



Velocity of Ecological System Trajectory

A new method for dimension reduction and ecological regime shift detection

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Ecosystems are Complex

(and complicated)

- **high dimensional**
- **many (∞ ?) interactions**
- **non-linear**
- **non-ergodic (open)**
- **dynamic**

Ecosystems are Complex

(and complicated)

- high dimensional
- many (∞ ?) interactions
- non-linear
- non-ergodic (open)
- dynamic
- difficult to model mathematically

Ecosystems are Complex



Image credit: coolkeywest.com

The Holy Grail of Ecology

forecasting change in time to prevent or
mitigate undesirable consequences

The Holy Grail of Ecology

Predicting undesirable change



Image credit: [The Ocean Agency](#)

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 **sparsedata**

few handle irregular sampling

Regime Shifts Detection Methods

Variance Index (max eigenvalue of covariance matrix)

Principal Coordinates Analysis

Fisher Information

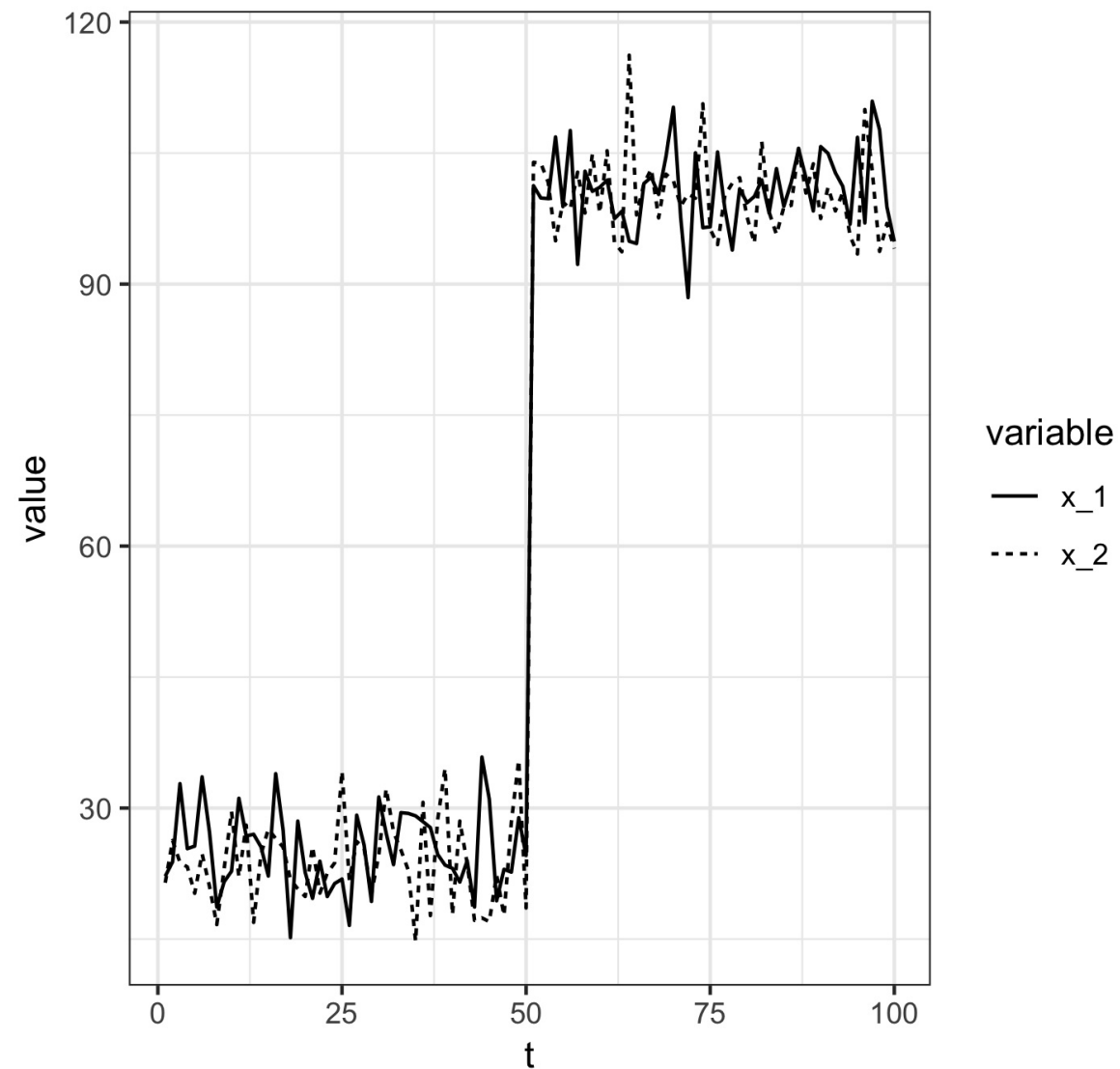
Regime Shifts Detection Methods

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Toy System

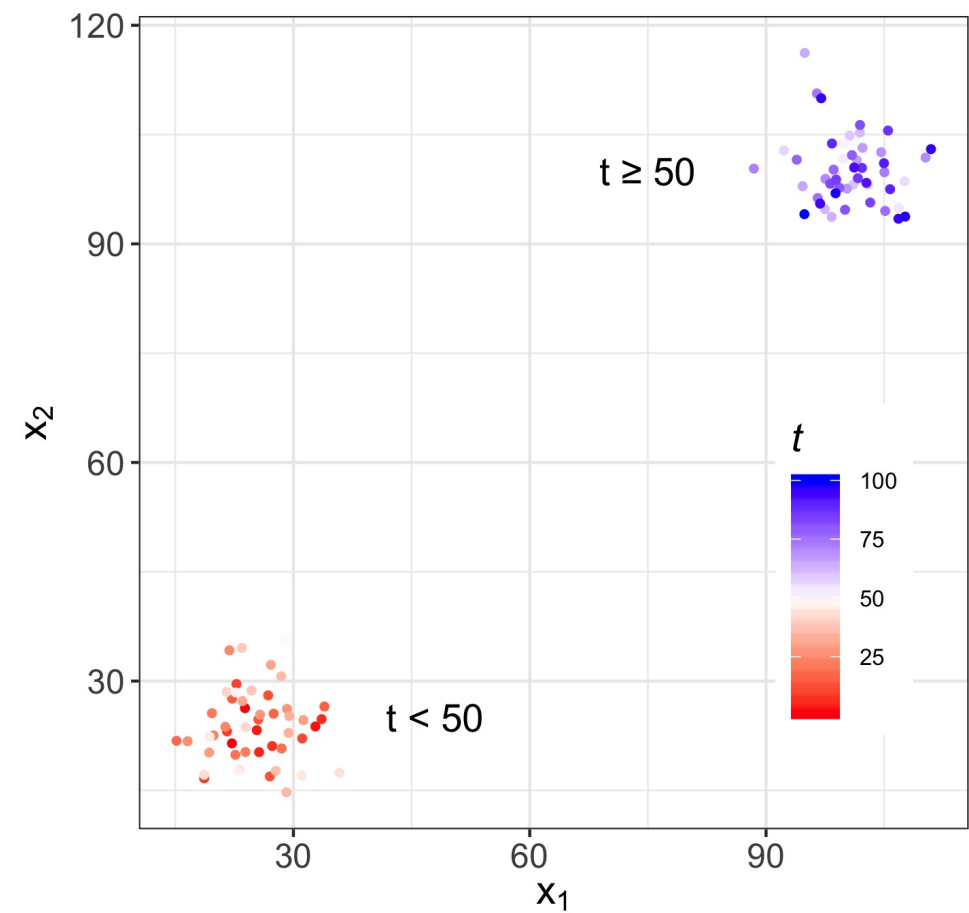
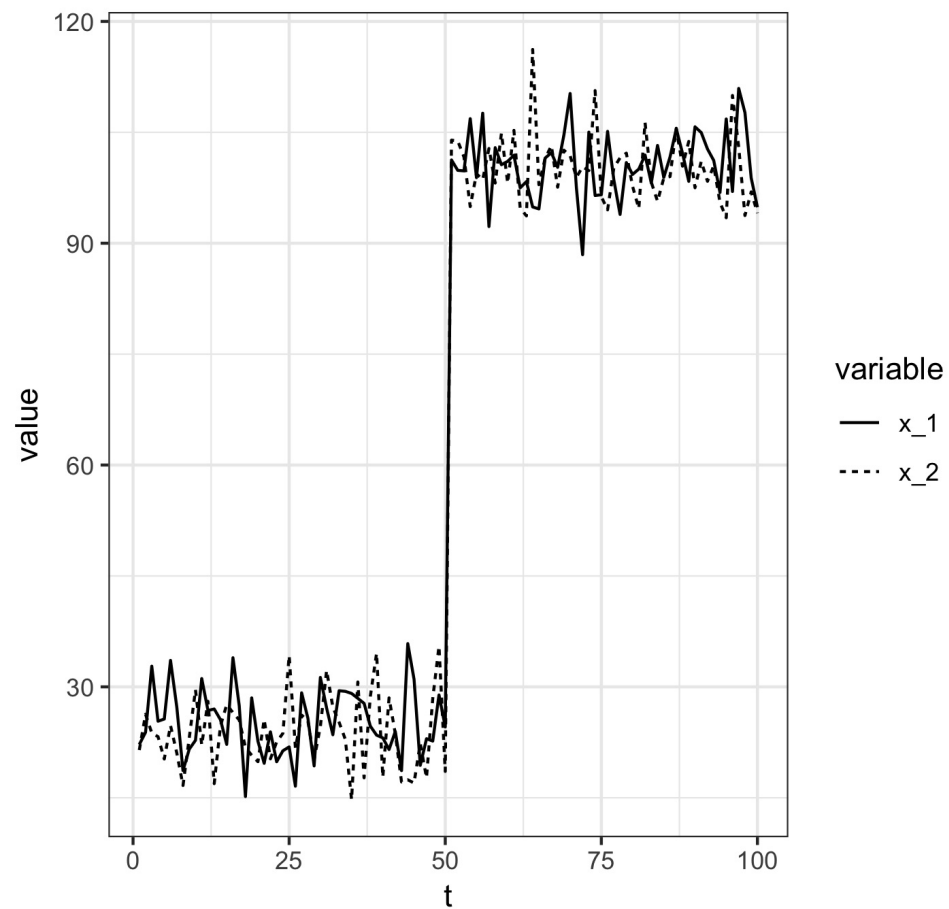


