Modelling the Effect of Climate on Mosquito Population Dynamics and Malaria Spread with Controls.

by

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Outline of Presentation

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Introduction

Malaria

- Malaria is a life-threatening disease caused by parasites that are transmitted to people through the bites of infectious female Anopheles mosquitoes.

Introduction Contd.

Malaria (Background)

- It is estimated that there were 228 million cases of malaria worldwide with 405 000 deaths in 2018 (WHO, 2020).
- In 2018, nearly **half of the world's population** was at risk of malaria with most cases and deaths occurring in sub-Saharan Africa (WHO, 2020)

Introduction contd.

Mosquitoes

- Mosquitoes remain one of the most efficient vectors of human and animal diseases and are responsible for transmitting some of the deadly diseases such as malaria, Dengue and Zika.
- Transmission of these diseases depend on the age-structure and population abundance of female adult mosquitoes.
- Mosquito's developmental stages are known to depend on climatic conditions such as temperature, rainfall, wind and humidity.

Mosquito Life Cycle

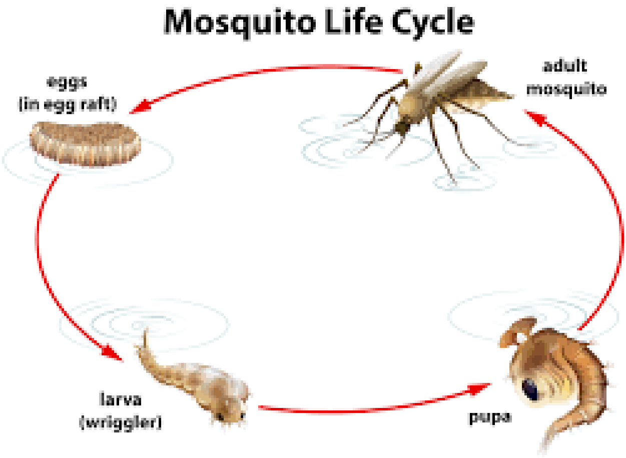

Figure: Mosquito life cycle with each of the developmental stages depending on climatic conditions. credit:vecteezy.com

Statement of Problem

- Malaria is the most prevalent human vector-borne disease, with **one half of the world population** living in areas where malaria is endemic (WHO, 2020).
- Transmission of malaria depends on the age-structure and population abundance of female adult mosquitoes.

Statement of Problem

- Mathematical models have been used by several researchers to predict mosquito population dynamics in the presence of climate change. A higher percentage of the existing models were formulated to study the population dynamics of a specific mosquito species within a specific geographical area and so may not be applicable to other species.

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- Mathematical models have been used by several researchers to predict mosquito population dynamics in the presence of climate change. A higher percentage of the existing models were formulated to study the population dynamics of a specific mosquito species within a specific geographical area and so may not be applicable to other species.
- This project seeks to develop models to study general mosquito species that could be useful in improving understanding of mosquito population dynamics at different regions. Improved understanding of population dynamics aids in better management strategies which reduces the cost of treatment of malaria.

Statement of Problem

- We also explore the impact of climate variability on the incidence of malaria in different regions. sensitivity of the model to climate-dependent parameters will be analyzed to establish how climate influences parameters to determine risk of malaria transmission.

Research Objectives

Main Objective

The main objective of this research project is to investigate the effects of climate on mosquito population dynamics and the risk of malaria transmission with controls.

Research Objectives

Sub-Objectives

- To develop a stage-structured population model that incorporate temperature and rainfall to study mosquito population dynamics.
- To predict mosquito abundances and malaria risk according to regional climate patterns.
- To analyze the effect of stage-specific controls and it's impact on mosquito abundance.
- To compare the effectiveness of stage-specific controls and to estimate the best periods where controls will be effective.

Research Objectives

Sub-Objectives

- To build a combined mosquito-human malaria transmisson model to analyze how climate determines risk.
- To analyze latency in malaria infections and it's impact on the disease dynamics using a delay differential equation version of the ordinary differential equation model.

Methodology

Climate-dependent, stage-structured Mosquito Model

- The framework of the stage-structured temperature and rainfall-dependent mosquito population model reflects details of the mosquito life-cycle.
- The model allows us to incorporate stage specific life history rate and process.
- The four main life stages that constitutes the stage structuring are eggs, larvae, pupae and adults

Methodology

Climate-dependent, stage-structured Mosquito Model

Each life stage has a natural mortality as well as climate dependent mortality rate.

