Rising variance as a leading indicator of tipping points in marine ecosystems: A test using Alaskan crustacean data

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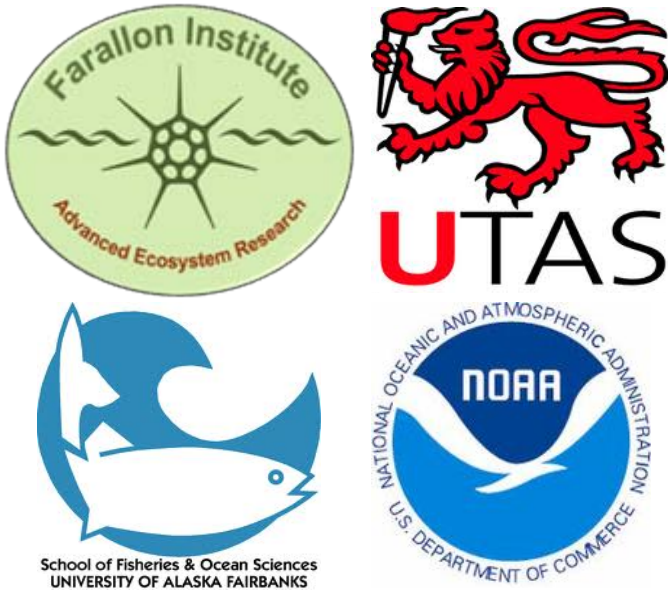
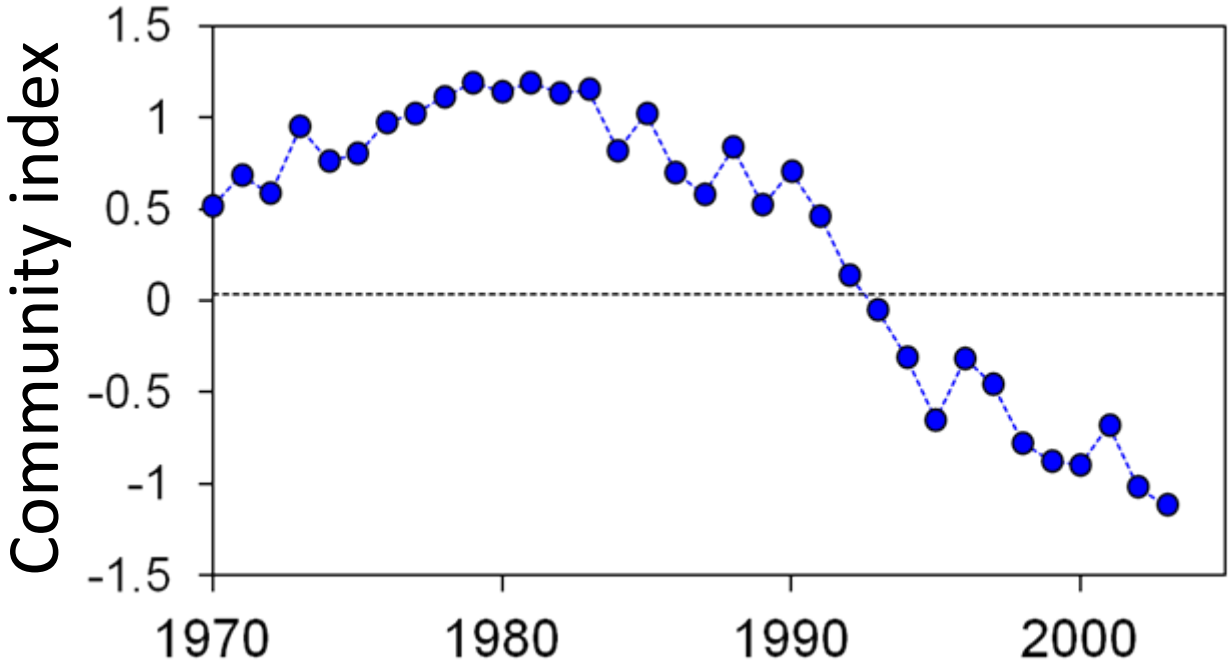
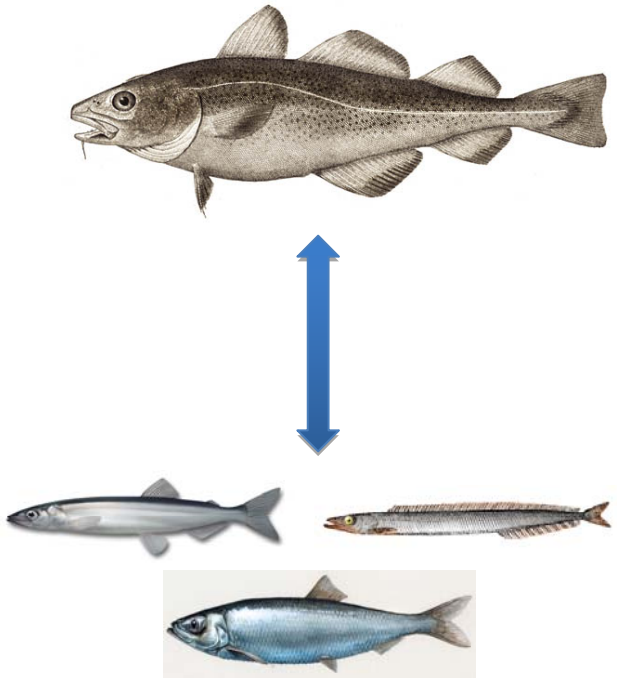


Tipping points in marine ecosystems & fisheries

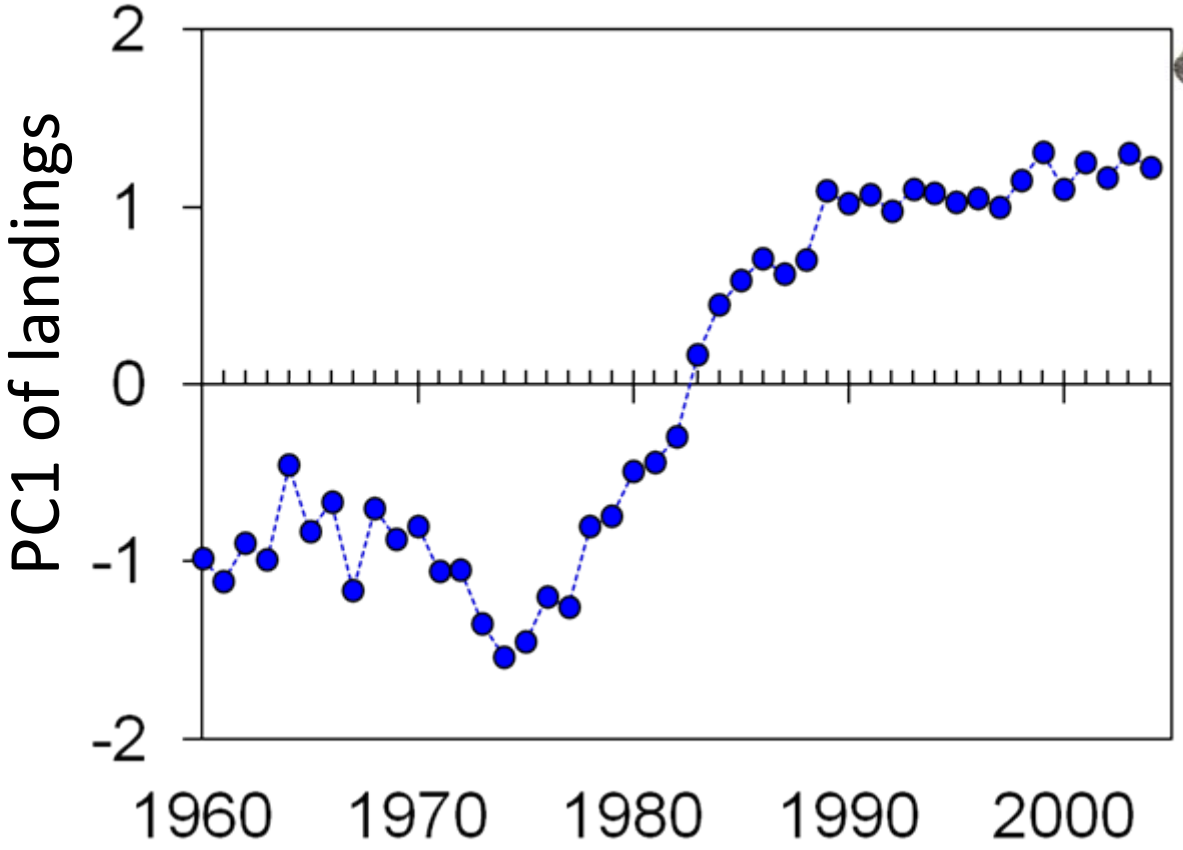
Relative abundance of cod and prey on the Scotian Shelf

