



Regime Detection Methods for the Practical Ecologist

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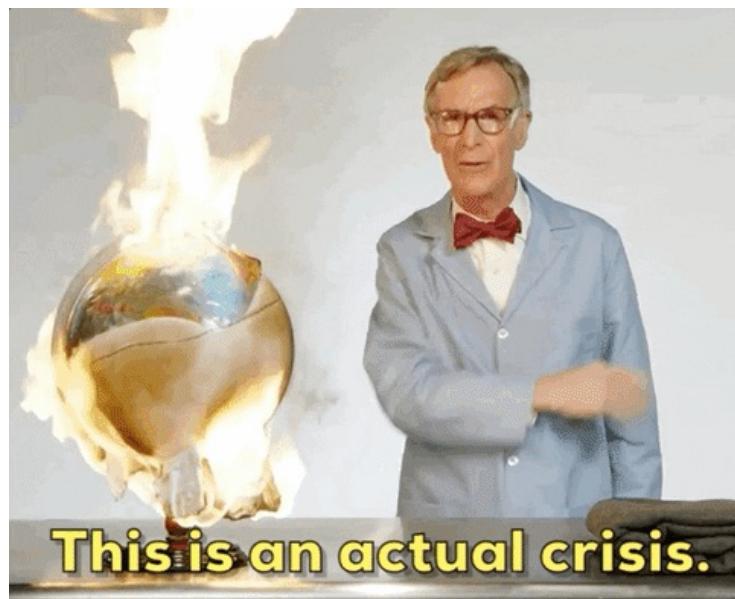
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Anthropogenic Activity is Changing the World



This is an actual crisis.

We are Inducing Ecological and Social-Ecological Changes



Can we foresee undesirable

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? detect or predict in time to prevent or mitigate

Regime Shift Example: Coral Reef Bleaching



- Ecotourism
- Fisheries
- Storm Protection

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When Threshold, Dynamics Known, Shifts 'Easier' To Predict



Shifts easier to foresee when thresholds known

- Water temps
- Acidification
- Algae loss

Most Ecosystems Not Well-Understood

- Predicting regime shifts difficult
- Ecosystems are complex
 - high dimensional
 - many (∞) interactions
 - dynamic (time dependence)
 - non-linear
 - non-ergodic (open)

Research Question Motivating this Research

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

Dissertation Aims

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

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
- **Appendix A:** bbsAssistant. Download and manipulate Breeding Bird Survey data

Dissertation Themes & Outline

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Chapter 2: Systematic Reviews of the Ecological Regime Shift Literature and Methods

Motivation

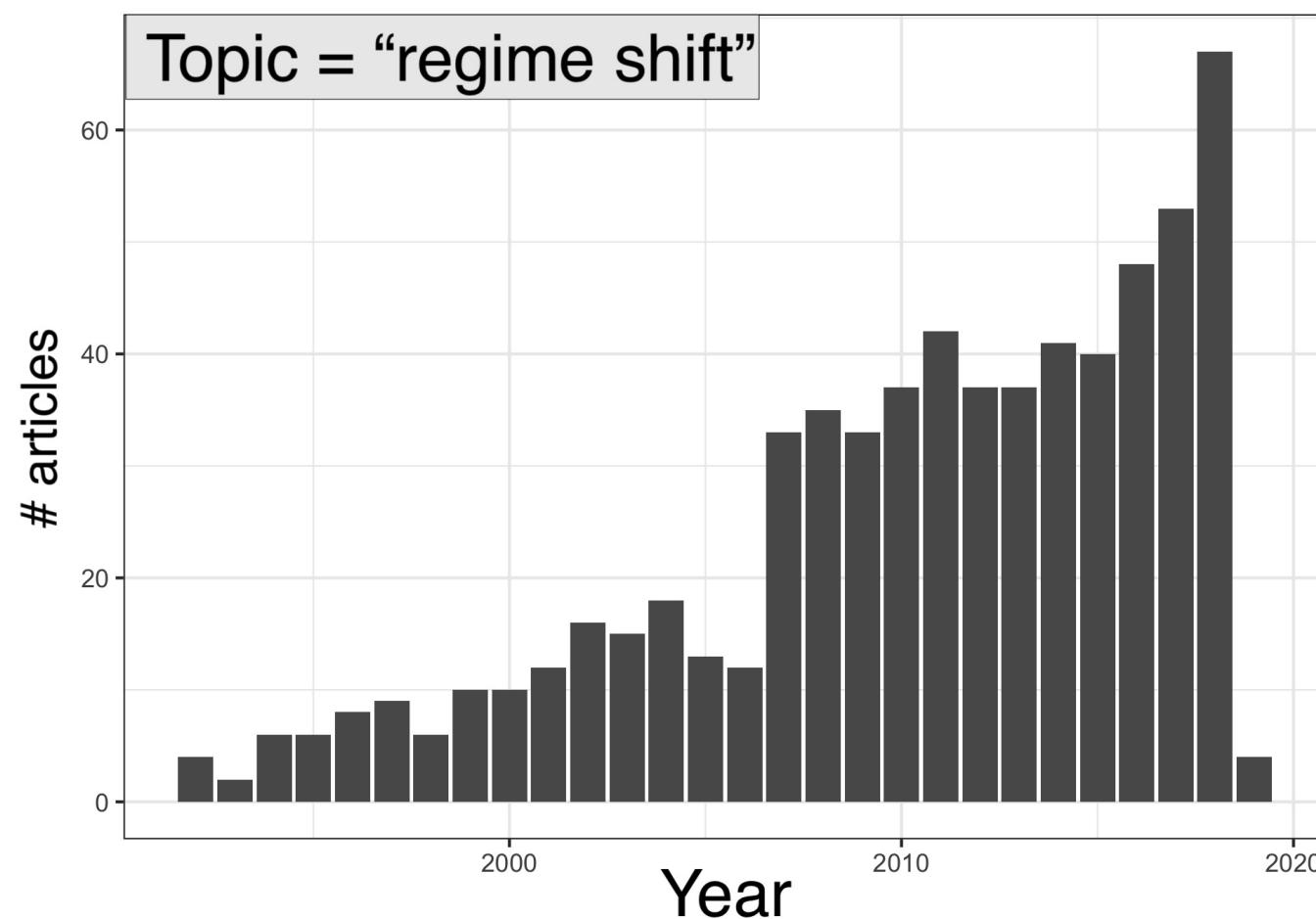
- Lack of use of concepts by practitioners
- No comprehensive source for methodologies

Approach

- Bibliographic analysis to identify themes in literature
- Build a comprehensive resource of methods

