Methodology to Identify, Analyze, Classify and Monitor the Reintroduction Risk Points of Foot-and-Mouth Disease

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***Abstract:** The aim of the current study is to develop a methodology able to identify, classify and monitor the reintroduction risk points of foot-and-mouth disease (FMD) in order to support an epidemiology monitoring system. The study was conducted in Maranhão State. The methodology was developed in six stages, namely: i) identifying the reintroduction risk points of foot-and-mouth disease; (ii) assessing the risk per identified point; iii) classifying the risk points; iv) analyzing the spatial distribution of risk points; v) identifying livestock properties under the highest epidemiological risk in comparison to the identified risk points; and vi) systematizing the model used to monitor risk points and livestock properties under the highest epidemiological risk. It was possible identifying and mapping possible points of introduction and/or dissemination of vesicular diseases in 2013 (917 points), 2014 (943 points) and 2015 (886 points). Three hundred and twenty-seven (36.91%) out of the 886 points identified in 2015 were classified as of low risk; 55.87% (n = 495), as of medium risk; and 7.22% (n = 64), as of high risk. The identified points were monitored on a monthly basis, as indicated for the herein assessed risk level, and it totaled 5,021; 5,382 and 5,441 inspections, respectively. Livestock properties under the highest epidemiological risk were also identified, and it totaled 2,894 properties in 2013; 3,057, in 2014; and 3,159, in 2015. These properties were inspected every six months, and it totaled 2,240; 2,294 and 2,353 inspections, respectively. It was concluded that the methodology enables epidemiologically monitoring the reintroduction risk points of Foot-and-Mouth Disease through risk analysis and geoprocessing in association with classic methods.*

***Index Terms**: Epidemiology, Foot-and-mouth disease, Risk analysis, Geoprocessing.*

I. INTRODUCTION

Risk analysis is a tool regularly used by the overwhelming majority of countries (80%) surveyed by the World Organization for Animal Health (OIE) to make decisions, mainly on the import and export of animals and animal products. These countries carry out risk analysis through a qualitative or descriptive approach, according to the type and quality of available data, as well as to the time needed to perform the assessments and to the lack of professional training to perform quantitative assessments [1] [2] [3] [4].

The literature [4] shows that the risk analysis at government level has been widely used to assess the risk of pathogenic agents to be introduced in the countries through the import of animal and plant products (Import Risk Analysis), as well as to estimate the probability of a given population to develop diseases - and their associated consequences - transmitted by pathogens found in animal-origin food (Microbiological risk analysis in food).

It is essential identifying risk areas in order to prevent and control the introduction of infectious agents in a given territory. These areas can be understood as places (and/or places nearby) wherein susceptible animals live at greater risk of having contact with other animals and animal-origin products that may carry pathogenic microorganisms [5] [6].

The model and the method currently used in risk control and analysis do not allow spatially locating the occurrence of the disease or making a rapid prognosis to indicate the risk areas or areas in need of emergency interventions [7]. Thus, it is worth highlighting the importance of using geotechnologies, mainly geoprocessing techniques, since they are powerful tools used to map the spatial distribution of diseases and worsening situations, as well as to assess risk areas in order to support administrative decisions and enable the optimized planning of preventive health actions [8] [9].

When it comes to the foot-and-mouth disease, the attainment and maintenance of the disease-free status through vaccination implies adopting permanent active-surveillance measures [10]. This surveillance requires identifying and monitoring risk points wherein the re-introduction and dissemination of the agent may occur. Thus, the aim of the current study is to develop a methodology to help identifying, classifying and monitoring FMD reintroduction risk points in order to support an epidemiology monitoring system.

II. MATERIAL E MÉTODOS

The study was carried out in Maranhão State (Brazil) from 2013 to 2015, according to the classification adopted by the official agricultural defense service, which divides the State in 18 regional units. The risk analysis process comprised 06 (six) stages, namely: i) identifying the reintroduction risk points of Foot-and-Mouth Disease; (ii) assessing the risk per identified point; iii) classifying the risk points; iv)

Revised Version Manuscript Received on February 01, 2017

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analyzing the spatial distribution of the risk points; v) identifying the livestock properties under the highest epidemiological risk in comparison to the identified risk points; and vi) systematizing the model used to monitor risk points and livestock properties under the highest epidemiological risk.