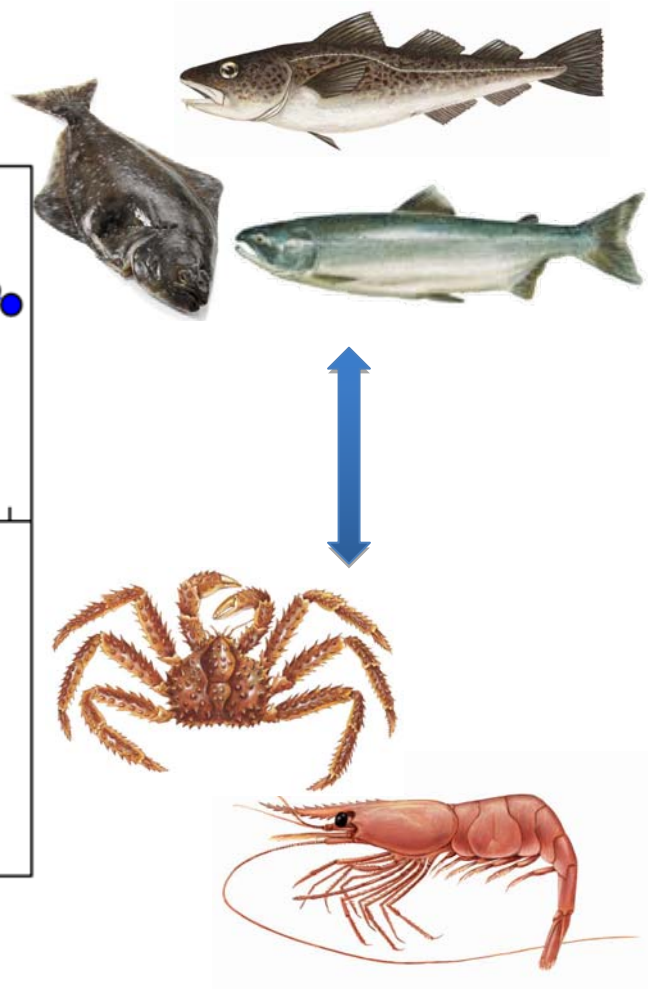




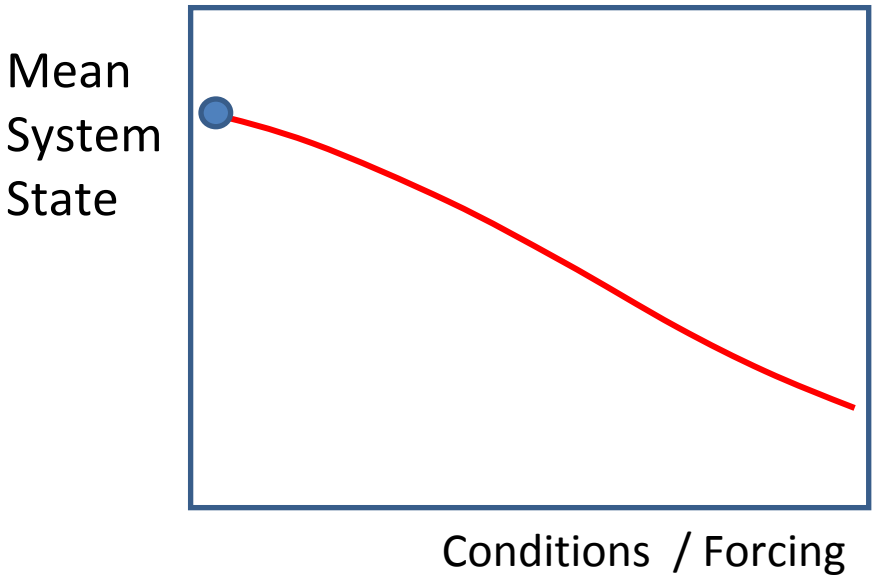
Tipping points in marine ecosystems & fisheries

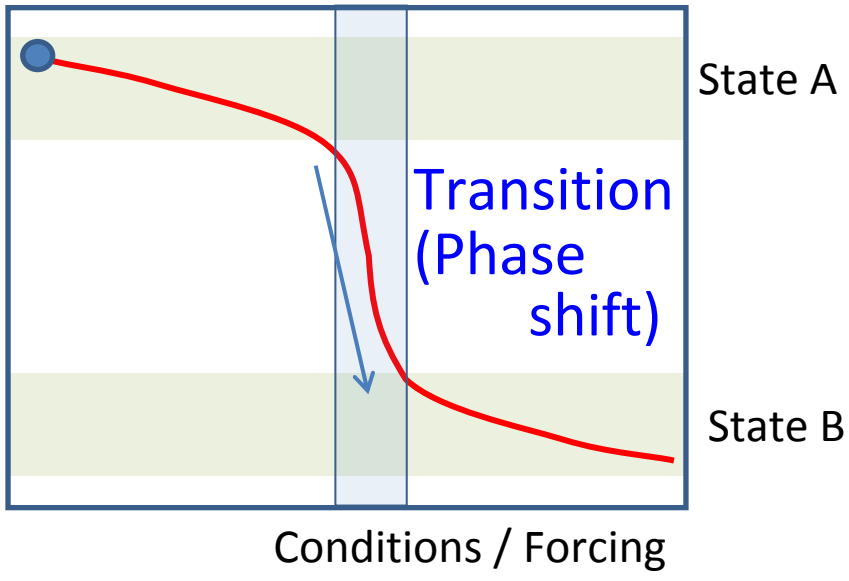
Gulf of Alaska commercial catch composition





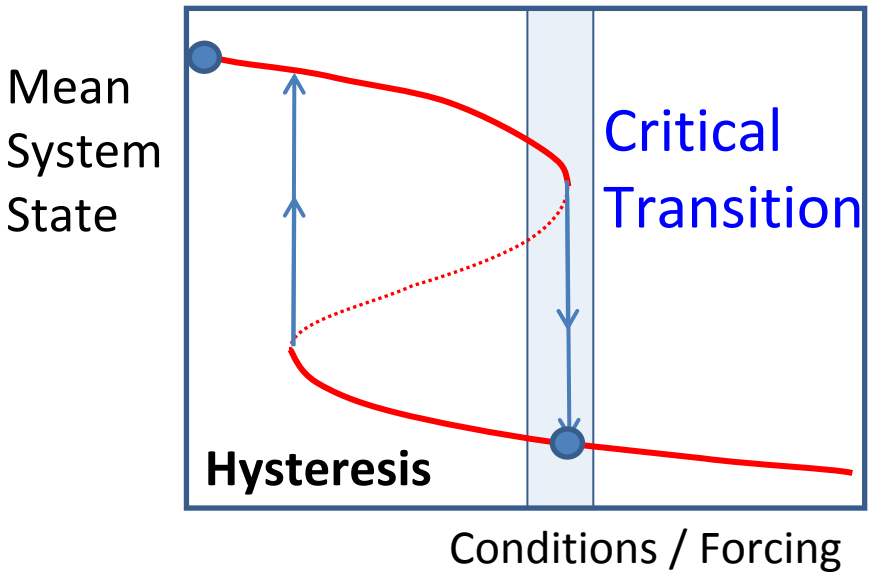
Transitions in theory





After Scheffer (2009)

