



Ticks (Acari: Ixodoidea) associated with mammals in Colombia: a historical review, molecular species confirmation, and establishment of new relationships

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Abstract

Ticks are considered the second most important vectors of pathogens worldwide, after mosquitoes. This study provides a systematic review of vector-host relationships between ticks and mammals (domestic and wild) and consolidates information from studies conducted in Colombia between 1911 and 2020. Using the PRISMA method, 71 scientific articles containing records for 51 tick species (Argasidae and Ixodidae) associated with mammals are reported. The existing information on tick-mammal associations in Colombia is scarce, fragmented, or very old. Moreover, 213 specimens were assessed based on morphological and molecular analyses, which allowed confirming eight tick species associated with mammals: *Amblyomma calcaratum*, *Amblyomma dissimile*, *Amblyomma mixtum*, *Amblyomma nodosum*, *Amblyomma ovale*, *Amblyomma varium*, *Ixodes luciae*, and *Ixodes tropicalis*. Several tick species are molecularly confirmed for Colombia and nine new relationships between ticks and mammals are reported. This research compiles and confirms important records of tick-mammal associations in Colombia.

Keywords Argasidae · Ixodidae · Mammalia · Pathogens · Vectors

Introduction

Ticks are considered the second most important vectors of pathogens, after mosquitoes (Anderson 2002; Anderson and Magnarelli 2008; de la Fuente et al. 2008; Cortés-Vecino

2018). Tick fauna currently comprises approximately 955 species belonging to three families, namely, Ixodidae (736 species), Argasidae (218 species), and Nuttalliellidae (1 species) (Dantas-Torres et al. 2019). Local tick diversity is attributed to the variety of thermal floors and plant diversity, which facilitate plasticity in these arachnids for colonizing diverse habitats (Guglielmone et al. 2003a, 2010; Estrada-Peña 2008). Approximately one-fourth of known tick species are found in the Neotropical region and nearly 70–80% of their hosts are mammals (Nava et al. 2008, 2017; Hornok et al. 2016; Labruna et al. 2016). The family Ixodidae includes species of medical and veterinary importance since these transmit a variety of bacteria (e.g., *Coxiella*, *Borrelia*, *Ehrlichia*, *Rickettsia*), protozoa (e.g., *Theileria*), and viruses (e.g., Crimean-Congo hemorrhagic fever virus) (Sonenshine 2018; Cabezas-Cruz et al. 2019; Rizzoli et al. 2019). Accordingly, mammals are epidemiologically important in pathogen-vector-host interactions due mainly to their habitats, areas of occupation, physiology, and body size (Monsalve et al. 2009; Heine et al. 2017). Several small- and medium-sized mammals are potential reservoirs of tick-borne pathogens; however, it is uncertain if they have a direct role as vectors in the transmission of infectious agents (Larson et al. 2018; Mlera and Bloom 2018).

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In Colombia, there are records on the occurrence of 58 tick species. According to the last review on Neotropical ticks (Guglielmone et al. 2003a), concerning 15 species of Argasidae and 37 species of Ixodidae, *Ixodes fuscipes* was excluded from the list of valid species for Colombia based on findings by Labruna et al. (2020). In addition, four species were reported for the country: *Amblyomma parvum* Aragão, 1908 (López and Parra 1985; confirmed by Nava et al. 2017), *Ixodes affinis* Neumann, 1889 (Mattar and López-Valencia 1998), *Ixodes auritulus* Neumann, 1904 (González-Acuña et al. 2005), and *Dermacentor imitans* Warburton, 1933 (Guglielmone et al. 2006). Nava et al. (2014) reevaluated the taxonomic status of *A. cajennense* and concluded that this taxon actually comprised six valid species, among which *A. cajennense* sensu stricto was not found in Colombia in the samples examined, and only *Amblyomma patinoi* Labruna, Nava, and Beati, 2014, and *Amblyomma mixtum* Koch, 1844, were confirmed for the country (Nava et al. 2014; Rivera-Páez et al. 2016). Apanaskevich and Bermúdez (2017) reported *Ixodes bocatorensis* Apanaskevich and Bermúdez 2017, in Colombia and, according to Bermúdez et al. (2015), the occurrence of *I. brunneus* needs to be confirmed.

In Colombia, many tick species are associated with small- and medium-sized wild and domestic mammals; however, several of these records raise uncertainty (Cortés-Vecino et al. 2010; Miranda et al. 2011; Faccini-Martínez et al. 2017; Acevedo-Gutiérrez et al. 2020). Despite the epidemiological importance and role of ticks in the transmission and circulation of infectious diseases, in Colombia, the literature records on ectoparasites associated with wild mammals are scarce and fragmented (Torres-Mejía and de la Fuente 2006; Londoño et al. 2017; Rivera-Páez et al. 2018; Acevedo-Gutiérrez et al. 2020). Given this, a comprehension of the dynamics of zoonosis (i.e., causes, factors, and mammals involved) is relevant to any country and contributes to understanding emerging and re-emerging tick-borne diseases (Betancur et al. 2015). Thus, this study provides an exhaustive review of tick-mammal relationships reported in specialized literature, as well as new reports of this type of relationship in Colombia to consolidate the information on ticks associated with mammals in the country.

