



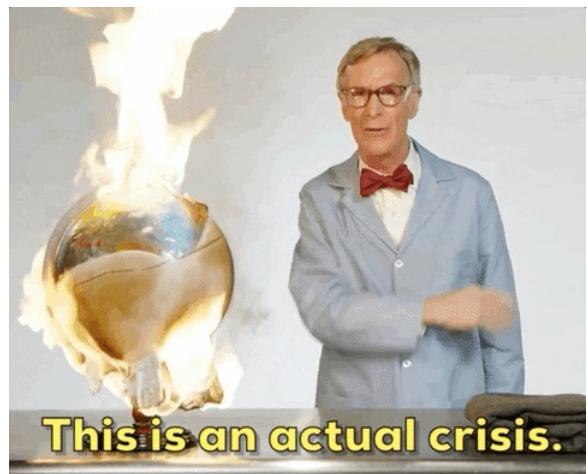
Regime Detection Methods for the Practical Ecologist

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Anthropogenic Activity is Changing the World



This is an actual crisis.



Humans Influence Regime Shifts, Impacting Ecological & Social Systems



Can we foresee & perhaps avoid undesirable change?

Ecological Regime Shifts

what? a persistent change in the structure or functioning of a system

how? loss of negative feedback(s) maintaining the system

goal? predict in time to prevent

Regime Shift Example: Coral Reef Bleaching



- Ecotourism
- Fisheries
- Storm Protection

Regime Shift Example: Coral Reef Bleaching



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- Fisheries
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Regime Shifts Example: Coral Reef Bleaching



Shifts easier to predict, avoid when thresholds known

- Water temps
- Acidification
- Algae loss

Problem: Ecosystems are Complex

- high dimensional
- many (∞) interactions
- dynamic (time dependence)
- non-linear
- non-ergodic (open)

Especially difficult when drivers are unknown in a high dimensional system

Research Question Motivating this Research

Can we detect & predict ecological regime shifts in under-described systems?

Dissertation Aims

Improve the utility and accessibility of regime shift detection methods for the practical ecologist

Dissertation Themes & Outline

Theme 1: Synthesize and review methods and literature

- **Chapter 1 & 8:** Introduction to and Synthesis of the State of Regime Detection Measures
- **Chapter 2:** A Brief Overview of the Ecological Regime Detection Methods

Theme 2: Test the utility and efficacy of methods

- **Chapter 4:** Spatial application of Fisher Information
- **Chapter 5:** Proposed method: velocity (v) of system trajectory
- **Chapter 6:** Relative performance of methods using resampling
- **Chapter 7:** Body mass distributions application

Theme 3: Improve method accessibility

- **Chapter 3:** Deconstructing Fisher Information calculation

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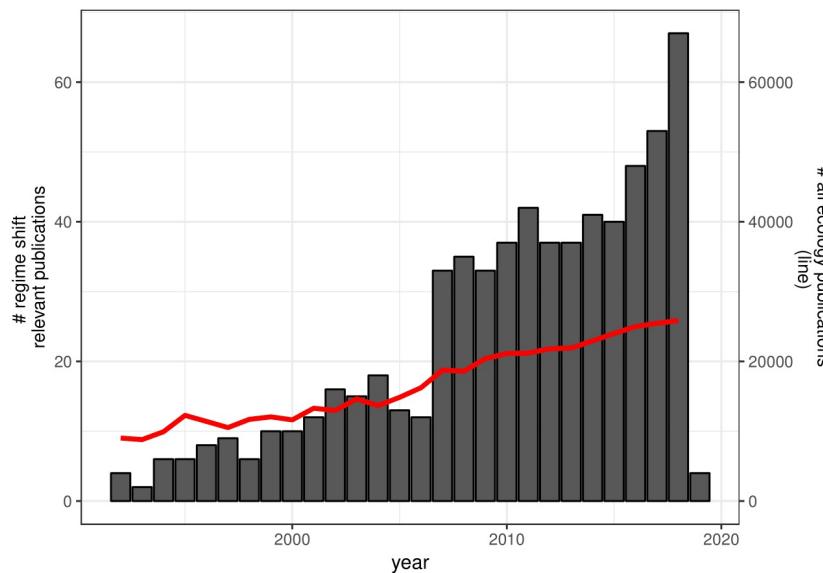
Theme 2: Test the utility and efficacy of methods

