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, 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, Qiongzhong, 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, Qiongzhong, and Sanya (*9,11,17–18*) (Figure 1).

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

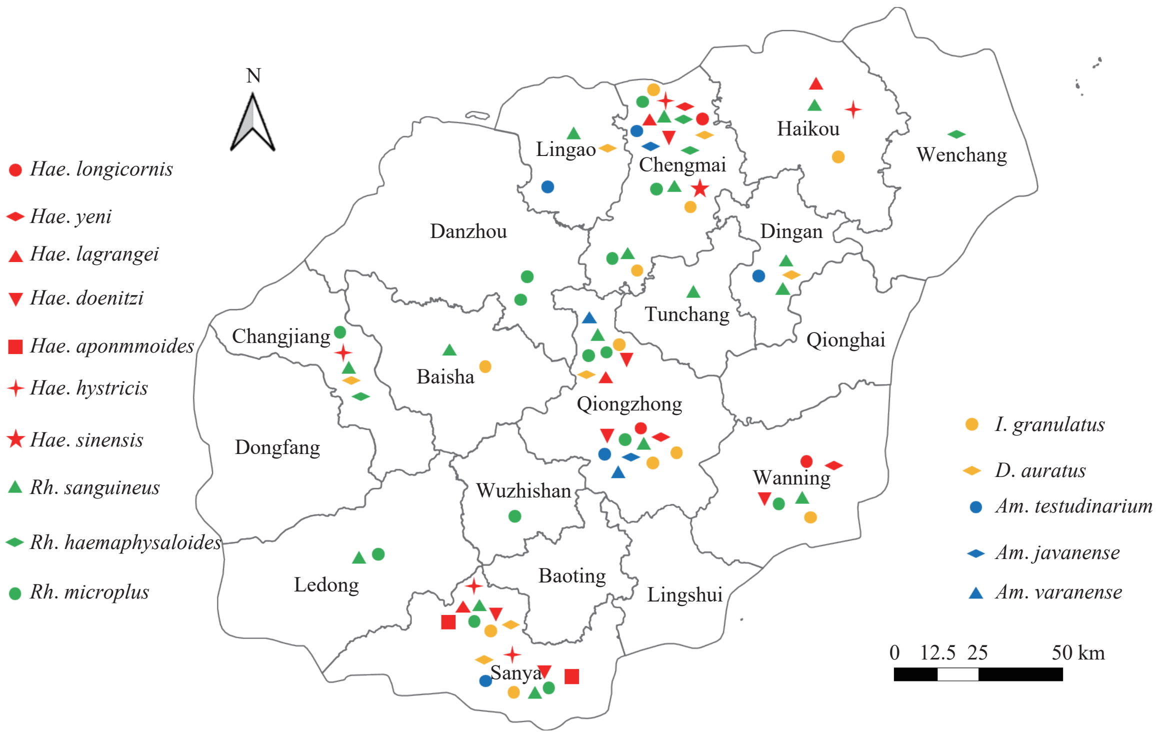


FIGURE 1. Geographical distribution of hard ticks on Hainan Island in China, 1980–2023.
Note: *Haemaphysalis formosensis, Hae. cornigera*, *Hae. mageshinaensis*, *Am. hainanense*, *Am. helvolum*, and *Hy. isaaci* were not drawn on the map due to the unspecified place recorded in the references.

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.chinadc.cn).

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

A comprehensive review of existing literature on TBPs 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, Qiongzhong 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 heilongjiangiensis*, 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