Materials and methods

Systematic review

To gather the information on ticks associated with mammals in Colombia and provide new records, we reviewed the information available in the literature retrieved from Science Direct, Web of Science, SciELO Scopus, and Google Scholar search engines using the keywords ((Colombia*)

AND (Tick*) AND (Ixodidae*) OR (Argasidae*)), without temporal restrictions ($n = 2940$) (1911—August of 2020). A total of 71 documents were compiled and selected, following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method (Moher et al. 2009, 2012; Urrútia and Bonfill 2010). The information was complemented with suggested references on ectoparasites of mammals of Colombia (Gonzalez-Astudillo et al. 2016). Updated lists of mammals in Colombia were used to update mammal names and synonymies (Solari et al. 2013; Ramírez-Chaves et al. 2016, 2018). Tick taxonomy was determined according to Dantas-Torres et al. (2019).

Tick identification and new records

A morphological analysis was performed on 213 ticks collected during samplings conducted in the departments of Antioquia, Caldas, and Cundinamarca (Colombia) between 2015 and 2018. The ticks were identified to the species level following the dichotomous keys of Robinson (1926), Aragão and Fonseca (1961), Jones et al. (1972), Barros-Battesti et al. (2006), Melhorn (2008), Nava et al. (2014, 2017), and Dantas-Torres et al. (2019), using a light microscope. Furthermore, a molecular analysis was performed to confirm the morphological identifications of the tick species. Twenty-two samples were analyzed, which included at least one individual from each morphotype per host and collection site. DNA was isolated using the DNeasy Blood and Tissue kit (Qiagen), according to the manufacturer's protocol. PCR amplification of fragments from two mitochondrial genes, namely, the 5' region of the cytochrome oxidase I (COI) gene with primers LCO1490 (F) 5'-GGTCAACAATCATAAAGATATTGG-3' and HCO2198 (R) 5'-TAAACTTCAGGGTGACCAA AAATCA-3' (Folmer et al. 1994), and the 16S rDNA gene using primers F 5'-CTGCTCAATGATTTTTTAAATTGCTGTGG-3' and R 5'-CCGGTCTGAACTCA GATCAAGT-3' (Norris et al. 1996), was performed. The amplicons were purified and sent to Macrogen (Geumcheon-gu, Seoul, South Korea) for Sanger sequencing. The sequences were assessed and edited using Geneious Trial v8.14 (Drummond et al. 2009). Furthermore, the sequences were searched against public databases, including GenBank and BOLD (Barcode of Life Data Systems, www.barcodinglife.com), using BLAST.

Results

In this review, 51 tick species are reported in association with mammals in Colombia (also includes records of *Amblyomma cajennense* s.l.). The ticks belong to the families Ixodidae (39 species) and Argasidae (12 species). Among these, 25 ectoparasite species (16 ixodids and 9 argasids) are reported

Table 1 Literature reports of relationships between ticks and mammals in Colombia

