2.2 Simulations of repeated interactions when strategies are defined in two dimensions

To demonstrate that prosocial strategies are fragile under repeated interactions because of ambiguous reciprocators, we also simulated the repeated interactions scenario using a restricted definition of strategies. Specifically, strategies are defined in two dimensions rather than three, and this precludes the appearance of ambiguous reciprocators. The definition of strategies is essentially the same as that above in the analytical section on two-dimensional strategies. For simulating, however, we rely on a quantity called "degree" to control the response function. Let $q_{ij} \in [-1, 1]$ be the degree for agent i in group j, and let $q_{i'j} \in [-1, 1]$ be the degree for her partner, agent i'. Arbitrarily designate i the first mover in this pair. Strategies take the form,

$$
\begin{aligned}
n = 1, \quad & x_n = \tilde{x}_i \\
& y_n = \begin{cases} (1 - q_{i'j})\tilde{x}_i + q_{i'j} & \text{if } q_{i'j} \geq 0 \\ (1 + q_{i'j})\tilde{x}_i & \text{otherwise,} \end{cases} \\
n \geq 2, \quad & x_n = \begin{cases} (1 - q_{ij})y_{n-1} + q_{ij} & \text{if } q_{ij} \geq 0 \\ (1 + q_{ij})y_{n-1} & \text{otherwise,} \end{cases} \\
& y_n = \begin{cases} (1 - q_{i'j})x_n + q_{i'j} & \text{if } q_{i'j} \geq 0 \\ (1 + q_{i'j})x_n & \text{otherwise.} \end{cases}
\end{aligned}
\tag{58}
$$

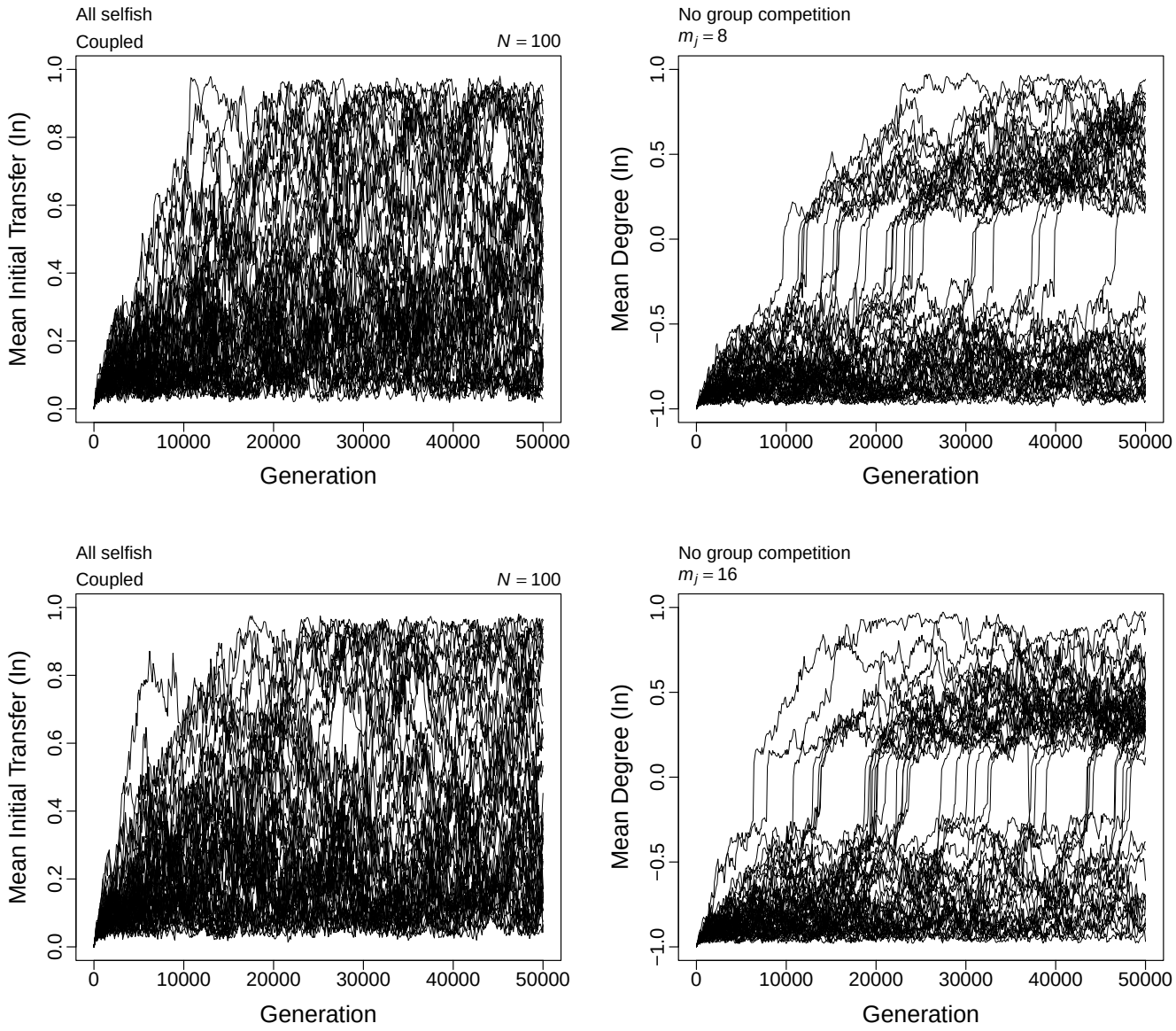
When using degree to control the response function, a value in $(0, 1)$ means the agent is an escalating reciprocator, while a value in $(-1, 0)$ means the agent is a de-escalating reciprocator. A value of -1 means the agent is unconditionally selfish, a value of 1 means the agent is unconditionally generous, and a value of 0 means the agent is a perfect reciprocator. No other possibilities exist. In particular, ambiguous reciprocators are not possible.

