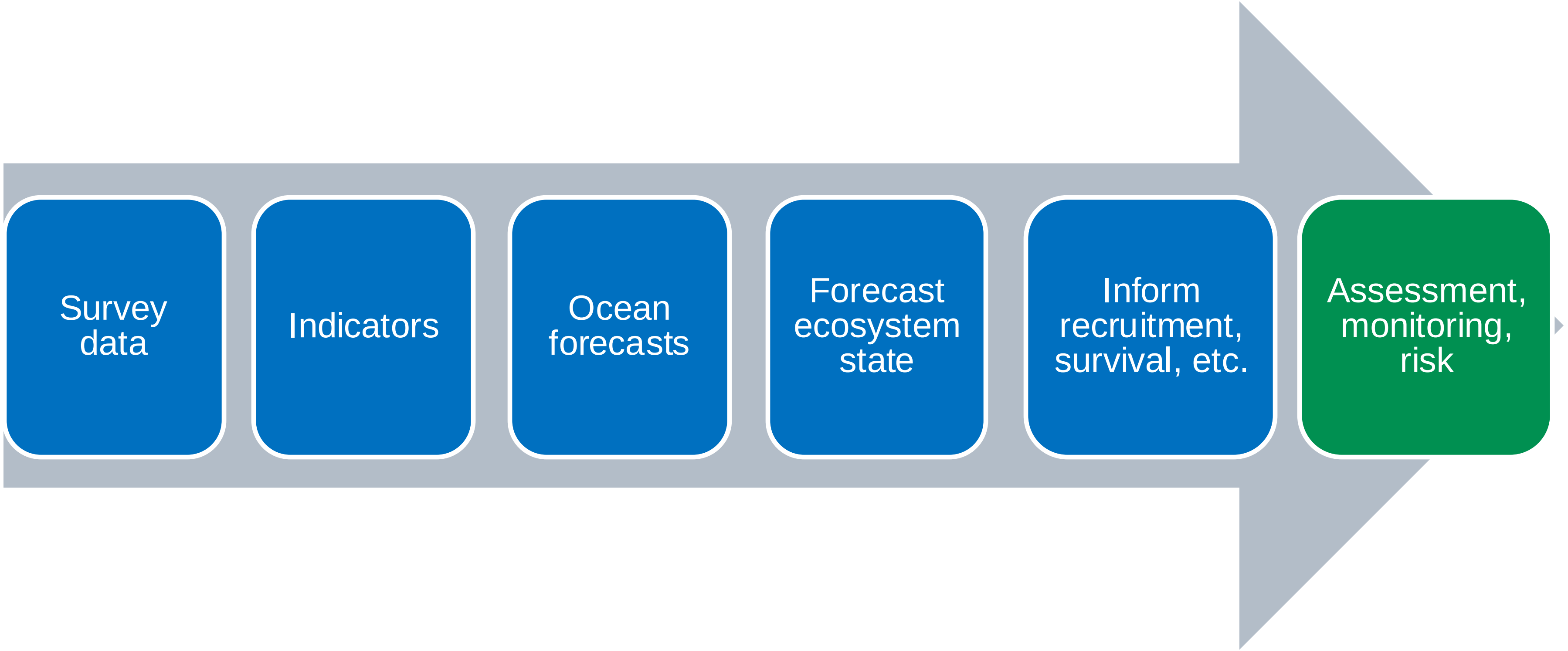
Cassin’s auklet




Common Murre

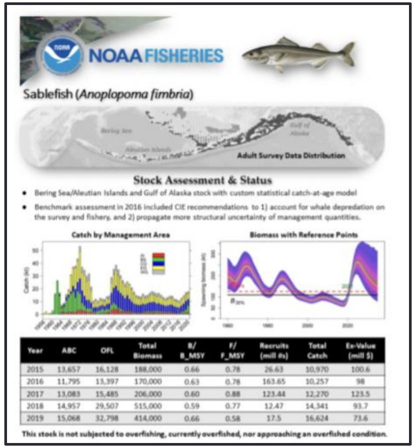


# Forecast ecosystem state to help inform management decisions



# How can we implement this information into management?

- Annual production of common trends and ecosystem state can streamline communication
- Operationalizing these tools in the management of GOA is achievable by building on existing frameworks
- These tools can provide ecosystem support to management decisions relative to groundfish productivity and resulting harvest specifications


**Stock Assessment & Status**

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# Collaborators

## Ecosystem thresholds

Kelly Andrews
Michele Conrad
Elliott Hazen
Kirstin Holsman
Julia Indivero
Scott Large
Mike Malick
Kristin Marshall
Stuart Munsch
Kiva Oken
Will Satterthwaite
Kalei Shotwell
Andrew Thompson

## Non-stationary change

Mike Litzow
Lauren Rogers
Matt Callahan
Wei Cheng
Seth Danielson
Brie Drummond
Emily Fergusson
Christine Gabriele
Kyle Herbert
Russ Hopcroft
Emily Lemagie
Jens Nielsen
Kally Spalinger
William Stockhausen
Wes Strasburg
Shannon Whelan

# Thank you!

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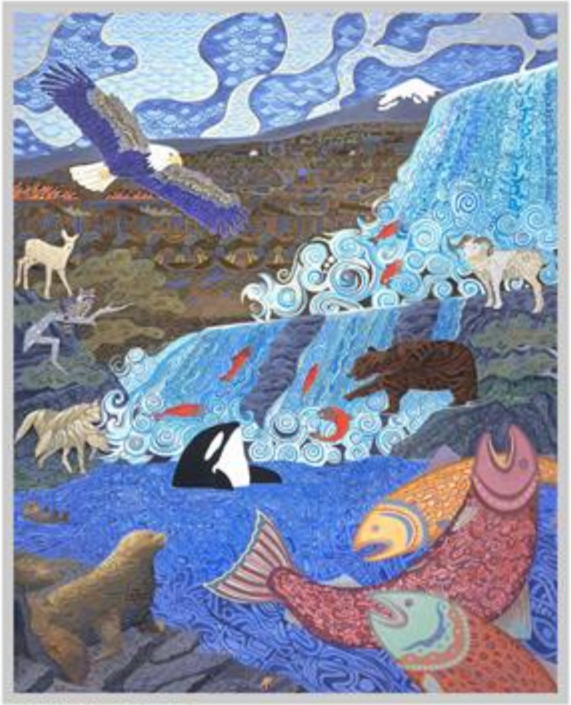

SPENCER FRAZER

STREAM OF CONSCIOUSNESS
(2020, OIL ON CANVAS)

5th National Climate Assessment
https://nca2023.globalchange.gov/art-climate/

NOAA FISHERIES