Transitions in theory

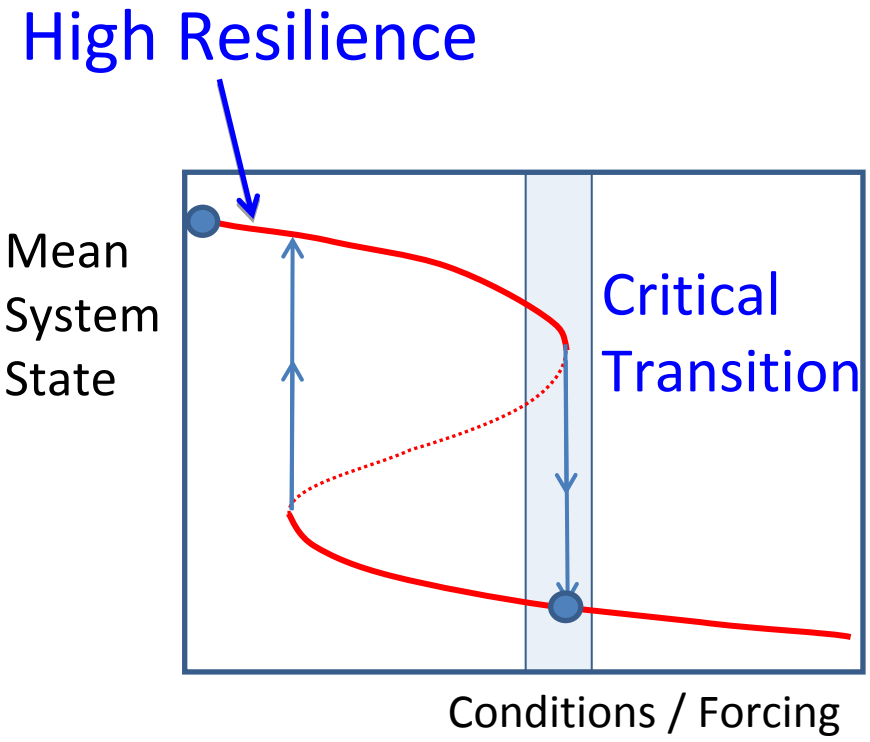


→Even gradual forcing can produce sudden shift

→Changes in mean state don't provide early warning

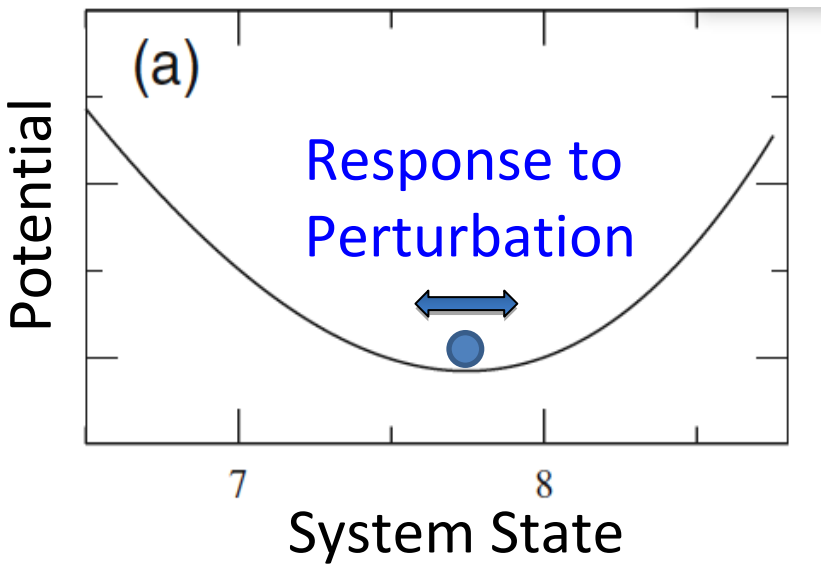
After Scheffer (2009)

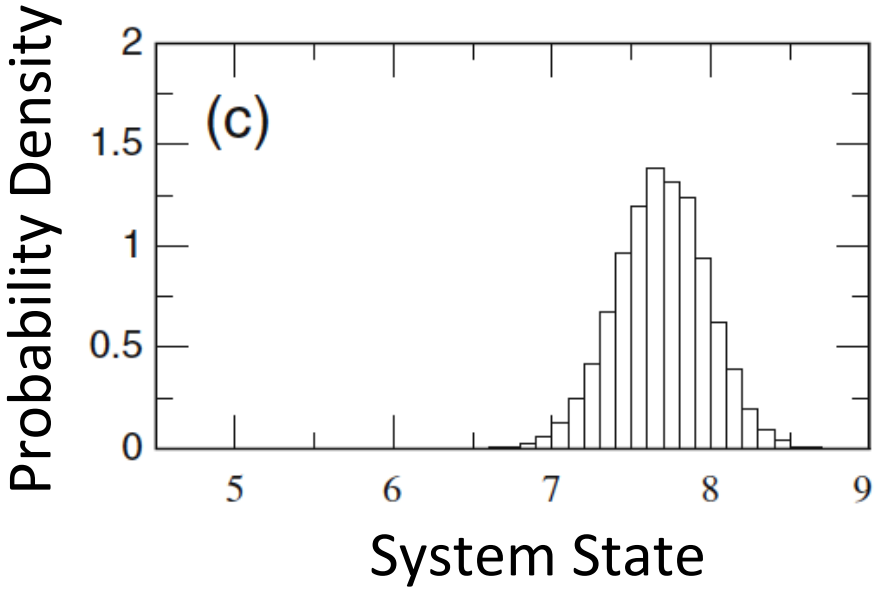
Increasing variance & skew near transition point



Increasing variance & skew near transition point

High Resilience

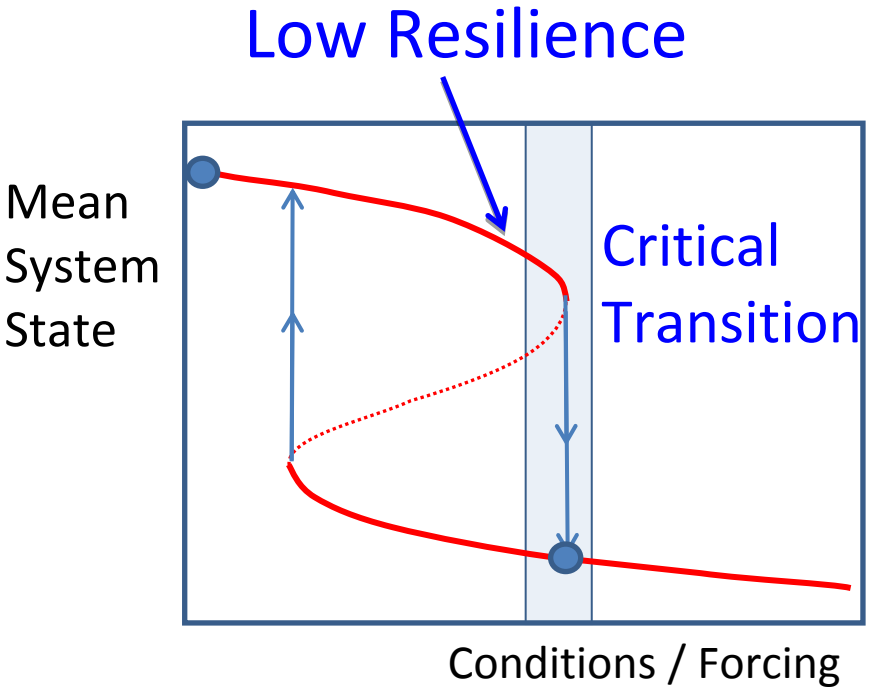




Redrawn from:

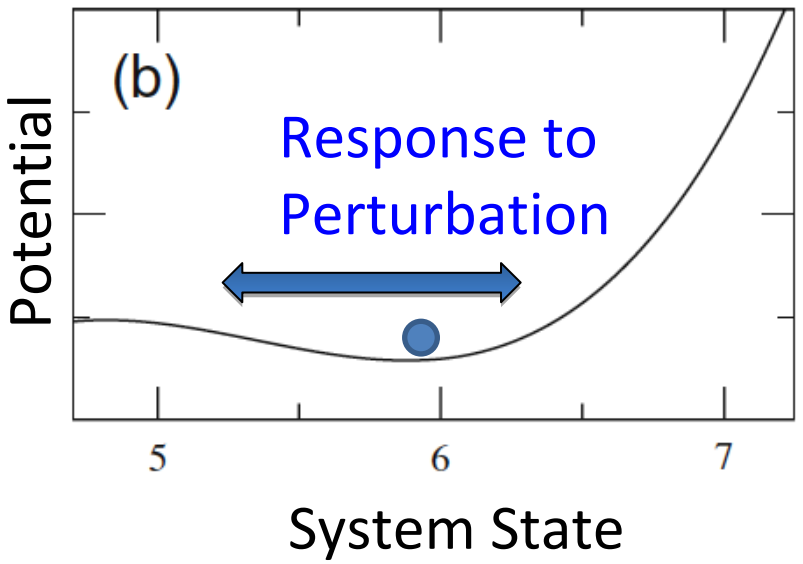
Guttal & Jayaprakash. 2009. Theor. Ecol.

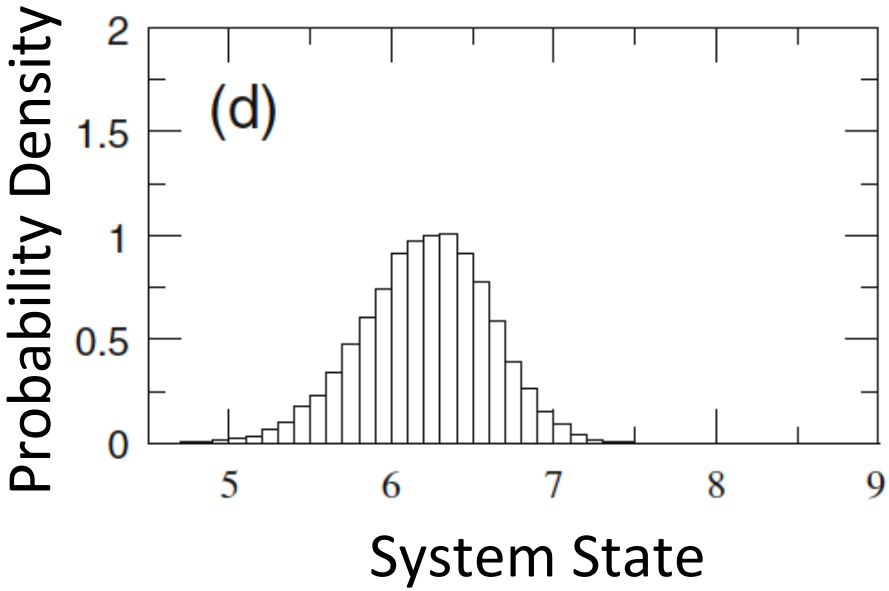
Increasing variance & skew near transition point