A. Identifying the Reintroduction Risk Points of Foot-and-Mouth Diseases

Based on the information about the epidemiology of foot-and-mouth disease and on the possible points of introduction and/or dissemination of vesicular diseases (PPIDVD) [6], the risk points in the agro productive sector of Maranhão State were identified in the following categories: slaughterhouses, tannery and salting companies, rendering companies, dairy product factories, cheese factories, dumping grounds and landfills, livestock event sites (animal agglomerations), droveways, airports, bus terminals, railway terminals, ports (pontoons, boat terminals).

B. Assessing the Risk per Identified Point

The qualitative assessment of risk points comprised the development of direct and indirect indicators (variables) to help estimating the risk level in each PPIDVD by taking vulnerability and receptivity into consideration. Thus, a risk assessment tool (closed-question questionnaires) was designed for each identified point.

C. Classifying the Risk Points

Different weights were considered for each indicator. The risk level classification was based on the results found in the Principal Component Analysis-PCA [11] [12]. The questionnaires considered the following aspects: (i) each question had a single answer; (ii) a predetermined value was attributed to each answer (1 to 3); (iii) the questions were grouped according to the vulnerability (subtotal X) and receptivity (subtotal Y) risk - the weight rates concerning the reintroduction and dissemination of infectious agents were 60% and 40%, respectively; (iv) at the end, the values attributed to the answers were summed up to find subtotals X and Y; (v) the subtotals were used to calculate the Risk Index (RI) through the following mathematical formula:

$$IR = \frac{0.6 \times subtotal\ of\ (X)}{Number\ of\ analyzed\ variables} + \frac{0.4 \times subtotal\ of\ (Y)}{Number\ of\ analyzed\ variables} \quad (1)$$

Each of the herein assessed probable risk points was classified at the end of the assessment and of the RI calculation, namely: High Risk (3.00 <RI> 2.41), Medium Risk (2.40 <RI> 1.61) and Low Risk (1.60 <RI> 1.00).

D. Analyzing the Spatial Distribution of the Risk Points

The geographic coordinates of the PPIDVDs were taken in a GARMIN® (eTrex Vista HCx) GPS device (Global Positioning by Satellite). The recorded data were transferred to the TrackMaker® Free Software (v. 13.0), which made it possible identifying the influence radius of each PPIDVD and allowed spatially assessing the risk [13] [14]. The coordinates allowed developing a database to prepare thematic maps using the Terra View free software. Alphanumeric and geographic data were used to develop the geodatabase.

E. Identifying the Livestock Properties under the Highest Epidemiological Risk (LPUHER) According to the Identified PPIDVDs

The identification of livestock properties under the highest epidemiological risk took into consideration the proximity of these properties to the identified risk points (3Km radius), as well as the existence of the following variables: the location of properties along droveways; the intense handling of animals susceptible to infectious diseases; properties that lend facilities, participate in collective vaccinations, provide lodging and rent grasslands; properties located on the borders with other states; properties holding livestock farms within rural settlements; indigenous villages; or any other situation wherein the livestock production system needs special veterinary care.

F. Systematizing the Model Used to Monitor the PPIDVDs and the Livestock Properties under the Highest Epidemiological Risk

The systematization of the model used to monitor the PPIDVDs and LPUHERs was based on the analysis applied to the identified risk [7] [15] [16]. Periodic inspections should be carried out in order to epidemiologically monitor the risk points. These inspections should be indicated according to the risk level classification: High Risk (3 times a month), Medium Risk (2 times a month), and Low Risk (once a month). On the other hand, properties under the highest epidemiological risk should be inspected once every six months.

III. RESULTS

Table I shows the identified risk points for the introduction of infectious agents and their classification per risk category. Of the 917 risk points identified in the classification performed in 2013, 38.60% (n = 354) were classified as of low risk; 53.76% (n = 493), as of medium risk; and 7.63% (n = 70), as of high risk. The classification performed in 2014 showed slight increase in the number of risk points. There were 943 risk points: 36.69% (n = 346) were classified as of low risk; 53.23% (n = 502), as of medium risk; and 10.07 % (N = 95), as of high risk. It was possible seeing decrease in the number of risk points in 2015. There were 886 risk points: 36.91% (n = 327) were classified as of low risk; 55.87% (n = 495), as of medium risk; and 7.22% (n = 64), as of high risk. There was statistically significant difference between the number of risk points per classification level throughout the assessed period (P <0.0001).

