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Canine rabies and risk of dog aggression in the city of Santa Cruz. A temporal-spatial perspective

Rabia canina y riesgo de agresión por perros en la ciudad de Santa Cruz. Una mirada temporo-espacial

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Abstract

Canine rabies and dog attacks represent a significant challenge to public health, particularly in endemic regions such as Santa Cruz de la Sierra, Bolivia. This study analyzed factors associated with dog bites and canine rabies cases in the city between 2019 and 2022, using georeferencing tools to identify key epidemiological patterns and provide relevant information for control strategies. In 2022, a total of 2900 animal attack cases were recorded, 81.6 % of which were caused by dogs. The victims were predominantly men (54 %) and adults aged 20 to 64 years (47 %). Most attacks occurred on the lower limbs (44.6 %) and were caused by known dogs (77.2 %). Additionally, the circumstances of the attacks varied, with accidental incidents being the most common. However, attacks without apparent cause were more likely when the aggressor was an unknown dog (OR 1.88, $p < .001$). Spatial analysis, conducted using the Kernel density method, identified clusters of attacks around the health centers included in the study, while canine rabies cases were concentrated in peri-urban areas of the city, particularly in the eastern regions. Of the 855 suspected canine rabies cases analyzed during the study period, 1.5 % (n=13) tested positive, primarily in unvaccinated male mixed-breed dogs. The proportion of positive cases decreased progressively since 2019, reflecting progress in vaccination campaigns and canine population control. This study highlights the need for comprehensive public health strategies, including mass vaccination programs, educational campaigns, and the promotion of responsible pet ownership. It also underscores the importance of improving epidemiological surveillance and access to medical services to reduce rabies transmission and respond more effectively to dog bites. The findings provide essential evidence for designing targeted interventions for vulnerable communities in endemic areas.

Resumen

La rabia canina y las agresiones por perros representan un desafío significativo para la salud pública, especialmente en regiones endémicas como Santa Cruz de la Sierra, Bolivia. Este estudio analizó los factores asociados a las mordeduras de perros y los casos de rabia canina en la ciudad entre 2019 y 2022, empleando herramientas de georreferenciación para identificar patrones epidemiológicos clave y proporcionar información relevante para estrategias de control. Durante el año 2022, se registraron 2900 casos de agresiones por animales, de los cuales el 81.6 % fueron causados por perros. Las víctimas fueron predominantemente hombres (54 %) y adultos de entre 20 y 64 años (47 %). La mayoría de las agresiones ocurrieron en los miembros inferiores (44.6 %) y fueron provocadas por perros conocidos (77.2 %). Asimismo, las circunstancias de las agresiones variaron, siendo las accidentales las más comunes, aunque los ataques sin causa aparente fueron más probables cuando el agresor era un perro desconocido (OR 1.88, $p < .000$). El análisis espacial, realizado mediante el método de densidad Kernel, identificó focos de agresiones alrededor de los centros de salud incluidos en el estudio, mientras que los casos de rabia canina se concentraron en zonas periurbanas de la ciudad, particularmente en las áreas al Este de

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la ciudad. De los 855 casos sospechosos de rabia canina analizados durante el periodo de estudio, el 1.5 % (n=13) resultaron positivos, principalmente en perros mestizos machos no vacunados. La proporción de casos positivos disminuyó progresivamente desde 2019, lo que refleja los avances en las campañas de vacunación y control de la población canina. Este estudio resalta la necesidad de estrategias integrales de salud pública que incluyan programas de vacunación masiva, campañas educativas y la promoción de la tenencia responsable de mascotas. Asimismo, subraya la importancia de mejorar la vigilancia epidemiológica y la accesibilidad a servicios de atención médica para reducir la transmisión de la rabia y responder de manera más efectiva a las mordeduras de perros. Los hallazgos proporcionan evidencia fundamental para el diseño de intervenciones dirigidas a comunidades vulnerables en áreas endémicas.

Introduction

Incidents of dog attacks and bites are widely recognized as a public health issue[1], especially due to the transmission of serious zoonotic diseases such as rabies[2]. In addition, dog bites cause significant psychological repercussions[3] and entail economic costs that affect both victims' families and the State[4-7], becoming a major concern for health authorities.