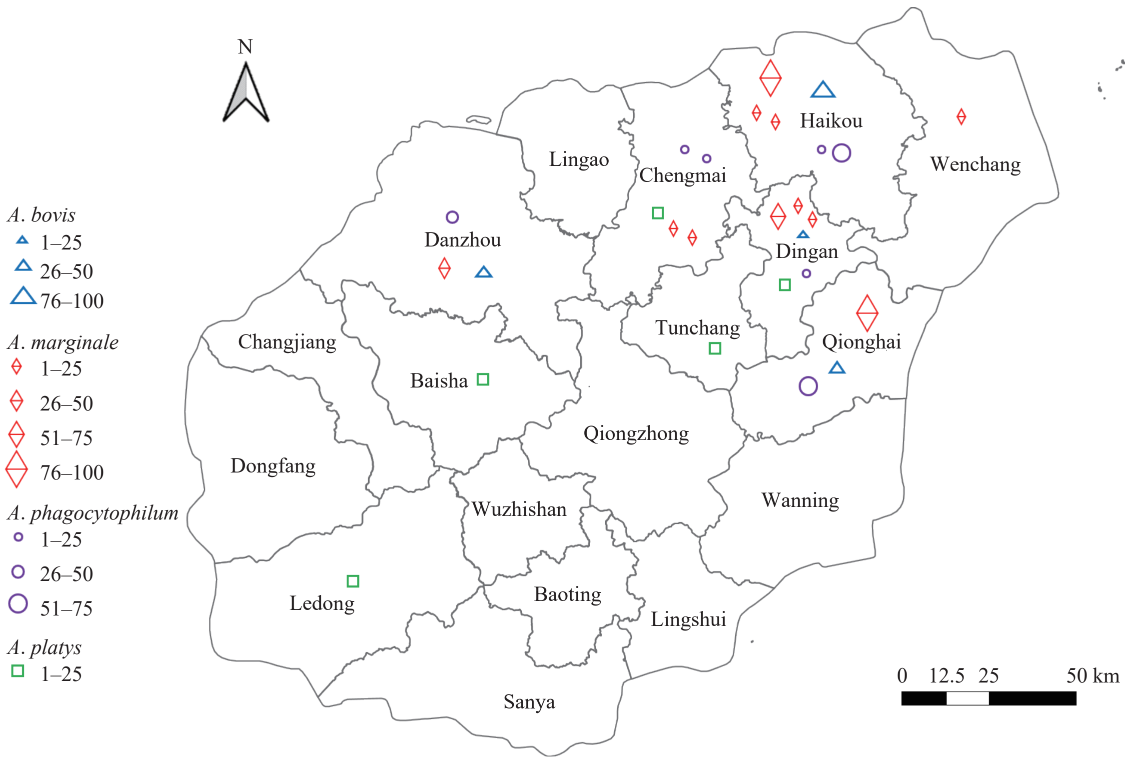


FIGURE 2. Geographic distribution of emerging infections caused by agents in the *Anaplasma* genus in ticks and animals in Hainan, China.
Note: In an uncharted area of the region, infection with *Anaplasma marginale* was detected, expanding its known presence to Haikou, the region's capital. Samples collected from Baisha, Ledong, Dingan, 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, Dingan, 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, Qiongzhong, 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 Dingan, 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

