Rabies

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Contents

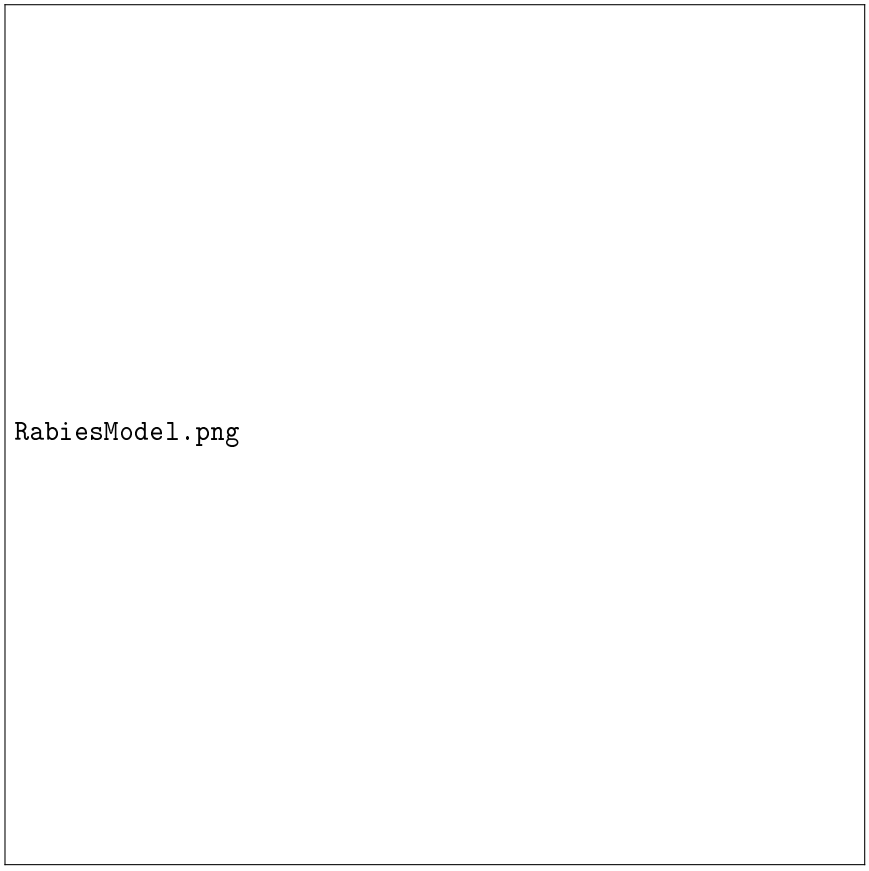
1 Introduction

1.1 Rabies papers from CIDMA and PHFI

Potential for Rabies control through dog vaccination in wildlife-abundant communities of Tanzania
Cost-effectiveness of canine vaccination to prevent human rabies in rural Tanzania
Rabies control initiative in Tamil Nadu, India: a test case for 'One Health' approach
Moving from rabies research to rabies control:lessons from India
Research & policy disconnect: The case of rabies research in India
Cost analysis of a population level rabies control programme in Tamil Nadu, India

2 Model

2.1 Model Diagram



2.2 Model Equations

$$
\begin{aligned}
\frac{dS_D}{dt} &= b_D(S_D + E_D + V_D) - \mu_D S_D - \gamma_D S_D N_D - \beta_{DD} I_D S_D - t_W \beta_{DW} I_W S_D - t_V(v_D N_D - V_D) \\
\frac{dE_D}{dt} &= \beta_{DD} I_D S_D + t_W \beta_{DW} I_W S_D - \mu_D E_D - \gamma_D E_D N_D - \sigma_D E_D \\
\frac{dI_D}{dt} &= \sigma_D E_D - \mu_D I_D - \gamma_D I_D N_D - \alpha_D I_D \\
\frac{dV_D}{dt} &= t_V(v_D N_D - V_D) - \mu_D V_D - \gamma_D V_D N_D \\
\frac{dS_W}{dt} &= [(b_W - \mu_W) S_W - \gamma_W S_W N_W - \beta_{WW} I_W S_W - \beta_{WD} I_D S_W] t_W \\
\frac{dE_W}{dt} &= [\beta_{WW} I_W S_W + \beta_{WD} I_D S_W - \mu_W E_W - \gamma_W E_W N_W - \sigma_W E_W] t_W \\
\frac{dI_W}{dt} &= [\sigma_W E_W - \mu_W I_W - \gamma_W I_W N_W - \alpha_W I_W] t_W
\end{aligned}
\tag{1}
$$

Parameters used in model fitting:

Parameters	Definitions	Values	Derivation
b_D	Dog's birthrate	0.0015	.475 pregnancies*5 pups per
μ_D	Dog's frequency dependent death rate	$b_D/1.1$	1/lifespan of 1.9 years at birt
β_{DD}	Dog to Dog transmission rate	-	We are fitting this now in for
γ_D	Dog's density dependent death rate	$(b_D - mu_D)/K$	-
σ_D	Incubation rate in dogs	0.045	1/incubation period
α_D	Rabies induced death rate in dogs	0.32	-
v_D	Vaccination rate in dogs	0	This value will change
K	Carrying capacity	1,600,000	An estimation from the curre
N0	Dog's population of Tamil Nadu	1,547,238	Tamil Nadu 2012 dog popula
b_r	Bite rates of rabid dogs to humans	Fitting	
PEP	PEP coverage for humans	0.9	This value will change

3 Delhi Meeting

3.1 Present and Explain model to Abbas and Hiral

- Assumptions and Outputs

We are using Meagan's rabies transmission model without wildlife in it. We have modeled dog vaccination as well as ABC in the model.

- Livestock related data (OIE data). Is it ok to use ?

  We learned from NIVEDI that the spike in the Kerala data is due to improved surveillance. Not sure, if we trust this

- Discussion about Wildlife related data

  1. No evidence of their being reservoir.
  2. Any sense of what are the benefits here ?

  We decided that we will not include wildlife as part of transmission cycle. Also, we do not have relevant information to relate the rabid dogs to rabies in wildlife (probability tree) so we will not use wildlife as dead-end host for main analysis. But we will do additional what if analysis with wildlife as dead end host.

- Model Fitting
  Currently we are fitting the model to the human incidence by fixing R_0 *to* 1.1.

3.2 Metric

- What are the sectors of interest ?
- What are measurable quantities for each sector ?
- Who pays for the program ?

Note: *We discussed these questions at the meeting. Abbas and Hiral are working on these currently. The third question might not be the immediate question of interest because we will mainly be emphasizing on the framework rather than the result.*

3.3 Interventions

- What are the interventions of interest ?
  - Human PEP + ARV
  - Human PEP + ABC

- Human PEP + ABC + ARV
- Human PEP + Culling
- Human PEP + ARV + Culling
- Washing wound with water+soap
- Awareness/Equation
- Solid waste management
- Livestock PEP

Note: *These are some of the interventions we discussed. We will only use top 3 or 5 for now.*

3.4 Go over cost data with Abbas and Hiral

- Human related costs
  - Cost of vaccination
  - Other associated costs Some of these costs are in Abbas's cost analysis paper and they have provided the associated data.
- Livestock related costs
  - Hiral and Abbas provided us some data and working to acquire more data.
- Wildlife related costs
  - We absolutely have nothing about wildlife related cost for now and our analysis will be not part of main result and so we will do it with assumed values.

3.5 Vaccine Efficacy

- Humans:
  - Does everyone get it ?
  - Is it perfect ?
  - What is the coverage due to delay and other reasons ?
- Dogs:
  - Is it perfect ?

3.6 Day 1

- PHFI vision:
  1. Modeling and intervention efficacy
  2. Cost Analysis
  3. Cost effectiveness analysis
  4. MCDA Looking at different perspective and finding the benefit. Feasibility of the intervention.

3.7 Day 2

Papers

- Stray dog population demographics in Jodhpur, India following population control/rabies vaccination program (Sarah C. Totton)
  - Extracting efficacy of ABC program
  - Urban setting
  - Dog population pre an post ABC
- Control of rabies in Jaipur, India by the sterlization and vaccination of neghbourhood - Reece
  - ABC-AR dog census
  - Human Rabies
  - Canine Rabies
- Disease control through fertility control: Secondary benefits of animal birth control in Indian street dogs- Yoak
  - Make it one the canine effectiveness outcome/measure
  - Secondary benefits (?)
  - Read the papers and references
- Copy of ABC report by financial year from NJ
  - Follow-up grant and potential partners
  - Jaipur data from 2004–>
- Before 2004, Reece data from Jaipur

  - Mainly females till 2000 and then some males
  - Strelization in males quicker (2012)

- Rabies data Human:Dog ratio in Jaipur, Jodhpur and Jaiselmer
- Demography data in Old Jaipur/Pink city (underestimate)
  - Percentage of female dogs sterlized
- Guidelines say PCR is gold standard, or FAT results.
- ABC-AR in Haryana (Public data)
  - Demographic surveys in Haryana Unowned street dogs, Owned street dogs. Humanesociety.org did this all over the world
  - Think about using Fig 9 from Haryana data to use for urban and rural dog to human density.
- Tamil Nadu Veterinary and Animal Sciences University In chennai, Animal Rabies cases between 01.01.2014-01.01,2015 Brain samples (most prob), Under-reporting. (Chennai).
  - Nadres Reports
    * Endemicity Map for whole countries. Highly under-estimation (2007-2011). Productivity > Death. Herd disease is more important.
    * What does outbreak mean ?
    * How many cases ?
    * How they report/under/over-report ?
    * OIE data
  - Incidence of Livestock diseases in India
  - Abbas's paper Rabies control in Tamil Nadu
  - B.B.Singh and A.A. Gajadhar,

