A CHECKLIST AND TAXONOMIC KEY TO THE TICKS [ACARI: IXODIDAE AND ARGASIDAE] OF ILLINOIS: ESTABLISHING A BASELINE FOR RESEARCH AND SURVEILLANCE

BY

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THESIS

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ABSTRACT

Ticks [Acari: Ixodidae and Argasidae] are major vectors of medical and veterinary importance, and over the last few decades the United States Midwest has become a hotspot for tick-borne disease risk. However, one major hurdle in understanding tick populations in the Midwest is the scarcity of resources available on tick taxonomy in this region. Checklists of tick species present in the Midwest are lacking, as are corresponding natural history and identification resources. The goal of this thesis was to develop taxonomic resources for the ticks of Illinois in order to gain a better understanding of the biodiversity and natural history of ticks in the state.

Chapter 1 addressed this goal through the development of a checklist of tick species present in Illinois, their distributions, and their host associations. This was done by synthesizing collection records from scientific literature, natural history collections, contemporary citizen submissions, and interception reports. This chapter found thirteen species of ticks, one in the family Argasidae and twelve in the family Ixodidae, that meet the criteria for establishment in Illinois. Records of these thirteen species have been recovered from seventy-seven different host species. There were another twenty-five species that were reported in Illinois on either native hosts, humans, migratory birds, or imports, but not in high enough quantities to be considered established.

Chapter 2 expanded upon these results through the creation of taxonomic keys for the fifteen species of nymphal hard ticks that have been either established or reported on native hosts in Illinois. Nymphal ticks are among the most important life stages for disease transmission, and the identification of nymphs is important for assessments of tick-borne disease risk. Two types of taxonomic keys were constructed: a traditional dichotomous key and a matrix-based key, with

the goal of making pictographic nymphal tick identification resources that are concise and easy to use. Combined, the results of these two chapters consolidate and update information on the biodiversity, distributions, host associations, and identification of ticks in Illinois, and in doing so establishes a baseline of knowledge from which robust tick surveillance, control, and research programs can be developed.

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CHAPTER 1

A Checklist and Assessment of Host Associations of Illinois Ticks [Acari: Ixodidae and Argasidae]

ABSTRACT

Tick-borne diseases present a major and growing public health concern, with their combined incidence doubling over the past fifteen years in the continental United States. The United States Midwest, where several tick species and associated disease agents are expanding, is a rapidly emerging and relatively understudied area of tick-borne disease concern. Yet, checklists and ecological reviews of tick and pathogen species present in the Midwest are lacking, and more research is necessary to understand their biodiversity in this area of the country. One aim of this study was to develop a comprehensive checklist to the ticks [Acari: Ixodidae and Argasidae] of Illinois. Another was to document and examine tick-host associations in the state, and a third was to review records of import interceptions and ticks in neighboring states to anticipate potential future invasions. These aims were achieved by compiling occurrence records from scientific literature, natural history collections, citizen tick submissions, and interception records. Thirteen tick species met the criteria to be considered established in Illinois, and an additional twenty-five species were reported within the state. The thirteen established tick species were reported on seventy-seven different host species. This work provides a baseline for studying tick biodiversity and tick-host relationships within the state of Illinois, from which future range expansions, introductions of potentially invasive ticks, and novel tick-host associations, may be assessed.

INTRODUCTION

Ticks are a diverse clade of ectoparasites that are widely distributed around the world, feed on a variety of vertebrate hosts, and are most well-known for their ability to transmit pathogens of medical and veterinary concern. The word “ticks” is used to describe species in three different families (Ixodidae, Argasidae, and Nuttalliellidae), two of which, the Ixodidae (hard ticks) and Argasidae (soft ticks) are found in North America (Keirans, 1992). As of the most recent surveys, there are approximately 750 species in the family Ixodidae and approximately 200 species in the family Argasidae worldwide (Guglielmone et al., 2010, 2020). The systematics and taxonomy of ticks has historically been challenging to untangle, but developing a better understanding of tick taxonomy and natural history is vital for developing a better understanding of vector-borne disease (Guglielmone et al., 2010).

Knowledge of baseline tick diversity plays an important, if often overlooked, role in the study of vectors and vector-borne disease. Accurate identification is an integral part of the tick-borne disease diagnostic process. As different species of ticks can be responsible for the transmission of different pathogens, knowing which species bit a person or other animal can be a crucial piece of information in the diagnostic process. Additionally, accurate identification of ticks and knowledge of natural history is an essential component of robust ecological studies on environmental and host associations, pathogen maintenance, and spillover. Thus, a lack of taxonomic and natural history resources can lead to a subsequent lack of resources and diagnostic support. In addition, characterizing tick diversity is necessary to understand tick population changes, detect novel tick-host associations, and understand how these factors may impact subsequent tick-borne disease risk (Hahn et al., 2020; Madison-Antenucci et al., 2020). As tick populations continue to shift, due to factors such as climate and land use change, we must be prepared to document these changes, and our understanding of regional tick diversity must also adapt to reflect them.

Within the United States, over the past few decades the Ohio River Valley region of the Midwest has emerged as an area of growing concern for tick-borne disease risk. Recent studies have documented several species historically considered tropical or subtropical, such as the lone star tick *Amblyomma americanum* (Linnaeus, 1758) and Gulf Coast tick *A. maculatum* Koch, 1844 occurring further north than previously recognized (Monzón et al., 2016; Phillips et al., 2020; Raghavan et al., 2019). Other studies have demonstrated the possible colonization or reemergence of additional species, such as the blacklegged tick *Ixodes scapularis* Say, 1821, farther into the Midwest (Eisen et al., 2016; Hahn et al., 2016; Sonenshine, 2018). While in some cases these apparent population range expansions and shifts are likely novel, in others they may represent recolonization or the correction of previous under-reporting (Eisen & Eisen, 2018; Gardner et al., 2020; Rochlin et al., 2022). Due to its size, diversity of landscapes and land use, and geographic location, Illinois can provide a baseline for documenting and understanding historic range shifts in tick and pathogen populations and serve as an exemplar for studying ticks and tick-borne disease risk in this area of the country.

Increasing human tick-borne disease rates in Illinois are likely primarily due to these shifts in tick populations, although some of the change may be attributed to prior underdiagnosis and growing awareness of tick-borne disease among clinicians (Delaney et al., 2020; Schiffman et al., 2018). The number of reported human tick-borne disease cases in Illinois has increased four-fold in the past two decades, with Lyme disease as the most common tick-borne disease reported (Centers for Disease Control and Prevention (CDC), 2020). Additional human tick-borne diseases reported from Illinois include Alpha-gal syndrome, anaplasmosis, ehrlichiosis, Heartland virus, and Rocky Mountain Spotted Fever (Adjemian et al., 2009; Heitman et al., 2016; Tuten et al., 2020; Wilson et al., 2021). Yet, despite an increase of research on tick-borne diseases in Illinois in recent decades, taxonomic works for this area of the country are still lacking.

The aims of this study were to begin to address this lack of resources for the Midwest by developing a checklist of the ticks of Illinois and assessing tick-host associations in the state.

METHODOLOGY

Tick collection records from Illinois were gathered from four types of sources: Scientific literature, natural history collections, interception records, and contemporary passive surveillance.

Scientific Literature

A systematic literature review of published tick collections in Illinois was completed in Web of Science on January 11th, 2021. The search terms used were: (Ixodidae OR Argasidae OR tick OR ticks OR Amblyomma OR Dermacentor OR Haemaphysalis OR Ixodes OR Rhipicephalus) AND Illinois. Abstracts indexed up until December 2020 were screened, and relevant papers were included. Relevant publications included those that documented original tick collections within the state. Papers that did not contain tick collections, did not include collections within Illinois, or only included data that were originally published elsewhere were excluded. Additional papers were included that documented tick collections in Illinois and were cited in papers from the initial review but did not appear in the initial search itself. In total, 45 scientific publications were included (Table 1.1).

Natural History Collections and Interception Records

Tick occurrence records were compiled from four natural history collections: the Illinois Natural History Survey Insect Collection, the United States National Tick Collection at Georgia Southern University, the Ohio State Acarology Collection, and the Milwaukee Public Museum. Interception records from USDA-APHIS from July 1st, 2008 through June 24th, 2021 were also included. These interception records included ticks collected from animals or materials during USDA inspections while entering the United States and suspected exotics forwarded to USDA-APHIS personnel from veterinarians in Illinois (Stephen Young, personal communication). Records were cross-referenced, and duplicate records (i.e. those reported in multiple databases) were removed.

Passive Tick Surveillance

Since 2019, the Illinois Natural History Survey Medical Entomology Lab has provided a public health tick identification service for Illinois. As part of this program, members of the Illinois community and visitors to the state can submit ticks, along with collection information and travel history, for identification and archiving. Ticks submitted to the program between March of 2019 and April of 2021, for which the reporter answered whether travel outside the county had occurred within the past ten days, were included in this review.

Development of Database

Occurrence records generated from these four types of sources were compiled into one database. When the information was provided, for each record data were included on genus, species, life stage, sex, number of ticks, host/collection method, specific collection locality, county, other occurrence information, and date of collection.

Classification of Establishment

All tick species were classified as either established or reported in Illinois based on CDC criteria for *I. scapularis* surveillance (Centers for Disease Control and Prevention (CDC), 2019). According to these guidelines, tick species are categorized as "established" if at least six individuals of one life stage or more than one life stage are recorded in one county within a twelve-month period. Species are recorded as "reported" if less than six individuals of one life stage are recorded within one county in a twelve-month period.

Host Records

Host records were scored in two different ways to account for differential reporting of records in the scientific literature. Each report of ticks collected from hosts was scored as presence/absence (i.e. if any number of ticks of a species were recorded on a host species) and, if said information was reported, total number of ticks collected from the host species. Occurrence records were excluded from this tick/host analysis if either the tick or host did not have a species-level identification or if the identification level was unclear from the report (e.g. records reported from a "mouse" were considered unclear, as there are several species to which this could be referring). Records from natural history collections and passive surveillance were similarly scored.

Photographs

For each tick species that met the criteria for established, macro-photographs of all life stages were taken using one of three camera set-ups. These set-ups were (1) a Canon EOS 5D Mark II camera with photograph stacking via Zerene stacker v. 1.04 at the Illinois Natural History Survey Insect Collection by E Struckhoff (2) a Nikon SMZ25 microscope with a Nikon DS-Ri2 camera at the Illinois Natural History Survey Medical Entomology Lab by E Struckhoff, and (3) a BK Plus Lab System (Visionary Digital) with photograph stacking via Helicon Focus v. 4.77 at the United States National Tick Collection by E Struckhoff and L Beati. All specimens photographed were definitively identified specimens from the Illinois Natural History Survey Insect Collection or the United States National Tick Collection or were collected by the Illinois Natural History Survey Medical Entomology Lab and definitively identified by E Struckhoff and H Tuten using the following keys and morphological descriptions: Brinton et al., 1965; Clifford et al., 1961; Cooley & Kohls, 1944, 1945; Durden & Keirans, 1996; Egizi et al., 2019; Keirans & Durden, 1998; Keirans & Litwak, 1989; Lado et al. 2018; McIntosh, 1932; Mertins et al., 2010.

For most species and life stages, full-body photographs of both the dorsal and ventral side of the specimen were taken and subsequently stacked using the respective image-stacking software for the camera set-up. The exception to this was four species of larvae which had been slide-mounted using Hoyer's solution. Because Hoyer's solution renders tick larvae translucent, for these specimens singular images were taken at different depths where either the dorsal or ventral features were visible and in focus. The slide-mounted specimens were the larvae of *A. maculatum* (Figure 1.3G, 1.3H), *I. baergi* (Figure 1.7G, 1.7H), *I. cookei* (Figure 1.8G, 1.8H), and *I. sculptus* (Figure 1.11G, 1.11H).

RESULTS

Thirteen species of ticks met the criteria for establishment in at least one county in Illinois (Table 1.2, Figures 1.1-1.13). This includes one species in the family Argasidae, *Carios kelleyi* (Cooley and Kohls, 1941), and twelve species in the family Ixodidae. These thirteen established species of ticks in Illinois were reported on seventy-seven different host species (Figure 1.14).

These seventy-seven different host species spanned thirteen orders: nine in the class Mammalia, three in the class Aves, and one in class Reptilia. On average, each tick species was found parasitizing 11 different hosts. *Ixodes scapularis* had the greatest host variety, being reported from 37 different host species, while *I. baergi* Cooley and Kohls, 1942 had the least, having only been reported from cliff swallows (*Petrochelidon pyrrhonota)* in Illinois. The host species with the greatest number of tick species recorded from them included humans (*Homo sapiens*) and eastern cottontail rabbits (*Sylvilagus floridanus*), both of which had records of six tick species parasitizing them. Domestic dogs (*Canis familiaris*) and white-tailed deer (*Odocoileus virginianus*) each had records of five tick species parasitizing them. Also notable is that only 1 species, the Argasid tick *Carios kelleyi*, has been reported from bats. Detailed descriptions of these thirteen species, and full lists of the hosts recorded for each species, can be found in the "Established species in Illinois" section below.

An additional twenty-five hard tick species were reported in Illinois but did not meet the criteria for establishment, with one species, *A. nodosum* Neumann, 1899 appearing in multiple categories (Table 1.2). Out of these twenty-five species, four were reported either on native hosts or humans. Two species, *A. longirostre* (Koch, 1844) and *A. nodosum*, were reported on migratory birds, and twenty species were reported on imports or exotic animals. Finally, five species were not reported within the state of Illinois, but records of these species from neighboring states were incidentally found when reviewing the literature from the Illinois review. These species were *Haemaphysalis longicornis* Neumann, 1901*; I. angustus* Neumann, 1899*; I. banksi* Bishopp, 1911*; I. kingi* Bishopp, 1911*;* and *I. woodi* Bishopp, 1911.

Established species in Illinois

Note: For brevity, the following abbreviations will be used to refer to specimens reported from natural history collections and passive surveillance: Illinois Natural History Survey Insect Collection (INHS-IC), Illinois Natural History Survey Medical Entomology Lab Passive Surveillance (INHS-MEL), Milwaukee Public Museum (MPM), Ohio State Acarology Collection (OSU-AC), United States National Tick Collection (USNTC), United States Department of Agriculture - Animal and Plant Health Inspection Service (USDA-APHIS).

Family: Argasidae

Carios kelleyi (Cooley and Kohls, 1941)

Photographs: Figure 1.1

Alternative names used in Illinois: *Ornithodoros kelleyi* Cooley and Kohls, 1941

First report in Illinois: September 1st, 1940 in Jackson Co., from *Myotis lucifugus* (INHS-IC)

County-level distribution in Illinois: Adams (INHS-IC), Carroll (INHS-IC; USNTC), Cass (INHS-IC), Champaign (INHS-IC), Cook (MPM), Jackson (INHS-IC; MPM; USNTC), Jersey (INHS-IC; MPM; USNTC), Jo Daviess (INHS-IC; USNTC), La Salle (INHS-IC; MPM; USNTC), Peoria (USNTC), Rock Island (INHS-IC)

Hosts in Illinois: *Eptesicus fuscus* (INHS-IC; MPM; USNTC), *Myotis lucifugus* (INHS-IC; MPM; USNTC), *Perimyotis subflavus* (MPM; USNTC), *Pituophis catenifer sayi* (MPM)

Type Host: *Pipistrellus sp.* (Cooley & Kohls, 1941)

Family: Ixodidae

Amblyomma americanum (Linnaeus, 1758)

Photographs: Figure 1.2

Common Name: Lone Star Tick

First report in Illinois: July 12th, 1956 in McHenry Co., from *Homo sapiens* (INHS-IC)

County-level distribution in Illinois: Adams (Gilliam et al., 2020; INHS-IC), Bond (Gilliam et al., 2020; Nieto et al., 2018), Brown (Gilliam et al., 2020; INHS-IC), Calhoun (Gilliam et al., 2020), Cass (Gilliam et al., 2020; Nieto et al., 2018), Champaign (Gilliam et al., 2020; INHS-IC), Clark (Gilliam et al., 2020), Clinton (Gilliam et al., 2020), Coles (INHS-MEL), Cook (Gilliam et al., 2020; MPM; USDA-APHIS; USNTC), Crawford (Gilliam et al., 2020), DeKalb (Gilliam et al., 2020), DeWitt (Gilliam et al., 2020), DuPage (Gilliam et al., 2020), Edwards (Gilliam et al., 2020, Nieto et al., 2018), Effingham (INHS-MEL), Fayette (Gilliam et al., 2020), Franklin (Gilliam et al., 2020), Fulton (Gilliam et al., 2020), Gallatin (Gilliam et al., 2020), Greene (Gilliam et al., 2020, INHS-MEL), Grundy (Gilliam et al., 2020; INHS-MEL), Hamilton (Gilliam et al., 2020; INHS-MEL), Hancock (Gilliam et al., 2018; Gilliam et al., 2020; Nieto et al., 2018), Hardin (Gilliam et al., 2020), Henderson (Gilliam et al., 2020), Henry (Gilliam et al., 2020; Nieto et al., 2018), Iroquois (Gilliam et al., 2020), Jackson (Gilliam et al., 2020; Lepitzki et al., 1992; Nieto et al., 2018; Zieman et al., 2017; INHS-MEL), Jasper (Gilliam et al., 2020), Jefferson (Gilliam et al., 2020), Jersey (Gilliam et al., 2020), Jo Daviess (Gilliam et al., 2020), Johnson (Gilliam et al., 2020; INHS-IC), Kane (Gilliam et al., 2020), Kankakee (Gilliam et al., 2020; Nieto et al., 2018; Tuten et al., 2020), Kendall (Gilliam et al., 2020), Knox (Gilliam et al., 2020; Nieto et al., 2018), Lake (Gilliam et al., 2020; INHS-MEL), La Salle (Gilliam et al., 2020), Lawrence (Gilliam et al., 2020; Nieto et al., 2018), Lee (Gilliam et al., 2020), Logan (Gilliam et al., 2020), Macon (Gilliam et al., 2020), Macoupin (Gilliam et al., 2020), Madison (Gilliam et al., 2020; INHS-MEL), Marion (Gilliam et al., 2020; INHS-MEL), Mason (Gilliam et al., 2020), McDonough (Gilliam et al., 2020), McHenry (Gilliam et al., 2020; INHS-IC), McLean (Gilliam et al., 2020), Menard (Gilliam et al., 2020), Mercer (Gilliam et al., 2020), Monroe (Gilliam et al., 2020), Morgan (Gilliam et al., 2020), Moultrie (Gilliam et al., 2020; INHS-IC), Ogle (INHS-IC), Peoria (Gilliam et al., 2020), Perry (Gilliam et al., 2020; INHS-IC), Piatt (Gilliam et al., 2020), Pike (Chapman & Siegle, 2000; Gilliam et al., 2020; Yoder & Benoit, 2003), Pope (Gilliam et al., 2020; Montgomery 1967; INHS-IC), Pulaski (Gilliam et al., 2020), Putnam (Gilliam et al., 2020; Nieto et al., 2018), Randolph (INHS-IC), Richland (Gilliam et al., 2020), Rock Island (Gilliam et al., 2020), Saline (Gilliam et al., 2020), Sangamon (Gilliam et al., 2020; INHS-MEL), Schuyler (Gilliam et al., 2020; INHS-MEL), Scott (Gilliam et al., 2020), Shelby (Gilliam et al., 2020; INHS-IC; OSU-AC), St. Clair (Gilliam et al., 2020), Tazewell (Gilliam et al., 2020), Union (Gilliam et al., 2020; Nieto et al., 2018; INHS-MEL), Vermilion (Gilliam et al., 2020); Wabash (Gilliam et al., 2020), Washington (Gilliam et al., 2020; INHS-IC), Wayne (Gilliam et al., 2020), Whiteside (Gilliam et al., 2020), Will (Gilliam et al., 2020; INHS-MEL), Williamson (Gilliam et al., 2020; Montgomery 1967; Tuten et al., 2020; INHS-IC; INHS-MEL; MPM; USNTC), Winnebago (Gilliam et al., 2020)

Hosts in Illinois: *Canis lupus familiaris* (INHS-IC; INHS-MEL; USNTC; MPM; USDA-APHIS), *Homo sapiens* (INHS-IC; INHS-MEL), *Odocoileus virginianus* (INHS-IC; MPM; USNTC; Montgomery 1967; Nelson 1984), *Sylvilagus floridanus* (Lepitzki et al., 1992)

Type Host: none

Amblyomma maculatum Koch, 1844

Photographs: Figure 1.3

Common Name: Gulf Coast Tick

First report in Illinois: September 1990 in Madison and Peoria Co., collection method unknown (INHS-IC)

County-level distribution in Illinois: Champaign (INHS-MEL), Effingham (INHS-IC), Jackson (Phillips et al., 2020), Madison (INHS-IC), Peoria (INHS-IC), Pulaski (Phillips et al., 2020), Saline (Phillips et al., 2020), Union (Phillips et al., 2020)

Hosts in Illinois: *Homo sapiens* (INHS-MEL), *Odocoileus virginianus* (INHS-IC)

Type Host: none

Dermacentor albipictus (Packard, 1869)

Photographs: Figure 1.4

Common Name: Winter Tick

First report in Illinois: February 28th, 1931 in Winnebago Co., from *Equus caballus* (INHS-IC)

County-level distribution in Illinois: Adams (INHS-IC), Alexander (INHS-IC), Brown (Cortinas & Kitron, 2006, INHS-IC), Bureau (Cortinas & Kitron, 2006; INHS-IC), Calhoun (Cortinas & Kitron, 2006, INHS-IC), Cass (Cortinas & Kitron, 2006; INHS-IC), Champaign (INHS-IC; USNTC), Coles (INHS-IC), Cumberland (INHS-IC), Fulton (Cortinas & Kitron, 2006), Grundy (Cortinas & Kitron, 2006), Hancock (INHS-IC), Henderson (INHS-IC), Henry (INHS-IC), Jackson (INHS-IC), Johnson (INHS-IC), Kane (INHS-IC), Knox (INHS-IC), La Salle (Cortinas & Kitron, 2006), Macoupin (INHS-IC), Madison (INHS-IC), Marshall (Cortinas & Kitron, 2006), Mason (Cortinas & Kitron, 2006; INHS-IC), Massac (INHS-IC), McDonough (INHS-IC), Menard (INHS-IC), Mercer (INHS-IC; INHS-MEL), Monroe (INHS-IC), Morgan (Cortinas & Kitron, 2006), Ogle (Cortinas & Kitron, 2006), Peoria (Cortinas & Kitron, 2006; INHS-IC), Perry (INHS-IC), Pike (Cortinas & Kitron, 2006; INHS-IC), Pope (INHS-IC), Pulaski (INHS-IC), Putnam (Cortinas & Kitron, 2006), Randolf (INHS-IC), Rock Island (INHS-IC), Saline (INHS-IC), Sangamon (INHS-IC), Schuyler (Cortinas & Kitron, 2006; INHS-IC), Scott (Cortinas & Kitron, 2006; INHS-IC), Tazewell (Cortinas & Kitron, 2006), Union (INHS-IC), Warren (INHS-IC), Washington (INHS-IC), Will (Cortinas & Kitron, 2006), Williamson (INHS-IC), Winnebago (INHS-IC), Woodford (Cortinas & Kitron, 2006)