Globally, rabies is estimated to cause around 59000 human deaths annually[8], and approximately 99 % of cases result from bites by dogs infected with the rabies virus. Notably, free-roaming domestic dogs have been identified as the main source of transmission[9,10]. At the continental level, most countries have eliminated rabies from their domestic dog populations, however, in low - and middle-income countries, rabies still persists in these poorly controlled populations[4,9,11]. According to the Pan American Health Organization (PAHO), Bolivia is one of the few countries in the Americas where cases of canine rabies (CR) are still reported[9].

In 2017, Bolivia reported 965 confirmed cases of CR and 8 cases of human rabies. These figures represent the highest number of CR cases and human rabies deaths recorded in the country over the past 10 years[12-14]. The department of Santa Cruz was the most affected in 2017, accounting for 658 of the 965 CR cases reported nationwide[14]. In the same year, at least 25000 individuals who were bitten by dogs were recorded across the country[13].

Human rabies is preventable by avoiding viral exposure[15,16]. This can be achieved through a detailed understanding of the modifiable factors that drive its transmission, as well as the epidemiological dynamics of dog bites. To do so, high-quality data are essential to quantify the disease burden and guide prevention and control efforts[16].

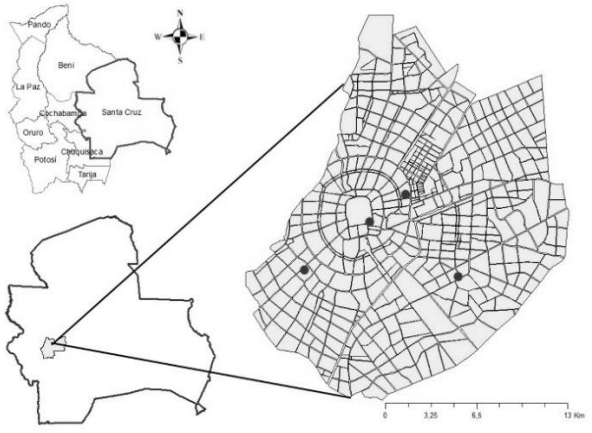
Within this approach, spatial analysis becomes a valuable tool for detecting changes in the patterns of endemic diseases[17]. Few epidemiological studies address the spatial distribution of dog aggression in the city of Santa Cruz, as well as the associated risk factors. This study aimed to identify the risk factors associated with dog aggression, the occurrence of RC cases in the city of Santa Cruz de la Sierra, and analyze their spatial distribution using georeferencing

tools, in order to determine key epidemiological patterns between 2019 and 2022, contributing to the design of effective strategies for the prevention and control of zoonotic diseases.

Materials and methods

Study Area. The study was conducted from 2019 to 2022 in the city of Santa Cruz de la Sierra, located in the eastern region of Bolivia (17º 45'S, 63º 14'W) at an altitude of 416 meters above sea level (Figure 1), characterized by a sunny, semi-tropical climate. The estimated population is 2 657 762 inhabitants[18], with a canine population of 390543[19]. The city is divided into four health networks and has a total of 65 health centers, which provide services to meet the healthcare needs of the population, including care for people who have been attacked by dogs, cats, and other animals.

Figure 1 Map of the city of Santa Cruz de la Sierra, indicating the location of the four health centers at each point



Study design and data collection. A retrospective cross-sectional study was carried out, gathering records of animal attacks in 2022 from four health centers: Elvira Wunderlich (part of the Central Health Network), Lazareto (part of the Northern Health Network), Preventiva Sud (part of the Eastern Health Network), and Sagrada Familia (part of the Southern Health Network) (Figure 1). The database of suspected CR cases from 2019 to 2022 was provided by the National Laboratory Unit (UNALAB) of the National Service for Agricultural Health and Food Safety (SENASAG).

Data Analysis. The analysis was based on descriptive and inferential statistics of the variables of interest, using measures of central tendency as well as bivariate frequencies and proportions. To analyze both CR cases and dog attack cases, a binary logistic regression analysis was performed with odds ratios (OR), assuming a 95 % confidence interval.

