Shape in ecological interaction matrices 2

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Mid–time dynamics and the role of ecological structure

This section examines why intermediate timescales reveal aspects of community organisation that neither short–term nor long–term responses are sensitive to. By comparing different rewiring operations, and how collectivity matching interacts with them, we gain a clearer understanding of what features of ecological networks matter most during recovery.

Three timescales, three governing mechanisms

Disturbance propagation in linearised dynamics involves more than stability margins. The recovery curve $r(t)$ reflects different structural components depending on the timescale.

At very small times, responses are dominated by the diagonal of the Jacobian. Individual self–regulation terms determine the initial direction of movement, so the fine arrangement of off–diagonal interactions hardly affects the outcome.

At asymptotically long times, behaviour is controlled by the leading eigenvalue or, equivalently, the spectral radius $\rho(A)$. Two matrices with the same $\rho(A)$ generate the same ultimate rate of approach to equilibrium, regardless of how their interactions are arranged.

Between these regimes lies an intermediate window. Here the response is shaped neither by direct self–effects nor by the eventual decay rate, but by the geometry of indirect pathways. This is the region where architectural differences among interaction matrices generate visibly different trajectories.

Why rewiring reveals mid–time sensitivity

Our rewiring operations separate two kinds of changes:

- whether the unordered pairs (A_{ij}, A_{ji}) are preserved or broken

- whether values are reassigned only among previously occupied pairs or onto unrelated pairs

These two operations affect the network in different ways.

Preserving pairs keeps the directional character of each interaction intact. The ecological meaning of a predator–prey pair is maintained even if the pair occurs between a different species combination. In contrast, breaking the pair destroys this directional information and introduces new forms of asymmetry. This has marked consequences for the propagation of disturbances.

Restricting rewiring to previously occupied pairs preserves the overall adjacency pattern of the network. Allowing values to move to arbitrary pairs destroys the trophic layout, degree distribution and hierarchical layering. This shifts the system onto a different structural manifold where different transient behaviours emerge.

When we re–scale a rewired matrix so that its collectivity matches that of the original, the magnitude of indirect amplification is restored, but its geometry is not. Mid–time deviations then become particularly pronounced when the original structural constraints are no longer present. This occurs because the re–scaling necessarily amplifies whichever directional patterns happen to be generated by the rewiring procedure.

Ecological interpretation

The mid–time interval is therefore the regime where network organisation expresses itself most strongly. It is the span during which disturbances have travelled beyond single species but have not yet aligned with the dominant eigenmode. The behaviour in this region reflects how energy or biomass flow is channelled through the interaction network.

This window is informative because multiple forms of ecological structure influence it:

- trophic directionality
- the presence or absence of cycles
- cascade–like ordering of interactions
- symmetry or asymmetry between opposing effects
- modular groupings and their connectivity
- layering by trophic position

These features route disturbances along different pathways, producing distinguishable transient signatures. When structure is retained, even after permutation of pair values, these mid–time signatures remain recognisable. When structure is broken, the transient portion of $r(t)$ changes substantially even if the total amplification level is matched by re–scaling.

Towards a finer understanding of which structures matter

The results so far show that intermediate–time behaviour is sensitive to structural information, but they do not yet isolate which components are most responsible. Some structural attributes may exert a large influence on transient behaviour, while others may be negligible once overall interaction magnitudes are accounted for. A more detailed analysis is needed to determine precisely which elements of community organisation drive mid–time sensitivity and how they do so.