2.2.1 Dynamics of strategies defined in two dimensions

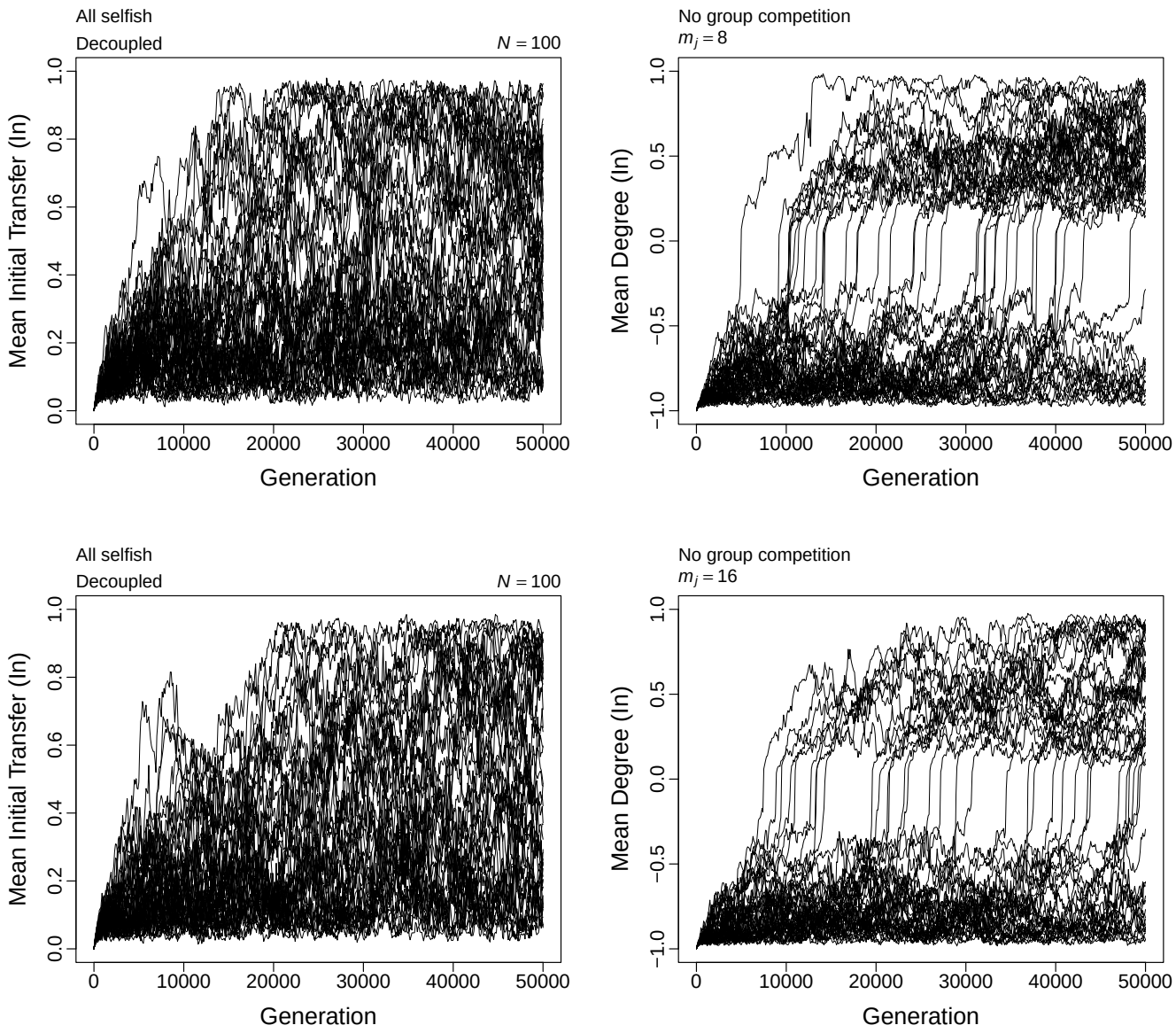
Supplementary Figures 108 – 113 show a number of illustrative results from simulations of repeated interactions ($N = 100$) with two-dimensional strategies. To save space, we do not include an extensive caption for each result. The graphs show the full dynamics from 50 independent simulations. For each of the two dimensions of strategy space, we calculate the mean value in a given generation for a single simulated population. The variables include "Initial Transfer" and "Degree." These variables correspond to $\tilde{x}_{ij}$ and q_{ij} respectively. For each of these two variables, we show the dynamics of the mean value for each simulation. Above each graph, we indicate the initial conditions (All selfish, All random, or All perfect reciprocity, see § 2.1.8), whether or not population structure at the game play stage is coupled to structure at the individual selection stage, and the number of migrants per group per generation (m_j).

2.2.2 Invasion of escalating strategies from unfavourable initial conditions under repeated interactions

Here we examine evolution from ancestral initial conditions that are relatively unfavourable for the evolution of cooperative strategies. Specifically, populations initially consist entirely of unconditionally selfish agents (All selfish). Supplementary Figures 108 – 109 show cooperative escalating strategies invading and proliferating when strategies are two-dimensional and interactions are repeated. In particular, the dynamics suggest that, for a given population, it takes time to escape the basin of attraction for uncooperative strategies. Once a population does so, cooperative (i.e. escalating) strategies persist. This pattern holds given more population structure ($m_j = 8$) or less ($m_j = 16$), and it holds whether population structures during game play and individual selection are coupled or not.