Hosts in Illinois: *Bos taurus* (INHS-IC; USNTC), *Equus caballus* (INHS-IC), *Microtus ochrogaster* (INHS-IC), *Odocoileus virginianus* (Cortinas & Kitron, 2006; INHS-IC; INHS-MEL)

Type Host: *Alces alces* (Packard, 1869)

Dermacentor variabilis (Say, 1821)

Photographs: Figure 1.5

Common Name: American Dog Tick

First report in Illinois: July 25th, 1905 in Jackson Co., collection method unknown (INHS-IC)

County-level distribution in Illinois: Adams (Gilliam et al., 2020; INHS-IC; USNTC), Alexander (Gilliam et al., 2020; INHS-IC), Bond (Gilliam et al., 2020; Nieto et al., 2018; INHS-IC), Boone (Gilliam et al., 2020; Nieto et al., 2018; INHS-IC), Brown (INHS-IC; USNTC), Bureau (Gilliam et al., 2020; Nieto et al., 2018), Calhoun (Gilliam et al., 2020; INHS-IC; USNTC), Carroll (Gilliam et al., 2020; Verts, 1967; INHS-IC; USNTC), Cass (Gilliam et al., 2020; INHS-IC), Champaign (Gilliam et al., 2020; INHS-IC; INHS-MEL; USNTC), Christian (Gilliam et al., 2020; INHS-IC), Clark (Gilliam et al., 2020; Nieto et al., 2018; INHS-IC), Clay (Gilliam et al., 2020; INHS-IC), Clinton (Gilliam et al., 2020), Coles (Gilliam et al., 2020; Nieto et al., 2018; INHS-MEL; OSU-AC; USNTC), Cook (Gilliam et al., 2020; Nieto et al., 2018; Rydzewski et al., 2012; INHS-IC; INHS-MEL; USNTC), Crawford (Gilliam et al., 2020), Cumberland (Gilliam et al., 2020; Nieto et al., 2018; INHS-IC), DeKalb (Gilliam et al., 2020), Douglas (Gilliam et al., 2020; INHS-IC; INHS-MEL), DuPage (Gilliam et al., 2020; Nieto et al., 2018; Rydzewski et al., 2012; INHS-MEL; USNTC), Edgar (Gilliam et al., 2020; INHS-IC;

INHS-MEL), Edwards(Gilliam et al., 2020; Nieto et al., 2018; INHS-IC), Effingham (Gilliam et al., 2020, Nieto et al., 2018; INHS-IC; INHS-MEL), Fayette (Gilliam et al., 2020; Nieto et al., 2018; INHS-IC), Ford (Gilliam et al., 2020), Franklin (Gilliam et al., 2020; INHS-IC), Fulton (Gilliam et al., 2020), Gallatin (Gilliam et al., 2020; INHS-IC), Greene (Gilliam et al., 2020; INHS-IC; INHS-MEL), Grundy (Gilliam et al., 2020; INHS-IC), Hamilton (INHS-MEL), Hancock (Gilliam et al., 2020; Gilliam et al., 2018; INHS-IC; USNTC), Hardin (Gilliam et al., 2020; INHS-IC; USNTC), Henderson (Gilliam et al., 2020; INHS-IC), Henry (Gilliam et al., 2020; INHS-IC; INHS-MEL), Iroquois (Gilliam et al., 2020; INHS-IC), Jackson (Gilliam et al., 2020; Nieto et al., 2018; Zieman et al., 2017; INHS-IC; USNTC), Jasper (Gilliam et al., 2020; INHS-IC), Jersey (Gilliam et al., 2020; Nieto et al., 2018), Jo Daviess (Gilliam et al., 2020; INHS-IC; USNTC), Johnson (Gilliam et al., 2020; INHS-IC; INHS-MEL; USNTC), Kane (Gilliam et al., 2020; Nieto et al., 2018; INHS-MEL), Kankakee (Gilliam et al., 2020; Nieto et al., 2018; Tuten et al., 2020; INHS-IC), Kendall (Gilliam et al., 2020; INHS-IC), Knox (Gilliam et al., 2020; Nieto et al., 2018; INHS-MEL), La Salle (Gilliam et al., 2020; INHS-IC; USDA-APHIS; USNTC), Lake (Gilliam et al., 2020; Rydzewski et al., 2012; INHS-IC; INHS-MEL; USNTC), Lawrence (Gilliam et al., 2020; Nieto et al., 2018; INHS-IC; USNTC), Lee (Gilliam et al., 2020; Stannard & Pietsch, 1958; INHS-IC; USNTC), Livingston (Gilliam et al., 2020), Logan (Gilliam et al., 2020), Macon (Gilliam et al., 2020; Nieto et al., 2018; INHS-MEL), Macoupin (Gilliam et al., 2020; INHS-IC; USNTC), Madison (Gilliam et al., 2020; INHS-IC; INHS-MEL; USNTC), Marion (Gilliam et al., 2020; INHS-IC; USNTC), Marshall (Gilliam et al., 2020; INHS-IC), Mason (Gilliam et al., 2020; INHS-IC; USNTC), Massac (Gilliam et al., 2020; INHS-IC; USNTC), McDonough (Gilliam et al., 2020; INHS-IC), McHenry (Gilliam et al., 2020; Nieto et al., 2018; Rydzewski et al., 2012; INHS-IC; INHS-MEL), McLean (Gilliam et al., 2020; Nieto et al., 2018; INHS-IC; INHS-MEL; USDA-APHIS), Menard (Gilliam et al., 2020; INHS-IC), Mercer (Gilliam et al., 2020; INHS-IC; INHS-MEL), Monroe (Gilliam et al., 2020; Nieto et al., 2018; INHS-IC; USNTC), Montgomery (Gilliam et al., 2020), Morgan (Gilliam et al., 2020), Moultrie (Gilliam et al., 2020; Nieto et al., 2018; INHS-IC), Ogle (Gilliam et al., 2020; INHS-IC; USNTC), Peoria (Gilliam et al., 2020; Nieto et al., 2018; INHS-IC; INHS-MEL; USNTC), Perry (Gilliam et al., 2020; INHS-IC; USNTC), Piatt (Gilliam et al., 2020; INHS-IC; INHS-MEL; USNTC), Pike (Gilliam et al., 2020; Chapman & Siegle, 2000; INHS-IC; USNTC), Pope (Gilliam et al., 2020; Montgomery, 1967; INHS-IC; USNTC), Pulaski (Gilliam et al., 2020; INHS-IC), Putnam (Gilliam et al., 2020; INHS-IC), Randolph (Gilliam et al., 2020; Nieto et al., 2018; INHS-IC), Richland (Gilliam et al., 2020), Rock Island (Gilliam et al., 2020; INHS-IC; INHS-MEL; USNTC), Saline (Gilliam et al., 2020; INHS-IC), Sangamon (Gilliam et al., 2020; Nieto et al., 2018; INHS-IC), Schuyler (Gilliam et al., 2020; INHS-IC; INHS-MEL; USNTC), Scott (Gilliam et al., 2020), Shelby (Gilliam et al., 2020; Nieto et al., 2018; INHS-IC; INHS-MEL; OSU-AC), St. Clair (Gilliam et al., 2020; Nieto et al., 2018; INHS-IC), Stephenson (Gilliam et al., 2020; Nieto et al., 2018), Tazewell (Gilliam et al., 2020; Nieto et al., 2018; OSU-AC), Union (Gilliam et al., 2020; INHS-IC; INHS-MEL; USNTC), Vermillion (Gilliam et al., 2020; INHS-IC; USNTC), Wabash (Gilliam et al., 2020; INHS-IC; USNTC), Warren (Gilliam et al., 2020), Washington (Gilliam et al., 2020; INHS-IC; USNTC), Wayne (Gilliam et al., 2020; INHS-IC), White (Gilliam et al., 2020; INHS-IC), Whiteside (Gilliam et al., 2020; INHS-IC; USNTC), Will (Gilliam et al., 2020; Nieto et al., 2018; INHS-IC; INHS-MEL; USNTC), Williamson (Gilliam et al., 2020; Nieto et al., 2018; Tuten et al., 2020; USNTC), Winnebago (Gilliam et al., 2020; Nieto et al., 2018; INHS-IC; INHS-MEL; USNTC), Woodford (Gilliam et al., 2020; Nieto et al., 2018; INHS-IC)

Hosts in Illinois: *Bos taurus* (INHS-IC), *Canis latrans* (INHS-IC), *Canis lupus familiaris* (INHS-IC; INHS-MEL; USDA-APHIS; USNTC), *Colinus virginianus* (Bergstrand & Klimstra, 1964), *Didelphis virginiana* (INHS-IC; USNTC), *Homo sapiens* (INHS-IC; INHS-MEL; MPM; USNTC), *Marmota monax* (INHS-IC; USNTC), *Mephitis mephitis* (Verts, 1967; INHS-IC), *Microtus ochrogaster* (INHS-IC), *Microtus pinetorum* (INHS-IC), *Mustela frenata* (USNTC), *Odocoileus virginianus* (Montgomery 1967; Nelson et al., 1984; INHS-IC; USNTC), *Ovis aries* (INHS-IC; USNTC), *Peromyscus leucopus* (INHS-IC), *Procyon lotor* (INHS-IC; INHS-MEL), *Sciurus carolinensis* (INHS-IC; USNTC), *Sciurus niger* (INHS-IC; USNTC), *Sylvilagus floridanus* (Stannard & Pietsch, 1958; INHS-IC), *Synaptomys cooperi* (INHS-IC), *Taxidea taxis* (INHS-IC), *Urocyon cinereoargenteus* (USNTC), *Vulpes vulpes* (USNTC)

Type Host: none

Haemaphysalis leporispalustris (Packard, 1869)

Photographs: Figure 1.6

Common Name: Rabbit Tick

First report in Illinois: June 10th, 1932 in Cass Co., from *Sylvilagus floridanus* (INHS-IC)

County-level distribution in Illinois: Adams (INHS-IC), Alexander (INHS-IC), Cass (INHS-IC), Champaign (Schneider et al., 2015; INHS-IC; USNTC), Coles (INHS-IC), Cook (Hamer, Goldberg, et al., 2012; INHS-IC; USNTC), Douglas (INHS-IC), Fayette (INHS-IC), Iroquois (INHS-IC), Jackson (Lepitzki et al., 1992; INHS-IC), Jasper (INHS-IC), Lake (INHS-IC; USNTC), Lee (Stannard & Pietsch, 1958), Mason (INHS-IC; USNTC), Monroe (INHS-IC), Perry (INHS-IC), Piatt (INHS-IC; USNTC), Pope (USNTC), Putnam (Schneider et al., 2015, INHS-IC; USNTC), Richland (INHS-IC), Sangamon (INHS-IC), Union (INHS-IC), Vermilion (INHS-IC; USNTC), White (INHS-IC; USNTC)

Hosts in Illinois: *Agelaius phoeniceus* (Hamer, Goldberg, et al., 2012), *Baeolophus bicolor* (INHS-IC), *Cardinalis cardinalis* (Hamer, Goldberg, et al., 2012; Parker et al., 2017; Schneider et al., 2015), *Catharus fuscescens* (Parker et al., 2017; Schneider et al., 2015), *Catharus guttatus* (Parker et al., 2017; Schneider et al., 2015), *Catharus minimus* (Hamer, Goldberg, et al., 2012; Parker et al., 2017; Schneider et al., 2015), *Catharus ustulatus* (Hamer Goldberg, et al., 2012; Parker et al., 2017; Schneider et al., 2015; INHS-IC), *Chordeiles minor* (INHS-IC), *Colinus virginianus* (Bergstrand & Klimstra, 1964; INHS-IC), *Cyanocitta cristata* (Parker et al., 2017), *Dumetella carolinensis* (Hamer, Goldberg, et al., 2012; Parker et al., 2017; Schneider et al., 2015), *Geothylpis formosa* (Parker et al., 2017), *Hylocichla mustelina* (Parker et al., 2017), *Melospiza georgiana* (Parker et al., 2017; INHS-IC), *Melospiza melodia* (Hamer, Goldberg, et al., 2012; Parker et al., 2017; Schneider et al., 2015), *Molothrus ater* (Parker et al., 2017), *Parkesia noveboracensis* (Parker et al., 2017; Schneider et al., 2015), *Parus bicolor* (USNTC), *Passer domesticus* (Hamer, Goldberg, et al., 2012), *Passerina cyanea* (Parker et al., 2017; Schneider et al., 2015), *Quiscalus quiscula* (Hamer, Goldberg, et al., 2012), *Seiurus aurocapilla* (Hamer, Goldberg, et al., 2012), *Sturnus vulgaris* (Hamer, Goldberg, et al., 2012), *Sylvilagus aquaticus* (Stannard & Pietsch, 1958; INHS-IC), *Sylvilagus floridanus* (Ecke and Yeater, 1956; Lepitzki et al., 1992; Stannard & Pietsch, 1958; INHS-IC; USNTC), *Thryothorus ludovicianus* (Parker et al., 2017), *Toxostoma rufum* (Parker et al., 2017; INHS-IC; USNTC), *Troglodytes aedon* (Hamer, Goldberg, et al., 2012; Parker et al., 2017), *Turdus migratorius* (Hamer, Goldberg, et al., 2012), *Tympanuchus cupido* (INHS-IC), *Zonotrichia albicollis* (Parker et al., 2017; Schneider et al., 2015), *Zonotrichia leucophrys* (Parker et al., 2017)

Type Host: *Sylvilagus palustris* (Packard, 1869)

Ixodes baergi Cooley and Kohls, 1942

Photographs: Figure 1.7

First report in Illinois: August 6th, 1961 in Jo Daviess Co., from *Petrochelidon pyrrhonota* (Kohls & Ryckman, 1962; USNTC)

County-level distribution in Illinois: Jo Daviess (Kohls & Ryckman, 1962; USNTC)

Hosts in Illinois: *Petrochelidon pyrrhonota* (Kohls & Ryckman, 1962; USNTC)

Type host: *Petrochelidon pyrrhonota* (Cooley & Kohls, 1942)

Ixodes cookei Packard, 1869

Photographs: Figure 1.8

Common Name: Groundhog Tick

First report in Illinois: June 15th, 1932 in Carroll Co., from *Marmota monax* (INHS-IC)

County-level distribution in Illinois: Carroll (INHS-IC), Cook (USNTC), DuPage (INHS-MEL; USNTC), Jackson (INHS-IC), Lake (INHS-IC; USNTC), Massac (INHS-IC), Pike (INHS-IC; USNTC), Pope (INHS-IC), Stephenson (INHS-IC), Union (INHS-IC; USNTC), Vermilion (INHS-IC; USNTC)

Hosts in Illinois: *Canis lupus familiaris* (USNTC), *Didelphis virginiana* (INHS-IC; USNTC), *Homo sapiens* (INHS-MEL), *Marmota monax* (INHS-IC; USNTC), *Mephitis mephitis* (Verts, 1967; INHS-IC), *Mustela furo* (Ghosh et al., 2020), *Neogale vison* (USNTC), *Neotoma floridana* (INHS-IC), *Urocyon cinereoargenteus* (INHS-IC), *Vulpes vulpes* (USNTC)

Type Host: *Marmota monax* (Packard, 1869)

Ixodes dentatus Marx, 1899

Photographs: Figure 1.9

First report in Illinois: December 5th, 1934 in Alexander co., from *Sylvilagus floridanus* (INHS-IC)

County-level distribution in Illinois: Alexander (INHS-IC), Champaign (Schneider et al., 2015), Coles (Ecke & Yeatter; INHS-IC; USNTC), Cook (Hamer, Goldberg, et al., 2012), Effingham (INHS-IC), Fayette (INHS-IC), Franklin (INHS-IC), Jackson (Lepitzki et al., 1992; INHS-IC), Johnson (INHS-IC), Lee (Stannard & Pietsch, 1958; INHS-IC), Putnam (Schneider et al., 2015), Schuyler (INHS-IC), Union (INHS-IC), Vermilion (INHS-IC; USNTC)

Hosts in Illinois: *Cardellina canadensis* (Parker et al., 2017), *Cardinalis cardinalis* (Parker et al., 2017; Schneider et al., 2015), *Catharus guttatus* (Parker et al., 2017; Schneider et al., 2015), *Catharus ustulatus* (Hamer, Goldberg, et al., 2012; Parker et al., 2017), *Cyanocitta cristata* (Parker et al., 2017; Schneider et al., 2015), *Dumetella carolinensis* (Parker et al., 2017), *Empidonax flaviventris* (Hamer, Goldberg, et al., 2012), *Melospiza lincolnii* (Parker et al., 2017), *Melospiza melodia* (Hamer, Goldberg, et al., 2012), *Quiscalus quiscula* (Hamer, Goldberg, et al., 2012), *Seiurus aurocapilla* (Parker et al., 2017), *Sylvilagus floridanus* (Ecke & Yeatter, 1956; Lepitzki et al., 1992; Sanderson, 1958; Stannard & Pietsch, 1958; INHS-IC), *Thryothorus ludovicianus* (Parker et al., 2017), *Toxostoma rufum* (Parker et al., 2017), *Troglodytes hiemalis* (Parker et al., 2017; Schneider et al., 2015), *Turdus migratorius* (Hamer, Goldberg, et al., 2012; Parker et al., 2017), *Zonotrichia albicollis* (Hamer, Goldberg, et al., 2012)

Type Host: Leporidae (Marx, 1899)

Ixodes scapularis Say, 1821

Photographs: Figure 1.10

Common Name: Blacklegged Tick

Alternative names used in Illinois: *Ixodes dammini* Spielman, Clifford, Piesman, and Corwin

First report in Illinois: April 9th, 1951 in Champaign Co., from *Canis lupus familiaris* (INHS-IC)

County-level distribution in Illinois: Boone (Gilliam et al., 2020; INHS-MEL), Brown (Cortinas & Kitron, 2006; Gilliam et al., 2020; INHS-IC), Bureau (Cortinas & Kitron, 2006; Gilliam et al., 2020; Guerra et al., n.d.; INHS-IC), Carroll (Bouseman et al., 1990; Gilliam et al., 2020; INHS-IC), Cass (Cortinas & Kitron, 2006; Gilliam et al., 2020), Champaign (Gilliam et al., 2020; Schneider et al., 2015; INHS-IC; INHS-MEL; MPM), Clark (Diuk-Wasser et al., 2010; Gilliam et al., 2020), Coles (Gilliam et al., 2020; INHS-IC; INHS-MEL), Cook (Diuk-Wasser et al., 2010; Gilliam et al., 2020; Hamer, Goldberg, et al., 2012; Jobe et al., 2006, 2007; Nieto et al., 2018; Rydzewski et al., 2012; INHS-IC), Crawford (Gilliam et al., 2020; Nieto et al., 2018), Cumberland (Gilliam et al., 2020; INHS-IC), DeKalb (Gilliam et al., 2020), DuPage (Gilliam et al., 2020; Jobe et al., 2006; Nieto et al., 2018; Rydzewski et al., 2012; INHS-IC), Edgar (Bouseman et al., 1990; Gilliam et al., 2020; INHS-IC), Fayette (Gilliam et al., 2020; INHS-IC), Franklin (Gilliam et al., 2020), Fulton (Cortinas & Kitron, 2006; Gilliam et al., 2020), Gallatin (Gilliam et al., 2020; INHS-IC), Greene (Gilliam et al., 2020), Grundy (Cortinas & Kitron, 2006; Gilliam et al., 2020; INHS-IC), Hancock (Gilliam et al., 2018, 2020), Henderson (Diuk-Wasser et al., 2010; Gilliam et al., 2020), Henry (Gilliam et al., 2020; INHS-IC), Iroquois (Gilliam et al., 2020; INHS-IC), Jasper (Gilliam et al., 2020), Jersey (Diuk-Wasser et al., 2010), Jo Daviess (Bouseman et al., 1990; Gilliam et al., 2020; Guerra et al., n.d.; Nieto et al., 2018; USNTC), Kane (Gilliam et al., 2020; Nieto et al., 2018), Kankakee (Bouseman et al., 1990; Cortinas & Kitron, 2006; Diuk-Wasser et al., 2010; Gilliam et al., 2020; Tuten et al., 2020; INHS-IC), Kendall (Gilliam et al., 2020; Nieto et al., 2018), Knox (Bouseman et al., 1990; Gilliam et al., 2020; Nieto et al., 2018; INHS-IC), La Salle (Cortinas & Kitron, 2006; Gilliam et al., 2020;

Guerra et al., n.d.; Nieto et al., 2018; INHS-IC), Lake (Gilliam et al., 2020; Jobe et al., 2007; Rydzewski et al., 2012), Lawrence (Diuk-Wasser et al., 2010; Gilliam et al., 2020; INHS-IC), Lee (Bouseman et al., 1990; Gilliam et al., 2020; INHS-IC), Livingston (Gilliam et al., 2020; INHS-MEL), Macon (Gilliam et al., 2020; Nieto et al., 2018), Macoupin (Gilliam et al., 2020), Madison (Gilliam et al., 2020; INHS-IC), Marshall (Cortinas & Kitron, 2006; Gilliam et al., 2020), Mason (Cortinas & Kitron, 2006; Gilliam et al., 2020), McDonough (Gilliam et al., 2020; INHS-IC), McHenry (Gilliam et al., 2020; Nieto et al., 2018; Rydzewski et al., 2012; INHS-IC), McLean (Diuk-Wasser et al., 2010; Gilliam et al., 2020; INHS-IC), Menard (Gilliam et al., 2020; Nieto et al., 2018; INHS-IC), Mercer (Bouseman et al., 1990; Gilliam et al., 2020; Nieto et al., 2018; INHS-IC; INHS-MEL), Montgomery (Gilliam et al., 2020), Monroe (Gilliam et al., 2020; INHS-IC), Morgan (Cortinas & Kitron, 2006; Gilliam et al., 2020), Ogle (Bouseman et al., 1990; Cortinas & Kitron, 2006; Diuk-Wasser et al., 2010; Gilliam et al., 2020; Guerra et al., n.d.; Jones & Kitron, 2000; Kitron et al., 1992; Kitron, Jones, et al., 1991; Mannelli et al., 1993a, 1993b, 1994; J. A. Nelson et al., 1991; Siegel et al., 1991; Slajchert et al., 1997; INHS-IC; USNTC), Peoria (Cortinas & Kitron, 2006; Gilliam et al., 2020; Nieto et al., 2018; INHS-IC), Perry (Gilliam et al., 2020; INHS-IC), Piatt (Gilliam et al., 2020; Bouseman et al., 1990; Rydzewski et al., 2012; INHS-IC), Pope (Gilliam et al., 2020), Putnam (Bouseman et al., 1990; Cortinas & Kitron, 2006; Diuk-Wasser et al., 2010; Gilliam et al., 2020; INHS-IC), Randolf (Gilliam et al., 2020), Richland (Gilliam et al., 2020), Rock Island(Bouseman et al., 1990; Gilliam et al., 2020; Guerra et al., n.d.; Kitron, Bouseman, et al., 1991; J. A. Nelson et al., 1991; INHS-IC), Saline (Gilliam et al., 2020; INHS-IC), Sangamon (Gilliam et al., 2020; Nieto et al., 2018; INHS-IC), Schuyler (Cortinas & Kitron, 2006; Gilliam et al., 2020), Scott (Gilliam et al., 2020; INHS-IC), Shelby (Diuk-Wasser et al., 2010; Gilliam et al., 2020; OSU-AC), St. Clair (Gilliam et al., 2020), Stephenson (Gilliam et al., 2020), Tazewell (Cortinas & Kitron, 2006; Gilliam et al., 2020; INHS-MEL), Union (Gilliam et al., 2020; INHS-IC), Vermilion (Gilliam et al., 2020), Wabash (Gilliam et al., 2020), Warren (Gilliam et al., 2020), Wayne (Gilliam et al., 2020; Nieto et al., 2018), Whiteside (Gilliam et al., 2020; Nieto et al., 2018), Will (Cortinas & Kitron, 2006; Gilliam et al., 2020; Nieto et al., 2018; INHS-IC), Williamson (Gilliam et al., 2020; INHS-IC), Winnebago (Gilliam et al., 2020; Nieto et al., 2018), Woodford (Cortinas & Kitron, 2006; Gilliam et al., 2020)

