Modeling Rabies Transmission Dynamics and Control in the Three Administrative Districts of Davao City

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BACKGROUND OF THE STUDY

- In the Philippines, rabies remains to be endemic wherein, every year, there are 200 to 800 dog bite incidences per 100,000 individuals
- Locally, the Davao City Veterinary Office (CVO) has been conducting rabies control and eradication programs to control the spread of rabies infection (see Figure 1 for rabies incidence) with a goal to make Davao City rabies-free sooner than the national goal of a Rabies-Free Philippines by 2020.
- However, despite the implementation of control measures and eradication programs, rabies remains to be endemic
- **Objective**: Formulate an epidemic model to determine the extent of control measures that are implemented in Talomo, Buhangin, and Poblacion districts in Davao City

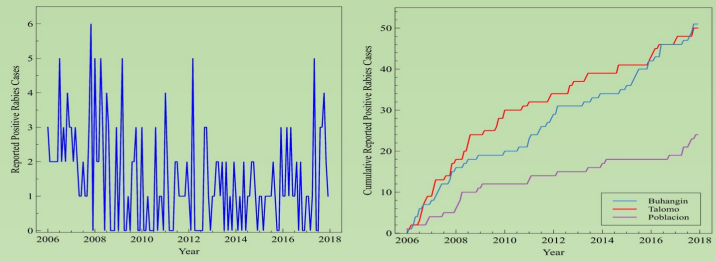

Fig. 1. Monthly positive rabies cases in Davao City (left) and cumulative monthly positive rabies cases for the three administrative districts (right) from January 2006 to December 2017.

METHODOLOGY

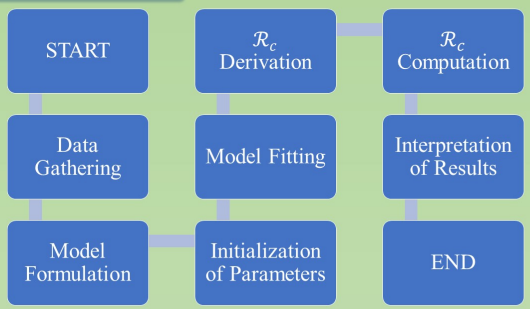

Fig. 2. The general flow of the study.

- Initial settings for unknown parameters that were used to fit to the data sets were obtained based from the datasets collected.
- For model fitting, the least squares approach was used where solution curves were fitted through the data such that the sum of squared errors (SSE) was as small as possible
- In this study, the MATLAB routine *ode15s*, which is an ODE solver that simultaneously implements an explicit fourth and fifth order Runge-Kutta, was used to solve the ODEs.

MODELLING FRAMEWORK

Variable Definition:

$\boldsymbol{S}$ – Number of susceptible dogs
$\boldsymbol{E}$ – Number of exposed dogs
$\boldsymbol{Y_0}$ – Number of examined dogs that are negative of rabies
$\boldsymbol{Y_1}$ – Number of dogs reported to CVO
$\boldsymbol{Y_2}$ –Number of examined dogs that are rabies positive
$\boldsymbol{I}$ – Number of infectious dogs
$\boldsymbol{R}$ – Number of recovered dogs

Parameters to be estimated

Λ – Average monthly dog birth rate
β – Direct transmission rate
γ_S– Reporting rate of susceptible dogs
γ_E– Reporting rate of exposed dogs
γ_I–Reporting rate of infectious dogs
γ_R – Reporting rate of recovered dogs
a – Proportion of total examined samples that are positive of rabies
p– Average examination rate
c_1 – Vaccination rate
c_2 – Castration rate
c_3– Impounding rate

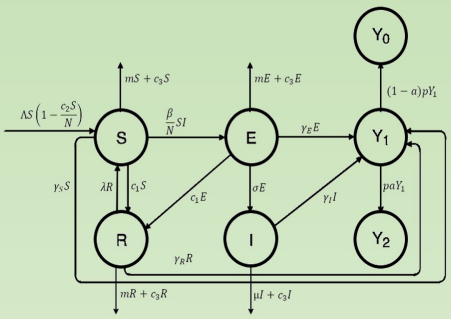

Fig. 3. Schematic diagram of the proposed model. Circles represent the population compartments. Solid arrows indicate the rate of transfer.