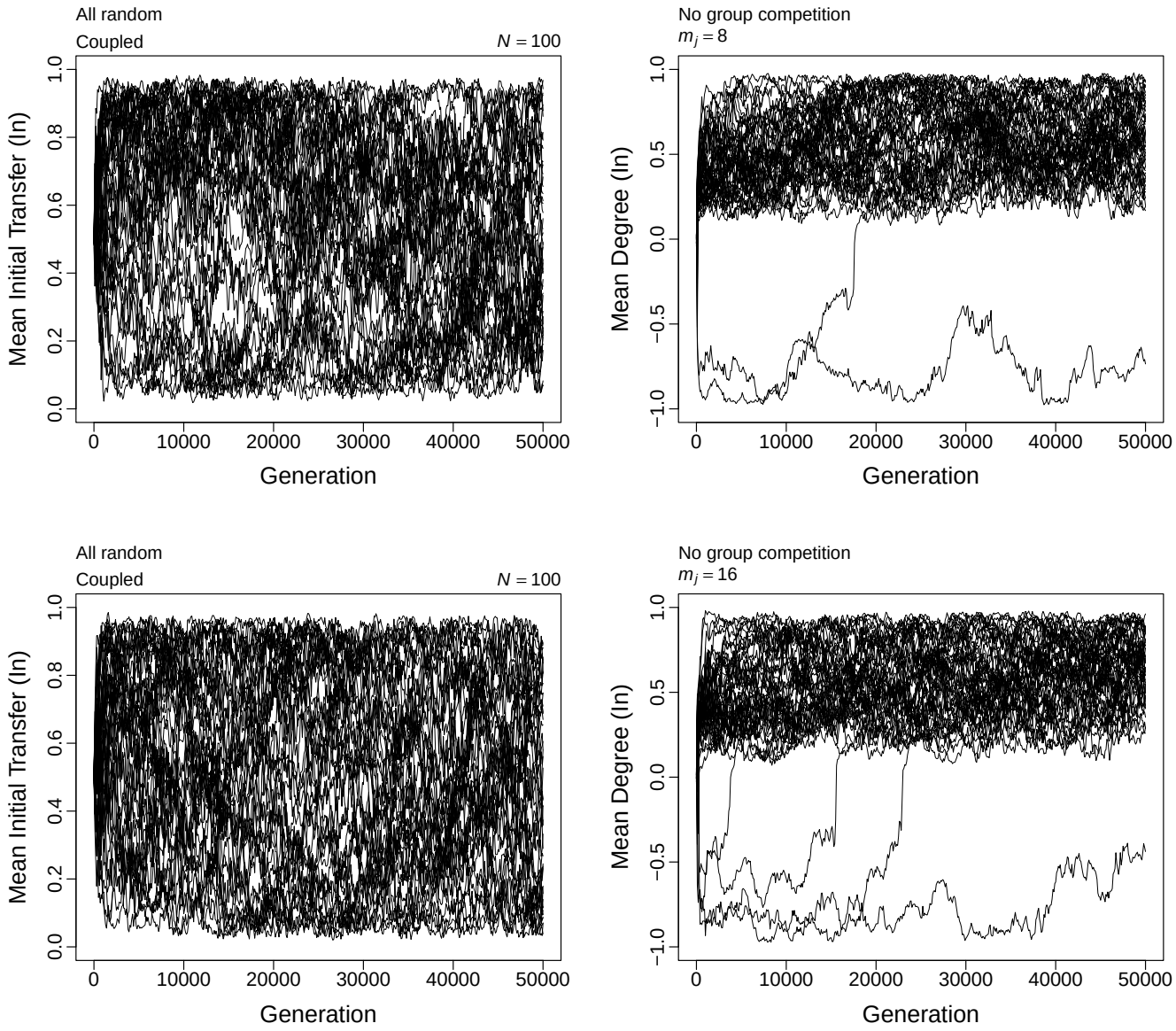
Supplementary Figure 108 | Repeated interactions in isolation.