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Theme 3: Improve method accessibility

- **Chapter 3:** Deconstructing Fisher Information calculation
- **Appendix A:** bbsAssistant. Download and manipulate Breeding Bird Survey data
- **Appendix B:** regimeDetectionMeasures. Calculate multiple regime detection measures
- **Appendix C:** bbsRDM. Spatial application of regimeDetectionMeasures

Chapter 2: Systematic Literature Reviews



Topic = regime, abrupt, catastrophic shifts | **Field** = ecology, biodiversity conservation

Chapter 2: Systematic Literature Reviews

Problem

- Applications outpacing theoretical advancement
- No comprehensive reviews or sources of methods
- Methods applied before statistically scrutinized

Aims

- Identify research themes and gaps
- Comprehensive source for all methods

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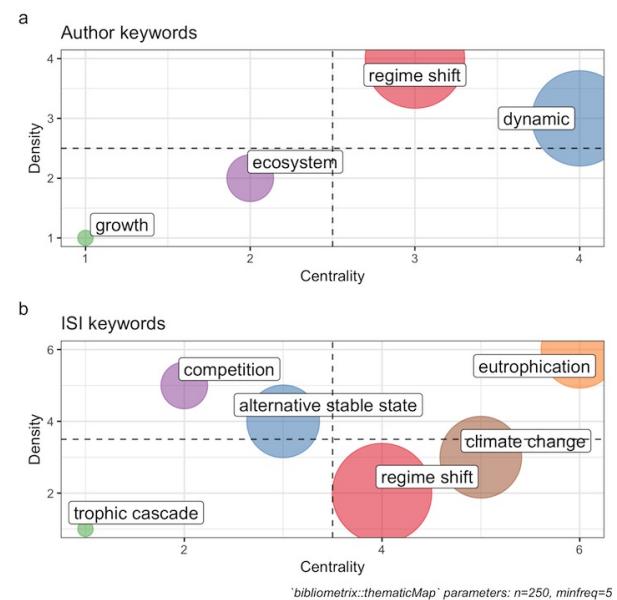
Approach

- Bibliographic analysis
- Systematic literature reviews

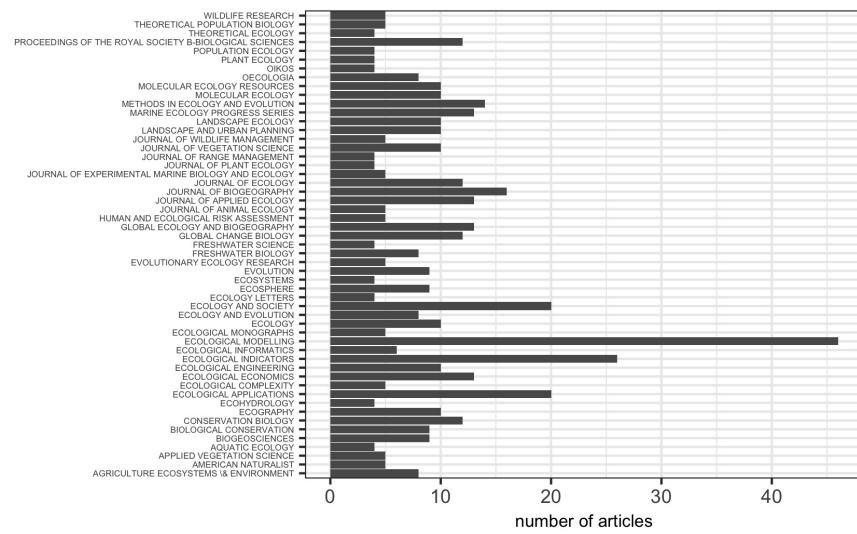
Bibliographic Analysis to Identify Themes in Ecological Regime Shift Development

