Regime Detection Methods for the Practical Ecologist

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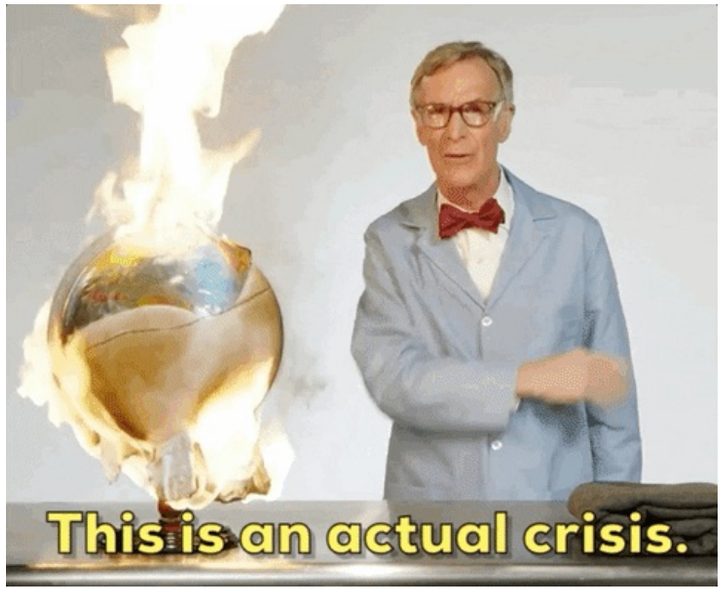
Anthropogenic Activity is Changing the World



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

Regime Shift Example: Coral Reef Bleaching

- Ecotourism
- Fisheries
- Storm Protection

Regime Shift Example: Coral Reef Bleaching

- ~~Ecotourism~~
- ~~Fisheries~~
- ~~Storm~~
- ~~Protection~~

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 accesibility 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

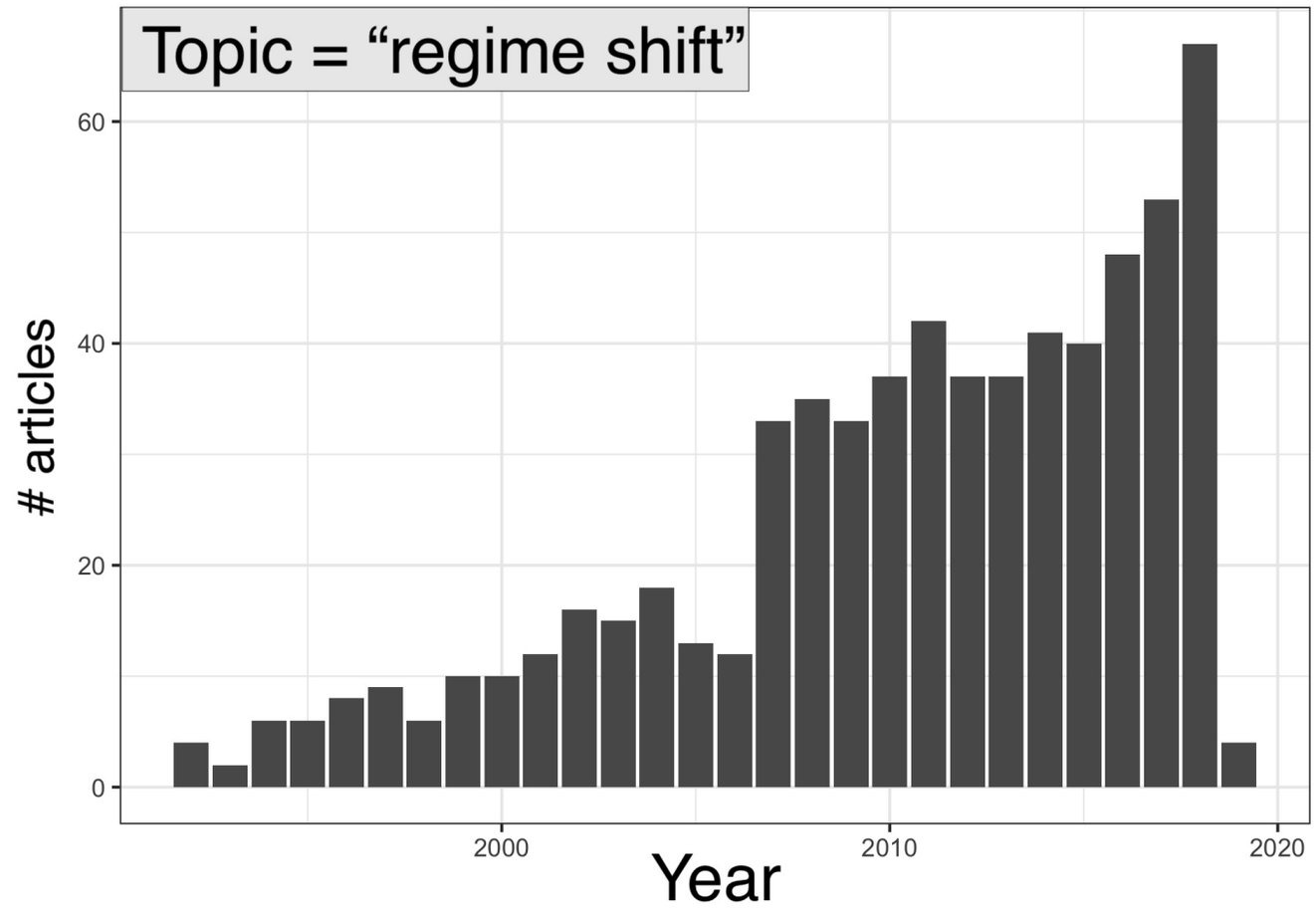
- Lack of use of concepts by practitioners
- No comprehensive source for methodologies

