Statistics Café SoSe 2018

Time Series III

“Using equation-free methods to analyse and forecast ecological systems from time series data.”

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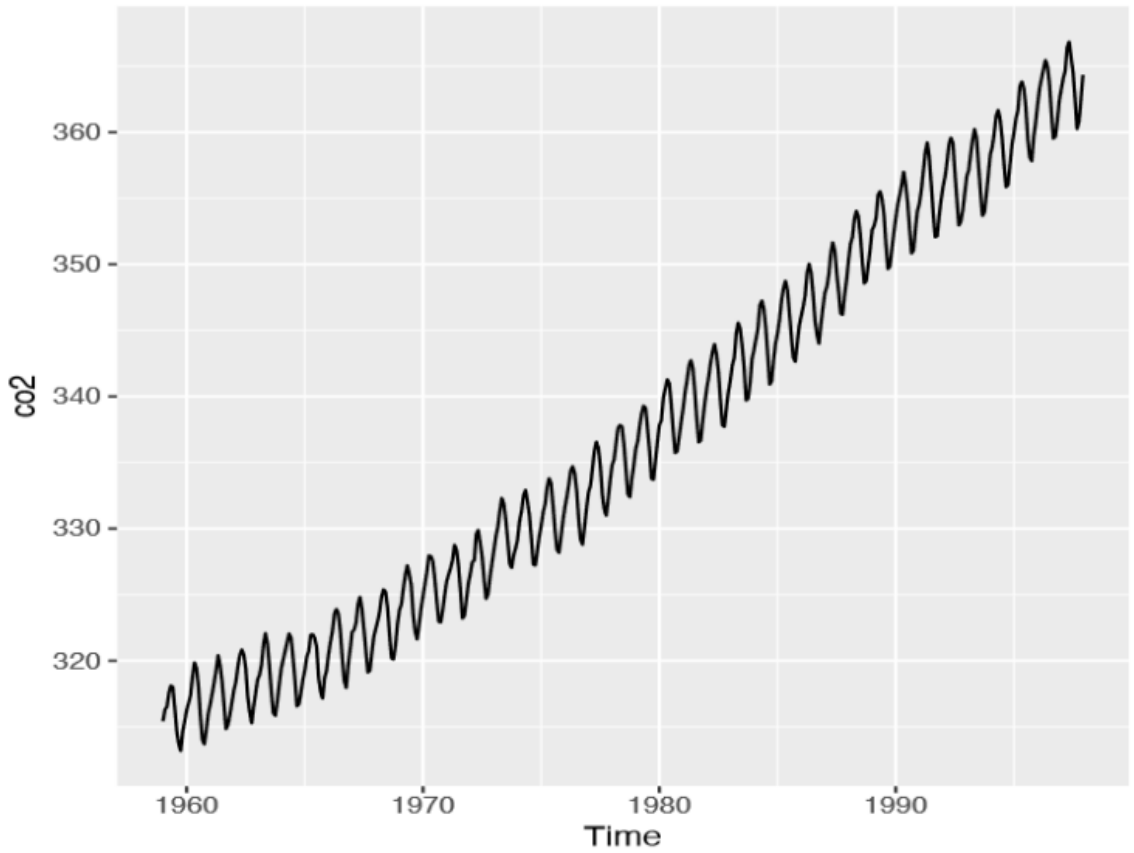


Dormann (2018)