Increasing variance & skew near transition point

Low Resilience



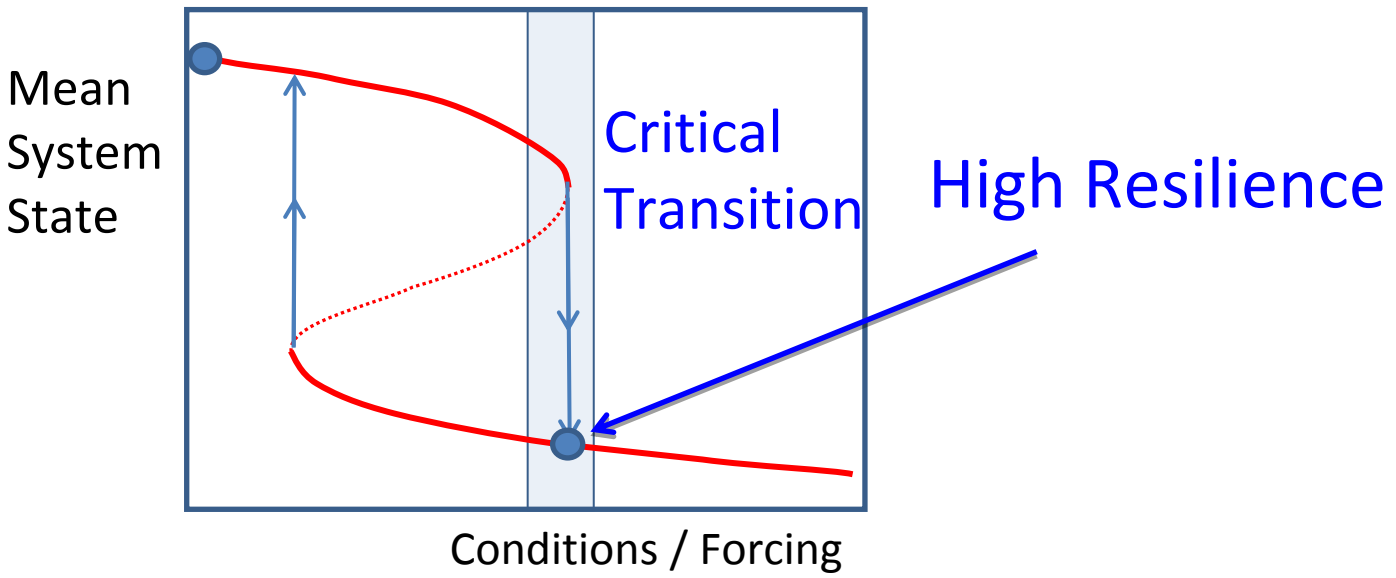


Rising variance & skew as "generic" regime shift indicators

→Don't require understanding of underlying dynamics
→Expected in both ecosystems and populations
→Primarily tested in models and small, simple ecosystems

Redrawn from:
Guttal & Jayaprakash. 2009. Theor. Ecol.

Ephemeral variance & skew near transition point



Predicts return to low variance / low skew after shift

Alaskan crustacean fisheries as a model system for "generic" indicators in large, complex systems

Approach

- Compile catch time series for stocks that have undergone pronounced transitions (collapse!)
- Test predictions of increasing variance & skew prior to collapse
- Test prediction of *declining* variance & skew following collapse

Data

- Time series of catches of 14 crustacean stocks off Alaska
- Fishery-independent surveys too short
- Some caveats
  - Short, inherently noisy time series
  - Catchability variable & unknown
  - Many drivers besides dynamics we are testing for (weather, management, economics, measurement error, etc.)

Pink shrimp

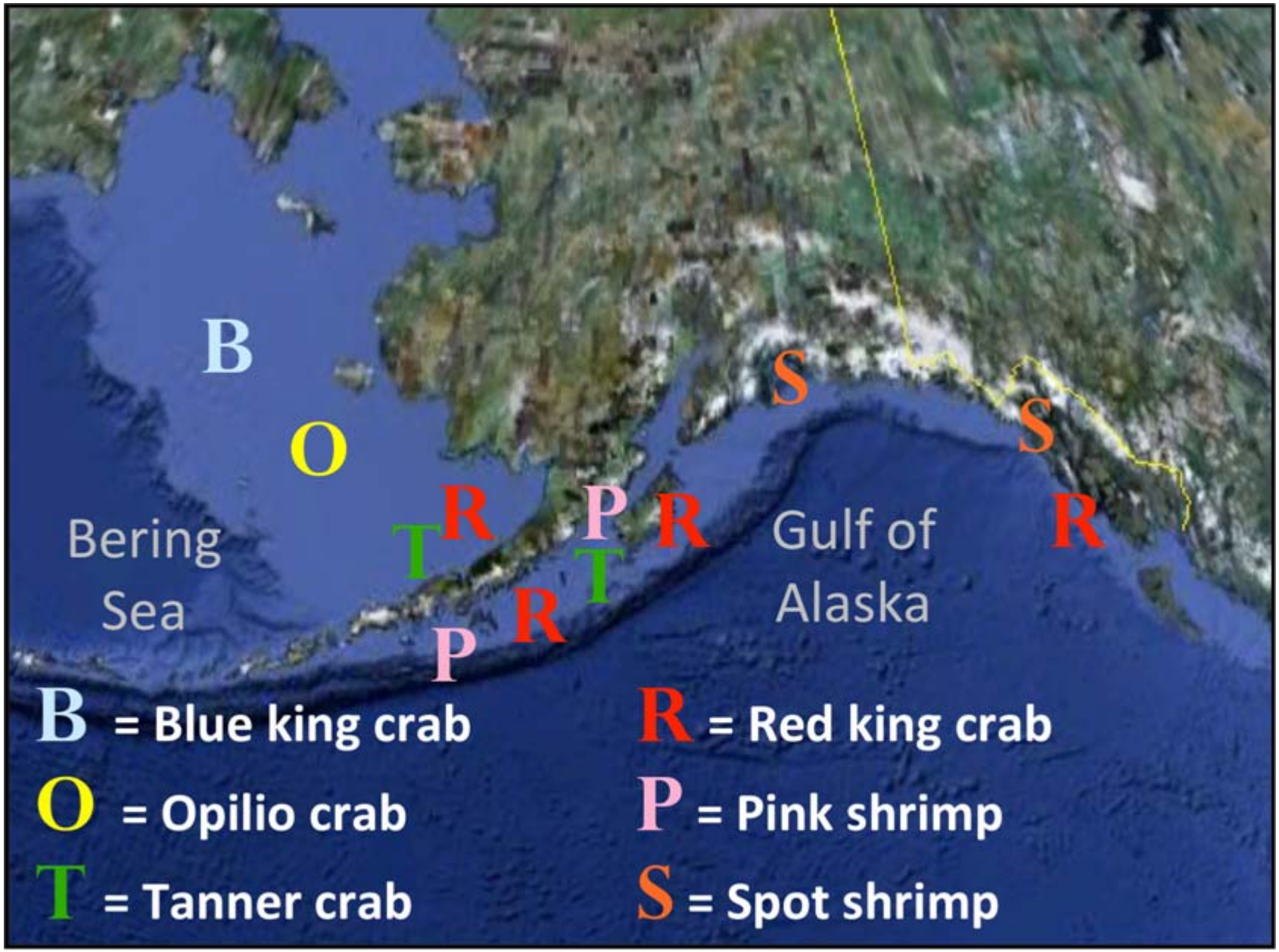
Red king crab

Snow crab (opilio)

