3 The gains from cooperation under three and four dimensions

To summarise and compare our three scenarios in an accessible way, Supplementary Figures 138 – 155 compare and decompose the gains from ingroup cooperation for simulations based on three-dimensional and four-dimensional strategy spaces. Before turning to these results, we would like to clarify an important point. We claim in the main paper that the dimensionality of strategy space is irrelevant in the group competition scenario. Although we do not show two-dimensional results here to save space, the group competition results in two dimensions are extremely similar to the group competition results we do show here for three and four dimensions (i.e. GC(1)). This similarity is the basis of our claim that dimensionality is irrelevant under group competition as a stand-alone mechanism.

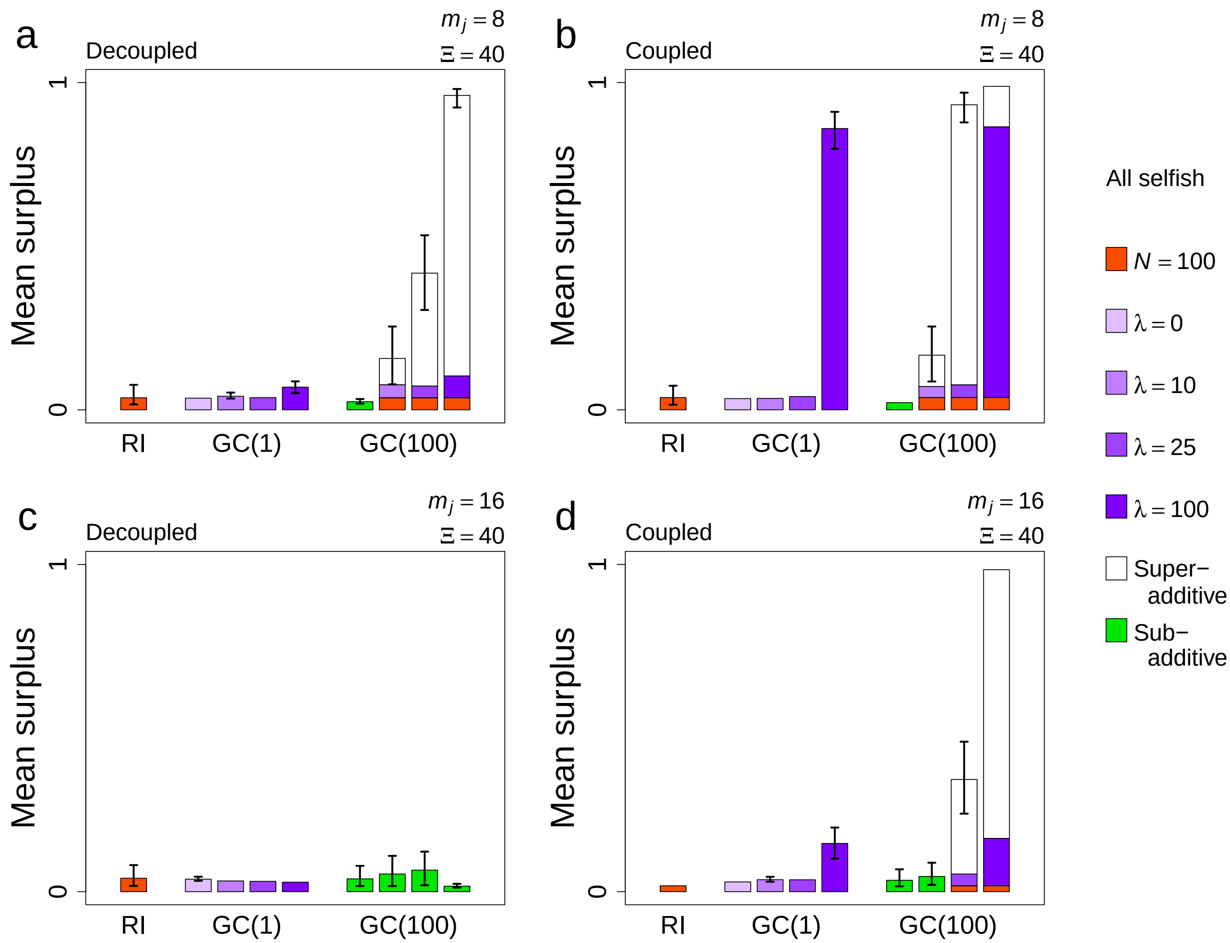
As in the main paper, we synthesise results across simulations by focusing on the average surplus generated in the final generations of simulated evolution, where the surplus per agent per interaction is the agent's endogenous payoff minus her endowment. One can easily verify that the average surplus per agent per interaction in an interacting pair takes some value in $[0, 1]$. Thus, the average surplus per agent per interaction over all agents and all interactions also takes a value in $[0, 1]$.

In the joint scenario we decompose average surplus values into effects from repeated interactions, effects from group competition, and super-additive effects that represent the positive interaction between the two mechanisms. Specifically, let $s_r \in [0, 1]$ be the average surplus for some combination of parameter values under repeated interactions in isolation. Analogously, let $s_g \in [0, 1]$ be the surplus under group competition in isolation and s_j be the surplus under the joint effect of repeated interactions and group competition. We compare s_j to the additive effect, which we define as $s_r + s_g - s_r s_g = s_r + s_g(1 - s_r) = s_g + s_r(1 - s_g)$. If s_j is less than the additive effect, the joint scenario yields a sub-additive surplus on average. If s_j is greater than the additive effect, the joint scenario produces an average surplus that is super-additive. For convenience, because the number of graphs is manageable, we present a detailed caption for each graph.

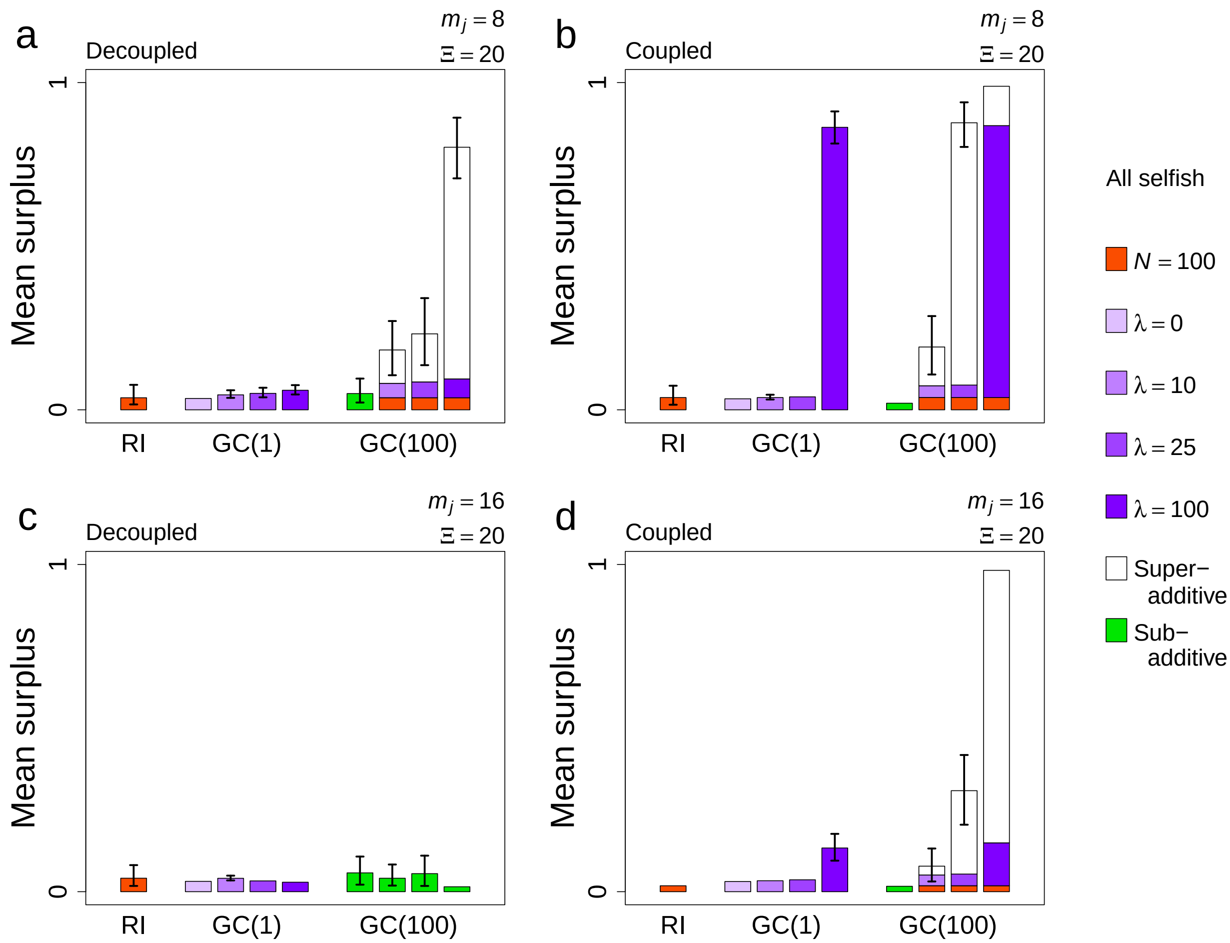
3.1 The ancestral case

Supplementary Figures 138 – 143 show results for simulations that begin with ancestral initial conditions, by which we mean a population that initially consists only of unconditionally selfish agents (All selfish, see § 2.1.8). Life cycles can yield population structures that are either decoupled or coupled at the game play and individual selection stages. In addition, migration (m_j), the sensitivity of group-level outcomes to group differences (λ), and group-level cancellation effects (Ξ) all vary. The figures show that super-additive interactions are common under the joint scenario, especially when group competitions have outcomes that are relatively sensitive to group differences ($\lambda \in \{25, 100\}$). Two caveats are important. First, when the life cycle decouples game play and individual selection, cooperative ingroup strategies do not evolve under the joint scenario when $m_j = 16$, and so super-additivity is also absent or present but relatively unimpressive. Second, as group-level cancellation effects become extreme ($\Xi = 0$), this same life cycle also supports little or no ingroup cooperation when $m_j = 8$, and so super-additivity is again absent or relatively unimpressive.

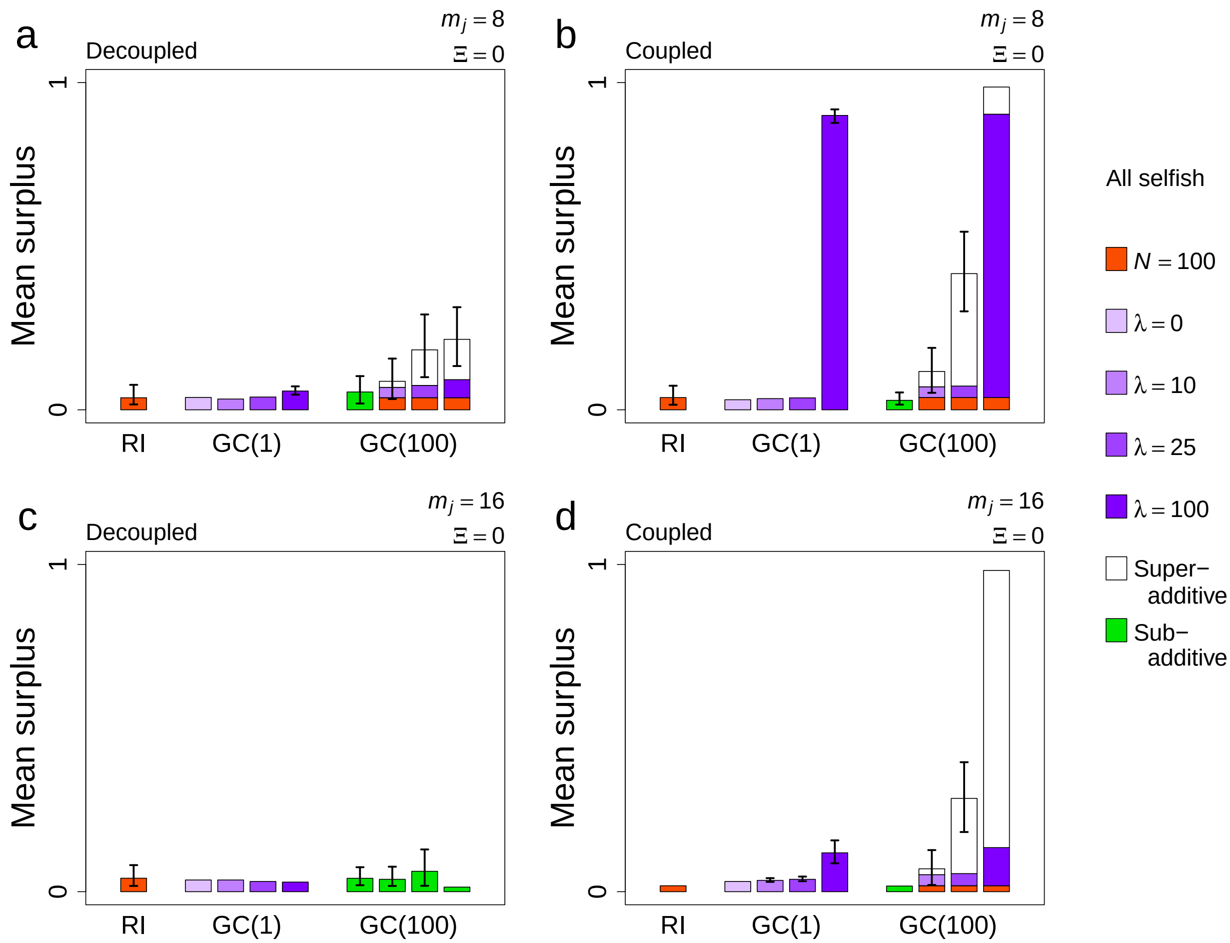
In other cases, super-additivity often has an enormous effect of the following sort. Under repeated interactions and group competition in isolation, ingroup cooperation after 50,000 generations of evolution is near the minimum possible level. However, the associated joint scenario generates ingroup cooperation approaching the maximum possible level.



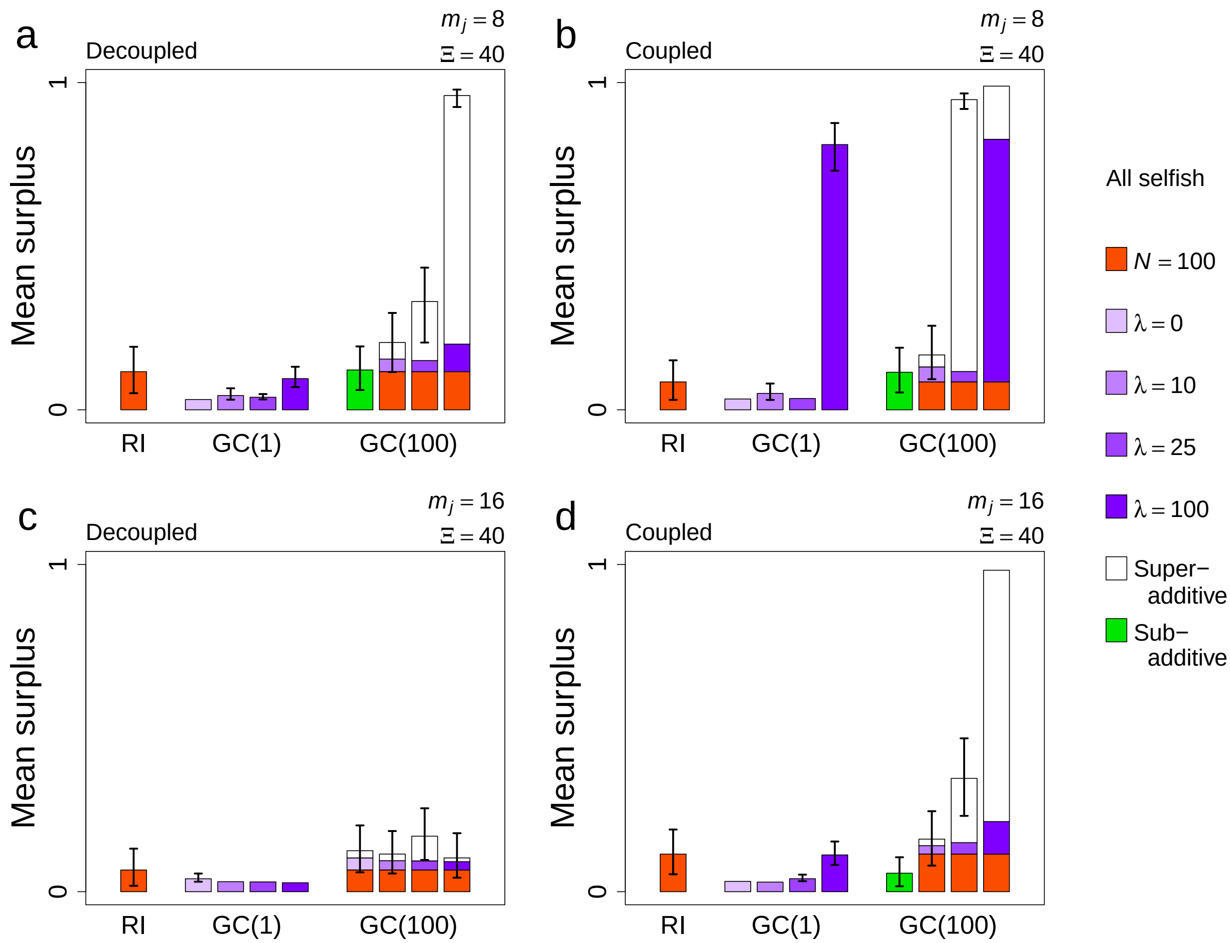
Supplementary Figure 138 | The gains from ingroup cooperation under different scenarios when strategies are three-dimensional. The mean surplus per ingroup interaction per agent is shown under the repeated interactions scenario (RI, $N = 100$), the group competition scenario (GC(1), $N = 1$ and $\lambda \in \{0, 10, 25, 100\}$), and the joint scenario (GC(100), $N = 100$ and $\lambda \in \{0, 10, 25, 100\}$). Under the joint scenario, we compare the mean surplus to an additive combination of the mean surplus in the repeated interactions scenario and the relevant group competition scenario (§ 3). If the mean surplus under the joint scenario is greater than this combination, the effect of combining repeated interactions within groups and competition between groups yields a surplus that is super-additive on average. If the mean surplus is less than the additive combination, the combined effect under the joint scenario is sub-additive. Panels differ in terms of whether or not the life cycle couples game play and individual selection and in terms of migration rates (m_j). Ξ controls group-level cancellation effects. Error bars denote 95% confidence intervals based on a bootstrapping algorithm clustered at the population level. We omit these confidence intervals when extremely narrow.



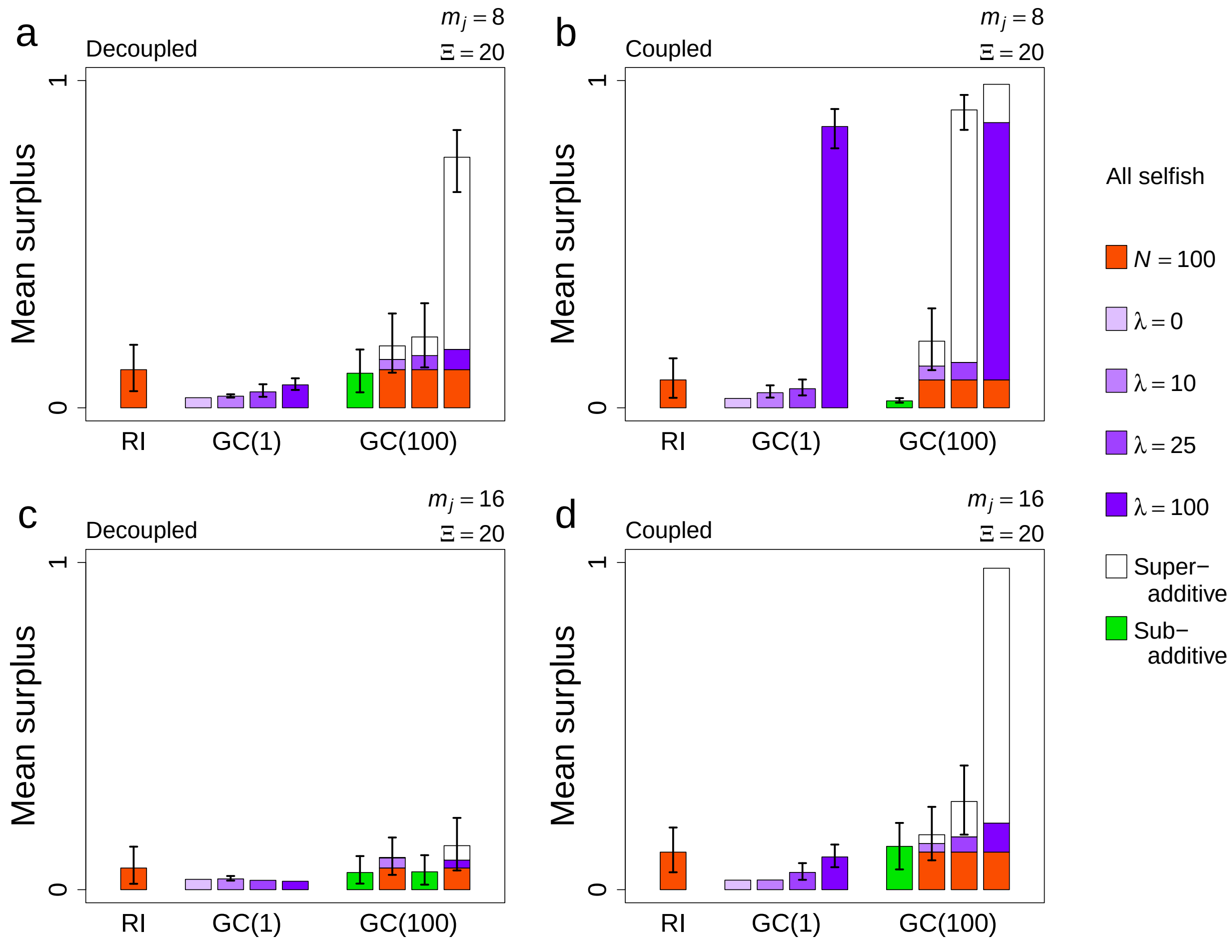
Supplementary Figure 139 | The gains from ingroup cooperation under different scenarios when strategies are three-dimensional. The mean surplus per ingroup interaction per agent is shown under the repeated interactions scenario (RI, $N = 100$), the group competition scenario (GC(1), $N = 1$ and $\lambda \in \{0, 10, 25, 100\}$), and the joint scenario (GC(100), $N = 100$ and $\lambda \in \{0, 10, 25, 100\}$). Under the joint scenario, we compare the mean surplus to an additive combination of the mean surplus in the repeated interactions scenario and the relevant group competition scenario (§ 3). If the mean surplus under the joint scenario is greater than this combination, the effect of combining repeated interactions within groups and competition between groups yields a surplus that is super-additive on average. If the mean surplus is less than the additive combination, the combined effect under the joint scenario is sub-additive. Panels differ in terms of whether or not the life cycle couples game play and individual selection and in terms of migration rates (m_j). Ξ controls group-level cancellation effects. Error bars denote 95% confidence intervals based on a bootstrapping algorithm clustered at the population level. We omit these confidence intervals when extremely narrow.



