Testing the Inefficient Task Stimulus Hypothesis: A Simple Computational Model for Hypometric Scaling of Metabolism in Social Insects

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In social insects, colony-level metabolism scales hypometrically with colony size; increases in colony size do not result in proportional increases in energy use. However, this phenomenon only occurs in normally functioning colonies, which suggests workers may be modulating collective behavior to use energy more efficiently as the colony size increases. A plausible mechanism for this size-dependent efficiency may be the increased probability of workers creating changes in task structure that increase the efficiency of other workers. For instance, the scattering of brood across the nest could be a latent cue of inefficiency, as workers need to walk longer distances to rear each brood item. However, if workers move brood to a more central location, then movement across workers can be minimized. We theoretically test the case where ants have a fixed probability of making an innovation that results in increasing the efficiency of other ants. Simultaneous innovation boosts are allowed to stack in this stochastic discrete-time model, meaning that an ant can experience multiple upsurges of efficiency within a single time step. This is more likely to occur with larger colonies, and thus the metabolism of these colonies scales with a near power law. This model is a proof-of-concept for the inefficient task stimulus hypothesis, but it also serves to demonstrate that any model which seeks to explain nonlinear scaling must have a multiplicative effect: it affects the supply or demand of energy for multiple individuals. Innovations that affect single individuals can only result in linear scaling of metabolism.