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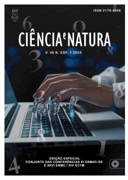

Simulation of the transmission dynamics of sporotrichosis in cats using the SI epidemiological model

Simulação da dinâmica de transmissão da esporotricose em gatos utilizando o modelo epidemiológico SI

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ABSTRACT

Sporotrichosis is an emerging and neglected mycosis with a worldwide distribution. In Brazil, a zoonotic epidemic is occurring, with two epicenters identified in the states of Rio de Janeiro and Rio Grande do Sul. However, little is known about the dynamics of this epidemic. In the present work, the incidence rate of the disease was calculated, and the SI (Susceptible Infected) mathematical model was employed to elucidate the epidemiological parameters and the epidemic curve of sporotrichosis in cats. Data from the urban area of Pelotas, the main city affected by sporotrichosis in southern Brazil, and secondary data from the main veterinary mycological diagnostic laboratory in the region were utilized. Through the results obtained, an average incidence rate of 79 cases per 100,000 cats was found, and R_0 of 1.45 (basic reproduction number) was determined, indicating that the epidemic is in its exponential phase. It was confirmed that the SI mathematical model was capable of inferring fundamental parameters of the dynamics and dissemination of sporotrichosis, and can be used as a tool for predicting the progression of this disease. As a consequence of the results found, we present an epidemiological scenario that necessitates immediate intervention with measures to contain the spread of this epidemic.

Keywords: Sporotrichosis; Incidence; Epidemic; Susceptible infected mathematical model

RESUMO

A esporotricose é uma micose emergente e negligenciada com distribuição mundial. No Brasil ocorre uma epidemia zoonótica com dois epicentros definidos nos estados do Rio de Janeiro e Rio Grande do

Sul. Porém, pouco se sabe sobre a dinâmica dessa epidemia. No presente trabalho foi calculada a taxa de incidência da doença, e utilizado o modelo matemático SI (Suscetível Infectado) para apresentar os parâmetros epidemiológicos e a curva epidêmica da esporotricose em gatos. Foram utilizados dados da área urbana de Pelotas, a principal cidade afetada pela esporotricose no Sul do Brasil, e dados secundários do principal laboratório de diagnóstico micológico veterinário da região. Através dos resultados obtidos encontrou-se a taxa de incidência média de 79 casos a cada 100.000 gatos, e R_0 de 1,45 (número de reprodução básico) através do qual é possível afirmar que a epidemia se encontra em sua fase exponencial. Confirmou-se que o modelo matemático SI foi capaz de inferir parâmetros fundamentais da dinâmica e disseminação da esporotricose, podendo ser utilizado como ferramenta para a predição da evolução dessa doença. Como consequência dos resultados encontrados, apresentamos um quadro epidemiológico que requer intervenção imediata com medidas para conter o avanço dessa epidemia.

Palavras-chave: Esporotricose; Incidência; Epidemia; Modelo matemático suscetível infectado

1 INTRODUCTION

Sporotrichosis is a neglected mycosis that affects humans and animals. In Brazil, the main fungal species responsible is *Sporothrix brasiliensis*, the most virulent, highly associated with zoonotic transmission by cats, and considered an emerging fungal pathogen (Rodrigues et al., 2016).

The disease has a global distribution, and in Brazil, the largest zoonotic epidemic ever recorded occurs, with well-defined epicenters in the South and Southeast regions of the country, specifically in the metropolitan area of Rio de Janeiro and the urban areas of the cities of Pelotas and Rio Grande in the state of Rio Grande do Sul (Gremião et al., 2017; Pereira et al., 2022; Sanchotene et al., 2015).

Over approximately two decades of evolution, the sporotrichosis epidemic has been recorded in practically all states of the country (Rabello et al., 2022), and in the last two years, it has also been reported in Argentina, Paraguay, and the United Kingdom (Barnacle et al., 2022), all sharing outbreaks in humans through transmission by infected cats.

Therefore, studying the population-level dynamics of sporotrichosis in cats is essential, as this knowledge is fundamental for reducing the transmission chain and controlling the disease. In this context, transmission-based models can assist the medical community in understanding and anticipating the spread of the disease in different populations, as well as help evaluate the potential effectiveness of different approaches for epidemic control (Keeling & Rohani, 2007)

2 METODOLOGY

2.1 Sources and Study Population

For the simulation of the epidemic model, cases of feline sporotrichosis diagnosed by the Center for Diagnosis and Research in Veterinary Mycology of the Federal University of Pelotas (MICVet/UFPel) located in the Southern Region of Rio Grande do Sul, during the period from 2011 to 2019, were used.