Table II shows the livestock properties under the highest epidemiological risk distributed by region during the assessed period. There were 2,894 LPUHERs in 2013; it corresponded to 3.11% (2,894/93,060) of the total number of properties registered in the State during that period. The number of LPUHER identified in 2014 was 3,446; it corresponded to 3.03% (3,057/100,976) of the total number of properties registered in the State during that period. As for 2015, the number of properties under the highest epidemiological risk was 3,159; it corresponded to 3.47% (3,159/90,900) of the properties registered during that period.

There was statistically significant difference in the number of properties in some regional units and between them ($P<0.0001$).

Table I: **Distribution of Reintroduction Risk Points of Foot-and-Mouth Disease According to Risk Level (2013-2015), in Maranhão State, Brazil.**

RISK POINTS	*BASE YEAR (RISK LEVEL)*											
	2013				**2014**				**2015**			
	Low Risk	**Medium Risk**	**High Risk**	**Total**	**Low Risk**	**Medium Risk**	**High Risk**	**Total**	**Low Risk**	**Medium Risk**	**High Risk**	**Total**
Slaughterhouses	39	96	12	**147**	36	98	17	**151**	34	100	7	**141**
Tannery and salting companies	23	73	6	**102**	24	68	12	**104**	26	67	11	**104**
Rendering companies	0	0	1	**1**	0	0	1	**1**	0	0	1	**1**
Dairy product factories	19	10	0	**29**	23	9	1	**33**	24	3	0	**27**
Cheese factories	15	6	0	**21**	10	12	0	**22**	8	10	0	**18**
Dumping grounds and landfills	48	113	22	**183**	38	125	32	**195**	30	121	23	**174**
Livestock event sites	78	50	7	**135**	85	59	6	**150**	78	58	4	**140**
Droveways	52	67	13	**132**	50	60	20	**130**	49	64	13	**126**
Airports	18	4	0	**22**	17	4	0	**21**	16	2	0	**18**
Bus terminals	33	24	3	**60**	35	27	1	**63**	31	23	1	**55**
Railway terminals	6	2	0	**8**	4	1	3	**8**	4	2	0	**6**
Ports (boat terminals)	14	21	5	**40**	21	22	1	**44**	17	19	3	**39**
Farms (swine breeding)	9	27	1	**37**	3	17	1	**21**	10	26	1	**37**
Total number of risk points	**354**	**493**	**70**	**917**	**346**	**502**	**95**	**943**	**327**	**495**	**64**	**886**

Table II: **Distribution of Properties under the Highest Risk of Foot-and-Mouth Disease Reintroduction per Regional unit in Maranhão State, Brazil (2013-2015).**

REGIONAL	**2013**	**2014**	**2015**
Acailandia	$167^{a,A}$	$168^{a,A}$	$100^{b,A}$
Bacabal	$218^{a,A}$	$221^{a,A}$	$221^{a,B}$
Balsas	$139^{a,A}$	$143^{a,A}$	$156^{a,A}$
Barra do corda	$416^{a,B}$	$283^{b,B}$	$361^{c,B}$
Caxias	$214^{a,A}$	$184^{a,A}$	$203^{a,B}$
Chapadinha	$75^{a,B}$	$79^{a,B}$	$79^{a,B}$
Codó	$67^{a,B}$	$63^{a,B}$	$63^{a,B}$
Imperatriz	$123^{a,A}$	$295^{b,B}$	$349^{c,B}$
Itapecuru-Mirim	$96^{a,B}$	$96^{a,B}$	$86^{a,B}$
Pedreiras	$126^{a,A}$	$133^{a,A}$	$25^{b,B}$
Pinheiro	$21^{a,B}$	$56^{a,B}$	$54^{a,B}$
Presidente Dutra	$419^{a,B}$	$543^{b,B}$	$551^{b,A}$
Rosário	$30^{a,B}$	$29^{a,B}$	$32^{a,B}$
Santa Inês	$229^{a,A}$	$227^{a,A}$	$327^{b,B}$
São João dos Patos	$183^{a,A}$	$207^{a,A}$	$170^{a,A}$
São Luis	$19^{a,B}$	$21^{a,B}$	$17^{a,B}$
Viana	$242^{a,A}$	$194^{b,A}$	$190^{b,A}$
Zé Doca	$110^{a,A}$	$115^{a,A}$	$175^{b,A}$
TOTAL	**2894**	**3057**	**3159**

$P<0{,}0001$

** Values followed by the same lowercase letters in the rows do not statistically differ from each other ($P>0{,}05$).*

** Values followed by the same capital letters in the columns do not statistically differ from each other ($P>0{,}05$).*

IV. DISCUSSION

All the risk points identified in the current study were epidemiologically relevant regardless of their classification. The results showed that the classification was not static. Thus, the risk level in the risk points could constantly change, mainly according to the vulnerability and receptivity aspects they showed at the time the assessments were performed.