Hosts in Illinois: *Agelaius phoeniceus* (Hamer, Lehrer, et al., 2012), *Baeolophus bicolor* (Parker et al., 2017), *Blarina brevicauda* (Mannelli et al., 1994), *Canis lupus familiaris* (INHS-IC; INHS-MEL; MPM; USNTC), *Cardinalis cardinalis* (Hamer, Goldberg, et al., 2012; Parker et al., 2017), *Catharus guttatus* (Parker et al., 2017), *Catharus minimus* (Hamer, Goldberg, et al., 2012; Parker et al., 2017), *Catharus ustulatus* (Hamer, Goldberg, et al., 2012; Parker et al., 2017; Schneider et al., 2015), *Cyanocitta cristata* (Hamer, Goldberg, et al., 2012; Mannelli et al., 1993b; Parker et al., 2017), *Didelphis virginiana* (Mannelli et al., 1993b), *Dumetella carolinensis* (Parker et al., 2017), *Felis catus* (INHS-MEL), *Homo sapiens* (INHS-IC; INHS-MEL), *Ictidomys tridecemlineatus* (INHS-IC), *Lynx rufus* (Zieman et al., 2020), *Melospiza melodia* (Parker et al., 2017), *Microtus ochrogaster* (Rydzewski et al., 2012), *Microtus pennsylvanicus* (Mannelli et al., 1994), *Molothrus ater* (Hamer, Lehrer, et al., 2012), *Odocoileus virginianus* (Bouseman et al., 1990; Cortinas & Kitron, 2006; Kitron et al., 1991, 1992; INHS-IC; INHS-MEL; USNTC), *Peromyscus leucopus* (Jones & Kitron, 2000; Kitron, Jones, et al., 1991; Mannelli et al., 1993a, 1994; Slajchert et al., 1997), *Pheucticus ludovicianus* (Hamer, Lehrer, et al., 2012; Parker et al., 2017), *Pipilo erythrophthalmus* (Parker et al., 2017), *Procyon lotor* (Mannelli et al., 1993b; Slajchert et al., 1997), *Quiscalus quiscula* (Hamer, Lehrer, et al., 2012), *Reithrodontomys* *megalotis* (Rydzewski et al., 2012), *Sciurus carolinensis* (Mannelli et al., 1993b), *Sciurus niger* (Mannelli et al., 1993b), *Seiurus aurocapillus* (Parker et al., 2017; Schneider et al., 2015), *Sorex cinereus* (Mannelli et al., 1994), *Sylvilagus floridanus* (Mannelli et al., 1993b), *Tamias striatus* (Kitron, Jones, et al., 1991; Mannelli et al., 1993a; Slajchert et al., 1997), *Toxostoma rufum* (Parker et al., 2017), *Troglodytes aedon* (Hamer, Lehrer, et al., 2012; Parker et al., 2017), *Turdus migratorius* (Hamer, Goldberg, et al., 2012; Parker et al., 2017), *Zapus hudsonius* (Mannelli et al., 1994; Rydzewski et al., 2012), *Zonotrichia albicollis* (Parker et al., 2017)

Type Host: none

Ixodes sculptus Neumann, 1904

Photographs: Figure 1.11

Common Name: none

First report in Illinois: "Summer 1930" in Champaign Co., from *Ictidomys tridecemlineatus* (INHS-IC)

County-level distribution in Illinois: Champaign (Ecke & Yeatter, 1956; INHS-IC; USNTC), Coles (INHS-IC), Cook (INHS-IC; USNTC), DeWitt (USNTC), DuPage (USNTC), Ford (INHS-IC), La Salle (INHS-IC), Macon (INHS-IC), Marshall (INHS-IC; USNTC), Mason (INHS-IC), McLean (INHS-IC; USNTC), Peoria (USNTC), Union (INHS-IC), Will (USNTC), Woodford (INHS-IC)

Hosts in Illinois: *Didelphis virginiana* (INHS-IC), *Geomys bursarius* (INHS-IC; USNTC), *Ictidomys tridecemlineatus* (INHS-IC; USNTC), *Poliocitellus franklinii* (INHS-IC; USNTC), *Sciurus carolinensis* (INHS-IC), *Sylvilagus floridanus* (Ecke & Yeatter, 1956; INHS-IC; USNTC), *Urocyon cinereoargenteus* (INHS-IC)

Type Host: none

Ixodes texanus Banks, 1909

Photographs: Figure 1.12

First report in Illinois: January 1959 in Union Co., from *Mephitis mephitis* (INHS-IC)

County-level distribution in Illinois: Edgar (INHS-IC), Edwards (INHS-IC), Ford (USNTC), McHenry (USNTC), Piatt (USNTC), Union (INHS-IC), Winnebago (INHS-IC)

Hosts in Illinois: *Mephitis mephitis* (INHS-IC), *Procyon lotor* (USNTC)

Type Host: *Procyon lotor* (Banks, 1909)

Rhipicephalus sanguineus (Latreille, 1806)

Photographs: Figure 1.13

Common Name: Brown Dog Tick or Kennel Tick

First report in Illinois: October 1st, 1933 from Champaign Co., collection method unknown (INHS-IC)

County-level distribution in Illinois: Adams (INHS-IC), Boone (INHS-IC), Champaign (INHS-IC), Cook (INHS-IC; USDA-APHIS; USNTC), Douglas (INHS-IC), DuPage (INHS-IC), Edgar (INHS-IC), Kankakee (INHS-IC), Knox (INHS-IC), La Salle (INHS-IC), Lake (INHS-IC; USNTC), Logan (INHS-IC), Macon (INHS-IC), Madison (INHS-IC), Mason (INHS-IC), McHenry (INHS-IC), McLean (INHS-IC), Mercer (INHS-IC), Ogle (USNTC), Peoria (INHS-IC), Pope (INHS-IC), Rock Island (INHS-IC), Sangamon (INHS-IC), Tazewell (INHS-IC), Vermilion (INHS-IC), White (INHS-IC), Winnebago (INHS-IC)

Hosts in Illinois: *Canis lupus familiaris* (INHS-IC; USDA-APHIS; USNTC), *Homo sapiens* (INHS-IC)

Type Host: none

DISCUSSION

The goal of this study was to develop a checklist to the ticks (Acari: Ixodidae and Argasidae) of Illinois and document their host associations within the state by compiling occurrence records from scientific literature, natural history collections, passive tick surveillance, and interception records. No other state-specific checklist of ticks within the midwestern United States has been published. This study found thirteen species of ticks that can be considered established within Illinois and twenty-five additional species that have been reported. State-specific species checklists can serve as an important framework for tick and tick-borne disease research and messaging, and these results greatly improve our understanding of tick diversity in Illinois (Hahn et al., 2020; Pak et al., 2019).

This study also gathered information about tick-host relationships by synthesizing information from existing tick collections and found that the thirteen species of ticks that are established have been recorded from seventy-seven host species. This methodology has its benefits and drawbacks. The major benefit is the ability to maximize the amount of information and number of collection events included, thus expanding the scope of the study as much as possible. In addition, identifying host species which are parasitized by many species of ticks may be useful for identifying suitable hosts for tick surveillance. The major drawback of this method is that tick collections from wildlife hosts have not been standardized. Different studies used different examination protocols when removing ticks from hosts, sampled different numbers of hosts, used different reporting methods, and sampled different host species with different intensities. These factors make drawing definitive, cross-study comparisons about tick-host associations difficult. Thus, while this study provides a baseline for understanding tick-host relationships which are present within Illinois, more standardization of the collection and reporting of ticks from wildlife hosts, and more wildlife surveys in general, is vital for understanding tick-host preference and the roles different hosts play in tick establishment and the maintenance of zoologic transmission cycles (Halsey et al., 2018).

The established tick species in Illinois extend beyond the commonly recognized four to five species of public health concern. While most research efforts and public health messaging is focused on those four to five species, there is the potential for species less frequently encountered via standard tick dragging or human activity to still have current or future public health importance. For example, *I. dentatus* and *I. cookei* are often not considered major vectors of medical concern because both are primarily associated with non-human hosts (Pak et al., 2019). In this survey of the published literature, *I. dentatus* was most commonly found on Eastern cottontail rabbits, followed by various Passeriform birds, and *I. cookei* was most commonly found on various small to medium-sized mammals, including skunks, groundhogs, and grey foxes. However, prior studies indicate both species have the potential to bite humans and be vectors of human pathogens (Anderson et al., 1996; Hassett & Thangamani, 2021; Sollers, 1955). *I. cookei* has been reported from a human once in Illinois via passive surveillance at the INHS-MEL. *I. dentatus* is a compatible vector for *Borrelia burgdorferi* s.s., a causative agent of Lyme disease, and *I. cookei* is considered the main vector of Powassan virus and can also be a vector of *Ehrlichia muris*, a causative agent of human ehrlichiosis (Anderson et al., 1989; Hassett & Thangamani, 2021; Xu et al., 2018). Therefore, even if these species are less frequently encountered by humans than others, they may still play a role in maintaining zoonotic transmission cycles and are still capable of zoonotic spillover concern for human health.

This study also found twenty-five tick species that have been recorded in Illinois but did not reach the criteria used for establishment in the state. Four of these species recorded on humans or native animal hosts might actually be established in Illinois but have been overlooked due to a historical paucity of robust tick surveillance (particularly from animals) in the state. The twenty-one species collected on migratory birds and at ports of entry suggests there are many species which, while maybe not native to Illinois, have the potential to be introduced and possibly establish reproductive populations in the Midwest. Accidental introduction via imports is one of the most important modes of entry for ixodid tick species into the United States (Bram & George, 2000). This study found twenty species of ticks that were either intercepted at USDA-APHIS inspection facilities or removed from exotic host species within the state. The most common genus intercepted was *Amblyomma*, with 11/20 of the species reported belonging to it. These findings show that introductions could occur via travel and import, even in landlocked states with fewer and smaller agricultural ports of entry.

Birds may also be responsible for the introduction and dispersal of ticks and associated disease agents. Migratory birds have been implicated as a pathway by which tropical and subtropical tick species are transported to more northern climates (Budachetri et al., 2017; Hasle, 2013; Hasle et al., 2009). Birds, especially passerine birds, also play a role in the dispersal of *I. scapularis* and associated disease agents, such as *Borrelia burgdorferi* (Schneider et al., 2015). Passerine birds were the most diverse order of hosts parasitized by ticks in Illinois, and the thirty-three recorded bird species were primarily parasitized by *H. leporispalustris*, *I. dentatus*, and *I. scapularis*. This review also found two non-established, tropical ticks that have been removed from birds in Illinois, *A. longirostre* and *A. nodosum*, both of which were recovered in Cook County (Hamer, Goldberg, et al., 2012).

Additional tick species may be present in the state but have yet to be discovered or reported. In particular, this study found five species of ticks, comprised of four *Ixodes* species and *H. longicornis*, that have not been reported in Illinois but have been found in neighboring states. All four of the *Ixodes* species (*I. angustus*, *I. banksi, I. kingi*, and *I. woodi*) feed on various small to medium-sized mammals and rarely, if ever, bite humans or are collected via other survey methods such as dragging/flagging (Hays & Lawrence, 1957; Robbins & Keirans, 1987; Salkeld et al., 2006; Stephenson et al., 2016). Because of the high host specificity of the four *Ixodes* species and the disjointed and limited nature of prior mammal surveys for ticks in Illinois, it is possible that these species are present within the state but have not yet been detected.

Perhaps the most likely species establishment that will soon take place in Illinois is of *H. longicornis,* also known as the Asian longhorned tick. *Haemaphysalis longicornis* is a highly invasive agricultural pest and has recently been reported in Missouri and confirmed as established in Kentucky (Roberts et al., 2021; Vogt et al., 2021). Recent habitat suitability modeling studies have found high prevalence of suitable habitat for *H. longicornis* in Illinois, especially in the southern portion of the state (Namgyal et al., 2020; Raghavan et al., 2019). Due to the speed at which it is spreading across the United States and large quantity of suitable habitats and hosts in Illinois, it is likely *H. longicornis* will soon be reported from Illinois. Considering almost all known occurrences of *H. longicornis* in the United States have been from livestock or deer, and considering that in its native range *H. longicornis* is a host generalist, increased animal surveillance may aid in the early detection of this species and could improve our knowledge of its current distribution in the Midwest (Heath, 2016; Raghavan et al., 2019; Roberts et al., 2021; Tufts et al., 2019)

Additionally, it is important to recognize that the taxonomic statuses of the tick species included in this study are not all resolved. In particular, the taxonomic standing of *Rhipicephalus sanguineus* has been called into question due to the lack of intact or well-described type specimens, large genomic differences among *R. sanguineus* ticks from different areas of the world, and high morphological variability (Nava et al., 2015). While individuals that fit within this taxon as currently understood are present in Illinois, where these specimens fall in the global genetic diversity of *R. sanguineus* is unknown. Prior studies have also found high genetic variation in specimens identified as *I. texanus* Banks, 1909, and it has been proposed that *I. texanus* as currently defined may be composed of several species (Ondrejicka et al., 2017). Additional taxonomic research remains to be done to resolve these issues.

The scope of this study is limited by the scope of prior tick collections in Illinois, and there are numerous concrete ways these results could be expanded. For example, the location of the first report of a species within Illinois is heavily influenced by the presence of universities, specifically the University of Illinois in Champaign Co. and Southern Illinois University – Carbondale in Jackson Co., in those counties. The reporting of tick occurrences in the future, such as from medical and veterinary records, additional natural history accessions, and currently unpublished tick collections could alter the results of this study. There are also many potential host species in Illinois that have never been sampled for ticks. The sampling of more host species could very well result in the detection new tick-host associations, or even new tick species, within the state. However, such concerns are outside the scope of this project, and overall, this demonstrates the need for more expansive and consistent host sampling to gain a greater understanding of the diversity of tick-host relationships in Illinois.

TABLES AND FIGURES

Table 1.1 Results of the literature review for tick collections in Illinois

Title	Publication year	First Author	DOI	Species collected in Illinois
Ticks of veterinary significance found on imports in the United States	1968	Becklund	10.2307/3277097	*Amblyomma cajennense, Dermacentor nitens*
Ectoparasites of the Bobwhite Quail in Southern Illinois	1964	Bergstrand	10.2307/2423520	*Dermacentor variabilis, Haemaphysalis leporispalustris*
Status of *Ixodes dammini* in Illinois	1990	Bouseman	10.1093/jmedent/27.4.556	*Ixodes scapularis (Ixodes dammini)*
Exotic ticks introduced into the United States on imported reptiles from 1962 to 2001 and their potential roles in international dissemination of dieseases	2003	Burridge	10.1016/S0304-4017(03)00060-8	*Amblyomma dissimile, Amblyomma latum, Amblyomma rotundum, Amblyomma scutatum, Bothriocroton hydrosauri*
A novel method for tick retrieval reveals northern migration of *Amblyomma americanum* into Pike County, IL	2000	Chapman	10.1080/01647950008684215	*Amblyomma americanum, Dermacentor variabilis*
Detection, characterization, and prediction of tick-borne disease foci	2002	Cortinas	10.1016/S1438-4221(02)80003-0	*Ixodes scapularis*
County-level surveillance of white-tailed deer infestation by *Ixodes scapularis* and *Dermacentor albipictus* along the Illinois River	2006	Cortinas	10.1603/0022-2585(2006)43[810:CSOWDI]2.0.CO;2	*Dermacentor albipictus, Ixodes scapularis*
Field and climate-based model for predicting the density of host-seeking nymphal *Ixodes scapularis*, an important vector of tick-borne disease agents in the eastern United State	2010	Diuk-Wasser	10.1111/j.1466-8238.2010.00526.x	*Ixodes scapularis*
Notes on the parasites of cottontail rabbits in Illinois	1956	Ecke		*Haemaphysalis leporispalustris, Ixodes dentatus, Ixodes sculptus*
Ixodes spp. From dogs and cats in the United States: Diversity, seasonality, and prevalence of *Borrelia burgdorferi* and *Anaplasma phagocytophilum*	2020	Ghosh	10.1111/j.1466-8238.2010.00526.x	*Ixodes cookei**
The Influence of Prescribed Fire, Habitat, and Weather on *Amblyomma americanum* (Ixodida: Ixodidae) in West-Central Illinois, USA	2018	Gilliam	10.3390/insects9020036	*Amblyomma americanum, Dermacentor variabilis, Ixodes scapularis*

Table 1.1 (cont.)				
Impact of unexplored data sources of the historical distribution of three vector tick species in Illinois	2020	Gilliam	10.1093/jme/tjz235	*Amblyomma americanum, Dermacentor variabilis, Ixodes scapularis*
Predicting the risk of Lyme disease: Habitat suitability for *Ixodes scapularis* in the North Central United States	2002	Guerra	10.3201/eid0803.010166	*Ixodes scapularis*
Wild birds as sentinels for multiple zoonotic pathogens along an urban to rural gradient in greater Chicago, Illinois	2012	Hamer	10.1111/j.1863-2378.2012.01462.x	*Ixodes scapularis*
Wild birds and urban ecology of ticks and tick-borne pathogens, Chicago, Illinois USA 2005-2010	2012	Hamer	10.3201/eid1810.120511	*Amblyomma longirostre, Amblyomma nodosum, Haemaphysalis leporispalustris, Ixodes dentatus, Ixodes scapularis*
Borrelia burgdorferi in *Ixodes scapularis* ticks, chicago area	2006	Jobe	10.3201/eid1206.060306	*Ixodes scapularis*
Lyme disease in urban areas, Chicago	2007	Jobe	10.3201/eid1311.070801	*Ixodes scapularis*
Populations of *Ixodes scapularis* (Acari : Ixodidae) are modulated by drought at a Lyme disease focus in Illinois	2000	Jones	10.1603/0022-2585(2000)037[0408:POISAI]2.0.CO;2	*Ixodes scapularis*
Invasion: Exotic ticks (Acari: Argasidae, Ixodidae) Imported into the United States. A Review and New Records	2001	Keirans	10.1603/0022-2585-38.6.850	*Amblyomma cayprium, Amblyomma dissimile, Amblyomma geayi, Amblyomma javanense, Amblyomma latum, Ablyomma nodosum, Ablyomma vairum, Bothriocroton concolor, Dermacentor auratus, Dermacentor nuttalli, Ixodes schillingsi, Rhipicephalus pulchellus*
Use of the ARC/INFO GIS to study the distribution of Lyme disease ticks in an Illinois county	1991	Kitron	10.1016/S0167-5877(05)80009-1	*Ixodes scapularis (Ixodes dammini)*
Spatial and temporal dispersion of immature *Ixodes dammini* on *Peromyscus leucopus* in Northwestern Illinois	1991	Kitron	10.2307/3282747	*Ixodes scapularis (Ixodes dammini)*

Table 1.1 (cont.)				
Spatial-analysis of the distribution of *Ixodes dammini* (Acari, Ixodidae) on white-tailed deer in ogle county Illinois	1992	Kitron	10.1093/jmedent/29.2.259	*Ixodes scapularis (Ixodes dammini)*
New Distribution Records of ticks associated with Cliff swallows, *Petrochelidon* spp., in the United States	1962	Kohls	10.2307/3275241	*Ixodes baergi*
Parasites of Cottontail Rabbits of Southern Illinois	1992	Lepitzki	10.2307/3283234	*Amblyomma americanum, Haemaphysalis leporispalustris, Ixodes dentatus*
Role of the Eastern chipmunk as a host for immature *Ixodes dammini* (Acari: Ixodidae) in Northwestern Illinois	1993	Mannelli	10.1093/jmedent/30.1.87	*Ixodes scapularis (Ixodes dammini)*
Ixodes dammini (Acari: Ixodidae) infestation on medium-sized mammals and blue jays in Northwestern Illinois	1993	Mannelli	10.1093/jmedent/30.5.950	*Ixodes scapularis (Ixodes dammini)*
Influence of season and habitat on *Ixodes scapularis* infestation on White-footed mice in Northwestern Illinois	1994	Mannelli	10.2307/3283457	*Ixodes scapularis*
Lone-star ticks from white-tailed deer in Illinois	1967	Montgomery		*Amblyomma americanum, Dermacentor variabilis*
Rate of tick attachment to a white-tailed deer fawn	1968	Montgomery		*Dermacentor variabilis*
Ticks on white-tailed deer fawns from southern Illinois	1984	Nelson	10.7589/0090-3558-20.4.300	*Amblyomma americanum, Dermacentor variabilis*
Isolation and characterization of *Borrelia burgdorferi* from Illinois *Ixodes dammini*	1991	Nelson	10.1128/JCM.29.8.1732-1734.1991	*Ixodes scapularis (Ixodes dammini)*
Using citizen science to describe the prevalence and distribution of tick bite and exposure to tick-borne diseases in the United States	2018	Nieto	10.1371/journal.pone.0199644	*Amblyomma americanum, Dermacentor variabilis, Ixodes scapularis*
Avian and habitat characteristics influence tick infestation among birds in Illinois	2017	Parker	10.1093/jme/tjw235	*Haemaphysalis leporispalustris, Ixodes dentatus, Ixodes scapularis*
Documentation of the Expansion of the Gulf Coast Tick (*Amblyomma maculatum*) and *Rickettsia parkeri*: First report in Illinois	2020	Phillips	10.1645/19-118	*Amblyomma maculatum*

