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MICROBIOLOGY

Multicriteria analysis model for foot-and-mouth disease risk classification in the state of Goiás – Brazil

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ABSTRACT: Foot-and-mouth disease (FMD) is a viral disease that affects several animal species, including domestic and wildlife ones. The occurrence of an FMD outbreak can potentially cause a large negative impact on countries or regions' livestock production and economy. Performed over several decades, mass herd vaccination has been the main strategy to control the disease. However, countries are beginning the stage of eradicating FMD, which involves suspending vaccinations. The present study carried out a risk classification for FMD occurrence in Goiás State, Brazil by evaluating and combining multiple risk factors involved in FMD introduction and dissemination. Data from 126,345 rural properties were collected and categorized by municipality. The risk factors were grouped into two modules and then scores for each module were obtained by adding and weighting the risk factors. These combined scores resulted in the final FMD occurrence risk score. Most of the municipalities, as well as the herds were found in the lowest likelihood levels. Variables linked to herd density and animal movement played a key role in the score composition. We believed that this model can be a useful tool in the decision-making process regarding actions and strategies related to FMD eradication.
Key words: eradication, risk assessment, risk factors, surveillance, vesicular diseases.

Análise multicritério para a classificação do risco de febre aftosa no estado de Goiás – Brasil

RESUMO: A febre aftosa (FA) é uma doença viral, febril, aguda e altamente contagiosa que afeta várias espécies domésticas e silvestres. Sua ocorrência resulta em grandes impactos negativos na cadeia pecuária e na economia de um país ou região. A FA está presente na América do Sul desde o fim do século XIX gerando esforços de órgãos oficiais no combate à enfermidade com vistas à erradicação, o que possibilitará futuramente a retirada da vacina, fato previsto no estado de Goiás para o ano de 2021. Neste sentido, o presente estudo objetivou classificar o risco de ocorrência de FA nos rebanhos do estado de Goiás. Para tanto, avaliou-se e combinou-se vários fatores de risco (FR) ligados à introdução e disseminação da FA obtidos de dados de 126.345 propriedades rurais. Estes FR foram agrupados em módulos formados por caminhos de introdução e disseminação da FA. A combinação dos FR se deu por meio de adição, sendo em seguida ponderados por pesos atribuídos por especialistas. Foram gerados os escores de introdução e disseminação de FA em Goiás, possibilitando a classificação do risco de ocorrência da doença no estado. Identificou-se que a maioria do rebanho e do território goiano se encontra em baixos níveis de risco. Foi identificada complexa composição nos níveis de risco obtidos, indicando ampla variação dos fatores que compuseram os escores de risco, especialmente nos municípios de mais alto escore de ocorrência. Variáveis ligadas à densidade de rebanho e trânsito e movimentação de animais apresentaram importante participação na composição dos escores. Acreditamos que os resultados deste trabalho podem compor uma ferramenta importante na tomada de decisão sobre as ações e estratégias de combate à FA em Goiás, ao passo que posteriores avaliações e adaptações poderão ser realizadas para a validação do modelo proposto.
Palavras-chave: avaliação de risco, doenças vesiculares, erradicação, fatores de risco, mapas.

INTRODUCTION

Foot-and-mouth disease (FMD) is a highly contagious viral infection that affects cloven-hoofed animals, both domestic and wildlife species (ARZT et al., 2011). Despite its general mortality, the disease can cause a large impact on the livestock production chain (BRITO et al., 2017). Even in countries with a long record of being free from FMD, reintroducing it would have a high impact in the economy (BESSELL et al., 2020) and globally there is an estimated cost of 6.5 billion US dollars per year on vaccinations alone (KNIGHT-JONES et al., 2017). Due to its great socio-economic importance, FMD is listed as a notifiable disease by the World Organization for Animal Health (WOAH) (WOAH, 2020).

