

Recollections

Assessment of Tick-Borne Diseases in Hainan Province, China

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ABSTRACT

China's six tropical regions include Guangdong Province, Yunnan Province, Hainan Province, Hong Kong Special Administrative Region (SAR), Macau SAR, and Taiwan, China. Hainan, seated in the southernmost tropical region of China, is home to ticks that remain active throughout all four seasons. This heightens their potential to transmit tick-borne diseases to both animals and humans. This study provides a succinct overview of the prevailing tick species' spatial distribution and offers an outline of the range and dispersion of emerging tick-borne infections in tick vectors, animal hosts, and human populations within Hainan, China.

INTRODUCTION

China encompasses six tropical regions, namely Guangdong Province, Yunnan Province, Hainan Province, Hong Kong Special Administrative Region (SAR), Macau SAR, and Taiwan, China. Of these, Hainan occupies the southernmost tropical region of China, notable for active vectors year-round which enhances their capacity to transmit vector-borne diseases (VBDs) to both animals and humans (1–2). Emerging and reemerging tick-borne diseases (TBDs) play a significant role in VBDs and present new health challenges to both humans and animals on this tropical island. The first recording of ticks on Hainan Island dates to 1981 with the documentation of a novel tick species, *Amblyomma hainanensis*, by the distinguished Chinese acarologist Kuofan Teng (commonly known as Guofan Deng in contemporary Chinese pronunciation) (3). Further, in 1985, the initial tick-borne pathogen (TBP), indicated by seropositivity to spotted fever group *Rickettsia* (SFGR), was identified in six of 402 healthy volunteers from the island (4). Since then, Professor Bihu Li has been recognized for significantly contributing to the reporting and research of *Rickettsia* infections in Hainan (5–7). The discovery of severe fever with thrombocytopenia syndrome

(SFTS) in Chinese mainland led to an increase in research on ticks and TBDs on Hainan Island. This study presents a succinct overview of the spatial distribution of tick species and illuminates patterns in the types and distribution of emerging tick-borne infections in tick vectors, animal hosts, and humans.

The Prevalence of Ixodid Tick Species on Hainan Island, China

In conducting a systematic review of current citations on ticks in Hainan (methods detailed in the [Supplementary Material](https://weekly.chinacdc.cn/), available in <https://weekly.chinacdc.cn/>), 21 species of hard ticks were identified. These include ten *Haemaphysalis* species, five *Amblyomma* species, three *Rhipicephalus* species, one *Ixodes* species, one *Hyalomma* species and one *Dermacentor* species. These were discovered on the island, representing approximately 17% of the 124 tick species in China (8). As of yet, there's no record of soft ticks from Hainan Island.

The *Rhipicephalus* genus is the most common tick genus found on Hainan Island, albeit consisting only of three species — *Rhipicephalus sanguineus* sensu lato (s. l.), *Rhipicephalus haemaphysaloides*, and *Rhipicephalus microplus*. *Rhipicephalus* ticks have been recorded almost everywhere on the island except for the southwestern county of Dongfang, the eastern county of Qionghai and the southeastern county of Linshui (9–17) (Figure 1).

Haemaphysalis ticks are plentiful in Chengmai, Qiongzong, and Sanya City but much less common in Wanning, Haikou City, and Changjiang. They have not been recorded in the rest of the island's counties or cities (9–17) (Figure 1). *Amblyomma* ticks have been reported in only five locations, inclusive of Chengmai, Lingao, Dingan, Qiongzong, and Sanya (9,11,17–18) (Figure 1).

Ixodes granulatus has been documented in Haikou, Chengmai, Baisha, Qiongzong, Wanning, and Sanya counties, with three incidences in Chengmai and Qiongzong counties (10–17,19–20). The remaining species, *Dermacentor auratus* and *Hyalomma isaaci*,

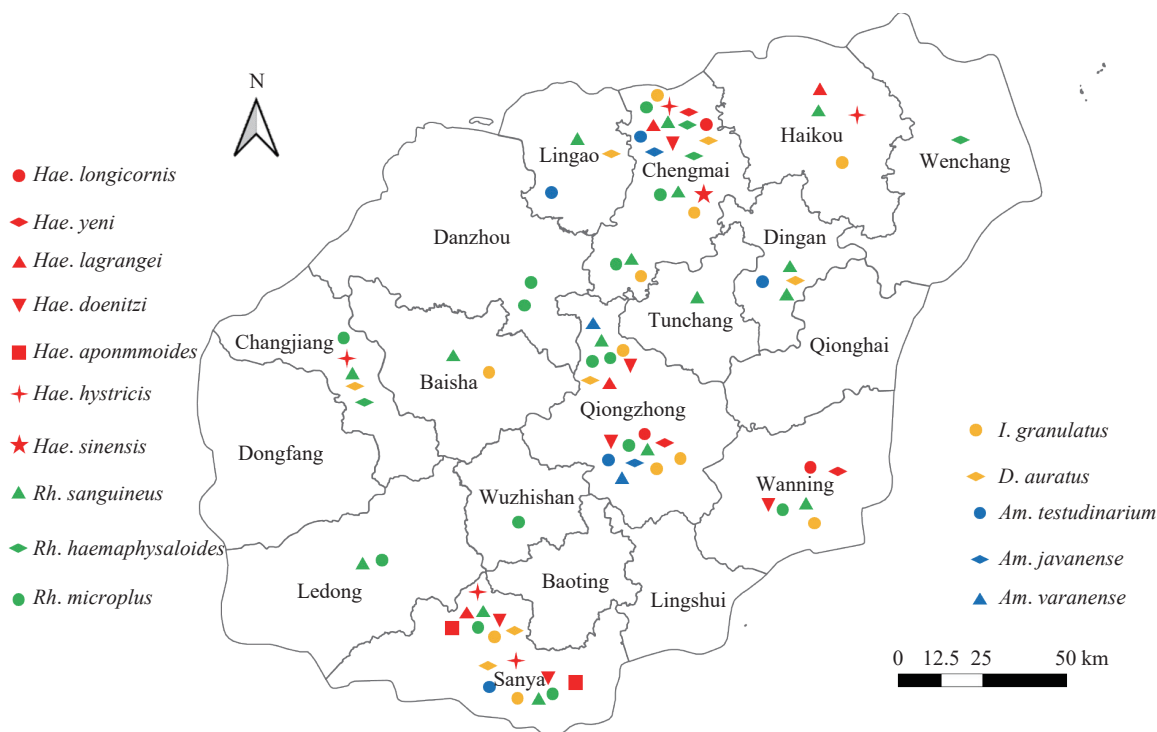


FIGURE 1. Geographical distribution of hard ticks on Hainan Island in China, 1980–2023.

Haemaphysalis formosensis, *Hae. cornigera*, *Hae. mageshinaensis*, *Am. hainanense*, *Am. helvolum*, and *Hy. isaaci* were not drawn on the map due to the unspecified place recorded in the references.

have likewise been recorded (9–11,13,15,17,18,21–22) (Figure 1). The host of these hard ticks on the island varies and ranges from birds and reptiles to mammals (Supplementary Table S1, available in <https://weekly.chinacdc.cn>).

The Emergence of Tick-borne Infections on Hainan Island, China.

A comprehensive review of existing literature on TBP in Hainan was undertaken (detailed methodology is provided in the [Supplementary Material](#)). The agents infecting ticks, animals, and humans can be classified into three categories: bacteria, protozoans, and viruses. Bacteria constitute the principal category of TBPs, represented by twenty species, including six *Borrelia*, four *Anaplasma*, four *Rickettsia*, four *Ehrlichia*, and two *Coxiella* species. Protozoans form the second largest group with ten species, including four *Babesia*, five *Theileria*, and one *Hepatozoon* species. There are only two known viral pathogens: a novel Alphavirus and the Crimean-Congo hemorrhagic fever virus (CCHFV). In the eighteen administrative divisions, TBPs are predominantly reported in the central and northern regions, with

fewer instances cited in the southern parts of Hainan Island (Figures 2–5).

Rickettsia species have emerged as the primary pathological agents causing TBDs in Hainan Island, China, with documented human infections present throughout the region. Cases have been noted in Chengmai and Haikou to the north, Qionghai and Wanning to the east, Qiongzong in the center, Danzhou City to the west, and Sanya to the south (6,12,23–25). As of mid-2023, the identified species of *Rickettsia* on Hainan Island include *Rickettsia siberica*, *Rickettsia heilongjiangensis*, and an unidentified member of the SFGR group (6,12,23–25) (Figures 2 and 5, [Supplementary Tables 2–3](#), available in <https://weekly.chinacdc.cn/>).