Table 1.1 (cont.)				
Ixodes scapularis and *Borrelia burgdorferi* among diverse habitats within a natural area in east-central IL	2011	Rydzewski	10.1089/vbz.2010.0160	*Ixodes scapularis*
Ixodes scapularis (Acari: Ixodidae) Distribution Surveys in the Chicago Metropolitan region	2012	Rydzewski	10.1603/ME11233	*Amblyomma americanum, Dermacentor variabilis, Haemaphysalis leporispalustris, Ixodes dentatus, Ixodes scapularis*
Assessing the Contribution of Songbirds to the movement of ticks and B*orrelia burgdorferi* in the midwestern united States during fall migration	2015	Schneider	10.1007/s10393-014-0982-3	*Haemaphysalis leporispalustris, Ixodes dentatus, Ixodes scapularis*
Spatial and temporal distribution of *Ixodes dammini* (Acari: Ixodidae) in a Northwestern Illinois state park	1991	Siegel	10.1093/jmedent/28.1.101	*Ixodes scapularis (Ixodes dammini)*
Role of the eastern chipmunk (*Tamias striatus*) in the epizootiology of Lyme borreliosis in northwestern Illinois, USA	1997	Slajchert	10.7589/0090-3558-33.1.40	*Ixodes scapularis*
Ectoparasites of the cottontail rabbit in Lee County, northern Illinois	1958	Stannard	10.5962/bhl.title.15127	*Dermacentor variabilis, Haemaphysalis leporispalustris, Ixodes dentatus, Ixodes sculptus*
Heartland Virus in Humans and Ticks, Illinois, USA, 2018-2019	2020	Tuten	10.3201/eid2607.200110	*Amblyomma americanum, Dermacentor variabilis, Ixodes scapularis*
The biology of the striped skunk	1967	Verts		*Dermacentor variabilis, Ixodes cookei*
Water vapor absorption by nymphal lone star tick, *Amblyomma americanum* (Acari: Ixodidae), and its ecological significance	2003	Yoder	10.1080/01647950308684337	*Amblyomma americanum*
Concurrent examination of bobcats and ticks reveals high prevalence of *Cytauxzoon felis* in Southern Illinois	2017	Zieman	10.1645/16-133	*Amblyomma americanum, Dermacentor variabilis*
Within-season changes in *Cytauxzoon felis* parasitemia in bobcats	2020	Zieman	10.1645/19-173	*Ixodes scapularis*

Table 1.2 Tick species established or reported in Illinois

Established	Reported			
	On native host or human	**On migratory bird**	**On imported or exotic animal**	
Carios kelleyi	*Ixodes brunneus*	*Amblyomma longirostre*	*Amblyomma cajennense*	*Dermacentor auratus*
Amblyomma americanum	*Ixodes marxi*	*Amblyomma nodosum*	*Amblyomma dissimile*	*Dermacentor nitens*
Amblyomma maculatum	*Ixodes muris*		*Amblyomma geayi*	*Dermacentor nuttalli*
Dermacentor albipictus	*Otobius megnini*		*Amblyomma javanense*	*Dermacentor pavlovskyi*
Dermacentor variabilis			*Amblyomma latum*	*Haemaphysalis leachi*
Haemaphysalis leporispalustris			*Amblyomma nodosum*	*Ixodes schillingsi*
Ixodes baergi			*Amblyomma rotundatum*	*Rhipicephalus pulchellus*
Ixodes cookei			*Amblyomma scutatum*	
Ixodes dentatus			*Amblyomma testudinarium*	
Ixodes scapularis			*Amblyomma triguttatum*	
Ixodes sculptus			*Amblyomma varium*	
Ixodes texanus			*Bothriocroton concolor*	
Rhipicephalus sanguineus			*Bothriocroton hydrosauri*	

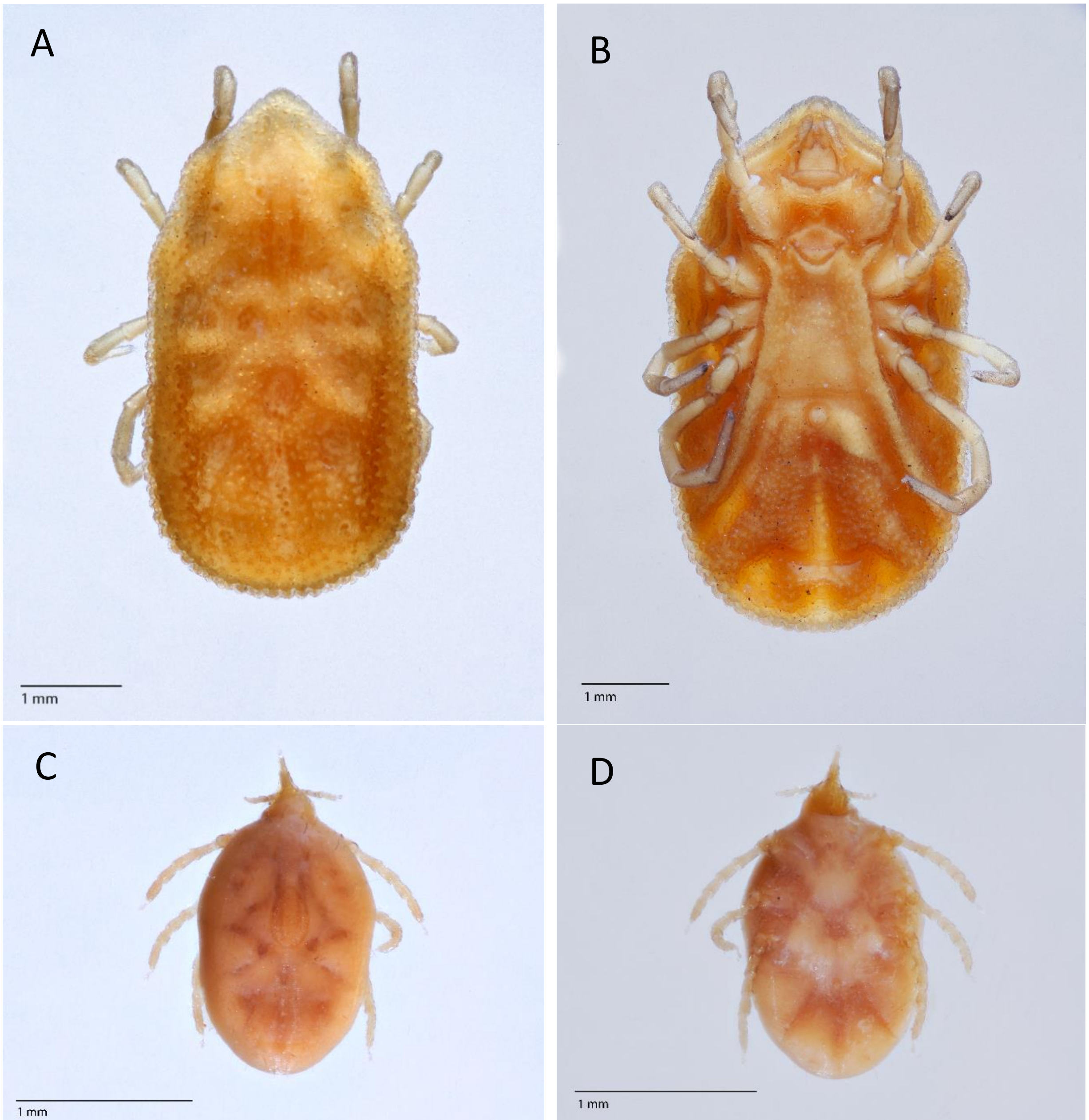

Figure 1.1 Dorsal and ventral views of a *Carios kelleyi* adult (1.1A &1.1B) and larva (1.1C & 1.1D)

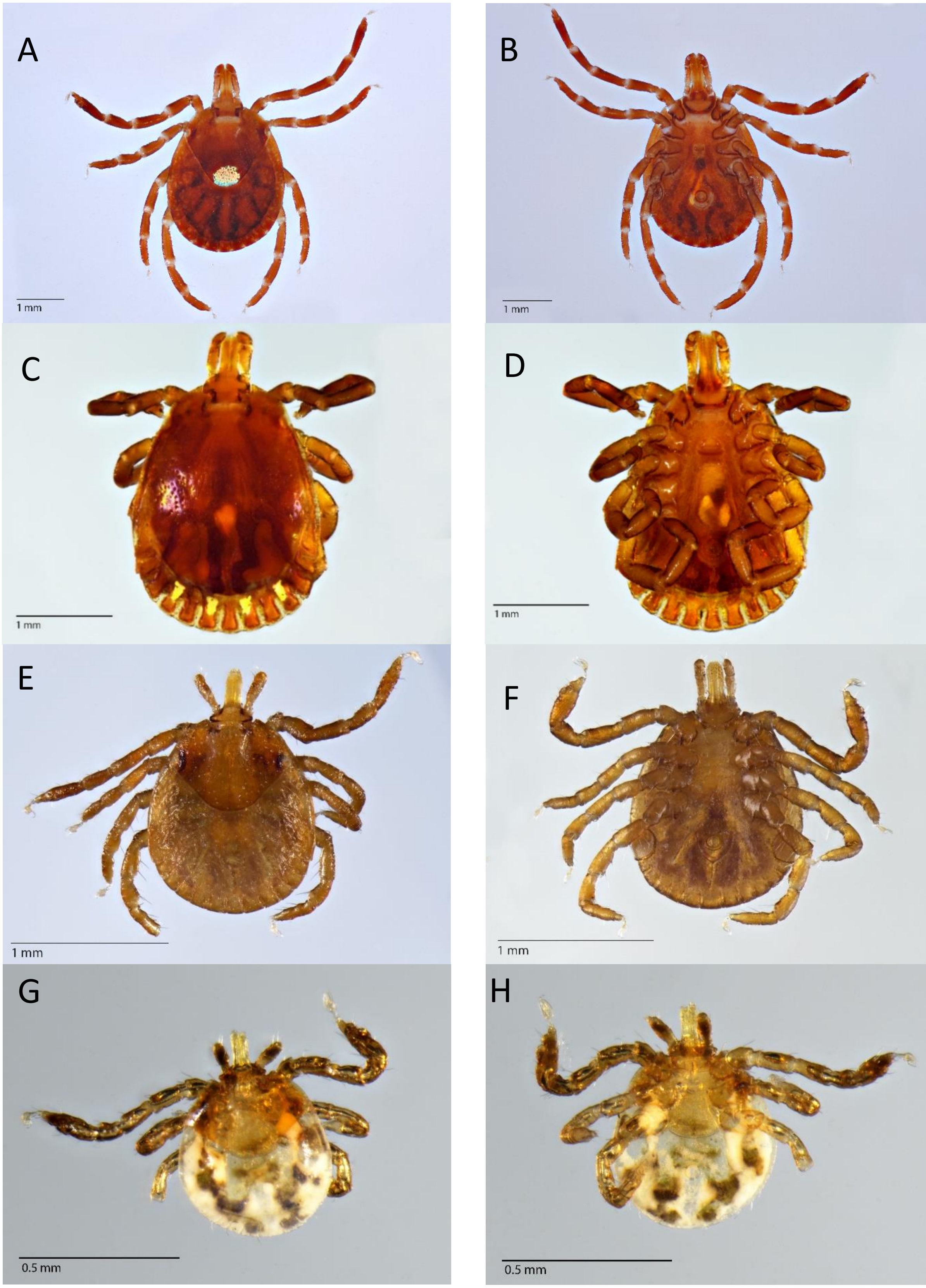

Figure 1.2 Dorsal and ventral views of an *Amblyomma americanum* adult female (1.2A & 1.2B), adult male (1.2C & 1.2D), nymph (1.2E & 1.2F), and larva (1.2G & 1.2H)

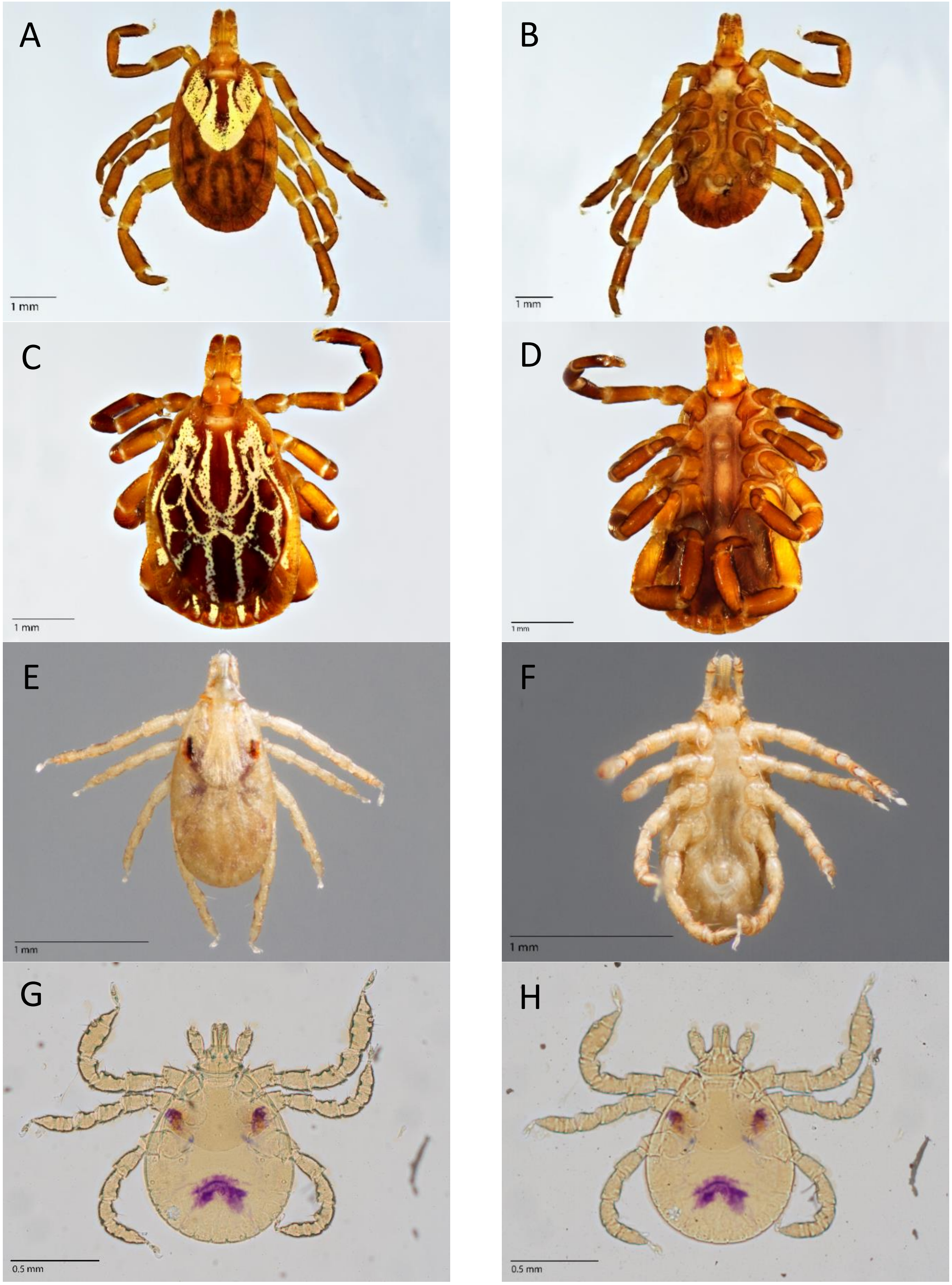

Figure 1.3 Dorsal and ventral views of an *Amblyomma maculatum* adult female (1.3A & 1.3B), adult male (1.3C & 1.3D), nymph (1.3E & 1.3F), and larva (1.3G & 1.3H). Note: Larvae were slide mounted with Hoyer's solution

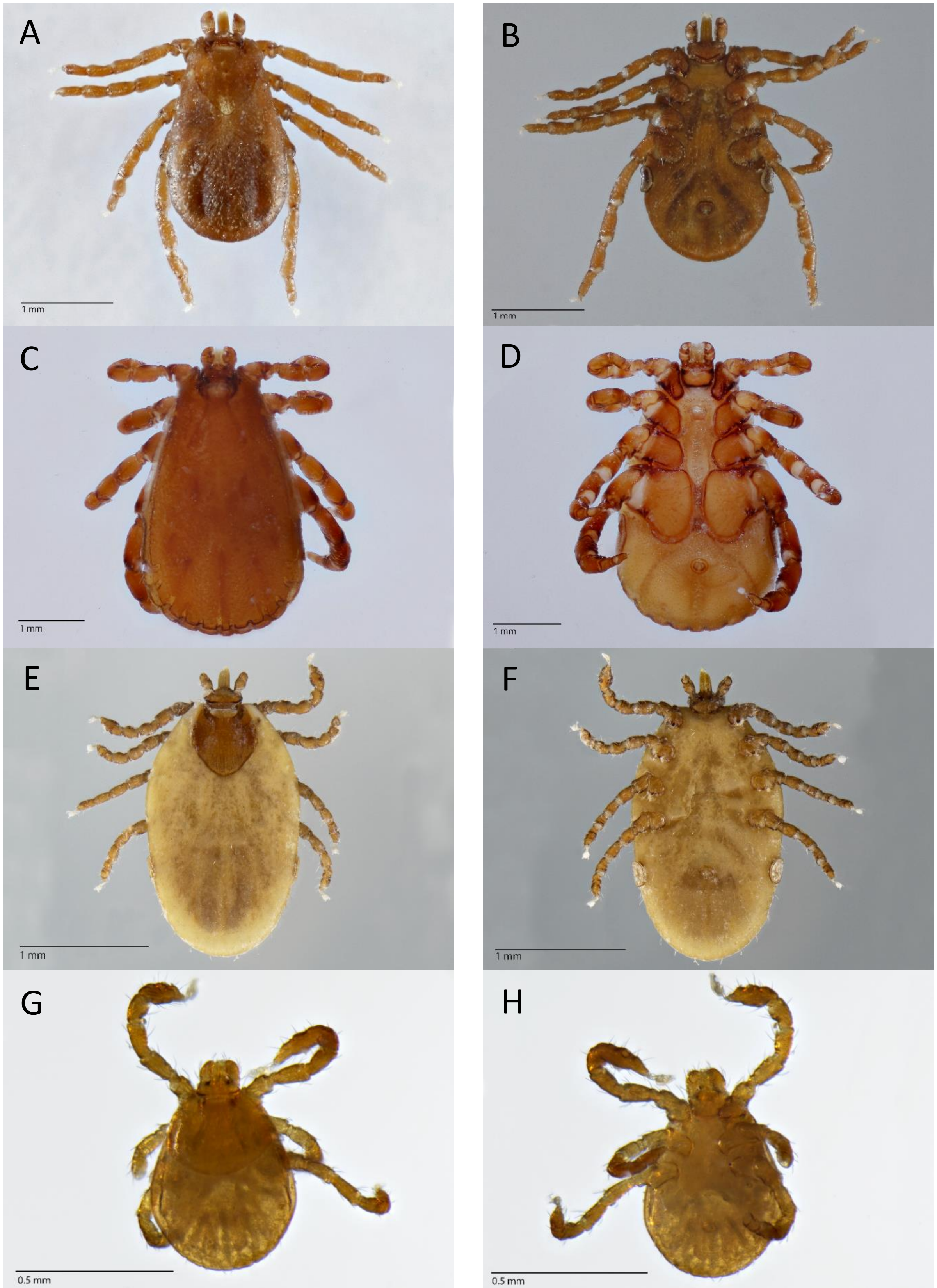

Figure 1.4 Dorsal and ventral views of a *Dermacentor albipictus* adult female (1.4A & 1.4B), adult male (1.4C & 1.4D), nymph (1.4E & 1.4F), and larva (1.4G & 1.4H)

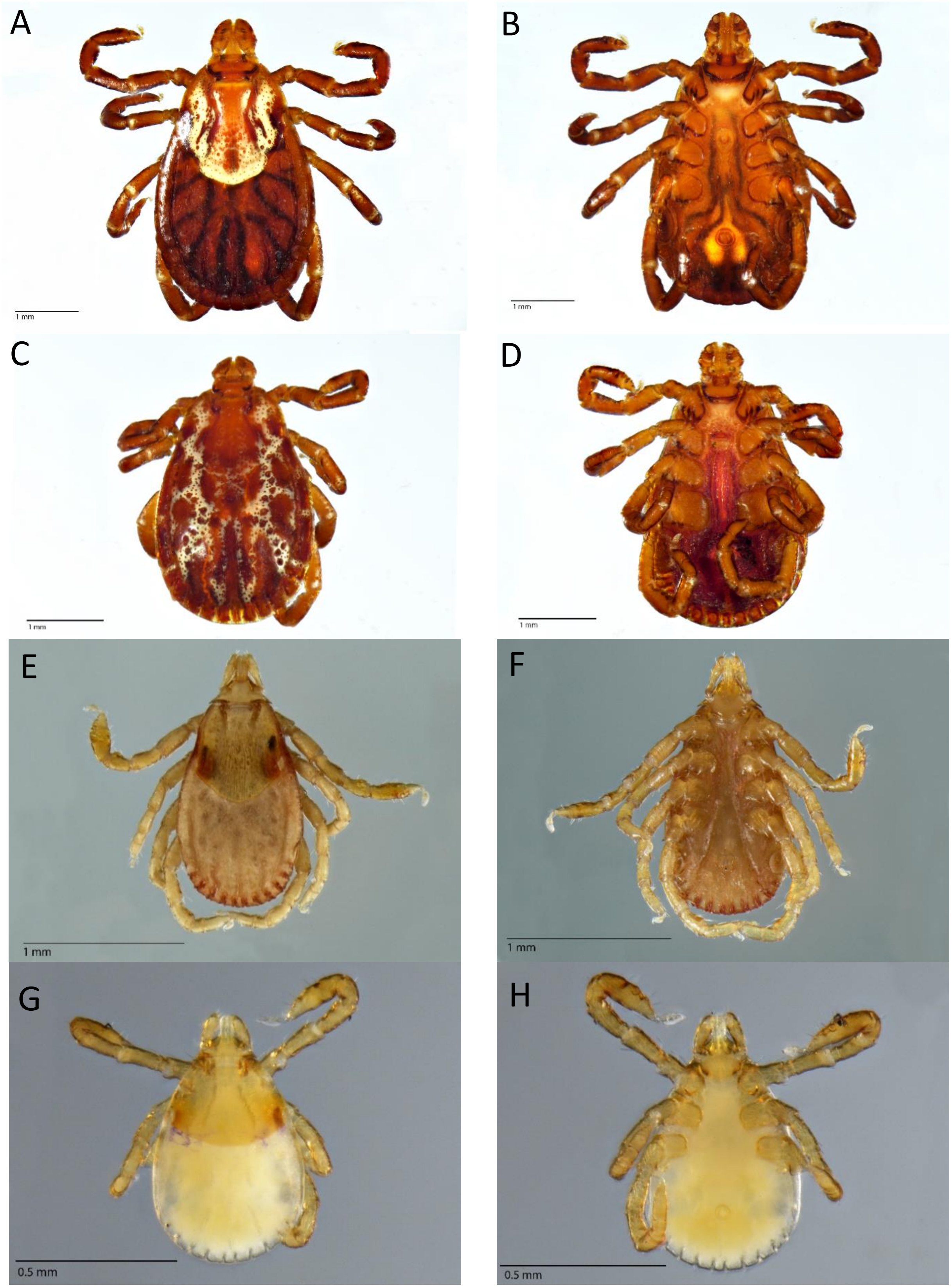

Figure 1.5 Dorsal and ventral views of a *Dermacentor variabilis* adult female (1.5A & 1.5B), adult male (1.5C & 1.5D), nymph (1.5E & 1.5F), and larva (1.5G & 1.5H)