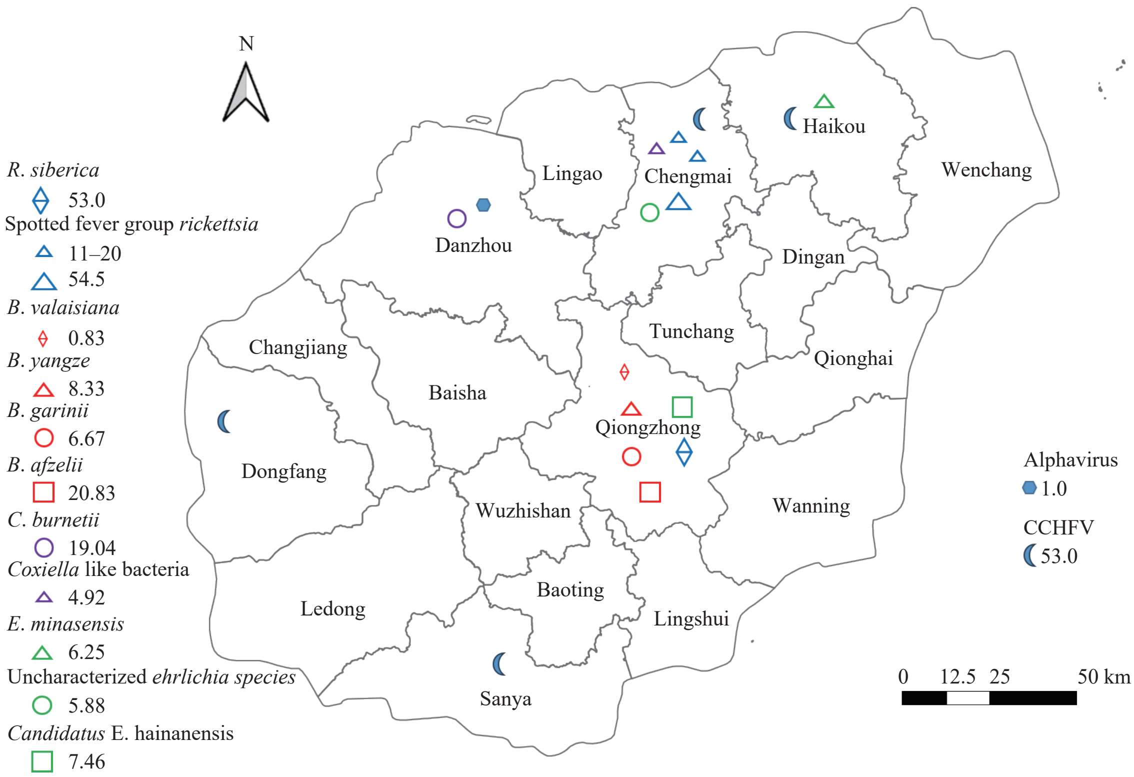


FIGURE 3. Geographic distribution of emerging infections from viruses and bacteria, excluding the *Anaplama* genus, in ticks and animals in Hainan, China.
Abbreviation: CCHFV=Crimean-Congo haemorrhagic fever virus.

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, Qiongzhong, 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

