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Original Article

Bovine rabies cases in Ecuador: a retrospective cross-sectional observational study (2007 to 2020)

Casos de raiva bovina no Equador: um estudo retrospectivo e observacional transversal (2007 a 2020)

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Abstract

The hematophagous bats are usually the main reservoir of sylvatic rabies, being one of the most important viral zoonoses affecting humans and livestock in Latin America. Despite the most countries have already studied spatio-temporal distribution of bovine rabies, however, in Ecuador, little has been reported about the state of rabies in the country. Aiming to this objective, a descriptive observational study was realized from 2007 to 2020 based on the formal reports by WAHI-OIE and surveillance of bovine rabies retrieved from its official website. During the study period in Ecuador, some 895 cases of rabies were confirmed in cattle. In addition, in the total of bovine rabies cases seen in Andean and Coast regions (185 effected bovines), Loja and Esmeraldas had 95 (6.16% cases per 10,000 animals) and 51 (1.7% cases per 10,000 animals), respectively. Furthermore, the Amazon region indicated higher rabies cases in cattle than to the observed in other regions (710 rabies cases) while it was highly fluctuating with respect to the years (9.74 to 42.82% cases per 10,000 animals). However, Zamora (292 rabies cases), Orellana (115 rabies cases) and Sucumbíos (113 rabies cases) yielded the highest incidence rates than other provinces (9 to 42% cases per 10,000 animals). Based on this evidence, it has been fundamental to assess the current national program for preventing and control of the sylvatic rabies, being also necessary to include concept of the ecology of the vampire bat. Regardless of these results, vaccination is vital for control programs to prevent rabies in livestock and need to be widely increased for limiting their geographic and temporal spread.

Keywords: cattle raising, Ecuador, small livestock farmers, sylvatic rabies, bats.

Resumo

Os morcegos hematófagos são geralmente o principal reservatório da raiva silvestre, sendo uma das mais importantes zoonoses virais que afetam humanos e rebanhos na América Latina. Apesar de a maioria dos países já ter estudado a distribuição espaço-temporal da raiva bovina, no Equador pouco foi relatado sobre o estado da raiva no país. Com o objetivo de abordar essa questão, foi realizado um estudo observacional descritivo de 2007 a 2020 com base nos relatórios formais da WAHI-OIE e vigilância da raiva bovina obtidos em seu site oficial. Durante o período do estudo no Equador, foram confirmados cerca de 895 casos de raiva em bovinos. Além disso, no total de casos de raiva bovina observados nas regiões andina e litorânea (185 bovinos afetados), Loja e Esmeraldas tiveram 95 (6,16% casos por 10.000 animais) e 51 (1,7% casos por 10.000 animais), respectivamente. Além disso, a região Amazônica indicou casos de raiva em bovinos mais elevados do que os observados em outras regiões (710 casos de raiva), embora tenha apresentado grande flutuação em relação aos anos (9,74% a 42,82% de casos por 10.000 animais). No entanto, Zamora (292 casos de raiva), Orellana (115 casos de raiva) e Sucumbíos (113 casos de raiva) produziram as taxas de incidência mais elevadas do que outras províncias (9% a 42% de casos por 10.000 animais). Com base nessas evidências, tem sido fundamental avaliar o atual programa nacional de prevenção e controle da raiva silvestre, sendo também necessário incluir o conceito da ecologia do morcego hematófago. Independentemente desses resultados, a vacinação é vital para os programas de controle para prevenir a raiva no gado e precisa de ser amplamente aumentada para limitar a sua propagação geográfica e temporal.

Palavras-chave: pecuária, Equador, pequenos criadores de gado, raiva silvestre, morcegos.