$x \text{ normal}(\mu = 25, \sigma = 5)$ for $t > 50$

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

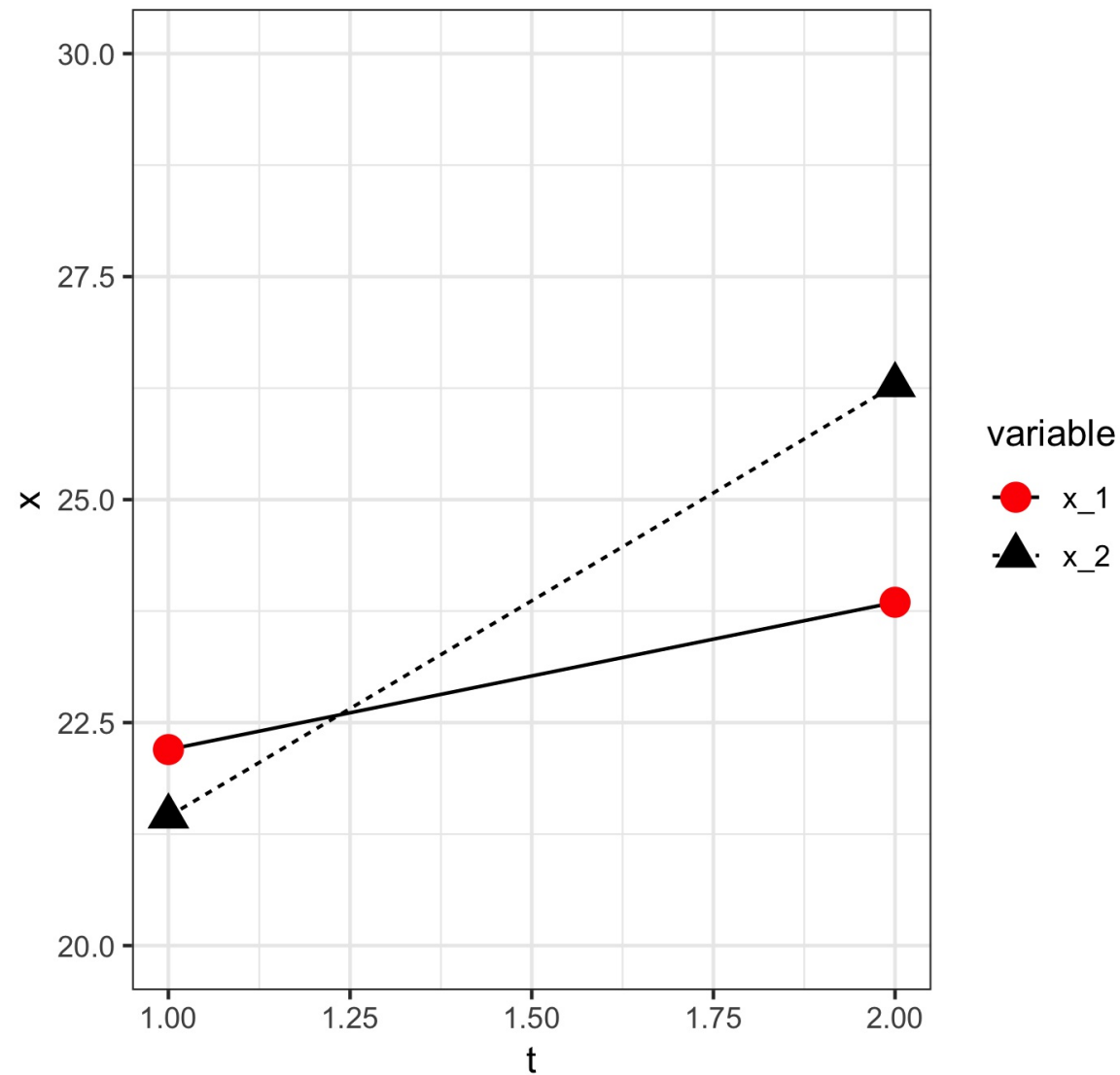
Velocity, $\frac{\Delta s}{\Delta t}$

the linear speed of a system's trajectory in phase space



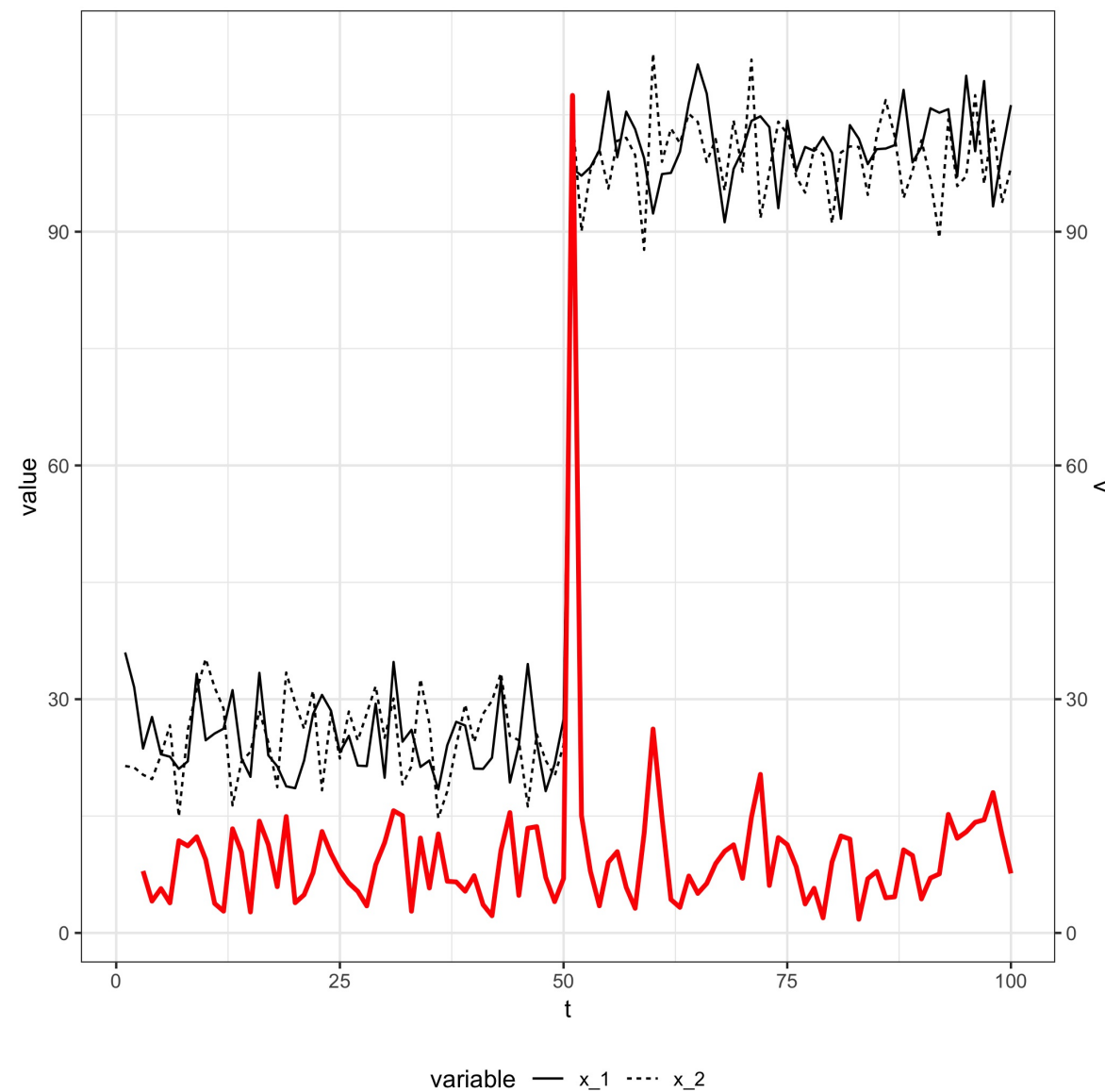
Step 1: Calculate s , 'distance travelled'

