Velocity of Ecological System Trajectory

A new method for dimension reduction and ecological regime shift detection

Jessica L. Burnett

N.B. Price, A.J. Tyre, C.R. Allen, D.G. Angeler, & D. Twidwell

2019.04.07

Ecosystems are Complex

(and complicated)

- high dimensional

- many (∞ ?) interactions

- non-linear

- non-ergodic (open)

- dynamic

- difficult to model mathematically

The Holy Grail of Ecology

forecasting change in time to prevent or mitigate undesirable consequences

"regime shifts"

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

Methods for Detecting Regime Shifts

> 70 (!) methods proposed in literature

10 suitable for multivariable data

few explicitly handle noisy data

few handle irregular sampling

Regime Shifts Detection Methods

Rising Variance/Critical Slowing Down

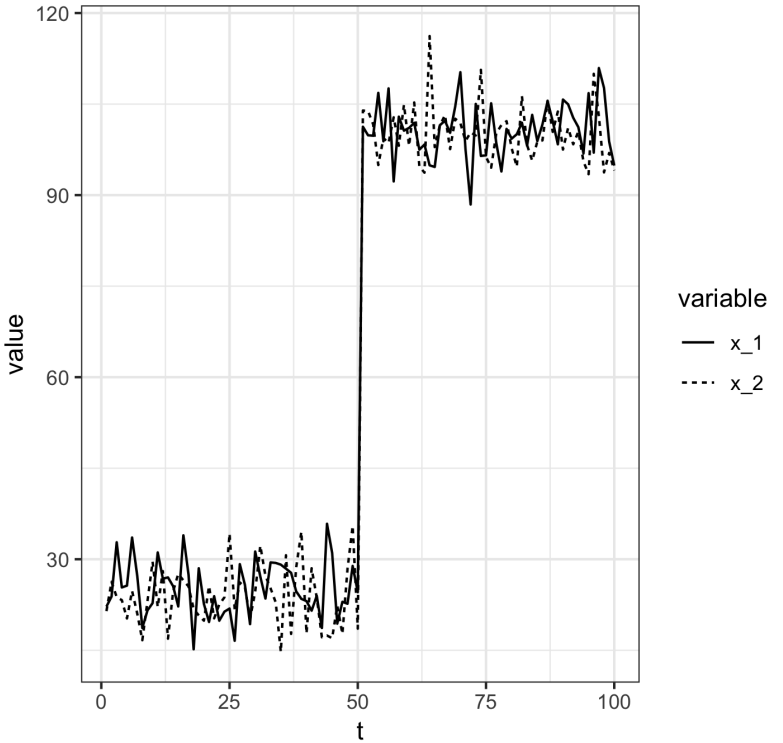
Variance Index (max eigenvalue of covariance matrix)

Principal Coordinates Analysis

Fisher Information

Velocity, v

Toy System

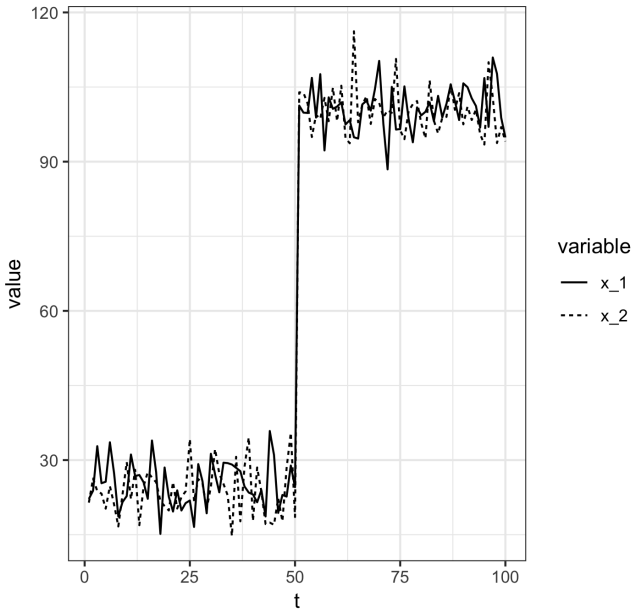


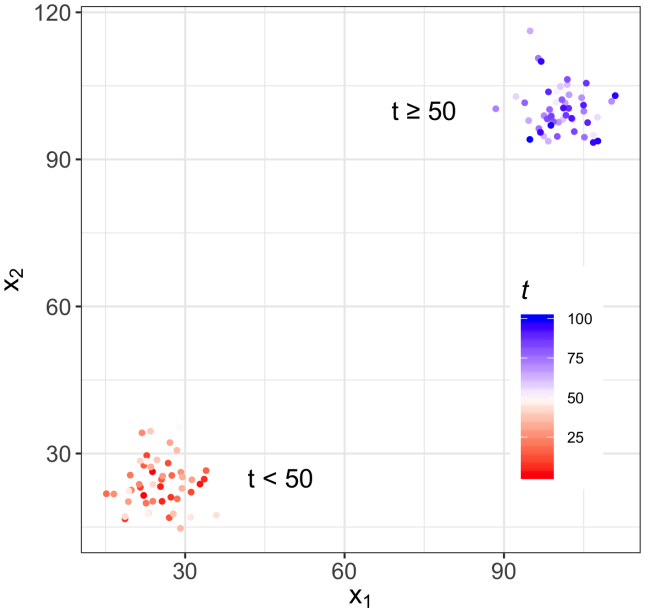
$$x\ normal(\mu = 25, \sigma = 5) \text{ for t } > 50$$

$$x\ normal(\mu = 100, \sigma = 5) \text{ for t } \geq 50$$

Velocity, $\frac{\Delta s}{\Delta t}$

the linear speed of a system's trajectory (e.g., in phase space)