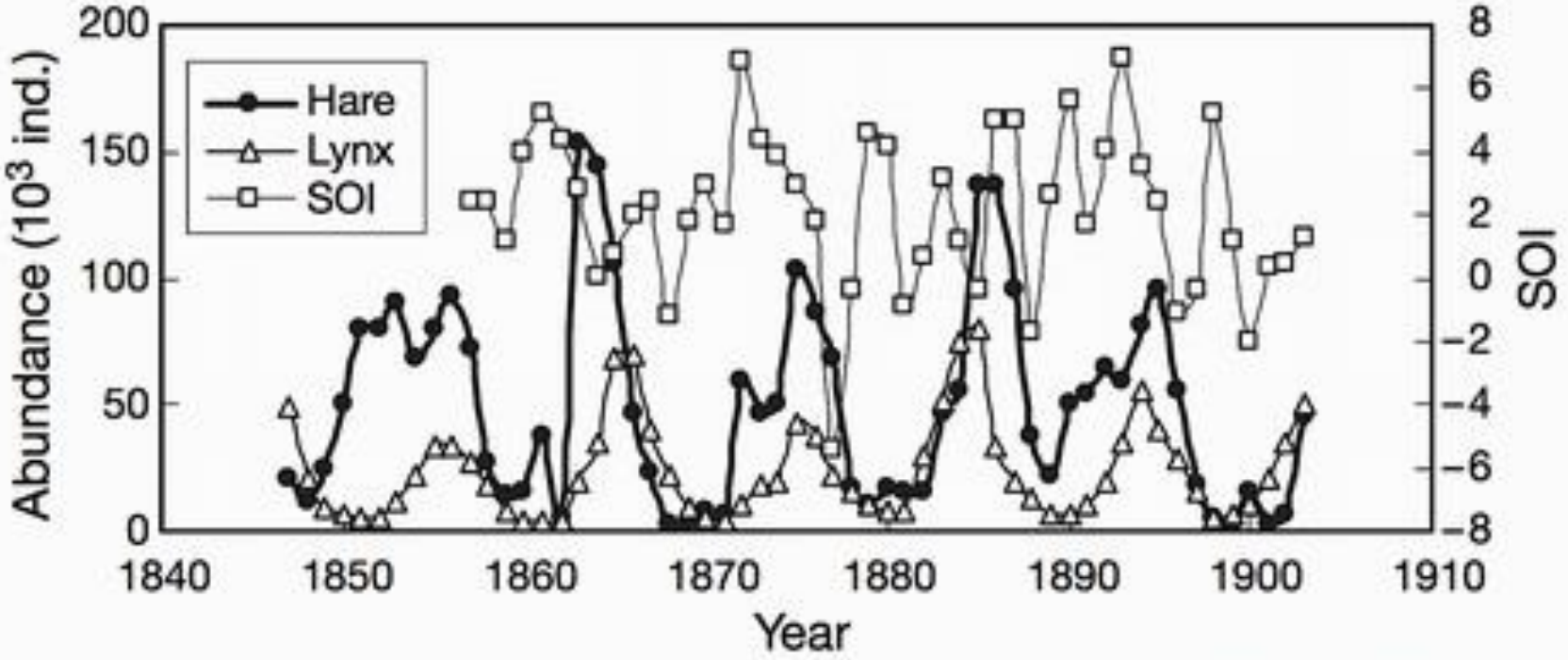
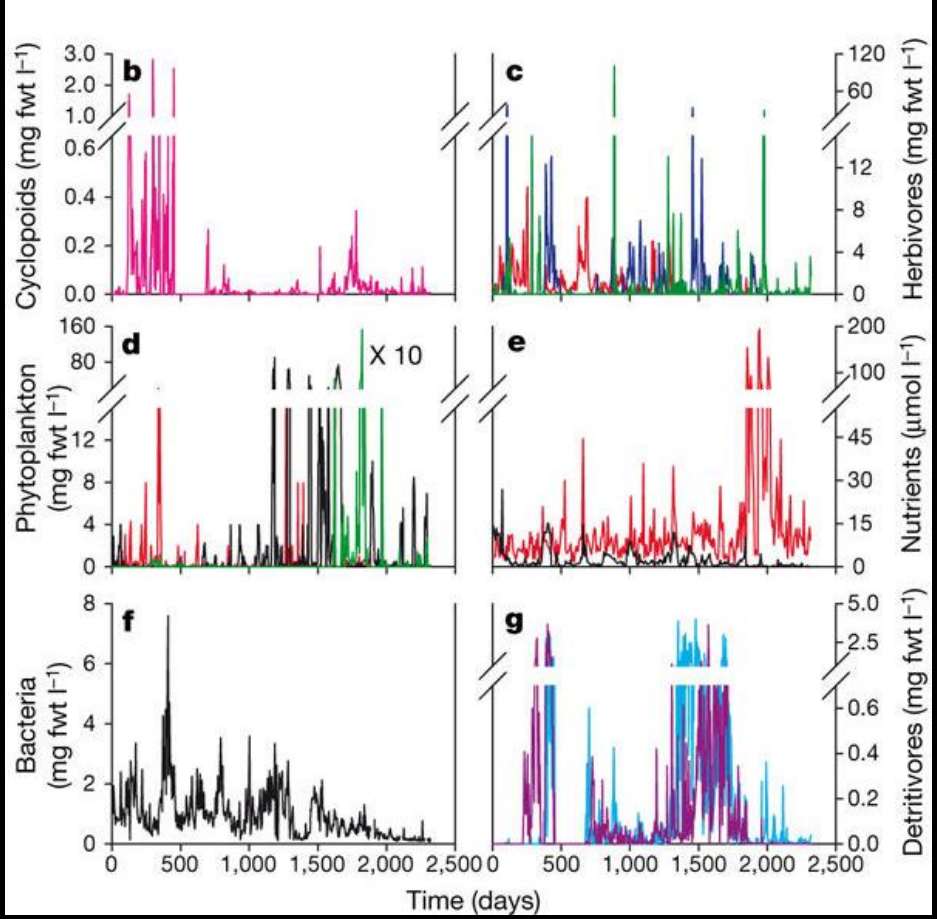
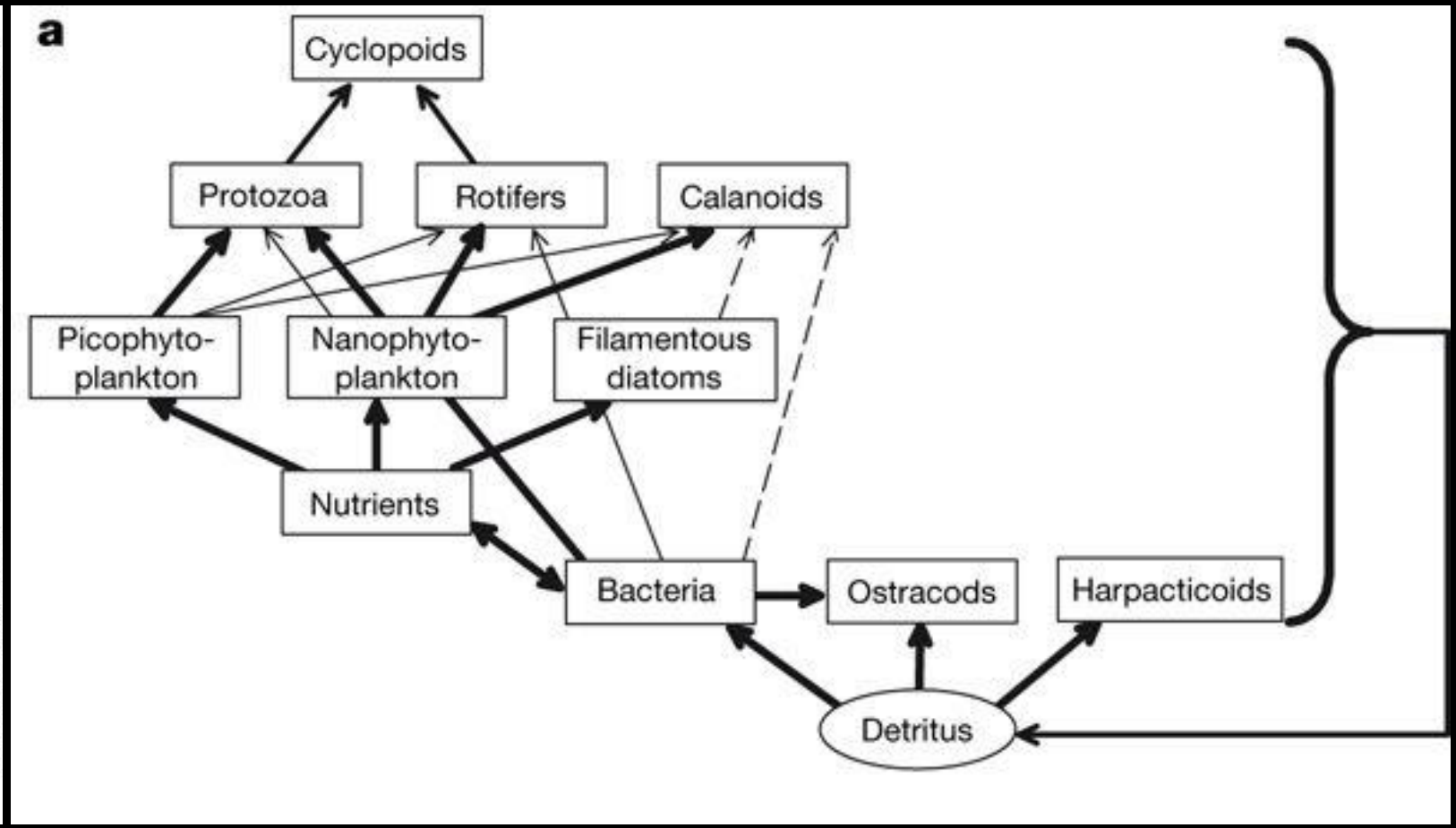


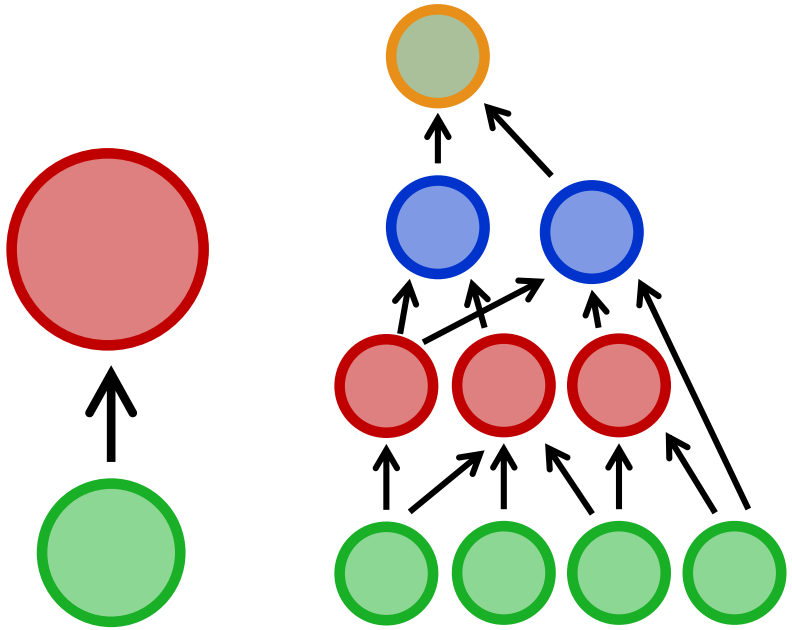
Fig. 1. *Lepus americanus* and *Lynx canadensis*. Hare and lynx abundances (redrawn from Leigh 1968) and Southern Oscillation Index (SOI) (data from Shi & Wang 1989) during 1847–1903

Zhang et al (2007) *Climate Research* 34:83–89.





