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The complex effect of the evolutionary rates on generalized mutualistic communities

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Mutualism or cooperation between and among species is ubiquitous in nature. The most well-known examples of mutualism are Müllerian mimicry and division of labour. In Müllerian mimicry, unpalatable species have evolved the similar appearances and they are less likely to be predated upon because the predators effectively learn that these species are noxious. In division of labour, each species specializes in a special task, such as producing different nutrients.

Conflict can arise in mutualism regarding the roles of each species. In Müllerian mimicry, it could be more advantageous to be a model species than a mimic because the life cycles, the habitats, and the body plans of model species are innate. In devision of labour, conflict can arise regarding species tasks; when producing nutrient, one type of nutrient might have a greater cost for the organism than another type of nutrient.

The effect of evolutionary rates on mutualistic symbioses with a degree of conflict has been conceptualized using the snowdrift game. Bergstrom and Lachmann (2003) [1] have found that in a model of the mutualistic symbiosis between two species, the slower evolution can be favoured. This effect was named Red King effect, which is converse to Red Queen effect, where the faster evolution is favoured mainly in, but not restricted in, antagonistic symbioses.

Mutualism, however, can involve more than two species. In the context of the mimicry, such phenomenon is known as the Müllerian mimicry ring. Mutual symbioses with devision of labour are not always limited in one-to-one relationship. For example, green algae can display mutualism with several phylogenetically broad fungal species.

In this study, the original model in Bergstrom and Lachmann (2003) was expanded by generalizing the number of species M ($M \geq 2$) in a community. In this model, Red Queen effect can shift to Red King effect and vice versa over time. For example, when $M = 3$, Red Queen effect can remain until one species (in many cases, the fastest-evolving species) fixes its strategy, after which Red King effect comes into play and the slowest-evolving species is favoured. As a result, the fastest- and slowest-evolving species exploit the remaining species.

This result suggests the complexity of the effect of evolutionary rates on mutualistic coevolution. Even when differences in evolutionary rates of two species are determined, predicting which species is more likely to exploit the other is challenging, because a third species with which both species mutually interact could also have an evolutionary effect on the other two species.

[1] Bergstrom, C. T., and Lachmann, M. (2003). The Red King effect: When the slowest runner wins the coevolutionary race. *PNAS*, **100**, 2, 593-598.

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