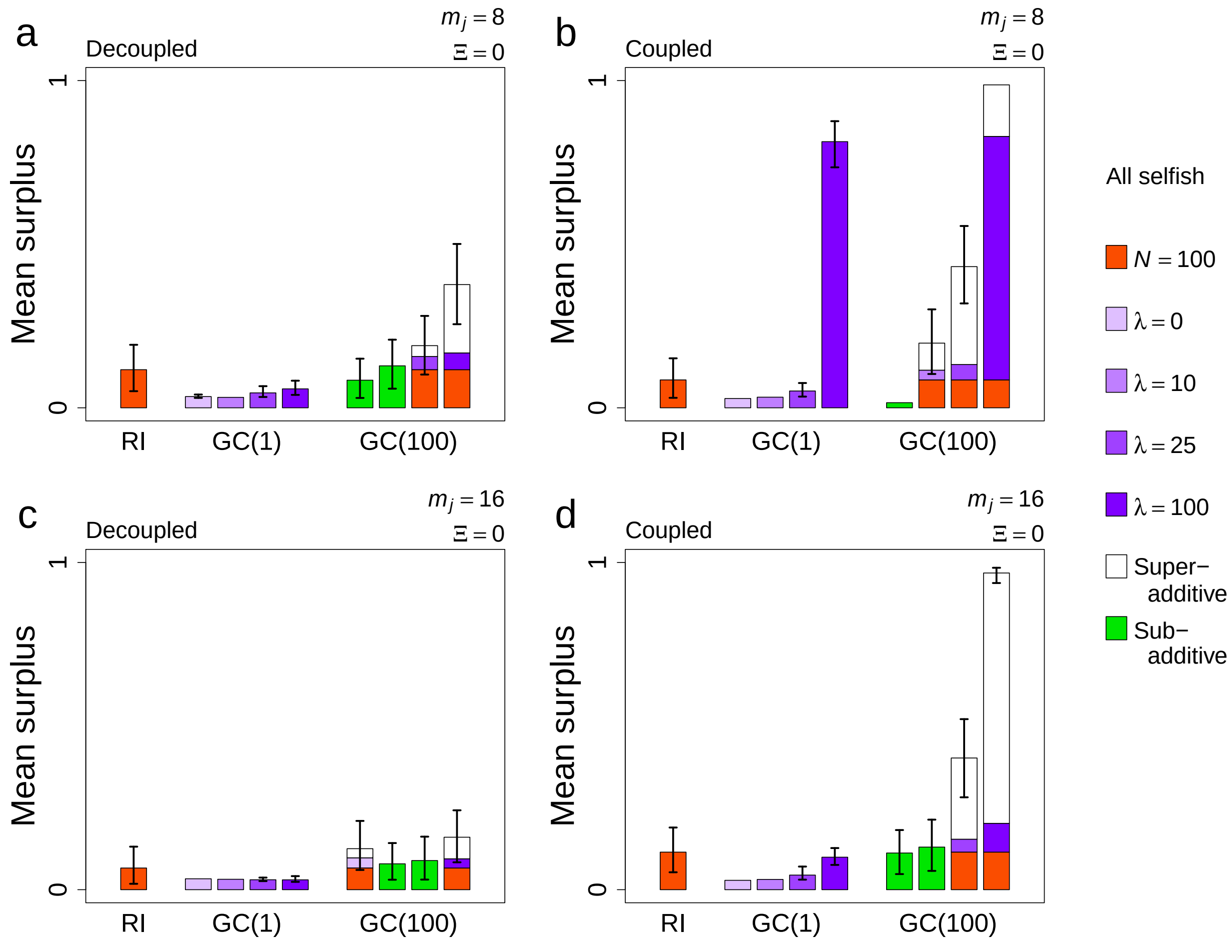
Supplementary Figure 140 | The gains from ingroup cooperation under different scenarios when strategies are three-dimensional. The mean surplus per ingroup interaction per agent is shown under the repeated interactions scenario (RI, $N = 100$), the group competition scenario (GC(1), $N = 1$ and $\lambda \in \{0, 10, 25, 100\}$), and the joint scenario (GC(100), $N = 100$ and $\lambda \in \{0, 10, 25, 100\}$). Under the joint scenario, we compare the mean surplus to an additive combination of the mean surplus in the repeated interactions scenario and the relevant group competition scenario (§ 3). If the mean surplus under the joint scenario is greater than this combination, the effect of combining repeated interactions within groups and competition between groups yields a surplus that is super-additive on average. If the mean surplus is less than the additive combination, the combined effect under the joint scenario is sub-additive. Panels differ in terms of whether or not the life cycle couples game play and individual selection and in terms of migration rates (m_j). Ξ controls group-level cancellation effects. Error bars denote 95% confidence intervals based on a bootstrapping algorithm clustered at the population level. We omit these confidence intervals when extremely narrow.



Supplementary Figure 141 | The gains from ingroup cooperation under different scenarios when strategies are four-dimensional. The mean surplus per ingroup interaction per agent is shown under the repeated interactions scenario (RI, $N = 100$), the group competition scenario (GC(1), $N = 1$ and $\lambda \in \{0, 10, 25, 100\}$), and the joint scenario (GC(100), $N = 100$ and $\lambda \in \{0, 10, 25, 100\}$). Under the joint scenario, we compare the mean surplus to an additive combination of the mean surplus in the repeated interactions scenario and the relevant group competition scenario (§ 3). If the mean surplus under the joint scenario is greater than this combination, the effect of combining repeated interactions within groups and competition between groups yields a surplus that is super-additive on average. If the mean surplus is less than the additive combination, the combined effect under the joint scenario is sub-additive. Panels differ in terms of whether or not the life cycle couples game play and individual selection and in terms of migration rates (m_j). Ξ controls group-level cancellation effects. Error bars denote 95% confidence intervals based on a bootstrapping algorithm clustered at the population level. We omit these confidence intervals when extremely narrow..



Supplementary Figure 142 | The gains from ingroup cooperation under different scenarios when strategies are four-dimensional. The mean surplus per ingroup interaction per agent is shown under the repeated interactions scenario (RI, $N = 100$), the group competition scenario (GC(1), $N = 1$ and $\lambda \in \{0, 10, 25, 100\}$), and the joint scenario (GC(100), $N = 100$ and $\lambda \in \{0, 10, 25, 100\}$). Under the joint scenario, we compare the mean surplus to an additive combination of the mean surplus in the repeated interactions scenario and the relevant group competition scenario (§ 3). If the mean surplus under the joint scenario is greater than this combination, the effect of combining repeated interactions within groups and competition between groups yields a surplus that is super-additive on average. If the mean surplus is less than the additive combination, the combined effect under the joint scenario is sub-additive. Panels differ in terms of whether or not the life cycle couples game play and individual selection and in terms of migration rates (m_j). Ξ controls group-level cancellation effects. Error bars denote 95% confidence intervals based on a bootstrapping algorithm clustered at the population level. We omit these confidence intervals when extremely narrow.

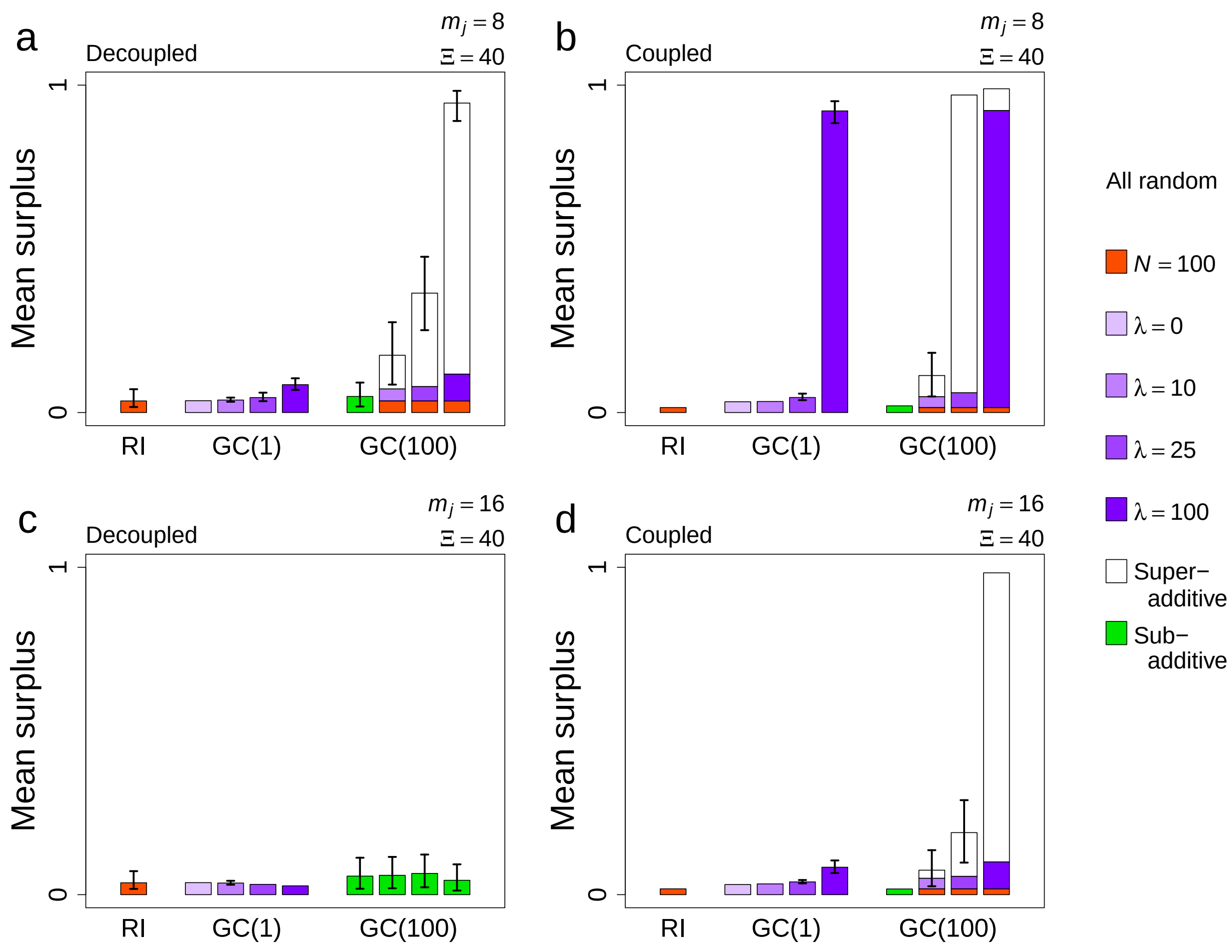


Supplementary Figure 143 | The gains from ingroup cooperation under different scenarios when strategies are four-dimensional. The mean surplus per ingroup interaction per agent is shown under the repeated interactions scenario (RI, $N = 100$), the group competition scenario (GC(1), $N = 1$ and $\lambda \in \{0, 10, 25, 100\}$), and the joint scenario (GC(100), $N = 100$ and $\lambda \in \{0, 10, 25, 100\}$). Under the joint scenario, we compare the mean surplus to an additive combination of the mean surplus in the repeated interactions scenario and the relevant group competition scenario (§ 3). If the mean surplus under the joint scenario is greater than this combination, the effect of combining repeated interactions within groups and competition between groups yields a surplus that is super-additive on average. If the mean surplus is less than the additive combination, the combined effect under the joint scenario is sub-additive. Panels differ in terms of whether or not the life cycle couples game play and individual selection and in terms of migration rates (m_j). Ξ controls group-level cancellation effects. Error bars denote 95% confidence intervals based on a bootstrapping algorithm clustered at the population level. We omit these confidence intervals when extremely narrow.

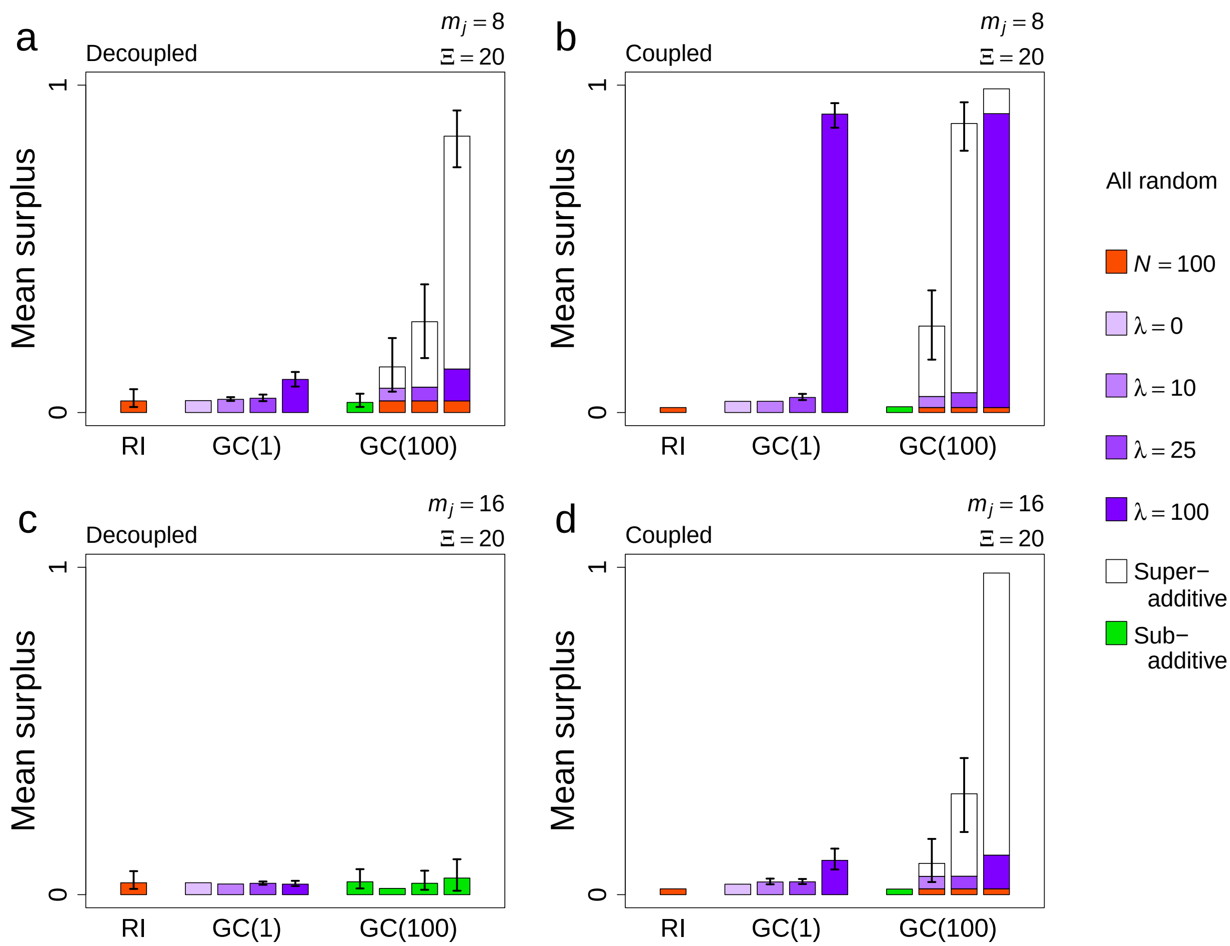
3.2 Other cases

Supplementary Figures 144 – 155 show results given initial conditions that we do not consider ancestral. Specifically, initial conditions can consist of random strategies (All random, see § 2.1.8) or perfect reciprocators (All perfect reciprocity, see § 2.1.8). In addition, population structures are either decoupled or coupled. Migration (m_j) and the sensitivity of group-level outcomes (λ) also vary. Ξ controls group-level cancellation effects.

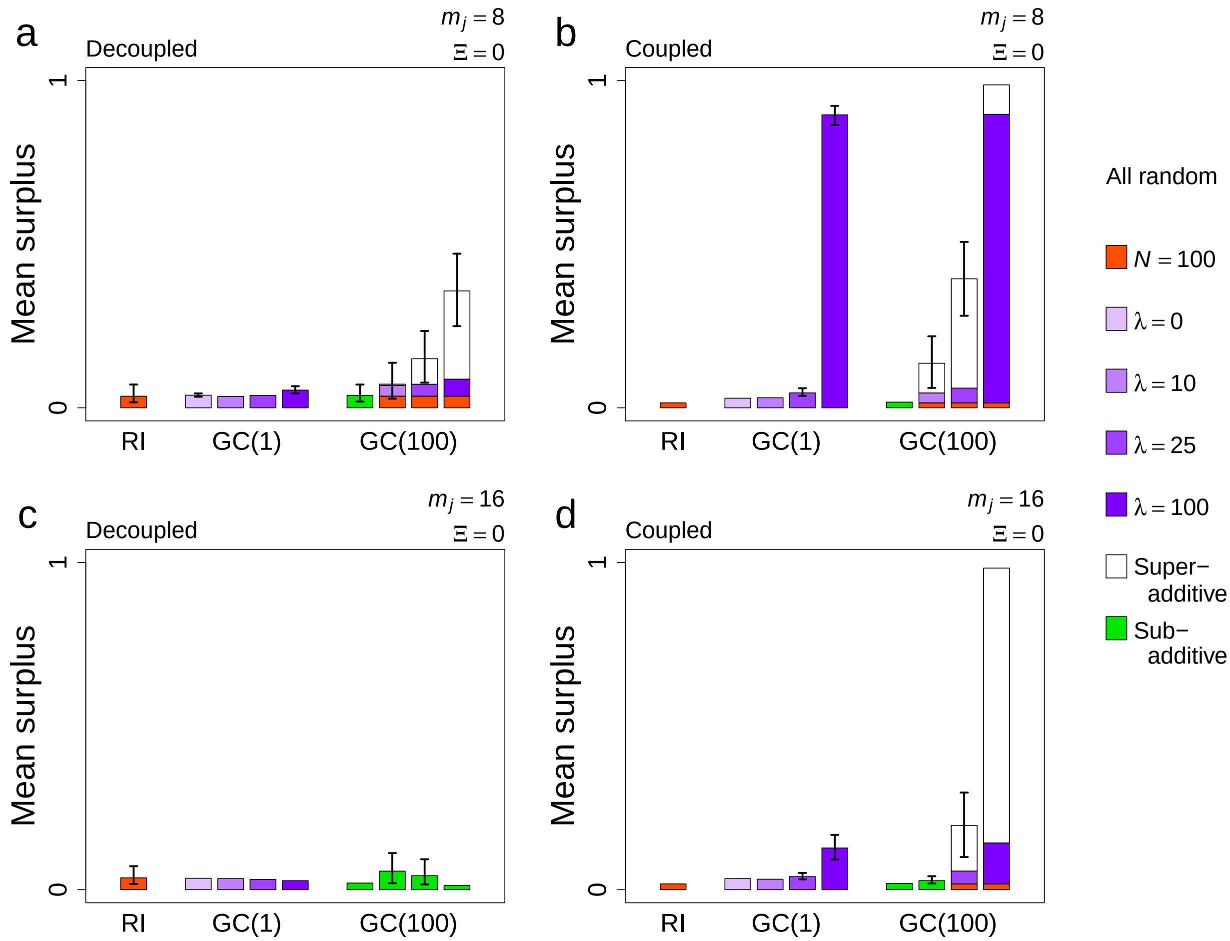
The figures show that, like the results for ancestral initial conditions, super-additive interactions are common, but with two caveats. The life cycle that decouples game play and individual selection does not support the evolution of ingroup cooperation under the joint scenario when $m_j = 16$, and this is even true when $\lambda = 100$. Moreover, this same life cycle also does not support ingroup cooperation when $m_j = 8$ and $\lambda = 100$ as cancellation effects at the group level become extreme ($\Xi = 0$). When super-additive interactions do occur, they often take us from a degree of ingroup cooperation near the minimum level possible to a degree of ingroup cooperation near the maximum level possible.