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

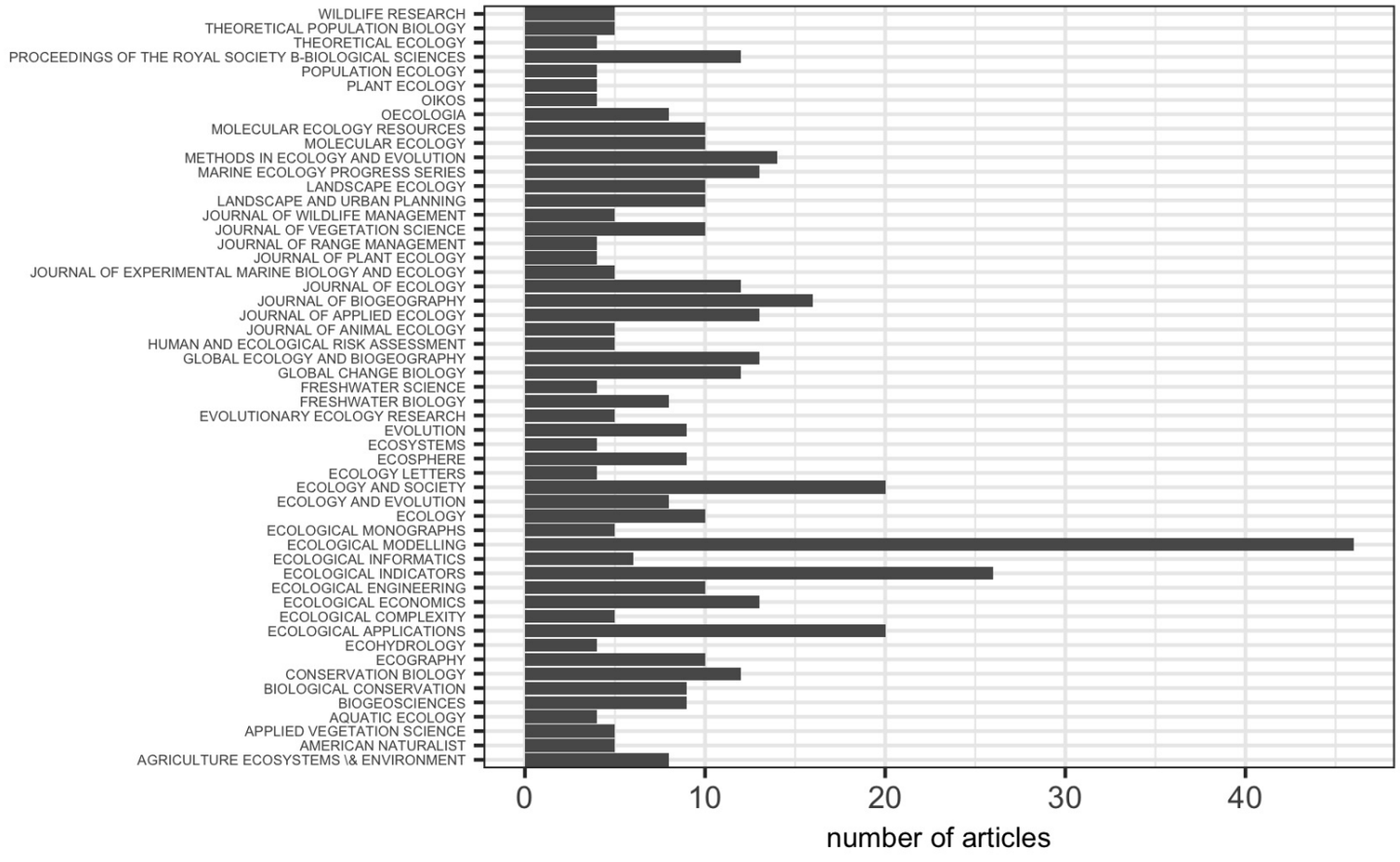


Many Methods, Not All Are Accesible Via Literature Review

- 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

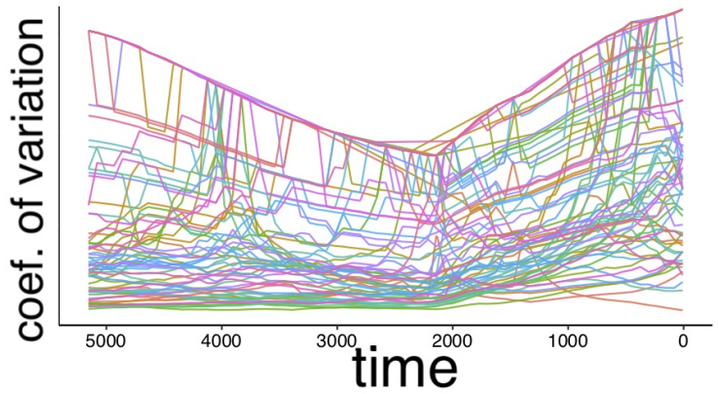
Methods Not Concentrated in Methodological Journals



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

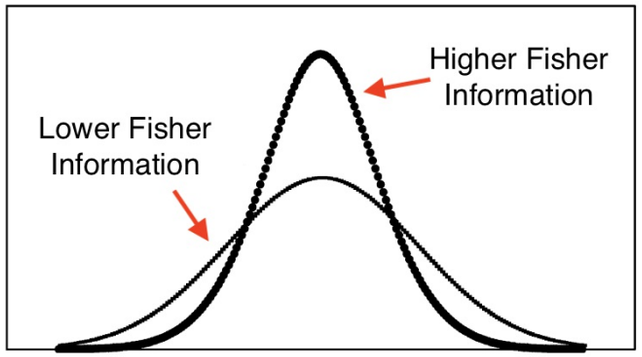
Regime shift indicators fail under noise levels commonly observed in ecological systems

CHARLES T. PERRETTI[1,3] AND STEPHAN B. MUNCH[2]

Composite Methods Proposed for Handling High-Dimensional Data

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

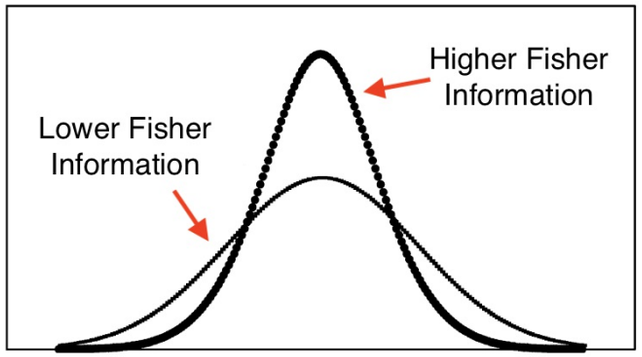
Fisher Information Proposed as a Multivariate Regime Shift Detection Method



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

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

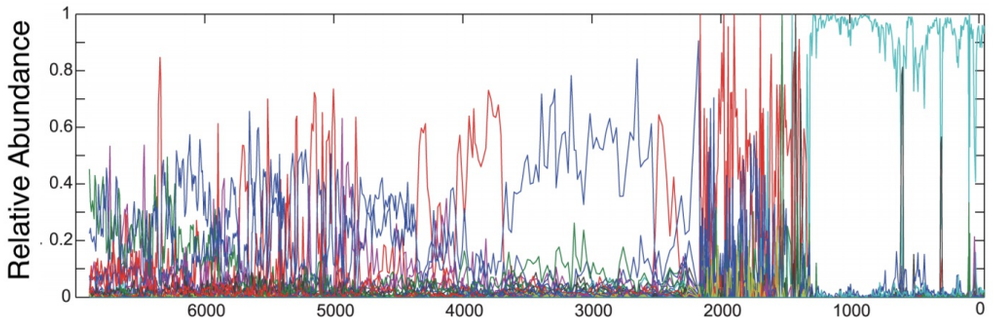
Fisher Information Proposed as a Multivariate Regime Shift Detection Method