One hundred and forty-one (141) slaughterhouses were identified in 2015, 07 (seven) of them were classified as of high risk and 100 were classified as of medium risk. Although there has been reduction in the number of slaughterhouses classified as of high risk when 2015 was compared to the previous years, the number of slaughterhouses classified as of medium risk was still high. The variables guiding the classification of these slaughterhouses were: (i) the proximity to rural properties housing animals susceptible to infectious diseases; (ii) properties receiving animals (for slaughter) coming from regions whose epidemiological risk classification is equivalent to that of Maranhão State, and whose FMD vaccination coverage is > 80% and ≤ 90% with no record of other infectious diseases; (iii) properties slaughtering cattle or pigs and, whenever necessary, small ruminants; (iv) the presence of medical-veterinary inspection; (v) the adequate disposal of slaughter wastes; (vi) the requirement of sanitary documentation for slaughter; (vii) the inadequate cleaning of the facilities; (viii) little restriction in the circulation of animals and people in the slaughterhouse area; and (ix) the record and notification of diseases found during the pre- and post-mortem inspections.

The salting companies were often found in the premises of slaughterhouses or in nearby areas; however, they were managed by third parties. Variables such as inadequate leather treatment conditions, slurry extravasation and inappropriate destination of wastes, as well as the traffic of animals and people, allowed classifying the salting companies' risk in 2015: 25% were classified as of low risk; 64.42%, as of medium risk; and 10.58%, as of high risk.

A single rendering company (meat and bone factory) was located in São Luís Island (metropolitan region of the State). This company receives wastes from four slaughterhouses, as well as wastes from supermarkets and salting companies. The other rendering companies were found inside the slaughterhouse area and they were also managed by the slaughterhouse manager. Therefore, they were assessed together with the slaughterhouses. The deficient material receipt and processing, the proximity to rural properties and the lack of registration in a sanitary inspection body resulted in the meat and bone factory's classification as of high risk.

Dairy product and cheese factories are places wherein milk is processed. Milk is an animal-origin product that may carry the FMD virus derived from infected animals; the virus can live in these products for a long period [17]. The current study identified 27 dairy product factories in 2015, 24 were classified as of low risk and 03 (three), as of medium risk. Of these, 60% (n = 16) were under official control, since they were registered in the State Inspection Service, fact that justified their classification as of low risk. Eighteen (18) cheese factories were identified in 2015, 08 (eight) were classified as of low risk and 10, as of medium risk. It is worth highlighting that most cheese factories were clandestine companies subjected to no inspection service. They were geographically concentrated in the following regional units: Açailândia, Bacabal, Imperatriz, Presidente Dutra and Zé Doca.

Twenty-three (23) out of 174 Maranhão State dumpsites assessed in 2015 were classified as of high risk and 121 were classified as of medium risk due to the presence of animals and garbage collectors in the landfills, to the existence of animal slaughter wastes and slurry extravasation, as well as to the proximity to rural properties and to inefficient garbage treatment. Studies [18] have stated that the leachate from dumpsites and landfills used as the place to dispose the carcass of susceptible animals represents a significant risk of spreading diseases to nearby properties. Therefore, they are important risk points that should be monitored in order to prevent the reintroduction of infectious diseases.

The number of livestock event sites and other animal agglomerations, as well as of dumpsites, was higher than that of other risk points. It happened due to local cultures and customs linked to the practice of animal-based sports such as vaquejadas, pole bending, barrel racing and roping competitions, grassland racing, among others; as well as to agglomerations such as animal fairs, exhibitions and auctions aimed at the commercialization of animals [19]. Of the 140 livestock event sites identified in the last risk classification, only 3% (n = 7) were classified as of high risk; 41% (n = 58), as of medium risk; and 56% (n = 78), as of low risk. The variables influencing this classification were: (i) holding the event in predetermined periods; (ii) little or no proximity to properties housing animals susceptible to infectious diseases; (iii) animals coming from regions under epidemiological risk classification higher than or equivalent to that of Maranhão State; (iv) inspections conducted by the state defense body; and (v) the presence of a technician responsible for the event.