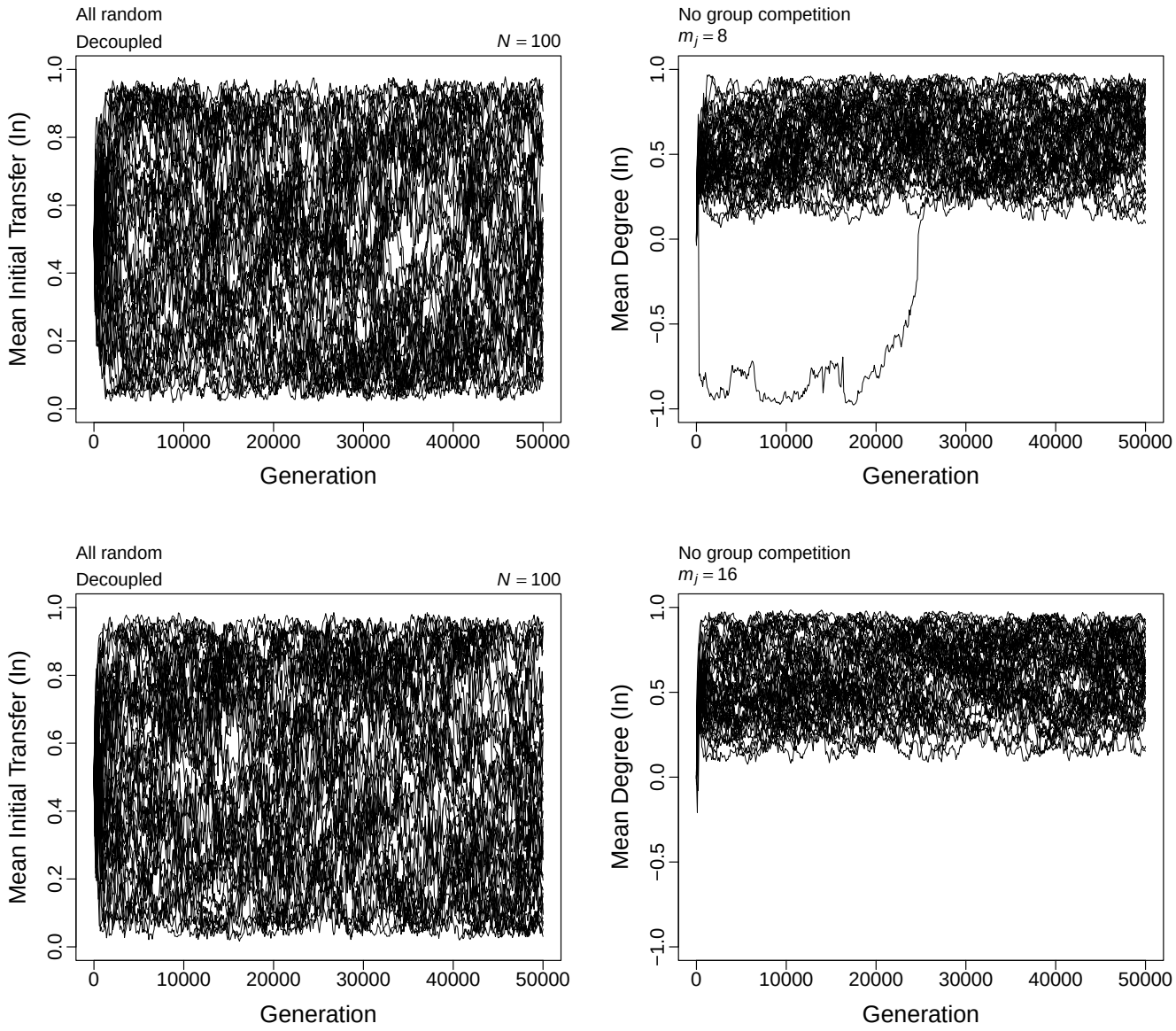
Supplementary Figure 109 | Repeated interactions in isolation.