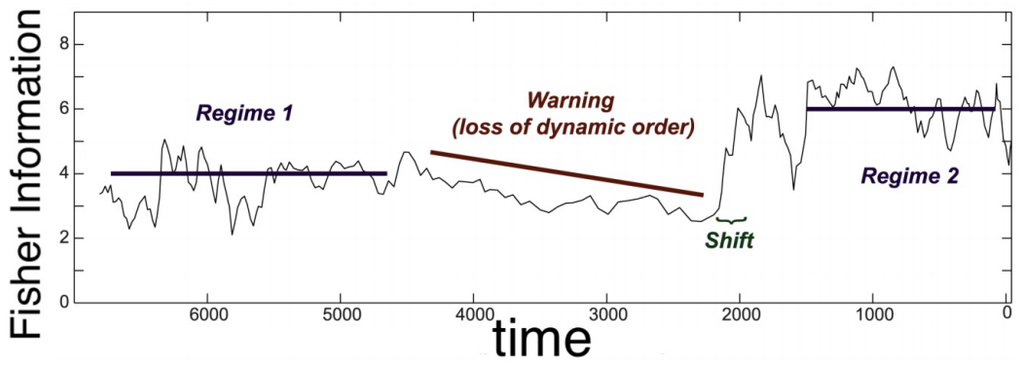


- Noisy data
- Irregularly sampled data
- **Infinite # of variables**

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

Chapter 3: Deconstructing the Steps for Calculating Fisher Information





1) Dimension Reduction

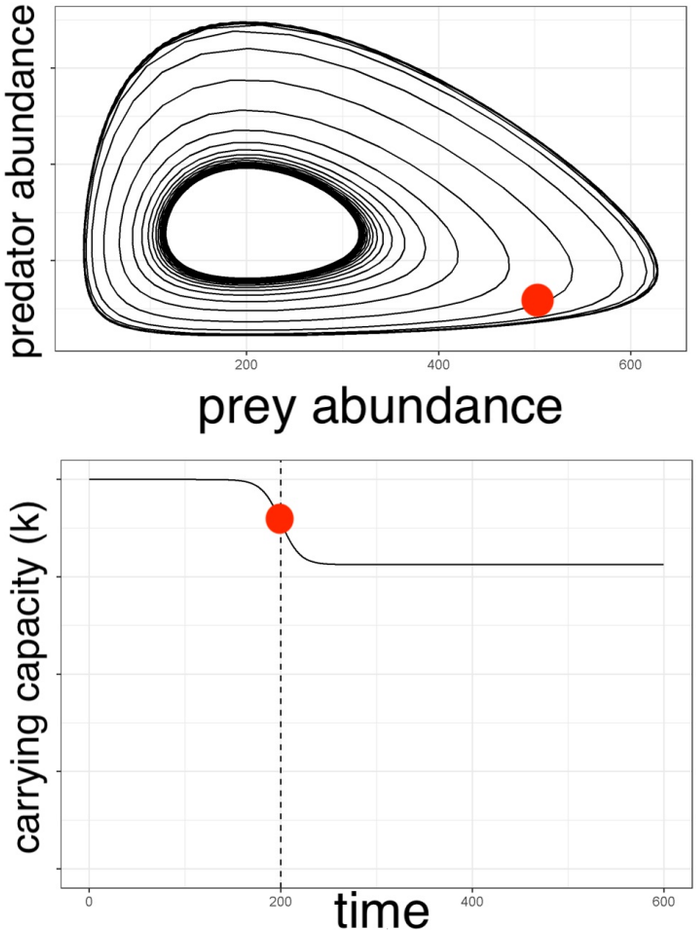
2) Rate of change

3) Fisher Information

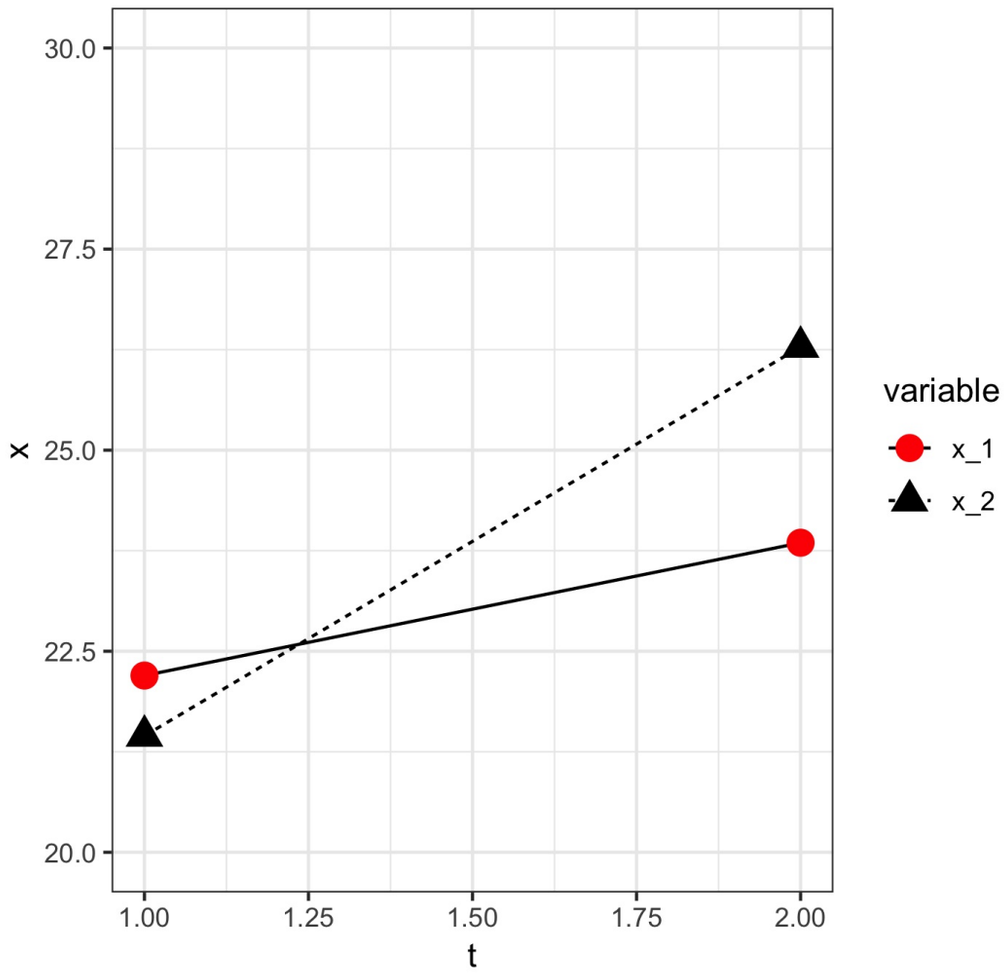
[1] Figure :Spanbauer et al. (2014) *Plos One*

