

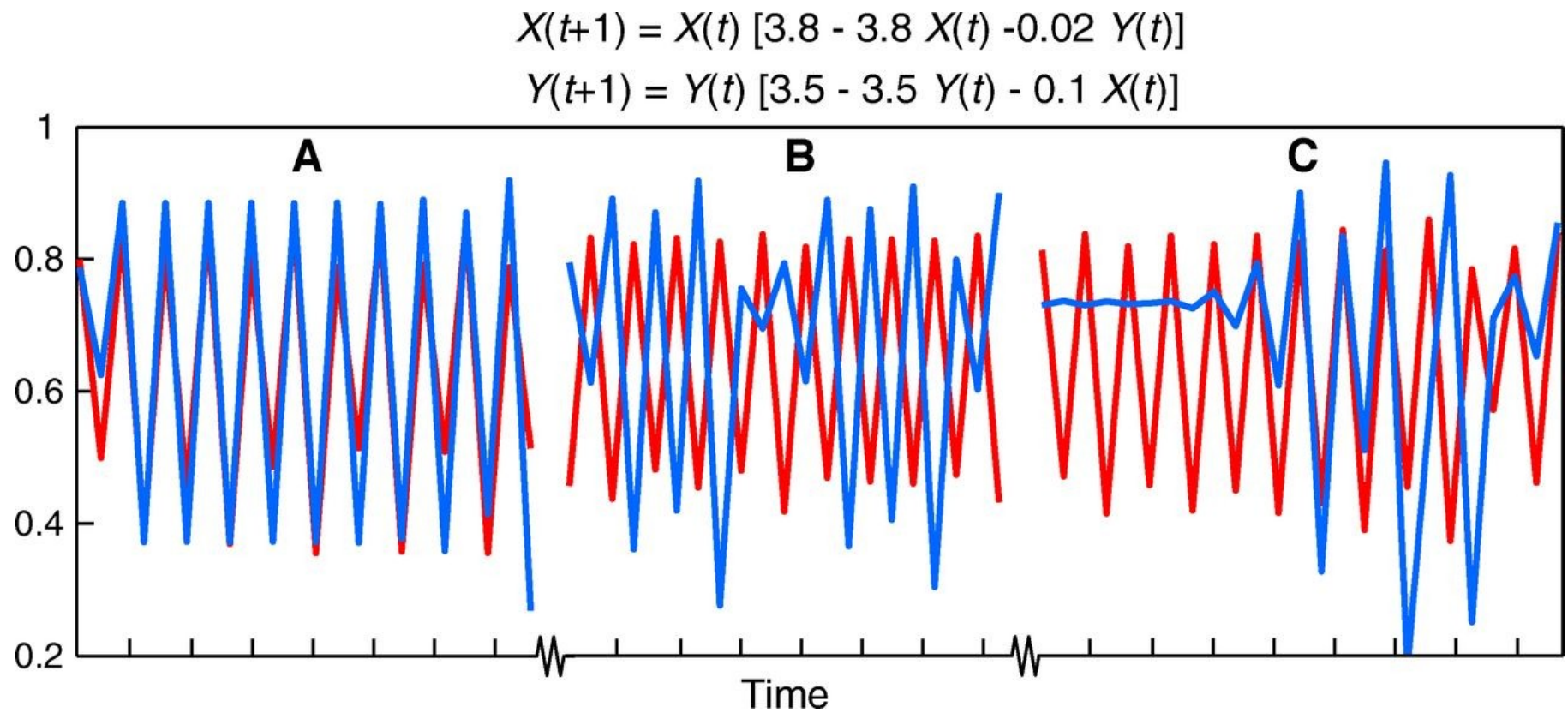
# Detecting Causality in Complex Ecosystems