4 Notes

- Bite data and probability of rabies after bites
  - **A:** From Shim et al. 2009

Probability description
Probability of developing rabies following a bite to the head by a rabid animal
Probability of developing rabies following a bite to an upper extremity by a rabid animal
Probability of developing rabies following a bite to the trunk by a rabid animal
Probability of developing rabies following a bite to a lower extremity by a rabid animal

- **B:** APCRI Journal Volume X, Issue II, January 2009 Page 19

Site	Number	Percentage (%)
Upper limb	168	36.1
Lower limb	245	52.7
Trunk	14	3.0
Head and Neck	27	5.7
Multiple site	11	2.5
Total	465	100

- **C:** APCRI Journal Volume X, Issue II, January 2009 Page 27

Site	Number	Percentage (%)
Head and Neck	9	2.81
Chest and Abdomen	12	3.75
Upper limb	30	9.37
Lower limb	238	74.37
Other	31	9.68
Total	320	100

- **D:** APCRI Journal Volume XVI, Issue II, January 2015 Page 22

Site	Number	Percentage (%)
Upper limbs	1223	31.5
Lower limbs	2496	64.3
Chest and Abdomen	94	2.4
Head and Neck	23	0.6
Multiple Sites	46	1.2
Total	3882	100.0

- We can use the above wound specific data, and probabilities to calculate probability of developing rabies, given a bite by a rabid animal without prompt delivery of PEP. **Note:** *The bite data is not necessarily from rabid dogs. Will have to think about them*
  I classified the Indian data to correspond to the values from **A** as follows:

From A	in B, C or D
Head/Neck	Head and Neck/Multiple site
Upper extremity	Upper limb
Trunk	Trunk/Other/Chest and Abdomen
Lower extremity	Lower limb

So, we have

wound site	Prob. from **B**	Prob. from **C**	Prob. from **D**
Head/Neck	0.0817	0.0281	0.0178
Upper extremity	0.3613	0.0938	0.3150
Trunk	0.0301	0.1344	0.0242
Lower extremity	0.5269	0.7438	0.6430
Prob. of developing rabies without PEP	0.1904	0.1374	0.1584

*Note that the data from **B** has more sample and close to the probability in Tanzania*

- There are 2500 dispensaries in the state of Tamil Nadu and it gets only about 50 ARV vaccines per year. This probably runs out in a week. People who can afford can get it from private pharmacies.

5 Things to do

5.1 DONE Provide Exposure Humans (Low, Medium, High).

5.2 TODO Provide results divided as urban and rural settings.

5.3 DONE Remove livestock columns

5.4 TODO Predictions with ABC

6 Stakeholder's Meeting

Parameters	Definitions	Values	Derivation
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7 My slides

- After developing the model, we needed to parametrize and validate it with data from India. For this, we used various resources from literature. For example, for dog's demography data, we used Livestock census done in 2012 to get an estimate of Stray and Owned dogs in Tamil Nadu as well as their breakdown to female and male dogs. Owned dogs were about 8.9 lakhs in Tamil Nadu as opposed to 6.4 lakhs stray dogs.

- We used data from a study by Sarah Totton published in Preventive Vetinery medicine in conjunction with Livestock census data to estimate the Dogs birth rate and used estimates of incubation period in dogs as well as Rabies induced mortality rate in dogs from an another study by Hampson that was published PLos Biology. We calibrated our model to estimate Rabies deaths data in humans for Tamil Nadu in year 2002 and for the model calibration, we assumed that the canine vaccination coverage was about 25% and PEP coverage in Human was 60%.

- For the model fitting to human rabies deaths, the connection was made through the rabid dog bites. i.e., human death happens when no PEP was given upon bite from a Rabid dog. The top figure is the distribution of Rabies deaths in humans that our transmission model was fitted to and as a result of model fitting, we found that the canine rabies reproductive number in India was between 1.1-1.24. And by reproductive number here, we mean the average number of dogs a rabid

dog infects during its infectious period in an otherwise fully susceptible dog population. It also, means that to control Rabies transmission in dogs this number needs to be pushed below 1.

- After the model validation through fitting, we obtained model predictions under various control interventions. But to run the control interventions like ARV or ARV along with the sterlization, we had to make some asssumptions. For example, for ARV, we assumed that dog owners who currently pay to vaccinate their dogs would start to use subsidized clinics once the intervention starts. And for the sterlization strategy, we assumed that about 50% of current dog owners would be willing to discontinue dog ownership in the future. Also, that as more and more dogs are captured and sterilized, capturing unsterilized dogs would become more difficult resulting in reduction in efficiency of dog catchers. For this, we used a functional form like this, which ensures that when only 10% of unsterilized fertile female dogs are left, the efficiency of catching dogs declines steeply.

- Next, Meagan will talk about some of our model predictions.

Note: Vaccination coverage 25%, Human PEP 60%. Last slide. About R0.