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

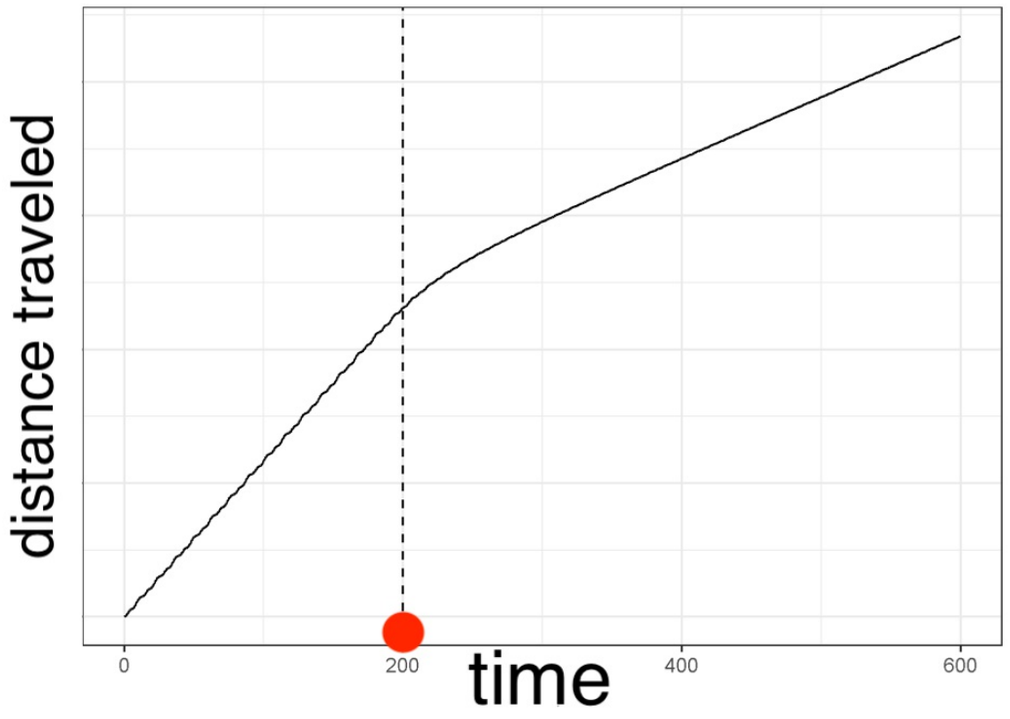


Step 1a: Dimension Reduction Using Euclidean Distance



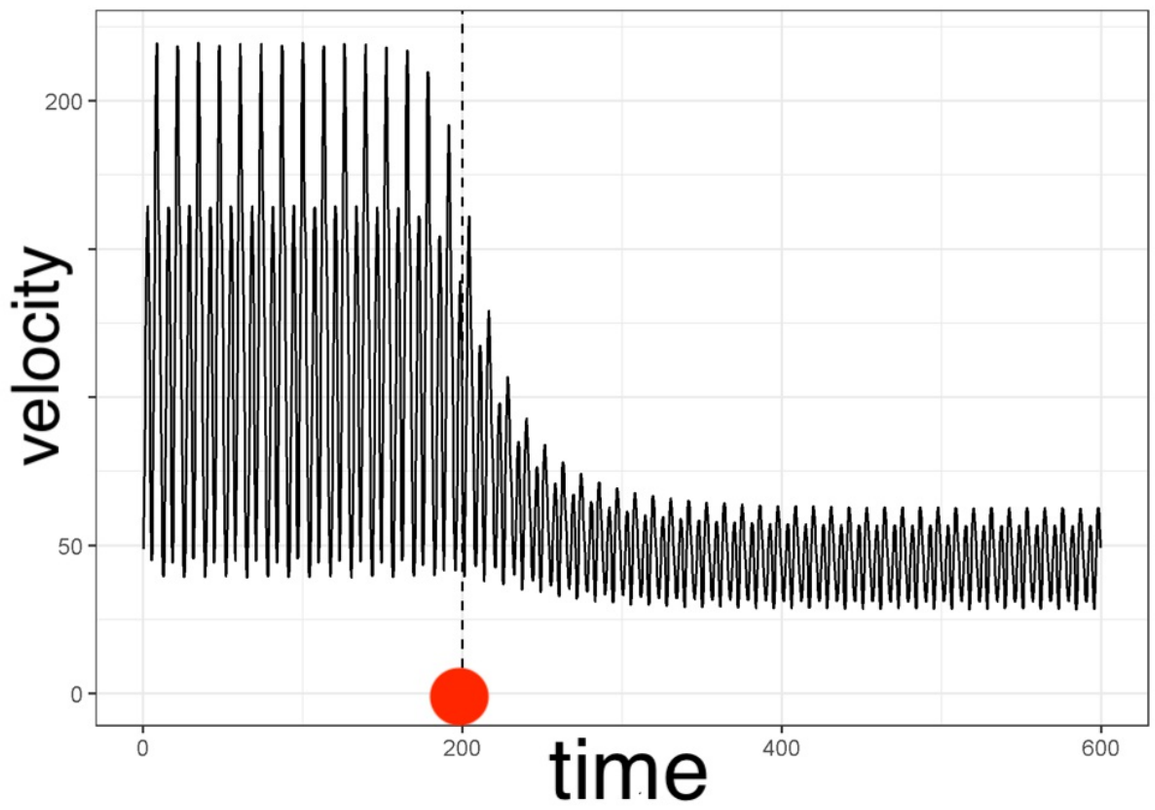
- Euclidean distance
  - all variables
  - between time points