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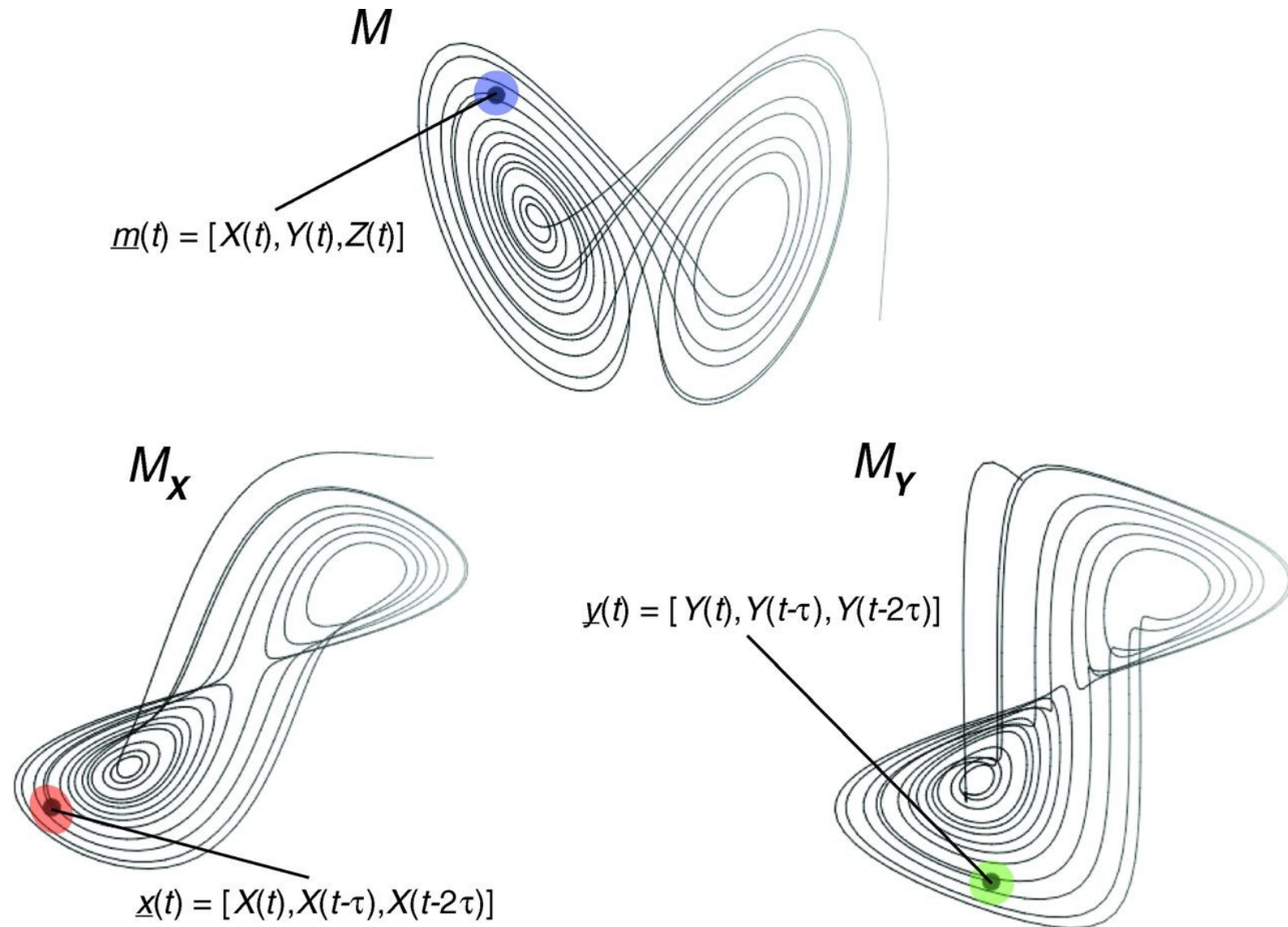