Tick species	Wild host (reference)	Domestic/exotic/human host (reference)
Family: Ixodidae		
<i>Amblyomma auricularium</i> (Conil, 1878)	<i>Dasypus pastasae</i> (Wells et al. 1981) <i>Dasypus novemcinctus</i> (Osorno-Mesa 1940; Guglielmone et al. 2003b) <i>Dasypus sabanicola</i> (CIAT 1973; Wells et al. 1981) <i>Myrmecophaga tridactyla</i> (Armed Forces Pest Management Board 1998) <i>Sigmodon alstoni</i> (CIAT 1973; Wells et al. 1981)	N.A.
<i>Amblyomma cajennense</i> s.l. (Fabricius, 1787)*	<i>Cuniculus paca</i> (Armed Forces Pest Management Board 1998) <i>Dasypus novemcinctus</i> (Muñoz-Rivas 1973) <i>Dasypus sabanicola</i> (Muñoz-Rivas 1973) <i>Didelphis marsupialis</i> (Wells et al. 1981) <i>Hydrochoerus hydrochaeris</i> (Wells et al. 1981; Miranda et al. 2011; Miranda and Mattar 2014) <i>Marmosa robinsoni</i> (Armed Forces Pest Management Board 1998) <i>Metachirus nudicaudatus</i> (Wells et al. 1981) <i>Myrmecophaga tridactyla</i> (Wells et al. 1981) <i>Nasua nasua</i> (Osorno-Mesa 1940) <i>Odocoileus cariacou</i> (Wells et al. 1981) <i>Tamandua tetradactyla</i> (Wells et al. 1981)	<i>Bos</i> sp. (Londoño et al. 2017) <i>Bos indicus</i> (Armed Forces Pest Management Board 1998; Jaimes-Dueñez et al. 2018) <i>Bos taurus</i> (Dunn 1929; Corrier et al. 1978; Rivera and Aycardi 1985; Labruna et al. 2011; Faccini-Martínez et al. 2017; Benavides-Montaño et al. 2018; Jaimes-Dueñez et al. 2018) <i>Bubalus bubalis</i> (López and Parra 1985; Jaimes-Dueñez et al. 2018) <i>Canis familiaris</i> (Osorno-Mesa 1940; López 1980; Faccini-Martínez et al. 2016; Faccini-Martínez et al. 2017; Londoño et al. 2017) <i>Equus</i> sp. (López 1980; López and Parra 1985; Londoño et al. 2017) <i>Equus asinus</i> (Dunn 1929) <i>Equus caballus</i> (Dunn 1929; Reyes 1938; Osorno-Mesa 1940; Faccini-Martínez et al. 2016; Faccini-Martínez et al. 2017; Benavides-Montaño et al. 2018; Santodomingo et al. 2019) <i>Equus mulus</i> (Dunn 1929; Benavides-Montaño et al. 2018) <i>Felis catus</i> (Osorno-Mesa 1940) <i>Homo sapiens</i> (Reyes 1938; Osorno-Mesa 1940; Guglielmone et al. 2006; Faccini-Martínez et al. 2016; Quintero et al. 2017) <i>Sus domesticus</i> (Dunn 1929; Osorno-Mesa 1940; Londoño et al. 2017)
<i>Amblyomma calcaratum</i> Neumann, 1899	<i>Tamandua</i> sp. (Wenzel and Tipton 1966; Fairchild et al. 1966) <i>Tamandua tetradactyla</i> (Osorno-Mesa 1940)	<i>Canis familiaris</i> (Reyes 1938)
<i>Amblyomma coelebs</i> Neumann, 1899	<i>Myrmecophaga tridactyla</i> (Jones et al. 1972) <i>Hydrochoerus hydrochaeris</i> (López-Valencia 2017)	<i>Bos</i> sp. (López and Parra 1985)
<i>Amblyomma dissimile</i> Koch, 1844	N.A.	<i>Bos taurus</i> (Rivera-Páez et al. 2018; Cotes-Perdomo et al. 2020) <i>Homo sapiens</i> (Reyes 1938; Guglielmone et al. 2006; Quintero et al. 2017)
<i>Amblyomma geayi</i> Neumann, 1899	<i>Bradypus variegatus</i> (Neumann 1911) <i>Caluromys</i> sp. (Armed Forces Pest Management Board 1998) <i>Coendou</i> sp. (CIAT 1973) <i>Choloepus didactylus</i> (Keirans and Brewster 1981)	N.A.
<i>Amblyomma longirostre</i> (Koch, 1844)	<i>Coendou</i> sp. (Osorno-Mesa 1940; CIAT 1973; Wells et al. 1981)	N.A.
<i>Amblyomma maculatum</i> Koch, 1844	<i>Cerdocyon thous</i> (CIAT 1973; Wells et al. 1981) <i>Hydrochoerus hydrochaeris</i> (Wells et al. 1981)	<i>Bos taurus</i> (Robinson 1926) <i>Canis familiaris</i> (Reyes 1938; Acero et al. 2011; Rivera-Páez et al. 2017, 2018) <i>Equus caballus</i> (Reyes 1938; Osorno-Mesa 1940; Benavides-Montaño et al. 2018)
<i>Amblyomma mixtum</i> Koch, 1844	<i>Hydrochoerus hydrochaeris</i> (Rivera-Páez et al. 2016)	<i>Bos taurus</i> (Rivera-Páez et al. 2018; Cotes-Perdomo et al. 2020; Ospina-Pérez et al. 2020) <i>Equus asinus</i> (Rivera-Páez et al. 2018) <i>Equus caballus</i> (Rivera-Páez et al. 2018; Cotes-Perdomo et al. 2020; Ospina-Pérez et al. 2020)

Table 1 (continued)

