Mathematical Modeling and control of co-transmitting Soil-Transmitted Helminthiases (STH)

Nichole Etienne
Mentors:
Brajendra K. Singh
Edwin Michael
The Center for Research Computing &
Department of Biological Sciences
University of Notre Dame
Soil-Transmitted Helminthiases (STH)?

Indirect transmission
Tape worms (Taenia solium)
Schistosomes.

Direct transmission (STHs):
Ascaris, trichuris, Hookworm

Fig. 5.17.1 Distribution of soil-transmitted helminthiases, worldwide, 2009

Transmission routes of macroparasitic infections
FLOW DIAGRAM OF THE BASIC IMMIGRATION-DEATH MODEL FOR MACROPARASITIC INFECTIONS
(DIRECT TRANSMISSION)

Parasites enter host
"Immigration"

Host

Parasites leave host
"Death"
FLOW DIAGRAM OF THE BASIC IMMIGRATION-DEATH MODEL FOR MACROPARASITIC INFECTIONS

(DIRECT TRANSMISSION)
Mathematical modeling?

• System of mathematical concepts and languages.

• Control and elimination is its main purpose when referring to Soil transmitted helminthes.
  – It has the ability to help in the understanding of parasite population and the effects of such dynamics of control intervention as well as the exploration of different parameters.
The STH model

• The model is based on basic model derived from Anderson and medley. It takes the host population into consideration
• The host population is divided into the age group with the group representing a portion of the population. The population of the worm is divided into the mature worms in the host and a pool of free living infection. The host groups differ based on two parameters, that is, their contact rate with infective stages in the environment and their contribution to the pool in infection stages. The two parameters represent a distinct process that is the contact rate basically refers to the acquisition rate while the contamination rate is related to the rate at which the individual group is contaminated in the environment. From those main ideas a series of differential equations are created.
Model 1:

\[
\frac{dP_i}{dt} = \lambda_i e^{-(\beta_i I_i + \nu D)} - \mu_i P_i \\
\frac{dI_i}{dt} = \chi_i P_i + \Gamma_{ji} P_j - \delta_i I_i \\
\frac{dD}{dt} = -\delta_d D
\]
THE SIMPLE MATHEMATICAL MODEL FOR MACROPARASITIC INFECTIONS

(DIRECT TRANSMISSION)

Model 2:

\[
\frac{dP_1}{dt} = \lambda_1 - P_1(\mu_1 e^{\tau T} + \rho P_1 + \rho P_3)
\]  
(4)

\[
\frac{dP_2}{dt} = \lambda_2 - P_2(\mu_2 + \rho P_2 + \rho P_1)
\]  
(5)

\[
\frac{dP_3}{dt} = \lambda_3 - P_3(\mu_3 + \rho P_3 - \rho P_2)
\]  
(6)

\[
\frac{dT}{dt} = -\delta T
\]  
(7)
What has been done?

- Literature review
- Coding in mathlab
- Testing the strongest parameter via simulations.
• %ODE version of the epiworm model
• % this version is just a simple Euler update of the single ODE model (the
  multiple ODE model, including explicitly the L equation, it to be found
• % as the code odeRun.m )
  clear all
  global w m i
  global beta k0 kLin k1 r1 signma1 psi1 psi2 mu alpha gamma b1
  global c lam phi del s2 ageLev bit cmfl0 demo l3
  global k2 gam2 tau c2
  % parameter intialization
  paramInit;
  dt=1;
  timeSteps=540*(1/dt);
  W=zeros(timeSteps,1);
  l=zeros(timeSteps,1);
  WFinal=zeros(timeSteps,1);
  W(1)=initW;
  I(1)=1;
  close all;

  clc
  matVal=matProb(W(1),shapeFun(W(1),k0,kLin));
for iNum=2:timeSteps;
  %the density dependency
  %1. Mating probability
  matVal=matProb(W(iNum-1),shapeFun(W(iNum-1),k0,kLin));
  %matVal=1;
  %2. Acquired immunity to worm establishment
  immVal=exp(-c*I(iNum-1));
  %immVal=1;
  %3. Worm fecundity due to overcrowding etc. (maybe entwined with
  %immunity?)
  fecund=densDepFecund(W(iNum-1),shapeFun(W(iNum-1),k0,kLin),gamma);
  %fecund=1;
  fprintf(1,'%f,%f,%f,%f
',W(iNum-1),matVal,immVal,fecund);

%main equations

% W(iNum)=W(iNum-1)+W(iNum-1)*(R0*fecund*matVal*immVal-mu)*dt;
% W(iNum)=W(iNum-1)+mu*W(iNum-1)*(R0*fecund*matVal*immVal-1)*dt;
%fprintf(1,'%f
',W(iNum));
I(iNum)=I(iNum-1)+(W(iNum-1)-delta*I(iNum-1))*dt;
WFinal(iNum)=prevFun(W(iNum),k0);
end
% WFinal=prevFun(W(timeSteps),k0)
%WFinal2=W(timeSteps)
WFinal3=prevFun(W(timeSteps),k0);

plot(1:timeSteps,WFinal,'-');
xlabel 'Age in months '
ylabel 'Worm load'
print('-djpeg','kLin testing');
Testing Strongest parameter

- Example 1: testing the Reproduction rate by changing the value of R0 in paraminit by

![Graphs showing changes in worm load over age in months.](image)
Testing strongest parameter
Testing Strongest parameters
Testing Strongest parameter
Future plans

- **Model fitting to STH data using Bayesian Melding technique.**
  - Bayesian melding techniques refers to a method for assuming uncertainty about quantities of interest using simulation models.
  - It encodes for all available information about models inputs and outputs in terms of prior probability distribution and likelihood of many quality of interest that is a function of the models input and or output.

- **Intervention (using drug)**

- **Sensitivity Analysis**