The main strategy to control this disease has been traditionally based on the mass vaccination of herds, especially in South America (RIVERA et al., 2023). Considering the reduction in the number

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of outbreaks in the late 20th century, the move towards eradication started in the early 2000's (PANAFTOSA & OPAS/OMS, 2010). As the mass vaccination was being suspended, different strategies began to be applied, such as risk based surveillance (CAPORALES et al., 2012) and multiple risk factor combinations and evaluations (CORBELLINI et al., 2020; EAST et al., 2013).

By using a multiple risk factor model, the present study produced the classification of the FMD occurrence likelihood in Goiás state using each municipality as a basic structural unit. Thus, we used the method described by SANTOS et al., (2017) which uses a multi-criteria decision-making analysis to evaluate various risk factors linked to FMD introduction and dissemination.

Data from 100% (126,345) of rural properties with susceptible animals in the state were analyzed. These data were obtained from the *Sistema de Defesa Agropecuária de Goiás* (SIDAGO), which is the database of the official veterinary service of the state, which contains registration information for all livestock inspection/control in Goiás. Data outside the state's official veterinary service, such as areas with wild boar presence and rainfall index were obtained by non-published official records from the Environment Ministry and state Industry and Commerce Secretary.

The presented model uses two modules to categorize the likelihood of FMD occurrence, called the Introduction Module (IM) and Dissemination Module (DM). Each module is divided into pathways that comprised a variety of risk factors formed with the collected variables. A specific weight in the analysis was given to each pathway and risk factor, obtained by a specialist consultation as described by SANTOS et al. 2017 (Figure 1A, 1B).

The risk factors were ranked between the municipalities on a scale of 0 to 1, in which 1 was the municipality with the highest value obtained. These ranked values were obtained by dividing the municipality risk factor found value by the highest value on the same risk factor. Once ranked, the risk factor values of each analytical unit were weighted and then combined to obtain the pathway score. The methodology used in the risk factor and pathway combination was described by EAST et al. 2013. Through this combination, we obtained the likelihood scores of FMD introduction and dissemination, which when combined resulted in the likelihood of the FMD occurrence score.

The likelihood scores were calculated by combining the risk factors and the pathways of each module (Equation 1 and equation 2). The score for each introduction pathway (I1-I4) of the introduction module was obtained by:

$$I_j = S_{I=1}^{I_j}(RFIij\ x\ WRFIij) \quad (1)$$

Where I (introduction pathways) is the score for j-th I; j = 1, ...4; RFIij is the value applied to the i-th RF of each pathway of Ij described in the IM, and WRFIij is the weight for the i-th RF within pathway j.

The score for each dissemination pathway (D1-D3) of the "Dissemination Module" (DM) was obtained by:

$$D_l = S_{k=1}^{k_l}(RFD_{kl}\ xWRFD_{kl}) \quad (2)$$

Where Dl (dissemination pathways) is the score for l-th D; l = 1, ...3; RFDkl is the value applied to the k-th RF of each pathway of Dl described in the DM, and W_RFDkl is the weight for the k-th RF within pathway l.

Once the score for each pathway was calculated, the score for the introduction (IM) and dissemination (DM) module was obtained by adding the scores of the four introduction pathways and the three dissemination pathways multiplied by their weights. (Equation 3 and equation 4).

$$IM = S_{j=1}^{4}(I_j\ x\ WI_j) \quad (3)$$

Where IM is the likelihood score for FMD introduction; Ij is the result of equation 1 and WIj is the weight for each pathway j.

$$IM = S_{j=1}^{4}(D_l\ x WD_l) \quad (4)$$

Where DM is the likelihood score for FMD dissemination; Dl is the result of equation 2 and WDl is the weight defined for each pathway l.

The likelihood score for FMD occurrence (Equation 5) was given by the multiplication of the likelihood score for FMD introduction (IM, equation 3) and dissemination (DM, equation. 3).