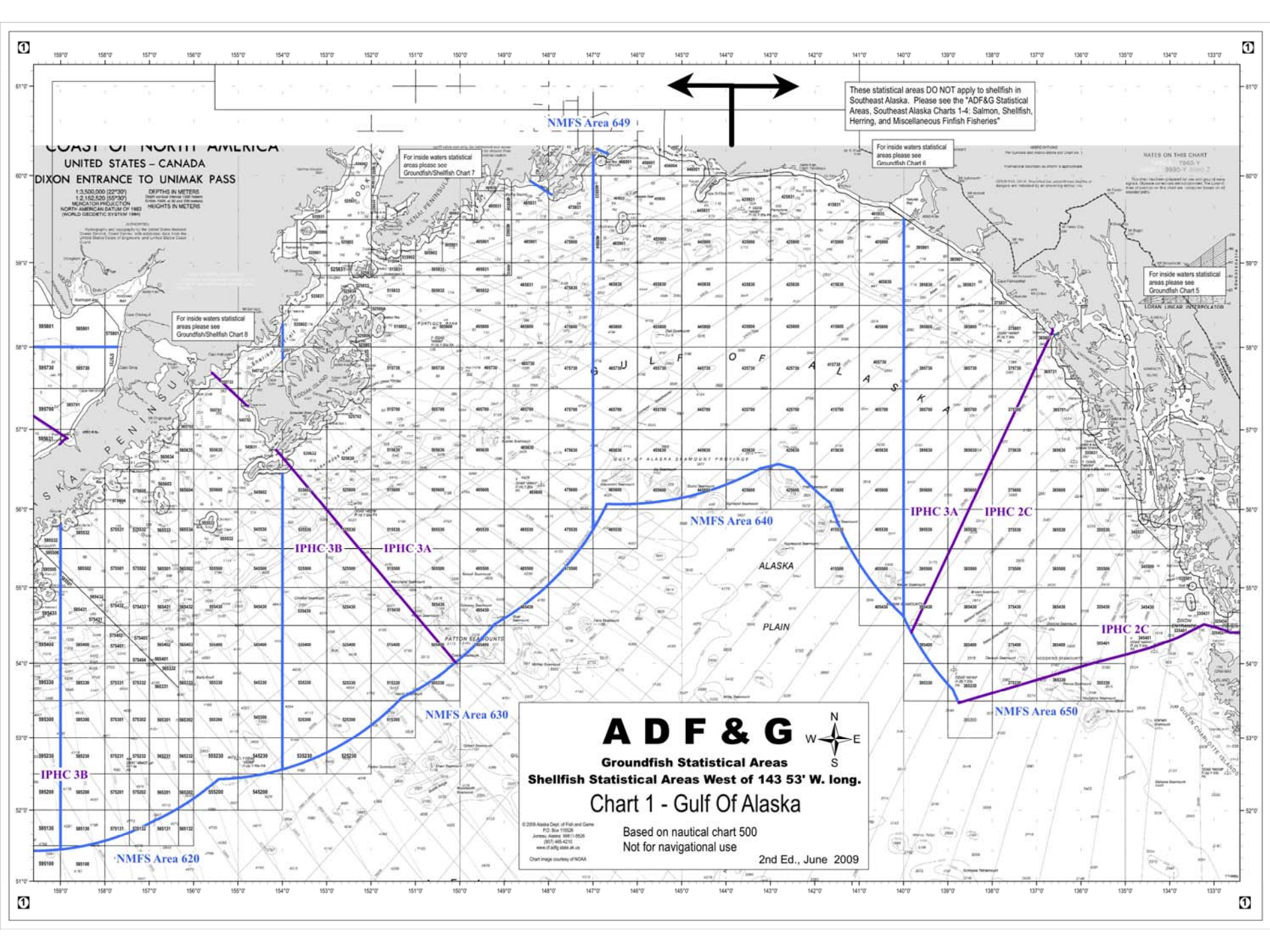
Spot shrimp

Blue king crab

Tanner crab (bairdi)



Combined shelf area ~ 4×10^5 km^2


These statistical areas DO NOT apply to shellfish in Southeast Alaska. Please see the "ADF&G Statistical Areas, Southeast Alaska Charts 1-4: Salmon, Shellfish, Herring, and Miscellaneous Finfish Fisheries"
NMFS Area 649
COAST OF NORTH AMERICA
UNITED STATES – CANADA
DIXON ENTRANCE TO UNIMAK PASS
1:3,500,000 (22°30')
1:2,152,520 (55°30')
MERCATOR PROJECTION
NORTH AMERICAN DATUM OF 1983
(WORLD GEODETIC SYSTEM 1984)
DEPTHS IN METERS
HEIGHTS IN METERS
For inside waters statistical areas please see Groundfish/Shellfish Chart 7
For inside waters statistical areas please see Groundfish Chart 6
For inside waters statistical areas please see Groundfish/Shellfish Chart 8
For inside waters statistical areas please see Groundfish Chart 5
GULF OF ALASKA
ALASKA PENINSULA
KODIAK ISLAND
KENAI PENINSULA
QUEEN CHARLOTTE ISLANDS
LORAN LINEAR INTERPOLATOR
RATES ON THIS CHART
IPHC 3B
IPHC 3A
IPHC 2C
NMFS Area 640
NMFS Area 630
NMFS Area 620
NMFS Area 650
PATTON SEAMOUNTS
KODIAK SEAMOUNTS
DIXON SEAMOUNTS
ALASKA PLAIN
GULF OF ALASKA SEAMOUNT PROVINCE
ADF&G
Groundfish Statistical Areas
Shellfish Statistical Areas West of 143 53' W. long.
Chart 1 - Gulf Of Alaska
© 2009 Alaska Dept. of Fish and Game
P.O. Box 115526
Juneau, Alaska 99811-5526
(907) 465-4210
www.cf.adfg.state.ak.us
Chart image courtesy of NOAA
Based on nautical chart 500
Not for navigational use
2nd Ed., June 2009
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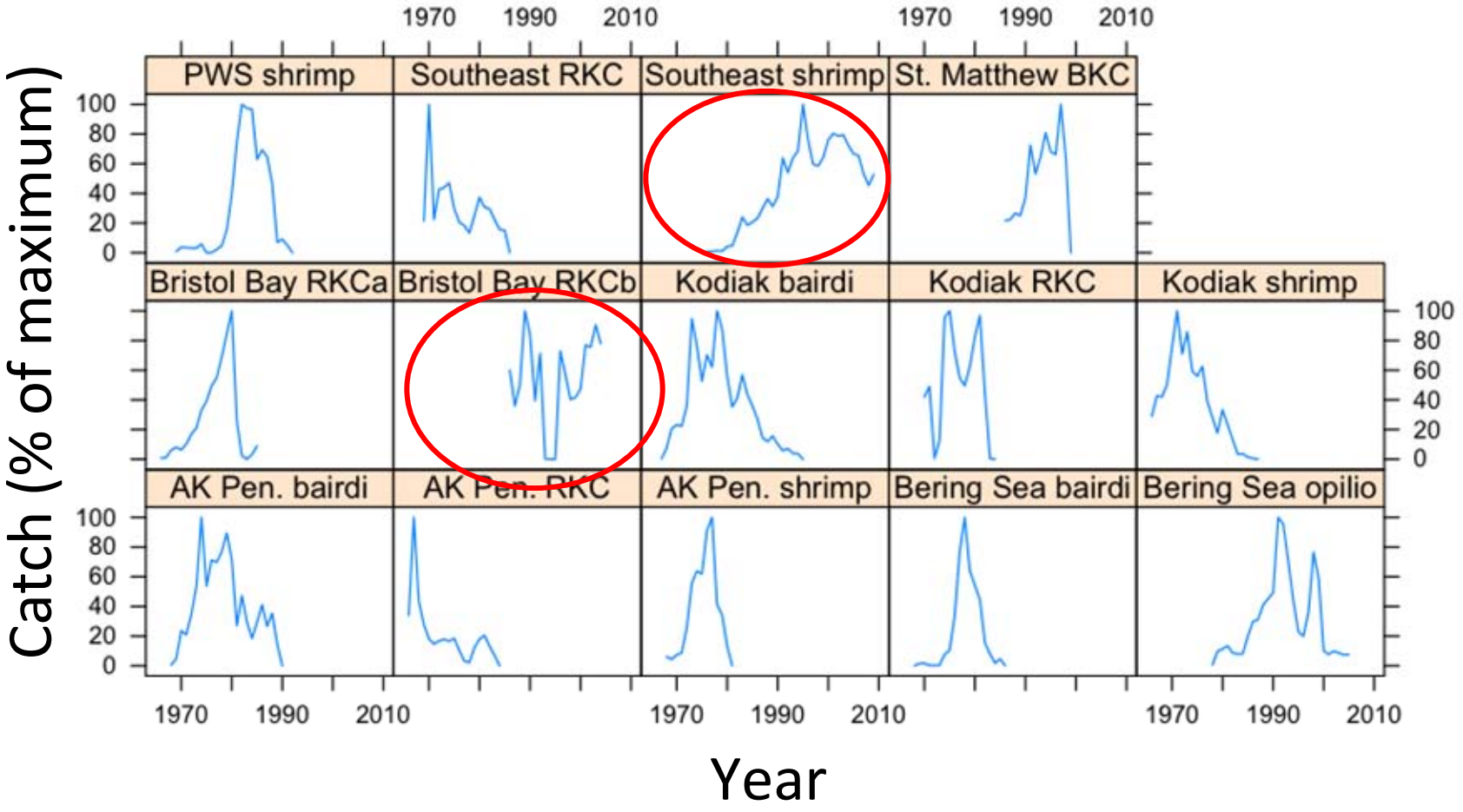
Analysis