Rapid Growth in Regime Shift Literature

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

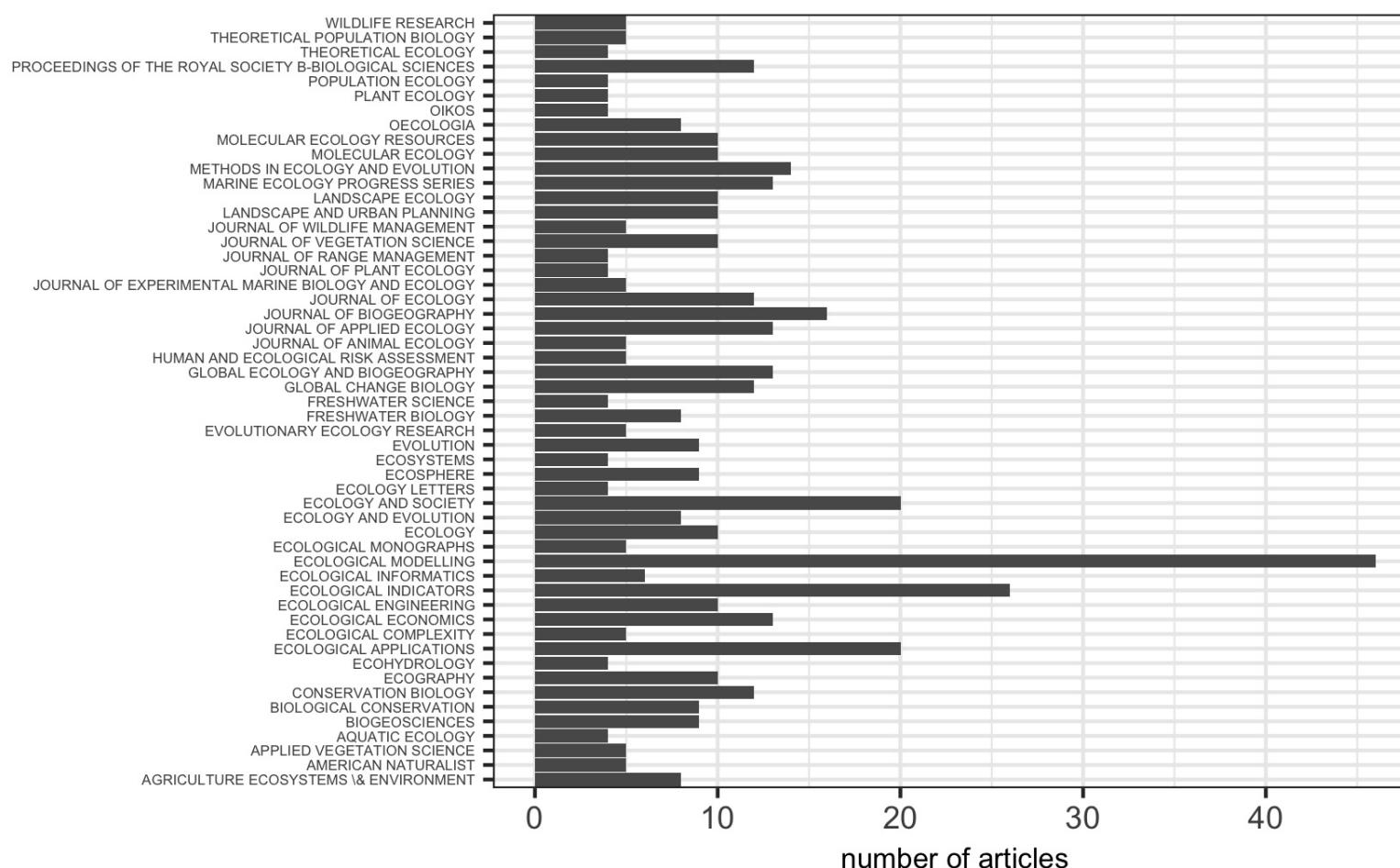


Many Methods, Not All Are Accessible Via Literature Review

- Systematic review **and** prior knowledge
 - 70+ methods
 - < $\frac{1}{2}$ identified in systematic review
- Method review papers exist
 - None are comprehensive
 - Most comprehensive are out of date
 - High overlap in methods covered

Methods Emphasize Results and Not Method Efficacy

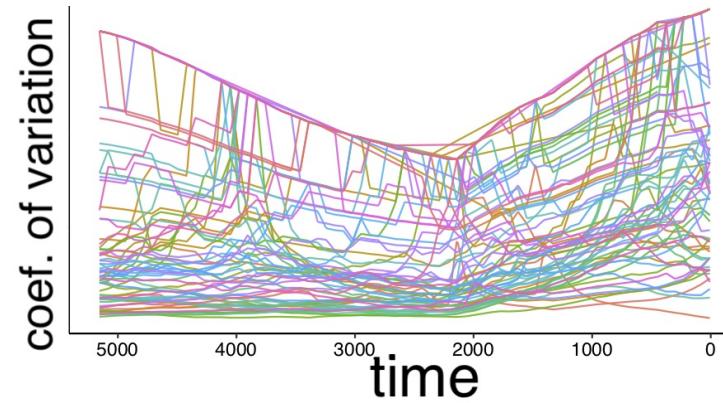
Methods Not Concentrated in Methodological Journals



Regime Detection Methods for Individual State Variables are Well-Tested

Univariate Methods

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



Performance of the Most Widely-Used Univariate Methods is Inconsistent

Journal of Applied Ecology 2016, **53**, 666–676

doi: 10.1111/1365-2664.12519

QUANTIFYING RESILIENCE

Do early warning indicators consistently predict nonlinear change in long-term ecological data?

Ecology Letters, (2010) **13**: 464–472

doi: 10.1111/j.1461-0248.2010.01439.x

LETTER

Regime shifts in ecological systems can occur with no warning

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

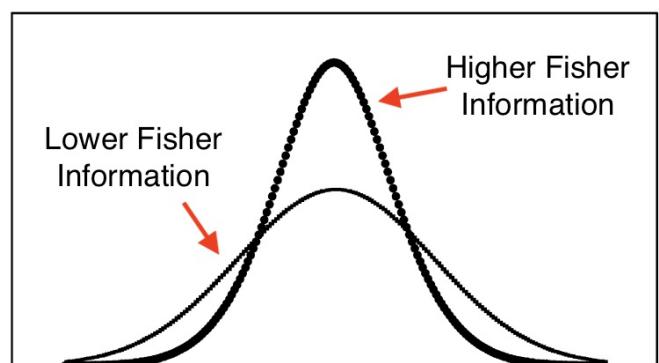
Regime shift indicators fail under noise levels commonly observed in ecological systems

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

Composite Methods Proposed for Handling High-Dimensional Data

- Variance Index
- Ordination
- Clustering algorithms
- **Fisher Information**

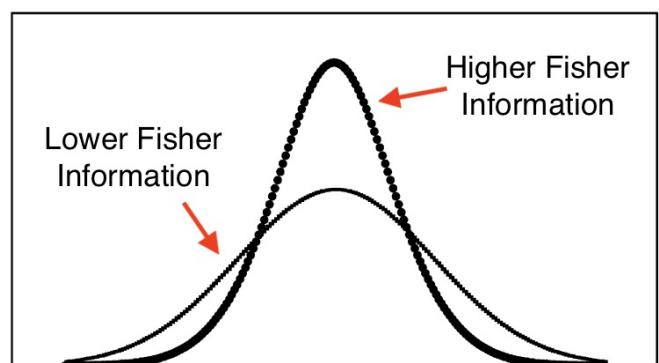
Fisher Information Proposed as a Multivariate Regime Shift Detection Method