Tick species	Wild host (reference)	Domestic/exotic/human host (reference)
		<i>Equus mulus</i> (Cotes-Perdomo et al. 2020) <i>Canis familiaris</i> (Cotes-Perdomo et al. 2020) <i>Homo sapiens</i> (Guglielmone and Robbins 2018)
<i>Amblyomma multipunctum</i> Neumann, 1899	<i>Tapirus pinchaque</i> (Kohls 1956; Voltzit 2007)	N.A.
<i>Amblyomma naponense</i> (Packard, 1869)	<i>Didelphis marsupialis</i> (Fairchild et al. 1966; Armed Forces Pest Management Board 1998) <i>Heteromys australis</i> (Fairchild et al. 1966; Armed Forces Pest Management Board, 1998) <i>Marmosa robinsoni</i> (Fairchild et al. 1966) <i>Melanomys caliginosus</i> (Fairchild et al. 1966) <i>Myrmecophaga tridactyla</i> (Armed Forces Pest Management Board 1998) <i>Pecari tajacu</i> (Fairchild et al. 1966; Wenzel and Tipton 1966; Armed Forces Pest Management Board 1998)	<i>Rattus rattus</i> (Fairchild et al. 1966)
<i>Amblyomma neumanni</i> Ribaga, 1902	<i>Hydrochoerus hydrochaeris</i> (López-Valencia 2017)	<i>Equus</i> sp. (López and Parra 1985)
<i>Amblyomma nodosum</i> Neumann, 1899	<i>Tamandua tetradactyla</i> (Osorno-Mesa 1940; Luque 1948; López and Parra 1985; Benavides-Montaña et al. 2018)	N.A.
<i>Amblyomma oblongoguttatum</i> Koch, 1844	<i>Dasyprocta fuliginosa</i> (Armed Forces Pest Management Board 1998) <i>Tayassu pecari</i> (Armed Forces Pest Management Board 1998)	<i>Homo sapiens</i> (Luque 1949)
<i>Amblyomma ovale</i> Koch, 1844	<i>Didelphis marsupialis</i> (Londoño et al. 2014) Didelphidae (López and Parra 1985) <i>Eira barbara</i> (Armed Forces Pest Management Board 1998) <i>Lontra longicaudis</i> (López 1980; López and Parra 1985) <i>Nasua nasua</i> (Armed Forces Pest Management Board 1998) <i>Proechimys semispinosus</i> (Londoño et al. 2014) <i>Transandinomys talamancae</i> (Londoño et al. 2014)	<i>Canis familiaris</i> (López 1980; López and Parra 1985; Paternina-Tuirán et al. 2009; Londoño et al. 2014, 2017; Faccini-Martínez et al. 2017; Quintero et al. 2017; Rivera-Páez et al. 2017, 2018) <i>Bos</i> sp. (Armed Forces Pest Management Board 1998) <i>Equus</i> sp. (Londoño et al. 2017) <i>Equus asinus</i> (Londoño et al. 2014) <i>Homo sapiens</i> (Quintero et al. 2017)
<i>Amblyomma pacae</i> Aragao, 1911	<i>Cuniculus paca</i> (Osorno-Mesa 1940; Wells et al. 1981; Keirans and Brewster 1981)	N.A.
<i>Amblyomma parvum</i> Aragao, 1908	<i>Dasypros sabanicola</i> (Armed Forces Pest Management Board 1998)	<i>Canis familiaris</i> (López and Parra 1985) <i>Equus caballus</i> (Santodomingo et al. 2019)
<i>Amblyomma patinoi</i> Labruna, Nava and Beati, 2014	N.A.	<i>Bos taurus</i> (Nava et al. 2014; Faccini-Martínez et al. 2015) <i>Equus caballus</i> (Nava et al. 2014) <i>Homo sapiens</i> (Quintero et al. 2020)
<i>Amblyomma rotundatum</i> Koch, 1844	<i>Hydrochoerus hydrochaeris</i> (Wells et al. 1981)	N.A.
<i>Amblyomma sabanerae</i> Stoll, 1894	N.A.	<i>Homo sapiens</i> (Quintero et al. 2020)
<i>Amblyomma sculpturatum</i> Neumann, 1906	<i>Tapirus</i> sp. (Jones et al. 1972) <i>Tapirus terrestres</i> (Labruna et al. 2005)	<i>Sus domesticus</i> (Labruna et al. 2005)
<i>Amblyomma tapirellum</i> Dunn, 1933	<i>Alouatta palliata</i> (Armed Forces Pest Management Board 1998) <i>Pecari tajacu</i> (Armed Forces Pest Management Board 1998)	N.A.
<i>Amblyomma triste</i> Koch, 1844	Cervidae (Armed Forces Pest Management Board 1998)	<i>Bos taurus</i> (Corrier et al. 1978) <i>Canis familiaris</i> (Armed Forces Pest Management Board 1998)
<i>Amblyomma varium</i> Koch, 1844	<i>Bradypus variegatus</i> (Robinson 1926; Osorno-Mesa 1940; Armed Forces Pest Management Board 1998) <i>Choloepus didactylus</i> (Torres-Mejía and de la Fuente 2006)	<i>Canis familiaris</i> (Rivera-Páez et al. 2018)

Table 1 (continued)