Benica et al (2008) *Nature* 451:822–825.

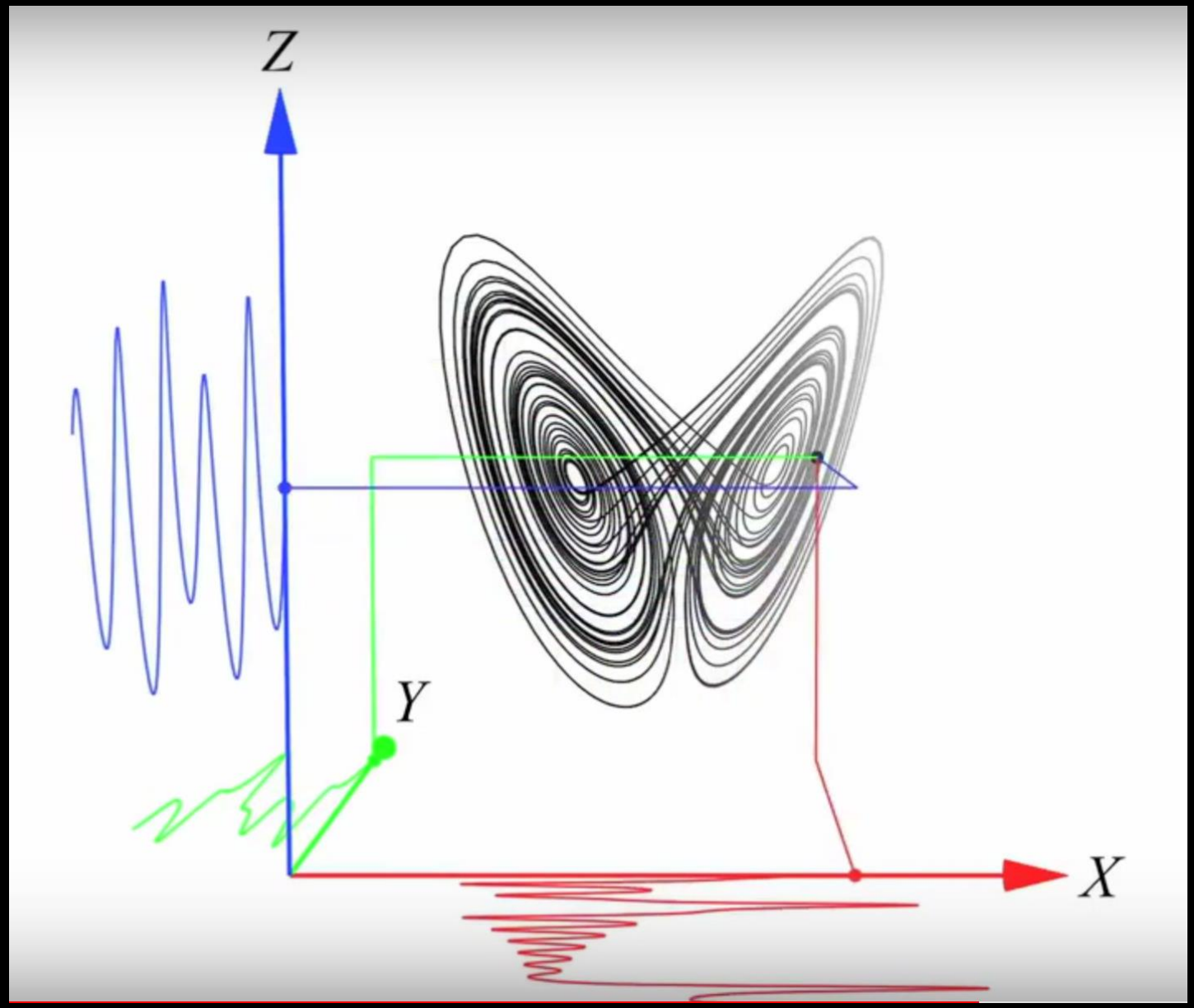


$$\frac{dX}{dt} = f(X, Y, Z, \ldots)$$

$$\frac{dY}{dt} = f(X, Y, Z, \ldots)$$

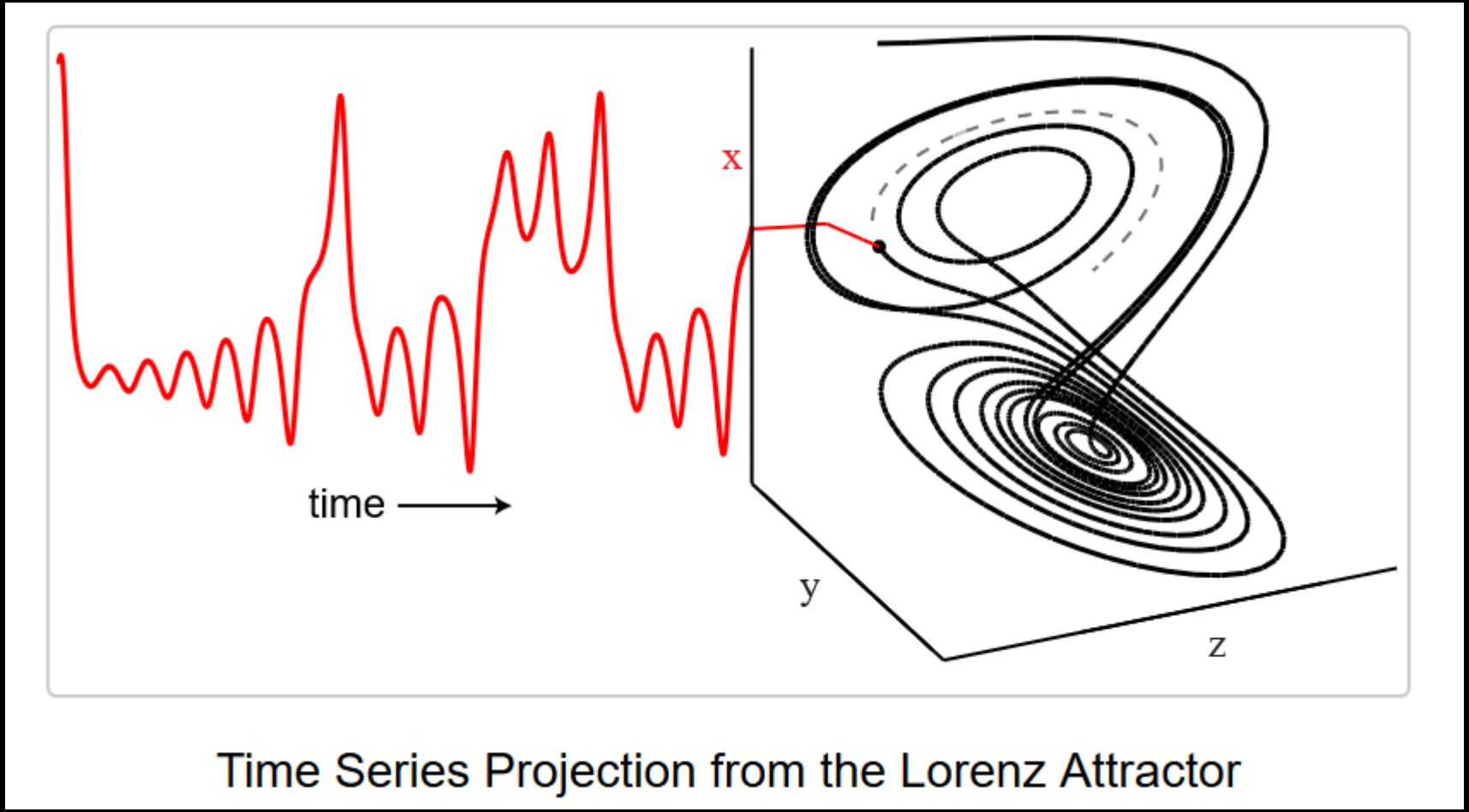
$$\frac{dZ}{dt} = f(X, Y, Z, \ldots)$$

- **Highly dynamic**
- **Non-linear**
- **State-dependent**
- **Time-lagged**
- **Fluctuating, chaotic, multi-stable**



Sugihara et al (2012) *Science* 338:496–500.