X axis: importance to field

Y axis:
less to more developed



Regime Detection Methods Difficult to Find Using Typical Literature Reviews



- A few things contributed to my inability to build this list using typical lit search methods:
 1. Jargon is inconsistent
 2. Methods are not often first proposed in either methods journals, nor proposed using theoretical data
 - rather, they are applied using empirical data, and put into more 'applied journals'

Regime Detection Methods for Individual State Variables are Well-Tested

Univariate Methods

- Autoregressive coefficient (lag-1)
- Standard deviation
- Skewness
- Kurtosis
- Coefficeint of Variation

Best Conditions

- Critical slowing down
- Few state variables (e.g. species)

Regime Detection Methods for Individual State Variables are Well-Tested... But Inconsistent

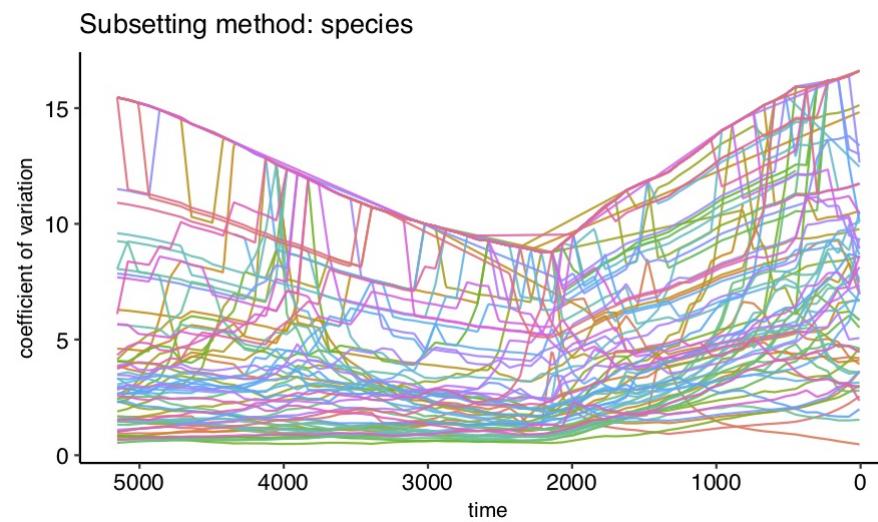


Ecological Applications, 22(6), 2012, pp. 1772–1779
© 2012 by the Ecological Society of America

Regime shift indicators fail under noise levels commonly observed
in ecological systems

CHARLES T. PERRETTI^{1,3} AND STEPHAN B. MUNCH²

Regime Detection Methods for Individual State Variables are Well-Tested... **Difficult to Use in High Dimensions**