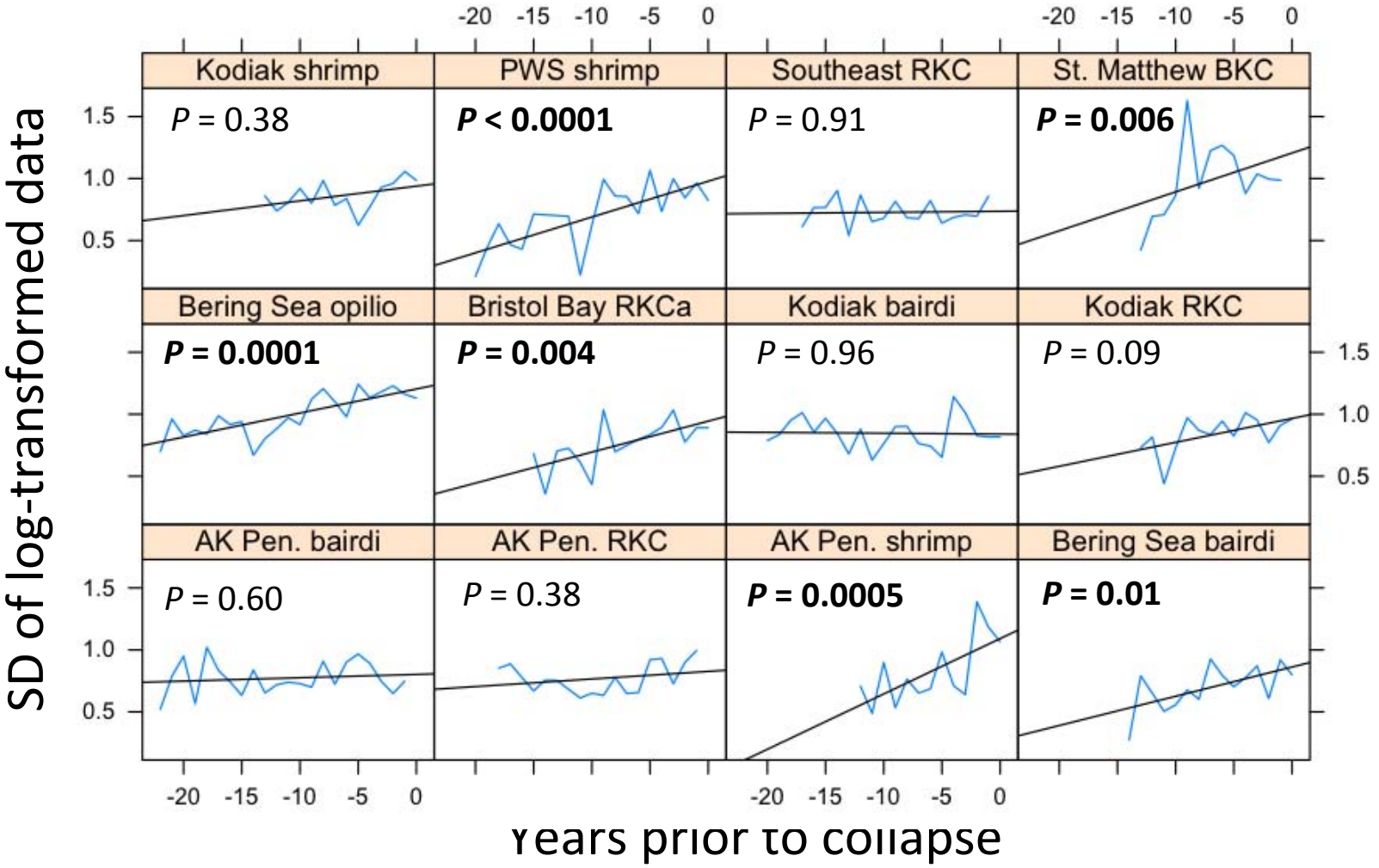
- Identify year of collapse
- For each year prior to collapse, compute variability & skew across statistical areas
- Measure of variability is critical
  - CV sensitive to skewed data
  - Standard deviation of log-transformed data (SDL)
- Examine SDL & skew for pre-collapse trends

Catch time series used in analysis



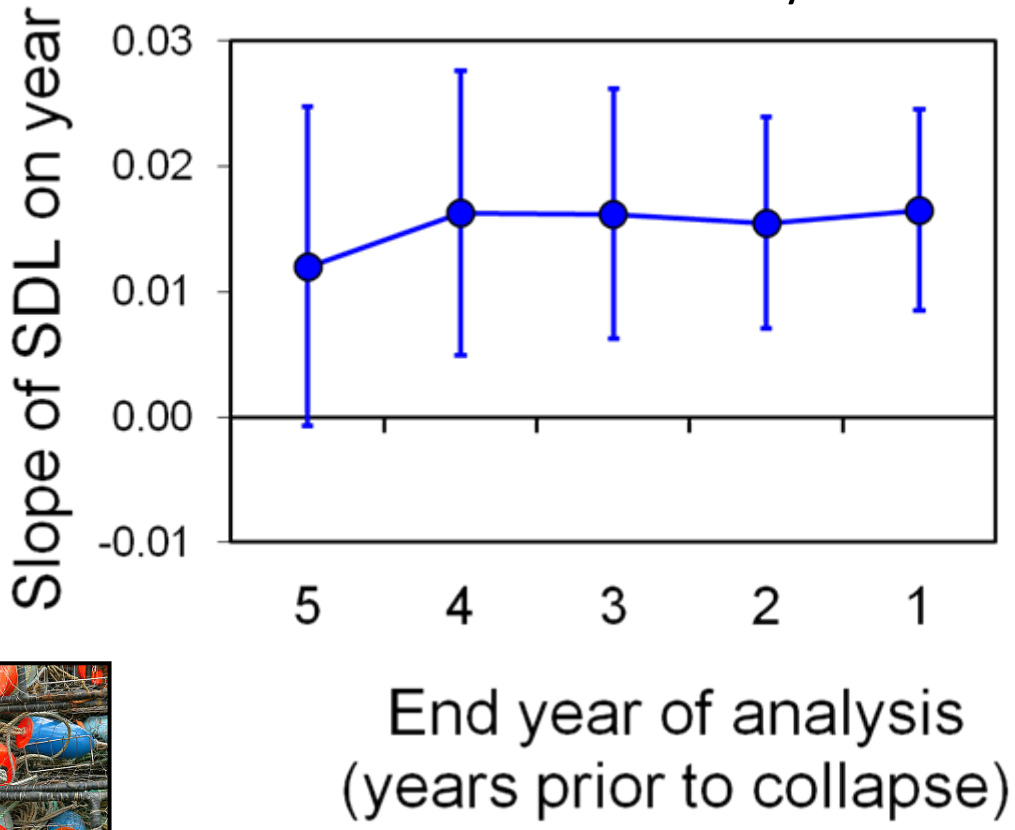
Trends in spatial variability – collapsing fisheries

(overall $P < 0.0001$)