For dog attack cases, the variable of interest was the animal's status (known vs. unknown) and potential exposure to the rabies virus. The independent variables considered were: sex (male, female), age (0-4, 5-9, 10-19, 20-64, >65 years), educational level (≤18 years, no education, primary, secondary, university), site of exposure (head/neck, upper limb, lower limb, trunk), post-exposure prophylaxis (PEP) (yes, no), circumstances of the attack (accidental, provoked, no apparent cause), first aid received (washing with soap and water, alcohol, povidone-iodine, none), time elapsed between the attack and seeking care (same day, 1-5 days, more than 6 days), completion of the vaccination schedule (yes, no, referred to another health center), receipt of anti-rabies serum (yes, no), breed of the attacking animal (mixed, characteristic of a specific breed), and vaccination status of the attacking animal (vaccinated, not vaccinated).

For the CR cases in suspected animals, the variable of interest was the laboratory test result (positive vs. negative). The independent variables were year (2019, 2020, 2021, 2022), sex (female, male), age (0-

1 year, >1 year), vaccination status (vaccinated, not vaccinated), breed (mixed, characteristic of a specific breed), and number of people bitten (none, 1-6).

The significance level was set at $p < 0.05$ throughout the analyses. Data were analyzed using the Minitab 19® statistical software[20].

Georeferencing and spatial pattern analysis. For the georeferencing analysis, the geographic coordinates listed in each case record were obtained using Google Maps® (www.google.com/maps/).

The point location datasets were then plotted using ArcGIS software within its ArcMap module, applying a non-parametric Kernel density analysis. A bandwidth of 0.6 km was used, calculated using the adaptive bandwidth selection method, and a grid cell size of 0.01 km².

Ethical Approval Statement. Use of the records of dog attacks on people and CR cases was authorized by the respective directorates of the four Health Networks and by UNALAB - SENASAG.

Results

Sociodemographic characteristics of individuals attacked by dogs. During 2022, a total of 2900 bite victims were recorded across the four health centers in the city of Santa Cruz. The Lazareto Health Center reported the highest number of incidents (n = 1216). Of these, 81.6 % were caused by dogs and 1.1 % by other species, such as mice, rabbits, bats, and monkeys (Table 1).

Table 1 Recorded cases of attacks by Health Center and species

Health Center	Red	N	Dogs		Cats		Other	
			n	%	n	%	n	%
Preventiva Sud	East	687	606	88.2	80	11.6	1	.1
Sagrada Familia	South	723	608	84.1	111	15.4	4	.6
Lazareto	North	1216	941	77.4	251	20.6	24	2.0
Elvira Wunderlich	Central	274	210	76.6	60	21.9	4	1.5
Total		**2900**	**2365**	**81.6**	**502**	**17.3**	**33**	**1.1**

Of the 2900 cases reported in 2022, 891 (30.7 %) were excluded because the attacks occurred outside the city's geographic area or due to incomplete records.

Since most attacks were caused by dogs, the variable analysis focused on this species. The cases were more frequent among males (54 %, n = 1084) than females (46 %, n = 925), with a statistically significant difference (Fisher's exact test p = .000). The mean age of those attacked was 25.4 years (ranging from 0.6 to 91 years). Adults (20-64 years old) were the most affected group, representing 47 % of cases (n = 944) (Table 2).

Education level data for individuals over 18 years old are not collected systematically in all health centers, resulting in a substantial proportion of missing data (35.8 %). Among cases with available information, 10.4 % (n = 209) had a secondary education level.

Table 2 Characteristics of individuals attacked by dogs according to the animal's status

Variable	N= 2009 (%)		Condition of the animal				OR	IC 95 %	P-value
			Known n= 1551 (77.2 %)		Unknown n=458 (22.8 %)				
Sex									
Female	925	(46.0)	731	(47.1)	194	(42.4)	1		
Male	1084	(54.0)	820	(52.9)	264	(57.6)	1.21	.80-1.50	.072
Age									
0-4 years	268	(13.3)	242	(15.6)	26	(5.7)	1		
5-9 years	304	(15.1)	265	(17.1)	39	(8.5)	1.37	.81-2.32	.241
10-19 years	383	(19.1)	306	(19.7)	77	(168)	2.34	1.46-3.77	.000
20-64 years	944	(47.0)	658	(42.4)	286	(62.4)	4.05	2.64-6.20	.000
≥65 years	110	(5.5)	80	(5.2)	30	(6.6)	3.49	1.95-6.25	.000
Educational level									
≤18 years	925	(46.0)	790	(50.9)	135	(29.5)	1		
No education	3	(.1)	2	(.1)	1	(.2)	2.93	.26-32.49	.382
Primary	31	(1.5)	24	(1.5)	7	(1.5)	1.71	.72-4.04	.224
Secondary	209	(10.4)	161	(10.4)	48	(10.5)	1.74	1.20-2.53	.003
University	122	(6.1)	69	(4.4)	53	(11.6)	4.49	3.01-6.72	.000
No data	719	(35.8)	505	(32.6)	214	(46,7)	2.48	1.95-3.16	.000