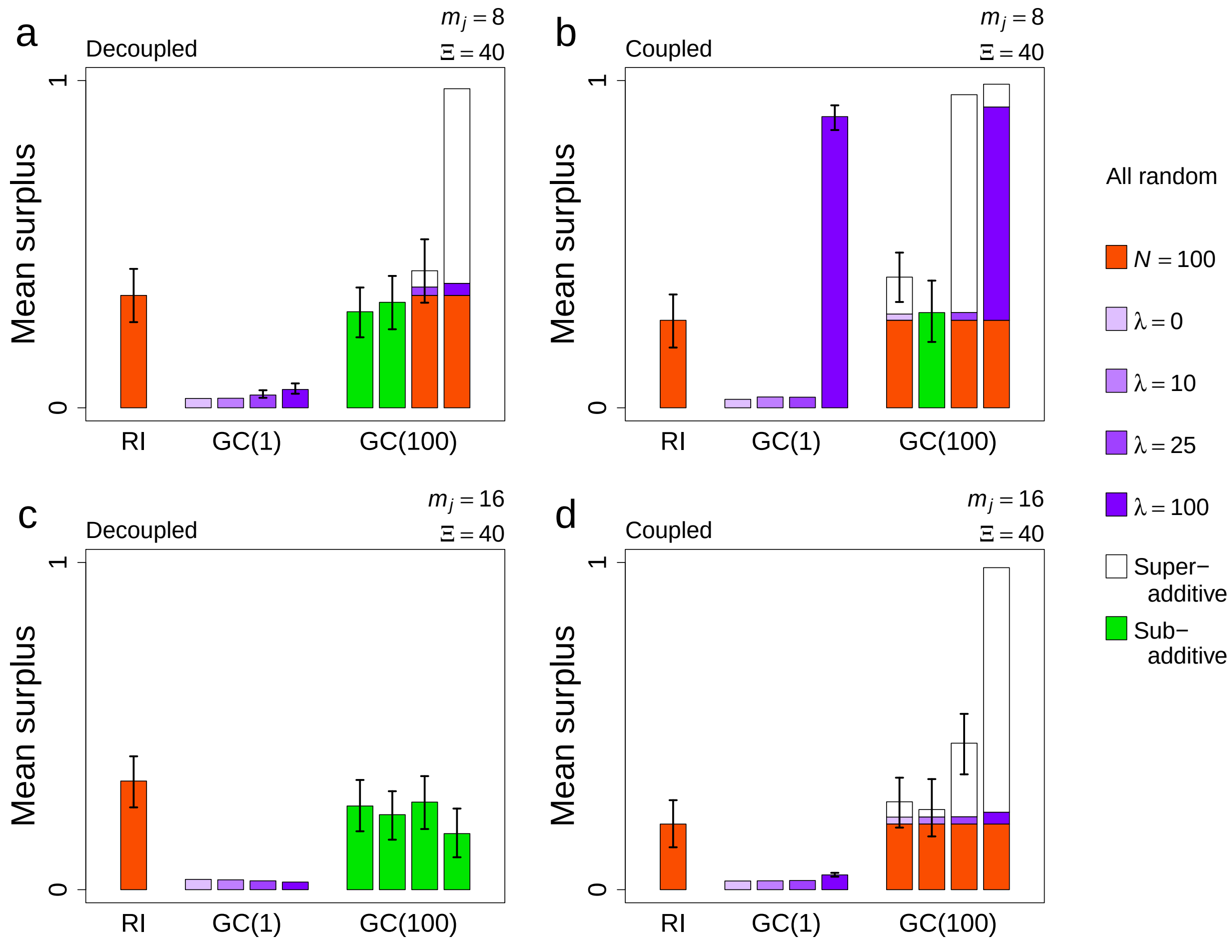
Supplementary Figure 144 | The gains from ingroup cooperation under different scenarios when strategies are three-dimensional. The mean surplus per ingroup interaction per agent is shown under the repeated interactions scenario (RI, $N = 100$), the group competition scenario (GC(1), $N = 1$ and $\lambda \in \{0, 10, 25, 100\}$), and the joint scenario (GC(100), $N = 100$ and $\lambda \in \{0, 10, 25, 100\}$). Under the joint scenario, we compare the mean surplus to an additive combination of the mean surplus in the repeated interactions scenario and the relevant group competition scenario (§ 3). If the mean surplus under the joint scenario is greater than this combination, the effect of combining repeated interactions within groups and competition between groups yields a surplus that is super-additive on average. If the mean surplus is less than the additive combination, the combined effect under the joint scenario is sub-additive. Panels differ in terms of whether or not the life cycle couples game play and individual selection and in terms of migration rates (m_j). Ξ controls group-level cancellation effects. Error bars denote 95% confidence intervals based on a bootstrapping algorithm clustered at the population level. We omit these confidence intervals when extremely narrow.



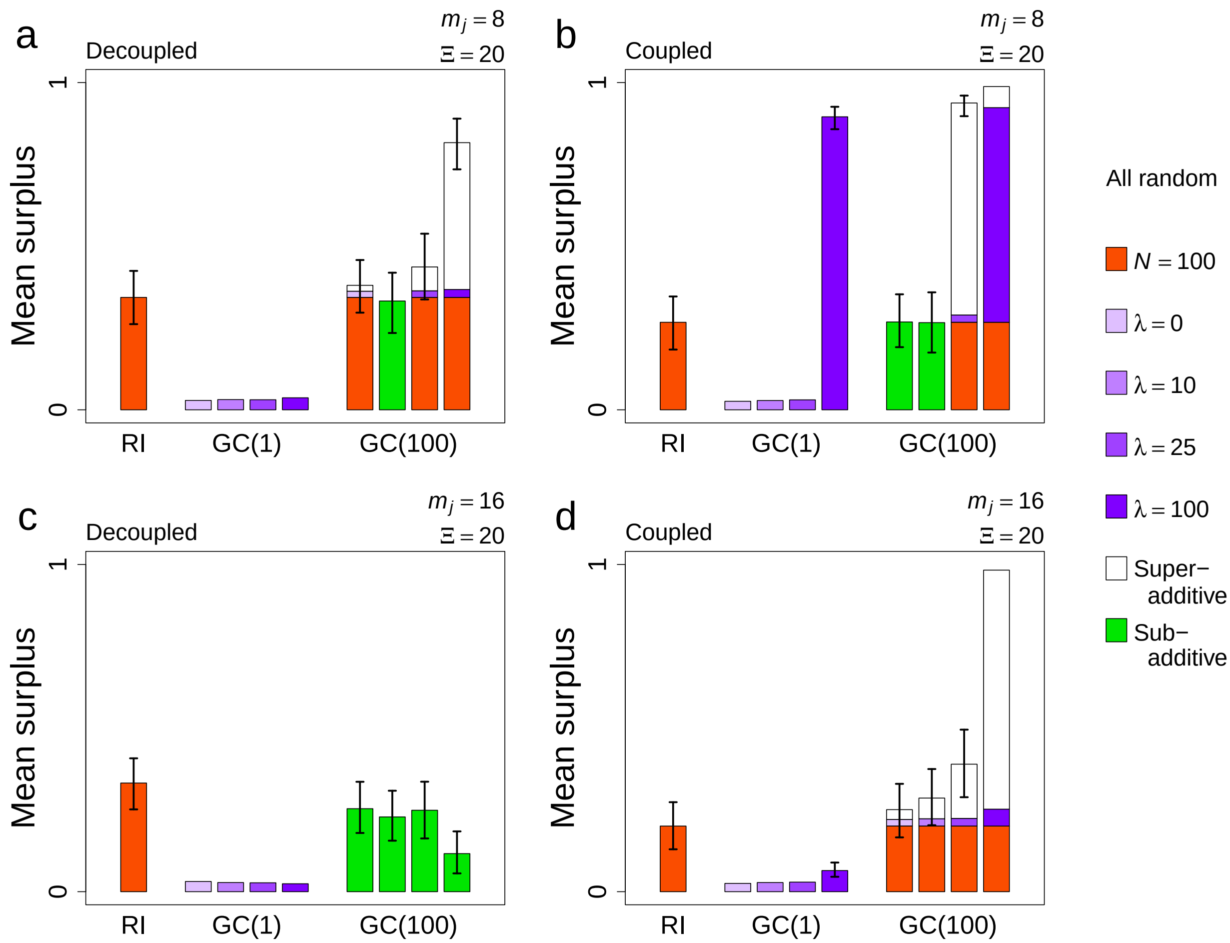
Supplementary Figure 145 | The gains from ingroup cooperation under different scenarios when strategies are three-dimensional. The mean surplus per ingroup interaction per agent is shown under the repeated interactions scenario (RI, $N = 100$), the group competition scenario (GC(1), $N = 1$ and $\lambda \in \{0, 10, 25, 100\}$), and the joint scenario (GC(100), $N = 100$ and $\lambda \in \{0, 10, 25, 100\}$). Under the joint scenario, we compare the mean surplus to an additive combination of the mean surplus in the repeated interactions scenario and the relevant group competition scenario (§ 3). If the mean surplus under the joint scenario is greater than this combination, the effect of combining repeated interactions within groups and competition between groups yields a surplus that is super-additive on average. If the mean surplus is less than the additive combination, the combined effect under the joint scenario is sub-additive. Panels differ in terms of whether or not the life cycle couples game play and individual selection and in terms of migration rates (m_j). Ξ controls group-level cancellation effects. Error bars denote 95% confidence intervals based on a bootstrapping algorithm clustered at the population level. We omit these confidence intervals when extremely narrow.



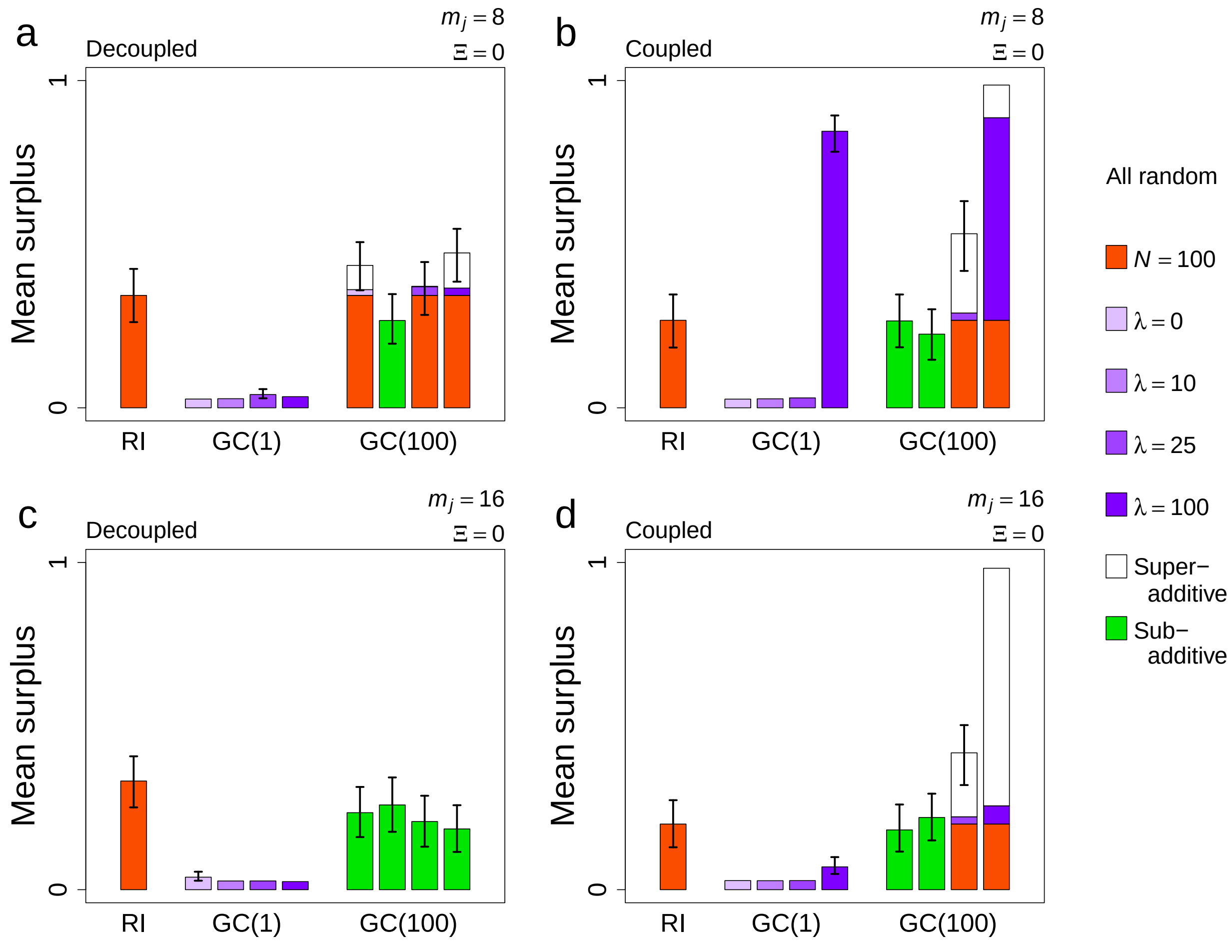
Supplementary Figure 146 | The gains from ingroup cooperation under different scenarios when strategies are three-dimensional. The mean surplus per ingroup interaction per agent is shown under the repeated interactions scenario (RI, $N = 100$), the group competition scenario (GC(1), $N = 1$ and $\lambda \in \{0, 10, 25, 100\}$), and the joint scenario (GC(100), $N = 100$ and $\lambda \in \{0, 10, 25, 100\}$). Under the joint scenario, we compare the mean surplus to an additive combination of the mean surplus in the repeated interactions scenario and the relevant group competition scenario (§ 3). If the mean surplus under the joint scenario is greater than this combination, the effect of combining repeated interactions within groups and competition between groups yields a surplus that is super-additive on average. If the mean surplus is less than the additive combination, the combined effect under the joint scenario is sub-additive. Panels differ in terms of whether or not the life cycle couples game play and individual selection and in terms of migration rates (m_j). Ξ controls group-level cancellation effects. Error bars denote 95% confidence intervals based on a bootstrapping algorithm clustered at the population level. We omit these confidence intervals when extremely narrow.



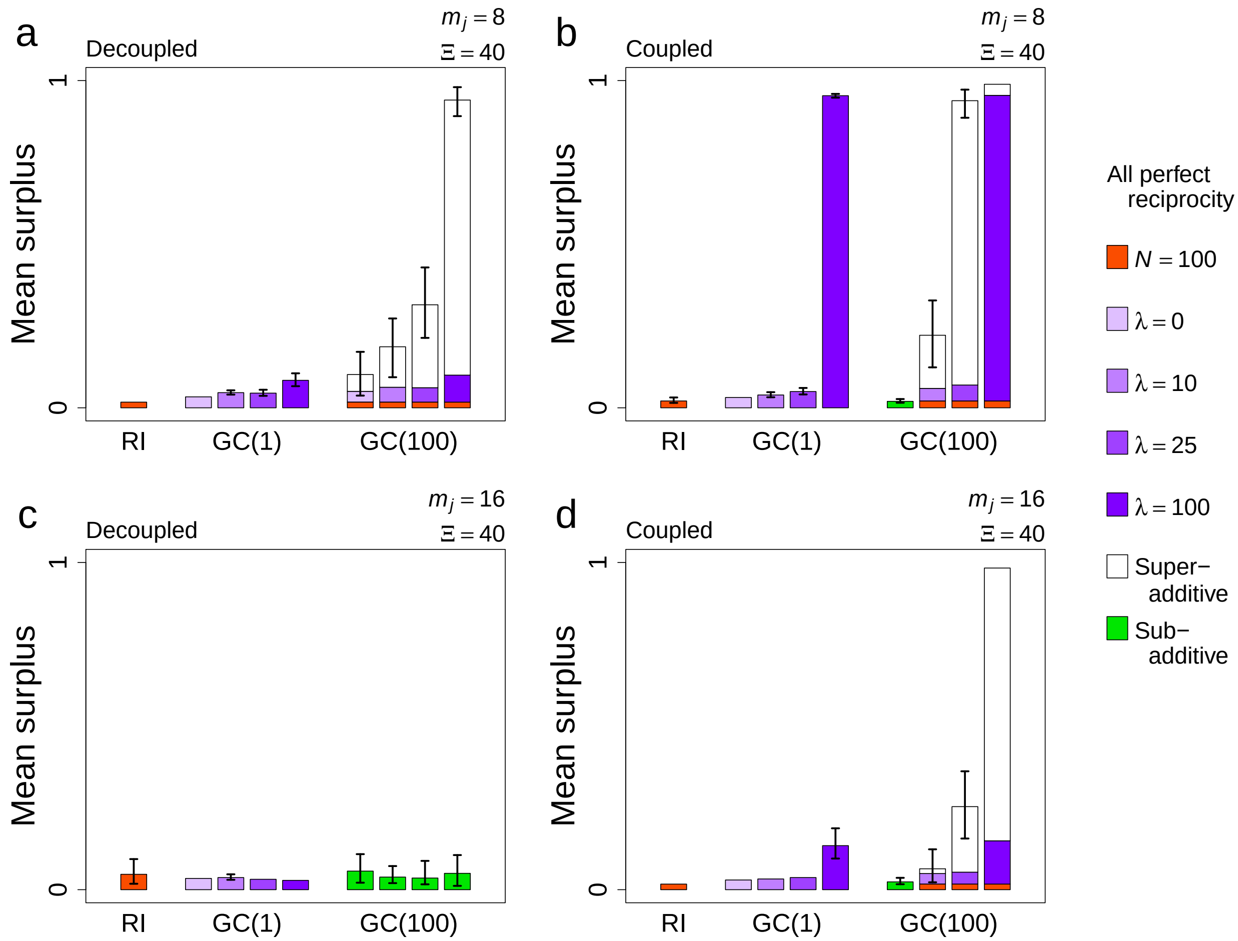
Supplementary Figure 147 | The gains from ingroup cooperation under different scenarios when strategies are four-dimensional. The mean surplus per ingroup interaction per agent is shown under the repeated interactions scenario (RI, $N = 100$), the group competition scenario (GC(1), $N = 1$ and $\lambda \in \{0, 10, 25, 100\}$), and the joint scenario (GC(100), $N = 100$ and $\lambda \in \{0, 10, 25, 100\}$). Under the joint scenario, we compare the mean surplus to an additive combination of the mean surplus in the repeated interactions scenario and the relevant group competition scenario (§ 3). If the mean surplus under the joint scenario is greater than this combination, the effect of combining repeated interactions within groups and competition between groups yields a surplus that is super-additive on average. If the mean surplus is less than the additive combination, the combined effect under the joint scenario is sub-additive. Panels differ in terms of whether or not the life cycle couples game play and individual selection and in terms of migration rates (m_j). Ξ controls group-level cancellation effects. Error bars denote 95% confidence intervals based on a bootstrapping algorithm clustered at the population level. We omit these confidence intervals when extremely narrow.



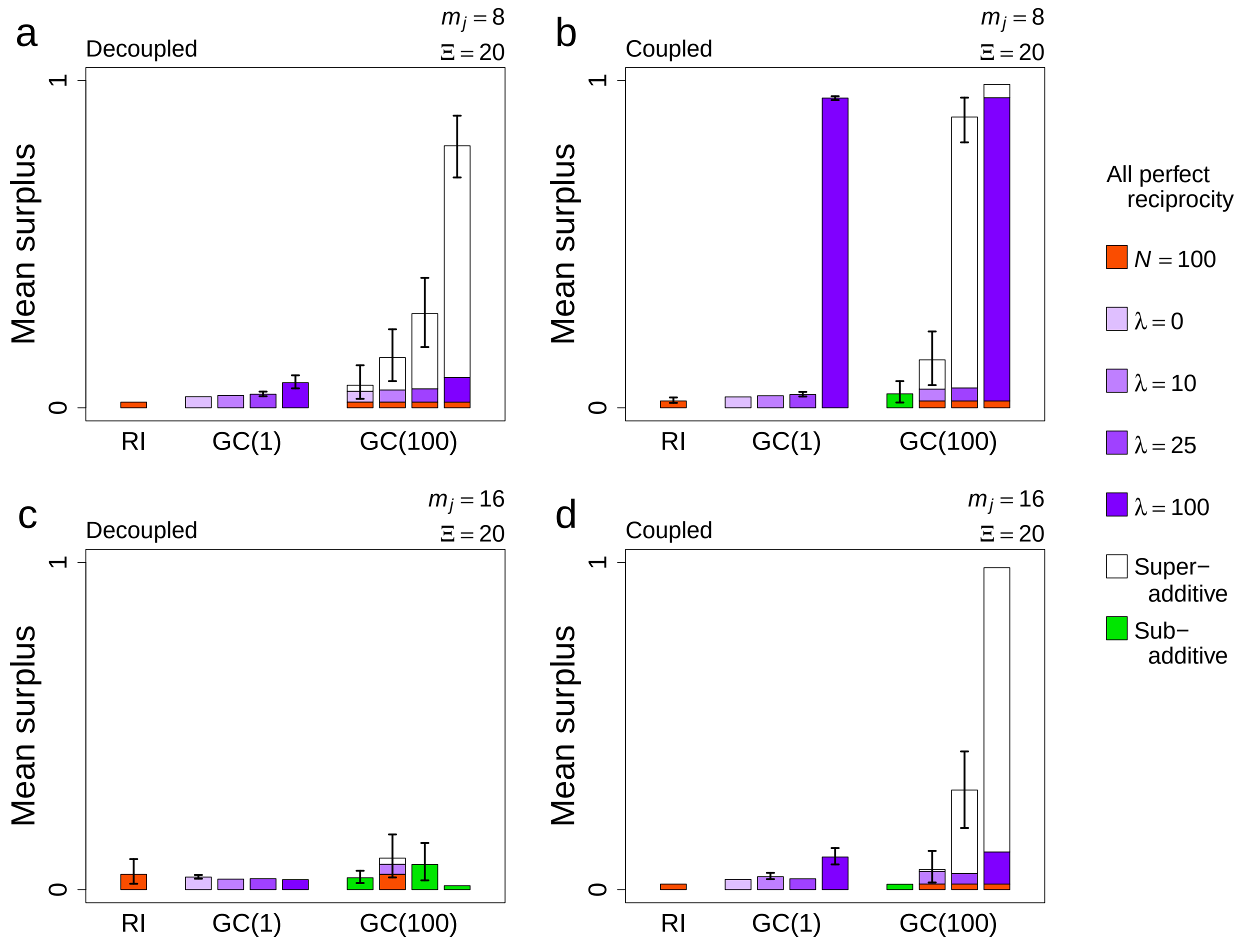
Supplementary Figure 148 | The gains from ingroup cooperation under different scenarios when strategies are four-dimensional. The mean surplus per ingroup interaction per agent is shown under the repeated interactions scenario (RI, $N = 100$), the group competition scenario (GC(1), $N = 1$ and $\lambda \in \{0, 10, 25, 100\}$), and the joint scenario (GC(100), $N = 100$ and $\lambda \in \{0, 10, 25, 100\}$). Under the joint scenario, we compare the mean surplus to an additive combination of the mean surplus in the repeated interactions scenario and the relevant group competition scenario (§ 3). If the mean surplus under the joint scenario is greater than this combination, the effect of combining repeated interactions within groups and competition between groups yields a surplus that is super-additive on average. If the mean surplus is less than the additive combination, the combined effect under the joint scenario is sub-additive. Panels differ in terms of whether or not the life cycle couples game play and individual selection and in terms of migration rates (m_j). Ξ controls group-level cancellation effects. Error bars denote 95% confidence intervals based on a bootstrapping algorithm clustered at the population level. We omit these confidence intervals when extremely narrow.