Step 1: Calculate Δs , 'distance travelled'

$$s = \text{system state}$$

$$\Delta s_i = \sqrt{\sum_{j=1}^{n} \left(x_{i,j} - x_{i-1,j} \right)^2}$$

Step 2: Calculate s , **cumulative** distance travelled

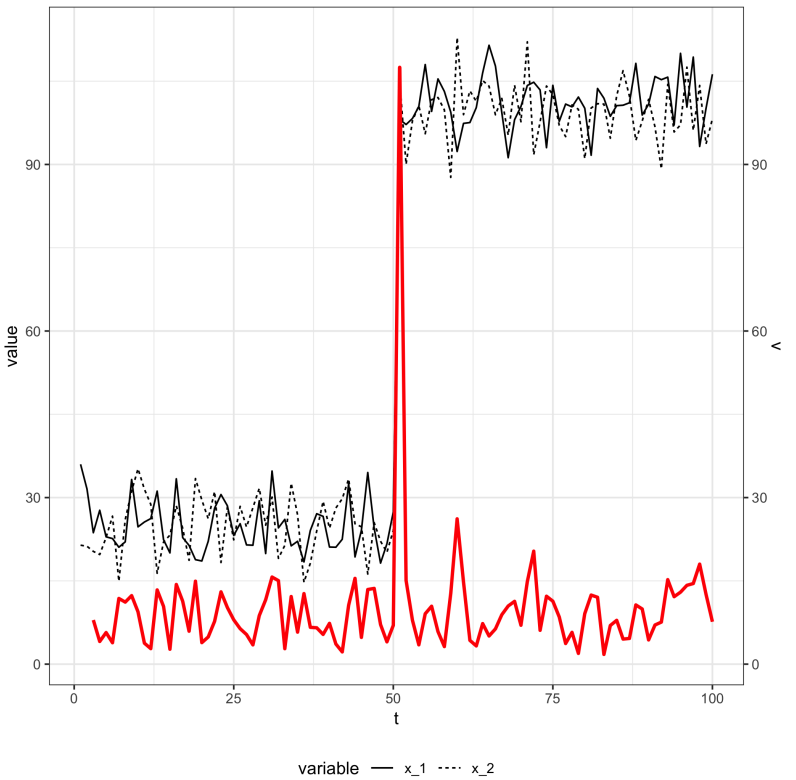
$$\Delta s_i = \sqrt{\sum_{j=1}^{n} (x_{i,j} - x_{i-1,j})^2}$$