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1. Introduction

Rabies is a worldwide distributed neurological zoonotic disease caused by a *Lyssavirus* of the *Rhabdoviridae* family and can affect all mammals (Rupprecht et al., 2002; Barecha et al., 2017; Mello et al., 2019; Scott and Nel, 2021). Furthermore, rabies occurs in two different epidemiological patterns, such as urban rabies with the domestic dog as the main reservoir and transmitter, and sylvatic or rural rabies (Heinemann et al., 2002) being the hematophagous bat *Desmodus rotundus* considered the main transmitter in cattle (Mialhe, 2013; Andrade et al., 2016; Mantovan et al., 2022). Therefore, rabies is a neglected viral zoonosis of mayor global public health and veterinary importance (Seetahal et al., 2019; Rupprecht et al., 2022). Rabies is listed as one of the World Health Organization's (WHO) Neglected Tropical Diseases Worldwide (Meske et al., 2021; Lin et al., 2022; Gan et al., 2023). Furthermore, it has been stated that rabies has a significant impact in South America, and it is one of the most prevalent neurological diseases in ruminants causing significant economic losses (Ulloa-Stanojlovic and Dias, 2020; Ortiz-Naveda et al., 2023; Viana et al., 2023). In the Amazon region of Ecuador, in the last 15 years, 23 human deaths were confirmed by rabies, being the transmission alluded to *Desmodus rotundus* (Ortiz-Prado et al., 2015; Martin-Solano et al., 2016; Orlando et al., 2019; Ortiz-Naveda et al., 2023).

Human activities have contributed to increase the common vampire bat densities and distribution, while anthropogenic promotion of the transmission of rabies is influences by the conversion of forest to pasture and the increasing intensive livestock (Ulloa-Stanojlovic and Dias, 2020; Meske et al., 2021). In fact, in Ecuador, the northern and central part of the Ecuadorian Amazon has experimented a process of rapid colonization since the 1960s due to agrarian reform laws (1964 and 1972), discovery of significant oil reserves by Texaco-Gulf in 1967, and due to new roads in inaccessible areas by oil companies (Torres et al., 2018). FAO stated that between 1990 and 2000, Ecuador had the highest deforestation rate, averaging 1.2% year. Consequently, these factors have led to a land-use change, and fragmentation of farms due to population growth (Mena et al., 2006; Heredia-R et al., 2021). Since, Botto-Nuñez et al. (2020) found association between forest fragmentation and pathogen spillover by contact with reservoir species (e.g., bats).

Bovine rabies transmitted by hematophagous bats has had disturbing levels of incidence in the provinces of the Amazon Region, and recently also in other provinces such as El Oro, Esmeraldas, Guayas, Loja, Manabí, Pichincha y Tungurahua (Vizcaino et al., 2016). Unfortunately, there is a lack of formal studies that need to demonstrate the status or shift of the epidemiological situation of the bovine rabies in Ecuador.

Therefore, mapping the spatial-temporal distribution of bovine rabies is an essential step in analysing transmission dynamics, which is critical to determine disease emergence and spread, to measure impact and ultimately improve prevention and control programs. Moreover, spatial analytical techniques as well as retrospective studies have been utilized successfully in countries such as Peru, in Brazil, as well as Colombia as a guide for improving surveillance and control strategies (Marín-Álvarez et al., 2014; Benavides et al., 2016; Rocha et al., 2017; Contreras, 2017; Mello et al., 2019; Ulloa-Stanojlovic and Dias, 2020; Bonilla-Aldana et al., 2022). With this objective, a descriptive observational study was performed of bovine rabies cases in Ecuador from 2007 to 2020 and describe the spread of the neurological disease.

2. Materials and Methods

2.1. Geographical setting

This belongs to an observational, descriptive, cross-sectional retrospective study on the incidence of sylvatic rabies in cattle (bovine) in Ecuador from 2007 to 2020. Ecuador is geographically divided into four regions, being the Highlands or Andean, the Coastal lowlands, the Galapagos archipelago and the Amazon basin (Figure 1). The Highlands or Andean are characterized for their impressive mountainous elevations, glacial-capped volcanoes and mountain ranges, whose altitude reach from 1800 up to 6300 m above sea level (m a.s.l.) (Merizalde Mora et al., 2022). The coastal lowlands are located between the Andean mountains and the Pacific Ocean, where the altitude ranges from sea level up to 800 m a.s.l. The Galapagos islands compose an archipelago which represents the second largest marine reserve on the planet. Finally, the last region considered in the current study is the Amazon region that constitutes 45% of the National territory, extending from the Andean Mountain foothills, with the appearance of transitional forests at 1300 m a.s.l. to the east of the Amazonian plain (Huera-Lucero et al., 2020).