Species of *Anaplasma* reported in the region include *Anaplasma bovis*, *Anaplasma marginale*, *Anaplasma phagocytophilum*, and *Anaplasma platys*. *Anaplasma*, predominantly located in the northeastern areas of Hainan, like Haikou and Qionghai, but with instances of *A. platys* infections in the southwestern and southern zones (11,26–30). Reservoir hosts for *A. phagocytophilum* on the island may include cattle, goats, and dogs, with *Rh. sanguineus* and *Rh. microplus* reported as potential vector species for agent

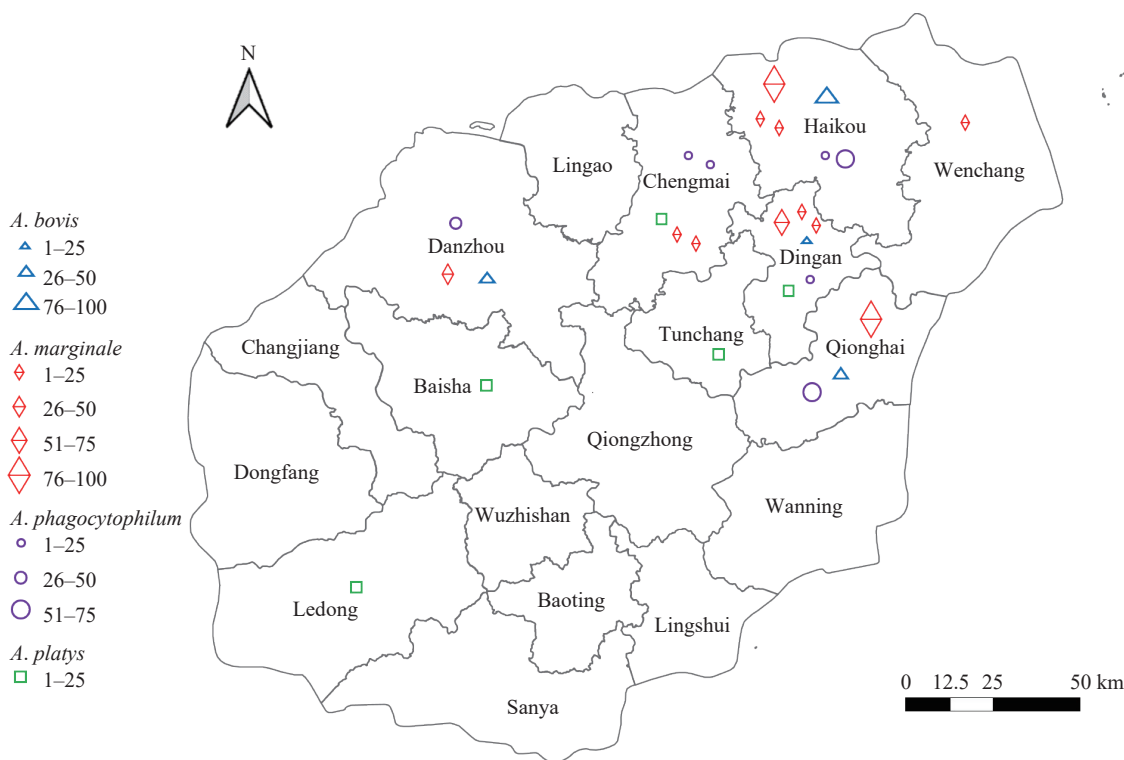


FIGURE 2. Geographic distribution of emerging infections caused by agents in the *Anaplasma* genus in ticks and animals in Hainan, China.

Note: In an uncharted area of the region, infection with *Anaplasma marginale* was detected, expanding its known presence to Haikou, the region's capital. Samples collected from Baisha, Ledong, Dangan, and Tunchang tested positive for *A. platys* with an infection rate of 1.1%. For the purposes of this study, specific values were assigned to each site: Baisha, Ledong, Dangan, and Tunchang.

circulation (26,28–29,31) (Figures 3 and 5, Supplementary Tables S2–S3).

Genospecies of *Borrelia burgdorferi* s. l., including *Borrelia garinii*, which cause human Lyme borreliosis, have been detected in human cases in Haikou (23), and other uncharacterized genospecies of *Bo. burgdorferi* s. l. have infected individuals in Wenchang, Danzhou, Dongfang, Qiongzong, Haikou, and Sanya, with prevalence rates between 1.99% and 9.96% (32–33). Four spirochetes of the *Bo. burgdorferi* s. l. group, including *Borrelia afzelii*, *Bo. garinii*, *Borrelia valaisiana*, and *Borrelia yangtzensis*, were found in *Rh. microplus* ticks (Figures 3 and 5, Supplementary Tables S2–S3).

Tick-borne protozoan infections, significant threats to animal health, have been frequently reported in the northern part of Hainan Island, especially in Dangan, Haikou, Danzhou, and Chengmai (11,30,34–37) (Figure 4, Supplementary Table S2). Also, two tick-borne viruses carry potential implications for bovine health; a novel Alphavirus was identified in ticks from cattle in Danzhou (38), and anti-CCHFV IgG was confirmed in bovine serum samples from Haikou,

Chengmai, Dongfang, and Sanya (39).

DISCUSSION AND CONCLUSION

The tick species *Haemaphysalis longicornis* is among the most extensively distributed across Chinese mainland, yet it has been identified in merely three out of 18 administrative regions on Hainan Island (8,11,17,40–41). This uneven distribution may be attributed to the potential limited exploration of hosts and associated vegetation types within other regions, which may consequently introduce a bias in its perceived distribution.

Serological methods have detected instances of human infections with SFGR on Hainan Island, an indication of the natural circulation of SFGR in this region. As such, there is a pressing need to intensify efforts to monitor infection rates and assess the risk of pathogen spillover from ticks and animals to humans in urban areas or counties where no human infection has been reported to date.

Recent years have seen an increased involvement of

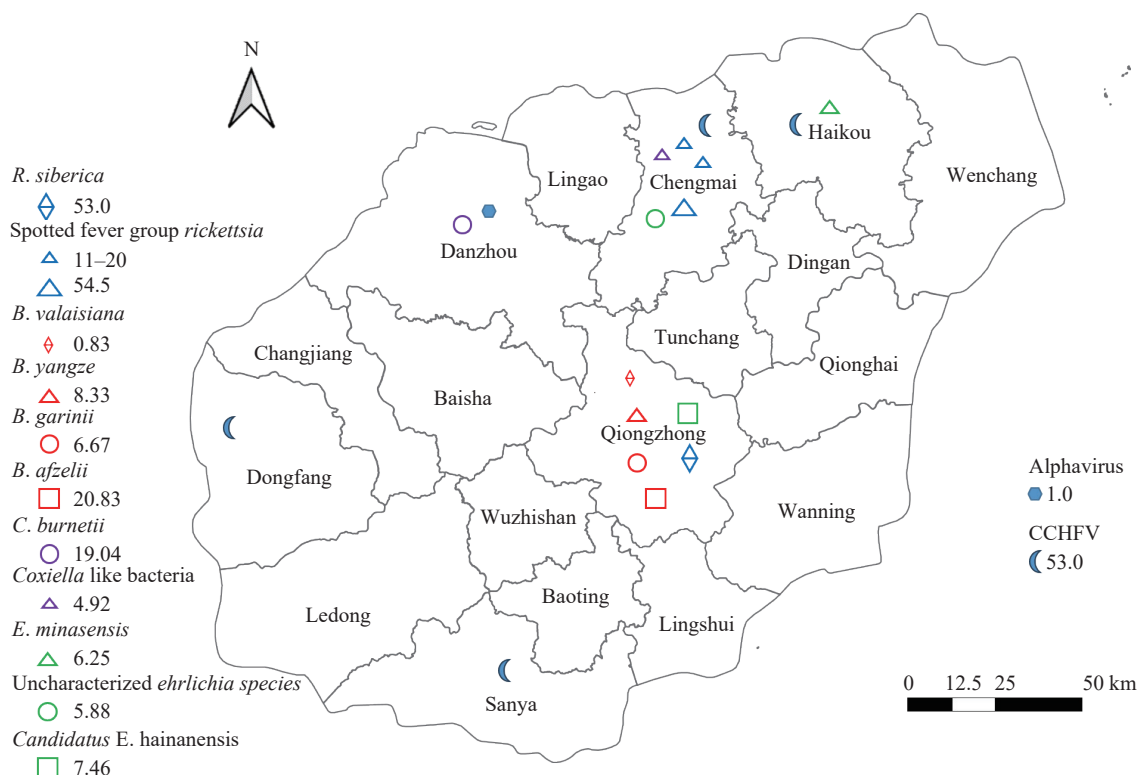


FIGURE 3. Geographic distribution of emerging infections from viruses and bacteria, excluding the *Anaplasma* genus, in ticks and animals in Hainan, China.

Abbreviation: CCHFV=Crimean-Congo haemorrhagic fever virus.

scientists from diverse academic backgrounds in tick and TBD research. This has undoubtedly broadened the scope of research topics and enriched academic discourse. However, this growth also introduces potential issues concerning data reliability, particularly regarding potential misidentification errors due to minor morphological differences amongst tick species, lack of researcher expertise, or inaccurate description of new species. As an illustration, the *Hae. longicornis* species was often confused with *Haemaphysalis bispinosa* in South China until a clarification was made based on dental formula differences and distinctly pointed spurs on coxae II–IV, a morphological feature specific to *Hae. bispinosa* (42). Inexperienced researchers, particularly in regions where *Haemaphysalis hystricis* and *Hae. longicornis* coexist, may encounter difficulties correctly distinguishing them. However, the two species can be readily identified by noting differences in dental formula and body size: *Hae. longicornis* has a 5/5 dental formula and a smaller body size compared to *Hae. hystricis*, which possesses a 4/4 dental formula (43). To ensure data reliability, crucial in assessing tick and TBD risks, it is suggested that future researchers in tick identification collaborate with

acarologists and employ molecular methods as means of verification and validation.

Ticks have been observed to be concentrated in specific regions of Hainan, China such as Chengmai, Qiongzong, and Sanya, but appear less common in areas like Wenchang, Baisha, and Wuzhishan. Remarkably, several regions including Qionghai, Dongfang, Baoting, and Lingshui have yet to record any tick species. However, this distribution does not align with the clustering of TBPs which predominantly occur in northern Hainan, specifically in Dingan and Haikou.