- Noisy data
- Irregularly sampled data
- Infinite # of variables

Figure adapted from Cabezas and Fath (2002) *Fluid Phase Equilibria*

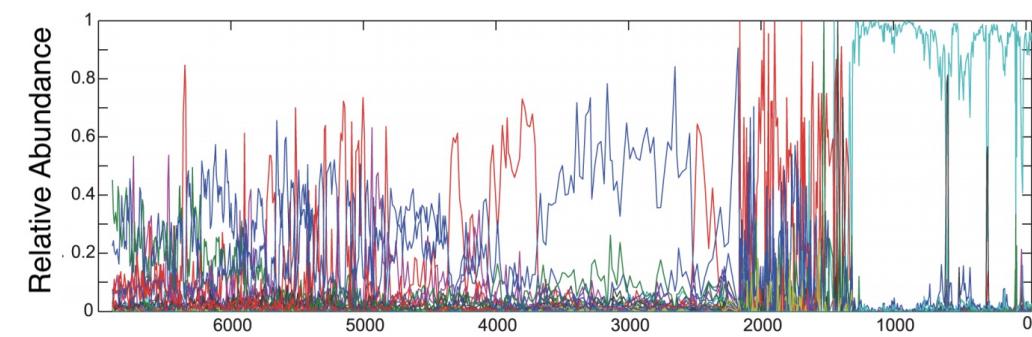
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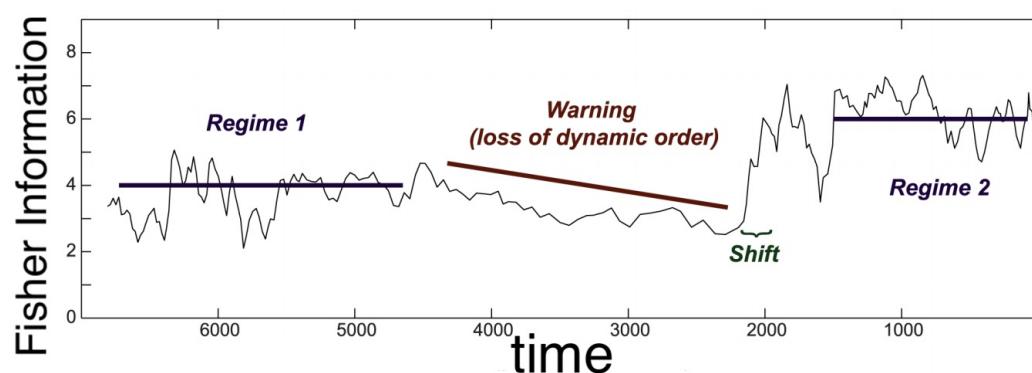
- Noisy data
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- **Infinite # of variables**