Climate-dependent, stage-structured Mosquito Model

The system of equations that describe the model are as follows:

$$\frac{dE(t)}{dt} = \phi(T,R)\left(1 - \frac{A(t)}{K}\right)A(t) - (\delta_E(T,R) + \pi_E(T,R) + \mu_E)\,E(t \tag{1a}$$

$$\frac{dL(t)}{dt} = \delta_E(T,R)E(t) - (\delta_L(T,R) + \pi_L(T,R) + \mu_L + \sigma_L L)\,L(t) \tag{1b}$$

$$\frac{dP(t)}{dt} = \delta_L(T,R)L(t) - (\delta_P(T,R) + \pi_P(T,R) + \mu_P)\,P(t) \tag{1c}$$

$$\frac{dA(t)}{dt} = \tau\delta_P(T,R)P(t) - (\pi_P(T,R) + \mu_P)\,A(t) \tag{1d}$$

where $T = T(t)$ and $R = R(t)$ represent temperature and rainfall respectively. T and R are bounded periodic functions determined from climate data (Abdelrazec & Gumel, 2017).

Model Variables

Table: Description of variables used in the model 1

Variables	Description
$E(t)$	Total number of eggs at time t
$L(t)$	Total number of larvae at time t
$P(t)$	Total number of pupae at time t
$A(t)$	Total number of adults at time t

Model Parameters

Table: Description of parameters used in the model 1

Parameters	Description
ϕ	Egg oviposition rate
τ	Proportion of new adult female mosquitoes
K	Carrying capacity of the female adult mosquitoes
$\delta_E(T,R)$	Hatching rate of eggs
$\delta_L(T,R)$	Transition rate from larvae into pupae
$\delta_P(T,R)$	Transition rate from pupae into adult
$\pi_E(T,R)$	Climate-dependent mortality rate of eggs
$\pi_L(T,R)$	Climate-dependent mortality rate of larvae
$\pi_P(T,R)$	Climate-dependent mortality rate of pupae
$\pi_A(T,R)$	Climate-dependent mortality rate of adults
μ_E	Natural mortality rate of eggs
μ_L	Natural mortality rate of larvae
μ_P	Natural mortality rate of pupae
μ_A	Natural mortality rate of adults

Data

General parameter values used in the model will be based on data from lab studies and experimental results from (Bayoh & Lindsay, 2004, 2003; Yang, da Graça Macoris, Galvani, & Andrighetti, 2011; Esteva & Yang, 2015).

Potential Results

Analysis of the autonomous version of the model produces the threshold quantity, R_m given by

$$R_m = \frac{\tau\phi\delta_E\delta_L\delta_P}{(\mu_A + \pi_A)(\delta_P + \mu_P + \pi_P)(\delta_L + \mu_L + \pi_L + \sigma_L)(\delta_E + \mu_E + \pi_E)}.$$

R_m is the vectorial reproduction number also known as basic offspring number. It measures the average expected number of female adult offsprings produced by a single female mosquito during it's life time (Abdelrazec & Gumel, 2017; Hamdan & Kilicman, 2020).

R_m will be used to study the impact of controls in managing mosquito abundance.

Numerical Simulations of the Autonomous Model

Figure 2 is a graph of mosquito population dynamics with the vectorial reproduction number, $R_m = 2.55$.

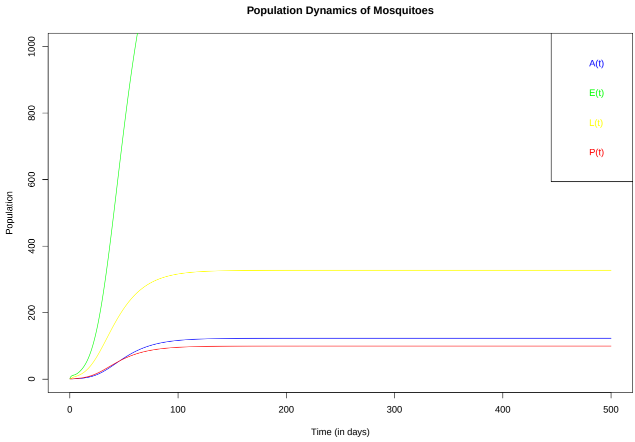

Figure: Population Dynamics of mosquitoes obtained from the autonomous version of (1)

The mosquito-human Model

It is expected that the mosquito-human model will produce a reasonable fit with observed malaria incidence data. In particular, they will capture all the spikes in malaria prevalence. Our findings will further highlight the importance of climate on malaria transmission and show the seasonality of malaria epidemics.

Conclusion

- We discussed the climate-dependent stage-structured mosquito population model.
- We calculated the vectorial reproduction number.
- We looked at a numerical simulation of the autonomous model.

References

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End of Presentation