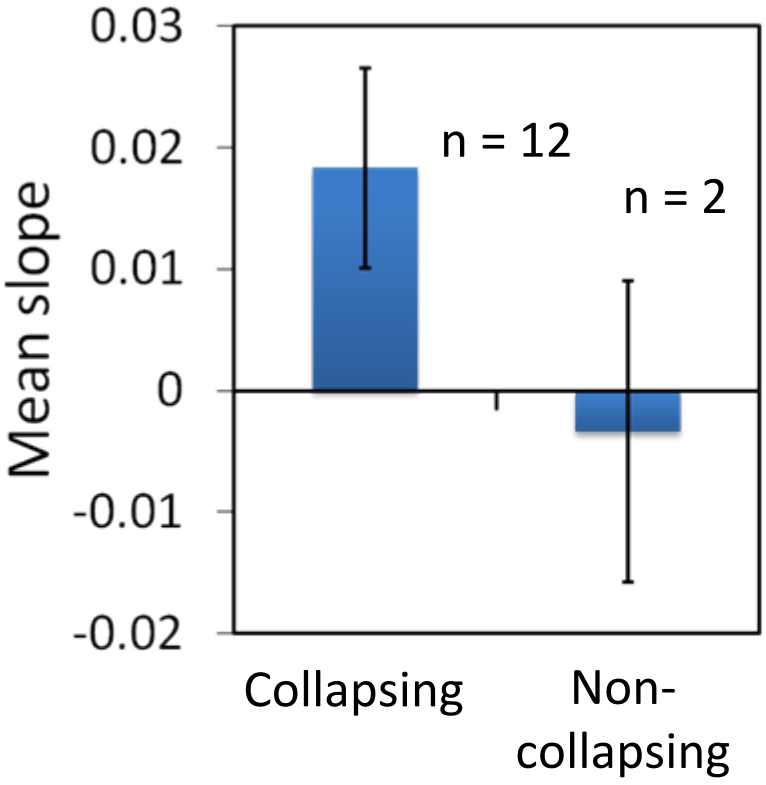


Increase in variability was detected 1-5 years prior to collapse

one-tailed $P \leq 0.03$ in all years

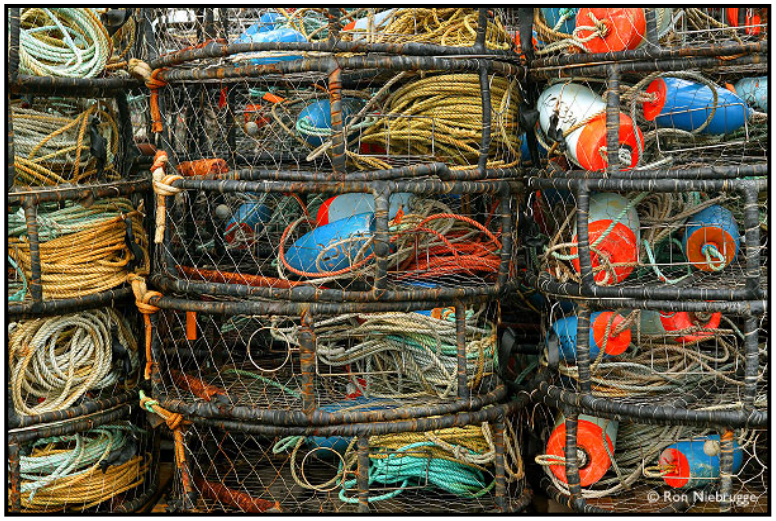


Collapsing and non-collapsing fisheries had different trends in variability



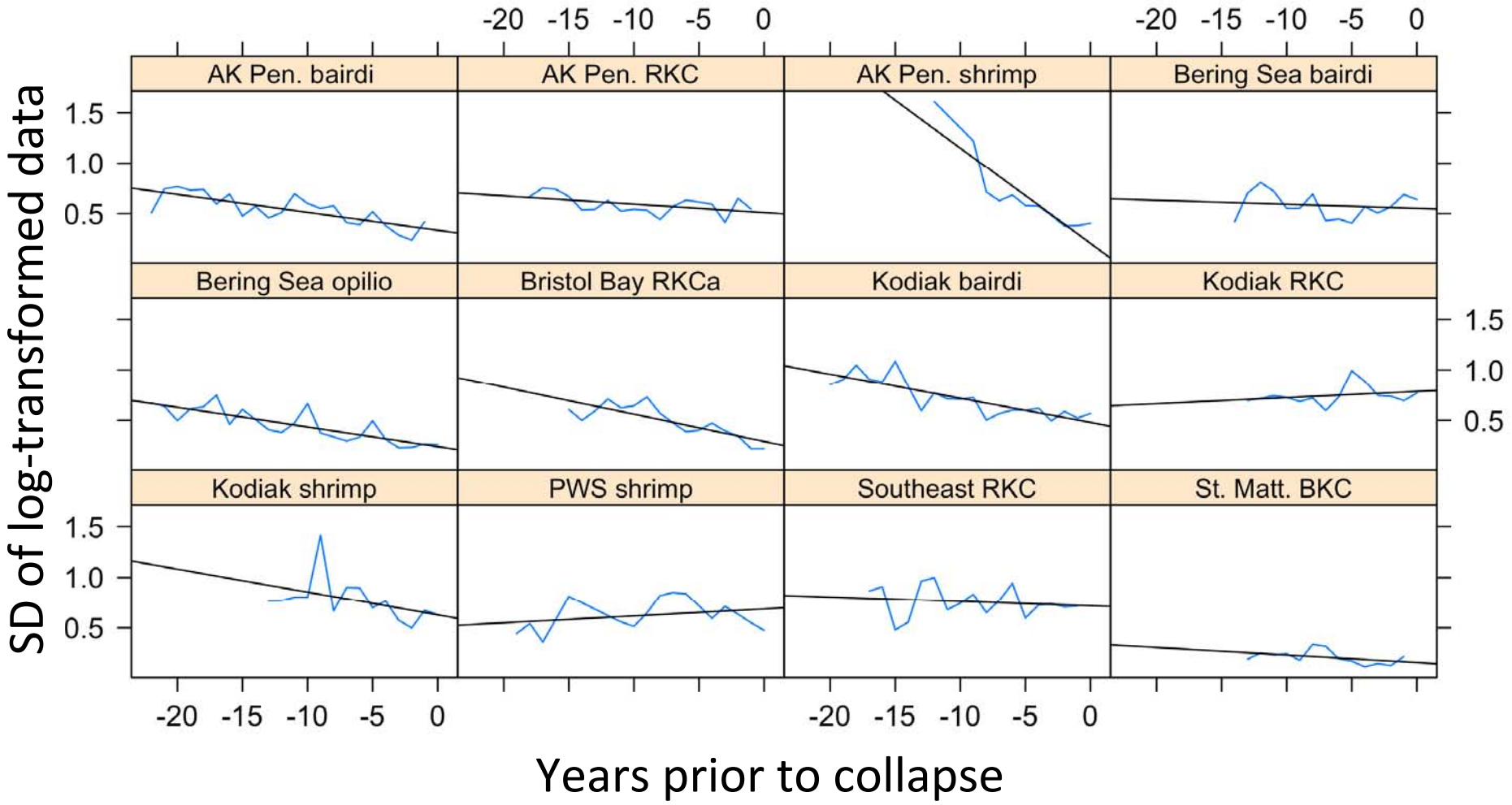
Error bars = 95% CI

One-tailed $P = 0.02$

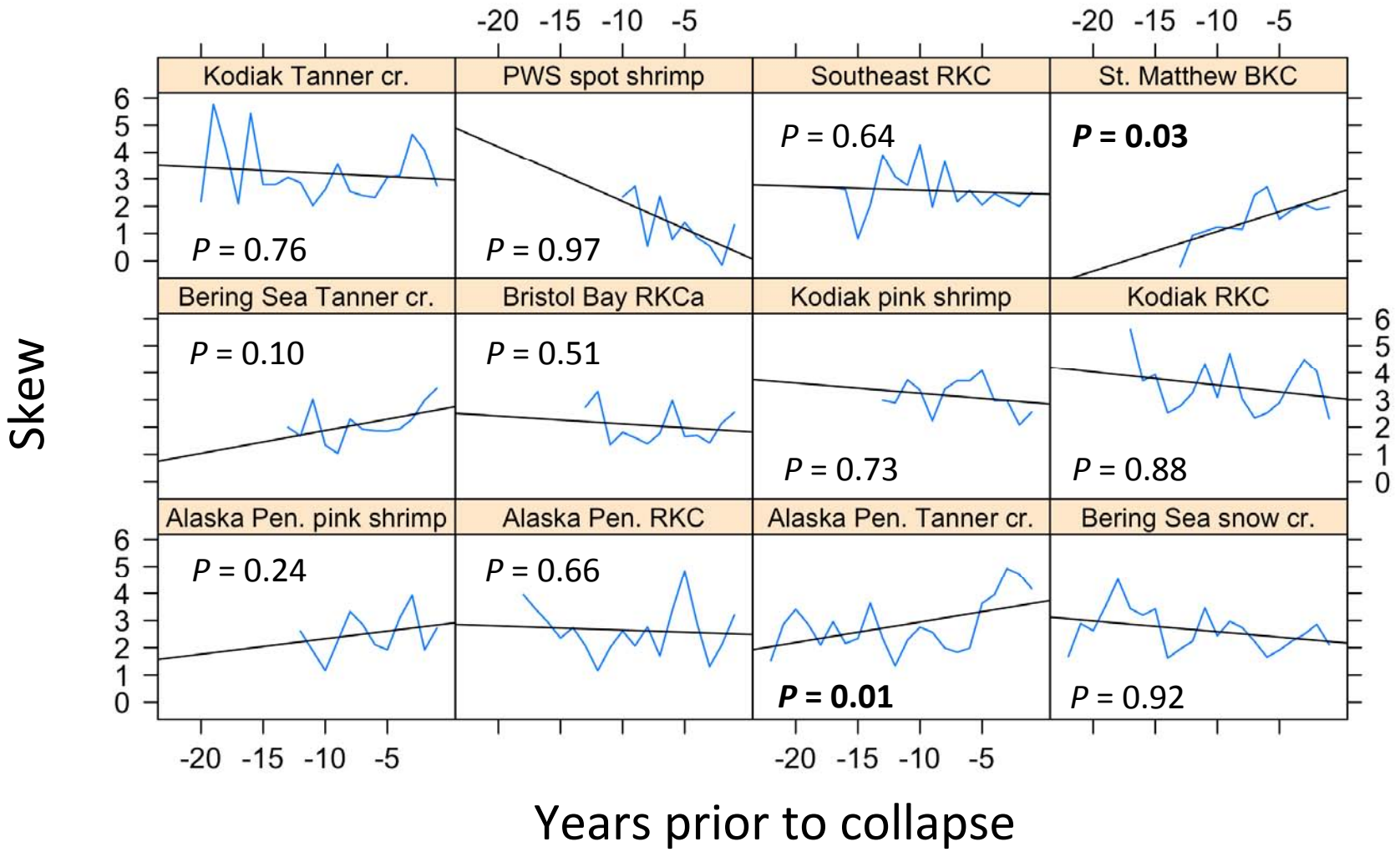


Trends in variability *among vessels*

(overall one-tailed $P = 0.98$)