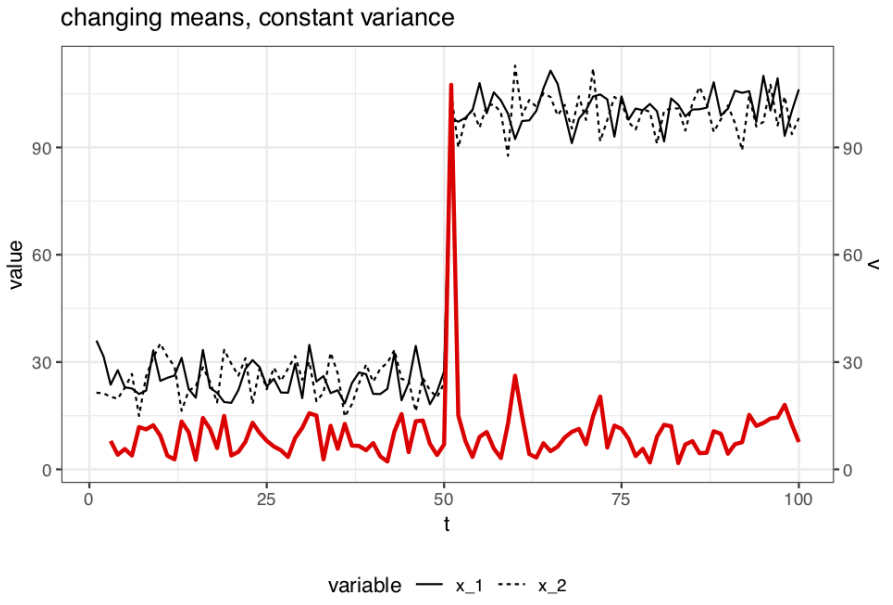
$$s_k = \sum_{i=2}^{k} \Delta s_i$$

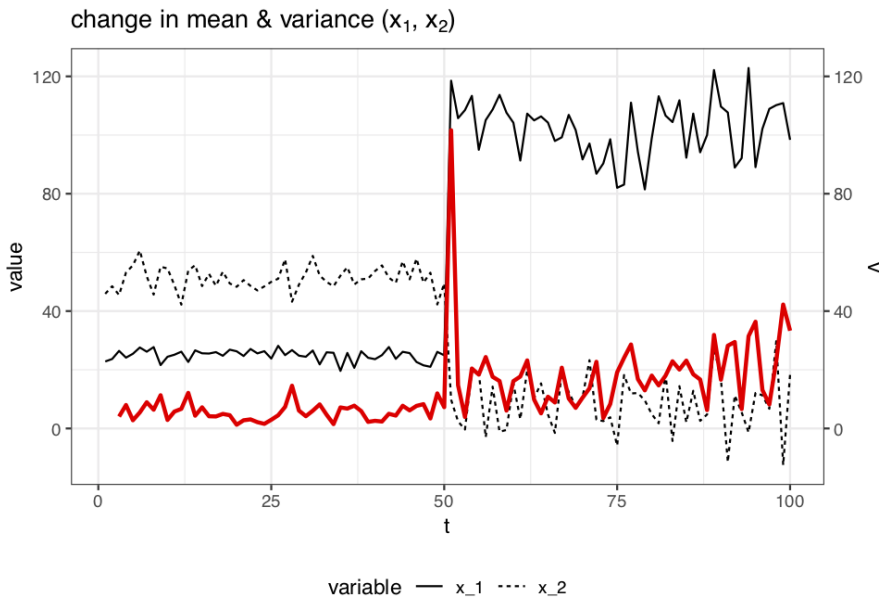
$$2 \leq k \leq n$$

Step 3: Calculate v , the linear speed of s

$$v = \frac{\Delta s}{\Delta t}$$

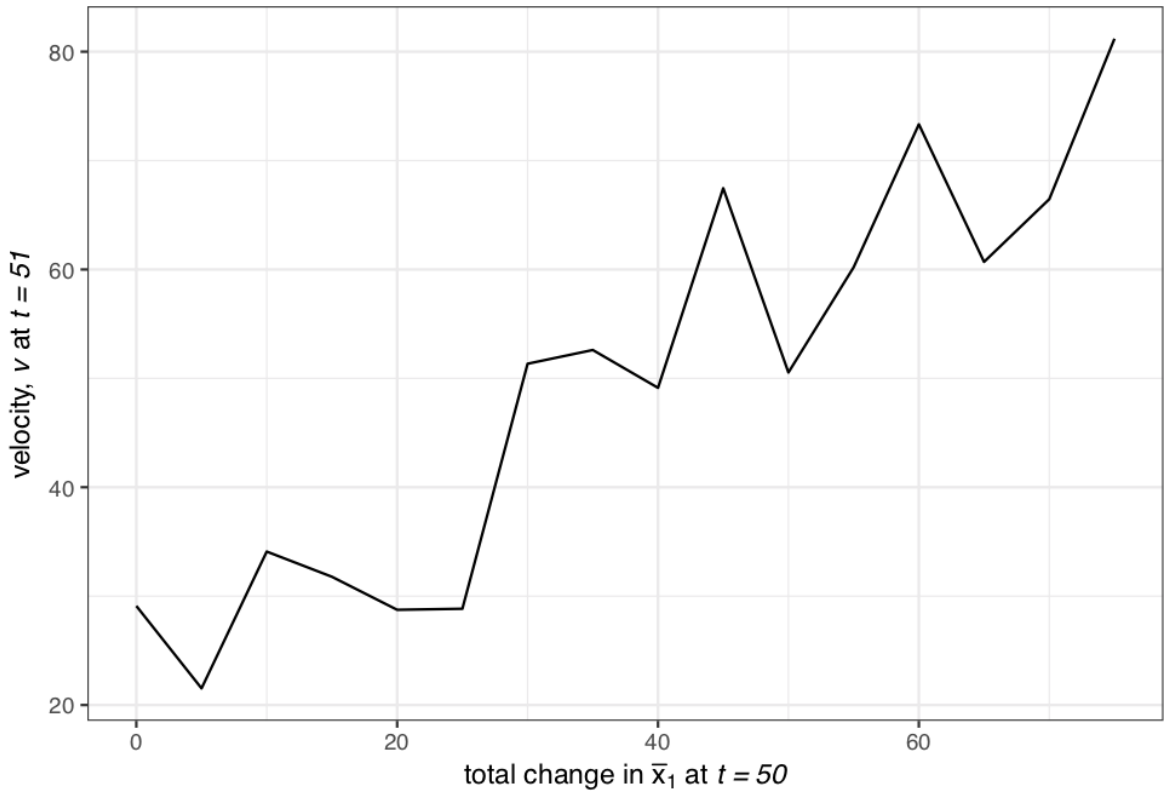



changing means, constant variance
value
t
0
25
50
75
100
0
30
60
90
variable
x_1
x_2


change in mean & variance (x_1, x_2)
value
t
0
25
50
75
100
0
40
80
120
variable
x_1
x_2