$$s_t = \sqrt{\sum_{i=1}^X (x_{it} - x_{it-1})^2}$$

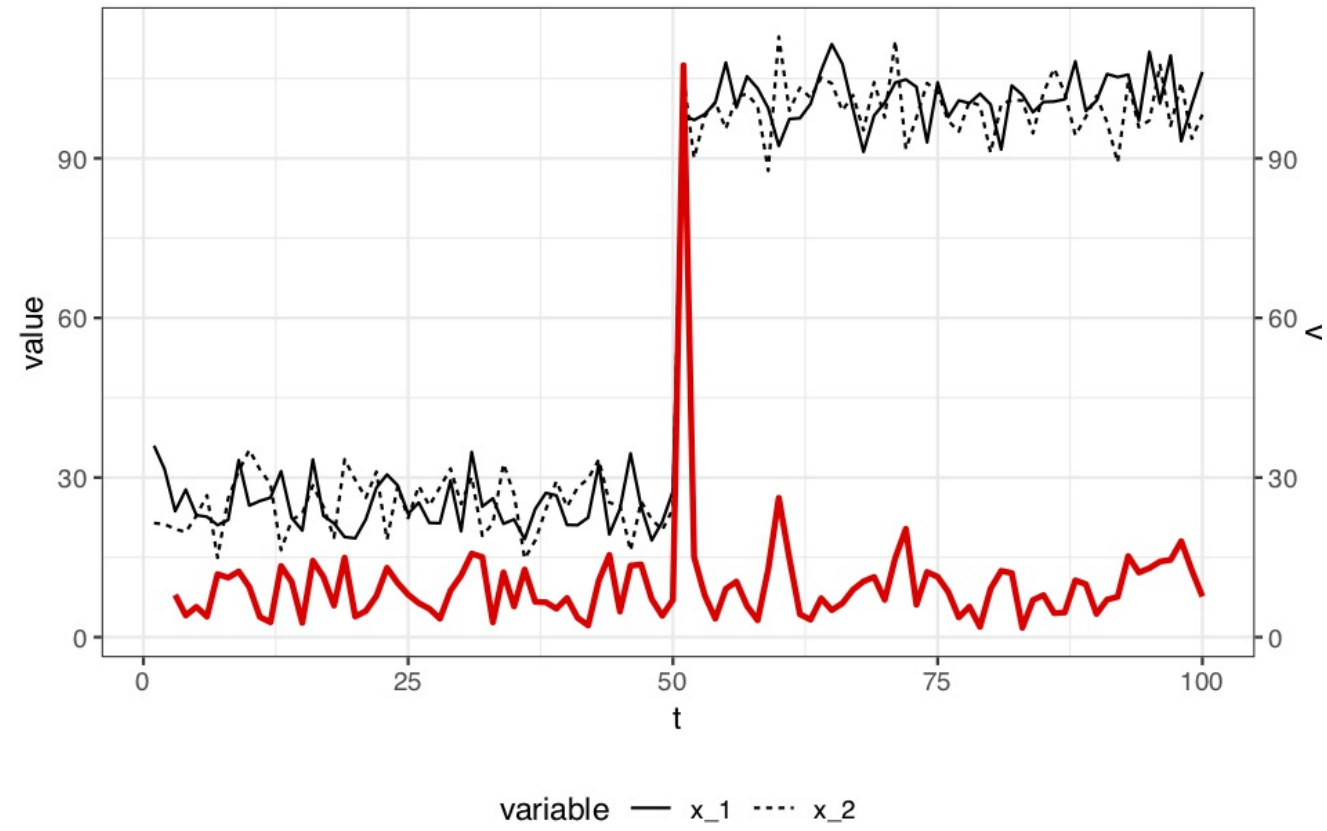


Step 2: Calculate v , the linear speed of s

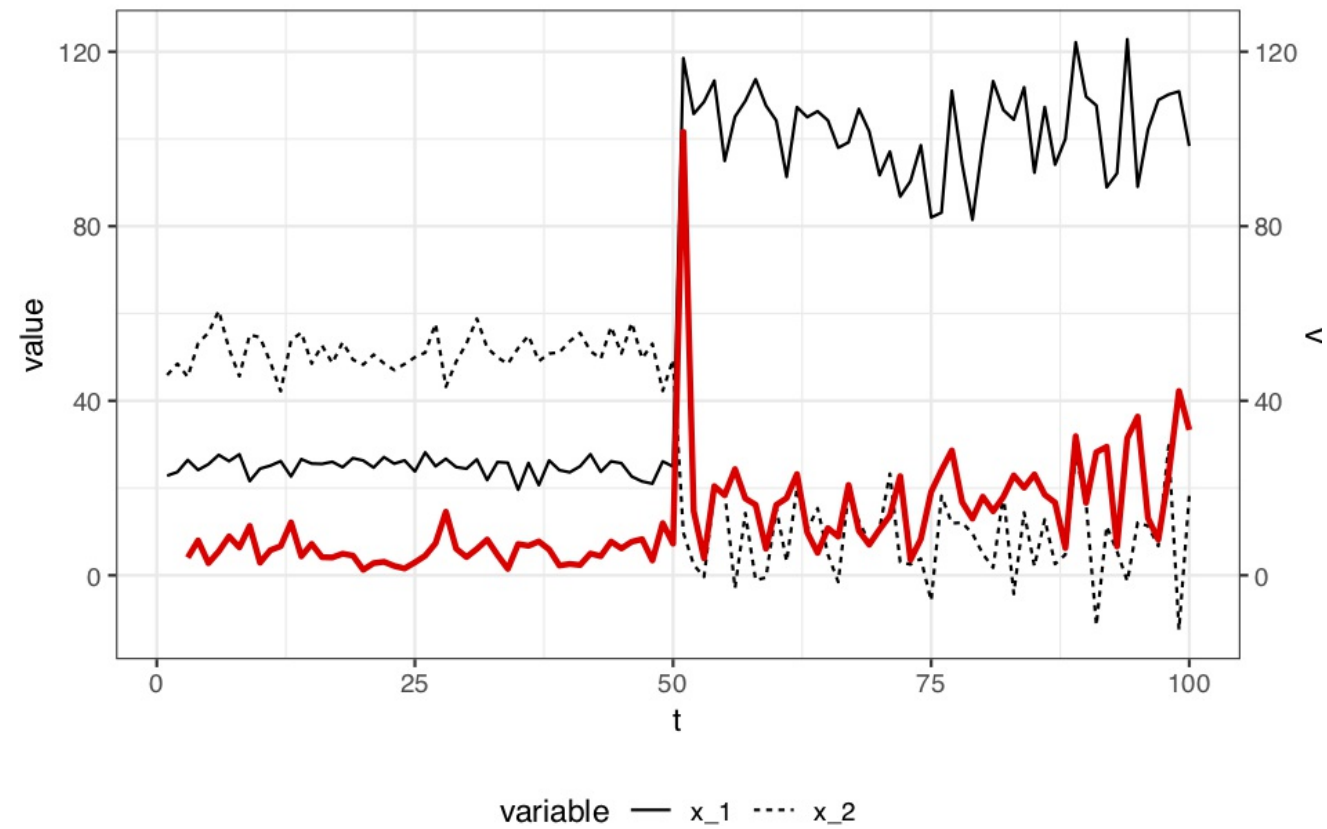