State-space or attractor reconstruction (after Takens' Theorem)

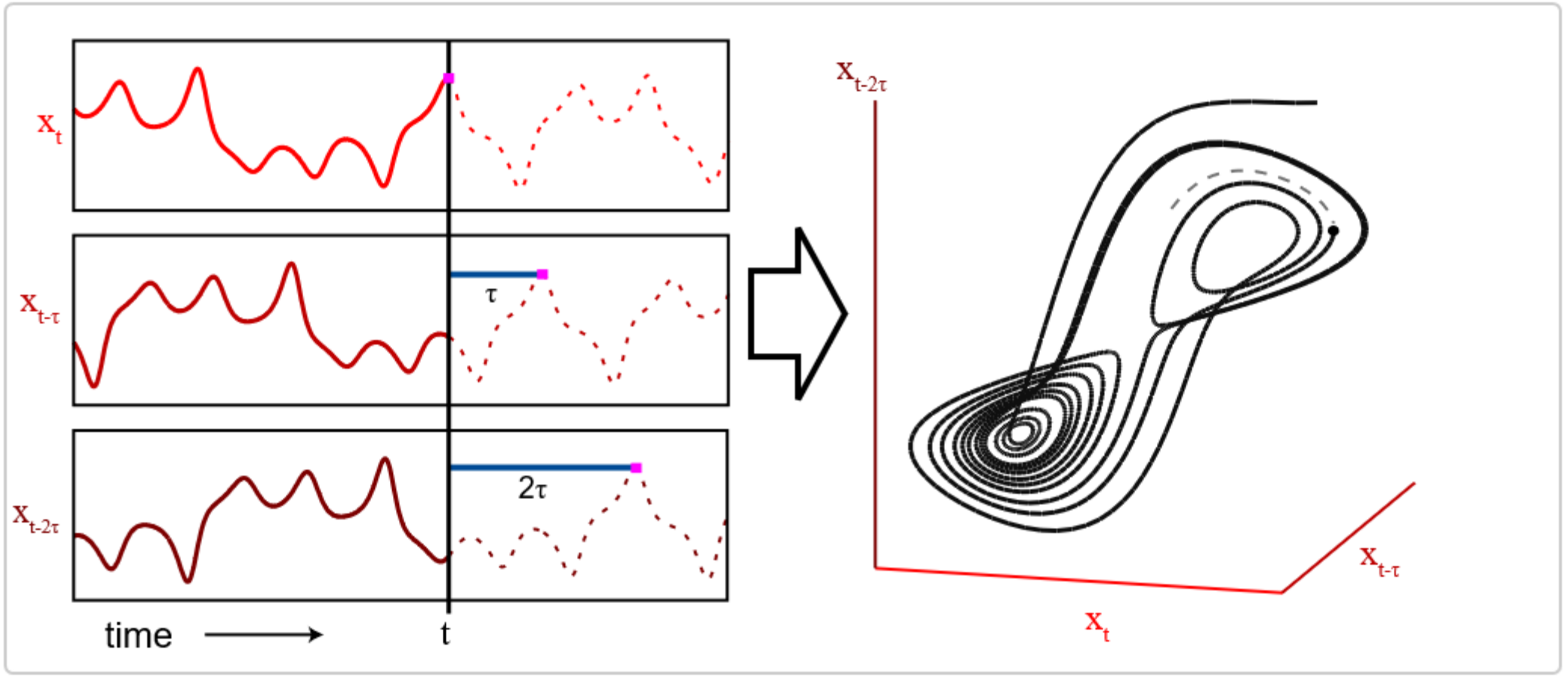


Time Series Projection from the Lorenz Attractor

Ye et al. (2017). https://cran.r-project.org/web/packages/rEDM/vignettes/rEDM-tutorial.html

Univariate embedding using lags

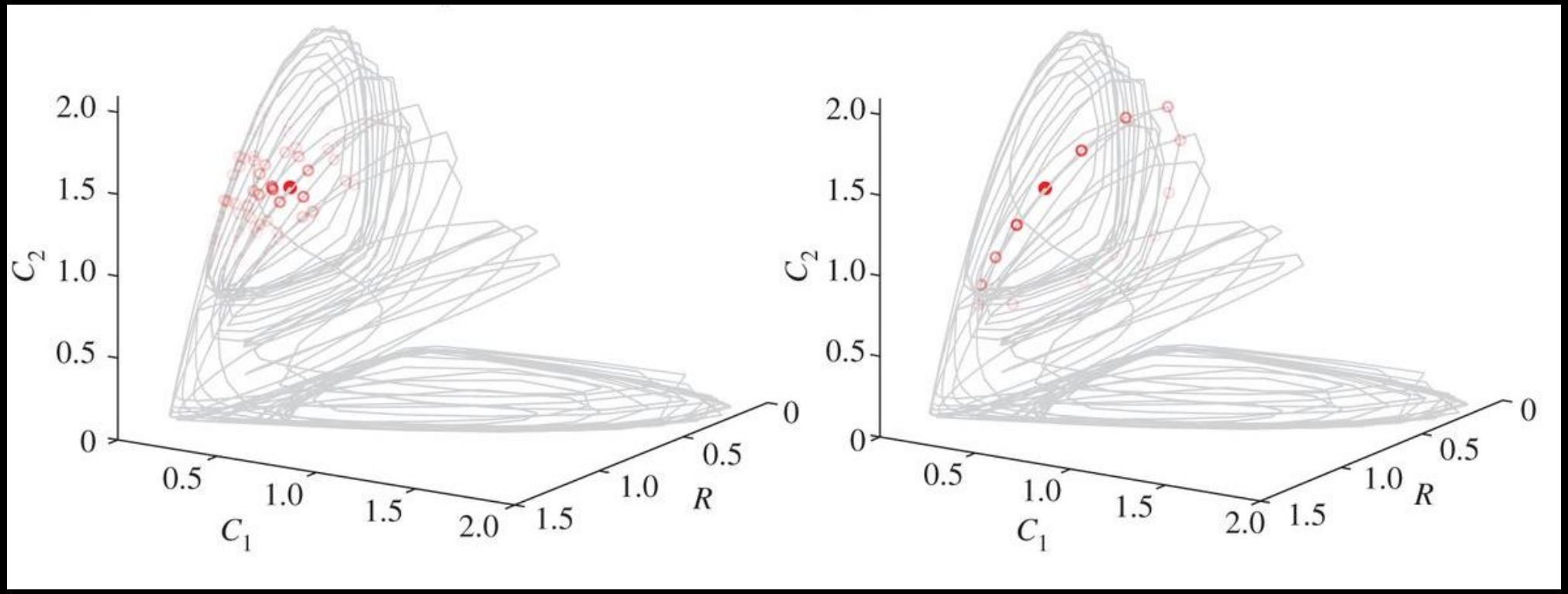
$$\vec{x}_t = \langle x_t, x_{t-\tau}, \ldots, x_{t-(E-1)\tau} \rangle$$