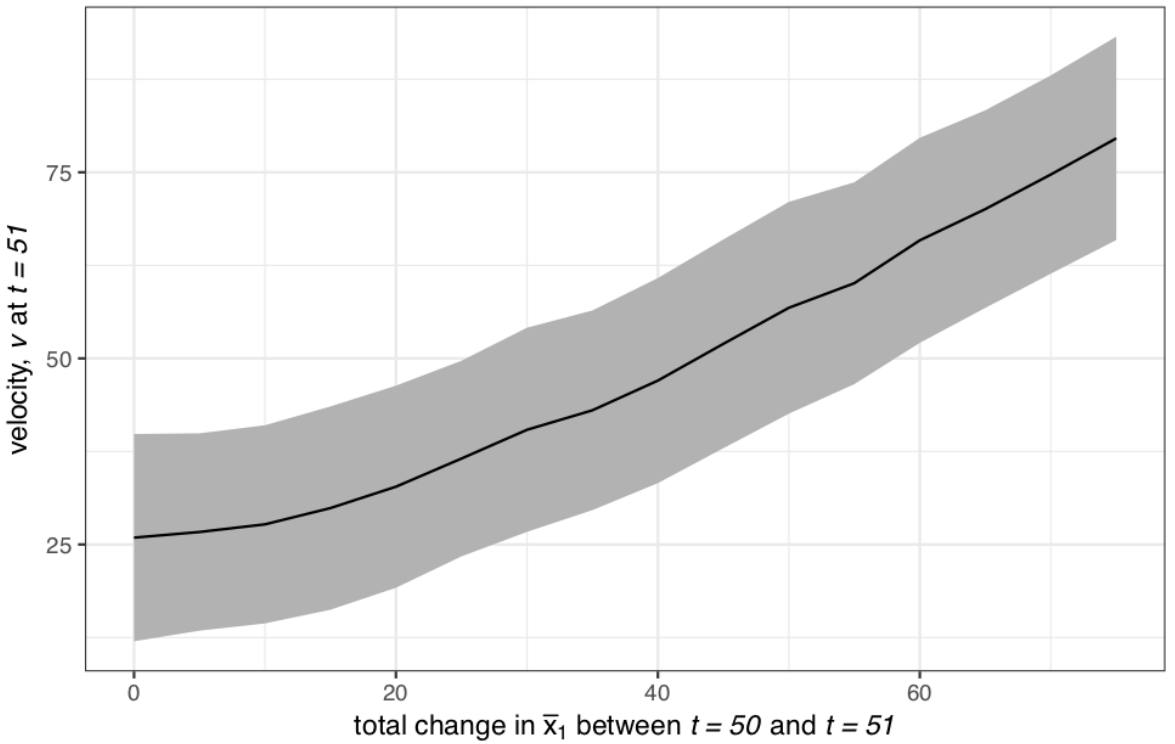
Potential Limitations of v

v increases with increasing effect size

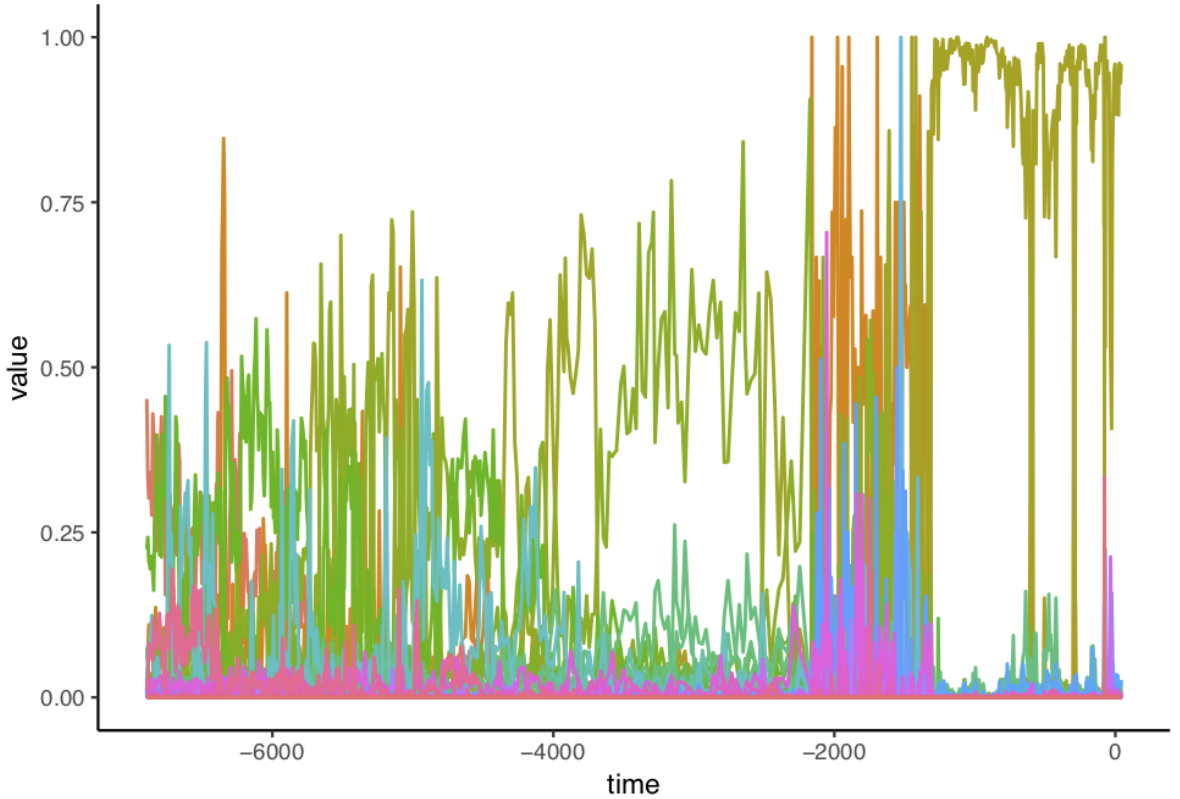


Potential Limitations of v

v increases with increasing effect size