2.2 Average Incidence Rate

From the number of diagnosed cases, the animal incidence rate (AIR) was constructed, where:

$$AIR := \left(\frac{\text{positive felines}}{\text{feline population}}\right) \times 100,000.$$

Due to the absence of official data, the estimation of the incidence in the cat population in the urban area of Pelotas-RS was calculated using data on the cat population in the urban area of Porto Alegre, the capital of the state of Rio Grande do Sul, due to both sharing similar geography and cultural habits. Thus, to estimate the number of resident felines in the urban area in the study region, the number of 177 cats per 1,000 households was considered, with 171,363 households in the urban area of Pelotas-RS, according to information from the Brazilian Institute of Geography and Statistics (IBGE - Instituto Brasileiro de Geografia e Estatística, 2019a,1,2).

2.3 Mathematical Model

Mathematical models play a crucial role in understanding and predicting a wide range of complex phenomena across various fields. They provide an abstract framework that enables us to grasp the interactions between different variables and how these interactions may evolve over time. In the context of epidemiology, mathematical models are essential for understanding disease spread and informing intervention and control strategies. They allow us to simulate hypothetical scenarios, assess the effectiveness of different public health measures, and predict the impact of epidemics and pandemics on the population. By dividing the population into compartments and describing transitions between these compartments, epidemiological models provide valuable insights into how diseases spread and how we can mitigate their impact.

The Susceptible-Infectious (SI) epidemiological model with continuous-time vital dynamics is part of a class of compartmental deterministic mathematical models, which classify the population in compartments concerning the disease spread. The transition rates between the compartments are constant, and the analysis of disease spread considers the transition of individuals between compartments without focusing on the processes occurring within the compartmental classes (Keeling, 2007).

In this work, the hypothesis that there is no recovery of infected cats was considered. Thus, the compartmental SI epidemiological model with vital dynamics was used, which classifies the population as susceptible (S) and infected (I). This model makes several simplifying assumptions that must be satisfied by the specific disease dynamics:

i) the infected population does not recover from the disease;
ii) there is spatial homogeneity in the distribution of infected individuals;
iii) the disease is only transmitted through direct contact between infected and susceptible individuals.

According to the SI model, the dynamics of disease spread are governed by the following system of differential equations (Ferreira, 2021):

$$\frac{dS}{dt} = \mu N - \frac{\beta S I}{N} - \mu S, \tag{1}$$

$$\frac{dI}{dt} = \frac{\beta S I}{N} - \mu I, \tag{2}$$

where S is the number of susceptible individuals; I is the number of infected individuals; β is the transmission or contact rate; μ is the birth/death rate, respectively, where mortality occurs only due to the disease, and t is time.

It is considered that the total population N is constant, with $N = S + I$. Thus, the population size does not change over time.

The model is oriented towards specific local data and is designed to be used as a dynamic model to be fed with new information. The foundation of the transmission model is the simulation of a population of stray cats growing in response to specific birth and death rates.

2.4 Estimation of the Basic Reproduction Number

The basic reproduction number (R_0) is defined as the average number of secondary cases originated from a single infected individual at the initial instant of dissemination (Delamater et al., 2019). The dimensionless parameter R_0 indicates the intensity of transmission of the infectious disease and is the main indicator for characterizing an epidemic (Delamater et al., 2019).

By dividing Equations (1) and (2) by N, we obtain:

$$\frac{ds}{dt} = \mu - \beta si - \mu s, \tag{3}$$
$$\frac{di}{dt} = \beta si - \mu i. \tag{4}$$

where $s = S/N$, $i = I/N$, with $N = 1$, and the susceptible class can be determined by $s = 1 - i$.

The R_0 can be defined as (Keeling, 2007):

$$R_0 = \frac{\beta}{\mu}. \tag{5}$$

It is observed that when $R_0 > 1$, there is a growth in the spread of the epidemic, and when $R_0 < 1$, there is mitigation of it.