The binary logistic regression analysis indicated no statistically significant difference between the animal's status and the sex of the attacked person. However, individuals older than 10 years (10-19, 20-64, and ≥65 years) were more likely to be attacked by an unknown dog compared to those under 4 years old (OR 2.34, 95 % CI: 1.46-3.77, OR 4.05, 95 % CI: 2.64-6.20, OR 3.49, 95 % CI: 1.95-6.25, respectively; p = .000).

A similar pattern was observed regarding academic level: higher educational levels (secondary and university) increased the likelihood that the attacker would be an unknown dog (OR 1.20, 95 % CI: 1.20-2.53, OR 4.49, 95 % CI: 3.01-6.72, p = .000, respectively), compared to those under 18 years old.

Epidemiological characteristics of dog attacks. The results show that most attacks occurred on the lower limbs (44.6 %, n = 897). Binary logistic regression analysis indicated that an unknown dog's probability of being attacked on the lower or upper limbs (OR 4.8 and OR 2.65, respectively, p = .000) was significantly higher than suffering attacks to the head and neck.

Most attacks took place accidentally, accounting for 28.4 % of cases (n = 570). However, there was a significantly higher probability that an unknown dog would attack without apparent cause (OR 1.88, 95 % CI: 1.38-2.56, p = .000) compared to accidental attacks.

Regarding first aid, 72 % (n = 1447) of victims washed the wound with soap and water, whereas 17.1 % received no immediate medical attention.

The time elapsed between the attack and seeking care at a health center ranged from 0 to 171 days. The majority of those attacked (57.5 %, n = 1155) sought care on the same day, although 3 % waited more than six days before going to a health center (Table 3).

The recommendation to administer PEP depends on factors such as the injury site, the animal's status, and the patient's vaccination history. Based on these cri-

teria, PEP was indicated in 58.7 % (n=1180) of cases. The likelihood of administering PEP was highly significant when the animal's status was unknown (OR 25.3, 95 % CI: 15.43-41.52, p=0.000) (Table 4).

Table 3 Epidemiological characteristics of dog bite exposure according to the animal's status

Variable	N= 2009 (%)	Condition of the animal				
		Known n= 1551 (77.2 %)	Unknown n=458 (22 8 %)	OR	IC 95 %	P-value
Exposed area						
Head and neck	411 (20.5)	375 (24.2)	36 (7.9)	1		
Upper limb	617 (30.7)	492 (31.7)	125 (27.3)	2.65	1.78-3.93	.000
Lower limb	897 (44.6)	614 (39.6)	283 (61.8)	4.80	3.32-6.95	.000
Trunk	79 (3.9)	67 (4.3)	12 (2.6)	1.87	.92-3.77	.082
No data	5 (.2)	3 (.2)	2 (.4)	6.94	1.12-42.93	.037
Circumstances of the attack						
Accidental	570 (28.4)	458 (29.5)	112 (24.5)	1		
Provoked	165 (8.2)	151 (9.7)	14 (3.1)	.38	.21-.68	.001
No apparent cause	337 (16.8)	231 (14.9)	106 (23.1)	1.88	1.38-2.56	.000
No data	937 (46.6)	711 (45.8)	226 (49.3)	1.30	1.01-1.68	.044
First aid						
Alcohol	74 (3.7)	58 (3.7)	16 (3.5)	1		
Washing with soap and water	1447 (72.0)	1113 (71.8)	334 (72.9)	1.09	.62-1.92	.771
Povidone-iodine	103 (5.1)	76 (4.9)	27 (5.9)	1.29	.64-2.61	.483
None	344 (17.1)	274 (17.7)	70 (15.3)	.93	.50-1.71	.806
Other	41 (2.0)	30 (1.9)	11 (2.4)	1.33	.55-3.22	.529
Time elapsed between the attack and care						
Same day	1155 (57.5)	906 (58.4)	249 (54.4)	1		
1-5 days	750 (37.3)	579 (37.3)	171 (37.3)	1.07	.86-1.34	.523
More than 6 days	60 (3.0)	42 (2.7)	18 (3.9)	1.56	.88-2.76	.126
No data	44 (2.2)	24 (1.5)	20 (4.4)	3.03	1.65-5.58	.000