LO = IM x DM (5)

The obtained values in each score were divided into four levels called very low (1), low (2), medium (3) and high (4). These four levels were obtained by a direct division of the difference between the highest and lowest score values in order to facilitate the observation of the risk scores distribution throughout the state. With all the information filed in spreadsheets, the data was inputted into QGIS™ software in order to obtain the risk maps representing the likelihood classification from each municipality for FMD introduction, dissemination and occurrence.

The average FMD occurrence likelihood was ranked between the state's five mesoregions (IMB,

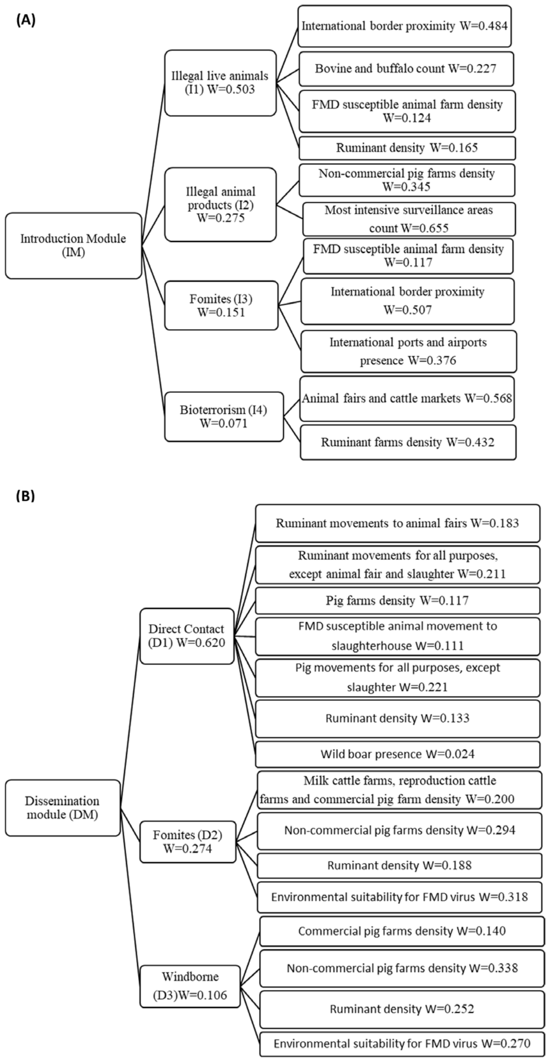

Figure 1 - Pathways, risk factors (RF) and their weights (W) composing the introduction (A) and dissemination (B) modules. RFs were multiplied by their respective weights given by specialist consultation, then added together resulting in the pathway values which were also multiplied by their weights in the analysis. IM formed by four pathways and DM by three pathways.

2018) to conduct a sensitivity analysis according to the described by SANTOS et al. (2017). Also, the variables were analyzed based on their sources and characteristics to determinate whether they could result in a high level of uncertainty. The ones evaluated with high uncertainty had their weight increased and decreased as described by SANTOS et al. (2017).

A kernel map indicating the concentration of vesicular diseases notifications received and attended by the state's official veterinary service between years 2005 and 2021 was also produced. The data used to make this map was collected from unpublished data gathered from official records kept by PANAFTOSA and Brazil's Ministry of Agriculture, Livestock and Supply.

Data processing from all 246 municipalities in the present model resulted in values for the introduction score (0.138 – 0.5312; $\bar{x}$ = 0.2859; σ = 0.0665), dissemination score (0.084 – 0.6134; $\bar{x}$ = 0.2149; σ = 0.0731) and occurrence score (0.0122 – 0.2287; $\bar{x}$ = 0.065; σ = 0.0352). Observing the distribution of the occurrence score among the risk levels, it was noted that the largest number of analytical units is found in the two lowest levels. Along the same lines, considering territorial extension (km2) and herd size (heads), we observed that 87.45% (297.389/340.086 km2) of the territory and 82.17% (20,705,615/25,198,290 heads) of the state's susceptible herd were also in the two lower likelihood levels.