Composite (Multivariate) Methods for Detecting Regime Shifts

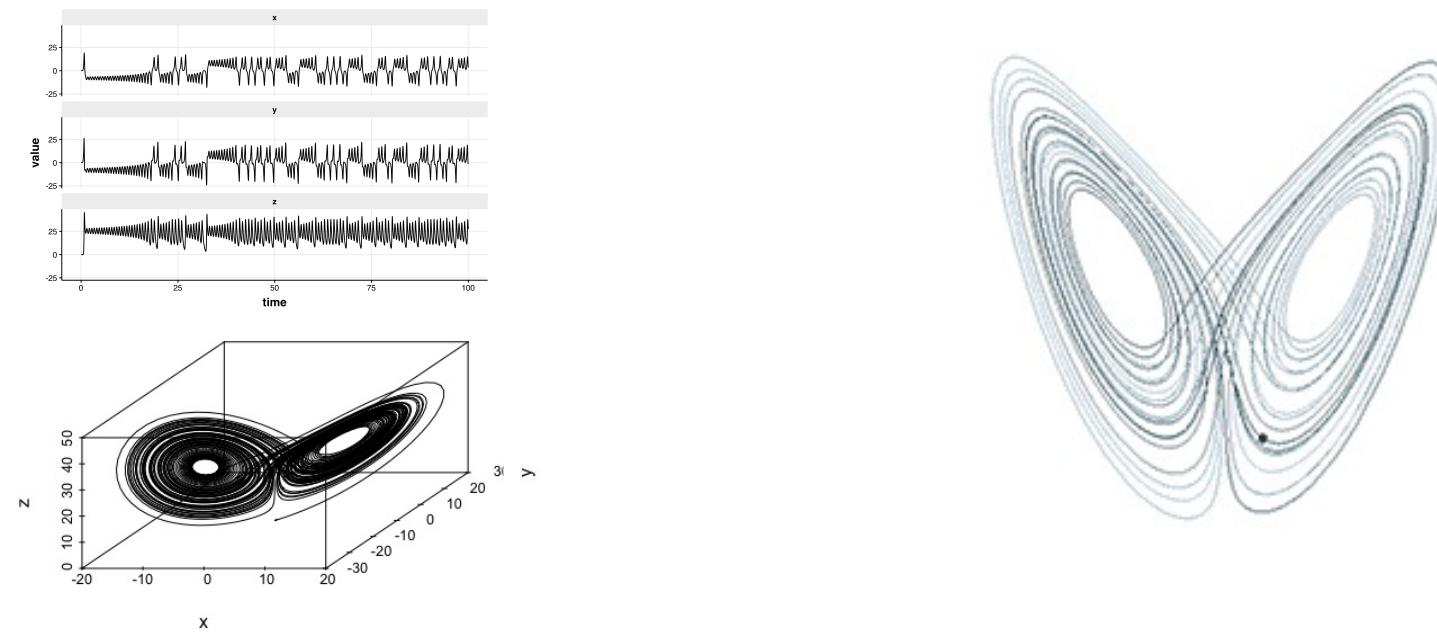
- Variance Index
- Ordination
- Clustering algorithms
- **Fisher Information**
 - Noisy data
 - n-Dimensions

Chapter 3: Demystifying Fisher Information

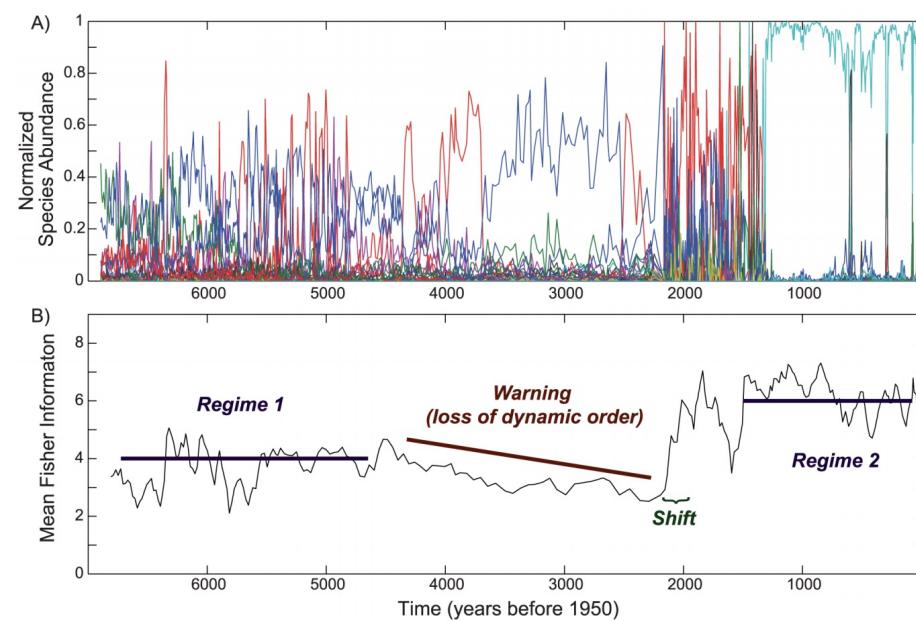
- 1) Clarify the calculation steps of Fisher Information
- 2) Highlight its reliance on **Euclidean distance**
- 3) Demonstrate the utility of velocity of the **Euclidean distance**
- 4) **Velocity of system trajectories as a "new" composite regime detection metric**
(Chapter 5)