2.2. Data sources and statistical analysis

The bovine cases rabies between 2007 to 2020 in Ecuador were retrieved from WAHIS-OIE interface (WHO, 2020) and entered into a Microsoft Excel (Microsoft, Corporation, Washington, DC, USA) spreadsheet. OIE's mandate is to ensure transparency in the global animal disease situation. These data are submitted to the OIE by the National Authorities of 182 OIE Member Countries that have the legal obligation to report data concerning notifiable animal diseases, including rabies. In addition, the bovine rabies cases retrieved in the database above mentioned, then were verified according to AGROCALIDAD (2022), which was realized with the purpose that laboratory-confirmed rabies positive samples have been considered in our study. Additionality, in Ecuador the last census on bovine population was realized in 2010 by the National Institute of Census and Statistics (INEC, 2022). For the present study, the more actual bovine population data was recovered from ESPAC (INEC, 2019), being detailed according to each region and by provinces where rabies cases occurred (Table 1), although Ecuador has had weaknesses in the traceability structured program. Additionally, there is a lack of the geographic coordinates of the bovine rabies cases. Nonetheless, the rabies cases from 2007 to 2020 by regions was elaborated in thematic map produced in Rstudio using the Terra package (Hijmans et al., 2022).

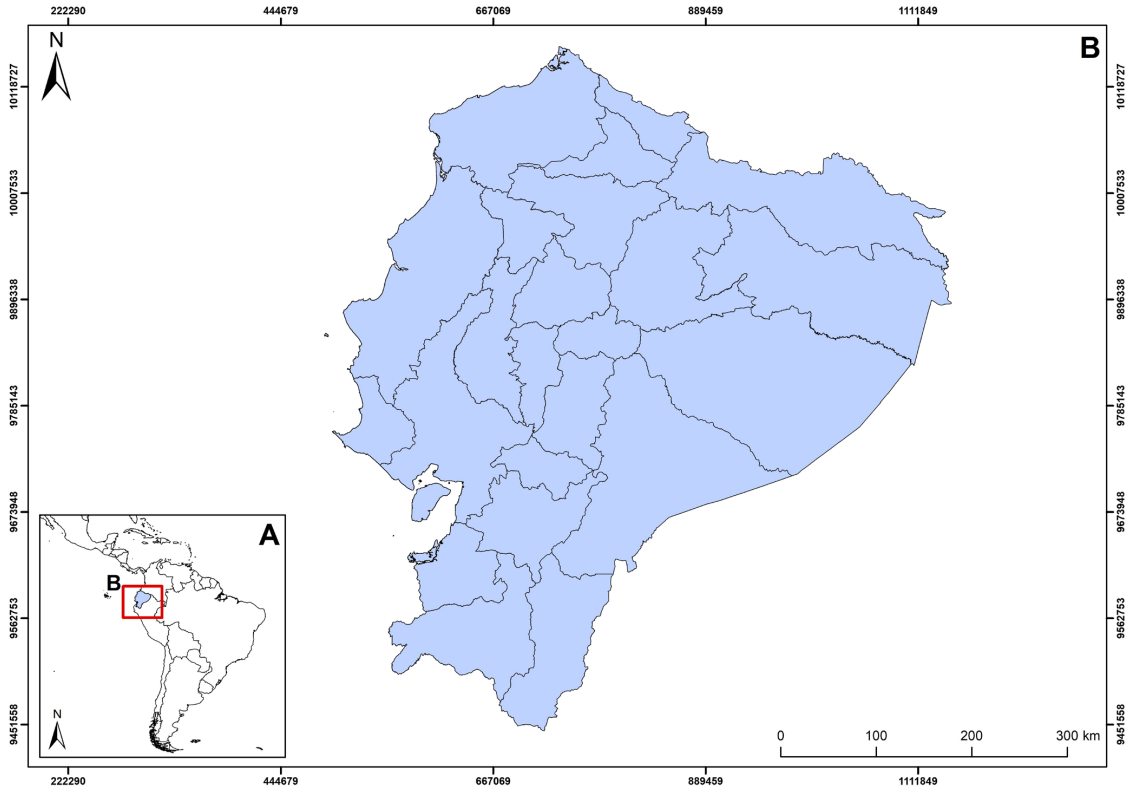

Figure 1. Location of the study area (A = Atlantic; B = Ecuador).

Table 1. Productive data by region, bovine population as well as incidence rates of rabies occurred from 2007 to 2020.