Figure adapted from Cabezas and Fath (2002) *Fluid Phase Equilibria*

Chapter 3: Deconstructing the Steps for Calculating Fisher Information



1) Dimension Reduction

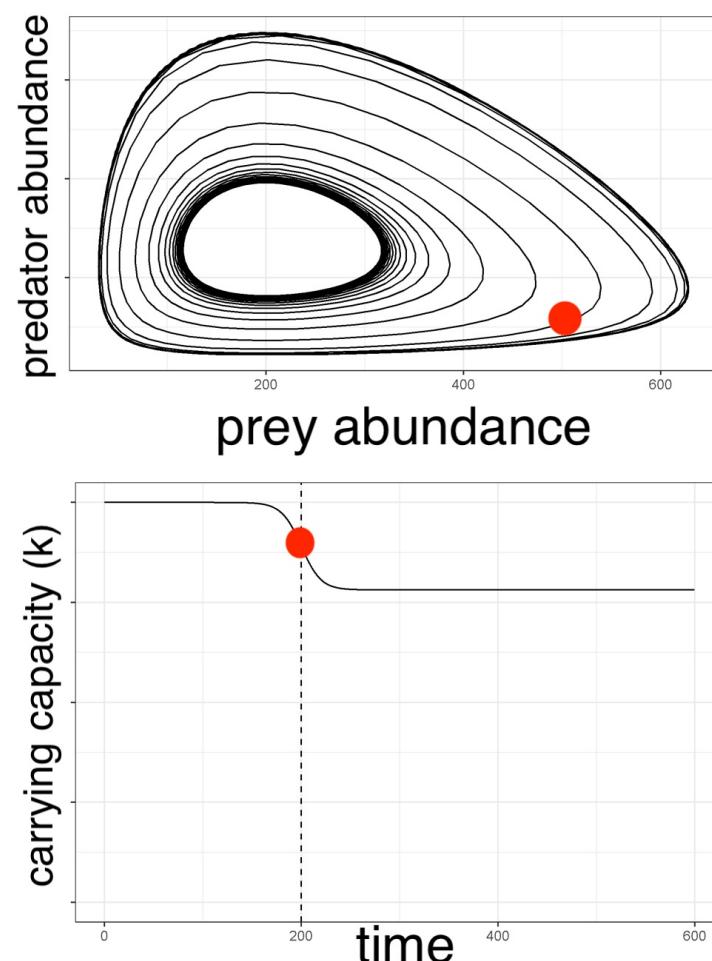


2) Rate of change

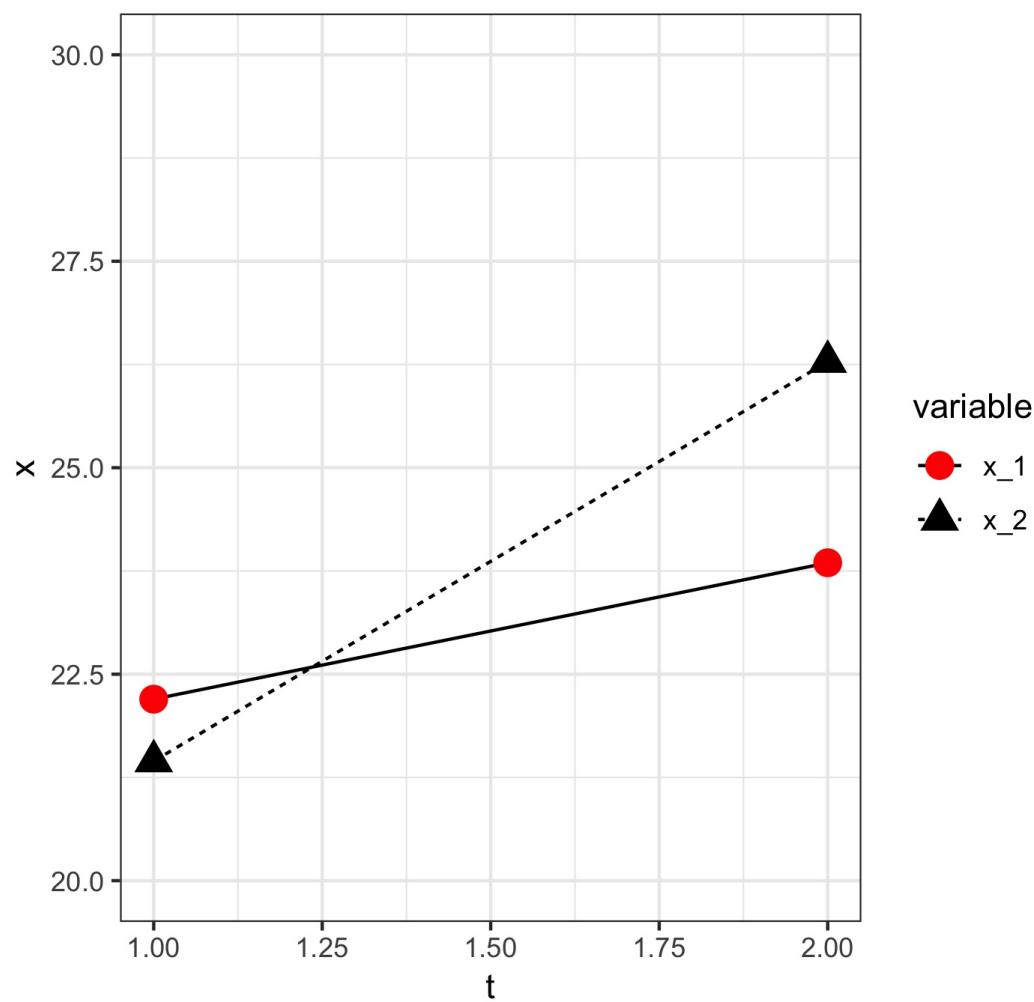
3) Fisher Information

Chapter 3: Aims and Approach

- Conceptually and numerically outline the calculation
- Highlight **dimension reduction** as a distinct step
- Using a 2-species predator-prey model
 - Shift in carrying capacity, K

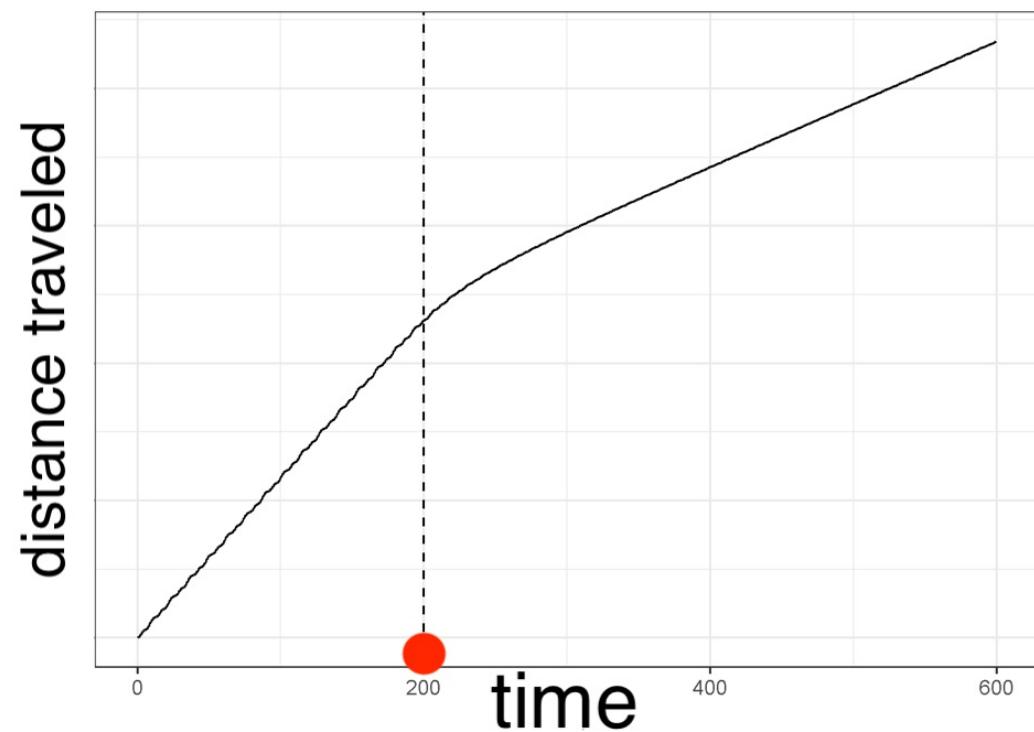


Step 1a: Dimension Reduction Using Euclidean Distance



- Euclidean distance
 - all variables
 - between time points

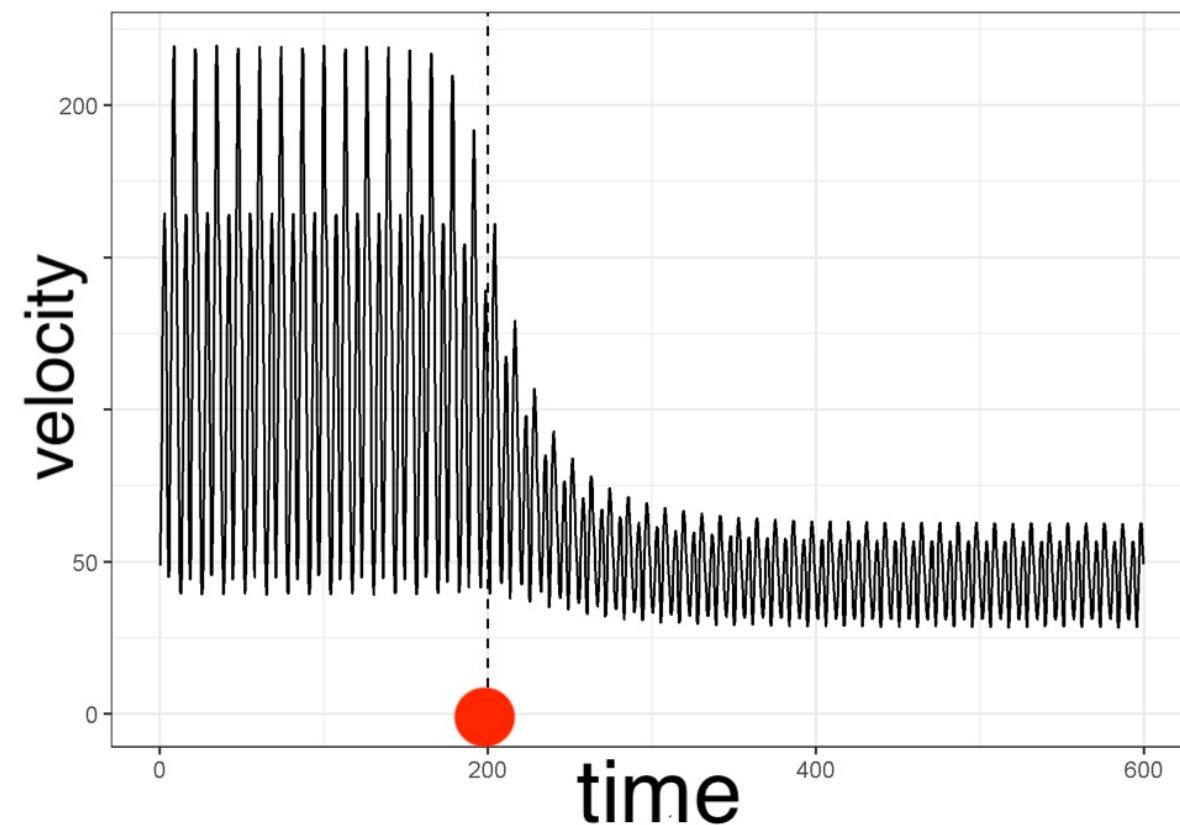
Step 1b: Calculate Distance Travelled Along Trajectory