Tick species	Wild host (reference)	Domestic/exotic/human host (reference)
	<i>Choloepus hoffmanni</i> (Torres-Mejía and de la Fuente 2006)	
<i>Dermacentor imitans</i> Warburton, 1933	N.A.	<i>Homo sapiens</i> (Guglielmo et al. 2006)
<i>Dermacentor nitens</i> Neumann, 1897	Cervidae (Osorno-Mesa 1940)	<i>Bos</i> sp. (López et al. 1975; López 1980; López and Parra 1985) <i>Bos taurus</i> (Reyes 1938; Rivera and Aycardi 1985; Rivera-Páez et al. 2018; Benavides-Montaño et al. 2018; Jaimes-Dueñez et al. 2018) <i>Bos indicus</i> (Benavides-Montaño et al. 2018; Jaimes-Dueñez et al. 2018) <i>Bubalus bubalis</i> (Jaimes-Dueñez et al. 2018) <i>Equus</i> sp. (López 1980; López and Parra 1985; Mattar and López-Valencia 1998; Londoño et al. 2017) <i>Equus asinus</i> (Osorno-Mesa 1940; Rivera-Páez et al. 2018) <i>Equus caballus</i> (Dunn 1929; Osorno-Mesa 1940; Miranda and Mattar 2015; Faccini-Martínez et al. 2016, 2017; Benavides-Montaño et al. 2018; Rivera-Páez et al. 2018; Santodomingo et al. 2019; Cotes-Perdomo et al. 2020) <i>Equus mulus</i> (Benavides-Montaño et al. 2018) <i>Homo sapiens</i> (Osorno-Mesa 1940; Guglielmo et al. 2006; Quintero et al. 2017; Quintero et al. 2020;) <i>Vicugna pacos</i> (López and Parra 1985) <i>Sus domesticus</i> (Rivera-Páez et al. 2018)
<i>Haemaphysalis juxtakochi</i> Cooley, 1946	<i>Mazama americana</i> (Kohls 1960) <i>Tapirus</i> sp. (Kohls 1960)	N.A.
<i>Haemaphysalis leporispalustris</i> (Packard, 1869)	<i>Sylvilagus</i> sp. (Osorno-Mesa 1940) <i>Metachirus nudicaudatus</i> (Kohl, 1960; Guglielmo et al. 2011)	<i>Homo sapiens</i> (Osorno-Mesa 1940)
<i>Ixodes affinis</i> Neumann, 1899	N.A.	<i>Canis familiaris</i> (Mattar and López-Valencia 1998) <i>Equus</i> sp. (Mattar and López-Valencia 1998)
<i>Ixodes bocatorensis</i> Apanaskevich and Bermúdez 2017	<i>Cuniculus paca</i> (Apanaskevich and Bermúdez 2017)	N.A.
<i>Ixodes boliviensis</i> Neumann, 1904	<i>Didelphis marsupialis</i> (Osorno-Mesa 1940) <i>Tremarctos ornatus</i> (Armed Forces Pest Management Board 1998)	<i>Canis familiaris</i> (López-Valencia 2017)
<i>Ixodes lasallei</i> Méndez Arocha and Ortiz, 1958	<i>Dasyprocta fuliginosa</i> (Apanaskevich and Bermúdez 2017)	N.A.
<i>Ixodes luciae</i> Sévenet, 1940	<i>Dasyprocta punctata</i> (Armed Forces Pest Management Board 1998) <i>Didelphis</i> sp. (López 1980; López and Parra 1985) <i>Didelphis marsupialis</i> (CIAT 1973; Wells et al. 1981; Faccini-Martínez et al. 2017)	N.A.
<i>Ixodes montoyanus</i> Cooley 1944	<i>Pudu</i> sp. (Keirans 1973) <i>Nasua olivacea</i> (Cooley 1944; Keirans 1973)	N.A.
<i>Ixodes pararicinus</i> Keirans and Clifford, 1985	N.A.	<i>Bos</i> sp. (Mattar and López-Valencia 1998) <i>Equus</i> sp. (Mattar and López-Valencia 1998)
<i>Ixodes tapirus</i> Kohls 1956	<i>Tapirus pinchaque</i> (Kohls 1956; Wenzel and Tipton 1966; Apanaskevich et al. 2017)	N.A.
<i>Ixodes tropicalis</i> Kohls 1956	<i>Handleyomys fuscatus</i> (Trapido and Sanmartín 1971) <i>Hyleamys</i> sp. (Armed Forces Pest Management Board 1998) <i>Nephelomys pectoralis</i> (Trapido and Sanmartín 1971) <i>Thomasomys aureus</i> (Kohls 1956)	N.A.
<i>Ixodes venezuelensis</i> Kohls 1953	<i>Melanomys caliginosus</i> (Kohls 1953; Durden and Keirans 1994)	N.A.

Table 1 (continued)

Tick species	Wild host (reference)	Domestic/exotic/human host (reference)
<i>Rhipicephalus microplus</i> (Canestrini, 1888)	<i>Sigmodontomys alfari</i> (Kohls 1953; Durden and Keirans 1994)	
	<i>Hydrochoerus hydrochaeris</i> (Wells et al. 1981)	<i>Bos</i> sp. (Mattar and López-Valencia 1998; López et al. 1975; López 1980; López and Parra 1985; Cortés-Vecino et al. 2010; Araque et al. 2014; Ríos-Tobón et al. 2014; Londoño et al. 2017; Gómez et al. 2020)
	<i>Odocoileus cariacou</i> (Wells et al. 1981)	<i>Bos taurus</i> (Dunn 1929; Osorno-Mesa 1940; Corrier et al. 1978; Rivera and Aycardi 1985; Faccini-Martínez et al. 2016, 2017; Benavides-Montaño et al. 2018; Jaimes-Dueñez et al. 2018; Osorio et al. 2018; Rivera-Páez et al. 2018; Cotes-Perdomo et al. 2020)
		<i>Bos indicus</i> (Miranda and Mattar 2015; Benavides-Montaño et al. 2018)
		<i>Bubalus bubalis</i> (Jaimes-Dueñez et al. 2018)
		<i>Canis familiaris</i> (López 1980; Paternina et al. 2009; Acero et al. 2011; Jaimes-Dueñez et al. 2018; Osorio et al. 2018; Rivera-Páez et al. 2018)
		<i>Equus</i> sp. (López 1980; López and Parra 1985; Londoño et al. 2017)
		<i>E. asinus</i> (Rivera-Páez et al. 2018)
		<i>E. caballus</i> (Faccini-Martínez et al. 2016; Osorio et al. 2018; Santodomingo et al. 2019)
		Caprinae (López 1980)
	<i>Homo sapiens</i> (Guglielmone et al. 2006; Quintero et al. 2017; Quintero et al. 2020)	
<i>Rhipicephalus sanguineus</i> s.l. (Latreille, 1806)	<i>Cerdocyon thous</i> (Torres-Mejía and de la Fuente 2006)	<i>Canis familiaris</i> (Dunn 1929; Reyes 1938; Osorno-Mesa 1940; López 1980; López and Parra 1985; Paternina-Tuirán et al. 2009; Acero et al. 2011; Miranda and Mattar 2015; Faccini-Martínez et al. 2016, 2017; Londoño et al. 2017; Benavides-Montaño et al. 2018; Osorio et al. 2018; Rivera-Páez et al. 2018; Cotes-Perdomo et al. 2020; Ospina-Pérez et al. 2020)
		<i>Equus caballus</i> (Benavides-Montaño et al. 2018; Rivera-Páez et al. 2018)
		<i>Bos taurus</i> (Rivera-Páez et al. 2018)
		<i>Homo sapiens</i> (Quintero et al. 2017)
Family: Argasidae		
<i>Antricola mexicanus</i> Hoffmann, 1958	<i>Corollia perspicillata</i> (Armed Forces Pest Management Board 1998)	N.A.
	<i>Desmodus rotundus</i> (Armed Forces Pest Management Board 1998)	
	<i>Mormoops megalophylla</i> (Marinkelle and Grose 1981; Armed Forces Pest Management Board 1998)	
	<i>Pteronotus psilotis</i> (Marinkelle and Grose 1981)	
<i>Ornithodoros azteci</i> Matheson, 1935	<i>Pteronotus personatus</i> (Armed Forces Pest Management Board 1998)	
	<i>Carollia perspicillata</i> (Jones et al. 1972; Armed Forces Pest Management Board 1998)	N.A.
	<i>Desmodus rotundus</i> (Armed Forces Pest Management Board 1998)	
<i>Ornithodoros brodyi</i> Matheson, 1935	<i>Peropteryx macrotis</i> (Kohls et al. 1965; Marinkelle and Grose 1981)	
	<i>Carollia perspicillata</i> (Marinkelle and Grose 1981)	N.A.
<i>Ornithodoros hasei</i> (Schulze, 1935)	<i>Natalus tumidirostris</i> (Marinkelle and Grose 1981)	
	<i>Artibeus jamaicensis</i> (Marinkelle and Grose 1981)	N.A.
	<i>Lasiurus cinereus</i> (Marinkelle and Grose 1981)	
	<i>Molossus molossus</i> (Marinkelle and Grose 1981)	
	<i>Noctilio albiventris</i> (Marinkelle and Grose 1981)	