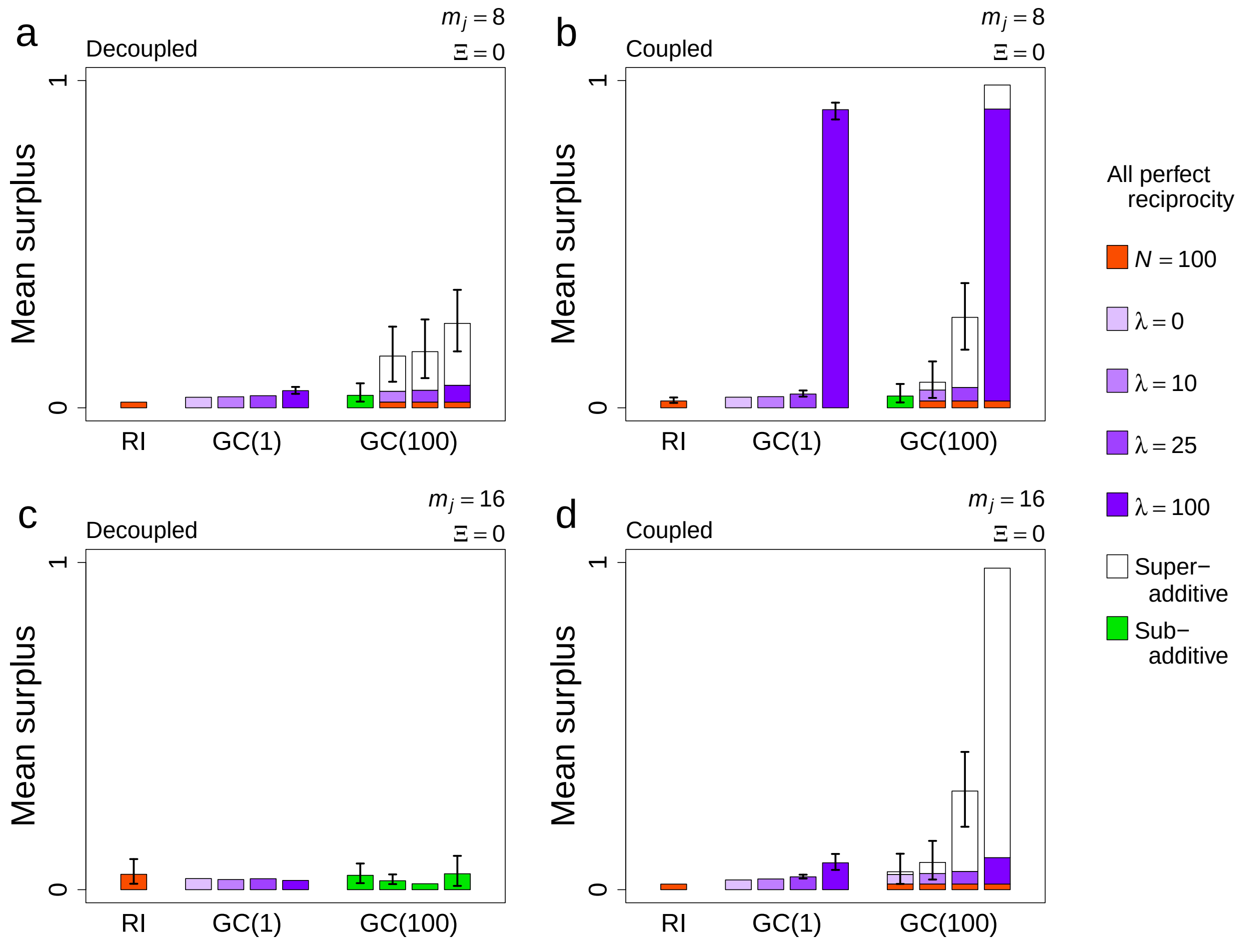
Supplementary Figure 149 | The gains from ingroup cooperation under different scenarios when strategies are four-dimensional. The mean surplus per ingroup interaction per agent is shown under the repeated interactions scenario (RI, $N = 100$), the group competition scenario (GC(1), $N = 1$ and $\lambda \in \{0, 10, 25, 100\}$), and the joint scenario (GC(100), $N = 100$ and $\lambda \in \{0, 10, 25, 100\}$). Under the joint scenario, we compare the mean surplus to an additive combination of the mean surplus in the repeated interactions scenario and the relevant group competition scenario (§ 3). If the mean surplus under the joint scenario is greater than this combination, the effect of combining repeated interactions within groups and competition between groups yields a surplus that is super-additive on average. If the mean surplus is less than the additive combination, the combined effect under the joint scenario is sub-additive. Panels differ in terms of whether or not the life cycle couples game play and individual selection and in terms of migration rates (m_j). Ξ controls group-level cancellation effects. Error bars denote 95% confidence intervals based on a bootstrapping algorithm clustered at the population level. We omit these confidence intervals when extremely narrow.



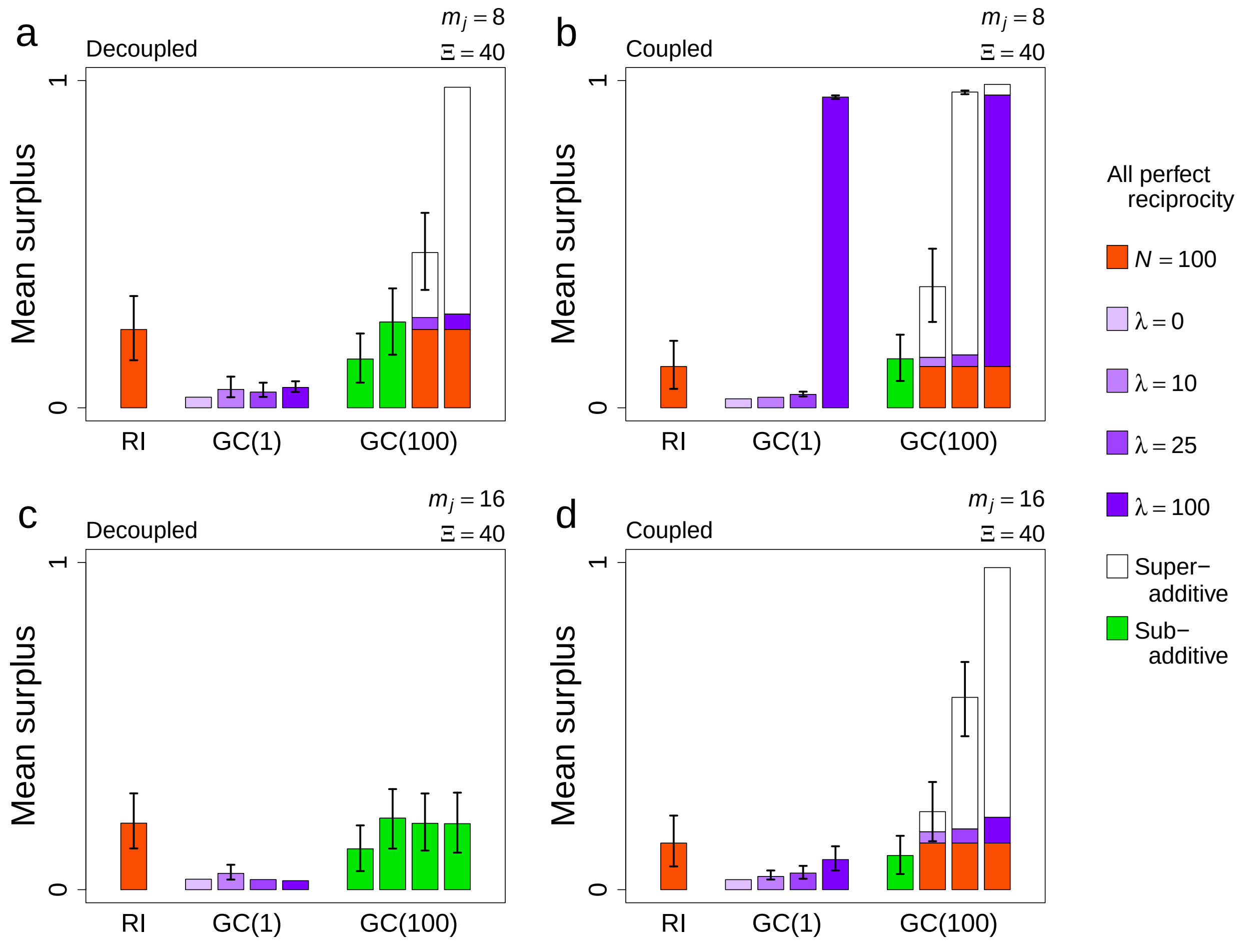
Supplementary Figure 150 | The gains from ingroup cooperation under different scenarios when strategies are three-dimensional. The mean surplus per ingroup interaction per agent is shown under the repeated interactions scenario (RI, $N = 100$), the group competition scenario (GC(1), $N = 1$ and $\lambda \in \{0, 10, 25, 100\}$), and the joint scenario (GC(100), $N = 100$ and $\lambda \in \{0, 10, 25, 100\}$). Under the joint scenario, we compare the mean surplus to an additive combination of the mean surplus in the repeated interactions scenario and the relevant group competition scenario (§ 3). If the mean surplus under the joint scenario is greater than this combination, the effect of combining repeated interactions within groups and competition between groups yields a surplus that is super-additive on average. If the mean surplus is less than the additive combination, the combined effect under the joint scenario is sub-additive. Panels differ in terms of whether or not the life cycle couples game play and individual selection and in terms of migration rates (m_j). Ξ controls group-level cancellation effects. Error bars denote 95% confidence intervals based on a bootstrapping algorithm clustered at the population level. We omit these confidence intervals when extremely narrow.



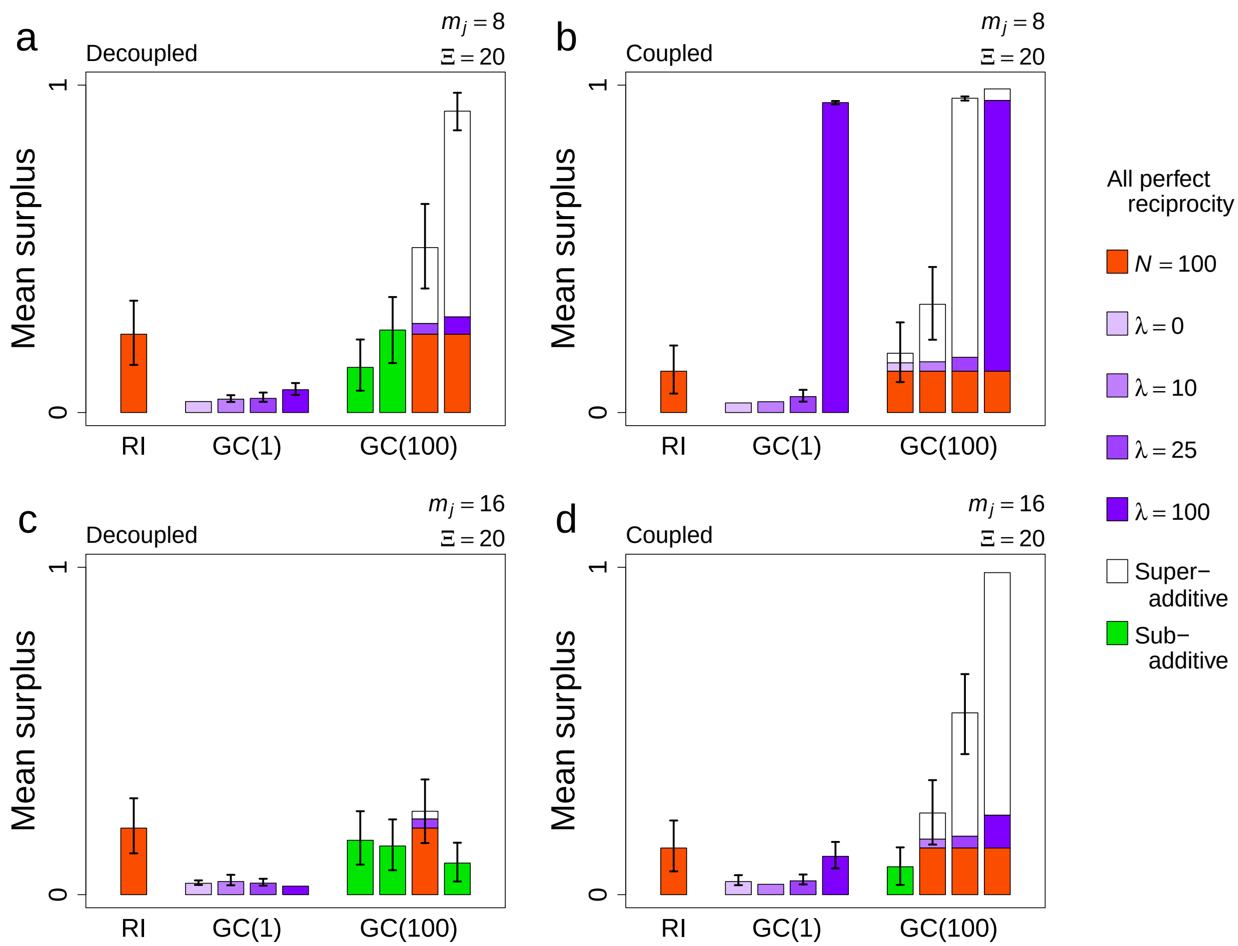
Supplementary Figure 151 | The gains from ingroup cooperation under different scenarios when strategies are three-dimensional. The mean surplus per ingroup interaction per agent is shown under the repeated interactions scenario (RI, $N = 100$), the group competition scenario (GC(1), $N = 1$ and $\lambda \in \{0, 10, 25, 100\}$), and the joint scenario (GC(100), $N = 100$ and $\lambda \in \{0, 10, 25, 100\}$). Under the joint scenario, we compare the mean surplus to an additive combination of the mean surplus in the repeated interactions scenario and the relevant group competition scenario (§ 3). If the mean surplus under the joint scenario is greater than this combination, the effect of combining repeated interactions within groups and competition between groups yields a surplus that is super-additive on average. If the mean surplus is less than the additive combination, the combined effect under the joint scenario is sub-additive. Panels differ in terms of whether or not the life cycle couples game play and individual selection and in terms of migration rates (m_j). Ξ controls group-level cancellation effects. Error bars denote 95% confidence intervals based on a bootstrapping algorithm clustered at the population level. We omit these confidence intervals when extremely narrow.



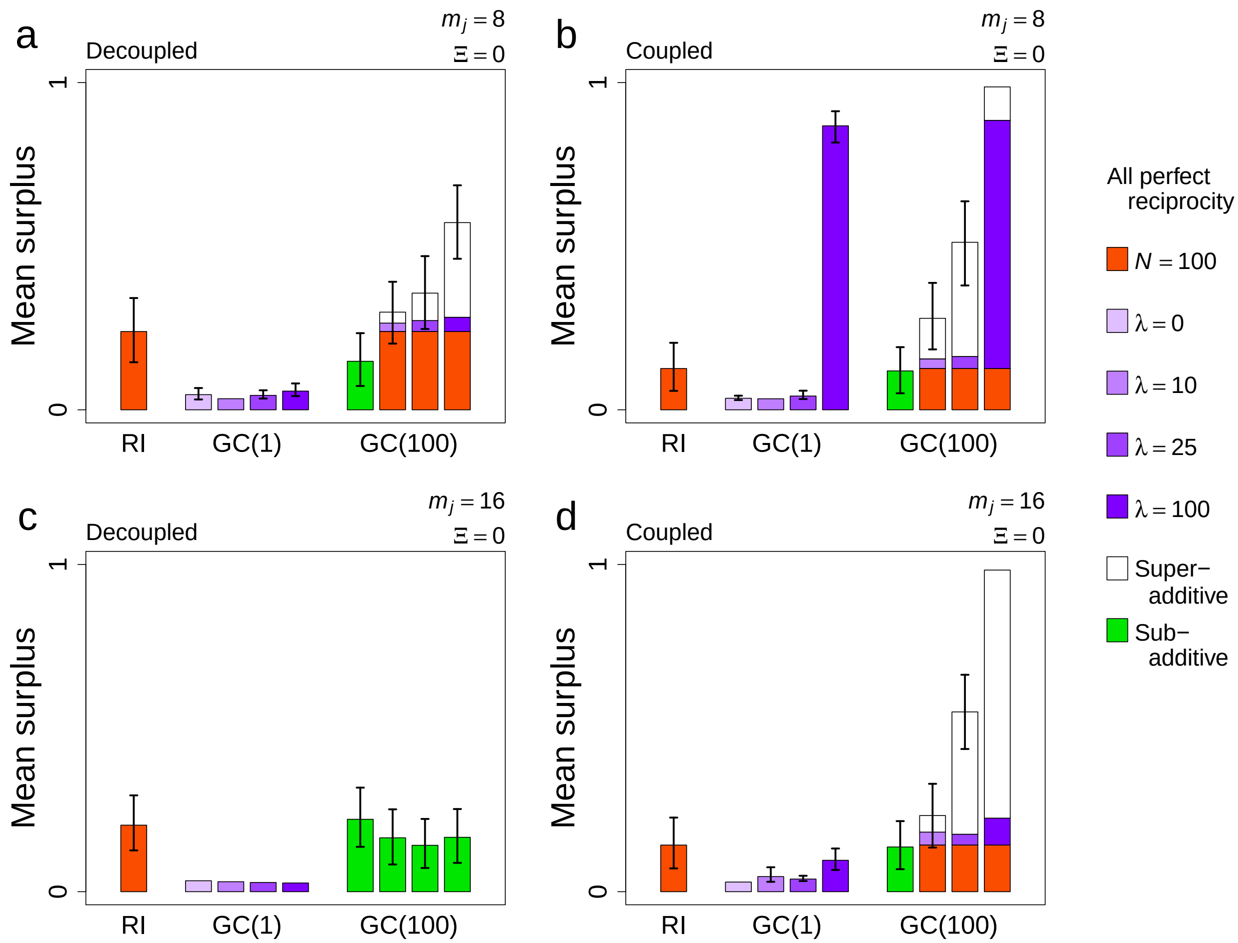
Supplementary Figure 152 | The gains from ingroup cooperation under different scenarios when strategies are three-dimensional. The mean surplus per ingroup interaction per agent is shown under the repeated interactions scenario (RI, $N = 100$), the group competition scenario (GC(1), $N = 1$ and $\lambda \in \{0, 10, 25, 100\}$), and the joint scenario (GC(100), $N = 100$ and $\lambda \in \{0, 10, 25, 100\}$). Under the joint scenario, we compare the mean surplus to an additive combination of the mean surplus in the repeated interactions scenario and the relevant group competition scenario (§ 3). If the mean surplus under the joint scenario is greater than this combination, the effect of combining repeated interactions within groups and competition between groups yields a surplus that is super-additive on average. If the mean surplus is less than the additive combination, the combined effect under the joint scenario is sub-additive. Panels differ in terms of whether or not the life cycle couples game play and individual selection and in terms of migration rates (m_j). Ξ controls group-level cancellation effects. Error bars denote 95% confidence intervals based on a bootstrapping algorithm clustered at the population level. We omit these confidence intervals when extremely narrow.



Supplementary Figure 153 | The gains from ingroup cooperation under different scenarios when strategies are four-dimensional. The mean surplus per ingroup interaction per agent is shown under the repeated interactions scenario (RI, $N = 100$), the group competition scenario (GC(1), $N = 1$ and $\lambda \in \{0, 10, 25, 100\}$), and the joint scenario (GC(100), $N = 100$ and $\lambda \in \{0, 10, 25, 100\}$). Under the joint scenario, we compare the mean surplus to an additive combination of the mean surplus in the repeated interactions scenario and the relevant group competition scenario (§ 3). If the mean surplus under the joint scenario is greater than this combination, the effect of combining repeated interactions within groups and competition between groups yields a surplus that is super-additive on average. If the mean surplus is less than the additive combination, the combined effect under the joint scenario is sub-additive. Panels differ in terms of whether or not the life cycle couples game play and individual selection and in terms of migration rates (m_j). Ξ controls group-level cancellation effects. Error bars denote 95% confidence intervals based on a bootstrapping algorithm clustered at the population level. We omit these confidence intervals when extremely narrow.



Supplementary Figure 154 | The gains from ingroup cooperation under different scenarios when strategies are four-dimensional. The mean surplus per ingroup interaction per agent is shown under the repeated interactions scenario (RI, $N = 100$), the group competition scenario (GC(1), $N = 1$ and $\lambda \in \{0, 10, 25, 100\}$), and the joint scenario (GC(100), $N = 100$ and $\lambda \in \{0, 10, 25, 100\}$). Under the joint scenario, we compare the mean surplus to an additive combination of the mean surplus in the repeated interactions scenario and the relevant group competition scenario (§ 3). If the mean surplus under the joint scenario is greater than this combination, the effect of combining repeated interactions within groups and competition between groups yields a surplus that is super-additive on average. If the mean surplus is less than the additive combination, the combined effect under the joint scenario is sub-additive. Panels differ in terms of whether or not the life cycle couples game play and individual selection and in terms of migration rates (m_j). Ξ controls group-level cancellation effects. Error bars denote 95% confidence intervals based on a bootstrapping algorithm clustered at the population level. We omit these confidence intervals when extremely narrow.



