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Mathematical analysis and control of a mosquito stage-structured model with gonotrophic cycle

Abstract

The gonotrophic cycle of mosquitoes conditions the frequency of mosquito-human contacts. The knowledge of this important phenomenon in the mosquito life cycle is a fundamental element in the epidemiological analysis of a communicable disease such as mosquito-borne diseases. In this paper, we analyse a deterministic model of complete life cycle of mosquitoes which takes into account the principal phases of female mosquitoes gonotrophic cycle. We begin by analysing the model without gonotrophic cycle by computing the traditional mosquito reproductive number $\mathcal{N}$, and prove the global stability of the trivial (resp. the non trivial) equilibrium whenever $\mathcal{N}$ is less than one (resp. greater than one) through the theory of cooperative systems. After that, we include blood meal seeking stage, blood meal digesting stage and gravid stage in our previous model. We also compute the corresponding mosquito reproductive number $\mathcal{N}^*$ and also prove the global asymptotic stability of equilibria. By local sensitivity analysis, we determine important parameters in the life cycle of mosquitoes. To control the mosquito populations, we use the sterile insect technique (SIT) combined with insecticides. We prove that the obtained model admits a trivial equilibrium which is globally asymptotically stable whenever $\mathcal{N}^* < 1$. Unlike the precedent models, for $\mathcal{N}^*$ is greater than one, this model admits two non trivial equilibria whenever $\mathcal{N}^*$ is greater than other threshold, $\mathcal{N}_c$, which depends of the total number of sterile mosquitoes. We finally formulate our optimal control model by replacing the previous constant controls by time-dependent controls. Pontryagyn's maximum principle is use to characterize the optimal control. Numerical simulations, using parameters *Aedes species*, are performed to illustrate analytical results, and permit to conclude that the combination of the sterile insect technique and insecticide can permit to decrease significantly mosquito populations.