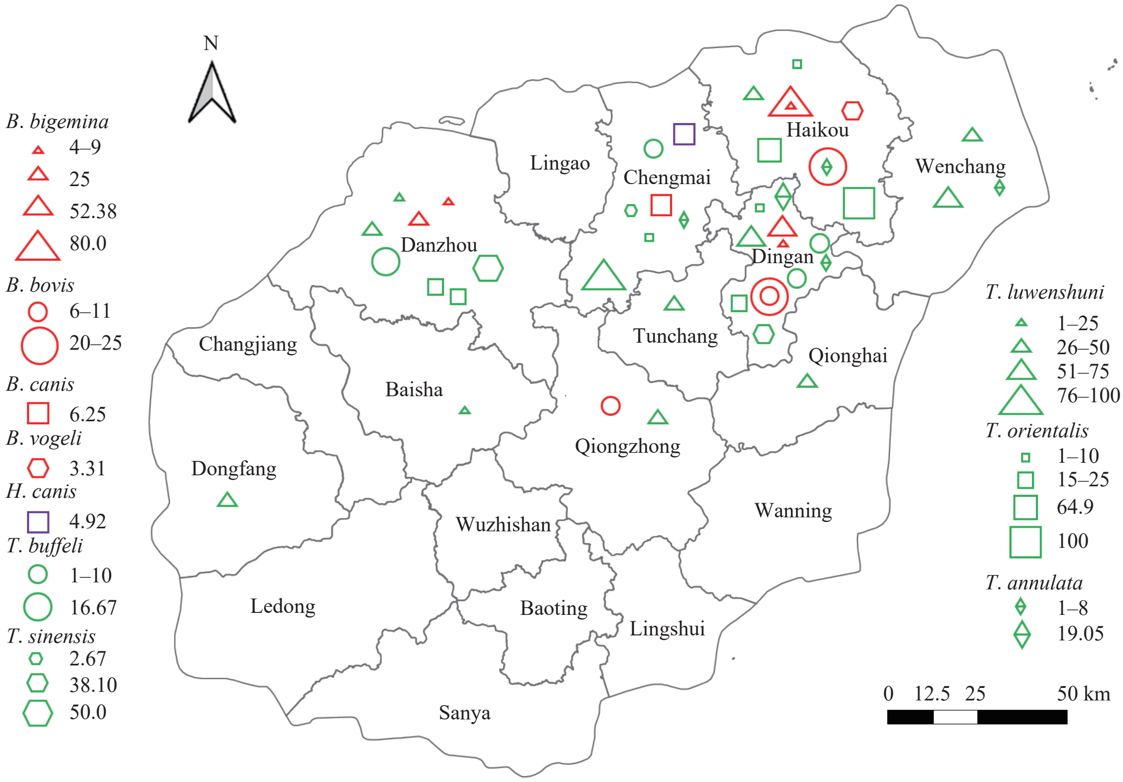


FIGURE 4. Geographic distribution of emerging protozoan infections in ticks and animals in Hainan, China.
Note: A documented case of *Babesia vogeli* infection was identified in an unspecified area of the region, extending its known occurrence to Haikou, the capital of this region. Furthermore, a case of *Babesia bovis* infection, previously found in Central Hainan, has now been registered within the location of Qiongzhong. The term "Qiongzhong" in Chinese denotes "Central part of Hainan," accurately portraying its geographical siting in the central part of the island.

and TBPs 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.