The classification of droveways was based on the following variables: highly intense animal flow, the existence of other risk points and rural properties in the animals' route, besides the on-foot traffic of animals. There was no significant change in the classification throughout the herein studied period: 49 points were identified as of low risk; 64, as of medium risk; and 13, as of high risk in the last assessment year of the current study.

As for the airports, there was no significant change in the number of risk points identified throughout the studied period. Eighteen (18) airports were classified in the last assessment year: 16 were of low risk and 02 (two) of medium risk. The largest airport operating regional, national and international flights in Maranhão State was among the assessed ones and it was classified as of low risk. The geographical distribution of these airports can be seen in Fig. 1.

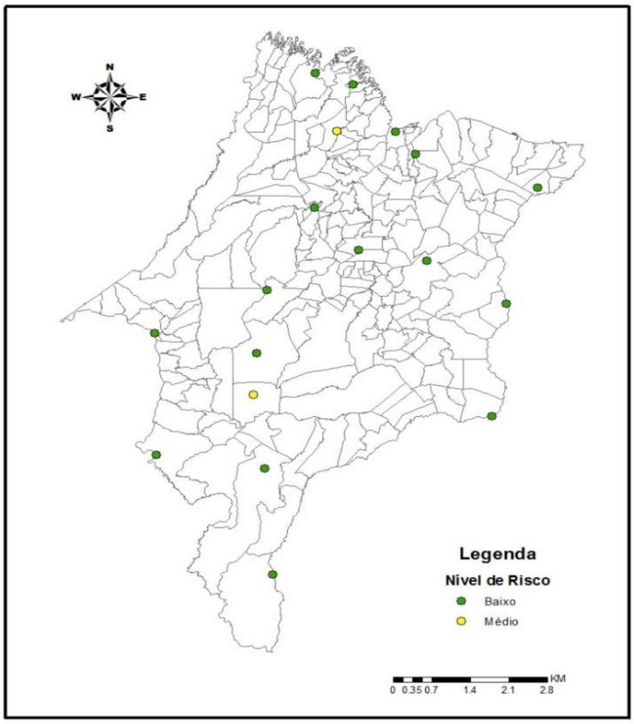

Fig. 1: Geographical distribution of airports, according to the risk level classification in Maranhão State, Brazil (2015).

Maranhão State has more than 52,000 km of highways: 3,248 km of them are federal; 5,161 km are state roads; and 44,376 km are municipal [20]. Fifty-five (55) bus terminals were identified throughout this road network in 2015; 31 were classified as of low risk; 23, as of medium risk; and only 01, as of high risk. The classification of these risk points, as well as of railway terminals, was influenced by the intense traffic of people, small animals and of products of animal and vegetable origin.

The 06 (six) railway terminals identified in the state are distributed along the Carajás Railroad, which connects Maranhão to Pará State; along the North-South Railroad, which links Açailândia-MA to Goiânia-GO; and along the Companhia Ferroviária do Nordeste (Northeast Railway Company), which links São Luís-MA to Fortaleza-CE [21]. Four (04) of these terminals were classified as of low risk and 02 (two), as of medium risk because they showed intense traffic of people, but limited traffic of animals and products of animal and vegetal origin. In addition, the Carajás Railroad (passenger train) management office works in partnership with the state's official health defense service through control and inspections aimed at preventing the possible transport of animals and products of animal and vegetable origin [22].

The risk assessment held in 2015 classified 39 ports, pontoons and ship terminals mainly located in coastal cities and on the state borders with Piauí and Tocantins states (Fig. 2). Seventeen (17) ports were classified as of low risk; 19, as of medium risk; and 03, as of high risk. The legal or illegal introduction of animals, products and by-products of animal origin through ports, airports and borders, as well as the inflow of people coming from contaminated areas, often lead to the reintroduction of diseases [23] [24] [25].