The system of Equations (3) and (4) is in equilibrium when

$$\frac{ds}{dt} = \frac{di}{dt} = 0. \tag{6}$$

Considering N as the fraction relative to the total percentage of the population, we have $S \approx N$, $N = 1$, and $s \approx 1$. Thus, the disease-free equilibrium point can be represented as (s^*, i^*) = (1, 0). The endemic equilibrium point can be calculated from the equation for the infected (Equation (4)):

$$\beta si - \mu i = 0 \Rightarrow i(\beta s - \mu) = 0, \tag{7}$$

which will be satisfied if, and only if, $i = 0$ or

$$s = \frac{\mu}{\beta} = \frac{1}{R_0}. \tag{8}$$

Considering now the equation for the susceptible individuals of the system Equation (3):

$$\mu - \beta si - \mu s = 0 \Rightarrow i = 1 - \frac{\mu}{\beta} \Rightarrow i = 1 - \frac{1}{R_0}. \tag{9}$$

Therefore, the endemic equilibrium point is given by (Ferreira, 2021):

$$(s^*, i^*) = \left(\frac{1}{R_0}, \frac{R_0 - 1}{R_0}\right). \tag{10}$$

3 RESULTS AND DISCUSSIONS

In this development, for the determination of the parameters involved in the solution of the SI model with vital dynamics, it was assumed that when the fraction of infected individuals is very small, i.e., s close to N ($s \approx 1$), the variation in the population of infected individuals grows proportionally to this population class:

$$\frac{di}{dt} = (\beta - \mu)i, \tag{11}$$

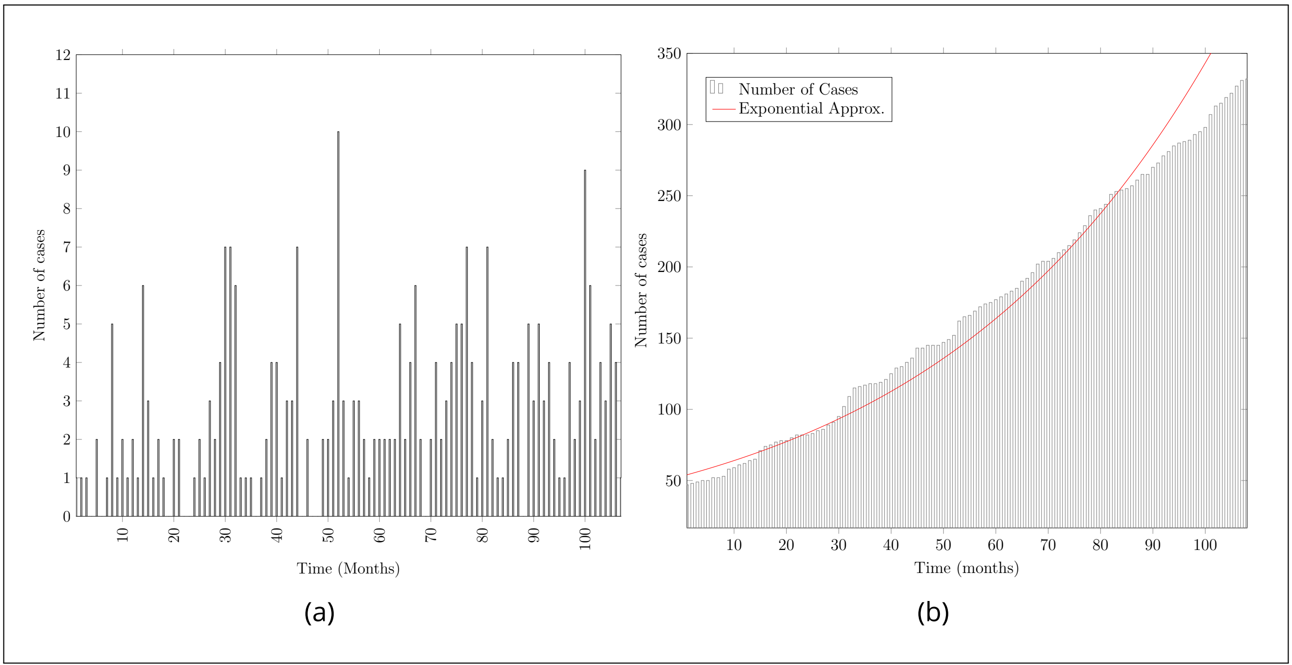
meaning, the larger the number of infected individuals, the greater the growth of this class. This behavior is mathematically described by an exponential growth in the number of infected individuals:

$$I(t) = I_0 \exp{(\beta - \mu)t}. \tag{12}$$

Thus, by creating an exponential trend line for the dataset of feline sporotrichosis incidence in the study region, the difference between the transmission and birth/death rates, $\beta - \mu$, is determined. The analysis covers the time interval between 2011 and 2019 as shown in Figure 3(b), and the trend line, considering the exponential behavior of the observed data, is given by:

$$I(t) = 53\exp\left(0.0192\,t\right). \quad (13)$$

Figure 1 – (a) Monthly cases from 2011-2019; (b) Evolution of cumulative cases and trend line of feline sporotrichosis in the time interval 2011-2019 in the city of Pelotas, Rio Grande do Sul, Brazil