**Acknowledgements**: Professor Guojing Yang and Mr. Mingfa Li for illustrating the geographical distributions of ticks and TBPs.

**Funding:** Supported by the Major Science and Technology Program of Hainan Province (grants ZDKJ202003, ZDKJ2021036, and SKJ10006). Additionally, financial support was received from the National Natural Science Foundation of China (grant 81960002) and the Science and Technology Plan of Hainan Province (specifically, the Hainan Province Clinical Medical Center, SRC220002). The research benefited from a grant awarded by the Hainan Provincial Natural Science Foundation of High-Level Talent Project (821RC1152).

**doi:** 10.46234/ccdcw2023.157

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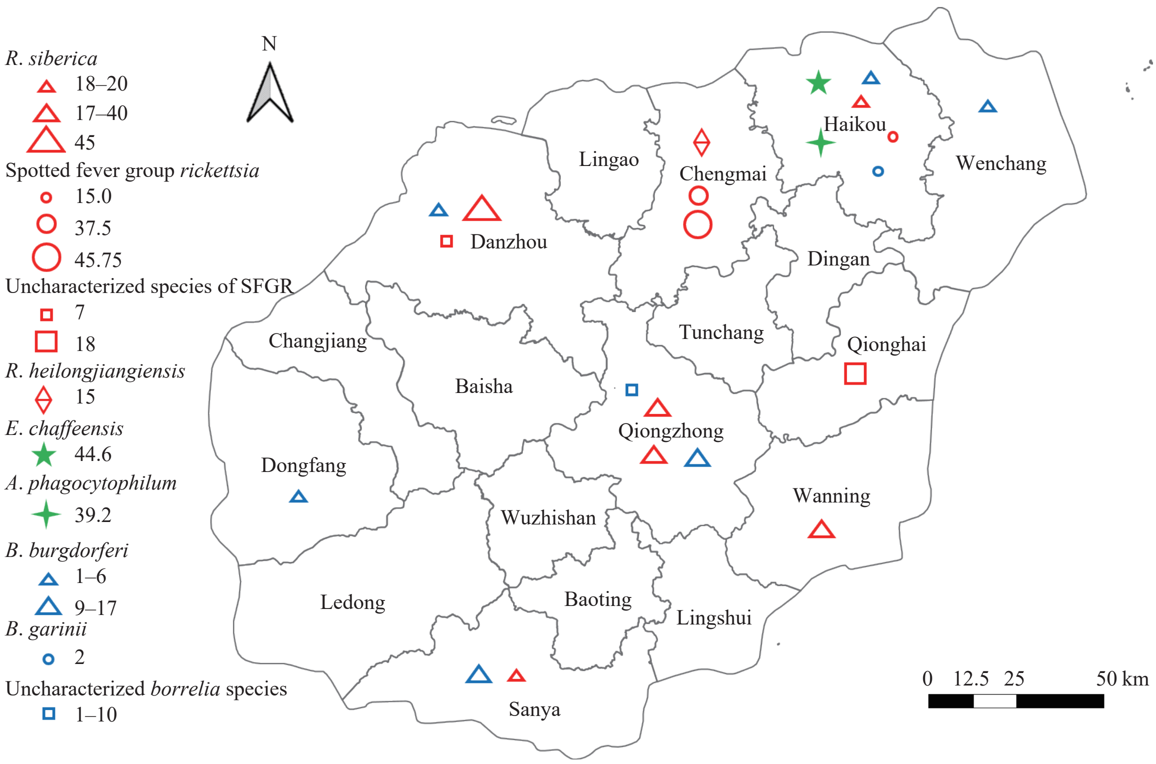