$$v = \frac{\Delta s}{\Delta t}$$



changing means, constant variance

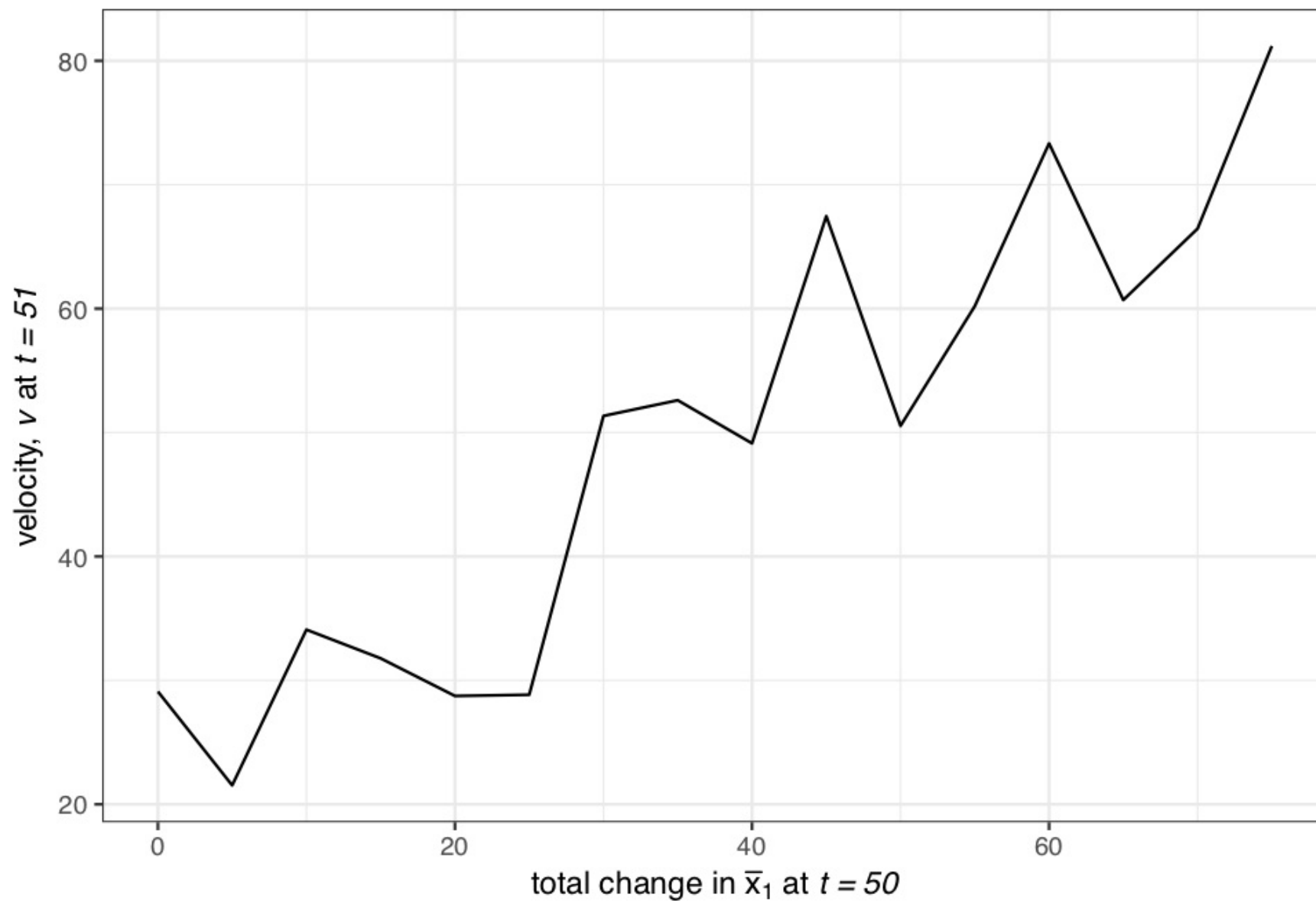


change in mean & variance (x_1, x_2)