Source: Authors, 2024

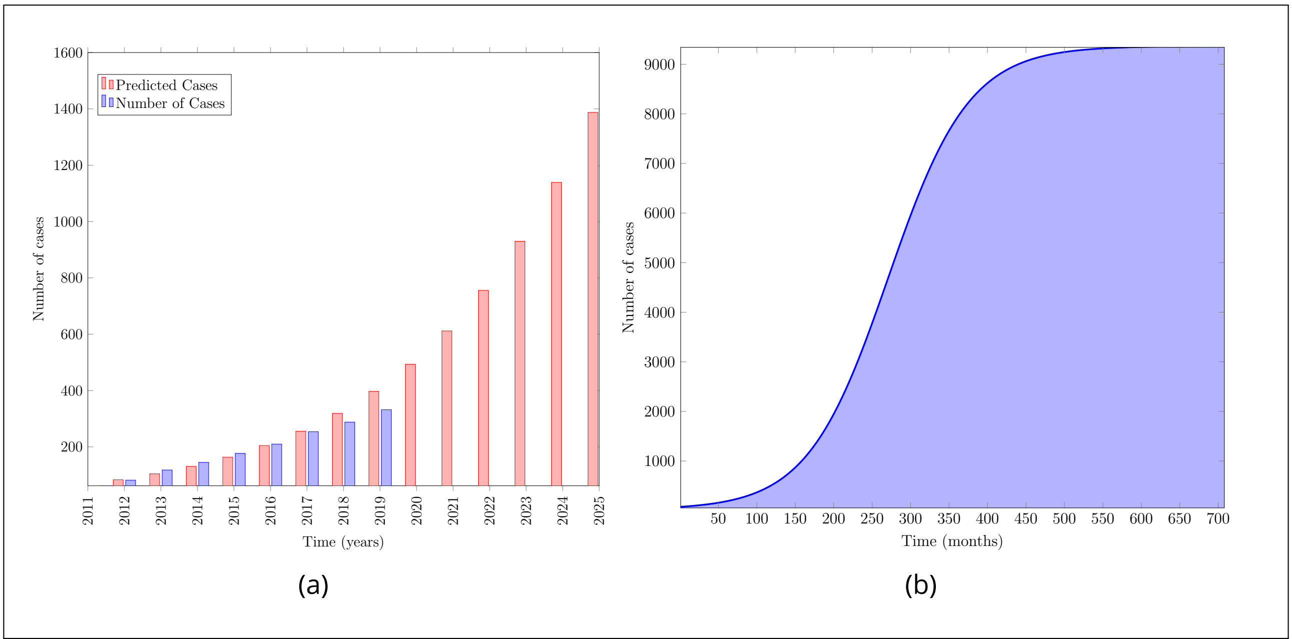
In turn, it was estimated that the infectious period is twenty-four months, and by definition, the removal rate is the inverse of this period, so μ=0.042 (month^{-1}). With this estimate, the transmission rate β was determined from the trend line expression:

$$\beta - \mu = 0.0192\ (\text{month}^{-1}), \quad (14)$$

$$\beta = 0.0612\ (\text{month}^{-1}). \quad (15)$$

These parameter estimates are sufficient to establish a prediction and forecast for the number of feline sporotrichosis cases in the region using the SI model. The temporal evolution from the solution of the SI model until the end of the year 2025 is shown in Figure 2.

Figure 2 – (a) Monthly cases from 2011-2019; (b) Evolution of cumulative cases and trend line of feline sporotrichosis in the time interval 2011-2019 in the city of Pelotas, Rio Grande do Sul, Brazil