**Fig. 1 Mirage correlations.**



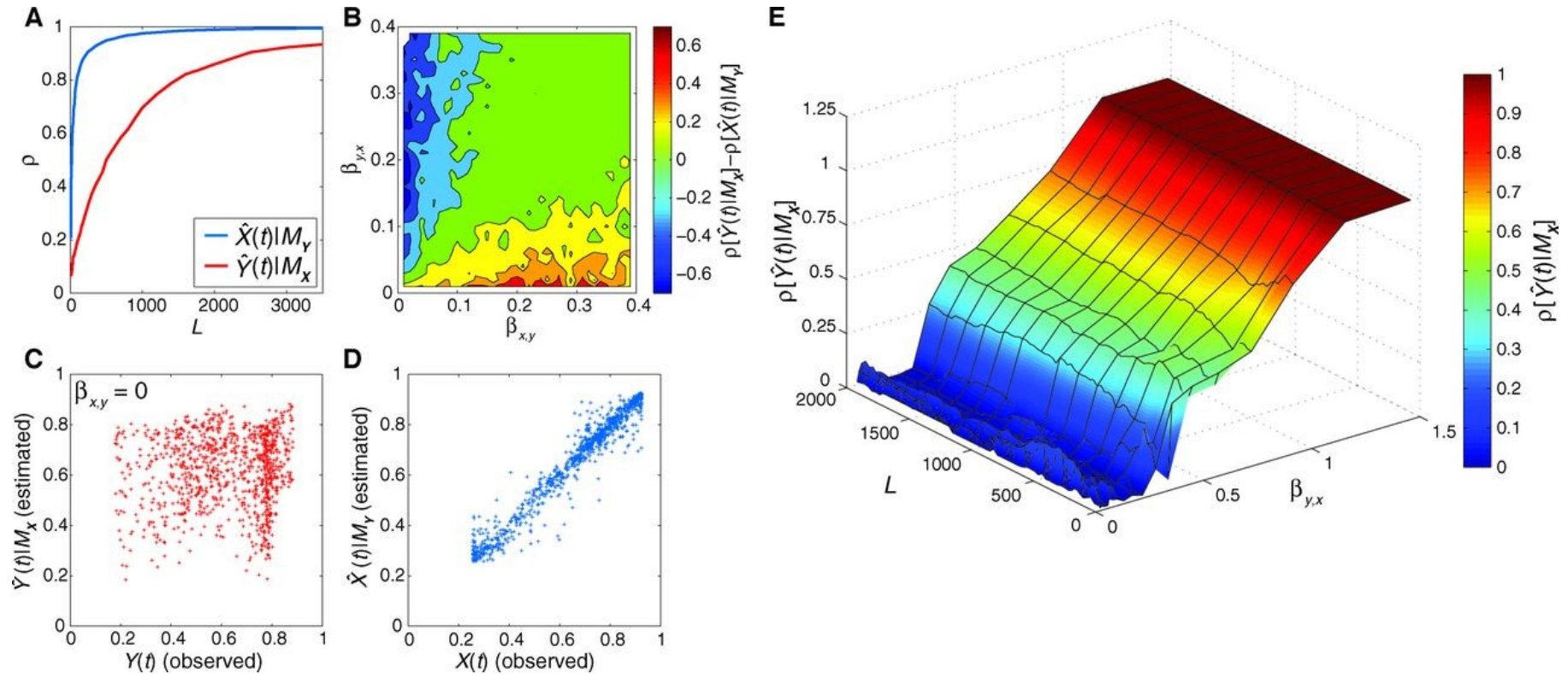
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**Fig. 2 Convergent cross mapping (CCM) tests for correspondence between shadow manifolds.**



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**Fig. 3 Detecting causation with CCM. With convergence, the skill of cross-map estimates, indicated by the correlation coefficient ( $\rho$ ), increases with time-series (library) length  $L$ . (A) CCM for Eq. 1, Fig. 1, where the effect of  $X$  on  $Y$  is stronger than in the reverse:  $\beta_{y,x} > \beta_{x,y}$ .**



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**Fig. 4 Model causal networks.**

**A**

Case i:

*Bidirectional coupling*



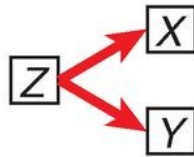
Case ii:

*Unidirectional coupling*



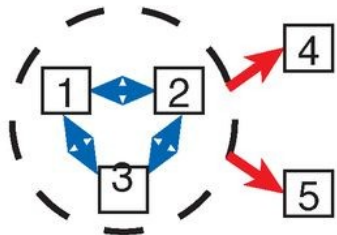
Example 1:

*External forcing of non-coupled variables*

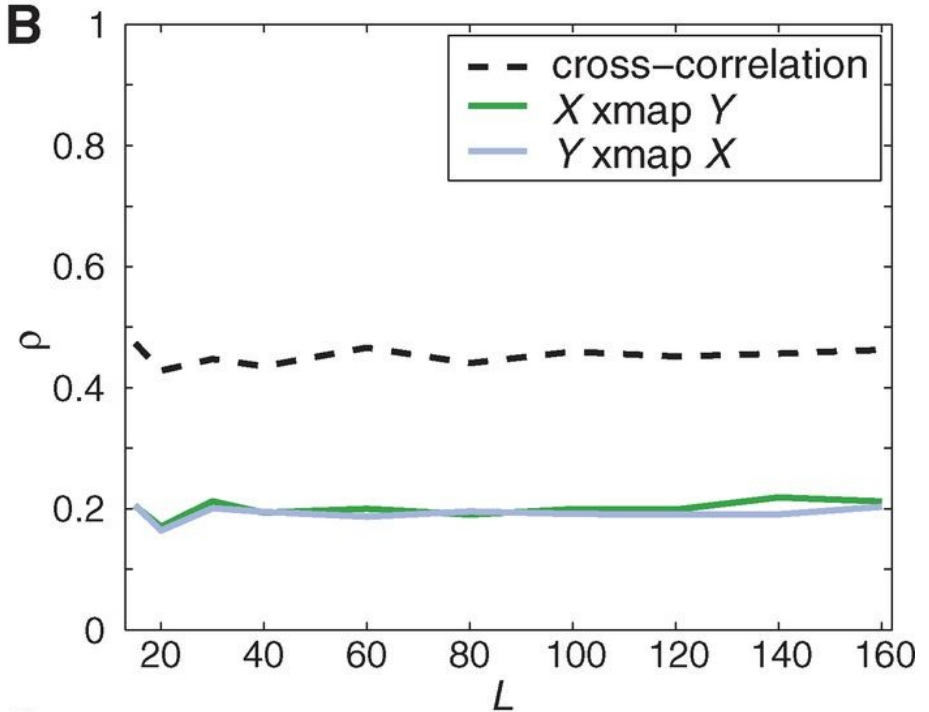


Example 2:

*Complex model*



**B**



**C**

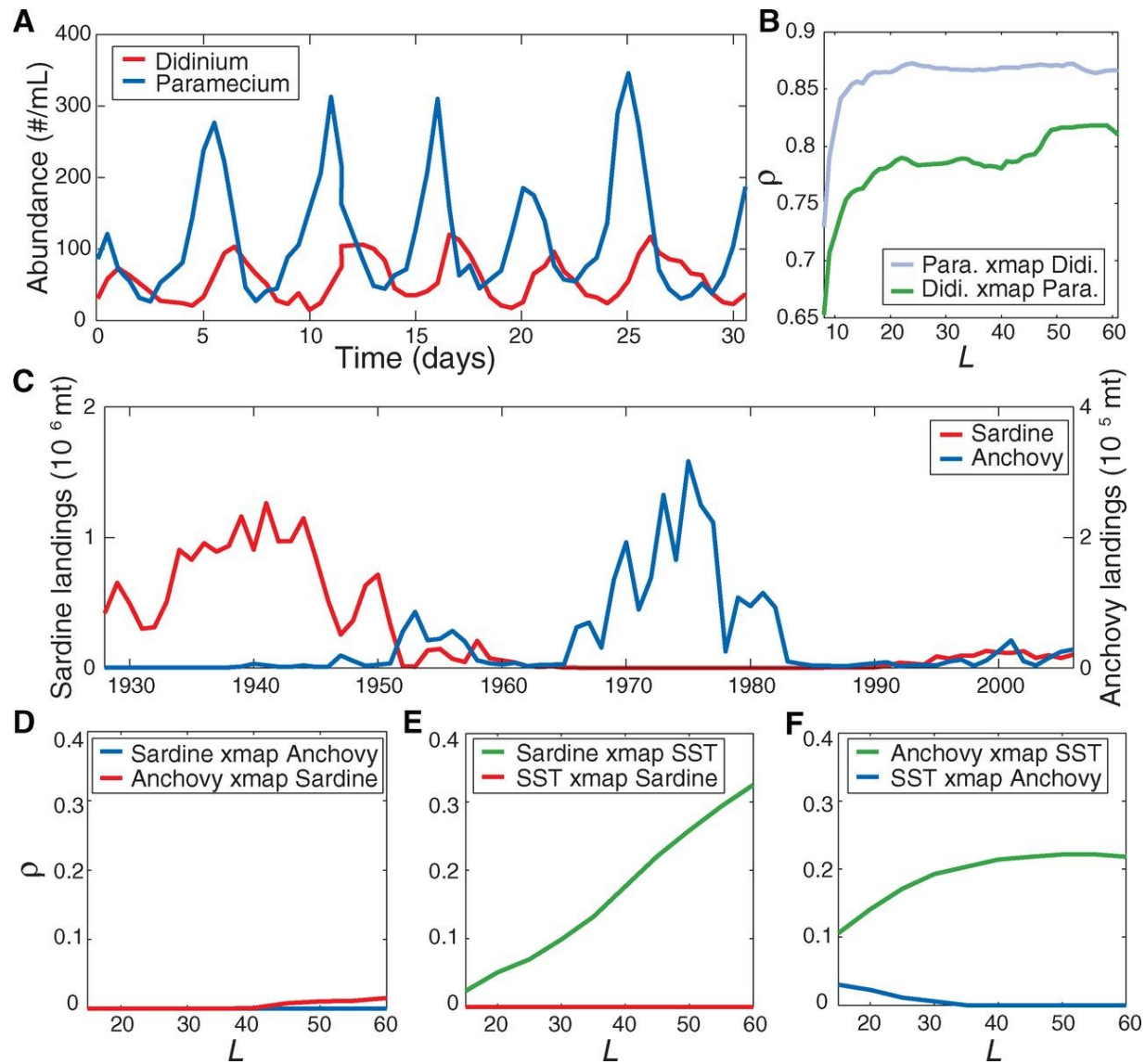
Causal links (cross map  $\rho$ ):

1 → 2 (1.00)	1 → 4 (0.50)	1 → 5 (0.21)
2 → 1 (1.00)	2 → 4 (0.60)	2 → 5 (0.13)
1 → 3 (1.00)	3 → 4 (0.51)	3 → 5 (0.25)
3 → 1 (1.00)		
3 → 2 (1.00)	*All other links not significant	
2 → 3 (1.00)		

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**Fig. 5 Detecting causation in real time series.**



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