Step 1b: Calculate Distance Travelled Along Trajectory

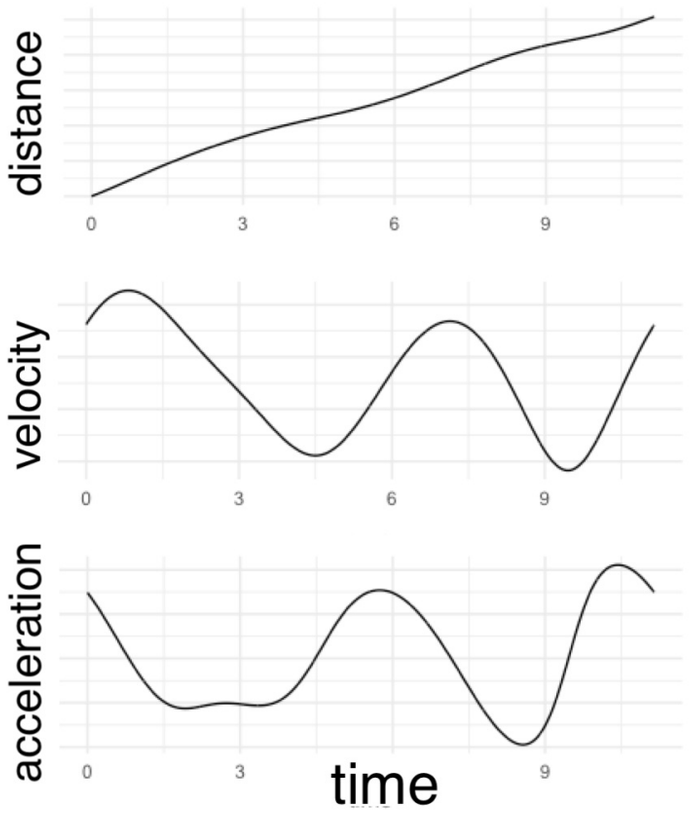


- One value at each time point

Step 2: Calculate Velocity & Acceleration of Distance Travelled

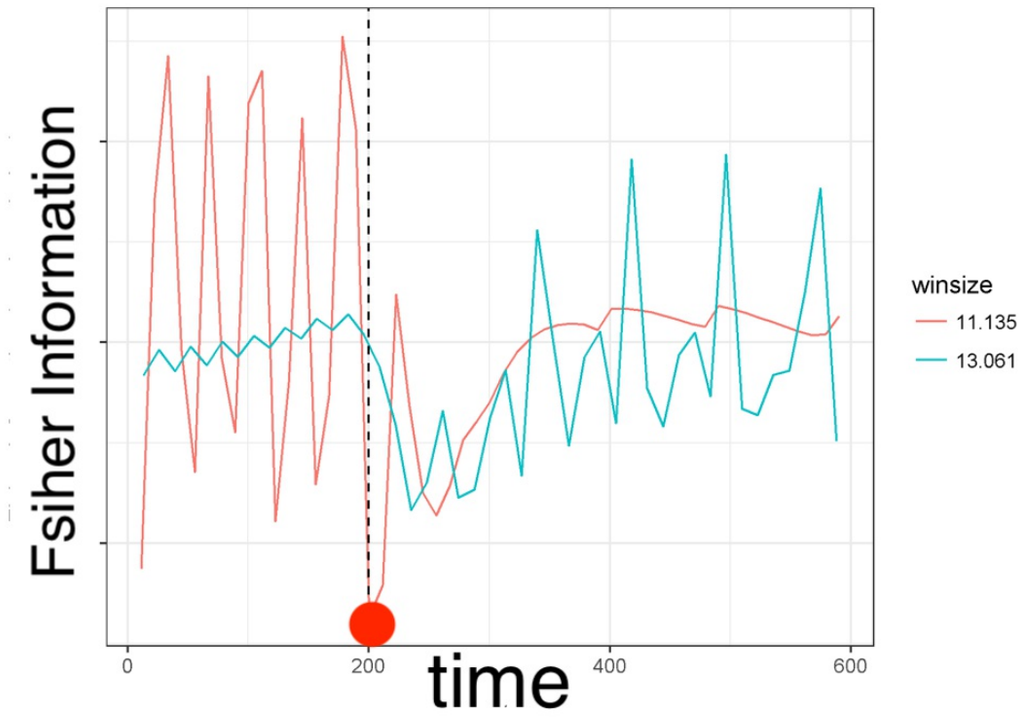


Step 3: Calculate Fisher Information Using Moving Windows



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

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

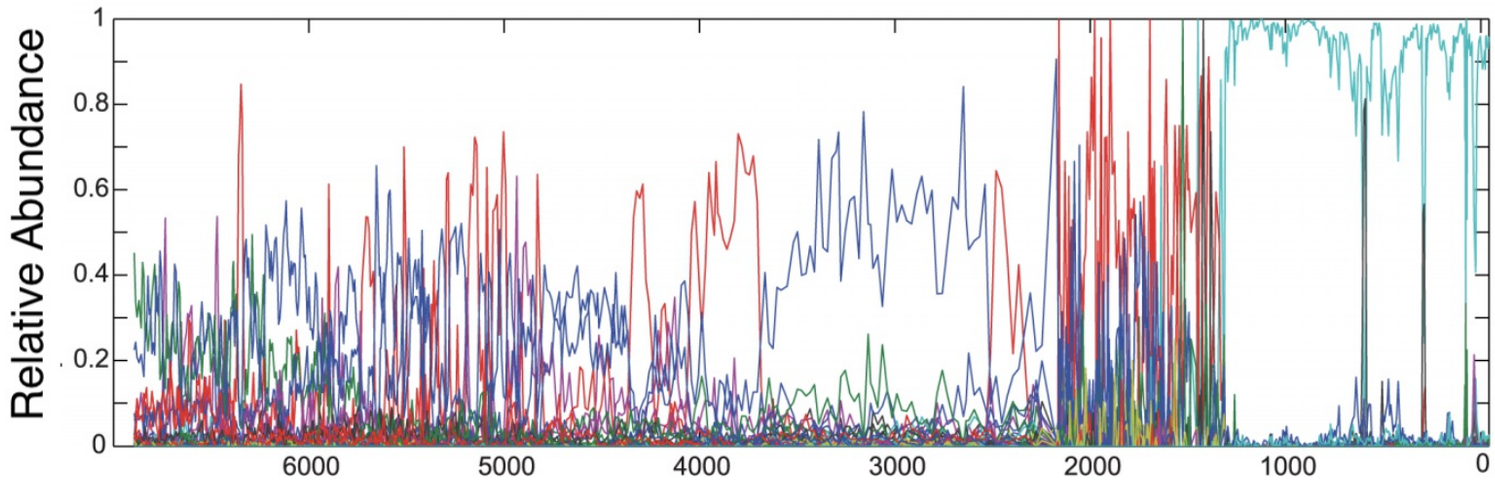
1) Fisher Information is separate from dimension reduction