2.2.3 Invasion of escalating strategies from favourable initial conditions under repeated interactions

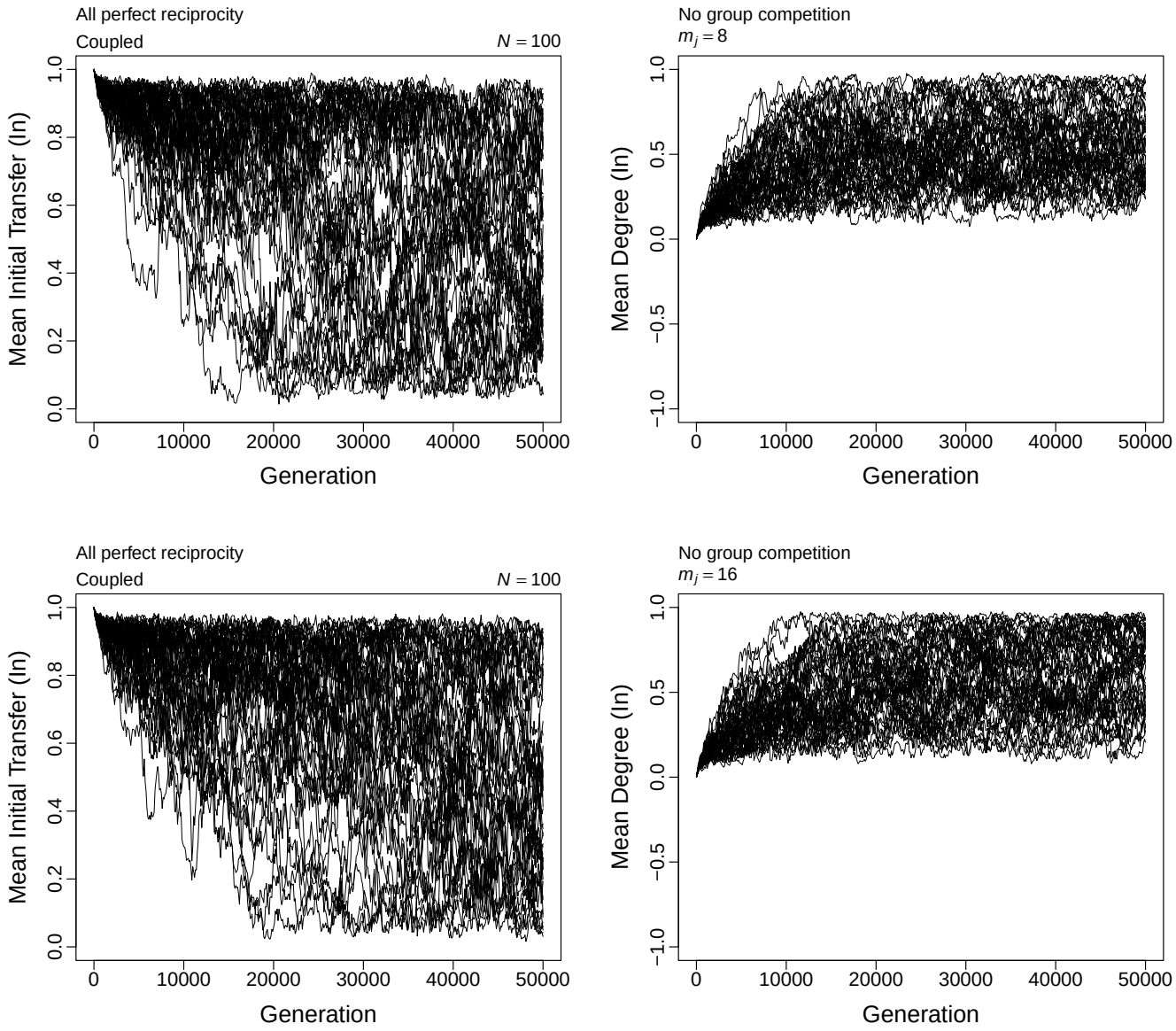
Here we show evolution from initial conditions that are relatively favourable for the evolution of cooperative strategies. In particular, populations are initially seeded with random strategies (All random) or with all perfect reciprocators (All perfect reciprocity). Supplementary Figures 110 – 113 show that, with these initial conditions, cooperative escalating strategies invade and persist when strategies are two-dimensional and interactions are repeated. This occurs given more population structure ($m_j = 8$) or less ($m_j = 16$), and it occurs regardless of whether population structures during game play and individual selection are coupled or not.