It appears that investigations into ticks and TBPs are incomplete in several areas, evidenced by absent or inadequate reports from locales such as Dingan, Haikou, and Sanya. To rectify this, the implementation of thorough surveillance for both ticks and TBPs is strongly advised under the following conditions: 1) where surveys have not yet been undertaken; 2) where ticks and TBPs are pervasive and surrounding areas have reported none or minimal occurrences; 3) where TBPs are rife, though ticks are sparsely identified; 4) where tick sightings are frequent, necessitating intensive TBP detection; 5) where ticks

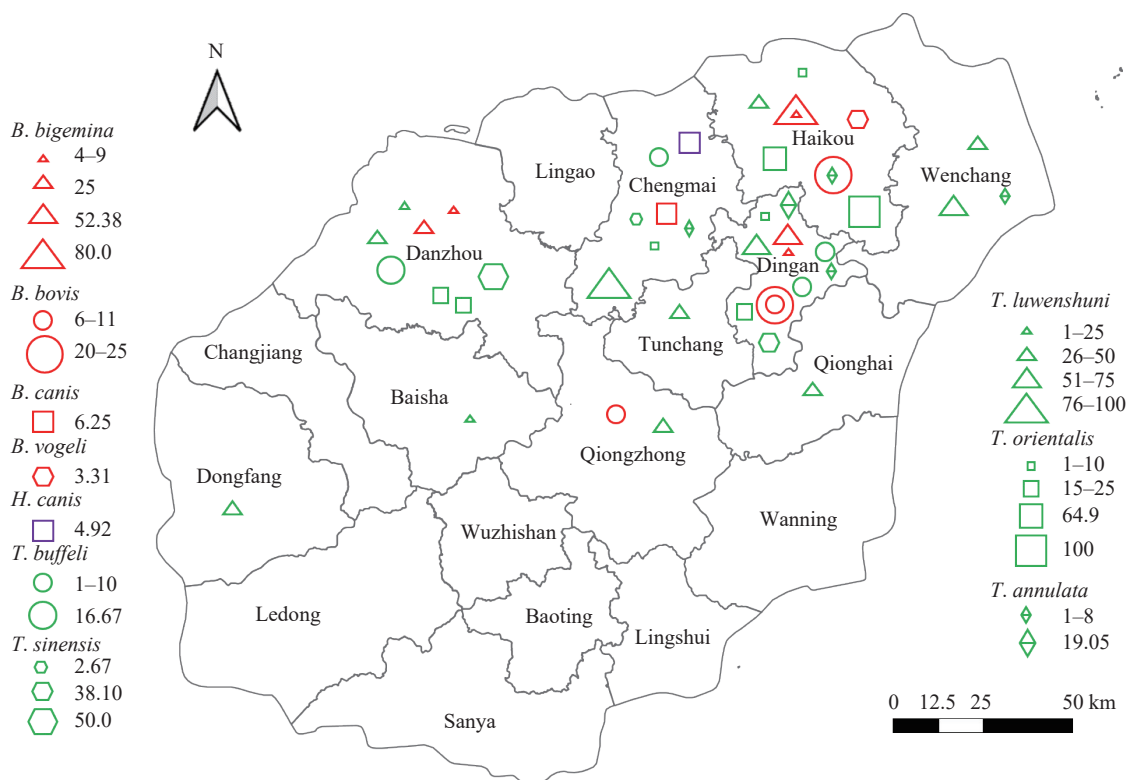


FIGURE 4. Geographic distribution of emerging protozoan infections in ticks and animals in Hainan, China.

Note: A documented case of *Babesia vogeli* infection was identified in an unspecified area of the region, extending its known occurrence to Haikou, the capital of this region. Furthermore, a case of *Babesia bovis* infection, previously found in Central Hainan, has now been registered within the location of Qiongzong. The term “Qiongzong” in Chinese denotes “Central part of Hainan,” accurately portraying its geographical siting in the central part of the island.

and TBP demonstrate high infection rates in humans and animals, necessitating strict monitoring of TBDs; and 6) if TBDs become epidemic, causing significant morbidity or mortality, and existing in similar latitudinal, biogeographical, or microclimatic conditions.

Finally, to streamline and boost the effectiveness of these efforts, the establishment of a comprehensive surveillance system for ticks and TBDs is critical.

The present study exhibits certain limitations. Initially, the non-random nature of the chosen locations for surveying ticks and TBPs could have potentially introduced bias into the determination of the distribution of ticks and TBPs. Furthermore, the majority of the ticks and TBPs were extracted from domestic animals, raising the likelihood of excluding ticks and TBPs associated with wild animals within the surveyed locations. Moreover, some ticks and TBP detection records used in the study date back more than four decades; given this substantial period, significant changes should be anticipated in the habits of ticks and TBPs. Despite these constraints, the study

still offers valuable insights into understanding ticks and TBDs in Hainan, China.

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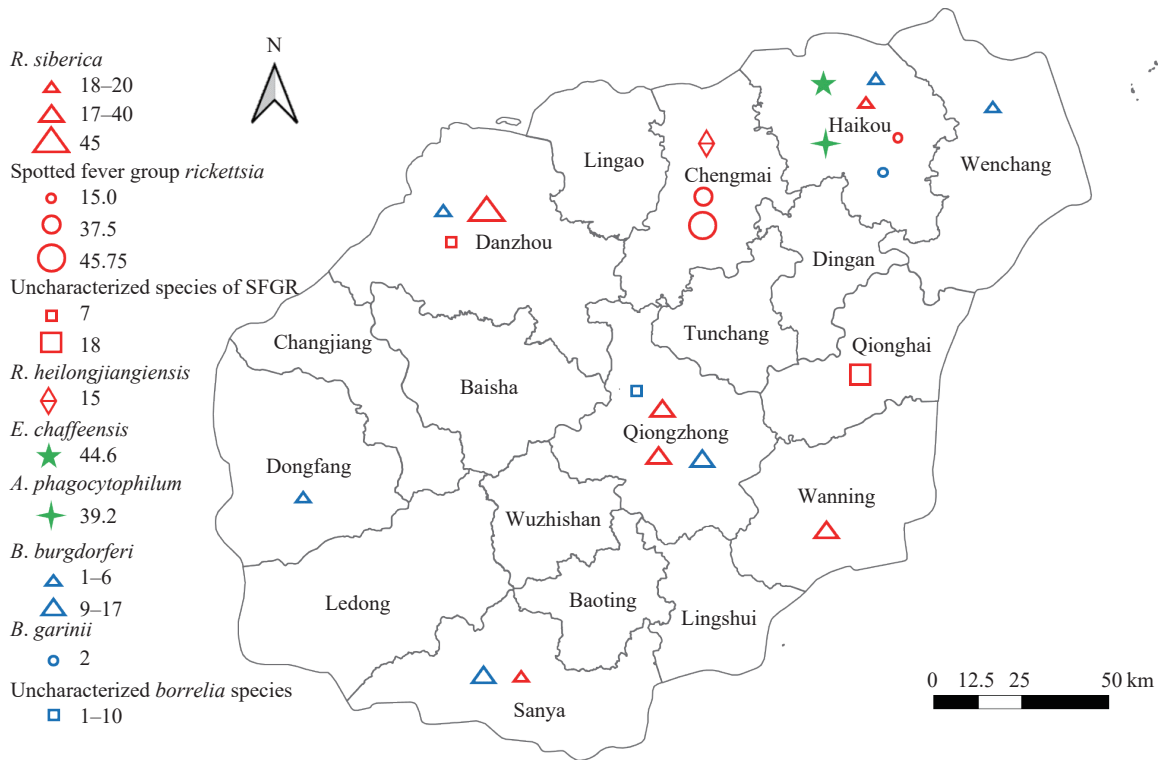


FIGURE 5. Documented distributions of human tick-borne pathogen infection at the county level in Hainan, China.

Note: The documentation of infections from the spotted fever group *Rickettsia*, *Anaplasma phagocytophilum*, and *Ehrlichia chaffeensis* has been extended to include an unidentified region within Haikou. Similarly, a case of infection with an uncharacterized species of *Borrelia* in the central area of Hainan has been reported in Qiongzong.