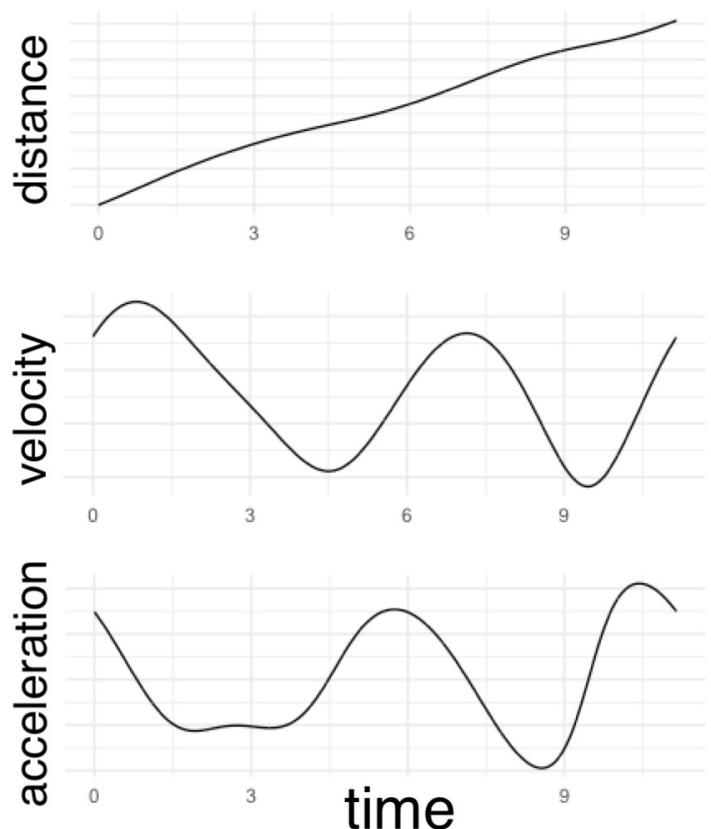
- One value at each time point

Step 2: Calculate Velocity & Acceleration of Distance Travelled

Velocity over entire time series

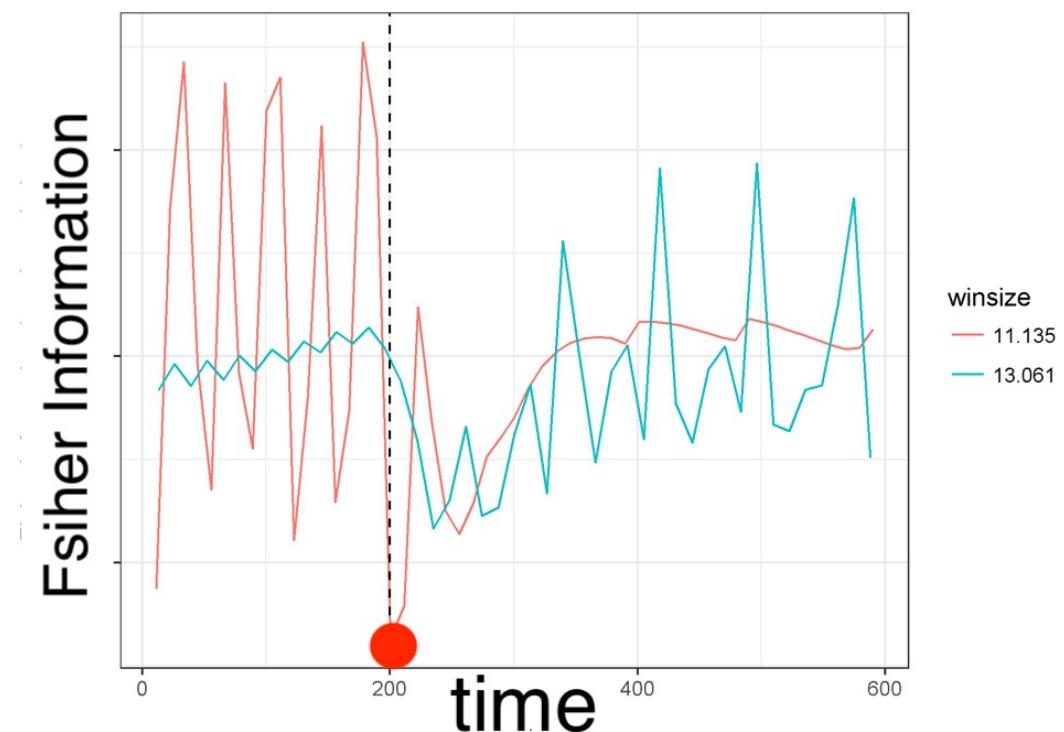


Step 3: Calculate Fisher Information Using Moving Windows



$$I = \frac{1}{T} \int_0^T \left[\frac{s''^2}{s'^4} \right]^2$$

Step 3: Calculate Fisher Information as a Function of Velocity & Acceleration of Distance Travelled