Attractor Reconstruction from Lagged Coordinates

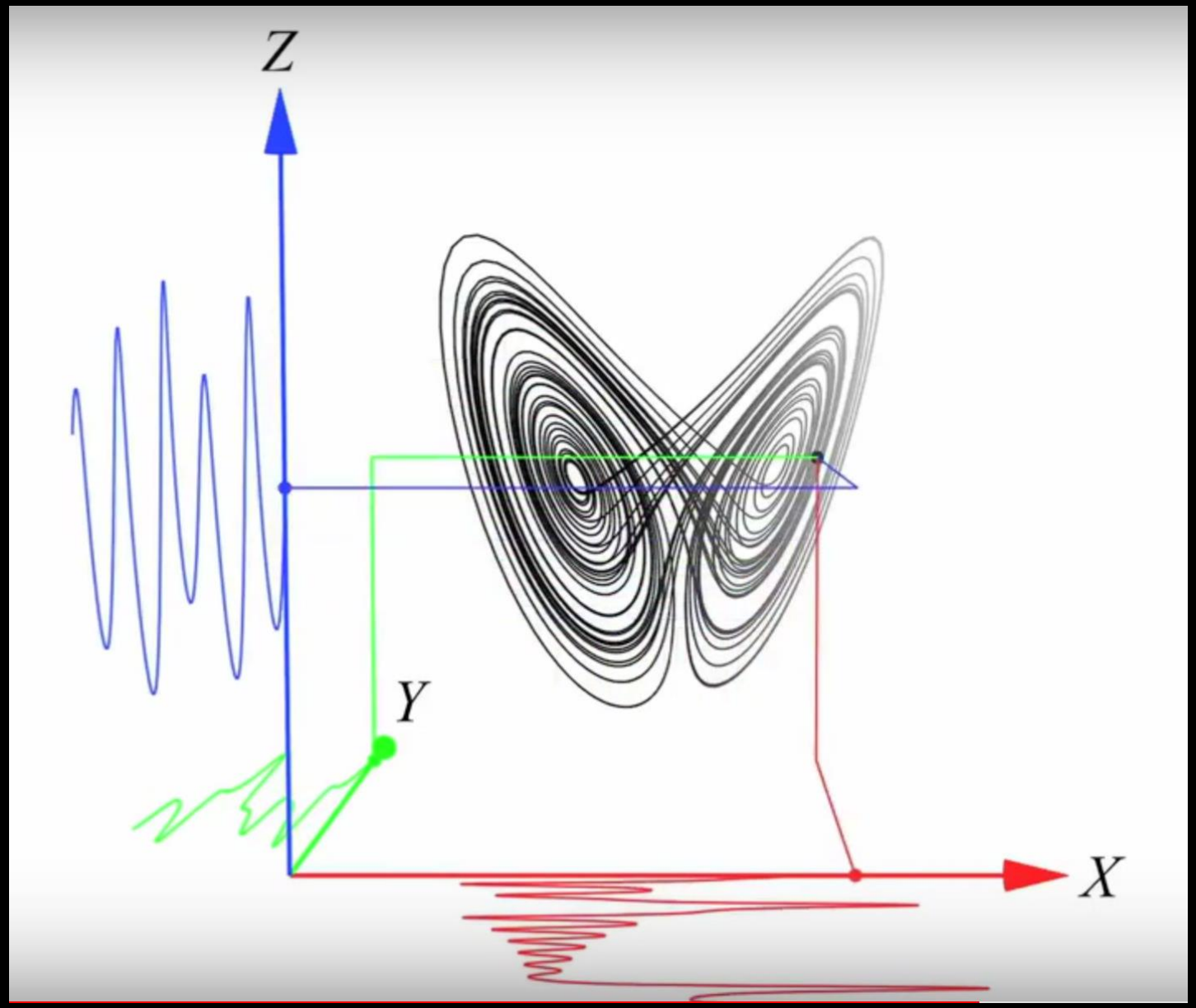
Ye et al. (2017). https://cran.r-project.org/web/packages/rEDM/vignettes/rEDM-tutorial.html

Simplex Projection and S-maps:
Forecasting using distance in state-space vs. distance in time



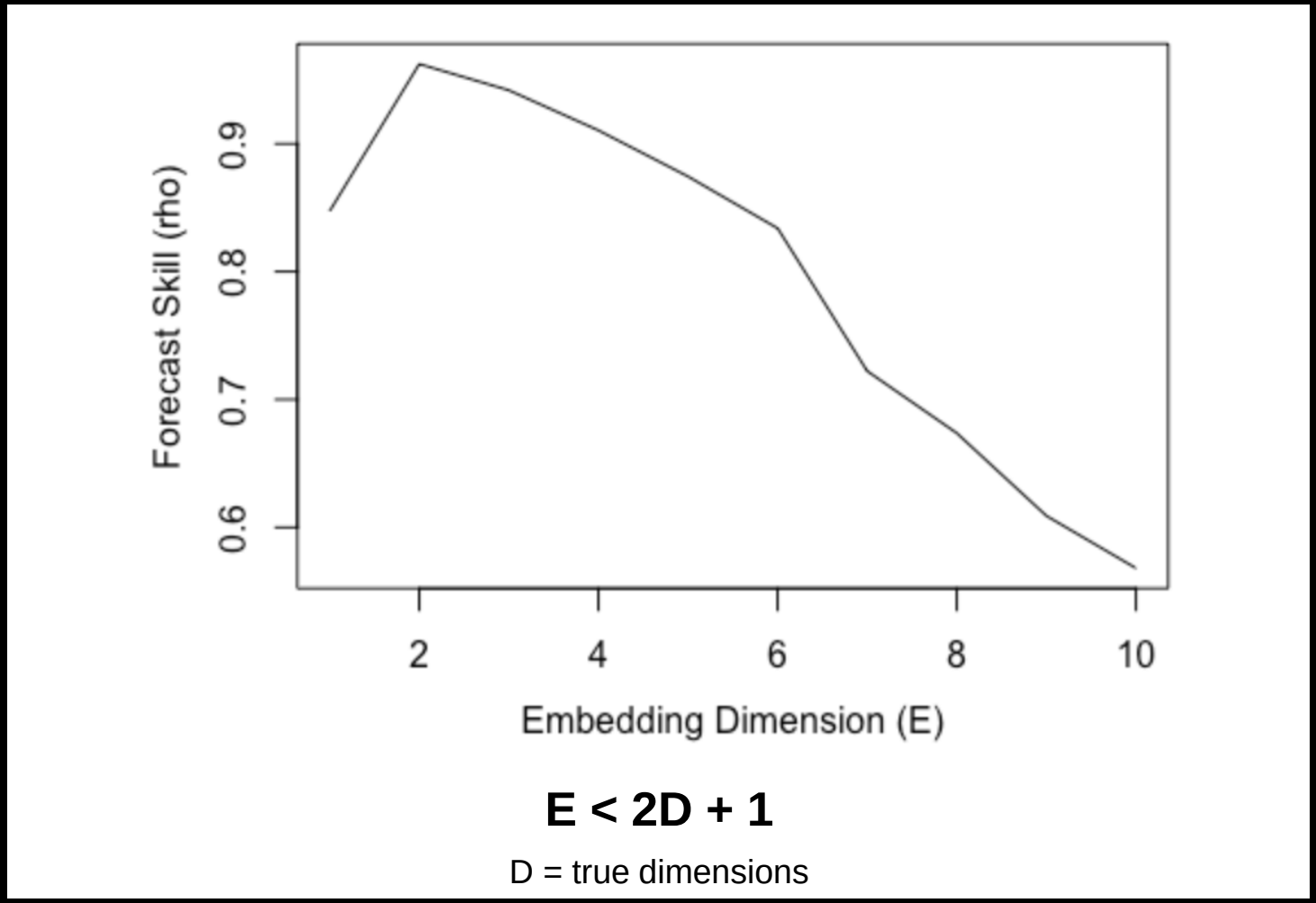
Ethan R. Deyle et al. Proc. R. Soc. B 2016;283:20152258