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REFERENCES

- Li YJ, Zhou GF, Zhong SF, Wang XM, Zhong DB, Hemming-Schroeder E, et al. Spatial heterogeneity and temporal dynamics of mosquito population density and community structure in Hainan Island, China. *Parasit Vectors* 2020;13(1):444. <http://dx.doi.org/10.1186/s13071-020-04326-5>.
- Sun DW, Wang SQ, Zhao W, Wang GR, Wang YY, Zeng LH, et al. Investigation of seasonal fluctuation of ticks on bulls and dogs in Chengmai County in Hainan Province. *China Trop Med* 2011;11(9):1081–2. <http://dx.doi.org/10.13604/j.cnki.46-1064/r.2011.09.005>. (In Chinese).
- Teng KF. A new species of *Amblyomma* from Hainan island, China (Acarina: Ixodidae). *Acta Zootaxon Sin* 1981;6(4):399–401. <https://kns.cnki.net/kcms2/article/abstract?v=Nk4cZQau9qG4sQaGHFMpobUzgAZOImtBX5tIrgel6KRCuiicwJ9jP6gVWXLBvFuG4wm0JC77YfKRKyCbnJGfPY3fyZsWdjI0P1uT1fgWDMr6ZdKhXviR9g=&uniplatform=NZKPT>. (In Chinese).
- Feng HM, Yi Q, Pang HL, Tu YY, Lin BH, Zhou SY, et al. Investigation on spotted fever *Rickettsia* seropositive individuals in healthy volunteers from Hainan Island. *Chin J Epidemiol* 1988;9(2):83. http://chinaepi.icdc.cn/zhlxbsen/ch/reader/view_abstract.aspx?file_no=19880219&flag=1. (In Chinese).
- Zhang JZ, Fan MY, Bi DZ, Sun FX, Cheng ZX, Lan FC, et al. The application of PCR to epidemiological study on spotted fever group rickettsiae. *Chin J Epidemiol* 1995;16(1):25–8. <http://dx.doi.org/10.3760/cma.j.issn.0254-6450.1995.01.112>. (In Chinese).
- Lin BH, Sun XJ, Zhan ZN, Lin YZ, Li WG. Serological and etiological studies on undefined rickettsiosis on Hainan island. *J Hainan Med Univ* 1997;3(3):97–102. <https://kns.cnki.net/kns8/Detail?sfid=fn&QueryID=0&CurRec=1&recid=&FileName=HNY703.000&DbName=CJFD9697&DbCode=CJFD&yx=&pr=&URLID=>. (In Chinese).
- Lin BH. Determination of species specific antibodies in *Rickettsia* by DEB-ELISA. *J Hainan Med Coll* 1996;2(2):49–51. <http://dx.doi.org/10.13210/j.cnki.jhmu.1996.02.011>.
- Zhao GP, Wang YX, Fan ZW, Ji Y, Liu MJ, Zhang WH, et al. Mapping ticks and tick-borne pathogens in China. *Nat Commun* 2021;12(1):1075. <http://dx.doi.org/10.1038/s41467-021-21375-1>.
- Deng GF, Jiang ZJ. Economic insect fauna of China. Fasc 39. Acarina: Ixodidae. Beijing: Science Press. 1991. <http://find.nlc.cn/search/showDocDetails?docId=-1480479448559231182&dataSource=ucs01&query=%E4%B8%AD%E5%9B%BD%E7%BB%8F%E6%B5%8E%E6%98%86%E8%99%AB%E5%BF%97>. (In Chinese).
- Huang JL, Long ZM, Dong QZ, Liu JH, Zhou PS, Yu XL. Investigation of Murine-like animal and their external parasites in Mountain area of Southern Hainan province. *Chin J Vector Biol Control* 1995;6(1):37–41. <https://kns.cnki.net/kns8/Detail?sfid=fn&QueryID=0&CurRec=1&recid=&FileName=ZMSK501.018&DbName=CJFD9495&DbCode=CJFD&yx=&pr=&URLID=>. (In Chinese).
- Lu M, Tang GP, Bai XS, Qin XC, Wang W, Guo WP, et al. Molecular detection of tick-borne pathogens in ticks collected from Hainan Island, China. *Biomed Environ Sci* 2021;34(7):581–6. <http://dx.doi.org/10.3967/bes2021.081>.
- Liu JH, Yu XL, Long ZM, Yang FR, Chen WJ, Tian XD, et al. Spotted fever foci in Hainan island. *J Prev Med Chin People's Liber Army* 1996;14(5):317–9. <https://kns.cnki.net/kns8/Detail?sfid=fn&QueryID=0&CurRec=1&recid=&FileName=JYYX605.001&DbName=CJFD9697&DbCode=CJFD&yx=&pr=&URLID=>. (In Chinese).

13. Huang JL, Zhou PS, Long ZM. The population structure and spatial distribution of ticks, mites and fleas on rodents. *Entomol Knowl* 1997;34(6):337-9. <https://d.wanfangdata.com.cn/periodical/QK199700781761>. (In Chinese).
14. Liu JH, Huang JL. Community structure of ticks parasitic on small mammals from Hainan, China. *Zool Res* 1994;15(4):45-8. <https://www.zoos.ac.cn/cn/article/id/2243>. (In Chinese).
15. Tian XD, Chen WJ, Lu ZZ, Zhang JZ, Liu JH, Yu XL. Investigation of the spotted fever vectors and host animals in Dafeng farm of Qiongzong in Hainan province. *Chin J Zoonoses* 1999;15(2):94. https://kns.cnki.net/kcms2/article/abstract?v=3uoqIhG8C44YL TIOAiTRKjKpgKvIT9Nkm5tS6uBYqSHTdS3ItQuTWgH5apOtHs3l XAhsKfKBME5-aSkUmdSXAR4-1uEVe_Rs&uniplatform=NZKPT. (In Chinese).
16. Lin LH, Bai ZJ, Cai J, Fang MY. Investigation of the ticks parasitized on the domestic animals in Qiongzong area of Hainan Province. *Chin J Vector Biol Control* 2008;19(6):544-5. <http://dx.doi.org/10.3969/j.issn.1003-4692.2008.06.016>. (In Chinese).
17. Sun DW, Zhao W, Zeng LH, Li SG. Investigation of species of Ixodidae and a new record species of Ixodidae in Hainan Province, China. *Chin J Vector Biol Control* 2013;24(5):442-3. <http://dx.doi.org/10.11853/j.issn.1003.4692.2013.05.018>. (In Chinese).
18. Zhao W, Lao SJ, Wang ZG, Jia PB, Zeng LH, Li SG, et al. Investigation of rodents and their ectoparasites in Hainan Province. *Chin J Vector Biol Control* 2007;18(6):519-21. <http://dx.doi.org/10.3969/j.issn.1003-4692.2007.06.031>. (In Chinese).
19. Li JJ, Liu XX, Mu JQ, Yu XB, Fei YD, Chang J, et al. Emergence of a novel *Ehrlichia minasensis* strain, harboring the major immunogenic glycoprotein trp36 with unique tandem repeat and C-terminal region sequences, in Haemaphysalis hystricis ticks removed from free-ranging sheep in Hainan province, China. *Microorganisms* 2019;7(9):369. <http://dx.doi.org/10.3390/microorganisms7090369>.
20. Sun DW, Wang SQ, Zhao W, Wang GR, Wang YR, Zeng LH, et al. Seasonal succession of ticks in small wild animals in Chengmai county of Hainan province. *Chin J Public Health* 2012;28(12):1620-2. <http://dx.doi.org/10.11847/zgggws-2012-28-12-25>. (In Chinese).
21. Chen Z, Yang XJ. Tick systematics. Beijing: Science Press. 2021. <http://find.nlc.cn/search/showDocDetails?docId=531020227369334721&dataSource=ucs01&query=%E8%9C%B1%E7%9A%84%E7%B3%BB%E7%BB%9F%E5%88%86%E7%B1%BB%E5%AD%A6>. (In Chinese).
22. Chen Z, Yang XJ, Bu FJ, Yang XH, Yang XL, Liu JZ. Ticks (acari: ixodoidea: argasidae, ixodidae) of China. *Exp Appl Acarol* 2010;51(4):393-404. <http://dx.doi.org/10.1007/s10493-010-9335-2>.
23. Fang LQ, Liu K, Li XL, Liang S, Yang Y, Yao HW, et al. Emerging tick-borne infections in mainland China: an increasing public health threat. *Lancet Infect Dis* 2015;15(12):1467-79. [http://dx.doi.org/10.1016/S1473-3099\(15\)00177-2](http://dx.doi.org/10.1016/S1473-3099(15)00177-2).
24. Wu J, Wang SL, Jin YM, Ma Y, Zeng XJ, Jia PB, et al. Detection of groEL gene in spotted fever group Rickettsia of patients with fever in Hainan province. *Mod Prev Med* 2014;41(13):2417-9. <https://d.wanfangdata.com.cn/periodical/xdyfyx201413037>. (In Chinese).
25. Jin YM, Zhang LJ, Sun LY, Lao SJ, Han J, Huang CH, et al. Epidemiological investigation of emerging spotted fever in Chengmai county, Hainan province. *Dis Surveill* 2011;26(1):18-22. <http://dx.doi.org/10.3784/j.issn.1003-9961.2011.01.007>. (In Chinese).
26. Huang LY, Zhou S, Liao HY, Wang JH. Molecular epidemiological investigation and genetic diversity analysis of Anaplasma cattle in Hainan. *Trop Agric Eng* 2021;45(6):9-15. <https://d.wanfangdata.com.cn/periodical/rdnygc202106003>. (In Chinese).
27. Zhou S, Lin Y, Zu HY, Wang JH. Identification of tick species and investigation of Anaplasma spp. in some areas of Hainan. *J Trop Biol* 2023;14(2):159-65. <http://dx.doi.org/10.15886/j.cnki.rdxwb.2023.02.004>. (In Chinese).
28. Zhang LJ, Liu H, Xu BL, Lu QY, Li L, Chang LT, et al. Anaplasma phagocytophilum infection in domestic animals in ten provinces/cities of China. *Am J Trop Med Hyg* 2012;87(1):185-9. <http://dx.doi.org/10.4269/ajtmh.2012.12-0005>.
29. Wang SW, He J, Zhang LJ. Serological investigation of vector-borne disease in dogs from rural areas of China. *Asian Pac J Trop Biomed* 2012;2(2):102-3. [http://dx.doi.org/10.1016/S2221-1691\(11\)60201-3](http://dx.doi.org/10.1016/S2221-1691(11)60201-3).
30. Bi TL. Molecular epidemiological investigation study on cattle infected with Anaplasma, Babesia and Theileria in Qiongzong area [dissertation]. Haikou: Hainan University; 2021. <http://dx.doi.org/10.27073/d.cnki.ghadu.2021.000933>. (In Chinese).
31. Zhang LJ, Liu H, Xu BL, Zhang ZL, Jin YM, Li WM, et al. Rural residents in China are at increased risk of exposure to tick-borne pathogens Anaplasma phagocytophilum and Ehrlichia chaffeensis. *BioMed Res Int* 2014;2014:313867. <http://dx.doi.org/10.1155/2014/313867>.
32. Zhang L, Zhu X, Hou XX, Li H, Yang XN, Chen T, et al. Prevalence and prediction of Lyme disease in Hainan province. *PLoS Negl Trop Dis* 2021;15(3):e0009158. <http://dx.doi.org/10.1371/journal.pntd.0009158>.
33. Zhu X, Zhang L, Hou XX, Geng Z, Chen H, Chen T, et al. Investigation on Lyme disease of patients with arthritis or neurological disorders in Hainan Province, China. *Chin J Zoonoses* 2015;31(4):353-6. <http://dx.doi.org/10.3969/cjz.j.issn.1002-2694.2015.04.013>. (In Chinese).
34. Wei FR, Lan QX, Zhu D, Ye JH, Liu Q, Zhang Y. Investigation on Babesia in ticks infested on police dogs in selected areas of China. *Chin J Parasitol Parasit Dis* 2012;30(5):390-2. <http://qikan.cqvip.com/Qikan/Article/Detail?id=43679584>. (In Chinese).
35. Wang JM, Yang JF, Gao SD, Wang XX, Sun H, Lv ZY, et al. Genetic diversity of Babesia bovis MSA-1, MSA-2b and MSA-2c in China. *Pathogens* 2020;9(6):473. <http://dx.doi.org/10.3390/pathogens9060473>.
36. Wang JM, Yang JF, Liu JL, Wang XX, Xu JL, Liu AH, et al. Molecular detection and genetic diversity of Theileria orientalis in cattle in China. *Parasitol Res* 2018;117(12):3689-94. <http://dx.doi.org/10.1007/s00436-018-6023-3>.
37. Yang L, Wang JH, Upadhyay A, Zhao JG, Huang LY, Liao CH, et al. Identification of Theileria spp. and investigation of hematological profiles of their infections in goats in Hainan Island, China. *Parasite* 2022;29:13. <http://dx.doi.org/10.1051/parasite/2022013>.
38. Chen WZ, Qiu FX, Calisher CH, Liu JC, Chen HX, Li XD, et al. Twenty-eight alphavirus strains isolated from mosquitoes and ticks captured from Hainan Island, China. *Chin J Exp Clin Virol* 1997;11(2):144-6. <http://dx.doi.org/10.3760/cma.j.issn.1003-9279.1997.02.117>. (In Chinese).
39. Qi JS, Chen YB, Wu JJ, Wang M, Chen WZ, Feng CH, et al. IgG antibodies against Crimean-Congo hemorrhagic fever virus were firstly found in bovine serum in Hainan province. *Chin J Vector Biol Control* 1995;6(2):158. <http://www.bmsw.net.cn/CN/Y1995/V06/I2/158>. (In Chinese).
40. Zheng WQ, Xuan XN, Fu RL, Tao HY, Xu RM, Liu YQ, et al. Preliminary investigation of ixodid ticks in Jiangxi Province of Eastern China. *Exp Appl Acarol* 2019;77(1):93-104. <http://dx.doi.org/10.1007/s10493-018-0324-1>.
41. Zhao L, Li J, Cui XM, Jia N, Wei JT, Xia LY, et al. Distribution of Haemaphysalis longicornis and associated pathogens: analysis of pooled data from a China field survey and global published data. *Lancet Planet Health* 2020;4(8):e320-9. [http://dx.doi.org/10.1016/S2542-5196\(20\)30145-5](http://dx.doi.org/10.1016/S2542-5196(20)30145-5).
42. Chen Z, Li YQ, Ren QY, Liu ZJ, Luo J, Li K, et al. Does Haemaphysalis bispinosa (Acari: Ixodidae) really occur in China? *Exp Appl Acarol* 2015;65(2):249-57. <http://dx.doi.org/10.1007/s10493-014-9854-3>.
43. Zheng WQ, Hu HJ, Tian JH, Liang SJ, Wang YY. Differentiation of Haemaphysalis hystricis from Haemaphysalis longicornis based on the QIAxcel Connect automated RNA/DNA analysis system. *Acta Parasitol Med Entomol Sin* 2023;30(1):18-24. <http://dx.doi.org/10.3969/j.issn.1005-0507.2023.01.004>. (In Chinese).

