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Population epidemiology under toxicant stress: a nested multilevel modelling framework

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Populations are formed of their constituent interacting individuals, each with their own respective within-host biological processes. Infection not only spreads within the host organism but also spreads between individuals. We propose and study a nested multilevel model which links the within-host statuses of immunity and parasite density to population epidemiology under sub-lethal and lethal toxicant exposure. We analyse this nested model in order to better understand how toxicants impact the spread of disease within populations. We demonstrate that the outbreak of infection within a population is completely determined by the level of toxicant exposure, and that it is maximised by intermediate toxicant dosage. We classify the population epidemiology into 5 phases of increasing toxicant exposure and calculate the conditions under which disease will spread, showing that there exists a threshold toxicant level under which epidemics will not occur. In general, higher toxicant load results in either extinction of the population or outbreak of infection. The within-host statuses of the individual host also determine the outcome of the epidemic at the population level. We discuss applications of our model in the context of eco-epidemiology, particularly for bee colony losses, predicting that increased exposure to toxicants could result in more epidemics and therefore greater colony losses. We predict that reducing sub-lethal toxicant exposure below our predicted safe threshold could contribute to controlling population level disease and infection.

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