Region	Province	Surface, ha[1]	Bovine population (2020)[2]	Bovine rabies cases (2007-2020)[3]	(%)	Incidence (Cases per 10,000 Animals)
Andean	Loja	523.057	153.994	95	77.24	6.16
	Azuay	533.732	311.649	5	4.07	0.16
	Tungurahua	155.486	176.658	14	11.38	0.79
	Pichincha	529.022	252.394	9	7.32	0.36
	4	1741.297	894.695	123	100	7.47
Coast	El Oro	368.726	197.213	6	9.68	0.30
	Manabi	1603.697	951.769	5	8.06	0.05
	Esmeraldas	1046.074	305.514	51	82.26	1.70
	3	3018.497	1454.496	62	100.00	9.52
Amazon	Zamora	259.134	68.187	292	41.13	42.82
	Morona Santiago	811.427	118.019	55	7.75	4.66
	Napo	447.517	35.319	50	7.04	14.16
	Pastaza	821.909	33.922	85	11.97	25.06
	Orellana	606.307	46.911	115	16.20	24.51
	Sucumbíos	772.054	115.997	113	15.92	9.74
	6	3718.348	418.355	710	100.00	73.47
Total	13	8478.142	2767.546	895	100	

[1]Surface regarding the productive use; [2]Bovine population retrieved from SIPA-MAGAP (2020); [3]Data retrieved from WAHIS-OIE interface (WHO, 2020).

Finally, incidence rates were calculated as the number of cases of rabies in bovines divided by the estimated population of bovine animals per 10,000 bovines.

2.3. Decomposition of the bovine rabies cases time series

In the current study, a time-series decomposition model was performed based on Cleveland et al. (1990). Hereby, the bovine rabies cases during 2007 to 2020 previously recorded from WAHIS-OIE interface (WHO, 2020) were used. The decomposition analysis was performed in SAS v. 9.4 (SAS Institute Inc., Cary, NC, USA) using PROC TIMESERIES procedure. Therefore, random, and seasonal components were evaluated (Alegria-Moran et al., 2017; Ulloa-Stanojlovic and Dias, 2020).

2.4. Dynamics of the regional number of bovine rabies cases in Ecuador in time

The evolution of the yearly number of cases in livestock from 2007 to 2020 was analysed. The period has been chosen in order to evaluate the recent evolution of rabies in cattle. The Spearman´s rank test was used to evaluate the correlation between years and number of cases, using Hochberg's correction test for counteract the problem of multiple comparisons (Bogdan et al., 2008; Brown and Russell, 1997). All statistical analyses were performed with SAS v. 9.4 (SAS Institute Inc., Cary, NC, USA).

2.5. Endemic channels of the bovine rabies cases in Ecuador from 2007 to 2020

With the objective to assess the behaviour of the bovine rabies in Ecuador, the endemic channels were built from the rabies cases in cattle occurred between 2007 to 2020. This endemic channel was based on the method of the median and the quartiles with raw numbers, using the method described by OPS (2002).

3. Results

3.1. Bovine rabies cases by Province, Ecuador, 2007 to 2020

In the Table 1 are listed the productive data by region, bovine population as well as incidence rates of rabies occurred from 2007 to 2020. The Coast and Amazon region yielded a 72% higher surface than the Andean (6376 vs. 1741 ha), but with lower bovine population (419.81 vs. 894.695 animals). However, mayor number of rabies cases from 2007 to 2020 have been confirmed in the Amazon (710) than Andean (123) and Coast (62) region, respectively. Regarding the incidences rates, in the Andean region, Loja (6.16 cases per 10,000 animals) indicated higher data than other provinces (ranged from: 0.16 to 0.79 cases per 10,000 animals). Similarly, data has been observed in the Coast region, being their incidences rates between (0.05 to 1.70 cases per 10,000 animals). On the contrary, the higher incidences rates of bovine rabies were observed in the Amazon region than the Andean and Coast, as listed in Table 1. In this sense, Zamora had the higher incidence rates (42.82 cases per 10,000 animals) than other provinces, which ranged from (9.74 to 25.06 cases per 10,000 animals).

Productive data by regions of Ecuador, bovine rabies cases confirmed and incidence rates between 2007 to 2020 (Table 1). During the study period (2007 to 2020), 895 bovines rabies cases have been confirmed in the different provinces of Ecuador. Regarding its temporal distribution, the number of cases varied from a maximum of 166 cases in 2018 to a minimum of 20 in 2015 (Figure 2). Whereas analysing each region, in the Andean, during 2008 to 2009 were not reported any rabies cases, but in 2018 have been 45 rabies cases confirmed (Figure 2). Simultaneously, in the Coast region in 2018 were reported 18 bovine rabies cases. Contrary to this, the amazon region had a different behaviour, indicating in 2008, 2012 y 2018 the highest bovine rabies cases (Figure 2). When the seasonal time-series decomposition of the bovine rabies cases were performed (Figure 3), the residuals represented an important group of stochastic fluctuations in the data.

