Intervention Model for Malaria

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What is Malaria?

- Criss cross, endemic infectious disease
- 3.3 billion people are at risk
- 300 million infected, $660,000$ deaths per year
- Sub-saharan Africa, Asia and Central and South America

Parasite, Vector and Host

- *Plasmodium* spp. parasites
    - *P. falciparum, P. vivax, P. ovale, P. malariae, P. knowlesi*
- Female Anopheles mosquito
- Human

Transmission Process

1. **Mosquito $\rightarrow$ Human**
   - Sporozoites pass through the bloodstream to the liver
   - Merozoites form from asexual reproduction and burst from the liver
   - Invade red blood cells (erythrocytes), multiply and burst
   - Cells then reproduce sexually forming gametocytes

Transmission Process

1. **Human $\rightarrow$ Mosquito**
    - Gametocytes are ingest and mature into gametes
    - They develop into ookinetes that burrow into the mosquito gut and oocysts form
    - Oocysts contain sporozoites that are released and travel to the salivary glands
    - Infection begins when the mosquito bites another human

Treatment

- Medication
  - Intravenous/intramuscular quinine
  - Mefloquine
  - Cholorquine
- Vaccine
  - RTS, S/A01
  - 23 million bases of DNA and $5,000$ genes

Control

- Sleeping/bed nets and baby nets
- Insecticide-treated nets (ITNs)
- Long-lasting insecticide-treated nets (LLINs)
- Insect Repellent/ Indoor Residual Spraying (IRS)
- Drain standing water

Biological Questions

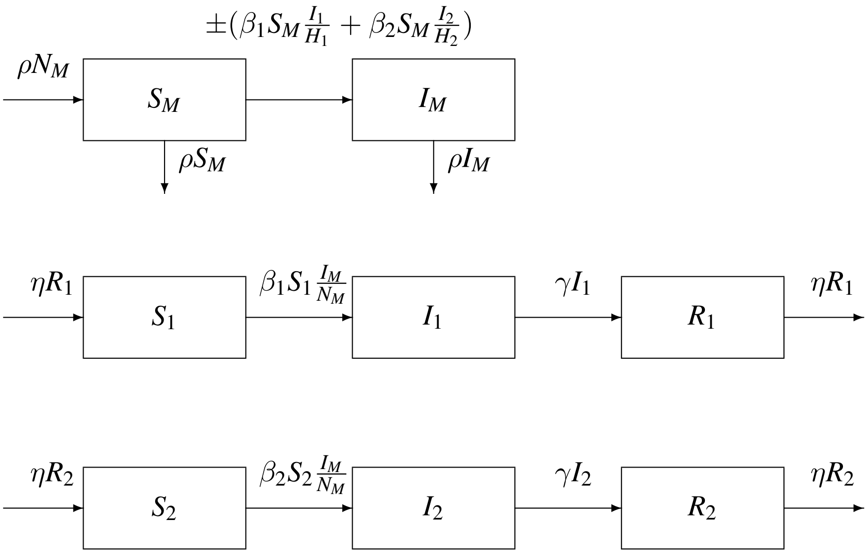
The overarching question determined whether malaria can be eliminated solely by the use of sleeping nets?

1. What proportion of the population needs to use sleeping nets for an infected population to reach an equilibrium of 0?
2. How does female mosquitoes living longer than 2 weeks effect the infectious populations?

Questions Cont'd

3. How would humans having a longer or shorter period to recover effect the infectious populations?
4. What is the minimum effective level for a sleeping net (50% and 100% net usage)?

Compartmental Model



Mosquito ODEs

$$S_M' = -\beta_1 S_M \frac{I_1}{H_1} - \beta_2 S_M \frac{I_2}{H_2} + \rho N_M - \rho S_M$$

$$I_M' = \beta_1 S_M \frac{I_1}{H_1} + \beta_2 S_M \frac{I_2}{H_2} - \rho I_M$$

H_1 ODEs

$$
\begin{aligned}
S_1' &= -\beta_1 S_1 \tfrac{I_M}{N_M} + \eta R_1 \\
I_1' &= \beta_1 S_1 \tfrac{I_M}{N_M} - \gamma I_1 \\
R_1' &= \gamma I_1 - \eta R_1
\end{aligned}
$$

H_2 ODEs

$$S_2' = -\beta_2 S_2 \frac{I_M}{N_M} + \eta R_2$$
$$I_2' = \beta_2 S_2 \frac{I_M}{N_M} - \gamma I_2$$
$$R_2' = \gamma I_2 - \eta R_2$$

Methods

- Non-dimensionalize
- Find the Jacobian matrix
- Define the DFS
  - $s_1 \rightarrow \alpha_1$
  - $s_2 \rightarrow \alpha_2$
- Find $det(J - \lambda I) = P(\lambda)$

Routh Hurwitz Conditions

- Took determinants of a sequence of matrices
- Checked several inequalities

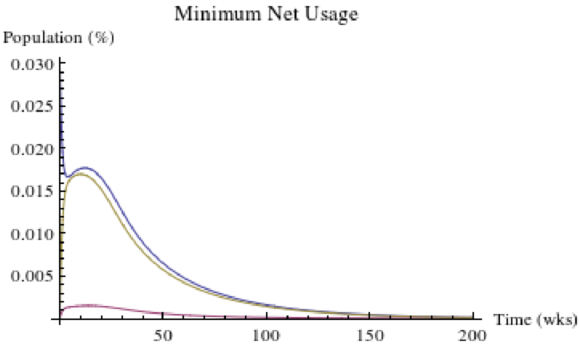
$$\frac{\beta_2^2\alpha_2+\beta_1^2\alpha_1}{\rho\gamma} < 1$$

- γ small, β_1 large

Results

Question 1: What proportion of the population needs to use sleeping nets for an infected population to reach 0?

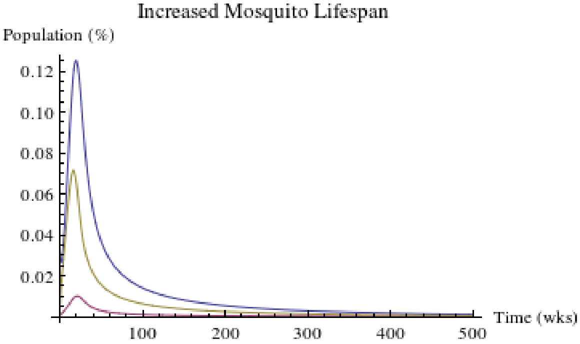
Only 20% net usage was needed to satisfy i_m, i_1 and $i_2 \to 0$.



Results

Question 2: How does female mosquitoes living longer than 2 weeks effect the infectious populations?

In this scenario, 57% net usage was needed in order to satisfy i_m, i_1 and $i_2 \to 0$.



Results

Question 3: How would humans having a longer or shorter period to recover effect the infectious populations?

Longer: Need at least 60% net usage ($\gamma = \frac{1}{4}$)

Shorter: No nets are needed ($\gamma = \frac{5}{8}$)

Results

Question 4: What is the minimum effective level for a sleeping net (50% and 100% net usage)?

With 50%: needed at least 20% effectiveness ($\beta_1 = 0.8 * \beta_2$)

With 100%: need at least 24% effectiveness ($\beta_1 = 0.86 * \beta_2$)

Future Work

1. Retrieve more accurate data
2. Key in on one country
3. Make non-constant population model
4. Incorporate vaccination in the model
5. Evaluate cost differences

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