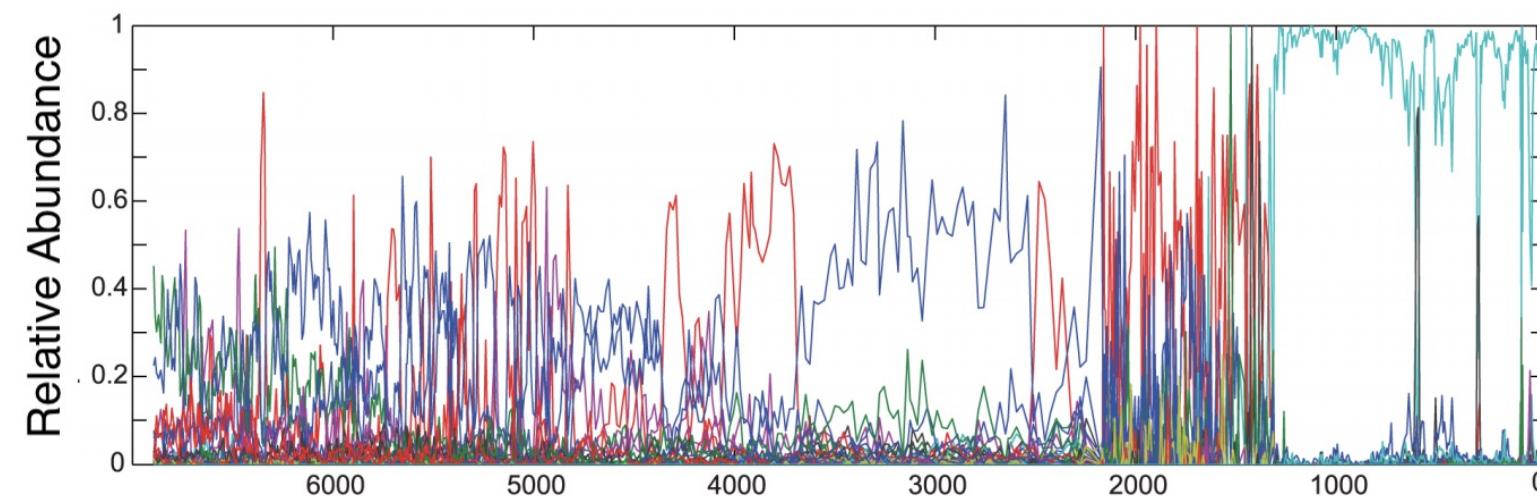
- Sensitive to window size

Chapter 3 Summary: Demystifying Fisher Information for Ecologists

- 1) Fisher Information is separate from dimension reduction
- 2) Is sensitive to user-defined parameter, window size
- 3) Velocity may be a useful alternative to Fisher Information

[1] Burnett *et al.*. Deconstructing the steps for calculating Fisher Information as a measure of abrupt change in ecological systems. *in review at Ecological Modelling*

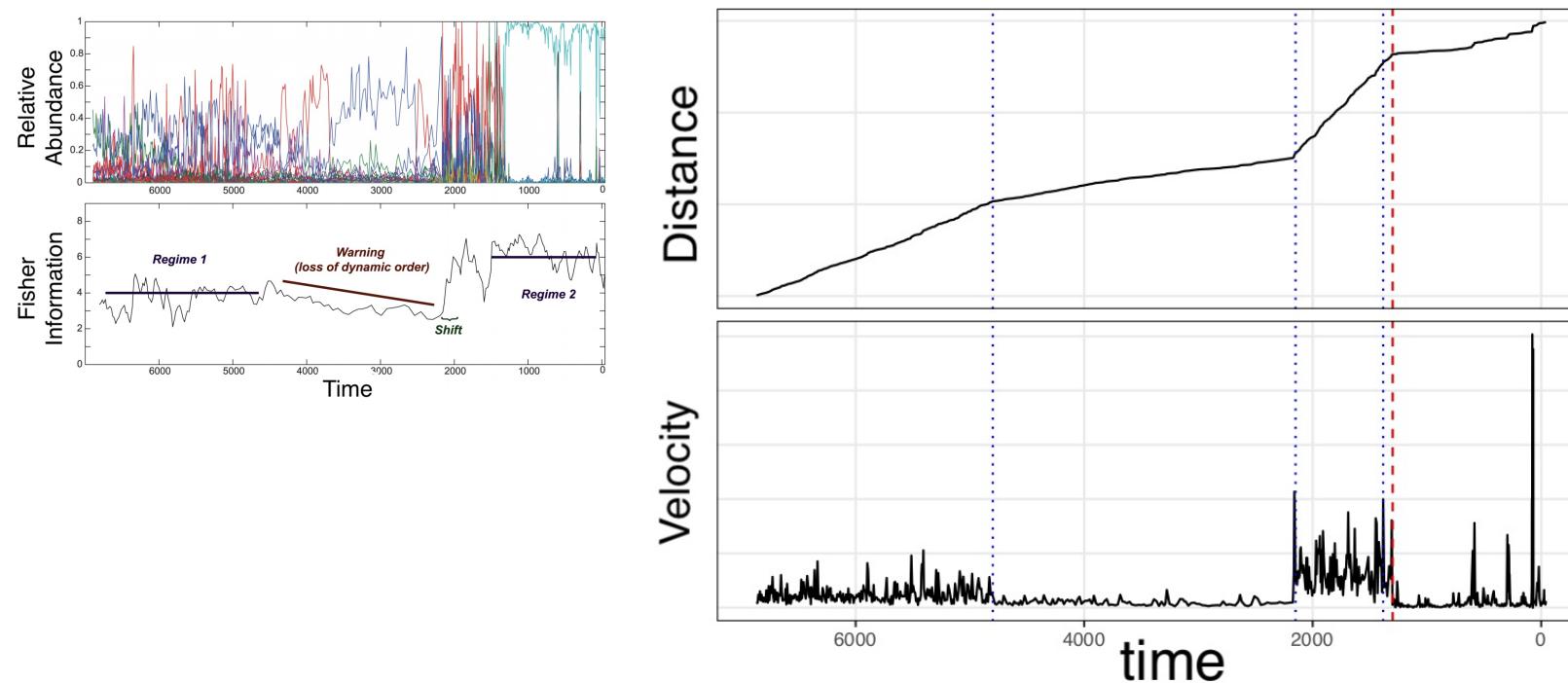
Chapters 5 & 6 Study System: Paleodiatom Community



[1] Data and figure: Spanbauer *et al* (2014) Plos One

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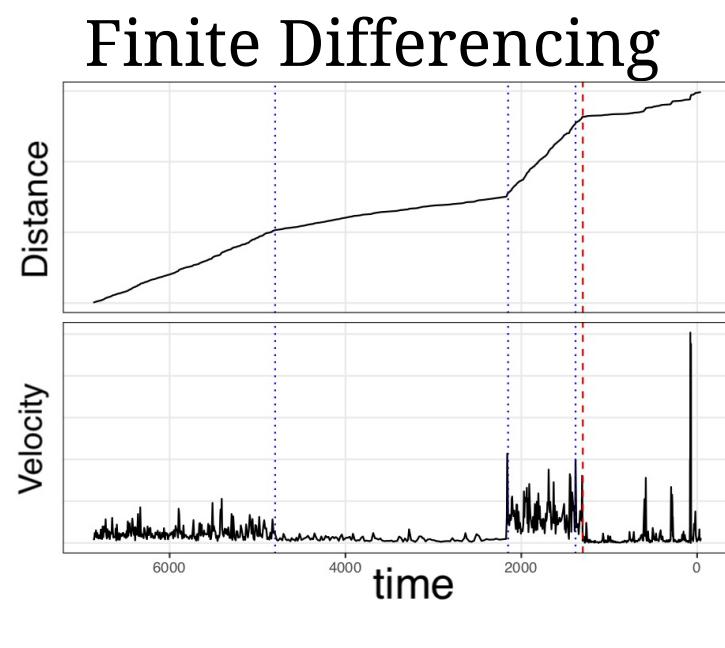
Regime Shifts in a Paleodiatom Community