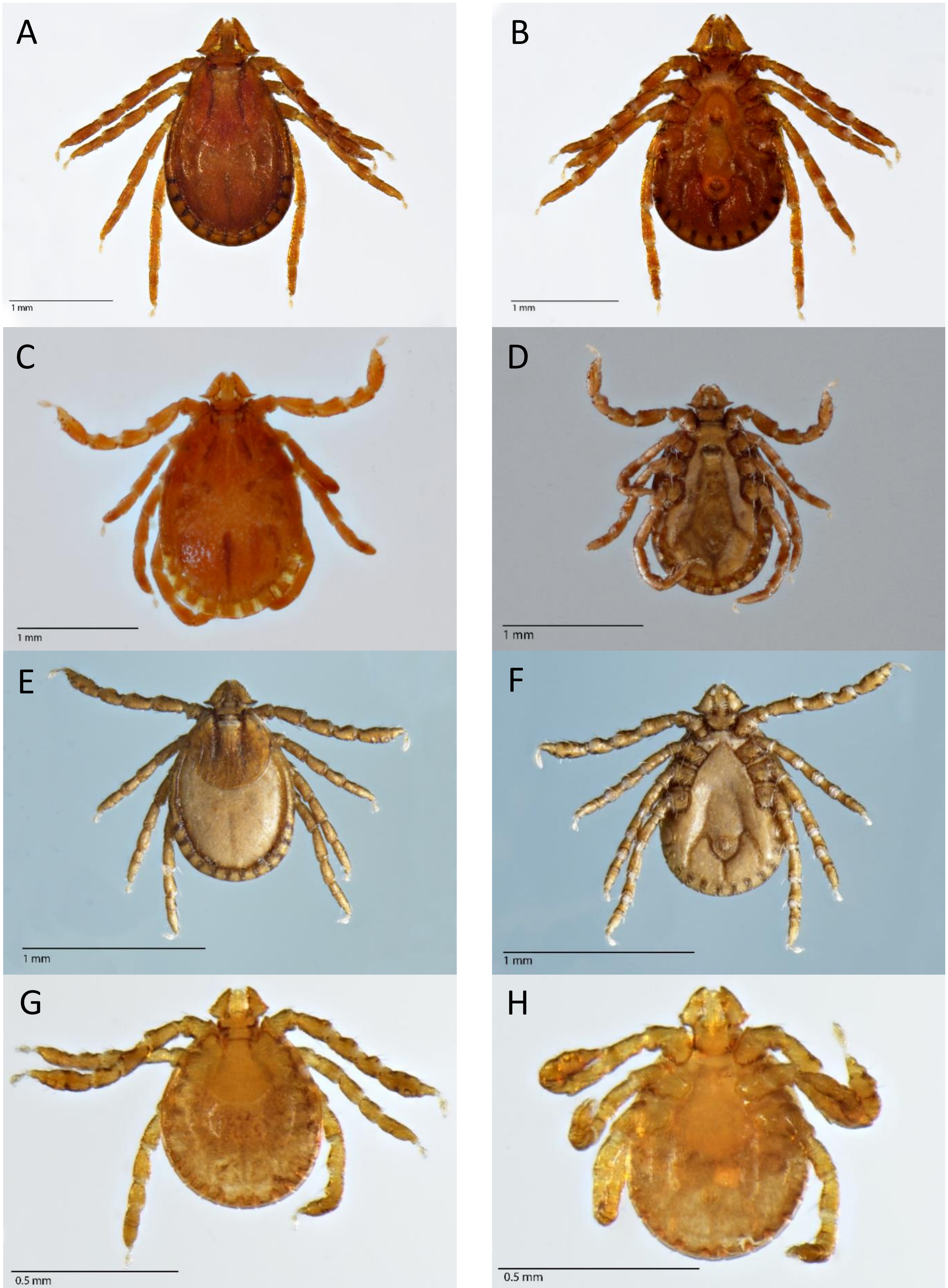

Figure 1.6 Dorsal and ventral views of a *Haemaphysalis leporispalustris* adult female (1.6A & 1.6B), adult male (1.6C & 1.6D), nymph (1.6E & 1.6F), and larva (1.6G & 1.6H)

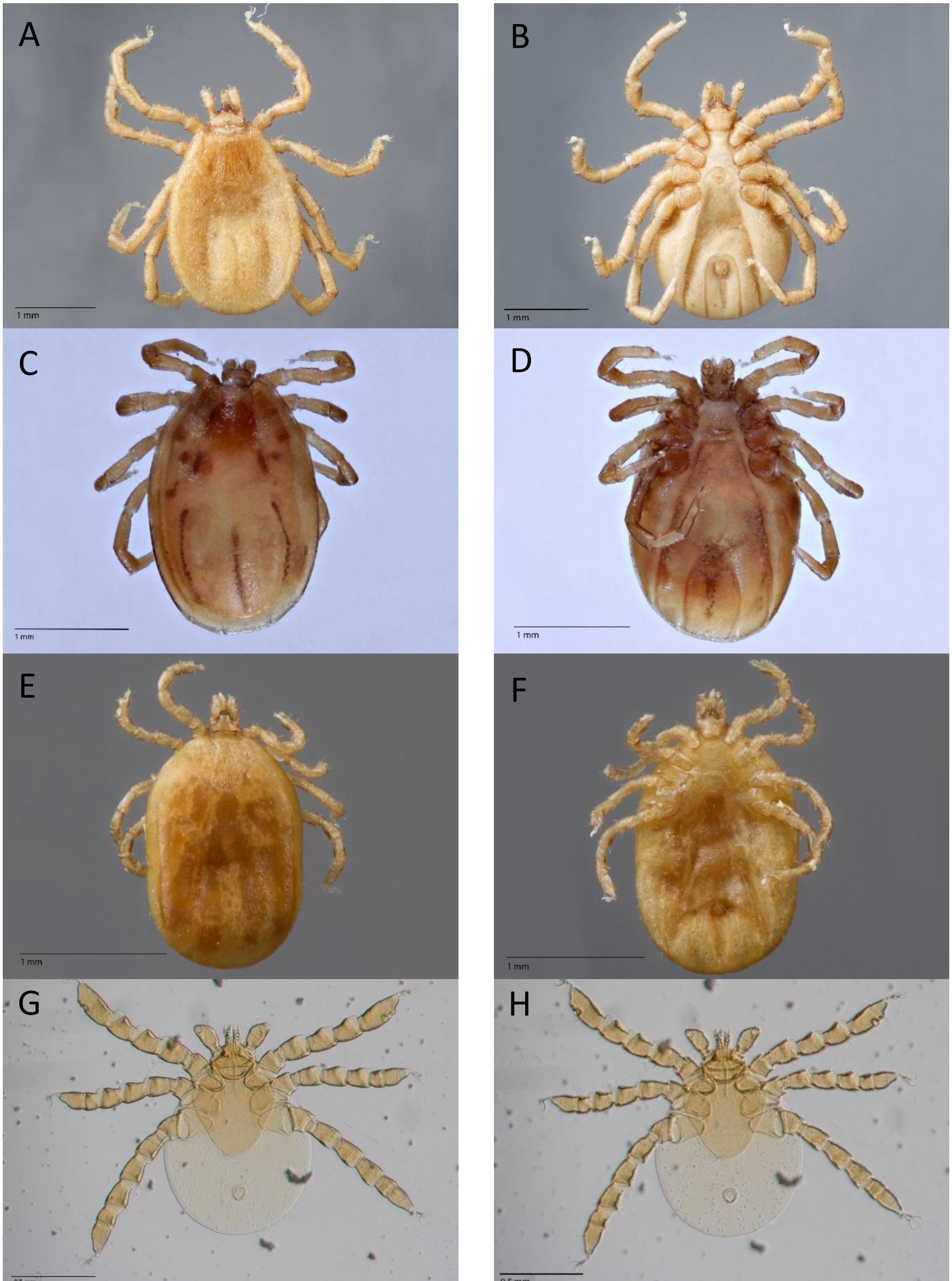

Figure 1.7 Dorsal and ventral views of an *Ixodes baergi* (1.7A & 1.7B), adult male (1.7C & 1.7D), nymph (1.7E & 1.7F), and larva (1.7G & 1.7H). Note: Larvae were slide mounted with Hoyer's solution

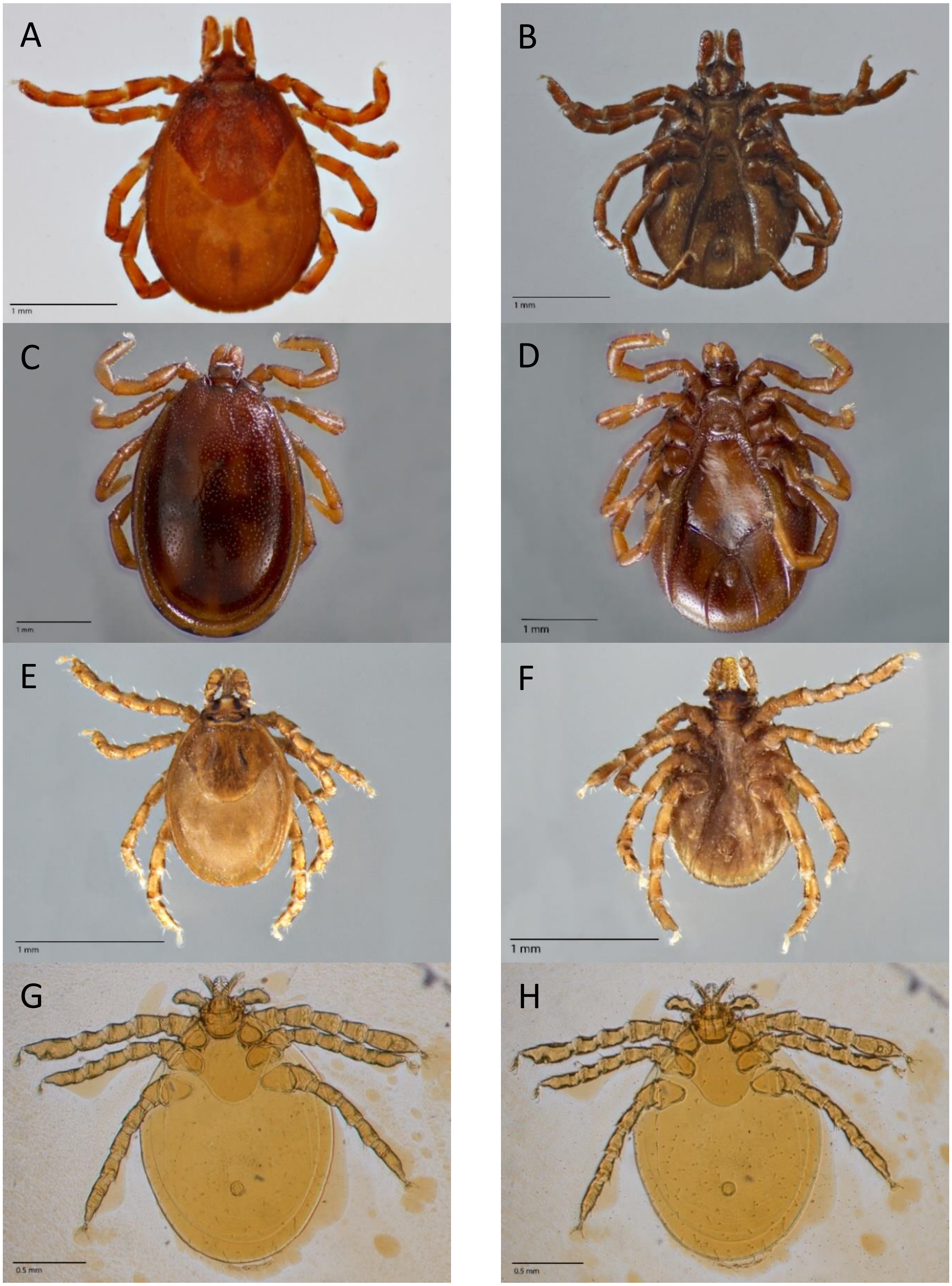

Figure 1.8 Dorsal and ventral views of an *Ixodes cookei* (1.8A & 1.8B), adult male (1.8C & 1.8D), nymph (1.8E & 1.8F), and larva (1.8G & 1.8H). Note: Larvae were slide mounted with Hoyer's solution

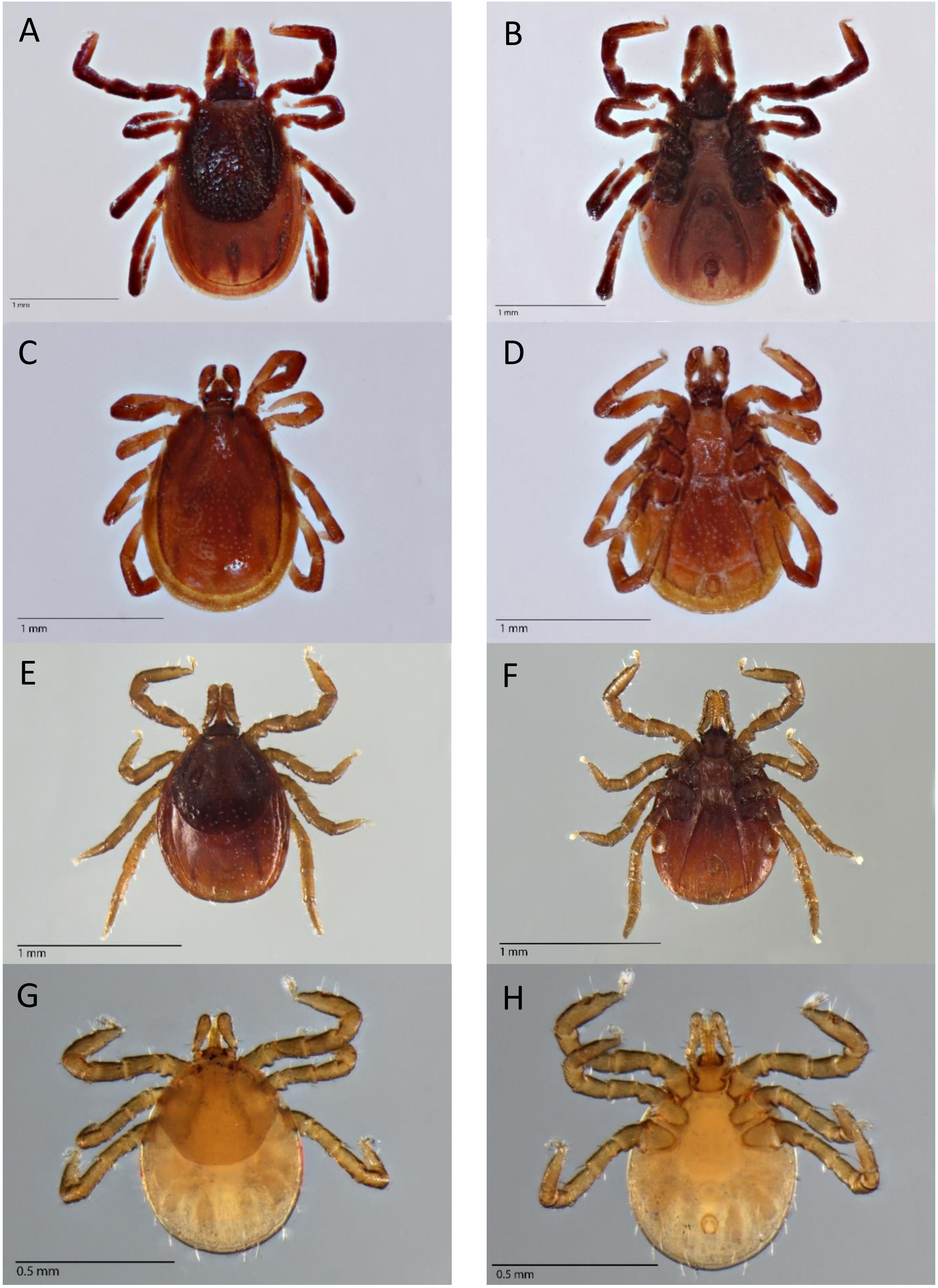

Figure 1.9 Dorsal and ventral views of an *Ixodes dentatus* (1.9A & 1.9B), adult male (1.9C & 1.9D), nymph (1.9E & 1.9F), and larva (1.9G & 1.9H)

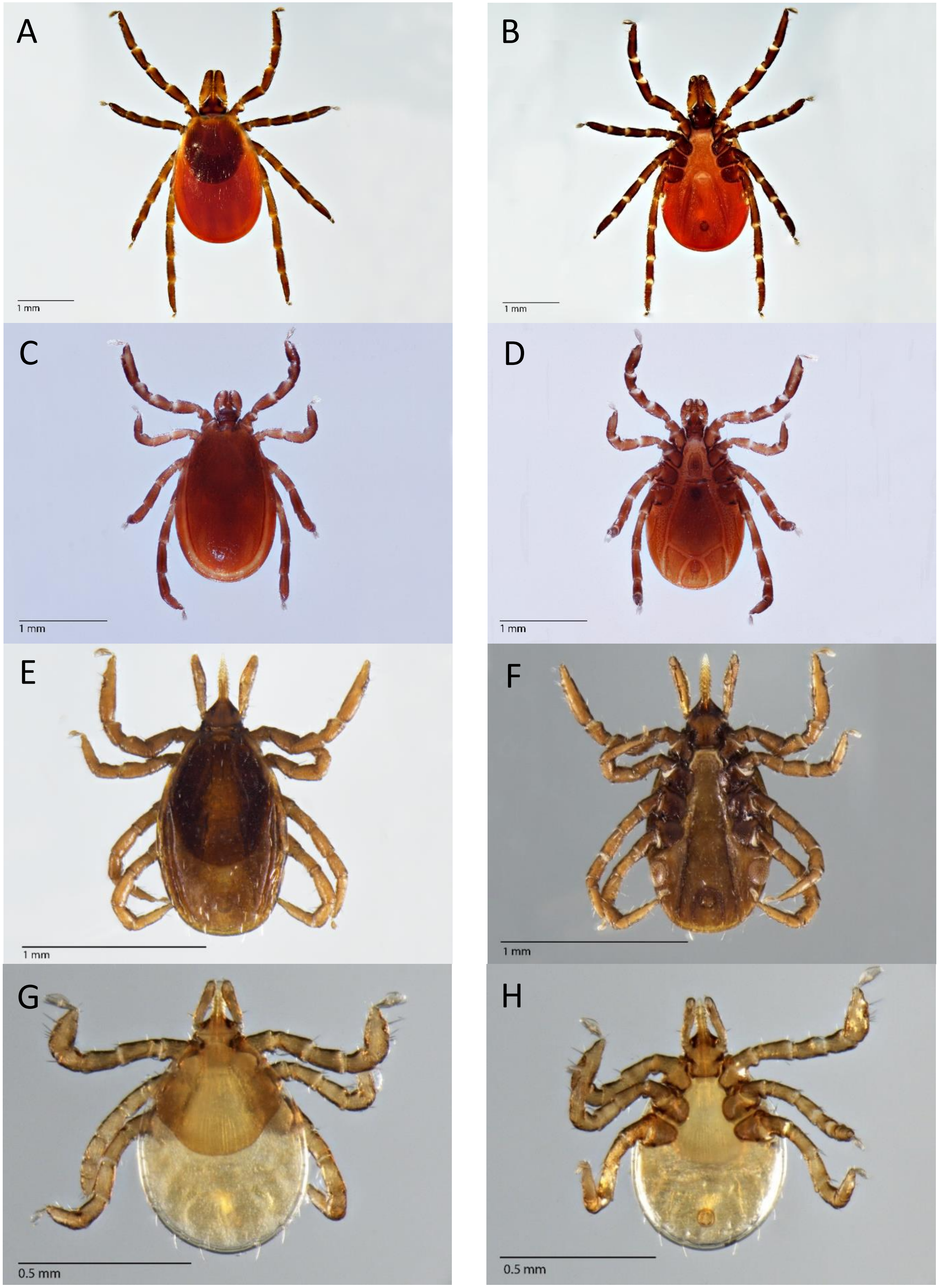

Figure 1.10 Dorsal and ventral views of an *Ixodes scapularis* (1.10A & 1.10B), adult male (1.10C & 1.10D), nymph (1.10E & 1.10F), and larva (1.10G & 1.10H)