Table 4 Characteristics of post-exposure prophylaxis

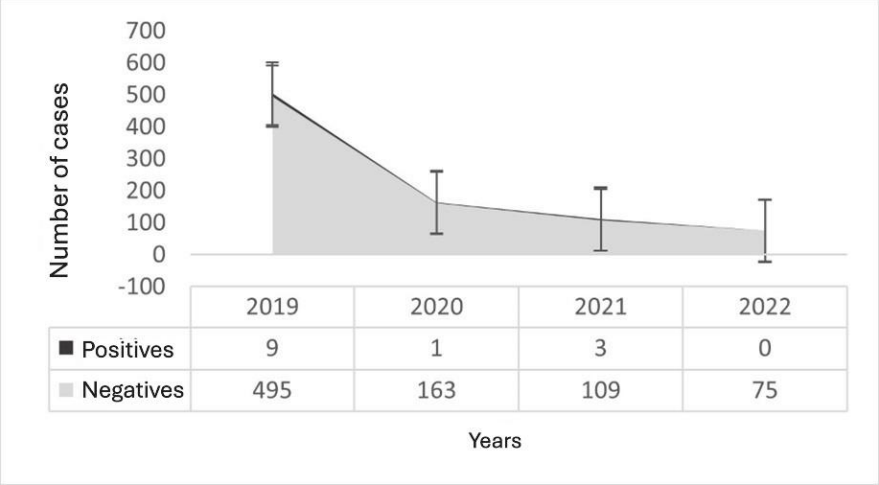
Variable	N (%)	Condition of the animal						
		Known		Unknown		OR	IC 95 %	P-value
		n	(%)	n	(%)			
Post-exposure prophylaxis (PEP)								
No	787 (39.2)	770	(49.6)	17	(3.7)	1		
Yes	1180 (58.7)	757	(48.8)	423	(92.4)	25.30	15.43-41.52	.000
No data	42 (2.1)	24	(1.5)	18	(3.9)	33.97	15.61-73.92	.000
Total	**2009 (100)**	**1551**	**(77.2)**	**458**	**(22.2)**	-	-	-
Completion of PEP regimen								
No	203 (38.0)	147	(39.6)	56	(34.4)	1		
Yes	295 (55.2)	201	(54.2)	94	(57.7)	1.23	.83-1.82	.307
Referred	36 (6.7)	23	(6.2)	13	(8.0)	1.48	.70-3.13	.300
Total	**534 (100)**	**371**	**(100)**	**163**	**(100)**	-	-	-
Received anti-rabies serum								
No	139 (36.5)	113	(35.2)	26	(43.3)	1		
Yes	242 (63.5)	208	(64.8)	34	(56.7)	.71	.41-1.24	.231
Total	**381 (100)**	**321**	**(100)**	**60**	**(100)**	-	-	-

Of the available data on PEP regimen follow-up in attacked individuals, only 55.2 % (n=295) completed their prophylactic regimen. Among the 381 patients who were advised to visit a tertiary-level health center to receive anti-rabies serum, 63.5 % (n=242) received it. No statistically significant difference was observed in the likelihood of being discharged, completing the vaccination schedule, or receiving anti-rabies serum between patients attacked by an unknown dog (Table 4).

