A Mathematical Model of Flexible Collective Defense: Crisis Response in Stingless Bees

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Animal societies accumulate resources and individuals in a single place, thus becoming a desirable target for robbers or parasites. This is the case of social insect colonies, which have evolved different forms of collective defense to mitigate risks. In particular, *Tetragonisca angustula* stingless bees employ a combination of strategies involving three different timescales: 1) morphological specialization, where distinct, efficient and costly soldiers (majors) are produced over weeks 2) age polyethism, where young major workers transition to guarding tasks over days, and 3) task switching, where non-specialized small individuals (minors) replace soldiers within minutes under crisis. In order to better understand how social insects regulate reproduction and defense efficiently, we developed a demographic model of task allocation in *Tetragonisca angustula* colonies using a system of differential equations that reflects the three timescales explicitly. Analytical results from our model suggest that increasing the production of majors may cause a decline in colony size for short maturation times. Moreover, when replacement is active and the maturation time is long, an increased soldier production can reduce the guarding population in the long run. In summary, the model provides the conditions under which the studied defense mechanisms work in tandem to improve collective defense, and the scenarios where their simultaneous implementation can be detrimental. This work contributes not only to understand the demographic factors constraining defense regulation in stingless bees but also to guide the design of potential social-insect inspired defense strategies in the human domain.