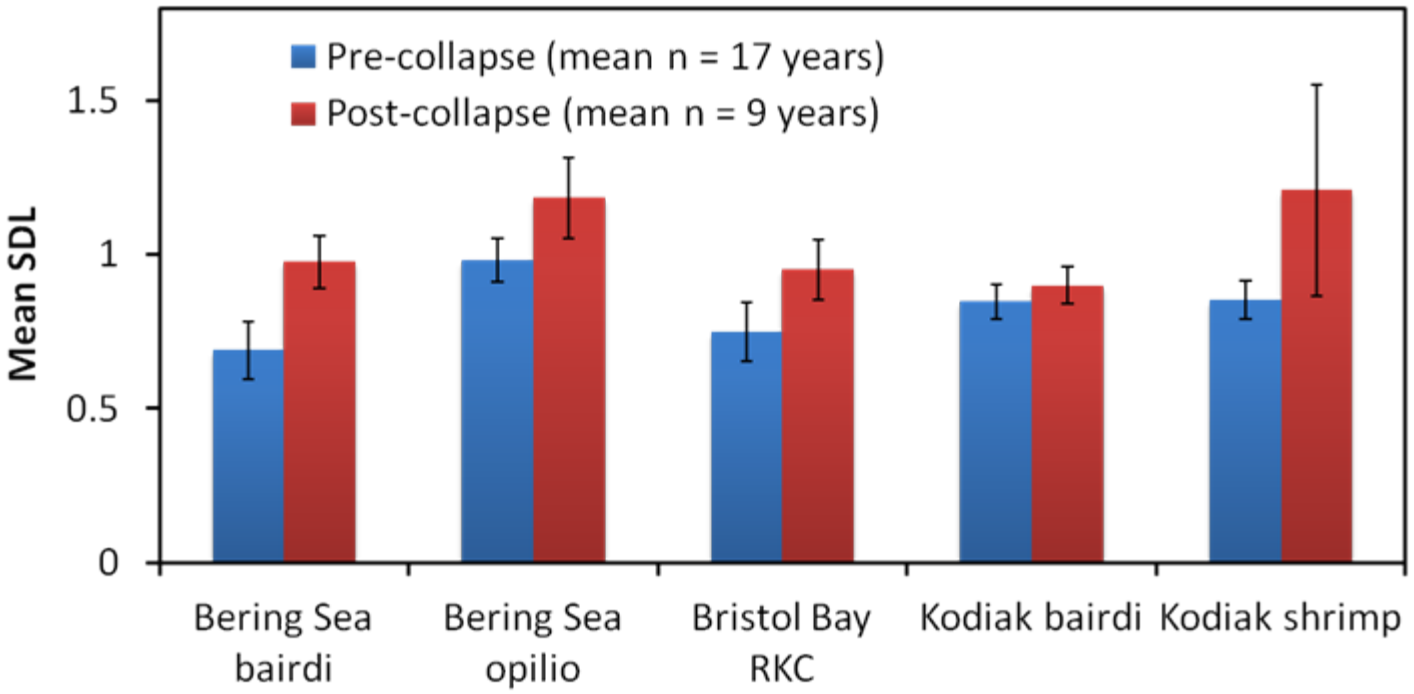


Spatial skew did not increase prior to collapse (overall one-tailed $P = 0.59$)



Increased variability persisted after collapse

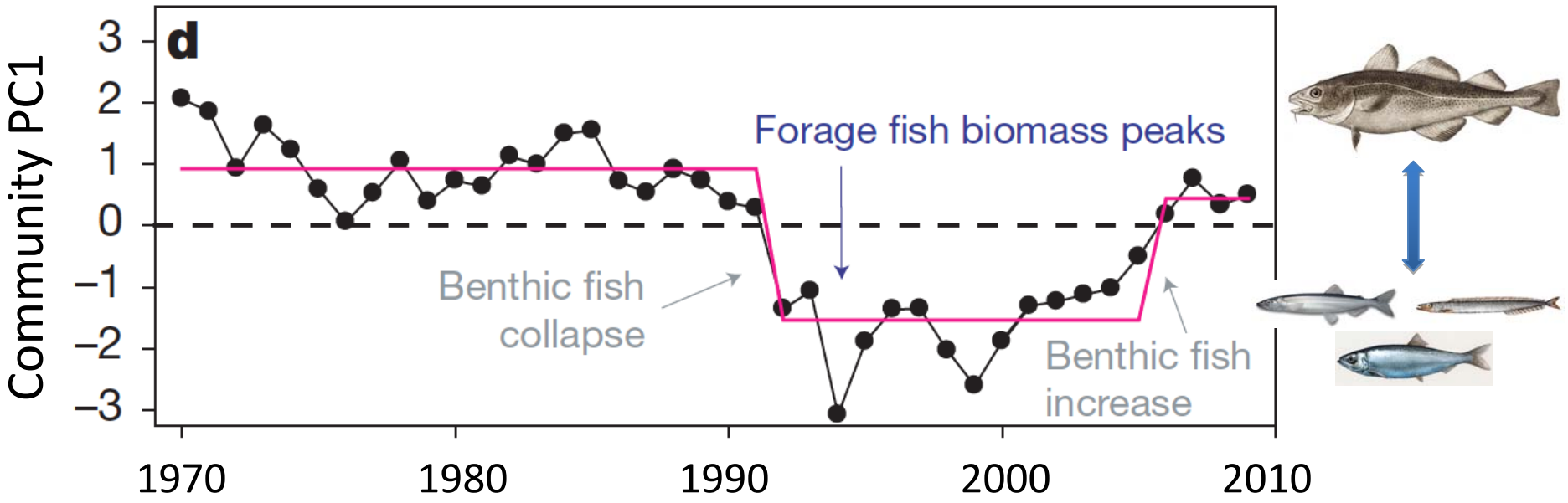
ANOVA, $P < 0.0001$



Error bars = 95% CI

Sudden ecosystem shifts may not involve alternate stable states

Scotian Shelf shift was transient



Frank et al. 2011. Nature.

Sudden ecosystem shifts may not involve alternate stable states

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Contribution to the Theme Section 'Threshold dynamics in marine coastal systems'

OPEN ACCESS

Phase shifts and stable states on coral reefs

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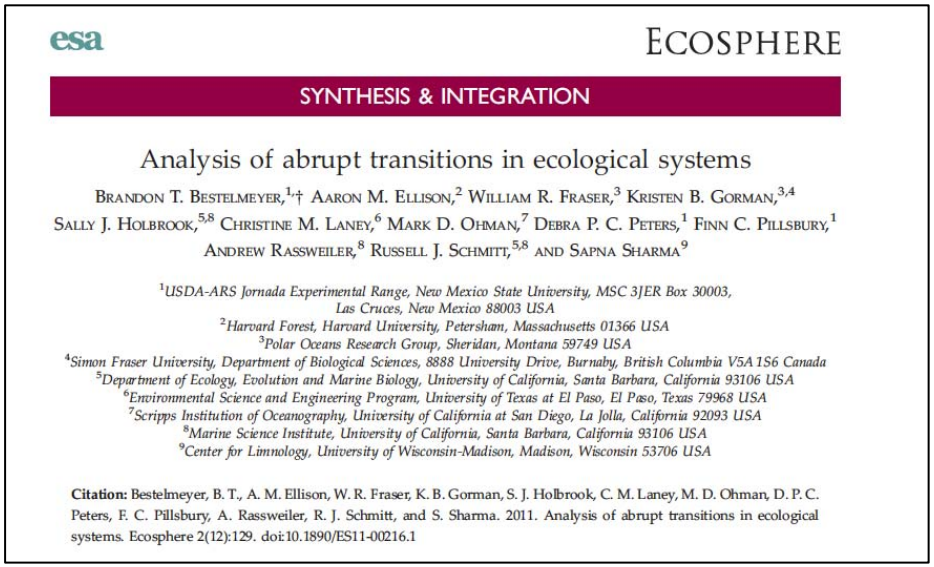
[4]Florida Keys National Marine Sanctuary, NOAA, PO Box 1083, Key Largo, Florida 33037, USA



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ECOSPHERE

SYNTHESIS & INTEGRATION

Analysis of abrupt transitions in ecological systems

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"On tropical reefs, a given environment evidently supports at most a single stable community."

"...the response (krill abundance) linearly tracked abrupt changes in the driver (Pacific Decadal Oscillation)..."

Rising variance was a useful indicator, but…

- For Managers: Our study supports the use of rising variance as an indicator of impending collapse
- For Ecologists: Failure to support some predictions casts doubt on general applicability of regime shift models
- For Everyone: The theory is useful, but requires empirical validation!

Acknowledgements

Data provided by the Alaska Department of Fish and Game, with help from Paul Converse, Kim Phillips and Gail Smith. Funding provided by Alaska Sea Grant College Program with funds from the NOAA office of Sea Grant, with additional support from the University of Tasmania and PICES.