Table 5 Characteristics of the attacking dog

Variable	N= 2009 (%)	Condition of the animal		OR	IC 95 %	P-value
		Known n= 1551 (77.2 %)	unknown n=458 (22.8 %)			
Race						
Characteristics of a specific race	270 (13.4)	245 (15.8)	25 (5.5)	1		
Mixed	781 (38.9)	626 (40.4)	155 (33.8)	2.43	1.55-3.80	.000
No data	958 (47.7)	680 (43.8)	278 (60.7)	4.01	2.59- 6.19	.000
Vaccination status of the attacking animal						
Not vaccinated	388 (19.3)	265 (17.1)	123 (26.9)	1		
Vaccinated	691 (34.4)	677 (43.6)	14 (3.1)	.04	.03-.08	.000
No data	930 (46.3)	609 (39.3)	321 (70.1)	1.14	.88-1.46	.325

Figure 2 Temporal distribution of suspected canine rabies cases in the city of Santa Cruz from 2019 to 2022



In Table 5, the characteristics of the attacking dogs are shown for the cases where information was available. Mixed-breed and vaccinated dogs were responsible for most bites (38.9 and 34.4 %, respectively). The likelihood that an unknown dog was mixed-breed was higher compared to purebred dogs (OR 2.43, 95 % CI: 1.15-3.80, p=.000), and the likelihood that an unknown dog was vaccinated was extremely low (OR 0.04, 95 % CI: 0.03-0.08, p=.000).

Risk factors associated with the occurrence of canine rabies (2019-2022). Suspected CR cases in Santa Cruz are analyzed using direct immunofluorescence (DIF) or polymerase chain reaction (PCR) and reported by the official laboratory UNALAB-SENASAG.

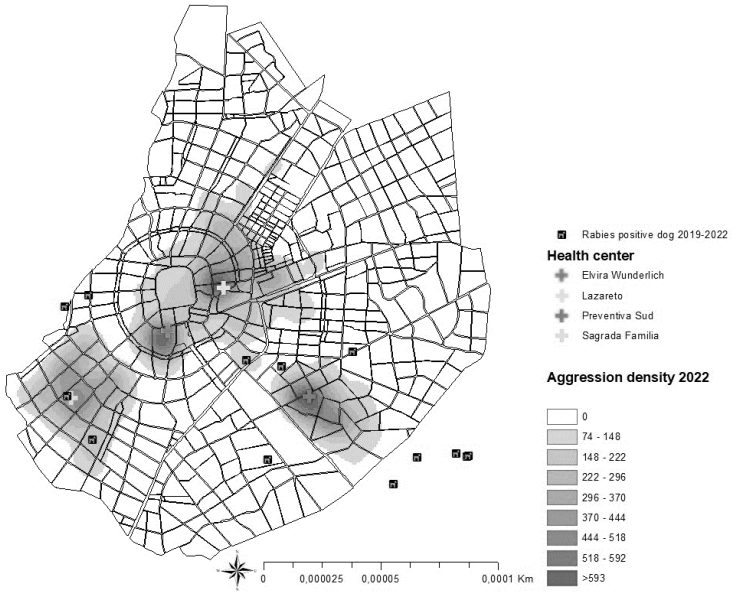
During the 2019-2022 period, the laboratory analyzed 876 suspected CR cases from the city of Santa Cruz. Twenty-one samples (2.4 %) were excluded because they were unsuitable for testing or in a state

of decay, and therefore no result could be obtained. Of the 855 samples evaluated, 1.5 % (n=13) tested positive. The largest proportion of analyzed cases (58.9 %, n=504) and positive cases (69.2 %, n=9) was recorded in 2019, with a progressive decrease noted in subsequent years (Figure 2).

Table 6 Characteristics of suspected canine rabies cases in the city of Santa Cruz from 2019 to 2022

Variable	N= 855 (%)	Result		OR	IC 95 %	P-value
		Positive n= 13 (1.5 %)	Negative n=842 (98.5 %)			
Sex						
Female	326 (38.1)	2 (15.4)	324 (38.5)	1		
Male	516 (60.4)	11 (84.6)	505 (60.0)	3.53	.78-16.02	.102
Unknown	13 (1.5)	0 (.0)	13 (1.5)	.00	-	-
Age						
0-1 year	354 (41.4)	6 (46.2)	348 (41.3)	1		
>1 years	477 (55.8)	7 (53.8)	470 (55.8)	.86	.29-2.59	.794
Unknown	24 (2.8)	0 (.0)	24 (2.9)	.00	-	-
Vaccination status						
Vaccinated	126 (14.7)	3 (23.1)	123 (14.6)	1		
Not vaccinated	589 (68.9)	8 (61.5)	581 (69.0)	.56	.15-2.16	.403
Unknown	140 (16.4)	2 (15.4)	138 (16.4)	1.05	.22-5.01	.572
Race						
Mixed	686 (80.2)	11 (84.6)	675 (80.2)	1		
Characteristics of a breed	168 (19.6)	2 (15.4)	166 (19.7)	.74	.17-3.37	.696
Unknown	1 (.1)	0 (.0)	1 (.1)	.00	-	-
Number of people bitten						
None	688 (80.5)	7 (53.8)	681 (80.9)	1		
1-6	159 (18.6)	6 (46.2)	153 (18.2)	3.82	1.26-11.51	.017
Unknown	8 (.9)	0 (.0)	8 (1.0)	.00	-	-