2) Is sensitive to user-define paramter, window size

3) **Velocity may be a useful alternative to Fisher Information**

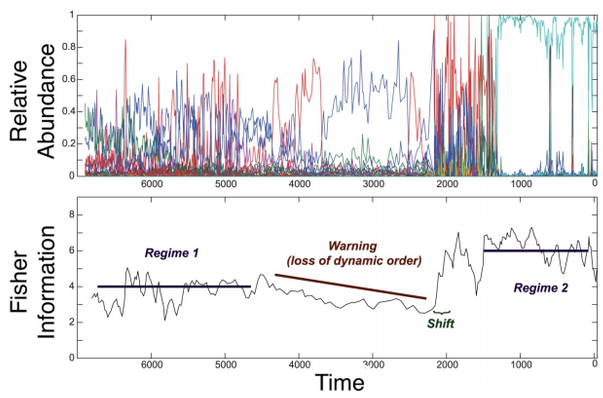
[1] Burnett *et al.*. Deconstructing the steps for calculating Fisher Information as a measure of abrupt change in ecological systems. *in review at Ecological Modelling*

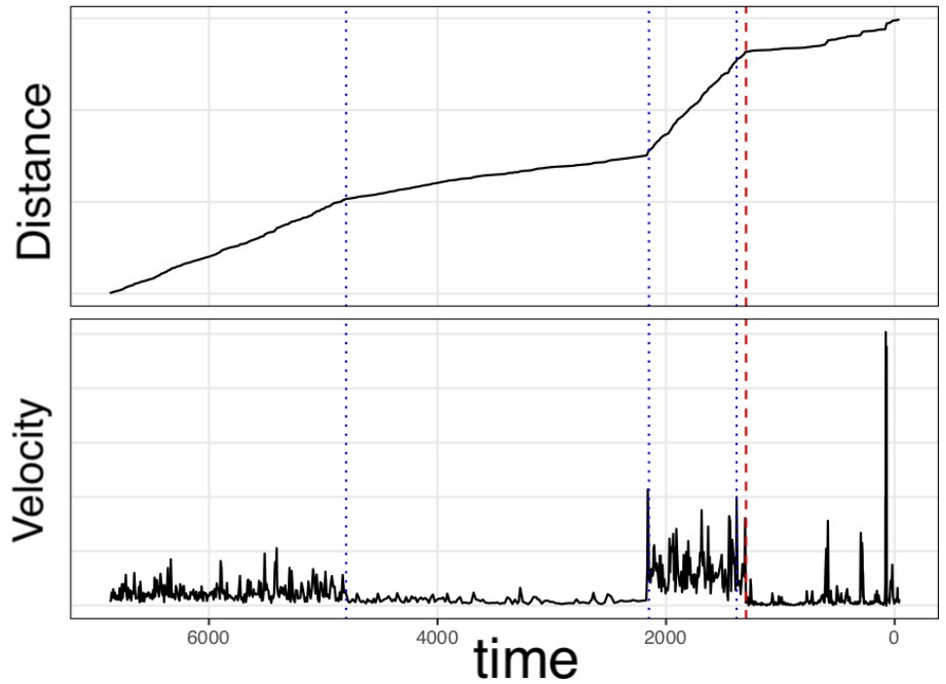
Chapters 5 & 6 Study System: Paleodiatom Community



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

Regime Shifts in a Paleodiatom Community

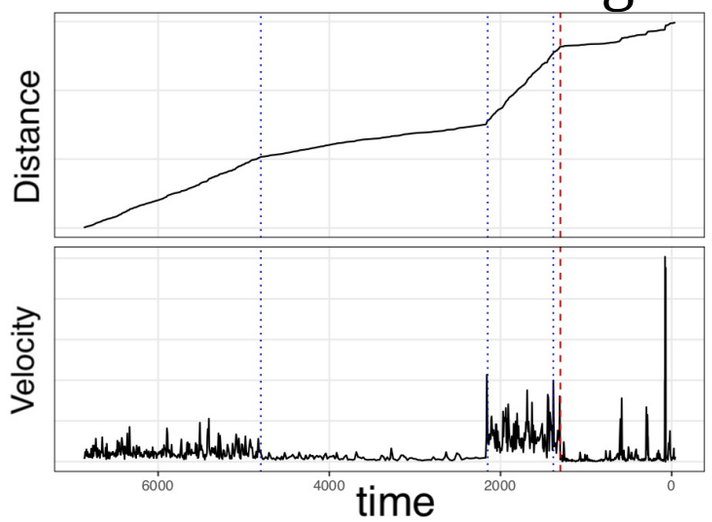




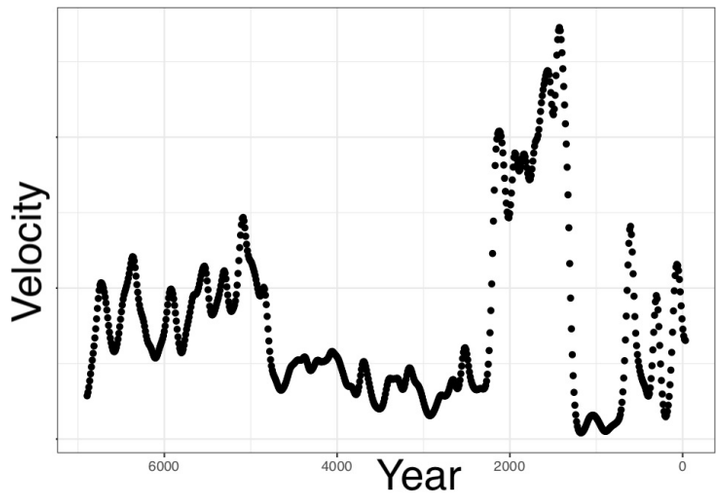
[1] Figure (left): Spanbauer *et al* (2014) Plos One

Velocity of Distance Travelled Signals Regime Shifts

Finite Differencing



Regularized Differentiation[1,2]