SUPPLEMENTARY MATERIAL

Search Strategy

This systematic review was devised and conducted in alignment with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Institute et al., 2020). The search for relevant literature primarily employed English language databases including Web of Science, PubMed, and Mendeley. In addition, Chinese language databases such as CNKI (China National Knowledge Infrastructure) and the Chinese Medical Journal Full-Text Database (CMJFTD) were utilized. We also incorporated other pertinent literature, including select Chinese professional texts about ticks and tick-borne diseases. Our keyword strategy incorporated terms such as “ticks of domestic animals,” “ticks of livestock,” “ectoparasite of domestic animals,” “ectoparasite of livestock,” “ticks of rodents,” “ticks of cattle or cows,” “ticks of cats and dogs,” “ticks from vegetation,” “ticks from breeding site,” “tick and tick-borne disease of livestock,” “the tropical island of China,” “the southernmost region of China,” and “Hainan.” We included all publications ranging from the 1980s to May 30, 2023. Literature was systematically screened by evaluating the title, abstract, and the results and conclusions of the manuscripts.

Criteria for Inclusion and Exclusion

This review incorporated articles from the aforementioned databases that referenced ticks or ticks in conjunction with other ectoparasites and TBPs in ticks or rodents and domestic animals (inclusive of ruminants, goats, cattle, dogs, and cats) in Hainan Island. Criteria for inclusion specified the tick or TBP’s collection location as Hainan Island or the tropical island of China, publication in English or Chinese, taxonomic identification of ticks to the species level, classification of tick-borne viruses to the family level, and analysis of other TBPs such as bacteria and protozoans to the genus level and then to the species level. The term “tick” also needed to be present in the title, abstract, results, or conclusion section of the text.

References were excluded from this review if they contained these characteristics: the depiction of ectoparasites other than ticks, the term “tick” or “tick-borne pathogen” only located in the introduction and discussion section, the term “tick” located in the results section but used within a phylogenetic analysis of ticks from different regions, the term “tick” linked with migratory birds or imported animals or goods on the tropical island, and tick or TBP study relying solely on laboratory data. Studies focusing on the insecticide chlorpyrifos, the Chinese term “毒死蜱” with the Chinese term “蜱”, along with studies where ticks were not identified to the species level also were excluded.

Selection of Studies and Evaluation of Quality

Duplicate articles found in multiple databases were removed, leaving only one copy for further analysis. Initial screening of articles was conducted by examining the titles and abstracts. Articles that did not meet the stipulated inclusion and exclusion criteria were then disregarded. Moreover, a comprehensive review of the full articles was performed, with unqualified ones being excluded based on the established criteria. The review process was independently executed by two reviewers (WQZ and GYZ), and, in cases of disagreement, a third reviewer was brought in.

To assess the quality of articles, a checklist was generated that included categories such as the title, abstract, introduction, methods, results, and discussion. If the terms “Hainan”, “South China”, or “the tropical region of China” and “tick” or “TBP” concurrently appeared in the title, abstract, results, or concluding sections of an article, the article was screened as a potential candidate for further analysis.

Articles pinpointing sample locale to the county level and identifying specific tick species or specific TBP genus was primarily included in this study. Furthermore, articles providing more detailed information such as hosts of ticks or TBPs, or that specified sample locations to the township level were considered high-quality articles.

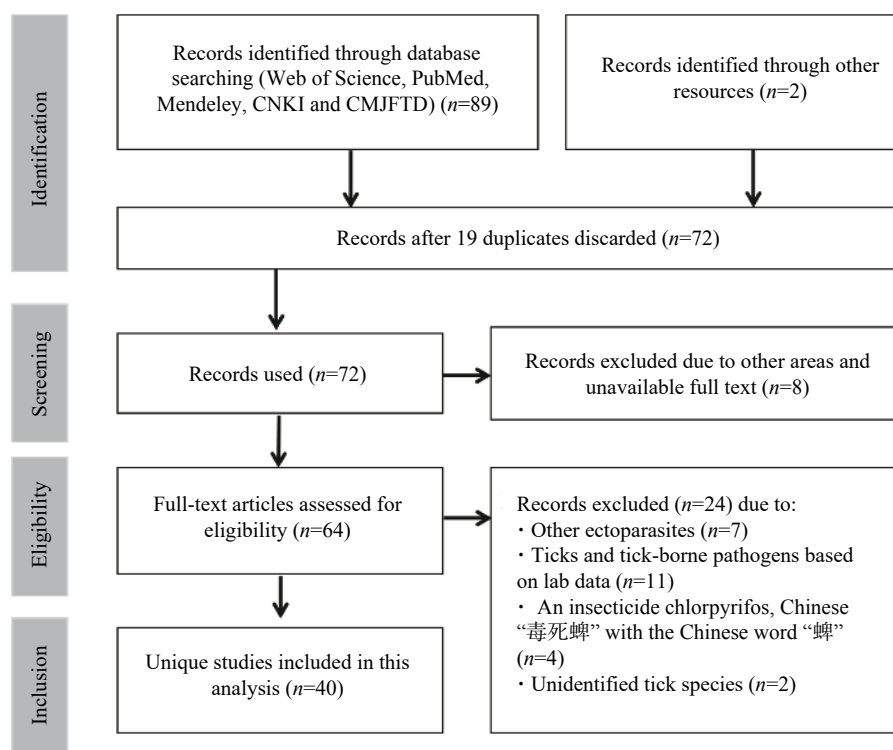
Data Extraction

The final studies included in this analysis provided the following data: 1) tick genus and species; 2) any available tick identification methods; 3) the specific county or city where the ticks were collected; and 4) details of the collection method and information on the host or environment, where applicable. The process of data extraction

was similarly implemented for tick-borne pathogens according to the aforementioned criteria. Subsequent data visualization and analysis were conducted using tables and maps.