Supplementary Figure 155 | The gains from ingroup cooperation under different scenarios when strategies are four-dimensional. The mean surplus per ingroup interaction per agent is shown under the repeated interactions scenario (RI, $N = 100$), the group competition scenario (GC(1), $N = 1$ and $\lambda \in \{0, 10, 25, 100\}$), and the joint scenario (GC(100), $N = 100$ and $\lambda \in \{0, 10, 25, 100\}$). Under the joint scenario, we compare the mean surplus to an additive combination of the mean surplus in the repeated interactions scenario and the relevant group competition scenario (§ 3). If the mean surplus under the joint scenario is greater than this combination, the effect of combining repeated interactions within groups and competition between groups yields a surplus that is super-additive on average. If the mean surplus is less than the additive combination, the combined effect under the joint scenario is sub-additive. Panels differ in terms of whether or not the life cycle couples game play and individual selection and in terms of migration rates (m_j). Ξ controls group-level cancellation effects. Error bars denote 95% confidence intervals based on a bootstrapping algorithm clustered at the population level. We omit these confidence intervals when extremely narrow.

4 Weak selection

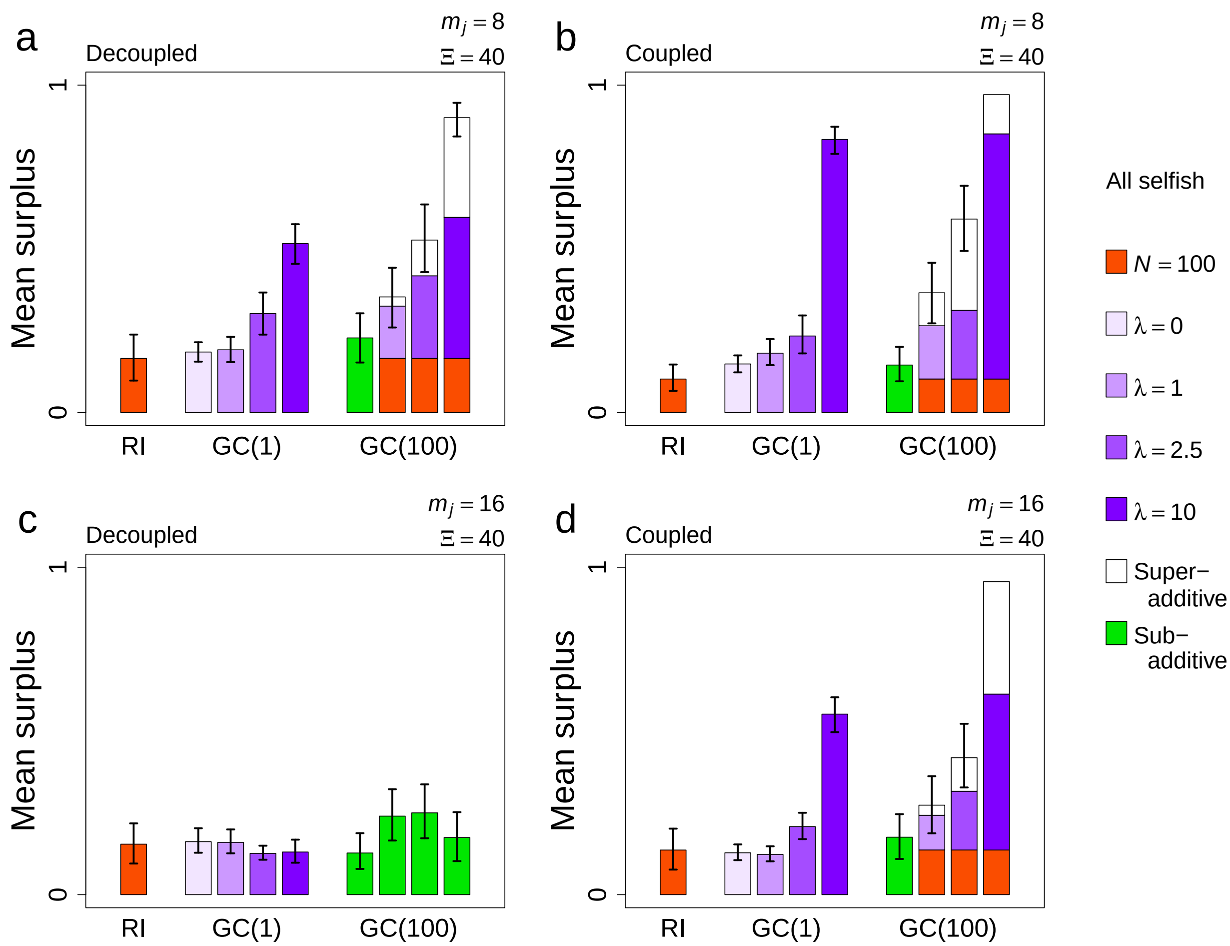
To implement simulations under relatively weak selection, we changed the values of both ζ and λ and reran the simulations with ingroup and outgroup strategies defined in three dimensions. For previous simulations, we relied on $\zeta = 0.5$ and $\lambda \in \{0, 10, 25, 100\}$. For weak selection, we reduced both by an order of magnitude, i.e. $\zeta = 0.05$ and $\lambda \in \{0, 1, 2.5, 10\}$. We reduced values of both ζ and λ because reducing ζ alone has no effect on the strength of selection between groups. Specifically, intergroup competition depends on the difference in aggregate resources between two paired groups, j and j', relative to Δ, and Δ is proportional to ζ. Thus, reducing ζ reduces the magnitude of unscaled differences in resources between groups, but it also reduces Δ. Consequently, differences in aggregate resources relative to Δ do not change.

All in all, changing the value of ζ may have an indirect effect on the strength of selection between groups because, for example, endogenous evolutionary dynamics are more or less subject to drift as ζ changes. Abstracting from these endogenous effects, however, the value of ζ can have no direct effect on the intensity of group-level selection because intergroup competition depends on the difference in resources between paired groups relative to $\Delta \propto \zeta$. Reducing the strength of selection both within and between groups thus requires reduced values of both ζ and λ. We ran simulations under weak selection for 100,000 generations.

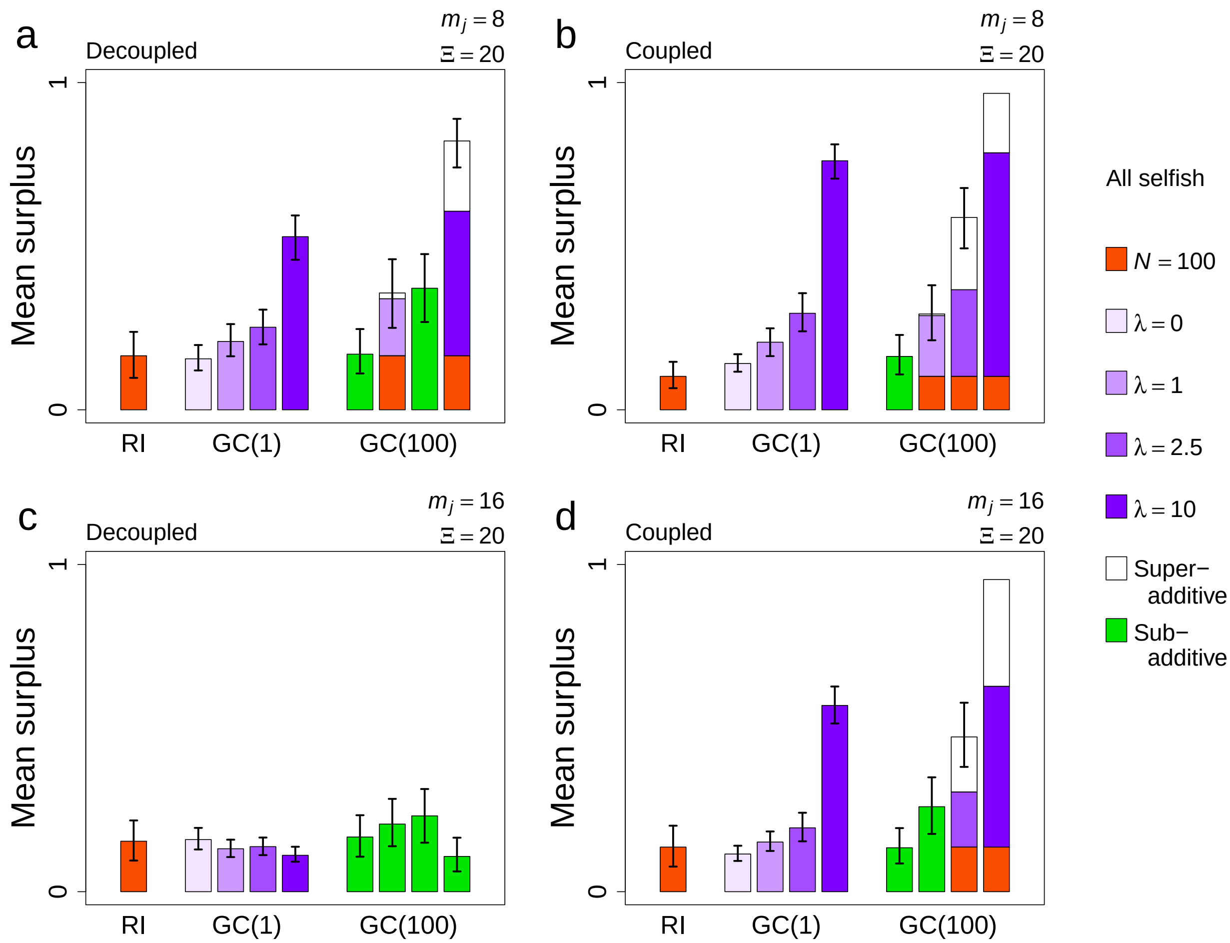
4.1 The ancestral case

Supplementary Figures 156 – 158 show results for simulations that begin with ancestral initial conditions, by which we mean a population that initially consists only of unconditionally selfish agents (All selfish, see § 2.1.8). Life cycles can yield population structures that are either decoupled or coupled at the game play and individual selection stages. In addition, migration (m_j), the sensitivity of group-level outcomes to group differences (λ), and group-level cancellation effects (Ξ) all vary.

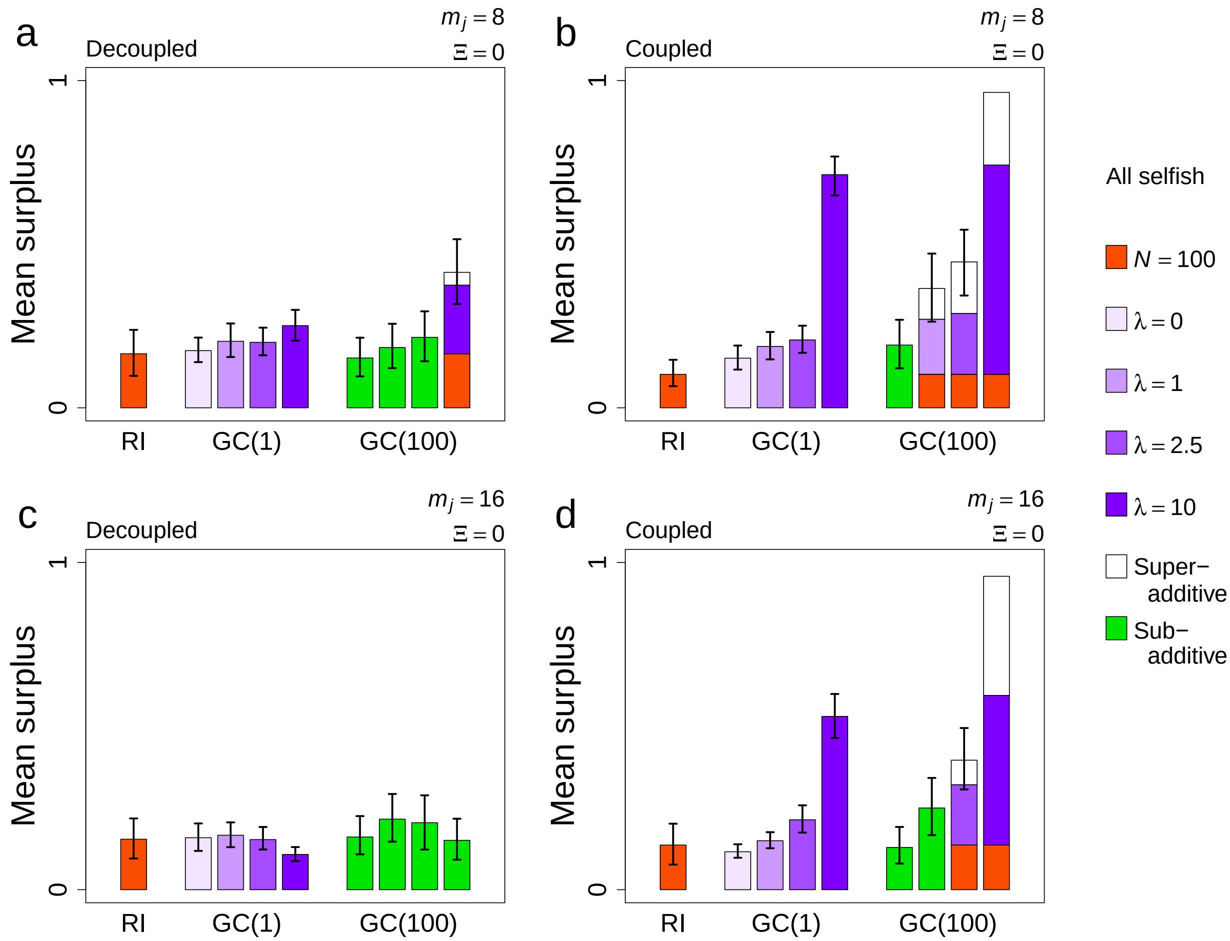
The figures show results that are broadly analogous to the results reported above (§ 3). However, relative to previous results (Supplementary Figures 138 – 140), conditions for the evolution of cooperation often improve in the group competition scenario. As an especially clear comparison, average surplus values are often higher under $\lambda = 1$ or $\lambda = 2.5$ and $\zeta = 0.05$ than they are under $\lambda = 10$ or $\lambda = 25$ and $\zeta = 0.5$. This occurs because drift at the group level increases in importance as ζ decreases in value. In particular, with selection within groups relatively weak (i.e. $\zeta = 0.05$ versus $\zeta = 0.5$), groups exhibit an increased tendency to diverge from each other because of drift. This tends to increase the differences in aggregate resources between paired groups, which in turn increases the rate of intergroup competition (e.g. Supplementary Figures 159 – 162). This seems to increase slightly the extent to which cooperative ingroup strategies evolve under group competition as a stand-alone mechanism, and this remains true even after reducing λ values. Nonetheless, so long as $\lambda > 0$, super-additive gains are common when repeated interactions and intergroup competition combine in the joint scenario. Incidentally, although we do not present the graphs here, group competition rates are also slightly higher for the joint scenario under weak selection than under $\zeta = 0.5$ and $\lambda \in \{0, 10, 25, 100\}$.



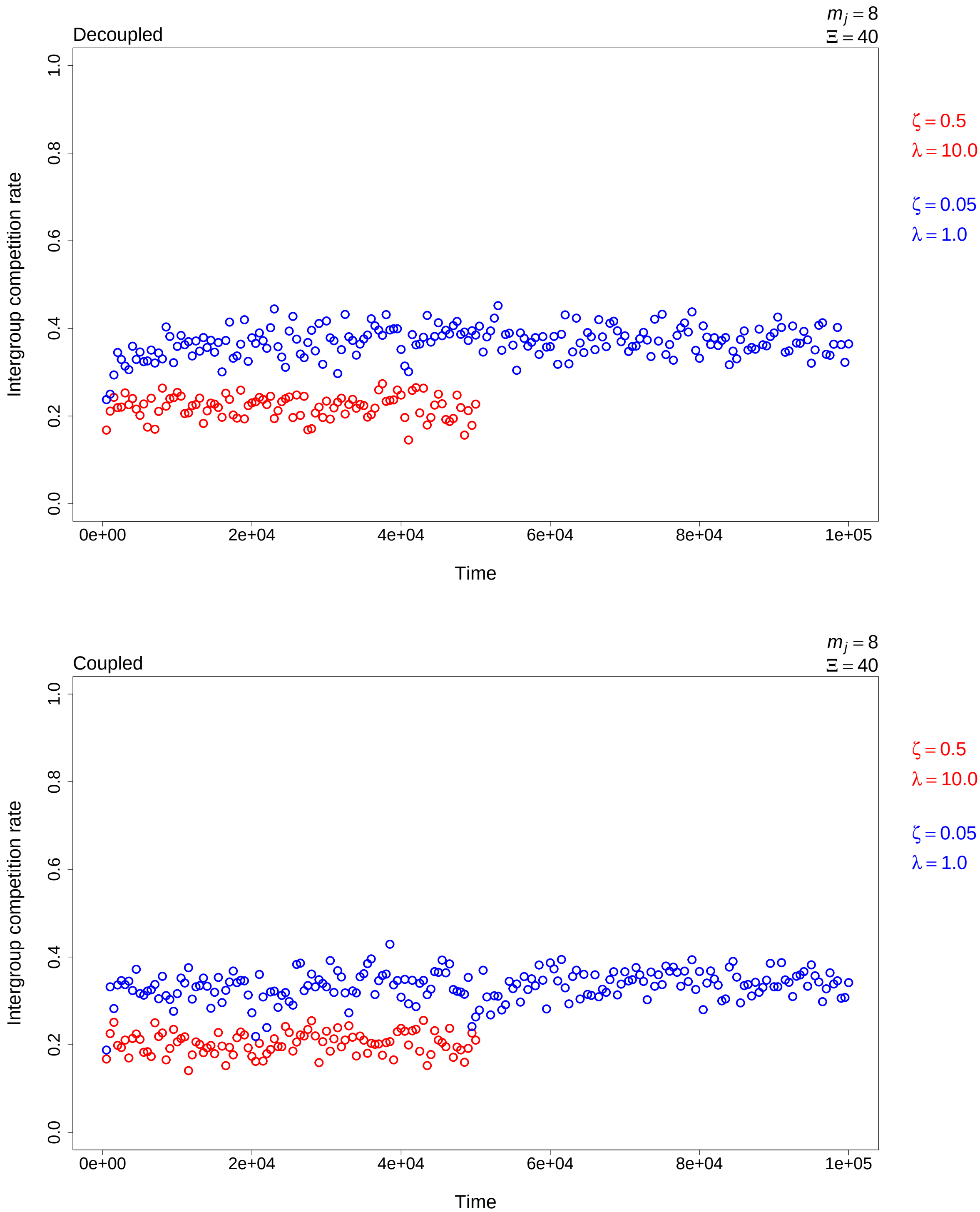
Supplementary Figure 156 | The gains from ingroup cooperation under different scenarios when strategies are three-dimensional and selection is relatively weak. The mean surplus per ingroup interaction per agent is shown under the repeated interactions scenario (RI, $N = 100$), the group competition scenario (GC(1), $N = 1$ and $\lambda \in \{0, 1, 2.5, 10\}$), and the joint scenario (GC(100), $N = 100$ and $\lambda \in \{0, 1, 2.5, 10\}$). Under the joint scenario, we compare the mean surplus to an additive combination of the mean surplus in the repeated interactions scenario and the relevant group competition scenario (§ 3). If the mean surplus under the joint scenario is greater than this combination, the effect of combining repeated interactions within groups and competition between groups yields a surplus that is super-additive on average. If the mean surplus is less than the additive combination, the combined effect under the joint scenario is sub-additive. Panels differ in terms of whether or not the life cycle couples game play and individual selection and in terms of migration rates (m_j). Ξ controls group-level cancellation effects. Error bars denote 95% confidence intervals based on a bootstrapping algorithm clustered at the population level. We omit these confidence intervals when extremely narrow.



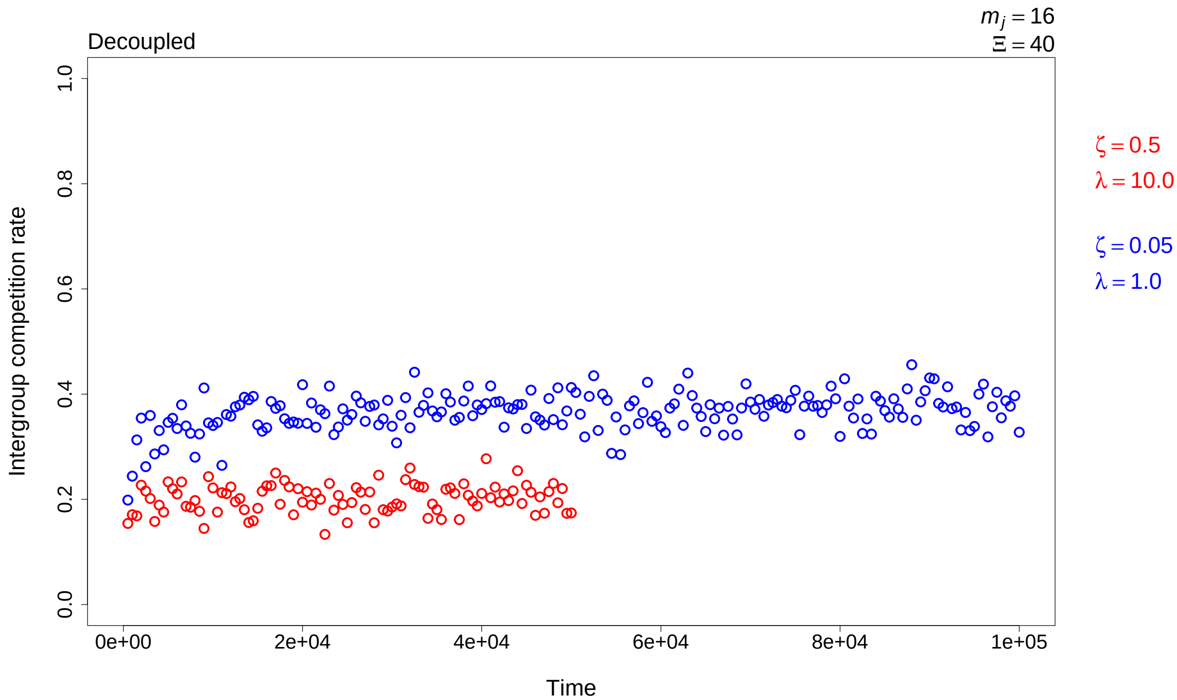
Supplementary Figure 157 | The gains from ingroup cooperation under different scenarios when strategies are three-dimensional and selection is relatively weak. The mean surplus per ingroup interaction per agent is shown under the repeated interactions scenario (RI, $N = 100$), the group competition scenario (GC(1), $N = 1$ and $\lambda \in \{0, 1, 2.5, 10\}$), and the joint scenario (GC(100), $N = 100$ and $\lambda \in \{0, 1, 2.5, 10\}$). Under the joint scenario, we compare the mean surplus to an additive combination of the mean surplus in the repeated interactions scenario and the relevant group competition scenario (§ 3). If the mean surplus under the joint scenario is greater than this combination, the effect of combining repeated interactions within groups and competition between groups yields a surplus that is super-additive on average. If the mean surplus is less than the additive combination, the combined effect under the joint scenario is sub-additive. Panels differ in terms of whether or not the life cycle couples game play and individual selection and in terms of migration rates (m_j). Ξ controls group-level cancellation effects. Error bars denote 95% confidence intervals based on a bootstrapping algorithm clustered at the population level. We omit these confidence intervals when extremely narrow.