[1] Burnett, JL, NB Price, AJ Tyre, DG Angeler, T Eason, D Twidwell, and CR Allen. Deconstructing the steps for calculating Fisher Information as a measure of abrupt change in ecological systems. *in review at Ecological Modelling*

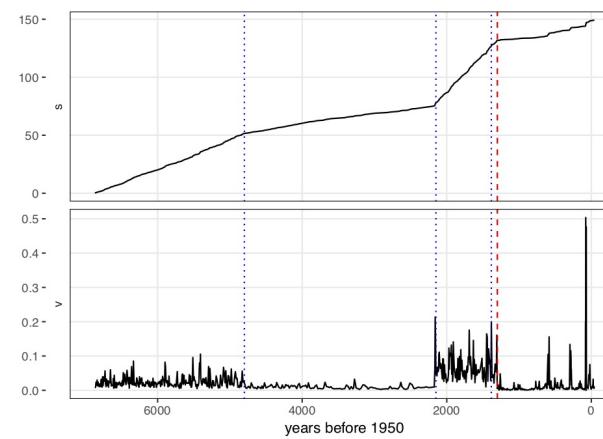
Reconstructing Trajectories of Multivariable Systems in Phase Space



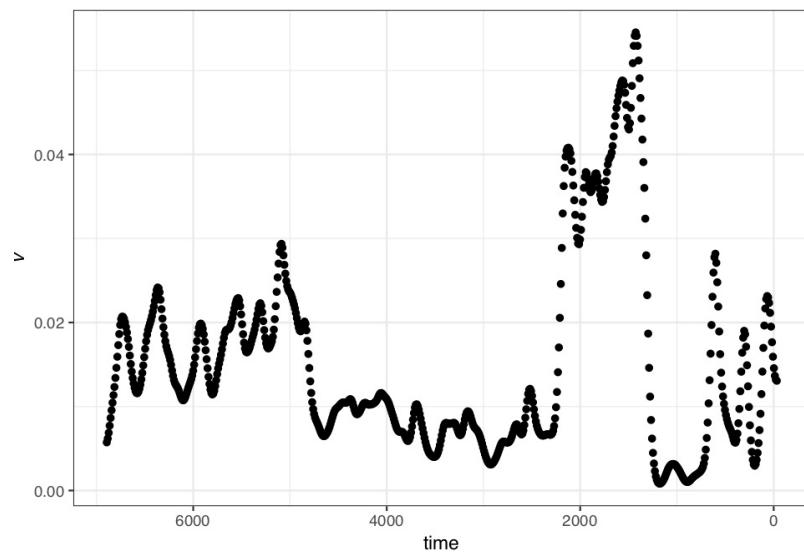
Chapter 5: Using Velocity of System Trajectory in Phase Space



Chapter 5: Using Velocity of System Trajectory in Phase Space



Smoothing May Improve Velocity

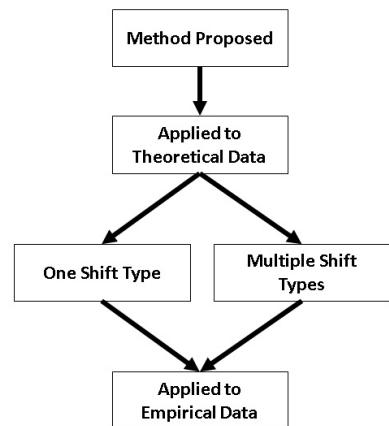


Next Steps:

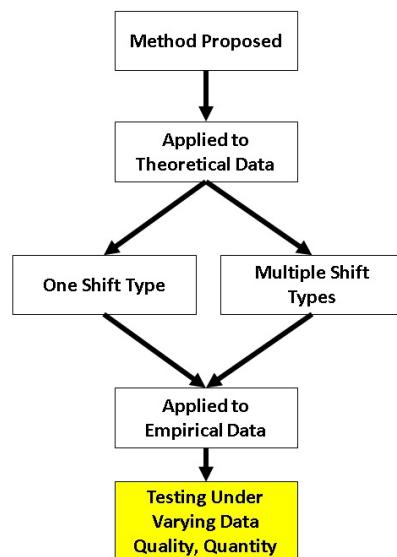
- Statistical identification of change point in velocity
- Compare Euclidean to other distance-based metrics
- Compare to ordination techniques
- Compare to other smoothing techniques (e.g. TVDiff¹, Generalized Additive Models)