FIGURE 5. Documented distributions of human tick-borne pathogen infection at the county level in Hainan, China.
Note: The documentation of infections from the spotted fever group *Rickettsia*, *Anaplasma phagocytophilum*, and *Ehrlichia chaffeensis* has been extended to include an unidentified region within Haikou. Similarly, a case of infection with an uncharacterized species of *Borrelia* in the central area of Hainan has been reported in Qiongzhong.

Submitted: August 07, 2023; Accepted: September 08, 2023

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# 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.

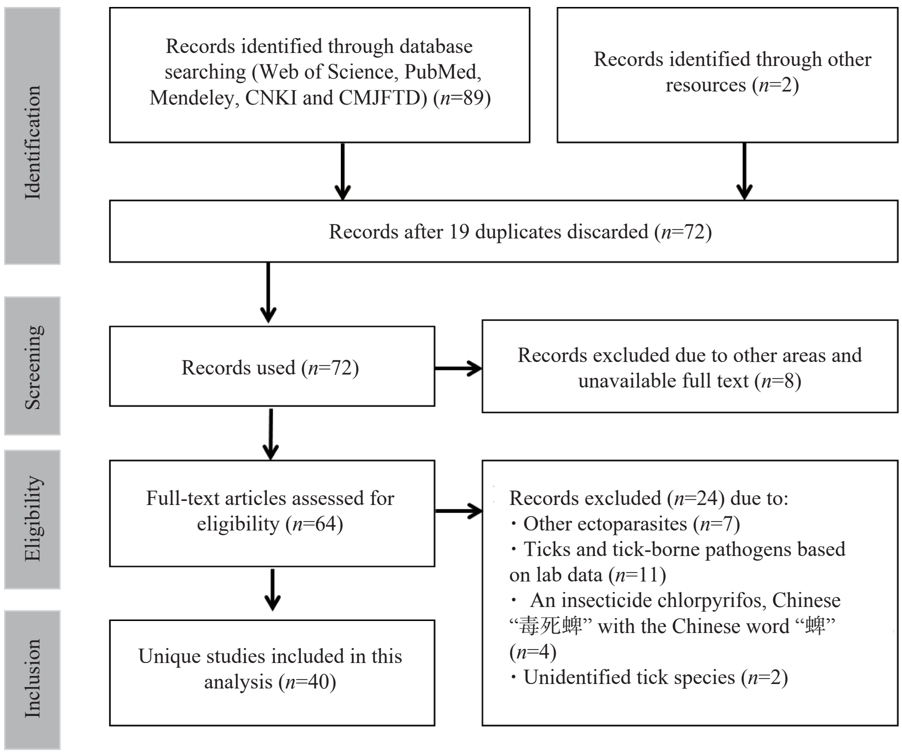
Articles pinpointing sample locale to the county level and identifying specific tick species or specific TBP genus was primarily included in this study. Furthermore, articles providing more detailed information such as hosts of ticks or TBPs, or that specified sample locations to the township level were 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 | *Hae. longicornis* | Wild animals and livestock, *Bubalus bubalis*, *Bos Taurus*, *Capra aegagrus hircus*, and *Canis lupus familiaris* | (*1*–*2*) |
| 2 | *Hae. formosensis* | *Sus scrofa*, dog and muntiacus | (*3*–*4*) |
| 3 | *Hae. yeni* | *Cervus unicolor*, *Cuon alpinus*, dog, wild and domestic animals, and *Capra aegagrus hircus* | (*1*–*3*) |
| 4 | *Hae. lagrangei* | *Muntiacus manijak* and other *Muntiacus* species, *Niviventer confucianus*, *Rattus fulvescents*, wild and domestic animals, rodent, *Bos Taurus*, and *Capra aegagrus hircus*, | (*1*, *3*, *5*–*9*) |
| 5 | *Hae. cornigera* | *Bubalus bubalis*, *Bos taurus* and rodents | (*3*–*4*) |
| 6 | *Hae. doenitzi* | *Francolinus pintadeanus*, *Centropus* spp., *Rycnonotus sinensis*, *Bambusicola thoracica*, *Rattus rattus hainanicus*, *Rattus rattus, Niviventer confucianus*, *Rattus fulvescents*, *Rattus coxingi*, *Rattus cremoriventer*, *Niviventer confucianus lotipes*, *Neohylomys hainanensis*, rodent, *Capra aegagrus hircus*, and *Gallus gallus domesticus* | (*1*–*3*, *5*, *7*–*11*) |
| 7 | *Hae. aponommoides* | *Rattus rattus hainanicus*, *Niviventer confucianus*, *Rattus coxingi*, *Rattus cremoriventer*, *Rattus rattus*, *Niviventer confucianus lotipes*, and *Neohylomys hainanensis* | (*5*, *7*–*8*) |
| 8 | *Hae. hystricis* | *Niviventer confucianus*, *Rattus coxingi*, *Dremomys pernyi*, wild and domestic animals, rodents, *Sus scrofa*, *Ovis aries*, | (*1*, *2*, *5*–*8*) |
| 9 | *Hae. sinensis* | *Bubalus bubalis*, *Canis lupus familiaris*, and farm's house | (*12*) |
| 10 | *Hae. mageshinaensis* | Wild and domestic animals | (*6*) |
| 11 | *Am. testudinarium* | *Bubalus bubalis*, *Bos Taurus*, *Sus scrofa*, *Cervus unicolor*, horses, goats, dogs, pigs, wild and domestic animals, and rodents | (*1*–*3*, *13*) |
| 12 | *Am. javanense* | *Manis pentadactyla*, *Python molurus*, *Varanus salvator*, *Geoemyda tricarinata*, wild and domestic animals, and snakes | (*1*–*3*, *6*) |
| 13 | *Am. hainanense* | Snake | (*3*–*4*) |
| 14 | *Am. varanense* | *Varanus salvator*, *Python molurus*, *Naja,* and rodent | (*3*, *9*–*10*) |
| 15 | *Am. helvolum* | Snake | (*4*, *14*) |