Table 1 (continued)

Tick species	Wild host (reference)	Domestic/exotic/human host (reference)
	<i>Noctilio leporinus</i> (Marinkelle and Grose 1981)	
	<i>Phyllostomus discolor</i> (Marinkelle and Grose 1981)	
	<i>Rhogeessa io</i> (Marinkelle and Grose 1981)	
	<i>Vampyriscus nymphaea</i> (Marinkelle and Grose 1981)	
<i>Ornithodoros marinkellei</i> Kohls, Clifford and Jones, 1969	<i>Pteronotus</i> sp. (Jones et al. 1972; Venzal et al. 2018)	N.A.
	<i>Pteronotus fuscus</i> (Kohls et al. 1969); Marinkelle and Grose 1981)	
	<i>Pteronotus gymnonotus</i> (Kohls et al. 1969)	
	<i>Pteronotus personatus</i> (Kohls et al. 1969; Marinkelle and Grose 1981)	
<i>Ornithodoros marmosae</i> Jones and Clifford, 1972	<i>Marmosa robinsoni</i> (Jones et al. 1972)	N.A.
<i>Ornithodoros peropteryx</i> Kohls, Clifford and Jones, 1969	<i>Pteropteryx macrotis</i> (Kohls et al. 1969)	N.A.
<i>Ornithodoros puertoricensis</i> Fox, 1947	N.A.	<i>Canis familiaris</i> (Patemina et al. 2009)
		<i>Mus musculus</i> (Londoño et al. 2017)
		<i>Rattus rattus</i> (Quintero et al. 2013; Londoño et al. 2017)
		<i>Rattus norvegicus</i> (Quintero et al. 2013)
		<i>Homo sapiens</i> (Quintero et al. 2020)
<i>Ornithodoros rossi</i> Kohls, Sonenshine and Clifford, 1965	Chiroptera (Jones et al. 1972)	N.A.
	<i>Desmodus rotundus</i> (Marinkelle and Grose 1981)	
	<i>Glossophaga longirostris</i> (Armed Forces Pest Management Board 1998)	
	<i>Micronycteris megalotis</i> (Marinkelle and Grose 1981)	
<i>Ornithodoros rudis</i> Karsch, 1880	<i>Hoplostomys gymnurus</i> (Armed Forces Pest Management Board 1998)	<i>Homo sapiens</i> (Dunn 1929; Osorno-Mesa 1940; Jones et al. 1972)
<i>Ornithodoros talaje</i> (Guerin-Meneville, 1849)	N.A.	<i>Rattus norvegicus</i> (Dunn 1929; Osorno-Mesa 1940)
<i>Ornithodoros yumatensis</i> Cooley and Kohls, 1941	<i>Peropteryx macrotis</i> (Marinkelle and Grose 1981)	N.A.
	<i>Saccopteryx bilineata</i> (Marinkelle and Grose 1981)	

*Registered as *Amblyomma cajennense* s.l. (Fabricius, 1787), as there is no record of the species *A. cajennense* sensu stricto

N.A. not associated

exclusively in at least 42 wild mammal species. In Colombia, 18 species of hard ticks (Ixodidae) interact with at least 10 domestic mammal species; two are associated with one hybrid (*Equus caballus* x *E. asinus*); three species are reported from three exotic-invasive species (*Mus musculus*, *Rattus rattus*, and *R. norvegicus*); 18 are associated with domestic and wild mammals; and one species (*Dermacentor imitans*) is reported exclusively from humans (Table 1).