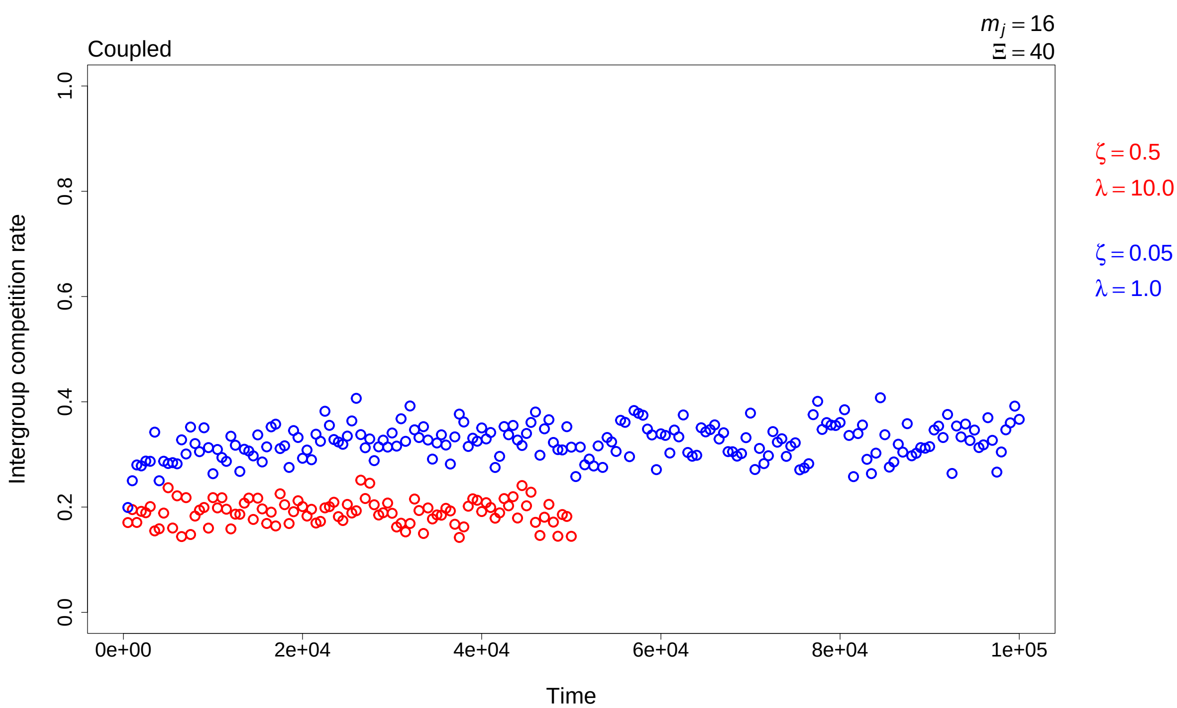


Supplementary Figure 158 | The gains from ingroup cooperation under different scenarios when strategies are three-dimensional and selection is relatively weak. The mean surplus per ingroup interaction per agent is shown under the repeated interactions scenario (RI, $N = 100$), the group competition scenario (GC(1), $N = 1$ and $\lambda \in \{0, 1, 2.5, 10\}$), and the joint scenario (GC(100), $N = 100$ and $\lambda \in \{0, 1, 2.5, 10\}$). Under the joint scenario, we compare the mean surplus to an additive combination of the mean surplus in the repeated interactions scenario and the relevant group competition scenario (§ 3). If the mean surplus under the joint scenario is greater than this combination, the effect of combining repeated interactions within groups and competition between groups yields a surplus that is super-additive on average. If the mean surplus is less than the additive combination, the combined effect under the joint scenario is sub-additive. Panels differ in terms of whether or not the life cycle couples game play and individual selection and in terms of migration rates (m_j). Ξ controls group-level cancellation effects. Error bars denote 95% confidence intervals based on a bootstrapping algorithm clustered at the population level. We omit these confidence intervals when extremely narrow.

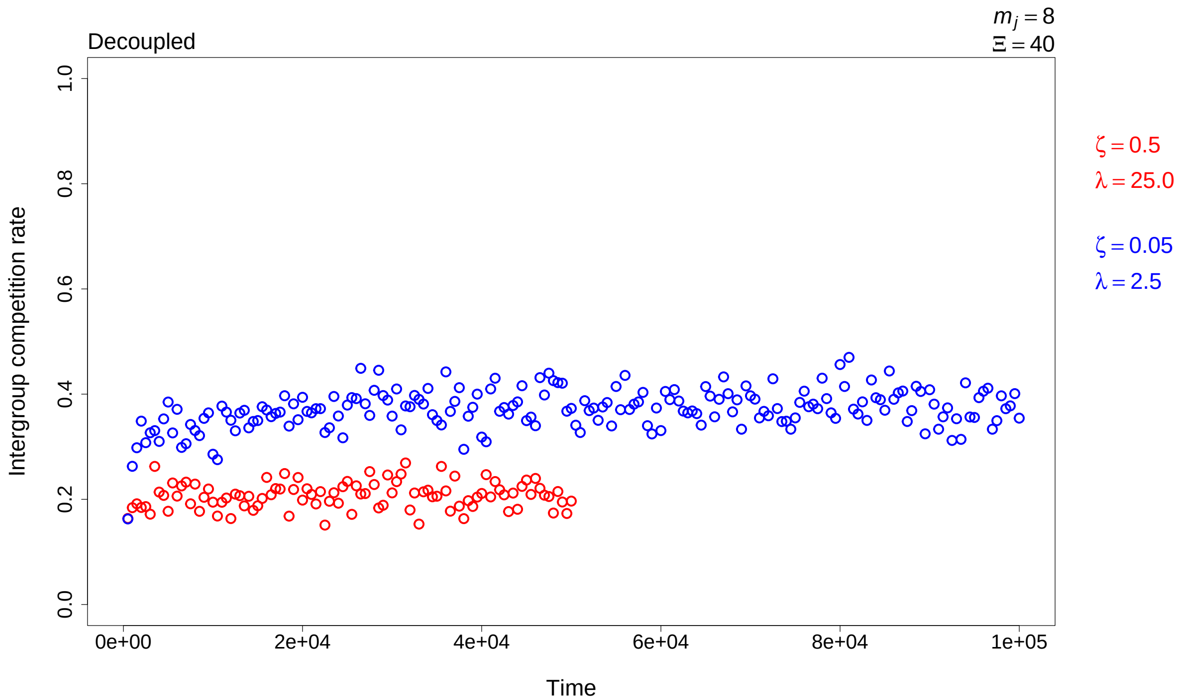


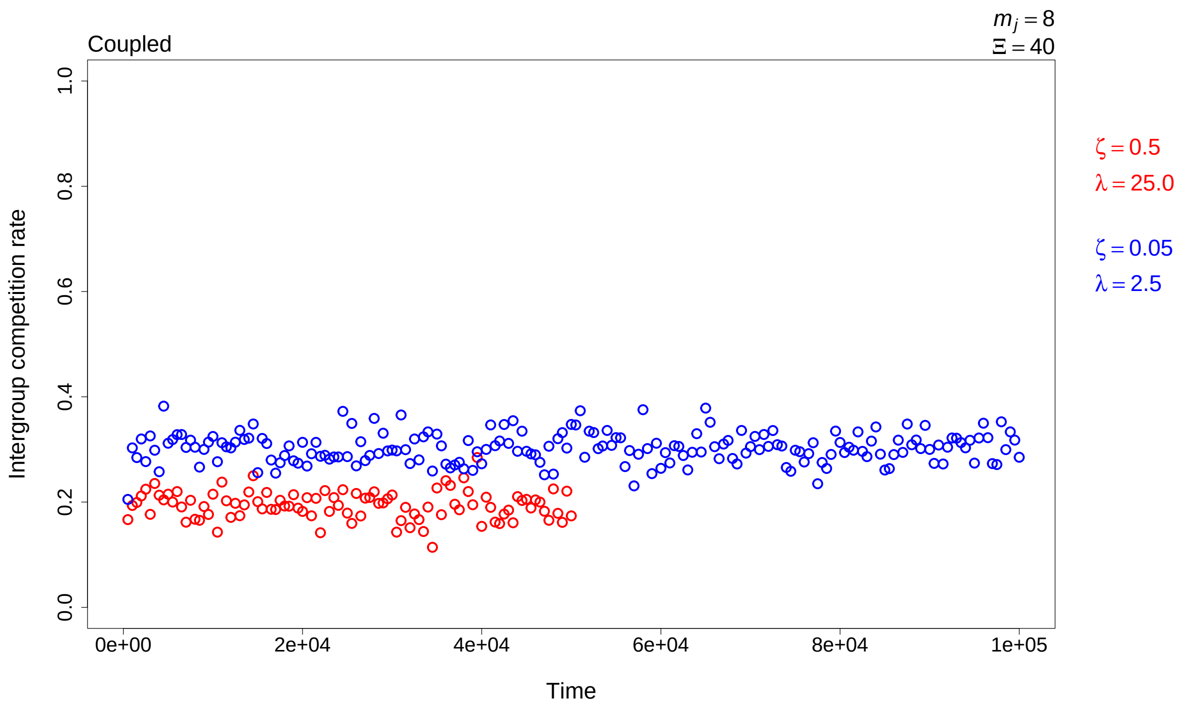
Supplementary Figure 159 | Mean intergroup competition, group competition scenario. Rates averaged over independent simulations under relatively weak (blue) and relatively strong selection (red).



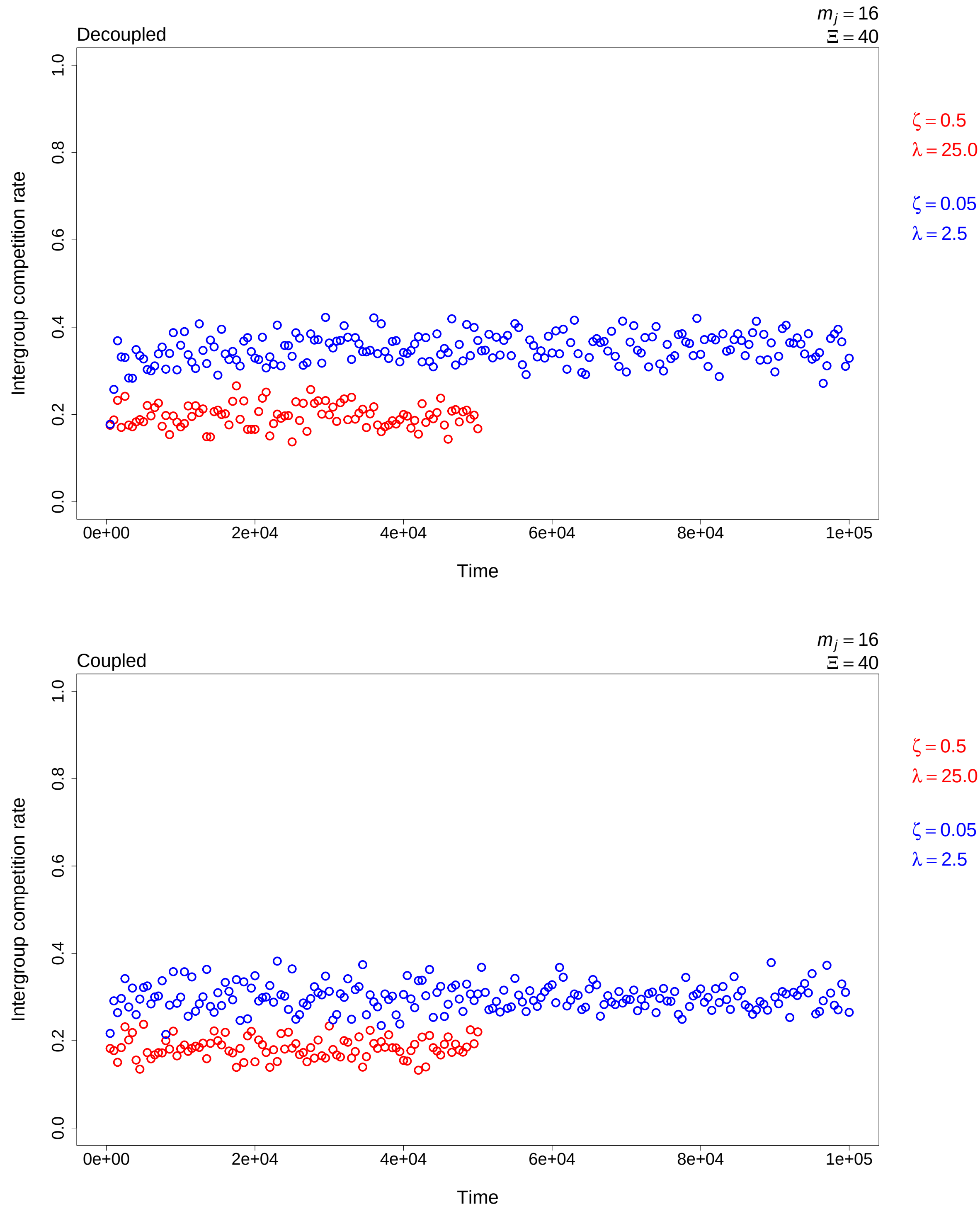


Supplementary Figure 160 | Mean intergroup competition, group competition scenario. Rates averaged over independent simulations under relatively weak (blue) and relatively strong selection (red).





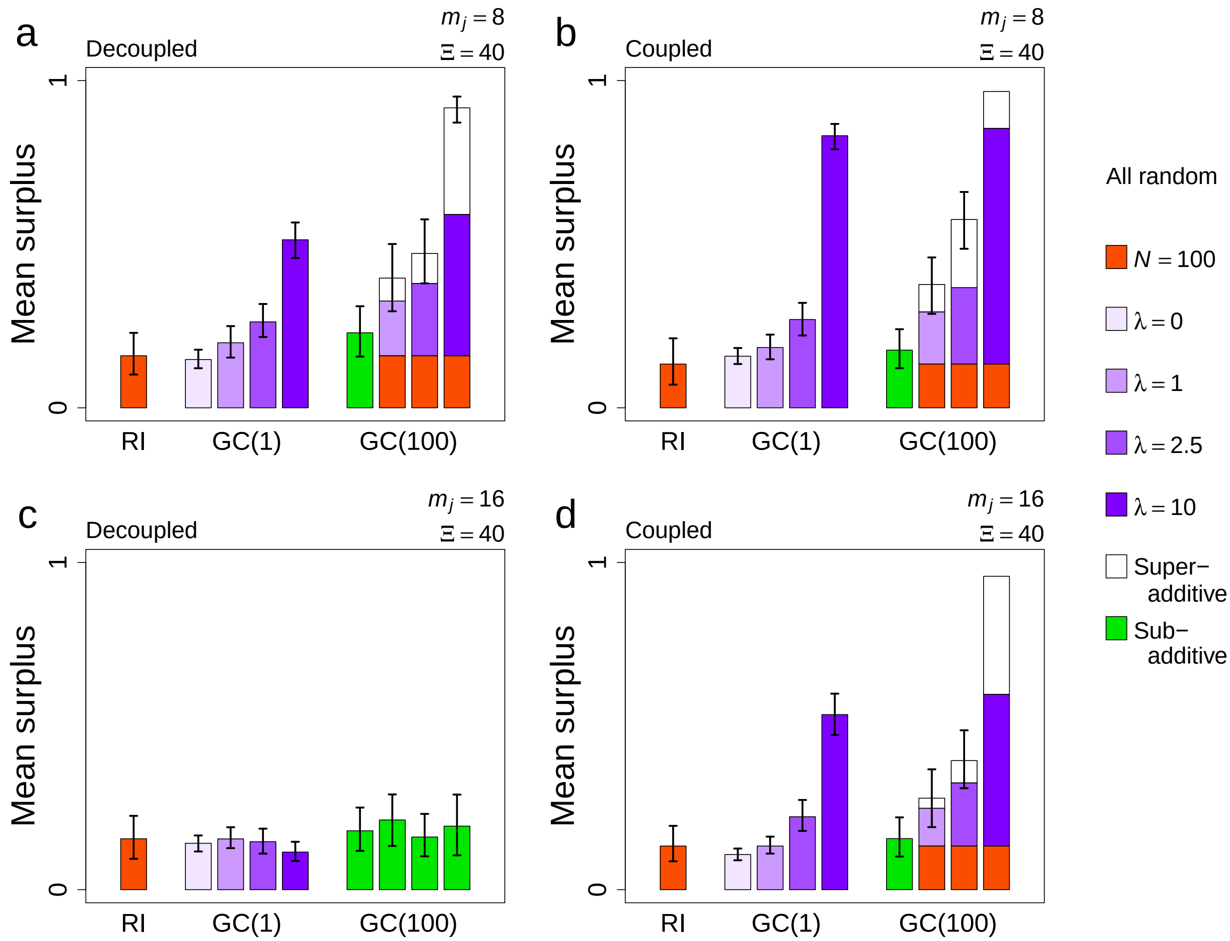
Supplementary Figure 161 | Mean intergroup competition, group competition scenario. Rates averaged over independent simulations under relatively weak (blue) and relatively strong selection (red).



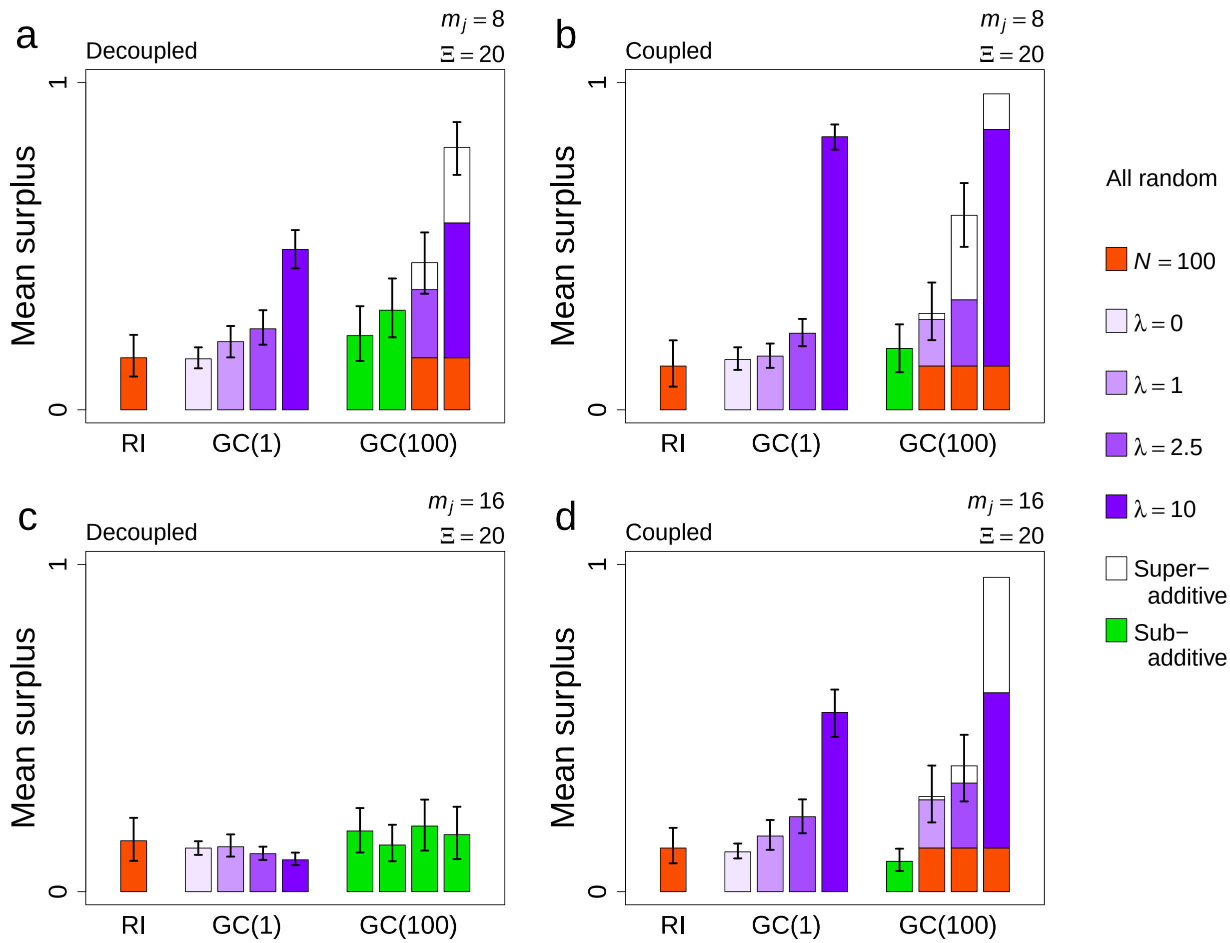
Supplementary Figure 162 | Mean intergroup competition, group competition scenario. Rates averaged over independent simulations under relatively weak (blue) and relatively strong selection (red).