Figura 3 Densidad Kernel de agresiones de perros a personas de 4 centros de Salud y casos positivos a rabia canina



The proportion of rabies-positive dogs was higher among males (84.6 %, n=11), over 1 year old (53.8 %, n=7), unvaccinated (61.5 %, n=8), and mixed breed (84.6 %, n=11). There was no statistically significant difference in the likelihood of obtaining positive results according to the year of detection, sex, age, vaccination status, or breed of the dogs (Table 6).

Most of the suspected rabid dogs (80.5 %, n=688) were not reported to have bitten any person, and there was a statistically significant lower probability that a positive dog would not bite anyone (OR 0.26, 95 % CI: 0.09–0.79, p=.017) (Table 6).

Spatial distribution of CR cases and dog attacks. A total of 2009 dog bite cases treated in 2022 at the four health centers included in the study were geolocated. Through a Kernel density analysis (Figure 3), four hotspots were identified, coinciding with the locations of the health centers: the first in UV 20 and 21 (DM 2), corresponding to Lazareto Health Center; the second in UV 27 (DM 4), where Elvira Wunderlich Health Center is located; the third encompassing UV 148 and 160 (DM 8), the location of the Preventiva Sud Health Center; and the last hotspot in UV 126 (DM 10), corresponding to Sagrada Familia Health Center.

Figure 3 shows the location of the 13 positive CR cases reported between 2019 and 2022. No positive cases were recorded within the area bounded by the 4th ring road. Most cases were concentrated in peripheral areas, especially in the eastern part of the city of Santa Cruz, which reported 9 positive cases (DM 7 and 8).

Discussion

The findings of this research confirm that dog bites remain the main type of aggression by domestic animals in urban settings, consistent with studies conducted in Peru[21] and Mexico[22], which reported a predominance of canine attacks over other species. Similarly, in 2017, Aguirre-Revollo[23] analyzed cases reported at the Northern University Health Center in the city of Santa Cruz, revealing a predominance of dog attacks.

The predominance of cases in males aligns with the findings of other authors[15,24,25]. However, the discovery of a higher number of attacks among adults (20-64 years old) contrasts with studies indicating a higher risk among children[23,26]. Our results suggest a more significant impact on the 20-64 age group, which could be attributed to this age range representing a larger proportion of the population in the department of Santa Cruz[18]. Nonetheless, when grouping all those attacked who are under 18 years old, they also represent a considerable population segment. This pattern suggests that sociocultural factors, such as household dynamics and the presence of dogs in the family setting[21], as well as vulnerability, physical condition, and children's size[22,25], may influence the age distribution of attacks.

The predominance of known dogs as aggressors is consistent with what has been observed in research conducted in various endemic regions, where owned dogs[21,27], often with roaming habits, can be significant rabies vectors. This point is reinforced by authors like Mshelbwala et al.[16], who found that responsible pet ownership and careful monitoring of dog vaccination status significantly reduce human rabies cases following an attack. However, our study also establishes that unknown or stray dogs increase the probability of exposure, a finding that underscores

the importance of dog identification programs and control of stray populations to reduce rabies transmission.

Regarding the educational level, we noted a higher proportion of adults who had finished school. This is important because a lack of education and awareness often leads to neglect in seeking care after an injury[24]. In this study, most attacks occurred on the lower limbs[2,23], which can be somewhat advantageous if the wound is isolated, as it allows the animal to be observed if it is known, serving as a prophylactic measure to better determine the timing of the vaccination schedule[26]. On the other hand, the age of the victim influences the anatomical location of the injury, since children are more likely to sustain bites to the head and neck compared to adults[1,27].