Multivariate embedding



Sugihara et al (2012) *Science* 338:496–500.

1) Complexity of the system

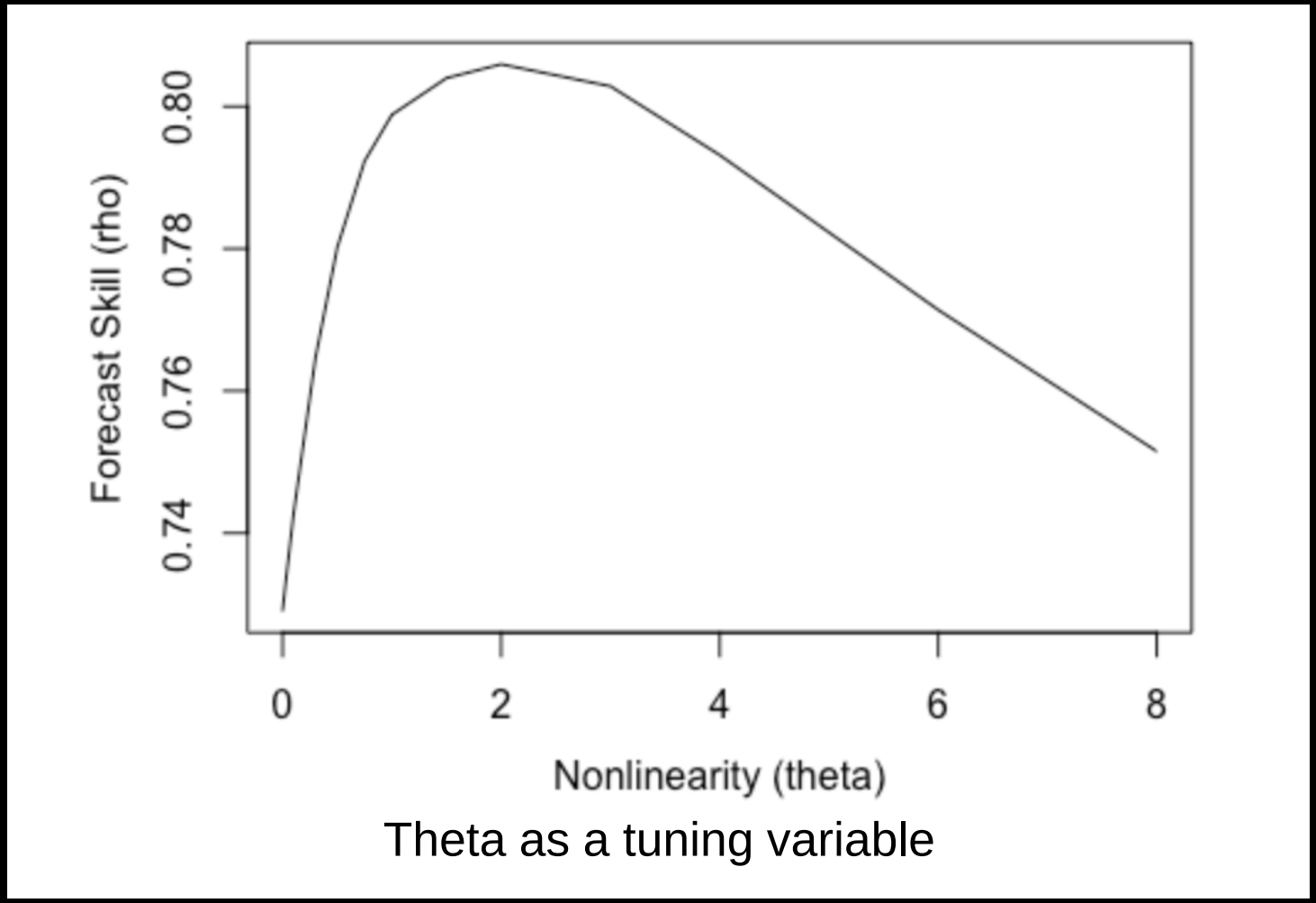


E < 2D + 1

D = true dimensions

Ye et al. (2017). https://cran.r-project.org/web/packages/rEDM/vignettes/rEDM-tutorial.html