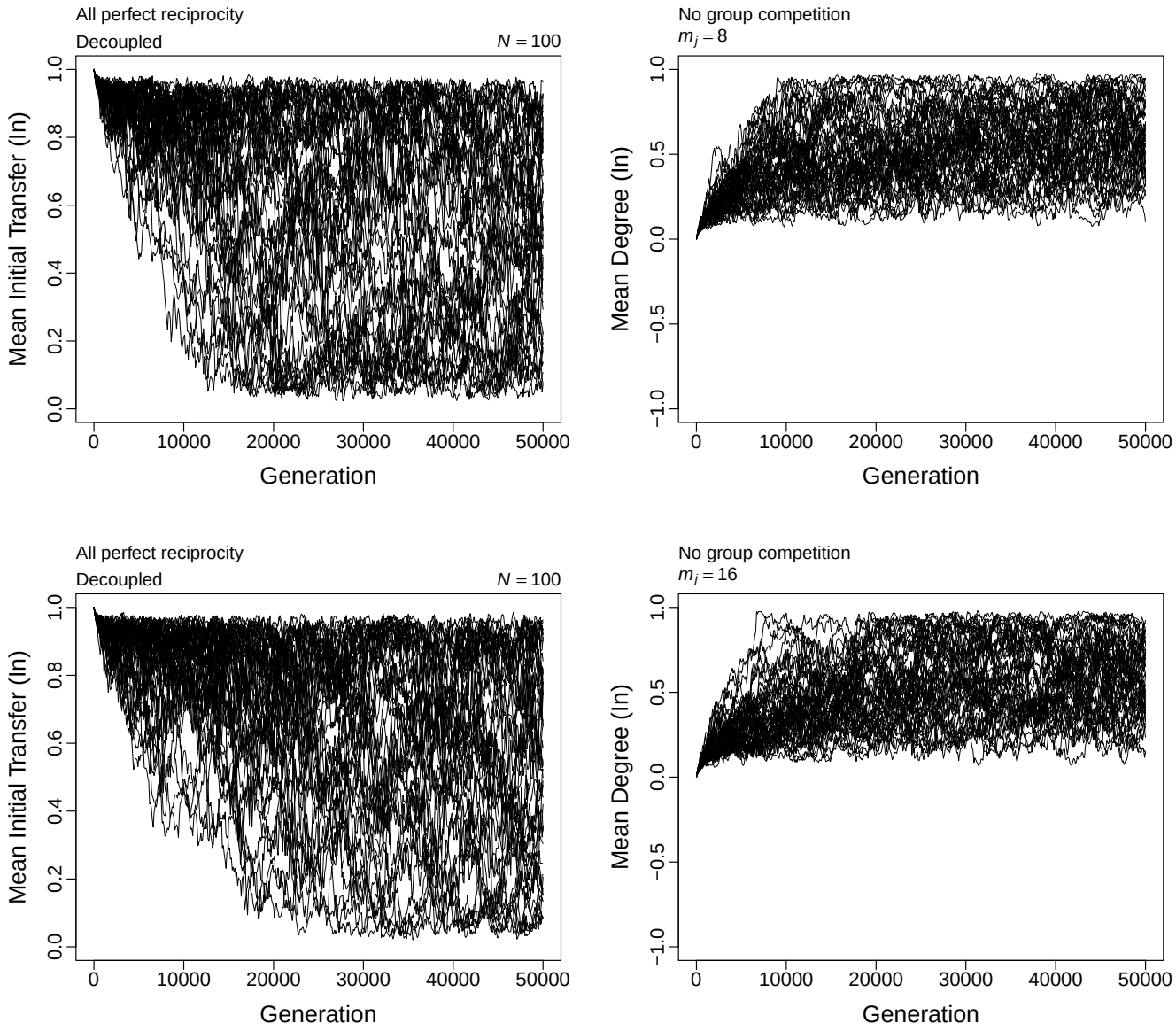
Supplementary Figure 110 | Repeated interactions in isolation.



Supplementary Figure 111 | Repeated interactions in isolation.



Supplementary Figure 112 | Repeated interactions in isolation.



Supplementary Figure 113 | Repeated interactions in isolation.