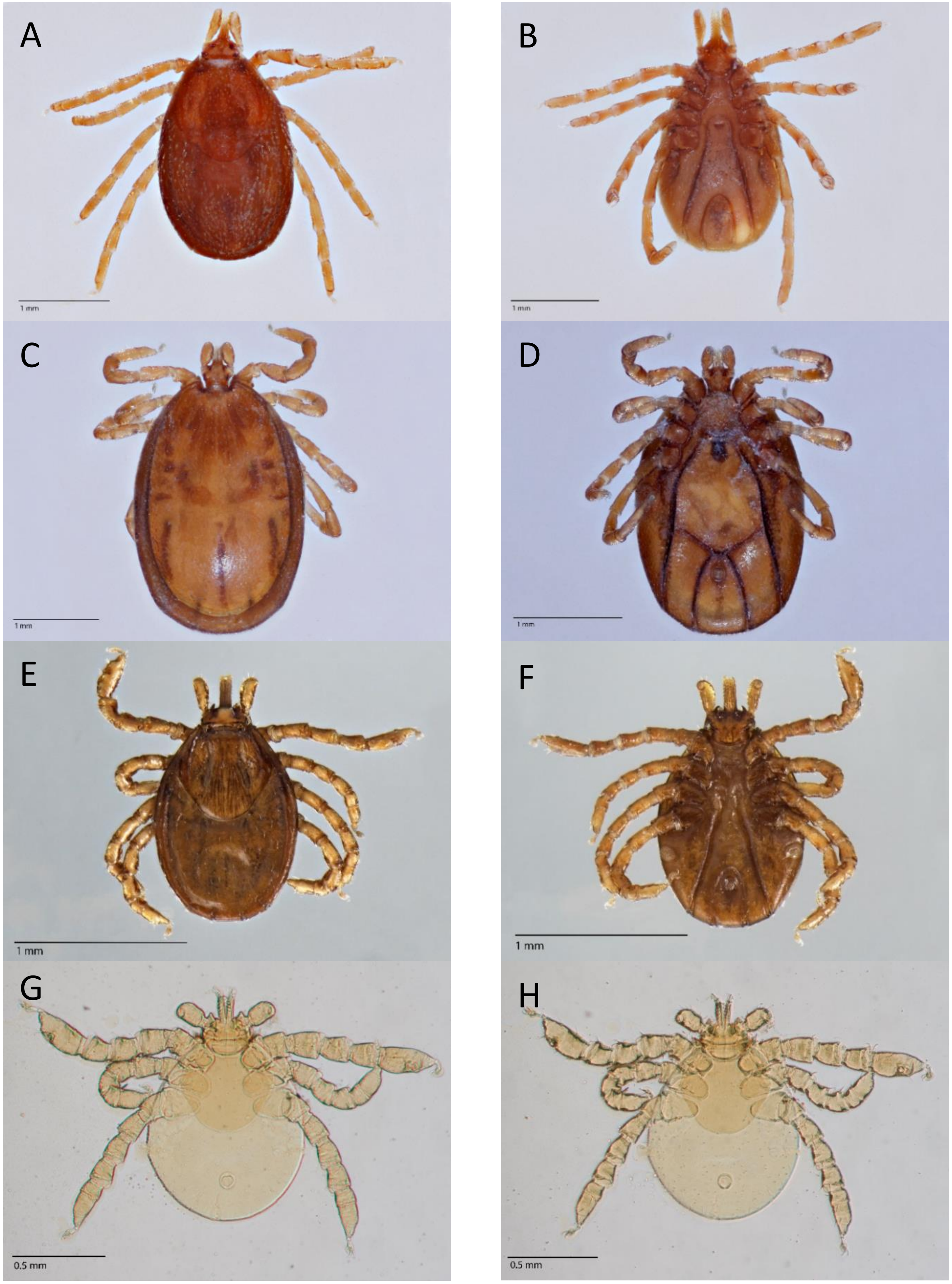

Figure 1.11 Dorsal and ventral views of an *Ixodes sculptus* (1.11A & 1.11B), adult male (1.11C & 1.11D), nymph (1.11E & 1.11F), and larva (1.11G & 1.11H). Note: Larvae were slide mounted with Hoyer's solution

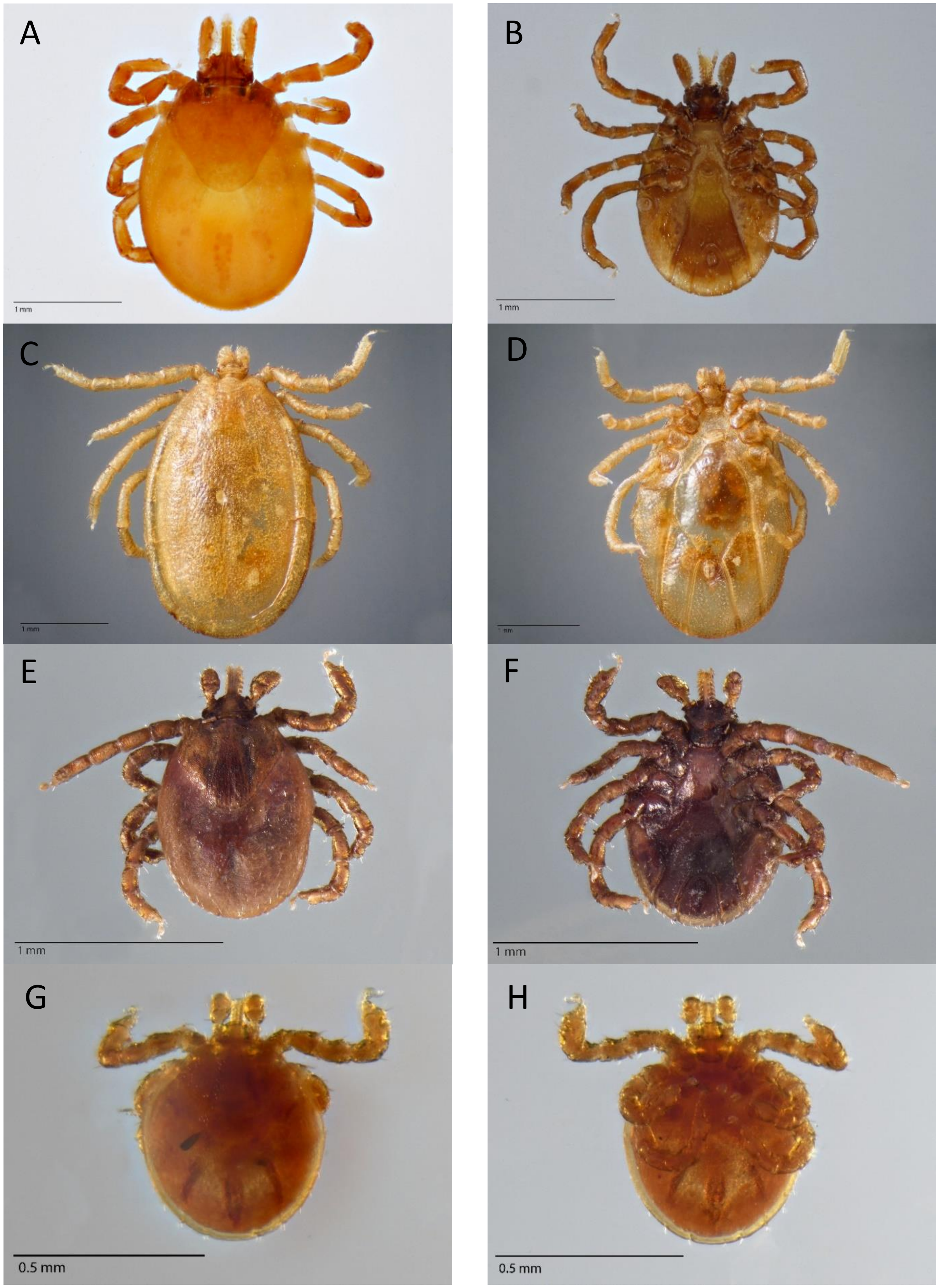

Figure 1.12 Dorsal and ventral views of an *Ixodes texanus* (1.12A & 1.12B), adult male (1.12C & 1.12D), nymph (1.12E & 1.12F), and larva (1.12G & 1.12H)

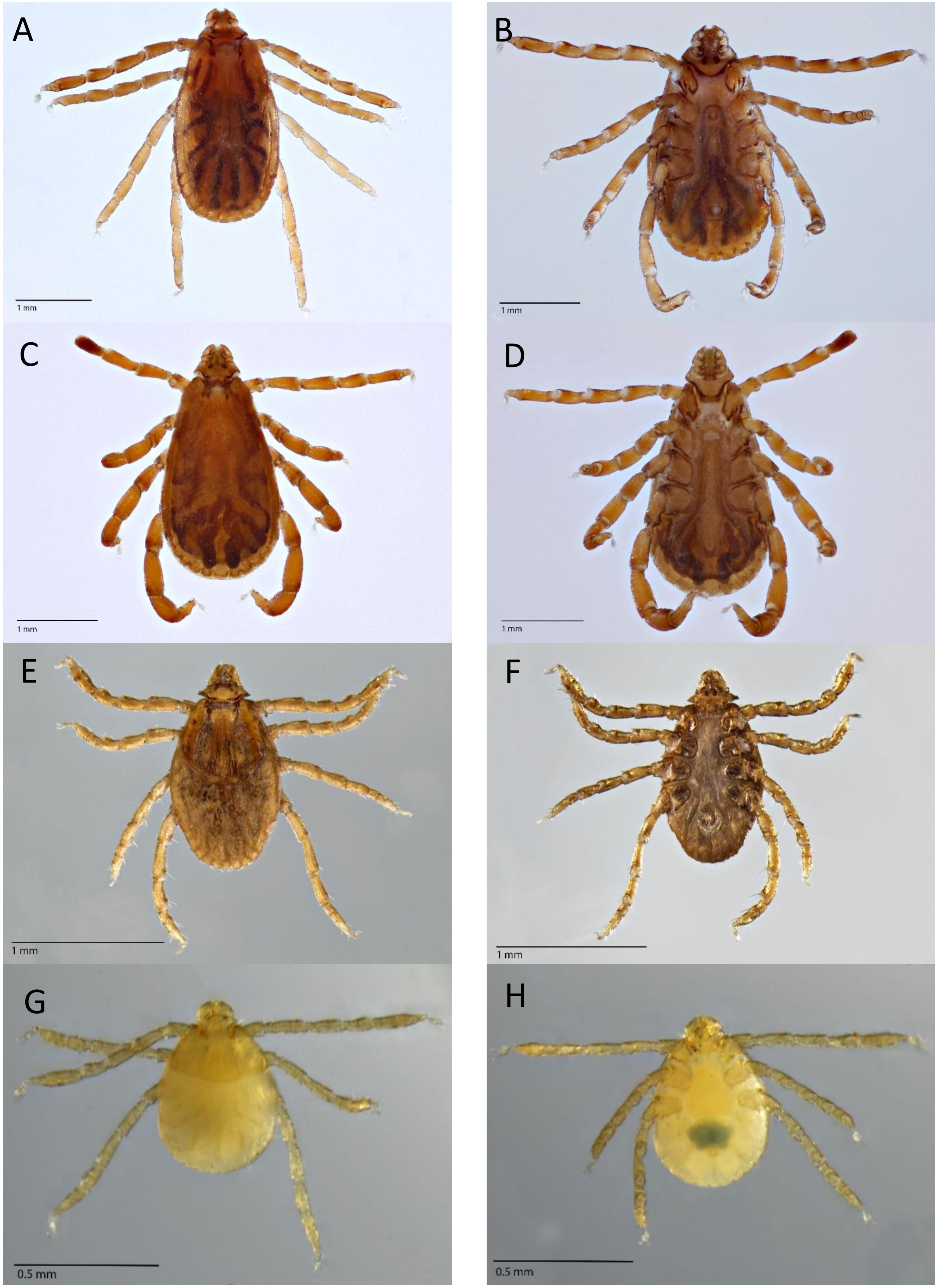

Figure 1.13 Dorsal and ventral views of a *Rhipicephalus sanguineus* (1.13A & 1.13B), adult male (1.13C & 1.13D), nymph (1.13E & 1.13F), and larva (1.13G & 1.13H)

Figure 1.14 Heatmaps showing the species of tick versus the host species parasitized for the 13 tick species established in Illinois. (1.14A) Color of heatmap corresponds to proportion of ticks associated with each host species based on all collection events where number of ticks was reported (1.14B) Color of heatmap shows the presence/absence of ticks found on each host species

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CHAPTER 2

An Illustrated Taxonomic Key to the Hard Tick [Acari: Ixodidae] Nymphs of Illinois

ABSTRACT

Nymphal ticks are an important life stage for pathogen transmission to humans. However, taxonomic resources for differentiating among genera and species of nymphal ticks in the United States are scant. The aim of this study was to develop easy-to-use, pictographic identification resources for the nymphal ticks of Illinois. Two types of taxonomic keys, a dichotomous key and a matrix-based key, were developed, and each key included the fifteen species of nymphal hard ticks [Acari: Ixodidae] that are either established or have been reported on native hosts in Illinois. Existing taxonomic keys and species descriptions were consulted to construct these keys. Descriptions and high-quality images of important diagnostic characters are also provided. These keys consolidate and update taxonomic resources for these medically important arthropods, and the results of this study can be adapted to serve a broad constituency.

INTRODUCTION

Ticks are among the most important arthropod vectors of medical and veterinary concern, and nymphal ticks in particular present some of the greatest challenges in the study of ticks and tick-borne diseases. While, depending on species, adult female, male, and nymphal ticks can be major vectors of tick-borne disease-agents (TBDs), nymphs are considered the highest risk life stage for the transmission of TBDs, especially the agents of Lyme disease, to humans (Barbour & Fish, 1993; Falco et al., 1999). For nymphal *Ixodes scapularis* Say, 1821 and Lyme disease, this is in part due to an activity peak in the late spring and summer which aligns with increased outdoor human activity (Eisen & Eisen, 2016; Falco et al., 1999; Spielman et al., 1985).

An additional challenge posed by nymphal ticks is their small size. Typically less than 2mm long, nymphal ticks are significantly less likely to be detected by humans than adult females (Falco et al., 1996). The small size of nymphal ticks also makes morphological identifications more difficult than adult identifications (Anderson et al., 2004; Eisen & Eisen, 2016). This is important because the disease risks presented by ticks are directly tied to which species they are, and thus, accurate identification of nymphal ticks is a vital part of the diagnostic process for tick-borne diseases (Brouqui et al., 2004).

Despite the public health importance of nymphal ticks, identification resources for this group are scattered. Most existing taxonomic keys for nymphal ticks in North America only focus on a single genus at a time (Brinton et al., 1965; Cooley & Kohls, 1945; Durden & Keirans, 1996; Egizi et al., 2019; Keirans & Durden, 1998). Intergeneric keys do exist, but they are scarce and geographically delimited (Furman and Loomis, 1984; Lindquist et al., 2016; Sonenshine 1979). This can make identifications difficult if an observer is not confident of the genus a tick belongs to. In addition, if the existing keys to nymphal ticks have illustrations, they are usually either line drawings (e.g., Brinton et al., 1965; Cooley & Kohls, 1945; Lindquist et al., 2016) or SEM photographs (e.g., Durden & Keirans, 1996; Egizi et al., 2019; Keirans & Durden, 1998) to depict diagnostic characters. Illustrations of diagnostic characters are vital for accurate tick identifications (Estrada-Peña et al., 2017). While both line drawings and SEM photographs are useful, they may also be difficult for non-experts to interpret when compared to a specimen under a dissection microscope, which is what most people have access to when identifying a tick. Finally, many tick identification resources are not available digitally, which makes them difficult to access. These factors can make tick diagnostic resources inaccessible or of little functional use, especially for non-experts. It’s currently recommended that ticks in medical and veterinary practices be preserved for identification by experts due to a lack of knowledge about tick identifications among veterinarians and physicians (Dantas-Torres et al., 2012). While other recently published keys have begun to ameliorate this lack of taxonomic resources for the most common tick species in the United States, more robust and comprehensive identification guides are still needed (Dubie et al., 2017). Recent advances in computer-assisted tick identification software show promise, but they lack taxonomic breadth and are not yet widely available (Luo et al., 2022). Ideally, these collective efforts will lead to illustrated tick identification resources that can be used with a high degree of accuracy by both experts and non-experts.

Another limitation of existing resources for nymphal tick identification is the format of available taxonomic keys. All existing keys for ticks in the United States are in the traditional, "dichotomous key" format, where one must proceed sequentially through pairs of characters to arrive at an identification. While these keys can be easy to use and understand, they also have their challenges. If a specimen is damaged or a descriptor is unclear, it may become difficult or impossible to continue through the key. This problem is especially prevalent for ticks. Ticks can be damaged during removal from a host, which can make the diagnosis of important characters, especially those on the capitulum, uncertain. Ticks are also able to engorge, or grow larger, during feeding, which can obscure diagnostic characters and generally add confusion to the identification process.

Many of the aforementioned problems can be avoided through the use of matrix-based keys. Matrix-based keys differ from dichotomous keys in that there is not one defined pathway to arrive at an identification (Walter & Winterton, 2007). Rather, users can start with any included character and can continue identifying characters in any order until a determination is reached.

Similar keys have been successfully developed to aid in the identification of other arthropods, including various economically and medically important species, and they are a promising resource for tick identification (Cerretti et al., 2012; Douglas et al., 2019; McElrath et al., 2016; Miller et al., 2014; *WRBU: Keys to the Medically Important Mosquito Species*, n.d.).

The objective of this study was to create comprehensive, easy to use identification resources for hard tick nymphs encountered in Illinois. To do this, two taxonomic keys for the hard tick nymphs of Illinois were created: a dichotomous key and a matrix-based key.

METHODOLOGY

Taxonomic coverage

Fifteen species of hard ticks in the family Ixodidae were included in this key. This includes twelve species classified as established in Illinois and three species classified as reported on native hosts in Illinois (Chapter 1).

The taxa included were: *Amblyomma americanum* (Linnaeus, 1758); *Amblyomma maculatum* Koch, 1844; *Dermacentor albipictus* (Packard, 1869); *Dermacentor variabilis* (Say, 1821); *Haemaphysalis leporispalustris* (Packard, 1869); *Ixodes baergi* Cooley & Kohls, 1942; *Ixodes brunneus* Koch, 1844; *Ixodes cookei* Packard, 1869; *Ixodes dentatus* Marx, 1899; *Ixodes marxi* Banks, 1908; *Ixodes muris* Bishopp & Smith, 1937; *Ixodes scapularis* Say, 1821; *Ixodes sculptus* Neumann, 1904; *Ixodes texanus* Banks, 1909; and *Rhipicephalus sanguineus* (Latreille, 1806).

Characters and character states

Characters and character states were determined by examining existing descriptions for each species. Descriptions for each species were identified using Guglielmone et al. (2020). For each species, the most recent, as indicated in Guglielmone et al. (2020), comprehensive species description was examined, and for each species the most recent comprehensive description was provided in Lindquist et al. (2016). From there, additional descriptions were examined as necessary to determine additional character states (Anastos & Smith, 1957; Brinton et al., 1965; Cooley, 1946; Cooley & Kohls, 1944, 1945; Durden & Keirans, 1996; Keirans et al., 1993; Keirans & Durden, 1998). In addition to species descriptions, existing taxonomic keys for nymphal ticks were also examined to compile characters useful for identification (Brinton et al., 1965; Cooley & Kohls, 1945; Dubie et al., 2016; Durden & Keirans, 1996; Egizi et al., 2019; Keirans & Durden, 1998; Lindquist et al., 2016.)**.**

Character states for seventeen characters were scored and included in the matrix-based key. A list of characters, character states, and important tick morphology terms can be found in the results section, and diagrams of the characters can be found in Figures 2.1-2.4.

Photographs

Photographs of diagnostic characters were taken using one of two set-ups: a Nikon SMZ25 microscope with attached Nikon DS-Ri2 camera at the Illinois Natural History Survey Medical Entomology Lab by Emily Struckhoff or a BK Plus Lab System (Visionary Digital) and stacked with Helicon Focus v. 4.77 at the United States National Tick Collection by Emily Struckhoff and Lorenza Beati. These photographs are included throughout both the matrix and dichotomous keys. Ticks photographed were expertly determined specimens from either the United States National Tick Collection, Illinois Natural History Survey (INHS) Insect Collection, or INHS Medical Entomology Lab tick archive.

Software

The matrix key was made in TaxonWorks version v0.23.1 using the “Observation matrix hub” task (Taxonworks community, 2022).

RESULTS

Dichotomous key to the nymphal ticks of Illinois

The dichotomous key to the nymphal ticks of Illinois can be found below, and a flowchart version with photographs included can be found in Figures 2.5-2.9. Please note that this key is only applicable for the identification of tick nymphs. Alternative keys should be consulted for the identification of larvae and adults. Tick nymphs can be differentiated from adults and larvae by (1) the presence of eight legs and (2) the lack of a genital aperture. In addition, this key was created to include species of hard ticks either established or reported on native hosts in Illinois. While the tick species of Illinois are likely very similar to those throughout the Midwest and Ohio River Valley regions of the United States, if using this key outside of Illinois be aware that there may be additional species present that are not included in this key.

The best way to view the characters presented in this key is with a dissecting microscope with 80x to 130x magnification capabilities.

1a. Anal groove posterior to anus; festoons present 2

1b. Anal groove anterior to anus; festoons absent 7

2a (1a). When oriented parallel to hypostome, lateral margin of 2nd palpal segment extends in a sharp projection beyond the lateral margin of the basis capitulum .... *Haemaphysalis* spp.*

2b. 2nd palpal segment does not extend laterally 3

3a (2b). Hexagon-shaped basis capitulum; 9 festoons .... *Rhipicephalus sanguineus*

3b. Triangular or subquadrangular-shaped basis capitulum; 11 festoons 4

4a (3b). Dorsal caudad corners of the basis capituli pointed and extending beyond lateral edges of scapulae, giving the capitulum a triangular appearance 5

4b. Dorsal caudad corners of the basis capitulum not pointed and not extending beyond the edges of the scapulae, giving the capitulum a sub-quadrangular appearance 6

5a. (4a). Coxa 1 with 2 spurs; coxa 3 with 1 spur; coxa 4 with occasional, faint spur; auriculae short and blunt; goblets of spiracular plate minute, but usually with circle of larger goblets surrounding the macula ....*Dermacentor variabilis*

5b. Coxa 1 with 1 spur; both coxa 3 and 4 without spurs; auriculae large and prominent; no circle of large goblets around the macula..*Amblyomma maculatum*

6a (4b). Length of palps longer than length of basis capitulum; palpal segment 2 three times longer than palpal segment 3; goblets of spiracular plate minute ....*Amblyomma americanum*

6b. Length of palps equal to the width of the basis capitulum; palpal segment 2 equal in length to palpal segment 3; goblets of spiracular plate large ....*Dermacentor albipictus*

7a (1b). Internal spur absent or faint on coxa 1; External spurs absent or faint on all coxae 8

7b. Internal spur present on coxa 1; External spur present on at least 1 coxa 10

8a (7a). Small humps present on either side of hypostome; anterolateral margins of scutum with rugose, wrinkled appearance; hosts are raccoons or other medium-sized carnivores ....*Ixodes texanus*

8b. Both sides of hypostome are flat or slightly concave with no distinct humps; scutum is smooth; hosts are not raccoons or other medium-sized carnivores 9

9a (8b). No internal spur on coxa 1; dorsal caudad corners of the basis capitulum rounded with no cornua; dentition is 3/3 apically and 2/2 at base; hosts are cliff swallows ....*Ixodes baergi*

9b. Faint internal spur present on coxa 1; dorsal caudad corners of the basis capitulum with distinct cornua; dentition is 2/2 throughout; hosts are usually squirrels ....*Ixodes marxi*

10a (7b). Anterior and/or posterior process present on palpal segment 1; palps blunt with length of palps equal to the width of the basis capitulum 11

10b. No processes present on palpal segment 1; palps elongate with length of palps longer than the width of the basis capitulum 12

11a (10a). Large prominent anterior and posterior processes present on palpal segment 1 .... *Ixodes sculptus*

11b. Large posterior process present on palpal segment 1, short anterior process on palpal segment 1 .... *Ixodes cookei*

12a (10b). Spurs present on trochanters; auriculae very large .... *Ixodes brunneus*

12b. Spurs absent on trochanters; auriculae range in size from small lobes to medium sized points 13

13a (12b). Scutum subcircular, as long as wide (1:1); dentition 4/4 apically, then 3/3, and 2/2 at base; when oriented parallel to hypostome, palpal segment 2 distinctly concave .... *Ixodes dentatus*

13b. Scutum ovate, longer than wide (not 1:1); dentition 3/3 apically, then 2/2 at base; when oriented parallel to hypostome, palpal segment 2 straight 14

14a (13b). Goblets of spiracular plate minute and close together, with no space between individual goblets; coxa 1 internal spur large stout triangle .... *Ixodes muris*

14b. Goblets of spiracular plate small, arranged in loose circles around the macula with space in between individual goblets; coxa 1 internal spur tapering to a point .... *Ixodes scapularis*

*Because of the highly invasive nature of *Haemaphysalis longicornis* and its presence in states neighboring Illinois, this key only goes to the genus *Haemaphysalis*. See Egizi et al. 2019 to identify nymphs of the genus *Haemaphysalis* to species.