3.2. Endemic channels of the bovine rabies cases in Ecuador from 2007 to 2020

The endemic channel of the bovine rabies cases reported and confirmed in Ecuador from 2007 to 2020 (Figure 4). The most rabies cases were into of alarm zone, except in 2019. Therefore, the bovine rabies in Ecuador is endemic since, all study years had high incidences, although predominantly in the Amazon region. In fact, according to the endemic channel, in the Amazon region of Ecuador, the bovine cases rabies demonstrated waved outbreaks along of the study, but all upon or nearly to alarm zone (Figure 5). Besides this, the Zamora, Napo y Orellana provinces were closely to the alerted zone, which corresponds to the high incidence of the outbreaks (Table 1).

4. Discussion

In the last decade, the combination of landscape change and increasing anthropogenic food availability for wildlife may influence wildlife demographics, foraging behaviour, and immune responses, affecting the spatial and temporal dynamics of infectious diseases (Botto-Nuñez et al., 2020). The present work demonstrates the growing importance of wildlife as a source of rabies in Ecuador, in accordance with what has already been observed in other countries (Rocha et al., 2017). To our knowledge, this is so far the very first study which explores the epidemiological situation of bovine rabies in the entire Ecuadorian territory. Thus, this findings of the bovine rabies cases during 13-years' time interval exhibited a pattern of epizootic waves such as previously described in Peru and in Colombia (Ulloa-Stanojlovic and Dias, 2020; Bonilla-Aldana et al., 2022). It is fundamental to highlight that in the case of Amazon region of Ecuador, as indicated in the results, the most bovine rabies cases have been confirmed (Table 1). Although in the present study, the bovine rabies cases yielded to be negatively correlated with the bovine population ($r = -0.43$), those were not significant ($p = 0.14$). It has been stated that localities with a high bovine density provide a reliable and ideal source of food for vampire bats, which could increase survival and reproductive opportunities (Ulloa-Stanojlovic and Dias, 2020).