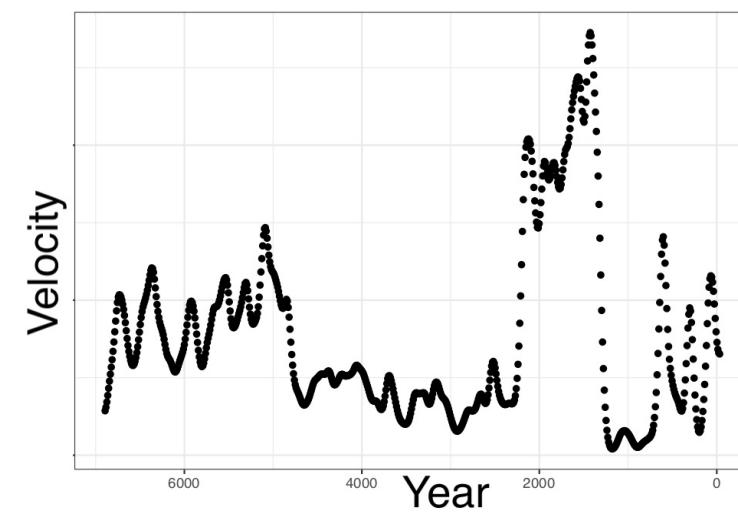
[1] Figure (left): Spanbauer *et al* (2014) Plos One

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Velocity of Distance Travelled Signals Regime Shifts



Regularized
Differentiation^{1,2}



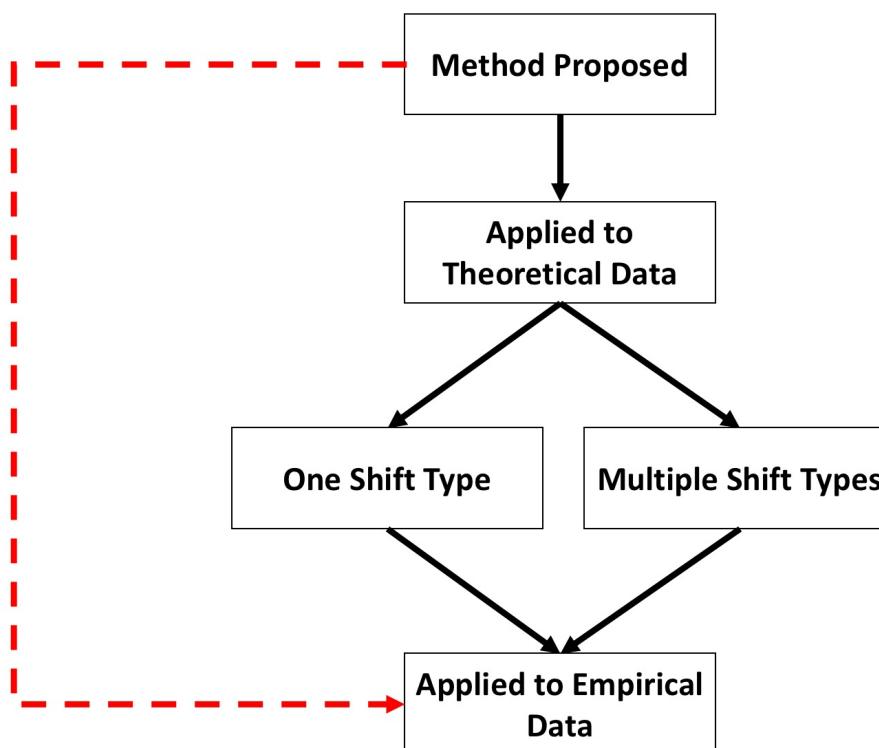
[1] Price & Burnett. R package `tvdiff`. [2]
Chartrand (2011) *ISRN Applied
Mathematics*

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. Generalized Additive Models)