4.2 Other cases

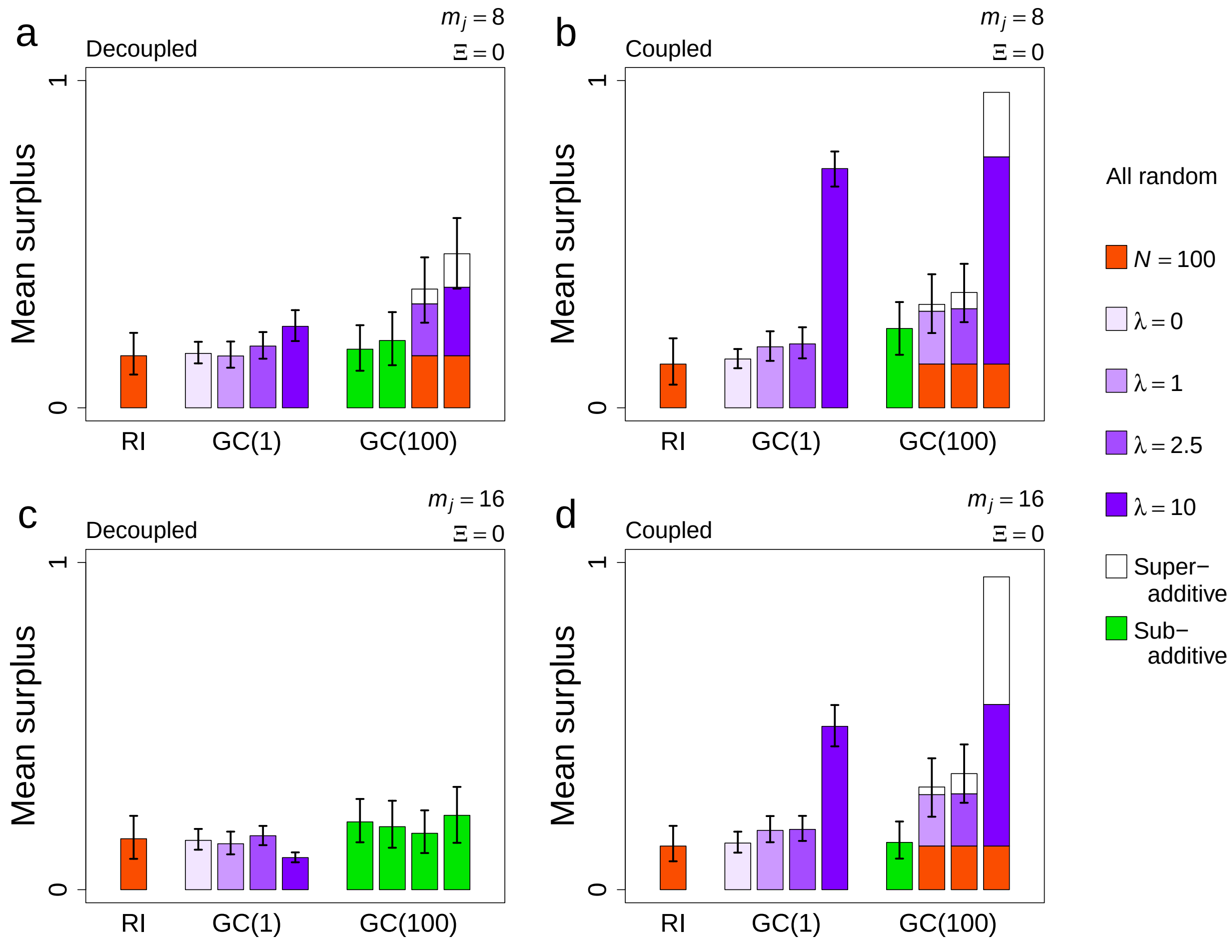
Supplementary Figures 163 – 168 show results given initial conditions that we do not consider ancestral. Specifically, initial conditions can consist of random strategies (All random, see § 2.1.8) or perfect reciprocators (All perfect reciprocity, see § 2.1.8). Life cycles can yield population structures that are either decoupled or coupled at the game play and individual selection stages. In addition, migration (m_j), the sensitivity of group-level outcomes to group differences (λ), and group-level cancellation effects (Ξ) all vary. Results are similar to those under ancestral initial conditions.



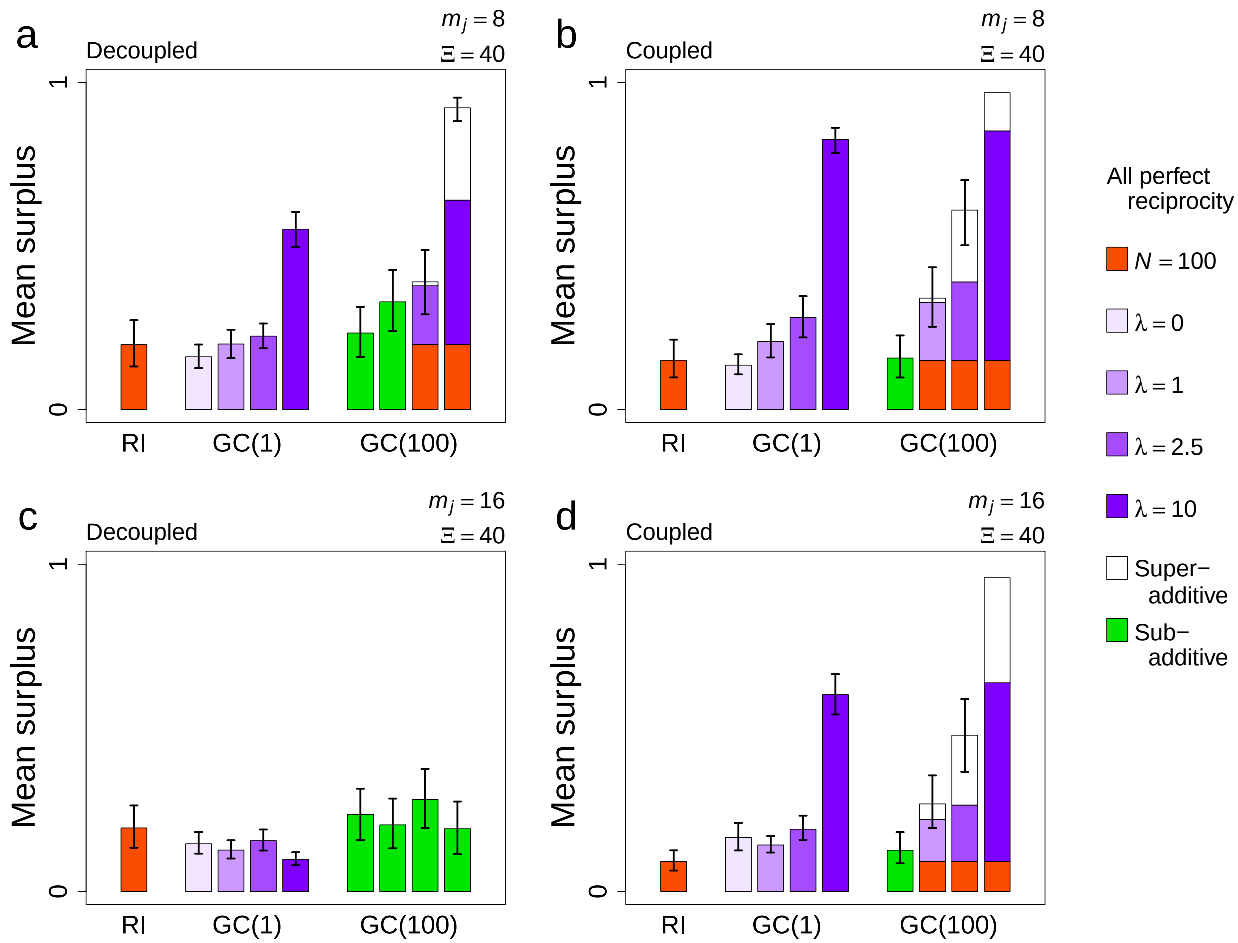
Supplementary Figure 163 | The gains from ingroup cooperation under different scenarios when strategies are three-dimensional and selection is relatively weak. The mean surplus per ingroup interaction per agent is shown under the repeated interactions scenario (RI, $N = 100$), the group competition scenario (GC(1), $N = 1$ and $\lambda \in \{0, 1, 2.5, 10\}$), and the joint scenario (GC(100), $N = 100$ and $\lambda \in \{0, 1, 2.5, 10\}$). Under the joint scenario, we compare the mean surplus to an additive combination of the mean surplus in the repeated interactions scenario and the relevant group competition scenario (§ 3). If the mean surplus under the joint scenario is greater than this combination, the effect of combining repeated interactions within groups and competition between groups yields a surplus that is super-additive on average. If the mean surplus is less than the additive combination, the combined effect under the joint scenario is sub-additive. Panels differ in terms of whether or not the life cycle couples game play and individual selection and in terms of migration rates (m_j). Ξ controls group-level cancellation effects. Error bars denote 95% confidence intervals based on a bootstrapping algorithm clustered at the population level. We omit these confidence intervals when extremely narrow.



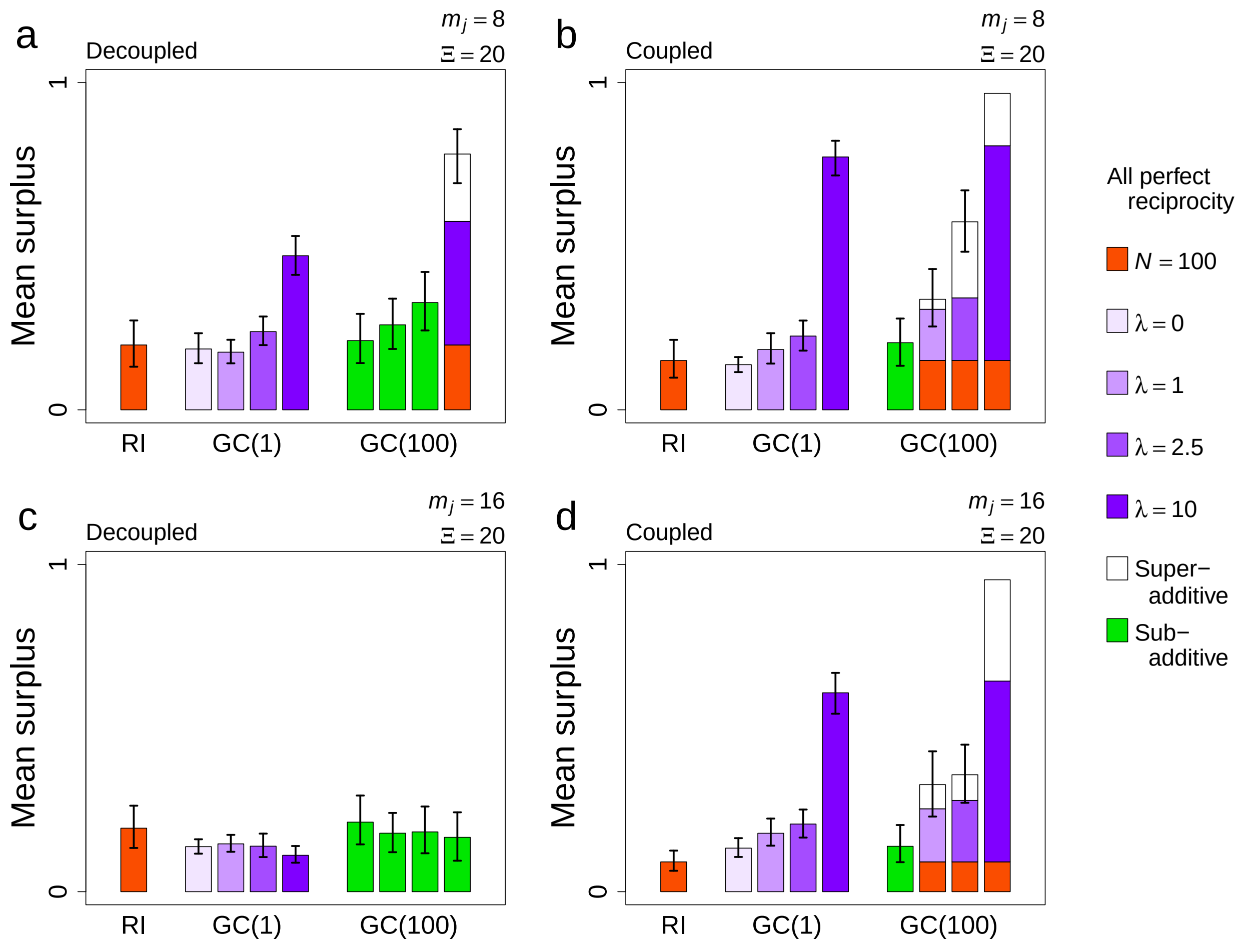
Supplementary Figure 164 | The gains from ingroup cooperation under different scenarios when strategies are three-dimensional and selection is relatively weak. The mean surplus per ingroup interaction per agent is shown under the repeated interactions scenario (RI, $N = 100$), the group competition scenario (GC(1), $N = 1$ and $\lambda \in \{0, 1, 2.5, 10\}$), and the joint scenario (GC(100), $N = 100$ and $\lambda \in \{0, 1, 2.5, 10\}$). Under the joint scenario, we compare the mean surplus to an additive combination of the mean surplus in the repeated interactions scenario and the relevant group competition scenario (§ 3). If the mean surplus under the joint scenario is greater than this combination, the effect of combining repeated interactions within groups and competition between groups yields a surplus that is super-additive on average. If the mean surplus is less than the additive combination, the combined effect under the joint scenario is sub-additive. Panels differ in terms of whether or not the life cycle couples game play and individual selection and in terms of migration rates (m_j). Ξ controls group-level cancellation effects. Error bars denote 95% confidence intervals based on a bootstrapping algorithm clustered at the population level. We omit these confidence intervals when extremely narrow.



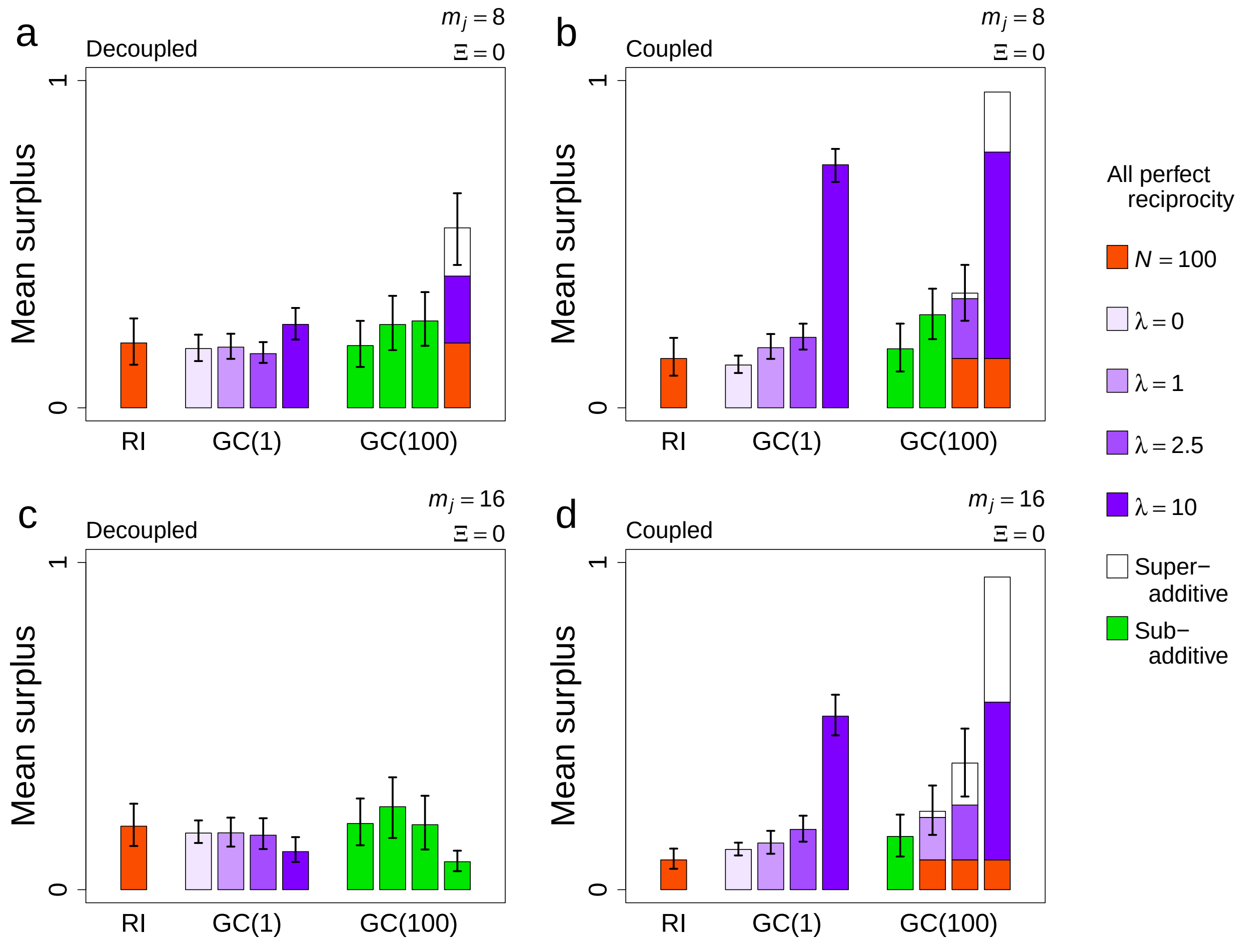
Supplementary Figure 165 | The gains from ingroup cooperation under different scenarios when strategies are three-dimensional and selection is relatively weak. The mean surplus per ingroup interaction per agent is shown under the repeated interactions scenario (RI, $N = 100$), the group competition scenario (GC(1), $N = 1$ and $\lambda \in \{0, 1, 2.5, 10\}$), and the joint scenario (GC(100), $N = 100$ and $\lambda \in \{0, 1, 2.5, 10\}$). Under the joint scenario, we compare the mean surplus to an additive combination of the mean surplus in the repeated interactions scenario and the relevant group competition scenario (§ 3). If the mean surplus under the joint scenario is greater than this combination, the effect of combining repeated interactions within groups and competition between groups yields a surplus that is super-additive on average. If the mean surplus is less than the additive combination, the combined effect under the joint scenario is sub-additive. Panels differ in terms of whether or not the life cycle couples game play and individual selection and in terms of migration rates (m_j). Ξ controls group-level cancellation effects. Error bars denote 95% confidence intervals based on a bootstrapping algorithm clustered at the population level. We omit these confidence intervals when extremely narrow.



Supplementary Figure 166 | The gains from ingroup cooperation under different scenarios when strategies are three-dimensional and selection is relatively weak. The mean surplus per ingroup interaction per agent is shown under the repeated interactions scenario (RI, $N = 100$), the group competition scenario (GC(1), $N = 1$ and $\lambda \in \{0, 1, 2.5, 10\}$), and the joint scenario (GC(100), $N = 100$ and $\lambda \in \{0, 1, 2.5, 10\}$). Under the joint scenario, we compare the mean surplus to an additive combination of the mean surplus in the repeated interactions scenario and the relevant group competition scenario (§ 3). If the mean surplus under the joint scenario is greater than this combination, the effect of combining repeated interactions within groups and competition between groups yields a surplus that is super-additive on average. If the mean surplus is less than the additive combination, the combined effect under the joint scenario is sub-additive. Panels differ in terms of whether or not the life cycle couples game play and individual selection and in terms of migration rates (m_j). Ξ controls group-level cancellation effects. Error bars denote 95% confidence intervals based on a bootstrapping algorithm clustered at the population level. We omit these confidence intervals when extremely narrow.



Supplementary Figure 167 | The gains from ingroup cooperation under different scenarios when strategies are three-dimensional and selection is relatively weak. The mean surplus per ingroup interaction per agent is shown under the repeated interactions scenario (RI, $N = 100$), the group competition scenario (GC(1), $N = 1$ and $\lambda \in \{0, 1, 2.5, 10\}$), and the joint scenario (GC(100), $N = 100$ and $\lambda \in \{0, 1, 2.5, 10\}$). Under the joint scenario, we compare the mean surplus to an additive combination of the mean surplus in the repeated interactions scenario and the relevant group competition scenario (§ 3). If the mean surplus under the joint scenario is greater than this combination, the effect of combining repeated interactions within groups and competition between groups yields a surplus that is super-additive on average. If the mean surplus is less than the additive combination, the combined effect under the joint scenario is sub-additive. Panels differ in terms of whether or not the life cycle couples game play and individual selection and in terms of migration rates (m_j). Ξ controls group-level cancellation effects. Error bars denote 95% confidence intervals based on a bootstrapping algorithm clustered at the population level. We omit these confidence intervals when extremely narrow.



Supplementary Figure 168 | The gains from ingroup cooperation under different scenarios when strategies are three-dimensional and selection is relatively weak. The mean surplus per ingroup interaction per agent is shown under the repeated interactions scenario (RI, $N = 100$), the group competition scenario (GC(1), $N = 1$ and $\lambda \in \{0, 1, 2.5, 10\}$), and the joint scenario (GC(100), $N = 100$ and $\lambda \in \{0, 1, 2.5, 10\}$). Under the joint scenario, we compare the mean surplus to an additive combination of the mean surplus in the repeated interactions scenario and the relevant group competition scenario (§ 3). If the mean surplus under the joint scenario is greater than this combination, the effect of combining repeated interactions within groups and competition between groups yields a surplus that is super-additive on average. If the mean surplus is less than the additive combination, the combined effect under the joint scenario is sub-additive. Panels differ in terms of whether or not the life cycle couples game play and individual selection and in terms of migration rates (m_j). Ξ controls group-level cancellation effects. Error bars denote 95% confidence intervals based on a bootstrapping algorithm clustered at the population level. We omit these confidence intervals when extremely narrow.