Qualified Studies Screening

A comprehensive review was undertaken from five databases, yielding 89 pertinent publications: 28 from PubMed and CNKI each, 18 from Mendeley, 14 from Web of Science, and one from CMJFTD. An additional two publications were identified in a manual search, aligning with the eligibility requirements and were thus included. Upon subtracting 19 duplicates from this pool of 91, 72 publications were left, which then underwent vetting based on title, abstract, and full-text availability. This process resulted in the exclusion of eight additional publications. The remaining 64 underwent a comprehensive eligibility evaluation, resulting in the exclusion of seven publications that pertained to other ectoparasites, and the removal of 11 that used lab-reared ticks or lab-cultured pathogens. Four other papers that included references to chlorpyrifos, or the Chinese term “毒死蜱”, were also omitted. Additionally, two more were removed due to a lack of specificity regarding the species of ticks, viral families, or other genera of the tick-borne pathogens. After two screening cycles, 40 unique studies met the selection criteria and were included in the final analysis (Supplementary Figure S1).



SUPPLEMENTARY FIGURE S1. Illustration of the study selection process for inclusion in this systematic review from 1980 to 2023, utilizing the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram. Abbreviation: CNKI=China National Knowledge Infrastructure; CMJFTD=the Chinese Medical Journal Full-Text Database.

SUPPLEMENTARY TABLE S1. Species of ticks found on the tropical island of China.

Number	Tick species	Ecological environment or zooparasite	Reference
1	<i>Hae. longicornis</i>	Wild animals and livestock, <i>Bubalus bubalis</i> , <i>Bos Taurus</i> , <i>Capra aegagrus hircus</i> , and <i>Canis lupus familiaris</i>	(1–2)
2	<i>Hae. formosensis</i>	<i>Sus scrofa</i> , dog and muntiacus	(3–4)
3	<i>Hae. yeni</i>	<i>Cervus unicolor</i> , <i>Cuon alpinus</i> , dog, wild and domestic animals, and <i>Capra aegagrus hircus</i>	(1–3)
4	<i>Hae. lagrangei</i>	<i>Muntiacus manijak</i> and other <i>Muntiacus</i> species, <i>Niviventer confucianus</i> , <i>Rattus fulvescens</i> , wild and domestic animals, rodent, <i>Bos Taurus</i> , and <i>Capra aegagrus hircus</i> ,	(1, 3, 5–9)
5	<i>Hae. cornigera</i>	<i>Bubalus bubalis</i> , <i>Bos taurus</i> and rodents	(3–4)
6	<i>Hae. doenitzi</i>	<i>Francolinus pintadeanus</i> , <i>Centropus</i> spp., <i>Ryncnonotus sinensis</i> , <i>Bambusicola thoracica</i> , <i>Rattus rattus hainanicus</i> , <i>Rattus rattus</i> , <i>Niviventer confucianus</i> , <i>Rattus fulvescens</i> , <i>Rattus coxingi</i> , <i>Rattus cremoriventer</i> , <i>Niviventer confucianus lotipes</i> , <i>Neohylomys hainanensis</i> , rodent, <i>Capra aegagrus hircus</i> , and <i>Gallus gallus domesticus</i>	(1–3, 5, 7–11)
7	<i>Hae. aponomoides</i>	<i>Rattus rattus hainanicus</i> , <i>Niviventer confucianus</i> , <i>Rattus coxingi</i> , <i>Rattus cremoriventer</i> , <i>Rattus rattus</i> , <i>Niviventer confucianus lotipes</i> , and <i>Neohylomys hainanensis</i>	(5, 7–8)
8	<i>Hae. hystricis</i>	<i>Niviventer confucianus</i> , <i>Rattus coxingi</i> , <i>Dremomys pernyi</i> , wild and domestic animals, rodents, <i>Sus scrofa</i> , <i>Ovis aries</i> ,	(1, 2, 5–8)
9	<i>Hae. sinensis</i>	<i>Bubalus bubalis</i> , <i>Canis lupus familiaris</i> , and farm's house	(12)
10	<i>Hae. mageshinaensis</i>	Wild and domestic animals	(6)
11	<i>Am. testudinarium</i>	<i>Bubalus bubalis</i> , <i>Bos Taurus</i> , <i>Sus scrofa</i> , <i>Cervus unicolor</i> , horses, goats, dogs, pigs, wild and domestic animals, and rodents	(1–3, 13)
12	<i>Am. javanense</i>	<i>Manis pentadactyla</i> , <i>Python molurus</i> , <i>Varanus salvator</i> , <i>Geoemyda tricarinata</i> , wild and domestic animals, and snakes	(1–3, 6)
13	<i>Am. hainanense</i>	Snake	(3–4)
14	<i>Am. varanense</i>	<i>Varanus salvator</i> , <i>Python molurus</i> , <i>Naja</i> , and rodent	(3, 9–10)
15	<i>Am. helvolum</i>	Snake	(4, 14)
16	<i>Rh. sanguineus</i>	Stray dogs, <i>Canis lupus familiaris</i> , <i>Niviventer confucianus</i> , wild and domestic animals, <i>Canis lupus familiaris</i> , rodent, <i>Bubalus bubalis</i> , <i>Bos Taurus</i> , <i>Capra aegagrus hircus</i> , rodents, and <i>Lepus sinensis</i>	(1–3, 5–7, 9, 11, 13, 15–17)
17	<i>Rh. haemaphysaloides</i>	<i>Bubalus bubalis</i> , <i>Bos Taurus</i> , <i>Equus asinus</i> , <i>Canis lupus familiaris</i> , <i>Capra aegagrus hircus</i> , <i>Ovis aries</i> , <i>Lepus sinensis</i> , <i>Sus scrofa</i> , <i>Cervus unicolor</i> , pig, farm's house, and wild and domestic animals	(1–3, 12)
18	<i>Rh. microplus</i>	<i>Bos Taurus</i> , <i>Capra aegagrus hircus</i> , <i>Bubalus bubalis</i> , <i>Rattus rattus hainanicus</i> , <i>Rattus norvegicus</i> , farm's house, wild and domestic animals, and rodents	(1–3, 5, 7, 9, 11, 16, 18–19)
19	<i>I. granulatus</i>	<i>Rattus rattus hainanicus</i> , <i>Rattus rattus</i> , <i>Niviventer confucianus</i> , <i>Rattus norvegicus</i> , <i>Rattus rattoides</i> , <i>Rattus fulvescens</i> , <i>Rattus coxingi</i> , <i>Rattus cremoriventer</i> , <i>Rattus losea</i> , <i>Rattus flavipectus</i> , <i>Rattus edwardsi</i> , <i>Rattus norvegicus</i> , <i>Niviventer confucianus lotipes</i> , <i>Dremomys pernyi</i> , <i>Neohylomys hainanensis</i> , <i>Tupaia glis</i> , <i>Tamiops swinhoei maritimus</i> , wild and domestic animals, rodents, <i>Bos Taurus</i> , and <i>Capra aegagrus hircus</i>	(1, 2, 5–11, 20)
20	<i>D. auratus</i>	<i>Sus scrofa</i> , <i>Bubalus bubalis</i> , <i>Arctonyx collaris</i> , <i>Selenarctos thibetanus</i> , <i>Canis lupus familiaris</i> and pig, <i>Rattus rattus hainanicus</i> , <i>Niviventer confucianus</i> , <i>Rattus cremoriventer</i> , wild and domestic animals, and rodents	(1–3, 5, 7, 9, 13)
21	<i>Hy. isaaci</i>	Birds, small mammals, <i>Bos Taurus</i> , and <i>Capra aegagrus hircus</i>	(4, 14)

SUPPLEMENTARY TABLE S2. Incidence of ticks and their hosts for tick-borne pathogens.

Group	Genus	Species	Hosts/vector	Detection location	Detection rate (%)	Reference
Bacteria	<i>Anaplasma</i>	<i>A. bovis</i> (Ab), <i>A. marginale</i> (Am), <i>A. phagocytophilum</i> (Ap), Ab+Ap, Ab+Am, Ap+Am, Ap+Am+Ab	Cattle	Dingan	Ab, 6.8%; Am, 1.2%; Ap, 1.2%.	(21)
				Haikou	Ab, 100.0%; Am, 25.0%; Ap, 75.0%.	
				Qionghai	Ab, 40.0%; Am, 80.0%; Ap, 60.0%.	
				Danzhou	Ab, 50.0%; Am, 50.0%; Ap, 50.0%.	
		<i>A. platys</i>	<i>Rh. Sanguineus</i> from dogs	Baisha, Ledong, Dingan, Tunchang	1.1%	(15)
		<i>A. phagocytophilum</i>	RSH (<i>Rh. sanguineus</i> from farmer's house); RMGC (<i>Rh. microplus</i> from goats and cattle), RSD (<i>Rh. sanguineus</i> from dogs)	Chengmai	3.6 (RSH), 7.5 (RMGC and RSD)	(22)
		<i>A. phagocytophilum</i>	Dogs	Unknown place of Hainan	25	(23)
		<i>A. marginale</i>	Tick and cattle	Haikou	7.69 (Tick), 100.0 (cattle)	(24)
			Cattle and buffalo	Dingan	57.14 (cattle), 2.17 (buffalo)	
			Wagyu cattle	Chengmai	2.67	
			Tick	Wenchang	8.7	
		<i>A. marginale</i>	<i>Rh. microplus</i>	Chengmai	8.82	(1)
		<i>A. platys</i>	<i>Rh. sanguineus</i>	Chengmai	3.28	
		<i>Rickettsia</i>	<i>R. siberica</i>	Rodent	Qiongzong	53.0
Spotted fever group <i>Rickettsia</i>	Rodent, dog, and tick (<i>Rh. Haemaphysaloides</i> and <i>Rh. microplus</i>)			Chengmai	15.9 (Rodent), 16.7 (dog), 54.5 (tick)	(12)
<i>Borrelia</i>	<i>Bo. afzelii</i>	<i>Rh. microplus</i>	Qiongzong	20.83	(25)	
				8.33		
				0.83		
				6.67		
<i>Coxiella</i>	<i>C. burnetii</i>	<i>Rh. microplus</i>	Danzhou	19.04	(19)	
		<i>Coxiella</i> like bacteria	<i>Rh. sanguineus</i>	Chengmai	4.92	(1)
<i>Ehrlichia</i>	<i>Candidatus E. hainanensis</i>	Rodents	Qiongzong	7.46	(26)	
		<i>E. minasensis</i>	<i>Hae. hystricis</i>	Haikou	6.25	(27)
		Uncharacterized <i>Ehrlichia</i> species	<i>Rh. microplus</i>	Chengmai	5.88	(1)