| 16 | *Rh. sanguineus* | Stray dogs, *Canis lupus familiaris*, *Niviventer confucianus*, wild and domestic animals, *Canis lupus familiaris*, rodent, *Bubalus bubalis*, *Bos Taurus*, *Capra aegagrus hircus*, rodents, and *Lepus sinensis* | (*1*–*3*, *5*–*7*, *9*, *11*, *13*, *15*–*17*) |
| 17 | *Rh. haemaphysaloides* | *Bubalus bubalis*, *Bos Taurus*, *Equus asinus*, *Canis lupus familiaris*, *Capra aegagrus hircus*, *Ovis aries*, *Lepus sinensis*, *Sus scrofa*, *Cervus unicolor*, pig, farm's house, and wild and domestic animals | (*1*–*3*, *12*) |
| 18 | *Rh. microplus* | *Bos Taurus*, *Capra aegagrus hircus*, *Bubalus bubalis*, *Rattus rattus hainanicus*, *Rattus norvegicus*, farm's house, wild and domestic animals, and rodents | (*1*–*3*, *5*, *7*, *9*, *11*, *16*, *18*–*19*) |
| 19 | *I. granulatus* | *Rattus rattus hainanicus*, *Rattus rattus*, *Niviventer confucianus*, *Rattus norvegicus*, *Rattus rattoides*, *Rattus fulvescents*, *Rattus coxingi*, *Rattus cremoriventer*, *Rattus losea*, *Rattus flavipectus*, *Rattus edwardsi*, *Rattus norvegicus*, *Niviventer confucianus lotipes*, *Dremomys pernyi*, *Neohylomys hainanensis*, *Tupaia glis*, *Tamiops swinhoei maritimus*, wild and domestic animals, rodents, *Bos Taurus*, and *Capra aegagrus hircus* | (*1*, *2*, *5*–*11*, *20*) |
| 20 | *D. auratus* | *Sus scrofa*, *Bubalus bubalis*, *Arctonyx collaris*, *Selenarctos thibetanus*, *Canis lupus familiaris* and pig, *Rattus rattus hainanicus*, *Niviventer confucianus*, *Rattus cremoriventer*, wild and domestic animals, and rodents | (*1*–*3*, *5*, *7*, *9*, *13*) |
| 21 | *Hy. isaaci* | Birds, small mammals, *Bos Taurus*, and *Capra aegagrus hircus* | (*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 | *Anaplasma* | *A. bovis* (Ab), *A. marginale* (Am), *A. phagocytophilum* (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%. | |
| | | *A. platys* | *Rh. Sanguineus* from dogs | Baisha, Ledong, Dingan, Tunchang | 1.1% | (*15*) |
| | | *A. phagocytophilum* | RSH (*Rh. sanguineus* from farmer's house); RMGC (*Rh. microplus* from goats and cattle), RSD (*Rh. sanguineus* from dogs) | Chengmai | 3.6 (RSH), 7.5 (RMGC and RSD) | (*22*) |
| | | *A. phagocytophilum* | Dogs | Unknown place of Hainan | 25 | (*23*) |
| | | *A. marginale* | 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 | |
| | | *A. marginale* | *Rh. microplus* | Chengmai | 8.82 | (*1*) |
| | | *A. platys* | *Rh. sanguineus* | Chengmai | 3.28 | |
| | *Rickettsia* | *R. siberica* | Rodent | Qiongzhong | 53.0 | (*10*) |
| | | Spotted fever group *Rickettsia* | Rodent, dog, and tick (*Rh. Haemaphysaloides* and *Rh. microplus*) | Chengmai | 15.9 (Rodent), 16.7 (dog), 54.5 (tick) | (*12*) |
| | *Borrelia* | *Bo. afzelii* | *Rh. microplus* | Qiongzhong | 20.83 | (*25*) |
| | | *Bo. yangze,* | | | 8.33 | |
| | | *Bo. valaisiana* | | | 0.83 | |
| | | *Bo. garinii* | | | 6.67 | |
| | *Coxiella* | *C. burnetii* | *Rh. microplus* | Danzhou | 19.04 | (*19*) |
| | | *Coxiella* like bacteria | *Rh. sanguineus* | Chengmai | 4.92 | (*1*) |
| | *Ehrlichia* | *Candidatus* E. hainanensis | Rodents | Qiongzhong | 7.46 | (*26*) |
| | | *E. minasensis* | *Hae. hystricis* | Haikou | 6.25 | (*27*) |
| | | Uncharacterized *Ehrlichia* species | *Rh. microplus* | Chengmai | 5.88 | (*1*) |