A total of 213 tick specimens (133 adults, 43 nymphs, and 37 larvae) were collected from 19 host individuals belonging to six mammalian orders: one individual of *Didelphis marsupialis* and one *Monodelphis adusta* (Didelphimorphia), two *Tamandua mexicana* (Pilosa), three *Cerdocyon thous* (Carnivora), five *Equus caballus* (Perissodactyla), three *Homo sapiens* (Primates), and three *Heteromys anomalus* and one *Nectomys grandis* (Rodentia). All ticks were morphologically examined

and adults and nymphs were identified. In total, eight species were recorded: *Amblyomma calcaratum*, *Amblyomma dissimile*, *Amblyomma mixtum*, *Amblyomma nodosum*, *Amblyomma ovale*, *Amblyomma varium*, *Ixodes luciae*, and *Ixodes tropicalis*. Larvae were identified to the genus level. The hosts and collection localities for each tick species are shown in Table 2. After the morphological identification, molecular methods were used to confirm the identity of *A. calcaratum* (one female and one male), *A. dissimile* (three males), *A. mixtum* (one female and one male), *A. nodosum* (two females), *A. ovale* (one female and one male), *A. varium* (one female and two larvae), *I. luciae* (four females), and *I. tropicalis* (one female and three nymphs).

From the samples collected, nine new relationships between ticks and mammals in Colombia were established, including eight new relationships between hard ticks and wild mammals. Furthermore, the first record of *A. varium* parasitizing humans

Table 2 Morphological and molecular information with its corresponding mammal host

Tick species	Host	Locality	Tick Stages	Closest identity (%) in GenBank [accession number] according to the tick gene	
				16SrRNA	COI
<i>A. calcaratum</i> *	<i>Tamandua mexicana</i>	3	16 male, 3 female, 2 nymph	N. D.	<i>A. calcaratum</i> [KF200085] 99.84%
<i>A. dissimile</i>	<i>Homo sapiens</i>	4	3 male	<i>A. dissimile</i> [MF353128] 100%	<i>A. dissimile</i> [MF363072] 99.84%
<i>A. mixtum</i>	<i>Equus caballus</i>	3	22 male, 31 female, 3 nymph, 12 larvae	<i>A. mixtum</i> [MF363074] 100%	<i>A. mixtum</i> [MF363080] 100%
<i>A. nodosum</i> *	<i>Tamandua mexicana</i>	3	1 male, 12 female, 5 larvae	<i>A. nodosum</i> [KP686064] 97.83	N.D.
<i>A. ovale</i>	<i>Homo sapiens</i>	1	1 male	<i>A. ovale</i> [MN879559] 98.24%	N.D.
<i>A. ovale</i> *	<i>Cerdocyon thous</i>	5	3 male, 13 female, 4 nymph	<i>A. ovale</i> [MN879559] 98.24%	N.D.
<i>A. varium</i> *	<i>Cerdocyon thous</i>	1	8 male, 4 female, 13 nymph	<i>A. varium</i> [KX544818] 99.74%	N.D.
<i>A. varium</i> *	<i>Homo sapiens</i>	1	7 larvae	<i>A. varium</i> [KX544818] 100%	N.D.
<i>I. luciae</i>	<i>Didelphis marsupialis</i>	2	1 male, 3 female, 1 nymph, 1 larvae	<i>I. luciae</i> [MH513305] 97.4	N.D.
<i>I. luciae</i> *	<i>Nectomys grandis</i>	1	4 female, 1 nymph	<i>I. luciae</i> [MH513305] 97.2	N.D.
<i>I. tropicalis</i> *	<i>Cerdocyon thous</i>	6	2 male, 3 female, 8 nymph	<i>I. tropicalis</i> [MT158325] 98.1%	N.D.
<i>I. tropicalis</i> *	<i>Monodelphis adusta</i>	1	11 nymphs, 12 larvae	<i>I. tropicalis</i> [MT158325] 98.1%	N.D.
<i>I. tropicalis</i> *	<i>Heteromys anomalus</i>	1	3 female	<i>I. tropicalis</i> [MT158325] 98.1%	N.D.
Total			213 (57 male, 76 female, 43 nymph, 37 larvae)		

*New relationships are highlighted

N.D. not done

N.D.: not performed. Localities of Colombia: Department of Caldas: (1) Samaná (05° 30' 22" N; 75° 02' 21" W); (2) Manizales, Tres Puertas (05° 04' 26.19" N; 75° 40' 22.47" W); (3) Manizales, Km 41 (05° 05' 42.6" N; 75° 39' 05.6" W). Department of Antioquia: (4) La Felisa (05° 06' 54.85" N; 75° 39' 28.68" W); (5) Valparaíso, La Pintada, Antioquia (5° 35' 46.3" N; 75° 34' 53.5" W). Department of Cundinamarca: (6) Guaduas (05° 06' 56" N; 74° 35' 25" W)

is reported for Colombia. Records of *A. calcaratum* and *I. tropicalis* were molecularly confirmed, providing updated information for these species since previous reports were outdated (Table 2). The partial nucleotide sequences generated in this study were deposited in GenBank under accession numbers [MN879555 – MN879567] for the mitochondrial 16S rRNA gene, and [MT000155 – MT000161] for the COI gene. The voucher specimens were deposited in the Collection of Ectoparasites of the Museo de Historia Natural de la Universidad de Caldas (Ramírez-Chaves et al. 2019).