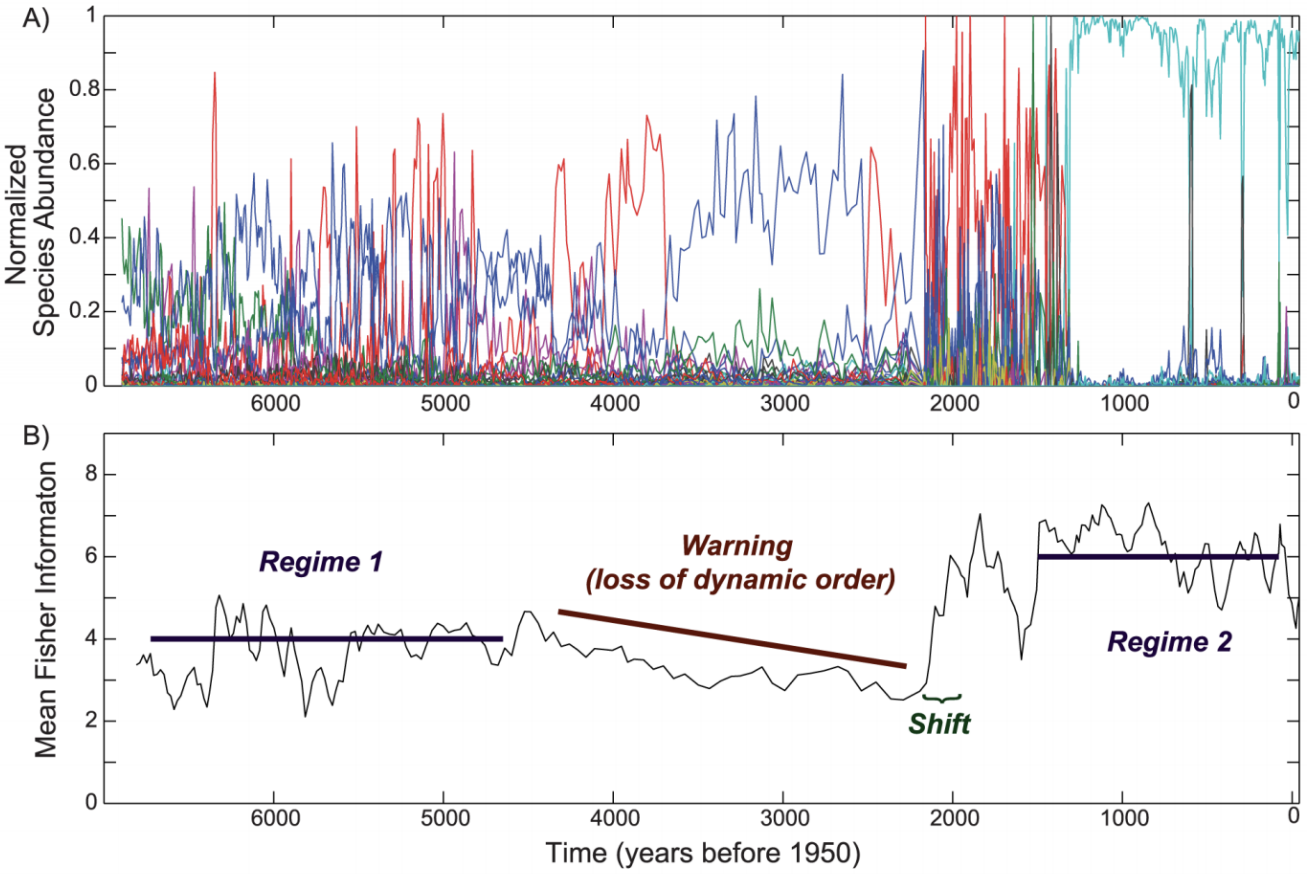


Empirical System: Paleodiatom

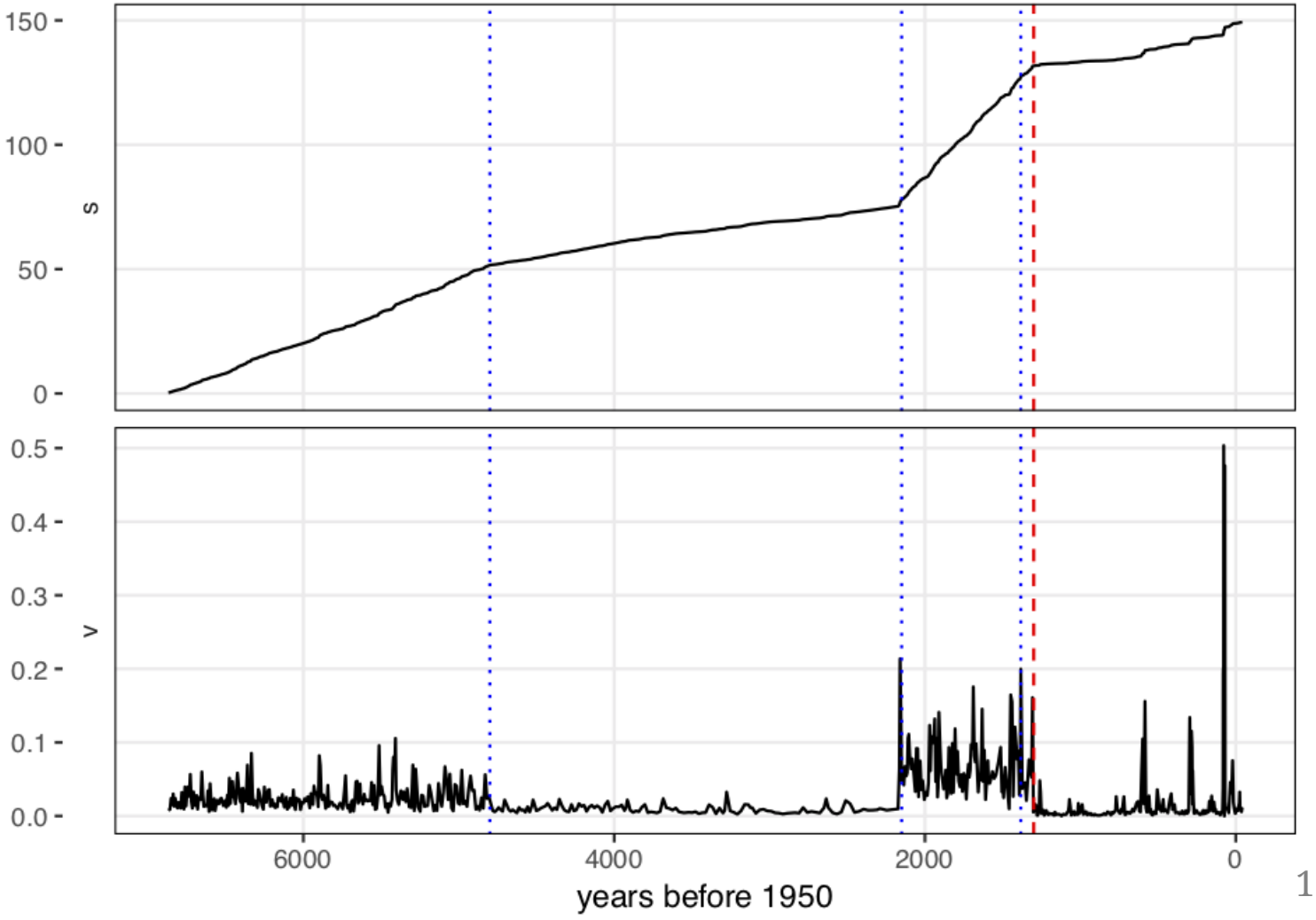


Data published in Spanbauer *et al.* 2014. Prolonged Instability Prior to a Regime Shift. PLoS One