Concerning the circumstances of attacks, the present study found that most bites occurred due to accidental causes, but there is a higher probability of being attacked for no apparent reason when the dog is unknown. This is because certain situations are likely to provoke aggressive behavior in dogs, such as territoriality, protection, guarding, or fear triggered by sudden noises[24], which may be deemed "no apparent cause" or "accidental" by the victim, even though it might actually be provoked.

In terms of prophylaxis and treatment, we identified a significant percentage of patients who did not complete the anti-rabies vaccination schedule or did not receive anti-rabies serum when indicated. This finding is consistent with reports by Talavera et al.[21] in Peru, where accessibility issues, lack of knowledge, or underestimation of risk impede the completion of prophylaxis. This suggests a need to strengthen community education about the importance of completing the vaccination schedule and seeking timely healthcare services.

In addition to PEP, psychotherapy can be essential, when warranted, to substantially reduce potential adverse effects on the health of patients who have suffered dog bites[28].

The number of CR cases significantly decreased in the city of Santa Cruz over the four years studied, unlike the results reported by Pessoa Villarroel[29], where the proportion of positive cases was 15 % (40/272) in 2014, 12 % (11/95) in 2015, 23 % (26/113) in 2016, and peaked at 48 % (558/1170) in 2017. Calizaya Robles[30] studied rabies cases reported in 2018, finding that 9.5 % (86/907) of all suspected cases were positive.

The decrease in CR-positive cases is the result of the combined efforts of the public medical and veterinary health system, which improved vaccination campaigns with cell-culture vaccines, raised awareness of the significance of CR, and encouraged seeking medical attention in case of exposure[24]. It may also have been influenced by the pandemic starting in 2020, during which most of the population remained confined to their homes, reducing the likelihood of exposure for both people and their pets.

The Kernel density analysis of attacks shows that most cases clustered around each health center, which may be explained by the large proportion of known dogs as the source of attacks, as well as people generally visiting the nearest health center for treatment. The positive CR cases were concentrated in the peri-urban areas of the city, especially in the

eastern zone of Santa Cruz (DM 7 and 8). This coincides with the findings of Calizaya Robles[30], who identified hotspots that included DM 7, 8, and 14, as well as those of Pessoa Villarroel[29], who noted a hotspot in DM 8. This finding helps identify critical areas where targeted strategies, such as mass vaccination campaigns and educational programs for vulnerable communities, can be implemented. Additionally, the absence of positive cases within the area bounded by the 4th ring road supports the hypothesis that central urban areas have better health-control levels, possibly due to the higher density of services. Among the limitations, it is important to highlight the reliance on clinical records and potential underreporting of bites that go unreported. Furthermore, not including all health centers in the city and lacking precise data on the vaccination status of many dogs could have biased the real incidence of bites and the risk assessment for rabies. The absence of post-vaccination follow-up data for patients also limited the ability to fully assess the impact of prophylactic interventions.

These findings underscore the need to strengthen epidemiological surveillance, improve reporting systems, and promote public education on the importance of completing anti-rabies prophylaxis. Future research should incorporate longitudinal analyses and involve a wider range of health centers to bolster data representativeness, as well as delve into the socioeconomic profile of families who own dogs. Overall, this study confirms the persistence of CR as an endemic problem in Santa Cruz de la Sierra and emphasizes the urgency of comprehensive public and veterinary health strategies that bolster vaccination campaigns and community awareness.

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Conflicts of interest

The authors declare no conflicts of interest.

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Authors' contribution to the article

Gladys Carolina Herbas Pérez, project conceptualization and execution, drafting, and preparation of the original manuscript. *Alvaro Guibarra Urquieta*, project conceptualization and execution. *Nestor Gomez Salvatierra*, project conceptualization and execution. *Saúl Jhonny Ruiz Justiniano*, project conceptualization and execution. *Ariel Jhonny Loza Vega*, project execution, supervision, and final review of the document.

Limitations in the research

The authors note that there were no limitations in the present research work.

Access to data

The data and information from this research are present in the article.

Permissions for publication

Not applicable

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