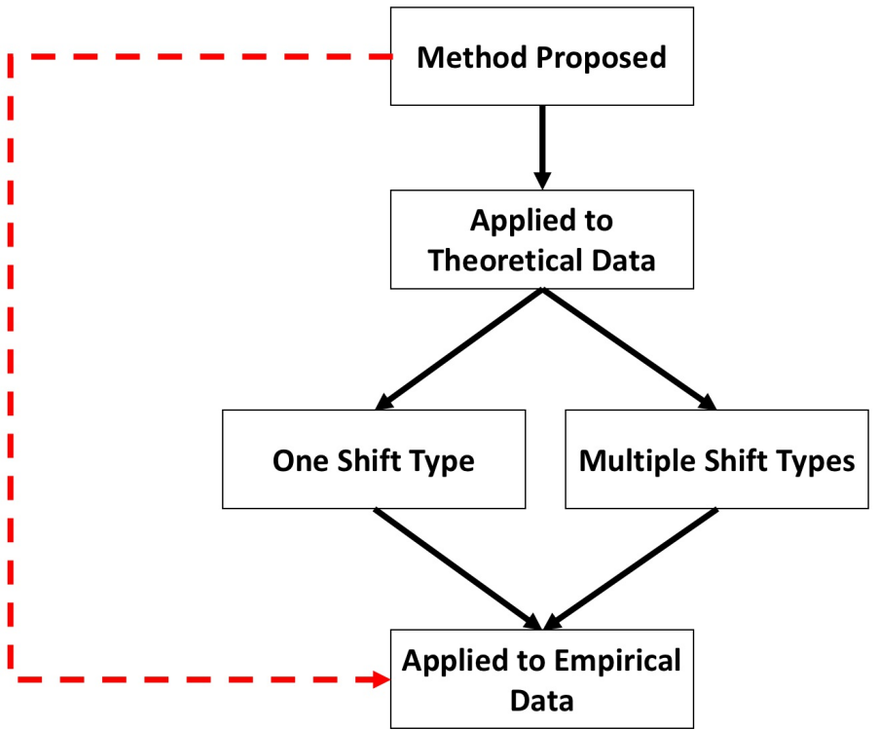
[1] Price & Burnett. R package `tvdiff`. [2] Chartrand (2011) *ISRN Applied Mathematics*

