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Evolution of optimal Hill coefficients in nonlinear public goods games

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Abstract

In evolutionary game theory, the effect of public goods like diffusible molecules has been modelled using linear, concave, sigmoid and step functions. The observation that biological systems are often sigmoid input-output functions, as described by the Hill equation, suggests that a sigmoid function is more realistic. The Michaelis-Menten model of enzyme kinetics, however, predicts a concave function, and while mechanistic explanations of sigmoid kinetics exist, we lack an adaptive explanation: what is the evolutionary advantage of a sigmoid benefit function? We analyse public goods games in which the shape of the benefit function can evolve, in order to determine the optimal and evolutionarily stable Hill coefficients. We find that, while the dynamics depends on whether output is controlled at the level of the individual or the population, intermediate or high Hill coefficients often evolve, leading to sigmoid input-output functions that for some parameters are so steep to resemble a step function (an on-off switch). Our results suggest that, even when the shape of the benefit function is unknown, biological public goods should be modelled using a sigmoid or step function rather than a linear or concave function.