The outcome of the sensitivity analysis showed that when increasing the weight values none of the variables or pathways involved in this study resulted in any change on the mesoregion FMD occurrence likelihood ranking. In regard of the uncertainty analysis, the variable "environmental suitability for FMD virus" was detected as a high level of uncertainty due to the way it was presented on its source. The uncertainty analysis results showed that varying or removing the value for this variable does not reflect in any change in the mesoregion FMD occurrence likelihood ranking as well.

This study's results are shown in risk maps representing the likelihood for FMD introduction, dissemination and occurrence in Goiás state, graded by each municipality on a scale from 0 to 1 using a color gradient to illustrate the risk classification. We identified a diffuse risk distribution throughout the state, with high score analytical units present in various regions of the state. A similar situation was reported by Amaral et al., (2016) when mapping the risk of FMD introduction along the Paraguay/Brazil border also using the risk factor combination.

Models using multiple data sources, such as our study, help build risk targeted surveillance strategies that can provide quick and effective responses when managing FMD (CAPORALES et al., 2012). Multifactor analysis models have been used to determine strategic actions aiming at FMD eradication in Brazil and other countries (CORBELLINI et al., 2020; EAST et al., 2013; SANTOS et al., 2017). In our case, the analysis resulted in a geographic classification of the information, another efficient approach adopted by other researchers (LEE et al., 2013; NEGREIROS et al., 2009).

Identification and categorization of risk factors linked to FMD occurrence have been described as of great importance in studies to help control the disease. Relevant variables in FMD epidemiology, particularly those related to animal movement and herd structure (dairy cattle, non-commercial farms) had significant influence in the occurrence of outbreaks (ELNEKAVE et al., 2016; HAMOONGA et al., 2014). We observed similar results, with similar risk factors having relevant contribution in the composition of the scores.

Regarding the FMD introduction score, we identified that the municipalities with highest values were concentrated in the center, west and southwest of the state (Figure 2A). The risk factors "ruminant density", "FMD susceptible animals farm density" and "most intensive surveillance areas count" had expressive influence on the scores results. Ruminant density was also described as associated to higher FMD introduction likelihood by SANTOS et al. (2017).

The dissemination score presented a homogenous distribution throughout the state (Figure 2B). There was no broad variation between the risk levels in the analytical units. Variables associated with the movement of animals, their products and by-products, in addition to the transit of people are known to increase the FMD dissemination risk (PATON et al., 2018).

In addition to the aforementioned ruminant density, variables associated with animal movement appeared as relevant factors in the composition of the dissemination score in the state. Ruminant movements to animal fairs, as well as transit between rural properties, presented high levels in analytical units with high values for the dissemination score.

The FMD occurrence risk map (Figure 2C) resulted from the combination of the two previous maps (Figure 2A and 2B), indicating the units where the disease outbreak likelihood is greater. This final map shows municipalities in different regions of the state standing out with highest FMD occurrence likelihood. In general, the highest likelihood was concentrated in the municipalities in the state's western portion, extending from the south to the north. Conversely, municipalities in the east of the state had a lower likelihood compared to the others, especially the northeast region, which had the lowest likelihood levels in the state.

Among the municipalities with the highest FMD occurrence score in Goiás, those located in the southwest of the state stand out. The largest number of pig farms is located in this region due to the presence of major pork slaughterhouses. This factor was associated with the high FMD occurrence score of municipalities in the region.