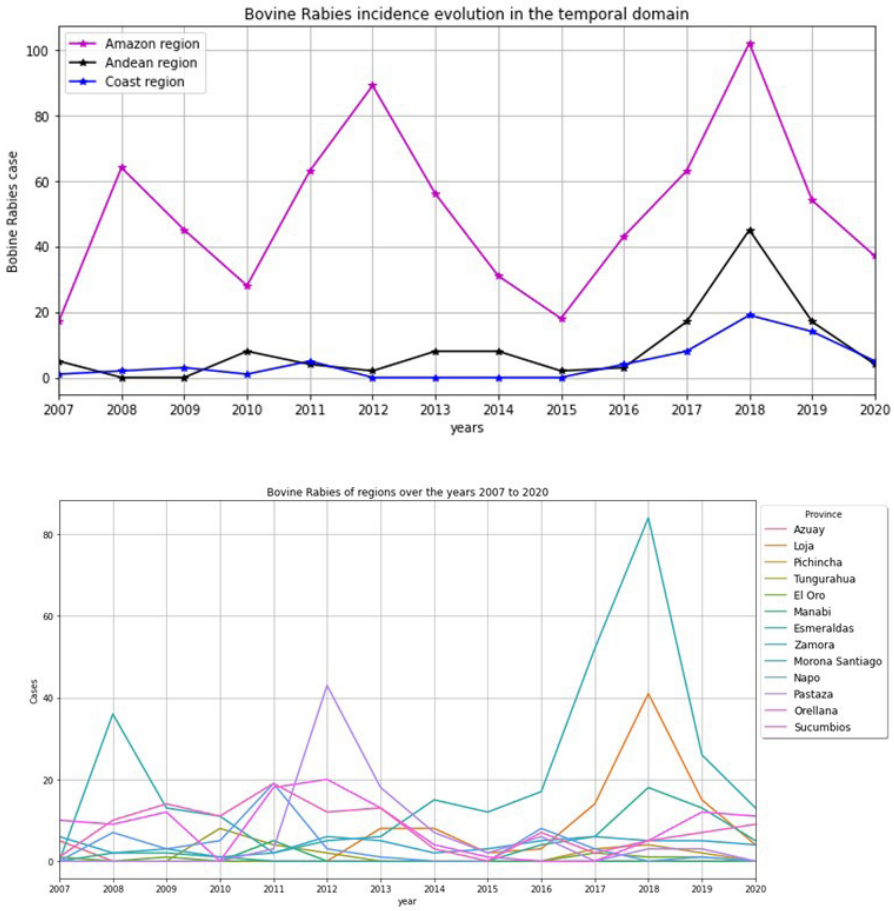

Figure 2. Bovine rabies cases per year and with regard to each region of Ecuador (2007 to 2020).

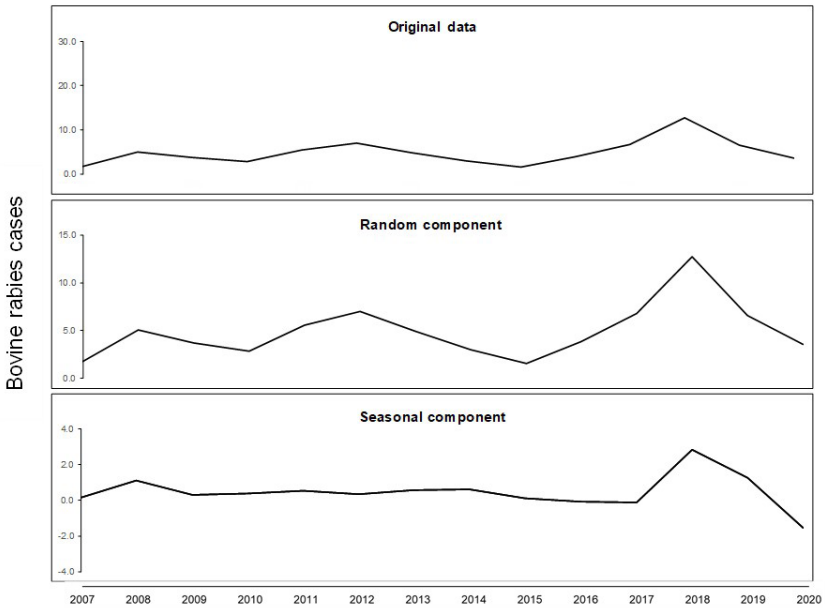

Figure 3. Seasonal additive decomposition based on loss from bovine rabies cases, Ecuador, 2007-2020.

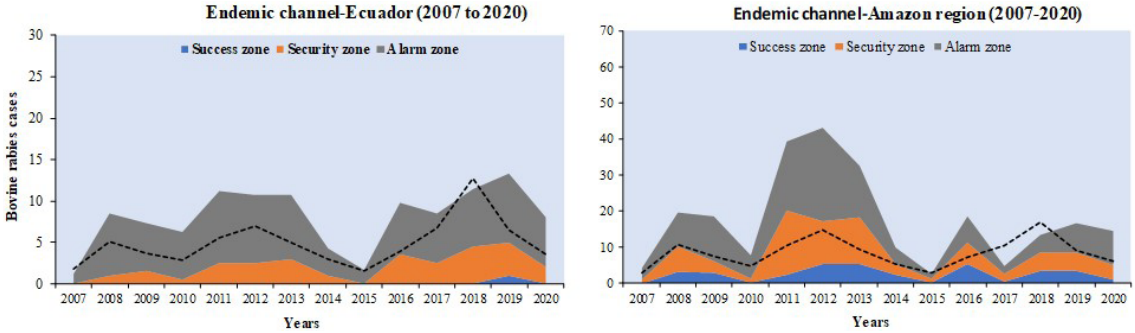

Figure 4. Endemic channel of bovine rabies cases in Ecuador and regard with amazon region from 2007 to 2021.