Matrix-based key to the nymphal ticks of Illinois

An interactive version of the matrix key can be found at the following link: https://sfg.taxonworks.org/tasks/observation_matrices/interactive_key?observation_matrix_id=63. A guide on how to navigate through the matrix key can be found in Figure 2.10. A list of characters and character states included in the matrix key can be found below, and the resulting matrix noting the character states for each species is located in Table 2.1.

Diagnostic characters and character states:

1. Dental formula

    1. 2/2 throughout, apical ultimate and penultimate rows may be 3/3

    2. Anterior third to half of hypostome 3/3, 2/2 posteriorly

    3. 4/4 at apex of hypostome, then 3/3, and 2/2 at base

2. Length of palpal segments 2 and 3

    1. Palpal segment 2 up to 2.5x as long as palpal segment 3

    2. Palpal segment 2 equal in length to palpal segment 3

3. Total palp length versus basis capituli length

    1. Length of palps is longer than greatest width of basis capituli

    2. Length of palps is equal to the greatest width of the basis capituli

4. Shape of basis capitulum

    1. Triangular

    2. Subquadrangular – cornua may or may not be present

    3. Hexagonal

5. Cornua presence and shape

    1. Cornua absent

    2. Cornua present, small and broadly rounded

3. Cornua present, small and pointed

4. Cornua present, large

6. Processes on palpal segment 1

1. No anterior or posterior processes

2. Short anterior process and large posterior process

3. Large anterior process and large posterior process

7. Palpal segment 2 shape

1. Straight

2. Pointed lateral extension

3. Concave with pronounced inward curve

8. Auriculae presence and shape

1. Auriculae absent

2. Auriculae present as rounded lobes or ridges

3. Auriculae present as small, pointed projections

4. Auriculae present as large, pointed projections with singular point

5. Auriculae present as large, pointed projections with 2 distinct corners

9. Humps on either side of hypostome

1. Absent

2. Present

10. Scutum shape

1. Scutum subtriangular to suboval, with posterior margin distinctly angled

2. Scutum ovate

3. Scutum circular

11. Scutum surface texture

    1. Scutum without a rugose, wrinkled appearance on the anterolateral margins

    2. Anterolateral margins of the scutum with a rugose, wrinkled appearance

12. Coxa 1 internal spur

    1. Internal spur absent

    2. Internal spur present

13. External coxal spurs

    1. No external coxal spurs

    2. External spurs present on coxa 2 only

    3. External spurs present on coxae 1-3

    4. External spurs present on coxae 1-4

14. Trochanter spurs

    1. Spurs absent

    2. Spurs present

15. Spiracular plate goblet arrangement

    1. Many minute goblets tightly clustered together with no apparent arrangement pattern

    2. Minute goblets arranged in loose circles around the macula, with space in between individual goblets

    3. Some minute goblets with a ring of slightly larger goblet cells surrounding the macula

    4. Few minute goblets with no apparent arrangement pattern

    5. Several large goblets

16. Anal groove location

    1. Posterior to anus

2. Anterior to anus

17. Festoons presence and number

1. Festoons absent

2. 9 festoons present

3. 11 festoons present

Glossary of tick morphology terms

Below is a list of common tick morphology terms. Definitions were adapted from Strickland et al. 1976, and photographs of major morphological features can be found in Figures 2.1-2.4.

Alloscutum – Area of tick that expands when engorged.

Anal groove – Semicircular groove which partly surrounds the anus. It is located either anterior or posterior to the anus on the ventral side of the alloscutum.

Anus – Posterior opening of the alimentary tract located ventrally posterior to the last pair of legs and partly surrounded by the anal groove.

Auriculae – Pair of posterior pointing projections on the ventral side of the basis capitulum.

Basis capitulum – Basal portion of the capitulum where the hypostome and palps attach.

Capitulum – Anterior movable portion of the body which includes the hypostome, palps, and basis capitulum.

Cornu (pl. cornua) – Pair of small projections extending from the dorsal, posterolateral corners of the basis capitulum.

Coxae – Small sclerotized plates on the ventral side of the tick at the base of each leg to which the trochanters are attached. Coxae are numbered 1-4 from the anterior to posterior of the tick.

Denticles – Small recurved, projections or "teeth" on the ventral side of the hypostome.

Dental formula – The arrangement of denticles on the hypostome. Dental formula is composed by counting the number of denticles in a row on either side of the midline (e.g. a dental formula of 3/3 indicates that in one row there are 3 denticles on either side of the hypostome). The dental formula may also change from the apex to the base of the hypostome (e.g. the hypostome may have a dental formula of 3/3 for the apical third of the hypostome and a dental formula of 2/2 to the base).

Festoons – Sub-rectangular areas along the posterior margin of the alloscutum which are separated by grooves.

Goblets – Small, round structures located in the spiracular plate. Variable in size and arrangement pattern.

Hypostome – Median ventral structure of the mouth parts that lies parallel to and between the palps and is immovably attached to the basis capitulum. Denticles are located on the ventral side of the hypostome.

Macula – Large sclerotized structure located in the center of the spiracular plate.

Palps – Paired articulated appendages located anterolaterally on the basis capitulum and lying parallel to the hypostome. Four segments are present in hard ticks, with the fourth segment reduced and lying in a cup-like depression of segment three. Segments are labeled 1-4 from the proximal to distal end of the palps.

Scutum – The sclerotized dorsal plate posterior to the capitulum in hard ticks. It covers approximately half the dorsal surface of unengorged nymphs.

Spiracular plate – Paired plates located ventrolaterally and posterior to coxa 4 in hard ticks. Vary in shape from oval to comma-shaped and contain the macula and goblets. They are the external evidence of the respiratory system.

Spurs – Coxal spurs are projections from the posterior surface or posterior margin of the coxae. Projections on the median side are called internal spurs, and those on the lateral side are called external spurs. Spurs may also be found on the palps or trochanters of some species.

Trochanter – Segment on the leg attached to the coxae. Ventral spurs may be present in some species.

DISCUSSION

The aim of this study was to develop comprehensive, easy to use identification resources for both experts and non-experts for the hard ticks [Acari: Ixodidae] with documented or potential establishment in Illinois. The creation of two types of keys, a dichotomous key and matrix key, allows users to capitalize on the strengths of each format. The matrix key enables users to proceed through an identification using any order of characters and lets them skip characters which may be unclear or missing. The matrix key also allows users to identify ticks without the use of characters on the capitulum, which is useful as the capitulum is often lost or damaged during tick removal. Meanwhile the dichotomous key is straightforward to understand and can be printed or used offline. This is the first taxonomic key specifically for ticks occurring in the Midwest, and one of only a few keys for nymphal ticks that combines different genera into one identification resource. This is also the first matrix-based key for ticks in the Americas.

One weakness of these keys is the depth of our knowledge of tick diversity in the Midwest. There are additional species not included in these keys that may be present in Illinois but have yet to be documented. Some species, especially nidicolous ticks (those that rarely to never leave the nests of their hosts) are difficult to collect without removing ticks directly from their hosts (Gray et al., 2013). Because of the slim number of host-based collections of ticks within the state of Illinois, it is likely there could be additional species present in the state that have yet to be documented. In addition, there are other tick species that have not been found in Illinois but could invade in the future. This includes the highly invasive *H. longicornis*, as models have suggested parts of Illinois fall within the potential niche of this species (Roberts et al., 2021; Vogt et al., 2021). This is the reason this key only determines *Haemaphysalis* nymphs to genus – so the user is directed to an existing key for nymphs that includes *H. longicornis* (Egizi et al., 2019). However, one strength of the matrix key is that it can be easily updated to include additional species as they are documented within the state.

These keys could also be improved by expanding upon the materials and data consulted in their construction. The construction of these keys relied on the consultation of previously published species descriptions. While descriptions for many species and life stages of ticks are robust due to their medical or veterinary importance, this is not the case for all species. Species like *I. baergi*, which has only been collected from a handful of localities in the United States, are relatively understudied, and thus data for some character states does not exist (Cooley & Kohls, 1942; Kohls & Ryckman, 1962). There are also some characters that could aid identification, such as features of the spiracular plate, that have been historically excluded from tick identification materials. This results in states for some characters being difficult to determine from existing literature. Consultation of additional data sources, such as type material, could add more characters or character states.

Accurate morphological identification of ticks is a necessary part of the tick-borne disease diagnostic process and for the study of disease ecology, and the availability of contemporary, robust taxonomic resources for this group is a pressing need in medical entomology. Prior to this study, the identification of nymphal ticks in Illinois, or more broadly the Ohio River Valley and Midwest regions of the United States, would require consultation of multiple taxonomic resources, with inadequate keys necessitating the use of species descriptions to make accurate identifications. This was compounded by the fact that some of these resources can be difficult to access, reference species names no longer in use, or lack detailed or easily understood illustrations. This project consolidated nymphal tick identifications into one robust, up-to-date resource. The results of this project make tick identification resources more accessible to a broad constituency, including medical and veterinary professionals, researchers, and local public health and extension stakeholder

TABLE AND FIGURES

Table 2.1 Matrix of Diagnostic Characters for the Nymphal Hard Ticks of Illinois

	Dental formula	Length of palpal segments 2 and 3	Total palp length versus basis capituli width	Shape of basis capituli	Cornua presence and shape	Processes on palpal segment 1	Palpal segment 2 shape	Auriculae presence and shape	Humps on side of hypostome	Scutum shape	Scutum surface texture	Coxa 1 internal spur	External coxal spurs	Trochanter spurs	Spiracular plate goblet arrangement	Anal groove location	Festoons presence and number
Amblyomma americanum (Linnaeus, 1758)	1	1	1	2	1	1	1	1	1	1	1	2	4	1	1	1	3
Amblyomma maculatum Koch, 1844	1	1	1	1	1	1	1	4	1	1	1	2	2	1	1	1	3
Dermacentor albipictus (Packard, 1869)	1	2	2	2	1	1	1	3	1	1	1	2	4	1	5	1	3
Dermacentor variabilis (Say, 1821)	1	2	2	1	1	1	1	3	1	1	1	2	4	1	3	1	3
Haemaphysalis leporispalustris (Packard, 1869)	1	2	2	2	1	1	2	3	1	3	1	2	4	1	1	1	3
Ixodes baergi Cooley & Kohls, 1942	2	2	2	2	2	1	1	2	1	1	1	1	1	1	?	2	1
Ixodes brunneus Koch, 1844	2	2	1	2	3	1	1	5	2	1	1	2	4	2	2	2	1
Ixodes cookei Packard, 1869	2	2	2	2	4	2	1	2	1	1	1	2	4	1	1	2	1
Ixodes dentatus Marx, 1899	3	2	1	2	1	1	3	2	1	3	1	2	4	1	1	2	1
Ixodes marxi Banks, 1908	1	2	2	2	3	1	1	2	1	1	1	1 2	1	1	4	2	1
Ixodes muris Bishopp & Smith, 1937	2	2	1	2	3	1	1	4	1	2	1	2	4	1	1	2	1
Ixodes scapularis Say, 1821	2	2	1	2	4	1	1	4	1	2	1	2	4	1	2	2	1
Ixodes sculptus Neumann, 1904	1	2	2	2	4	3	1	2	1	1	1	2	4	1	5	2	1

Table 2.1 (cont.)

Ixodes texanus Banks, 1909	1	2	2	2	3	1	1	2	2	1	2	1 2	1	1	4	2	1
Rhipicephalus sanguineus (Latreille, 1806)	1	2	2	3	1	1	1	3	1	1	1	2	3	1	?	1	2

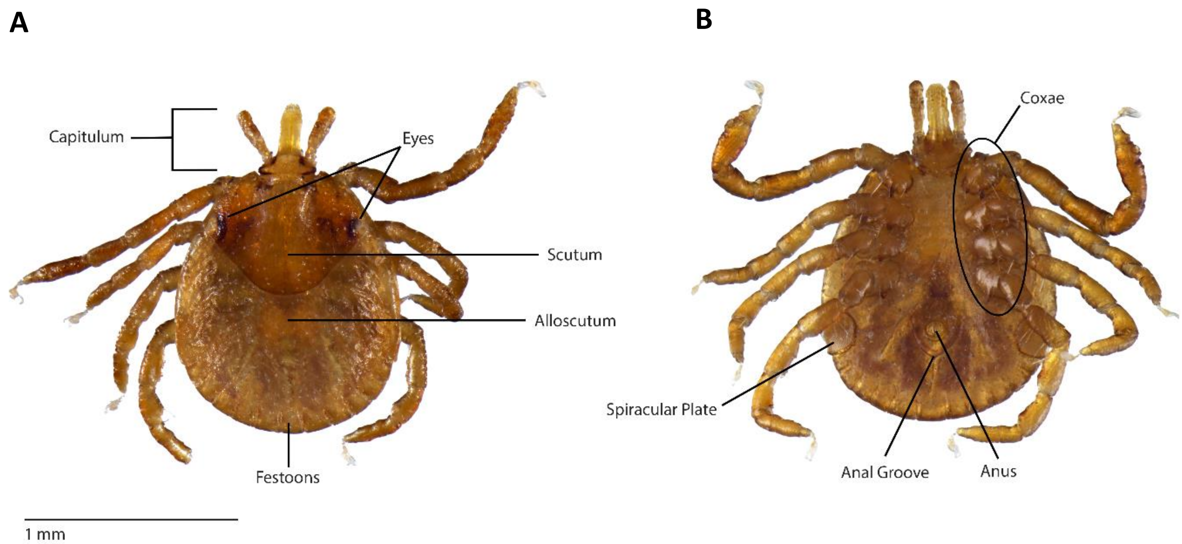


Figure 2.1 Guide to important diagnostic characters on the dorsal (2.1A) and ventral (2.1B) surface of a nymphal tick. Species pictured: *Amblyomma americanum*

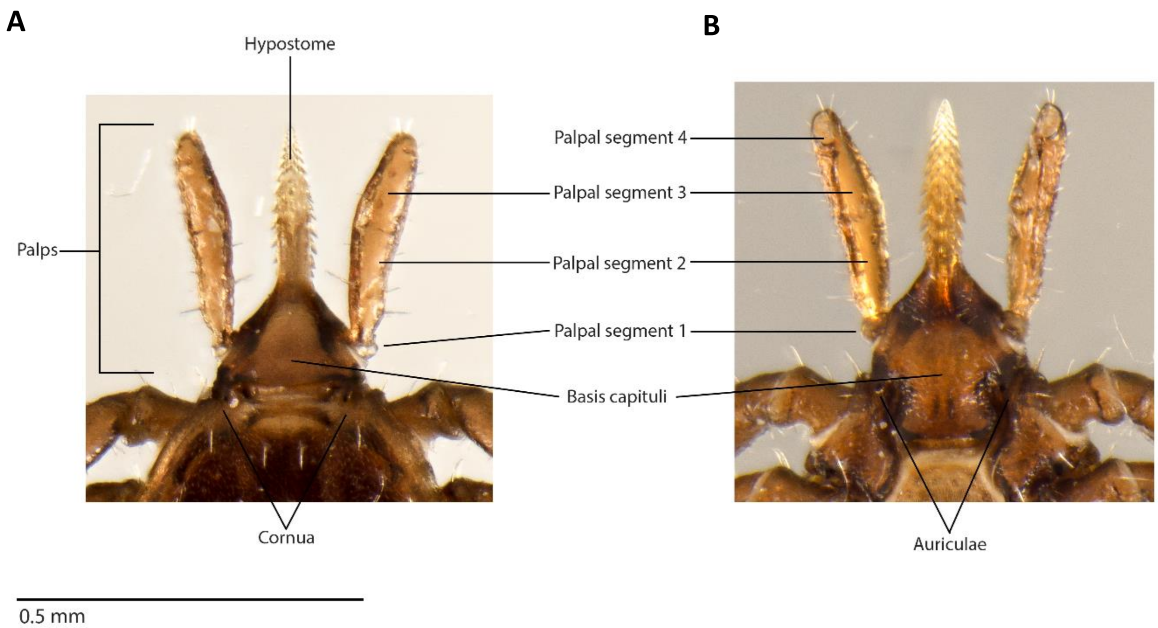


Figure 2.2 Guide to important diagnostic characters on the dorsal (2.2A) and ventral (2.2B) surface of the capitulum of a nymphal tick. Species pictured: *Ixodes scapularis*

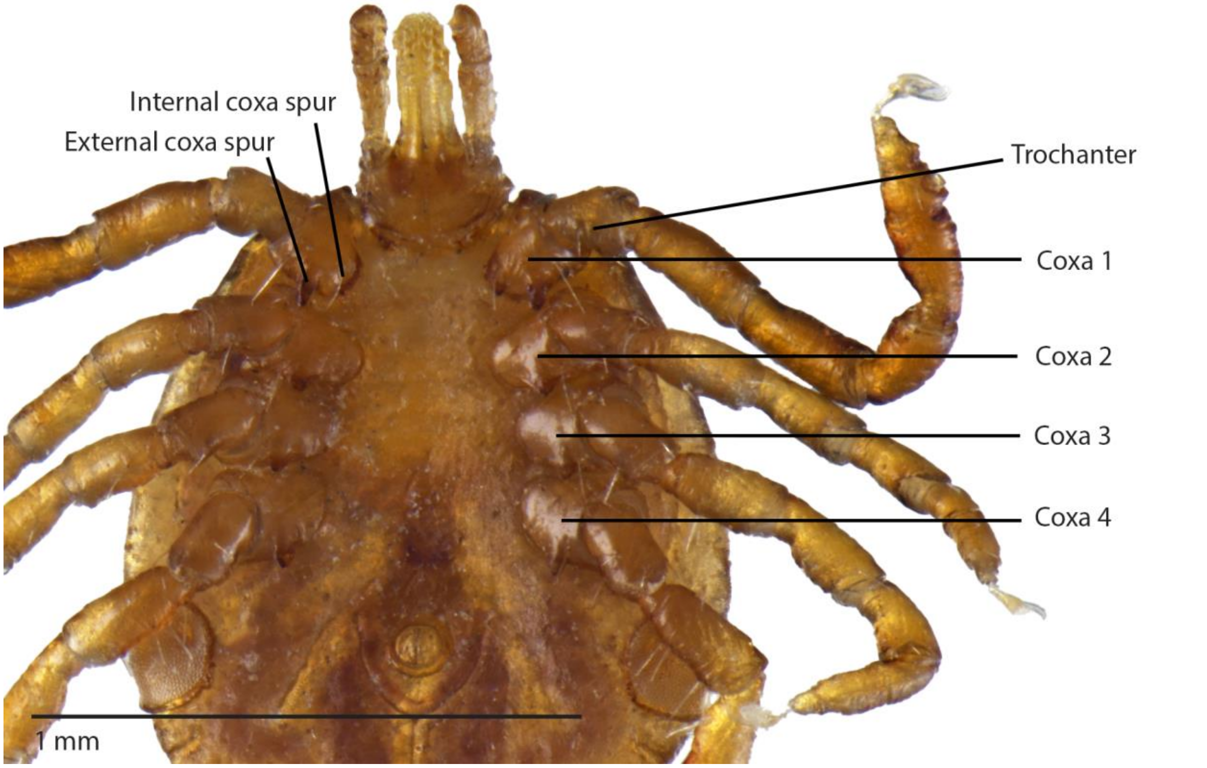


Figure 2.3 Guide to important diagnostic characters on the coxa and legs of the tick. Species pictured: *Amblyomma americanum*

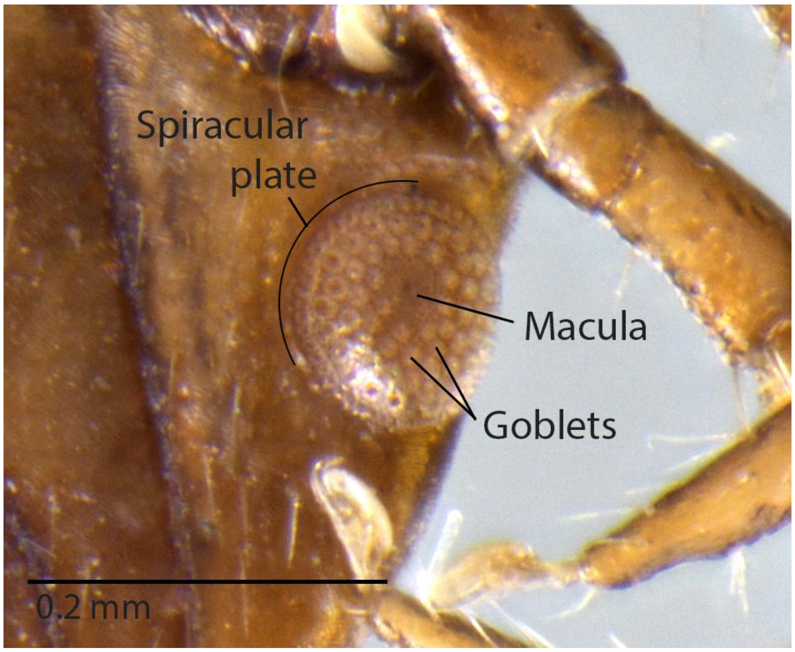


Figure 2.4 Guide to important diagnostic characters on the spiracular plate. Species pictured: *Ixodes scapularis*