Model Equations:

$$\frac{dS}{dt} = \Lambda S\left(1-\frac{c_2 S}{N}\right) + \lambda R - mS - \gamma_S S - \frac{\beta}{N} SI - (c_1+c_3)S \quad (1)$$

$$\frac{dE}{dt} = \frac{\beta}{N} SI - mE - \gamma_E E - \sigma E - (c_1+c_3)E \quad (2)$$

$$\frac{dY_0}{dt} = (1-a)pY_1 \quad (3)$$

$$\frac{dY_1}{dt} = \gamma_E E + \gamma_I I + \gamma_R R + \gamma_S S - paY_1 - (1-a)pY_1 \quad (4)$$

$$\frac{dY_2}{dt} = paY_1 \quad (5)$$

$$\frac{dI}{dt} = \sigma E - \gamma_I I - \mu I - c_3 I \quad (6)$$

$$\frac{dR}{dt} = c_1(S+E) - \lambda R - mR - c_3 R - \gamma_R R \quad (7)$$

Control reproduction number

$$\mathcal{R}_c = \frac{\beta\sigma\left(\Lambda + \frac{\lambda c_1}{(\lambda + m + c_3 + \gamma_r)}\right) - m - \gamma_S - c_1 - c_3}{\Lambda c_2 (m + \gamma_E + \sigma + c_1 + c_3)(\gamma_I + \mu + c_3)}$$

The model is an extension of the SEIR (Susceptible-Exposed-Infected-Recovered) model formulated by Zhang, et.al. (2011) with three additional compartments ($\boldsymbol{Y_0}$, $\boldsymbol{Y_1}$, and $\boldsymbol{Y_2}$). The populations are functions of time t (in months), The rate of transfer from one population compartment to another and the interactions of the dynamic variables with the parameters are described in the schematic diagram shown in Figure 4. The control reproduction number $\mathcal{R}_c$ describes the average number of secondary infections caused by an average infective in a completely susceptible population with control measures (Leung and Davis, 2017)

RESULTS

- In comparing the three districts (Table 1), Poblacion had the lowest vaccination and castration rate but had the highest impounding rate.
- Since this district had the lowest rabies incidence, this could also imply that impounding dogs can effectively reduce the number of positive rabies cases, so controlling the population of dogs should be the goal to eradicate rabies in these areas.
- From Table 2, rabies is not yet epidemic in Davao City as well as in the three districts since the value of $\mathcal{R}_c$ is not yet greater than 1.
- $\mathcal{R}_c$ is directly proportional to β. This means that among the three districts in the study, Talomo district has the highest tendency to be epidemic, so interventions in the said district must be intensified.

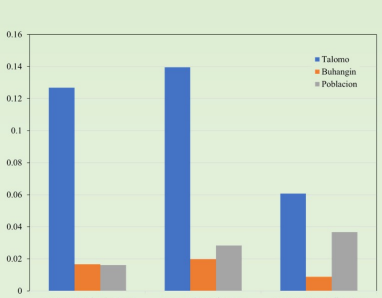

Fig. 4. Estimated parameter values for intervention efforts per district in the study.

Table 1. Control reproduction number for the first and second data set.

Data Set	$\mathcal{R}_c$
First Set: Davao City	8.7500×10^{-9}
Second Set: Talomo District	1.9880×10^{-7}
Second Set: Buhangin District	1.3002×10^{-8}
Second Set: Poblacion District	1.0453×10^{-8}

CONCLUSION AND RECOMMENDATIONS

- It is estimated that in Davao City, one dog is born per capita approximately every three months and per 100 million susceptible dogs, 3 dogs will be infectious.
- Vaccination on dogs was administered at the fastest rate, followed by impounding of dogs, and then by castration of dogs.
- It is recommended that this methodology can also be used for the other remaining districts in Davao City.
- This study emphasized on the role of dog population control through impounding. However, by practice, impounded dogs that will not be claimed within a certain time period are euthanized. Hence, it is also recommended that the city must implement a program that allows the impounded dogs to be adopted.

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