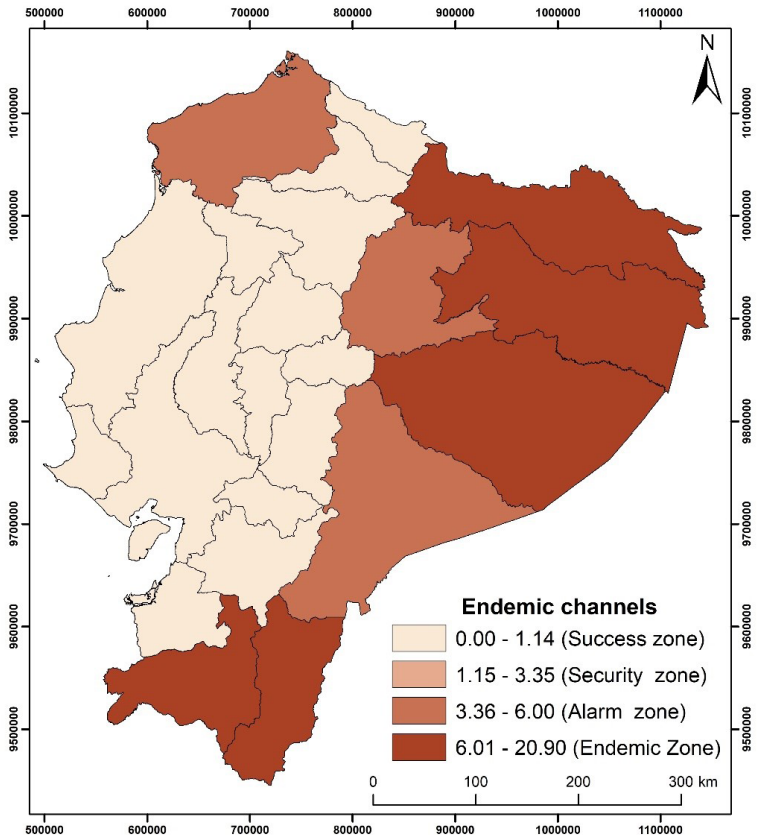

Figure 5. Endemic channel of bovine rabies cases according to Ecuador provinces.

Whereas, in Brazil it has been observed that in the extensive breeding system, the total number of cattle and the behaviour of the cattle breeds facilitates bats feeding on these animals instead of seeking the blood of other wildlife (Braga et al., 2014).

It has been observed that the low risk has low livestock density, a risk factor that influences the distribution of the disease in cattle but is less important than the potential areas with climatic conditions that influence the distribution of *D. rotundus* (Galicia-Castillo, 2015). In fact, in Loja and Santa Elena the bovine rabies cases were majority close to wooded or jungle areas (Briceño-Loaiza and Alegría-Morán, 2019; Orlando et al., 2019). Anyhow, in the context of Ecuadorian conditions, the present study indicates that the circulation of the virus in animals continues to represent a public health threat, but with marked differences among regions (Table 1; Figure 4).

Trying to solve with this issue, since 2012 the Ministry of Agriculture, livestock aquaculture and fish (MAGAP) of Ecuador through from AGROCALIDAD (2022) developed a program for rabies control, with directs strategics actions for the prevention and control of rabies in animal species of zootechnical importance (bovines, horses, pig and poultries).

The bovine rabies surveillance system is passive, relying on the communication of suspicious symptomatic or bitten animals to the official veterinary services by the farm owners. Whereas active vampire bat trapping and testing is also conducted based on public reporting of bat biting cases in livestock and location of confirmed bovine rabies cases. Besides this, trying to prevent this, the MAGAP reduced vampire bat populations in rural areas through the use of *diphenadione*, an anticoagulant given to cattle, despite the ecological costs of killing bats. Therefore, in continental Ecuador, there is a need to assess prediction models for selecting the suitable prediction and to be able to differentiate between those of biological and those of statistical importance. Subsequently, in the context of the national activities, it should be led to enhance surveillance, including active searches for foci, and sentinel surveillance and more education for the population and the academic sector, mainly oriented to farmers and producers. Unfortunately, in Ecuador lacks to conduct studies like in other countries such as Colombia (Contreras, 2017; Bonilla-Aldana et al., 2022) and Brazil (Andrade et al., 2020; Rocha et al., 2017; Heinemann et al., 2002). Therefore, the epidemiological situation of bovine rabies in the Ecuador is not well understanding.

According to our data, the seasonal variation represents an important component over the years. It is fundamental to highlight that Ecuador has four regions that are very well defined (Andean, Coast, Galapagos islands and Amazon regions), while in the case of the Amazon the rainy average is > 2000 mm/year as well as ambient temperature (28 to 32 °C) and relative humidity (85%). Therefore, bovine rabies cases in Ecuador and the Amazon region have been frequent, with records for all years in the study period. Therefore, this first performed study in Ecuador allowed to identify the existence of a possible underlying seasonal pattern, being to need to evaluate any changes in seasonality over time.