Continued

| Group | Genus | Species | Hosts/vector | Detection location | Detection rate (%) | Reference |
|---|---|---|---|---|---|---|
| Protozoans | *Babesia* | *Ba. vogeli* | Ticks from dogs | Unknown place | 3.31 | (*28*) |
| | | *Ba. bovis* | Cattle | Central part of Hainan | 10.2 | (*29*) |
| | | | Cattle | Haikou | 20 | (*24*) |
| | | | Cattle and buffalo | Dingan | 23.81 (cattle), 6.52 (buffalo) | (*24*) |
| | | *Ba. bigemina* (Bb), *Ba. bovis* (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) | |
| | | *Ba. canis* | *Rh. sanguineus* | Chengmai | 6.25 | (*1*) |
| | *Theileria* | *T. orientalis* | Cattle | Haikou | 64.9 | (*30*) |
| | | *T. luwenshuni* | Goat | Baisha | 20.7 | (*31*) |
| | | | | Qiongzhong | 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 | |
| | | *T. annulata* | Tick | Haikou | 7.69 | (*24*) |
| | | *T. orientalis* | Tick | | 7.69 | |
| | | *T. orientalis* | Cattle | | 100 | |
| | | *T. sinensis* | Cattle | Danzhou | 50 | |
| | | *T. orientalis* | Cattle | | 25 | |
| | | *T. orientalis* | Tick | | 16.67 | |
| | | *T. luwenshuni* | Tick | | 8.33 | |
| | | *T. buffeli* | Tick | | 16.67 | |
| | | *T. sinensis* | Cattle | Dingan | 38.10 | |
| | | *T. orientalis* | Cattle | | 23.81 | |
| | | *T. buffeli* | Cattle | | 9.52 | |
| | | *T. annulata* | Cattle | | 19.05 | |
| | | *T. orientalis* | Buffalo | | 2.17 | |
| | | *T. buffeli* | Buffalo | | 8.70 | |
| | | *T. annulata* | Buffalo | | 4.35 | |
| | | *T. sinensis* | Wagyu cattle | Chengmai | 2.67 | |
| | | *T. orientalis* | Wagyu cattle | | 8.00 | |
| | | *T. buffeli* | Wagyu cattle | | 2.67 | |
| | | *T. annulata* | Wagyu cattle | | 2.67 | |
| | | *T. luwenshuni* | Tick | Wenchang | 47.83 | |
| | | *T. annulata* | Tick | | 4.35 | |
| | *Hepatozoon* | *Hepatozoon canis* | *Rh. sanguineus* | 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 | *Rickettsia* | *R. siberica* | Qiongzhong | 38.3 | (*10*) |
| | | *R. heilongjiangiensis* | Chengmai | 15* | (*33*) |
| | | Uncharacterized species of SFGR | Danzhou,<br>Qionghai | 7*<br>18* | (*33*) |
| | | SFGR | UP | 15.0 | (*34*) |
| | | *R. siberica* | Wanning<br>Sanya<br>Danzhou<br>Haikou<br>Qiongzhong | 27.62<br>18.56<br>45.00<br>19.15<br>39.71 | (*35*) |
| | | SFGR | Chengmai | 37.5 or<br>45.75 | (*12*) |
| | *Borrelia* | *Bo. garinii* | Haikou | 2* | (*33*) |
| | | Uncharacterized species of *Bo. burgdorferi* sensu lato | Central part of Hainan | 1–10* | (*33*) |
| | | *Bo. burgdorferi* s. l. | Wenchang<br>Danzhou<br>Dongfang<br>Qiongzhong<br>Haikou | 1.99<br>3.36<br>4.62<br>16.67<br>5.88 | (*36*) |
| | | *Bo. burgdorferi* s. l. | Sanya | 9.96 | (*37*) |
| | *Anaplasma* | *A. phagocytophilum* | UP | 39.2 | (*38*) |
| | *Ehrlichia* | *E. chaffeensis* | UP | 44.6 | (*38*) |
| | *Coxiella* | *C. burneti* | UP | NA | (*39*) |
| Viruses | *Coltivirus* | Colorado tick fever virus | UP | NA | (*39*) |
| | *Nairovirus* | 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*.

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