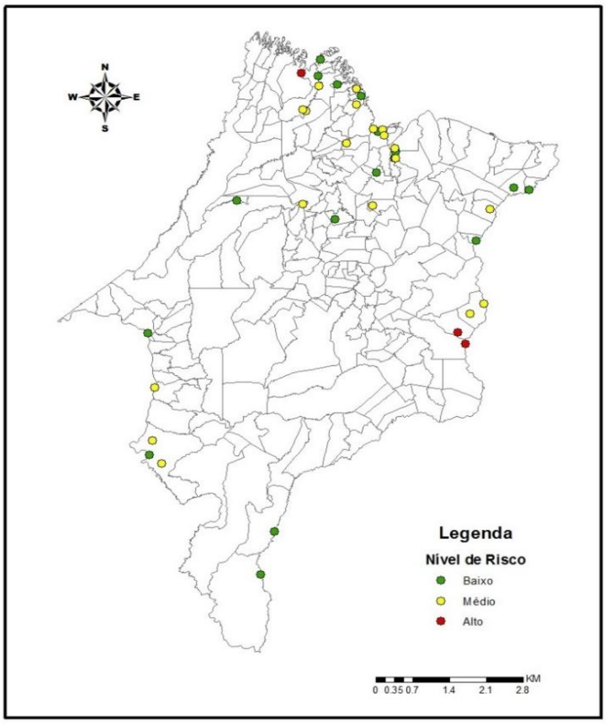

Fig. 2: Geographical distribution of ports (pontoons and boat terminals) according to the risk level classification in Maranhão State, Brazil (2015).

It is worth highlighting that the port of Itaqui was classified as of low risk in the current study. This port is nationally known for having the largest tidal amplitudes, excellent navigability due to its natural access depth (27m) and to the width of the canal. The state has been using this port to ship cattle to other countries, after it reached the "Foot-and-Mouth Disease Free status due to Vaccination" in 2014. Thus, it is essential holding permanent surveillance in order to avoid the spread of diseases. Pará and Maranhão states all together exported 16,000 cattle in 2015, whereas 12,000 cattle from Maranhão State were exported in 2016 [26].

The 37 family and commercial pig farms identified in 2015 were classified as follows: 10 were of low risk; 26, of medium risk; and 1 of high risk. This classification was influenced by the following variables: (i) the origin of the animals; (ii) the type of feed provided to them; (iii) the location of the farm; (iv) the waste destination; (v) the commercialization of the animals; and (vi) the coexistence with cattle herds. These features are essential to the adoption of preventive measures, since pigs get infected with reduced virus doses and excrete them in larger amounts than ruminants do [23] [27].

The LPUHERs were found through a multicriteria analysis that took the following variables into consideration: (i) the proximity to PPIDVDs; (ii) the location on the border with other states; (iii) vulnerability practices (the loan of facilities, the provision of lodging, the high traffic of animals); and (iv) the receipt of animals from areas whose status is lower than that of Maranhão State [28].

The statistically significant difference in the number of properties in some regional units and between regional units may be associated with the change in the number of risk points throughout the studied period, since the classification of these risk points was based on the 3km-distance from the risk points, as well as on vulnerability practices and on the receipt of animals. The LPUHERs identified in the current study should be subjected to intense monitoring since they are more prone to the introduction of infectious agents able to compromise the success of any animal defense system and to adversely affect the health status of animals [29].

All PPIDVDs identified in 2013, 2014 and 2015 were inspected on a monthly basis, according to the technical indication to the assessed risk level [6] [30]; it totaled 5,021; 5,382 and 5,441 inspections, respectively. The herein identified LPUHERs were also inspected according to the number of properties registered in each county; it totaled 2,240; 2,294 and 2,353 inspections in 2013, 2014 and 2015, respectively. Eighty percent (80%) of the properties were inspected, fact that indicates the need for the official defense service to implement control actions in order to assure 100% surveillance over the risk properties, since they are more prone to the introduction of infectious agents able to compromise the success of any animal defense system [11].

V. CONCLUSION

The results found in the current study allowed concluding that:

1. The herein applied methodology is an important tool for the identification of risk points in the studied area;
2. The classification of risk points is dynamic; it varied among 3 risk levels (low, medium and high) throughout the studied period. It is necessary continuously monitoring these risk points through periodic inspections in order to achieve the lowest risk level;
3. It is necessary identifying risk properties in order to guide the official health defense service. It is also necessary continuously monitoring these properties through periodic inspections aimed at minimizing their receptivity and vulnerability, as well as at preventing the adoption of dangerous practices that allow introducing and/or disseminating infectious agents;
4. The current study contributes to the animal defense service, since it determines risk areas for the introduction of infectious agents and enables faster and more effective health interventions.

ACKNOWLEDGMENT

The authors would like to thank Maranhão Fund for Research Support (FAPEMA - Fundo de Amparo à Pesquisa do Maranhão) for funding the dissemination of the current research, as well as Maranhão State Agency of Agricultural and Livestock Defense (AGED-MA - Agência Estadual de Defesa Agropecuária do Maranhão) for providing the data used to prepare the current study.

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