Empirical System: Paleodiatom

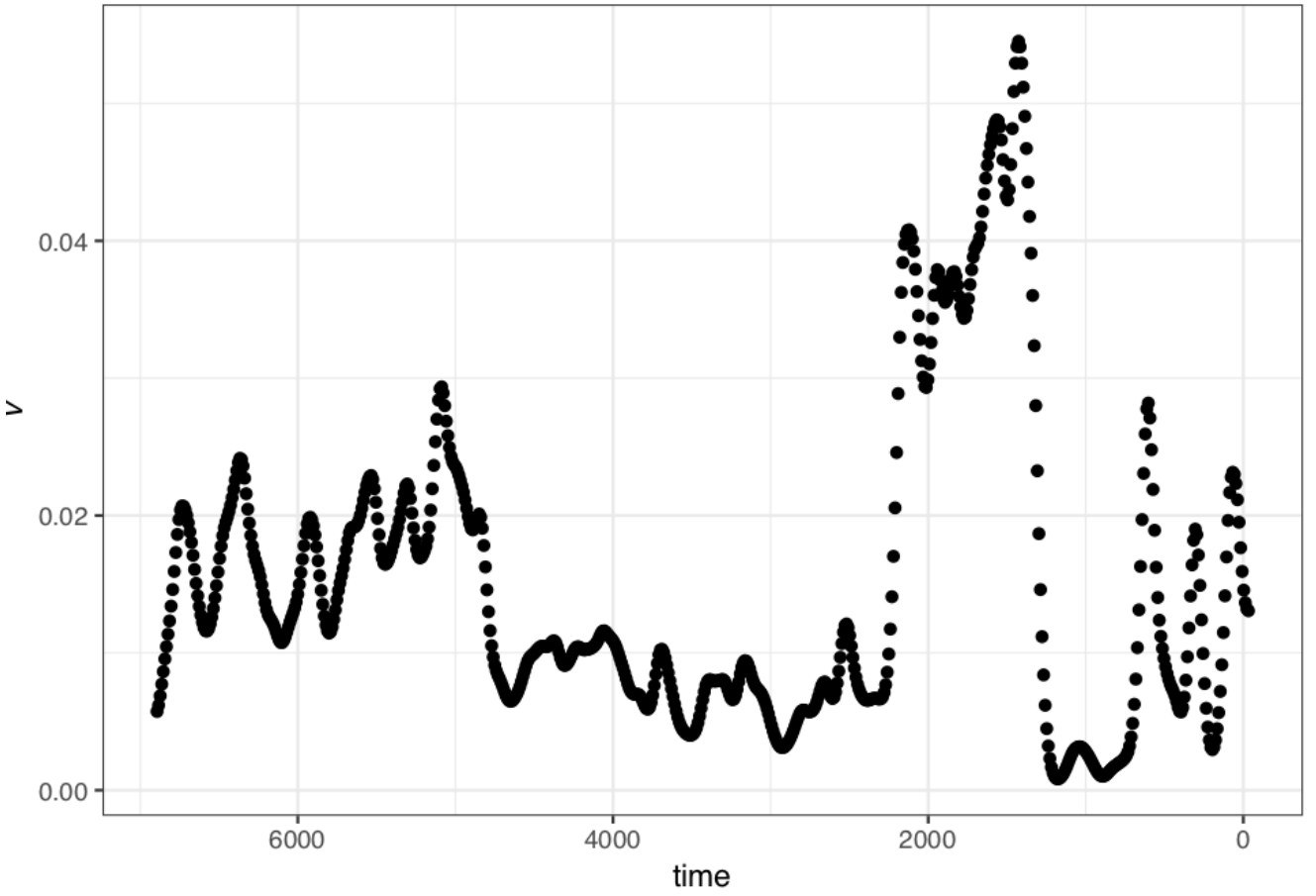


Empirical System: Paleodiatom

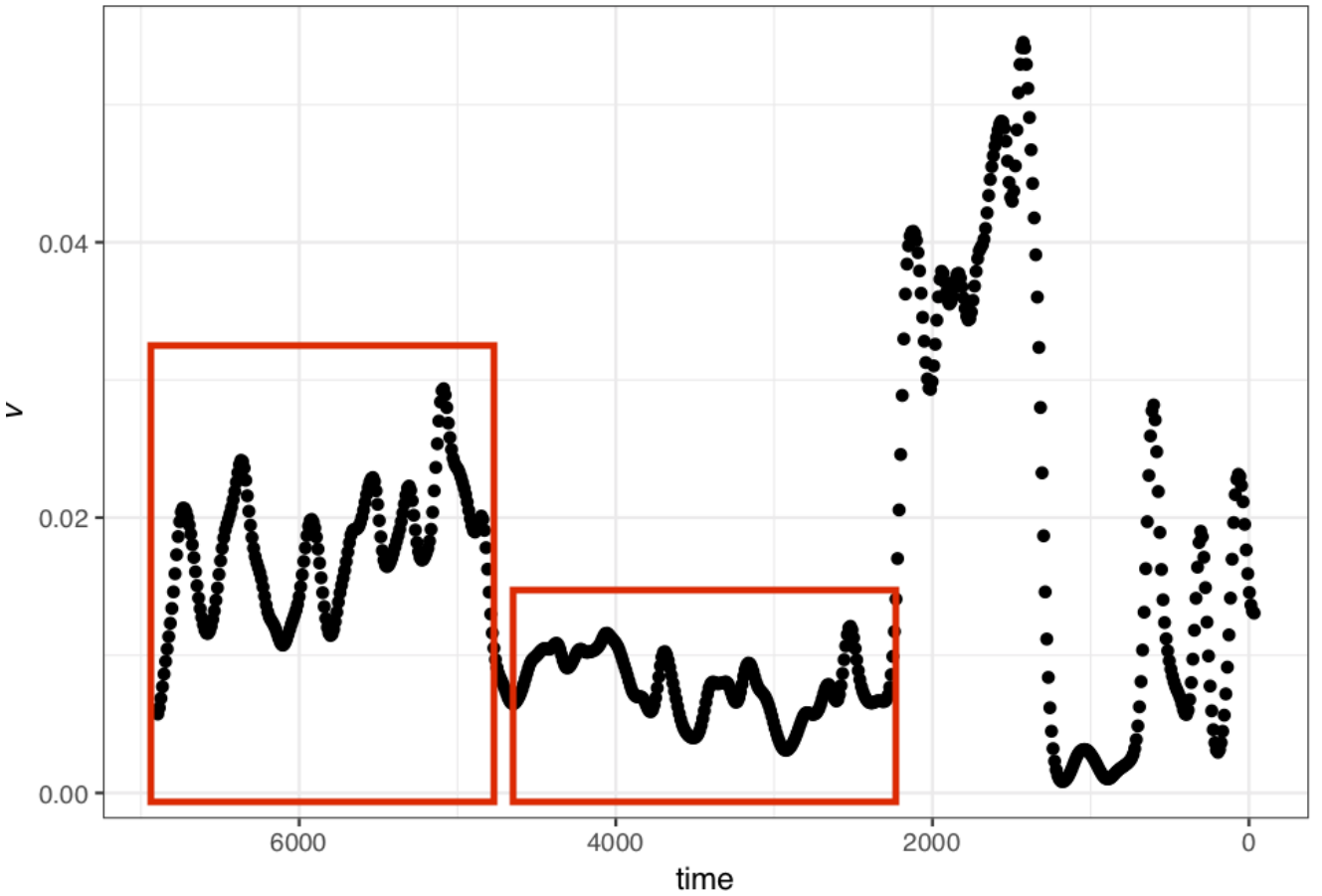


Smoothing Noisy Data Before Calculating v

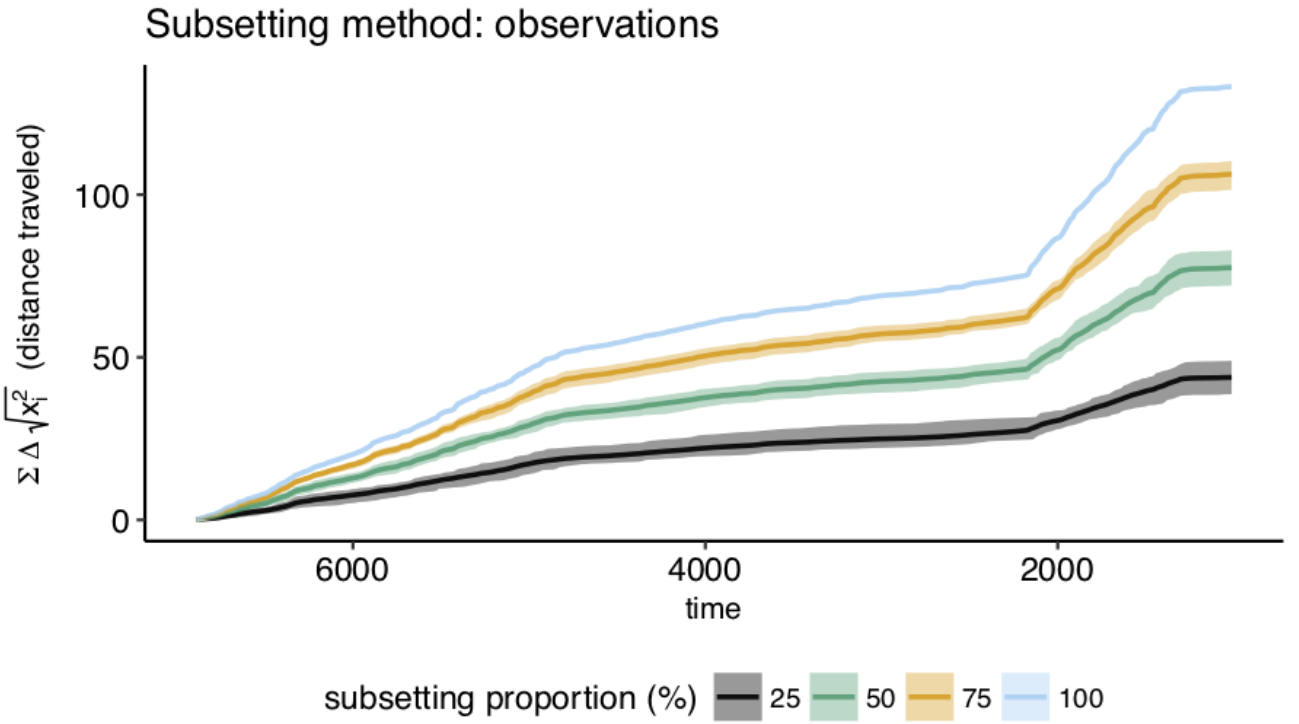
Total Variation Regularized Numerical Differentiation



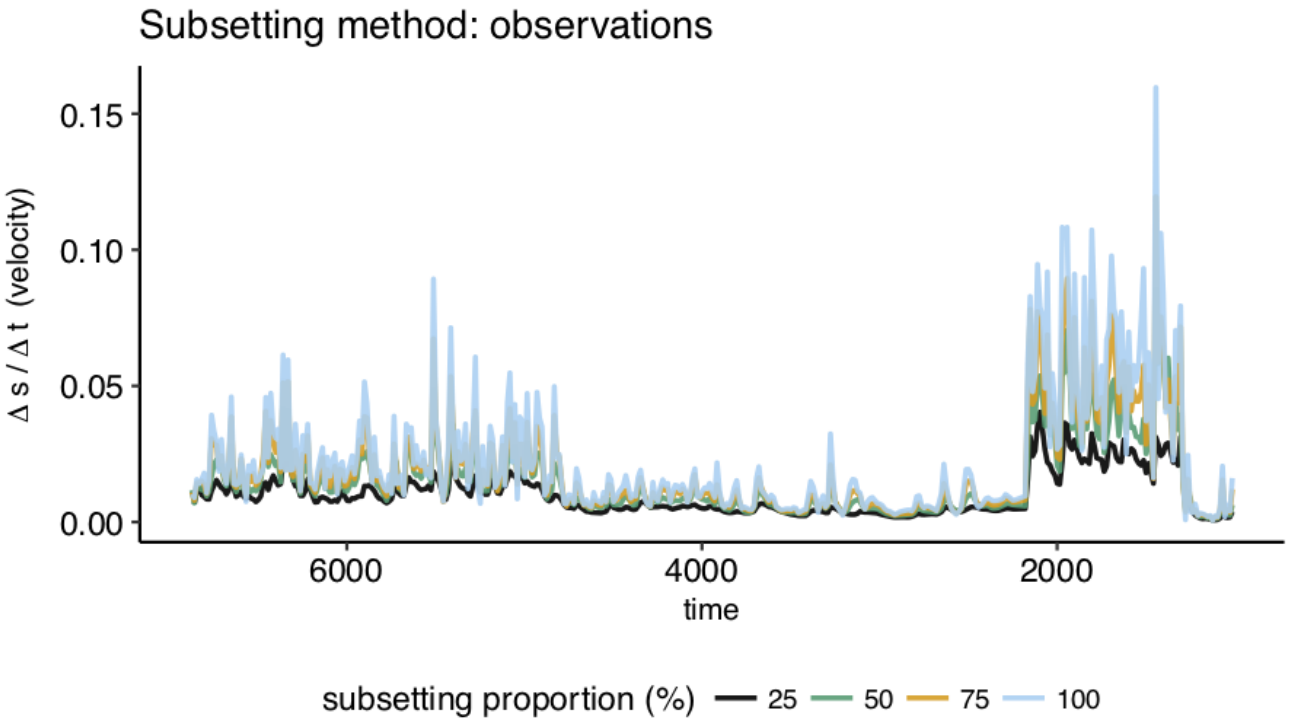
v Identifies Potential Periodicities in Certain Regimes



Impacts of Changes in Data Quality on s and v



Impacts of Changes in Data Quality on s and v



Conclusions

Reduction of high dimensional data

Capable of handling noisy data

Is not sensitive to data quality issues common in ecology

Best when mean > variance

Identifies regime shifts known *a priori*

Next Steps

Numerical identification of change point in v

Compare to distance-based metrics (feedback?)

Compare to ordination techniques

Predictive capacity

Related Software

R packages (dev versions):

`trashbirdecology/distanceTravelled` **(calculate s and v)**

`trashbirdecology/regimeDetectionMeasures` **(calculate multiple regime detection metrics)**

`trashbirdecology/bbsRDM` **(application to spatial data)**

`natbprice/tvdiff` **(regularized differentiation)**