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

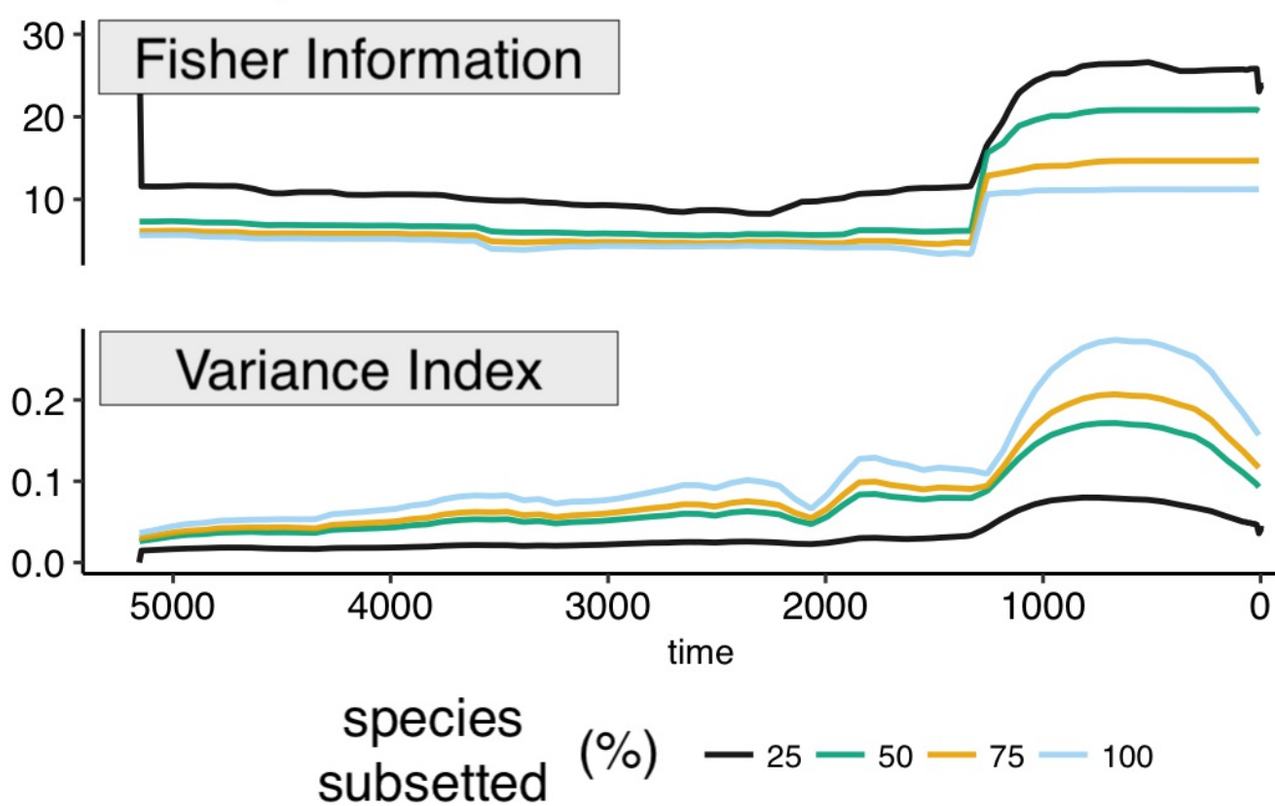
Aims

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

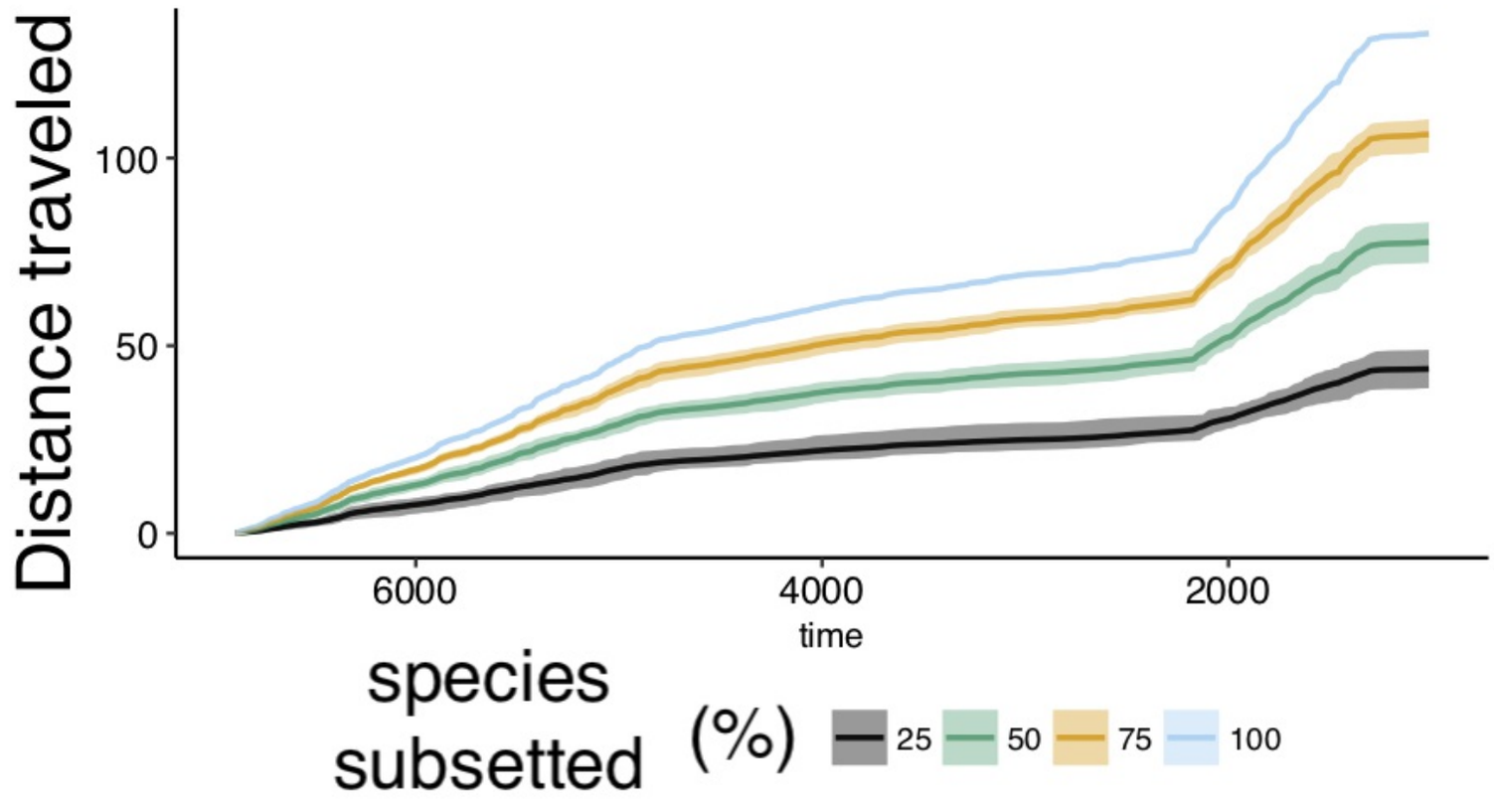
Approach

- 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

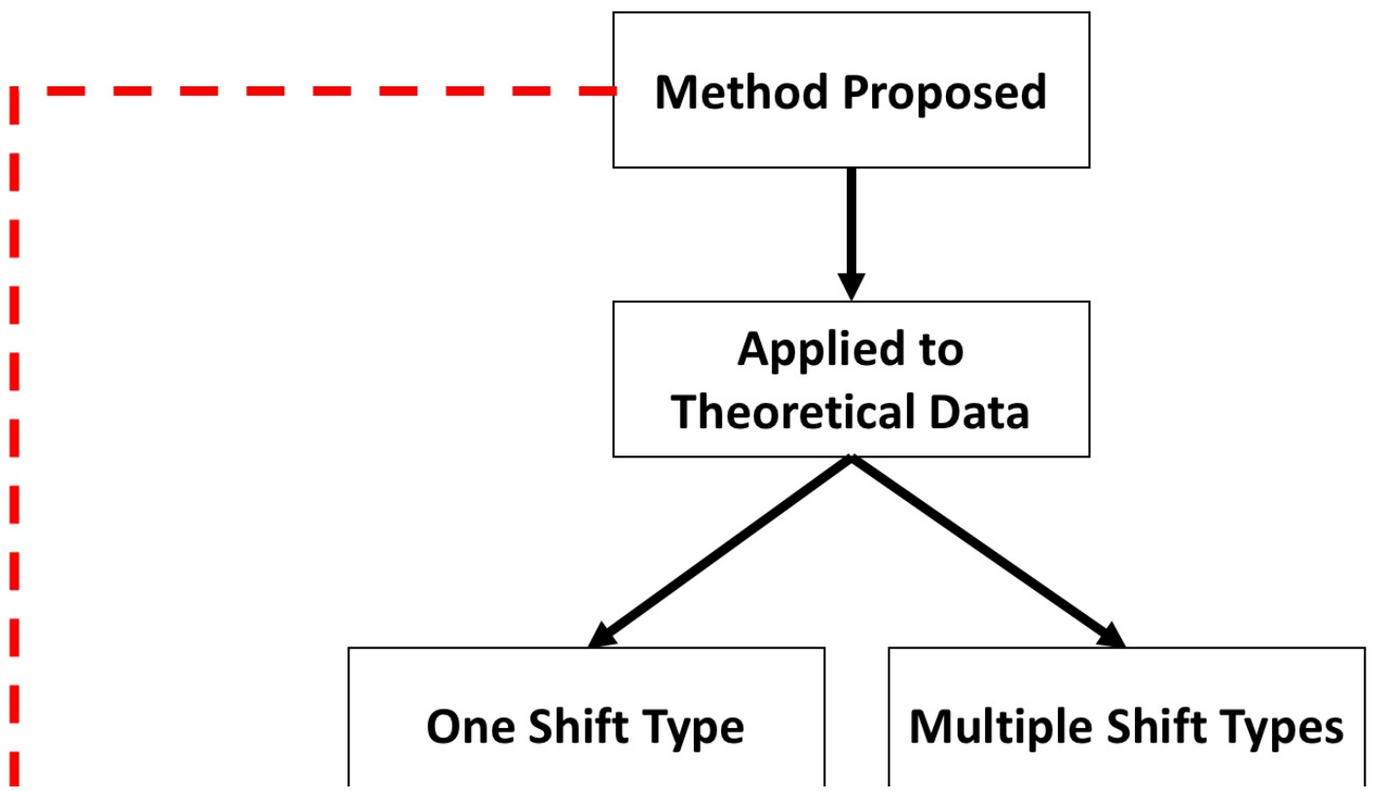
- Simple calculation
- Smoothing improves signals
- Robust to data quality & quantity
- Fails when variance >>> mean
- Numerical identification of exact change points
- Compare to distance-based metrics
- Compare to ordination techniques

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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- Tarsha Eason
- Keith Hurley
- Hao Ye
- Dennis Ferraro
- Kelly Willemssens
- Frank La Sorte
- Lego Grad Student
- Scott Robinson
- Chrisie Bahlai
- Katya Perez
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- My parents for creating me

[1] Dogtoral Degree in Personnel Management and Security Services
[2] thanks for the free racquetball coaching

Acknowledgements: Data & Software

- 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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