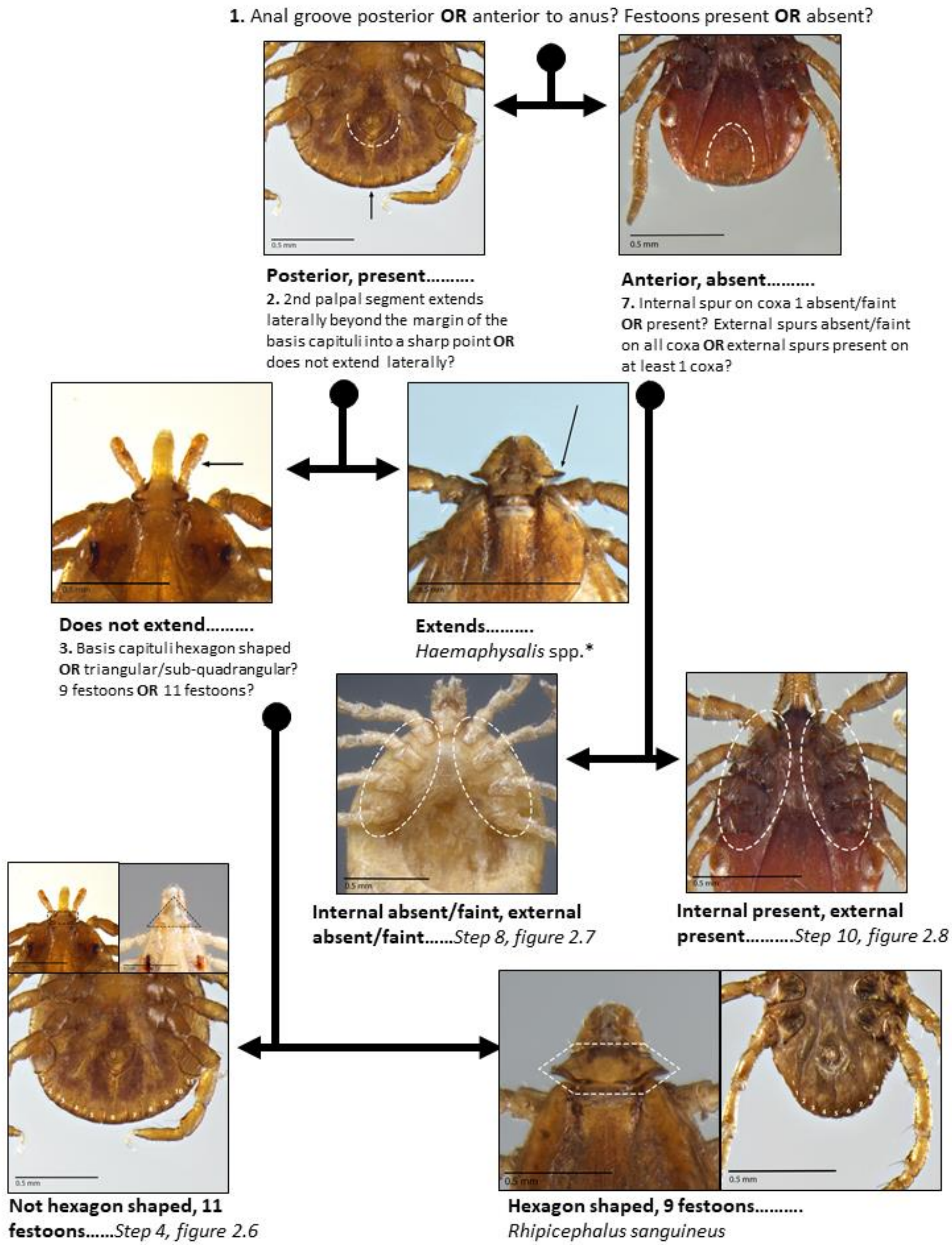


Figure 2.5 Taxonomic key flowchart to the hard tick nymphs of Illinois

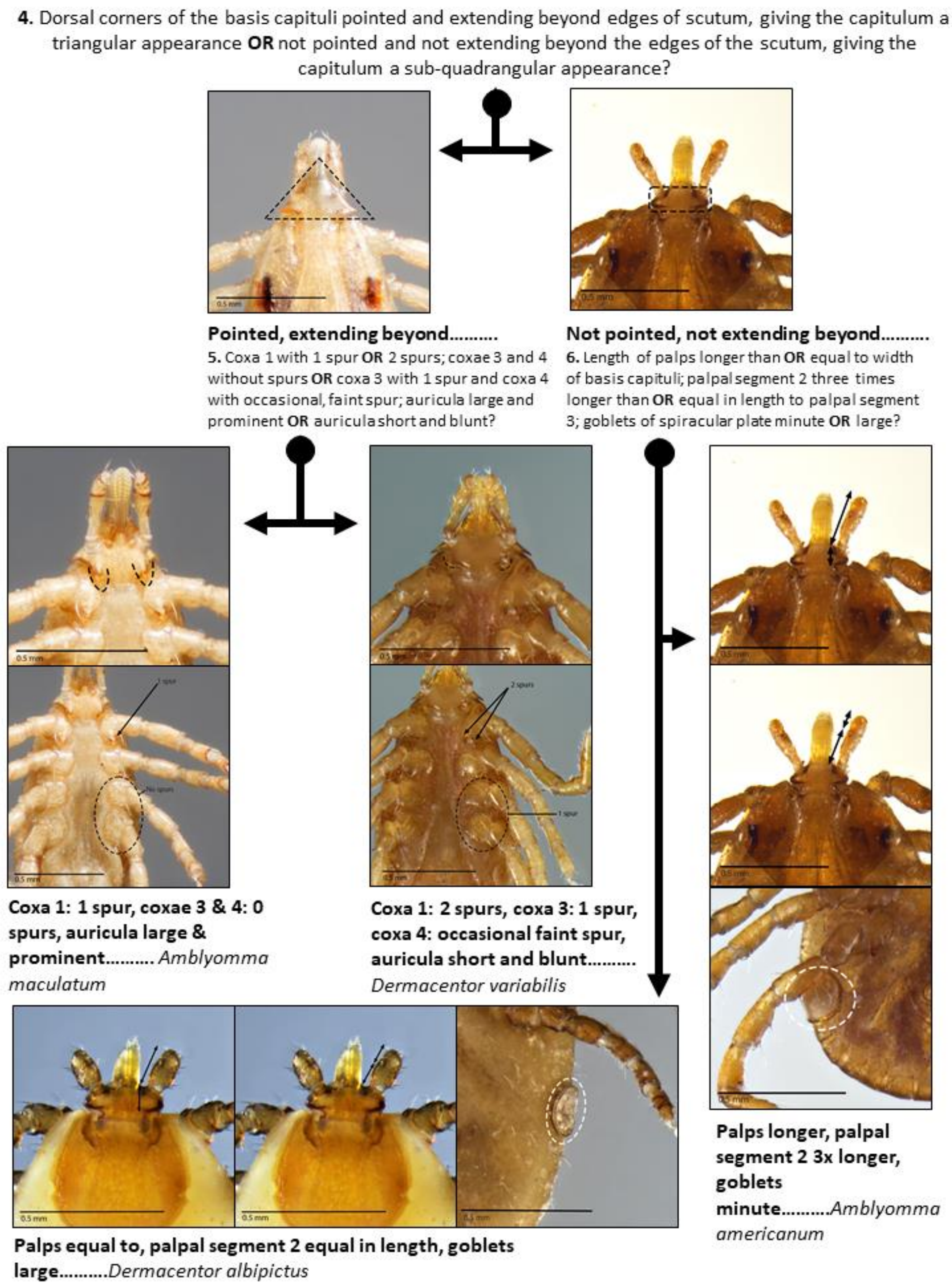


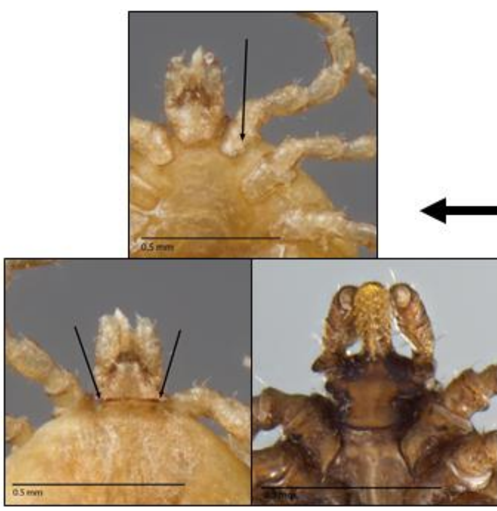
Figure 2.6 Taxonomic key flowchart to the hard tick nymphs of Illinois (continued)

8. Small humps present **OR** no humps or concave depression on either side of base of hypostome; anterolateral margins of scutum rugose, wrinkled in appearance **OR** smooth; hosts are racoons or other medium-sized carnivores **OR** not?

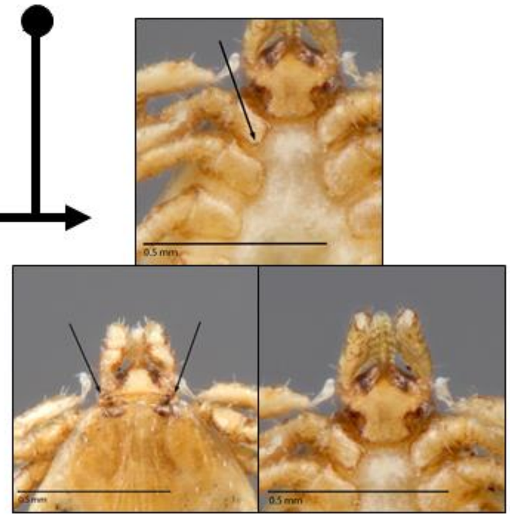
Humps present, scutum rugose, hosts raccoons or other medium-sized carnivores.......... *Ixodes texanus*

Humps not present, scutum smooth, hosts not raccoons or other medium-sized carnivores

9. Coxa 1 with no internal spur **OR** faint internal spur; dorsal caudad corners of the basis capituli rounded with no cornua **OR** with distinct cornua; dentition is 3/3 apically and 2/2 at base **OR** 2/2 throughout; hosts are cliff swallows **OR** usually squirrels



No internal spur, corners basis capituli rounded, dentition 3/3 then 2/2, hosts cliff swallows..........*Ixodes baergi*



Faint internal spur, corners basis capituli with cornua, dentition 2/2, hosts usually squirrels..........*Ixodes marxi*

Figure 2.7 Taxonomic key flowchart to the hard tick nymphs of Illinois (continued)

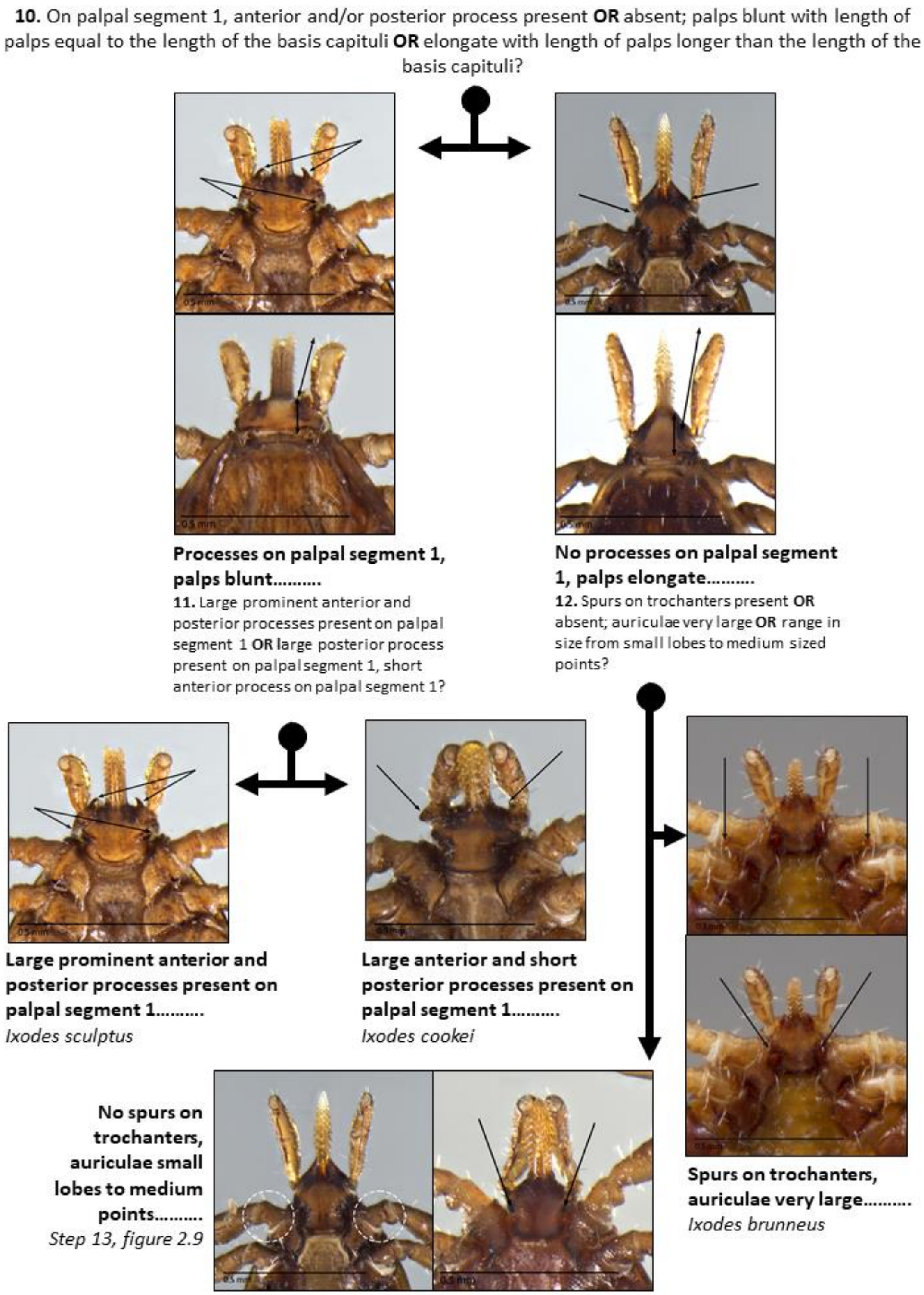


Figure 2.8 Taxonomic key flowchart to the hard tick nymphs of Illinois (continued)

13. Scutum subcircular, as long as wide **OR** scutum ovate, longer than wide; dentition 4/4 apically, then 3/3, and 2/2 at base **OR** dentition 3/3 apically, then 2/2 at base; when oriented parallel to hypostome, palpal segment 2 distinctly concave **OR** straight?

Scutum subcircular, dentition 4/4|3/3|2/2, palpal segment 2 concave……….
Ixodes dentatus

Scutum ovate, dentition 3/3|2/2, palpal segment 2 straight……….

14. Goblets of spiracular plate minute and close together, with no space between individual goblets **OR** small, arranged in loose circles around the macula with space in between individual goblets; interior spur on coxa 1 large, stout triangle OR interior spur on coxa 1 prominent but tapering to a sharp point?

Goblets minute, coxa 1 interior spur large stout triangle……….
Ixodes muris

Goblets small, coxa 1 interior spur tapering to point……….
Ixodes scapularis

Figure 2.9 Taxonomic key flowchart to the hard tick nymphs of Illinois (continued)

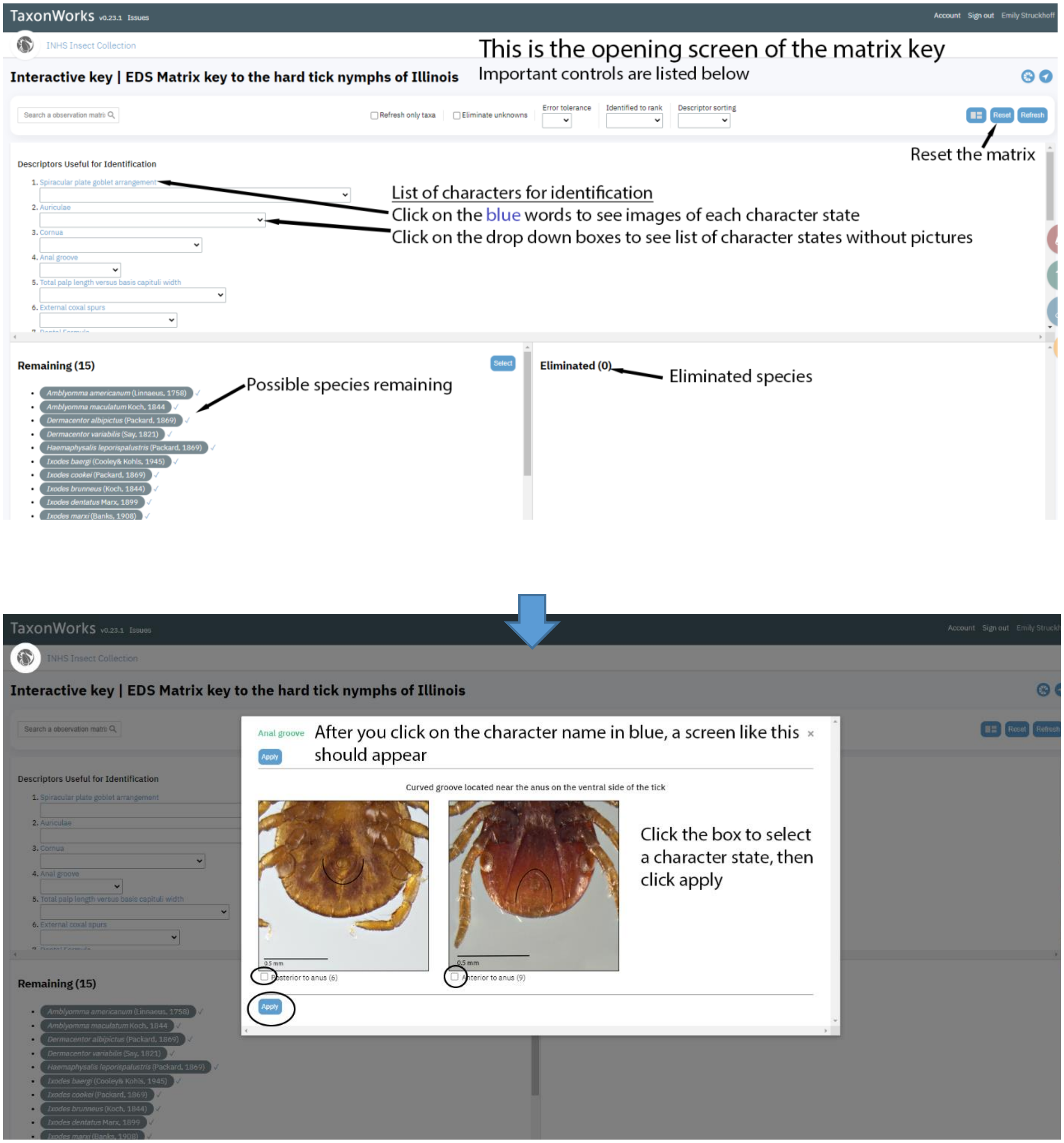


Figure 2.10 Guide for navigating through the matrix key in TaxonWorks

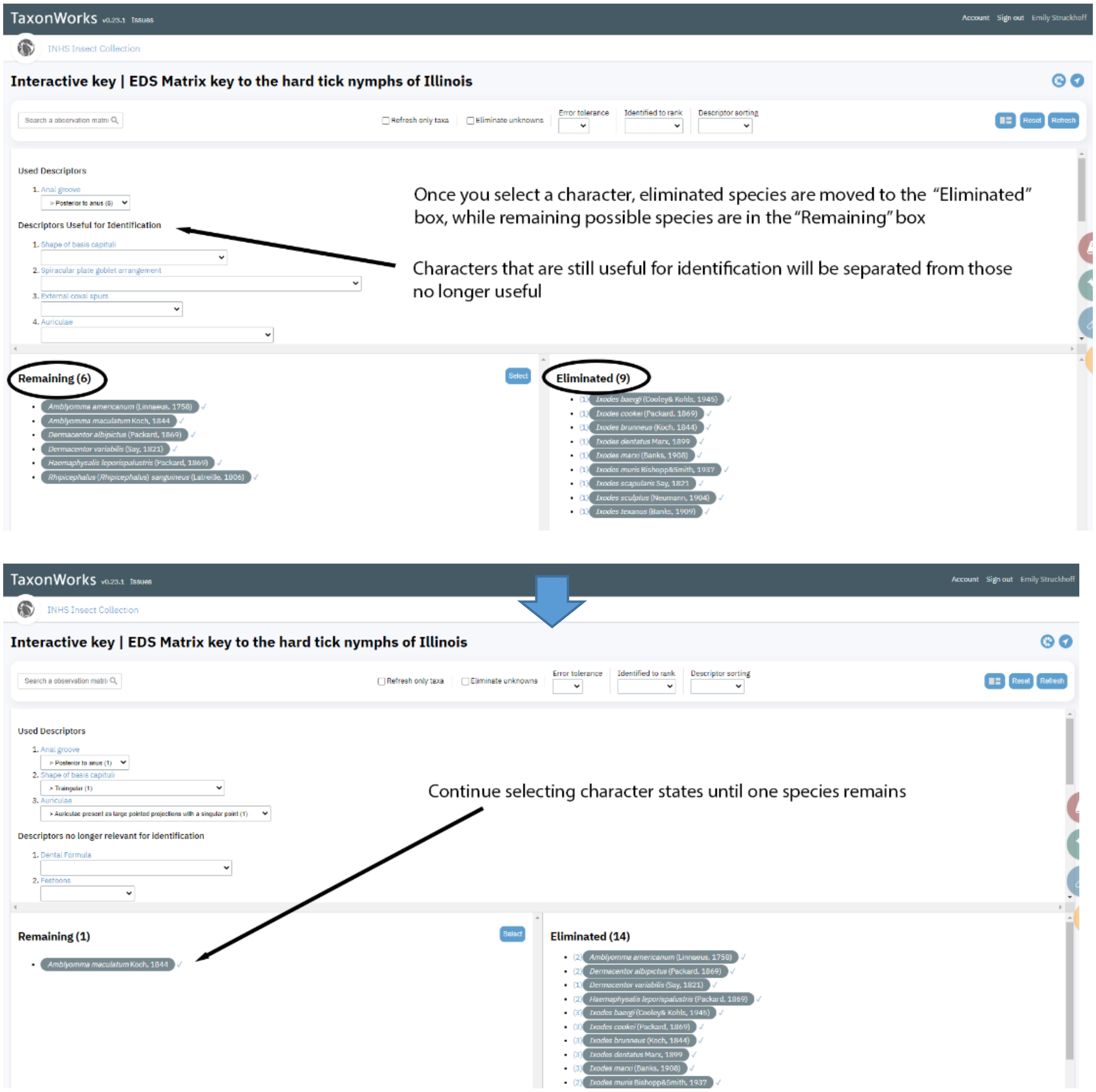


Figure 2.10 (cont.)

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