[1] Price, NB, JL Burnett. `tvdiff`. An R package for numerical differentiation of noisy, nonsmooth data. github.com/natbprice/tvdiff

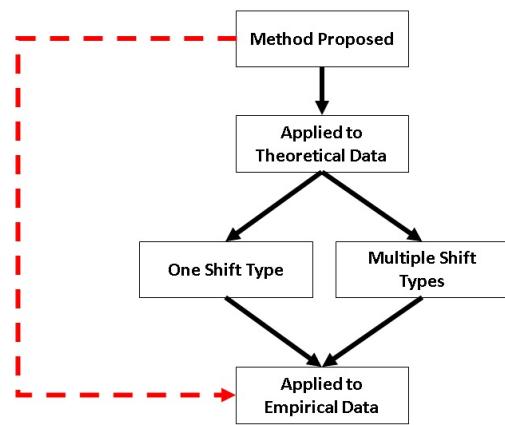
Methods Evolution: Multiple Paths Taken



Methods Evolution: Multiple Paths Taken



Rigorous Testing of the Methods Required to Ensure Efficacious Methods

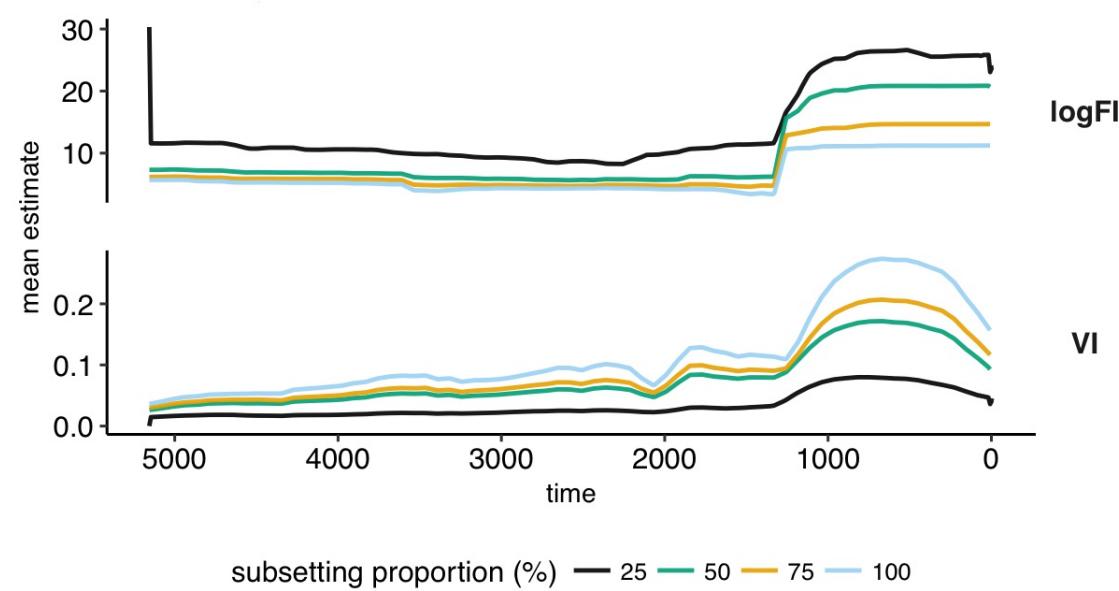


Chapter 6: Identify Impact of Data Quality & Quantity on Methods

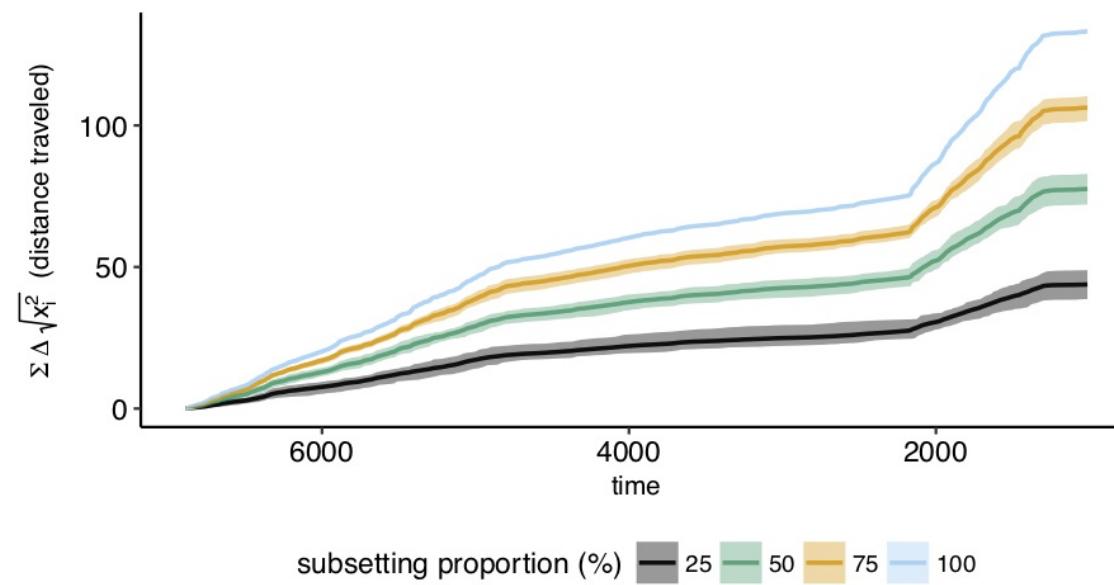
Data quality issues

- Common/dominant species
- Infrequent sampling
- Irregular sampling
- Undetected species

Fisher Information & Variance Index Sensitivity to Randomly Removing Species



Velocity is Robust to Random Removal of Observations



Chapters 5 & 6

Summary

- Simple calculation, relative to other regime detection methods
- Handles noisy and sparse data
- Less sensitive to data quality issues common in ecology
- Velocity is best when mean > variance

Next Steps

- Numerical identification of exact change points
- Compare to distance-based metrics
- Compare to ordination techniques
- Identify out-of-sample predictive capacity

Prediction is ~The~ Holy Grail of Ecology

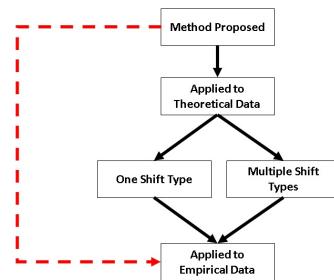


Applications Exceed Regime Shift Theory and Method Efficacy

- Too many methods proposed
- Few rigorously tested
- Still no generalizable methods
- Some methods sensitive to data quality/quantity
 - but velocity appears robust
- Divergence of regime shift theory from dynamical systems theory

Remaining Questions & Future Work for Advancing Ecological Regime Shift Methods

- Does the method assume **smooth potential?**¹
- Types of shifts detected
- Sensitivity to:
 - data quality & quantity
 - process lags



[1] Hastings and Wysham (2010) Regime shifts in ecological systems can occur with no warning. Ecology Letters

Software Associated with this Research Program

- **distanceTravelled** calculate velocity
- **regimeDetectionMeasures** calculate various metrics spatial
- **bbsRDM** application BBS data program
- **bbsAssistant**

Acknowledgements

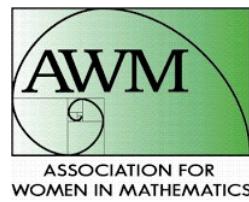
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[1] thanks for the free racquetball coaching services!

[2] Unaccredited Dogtoral Degree in personnel management and security services

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- Thanks to the participatory scientists of the North American Breeding Bird Survey
- Paleodiatom data
 - Spanbauer et al. (2014) Plos One
 - Stevens and Fritz (2006) Quaternary Research

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