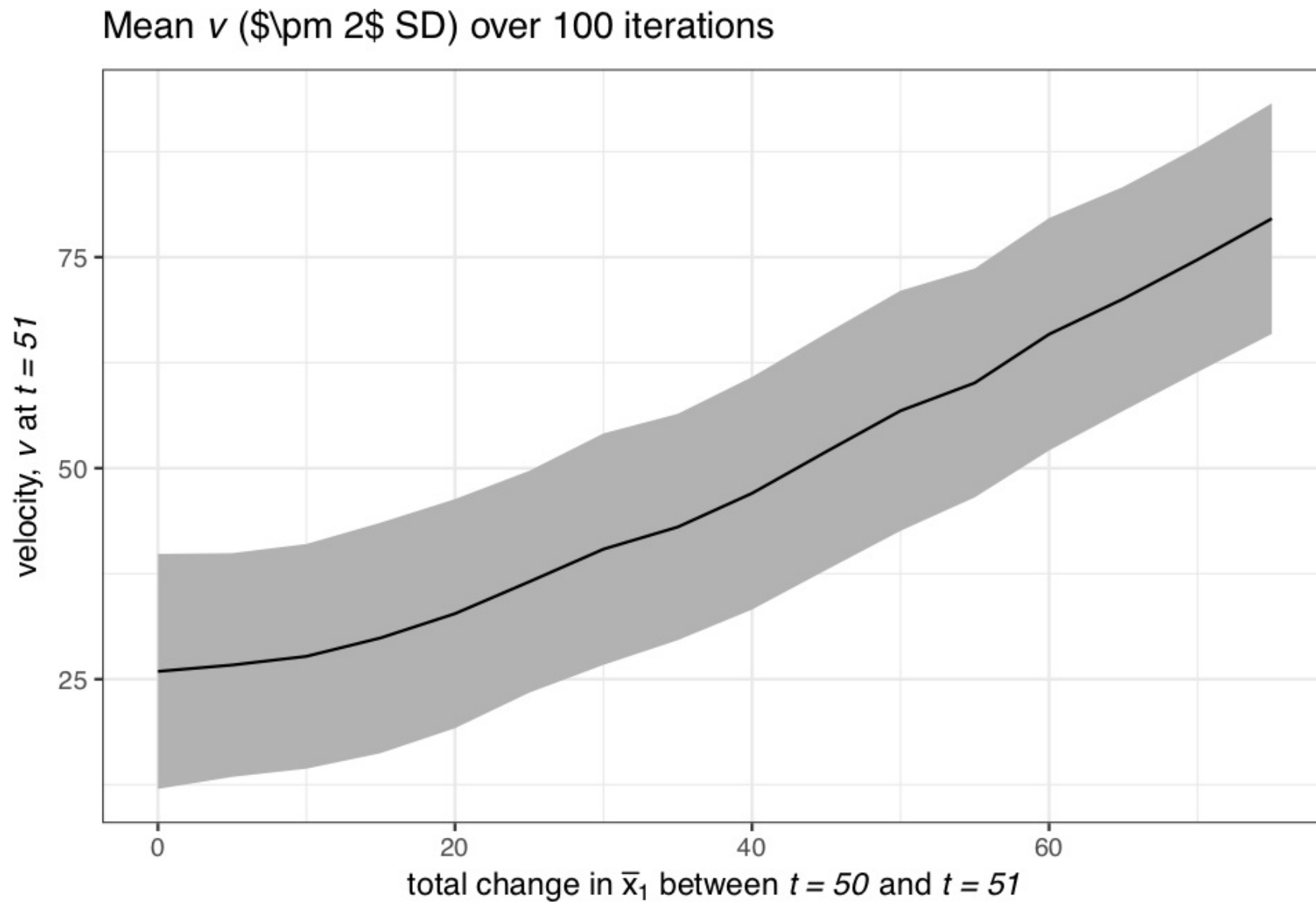


Potential Limitations of ν

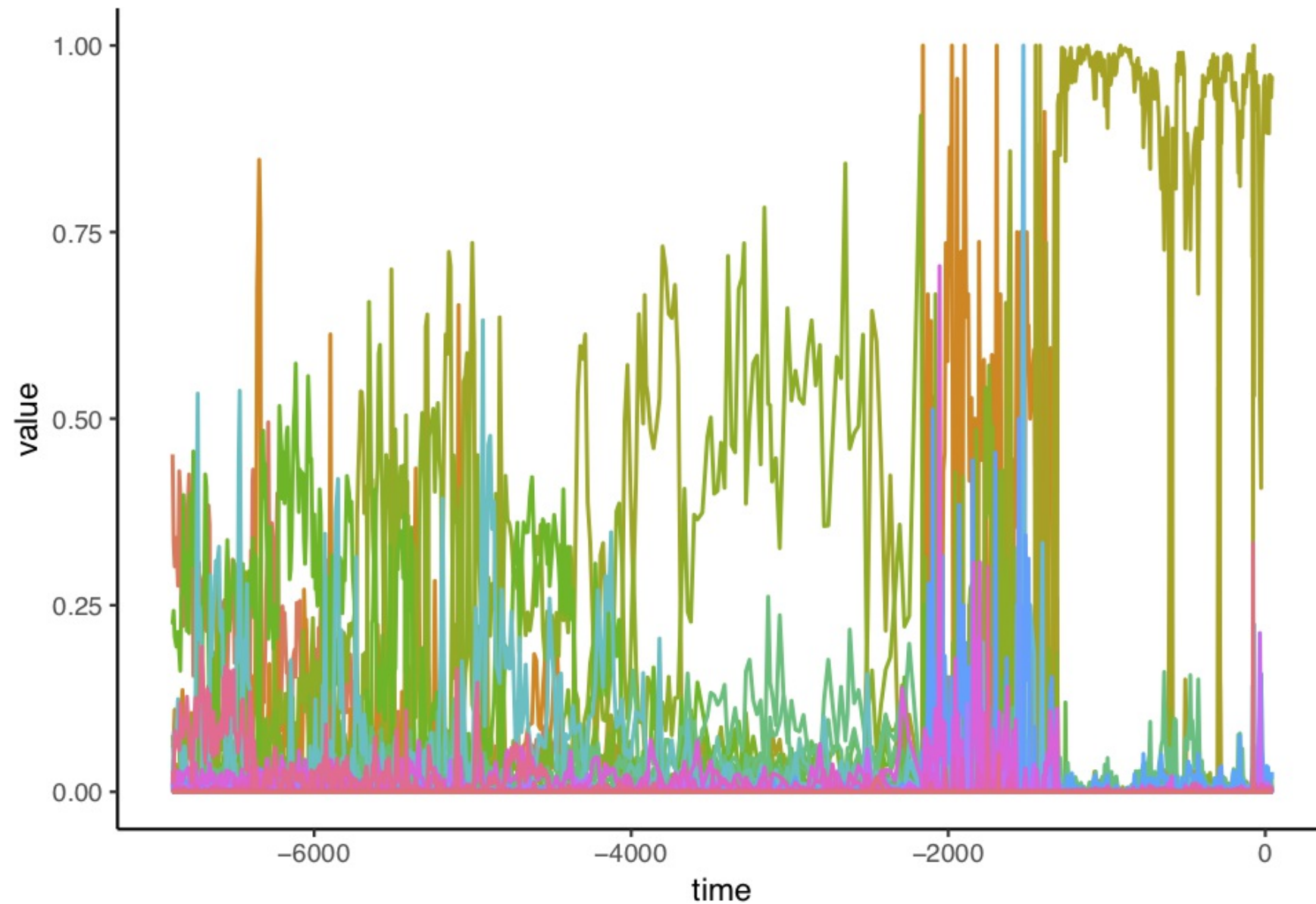
ν increases with increasing effect size



v increases with increasing effect size

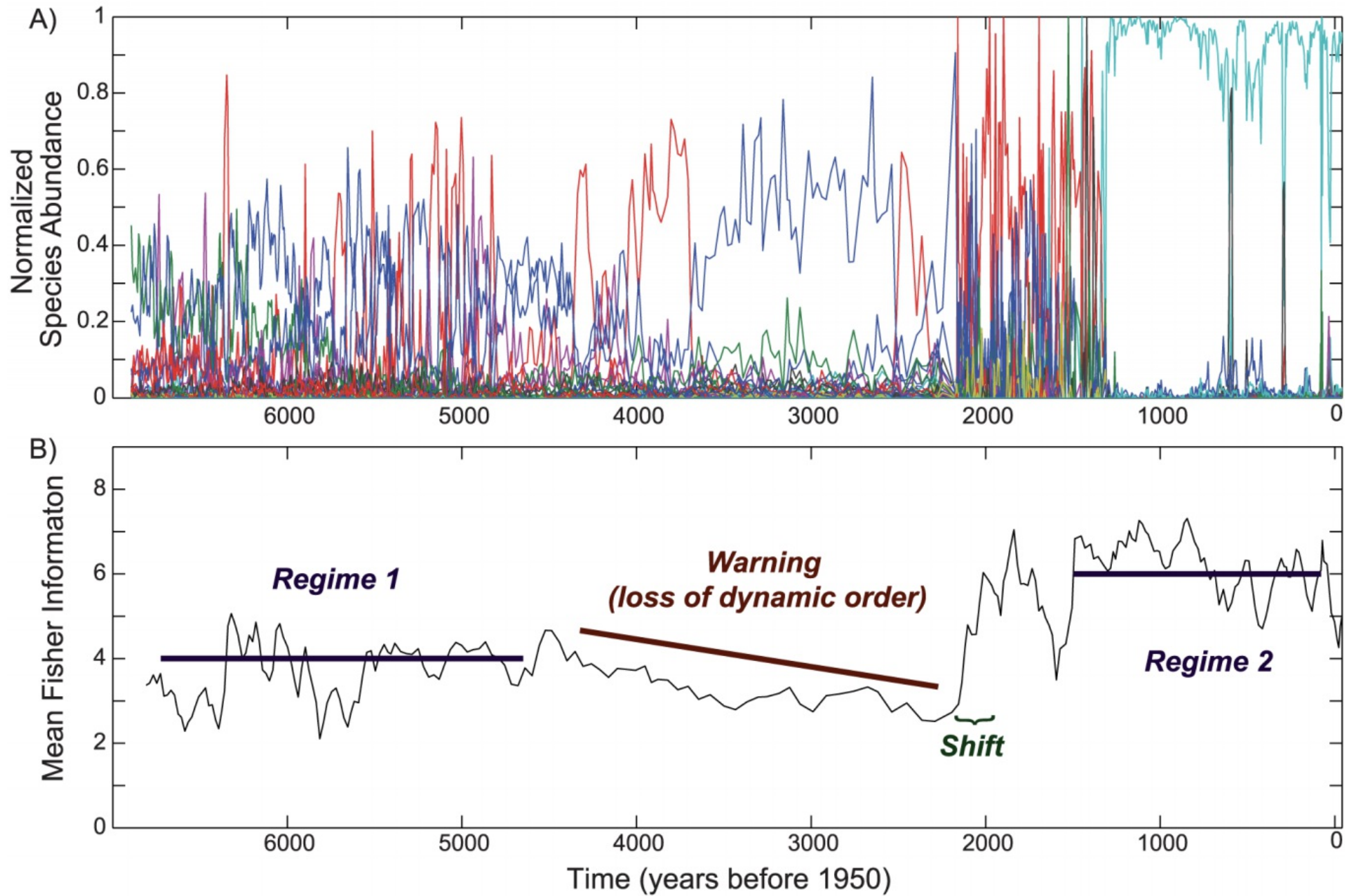


Empirical System: Paleodiatoms