Discussion

The current information on tick-mammal associations for Colombia comprises records of 51 tick species associated with wild and domestic, exotic, human mammal hosts. This review

consolidated information on mammals in Colombia in the last century, concerning their association with ticks and changes in tick-mammal relationships throughout this period (Guglielmone et al. 2003a, 2006, 2014; Guglielmone and Robbins 2018; Nava et al. 2017). Species such as *Amblyomma incisum* Neumann, 1906; *Amblyomma pecarium* Dunn, 1933; *Amblyomma tigrinum* Koch, 1844; and *Ixodes loricatus* Neumann, 1899, as well as other tick species reported by López-Valencia (2017), are recorded in association with mammals in Colombia (Acevedo-Gutiérrez et al. 2020). The confirmation of these species would broaden the list of valid species in Colombia. However, Guglielmone et al. (2011) and Guglielmone and Robbins (2018) did not report these species in Colombia. In this study, these species were not considered since their records must be confirmed and they can be confused with other species.

The morphological confirmation and generation of new genetic sequences of ticks associated with mammals in Colombia allowed inferring the state of the knowledge on these interactions in the country compared with other countries in America (Nava et al. 2014; Rivera-Páez et al. 2018; Dantas-Torres et al. 2019). We highlight the need to review and support several vector-host relationships between ticks and mammals in Colombia (e.g., *Amblyomma geayi* with *Bradypus variegatus*; *Haemaphysalis leporispalustris* with *Homo sapiens*). Especially, there are several outdated records and morphological and molecular confirmations are needed for several species according to new studies in America (e.g., Labruna et al. 2020; Onofrio et al. 2020) that describe new tick species, synonymies, and reinstatement of species. In addition, new records of *Ixodes* species from Colombia, which yielded DNA sequences lacking high identity ($\leq 95\%$) to any species in GenBank (Martínez-Sánchez et al. 2020).

Moreover, several mammal species, such as *Dasyopus novemcinctus*, *D. marsupialis*, *Hydrochoerus hydrochaeris*, *Myrmecophaga tridactyla*, and *Tamandua tetradactyla*, are associated with a high species richness of ticks (14 species), which agrees with reports for other Neotropical countries (Muñoz-García et al. 2019; Nava et al. 2017). Furthermore, several associations were specific; for example, *Sigmodon alstoni* is exclusively associated with a single tick species (*Amblyomma auricularium*). These specific relationships were reported in other countries of the American continent (Wells et al. 1981; Lopes et al. 2016).

This study reports the first record for Colombia of *A. varium* from humans; particularly, this species rarely parasitizes humans and has only been confirmed in this association in Panama and Costa Rica (Guglielmone and Robbins 2018). Among 39 hard tick species associated with mammals in Colombia, according to Guglielmone and Robbins (2018), eight species are confirmed parasitizing humans: *A. dissimile*, *A. mixtum*, *A. oblongoguttatum*, *A. ovale*, *D. imitans*, *D. nitens*, *R. microplus*, and *R. sanguineus* s. l. Furthermore, Guglielmone and Robbins (2018) did not include *H. leporispalustris* in the list of species that parasitize humans in Colombia, although Osorno Mesa (1940) found a nymph of *Haemaphysalis proxima* Aragão on a human from Colombia, and this name is treated as a synonym of *H. leporispalustris* by Camicas et al. (1998) and others. However, this synonymy was not accepted by Guglielmone and Nava et al. (2014), who classified *H. proxima* as a *nomen dubium*. In this study, the record from Osorno-Mesa (1940) is included in Table 2. In addition to providing the first record of *A. varium* parasitizing humans in Colombia, this study also gathered records for *Amblyomma patinoi*, *Amblyomma sabanerae*, *Ornithodoros puertoricensis* (Quintero et al. 2020), and *Ornithodoros rudis* (Dunn 1929; Osorno-Mesa 1940; Jones et al. 1972) parasitizing humans in Colombia.

Overall, 14 out of 51 tick species associated with mammals were found parasitizing humans in the Colombian territory.

A large fraction of these tick species comprises endemic vectors of pathogens with global epidemiological impact in recent decades (Guglielmone et al. 2003a, 2006, 2014; Estrada-Peña 2008; Barros-Battesti et al. 2013; Nava et al. 2017; López-Valencia 2017; Dantas-Torres et al. 2019; Acevedo-Gutiérrez et al. 2020). On this basis, the study of tick-borne pathogens in Colombia requires greater sampling efforts since many tick species reported in Colombia are confirmed vectors of infectious pathogens of medical and veterinary importance (McCown et al. 2014; Osorio et al. 2018; Santodomingo et al. 2019). Research on this topic should include wildlife, exotic, and domestic mammals as a whole.

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Compliance with ethical standards

Conflict of interests The authors have no conflict of interest to declare.

Ethical approval This research was conducted with the approval of the Bioethics Committee of the Faculty of Exact and Natural Sciences – Universidad de Caldas (June 2nd of 2017) and under a framework permit granted to Universidad de Caldas by the *Autoridad Nacional de Licencias Ambientales (ANLA)* of Colombia (resolution 02497 of December 31 of 2018).

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