Due to the absence of FMD outbreaks in the state since 1995, the number of vesicular diseases notifications received was used in order to perform a comparison map with the FMD occurrence score map. Between 2005 and 2021, 534 vesicular disease notifications were received by the state's official veterinary service and the southwest region of the state

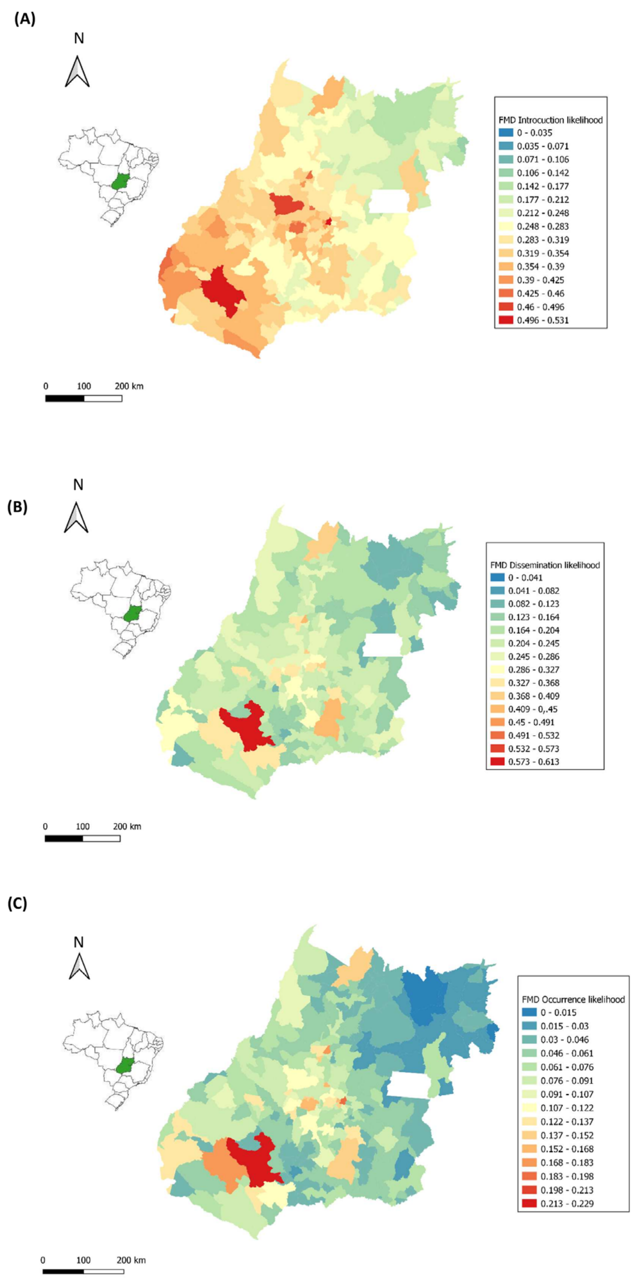

Figure 2 - FMD introduction (A), dissemination (B) and occurrence (C) likelihood maps in Goiás. Classification by each municipality, illustrated by color graduation, from the unit with the lowest score to the one with the highest score.

received the most notifications. The result was a kernel map showing the notification's concentration (Figure 3). Comparing the two maps, we observed similarity, as the regions with the highest FMD occurrence score were also the regions with the higher numbers of vesicular diseases notifications.

CONCLUSION

We demonstrated that our results were similar to those obtained by SANTOS et al. (2017) regarding the variables that most influenced the score values in our study. Elements such as distance to the