The WHO (2020) reported that rabies is a viral disease that causes tens of thousands of deaths and more than 15 million post- exposure treatments every year. Due to in the most countries in Latin America proper surveillance for rabies in bats is not performed (Bonilla-Aldana et al., 2022). As the *hematophagous* bats, are involved in all confirmed cases (WHO 2020) our results hint that bat attacks on humans and livestock represent both an animal health and public health concern. Besides, due to the most raising cattle are development under small livestock system (Vasco et al., 2018) the present study is able to demonstrate the huge risks represented by the circulation of the virus in common vampire bats. In this sense, surveillance systems need to be strengthened in Ecuador, since most rabies cases are reported from rural areas, where underreporting is likely (Ortiz-Prado et al., 2015). Anyhow, we conjecture that it could explain the waves of bovine rabies cases observed throughout the study (Figures 2 and 4). In the last 15 years in Ecuador, has been reported three important sylvatic rabies breakouts. The first one occurred in 1997, when eight human deaths by rabies were confirmed in the Numbat-kaime and Kunkuki communities, located in Morona Santiago province. Whereas one second, was reported in Jatun Molino, Pastaza province was caused four deaths. So, other studies reinforce the fact that vampire bat-transmitted rabies in South America is currently one of the most serious diseases affecting livestock and humans (Meske et al., 2021).

In all study years, the current study indicated also that endemic channel was upon o nearly to the alarm zone in the Amazon region, as illustrated in Figure 4. Consequently, based on these findings, the higher bovine rabies cases observed in amazon than in other regions could be conditioned to two factors. A biological factor, include the presence of Hematophagous bat as well as adequate shelter for them (Voigt and Kingston, 2011) due to exuberant vegetation (forests). In this sense, the factors that most contribute to the spatial distribution of rabies in livestock are temperature and precipitation as these variables offer a microclimate inside bat refuges that favour the distribution of possible infected vampire bats with the rabies virus (Bárcenas-Reyes et al., 2019). One second is related to nonbiological factors in which include diversity of productive systems and anthropogenic changes such as deforestation and land use changes (Benavides et al., 2016). In this sense, it has been determined that the deforestation could have reduced the numbers of natural prey species and brought vampire bats into contact with livestock (Johnson et al., 2014). Even though vampire bats have a great capacity to adapt to anthropogenic actions in the environment, bats are particularly susceptible to anthropogenic changes because of their low reproductive rate, longevity, and high metabolic rates (Voigt and Kingston, 2016; Ulloa-Stanojlovic and Dias, 2020). Regardless to above mentioned, diseases shared at the animal– human– ecosystem interface can have a significant impact on public health, global economies, livelihood and biodiversity (Fanelli et al., 2022). Based on our analysis, the rabies outbreaks in Amazon region occurred without showing seasonality or relationship with the rainfall regime (mean annual rainfall > 2000 mm) (Brito-Hoyos et al., 2013). Therefore, we suppose that the hematophagous bats remain active because it does not hibernate or migrate (Delprieto and Russo, 1996), which should be confirmed with further epidemiological studies. Similar to our study, geographical information systems are also valuable for mapping rabies in different populations, as shown in (Figure 4; Bonilla-Aldana et al., 2022).

5. Conclusions

Based to the findings of the current study, the data indicated that bovine rabies by *Hematophagous* bats have widespread in other regions which apparently did not provide the weather conditions (i.e., Andean region). Therefore, it necessary to re-evaluate the national program of control and prevention of livestock rabies. We propose some strategies such as vaccination, education programs as well as coordinated efforts from regional, national, and local governments to avoid rabies-related human deaths and cases in livestock. As Amazon region had the most bovine rabies cases reported during the study period (2007-2020), we should realize a risk characterization for knowing the anthropogenic or productive changes, limiting economic losses in small livestock farmers.

Accordingly, through this pioneering study, we will propose other epidemiological studies in order to evaluate the ecology of the vampire bat and establish sustainable actions as alternative to habitat destruction and indiscriminate use of anticoagulants. However, vaccination is vital for control programs to prevent rabies in livestock and should be widely increased.

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