5 Experimental subjects

5.1 Basic economy and environment

To observe how group affiliation influences transfer motives and transfer decisions, we needed distinct, pre-existing groups with no known hostilities between them. Accordingly, we chose to conduct the study with Ngenikas and Perepkas. At the time of the experiment in July 2004, these clans were located about 30 kilometres from each other. Ngenikas numbered about 600 people, while Perepkas consisted of roughly 800 people. Subsistence was based on sweet-potato horticulture, pig husbandry, and small amounts of hunting and gathering. Ngenikas, in particular, often hunted successfully for small animals like cuscuses, tree kangaroos, and birds. Hunters provided useful materials like feathers, skins, and bones[14]. Apart from horticulture and animal husbandry, coffee was an important commercial crop. Sweet potatoes were ubiquitous, but substantial quantities were fed to pigs. Owning many pigs provided prestige. Pig meat and pig fat were prised delicacies, and pigs were a recurring focus of gift giving, exchange, and ceremony among both Ngenikas and Perepkas.

The two groups spoke Wahgi, with differences in dialect between them. Members of both clans were also conversant in Neo-Melanesian (Pidgin, Tok Pisin), and so experiments were conducted by H.B. in Neo-Melanesian. Ngenikas lived in the Mondomil Valley in small hamlets spread throughout dense rainforest, and Perepkas lived in rough and bushy terrain in the Wahgi Valley in similar hamlets dispersed among their gardens. Although the two groups were aware of each other, at the time of the experiments no one in either group had any memory of hostilities between members of the two clans. Members of the two clans also did not typically exchange gifts or goods with each other, apart from the rare case of a marriage involving both groups. Surplus production was sold at markets. There were small outdoor markets to be found everywhere along the roads, and there women and children sold garden produce, string bags, betel nut, coffee, and lime.

Markets were also ideal places to sit and gossip and play cards for money, betel nut, or beer. Selling and buying food at the market in Mt. Hagen was a special highlight. The market at Mt. Hagen was a crowded meeting place for trading, and it attracted people from all over the province. Villagers marketed their products to supplement other sources of income, to add to their subsistence activities, and to offset the expense of travelling to town for reasons like visiting relatives or purchasing beer and packaged foods. While Perepkas tended to travel to Mt. Hagen every few weeks, Ngenikas made the trip much more seldom, maybe once every six months. Ngenikas made the trip less often because the walk to a road with public transportation was relatively far (3-4 hours), and they also had to walk through the territories of hostile, neighbouring clans. At the time of the experiments, Ngenikas had had many recent wars with their neighbours, which might have explained their somewhat withdrawn and suspicious attitude. Once Ngenikas trusted someone, however, they were friendly and loyal.

5.2 The Wantok system

The Wantok system was widespread in Papua New Guinea, and it revolved around an extended network of social ties that bound people together via cooperation and generalised reciprocity[15]. A "wantok" (one talk) was literally a person who spoke the same language. With over 800 languages in Papua New Guinea, some people might only have had a handful of wantoks. In some areas, however, people from many different tribes spoke the same language, and these people were not all wantoks. Practically speaking, a wantok was a clan member. The Wantok system linked people together in ways that had both positive and negative consequences. On the one hand, it provided a strong support network based on ingroup cooperation and generalised reciprocity, and this created a safety net associated with risk sharing and access to productive resources like labour and land. On the other hand, the Wantok system could impose heavy demands on the individual because of the generalised ingroup reciprocity on which it was based. If a wantok asked a member of his clan for a desired item (e.g. betel nut, money) or some kind of service (e.g. search for lice in one's hair), the request had to be honoured, or the wantok was held in contempt by his community. As a result, the Wantok system frequently constrained those who had adapted to the cash economy. The clash between the traditional Wantok system and the modern cash economy is clear. If a cash labourer came home from town, ready to enjoy a few days at home after working hard, his friends and family would often clamber after every material good and every hard-earned Kina. This conflict could dissipate the motivation to work in the cash economy, and for those who did work in the cash economy it sometimes led to secretive behaviour.

6 Experimental procedures

At the beginning of week 1 of the experiments we collected the behavioural and survey responses of Ngenikas, who were located in Mondomil. Afterwards we collected the responses of Perepkas, who were located in Kugark. Due to the sequential structure of data collection, Perepkas received their experimental earnings immediately after the experimental session, while Ngenikas had to wait one week for their payment. This sequential structure, however, was implemented regardless of player position (i.e. for player A and B in the trust game) and regardless of group condition (i.e. for ingroup pairs and for outgroup pairs).

In each experimental session, participants received introductory verbal instructions in a group, as explained below. We ensured that participants did not communicate about the game before participating. In order to make decisions privately, each participant drew a number. After listening to the group instructions, in the order of the numbers drawn, participants entered a private room one at a time to actually participate in the experiment and make their decisions.

After entering this separate room, the experimenter explained the game to the participant in considerable detail. In particular, as detailed in the instructions below, each participant was informed about her role in the game and the group affiliation of her partner. Because many of the participants had little formal education, the experiment and the associated examples were explained using coins and distinct piles of money. After explaining the game, the experimenter tested the participants understanding with several control questions designed to evaluate comprehension of how the game worked. Participants who failed to grasp the game were dismissed from the experiment, but they kept their show-up fee of two Kina. Participants who answered the control questions correctly were then asked how much they would like to transfer to Player B.

Decisions from participants in the role of Player B were determined using the strategy method. Specifically, each of these participants was asked how much she would like to back transfer for an initial transfer of zero, one, two, three, four, and five Kina. After the complete strategy of Player B had been recorded, the actual transfer of Player A was revealed, and payoffs for both players were determined according to both the transfer of Player A and the relevant back transfer specified by Player B.

7 Experimental instructions

7.1 Writing and translation

The writing and translation of the instructions used the two-person, back translation procedures used in other experimental studies conducted in small-scale societies[16,17]. Specifically, instructions were written in English. H.B. then translated the instructions into Neo-Melanesian. Another person fluent in both languages then back translated from the Neo-Melanesian translation to English, which pinpointed problems with the original Neo-Melanesian translation. The Neo-Melanesian translation was then further modified until it produced a reliable back translation into English. Below we provide a detailed overview of the instructions used.

7.2 Introductory instructions

Thank you all for taking the time to come today. Today's experiment may take 3-4 hours, so if you think you will not be able to stay that long let us know now. Before we begin I want to make some general comments about what we are doing here today and explain the rules we must follow. We will be doing some experiments in which you can get some money. Whatever money you will get in the experiments will be yours to keep and take home. [**In Mondomil:**] (You should all come again next week [date and time] to check if you got some money and collect the money.) Maybe you won't get any money from the experiment, but today Marc [i.e. one of the experimenters] will pass out K2 to each of you to thank you for coming today. This money is not part of the experiment; it is yours to keep. Marc and I will be supplying the money. But you should understand that this is not our own money. It is money given to us by my school in Switzerland.

Before we proceed any further, let me stress something that is very important. You were invited here without understanding very much about what we are planning to do today. If at any time you find that this is something that you do not wish to participate in for any reason, you are, of course, free to leave whether we have started the experiment or not.

I will now explain the experiment to you in the group, and afterwards one after the other you will come into the classroom with me and carry out the experiment. It is important that you listen as carefully as possible because only people who understand the experiment will actually be able to participate. We will run through some examples here while we are all together. You cannot ask questions or talk while here in the group. This is very important. Please be sure that you obey this rule, because it is possible for one person to spoil the experiment for everyone. If one person talks about the experiment while sitting in the group, we would not be able to carry out the experiment today. Do not worry if you do not completely understand the experiment as we go through the examples here in the group. Each of you will have a chance to ask questions in private to be sure that you understand what you have to do.

7.3 Game script for the group

There are two persons in this experiment - Person A and Person B. The two persons can come from two different clans, Perepkas and Ngenikas. None of you will know exactly with whom you are interacting. You will only know if the other person is a Perepka or a Ngenika. Only I know who will interact with whom, and I will never tell anyone else.

Person A receives K5, and Person B receives K5. Person A then has the opportunity to give a portion of his K5 to Person B. He can give K5, K4, K3, K2, K1 or nothing to Person B. Whatever amount Person A decides to give to Person B will be doubled by me before it is passed on to Person B. This means that my school will also give Person B exactly the same amount as Person A had transferred. After Person B hears what Person A has passed on to him, he has the option of returning any portion of his own K5 to Person A. As before this amount will be doubled by me, that means my school will also give Person A the same amount as Person B transferred. Then the experiment is over. Person A goes home with whatever he or she kept from their original K5, plus anything returned to them by Person B and doubled by me. Person B goes home with the amount Person A had transferred, which was doubled by me, plus whatever he or she kept from their original K5. Here are some examples [piles of money will be used for all examples]:

E1. Imagine that Person A gives K5 to Person B. My school will give the same amount – also K5 – so Person B gets K10 (2 times K5 equals K10). At this point, Person A has nothing, and Person B has K15. Then Person B has to decide whether he wishes to give anything back to Person A and, if so, how much.

- Suppose Person B decides to return K5 to Person A. My school will give the same amount –

also K5 – so Person A gets K10. At the end of the experiment Person A will go home with K10, and Person B will go home with K10. Both have doubled their initial endowments.

- Suppose Person B decides to return K3 to Person A. My school will give the same amount – also K3 – so Person A gets K6 (2 times K3 equals K6). At the end of the experiment Person A will go home with K6, and Person B will go home with K12.

- Suppose Person B decides to return K0 to Person A. My school won't give anything either. At the end of the experiment Person A will go home with K0, and Person B will go home with K15.

E2. Now let's try another example. Imagine that Person A gives K3 to Person B. My school will give the same amount – also K3 – so Person B gets K6 (2 times K3 equals K6). At this point, Person A has K2, and Person B has K11. Then Person B has to decide whether he wishes to give anything back to Person A and, if so, how much.

- Suppose Person B decides to return K5 to Person A. My school will give the same amount – also K5 – so Person A gets K10. At the end of the experiment Person A will go home with K12, and Person B will go home with K6. Both have more than their initial endowments.

- Suppose Person B decides to return K2 to Person A. My school will give the same amount – also K2 – so Person A gets K4 (2 times K2 equals K4). At the end of the experiment Person A will go home with K6, and Person B will go home with K9. Both have more than their initial endowments.

- Suppose Person B decides to return K0 to Person A. My school won't give anything either. At the end of the experiment Person A will go home with K2, and Person B will go home with K11.

E3. Now let's try another example. Imagine that Person A gives K0 to Person B. My school won't give anything either, so Person B gets K0 from Person A. At this point, Person A has K5, and Person B has K5. Then Person B has to decide whether he wishes to give anything to Person A and, if so, how much.

- Suppose Person B decides to give K5 to Person A. My school will give the same amount – also K5 – so Person A gets K15. At the end of the experiment Person A will go home with K15, and Person B will go home with K0.
- Suppose Person B decides to return K2 to Person A. My school will give the same amount – also K2 – so Person A gets K4 (2 times K2 equals K4). At the end of the experiment Person A will go home with K9, and Person B will go home with K3.
- Suppose Person B decides to return K0 to Person A. My school won't give anything either. At the end of the experiment Person A will go home with K5, and Person B will go home with K5. That is exactly what they had in the beginning.

Note that the larger the amount that Person A gives to Person B, and Person B gives to Person A, the greater the amount that can be taken home by the two persons together. However, it is entirely up to Person A to decide what he wants to transfer to Person B, and it is entirely up to Person B to decide what he should give back to Person A. Both persons can end up with more or less than K5 as a result. I will go through more examples with each of you individually when you come to do the experiment.

In the mean time, do not talk to anyone about the experiment. Even if you are not sure that you understand the experiment, do not talk to anyone about it. This is important. If you talk to anyone about the experiment while you are waiting to come in, we must disqualify you from taking part in the experiment.

We have here a box of papers with numbers from 1 to 11. Now [Assistant 3] will come to each one of you and you can pick a number. Marc will give you K2 as a thank you for coming today. We will then call each of you in turn to play the experiment, starting with the person who picked number 1. While you are waiting for your turn, [Assistant 2] will help you fill out a form. When its your turn to do the experiment, you can come inside the classroom. I will tell you whether you are Person A or Person B and the clan from which the other person you are playing with comes (Perepka or Ngenika). Then I will explain the experiment again and ask you to work through a couple of examples to be sure you understand. After you have completed the experiment, you can go to the table to [Assistant 1] and have a snack. Then you can go to [Assistant 3] and [Assistant 4], who will help you fill out another form.

[**In Mondomil:**] (When you have finished there, you can go home. Remember that you are not allowed to come and talk to the people still waiting to do the experiment. Next week on [date and time] you should come to this classroom again. Please don't come on another day because I won't be here anymore, and nobody else can give out any money to you. If you come on that day, you will get K2 as a thank you for coming again, and we will tell you whether you got any money from the experiment. If yes, you will be paid that amount as well. Please make sure you bring along your slip of paper with the number on it!)

[**In Kugark:**] (When you have finished there, you have to wait until everybody has done the experiment inside the classroom. Remember that you are not allowed to come and talk to the people still waiting to do the experiment. When everyone has finished the experiment, I will call you in one by one again and pay you your money, in case you get any.)

[Marc gives each participant K2 and Assistant 1 hands around the box holding the paper slips with numbers.]

7.4 Trust game script for Person A in the Perepka-Perepka Treatment

As I have told you, there are two persons in this experiment – Person A and Person B. Now you yourself are Person A. Person B whom you will be interacting with is also a Perepka. None of you will know exactly with whom you are interacting. You only know that you are both Perepkas. Only I know who will interact with whom, and I will never tell anyone else.

Now you will receive K5, and Person B will also receive K5. You have the opportunity to give a portion of your K5 to Person B from Perepka. You can give K5, K4, K3, K2, K1 or nothing to Person B. Whatever amount you decide to give to Person B will be doubled by me before it is passed on to Person B (my school will give the same amount as you did to Person B). Person B from Perepka then has the option of giving any portion of his K5 to you. Whatever he wants to transfer to you will also be doubled by me. Then, the experiment will be over. You will go home with whatever you kept from your original K5, plus anything given to you by Person B from Perepka and doubled by me. Person B goes home with whatever you gave him, that has been doubled by me, plus whatever he kept from his original K5. Here are some examples [piles of money will be used for all examples, but H.B. runs through only as many examples as needed until player seems to understand the game]:

E1. Imagine that you give K1 to Person B from Perepka. My school will give the same amount – also K1 – so Person B gets K2. At this point, you have K4, and Person B has K7. Then Person B has to decide whether he wishes to give anything to you and, if so, how much.

- Suppose Person B decides to give K0 to you. My school won't give anything either, so you will get K0. At the end of the experiment you will go home with K4, and Person B will go home with K7.

- Suppose Person B decides to return K3 to you. My school will give the same amount – also K3 – so you will get K6 (2 times K3 equals K6). At the end of the experiment you will go home with K10, and Person B will go home with K4.
- Suppose Person B decides to return K5 to you. My school will give the same amount – also K5 – so you will get K10. At the end of the experiment you will go home with K14, and Person B will go home with K2.

E2. Imagine that you give K4 to Person B from Perepka. My school will give the same amount – also K4 – so Person B gets K8. At this point, you have K1, and Person B has K13. Then Person B has to decide whether he wishes to give anything to you and, if so, how much.

- Suppose Person B decides to give K0 to you. My school won't give anything either, so you will get K0. At the end of the experiment you will go home with K1, and Person B will go home with K13.
- Suppose Person B decides to return K4 to you. My school will give the same amount – also K4 – so you will get K8 (2 times K4 equals K8). At the end of the experiment you will go home with K9, and Person B will go home with K9.
- Suppose Person B decides to return K5 to you. My school will give the same amount – also K5 – so you will get K10. At the end of the experiment you will go home with K11, and Person B will go home with K8.

Now can you work through these examples for me?

T1. Imagine that you give K3 to Person B from Perepka. So, Person B gets K6 (2 times K3 equals K6). At this point, you have K2 and Person B has K11. Suppose Person B from Perepka decides to return K3 to you.

- How much will you have at the end of the experiment? (K8)
- How much will Person B from Perepka have? (K8)

T2. Imagine that you give K1 to Person B from Perepka. So Person B gets K2 (2 times K1 equals K2). Then, suppose that Person B decides to give K1 back to you.

- How much will you have at the end of the experiment? (K6)
- How much will Person B from Perepka have? (K6)

Here are your K5. [At this point K5 is placed on the table in front of the player.] You can now hand me the amount of money you want to be doubled and passed on to Person B from Perepka. You can give Person B nothing, K1, K2, K3, K4 or K5. Person B will receive this amount, doubled by me, plus their own initial K5. Remember the more you give to Person B the greater the amount of money at his or her disposal. While Person B from Perepka is under no obligation to give anything back, we will pass on to you whatever he or she decides to return, and my school will pay the same amount as well. That means, whatever Person B gives back will be doubled by me. [Now the player hands back whatever he or she wants to have doubled and passed to Person B.] Okay, I will double this amount and give it to Person B from Perepka. To see how much you can take home of the money you have kept for yourself, we first have to find out what Person B decides to do. [Belief questions are now asked.]

B1. How much do you think person B would transfer to you if you transferred K0?

B2. How much do you think person B would transfer to you if you transferred K2?

B3. How much do you think person B would transfer to you if you transferred K5?

8 Regression analysis of second mover data

Because second mover transfers choices fall into a number of discrete ordered categories, we modelled second mover strategies using an ordinal logistic regression (Supplementary Table 1). This approach is especially appropriate for at least two reasons. First, we have several observations at the boundaries of the action space (i.e. zero and five). As a latent variable model, ordinal logistic regressions are well suited for this situation. Second, an ordinal model only requires us to assume that our participants value more money over less money. In particular, we do not have to make cardinal assumptions about the hedonic value of material rewards.

Supplementary Table 1 | Ordinal logistic regression with second mover back transfers as the dependent variable. Independent variables include the age, sex, education, and group affiliation of the second mover. They additionally include a dummy variable indicating participation in an ingroup treatment, a variable giving the transfer of the first mover (FM), and the interaction between these latter two variables. Because the relevant estimates are significantly larger than one, second movers transferred significantly more to ingroup first movers than to outgroup first movers (Ingroup), and they transferred significantly more in response to high first mover transfers than in response to low first mover transfers (Transfer (FM)). All other effects are not significant. The regression models 420 observations, and robust standard errors are calculated by clustering on subject.

Parameter	Estimate	Cluster Robust Std. Error	t	p value
Age	0.025	0.026	0.940	0.348
Male	0.536	0.413	1.300	0.194
Education (years)	-0.039	0.075	-0.520	0.603
Perepka second mover	-0.399	0.436	-0.914	0.361
Ingroup	1.557	0.443	3.518	$<$ 0.001
Transfer (FM)	0.737	0.129	5.698	$<$ 0.001
Ingroup $\times$ Transfer (FM)	0.092	0.122	0.757	0.500
Intercepts	Estimate			
Intercept 0/1	1.549			
Intercept 1/2	2.355			
Intercept 2/3	3.295			
Intercept 3/4	3.891			
Intercept 4/5	4.780			

9 References

1. Cressman, R. Continuously stable strategies, neighborhood superiority and two-player games with continuous strategy space. *International Journal of Game Theory* **38**, 221–247 (2009).

2. McGill, B. J. & Brown, J. S. Evolutionary game theory and adaptive dynamics of continuous traits. *Annu. Rev. Ecol. Evol. Syst.* **38**, 403–435 (2007).

3. Leimar, O. Multidimensional convergence stability. *Evolutionary Ecology Research* **11**, 191–208 (2009).

4. Taylor, P. D. Altruism in viscous populations: an inclusive fitness model. *Evolutionary Ecology* **6**, 352–356 (1992).

5. Akdeniz, A. & van Veelen, M. The cancellation effect at the group level. *Evolution* (2020).

6. Taylor, P. D. Inclusive fitness in a homogeneous environment. *Proceedings of the Royal Society of London. Series B: Biological Sciences* **249**, 299–302 (1992).

7. Lehmann, L. & Rousset, F. How life history and demography promote or inhibit the evolution of helping behaviours. *Philosophical Transactions of the Royal Society B: Biological Sciences* **365**, 2599–2617 (2010).

8. Gat, A. *War in Human Civilization* (Oxford: Oxford University Press, 2006).

9. Chagnon, N. A. *Yąnomamö* (Fort Worth: Harcourt Brace Jovanovich College Publishers, 1992), 4th edn.

10. Keeley, L. H. (ed.) *War Before Civilization: The Myth of the Peaceful Savage* (Oxford: Oxford University Press, 1996).

11. Bowles, S. Did warfare among ancestral hunter-gatherers affect the evolution of human social behaviors? *Science* **324**, 1293–1298 (2009).

12. Wiessner, P. & Pupu, N. Toward Peace: Foreign Arms and Indigenous Institutions in a Papua New Guinea Society. *Science* **337**, 1651–1654 (2012).

13. Fry, D. P. & Söderberg, P. Lethal aggression in mobile forager bands and implications for the origins of war. *Science* **341**, 270–273 (2013). URL `http://www.sciencemag.org/content/341/6143/270.abstract`. `http://www.sciencemag.org/content/341/6143/270.full.pdf`.

14. Rannells, J. *PNG: A Fact Book on Modern Papua New Guinea* (Oxford: Oxford University Press, 1990).

15. de Renzio, P. Bigmen and *Wantoks*: Social Capital and Group Behaviour in Papua New Guinea. QEH Working Paper No. 27, University of Oxford (2000).

16. Henrich, J. *et al.* Costly punishment across human societies. *Science* **312**, 1767–1770 (2006).

17. Henrich, J. *et al.* Markets, religion, community size, and the evolution of fairness and punishment. *Science* **327**, 1480–1484 (2010).