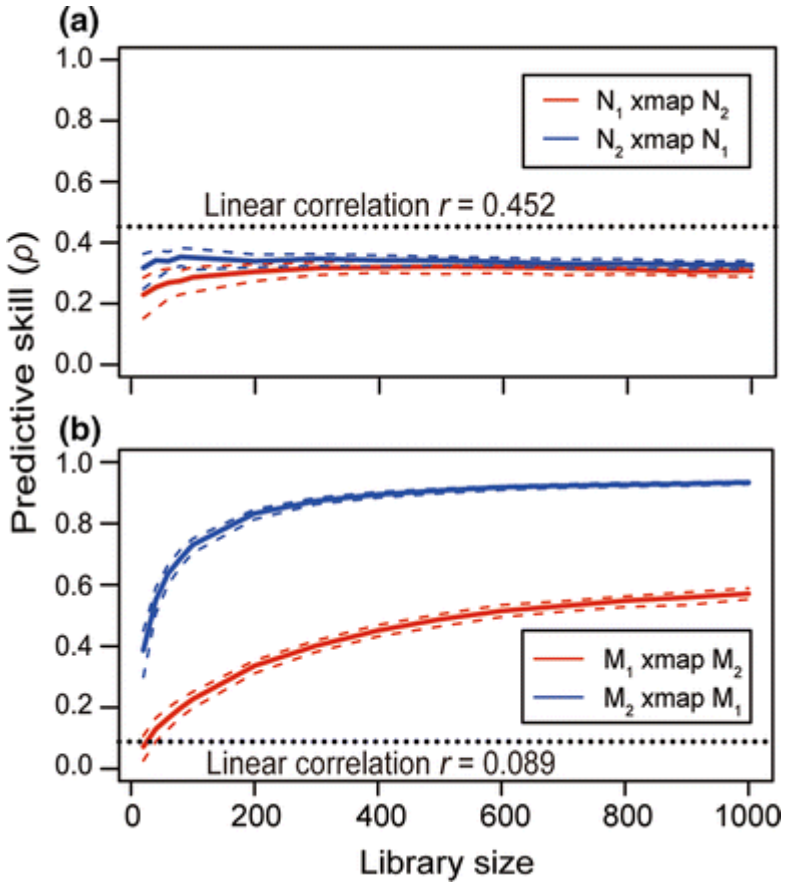
2) Nonlinearity of the system



Theta as a tuning variable

Ye et al. (2017). https://cran.r-project.org/web/packages/rEDM/vignettes/rEDM-tutorial.html

3) Causality

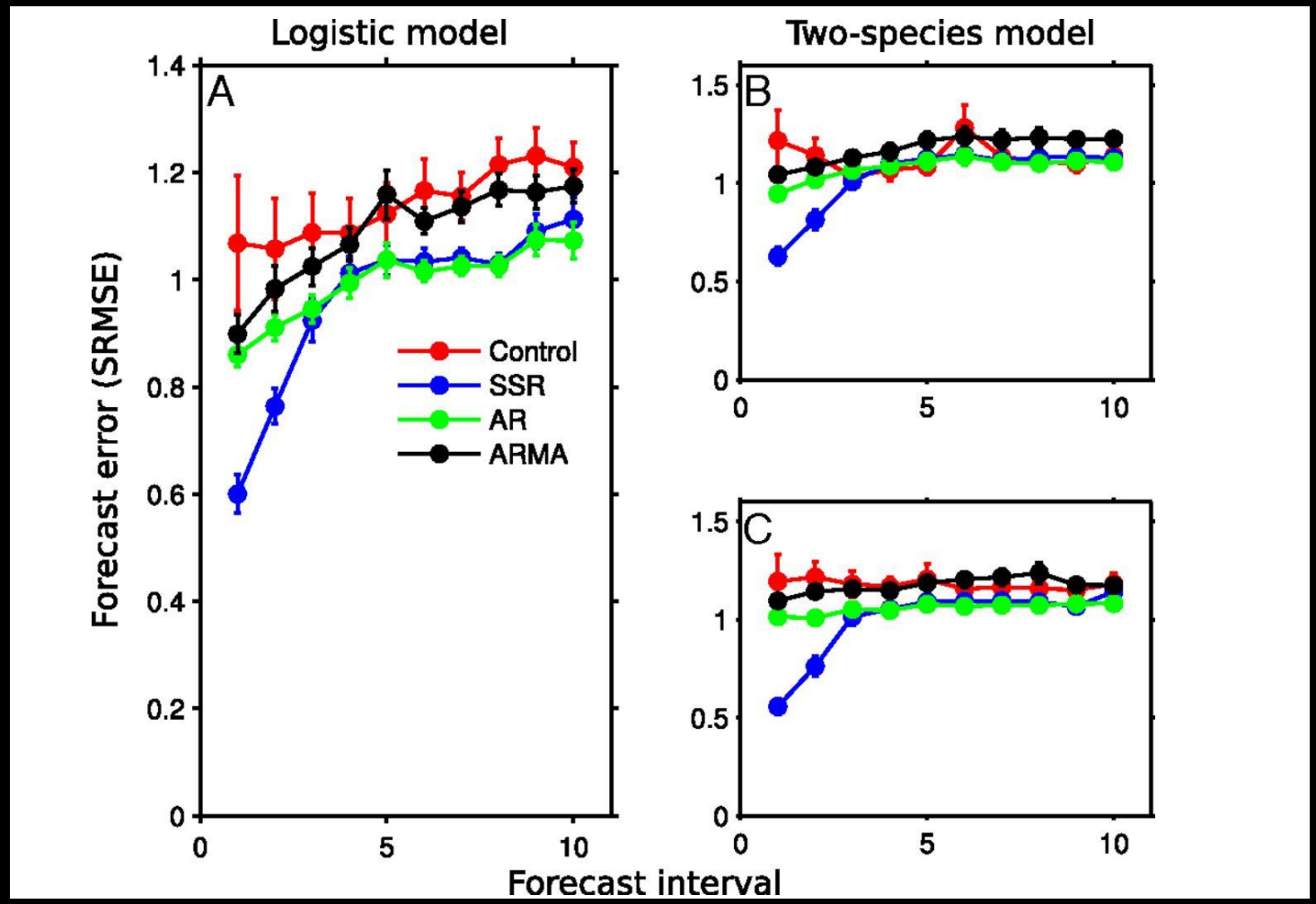


skill of forecasting one time series from a coupled one increases with information (= time series length used for attractor reconstruction = library size)