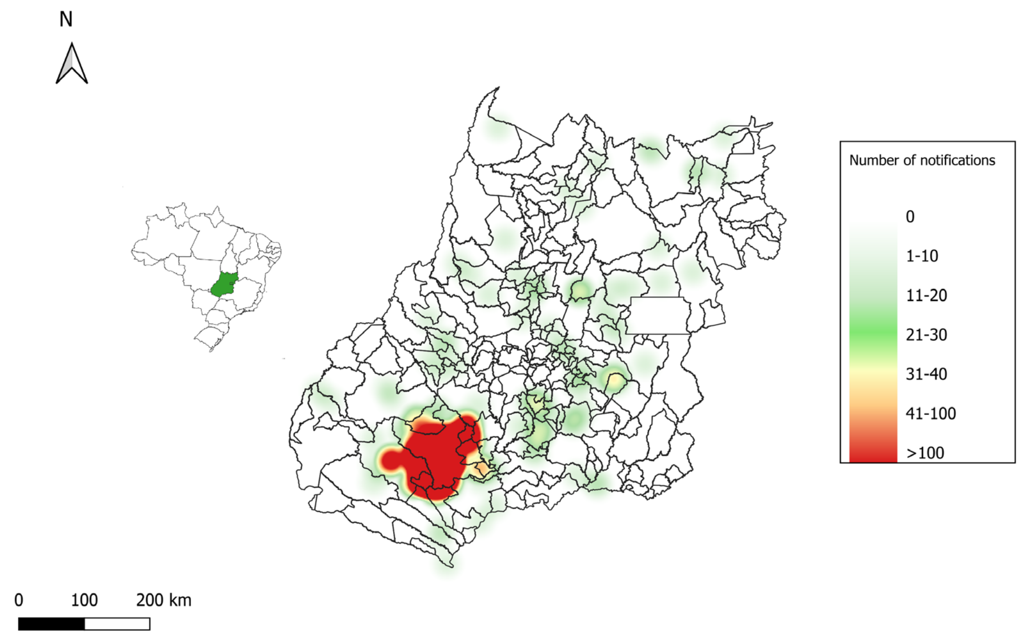

Figure 3 - Vesicular diseases notifications received in Goiás, years 2005 to 2021.

international border had a relevant impact on the results, and we think that this variable in particular should be revised to better suit Goiás state. The results demonstrated that FMD control efforts must be concentrated mainly in the southwest, central and north of the state. We believed that with some adjustments, the model can be used in various regions and countries to help eradicate FMD.

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DECLARATION OF CONFLICT OF INTERESTS

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTIONS

The authors contributed equally to the manuscript.

REFERENCES

ARZT, J. et al. The pathogenesis of foot-and-mouth disease I: Viral pathways in cattle. **Transboundary and Emerging Diseases**, v.58, n.4, p.291–304, 2011. Available from: <https://doi.org/10.1111/j.1865-1682.2011.01204.x>. Accessed: Sep. 10, 2021. doi: 10.1111/j.1865-1682.2011.01204.x.

BESSELL, P. R. et al. A tool for prioritizing livestock disease threats to Scotland. **Frontiers in Veterinary Science**, 2020. v.7, April. Available from: <https://www.frontiersin.org/articles/10.3389/fvets.2020.00223/full>. Accessed: Sep. 10, 2021. doi: 10.3389/fvets.2020.00223.

BRITO, B. P. et al. Review of the global distribution of foot-and-mouth disease virus from 2007 to 2014. **Transboundary and Emerging Diseases**, v.64, n.2, p.316–332, 2017. Available from: <https://doi.org/10.1111/tbed.12373>. Accessed: Sep. 21, 2021. doi: 10.1111/tbed.12373.

CAPORALES, V. et al. Surveillance strategies for foot and mouth disease to prove absence of disease and absence of viral circulation. **OIE Revue Scientifique et Technique**, v.31, n.3, p.747–759, 2012. Available from: <https://doc.woah.org/dyn/portal/index.xhtml?page=alo&aloId=31458>. Accessed: May, 18, 2021. doi: 10.20506/rst.31.3.2156.

CORBELLINI, L. G. et al. Shifting to foot-and-mouth disease-free status without vaccination: Application of the PROMETHEE method to assist in the development of a foot-and-mouth national program in Uruguay. **Preventive Veterinary Medicine**, v.181, June, p.105082, 2020. Available from: <https://doi.org/10.1016/j.prevetmed.2020.105082>. Accessed: Aug. 16, 2021. doi: 10.1016/j.prevetmed.2020.105082.