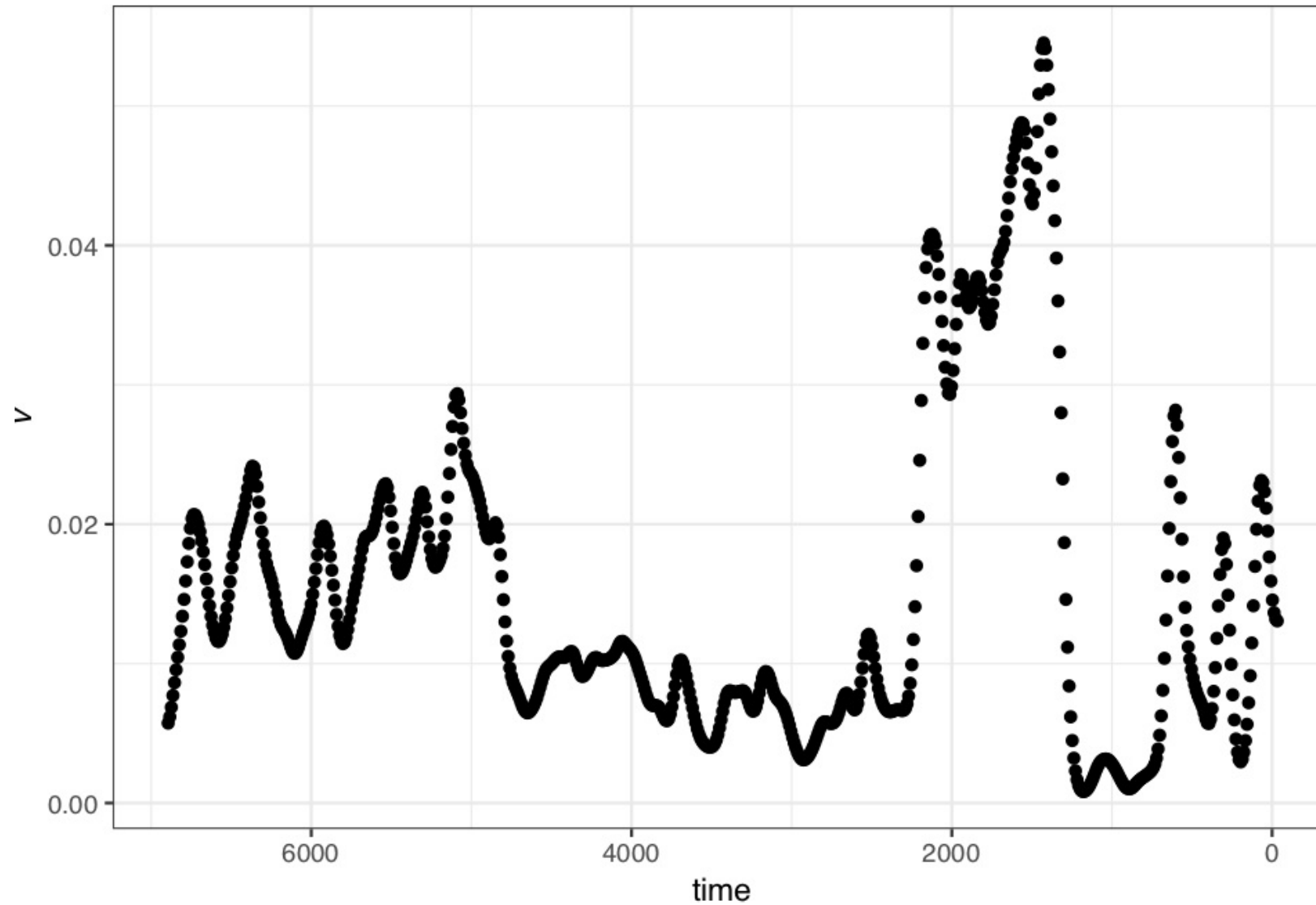
Data published in Spanbauer *et al.* 2014. Prolonged Instability Prior to a Regime Shift. PLoS One

Empirical System: Paleodiatoms

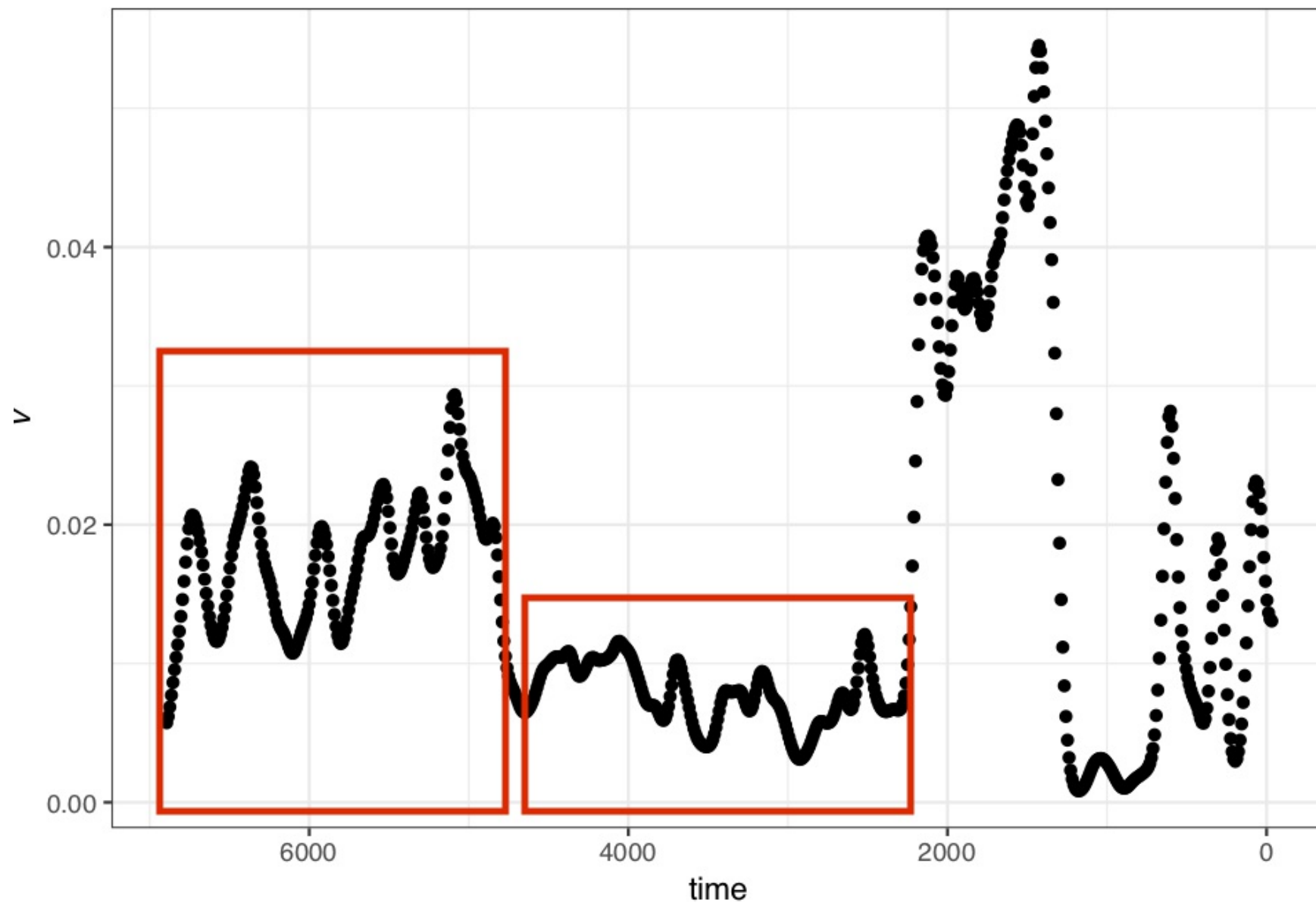


Distance travelled s & Velocity v identify these turnover events

Smoothing Noisy Data Before Calculating ν



✓ Identifies Potential Periodicities in Certain Regimes



Conclusions: ν is Simple, Intuitive

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 ν

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**)