Continued

Group	Genus	Species	Hosts/vector	Detection location	Detection rate (%)	Reference		
Protozoans	<i>Babesia</i>	<i>Ba. vogeli</i>	Ticks from dogs	Unknown place	3.31	(28)		
		<i>Ba. bovis</i>	Cattle	Central part of Hainan	10.2	(29)		
			Cattle	Haikou	20	(24)		
			Cattle and buffalo	Dingan	23.81 (cattle), 6.52 (buffalo)	(24)		
		<i>Ba. bigemina</i> (Bb), <i>Ba. bovis</i> (Bbo), Am+Bbo, Am+Bb, Bbo+Bb, Am+Bbo+Bb	Tick and cattle	Haikou	Bb: 7.69 (tick), 80 (cattle)	(24)		
			Tick and cattle	Danzhou	Bb: 25 (cattle), 8.3 (tick)			
			Cattle and buffalo	Dingan	Bb: 52.38 (cattle), 4.35 (buffalo)			
		<i>Ba. canis</i>	<i>Rh. sanguineus</i>	Chengmai	6.25	(1)		
		<i>Theileria</i>	<i>T. orientalis</i>	Cattle	Haikou	64.9	(30)	
			<i>T. luwenshuni</i>	Goat	Baisha	20.7	(31)	
	Qiongzong				33.3			
	Dongfang				26.1			
	Chengmai				100			
	Qionghai				27.6			
	Dingan				62.2			
	Wenchang				65.1			
	Danzhou				31.0			
	Haikou				27.1			
	Tunchang				30.8			
	<i>T. annulata</i>				Tick	Haikou	7.69	(24)
	<i>T. orientalis</i>				Tick		7.69	
	<i>T. orientalis</i>				Cattle		100	
	<i>T. sinensis</i>		Cattle	Danzhou	50			
	<i>T. orientalis</i>		Cattle		25			
	<i>T. orientalis</i>		Tick		16.67			
	<i>T. luwenshuni</i>	Tick		8.33				
	<i>T. buffeli</i>	Tick		16.67				
<i>T. sinensis</i>	Cattle	Dingan	38.10					
<i>T. orientalis</i>	Cattle		23.81					
<i>T. buffeli</i>	Cattle		9.52					
<i>T. annulata</i>	Cattle		19.05					
<i>T. orientalis</i>	Buffalo		2.17					
<i>T. buffeli</i>	Buffalo		8.70					
<i>T. annulata</i>	Buffalo		4.35					
<i>T. sinensis</i>	Wagyu cattle	Chengmai	2.67					
<i>T. orientalis</i>	Wagyu cattle		8.00					
<i>T. buffeli</i>	Wagyu cattle		2.67					
<i>T. annulata</i>	Wagyu cattle		2.67					
<i>T. luwenshuni</i>	Tick	Wenchang	47.83					
<i>T. annulata</i>	Tick		4.35					
Hepatozoon	<i>Hepatozoon canis</i>	<i>Rh. sanguineus</i>	Chengmai	4.92	(1)			
Virus	Alphavirus NA	tick	Danzhou	1	(32)			

Note: NA indicates data not available.

SUPPLEMENTARY TABLE S3. Incidence of tick-borne pathogens in humans.

Group	Genus	Species	Detection location	Detection rate (%) or persons	Reference	
Bacteria	<i>Rickettsia</i>	<i>R. siberica</i>	Qiongzong	38.3	(10)	
		<i>R. heilongjiangensis</i>	Chengmai	15*	(33)	
		Uncharacterized species of SFGR	Danzhou, Qionghai	7* 18*	(33)	
		SFGR	UP	15.0	(34)	
		<i>R. siberica</i>	Wanning	27.62	(35)	
			Sanya	18.56		
			Danzhou	45.00		
			Haikou	19.15		
			Qiongzong	39.71		
		SFGR	Chengmai	37.5 or 45.75	(12)	
		<i>Borrelia</i>	<i>Bo. garinii</i>	Haikou	2*	(33)
			Uncharacterized species of <i>Bo. burgdorferi</i> sensu lato	Central part of Hainan	1–10*	(33)
			<i>Bo. burgdorferi</i> s. l.	Wenchang	1.99	(36)
				Danzhou	3.36	
				Dongfang	4.62	
				Qiongzong	16.67	
				Haikou	5.88	
	<i>Bo. burgdorferi</i> s. l.	Sanya	9.96	(37)		
	<i>Anaplasma</i>	<i>A. phagocytophilum</i>	UP	39.2	(38)	
	<i>Ehrlichia</i>	<i>E. chaffeensis</i>	UP	44.6	(38)	
	<i>Coxiella</i>	<i>C. burnetii</i>	UP	NA	(39)	
Viruses	<i>Coltivirus</i>	Colorado tick fever virus	UP	NA	(39)	
	<i>Nairovirus</i>	Crimean-Congo haemorrhagic fever virus	UP	NA	(39)	

Note: UP stands for unspecified locations, which were not named in the relevant documents. NA indicates data not available.

* Denotes individuals with pathogen infection, rather than detection rate. SFGR refers to spotted fever group *Rickettsia*.

REFERENCES

- Lu M, Tang GP, Bai XS, Qin XC, Wang W, Guo WP, et al. Molecular detection of tick-borne pathogens in ticks collected from Hainan Island, China. *Biomed Environ Sci* 2021;34(7):581 – 6. <http://dx.doi.org/10.3967/bes2021.081>.
- Sun DW, Zhao W, Zeng LH, Li SG. Investigation of species of Ixodidae and a new record species of Ixodidae in Hainan province, China. *Chin J Vector Biol Control* 2013;24(5):442 – 3. <http://dx.doi.org/10.11853/j.issn.1003.4692.2013.05.018>. (In Chinese).
- Deng GF, Jiang ZJ. Economic insect fauna of China. Fasc 39. Acarina: Ixodidae. Beijing: Science Press. 1991. <http://find.nlc.cn/search/showDocDetails?docId=-1480479448559231182&dataSource=ucs01&query=%E4%B8%AD%E5%9B%BD%E7%BB%8F%E6%B5%8E%E6%98%86%E8%99%AB%E5%BF%97>. (In Chinese).
- Chen Z, Yang XJ. Tick systematics. Beijing: Science Press. 2021. <http://find.nlc.cn/search/showDocDetails?docId=531020227369334721&dataSource=ucs01&query=%E8%9C%B1%E7%9A%84%E7%B3%BB%E7%BB%9F%E5%88%86%E7%B1%BB%E5%AD%A6>. (In Chinese).
- Huang JL, Long ZM, Dong QZ, Liu JH, Zhou PS, Yu XL. Investigation of Murine-like animal and their external parasites in Mountain area of Southern Hainan Province. *Chin J Vector Biol Control* 1995;6(1):37-41. <https://kns.cnki.net/kns8/Detail?sfid=fn&QueryID=0&CurRec=1&recid=&FileName=ZMSK501.018&DbName=CJFD9495&DbCode=CJFD&yx=&pr=&URLID=>. (In Chinese).
- Li JJ, Liu XX, Mu JQ, Yu XB, Fei YD, Chang J, et al. Emergence of a novel *Ehrlichia minasensis* strain, harboring the major immunogenic glycoprotein trp36 with unique tandem repeat and C-terminal region sequences, in *Haemaphysalis hystricis* ticks removed from free-ranging sheep in Hainan province, China. *Microorganisms* 2019;7(9):369. <http://dx.doi.org/10.3390/microorganisms7090369>.
- Huang JL, Zhou PS, Long ZM. The population structure and spatial distribution of ticks, mites and fleas on rodents. *Entomol Knowl* 1997;34(6):337-9. <https://d.wanfangdata.com.cn/periodical/QK199700781761>. (In Chinese).
- Liu JH, Huang JL. Community structure of ticks parasitic on small mammals from Hainan, China. *Zool Res* 1994;15(4):45-8. <https://www.zoores.ac.cn/cn/article/id/2243>. (In Chinese).
- Tian XD, Chen WJ, Lu ZZ, Zhang JZ, Liu JH, Yu XL. Investigation of the spotted fever vectors and host animals in Dafeng farm of Qiongzong in Hainan province. *Chin J Zoonoses* 1999;15(2):94. https://kns.cnki.net/kcms2/article/abstract?v=3uoqIhG8C44YLTIOAiTRKjkpgKvIT9Nkm5tS6uBYqSHTdS3ItQuTWgH5apOtHs3IXAhskFkBME5-aSkUmdSXAR4-1uEVe_Rs&uniplatform=NZKPT. (In Chinese).
- Liu JH, Yu XL, Long ZM, Yang FR, Chen WJ, Tian XD, et al. Spotted Fever foci in Hainan island. *J Prev Med Chin People's Liber Army* 1996;14(5):317-9. <https://kns.cnki.net/kns8/Detail?sfid=fn&QueryID=0&CurRec=1&recid=&FileName=JYYX605.001&DbName=CJFD9697&DbCode=CJFD&yx=&pr=&URLID=>. (In Chinese).
- Lin LH, Bai ZJ, Cai J, Fang MY. Investigation of the ticks parasitized on the domestic animals in Qiongzong area of Hainan province. *Chin J Vector Biol Control* 2008;19(6):544 – 5. <http://dx.doi.org/10.3969/j.issn.1003-4692.2008.06.016>. (In Chinese).
- Jin YM, Zhang LJ, Sun LY, Lao SJ, Han J, Huang CH, et al. Epidemiological investigation of emerging spotted fever in Chengmai county, Hainan province. *Dis Surveill* 2011;26(1):18 – 22. <http://dx.doi.org/10.3784/j.issn.1003-9961.2011.01.007>. (In Chinese).