Pathways for Methods Evolution

Rigorous Testing of the Methods Required to Ensure Efficacious Methods



Chapter 6: Relative Performance of Composite Regime Detection Methods

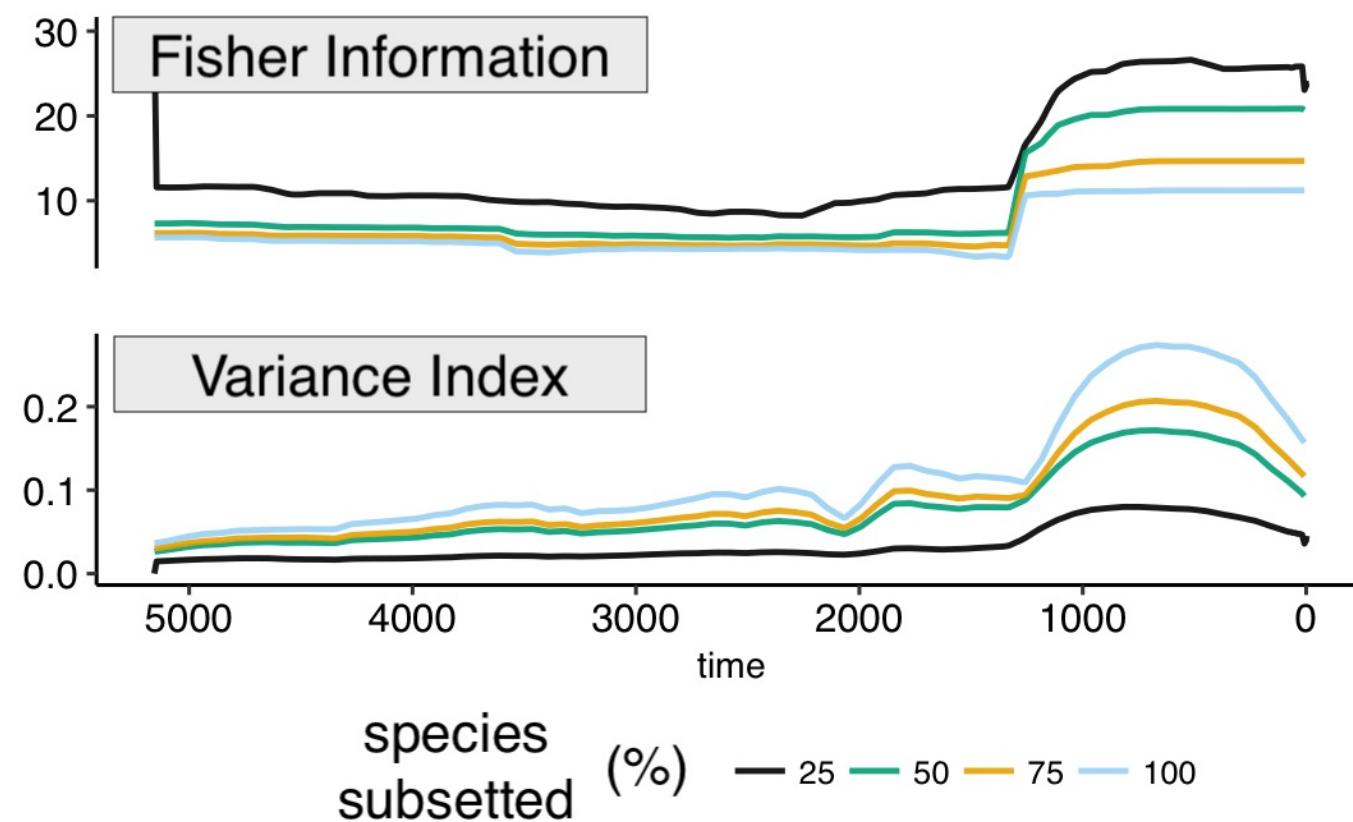
Aims

- Impact of
 - data quality
 - data quantity
- Composite methods
 - Velocity
 - Fisher Information
 - Variance Index

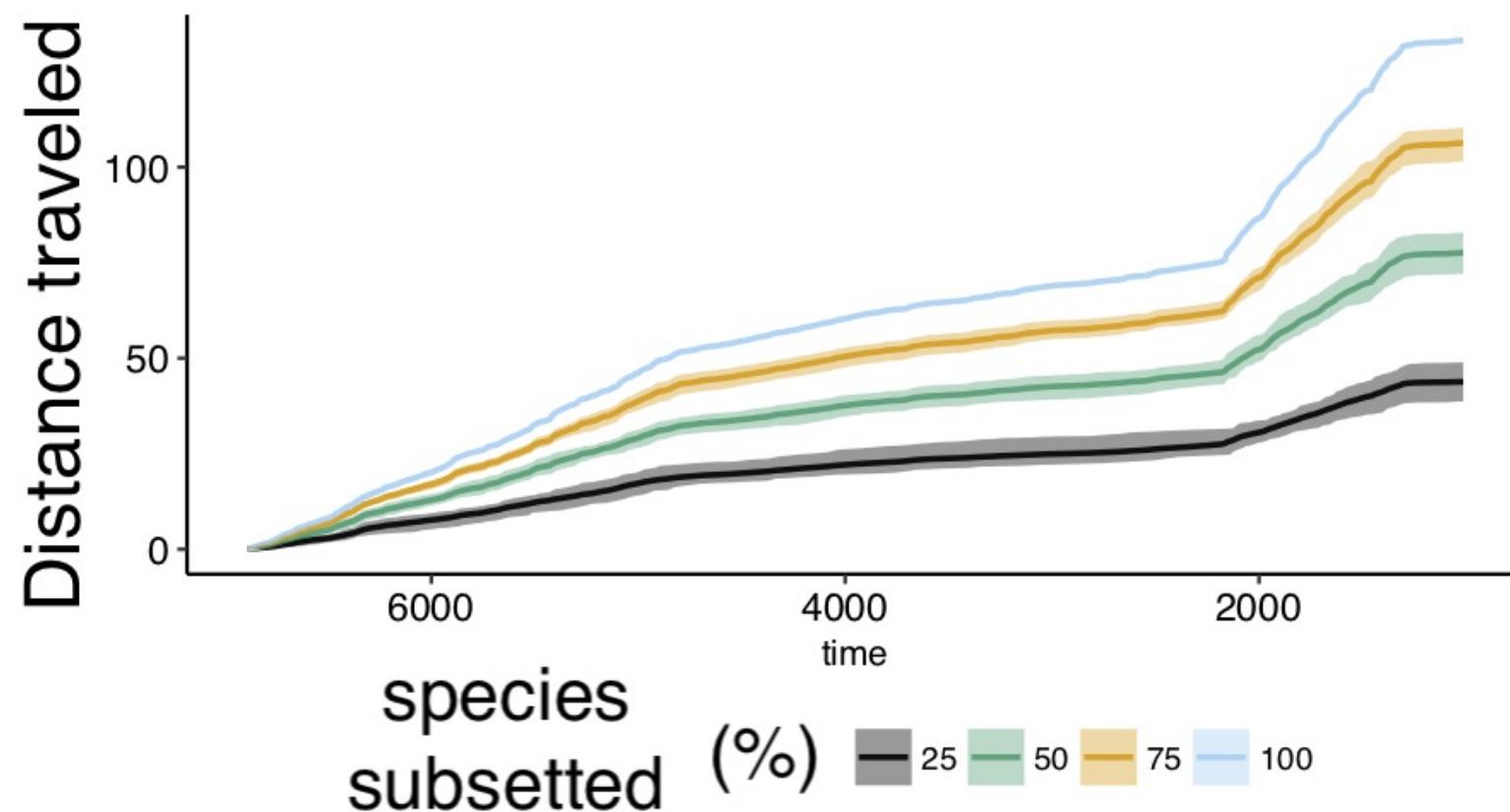
Approach

- Resampling %
 - species
 - time
- Retain dominant species

Randomly Removing Species: Fisher Information & Variance Index



Randomly Removing Time Points: Distance Traveled



Summary of Findings: Velocity of Distance Travelled

- Simple calculation
- Smoothing improves signals
- Robust to data quality & quantity
- Fails when variance >>> mean
- Numerical identification of exact change points
- Compare to distance-based metrics
- Compare to ordination techniques

Prediction is The Holy Grail of Ecology



Dissertation Summary: Regime Detection Methods Need Work Before Application

- Many methods (> 70!); (Ch. 2, 8)
- Rigorous testing of methods (Chs. 3, 4, 5, 6)
- Sensitivity to data quality & quantity (Ch. 3, 5, 6)
- Divergence of regime shift theory from dynamical systems theory (Ch. 1, 8)

Regime Shift Methods and Theory Lagging Behind the Applications: Has Implications for the Practical Ecologist

Software Associated with this Research Program

- **distanceTravelled**¹: calculate velocity, distance
- **regimeDetectionMeasures**¹: calculate FI, VI, CV, etc.
- **bbsRDM**¹: spatial application of methods
- **bbsAssistant**¹: retrieve & handle BBS data
- **tvdiff**²: regularized numerical differentiation

[1] github.com/trashbirdecology

[2] github.com/natbprice

Acknowledgements

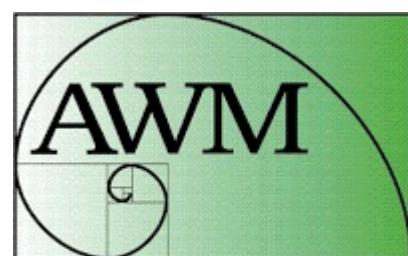
Dissertation Committee

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NATIONAL ACADEMY
OF SCIENCES

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[1] Dogtoral Degree in Personnel Management and Security Services

[2] thanks for the free racquetball coaching

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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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