Convergent cross-mapping

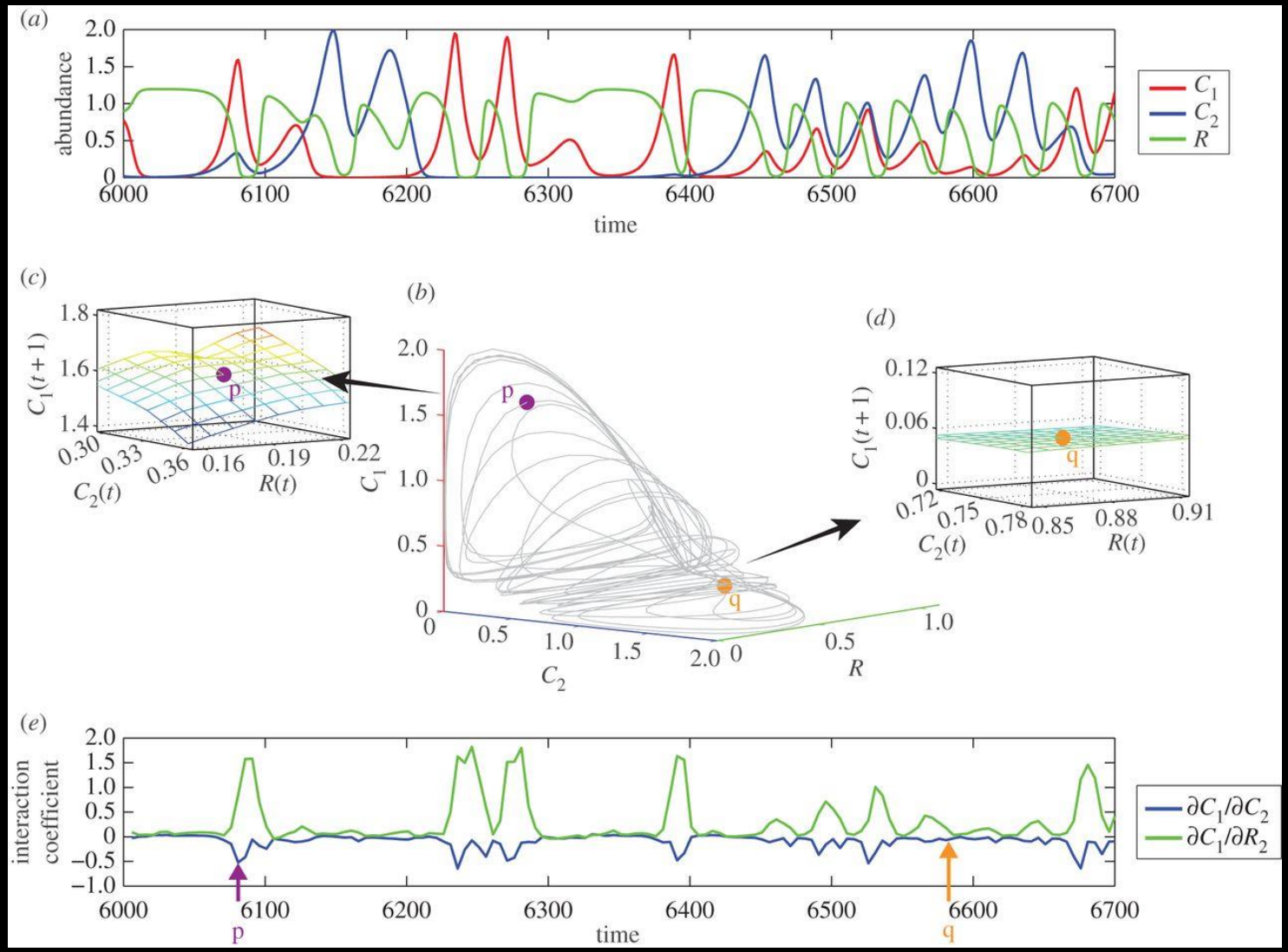
Chang et al. (2017) Ecol Res 32:785-796

4) Forecasting ahead



Perretti et al (2013) PNAS 110:13:5253-5257

5) Interaction signs and strengths



Ethan R. Deyle et al. Proc. R. Soc. B 2016;283:20152258

S-map coefficients as approximations of the elements of the Jacobian interaction matrix

References and resources:

- Ye, Clark, Deyle & Sugihara (2017). rEDM: an R package for Empirical Dynamic Modelling.
  more on CRAN (https://CRAN.R-project.org/package=rEDM) and GitHub (https://github.com/ha0ye/rEDM)

- Deyle et al. (2016). Tracking and forecasting ecosystem interactions in real time. Proc. R. Soc. B 283:20152258.

- Chang, Ushio, Hsieh (2017). Empirical dynamic modelling for beginners. Ecol. Res. 32:785-796

- Sugihara et al. (2012). Detecting causality in complex ecosystems. Science 338:496-500

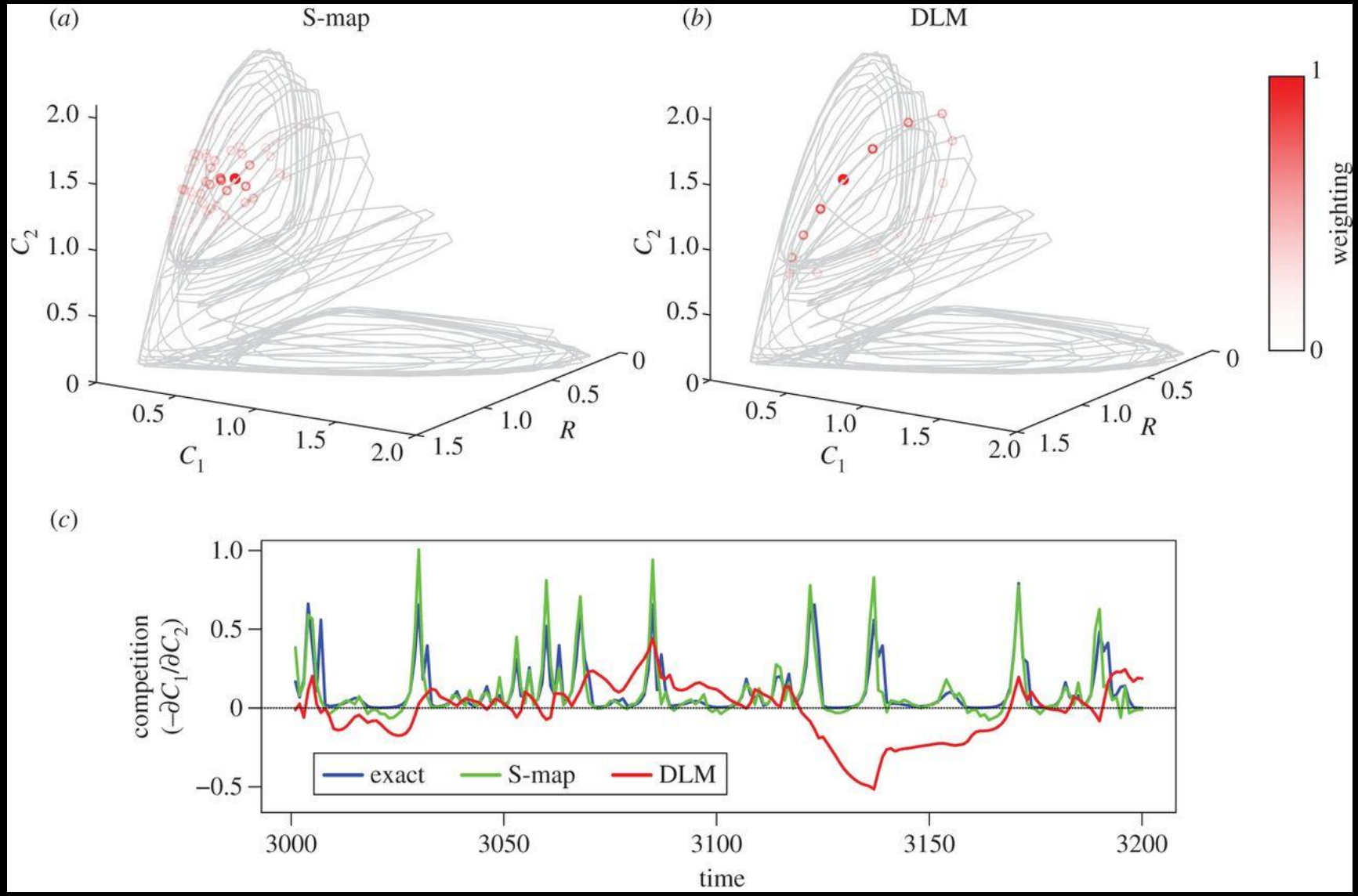
- Perretti et al. (2013). Model-freeforecasting outperforms the correct mechanistic model for simulated and experimental data.PNAS 110:5253-5257

- Videos on https://www.youtube.com/watch?v=8DikuwwPWsY and in the Online Supplementary Material of Sugihara et al. (2012)

- Background and further reading on Takens Theorem: https://en.wikipedia.org/wiki/Takens%27s_theorem

Some antidote: *(at least regarding the forecasting performance)*

Hartig & Dormann (2013). Does model-free forecasting really outperform the true model? PNAS 110:E3975



Ethan R. Deyle et al. Proc. R. Soc. B 2016;283:20152258