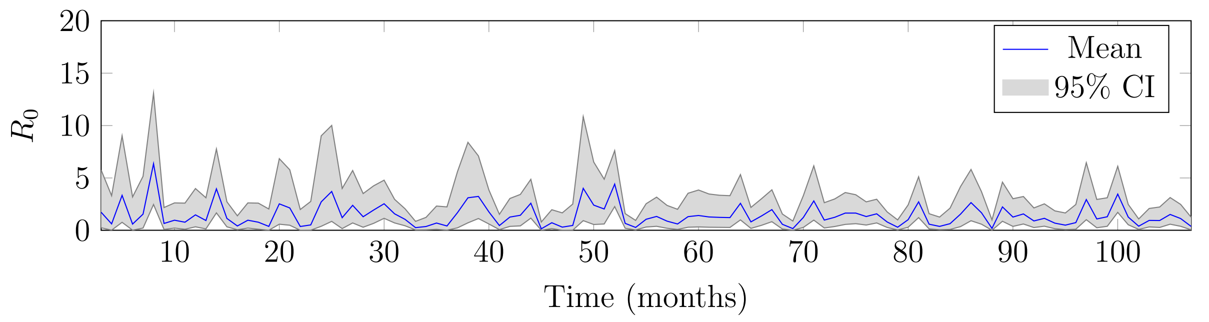


Source: Authors, 2024

According to the SI model, approximately 1,400 cumulative cases of feline sporotrichosis are estimated by 2025 in the city of Pelotas alone (Figure 2). Figure 2 presents the forecast until 2070, when over nine thousand cases of feline sporotrichosis are reached. Using the formula described in Equation (10), the endemic equilibrium will be reached when approximately 31% of the population is infected. The results obtained were also used to estimate R_0, which is 1.45, indicating that the epidemic is in an expansion phase.

There are various ways to calculate R_0. In order to show the reliability of the obtained result, Figure 3 presents the monthly reproduction number (R_t), considering the incidence. R_t values are calculated through a parametrized model for epidemics developed by researchers from Imperial College London, United Kingdom (Cori et al., 2013; Thompson et al., 2019). This model takes into account the incidence of reported cases. The values can vary considerably depending on the data window and standard deviations used in the simulation. Through this parametrized model, the average R_t over the entire period shown in Figure 3 provides the same value as previously obtained, 1.45.

Figure 3 – Monthly basic reproduction number obtained by the parametrized model of Thompson et al. for feline sporotrichosis in the Southern Region of Rio Grande do Sul, Brazil, from 2011 to 2019



Source: Authors

Analyzing the results presented by the model, it can be stated that the epizootic of sporotrichosis in Southern Brazil is in its early stages. Moreover, considering that cases of feline sporotrichosis usually precede the increase in human cases, it can be inferred that there will be a considerable increase in zoonotic cases, which means that, in addition to the damage related to the disease itself, the monetary and social costs of this disease will also increase considerably. In this study, a forecast of approximately five thousand infected felines was observed by mid-2034.

The inflection point of the disease predicts the growth of the epidemic curve and reinfection of the population until the year 2043. Similarly, the R_0 = 1.45 demonstrated a trend of disease spread in the study region, which was previously unknown for sporotrichosis.

This expansion of sporotrichosis, predicted by the SI epidemiological model and demonstrated by R_0 used in the study, is likely related to socioeconomic and environmental factors, such as economic and social inequality, poverty, unemployment, urban overcrowding, and poor sanitation, associated with scarce and inadequate health services. However, the observed numbers were obtained by simulating that no prevention and control measures are implemented in the region, revealing a concerning epidemiological scenario, largely due to the lack of public policies related to sporotrichosis.

The predicted epidemiological situation demonstrates the need for the adoption of emergency prevention and control measures capable of preventing the spread of the disease in the region, such as education strategies for adequate management of felines, neutering, responsible pet ownership, and training of healthcare personnel to recognize the disease. However, when studying the complex epidemiological chain of sporotrichosis, it becomes clear that no public policy will be effective unless it includes the principles of One Health, involving factors of animal, human, and environmental health, with coordinated and cooperative actions between veterinarians, laboratory professionals, surveillance agents, physicians, and other healthcare professionals, as well as public health managers.

The development of this work also highlights the difficulties encountered in disease surveillance systems, with one of the limitations of this study being due to the lack of public data related to the disease, which has been considered an epidemic since the 2000s. The data used here are secondary, originating from a passive surveillance system, since sporotrichosis is not a compulsorily notifiable disease in the study region, although it is the second region with the highest number of cases in the country. Additionally, some parameter values used were estimated due to the lack of official data.

Thus, the difficulties encountered in obtaining the data, and consequently conducting this study, as well as its alarming results, make it evident that sporotrichosis should be included in the national list of compulsorily notifiable diseases, so that the real burdens can be included in the National System of Information on Notifiable Diseases (SINAN), allowing a dynamic diagnosis of sporotrichosis in the human and animal population.

4 CONCLUSIONS

In this study, an appropriate methodological approach was developed to study the dynamics of sporotrichosis in cats, using the SI model to predict the number of cases over time. The average incidence rate of 79/100,000 cats and an R_0 of 1.45 for animal sporotrichosis in Pelotas were obtained. The model proved capable of highlighting the current epidemiological phase of the disease and predicting its evolution in the absence of control and prevention measures, revealing an alarming situation in terms of public health. Thus, the use of the SI epidemiological model is suggested for understanding and anticipating the spread of the disease, emphasizing the need for the development of active and constant surveillance programs, and urgent adoption of prevention and control measures for the disease with cooperation among animal, human, and environmental sciences to reduce its spread.

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