EAST, I. J. et al. Use of a multi-criteria analysis framework to inform the design of risk based general surveillance systems for animal disease in Australia. **Preventive Veterinary Medicine**, v.112, n.3–4, p.230–247, 2013. Available from: <http://dx.doi.org/10.1016/j.prevetmed.2013.09.012>. Accessed: Mar. 16, 2021. doi: 10.1016/j.prevetmed.2013.09.012.

ELNEKAVE, E. et al. Prevalence and risk factors for foot and mouth disease infection in cattle in Israel. **Preventive Veterinary Medicine**, v.130, p.51–59, 2016. Available from: <http://dx.doi.org/10.1016/j.prevetmed.2016.05.013>. Accessed: Sep. 21, 2021. doi: 10.1016/j.prevetmed.2016.05.013.

HAMOONGA, R. et al. Risk factors for foot-and-mouth disease in Zambia, 1981-2012. **Preventive Veterinary Medicine**, v. 114, n. 1, p. 64–71, 2014. Available from: <http://dx.doi.org/10.1016/j.prevetmed.2014.01.014>. Accessed: Sep. 22, 2021. doi: 10.1016/j.prevetmed.2014.01.014.

KNIGHT-JONES, T. J. D. et al. Foot-and-Mouth Disease Impact on Smallholders - What Do We Know, What Don't We Know and How Can We Find Out More? **Transboundary and Emerging Diseases**, v.64, n.4, p.1079–1094, 2017. Available from: <https://doi.org/10.1111/tbed.12507>. Accessed: Oct. 20, 2021. doi: 10.1111/tbed.12507.

LEE, S. Y. et al. **Analysis of FMD (foot and mouth disease) diffusion route by using GIS in gyeongbuk area**. [S.l.]: IFAC, 2013. v.1. Available from: <https://doi.org/10.3182/20130327-3-JP-3017.00040>. Accessed: Sep. 10, 2021. doi: 10.3182/20130327-3-JP-3017.00040.

NEGREIROS, R. L. et al. Spatial clustering analysis of the foot-and-mouth disease outbreaks in Mato Grosso do Sul state, Brazil - 2005. **Ciência Rural**, v.39, n.9, p.2609–2613, 2009. Available from: <https://www.scielo.br/j/cr/a/ryFWyVrtKgmvvQZpvFFynnn/?lang=en>. Accessed: Jun. 18, 2021. doi: 10.1590/S0103-84782009005000203.

PANAFTOSA; OPAS/OMS. **Programa Hemisférico de Erradicação da Febre Aftosa (PHEFA)**: Plano de Ação 2011-2020. 2010. Available from: <http://ww3.panaftosa.org.br/Comp/MAPA/432844.pdf>. Accessed: Jan. 28, 2021.

PATON, D. J. et al. Understanding the transmission of foot-and-mouth disease virus at different scales. **Current Opinion in Virology**, v.28, Figure 2, p.85–91, 2018. Available from: <http://dx.doi.org/10.1016/j.coviro.2017.11.013>. Accessed: Sep. 22, 2021. doi:10.1016/j.coviro.2017.11.013.

RIVERA, A. M. et al. Advances in the eradication of foot-and-mouth disease in South America: 2011–2020. **Frontiers in Veterinary Science**, 9 jan. 2023. v.9, n.1024071. Available from: <https://www.frontiersin.org/articles/10.3389/fvets.2022.1024071/full>. Accessed: Jan. 17, 2021. doi: 10.3389/fvets.2022.1024071.

SANTOS, D. V. dos et al. Identification of foot and mouth disease risk areas using a multi-criteria analysis approach. **PLoS ONE**, v.12, n.5, p.1–19, 2017. Available from: <https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0178464>. Accessed: Jan. 28, 2021. doi: 10.1371/journal.pone.0178464.

WOAH (World Organisation for Animal Health). **OIE-Listed diseases, infections and infestations in force in 2020**. Office International des Epizooties (OIE), 2020. Available from: <http://www.oie.int/en>. Accessed: Aug. 10, 2021.

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Erratum

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