13. Zhao W, Lao SJ, Wang ZG, Jia PB, Zeng LH, Li SG, et al. Investigation of rodents and their ectoparasites in Hainan province. *Chin J Vector Biol Control* 2007;18(6):519 – 21. <http://dx.doi.org/10.3969/j.issn.1003-4692.2007.06.031>. (In Chinese).
14. Chen Z, Yang XJ, Bu FJ, Yang XH, Yang XL, Liu JZ. Ticks (acari: ixodoidea: argasidae, ixodidae) of China. *Exp Appl Acarol* 2010;51(4):393 – 404. <http://dx.doi.org/10.1007/s10493-010-9335-2>.
15. Zhou S, Lin Y, Zu HY, Wang JH. Identification of tick species and investigation of *Anaplasma* spp. in some areas of Hainan. *J Trop Biol* 2023;14(2):159 – 65. <http://dx.doi.org/10.15886/j.cnki.rdsxb.2023.02.004>. (In Chinese).
16. Sun DW, Wang SQ, Zhao W, Wang GR, Wang YY, Zeng LH, et al. Investigation of seasonal fluctuation of ticks on bulls and dogs in Chengmai County in Hainan Province. *China Trop Med* 2011;11(9):1081 – 2. <http://dx.doi.org/10.13604/j.cnki.46-1064/r.2011.09.005>. (In Chinese).
17. An LP, Pei YX, Suo PH, Han Q, Zhao JG. Biological characteristics and artificial laboratory rearing of *Rhipicephalus sanguineus* in Hainan. *China Trop Med* 2022;22(6):522 – 8. <http://dx.doi.org/10.13604/j.cnki.46-1064/r.2022.06.07>. (In Chinese).
18. Zhang L, Wen S, Hou XX, Li S, Yang XN, Chen T, et al. Detection and genotyping of *Borrelia burgdorferi* in parasitic ticks in Qiongzong area of Hainan province, China. *Chin J Vector Biol Control* 2020;31(4):426 – 9,464. <http://dx.doi.org/10.11853/j.issn.1003.8280.2020.04.009>. (In Chinese).
19. Chen SD, Wu BW, Chen JR, Lian JH, Lin DX. Isolation of *Q Rickettsia* from *Boophilus microplus* in Hainan province. *J Guangdong Pharm Univ* 1989;5(2):42 – 5. <http://dx.doi.org/10.16809/j.cnki.1006-8783.1989.02.011>. (In Chinese).
20. Sun DW, Wang SQ, Zhao W, Wang GR, Wang YR, Zeng LH, et al. Seasonal succession of ticks in small wild animals in Chengmai county of Hainan province. *Chin J Public Health* 2012;28(12):1620 – 2. <http://dx.doi.org/10.11847/zggws-2012-28-12-25>. (In Chinese).
21. Huang LY, Zhou S, Liao HY, Wang JH. Molecular epidemiological investigation and genetic diversity analysis of Anaplasmas cattle in Hainan. *Trop Agric Eng* 2021;45(6):9-15. <https://d.wanfangdata.com.cn/periodical/rdnygc202106003>. (In Chinese).
22. Zhang LJ, Liu H, Xu BL, Lu QY, Li L, Chang LT, et al. *Anaplasma phagocytophilum* infection in domestic animals in ten provinces/cities of China. *Am J Trop Med Hyg* 2012;87(1):185 – 9. <http://dx.doi.org/10.4269/ajtmh.2012.12-0005>.
23. Wang SW, He J, Zhang LJ. Serological investigation of vector-borne disease in dogs from rural areas of China. *Asian Pac J Trop Biomed* 2012;2(2):102 – 3. [http://dx.doi.org/10.1016/S2221-1691\(11\)60201-3](http://dx.doi.org/10.1016/S2221-1691(11)60201-3).
24. Bi TL. Molecular epidemiological investigation study on cattle infected with *Anaplasma*, *Babesia* and *Theileria* in Qiongbai area [dissertation]. Haikou: Hainan University; 2021. <http://dx.doi.org/10.27073/d.cnki.ghadu.2021.000933>. (In Chinese).
25. Zhang L, Wen S, Hou XX, Li S, Yang XN, Chen T, et al. Detection and genotyping of *Borrelia burgdorferi* in parasitic ticks in Qiongzong area of Hainan province, China. *Chin J Vector Biol Control* 2020;31(4):426 – 9,464. <http://dx.doi.org/10.11853/j.issn.1003.8280.2020.04.009>. (In Chinese).
26. Zhao HQ, Liu PP, Xue F, Lu M, Qin XC, Li K. Molecular detection and identification of *Candidatus Ehrlichia hainanensis*, a novel *Ehrlichia* species in rodents from Hainan province, China. *Biomed Environ Sci* 2021;34(12):1020 – 3. <http://dx.doi.org/10.3967/bes2021.138>.
27. Li JJ, Liu XX, Mu JQ, Yu XB, Fei YD, Chang J, et al. Emergence of a novel *Ehrlichia minasensis* strain, harboring the major immunogenic glycoprotein trp36 with unique tandem repeat and C-terminal region sequences, in haemaphysalis hystricis ticks removed from free-ranging sheep in Hainan Province, China. *Microorganisms* 2019;7(9):369. <http://dx.doi.org/10.3390/microorganisms7090369>.
28. Wei FR, Lan QX, Zhu D, Ye JH, Liu Q, Zhang Y. Investigation on *Babesia* in ticks infested on police dogs in selected areas of China. *Chin J Parasitol Parasit Dis* 2012;30(5):390-2. <http://qikan.cqvip.com/Qikan/Article/Detail?id=43679584>. (In Chinese).
29. Wang JM, Yang JF, Gao SD, Wang XX, Sun H, Lv ZY, et al. Genetic diversity of *Babesia bovis* MSA-1, MSA-2b and MSA-2c in China. *Pathogens* 2020;9(6):473. <http://dx.doi.org/10.3390/pathogens9060473>.
30. Wang JM, Yang JF, Liu JL, Wang XX, Xu JL, Liu AH, et al. Molecular detection and genetic diversity of *Theileria orientalis* in cattle in China. *Parasitol Res* 2018;117(12):3689 – 94. <http://dx.doi.org/10.1007/s00436-018-6023-3>.
31. Yang L, Wang JH, Upadhyay A, Zhao JG, Huang LY, Liao CH, et al. Identification of *Theileria* spp. and investigation of hematological profiles of their infections in goats in Hainan Island, China. *Parasite* 2022;29:13. <http://dx.doi.org/10.1051/parasite/2022013>.
32. Chen WZ, Qiu FX, Calisher CH, Liu JC, Chen HX, Li XD, et al. Twenty-eight alphavirus strains isolated from mosquitoes and ticks captured from Hainan Island, China. *Chin J Exp Clin Virol* 1997;11(2):144 – 6. <http://dx.doi.org/10.3760/cma.j.issn.1003-9279.1997.02.117>. (In Chinese).
33. Fang LQ, Liu K, Li XL, Liang S, Yang Y, Yao HW, et al. Emerging tick-borne infections in mainland China: an increasing public health threat. *Lancet Infect Dis* 2015;15(12):1467 – 79. [http://dx.doi.org/10.1016/S1473-3099\(15\)00177-2](http://dx.doi.org/10.1016/S1473-3099(15)00177-2).
34. Wu J, Wang SL, Jin YM, Ma Y, Zeng XJ, Jia PB, et al. Detection of groEL gene in spotted fever group Rickettsia of patients with fever in Hainan province. *Mod Prev Med* 2014;41(13):2417-9. <https://d.wanfangdata.com.cn/periodical/xdyfyx201413037>. (In Chinese).
35. Lin BH, Sun XJ, Zhan ZN, Lin YZ, Li WG. Serological and etiological studies on undefined rickettsiosis on Hainan island. *J Hainan Med Univ* 1997;3(3):97-102. <https://kns.cnki.net/kns8/Detail?sfid=fn&QueryID=0&CurRec=1&recid=&FileName=HNY703.000&DbName=CJFD9697&DbCode=CJFD&yx=&pr=&URLID=>. (In Chinese).
36. Zhang L, Zhu X, Hou XX, Li H, Yang XN, Chen T, et al. Prevalence and prediction of Lyme disease in Hainan province. *PLoS Negl Trop Dis* 2021;15(3):e0009158. <http://dx.doi.org/10.1371/journal.pntd.0009158>.
37. Zhu X, Zhang L, Hou XX, Geng Z, Chen H, Chen T, et al. Investigation on Lyme Disease of patients with arthritis or neurological disorders in Hainan Province, China. *Chin J Zoonoses* 2015;31(4):353 – 6. <http://dx.doi.org/10.3969/cjz.j.issn.1002-2694.2015.04.013>. (In Chinese).
38. Zhang LJ, Liu H, Xu BL, Zhang ZL, Jin YM, Li WM, et al. Rural residents in China are at increased risk of exposure to tick-borne pathogens *Anaplasma phagocytophilum* and *Ehrlichia chaffeensis*. *Biomed Res Int* 2014;2014:313867. <http://dx.doi.org/10.1155/2014/313867>.
39. Wu XB, Na RH, Wei SS, Zhu JS, Peng HJ. Distribution of tick-borne diseases in China. *Parasit Vectors* 2013;6:119. <http://dx.doi.org/10.1186/1756-3305-6-119>.